# Benefits of Reducing Demand for Gasoline and Diesel

## Volume 3, Task 1 Report

**Joint Report to**
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## Disclaimer

This report was prepared by Arthur D. Little, Inc., with the assistance of the staffs of the California Energy Commission and California Air Resources Board. Opinions, conclusions and findings expressed in this report are those of the authors. The report does not represent the official position of the Energy Commission or the California Air Resources Board. This consultant draft report is a compilation of the preliminary results based on objective technical analyses of the status of technologies, their relative petroleum reduction impacts and costs. The report presents a range of possible costs and impacts from an illustrative group of options. The cost and benefit calculations contained in these analyses account only for environmental impacts. These preliminary results should not be construed as indicating policy preference for a particular technology or strategy.

## Schedule

Note to Reviewers and Stakeholders: Initial comments on this Consultant Report are requested at the April 15 public workshop. At that workshop, there will be a discussion of the overall schedule for the completion of this report. In addition, there will be other opportunities for public comments.

This report, along with previous reports issued by the California Energy Commission (Base Case Forecast of California Transportation Energy Demand, CEC Report No P600-01-019, December 2001 and Task 3: Petroleum Reduction Options, CEC Report No. P600-02-011D) should be evaluated together. However, at the time of publishing this draft, we realize that there are still inconsistencies in assumptions and modeling between these reports and these inconsistencies will be corrected in the final version.

**Acknowledgements**

The draft report was prepared by Arthur D. Little/Acurex Environmental (ADL) for the California Air Resources Board (ARB) and the California Energy Commission. ADL was responsible for estimating emissions (Section 2), valuating emissions reductions (Section 3), evaluating petroleum spill impacts (Section 4) and determining the environmental cost benefits of fuel reduction or displacement options previously analyzed by the Energy Commission (Section 5). University of California, Berkeley (UCB) was responsible for assessing the economic impacts to the California economy of various petroleum reduction strategies (Section 6). Both staffs of the Energy Commission and ARB contributed to the work in this report.

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# 1. Introduction

Assembly Bill 2076 (Chapter 936, Statutes of 2000) requires the California Energy Commission and the California Air Resources Board (ARB) to develop and submit a strategy to the Legislature to reduce petroleum dependence in California. The statute requires the strategy to include goals for reducing the rate of growth in the demand for petroleum fuels. Options to be considered include increasing transportation energy efficiency, as well as using non-petroleum fuels, and advanced transportation technologies including alternative fueled vehicles and hybrid vehicles.

The Energy Commission and the ARB have developed a program and methodologies to evaluate and analyze possible petroleum reduction options. The goal of this effort is to provide policy makers with a robust analysis of the possible measures that could be implemented to meet the fuel demands of consumers and industry. This analysis needs to account for the costs of these measures as well as the benefits. The overall effort is guided by consultant services provided by Acurex Environmental, an Arthur D. Little Company (ADL).

This work has been divided into several tasks and assigned to Energy Commission and ARB staff.

- The ARB leads Task 1 to determine the possible benefits of reducing the demand for gasoline and diesel fuel in California. Monetizing the indirect impacts of reducing petroleum consumption is the focus of this report.

- Task 2 is lead by the Energy Commission to determine the future demand for refined products, especially gasoline and diesel fuels. The results of this task are contained in a report entitled Base Case Forecast of California Transportation Energy Demand that was published December 2001. In this report, the Energy Commission projected total personal income, population, vehicle miles traveled, and demand for gasoline and diesel fuels.

- The Energy Commission also leads Task 3, which assesses possible options to reduce petroleum dependency and the level of petroleum reduction and costs.

- The Energy Commission and the ARB will jointly lead Task 4, which provides integration of the results of Tasks 1, 2, and 3. Staff will develop strategies and provide recommendations to stakeholders for discussion. Alternative strategies may also be developed and presented to the Energy Commission and ARB. Recommendations for establishing statewide petroleum reduction goals and possible policies to achieve these goals will be considered for adoption and presented to the Governor and Legislature.

**Benefits of Reducing Demand for Gasoline and Diesel**

This volume describes the methodology for determining possible benefits of petroleum reduction options. Indirect impacts can be divided into two general categories: environmental and economic.

Environmental impacts include both air emissions and multimedia effects. The analysis of air emission impacts focus on hydrocarbons (HC), oxides of nitrogen ($NO_x$), carbon monoxide (CO), particulate matter (PM), toxics, and greenhouse gases (GHG). These species were evaluated over the fuel-cycle (well-to-tank) and vehicle life (tank-to-wheels). Multimedia impacts address decreased spill volumes due to reductions in handling petroleum products. These multimedia effects include primarily bulk fuel handling.

The economic impacts considered in this report target the impact to the California economy associated with different reduced petroleum use scenarios. For the purposes of this report, direct benefits – which are evaluated in Task 3 – include consumer expenditures on goods such as vehicles, fuels, and services. Indirect impacts, sometimes referred to as externalities, are considered in this report.

**What options were considered?**

A host of options were considered to reduce petroleum consumption. These options have been divided into four categories:

Group 1 — Fuel Efficiency Options

- Improved Vehicle Fuel Economy
- Fuel-Efficient Replacement Tires and Tire Inflation
- Efficient Vehicles in Government Fleets
- Vehicle Maintenance Practices
- Light-Duty Diesel Vehicles

Group 2 — Fuel Displacement Options

- Fuel Cells
- Battery Electric Vehicles
- Grid-Connected Hybrid Vehicles
- CNG for Light-Duty Vehicles
- Liquefied Petroleum Gas (LPG)
- Alcohol Fuels in Flexible Fuel Vehicles
- Ethanol as a Gasoline Blending Component
- LNG and Advanced Natural Gas Engines for Medium- and Heavy-Duty Vehicles

- Fischer-Tropsch Diesel (gas to liquid fuels)
- Biodiesel

Group 3 — Pricing Options

- Gasoline Tax
- Pay-at-the-Pump Auto Insurance
- Tax on Vehicles Miles Traveled
- Registration Fee Transfer
- Purchase Incentives for Efficient Vehicles
- Feebate — Registration Fees Increase with Fuel Consumption

Group 4 — Other Options

- Expanded Use of Public Transit
- Land Use Planning
- Telecommuting
- Reducing Speed Limits
- Voluntary Accelerated Vehicle Retirement

**How are the benefits organized?**

These benefits are separated into two general categories: Environmental and Economic.

Environmental Benefits

- Environmental benefits in this analysis include air emissions associated with vehicle operation and fuel production and distribution in California as well as multi-media impacts which include fuel spills in water and on the ground. Monetary values for both air emissions and multi-media impacts are estimated. These monetary estimates are then discounted using a present value (PV) analyses over the vehicle life. These results then can be compared or added to the PV analyses performed by California Energy Commission on the direct costs and benefits of petroleum reduction options.

Economic Benefits

- Economic impacts were estimated using a sophisticated economic model of the California economy. The model was used to estimate economic conditions without any petroleum reduction options (base year analyses) and then by analyzing the effect of petroleum reduction and/or displacement scenarios (combinations of petroleum reduction options). The results are expressed as detailed effects on the

California economy, and as such can be used to “screen” how various scenarios may affect the California economy.

**How this report is organized**

Volume 3, which details analysis done for Task 1, is divided into seven sections, each of which is addressed in its own section:

- Introduction (Section 1)
- Air Emission Impacts (Section 2)
- Value of Emission Reductions (Section 3
- Multimedia Impacts (Section 4)
- Valuation of Indirect Benefits (Section 5)
- Impacts of Petroleum Strategies on the California Economy (Section 6)
- Summary of Findings (Section 7)

## 2. Air Emission Impacts

The choices of fuels, their feedstocks, the processes undergone to eventually deliver them to the vehicle, and the vehicle itself, all affect air emissions associated with vehicle operation. This section identifies emissions aspects of several fuel and feedstock combinations. The vehicle is also analyzed to determine the overall emissions resulting from fuel/feedstock/vehicle combinations.

Figure 2-1 identifies activities that are related to the life cycle of fuels from manufacturing a fuel production facility to recycling vehicles. Estimates of air emission impacts are made for the vehicle and fuel cycle as these activities have a more direct connection with petroleum reduction and miles driven.

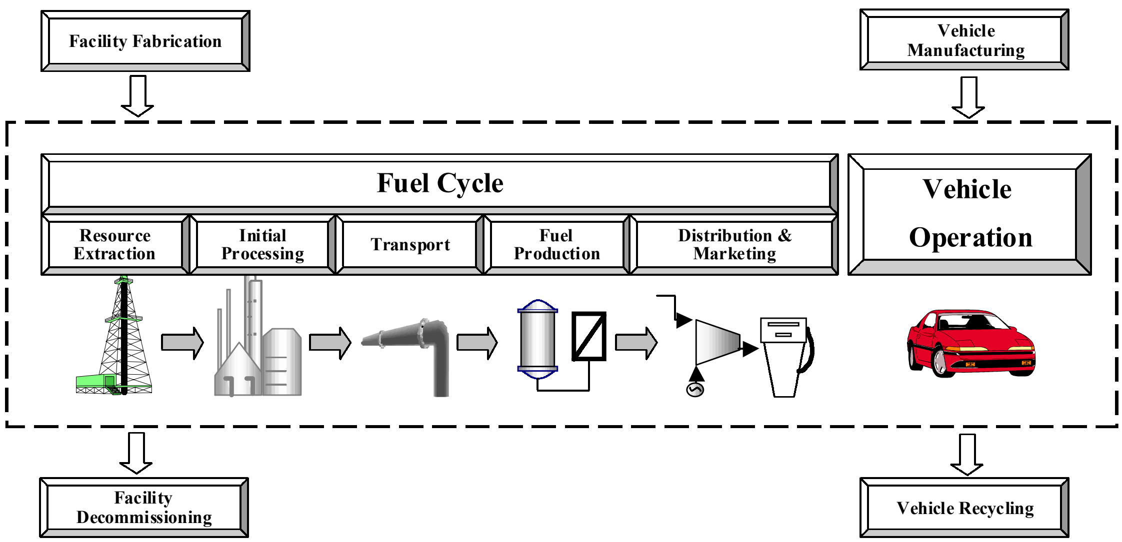
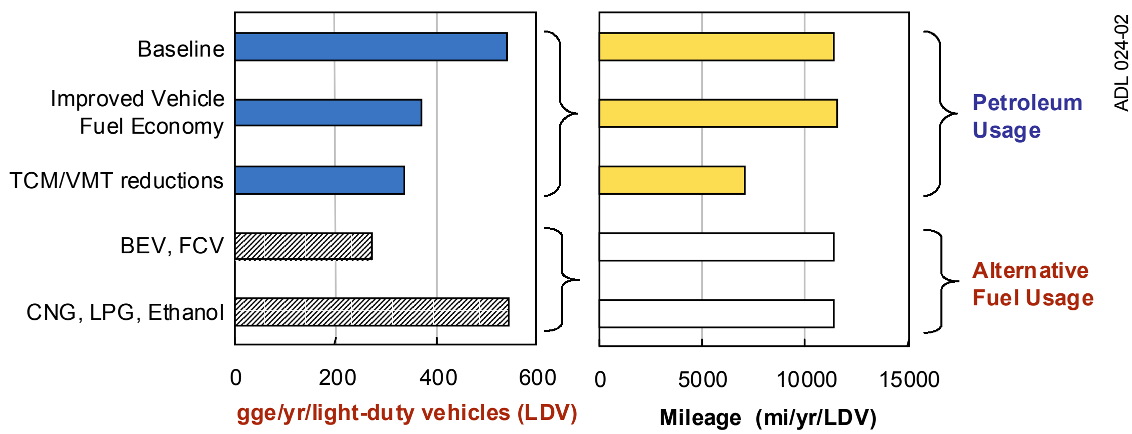



**Figure 2-1. Activities Related to Fuel Production and Vehicle Operation**

The fuel cycle (well-to-tank) results include the extraction of feedstocks, processing or refining, transport and local distribution. The construction and decommissioning of facilities are not included in this analysis. An increased usage of fuel, within the context of this study, might not result in increased fuel production facility activity. An example could be debottlenecking oil refineries or operating power plants at night for EV charging. The vehicle cycle (tank-to-wheels) includes the emissions associated with operating the vehicle. Emissions associated with producing and recycling the vehicle are not included in the analysis for several reasons. The impact, although large, is small relative to overall vehicle-related emissions. Furthermore, with some strategies such as VMT reductions, an estimate of vehicle manufacturing and recycling emissions on a per mile basis would provide a poor estimate of the actual impacts. These activities may well remain constant over the calendar life of the vehicle even as mileage is reduced. Secondly, the degree of recyclability of some materials like platinum for exhaust or fuel cell catalysts could be quite variable and the cause and effect between vehicle purchase and operation is not as closely coupled to vehicle operation as fuel production or vehicle operation emissions.

Emission impacts are determined from fuel usage and miles traveled for various petroleum displacement options. Some options (Group 1) result in the reduction of fuel consumption due to improved vehicle fuel efficiency. A minor increase in miles driven can also occur due to additional disposable income from fuel savings (rebound effect); however, this effect is likely to be under 5 percent increase in miles driven. Figure 2-2 illustrates fuel savings and VMT for various petroleum based fuel reduction options. Emission impacts are determined by the energy used for each system.




Abbreviations:
TCM = transportation control measure
VMT = vehicle miles travel
BEV = battery electric vehicle
FCV = fuel cell vehicles
CNG = compressed natural gas
LPG = liquefied petroleum gas
gge = equivalent gallons of gasoline in energy /Btu basis

**Figure 2-2. Emission Impacts Depend on Changes in Fuel Usage and Miles Driven**

Other options reduce both gasoline usage and miles driven (Group 3 and 4 options). These options result in emission reductions associated with less fuel usage and lower miles driven.

Alternative fuel displacement options result in a replacement of gasoline with an alternative fuel and a replacement of gasoline miles with alternative fueled vehicle mileage. For these Group 2 options, new emissions occur from alternative fuel production and vehicles driving while gasoline related emissions are reduced. Two broad categories of alternative fuel options are illustrated in Figure 2-2. Battery electric and fuel cell vehicles result in a reduction of fuel used on a gasoline equivalent basis (factor of 2.9 to 2, respectively) and the vehicles produce zero exhaust emissions. Alternative fuels in ICE engine require approximately the same amount of energy on a gasoline equivalent basis (within 10 percent for identical vehicles) and the vehicles also produce exhaust emissions that need to be taken into account. Diesel also falls into this category except less diesel fuel is used for the same miles driven. Actual fuel use projections were developed by the Energy Commission and are taken from the Task 3 report (CEC/ARB 2002).

A variety of vehicles can also operate on the fuels analyzed in this study. Table 2-1 summarizes the combinations of fuels and vehicles considered. As most of the fuel cycle impacts depend primarily on the fuel production and distribution activities, other combinations of the results are possible. For example, methanol or hydrogen could be used in ICE or ethanol could be used in fuel cell vehicles.

**Table 2-1. Fuel/Vehicle Combinations Considered in this Study**

| Fuel | Light-Duty Vehicle | Heavy-Duty Vehicle |
|---|---|---|
| Gasoline | ICEV | — |
| Diesel | ICEV | ICEV |
| LPG | ICEV | ICEV |
| FTD | ICEV | ICEV |
| CNG | ICEV | ICEV |
| LNG | ICEV | ICEV |
| Methanol | FCV | — |
| Hydrogen | FCV | — |
| Ethanol | ICEV | — |
| Electricity | EV | — |

ICEV= Internal Combustion Engine Vehicle
FCV = Fuel Cell Vehicle
BEV= Battery Electric Vehicle

This section provides and overview of the analysis of air emissions associated with vehicle operation. A complete discussion of the fuel cycle emissions is included in Appendix A. Section 2.1, 2.2, and 2.3 describe the assumptions that relate to fuel cycle emissions of vehicle operation in California. Emissions from fuel production and vehicle operation including local criteria pollutants and toxics as well as global GHG emissions are discussed in Section 2.4 and 2.5. Estimates of the monetary value of emission reductions are discussed in Sections 3.

## 2.1 Fuel Cycle Analysis

This study analyzes the fuel cycle of fuel/feedstock combinations currently used in California or those that are expected to increase in use with introduction of evolving technologies. The fuel cycle analysis is a "well-to-tank" analysis that evaluates the entire process of a fuel, from extraction of feedstocks to delivery of the fuel to the vehicle. The fuel cycle results are presented on a per unit fuel basis. This approach allows for the most direct determination of criteria pollutant emissions as many local fuel cycle emissions are regulated on a per gallon basis.

Table 2-2 summarizes the fuel/feedstock combinations that were considered in this study. As indicated in the table, several fuel/feedstock combinations are complicated by the fact that some products are made from the same feedstock and many fuels can be produced from several feedstocks. Different mixes of feedstocks are also used in fuel production. For example, a variety of crude oil sources make up the feedstock for California refineries, and this mixture will change in the future. While most methanol in the world is produced from natural gas, biomass resources can also be used as feedstocks. These feedstocks include landfill gas, urban waste, sewage sludge, and woody materials. Producing methanol from these feedstocks would result in almost no fossil fuel CO2 emissions and the local emissions in urban areas would be similar to those for other liquid fuel options as discussed in an ARB study of fuel cycle emissions from alternative fuels (ARB 2001).

**Table 2-2. Vehicle Fuels Considered in this Study**

| Feedstock | Fuel | Type of Fuel |
|---|---|---|
| Petroleum | Gasoline | Liquid, crude and refined marine import |
| Petroleum | Diesel | Liquid, crude and refined marine import |
| Petroleum | LPG | Liquid, marine crude import |
| Natural Gas | LPG | Liquid, rail transport |
| Natural Gas | FTD | Liquid, marine import |
| Natural Gas | CNG | Gaseous |
| Natural Gas | LNG | Liquid, marine import |
| Natural Gas | Methanol | Liquid, marine import |
| Natural Gas | Hydrogen | Gaseous, compressed |
| Electricity | Hydrogen | Gaseous, compressed |
| Corn | Ethanol | Liquid, rail and marine transport |
| Biomass | Ethanol | Liquid, rail or pipeline transport |
| Natural Gas | Electricity | Electric Power |

LPG: Liquefied petroleum gas, FTD: Fischer Tropsch diesel (synthetic diesel), CNG: compressed natural gas, LNG: liquefied natural gas.

Natural gas is produced from gas fields and as a by-product of oil production, and the gas can be used for many purposes, including the manufacture of synthetic liquid fuels or methanol. LPG is produced during oil refining and derived from natural gas liquids, as a product of oil and natural gas production. Electricity can be produced from a myriad of feedstocks, which range in GHG emission impact from solar energy to coal.

The fuel cycle emissions are largely associated with the fuel properties and transportation mode. The type of feedstock typically relates to a geographic region, transportation mode, and transportation distance. For example, distances were determined for transporting LPG by rail from western states. The length of rail operation in California determines emissions in California. Total transport emissions determine worldwide GHG emissions. The analysis of energy inputs and GHG emissions relates more closely to the type of feedstock. The effect of both feedstock type and transportation mode is discussed in Section 2.3.

### 2.1.1 Fuel Cycle Emission Scenarios

Emissions estimates in this study are based on both vehicles and stationary sources complying with all applicable State and Federal requirements. Emission rates for fuel cycle emissions are determined according to the scenarios listed in Table 2-3. The calculations in this report reflect the base case with an assessment of the uncertainties presented in a sensitivity analysis. A previous ARB study (ARB 2001) considered the fuel cycle emission impacts associated with diesel, methanol, LPG, and FTD production. The timeframe for this study was 2010. The primary differences between this previous study and future dates is a complete roll in of the 1997 heavy-duty emission standards for heavy-duty engines which require a 90 percent reduction in $NO_x$ and PM over 1994 standards. The impact is approximately a 40 percent reduction in fuel cycle $NO_x$. Liquid fuel storage facilities are also assumed to be at best available control technology (BACT) levels by 2020 (likely for new facilities). Finally, power plant efficiency would improve and resulting carbon dioxide ($CO_2$) emissions are reduced in 2020 and beyond.

**Table 2-3. Fuel Cycle Emission Scenarios**

| Scenario | Description |
|---|---|
| 2020 Worst Case | Compliance with ARB stationary source standards except 4% defect rate on fueling stations, higher vehicle spillage. HD trucks meet 2004 standards |
| 2020 Base Case | Compliance with ARB stationary source. All HD trucks meet 2007 standards. |

### 2.1.2 Calculation of Emissions — Marginal Analysis

The purpose of this report is to provide fuel cycle emissions on a per unit fuel basis (emission factors) which can be used to evaluate the impact on local emissions in California and global GHG emissions. Therefore, considerable effort has gone into evaluating the relationship between quantity of fuel used or displaced and the associated emissions impact. The analysis presented here reflects the impact of fuel savings or displacement options, which correspond to the incremental or marginal gallon of fuel reduced or displaced in California.

Marginal emissions represent the impact on air quality from using or avoiding additional fuel. As shown in Figure 2-3, gasoline demand is expected to double by 2030 and gasoline supply from California refineries[1] is expected to remain relatively flat. Options for reducing this demand include increase vehicle efficiencies and pricing strategies. Gasoline demand could also be reduced by implementing alternative fuels. However, given that California's vehicle population is over 20 million, a very large penetration of alternative fuel vehicles is necessary. Similarly, aggressive fuel economy improvements are needed to return gasoline demand to 2000 levels. Therefore, this analysis needs to also consider the possibility of importing refined products to meet the growing demand. A small expansion of California refinery capacity is projected through 2020. This expansion is expected as refineries continue to upgrade equipment and processes. The estimated expansion is 0.5 percent per year (Stillwater) or an increase of 70 million barrels per year compared to 629 million barrels of California production in 1999. Refinery expansion is discussed further in Appendix A.

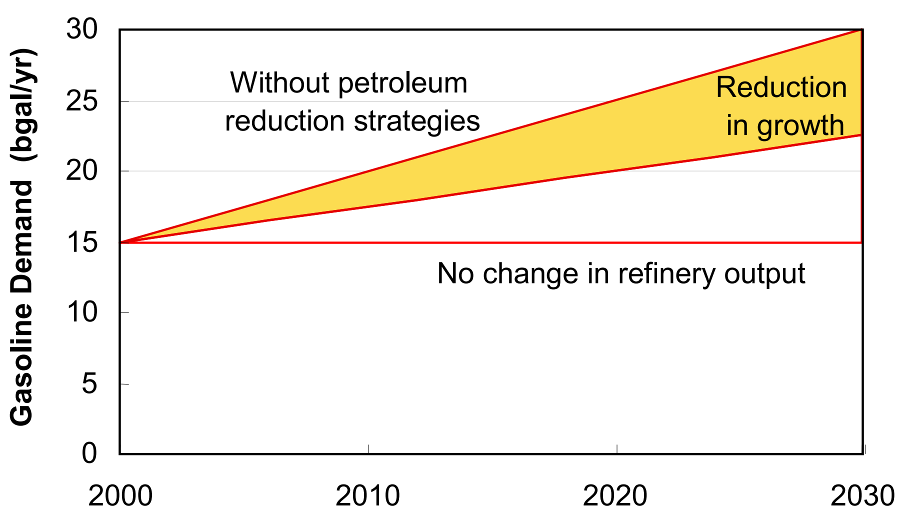



**Figure 2-3. California Refinery Output Will Not Meet Growing Gasoline Demand**

[1] See discussion of petroleum fuels in Appendix A. This conclusion implies that marginal refinery emissions from diesel and LPG production would be zero. The emission impact of displacing a very large fraction of refinery capacity with alternative fuels is not analyzed here. Even if such a scenario were to occur, it is uncertain that average emission rates would accurately reflect the impact on emissions as the disposition of emission permits and offsets would need to be taken into account.

Local emissions for marginal alternative fuel production and gasoline displacement were calculated for vehicle operation in the South Coast Air Basin (SoCAB). The vehicle operation results in emissions in the SoCAB and in some cases in the rest of California. Emissions in both regions were determined. The net result of the marginal analysis is that $NO_x$ emissions amount only to tanker ship and truck emissions in the SoCAB. All other $NO_x$ emissions are either controlled by Regional Clean Air Incentives Market (RECLAIM) or are associated with fuel production outside of the SoCAB. Non-methane organic gases (NMOG)[2] emissions correspond to fuel storage and distribution activities as well as power production for EVs. Marginal emission sources are identified for each fuel in Table 2-4.

**Table 2-4. Adjustments for Marginal Fuel-Cycle Emission Analysis in the SoCAB, 2010**

| Fuel | Marginal Analysis Assumptions |
|---|---|
| Gasoline | Import finished product. Zero emissions for crude oil production and refinery. Also considered refinery capacity expansion in Appendix A. |
| Diesel, LPG | Import finished product. Zero emissions for crude oil production and refinery. Also considered refinery capacity expansion in Appendix A. |
| Methanol, LPG, FTD from natural gas, ethanol from biomass | Produced outside of the South Coast or California. Feedstock extraction and refinery do not result in SoCAB or California emissions. |
| EV | Marginal power from natural gas. $NO_x$ would be zero for electric power generation due to purchase of offsets and RECLAIM requirements. |

GHG emissions were also determined on a marginal basis. In this case, any increases in production or generation are assumed to come from new, more efficient plants compared to considering averaging older plants and new plants which will be needed to meet the growing demand. The analysis corresponds to how the last gallons of gasoline or other fuels are produced. For example, a consequence of this analysis is that no hydroelectric or nuclear power are included in the fuel cycle analysis. Reducing gasoline demand by increasing electric power output for EVs does not increase the output from these generation facilities. The marginal source of electric power if needed was assumed to be generated from natural gas. Another consequence of the marginal analysis is that substantial transportation distances are assumed for natural gas for CNG and hydrogen vehicles. Some analysts argue that natural gas resources in the U.S. are limited and if hydrogen FCVs or CNG vehicles are used on a large-scale basis, additional natural gas would need to come from foreign sources of LNG. In this

[2] Hydrocarbon emissions are classified as reactive organic gases (ROG) or non-methane organic gases (NMOG).

analysis, foreign sources of LNG were not included, but pipeline transportation from Canada was. This pipeline transportation requires a substantial amount of energy and results higher GHG emissions for natural gas or natural gas derived fuels.

## 2.2 Fuel and Feedstock Properties

The properties and compositions of the fuels affect their fuel-cycle emissions. This report accounts for the effect of fuel composition on processing requirements and efficiency, evaporative and fugitive emissions, and combustion emissions. The properties and compositions of fuels in this study are summarized in Table 2-5. Included are the liquid or gas densities and the lower heating values in metric and English units. The relevant vapor pressures and vapor molecular weights are described in Appendix A. A range of properties corresponds to most of the fuels and feedstocks in

**Table 2-5. Fuel Properties**

| Type of Fuel | Density lb/gal | Density g/L | LHV[a] Btu/gal | LHV MJ/L | Carbon wt % |
|---|---|---|---|---|---|
| Gasoline (CA RFG3)[b] | 6.0 | 719 | 111,000 | 30.8 | 82.1 |
| Gasoline blendstock (CARB OB)[c] | 6.0 | 719 | 113,000 | 31.5 | 82.8 |
| Diesel (low sulfur) | 7.1 | 854 | 130,800 | 36.5 | 86.7 |
| FT Diesel | 6.4 | 770 | 118,800 | 33.1 | 86.0 |
| LPG from petroleum | 4.2 | 503 | 83,200 | 23.2 | 82.0 |
| LPG from natural gas | 4.2 | 501 | 82,600 | 23.0 | 81.8 |
| Natural Gas | 4.6[d] | 729[c] | 92,800[d] | 97.9[e] | 73.6 |
| LNG | 3.5 | 419 | 72,900 | 20.3 | 74.0 |
| Methanol | 6.6 | 791 | 57,000 | 15.9 | 37.5 |
| Hydrogen | 2.205[e] | 84[f] | 27,400[d] | 119.9[d] | 0 |
| Ethanol | 6.6 | 791 | 76,000 | 21.2 | 52.1 |
| Electricity | — | — | 3412[g] | 3.6[g] | 0 |

[a]LHV: Lower heating value.
[b]Contains 5.7% ethanol (2% oxygen).
[c]CARB OB is mixed with ethanol to make RFG3.
[d]Per 100 scf.
[e]Per kg.
[f]Per cubic meter.
[g]Per kWh.

*Sources: ARB 1996, Wang 1999, MathPro 1998, MathPro 1999.*

Table 2-5. The values in the table are representative of average compositions since many fuels vary. Methanol, ethanol, and hydrogen are compounds with invariant compositions. The English and metric units presented here are intended to allow for the comparison of emission factors in different studies and also convert fuels to a gasoline or diesel equivalent basis for estimating vehicle fuel economy. Vehicle fuel economy is generally judged on a lower heating value basis both as industry practice and because ICE does not recover energy from condensing water vapor. The fuel properties are also presented in typical units of measure and commerce such as gallons of methanol or kW-hr is of electricity. However, care must be taken to track both the energy content of the fuel and its efficiency when used in an energy conversion device such as a fuel cell or ICE. It is also easier to visualize tracking fuels through the various fuel cycle steps compared to equivalent gallons of gasoline or Btus.

### 2.3 Definition of Fuel Cycles

This study considers fuel cycle emissions from vehicle fuels. The analysis considers the marginal, or incremental gallon (or equivalent fuel unit) consumed in the SoCAB. The SoCAB region is used as a surrogate for urban area emissions. The San Francisco Bay Area also has marine terminals and the emission estimates developed for the SoCAB are reasonable for other urban areas in California.

A fuel cycle emissions analysis is one aspect of a life cycle analysis for motor vehicles. The fuel cycle portion in this study covers the emissions associated with the fuel, from the point of the feedstock extraction or production, through the fueling of the vehicle (see Figure 2-4). This includes eight fuel production phases described in Section 2.3.1. Vehicle emissions analysis (including vehicle evaporative and tailpipe emissions) is

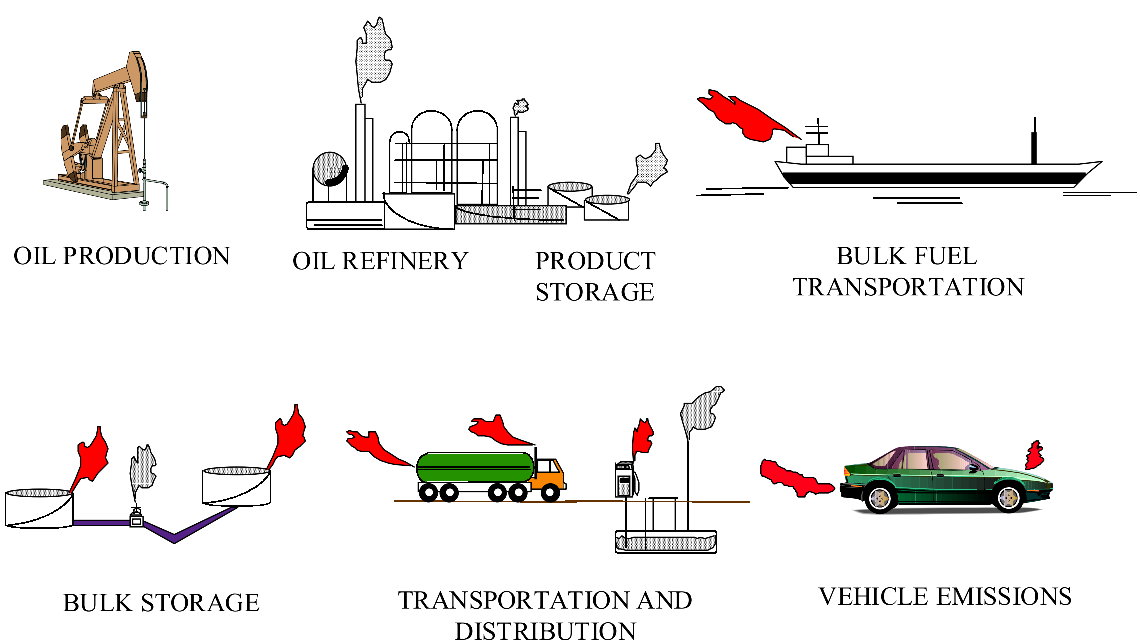



**Figure 2-4. Fuel-Cycle and Vehicle Emission Sources**

performed separately and is described in Section 2.3.2. This fuel cycle study analyzes emissions of $NO_x$, PM, CO, NMOG, and toxics in the SoCAB, and it also estimates total GHG emissions of $CO_2$, nitrous oxide ($N_2O$), and methane ($CH_4$). Other portions of a life cycle analysis include the costs, materials, energy, or emissions associated with the vehicle itself, from production of the primary materials to the recycling of the parts after the useful life is finished. For electric vehicles, the vehicle life cycle also includes the life analysis of its batteries.

The fuel-cycle emissions in this study are represented as the weighted average of different production and distribution technologies described in this section. Some fuel/feedstock combinations, such as methanol from natural gas, were represented separately while others were combined to simplify the comparison of fuels. The basis for scenarios, mix of feedstocks, as well as production and distribution technologies is described in the following sections.

### 2.3.1 Geographic Distribution

Because some fuels are produced outside of California, emissions from the entire fuel-cycle will not directly impact California urban areas. For this reason, it is important to identify the percentage of feedstock extracted or fuel produced in each area. In order to help evaluate the impact on local emission inventories and air quality as well as to take into consideration the differences between local emission rules, the emissions were geographically categorized. Emissions from fuel production can then be allocated according to the locations in Table 2-6. This table also shows the acronyms used to identify each of these areas for this report. This geographic distinction was not made for GHG emissions since its effect is global in nature.

**Table 2-6. Locations of Emissions**

| Location | Acronym |
|---|---|
| Within the SoCAB | SC |
| Within California, but outside the SoCAB | CA |
| Within the U.S., but outside of California | US |
| Rest of the World, outside the U.S. | ROW |

Emissions for fuel or feedstock transportation and distribution are also divided into the four geographic distribution categories. For example, emissions for ships entering and exiting the San Pedro ports are attributed to the SoCAB for a portion of the trip. The balance of these emissions is attributed to the rest of the world. Both land and sea transport emissions are allocated proportionally according to their transport route.

This study is intended to be used to evaluate marginal emissions from fuel production. The interpretation of which emissions correspond to marginal fuel production depends on several factors that are discussed in the following section. The focus on marginal emissions raises questions of transporting emissions into and out of the state. For example, methanol could be sold for vehicle use in the SoCAB without any production emissions affecting local air quality. Similarly, gasoline is transported to other states from the SoCAB, while the refinery emissions contribute to emission inventories in the SoCAB.

### 2.3.2 Petroleum Fuels: Gasoline, Diesel, LPG

Gasoline, diesel and LPG are produced from crude oil. These fuels share the same crude oil feedstock and therefore the same extraction and feedstock distribution paths (LPG is also produced from natural gas). See the Appendix A for discussion of crude oil extraction, transport, and refining.

Of these three petroleum-based fuels, refined gasoline and diesel or refined gasoline and diesel components are imported to the SoCAB by marine transport, in the marginal scenario. In addition, LNG, methanol, and FTD are also imported by sea. As a result of these fuels being complete[3] when they arrive in the SoCAB, there are no emissions associated with crude oil production or refining in the region. For gasoline, diesel, and LNG, there are, however, marine vessel local emissions, which are calculated in the same manner for each of these fuels since the distance traveled by the ships within the SoCAB is identical. See the Appendix A for distance estimations.

LPG is also imported to California in significant quantities but it is transported by rail. Its marginal uses are as a motor fuel or as a refinery fuel or feedstock. This LPG comes from natural gas processing facilities in Canada and the southwest United States. Some LPG is also imported from refineries in Utah. Future demand for LPG could be so high that marginal demand must come largely from natural gas liquids. However, given the opportunities for displacing LPG from refinery use, and the source of current LPG, this study assumes refinery-based and natural-gas-based LPG production (natural gas-based production is discussed in Section 2.3.2).

After each of the imported fuels is transported to the South Coast, it is stored in bulk tanks and distributed to fueling stations in tank trucks. Emissions resulting from the storage of petroleum and petroleum fuels consist of two main types: fugitive and spillage emissions. Fugitive emissions are hydrocarbon emissions that escape from storage tanks, pipes, valves, and other sources of leaks. These emissions are generally greater for gasoline than diesel, due to its higher vapor pressure.

The low vapor pressure of diesel has generally resulted in limited requirements on vapor recovery from storage and fueling equipment. The vapor pressure from diesel is so

[3] Any additional refining to manufacture gasoline or diesel fuels meeting California specifications is not included in this analysis.

much lower than that of gasoline, that the uncontrolled diesel vapor losses are less than 10 percent of gasoline emissions with 95 percent emission control.

Vapor losses primarily occur when tank trucks are filled at the bulk terminal, unloaded at the fueling station, and during vehicle fueling. Spillage during vehicle fueling is also a significant source of emissions. Table 2-7 summarizes phases of conversion of crude oil to gasoline, diesel and LPG and natural gas to FTD, LNG, and methanol. They are grouped together since they share common means of transportation and emissions in the SoCAB. FTD, LNG, and methanol are discussed further in Section 2.3.3, along with other natural gas-based fuels.

**Table 2-7. Marine Imported Liquid Fuel Production and Distribution Phases[a]**

| Phase | Process | Emission Sources | Marginal Emissions[b] | |
|---|---|---|---|---|
| | | | $NO_x$ | NMOG |
| 1 | Extraction | Heaters, pumps, fugitive | — | — |
| 2 | Transport | Pipeline (pumps), ships (engines), fixed roof storage tanks | — | — |
| 3 | Refining | Fugitive emissions, refinery heaters, refinery process emissions | — | — |
| 4 | Site Storage | Refinery tanks | — | — |
| 5 | Transport to bulk storage | Marine tanker | M | M |
| 6 | Bulk storage | Floating roof tanks or pressurized tanks | 0 | M |
| 7 | Transport to local station | Tanker trucks (engines and fugitive) | M | M |
| 8 | Local station distribution | Underground tanks, refueling vapors, spills; above grounds tanks for LPG | 0 | M |

[a] Gasoline, diesel, LPG from petroleum, FTD, methanol from natural gas, ethanol from corn.
[b] M indicates if marginal emissions occur in the SoCAB. — indicates no marginal emissions, while zero emission sources are indicated with a 0.

### 2.3.3 Natural Gas Based Fuels: CNG, LNG, LPG, Methanol, FTD, and Hydrogen

The natural gas and natural gas-based fuels for transportation included in this study are CNG, LNG, LPG, methanol, FTD, and hydrogen. As mentioned in the previous section, LPG can be produced either from petroleum or natural gas. The distribution modes for LNG, methanol, and FTD were summarized in Table 2-7, while the conversion processes are described in this section.

Natural gas is recovered and collected from oil and natural gas fields. The gas is then transported by pipeline to processing facilities, which are usually located near the gas field. For commercial natural gas, the gas is processed to remove propane, butane, moisture, sulfur compounds and $CO_2$. When flared gas is used as a feedstock, no $CO_2$

emissions from the natural gas feedstock are attributable to the end product. See Appendix A for discussion of natural gas transport distances and the mix of diverted flared gas and new gas that was assumed for this study.

All of the natural gas-based fuels have identical fuel cycles in the extraction and feedstock transport phases. After this point, the processing steps differ.

### CNG and Hydrogen

Natural gas is a feedstock for CNG and for hydrogen by steam reforming. Pipeline natural gas is compressed to 3600 psi to produce CNG. Hydrogen can be produced at central fueling stations and transported as a liquid or by pipeline. These options have been analyzed extensively (ADL 2002). The on-site steam reformer option was selected for this analysis, as it appears to provide the best opportunity for low cost and widespread distribution (ADL 2002, Shell 2001).

CNG and compressed hydrogen are most similar due to their similar distribution phases. Hydrogen can be produced from various feedstocks and through several processes but this study we have assumed that hydrogen is produced from natural gas in a refueling station on-site reformer or electrolyzer. In the case of the reformer, the fuel cycle emissions are identical to those of compressed natural gas except that hydrogen production produces reformer emissions but avoids small ROG refueling emissions, as described in Table 2-8. The electrolyzer option is discussed later in this section with electricity.

### LPG

As mentioned in Section 2.3.4, LPG can be produced from the extracted liquids of natural gas, as a byproduct of petroleum refining. Marginal production emissions in the SoCAB are still zero, like the case of petroleum refining since processing of LPG occurs in Canada or the Southwest states. The principal difference affecting marginal fuel cycle emissions is the additional transportation by rail car from outside California. The fuel cycle steps for LPG parallel those for diesel and gasoline after it reaches the SoCAB except for pressurization of tanks, as indicated in Table 2-9. Fugitive emissions from LPG transfer occur when fuel is transferred from a storage tank as well as rail car, truck, and vehicle tanks. When a tank is filled, liquid LPG fills the tank and LPG vapors condense. When a tank is filled, a small amount of LPG vapor is vented as part of the tank filling procedure. Further details of fugitive emissions for LPG production and distribution are in Appendix A.

Although ethanol is a biomass fuel and discussed in the following section, its emission sources are represented in Table 2-9 because it is also a liquid fuel transported by rail.

### Table 2-8. Natural Gas-based Gaseous Fuels Production and Distribution Phases[a]

| Phase | Process | Emission Sources | Marginal Emissions[b] | |
|---|---|---|---|---|
| | | | $NO_x$ | NMOG |
| 1 | Extraction | Compressors, fugitive | — | — |
| 2 | Transport | Natural gas pipeline (compressors and fugitive) | — | — |
| 3 | Refining | Fugitive emissions, vent gas combustion | — | — |
| 4 | Site Storage | None | — | — |
| 5 | Transport to bulk storage | Pipeline (pumps and fugitive) | M | M |
| 6 | Bulk storage | Underground storage | — | — |
| 7 | Transport to local station | Pipeline (pumps and fugitive) | M | M |
| 8 | Local station compression reforming | Refueling losses, electric power for compression, reformer emissions | M | M |

[a] Gasoline, diesel, LPG from petroleum, FTD, methanol for natural gas, ethanol from corn.
[b] M indicates if marginal emissions occur in the SoCAB. — indicates no marginal emissions, while zero emission sources are indicated with a 0.

### Table 2-9. Production and Distribution Phases for Rail-Transported Fuels[a]

| Phase | Process | Emission Sources | Marginal Emissions[b] | |
|---|---|---|---|---|
| | | | $NO_x$ | NMOG |
| 1 | Extraction | Compressors, fugitive or agricultural equipment | — | — |
| 2 | Transport | Pipeline (compressors and fugitive), truck (engine) | — | — |
| 3 | Refining/Production | Fugitives, compressor engines, gas combustion | — | — |
| 4 | Site Storage | Onsite tanks | — | — |
| 5 | Transport to bulk storage | Rail car (engines and fugitives) | M | M |
| 6 | Bulk storage | Pressurized (LPG) or non-pressurized tanks (ethanol) | 0 | M |
| 7 | Transport to local station | Tanker trucks (engines and fugitive) | M | M |
| 8 | Local station distribution | Above grounds tanks, refueling vapors | 0 | M |

[a] LPG and LNG from natural gas, ethanol from corn, ethanol from biomass.
[b] M indicates if marginal emissions occur in the SoCAB. — indicates no marginal emissions, while zero emission sources are indicated with a 0.

### Synthetic Diesel (FTD)

Synthetic diesel and other synthetic liquid fuels are formed from a three-step process (known as the Fischer-Tropsch [FT] Process) which converts coal, biomass, or natural gas to liquid fuels. It is an attractive air quality option to conventional diesel fuels because it contains no sulfur or aromatics and has a higher cetane number. This study considers only synthetic diesel from natural gas because it is the most economically attractive option.

As a result of this process, the fuel cycle for synthetic diesel at the upstream end is similar to that of methanol.

### Methanol

Methanol, like synthetic diesel, can be produced from a variety of feedstocks. Most methanol in the world and the entire methanol used in California as a vehicle fuel is made from natural gas. The conversion process typically used, called steam reforming, is similar to the process used to make synthetic diesel, but uses different catalysts, temperatures, and pressures. The upstream fuel cycle is similar to compressed natural gas. Fuel distribution for methanol consists of bulk storage terminals and transfer systems similar to those for gasoline. At the margin, it is imported to California by marine transport.

See Table 2-7 in Section 2.3.4 for production phases of methanol and FTD.

### LNG

Liquid natural gas is produced from natural gas in liquefaction facilities. As a result, the extraction phases for LNG are the same as for other natural gas fuels. The natural gas is compressed, cooled, and expanded in a multi-stage operation, using natural gas-powered engines for compression. LNG is then stored as a cryogenic liquid in insulated storage vessels. LNG can be produced in a variety of locations. Pressure let down facilities in California could be a source of LNG. Local liquefier technologies have also been considered. However, most of the resources for LNG lie outside of California. The analysis in this study is based on LNG imported from out-of-state sources that are shipped to California by rail. The primary source of LNG is assumed to be Western States. LNG could also be transported by tanker ship to Mexico and shipped by rail car to California. An LNG marine terminal in California was not considered a likely option; however the emission impacts would be similar to those related to import by rail. Marginal emission sources are indicated in Table 2-9.

The distribution of LNG has several emission sources that include venting from storage tanks, tank truck fuel transfers, tank truck gas purging.

### 2.3.4 Biomass Fuels

Ethanol can be produced from various sources, including many types of biomass. In this analysis, ethanol is produced from the fermentation of corn and imported from corn-producing states in the mid-west United States. There is potential for significant production of ethanol within California from cellulosic and starch-based biomass, such as agricultural residues and sugar beets. In the non-starch process, cellulose and ligno-cellulose are hydrolyzed and converted to starches. These are then fermented and converted to ethanol.

In this study, the ethanol is imported by rail. Once the fuel is transported to the SoCAB, its emission sources are much like other liquid transportation fuels.

### 2.3.5 Power Generation: Electricity and Hydrogen

Due to the ARB ZEV rules, sales of electric vehicles are expected to climb significantly beginning in MY 2003 (Autumn of 2002). Also tapping electric resources in the future may be fuel cell vehicles, including cars and buses, which can use hydrogen produced by electrolysis. The electrolysis separates water into hydrogen and oxygen by passing a current through an electrochemical cell. Although electrolysis is not the overall most energy efficient method to produce hydrogen if the electricity is produced from fossil fuels, it does have the advantage of no local emissions. Also, electrolysis could use renewable resources on-site in order to avoid the use of conventional electric power. In this study, however, hydrogen is electrolyzed using power from the grid as non-fossil sources would not be developed solely to meet vehicle demand.

In California, the additional electricity required to fuel electric vehicles, fuel cell vehicles, and other electro-drive equipment will be generated using natural gas. The rationale behind this assumption is discussed in a prior study on fuel cycle emissions (ARB 2001). Since all marginal electricity is expected to be derived from natural gas, the fuel extraction and transport aspects of the fuel cycle are identical to other natural gas-based fuels. The distribution of electricity is not associated with any emissions, as indicated in Table 2-10. However, the losses in the fuel chain affect how much power must be produced at the power plant.

## 2.4 Local Emissions

Local criteria pollutant and toxic emissions associated with vehicle operation are used to assess the impact of petroleum product reduction and/or displacement. Fuel cycle emissions are determined on a g/gal (or unit fuel) basis so the total impact on emissions can determined from the total fuel used in a region for a variety of vehicle technologies. Vehicle emissions were estimated for PZEV complying light-duty vehicles and heavy-

**Table 2-10. Electricity Production and Distribution Phases[a]**

| Phase | Process | Emission Source and Energy Loss | Marginal Emissions[b] | |
|---|---|---|---|---|
| | | | $NO_x$ | NMOG |
| 1 | Extraction | Compressors, fugitive | — | — |
| 2 | Transport | Natural gas pipeline (compressors and fugitive) | M | M |
| 3 | Production | Fugitive emissions, combustion emissions | 0 | M |
| 4 | Site storage | — | 0 | 0 |
| 5 | Transport to bulk storage | Transmission line losses | 0 | 0 |
| 6 | Bulk storage | — | — | — |
| 7 | Transport to local station | — | — | — |
| 8 | Local station distribution | Distribution, lines, substation transformers, electrolyzer for hydrogen | 0 | 0 |

[a] Electricity for battery EVs and hydrogen from electrolysis.
[b] M indicates if marginal emissions occur in the SoCAB. — indicates no marginal emissions, while zero emission sources are indicated with a 0.

duty vehicles meeting future ARB and EPA 2007 emissions standards. Table 2-11 shows the criteria pollutants and toxics associated with marginal fuel production.

### 2.4.1 Local Fuel Cycle Emissions

The purpose of calculating fuel cycle emissions was to identify g/gal emission factors that could be used to determine statewide emissions that correspond to petroleum reduction options. These emission values are inputs to an assessment that estimates the monetary impact of the various emission reductions.

Fuel cycle emissions were analyzed on a marginal basis based on fuel use in the SoCAB. The geographic distribution of the emissions was also assessed (see 1996 Acurex study, Unnasch 1996). For the purposes of this study, the results focus on emissions in the SoCAB as a surrogate for the rest of the state to provide a basis for population exposure assessments that are typical for fuel distribution and vehicle operation in urban areas of California.

Fuel cycle emissions are shown for both light and heavy duty vehicles, as there could be minor differences in refueling emissions. The main difference involves the spillage rate for vehicle refueling. In the case of heavy-duty vehicles, fuel flow rates and tank volumes are generally larger and the quantity of fuel spilled may also increase due to

## Table 2-11. Summary of Criteria Pollutants and Toxic Emissions (Emissions in Urban Areas)[a]

| Pollutant | Light Duty Vehicles | | | | | | | | | | | Heavy-Duty Vehicles | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | RFG3 | RFD | LPG | LPG NG | FTD | M100 NG | Ethanol E85 | CNG | LNG | cH2 NG SR | Electric | RFD HDV | FTD HDV | CNG HDV per 100 scf | LNG HDV |
| Fuel Cycle (g/unit fuel) | gal | gal | gal | gal | gal | gal | gal | 100 scf | gal | kg | kWh | gal | gal | gal | gal |
| $NO_x$ | 0.033 | 0.033 | 0.032 | 0.101 | 0.031 | 0.028 | 0.040 | 0.0015 | 0.101 | 0.0036 | 0.0001 | 0.033 | 0.031 | 0.0015 | 0.101 |
| CO | 0.010 | 0.010 | 0.037 | 0.052 | 0.0095 | 0.0092 | 0.010 | 0.0096 | 0.052 | 0.035 | 0.0005 | 0.010 | 0.0095 | 0.0096 | 0.052 |
| NMOG | 0.49 | 0.35 | 0.47 | 0.48 | 0.31 | 0.27 | 0.310 | 0.0096 | 0.024 | 0.026 | 0.0071 | 0.35 | 0.31 | 0.0096 | 0.024 |
| Toxics (total mg/unit fuel) | 65 | 3.89 | 0.68 | 2.31 | 0.77 | 0.77 | 11.8 | 1.108 | 2.310 | 0.104 | 0.120 | 3.89 | 0.77 | 1.11 | 2.31 |
| Benzene | 4.43 | 0.08 | 0.06 | 0.21 | 0.07 | 0.07 | 0.8 | 0.949 | 0.208 | 0.000 | 0.032 | 0.08 | 0.07 | 0.95 | 0.21 |
| 1,3 Butadiene | 0.04 | 0.02 | 0.06 | 0.06 | 0.02 | 0.02 | 0.0 | 0.005 | 0.064 | 0.000 | 0.000 | 0.02 | 0.02 | 0.01 | 0.06 |
| Formaldehyde | 0.95 | 0.59 | 0.42 | 1.52 | 0.51 | 0.51 | 0.7 | 0.117 | 1.523 | 0.104 | 0.086 | 0.59 | 0.51 | 0.12 | 1.52 |
| Acetaldehyde | 0.31 | 0.19 | 0.14 | 0.50 | 0.17 | 0.17 | 0.2 | 0.036 | 0.495 | 0.000 | 0.001 | 0.19 | 0.17 | 0.04 | 0.50 |
| PAHs | 59 | 3.01 | 0.01 | 0.02 | 0.01 | 0.01 | 10.0 | 0.000 | 0.020 | 0.000 | 0.000 | 3.01 | 0.01 | 0.00 | 0.02 |
| Particulate Matter (g/unit fuel) | gal | gal | gal | gal | gal | gal | gal | 100 scf | gal | kg | kWh | gal | gal | gal | gal |
| Diesel exhaust | 0.0024 | 0.0025 | 0.0022 | 0.0019 | 0.0023 | 0.0023 | 0.0 | 0 | 0.0019 | 0 | 0 | 0.0025 | 0.0023 | 0 | 0.0019 |
| Power plant combustion | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0039 | 0 | 0.011 | 0.0032 | 0 | 0 | 0.0039 | 0 |
| Tire | 0.0002 | 0.0002 | 0.0002 | 0.0002 | 0.0002 | 0.0002 | 0.0002 | 0 | 0.0002 | 0 | 0 | 0.0002 | 0.0002 | 0.0002 | 0.0002 |
| Brake | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0 | 0.0001 | 0 | 0 | 0.0001 | 0.0001 | 0.0001 | 0.0001 |
| Vehicle (g/mi) | ICEV | ICEV | ICEV | ICEV | ICEV | FCV | ICEV | ICEV | ICEV | FCV | BEV | ICEV | ICEV | ICEV | ICEV |
| $NO_x$ | 0.024 | 0.024 | 0.024 | 0.024 | 0.024 | 0 | 0.024 | 0.024 | 0.024 | 0 | 0 | 0.70 | 0.70 | 0.70 | 0.70 |
| CO | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0 | 0.04 | 0.04 | 0.04 | 0 | 0 | 2.06 | 2.06 | 2.06 | 2.06 |
| NMOG | 0.0267 | 0.00701 | 0.0067 | 0.0067 | 0.00701 | 0.01646 | 0.01158 | 0.0067 | 0.0067 | 0 | 0 | 0.29 | 0.29 | 0.29 | 0.29 |
| Toxics (total mg/mi) | 2.51 | 1.33 | 0.83 | 0.83 | 1.19 | 0.80 | 0.825 | 0.92 | 0.92 | 0 | 0 | 57.5 | 51.7 | 39.8 | 39.8 |
| Benzene | 0.36 | 0.12 | 0.10 | 0.10 | 0.00 | 0.00 | 0.1 | 0.02 | 0.02 | 0 | 0 | 5.17 | 0.00 | 0.87 | 0.87 |
| 1,3 Butadiene | 0.05 | 0.04 | 0.02 | 0.02 | 0.04 | 0.00 | 0.02 | 0.01 | 0.01 | 0 | 0 | 1.58 | 1.58 | 0.35 | 0.35 |
| Formaldehyde | 0.60 | 0.87 | 0.30 | 0.30 | 0.87 | 0.00 | 0.3 | 0.87 | 0.87 | 0 | 0 | 37.8 | 37.8 | 37.7 | 37.7 |
| Acetaldehyde | 0.13 | 0.28 | 0.40 | 0.40 | 0.28 | 0.80 | 0.4 | 0.02 | 0.02 | 0 | 0 | 12.29 | 12.29 | 0.87 | 0.87 |
| PAHs | 1.36 | 0.01 | 0.01 | 0.01 | 0.00 | 0.00 | 0.005 | 0.00 | 0.00 | 0 | 0 | 0.61 | 0.00 | 0.00 | 0.00 |
| Particulate Matter (g/mi) | | | | | | | | | | | | | | | |
| Vehicle exhaust | 0.004 | 0.01 | 0.004 | 0.004 | 0.006 | 0 | 0.004 | 0.004 | 0.004 | 0 | 0 | 0.04 | 0.04 | 0.04 | 0.04 |
| Power plant combustion | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Tire | 0.0098 | 0.0098 | 0.0098 | 0.0098 | 0.0098 | 0.0069 | 0.0098 | 0.0098 | 0.0098 | 0.0069 | 0.0069 | 0.0274 | 0.0274 | 0.0274 | 0.0274 |
| Brake | 0.0157 | 0.0157 | 0.0157 | 0.0157 | 0.0157 | 0.0110 | 0.0157 | 0.0157 | 0.0157 | 0.0110 | 0.0110 | 0.0126 | 0.0126 | 0.0126 | 0.0126 |

[a]Marginal emission calculation.

[b]Abbreviations used: Reformulated gasoline Phase III (RFG3), reformulated diesel (RFD) meeting ultra low, sulfur diesel ARB and EPA requirement (<15 ppm), liquefied petroleum gas (LPG), Fischer Tropsch Diesel (FTD), 100% methanol from natural gas (M100 NG), 85% ethanol mixed with 15% gasoline (E85), compressed natural gas (CNG), liquefied natural gas (LNG), compressed hydrogen from steam reforming natural gas ($CH_2$ NG SR), heavy-duty vehicle (HDV).

larger fuel connection fittings. Some heavy-duty vehicles are fueled with "dry break" fittings that shut off automatically when the fuel nozzle is removed from the vehicle. Even these fittings can result in small levels of spillage.

Marginal fuel cycle emissions correspond primarily to fuel transport, storage, and distribution emissions for all fuels except hydrogen and electricity. Most of the NMOG emissions are due to fuel and vapor losses. $NO_x$ and diesel PM are caused by marine vessels and delivery trucks.

In the case of on-site hydrogen production, CNG compression, and electric power production, the fuels are all produced from natural gas (natural gas is considered to be the likely fuel for marginal power production in California). Some storage losses are associated with natural gas transmission. The emissions from natural gas pipeline engines also contribute to the fuel cycle emissions.

Table 2-12 shows the emissions associated with fuel production outside the SoCAB but still in California. These correspond to fuel transportation and power plant emissions. The emissions impact is zero for liquid fuels that are imported by marine vessel. Emissions from ethanol production from biomass were also assumed negligible, as there are a variety of new emission sources, which are offset by emission reductions associated with the use of biomass feedstocks. On balance these feedstock production activities result in net emission reductions. Since the results vary considerably among feedstock choices and the options for ethanol production are still under evaluation,

**Table 2-12. Summary of Criteria Pollutants and Toxic Emissions (Additional Fuel Cycle Emissions outside Urban Areas in California)**

| Pollutant | RFG3 | RFD | LPG | LPG NG | FTD | M100 NG | E85 Ethanol FFV | CNG | LNG | cH2 SR NG | Electric |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Fuel Cycle (g/unit fuel) | gal | gal | gal | gal | gal | gal | gal | 100 scf | gal | kg | kWh |
| $NO_x$ | 0 | 0 | 0 | 0.051 | 0 | 0 | 0 | 0.039 | 0.051 | 0.082 | 0.011 |
| CO | 0 | 0 | 0 | 0.026 | 0 | 0 | 0 | 0.306 | 0.026 | 0.870 | 0.248 |
| NMOG | 0 | 0 | 0 | 0.0078 | 0 | 0 | 0 | 0.0155 | 0.0078 | 0.043 | 0.012 |
| Toxics (total mg/unit fuel) | 0 | 0 | 0 | 1.155 | 0 | 0 | 0 | 1.048 | 1.155 | 0.104 | 0.117 |
| Benzene | 0 | 0 | 0 | 0.104 | 0 | 0 | 0 | 0.902 | 0.104 | 0.000 | 0.032 |
| 1,3 Butadiene | 0 | 0 | 0 | 0.032 | 0 | 0 | 0 | 0.004 | 0.032 | 0.000 | 0.000 |
| Formaldehyde | 0 | 0 | 0 | 0.762 | 0 | 0 | 0 | 0.109 | 0.762 | 0.104 | 0.084 |
| Acetaldehyde | 0 | 0 | 0 | 0.248 | 0 | 0 | 0 | 0.033 | 0.248 | 0.000 | 0.001 |
| PAHs | 0 | 0 | 0 | 0.0098 | 0 | 0 | 0 | 0.0000 | 0.0098 | 0 | 0 |
| Particulate Matter | | | | | | | | | | | |
| Exhaust PM (g/mi) | 0 | 0 | 0 | 0.0009 | 0 | 0 | 0 | 0 | 0.0009 | 0 | 0 |
| Power Plant PM | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.0073 | 0.0000 | 0.0205 | 0.0032 |

[a] Marginal emission calculation.

[b] Abbreviations used: Reformulated gasoline Phase III (RFG3), reformulated diesel (RFD) meeting ultra low, sulfur diesel ARB and EPA requirement (<15 ppm), liquefied petroleum gas (LPG), Fischer Tropsch Diesel (FTD), 100% methanol from natural gas (M100 NG), 85% ethanol mixed with 15% gasoline (E85), compressed natural gas (CNG), liquefied natural gas (LNG), compressed hydrogen from steam reforming natural gas ($CH_2$ NG SR), heavy-duty vehicle (HDV).

credits for emission reductions were not included in this analysis. The magnitude of estimated emission reductions due to biomass fuel production is estimated in a report by the California Energy Commission (CEC 2001).

### 2.4.2 Local Vehicle Emissions

Emissions from light and heavy-duty vehicles were shown in Table 2-11. Emissions from light-duty vehicles are estimated from ARB assessment of the in-use emissions from partial zero emission vehicles (PZEVs) (ARB 1999). In-use emissions are expected to be different than the standard due to deterioration over time, emission control malfunctions, and lower zero mileage emissions that allow for compliance over the life of the vehicle. For example, the PZEV NMOG standard is 0.01 g/mi but the in-use estimate is 0.0067 g/mi. ARBs estimates of in-use emissions are presented in their ZEV staff report (ARB 2000b). Toxic emissions were estimated from speciated profiles for each emission source such as truck exhaust, gasoline spillage, etc. Emissions from heavy-duty vehicles correspond to estimates for the model year 2007. At this time, all prevailing emission standards would be rolled in.

The values that correspond to the inventory for gasoline light- and diesel heavy-duty vehicles are shown in Table 2-13. For most alternative fuel options, the emission levels are assumed to be the same even though alternative fuels may provide advantages in complying with emission standards. The standards are at such low levels, that CNG NMOG and PM were assumed to emit at the standard. Although PZEVs are intended to have zero evaporative emissions, the ARB emissions inventory includes a non-zero value of 0.02 g/mi (ARB 1999). This value primarily is based on the detection limit for the certification test for evaporative emissions. However, the in-use value for evaporative emissions may also reflect expectations for degradation over the life of the vehicle.

**Table 2-13. In-Use Emissions from LDVs and HDVs (g/mi)**

| Pollutant | PZEV | 2007 HDV |
|---|---|---|
| $NO_x$ | 0.024[a] | 0.7[b] |
| CO | 0.04[a] | 2.1[c] |
| Exhaust NMOG | 0.0067[a] | 0.29[c] |
| Evaporative NMOG | 0.02[a] | 0.0006[d] |
| Exhaust PM | 0.004[a] | 0.04[b] |
| Tire PM | 0.01[c] | 0.0274[c] |
| Brake PM | 0.016[c] | 0.0126[c] |

[a] ARB 1999.
[b] 90% reduction from EMFAC 2000 MY2004.
[c] EMFAC 2000.
[d] Estimated from fuel vapor pressure.

Table 2-14 shows adjustments that were made for electric drive and diesel LDV technologies. For battery EVs and hydrogen FCVs, exhaust emissions are zero. These are also zero for methanol FCVs. Reformers from fuel cell vehicles are expected to produce no $NO_x$, CO, or particulate, but they would produce NMOG (Panik). Tire and brake emissions were also estimated to be lower because of regenerative braking capability for vehicles with electric drive capability.

Figure 2-5 shows the fuel cycle, evaporative, and exhaust emissions from light-duty vehicles. As the fuel cycle emissions depend on fuel economy, these values are meant to be illustrative.

**Table 2-14. Low Emission Vehicle Assumptions**

| Pollutant | Vehicle Technology[a] |
|---|---|
| Zero $NO_x$ | EV, $cH_2$ FCV, Methanol FCV |
| Zero CO | EV, $cH_2$ FCV, Methanol FCV |
| Zero NMOG | EV, $cH_2$ FCV |
| Zero combustion PM | EV, $cH_2$ FCV, Methanol FCV |
| Low tire, brake PM | EV, $cH_2$ FCV, Methanol FCV |

[a] CNG and LNG are possible low PM options but no data are available for PZEV or 2007 HDV certified vehicles.

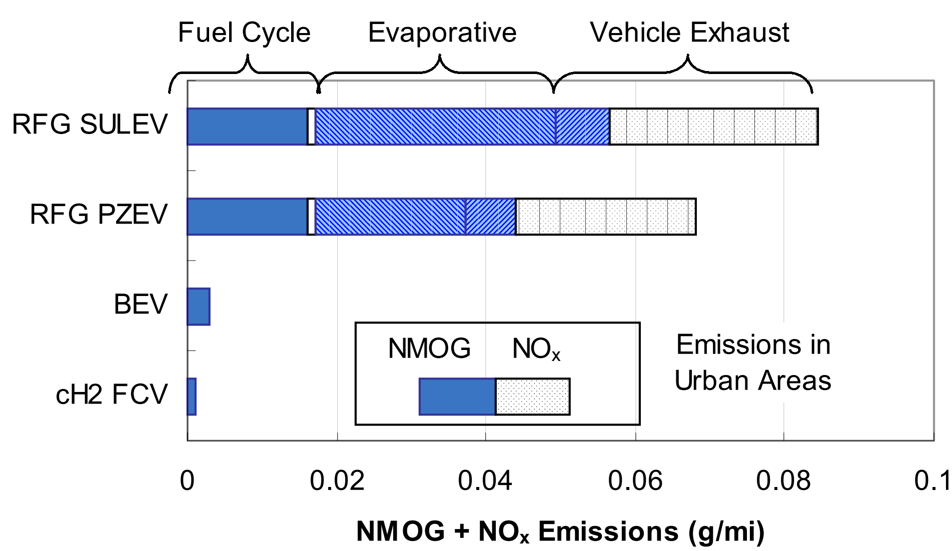



**Figure 2-5. Fuel Cycle Evaporative and Exhaust Emissions from LDVs**

Toxic emissions were estimated from the speciation profiles of various emission sources described in Appendix A. The results for gasoline PZEVs and ZEVs are shown in Figure 2-6. The impact of toxic emissions was determined based on the mortality impact from studies by ARB and the South Coast Air Basin (SCAQMD). The weighted toxic results are shown in Figure 2-7.

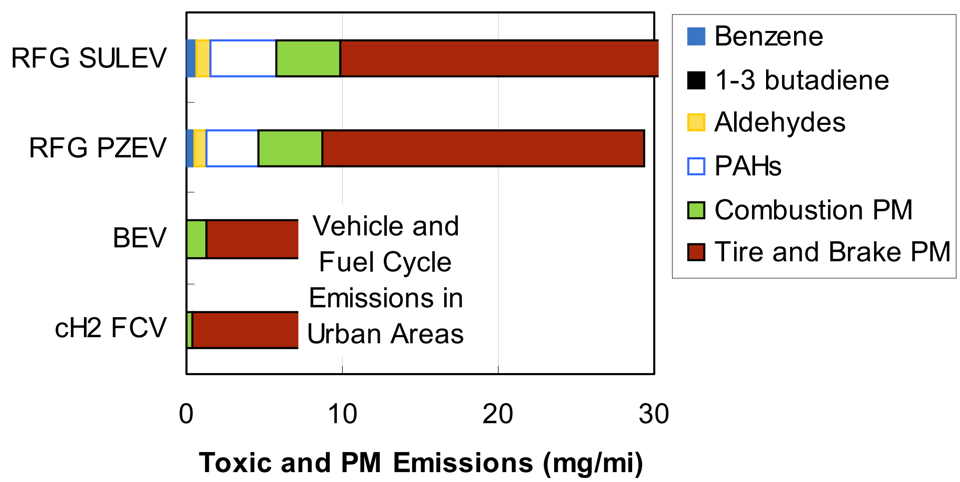



**Figure 2-6. Toxic and PM Emissions from LDVs**

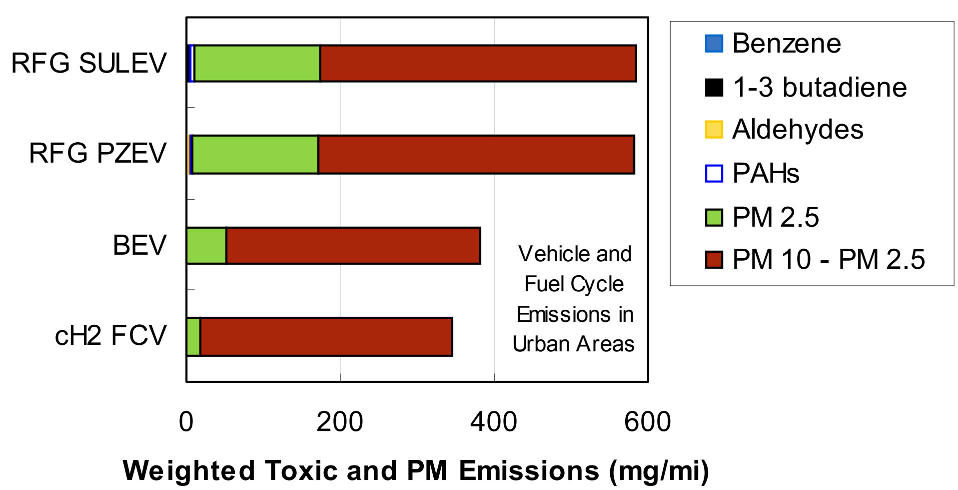



**Figure 2-7. Weighted Toxic and PM Emissions from LDVs**

## 2.5 Greenhouse Gas Emissions

Table 2-15 shows the fuel cycle and vehicle greenhouse gas emissions on a g/unit fuel basis. GHG emissions were determined from the energy inputs associated with fuel production, transportation and distribution and vehicle operation. The assumptions for the GHG analysis reflect marginal fuel use in the SoCAB. Marginal in this context does not imply that we are not accounting for all $CO_2$, $N_2O$, or $CH_4$ emissions generated during production, distribution, and use. Marginal as used here means that we are accounting for all these GHG emissions, but only from new plants that would be needed to meet increased demands. The GHG emissions are not presented on a per mile basis as they are intended to be used to assess the impact of fuel displacement options. GHG emissions from the vehicle are proportional to the amount of fuel used, so, per gallon factors avoid unnecessary, and potentially error inducing calculations (by others).

For petroleum products the difference between average and marginal GHG emissions is minimal. Differences between average and marginal GHG emissions vary greatly for electric power and to a lesser extent for other fuels.

The emissions associated with fuel production facility construction as well as vehicle construction and recycling were not considered in this analysis. Energy inputs and corresponding GHG associated with these activities represent about 10 percent of the fuel production and vehicle operation on an average basis (MIT). However, given the long life of fuel production emissions, attributing GHG emissions from fuel production to vehicle operation does not carry the same causality as vehicle and fuel cycle emissions.

The total emissions impact was determined for various petroleum reduction options. Figure 2-8 illustrates the extent of petroleum reduction and corresponding vehicle fuel economy for Group 1A and Group 2 options. Group 1A options result in the reduction of gasoline usage with only minor impacts on miles traveled. Group 2 options result in the reduction of petroleum fuel usage and corresponding fuel cycle emissions and the reduction in vehicle exhaust emissions. These emissions are replaced with alternative fuel cycle and exhaust emissions (which are zero in the case of ZEVs).

Tables 2-16 through 2-18 summarize the extent of emission impacts for the year 2020. In Section 5, the timing of these emission reductions is taken into account.

**Table 2-15. Summary of Greenhouse Gas Emissions**

| GHG Emissions | Light-Duty Vehicles | | | | | | | | | | | Heavy-Duty Vehicles | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | RFG3 | RFD | LPG | LPG NG | FTD | M100 NG FCV | Ethanol FFV | CNG | LNG | cH2 SR NG | Electric | RFD | FTD | CNG | LNG |
| GHG (g/per unit fuel) | | | | | | | | | | | | | | | |
| Total | 11362 | 12882 | 6711 | 7696 | 13374 | 5826 | 294 | 7803 | 8185 | 12150 | 470 | 12882 | 13374 | 7803 | 8185 |
| Fuel Cycle | 2735 | 2127 | 643 | 1689 | 9476 | 1653 | 294 | 1997 | 2379 | 12150 | 470 | 2127 | 9476 | 1997 | 2379 |
| Vehicle | 8626 | 10755 | 6068 | 6007 | 3898 | 4173 | net = 0 | 5806 | 5806 | 0 | 0 | 10755 | 3898 | 5806 | 5806 |
| GHG (g/MJ) | | | | | | | | | | | | | | | |
| Total | 95.6 | 93.5 | 76.4 | 88.4 | 106.9 | 96.9 | 3.5 | 79.7 | 83.6 | 101.33 | 130.6 | 93.5 | 106.9 | 79.7 | 83.6 |
| Fuel Cycle | 23.0 | 15.4 | 7.3 | 19.4 | 75.7 | 27.5 | 3.5 | 20.4 | 24.3 | 101.33 | 130.6 | 15.4 | 75.7 | 20.4 | 24.3 |
| Vehicle | 72.6 | 78.1 | 69.1 | 69.0 | 31.2 | 69.4 | net = 0 | 59.3 | 59.3 | 0 | 0.0 | 78.1 | 31.2 | 59.3 | 59.3 |
| LHV (MJ/unit fuel) | 118.8 | 137.8 | 87.8 | 87.1 | 125.1 | 60.1 | 84.0 | 97.9 | 76.8 | 119.9 | 3.6 | 137.8 | 125.1 | 97.9 | 76.8 |
| Equivalent MJ/MJ gasoline | 1 | 1.159 | 0.739 | 0.732 | 1.053 | 0.506 | 0.707 | 0.824 | 0.646 | 1.009 | 0.030 | 1.159 | 1.053 | 0.824 | 0.646 |
| Fuel (Units) | gal | gal | gal | gal | gal | gal | gal | 100 scf | gal | kg | kWh | Gal | gal | 100 scf | gal |

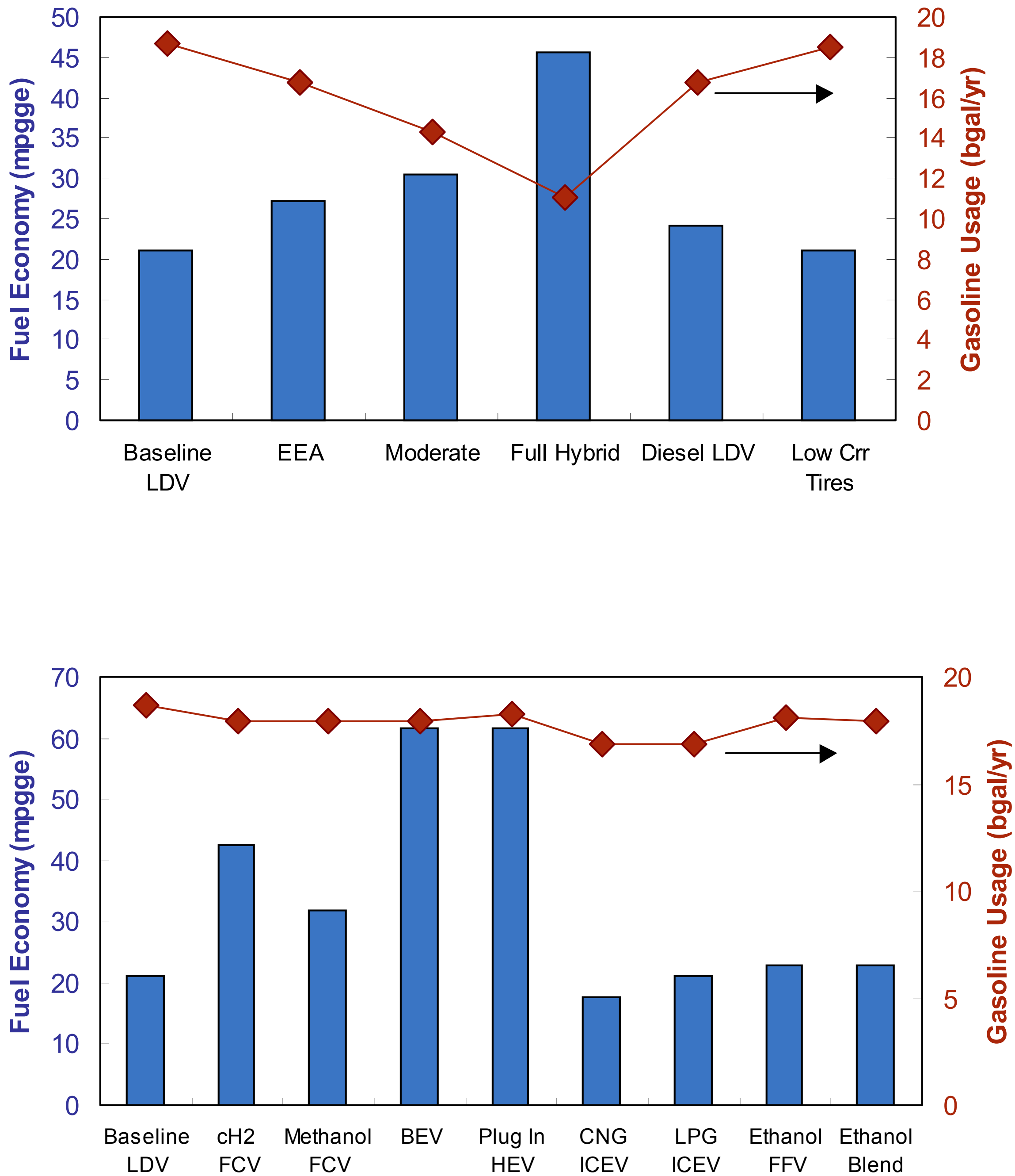



**Figure 2-8. Fuel Economy Petroleum Displacement for Groups 1 and 2 Options for 2020**

## Table 2-16.  Group 1 Emission Reductions

| Emission Reductions | Improved Vehicle Fuel Economy | | | Efficient Tires & Inflation | Governmen Fleets | Vehicle Maintenance | LD Diesel |
|---|---|---|---|---|---|---|---|
| | EEA | ACEEE-Moderate | ACEEE-Full Hybrid | | | | |
| Petro. Reduction (million g.g.e/yr) | 2,561 | 4,581 | 7,785 | 213 | 27 | 57 | 1,952 |
| Savings (% LD Gasoline Baseline) | 13.7% | 24.5% | 41.6% | 1.1% | 0.1% | 0.3% | 10.4% |
| Fuel Cycle (tons/year) | | | | | | | |
| $NO_x$ | 92.78 | 165.96 | 282.04 | 7.72 | 0.98 | 2.07 | 17.40 |
| CO | 27.53 | 49.24 | 83.68 | 2.29 | 0.29 | 0.61 | 4.33 |
| NMOG | 1,368.23 | 2,447.43 | 4,159.19 | 113.80 | 14.91 | 30.34 | 1,856.32 |
| Toxics | 182.01 | 325.56 | 553.27 | 15.14 | 2.00 | 4.05 | 135.85 |
| Particulate Matter | 12.48 | 22.32 | 37.93 | 1.04 | 0.13 | 0.20 | 1.45 |
| Vehicle (tons/year) | | | | | | | |
| $NO_x$ | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| CO | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| NMOG | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Toxics | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 81.45 |
| Particulate Matter | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | -414.20 |
| Greenhouse Gases (tons/year) | 31,067,629 | 55,572,357 | 94,440,254 | 2,576,695 | 338,670 | 688,892 | 3,016,702 |
| New LDV Fleet On-Road FE (mpg) | 34.8 | 30.5 | 45.7 | | | | |

**Table 2-17. Group 2 Emissions Reductions**

| Emission Reductions tons/year | H2 FCVs | BEVs | Grid-Connect EV | LDV CNG | LPG | Alcohol FFVs | Ethanol |
|---|---|---|---|---|---|---|---|
| Petroleum Disp. (million gallons) | 750 | 750 | 470 | 1870 | 1870 | 1460 | 760 |
| Gasoline Baseline (%) | 4.0% | 4.0% | 2.5% | 10.0% | 10.0% | 7.8% | 4.1% |
| Emission Reductions (tons/yr): | | | | | | | |
| Fuel Cycle | | | | | | | |
| $NO_x$ | 17.35 | 4.72 | 3.53 | 36.99 | -212.29 | 17.35 | -1.29 |
| CO | -96.51 | -478.12 | -287.34 | -257.47 | -122.72 | -96.51 | -0.17 |
| NMOG | 387.83 | 322.88 | 204.32 | 1,043.14 | -322.30 | 387.83 | 8.60 |
| Toxics | 53.55 | 52.21 | 32.75 | 140.14 | 127.73 | 53.55 | 4.08 |
| Particulate Matter | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Vehicle | | | | | | | |
| $NO_x$ | 422.14 | 420.27 | 224.66 | 0.00 | 0.00 | 422.14 | 0.00 |
| CO | 703.56 | 700.45 | 374.44 | 0.00 | 0.00 | 703.56 | 0.00 |
| NMOG | 469.63 | 467.55 | 249.94 | 948.85 | 498.24 | 469.63 | 0.00 |
| Toxics | 44.06 | 43.87 | 23.45 | 75.34 | 41.85 | 44.06 | 2.54 |
| Particulate Matter | 122.07 | 121.53 | 64.97 | 0.00 | 0.00 | 122.07 | 0.00 |
| Greenhouse Gases | 4,117,922 | 5,451,404 | 3,508,660 | -651,224 | 1,593,008 | 4,117,922 | 312,275 |

| Emission Reductions tons/year | HD NG* | | | HD GTL[a] | Biodeisel[a] |
|---|---|---|---|---|---|
| | CNG (Class 3-6) | CNG (Class 7-8) | LNG (Class 7-8) | | |
| Petroleum Disp. (million gallons) | 60 | 60 | 60 | 2759 | 83.5 |
| Gasoline Baseline (%) | 1.4% | 1.4% | 1.4% | 66.1% | 2.0% |
| Emission Reductions (tons/yr): | | | | | |
| Fuel Cycle | | | | | |
| $NO_x$ | 161.90 | 749.73 | -1,754.72 | 29.98 | -6.40 |
| CO | 5.74 | -20.03 | -1,050.19 | 10.26 | -3.88 |
| NMOG | 1,710.46 | 7,949.50 | 7,612.67 | 449.54 | 30.42 |
| Toxics | 14.27 | 61.30 | 34.08 | 35.09 | 0.15 |
| Particulate Matter | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Vehicle | | | | | |
| $NO_x$ | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| CO | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| NMOG | 38.59 | 93.82 | 93.82 | 0.00 | 0.40 |
| Toxics | 1,119.32 | 2,721.03 | 2,721.03 | 454.43 | 11.66 |
| Particulate Matter | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Greenhouse Gases | 26,971,758 | 87,986,650 | 99,266,223 | -5,531,183 | 771,031 |

[a] HD options are normalized by diesel baseline.

## Table 2-18. Group 3 Emissions Reductions

| Emission Reductions tons/year | Gasoline Tax | Pay @ Pump Insurance | VMT Tax | Feebates | Registration Transfer | Eff. Vehicle Incentive |
|---|---|---|---|---|---|---|
| Petro. Reduction (million g.g.e/yr) | 891 | 743 | 554 | 1,023 | 145 | 527 |
| Savings (% LD Gasoline Baseline) | 4.8% | 4.0% | 3.0% | 5.5% | 0.8% | 2.8% |
| Fuel Cycle (tons/year) | | | | | | |
| $NO_x$ | 299.35 | 248.44 | 190.50 | 267.58 | 48.51 | 141.86 |
| CO | 88.81 | 73.71 | 56.52 | 79.39 | 14.39 | 42.09 |
| NMOG | 4,414.52 | 3,663.79 | 2,809.29 | 3,945.95 | 715.43 | 2,091.99 |
| Toxics | 587.23 | 487.37 | 373.70 | 524.90 | 95.17 | 278.28 |
| Particulate Matter | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Vehicle (tons/year) | | | | | | |
| $NO_x$ | 4,530.74 | 3,743.50 | 2,847.44 | 0.00 | 651.75 | 2,095.26 |
| CO | 7,551.24 | 6,239.17 | 4,745.74 | 0.00 | 1,086.25 | 3,492.10 |
| NMOG | 5,040.45 | 4,164.65 | 3,167.78 | 0.00 | 725.07 | 2,330.98 |
| Toxics | 472.90 | 390.73 | 297.20 | 0.00 | 68.03 | 218.69 |
| Particulate Matter | 5,569.04 | 4,601.39 | 3,499.98 | 0.00 | 801.11 | 2,575.42 |
| Greenhouse Gases (tons/year) | 100,237,872 | 83,191,483 | 63,788,841 | 89,598,302 | 16,244,778 | 47,501,553 |

## 3. Value of Emission Reductions

It is evident through the establishment of air quality regulations and incentive programs that the state places value on reducing emissions. Air quality is important for human health, ecological health, visibility, and many of California's industries (e.g., agriculture and tourism).

Environmental impacts were determined for a range of petroleum displacement options and expressed in monetary terms. As shown in Table 3-1, the methods for comparing the environmental impacts vary. The monetary impacts were determined either from health impacts, the cost of emission reductions, or market prices for achieving emission reductions.

**Table 3-1. Method for Determining Monetary Value of Environmental Impacts**

| Pollutant | Approach for Monetization |
|---|---|
| PM, Toxics | Cost of health impacts to California |
| NOx, CO, NMOG | Market price for trading |
| Greenhouse gases | Cost of control and market pricing |
| Multimedia impacts | Cost of cleanup |

In the case of toxics and PM, the monetization is expressed as the cost of health impacts. This philosophy was used since any exposure to toxics and PM may be harmful. Thus, there is a health cost associated with exposures for toxics and PM that could be reduced with petroleum reduction options.

Criteria pollutants are frequently traded in industry. The market price for criteria pollutants was selected as a basis for cost as the people of the State of California could purchase reductions in these pollutants. One rational for allowing a trading in pollutant reductions is that the market will find the lowest cost. Secondary PM from $NO_x$ was not included in the analysis as the value is covered in the cost of $NO_x$ reductions. While the consequences of secondary PM from $NO_x$ may be high (as PM appears to have a much higher health cost than the cost of control for criteria pollutants), reductions in these emissions can be obtained by purchasing $NO_x$ emission reductions.

The valuation of GHG reductions was based on the cost of control that is frequently cited in studies on GHG trading (Rosenzweig) and in limited market trading data. Determining the possible global warming damages to California and then quantifying these damages is beyond the scope of this effort. Furthermore, GHG emissions would potentially result in more impacts outside of California and the extent of the costs, impacts, and time horizon are difficult to determine. Finally, many sources of $CO_2$ exist, so, a cost of control that would apply to California was viewed as a reasonable measure for the value of GHG reductions. As the market for trading GHG emissions is just evolving, market prices may be lower than the cost of control in future years.

The valuation of multimedia impacts is based on the cost of cleanup. This valuation takes into account the fact that most major spills are cleaned up and the expense is passed on to fuel companies or government agencies. Since major spills are cleaned up sufficiently to comply with water quality requirements, the rational is that the cost of cleanup represents the cost to the State. The valuation does not take into account the health and environmental impact of incidental drips and small scale spills that enter the environment or the environmental consequences of larger oil spills after they are cleaned up.

### 3.1 Value of PM and Toxics Reductions

The monetary value of PM emissions was estimated from a population-based system for modeling responses to criteria air pollutants. The analysis first estimated possible PM reductions from light-duty vehicles. Two scenarios or limiting cases were then developed and analyzed using the California version of the U.S. EPA's Criteria Air Pollutant Modeling System (CalCAPMS). Monetary estimates were determined for each health end point and then totaled to estimate overall health benefits in dollars. These estimates were then normalized by population and PM reductions to provide an average $/person/tpd estimate. This estimate for PM was then used to determine the monetary value of various toxic emissions.

The health based estimates of PM reductions were modeled using CalCAPMS. This model is a population-based system for modeling exposures to criteria air pollutants and estimating health benefit. The model uses concentration-response (C-R) functions to estimate the relationship between air pollution exposure and adverse health effects. The C-R functions were derived from epidemiological studies in the science literature. Most studies were published in peer-reviewed journals. The model divides California into 8 kilometer by 8 kilometer grid cells, and estimates the changes in incidence of adverse health effects associated with given changes in air quality in each grid cell. The incidence change for the state or individual counties is then calculated as sum of grid-cell-specific changes. The monetary value of a change in the incidence of a given adverse health effect is then calculated. The monetary values for each health endpoint were obtained from economic literature.

The model is developed by Abt Associates. It is a modified version of CAPMS that U.S. EPA used for air pollution health effects analyses including Section 812 — the benefits and Costs of the Clean Air Act and the Diesel Fuel Rule.

Table 3-2 shows the breakdown of PM emissions for light-duty vehicles in 1999. This estimate was obtained using ARB's EMFAC 2000 model. The inventory is composed of emissions from vehicle exhaust or combustion, brakes, and tires. Total light-duty passenger cars, including gasoline and diesel emissions, are 20.2 tpd. Total light-duty truck emissions are 14.5 tpd.

## Table 3-2. Baseline, Bounding Cases A and B, PM Emissions

**Table 3-2a: Baseline - Calendar 2001 Emission Inventory (EMFAC 2000, v. 2.02)**

| Vehicular Source | PM Emission Inventory (tons/day) | | | | | | |
|---|---|---|---|---|---|---|---|
| | Exhaust-Running | Exhaust-Idling | Exhaust-Start | Brake | Tire | Total | Reduction |
| Light-Duty Passenger Cars | | | | | | | |
| Gasoline (No-Cat + Cat) | 8.15 | 0.00 | 0.68 | 4.10 | 6.57 | 19.500 | 0.000 |
| Diesel | 0.60 | 0.00 | 0.00 | 0.02 | 0.04 | 0.660 | 0.000 |
| Light-Duty Trucks | | | | | | | |
| Gasoline (No-Cat + Cat) | 5.58 | 0.00 | 0.44 | 3.20 | 5.12 | 14.340 | 0.000 |
| Diesel | 0.18 | 0.00 | 0.00 | 0.01 | 0.01 | 0.200 | 0.000 |

**Table 3-2b: Bounding Case A - Assume zero PM exhaust emissions for LD Passenger Cars and LD Trucks**

| Vehicular Source | PM Emission Inventory (tons/day) | | | | | | |
|---|---|---|---|---|---|---|---|
| | | Exhaust-Idling | Exhaust-Start | Brake | Tire | Total | Reduction |
| Light-Duty Passenger Cars | | | | | | | |
| Gasoline (No-Cat + Cat) | 0.00 | 0.00 | 0.00 | 4.10 | 6.57 | 10.670 | 8.830 |
| Diesel | 0.00 | 0.00 | 0.00 | 0.02 | 0.04 | 0.060 | 0.600 |
| Light-Duty Trucks | | | | | | | |
| Gasoline (No-Cat + Cat) | 0.00 | 0.00 | 0.00 | 3.20 | 5.12 | 8.320 | 6.020 |
| Diesel | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 | 0.020 | 0.180 |
| | | | | | | Total combustion | 15.630 |

**Table 3-2c: Bounding Case B - Assume zero PM emissions for LD Passenger Cars and LD Trucks**

| Vehicular Source | PM Emission Inventory (tons/day) | | | | | | |
|---|---|---|---|---|---|---|---|
| | Exhaust-Running | Exhaust-Idling | Exhaust-Start | Brake | Tire | Total | Reduction |
| Light-Duty Passenger Cars | | | | | | | |
| Gasoline (No-Cat + Cat) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.000 | 19.500 |
| Diesel | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.000 | 0.660 |
| Light-Duty Trucks | | | | | | | |
| Gasoline (No-Cat + Cat) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.000 | 14.340 |
| Diesel | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.000 | 0.200 |
| | | | | Total | | | 34.700 |
| | | | | Total Tire & Brake | | | 19.070 |

We considered two bounding cases. Both are unrealistic but provide upper bounds on possible PM reductions. The first was to assume that all combustion sources of PM were eliminated. This eliminated 15.6 tpd of PM exhaust emissions. These emissions are almost entirely less than 1 μm and can be classified as $PM_{2.5}$. The second case was to eliminate all light-duty PM emissions or 34.7 tpd from the inventory. This would be the maximum possible reduction. The difference between eliminating all emissions and combustion or exhaust PM emissions is the emissions from brakes and tires. These emissions are typically in the range of 2.5 μm to 10 μm or referred to as $PM_{10}$.

The first case, labeled Bounding Case A, could be characteristic of an all fuel cell or battery vehicle fleet. The second case, labeled Bounding Case B, is unrealistic since total brake and tire emissions cannot be completely eliminated. However, electrodrive technologies incorporating regeneration will reduce brake emissions by perhaps 1/3 as discussed in Section 2.

Given these two bounding cases, ARB performed an analysis with CalCAPMS for 2010 and 2020. Example results for 2010 are shown in Tables 3-3 and 3-4 for Bounding Case A and B, respectively. Similar analyses were also performed for 2020. The results for 2010 and 2020 show mortality provides the largest health related benefit. Chronic illness associated with bronchitis, hospitalization associated with asthma and cardiovascular disease, and minor illnesses are all small in comparison to mortality.

We used the results of the CalCAPMS analysis to estimate $/ton of PM reduced. Table 3-5 summarizes our analysis. Shown in the upper portion of this table are the CalCAPMS results for the bounding cases. Here we have label Case B as total and Case A as exhaust. The difference between total and exhaust emissions or monetary benefit is brake and tire emissions or brake and tire monetary benefits. The dollar estimates for 2010 are taken from Tables 3-3 and 3-4. These dollar amounts were then normalized by population and averaged between 2010 and 2020. This average was normalized by PM emissions to give an average $/person/tpd.

Estimates of $/ton PM factors by year were then determined based on the assumptions that all combustion or exhaust related PM is $PM_{2.5}$ and that brakes and tires are $PM_{10}$. Population growth was projected by the Energy Commission in their base case forecast to grow at 1.4 percent annually (CEC 2001). Population was calculated and used to determine $/ton PM estimate for the years identified in Table 3-5. The results indicate that $PM_{2.5}$ is nearly 3 times as dangerous as $PM_{10}$. The results also indicate that from a health perspective, PM is at least an order of magnitude more dangerous than other criteria pollutants such as $NO_x$ and CO, which are valued less than $20,000/ton.

$PM_{2.5}$ values range from $209,000/ton in 1999 to $425,000/ton in 2050 as population grows and more people are exposed to these emissions. Similarly, $PM_{10}$ values range from $86,000/ton in 1999 to $176,000/ton in 2050.

## Table 3-3. Annual PM-related Health Benefits in 2010 — Case A

| Health Endpoint | Reference | Estimated Beta (Standard Error) | Avoided Incidence (cases/year) | | | Monetary Benefits (1999$) | | |
|---|---|---|---|---|---|---|---|---|
| | | | 5th Percentile | Mean | 95th Percentile | 5th Percentile | Mean | 95th Percentile |
| **Mortality** | | | | | | | | |
| **Long-Term Exposures Mortality** | | | | | | | | |
| Ages 30+ | Krewski et al., 2000 | 0.0046257 (0.0012046) | 157 | 275 | 390 | 182,000,000 | 1,300,000,000 | 3,185,000,000 |
| **Chronic Illness** | | | | | | | | |
| Chronic Bronchitis (Age 27+) | Abbey, 1993 | 0.00932 (0.00475) | 40 | 250 | 450 | 12,000,000 | 80,000,000 | 150,000,000 |
| **Hospitalization** | | | | | | | | |
| COPD (ICD codes 490-492, 494-496), Age 65+ | Samet et al., 2000 | 0.002880 (0.001390) | 5 | 20 | 35 | 50,000 | 250,000 | 440,000 |
| Pneumonia (ICD codes 480-487), Age 65+ | Samet et al., 2000 | 0.002070 (0.000580) | 15 | 30 | 40 | 225,000 | 420,000 | 610,000 |
| Cardiovascular (ICD codes 390-429), Age 65+ | Samet et al., 2000 | 0.001190 (0.000110) | 40 | 50 | 60 | 780,000 | 920,000 | 1,055,000 |
| Asthma (ICD codes 493), Age 64- | Sheppard et al., 1999 | 0.002270 (0.000948) | 10 | 30 | 55 | 67,000 | 215,000 | 362,000 |
| Asthma-related ER Visits, Age 64- | Schwartz et al., 1993 | 0.003670 (0.001260) | 30 | 60 | 100 | 7,000 | 19,000 | 32,000 |
| **Minor Illness** | | | | | | | | |
| URS, Age 9-11 | Pope et al., 1991 | 0.00360 (0.0015) | 1,950 | 6,200 | 10,400 | 33,000 | 150,000 | 266,000 |
| LRS, Age 7-14 | Schwartz et al., 1994 | 0.01823 (0.00586) | 4,000 | 8,400 | 12,800 | 36,000 | 127,000 | 200,000 |
| Asthma Attacks, All ages | Whittemore and Korn, 1980 | 0.00144 (0.000556) | 1,800 | 5,100 | 8,400 | 76,000 | 210,000 | 340,000 |
| Work Loss Days | Ostro, 1987 | 0.0046 (0.00036) | 51,200 | 58,700 | 66,290 | 5,400,000 | 6,220,000 | 7,015,000 |
| ***Total*** | | | | | | | ***1,388,531,000*** | |

## Table 3-4. Annual PM-related Health Benefits in 2010 — Case B

| Health Endpoint | Reference | Estimated Beta (Standard Error) | Avoided Incidence (cases/year) | | | Monetary Benefits (1999$) | | |
|---|---|---|---|---|---|---|---|---|
| | | | 5th Percentile | Mean | 95th Percentile | 5th Percentile | Mean | 95th Percentile |
| **Mortality** | | | | | | | | |
| **Long-Term Exposures Mortality** | | | | | | | | |
| Ages 30+ | Krewski et al., 2000 | 0.0046257 (0.0012046) | 235 | 410 | 590 | 275,800,000 | 1,970,000,000 | 4,826,500,000 |
| **Chronic Illness** | | | | | | | | |
| Chronic Bronchitis (Age 27+) | Abbey, 1993 | 0.00932 (0.00475) | 55 | 360 | 670 | 18,300,000 | 120,000,000 | 222,000,000 |
| **Hospitalization** | | | | | | | | |
| COPD (ICD codes 490-492, 494-496), Age 65+ | Samet et al., 2000 | 0.002880 (0.001390) | 10 | 45 | 80 | 112,000 | 545,000 | 976,000 |
| Pneumonia (ICD codes 480-487), Age 65+ | Samet et al., 2000 | 0.002070 (0.000580) | 35 | 60 | 90 | 498,000 | 925,000 | 1,331,000 |
| Cardiovascular (ICD codes 390-429), Age 65+ | Samet et al., 2000 | 0.001190 (0.000110) | 95 | 110 | 130 | 1,725,000 | 2,035,000 | 2,345,000 |
| Asthma (ICD codes 493), Age 64- | Sheppard et al., 1999 | 0.002270 (0.000948) | 30 | 55 | 83 | 188,000 | 370,000 | 552,000 |
| Asthma-related ER Visits, Age 64- | Schwartz et al., 1993 | 0.003670 (0.001260) | 60 | 135 | 210 | 16,000 | 43,000 | 72,000 |
| **Minor Illness** | | | | | | | | |
| URS, Age 9-11 | Pope et al., 1991 | 0.00360 (0.0015) | 4,300 | 13,700 | 23,000 | 74,000 | 330,000 | 592,000 |
| LRS, Age 7-14 | Schwartz et al., 1994 | 0.01823 (0.00586) | 6,000 | 12,500 | 19,000 | 71,000 | 191,000 | 355,000 |
| Asthma Attacks, All ages | Whittemore and Korn, 1980 | 0.00144 (0.000556) | 4,000 | 11,350 | 18,500 | 169,000 | 463,000 | 757,000 |
| Work Loss Days | Ostro, 1987 | 0.0046 (0.00036) | 76,400 | 87,690 | 99,000 | 8,086,000 | 9,280,000 | 10,473,000 |
| ***Total*** | | | | | | | ***2,104,182,000*** | |

**Table 3-5. Valuating $PM_{10}$ and $PM_{2.5}$ Emissions**

| Class of Emissions | PM Reduction tpd | 2010 $B | 2020 $B | 2010 $B/pop | 2020 $B/pop | Average $/person | Average $/person/tpd |
|---|---|---|---|---|---|---|---|
| Total Case B | 34.7 | 2.1042 | 2.3946 | 78.0330 | 77.2778 | 77.6554 | 2.2379 |
| Exhaust (Case A) | 15.63 | 1.3885 | 1.6028 | 51.4933 | 51.7258 | 51.6095 | 3.3020 |
| Brakes and Tires (Case B-Case A | 19.07 | 0.7157 | 0.7918 | 26.5397 | 25.5520 | 26.0459 | 1.3658 |
| Population in 1999 (million) | 23.1413 | | | | | | |
| Projected Population (1.4% growth) | | 26.9653 | 30.9874 | | | | |

$/ton PM Factors

| | 1999 | 2010 | 2020 | 2030 | 2040 | 2050 |
|---|---|---|---|---|---|---|
| <PM2.5 Exhaust | 209,346 | 243,940 | 280,326 | 322,138 | 370,188 | 425,404 |
| 2.5<PM<10 Brakes and Tires | 86,593 | 100,902 | 115,952 | 133,248 | 153,123 | 175,962 |

### 3.1.1 Valuation of Toxic Emissions

In Section 2, we tracked the various speciated components of the hydrocarbon exhaust for each of the fuel technologies. Many of these components have been listed by ARB as toxic air contaminants (TAC). A TAC is defined[4] as "an air pollutant which may cause or contribute to an increase in mortality or an increase in serious illness; or which may pose a present or potential hazard to human health." ARB has listed benzene, 1,3-butadiene, formaldehyde, acetaldehyde, PAHs, diesel PM as TACs.

ARB has estimated the risk of these TAC in basins like Los Angeles (South Coast Air Basin). Table 3-6 shows the unit risk factors for the toxics tracked in Section 2.

Given the unit risk factors or weighting factors, monetary estimates were made based on $PM_{2.5}$ valuation. This results in the values shown in Table 3-7. Again, results are present for several years as population exposure increases the health risks and, therefore, increases the potential value of reducing exposure. Aldehydes and PAHs are under $10,000/ton, carbon chlorides are in the range of $14,000 to $28,000/ton, benzene is in the $20,000 to 40,000/ton range, and $PM_{10}$ and diesel PM are considerably higher.

To simplify the analyses, values for 2030 where chosen for each of the toxics shown in Table 3-7.

[4] California Health and Safety Code, Section 39655.

**Table 3-6. Unit Risk Factors for TACs**

| TAC | Unit Risk Factor | Weighting[a] |
|---|---|---|
| Formaldehyde | 6 | 1 |
| Acetaldehyde | 2.7 | 0.45 |
| Benzene | 29 | 4.8 |
| 1,3-Butadiene | 170 | 28.3 |
| Carbon chlorides | 20 | 3.4 |
| PAHs | 6 | 1 |
| $PM_{10}$ | 124 | 20.7 |
| Diesel PM ($PM_{2.5}$) | 300 | 50 |

[a] Normalized by formaldehyde unit risk factor.

**Table 3-7. Valuating Toxic Emissions ($/ton)**

| Compound | Weighting | 1999 | 2010 | 2020 | 2030 | 2040 | 2050 |
|---|---|---|---|---|---|---|---|
| Benzene | 4.8 | 20,097 | 23,418 | 26,911 | 30,925 | 35,538 | 40,839 |
| Carbon Chlorides | 3.4 | 14,236 | 16,588 | 19,062 | 21,905 | 25,173 | 28,927 |
| 1,3-Butadiene | 28.3 | 118,490 | 138,070 | 158,664 | 182,330 | 209,526 | 240,779 |
| Formaldehybe | 1 | 4,187 | 4,879 | 5,607 | 6,443 | 7,404 | 8,508 |
| Acetaldehybde | 0.5 | 2,093 | 2,439 | 2,803 | 3,221 | 3,702 | 4,254 |
| PAHs | 1 | 4,187 | 4,879 | 5,607 | 6,443 | 7,404 | 8,508 |
| Diesel PM<2.5 | 50 | 209,346 | 243,940 | 280,326 | 322,138 | 370,188 | 425,404 |
| 2.5<PM<=10 | 20.7 | 86,593 | 100,902 | 115,952 | 133,248 | 153,123 | 175,962 |

## 3.2 Value of Criteria Pollutant Emissions

Since the State and several air districts are making an effort to reduce local air pollution through control measures, this study found it appropriate to value emissions reductions according to avoided control costs for particular pollutants and sources. This type of valuation employs median rates for emissions trading credits or reduction effectiveness factors and is commonly used to determine the value of pollution reductions in the State and locally.

Trading credit prices are based on the willingness to pay for permission to pollute in a market where total emissions are capped. For example, the market supply and demand sets the price of a marginal $NO_x$ credit based on the cost a growing company would incur to retrofit its equipment or offset its new emissions. If the price were equal or more than the offset cost, the company might choose the retrofit instead of purchasing credits. This reduction in demand would then drive down the price of the credits to the point where they are again deemed valuable by companies.

Although other costing methods are sometimes used to evaluate the economics of pollution impacts, it is most appropriate to use the avoided cost of emissions offsets since the market trades the pollutants emitted in fuel production and distribution in the SoCAB. Emission reductions from petroleum reduction would also occur primarily in urban areas.

California median trading values for $NO_x$, CO, and HC in 2000 are listed in Table 3-8. These factors are the median of actual prices paid throughout California in 2000 for permits to pollute (ARB 2000). It is important to note that valuation of emissions reductions can vary widely since they are market driven.

**Table 3-8. Market Prices for Emissions Reductions (2000)**

| Pollutant | Median Market Value ($/ton) |
|---|---|
| Oxides of nitrogen, $NO_x$ | 15,000 |
| Hydrocarbons, HC | 5,000 |
| Carbon Monoxide, CO | 5,625 |

## 3.3 Value of GHG Reductions

Assessing the monetary value of GHG reductions is difficult because the increase in anthropogenic GHG emissions is a global problem. Since California GHG emissions can impact California as well as the rest of the world the value of reducing GHG emissions needs to consider both regional and global effects. The cost of damages from GHG emissions or alternative costs of reducing GHG emissions are discussed as means for valuing GHG reductions. However, determining the cost of damages and attributing these costs to California GHG reductions is not within the scope of this study, but the issues related to such a valuation are described. The valuation for GHG reductions in this study was based on a comparison of control costs and the current market for GHG.

### 3.3.1 Cost of GHG Damages

The vast majority of the world's scientists that participated in the IPCC's Third Assessment released last year, believe there is sufficient scientific evidence to claim that humans are altering the planet's climate system through rising levels of greenhouse gas emissions. California has seen its sea level rise and its Sierra Nevada Mountain snow melt earlier in the year. Mean global temperatures are increasing and greenhouse gas emissions from California's use of gasoline and diesel contribute, at some level, to the warming of the atmosphere.

Within the United States, the state of California is second only to Texas in the amount of greenhouse gas released each year from human activities. In 1999, California emitted within its boarders an estimated 429 million metric tons of carbon dioxide equivalent emissions. The transportation sector accounted for 58% of all $CO_2$ released from the combustion of fossil fuels.

One approach to measuring the benefits of reduced greenhouse gas emissions, involves the assessment and valuation of changes in the risk of damages expected to result from increased climate variability within California. Historical data can be used to estimate changes in the frequency and severity of extreme weather events (floods, fires, droughts, heat waves, El Nino's). Damages can be calculated for many of the adverse affects of increasing the variability of California's climate. Recognizing that atmospheric concentrations of greenhouse gases is a global issue, sensitivity analyses can be performed to evaluate small changes in the probability of a broad range of expected damages that would result from gradual or abrupt changes in California's climate regime.

Examples of losses or damages California faces from increased climate variability include:

- Increased frequency of floods in winter, early spring
- Reduced water supply in summer and fall
- Increased energy demand for cooling
- Increased number of heat strokes and respiratory illnesses
- Increased frequency of large forest fires
- Reduced forest production due to pest species
- Coastal structure damage from sea level rise and more severe storms
- Agricultural crop losses from temperature and precipitation extremes

Finally, one important assessment under this approach would involve the valuation of benefits derived by the California public from reducing the risk climate change impacts to California's economy, natural resources and citizenry. As with changes in the probability of damages, sensitivity analyses can be performed to evaluate the public's value for small changes in risk that are linked to impacts that are both potentially large and distant in time. Unfortunately quantifying any of these parameters is not practical within the scope of this study. Considering the seriousness of climate change, we assert that GHG reductions are worthwhile and that the value of the reductions should be attributed to clean-up costs or market values.

The rationale for controlling GHG emissions needs to be based on societal responsibilities to reduce the potential impact of GHG emissions worldwide rather than a specific cost impact to the State of California. As there are many sources of GHG emissions and the consequences of climate change are presumably serious, we assume that controlling the emissions is preferred to encountering the consequences of global warming.

### 3.3.2 Cost of Controlling GHG emissions

A variety of options have been considered for controlling GHG emissions. The major $CO_2$ reduction strategies can be broken down into the following categories: environmental sequestration, improved vehicle technology, efficiency changes and fuel switching from power generation, and emissions reductions from stationary sources. These include some of the following:

- **Environmental Capture**
  - Reduce deforestation
  - Grow more forests
  - Reduce methane emissions from landfills

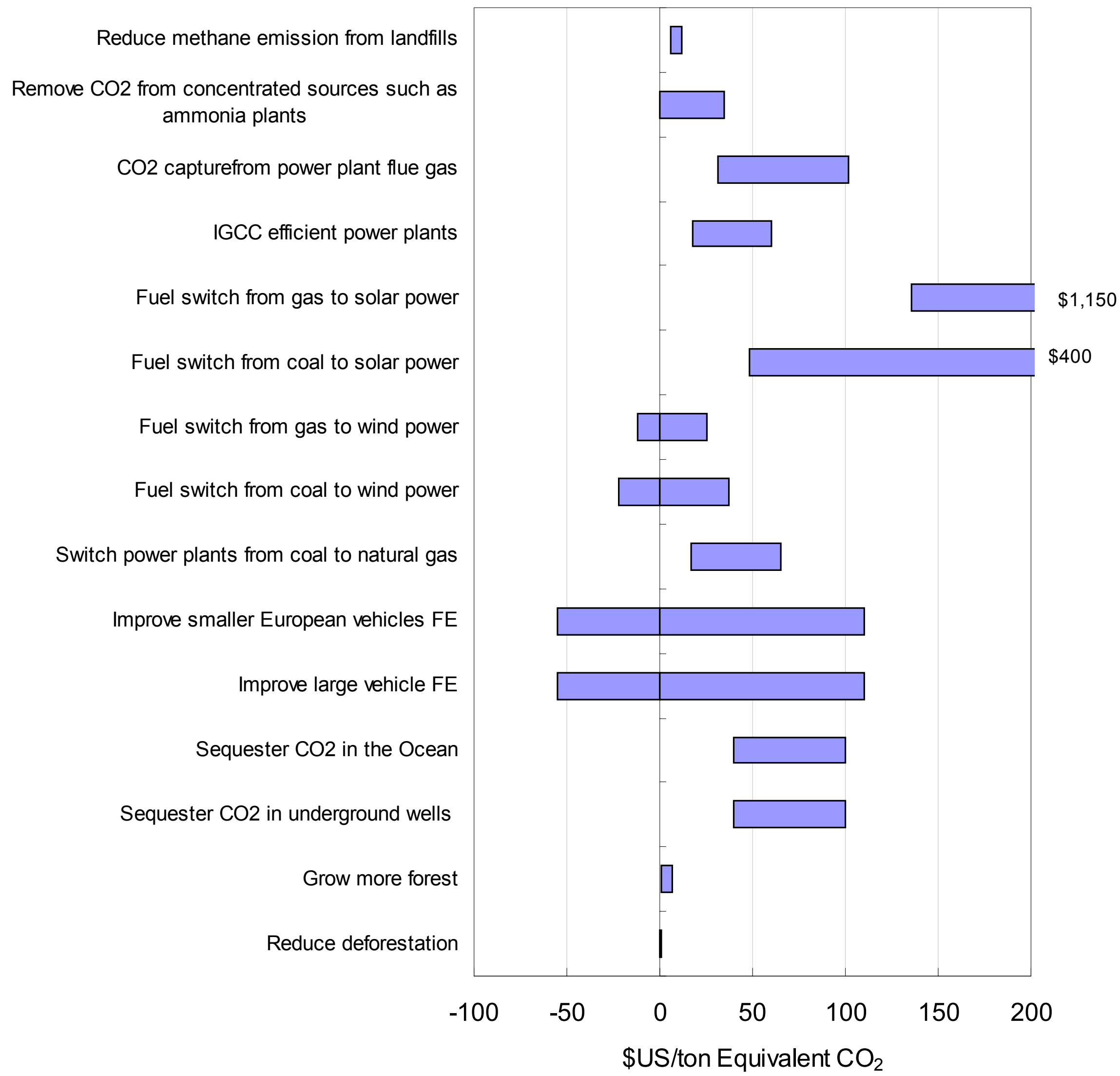
- **Improve Vehicle Technology**
  - Improve large vehicle fuel economy (and other options discussed in this report)
  - Improve smaller European vehicle fuel economy

- **Reduce Emissions from Power Generation**
  - Switch power plants from coal to natural gas
  - Generate more power from solar, wind and other non fossil sources
  - Improved power plant efficiency

- **Sequestration from Fossil Sources**
  - Capture $CO_2$ from power plant flue gas
  - Remove $CO_2$ from concentrated sources such as ammonia plants
  - Sequester $CO_2$ in oceans or underground reservoirs

Several studies have attempted to estimate the costs of different $CO_2$ reduction strategies, and these predictions show a broad variation between the potential costs of different strategies. Although these predictions are not specific to the California market, they provide a basis for comparison between potential GHG reduction strategies.

The actual cost of GHG reduction will depend on future conditions such as available control technologies, fuel prices, and energy demand. These conditions change continuously and the values represented in this report reflect present day predictions of future trends. Figure 3-1 shows estimated costs of several strategies. The cost of control of reforestation is very low. Vehicle fuel economy improvements and power plant efficiency improvements have costs that range from negative (benefit to the consumer) to \$100/ton $CO_2$. More aggressive technology oriented options such as fuel switching and active $CO_2$ removal have much higher costs.




*Sources: IPCC, DOE 2002a, MIT, Stevens, Unnasch 1990, DOE 2002b*

**Figure 3-1. Cost of GHG reductions strategies**

Reforestation options are potentially inexpensive means of reducing GHG emissions. Much of the forest land considered for reforestation is outside of California; however, trading strategies could provide a more cost effective means of reducing GHG emissions. The opportunity costs of reserving large tracts of land for forestation and altering the ecological balance of the oceans by introducing large amounts of $CO_2$ or algae may not be fully accounted for in the costs listed in Figure 3-1. Nonetheless, $CO_2$ sequestration in forests or oceans provides an alternative to higher cost technology solutions.

The cost of improving vehicle technology depends on the type of technology employed in the vehicles, the capital cost of the specific technology used, future fuel prices, variability in miles driven, and consumer preferences. A conservative estimate based on the capital cost of implementing improved vehicle fuel efficiency may give a $CO_2$ reduction cost of near $50/ton $CO_2$. However, an estimate that accounts for higher future gasoline and diesel prices and for fuel savings due to the higher efficiency and the effects of economies of scale in manufacturing brings this cost much lower, perhaps even results in an overall cost benefit.

The costs of converting power generating facilities to cleaner burning fuels such as natural gas or phasing in more renewable power sources are also dependent on available technologies and fuel prices. Coal power plants are not necessarily an issue for GHG emissions in California, but provide a benchmark for determining the costs of GHG reductions.

Reducing the levels of $CO_2$ emissions from stationary industrial sources can involve both capturing the $CO_2$ and then sequestering it environmentally, or chemically removing it as an inert solid from the exhaust gases using a scrubber. These control options require extensive technology development and demonstration before they can be implemented.

The cost of control varies from as little as $1/ton of $CO_2$ or even potentially negative for some options to over $200/ton for more technologically complex strategies. Some of the control strategies mentioned above are developing technologies, and will become less expensive when widely adopted, while some of the less expensive strategies may incur unforeseen costs.

### 3.3.3 Cost of GHG Trades

The market for trading greenhouse gas emissions is currently in its infancy. Limited trading has occurred in several countries over the last five years through pilot marketplace projects patterned on other successful emission trading programs such as the United States' acid rain program. A variety of trading program types emerged including cap and trade programs where permits to emit (allowances) are traded or baseline and credit programs where reductions against the emission baseline are traded (Pew). Most emissions are traded under government or institutional programs or by corporations anticipating future legislation, or to be retired as offsets for increased activities (Canton). In order to determine the current market value of traded $CO_2$ equivalent emissions, we reviewed several recent published reports as well as data made available on $CO_2$ marketplace websites. The results of this survey are presented in Table 3-9. The data consist of actual trade values and market modeling results. The variability in price ranges is illustrated in Figure 3-2.

**Table 3-9. Examples of $CO_2$ Equivalent Emissions Market Value**

| Source | Price ($/ton $CO_2$ eq.) | Notes | Reference |
|---|---|---|---|
| **Actual Traded Value** | | | |
| $CO_2$e | $0.10-$18.14 | Price based on previous worldwide transactions. | CF2001 |
| Pew Center on Global Climate Change | $0.54-$3.17 | Price based on previous worldwide transactions. | Pew2002 |
| GERT | $1.31-$11.95 | Price range from listed sales bids. Lower range is a reforestation project; upper range is a building energy efficiency project. | GERT |
| UK Emission Trading Group | $69.71 | Price set at auction in February 2002. Trading starts April 2002. Most participants include manufacturers | UKETG |
| **Trade Value Estimates** | | | |
| Weathervane | $7.10 to $29.5 | Range based on ability to trade. Estimate in paper is $108 to $26/ton Carbon | RFF1998 |
| Center for Clean Air Policy | $1 to $25 | $1.00 is the current price estimate, $25 is the 2010 projection | CCAP1999 |

*Sources: CF2001, GERT, UKETG, RFF1998, CCAP199*

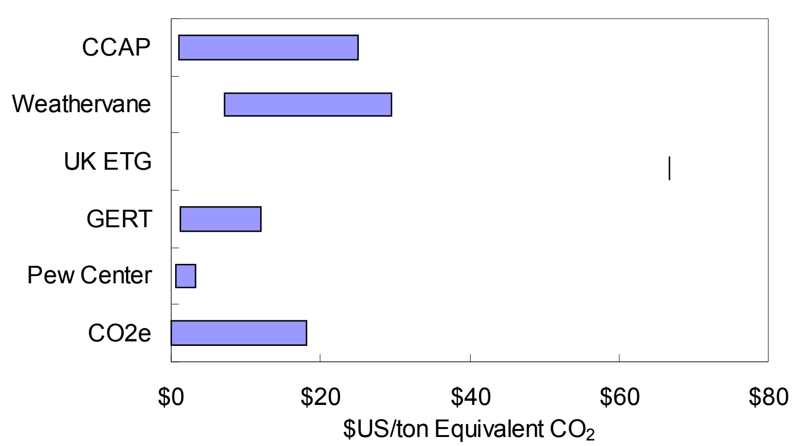



**Figure 3-2. Examples of $CO_2$ Equivalent Emissions Market Value**

The variability of the current market for $CO_2$ equivalent emissions is due to a number of factors. These include the cost to generate the credits or allowances, the quality of the emission certification, and the level of risk associated with the transaction. In general, emission reductions generated by reforestation or reduced deforestation are in the lower price range. Higher price $CO_2$ equivalent emission credits or allowances tend to be higher cost, third-party certified, and/or low risk credits such as those generated, for example, by manufacturing processing changes in plants. Another factor affecting the market price is the currently low demand for $CO_2$ equivalent emissions. As more manufacturers and corporations need emissions credits or allowances to operate, upward market pressure will develop.

### 3.3.4 Valuing $CO_2$ Emissions

We have briefly discussed three possible methodologies for valuing $CO_2$ emissions: assessing damage to California due to global warming, assessing control costs for reducing $CO_2$ emissions, and assessing the infant $CO_2$ trading market. Clearly, none of these methodologies provides a sound rationale for valuing $CO_2$ emissions at this time. Little work has been done on assessing damages to California and we would expect this effort to be quite complicated and have lots of uncertainties. Nevertheless, California should start to look at such a methodology to investigate reasonableness and costs. Cost of control provides quite a range of possible $CO_2$ valuation, but what is lacking in this analysis is the magnitude of the possible $CO_2$ reductions for each control measure. Also missing are the needed $CO_2$ reductions (worldwide not just California) to stabilize atmosphere concentrations of $CO_2$ levels. If both of these factors were known, a supply-demand relationship could be established to provide insight into the level of needed controls and their associated costs. For example, if the needed world $CO_2$ reduction (demand) was small enough then perhaps global reforestation (supply) would be sufficient to stabilize $CO_2$ concentrations. This could be accomplished as shown in Figure 3-1 at low costs. However, if higher $CO_2$ reductions are needed, this will require higher cost control options and the overall $CO_2$ control costs will be driven up.

A market in trading GHG emissions is also developing. As expected with this developing market there is adequate supply of $CO_2$ credits that are being generated currently at low control costs. The current values range from a few dollars to $30/ton of $CO_2$. One recent incentive was announced at about $70/ton. As with the cost of control these emerging market trades provide only guidance on $CO_2$ valuation.

Lacking better information we choose to value $CO_2$ emissions at $25/ton. This value is on the high side of the current market which we believe is appropriate since there is little demand for $CO_2$ credits now and those that are being traded are very inexpensive ("low lying fruit"). $25/ton is also consistent with current estimates of the cost of control which for most reasonably priced options cap out at $100/ton of $CO_2$. Thus $25/ton seems like a reasonable compromise given the current data on cost of control and current market conditions. That said it is also obvious to us that more work in this area is needed and we would recommend that the State initiate an effort to get a better estimate of the benefits of $CO_2$ reductions

# 4. Multimedia Impacts

Each step in the production and marketing of petroleum-based fuels and products potentially impact the environment and public health. Marine environments and coastal beaches are impacted by marine tanker spills. Soil, surface and groundwater are affected by releases from pipelines. Discharge from refineries impacts the environment, and accidents at refineries are responsible for the deaths and injuries of workers. Transportation by tanker trucks places other drivers at risk, and in the event of a rollover and spill, can cause soil, surface water and groundwater contamination. Leaks from underground tanks at dispensing facilities can compromise the quality of drinking water supplies. Air pollution and impacted public health are the end result of exhaust from gasoline- and diesel-fueled engines. The combined effect on water, soil, and air are known as multimedia impacts. This section focuses on water and soil impacts

Although consumers can readily see the price paid for petroleum fuels at the pump, some environmental impacts are not reflected in the price. Most components of spill cleanup are internalized costs, likely included in the petroleum pricing structure. However, there are externalized costs, such as the damage to public health, and deaths of animals and plants, that are difficult to quantify in monetary terms and are not typically passed on to the consumer on a per gallon of fuel basis.

For this report we are using the costs of spills as a surrogate for estimating the entire range of cost impacts associated with petroleum use in our economy. On the one hand, we are overestimating the costs of spills since some of these costs are emissions or monetary benefit in the price of gasoline or diesel. But, we are also not including many other cost impacts as discussed briefly below.

## 4.1 Types of Multimedia Impacts

Spilled petroleum affects many aspects of the environment, including marine waters, coastline, soil, surface water bodies, groundwater supplies, and air. There are many opportunities for spills to occur along the petroleum distribution chain, and spills can be damaging in each of petroleum's many forms – crude oil, refined gasoline and diesel fuels, and additives such as MTBE. Oil pollution in the form of land- and marine-based spills poses a serious threat not only to the environment, but also to public and commercial property and interests.

Impacts to marine environments are often high-profile events, such as the Exxon Valdez spill. Spills in the open ocean are often difficult to contain, as they are subject to prevailing winds and ocean currents. Petroleum spills can impact environmental receptors such as kelp beds and associated fish and animal life – animals such as otters, and birds such as brown pelicans, gulls, cormorants and murres can be oiled and potentially die. Marine spills that reach and contaminate the coastline can have not only environmental impacts, but also commercial impacts to tourism and industry, and public health impacts in residential coastal areas.

Land-based spills impacting soil not only have environmental ramifications, but also can damage public and private properties. Petroleum spills initially impacting soil also have the potential to migrate downward or laterally, and impact groundwater and surface water, or affect air quality by volatilizing beneath an enclosed space.

Petroleum released to surface water bodies can impact wildlife such as fish, amphibians, bird and animal life. Moving bodies of water can transport contamination over a wide area. Public health is impacted in the event a petroleum release occurs to a drinking water supply.

Groundwater supplies can be contaminated by releases to adjacent surface water bodies and soil. Depending on the nature of the petroleum product or additive, it can accumulate and travel in a layer on top of the water table, or in solution after dissolving. A threat to public health can result if volatilization from a shallow water table occurs to enclosed structures. A considerable threat to public health occurs in the event that a petroleum release impacts an aquifer utilized as a public drinking water supply.

The production and distribution of petroleum inherently produces air pollution at every step – from production, to flaring and emissions at refineries, to volatilization of spills during transportation, to emissions from combustion in vehicles. There are a host of environmental impacts that have far-reaching implications to public health. Many of these impacts are associated with externalized costs, not allotted for in the pricing structure for petroleum fuels. Examples of these environmental impacts, which translate to public health and economic effects include:

- Pollution from smog associated with cars and trucks causes an estimated $300M in annual losses to California agriculture (Toxics 1988)
- Air pollution caused by passenger vehicles ranks them as the largest source of carbon monoxide, and the second largest source of hydrocarbons and nitrogen oxides (UCS 1997)
- Scientists estimate that the number of U.S. deaths associated with air pollution range from 50,000 to 100,000 per year (CEERT 2000)
- A 1999 study (ABT) estimates that smog pollution was responsible for more that 6 million asthma attacks, 159,000 emergency room visits and 53,000 hospitalizations nationally.

### 4.2 Petroleum Spills

To evaluate spills of petroleum imported into California, it is helpful to first examine California's petroleum distribution system. Imported petroleum arrives via both marine tanker (crude and refined products) and interstate pipeline (refined products only). Petroleum arriving by marine tanker is offloaded at the marine terminal to storage tanks or to feeder pipelines. Petroleum is transported by tanker truck or feeder pipeline to refineries. Crude and refined products are stored in tanks at the refinery. Refined products are transported from the refinery via tanker truck or terminal pipeline. Refined petroleum products are stored in above and underground storage tanks at commercial and private dispensing facilities.

There is a distinct risk of petroleum spills at each point along the distribution chain. The following subsections examine the mechanisms and possible effects of potential petroleum spills. This section includes an evaluation of existing spill volume and cleanup cost data for each of these dominant distribution points, and estimated cleanup costs per gallon of petroleum spilled. Additionally, an estimated cost for cleanup of spilled petroleum was estimated for each gallon of each fuel consumed in California.

### 4.2.1 Open Ocean Marine Spills

Marine oil spills can pose a serious threat to the environment as well as to commercial interests (see Figure 4-1). Spills can leave waterways and their surrounding shores uninhabitable for some time. Such spills often result in the loss of plant and animal life. Periodic spill disasters maintain public awareness of these marine events.

**Figure 4-1. Beach Cleanup Followig Marine Petroleum Spill**

The volume of spills in U.S. waters has been on a steady downward trend since 1973. According to data compiled by the U.S. Coast Guard (USCG), 46.8% of the volume of oil spilled from 1973 to 1999 came from tank vessels (ships/barges); 22.0% from facilities and other non-vessels; 17.5 percent from pipelines; 7.7 percent from mystery spills; 5.9 percent from non-tank vessels. Figure 4-2 presents USCG data on the breakdown of marine spill volumes and sources from 1973 – 1999 (USCG 2001).

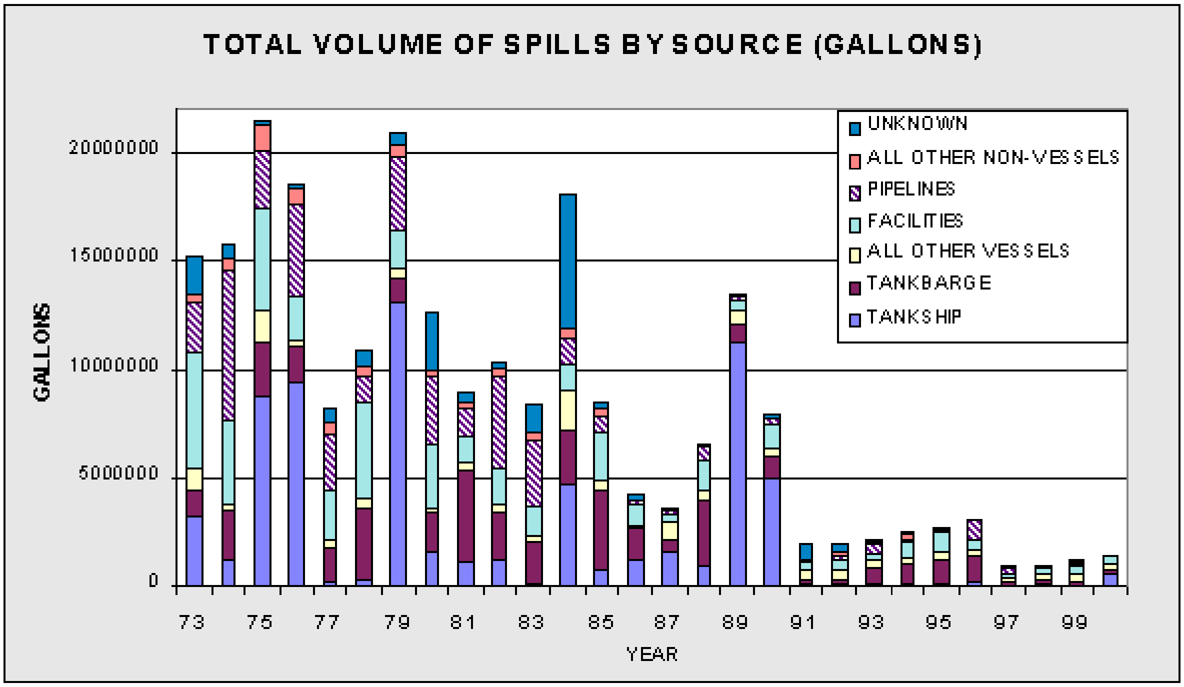



**Figure 4-2. Historical Marine Petroleum Marine Spill Volumes by Source — USCG Data**

As evidenced in the above figure, the total volume of petroleum spills in U.S. waters is on the decline. In light of this declining trend, more recent data are used to represent the impact of marine spills. Average annual spills and average annual spill volumes based on USCG data for 1994 through 1998 are data is presented in Table 4-1.

**Table 4-1. Marine Petroleum Spill Frequency**

| Parameter | Annual Averages |
|---|---|
| Number of spills | 822 |
| Average spill volume (gal) | 60,157 |

[a] USCG 1994 to 1998 data.

Records of spill cleanup costs are kept by the Office of Spill Prevention and Response (OSPR), a division of the U.S. Department of Fish and Game. These records are not comprehensive, but several examples indicate that cleanup costs can be extremely high, and are heavily dependent upon wind and current conditions, and spill proximity to sensitive receptors. For example[5]:

- September 1998 — **3,000 gallons** ISO 180 fuel oil spilled in San Francisco Bay, affecting San Mateo County coast. $1.23M cleanup cost, $9.4M criminal and civil penalties and restoration costs. **~$3,500/gallon cleanup**
- February 1990 — **416,598 gallons** crude spilled off Huntington Beach. $12M to date spent on cleanup, not settled yet. **~$30/gallon cleanup**

According to California State law, the party responsible for a petroleum spill is liable for all incurred cleanup costs. However, in the event that the responsible party cannot be identified, funding for cleanup is provided by the Oil Spill Liability Trust Fund (OSLTF), which was created in 1991. The OSLTF was established using a $0.25 per barrel fee levied upon crude oil transported into or out of California marine waters. Once the OSLTF accumulated $50M in funds, the fee was reduced to $0.04 per barrel crude. The OSLTF is available to fund OSPR, and also to assist in spill cleanup costs. The US Coast Guard manages the Federal Oil Spill Liability Trust Fund (a more complete description of this fund is included in Appendix B. Selected criteria must be met to open this federal fund for spill cleanup. If these criteria are not met, then the state-level OSLTF is utilized.

Marine oil spill cleanup is therefore funded by means other than public funding and tax dollars. These cleanup costs may be internalized in the pricing structure of the California petroleum market.

Estimated cleanup costs of open ocean marine spills provided as basis for calculating the cost associated with each gallon of gasoline and diesel fuel produced annually in California. The following rationale and assumptions apply to this analysis:

- Applied average annual spill volumes of petroleum, according to USCG data for 1994 through 1998
- Conservatively utilized the upper limit of estimated cleanup cost per gallon spilled ($3,500/gallon), based upon personal communication with OSPR
- Assumed all spilled petroleum is crude oil
- Assumed that 72 percent of PAD V production volumes apply to California, as presented by the Energy Information Administration (EIA)
- As presented in EIA 2000, applied California refinery production values of 45.7 and 18.5 percent of total refined volumes processed into gasoline and diesel, respectively. This allows an estimate of fuel volumes that spilled crude translates to

[5] Based upon personal communication on 2/20/02 between Robb Barnitt (Arthur D. Little) and Dana Michaels (OSPR)

- Assumed that cleanup costs would follow the same breakdown of 45.7 and 18.5 percent for gasoline and diesel

The corresponding cleanup costs are presented in Table 4-2 below.

**Table 4-2. Estimated Open Ocean Marine Cleanup Costs Per Gallon Fuel Produced in California**

| Spill Parameter | Cleanup Cost Calculation |
|---|---|
| Average annual spill volume (gal) | 60,157 |
| Equivalent volume gasoline (gal) | 27,492 |
| Equivalent volume diesel (gal) | 11,129 |
| Cleanup cost ($/gal spilled) | $3,500 |
| Annual spill cleanup cost | $210,548,100 |
| Cleanup cost gasoline | $96,220,482 |
| Cleanup cost diesel | $ 38,951,399 |
| CA annual gasoline produced (gal) (EIA 2000) | 15,020,570,880 |
| CA annual diesel produced (gal) (EIA 2000) | 5,165,324,640 |
| Cleanup cost per gallon consumed gasoline | $0.0064 |
| Cleanup cost per gallon consumed diesel | $0.0075 |

### 4.2.2 Marine Terminal Spills

Petroleum spills can occur during delivery and offloading of ocean tankers at marine terminals. The potential for a spill exists at several points, including:

- Navigation into port
- Cargo offload
- Transfer to tanker truck transport
- Transfer to feeder pipelines

The USCG keeps records specific to the total number and volumes of spills occurring in marine waters. The California State Lands Commission – Marine Terminals Division, keeps a subset of this information, which is specific to spills occurring in marine terminals. The State Lands Commission (SLC) spills database encompassing 1999 through 2001, which contains spill volumes, cleanup costs (if any), and associated federal and/or state fines provided data for evaluating marine terminal spills. According to SLC staff, the cleanup costs listed in the database are not comprehensive. The SLC data includes all petroleum products spilled, and includes unrefined crude, gasoline, diesel, jet fuel, and other refined petroleum products.  According to federal and state law, cleanup costs are to be paid by the responsible party.

Table 4-3 presents a summary of the SLC data, and our estimated cleanup cost per gallon spilled.

**Table 4-3.    Marine Terminal Petroleum Spill Annual Averages**

| Spill Parameter | Annual Averages | Source |
|---|---|---|
| Petroleum products spill volume | 3,357 gallons | State Lands Commission Marine Terminal data 1999 through 2001 |
| Federal/State fines | $6,417 | State Lands Commission Marine Terminal data 1999 through 2001 |
| Cost of clean-up | $16,698 | State Lands Commission Marine Terminal data 1999 through 2001 |
| Spilled petroleum product cleanup cost | $5.28 per gallon | Arthur D. Little Calculation |
| Spilled petroleum product cleanup cost (including fines) | $7.31 per gallon | Arthur D. Little Calculation |

ADL estimated the cleanup costs of marine terminal spills, and calculated the cost associated with each gallon of gasoline and diesel fuel produced annually in California. The following rationale and assumptions apply to this analysis:

- Applied average annual spill volumes of petroleum, according to State Lands Commission data for 1999 through 2001
- Conservatively utilized the higher cleanup cost figure ($7.31/gallon) calculated for cleanup costs including federal and state fines
- Assumed all spilled petroleum is crude oil
- Assumed that 72 percent of PAD V production volumes apply to California, as presented in EIA 2000
- As presented in EIA 2000, applied California refinery production values of 45.7 and 18.5 percent of total refined volumes are processed into gasoline and diesel, respectively.  This allows an estimate of fuel volumes that spilled crude translates to.
- Assumed that cleanup costs would follow the same breakdown of 45.7 and 18.5 percent for gasoline and diesel

Estimated cleanup costs are presented in Table 4-4 below.

**Table 4-4. Estimated Marine Terminal Cleanup Costs Per Gallon Fuel Produced in California**

| Spill Parameter | Marine Terminal Calculation |
|---|---|
| Average annual spill volume (gal) | 3,357 |
| Equivalent spill volume — gasoline (gal) | 1,534 |
| Equivalent spill volume — diesel (gal) | 621 |
| Annual spill cleanup cost | $16,698 |
| Estimated cleanup cost — gasoline | $7,631 |
| Estimated cleanup cost — diesel | $3,089 |
| CA annual gasoline consumption (gal) (EIA 2000) | 15,020,570,880 |
| CA annual diesel consumption (gal) (EIA 2000) | 5,165,324,640 |
| Cleanup cost per gallon consumed gasoline | $0.0000005 |
| Cleanup cost per gallon consumed diesel | $0.0000006 |

### 4.2.3 Pipeline Spills

Pipelines transport about 65 percent of the crude oil and refined petroleum products produced in the United States (CEERT). These pipelines carry crude oil to refineries and refined products to distribution points after refining. Pipeline ruptures can release crude or refined petroleum products, with the potential to impact soil, surface water bodies, and groundwater. Commercial and private property can also be damaged.

The Department of Transportation (DOT) Office of Pipeline Safety (OPS) enforces pipeline safety regulations and compiles a database of spill volumes and associated property damages. According to OPS data, the number of spills has decreased nationally. However, spill volumes and property damages have not decreased significantly. It can be assumed that this fact is due to increased petroleum demand. Figure 4-3 presents national DOT OPS data from 2001. Spill volumes refer to all petroleum products.

Based upon 1984 through 1999 DOT OPS data specific to California, we determined annual averages for spill incidents, volumes, and associated property damage costs. Table 4-5 presents this information.

ADL estimated the cleanup costs of pipeline spills, and calculated the cost associated with each gallon of gasoline and diesel fuel produced annually in California. The following rationale and assumptions apply to this analysis:

- Applied average annual spill volumes of petroleum, according to DOT OPS data for 1984 through 1999
- Utilized the estimated cleanup cost figure of $19.91 per gallon

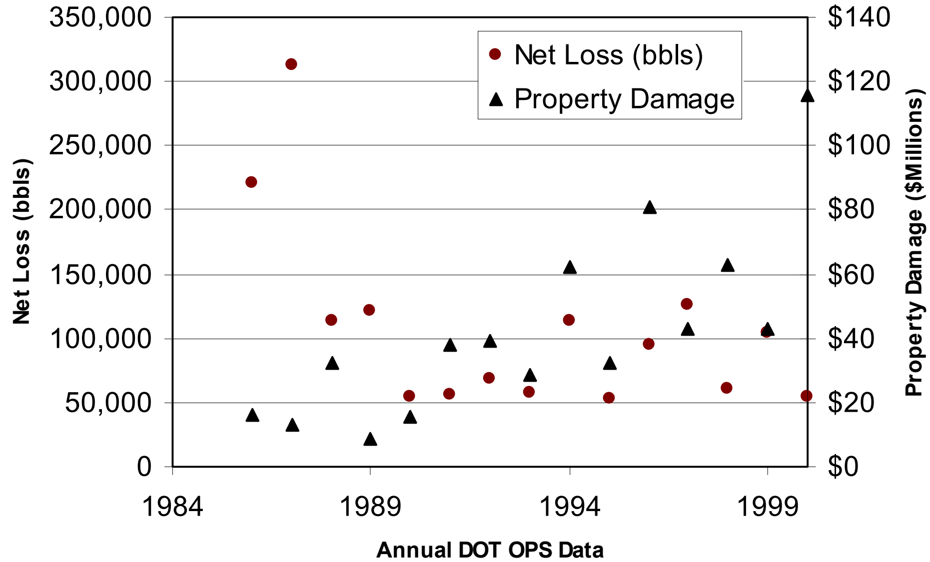



**Figure 4-3. Historical Data — Pipeline Spill Volumes and Associated Property Damage**

**Table 4-5. Pipeline Petroleum Spill Annual Averages**

| Spill Parameter | Annual Averages | Source |
|---|---|---|
| Number of accidents per year | 31 | DOT OPS Data CA 1984-1999 |
| Average spill size (gal) | 14,815 | DOT OPS Data CA 1984-1999 |
| Property Damage | $9,126,581 | DOT OPS Data CA 1984-1999 |
| Fatalities | 1.94 | DOT OPS Data CA 1984-1999 |
| Injuries | 8.13 | DOT OPS Data CA 1984-1999 |
| Gross loss (bbls) | 10,913 | DOT OPS Data CA 1984-1999 |
| Gross loss (gal) | 458,338 | DOT OPS Data CA 1984-1999 |
| Spilled petroleum product cleanup cost | $19.91 per gallon | Arthur D. Little Calculation |

- Assumed all spilled petroleum is refined product
- As presented in EIA 2000, California refinery production values of 45.7 and 18.5 percent of total refined volumes are processed into gasoline and diesel, respectively. Applied like estimated volumes to determine amount of spilled refined products from pipelines.
- Assumed that cleanup costs would follow the same ratio of 2.47:1 for gasoline to diesel

Estimated cleanup costs are presented in Table 4-6.

**Table 4-6. Estimated Pipeline Spill Cleanup Costs Per Gallon Fuel Produced in California**

| Spill Parameter | Pipeline Calculation |
|---|---|
| Average annual spill volume (gal) | 488,894 |
| Equivalent spill volume — gasoline (gal) | 348,013 |
| Equivalent spill volume — diesel (gal) | 140,881 |
| Annual spill cleanup cost | $9,735,020 |
| Estimated cleanup cost — gasoline | $6,929,757 |
| Estimated cleanup cost — diesel | $2,805,263 |
| CA annual gasoline produced (gal) (EIA 2000) | 15,020,570,880 |
| CA annual diesel produced (gal) (EIA 2000) | 5,165,324,640 |
| Cleanup cost per gallon consumed gasoline | $0.00046 |
| Cleanup cost per gallon consumed diesel | $0.00054 |

### 4.2.4 Refinery Spills

Crude oil delivered to refineries is converted to gasoline, diesel, and other fuels and petroleum products. Refineries use physical, thermal, and chemical separation techniques, which require extremely high temperatures and pressures to separate crude oil into other products. Approximately 90 percent of all petroleum products that are produced in the United States are fuels. Gasoline and diesel account for 45.7 and 18.5 percent, respectively of the total output from refineries (EIA 2000). Refining causes air and water pollution and produces hazardous wastes, and oil refineries use and release toxic chemicals into the environment (CEERT).

In addition to environmental impacts, refineries are also subject to lethal accidents involving workers. These accidents, often involving explosions and fires, are dangerous to those working on the site and to surrounding residents. Examples of recent refinery accidents include (CEERT):

- February 1, 1996: A hydrogen unit at a Shell refinery exploded, igniting a fire and causing minor injuries to two workers
- August 22, 1994: Unocal's Rodeo refinery started releasing Catacarb, a toxic catalyst that can cause skin burning, shortness of breath and headaches. The leak continued for 16 days before the company notified state and federal authorities. Almost 600 residents and 75 employees reported symptoms in the days following the company's disclosure. Unocal later pleaded no contest to 12 criminal counts by the state and agreed to pay a $3M fine.
- April 10, 1989: Three workers were burned in a fire and explosion at the Chevron refinery in Richmond

According to the EIA 2000, there are currently 23 refineries operating in California (see Figure 4-4).

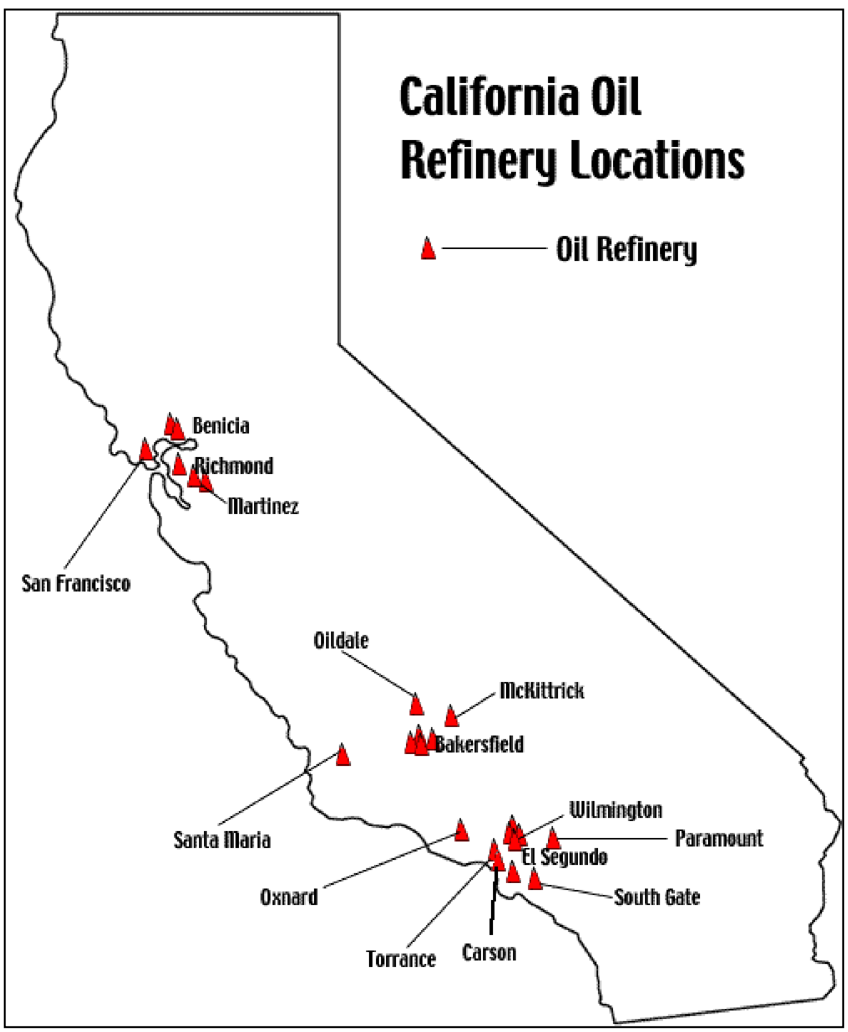



**Figure 4-4. California Oil Refinery Locations**

Spills of crude and refined products can occur during the refining process, as well as during storage. Spills during storage may occur prior to refining, or after refining has occurred, but before transport from the refinery itself.

Limited data are available on spills from refineries. It has been estimated that an average size refinery releases 10,000 gallons of oily liquid per day to the air, water and land (Environmental Defense Fund 1995). It is not known what the recovered and remediated spill volumes are from refineries. However, according to federal and state law, cleanup costs are to be paid by the responsible party.

We estimated the cleanup costs of refinery spills, and calculated the cost associated with each gallon of gasoline and diesel fuel produced annually in California. The following rationale and assumptions apply to this analysis:

- Applied estimated daily oily liquid release per refinery of 10,000 gallons
- This spill volume estimate was expanded to an annual figure, and to encompass all 23 California refineries
- Assumed all spilled petroleum is crude
- Utilized the estimated cleanup cost figure of $7.31 per gallon, as estimated for crude oil spills in marine terminals
- Assumed that 72 percent of PAD V production volumes apply to California, as presented in EIA 2000
- As presented in EIA 2000, applied California refinery production values of 45.7 and 18.5 percent of total refined volumes are processed into gasoline and diesel, respectively. This allows an estimate of fuel volumes that spilled crude translates to.
- Assumed that cleanup costs would follow the same breakdown of 45.7 and 18.5 percent for gasoline and diesel

Estimated cleanup costs are presented in Table 4-7.

### 4.2.5 Transportation Spills

Spills of refined fuels gasoline and diesel during transportation can impact soil, surface water, and groundwater. Tanker rollovers can be dangerous to the public, and create road closures.

The U.S. EPA has estimated that petroleum spill volumes from pipelines are 10 to 20 times greater that from tanker truck spills (The Seattle Times). However, truck accidents are 300 times more likely to kill people than pipeline accidents (The Seattle Times). The societal costs of these deaths are not included in this analysis.

Spills of refined gasoline and diesel fuel can occur in many modes during transport to private and commercial distribution centers. Modes of fuel loss during fuel transportation were summarized from previous studies. Table 4-8 presents the dominant modes of fuel loss. Approximately 85 percent of the total volumetric loss occur during spillage.

**Table 4-7. Estimated Refinery Spill Cleanup Costs Per Gallon Fuel Produced in California**

| Spill Parameter | Refinery Spill Calculation |
|---|---|
| Average annual spill volume (gal) | 83,950,000 |
| Equivalent spill volume — gasoline (gal) | 38,365,150 |
| Equivalent spill volume — diesel (gal) | 15,530,750 |
| Annual spill cleanup cost | $613,674,500 |
| Estimated cleanup cost — gasoline | $280,449,247 |
| Estimated cleanup cost — diesel | $113,529,783 |
| CA annual gasoline produced (gal) (EIA 2000) | 15,020,570,880 |
| CA annual diesel produced (gal) (EIA 2000) | 5,165,324,640 |
| Cleanup cost per gallon consumed gasoline | $0.0187 |
| Cleanup cost per gallon consumed diesel | $0.0220 |

**Table 4-8. Modes of Fuel Loss during Transportation**

| Mode of Fuel Loss During Transportation |
|---|
| • Feedstock transport |
| • Fuel transport |
| • Fuel unloading |
| • Bulk terminal |
| • Truck loading |
| • Truck spillage |
| • Truck exhaust |
| • Truck unloading |
| • Storage tank breathing |
| • Vehicle working loss spillage |

Previously estimated volume losses and California petroleum production values (EIA 2000) provided an estimate of total annual spill volumes during transportation. An estimated annual cost of cleanup was derived using an estimated cleanup cost per spilled gallon. This cleanup cost per gallon is based upon a broad estimate used by ADL's Global Environment and Risk practice. These estimated spill volumes and cleanup costs are presented in Table 4-9.

**Table 4-9. Estimated Annual Average Transportation Spill Volumes and Costs**

| Spill Parameter | Transportation Spill Calculation |
|---|---|
| % volume loss diesel | 0.0100% |
| % volume loss gasoline | 0.0106% |
| Annual CA diesel production | 5,165,324,640 |
| Annual CA gasoline production | 15,020,570,880 |
| Annual volume loss/spill diesel | 517,864 |
| Annual volume loss/spill gasoline | 1,588,078 |
| Total annual volume loss (gal) | 2,105,942 |
| Estimated cleanup cost per gallon | $30.00 |
| Annual cleanup cost | $63,178,257 |

We estimated the cleanup costs of transportation spills, and calculated the cost associated with each gallon of gasoline and diesel fuel produced annually in California. The following rationale and assumptions apply to this analysis:

- Applied estimated annual spill volumes of petroleum, according to ADL calculation
- Utilized the estimated cleanup cost figure of $30 per gallon
- Assumed all spilled petroleum is refined product
- As presented in EIA 2000, applied California refinery production gasoline-diesel ratio of 2.47:1 to estimate volumes of spilled refined products from pipelines
- Assumed that cleanup costs would follow the same ratio of 2.47:1 for gasoline to diesel

Estimated cleanup costs are presented in Table 4-10.

**Table 4-10. Estimated Transportation Spill Cleanup Costs Per Gallon Fuel Produced in California**

| Spill Parameter | Transportation Spill Calculation |
|---|---|
| Annual spill volume (gal) | 2,105,942 |
| Equivalent spill volume — gasoline (gal) | 1,499,089 |
| Equivalent spill volume — diesel (gal) | 606,852 |
| Annual spill cleanup cost | $63,178,257 |
| Estimated cleanup cost — gasoline | $44,972,685 |
| Estimated cleanup cost — diesel | $18,205,573 |
| CA annual gasoline consumption (gal) (EIA 2000) | 15,020,570,880 |
| CA annual diesel consumption (gal) (EIA 2000) | 5,165,324,640 |
| Cleanup cost per gallon consumed gasoline | $0.0029941 |
| Cleanup cost per gallon consumed diesel | $0.0035246 |

### 4.2.6 Leaking Underground Storage Tank Spills

Spills of refined gasoline and diesel fuel can occur from Leaking Underground Storage Tanks (LUSTs). These spills can impact soil, and after percolating down to the water table, can impact groundwater. Plumes of contamination can travel on and in groundwater, impacting other regions. Of particular concern is contamination impacting a groundwater aquifer, which is used as a public drinking water supply. The fuel additive MTBE is a considerable threat to groundwater resources, as it dissolves in water more readily than other gasoline constituents.

The California EPA and State Water Board oversee the LUST Cleanup Fund. This fund has been in operation for 10 years, and provides reimbursement for LUST cleanup. The LUST Cleanup Fund is comprised of an annual total of $195M, accrued by assessing a fee of $0.012 per gallon of fuel, paid by UST owners (Barnitt 2002). The Fund can not be applied to surface spills (i.e., tanker rollovers), or bulk terminals, but is specific to fleet and commercial fuel dispensing facilities. Typically, remedial costs reimbursed by the LUST Cleanup Fund include LUST excavation and removal, and soil and groundwater remediation. According to Alan Patten of the California EPA, the average LUST cleanup costs about $150K, but the range is $20K to $1.5M.

Only a portion of the claims made requesting reimbursement are funded, and a portion of those funded claims have been closed to date. Table 4-11 presents some basic information with regard to the LUST Cleanup Fund's progress to date.

**Table 4-11. LUST Cleanup Fund Accomplishments to Date**

| LUST parameter | CA LUST Fund |
|---|---|
| Number of claims | 17,000 |
| Number of claims funded | 9,000 |
| Number of cases closed | 4,500 |
| Average claims per year | 1700 |
| Number of claims funded per year | 900 |
| Total annual funding monies | $195,000,000 |
| Average cost cleanup per case | $150,000 |

We estimated the cleanup costs of LUST spills, and calculated the cost associated with each gallon of gasoline and diesel fuel produced annually in California. The following rationale and assumptions apply to this analysis:

- Assumed total available funding of $195M applied to LUST cleanup annually.
- Assumed funding applied to gasoline and diesel followed ratio of gasoline and diesel produced annually in California.

Estimated cleanup costs are presented in Table 4-12.

**Table 4-12. Estimated LUST Spill Cleanup Costs Per Gallon Fuel Produced in California**

| Spill Parameter | Spill Cleanup Calculation |
|---|---|
| Annual spill cleanup cost | $195,000,000 |
| Estimated cleanup cost — gasoline | $145,101,877 |
| Estimated cleanup cost — diesel | $49,898,123 |
| CA annual gasoline consumption (gal) (EIA 2000) | 15,020,570,880 |
| CA annual diesel consumption (gal) (EIA 2000) | 5,165,324,640 |
| Cleanup cost per gallon consumed gasoline | $0.0097 |
| Cleanup cost per gallon consumed diesel | $0.0097 |

## 4.3 Summary of Multimedia Impacts

Petroleum spills are responsible for considerable environmental damage to water, soil and air. Not only are the environment, plants and animals impacted, but commercial activities are affected, as is public health.

The costs of petroleum spill cleanup were estimated at several of the dominant points in the petroleum distribution chain. These annual costs are significant, but are considered to be internalized, and are likely included in the petroleum pricing structure. A summary total of these estimated spill volumes and cleanup costs are presented in Table 4-13.

**Table 4-13. Estimated Total Annual Spill Cleanup Costs Per Gallon Fuel Produced in California**

| Spill Parameter | Spill Cleanup Calculation |
|---|---|
| Annual spill volume (gal) | 86,608,350 |
| Equivalent spill volume — gasoline (gal) | 40,241,279 |
| Equivalent spill volume — diesel (gal) | 16,290,233 |
| Annual spill cleanup cost | $1,092,152,575 |
| Estimated cleanup cost — gasoline | $573,681,678 |
| Estimated cleanup cost — diesel | $223,393,229 |
| CA annual gasoline consumption (gal) (EIA 2000) | 15,020,570,880 |
| CA annual diesel consumption (gal) (EIA 2000) | 5,165,324,640 |
| Cleanup cost per gallon consumed gasoline | $0.038 |
| Cleanup cost per gallon consumed diesel | $0.043 |

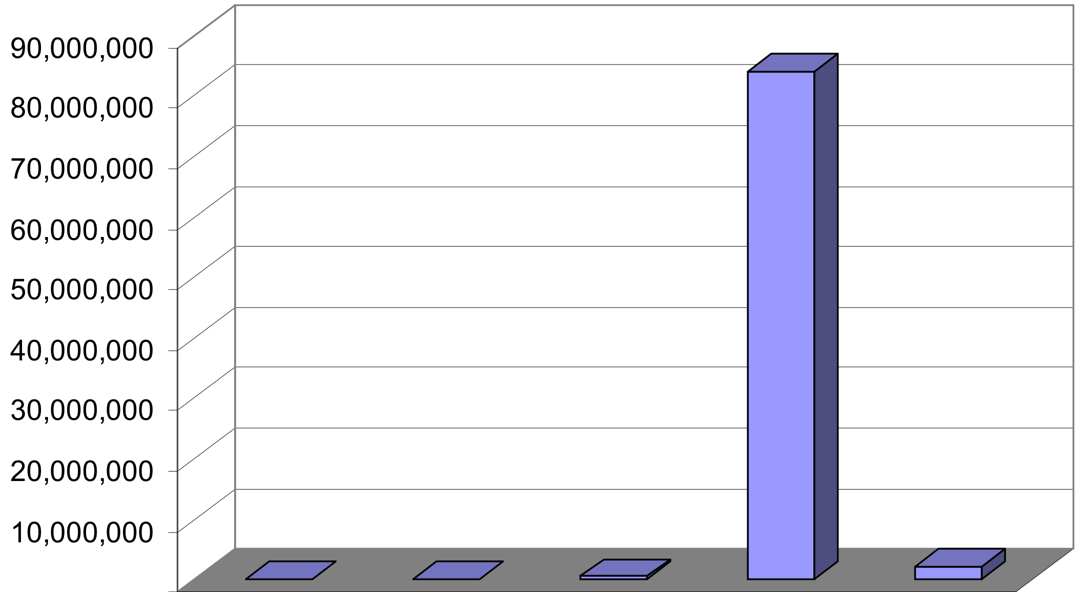
Note: Estimated spill volumes does not include an estimate for LUSTs.

Figures 4-5 through 4-7 illustrate the estimated annual spill volumes and cleanup costs associated with each dominant petroleum distribution point. It is important to note that no spill volume estimate was made for LUSTs. In general, the spill volumes and cleanup costs are dominated by the refinery estimates. However, these volume and costing estimates are based upon available sources, and not a comprehensive database.

There are however, additional costs, which should be considered as external costs. These are societal costs associated with petroleum use, and are difficult to assign a dollar figure to. These societal costs might include:

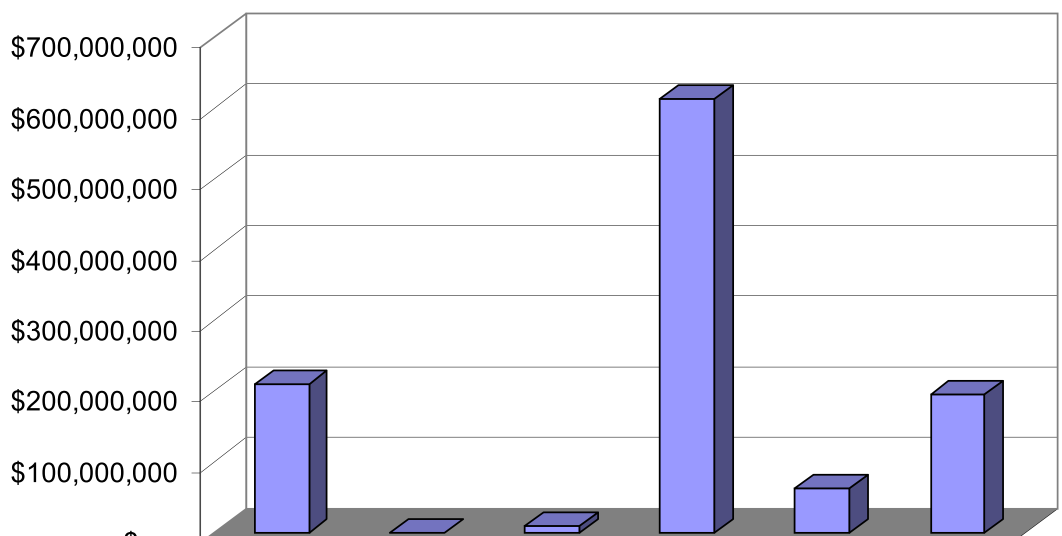
- Deaths of animals and plants, and destruction of habitat
- Loss of blue sky due to air pollution
- Impacted public health due to multimedia contamination

By reducing petroleum dependency, significant savings may be realized both in internalized and externalized multimedia petroleum spill cleanup costs.



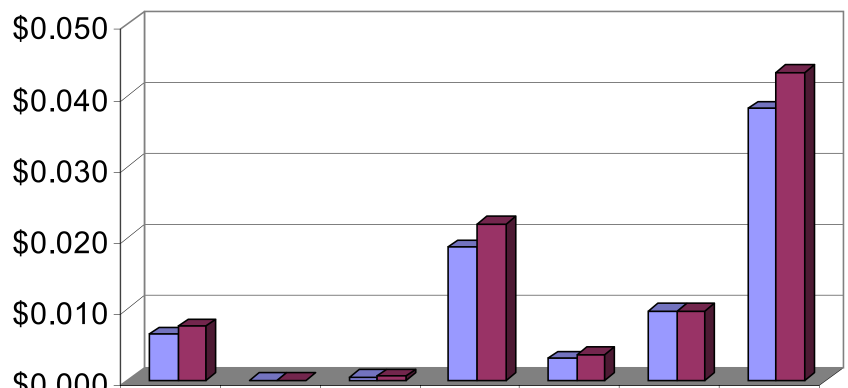

| | Marine Open Ocean | Marine Terminals | Pipeline | Refineries | Transport |
|---|---|---|---|---|---|
| Spill Volume (gal) | 60,157 | 3,357 | 488,894 | 83,950,000 | 2,105,942 |

**Figure 4-5. Estimated Annual Petroleum Spill Volumes**




| | Marine Open Ocean | Marine Terminals | Pipeline | Refineries | Transport | LUSTs |
|---|---|---|---|---|---|---|
| Annual Spill Cleanup Cost | $210,548,100 | $16,698 | $9,735,020 | $613,674,500 | $63,178,257 | $195,000,000 |

**Figure 4-6. Estimated Annual Petroleum Spill Cleanup Costs**




| | Marine Open Ocean | Marine Terminals | Pipeline | Refineries | Transport | LUSTs | Total |
|---|---|---|---|---|---|---|---|
| Cleanup Cost per Gallon Consumed Gasoline | $0.00641 | $0.0000005 | $0.00046 | $0.01867 | $0.00299 | $0.00966 | $0.038 |
| Cleanup Cost per Gallon Consumed Diesel | $0.00754 | $0.0000006 | $0.00054 | $0.02198 | $0.00352 | $0.00966 | $0.043 |

**Figure 4-7. Estimated Cleanup Costs Per Gallon Fuel Consumed in California**

# 5. Valuation of Indirect Benefits

Monetized indirect benefits are included in this report to complete the analysis initiated in Task 3, which focuses on the direct, or monetary, impacts associated with each petroleum reduction option. The indirect benefits presented here supplement the analysis in Task 3 to provide a broader context of the benefits or costs of each petroleum reduction option. This section addresses monetized benefits from decreased air and multimedia emissions. Each of these categories is discussed briefly below, with detailed analysis provided within the body of this section.

### Air Emissions

Each petroleum reduction option is evaluated in terms of its airborne emissions, on a full fuel cycle (well-to-wheels) analysis. This work examines $NO_x$, CO, NMOG, Toxics, PM, and GHG. Benzene, 1,3 butadiene, formaldehyde, acetaldehyde, and poly-aromatic hydrocarbons are included within the Toxics category.

### Multimedia

Decreased use in petroleum — both refined product and crude oil — results in lower volumes of petroleum spills, as less material is handled, refined, and distributed. The benefits of decreased petroleum spillage are described and quantified in multimedia impacts.

### Monetized Indirect Benefits

The air emissions and multimedia impacts are monetized for each option based on the valuations, listed in $/ton, shown in previously in Table 3-2. A monetized indirect benefit stream is constructed for each option, by combining emission valuations and annual emission reductions.

For each year that an option is employed, it accrues indirect benefits. These benefits are tracked annually for each option, between 2002 and 2050. These annual benefits are discounted at 5% annually and expressed in 2001 dollars. This accounting allows each option to be evaluated for a specific year or over a given time period. Details of these benefit calculations are discussed by group, below. Monetized indirect benefits are generated here, so they may be compared against the direct benefits calculated in Task 3. All of the indirect benefits shown in this section, are based on the analysis shown in March 18th Draft Task 3 Report.

## 5.1 Group 1 — Fuel Efficiency Options

Petroleum reduction through fuel efficiency options were evaluated in terms of fuel demand reduction – for both gasoline and diesel – and the environmental benefits associated with these reductions. Options 1B through 1D result in fuel cycle (well-to-tank) benefits, as fuel-efficient vehicles require less fuel for a fixed amount of travel. Option 1E (Light Diesel Vehicles) displaces gasoline through the use of improved diesel engine efficiency and diesel fuel. As a result, Option 1E results in decreased gasoline use both in terms of fuel volume and VMT, while increasing diesel demand in terms of fuel volume and VMT. Each Group 1 option was evaluated on an annual basis between 2002 and 2030.

**Table 5-1. Summary of Indirect Benefits for Group 1 Options**

| Indirect Benefits Summary (2020) | Group 1 Options | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1A (Improved FE – EEA) | 1A (Improved FE - ACEEE Moderate) | 1A (Improved FE - ACEEE Full Hybrid) | 1B (Fuel-Efficient Tires) | 1C (Government Fleets) | 1D (Vehicle Maintenance) | 1E (LDV Diesel) |
| Petroleum Reduction (million ggge/year): | 2,561.0 | 4,581.0 | 7,785.0 | 212.1 | 27.9 | 56.7 | 290.6 |
| Emissions (tons/yr): | | | | | | | |
| $NO_x$ | 92.78 | 165.96 | 282.04 | 7.7 | 1.0 | 2.1 | 17.4 |
| CO | 27.53 | 49.24 | 83.68 | 2.3 | 0.3 | 0.6 | 4.3 |
| NMOG | 1368.23 | 2447.43 | 4159.19 | 113.5 | 14.9 | 30.3 | 1856.3 |
| Toxics | 182.01 | 325.56 | 553.27 | 34.3 | 4.5 | 9.2 | 390.9 |
| Particulate Matter | 12.48 | 22.32 | 37.93 | 0.6 | 0.1 | 0.2 | -412.7 |
| Greenhouse Gases | 31,067,629 | 55,572,357 | 94,440,254 | 2,576,695 | 338,670 | 688,892 | 3,016,702 |
| Indirect Benefits (million 2001$): | 352.0 | 630.0 | 1071.0 | 28.4 | 3.7 | 7.6 | -12.8 |

**Table 5-2. Cumulative Indirect Benefits for Group 1 Options by Time Period**

| Group 1 -Fuel Efficiency Options | Cumulative Indirect Benefits (million 2001$) | | | | |
|---|---|---|---|---|---|
| | 2002-10 | 2002-20 | 2002-30 | 2002-40 | 2002-50 |
| 1A: EEA | 354 | 2,819 | 6,876 | 10,534 | 13,261 |
| 1A ACEEE Moderate | 631 | 6,028 | 12,037 | 16,798 | 20,335 |
| 1A: ACEEE Full Hybrid | 1,073 | 10,244 | 20,457 | 29,001 | 35,679 |
| 1B: Efficient Tires | 236 | 591 | 824 | 1,004 | 1,423 |
| 1C: Government Fleets | 23 | 64 | 96 | 117 | 165 |
| 1D: Vehicle Maintenance | 62 | 157 | 219 | 266 | 376 |
| 1E: LD Diesel | -31 | -140 | -253 | -311 | -120 |

### 5.2 Group 2 — Fuel Displacement Options

Group 2 options are based on the use of non-petroleum fuels to substitute petroleum demand with alternative sources. Group 2 options, therefore, decrease both petroleum vehicle and fuel cycle emissions, while incurring analogous emissions associated with the replacement fuel in question. As a result, Group 2 options can result in decreases in certain species of emissions, and increases in others. The changes in emissions, both increases and decreases, are monetized in the same manner as other options, and summed.

The Draft Task 3 Report assumes that all Group 2 options were implemented beginning in 2002, using a single model year of vehicles. These vehicles were assumed to have a 10-year lifetime, with constant annual VMT. The indirect benefits shown here replicate this assumption, so the direct and indirect benefits for each option can be compared side-by-side.

Figures 5-1 and 5-2 show an example of the NPV calculation for compressed hydrogen fueled fuel cell vehicle. Figure 5-1 shows the NPV in a per vehicle basis and Figure 5-2 shows the NPV on a displaced gasoline gallon basis.

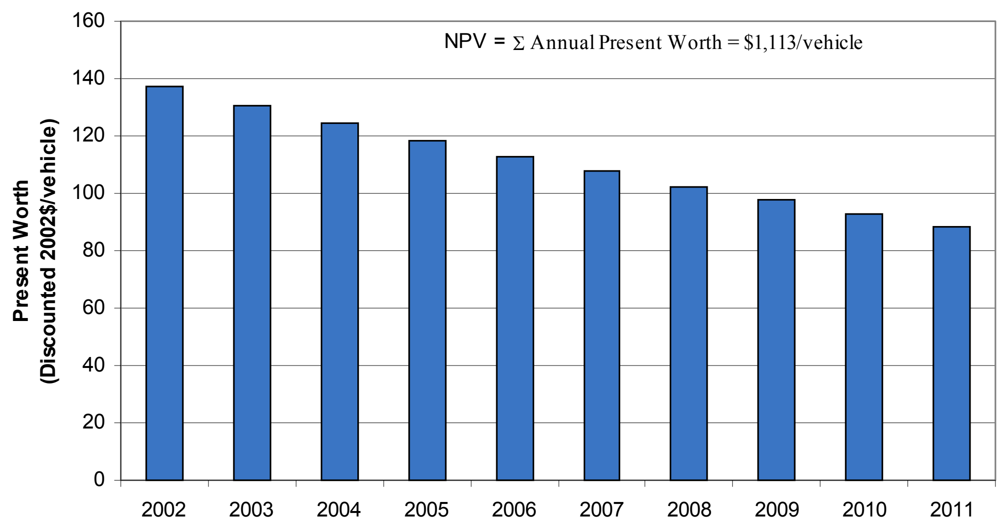



**Figure 5-1 Indirect Benefit Stream Over the 10-Year Life of a Light-Duty Hydrogen Fuel Cell Vehicle (Option 2A), Used to Calculate the NPV of Each Option, Expressed in $/vehicle**

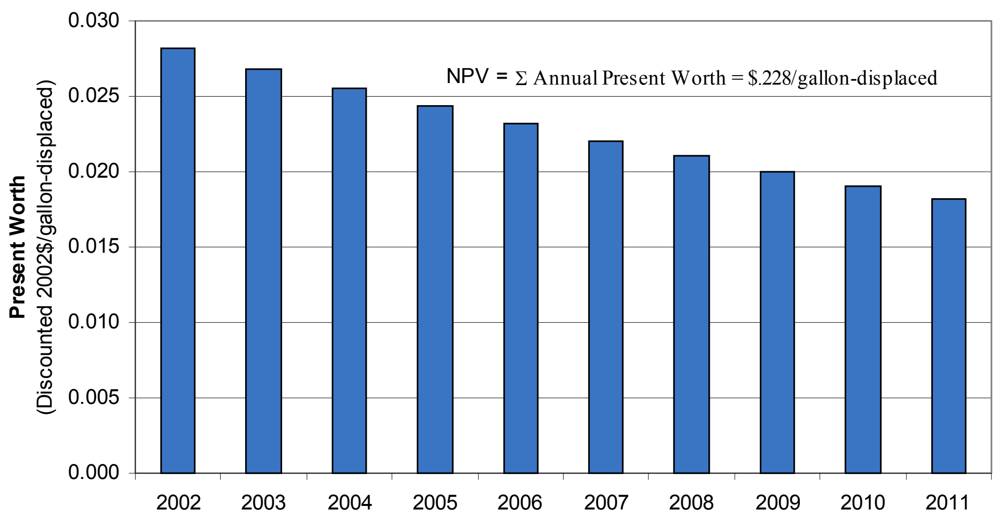



**Figure 5-2. Indirect Benefit Stream over the 10-Year Life of a Light-Duty Hydrogen Fuel Cell Vehicle (Option 2A), Used to Calculate the NPV of Each Option, Expressed in $/gallon-displaced**

The indirect benefits shown here are discounted and expressed in $2002. As such, the phase-in or introduction of each option plays a significant role in its valuation. In general, the sooner an option of fixed emission reduction is implemented, the larger its NPV. Given the time horizon of this study, there is significant uncertainty in how each option will be executed, with its valuation subject to similar uncertainty. Table 5-3 summarizes these calculations for all Group 2 options.

## Table 5-3. Estimates of Indirect Benefits for Group 2 Options

| Monetized Indirect Benefits | Group 2 Options | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2A (H2 FCV) | 2B (BEV) | 2C (GC BEV) | 2D (CNG) | 2E (LPG) | 2F (E85 FFV) | 2G (E10) | 2H (HD NG) | 2I (HD FTD) | 2J (HD BD) |
| NPV ($/vehicle) | | | | | | | | | | |
| Total | 1,346.59 | 1,101.79 | 1,245.21 | 217.09 | 277.98 | 538.82 | 58.52 | 20,394.01 | 1,471.05 | 6,440.92 |
| $NO_x$ | 42.03 | 40.36 | 40.36 | 1.29 | -8.14 | -1.44 | -0.12 | 79.74 | 3.83 | -97.56 |
| CO | 22.42 | 5.79 | 5.79 | -3.45 | -1.76 | -0.08 | -0.01 | -0.82 | 0.49 | -22.19 |
| NMOG | 27.30 | 24.88 | 24.88 | 23.43 | 6.97 | 12.65 | 0.26 | 285.18 | 19.13 | 19.13 |
| Toxics | | | | | | | | | | |
| Benzene | 0.19 | 0.18 | 0.18 | 0.16 | 0.15 | 0.12 | 0.01 | 13.54 | 10.38 | 10.38 |
| 1,3 Butadiene | 0.02 | 0.02 | 0.02 | 0.01 | 0.01 | 0.01 | 0.000 | 4.05 | 0.00 | 0.00 |
| Formaldehyde | 0.22 | 0.20 | 0.20 | -0.08 | 0.08 | 0.08 | 0.01 | 0.64 | 0.02 | 0.02 |
| Acetaldehyde | 0.05 | 0.05 | 0.05 | 0.04 | -0.09 | -0.07 | -0.01 | 37.45 | 0.01 | 0.01 |
| PAHs | 1.39 | 1.39 | 1.39 | 1.39 | 1.38 | 1.05 | 0.11 | 3.51 | 2.09 | 2.09 |
| Particulate Matter | | | | | | | | | | |
| Exhaust PM | 147.96 | 147.96 | 147.96 | 76.06 | -0.17 | -4.59 | -0.39 | 133.71 | 6.04 | 6.04 |
| Power Plant PM | -10.90 | -72.53 | -72.53 | -14.26 | 0.00 | 0.00 | 0.000 | -248.55 | 0.00 | 0.00 |
| Tire PM | 43.71 | 43.71 | 43.71 | 0.00 | -0.17 | -0.04 | 0.000 | 0.00 | 0.00 | -2.24 |
| Brake PM | 70.03 | 70.03 | 70.03 | 0.00 | -0.08 | -0.02 | 0.000 | 0.00 | 0.00 | -1.03 |
| Weighted Toxics | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Greenhouse Gases | 858.77 | 839.75 | 839.75 | -10.92 | 136.38 | 421.38 | 46.77 | 15,516.19 | -1,177.03 | 3,920.18 |
| Multimedia | 143.42 | 143.42 | 143.42 | 143.42 | 143.42 | 109.78 | 11.89 | 4,569.37 | 2,606.09 | 2,606.09 |
| NPV ($/gallon-displaced) | | | | | | | | | | |
| Total | 0.228 | 0.187 | 0.211 | 0.037 | 0.047 | 0.114 | 0.010 | 0.095 | 0.014 | 0.060 |
| $NO_x$ | 0.007 | 0.007 | 0.007 | 0.000 | -0.001 | 0.000 | 0.000 | 0.000 | 0.000 | -0.001 |
| CO | 0.004 | 0.001 | 0.001 | -0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| NMOG | 0.005 | 0.004 | 0.004 | 0.004 | 0.001 | 0.003 | 0.000 | 0.001 | 0.000 | 0.000 |
| Toxics | | | | | | | | | | |
| Benzene | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1,3 Butadiene | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Formaldehyde | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Acetaldehyde | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| PAHs | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Particulate Matter | | | | | | | | | | |
| Exhaust PM | 0.025 | 0.025 | 0.025 | 0.013 | 0.000 | -0.001 | 0.000 | 0.001 | 0.000 | 0.000 |
| Power Plant PM | -0.002 | -0.012 | -0.012 | -0.002 | 0.000 | 0.000 | 0.000 | -0.001 | 0.000 | 0.000 |
| Tire PM | 0.007 | 0.007 | 0.007 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Brake PM | 0.012 | 0.012 | 0.012 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Weighted Toxics | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Greenhouse Gases | 0.146 | 0.142 | 0.142 | -0.002 | 0.023 | 0.089 | 0.008 | 0.072 | -0.011 | 0.037 |
| Multimedia | 0.024 | 0.024 | 0.024 | 0.024 | 0.024 | 0.023 | 0.002 | 0.021 | 0.024 | 0.024 |

**Table 5-4. Summary of Indirect Benefits for Group 2 Options**

| Indirect Benefits Summary | Group 2 Options | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2020 | 2A | 2B | 2C | 2D | 2E | 2F | 2G | 2H1 | 2H2 | 2H3 | 2I | 2J |
| Petroleum Reduction (million gallons/year): | 750 | 750 | 470 | 1870 | 1870 | 1460 | 760 | 60 | 60 | 60 | 2759 | 83.5 |
| Emissions (tons/yr): | | | | | | | | | | | | |
| $NO_x$ | 438 | 425 | 228 | 34 | -211 | -38 | -1 | 2 | 2 | -5 | 24 | -6 |
| CO | 604 | 222 | 87 | -237 | -122 | -6 | 0 | 0 | 0 | -3 | 8 | -4 |
| NMOG | 854 | 790 | 454 | 1832 | 175 | 1009 | 9 | 23 | 22 | 22 | 365 | 30 |
| Toxics | 97 | 96 | 56 | 198 | 168 | 157 | 7 | 15 | 8 | 8 | 397 | 12 |
| Particulate Matter | 117 | 92 | 47 | -12 | 0 | -6 | 0 | 0 | 0 | 0 | 2 | 0 |
| Greenhouse Gases | 4,099,647 | 5,451,365 | 3,508,630 | -599,038 | 1,580,331 | 6,725,153 | 312,273 | 352,244 | 245,795 | 277,305 | -4,485,942 | 753,624 |
| Indirect Benefits (million 2001$) | 66 | 75 | 47 | 18 | 7 | 85 | 4 | 4 | 3 | 3 | -10 | 8 |

## 5.3 Group 3— Pricing Options

Group 3 options are based on altering the cost of driving, to decrease transportation demand or to encourage the use of efficient vehicles. Options 3A-3C represent measures that increase the cost of driving, resulting in decreased VMT, and decreased gasoline use. Options 3D and 3E are intended to transfer the cost of driving to vehicles with higher carbon emissions or increased driving. This results in a decrease in gasoline demand, as the increased cost of driving, results in a decreased VMT. Option 3F provides purchase incentives to vehicles with higher fuel economy levels. Encouraging the purchase of higher-efficiency vehicles leads to a lower demand for gasoline. Each Group 3 option results in emission decreases from vehicles, though decreased VMT, and/or lower fuel cycle emissions as gasoline demand is decreased.

**Table 5-5. Summary of Indirect Benefits for Group 3 Options**

| Indirect Benefits Summary | Group 3 Options | | | | | |
|---|---|---|---|---|---|---|
| 2020 | 3A (Gasoline Tax) | 3B (Pay @ Pump) | 3C (VMT Tax) | 3D (Feebates) | 3E (Reg Fee Transfer) | 3F (Incentives) |
| Petroleum Reduction (million gallons/year): | 891 | 743 | 554 | 1023 | 145 | 527 |
| Emissions (tons/yr): | | | | | | |
| $NO_x$ | 521.6 | 433.2 | 320.4 | 37.1 | 76.1 | 304.2 |
| CO | 825.1 | 685.1 | 506.4 | 11.0 | 119.6 | 480.9 |
| NMOG | 1,020.9 | 849.4 | 630.4 | 547.2 | 156.4 | 599.1 |
| Toxics | 114.5 | 95.3 | 70.8 | 72.8 | 17.7 | 67.3 |
| Particulate Matter | 604.1 | 501.6 | 370.7 | 3.0 | 87.5 | 352.0 |
| Greenhouse Gases | 10,821,755 | 9,024,202 | 6,728,678 | 12,424,978 | 1,761,116 | 6,400,746 |
| Indirect Benefits (million 2001$) | 162.85 | 135.64 | 100.90 | 136.85 | 25.72 | 95.94 |

**Table 5-6. Cumulative Indirect Benefits for Group 3 Options, by Time Period**

| Petroleum Reduction Options | Cumulative Indirect Benefits (million 2001$) | | | | |
|---|---|---|---|---|---|
| | 2002-10 | 2002-20 | 2002-30 | 2002-40 | 2002-50 |
| Group 3 -Pricing Options | | | | | |
| A: Gasoline Tax | 1,117 | 3,000 | 4,373 | 5,361 | 6,072 |
| B: Pay-at-the Pump Ins. | 918 | 2,479 | 3,628 | 4,459 | 5,057 |
| C: VMT Tax | 730 | 1,927 | 2,762 | 3,353 | 3,779 |
| D: Feebates | 429 | 1,628 | 2,899 | 3,885 | 4,595 |
| E: Registration Fee Transfer | 169 | 465 | 682 | 840 | 953 |
| F: Purchase Incentives | 328 | 1,193 | 2,201 | 3,042 | 3,648 |

## 5.4 Comparison of Indirect Benefits for Petroleum Reduction Options

The results shown in Sections 5.1 through 5.3 above are summarized here, and displayed side-by-side to show the relative merit of each option under consideration. Figures 5-3 to 5-6 show a comparison of each option's benefits, expressed on a per-displaced-gallon basis.

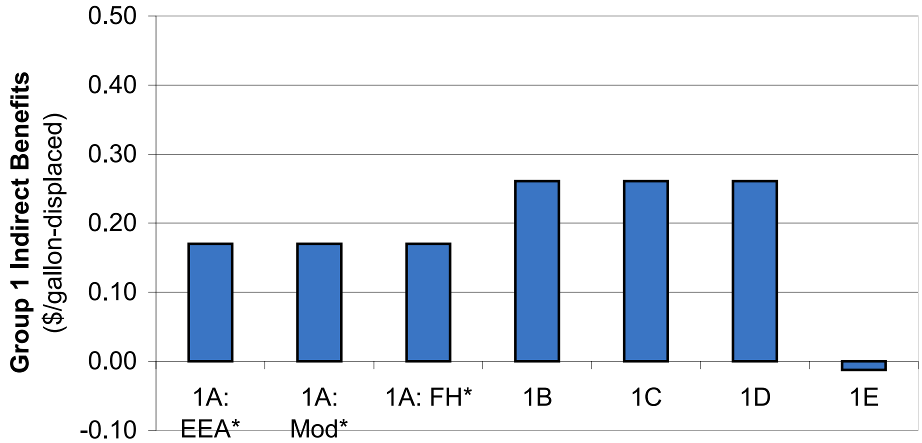



**Figure 5-3. Indirect Benefits for Group 1 Normalized by Total Fuel Volume Reduction**

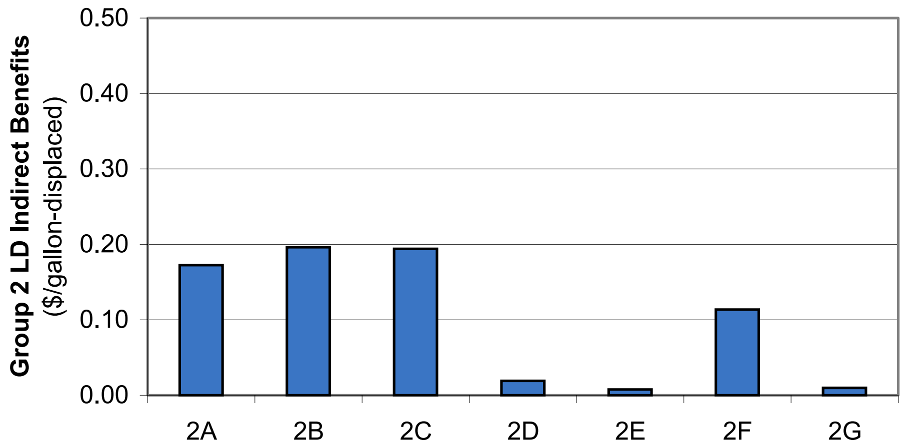



**Figure 5-4. Indirect Benefits for Group 2 (Light Duty) Normalized by Total Fuel Volume Reduction**

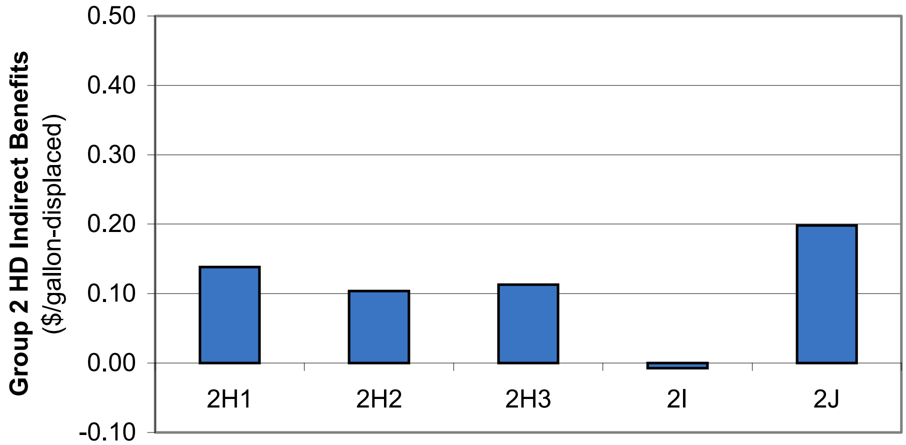



**Figure 5-5. Indirect Benefits for Group 2 (Heavy Duty) Normalized by Total Fuel Volume Reduction**

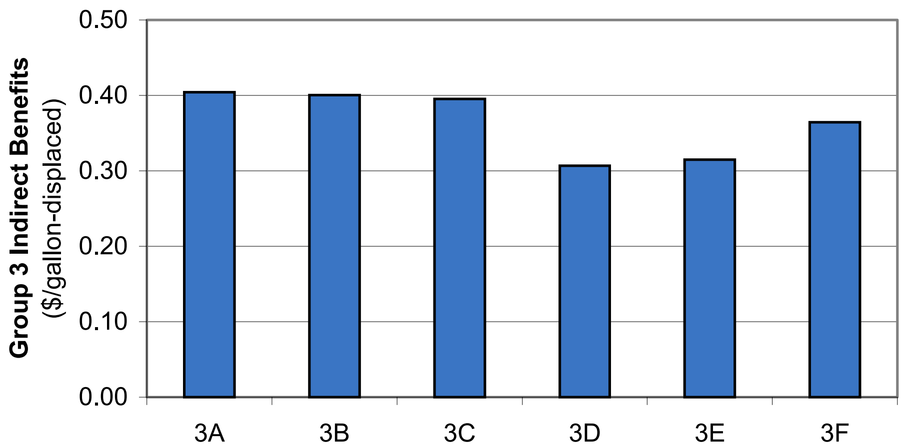



**Figure 5-6. Indirect Benefits for Group 3 Normalized by Total Fuel Volume Reduction**

## 6. Impacts of Petroleum Reduction Strategies on the California Economy (by Peter Hess and Peter Berck, University of California, Berkeley)

### 6.1 Introduction

This section presents the methodology and results of assessing the impacts of petroleum reduction strategies on the California economy. Methodology is discussed first, then results.

The methodology employed is computable general equilibrium (CGE) modeling. CGE models are designed to captures the fundamental economic relationships between producers, consumers, and government. The models are "computable" because numeric solutions are found using computers rather than solved for algebraically. They are "general" in the sense that all markets and all income flows in the economy are accounted for. They reflect "equilibrium" insofar as prices adjust to equilibrate the demand for and supply of goods, services, and factors of production (labor and capital) the model.

The specific model employed here is a modified version of E-DRAM (Environmental-Dynamic Revenue Analysis Model). E-DRAM was built for the California Environmental Protection Agency's Air Resources Board (ARB) by researchers at the University of California, Berkeley (UCB). E-DRAM evolved from DRAM (Dynamic Revenue Analysis Model), which was developed jointly by the California Department of Finance (DOF) and Berkeley researchers to perform dynamic revenue analyses of proposed legislation as mandated by California State Senate bill 1837 in 1994. Much of the description of E-DRAM below is closely adapted from Berck, et. al. (Summer 1996), which henceforth will be referred to as the DRAM Report.[6]

The remainder of this introduction is a non-technical description of E-DRAM. Section 6.2 outlines modifications made to E-DRAM for this project. Section 6.3 presents baseline solutions to the model for the years 1999, 2020, and 2050. Section 6.4 evaluates various policy scenarios in 2020 and 2050. Section 6.5 analyses the sensitivity of the results to select model parameters. Section 6.6 offers concluding remarks.

#### 6.1.1 A Description of the E-DRAM Model

E-DRAM describes the relationship among California producers, California households, California governments, and the rest of the world. Rather than tracking each individual producer, household, or government agency in the economy, however, E-DRAM combines similar agents into single sectors. Constructing a cogent sectoring scheme, the first step of model construction, is discussed immediately below; this discussion is followed by a description of the key agents in the economy – producers and consumers.

[6] The DRAM Report, *"Dynamic Revenue Analysis for California"* (Berck, *et. al.*, Summer 1996), is available at www.dof.ca.gov/HTML/FS_DATA/dyna-rev/dynrev.htm. .

#### 6.1.1.1 Aggregation and Data Sources

E-DRAM, like all other empirical economic models, treats aggregates rather than individual agents. This is done both to provide focus for the analysis and contain the number of variables in the model. Constructing a cogent aggregation (or sectoring) scheme is critical in the development of a CGE model because it determines the flows that the model will be able to trace explicitly. For the E-DRAM model, the California economy has been divided into 93 distinct sectors: 29 industrial sectors, 2 factor sectors (labor and capital), 9 consumer good sectors, 7 household sectors, 1 investment sector, 45 government sectors, and one sector representing the rest of the world. The complete details of the sectoring are given in Chapter II of the DRAM Report.

For industrial sectoring purposes, all California firms making similar products are lumped together. The agriculture sector, for example, contains all California firms producing agricultural products. The output value of that sector is the value of all crops produced by California growers. A sector's labor demand is the sum of labor used by all firms in the sector. Along with agriculture, there are 28 other producer aggregates in the model. These aggregates generally represent the major industrial and commercial sectors of the California economy, though a few are tailored to capture sectors of particular regulatory interest. For instance, production of internal combustion engines and consumer chemicals are each delineated as distinct sectors at the request of ARB.[7]

Data for the industrial sectors originates from the U.S. Department of Commerce's Bureau of Economic Analysis (BEA), and is based on the Census of Business – a detailed survey of U.S. companies conducted every five years.[8] The survey contains information about intermediate purchases, factor (labor, capital, land and entrepreneurship) payments, and taxes. Although quite extensive, the survey only allows inference about groups of firms at the national level. The conversion of national data to updated California data is accomplished using a combination of state level employment data and estimates from DOF's econometric modeling.

Like firms, households are also aggregated. California households are divided into categories based upon their income. There are seven such categories in the model, each one corresponding to a California Personal Income Tax marginal tax rate (0, 1, 2, 4, 6, 8, and 9.3 percent). Thus, the income from all households in the one-percent bracket is added together and becomes the income for the "one-percent" household sector. Similarly, all expenditure on agricultural goods by the one-percent households is added and becomes the expenditure of the one-percent household sector on agricultural goods. Total household expenditure on agricultural goods is the sum of expenditures by all seven household sectors. Household income data come from the California Franchise

[7] The alcohol, tobacco, and horse racing sector, distinct in DRAM, is been folded into the foods sector in the latest version of E-DRAM.

[8] The survey is conducted in years ending in 2 and 7 and data is released after processing. E-DRAM uses data from the 1997 release, which contains processed 1992 survey data.

Tax Board Personal Income Tax "sanitized" sample. Data on consumption by income class is derived from national survey data.

The government sectors in DRAM are organized so that both government revenue flows and expenditure flows are traced explicitly. The DRAM includes 45 government sectors: 7 federal, 27 state, and 11 local. Government sector data is culled from published federal, state, and local government reports.

#### 6.1.1.2 Producers and Households

Fundamental to the California economy, and hence E-DRAM, are the relationships between the two principal types of economic agents – producers and households.

Producers, also known as firms, are aggregated into industrial sectors, and each sector is modeled as a competitive firm. For instance, the output of all of California's agricultural firms is modeled as coming from a single entity, the agriculture sector. Each sector takes the price that it receives for its output and the prices that it pays for its inputs (capital and labor, called "factors of production," and other inputs, called "intermediate goods") as fixed. This is the competitive model: producers do not believe that their decisions have any effect on prices. Each producer is assumed to choose inputs and output to maximize profits. Inputs are labor, capital, and intermediate goods (outputs of other firms). Thus, the producer's supply of output is a function of price and the producer's demand for inputs is a function of price. More information on producers is provided in Chapter IV of the DRAM Report.

Households make two types of decisions: they decide to buy goods and services; they also decide to sell labor and capital services. They are assumed to make these decisions in the way that maximizes their happiness (called "utility" in the economics literature). Like firms, they take the prices of the goods that they buy and the wage of the labor that they sell as fixed. In addition to their labor income, households receive dividends and interest from their stocks and bonds and other ownership interests in capital.

Households' supply of labor, as a function of the wage rate, is called the "labor-supply function." A more detailed description of the supply of labor is given in Chapter VII of the DRAM Report.

Households' demand for goods or services, as a function of prices, is simply called the "demand function." A more detailed description of the demand for goods and services is given in Chapter III of the DRAM Report, as well as in *"Estimation of Household Demand for Goods and Services in California's Dynamic Revenue Analysis Model,"* (Berck, Hess, and Smith, Sept. 1997) currently available at www.are.berkeley.edu/~phess/demand.pdf. The latter explains how the distribution of household spending across the 29 industrial sectors via the nine consumer goods sectors is based on analysis of U.S. Bureau of Labor Statistics' Consumer Expenditure Survey data.

#### 6.1.1.3 Equilibrium

So far, two types of agents have been described: firms and households. It remains to be explained how these agents relate. They relate through two types of markets: factor markets and goods-and-services markets. Firms sell goods and services to households on the goods-and-services markets. Households sell labor and capital services to firms on the factor markets. There is a price in each of these markets. There is a price for the output of each of the 29 industrial sectors. There is a price for labor, called the "wage," and a price for capital services, called the "rental rate." Equilibrium in a market means that the quantity supplied (which is a function of price) is equal to the quantity demanded (which is also a function of price) in that market. Equilibrium in the factor markets for labor and capital and in the goods-and-services markets for goods and services defines a simple general equilibrium system. That is, there are 31 prices (the wage, the rental rate, and one for each of the 29 goods made by the 29 sectors) and these 31 prices have the property that they equate quantities supplied and demanded in all 31 markets. They are market-clearing prices.

These relationships are shown in more detail in Figure 6-1, called a "circular-flow diagram." The outer set of flows, shown as solid lines, are the flows of "real" items, goods, services, labor, and capital. The inner flows, shown as broken lines, are monetary flows. Thus, firms supply goods and services to the goods-and-services market in return for revenues that they receive from the goods-and-services markets. Firms demand capital and labor from the factor markets and in return pay wages and rents to the factor markets.

Households, the other type of agent in a simple model, buy, or in economic parlance, demand, goods and services from the goods-and-services markets and give up their expenditure as compensation. They sell capital and labor services on the factor markets and receive income in exchange.

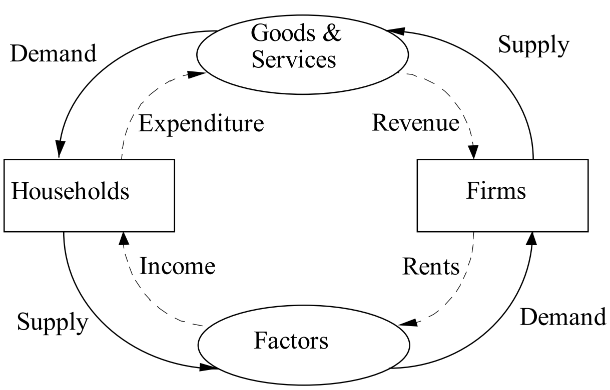



**Figure 6-1. The Basic Circular-Flow Diagram**

#### 6.1.1.4 Intermediate goods

The economy of California is far more complex than that shown in Figure 6-1. There are not only final goods-and-services markets but also intermediate goods markets in which firms sell to firms. A typical example of this would be chemicals sold to agricultural firms. The final output of the chemical industry (perhaps fertilizer) is said to be an intermediate good in the agricultural industry. This type of market is demonstrated in Figure 6-2. Here, part of the supply of a firm (chemical industry in the example) is not sold to households but rather to another firm in exchange for revenue. From the other firm's point of view, it buys an input to production from a firm rather than from a household. The expense of buying the input is a cost of production. Chapter IV of the DRAM Report contains the model specification for these types of transactions, which are based upon a national input-output (I-O) table.

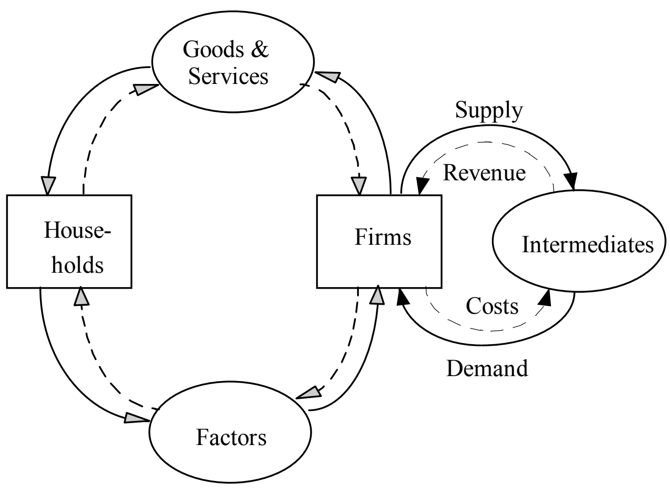



**Figure 6-2. The Circular-Flow Diagram with Intermediate Goods**

#### 6.1.1.5 Rest of the World

California is an open economy, which means that it trades goods, services, labor, and capital readily with neighboring states and countries. In this model, all agents outside California are modeled in one group called "Rest of World (ROW)." No distinction is made between the rest of the U.S. and foreign countries. California interacts with two types of agents: foreign consumers and foreign producers. Taking the producers first, Figure 6-3 shows that the producers sell goods on the (final) goods-and-services markets and on the intermediate markets, i.e., they sell goods to both households and firms. The model takes these goods as being imperfect substitutes for the goods made in California. Agricultural products from outside of California (e.g., feed grains, bananas) are taken as being close to, but not identical to, California-grown products (e.g., avocados, fresh chicken). The degree to which foreign and domestic goods substitute for each other is very important, and the evidence is described in Chapter V. Foreign households buy

California goods and services on the goods-and-services markets. They and foreign firms both can supply capital and labor to the California economy, and domestic migration patterns are described in Chapter VIII of the DRAM Report.

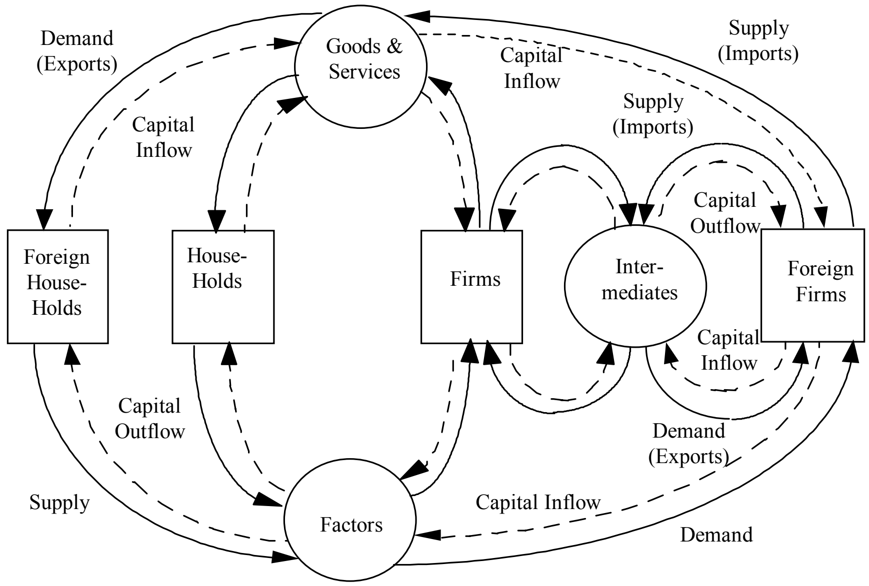



**Figure 6-3 The Circular-Flow Diagram with Intermediate Goods and Trade**

### 6.1.1.6 Government

Finally, government is considered. Combining the taxing and spending effects of the three levels of government (federal, state, and local) gives the additional flows in Figure 6-4. Beginning at the top, the figure shows that government buys goods and services and gives up expenditure. It supplies goods and services for which it may or may not receive revenue. Government also supplies factors of production, such as roads and education. The model does not currently include goods such as K-12 education as such goods are not always traded in organized markets. Government also makes transfers to households, which are not shown in the diagram. The middle section of the diagram shows the myriad of ways in which government raises revenue through taxation. Chapter II of the DRAM Report includes a detailed description of the government activities in the model.

### 6.1.1.7 Data Organization: The Social Accounting Matrix

The first step in constructing a CGE model is to organize the data. The traditional approach to data organization for a CGE model is to construct a Social Accounting Matrix (SAM). A SAM is a square matrix consisting of a row and column for each

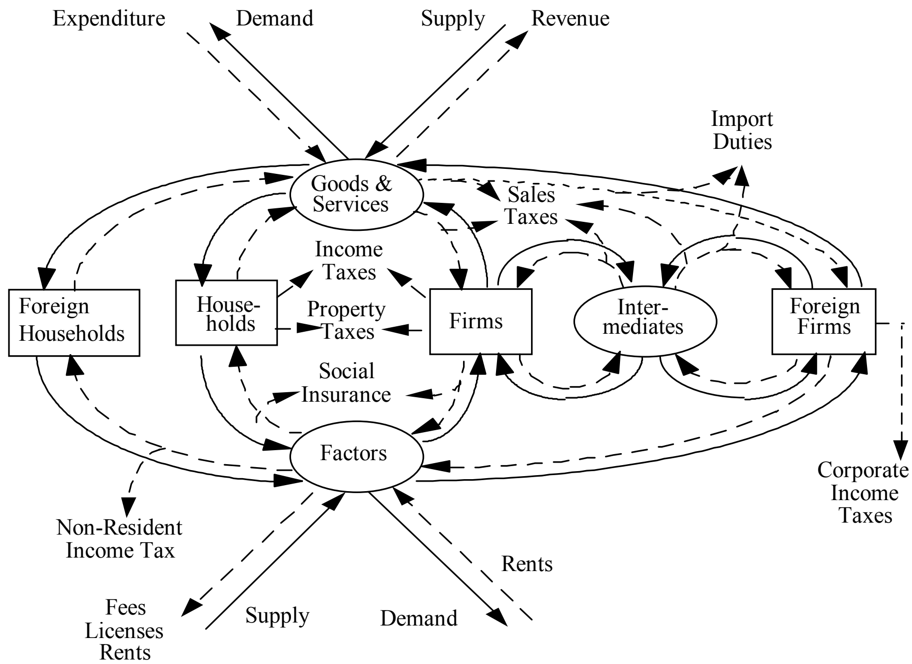



**Figure 6-4. The Complete Circular-Flow Diagram**

sector of the economy. Each entry in the matrix identifies an exchange of goods and services purchased by one sector from another sector (or itself). The entries along a row in the SAM show each payment received by that particular row sector from each column sector. Summing across the row gives total payments made to that row sector by all column sectors. The entries down a column in the SAM show the expenditures made by that particular column sector to all row sectors. Summing down a column gives total expenditures by that column sector to all row sectors. For accounting purposes, a SAM must "balance," i.e., the each row sum and corresponding column sum must be equal. This balancing ensures that no money "leaks" out of the economy, i.e. that all money received by firms (row sum) is spent by them (column sum).

### 6.1.2 Regional and National Model Differences

There have been hundreds of CGE models built and used for analyzing public policy at the national and international level. Regional, or sub-national, CGE models are very similar in design to national and international models, but exhibit major differences in several key assumptions. The seven most important differences between national and regional CGE models are discussed below.

The first, and maybe most important, difference is that regional CGE models do not require that regional savings equal regional investment. When Californians save more than California investors want to use, excess savings flow out of the state. When the converse is true, savings flow into the state. Rational economic agents would not accept less interest on their savings from California investors if higher interest rates were available in other states or countries. Conversely, rational investors in California would not pay higher interest for the use of Californian savings if other states or countries offered lower rates.

The second difference is that regional economies trade a larger share of their output. Therefore, trade is more important in regional models. Note that interstate trade is part of the Rest of World for California but ignored in national considerations of trade.

The third difference is that regional economies face larger and more volatile migration flows than nations. Regional and international migration to California is a major factor in the State's economy.

The fourth difference between national and regional CGE's is that regional economies have no control over monetary policy. The Federal Reserve is responsible for monetary policy and is a national institution.

The fifth difference is that in regional models taxes are interdependent through deductibility. Some local taxes are deductible from incomes subject to California Personal Income Taxes and Bank and Corporation taxes. Some local and state taxes are deductible from incomes subject to Federal Personal Income Tax and may be eligible for deduction from corporate incomes for federal purposes. In E-DRAM, the personal tax deductibility is explicitly modeled. Since corporate deductibility is more uncertain and since the apportionment rules may reduce the connection to federal corporate taxes, corporate deductibility has not been included in E-DRAM.

Sixth, while good data for a CGE are hard to find at the national level, in many cases they are nonexistent for regional economies. The E-DRAM uses published economic and statistical literature to simulate much of the data important to our model. In some cases, such as labor supply, a wide variety of results are presented in the literature. This problem is addressed in three ways: (1) values are chosen so as to avoid the extremes, (2) the model is tested to determine the degree to which results are dependent upon our assumptions (this process is called "sensitivity analysis"), and (3) the use of published literature, especially of national results, has been minimized.

Seventh, the California CGE differs from a national CGE in that California faces a balanced-budget requirement. Even if this is ignored in the short run, bond markets tend to reflect this fact. When California issued bonds to cover short-term deficit spending in the early 1990s, bond ratings forced up the cost of borrowing. Ultimately, California would face unreasonable borrowing costs should it decide to maintain this level of borrowing.

### 6.1.3 Other Considerations and Model Building

The CGE models are not forecasting models; they are calibrated to reproduce a base year. In the case of E-DRAM, the model is constructed to exactly reproduce the economic conditions of fiscal year 1998/99. Of course, there are forecasting models. However, such models typically do not have the level of detail needed to examine dynamic policy effects. Given the paucity of California-specific data, it seems a better compromise to use a forecasting model, such as the one maintained by DOF, to set a base case and then use a policy model, such as DRAM, to analyze deviations from that case.

The E-DRAM model incorporates two assumptions that require some comment. It assumes competitive behavior in all private sectors. This is a good first approximation, particularly at the level of a sector. The alternative, oligopoly behavior, may well be present, but the degree of markup of price over marginal cost is not likely to be significant. The second assumption is that involuntary unemployment is constant. This is unlikely to be strictly true. The model has voluntary unemployment, which are agents deciding to work less when the wage is lower. This assumption is common to all equilibrium models. Technical issues of model closure are described in Chapter IX of the DRAM Report.

Once the major agents in the economy have been identified and the relationship between these agents has been specified, the model can be built. In E-DRAM, the algebraic representation of the relationships between the agents in the California economy is achieved with General Algebraic Modeling System (GAMS). The model currently has 1,100+ equations, exclusive of definitions and of the code to read in and organize the data. All of the model's equations and GAMS code are detailed in Chapter X.

### 6.1.4 Further Documentation

Fuller description of common features shared by E-DRAM and DRAM is available in the report cited above (see footnote 5). The primary contents of that report, the presentation of which mirrors the sequence of tasks involved in building DRAM, are as follows. In Chapter II of the DRAM Report, the major agents in the economy are identified and aggregated into sectors. These aggregates are constructed to focus the model on the major industries, taxpayers, and government agencies in the California economy. Data sources are also identified.

Chapters III through VIII of the DRAM Report review the literatures, functional forms, and elasticities relevant to the six primary behavioral equations that link all the various sectors of the model and drive its results. Chapter III of the DRAM Report reviews the literature on the economic behavior of households with respect to consumption and savings decisions. The literature on the production decisions of firms is examined in Chapter IV of the DRAM Report. Chapter V of the DRAM Report summarizes the literature on international and interregional trade. Investment theory is discussed in Chapter VI of the DRAM Report. Chapter VII of the DRAM Report covers the literature on regional labor-supply response to taxation and economic growth, while the literature on migration and economic growth is examined in Chapter VIII of the DRAM Report.

After establishing the sectoring scheme, data sources, and behavioral equations for the model, all that remains before the actual model can be built is a description of the model-closure rules. Closure rules concern the mathematics of insuring that a solution exists to the 1,100+ equations of the model. Model closure is developed in Chapter IX of the DRAM Report.

Chapter X of the DRAM Report describes the mathematical and corresponding GAMS notation for each equation in DRAM. It is a technical description of the complete California Dynamic Revenue Analysis Model.[9, 10]

Chapter XI of the DRAM Report presents some preliminary sensitivity analyses.

Appendices follow Chapter XI of the DRAM Report. They include the original literature search by Dr. Berck and Mr. Dabalen in the Summer of 1995, explanations of notational methods used, lists of parameter and variable names used in the mathematical and software input files, and printed copies of the input files themselves.

### 6.2 Model Enhancements

For examining petroleum dependency issues in particular, the E-DRAM built for ARB as described in Berck and Hess (Feb. 2000) is enhanced in three ways. First, Petroleum sector data is modified. Second, the 1998/1999 base year model is extrapolated out to 2020 and 2050 based on state population, personal income, and industry-specific forecasts. Third, parameters to adjust for technological change in the form of increased fuel efficiency and fuel displacement are incorporated into the model. Each of these enhancements is discussed in turn in the subsections below.

#### 6.2.1 Petroleum Sector Base Data Modification

As indicated in Section 6.1.1.1, E-DRAM's original industrial accounts are national accounts scaled to the state level using California employment data. These accounts have been reconciled with more California-specific Petroleum sector figures provided by ADL in consultation with ARB, the California Energy Commission (CEC), and the Berkeley team.

ADL estimated California refinery flows from EIA data.[11] A summary of these data for 1999 is shown in Table 6-1. Several assumptions were made to get both specific California data and data for California supplies to Nevada and Arizona. First, ADL

[9] See Berck, Hess, and Smith (Sept. '97) for revisions to the consumer demand portion of the model.

[10] Modification of equations from DRAM to E-DRAM are discussed in *"Developing a Methodology for Assessing the Economic Impacts of Large Scale Environmental Regulations,"* (Berck and Hess, Feb. 2000). Changes introduce parameters that facilitate running policy scenarios as some combination of price, intermediate good, and/or investment changes.

[11] Energy Information Administration, Office of Oils & Gas, U.S. DOE, "Petroleum Supply Annual 1999," Vol. 1, June 2000 (www.eia.doe.gov/oil_gas/petroleum/data_publications/petroleum supply_annual/psa_volume 1/psa_volume1.html)

assumed that California refining capacity and products are 72 percent of PAD V (28 percent is associated primarily with refining in Washington). Second, we also assumed that California refineries supply 80 percent of Nevada's needs and 50 percent of Arizona's needs. Prices for products indicated in Table 6-1 are actual 1999 prices as reported by EIA. For example, average crude oil price was $17.81/bbl in 1999 and average finished motor gasoline price was $1.30/gal.

Estimates for 2020 and 2050 were obtained by first determining the overall demand for finish products. This was estimated from the CEC projections of baseline fuel demands (CEC, 2001). In this report, fuels are projected to grow at the following annual rates:

| Product | % Growth rate/yr |
|---|---|
| Gasoline | 1.6 |
| Diesel | 2.4 |
| Jet | 3.4 |

We also assumed a nominal growth rate of 2 percent per year for residual and 1 percent per year for LPG and other products. The California growth rates were also applied to Nevada and Arizona.

Based on the total products supplied in 2020 and 2050, we then estimated how the refineries would produce these fuels. Several assumptions were used to make these predictions. California refinery capacity was assumed to grow at 0.5 percent per year through 2020 (Stillwater). This adds about 11 percent to the 1999 capacity of about 628.8 million barrels. After 2020 the capacity was held fixed and increase demand had to be met with importing refined products.

California oil production was assumed to decline from 1999 levels of 273 million barrels to 90 million barrels in 2020 and no in-state production in 2050. This estimate was based on linear extrapolation of either historical production or reserves. Either of these indicated California production being eliminated in the 2030-2040 time frame. Also, Alaska production (assuming no new drilling) declines to zero in the 2020-2030 time frame. Thus, California will be far more dependent on foreign oil supplies in the post 2020 years. 2020 and 2050 prices were also determined or scaled from CEC projections. CEC projects crude oil prices at $22.50/bbl and gasoline at $1.64/gallon and diesel at $1.65 gallon. So the prices in Table 6-1 are comparable for 2020 and 2050 and are higher than 1999 by about the ratio of $22.50 to $17.81.

## Table 6-1. Summary of California Supply and Demand for Refinery Products

| Description | 1999 | | 2020 | | 2050 | |
|---|---|---|---|---|---|---|
| | 000 bbls | $ million | 000 bbls | $ million | 000 bbls | $ million |
| **Imports to California** | | | | | | |
| Crude oil | 391,395 | 6,971 | 608,140 | 13,683 | 698,236 | 15,710 |
| Natural gas liquids | (1) | — | — | — | — | — |
| Other liquids (unfinished oils and gasoline blend components like oxygenates) | 29,227 | 1,228 | 37,979 | 1,595 | 75,959 | 3,190 |
| Refined products | 64,514 | 2,723 | 291,000 | 15,725 | 1,192,500 | 64,438 |
| Total Import Value | | 10,921 | | 31,003 | | 83,339 |
| **California Oil Production** | 273,019 | 4,862 | 90,096 | 2,027 | — | — |
| Total Input to California | | 15,784 | | 33,030 | | 83,339 |
| **California Transportation Consumption** | | | | | | |
| Finished motor gasoline | 335,633 | 18,364 | 463,151 | 31,902 | 745,648 | 51,360 |
| Distilled fuel oil | 64,078 | 3,199 | 128,190 | 8,884 | 261,128 | 18,096 |
| Residual fuel oil | 27,881 | 317 | 68,642 | 987 | 124,336 | 1,788 |
| Jet fuel | 98,673 | 2,383 | 218,894 | 6,680 | 596,829 | 18,213 |
| Liquefied petroleum gases | 384 | 15 | 592 | 30 | 592 | 30 |
| Other | 3,796 | 148 | 5,236 | 258 | 5,236 | 258 |
| California demand | 530,445 | 24,427 | 884,705 | 48,740 | 1,733,769 | 89,745 |
| **California Other Consumption** | | | | | | |
| Finished motor gasoline | 2,158 | 118 | 2,697 | 186 | 4,342 | 299 |
| Distillate fuel oil | 10,584 | 328 | 16,421 | 1,138 | 33,451 | 2,318 |
| Residual fuel oil | 684 | 12 | 1,404 | 30 | 2,544 | 54 |
| Jet fuel | — | — | — | — | — | — |
| Liquefied petroleum gases | 11,787 | 374 | 14,630 | 586 | 14,630 | 566 |
| Other | 62,101 | 3,391 | 85,146 | 5,873 | 85,146 | 5,873 |
| California demand | 87,314 | 4,222 | 120,300 | 7,813 | 140,114 | 9,120 |
| **Exports from California** | | | | | | |
| Crude oil | 35,610 | 634 | — | — | — | — |
| Refined products | 62,425 | 2,439 | 69,292 | 3,420 | 69,292 | 3,420 |
| California production to Arizona, Nevada for transportation and other | | | | | | |
| Finished motor gasoline | 44,908 | 2,457 | 61,932 | 4,266 | 99,707 | 6,868 |
| Distillate fuel oil | 18,054 | 901 | 34,968 | 2,423 | 71,231 | 4,936 |
| Residual fuel oil | 114 | 1 | 280 | 4 | 506 | 7 |
| Jet fuel | 11,497 | 278 | 25,504 | 778 | 69,538 | 2,122 |
| Liquefied petroleum gases | 3,179 | 127 | 3,976 | 201 | 3,976 | 201 |
| Other | 7,268 | 284 | 9,969 | 492 | 9,969 | 492 |
| Out of State Demand | 85,019 | 4,048 | 136,628 | 8,164 | 254,928 | 14,626 |
| Export value | | 7,121 | | 11,584 | | 18,046 |
| Total output | | 33,987 | | 63,744 | | 111,211 |

There are several interesting trends suggested in the data shown in Table 6-1. California will be importing more crude in the out years due to dwindling in-state production. In 1999, crude imports (including mostly Alaska) were 391 million barrels. This will grow to 698 million barrels in 2050 and this supply will all have to come from foreign sources. In 1999, California imported 64.5 million barrels of refined products, which will grow to 1.19 trillion barrels in 2050.

Table 6-2 itemizes our estimate of California refinery supply and demand expressed in dollars. This also shows in the out years that California will be much more dependent on imported refined products.

**Table 6-2. Estimate of Supply and Demand Balance for California Refineries**

| Description | 1999 $ million | 2020 $ million | 2050 $ million |
|---|---|---|---|
| Supply California refineries | 32,413 | 52,413 | 52,483 |
| Refined products imported | 2,723 | 15,725 | 64,438 |
| Total demand | 35,136 | 68,137 | 116,922 |
| California | 28,649 | 56,553 | 98,876 |
| Export to Arizona, Nevada | 4,048 | 8,164 | 14,626 |
| Export from refineries | 2,439 | 3,420 | 3,420 |
| Crude imports | 6,971 | 13,683 | 15,710 |
| Supply | 32,413 | 52,413 | 52,483 |
| Demand | 35,136 | 68,137 | 116,922 |
| Import of refined products | (2,723) | (15,725) | (64,438) |

Modifications to the petroleum sector 1999 base data are as follows. First, E-DRAM's original petroleum sector (PETRO) import and export figures were replaced with those provided by ADL.[12] Petroleum exports from California, as recorded in the (PETRO, ROW) cell of the SAM, were decreased from $11 billion down to $6.5 billion.[13] Petroleum imports to California, as recorded in the (ROW, PETRO) cell of SAM, were increased from $0.5 billion up to $2.7 billion.

Second, E-DRAM's California petroleum demand was raised to match ADL’s California petroleum demand estimate by increasing in-state consumer demand for petroleum (CFUEL).[14] Operationally, this was achieved by increasing the SAM cell (PETRO,

[12] Trade flow data is typically one of the weakest links in regional economic models.

[13] Following convention, matrix cells are referenced by (row name, column name).

[14] All adjustment came through the consumer sector due to perceived weakness in E-DRAM's household demand data vise-a-vise government and industry demand data and the relative strength of indications from outside sources that household consumption was higher than the model's original base data suggested.

CFUEL) from $6.3 billion to $13.7 billion. For consistency, this change was traced through household (HOUSE#) spending on CFUEL by raising each SAM (CFUEL, HOUSE#) cell by 20 percent. Increased fuel spending was offset via 0.8-1.6 percent (depending on each household sectors' overall expenditure levels) spending cuts applied uniformly across the other eight consumer good sectors.

Third, E-DRAM's petroleum supply was raised to equal California demand ($28.6 billion) plus exports from California ($6.5 billion) minus imports to California ($2.7 billion) as calculated from the revised numbers above. This supply shift was implemented by increasing petroleum sector inputs (intermediates, factors, and taxes thereon) by 2.2 percent across the board.[15]

Once these changes were made, the 1999 SAM had to be re-balanced, that is the SAM needed to be adjusted so that the row and column totals were again the same. Re-balancing was done using a program written by Sherman Robinson and Moataz El-Said in November 2000.[16]

### 6.2.2 Extrapolation from 1999 to 2020 and 2050

As discussed in Section 6.1.3, E-DRAM is not a forecasting model, but rather a model constructed to exactly reproduce the economic conditions of fiscal year 1998/99. To answer questions concerning the impacts of petroleum dependency reduction strategies far into the future, E-DRAM must be augmented to reflect future conditions. To "re-base" E-DRAM, *i.e.*, move from a model of the 1999 economy to models of the economy in 2020 and 2050, E-DRAM's input data must be modified to reflect economic conditions in those "out years." The following process leaves the basic structure of economic relationships intact, while scaling up 1998/1999 monetary and employment data using state personal income, population, and industry-specific forecasts.

#### 6.2.2.1 Incorporating General Growth Forecasts

The first step in re-basing E-DRAM is to forecast economic growth. Borrowing from the University of California, Los Angeles (UCLA) business forecast, an average annual growth rate of 2.84 percent was assumed for the years 2000 to 2020; an average annual growth rate of 2.58 percent was assumed for 2020 to 2050. Compounding these growth rates delivered scale factors for re-basing monetary flows recorded in the SAM. In re-basing from 1998/1999 to 2020, each 1999 SAM transaction – unless otherwise noted below – was scale up by a factor of 2.2515; in re-basing from 2020 to 2050, each 2020 SAM transaction – unless otherwise noted below – was scaled by a factor of 2.1520.[17]

[15] Production is constant returns-to-scale.

[16] The method is described in S. Robinson, A. Cattaneo and, M. El Said, "Updating and Estimating a Social Accounting Matrix Using Cross Entropy Methods." TMD Discussion Paper No. 58, IFPRI, August 2000. (This paper was also to be published in Economic Systems Research, March/June 2001.)

[17] The UCLA forecast for state personal income (SPI) is $1.1 trillion in 2000 and implies an average annual SPI growth rate of 2.84% to 2012. Given that the 2000 SPI forecast is roughly 28% above the original 1998/1999 E-

The second, related, step in re-basing E-DRAM is to forecast population and/or employment growth. DOF projections suggest a California population growth rate of 1.36 percent annually. Compounding this rate delivered scale factors for re-basing employment data. In re-basing from 1998/1999 to 2020, each employment-by-industry cell in the 1999 MSC matrix (in the MSC input file) was scaled up by a factor of roughly 1.3; in re-basing from 2020 to 2050, the each employment-by-industry cell in the 2020 MSC matrix was scaled up by roughly 1.5.[18]

The third step in re-basing E-DRAM is to reconcile income and property tax accounts. Receipts scaled up via step one above, change model calculated rates – which act as incentives in economic decision making – when the population grows at a different pace than the economy as a whole. Rates and receipts are reconciled via tax adjustment parameter, TAXCVC (GI,H).[19]

#### 6.2.2.2 Incorporating Petroleum Sector Forecasts

Petroleum sector and energy and mining sector (ENMIM), supply, demand, and trade flows were scaled according to ADL's projections as detailed in Tables 6-1 and 6-2.[20]

#### 1999 to 2020

ADL projects demand (including exports) for California refined petroleum rising from $35.1 billion in 1999 to $68.1 billion in 2020, and California supply (excluding imports) rising from $32.4 billion to $52.4 billion over the same time period. Operationally, this meant increasing California refined petroleum demand (all cells, except ROW, in the PETRO row of SAM) by a factor of nearly 2, while increasing California refined petroleum supply (all cells, except ROW, in the PETRO column of SAM) by a factor of roughly 1.6 when re-basing E-DRAM from 1998/1999 to 2020.[21] The gap in domestic supply and demand was offset by higher net imports. Refined imports, SAM cell (ROW, PETRO), were raised from $2.7 billion in the 1999 SAM to $15.7 billion in the 2020 SAM; refined exports, SAM cell (PETRO, ROW) were raised from $6.5 billion to $11.6 billion.

ADL projects California crude oil production dropping from roughly $4.9 billion in 1999 to roughly $2 billion in 2020. With crude oil accounting for 79 percent of energy

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DRAM SPI level, and extrapolating the 2.84% growth rate out to 2020, each cell of the SAM – unless otherwise noted – was scaled up by $1.28*(1.0284)^{20} = 2.2515$ in re-basing the model from '98/'99 to 2020. Assuming 2.58% average annual SPI growth from 2020 to 2050 led to scaling each cell of the SAM – unless otherwise notes – by a by factor of $(1.0258)^{30} = 2.1520$.

[18] Scale factors for employment in the petroleum sector and the energy and mining sector were slightly lower, in accordance with growth forecasts for those industries (see next section).

[19] GI indexes government income tax units, *i.e.*, federal and state income tax as well as local property tax; H indexes household types (which, recall, are classified by income tax bracket).

[20] Capital stocks in the energy sectors were fixed to reflect capacity constraints.

[21] The increases in consumer petroleum demand, SAM cell (PETRO, CFUEL), was again translated through household sectors' increased expenditure on CFUEL and decreased expenditure on other consumer goods as discussed in Section 6.2.1.

and mining sector (ENMIN) output value in 1999, that sector's production was projected to be only 2.4 percent higher in 2020 than 1999.[22] Assuming ENMIN sector demand (including exports) grows at 2.84 percent annually along with rest of the economy, the resulting gap in domestic supply and demand was offset with higher imports. ENMIN sector imports, SAM cell (ROW, ENMIN), were raised from $17.5 billion in the 1999 SAM to $36.0 billion in the 2020 SAM.

Once these changes were made, the 2020 SAM was re-balanced using the cross entropy program written by Sherman Robinson and Moataz El-Said.

**2020 to 2050**

Gaps between supply and demand are more pronounced in the 2050 projections.

ADL projects demand (including exports) for California refined petroleum rising from $68.1 billion in 2020 to $116.9 billion in 2050, and California supply (excluding imports) rising from $52.4 billion to only $52.5 billion over the same time period. Operationally, this meant increasing California refined petroleum demand (all cells, except ROW, in the PETRO row of SAM) by a factor of 1.775, while increasing California refined petroleum supply (all cells, except ROW, in the PETRO column of SAM) by a factor of roughly 1.008 when re-basing E-DRAM from 2020 to 2050.[23] The gap in domestic supply and demand was offset by higher net imports. Refined imports, SAM cell (ROW, PETRO), were raised from $15.7 billion in the 2020 SAM to $64.4 billion in the 2050 SAM; refined exports, SAM cell (PETRO, ROW) were raised from $11.6 billion to $18.0 billion.

ADL projects California crude oil production dropping from roughly $2.0 billion in 2020 to zero in 2050. With crude oil accounting for 31 percent of energy and mining sector (ENMIN) output value in 2020, that sector's production was projected to be 19 percent higher in 2050 than 2020.[24] Assuming ENMIN sector demand (including exports) grows at 2.58 percent annually along with rest of the economy, the resulting gap in domestic supply and demand was offset with higher imports. ENMIN sector imports, SAM cell (ROW, ENMIN), were raised from $36.0 billion in the 1999 SAM to $57.0 billion in the 2020 SAM.

Once these changes were made, the 2050 SAM was re-balanced using the cross entropy program written by Sherman Robinson and Moataz El-Said.

[22] The remaining 21% of the ENMIN sector was assumed to grow at the same rate as the rest of the economy, *i.e.*, 2.84% annually.

[23] The increases in consumer petroleum demand, SAM cell (PETRO, CFUEL), was again translated through household sectors' increased expenditure on CFUEL and decreased expenditure on other consumer goods as discussed in Section 6.2.1.

[24] The remaining 69% of the ENMIN sector was assumed to grow at the same rate as the rest of the economy, *i.e.*, 2.58% annually.

### 6.2.3 Adjusting for Technological Change

Parameters for modeling technological change built into the original E-DRAM were augmented for the current analyses.

As described in Berck and Hess (Feb. 2000), the original E-DRAM allows for changes in production technology. Each industrial sector in E-DRAM is implicitly characterized by a production function that relates output to factor (capital and labor) and intermediate inputs. Technological change is modeled by altering the relationships of input mix per unit of output as follows. Industry *J*'s demand for intermediates from industry *I* per unity of output is governed by production parameters AD(*I,J*), which are input-output coefficients calculated from primary data contained in the SAM. These coefficients can be altered via technology multiplier parameters REG1(*I,J*). Changing REG1(*I*, *'industry J label'* ) from its default setting of unity to 0.9, for example, simulates a technological change enabling one unit of industrial good *J* to be produced using only 90 percent of the intermediate inputs (from all 29 industries) previously required. Specifying AD(*'industry I label'*, *'industry J label'*) = 0.9, in contrast, simulates a technological change enabling one unit of good *J* to be produced using 90 percent of the intermediate inputs previously required from industry *I* (with inputs from the 28 other industries unchanged). See Section 6.4 for implementation.

For the current project, an additional parameter is added to allow for technological changes in consumption. This new parameter is REG16(*I,C*), where *C* indexes the nine consumer good categories. REG16(*I,C*) is inserted into E-DRAM as a technology multiplier parameter wherever parameter PHI(*I,C*) appears.[25] PHI(*I,C*) regulates the distribution of household spending on industry *I* via consumer good *C*. Changing REG16(*I*, *'consumer good C label'*) from its default setting of unity to 0.8, for example, simulates a technological change enabling one unit of consumer good *C* to be enjoyed using only 80 percent of the inputs previously required (from all 29 industries). Specifying REG16(*'industry I label'*, *'consumer good C label'*) in contrast, simulates a technological change enabling one unit of consumer good *C* to be enjoyed using 80 percent of the inputs previously required from industry *I* (with inputs from the other 28 industries unchanged). See Section 6.4 for implementation.

## 6.3 1999, 2020, and 2050 Base Case Models

The table below displays selected input data and corresponding model output for the 1999, 2020, and 2050 base case models. Comparing the columns labeled "DATA" and "MODEL" for any given year indicates that the model is well calibrated, i.e., it produces model solutions that match the input data to within tenths or hundredths of one percent. Achieving such calibration is an essential starting point for policy analysis, as policy scenario results that differ from the base model by less than the level of calibration are not empirically significant.

[25] PHI(I,C) appears in equations 1.05 and 1.06.

Comparing across model years demonstrates how the economy grows by roughly the scale factors discussed in Section 6.2.2.1. State output and personal income increase by factors of roughly 2.25 from 1999 to 2020 and 2.15 from 2020 to 2050, respectively, while state population and employment grow by factors of roughly 1.3 from 1999 to 2020 and 1.5 from 2020 to 2050. The petroleum (PETRO) and energy and mining (ENMIN) sectors both also grow by roughly the scale factors implemented.[26]

| | 1999 | | 2020 | | 2050 | |
|---|---|---|---|---|---|---|
| | DATA | BASE MODEL | DATA | BASE MODEL | DATA | BASE MODEL |
| CA OUTPUT ($BILLION) | 1377.0067 | 1378.0905 | 3075.0665 | 3078.0223 | 6561.4202 | 6568.5732 |
| % CHANGE CA OUTPUT | | 0.08% | | 0.10% | | 0.11% |
| CA PERSONAL INCOME ($BILLION) | 891.6942 | 892.4894 | 2007.3821 | 2009.5373 | 4319.8863 | 4325.2331 |
| % CHANGE CA PERS. INC. | | 0.09% | | 0.11% | | 0.12% |
| CONSUMER PRICE INDEX (BASE=1) | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0001 |
| % CHANGE AGGREGATE CPI | | 0.00% | | 0.00% | | 0.01% |
| POPULATION (MILLION FAMILIES) | 23.1413 | 23.1431 | 30.7317 | 30.7362 | 46.0883 | 46.0978 |
| % CHANGE POPULATION | | 0.01% | | 0.01% | | 0.02% |
| WAGE INDEX (BASE = 100) | 100.0000 | 100.0517 | 100.0000 | 100.0688 | 100.0000 | 100.0880 |
| % CHANGE WAGE INDEX | | 0.05% | | 0.07% | | 0.09% |
| LABOR DEMAND (MILLIONS) | 14.0459 | 14.0483 | 18.6552 | 18.6605 | 27.9572 | 27.9673 |
| % CHNGE LABOR DEMAND | | 0.02% | | 0.03% | | 0.04% |
| RETURN TO K INDEX (BASE=100) | 100.0000 | 100.0060 | 100.0000 | 100.0067 | 100.0000 | 100.0075 |
| % CHANGE RETURN TO K INDEX | | 0.01% | | 0.01% | | 0.01% |
| CAPITAL STOCK ($100 BILLION) | 14.5720 | 14.5863 | 32.7161 | 32.7557 | 70.3030 | 70.4023 |
| % CHANGE CAPITAL STOCK | | 0.10% | | 0.12% | | 0.14% |
| ENMIN | | | | | | |
| OUTPUT ($BILLION) | 5.8738 | 5.8789 | 6.2035 | 6.2086 | 7.6830 | 7.6887 |
| % CHANGE OUTPUT | | 0.09% | | 0.08% | | 0.07% |
| JOBS (MILLIONS) | 0.0178 | 0.0178 | 0.0182 | 0.0182 | 0.0216 | 0.0216 |
| % CHANGE JOBS | | 0.16% | | 0.15% | | 0.14% |
| PRICE (BASE=1) | 1.0000 | 1.0001 | 1.0000 | 1.0001 | 1.0000 | 1.0000 |
| % CHANGE PRICE | | 0.01% | | 0.01% | | 0.00% |
| IMPORTS ($BILLION) | 17.5309 | 17.5404 | 35.9865 | 36.0105 | 57.3622 | 57.4093 |
| % CHANGE IMPORTS | | 0.05% | | 0.07% | | 0.08% |
| EXPORTS ($BILLION) | 0.4377 | 0.4375 | 1.0973 | 1.0965 | 2.6420 | 2.6396 |
| % CHANGE EXPORTS | | -0.06% | | -0.07% | | -0.09% |
| PETRO | | | | | | |
| OUTPUT ($BILLION) | 24.8013 | 24.8156 | 39.2783 | 39.3048 | 39.2124 | 39.2540 |
| % CHANGE OUTPUT | | 0.06% | | 0.07% | | 0.11% |
| JOBS (MILLIONS) | 0.0220 | 0.0220 | 0.0292 | 0.0292 | 0.0294 | 0.0295 |
| % CHANGE JOBS | | 0.09% | | 0.10% | | 0.15% |
| PRICE (BASE=1) | 1.0000 | 1.0001 | 1.0000 | 1.0001 | 1.0000 | 1.0000 |
| % CHANGE PRICE | | 0.01% | | 0.01% | | 0.00% |
| IMPORTS ($BILLION) | 2.8054 | 2.8058 | 15.6811 | 15.6834 | 63.6238 | 63.6368 |
| % CHANGE IMPORTS | | 0.01% | | 0.01% | | 0.02% |
| EXPORTS ($BILLION) | 6.4755 | 6.4746 | 11.9998 | 11.9979 | 19.1462 | 19.1419 |
| % CHANGE EXPORTS | | -0.01% | | -0.02% | | -0.02% |

[26] Small divergence between scaling input to the model and output from the model occur due to SAM balancing.

## 6.4 Scenarios

The subsections below analyze four alternate strategies for reducing California's petroleum dependence. Each scenario is built around two elements: (1) reduced gasoline demand from improved light-duty vehicle fuel economy, and (2) diesel fuel displacement from gas-to-liquid (GTL) or Fischer Tropsch diesel fuels. The scenarios were constructed to try to “bound” the possible impacts to the California economy. Scenario 1 combines off-the-shelf fuel efficiency improvements in light-duty vehicles with a 33 percent blend of FTD in diesel fuel to meet ARB’s future ULSD specification. Conversely, Scenarios 3 and 4 incorporate more aggressive and therefore more costly fuel efficiency or displacement options.

These strategies, developed in a collaborative process between ARB, CEC, and ADL are summarized in Appendix C. Each strategy is described briefly and GAMS code for its implementation into E-DRAM presented. Select model output is given and discussed.

Each scenario is modeled and coded as some combination of increased transportation costs and altered – generally decreased – fuel costs. The rationale is that more efficient transportation is costlier to produce, but saves fuel.

Industries and households buy transportation and fuel. In E-DRAM, industries buy some vehicle engines directly, while households buy them indirectly via the consumer goods sectors. Industrial purchases from the engine (ENGIN) and petroleum (PETRO) sectors are recorded in SAM cells ('ENGIN', I) and ('PETRO', I), respectively. Households' purchases from the consumer transportation sector (CTRANS) are recorded in the SAM cells (I, 'CTRANS'). Households' purchases of petroleum via the consumer fuel sector (CFUEL) are recorded in SAM cells (I, 'CFUEL').

Following the explanation of technological change parameters in Section 6.2.3, increases in consumer and industrial transportation costs are modeled using parameters REG16(*I, 'CTRNS'*) and REG1(*'ENGIN',I*), respectively. Decreases in consumer and industrial fuel costs are modeled using parameters REG16(*'PETRO', 'CFUEL'*) and REG1('PETRO', I), respectively. Switches from petroleum to hydrogen based fuels (scenario 3 only) are modeled as increases in REG1(*'ENMIN', 'PETRO'*), accompanied by offsetting increases in REG1(*'CHEMS', 'PETRO'*).[27]

The CEC estimates that residential use accounts for roughly 90 percent of gasoline consumption in the state. Hence, 90 percent of projected increases in engine costs are apportioned to household and 10 percent are apportioned to industries. Likewise, 90 percent of projected fuel savings are apportioned to households and 10 percent are apportioned to industries.

[27] This implementation assumes that the much the same fuel distribution system would be used regardless of the fuel variety.

The following four subsections detail four alternate policy scenarios for reducing California's petroleum dependence. A short policy description, GAMS code that models the projected costs and benefits via the channels outlined immediately above, and select E-DRAM output along with corresponding analysis are presented for each.

### 6.4.1 Scenario 1: EEA/Duleep Fuel Economy Improvements[28]

Scenario 1 is a combination of fuel efficiency measures applied to light-duty vehicles starting in 2008 and FTD blended with other diesel feedstocks at 33 percent to meet ARB's future ULSD specification. Table 6-5 summarizes the costs and benefits of this combined strategy. Light-duty vehicle costs in 2020 and 2050 where taken from CALCARS analyses performed by CEC. The EEA/Duleep case phases in off-the-shelf fuel economy improvements in the early years of implementation and introduces higher fuel economy technologies in the later years. The benefits at the household level result from fuel savings associated with the higher fuel economy technologies. The estimates for 2020 and 2050 include vehicles that have been introduced earlier; that is the technology is applied to new vehicles starting in 2008 and continuous as other vehicles retire from the fleet. Thus, the cost and benefits are a "slice" in time of what the fleet would look like and what the costs would be. These costs were then input into the model to assess economic impact.

**Figure 6-5. Estimated Economic Inputs for Scenario 1: EEA/Duleep Fuel Economy Improvements**

| Changes in Consumer Expenditures | Million 2002 $ | | Changes in Sector Revenue | Million 2002 $ | |
|---|---|---|---|---|---|
| | 2020 | 2050 | | 2020 | 2050 |
| Cost | | | Benefit | | |
| Household (inc. vehicle cost) | 1,460 | 4,900 | Vehicle Mfg. (inc. vehicle revenue) | 1,460 | 4,900 |
| Household (inc. PZEV cost) | 501 | 812 | Vehicle Mfg. (inc. PZEV revenue) | 501 | 812 |
| Commercial (inc. GTL-diesel cost) | 125 | 146 | Foreign GTL Producer (inc. revenue) | 125 | 146 |
| Total Cost | 2,087 | 5,858 | Total Benefits | 2,087 | 5,858 |
| Benefits | | | Cost | | |
| Household (dec. gasoline expenditure | 3,264 | 14,617 | Refiners (decrease in revenue) | 2,547 | 11,409 |
| | | | California Excise Tax (dec. revenue) | 358 | 1,604 |
| | | | Federal Excise Tax (dec. revenue) | 358 | 1,604 |
| Total Benefits | 3,264 | 14,617 | Total Costs | 3,264 | 14,617 |

Scenario 1 is implemented in the following manner (see footnotes for actual GAMS code).

[28] Numbers in the illustrative scenario coding correspond to 2020 cost/benefit projections.

The cost of consumer transportation (CTRNS) increases by 90 percent of projected consumer cost. These additional costs are inserted such that the new, higher amount of consumer transportation spending is expressed as the appropriate multiple of old spending.[29]

The cost of industrial engines increases by 10 percent of the projected consumer cost, plus the commercial costs. These additional costs are inserted such that the new, higher amount of industrial spending on engines is expressed as the appropriate multiple of old spending.[30]

90 percent of the projected savings from increased fuel efficiency accrue to consumers. These savings are inserted such that the new, lower amount of consumer fuel spending is expressed as the appropriate fraction of old spending.[31]

10 percent of the projected savings from increased fuel efficiency accrue to industry. These savings are inserted such that the new, lower amount of industrial spending on fuel is expressed as the appropriate multiple of old spending.[32]

The table below compares selected results for base model and Scenario 1 runs of E-DRAM in both 2020 and 2050. Results show that scenario 1 slightly reduces state output (by 0.10 percent in 2020 and 0.17 percent in 2050) while slightly increasing state personal income (by 0.1 percent in 2050). *Real* personal income (what's reported in the table) rises while output falls because of increased consumer purchasing power due to improved fuel efficiency. Results indicate that the price of consumer fuel – interpreted as the price of vehicle miles traveled – is roughly 3 percent lower in 2020 and 7 percent lower in 2050 in Scenario 1 than in base.

Increased fuel efficiency reduces the demand for refined petroleum products. E-DRAM predicts petroleum sector output being 4 percent lower in 2020 and 16 percent lower in 2050 under Scenario 1 *vs.* base. Decreased petroleum sector output adversely affects upstream crude oil suppliers. The model predicts energy and mining sector output being 4 percent lower in 2020 and 16 percent lower in 2050 under Scenario 1 than base.

Money freed from fuel expenditure is spent in other sectors. Scenario 1 raises both food (FOODS) and apparel (APPAR) sector output by roughly 2 percent over base in 2020 and by 5 percent over base in 2050.

Sectors such as motor vehicle manufacturing (MOTOR) that rely heavily on combustion engine inputs, see costs rise; thus their prices rise and output falls. The price of consumer transportation (CTRANS) rises 0.72 percent and 0.95 percent in 2020 and 2050, respectively, while motor vehicle sector output falls 0.35 percent and .50 percent in those same times.

[29] REG16(I,'CTRNS') = (SUM(J, SAM(J,'CTRNS')) + 0.9*1.961)/SUM(J, SAM(J,'CTRNS'));
[30] REG1('ENGIN',I) = (SUM(J,SAM('ENGIN',J)) + .1*1.961 + .125)/SUM(J,SAM('ENGIN',J));
[31] REG16(I,'CFUEL') = (SUM(J, SAM(J,'CFUEL')) - .9*3.264 )/SUM(J, SAM(J,'CFUEL'));
[32] REG1('PETRO',I) = (SUM(J,SAM('PETRO',J)) - .1*3.264)/SUM(J,SAM('PETRO',J));

| | 2020 | | 2050 | |
|---|---|---|---|---|
| | BASE MODEL | SCNRIO1 | BASE MODEL | SCNRIO1 |
| CA OUTPUT ($BILLION) | 3078.0223 | 3074.9243 | 6568.5732 | 6557.2797 |
| % CHANGE CA OUTPUT | 0.10% | -0.10% | 0.11% | -0.17% |
| CA PERSONAL INCOME ($BILLION) | 2009.5373 | 2009.5213 | 4325.2331 | 4329.6794 |
| % CHANGE CA PERS. INC. | 0.11% | 0.00% | 0.12% | 0.10% |
| LABOR DEMAND (MILLIONS) | 18.6605 | 18.6767 | 27.9673 | 28.0326 |
| % CHNGE LABOR DEMAND | 0.03% | 0.09% | 0.04% | 0.23% |
| PRICE OF CFOOD | 1.0001 | 1.0001 | 1.0001 | 1.0000 |
| PRICE OF CHOME | 1.0000 | 1.0000 | 1.0001 | 0.9999 |
| PRICE OF CFUEL | 1.0000 | 0.9687 | 1.0000 | 0.9324 |
| PRICE OF CFURN | 1.0001 | 1.0001 | 1.0001 | 1.0000 |
| PRICE OF CCLOTH | 1.0001 | 1.0001 | 1.0001 | 1.0000 |
| PRICE OF CTRANS | 1.0000 | 1.0072 | 1.0001 | 1.0095 |
| PRICE OF CMED | 1.0001 | 1.0002 | 1.0001 | 1.0003 |
| PRICE OF CAMUS | 1.0000 | 1.0001 | 1.0001 | 0.9999 |
| PRICE OF COTHR | 1.0000 | 1.0000 | 1.0001 | 0.9999 |
| ENMIN | | | | |
| OUTPUT ($BILLION) | 6.2086 | 6.0575 | 7.6887 | 7.2328 |
| % CHANGE OUTPUT | 0.08% | -2.43% | 0.07% | -5.93% |
| IMPORTS ($BILLION) | 36.0105 | 34.8290 | 57.4093 | 52.2725 |
| % CHANGE IMPORTS | 0.07% | -3.28% | 0.08% | -8.95% |
| EXPORTS ($BILLION) | 1.0965 | 1.1122 | 2.6396 | 2.7452 |
| % CHANGE EXPORTS | -0.07% | 1.43% | -0.09% | 4.00% |
| PETRO | | | | |
| OUTPUT ($BILLION) | 39.3048 | 37.6902 | 39.2540 | 32.6620 |
| % CHANGE OUTPUT | 0.07% | -4.11% | 0.11% | -16.79% |
| IMPORTS ($BILLION) | 15.6834 | 15.5646 | 63.6368 | 62.1426 |
| % CHANGE IMPORTS | 0.01% | -0.76% | 0.02% | -2.35% |
| EXPORTS ($BILLION) | 11.9979 | 12.0739 | 19.1419 | 19.5219 |
| % CHANGE EXPORTS | -0.02% | 0.63% | -0.02% | 1.99% |
| ENGIN | | | | |
| OUTPUT ($BILLION) | 40.4675 | 40.5818 | 87.0335 | 87.2217 |
| % CHANGE OUTPUT | 0.05% | 0.28% | 0.05% | 0.22% |
| IMPORTS ($BILLION) | 9.0494 | 9.0815 | 19.4495 | 19.5153 |
| % CHANGE IMPORTS | 0.02% | 0.35% | 0.04% | 0.34% |
| EXPORTS ($BILLION) | 13.8359 | 13.7822 | 29.7408 | 29.6307 |
| % CHANGE EXPORTS | -0.03% | -0.39% | -0.05% | -0.37% |
| CHEMS | | | | |
| OUTPUT ($BILLION) | 30.2836 | 30.6482 | 64.9941 | 66.6697 |
| % CHANGE OUTPUT | 0.22% | 1.20% | 0.24% | 2.58% |
| IMPORTS ($BILLION) | 39.3028 | 39.2943 | 84.2137 | 84.1483 |
| % CHANGE IMPORTS | 0.01% | -0.02% | 0.02% | -0.08% |
| EXPORTS ($BILLION) | 2.0905 | 2.0910 | 4.6502 | 4.6542 |
| % CHANGE EXPORTS | -0.01% | 0.02% | -0.02% | 0.09% |
| FOODS | | | | |
| OUTPUT ($BILLION) | 92.9579 | 95.1127 | 200.2299 | 210.4874 |
| % CHANGE OUTPUT | 0.14% | 2.32% | 0.17% | 5.12% |
| APPAR | | | | |
| OUTPUT ($BILLION) | 25.9513 | 26.4969 | 55.8814 | 58.7842 |
| % CHANGE OUTPUT | 0.20% | 2.10% | 0.25% | 5.19% |
| MOTOR | | | | |
| OUTPUT ($BILLION) | 18.2243 | 18.1613 | 39.3478 | 39.1508 |
| % CHANGE OUTPUT | 0.23% | -0.35% | 0.24% | -0.50% |

### 6.4.2 Scenario 2: ACEE-Advanced Fuel Economy Improvements

Scenario 2 is similar to Scenario 1 but incorporates more aggressive fuel economy technologies in light-duty vehicles. In this case, technology costs and benefits were determined from ACEEE analysis for advanced fuel economy improvements. It was assumed that these improvements would be implemented in all new light-duty passenger cars and trucks starting in 2008.

The ACEEE-Advance case is more aggressive in increasing fuel economy compared to the EEA/Duleep case and the ACEEE costs tend to be lower than those estimated by EEA. Further, the EEA technologies are phased in at a much slower penetration than those assumed in this scenario.

Table 6-3 shows our estimates of the economic inputs for modeling. As indicated, costs are higher in 2020 compared to Scenario 1 primarily due to the high penetration rate. Likewise, benefits are also considerably higher in 2020. At 2050 the two scenarios are more similar since EEA has fully phased in the higher fuel economy technologies and the ACEEE technologies are also fully phased in. Scenario 2 also includes the GTL or FTD blend as in Scenario 1.

**Table 6-3. Estimated Economic Inputs for Scenario 2: ACEE-Advanced Fuel Economy Improvements**

| Changes in Consumer Expenditures | Million 2002 $ | | Changes in Sector Revenue | Million 2002 $ | |
|---|---|---|---|---|---|
| | 2020 | 2050 | | 2020 | 2050 |
| Cost | | | Benefit | | |
| Household (inc. vehicle cost) | 4,197 | 6,794 | Vehicle Mfg. (inc. vehicle revenue) | 4,197 | 6,794 |
| Household (inc. PZEV cost) | 501 | 812 | Vehicle Mfg. (inc. PZEV revenue) | 501 | 812 |
| Commercial (inc. GTL-diesel cost) | 125 | 146 | Foreign GTL Producer (inc. revenue) | 125 | 146 |
| Total Cost | 4,824 | 7,752 | Total Benefits | 4,824 | 7,752 |
| Benefits | | | Cost | | |
| Household (dec. gasoline expenditure | 9,284 | 19,746 | Refiners (decrease in revenue) | 7,246 | 15,411 |
| | | | California Excise Tax (dec. revenue) | 1,019 | 2,167 |
| | | | Federal Excise Tax (dec. revenue) | 1,019 | 2,167 |
| Total Benefits | 9,284 | 19,746 | Total Costs | 9,284 | 19,746 |

Scenario 2 is implemented in the following manner.

The cost of consumer transportation (CTRNS) increases by 90 percent of projected consumer cost. These additional costs are inserted such that the new, higher amount of consumer transportation spending is expressed as the appropriate multiple of old spending.[33]

The cost of industrial engines increases by 10 percent of the projected consumer cost, plus the commercial costs. These additional costs are inserted such that the new, higher amount of industrial spending on engines is expressed as the appropriate multiple of old spending.[34]

90 percent of the projected savings from increased fuel efficiency accrue to consumers. These savings are inserted such that the new, lower amount of consumer fuel spending is expressed as the appropriate fraction of old spending.[35]

10 percent of the projected savings from increased fuel efficiency accrue to industry. These savings are inserted such that the new, lower amount of industrial spending on fuel is expressed as the appropriate multiple of old spending.[36]

The table below compares selected results for base model and Scenario 2 runs of E-DRAM in both 2020 and 2050. Results show that Scenario 2 slightly reduces state output (by 0.26 percent in 2020 and 0.23 percent in 2050) while leaving state personal income essentially unchanged. *Real* personal income remains constant while output falls because of increased consumer purchasing power due to improved fuel efficiency. Results indicate that the price of consumer fuel – interpreted as the price of vehicle miles traveled – is roughly 9 percent lower in both 2020 and 2050 in Scenario 2 than in base.

Increased fuel efficiency reduces the demand for refined petroleum products. E-DRAM predicts petroleum sector output being 12 percent lower in 2020 and 23 percent lower in 2050 under Scenario 2 *vs.* base. Decreased petroleum sector output adversely affects upstream crude oil suppliers. The model predicts energy and mining sector output being 7 percent lower in 2020 and 8 percent lower in 2050 under scenario two than base.

Money freed from fuel expenditure is spent in other sectors. Scenario two raises both food and apparel sector output by 6- to 7 percent over base in 2020 and 2050.

Sectors such as motor vehicle manufacturing that rely heavily on combustion engine inputs, see costs rise; thus their prices rise and output falls. The price of consumer

[33] REG16(I,'CTRNS') = (SUM(J, SAM(J,'CTRNS')) + .9*4.698)/SUM(J, SAM(J,'CTRNS'));
[34] REG1('ENGIN',I) = (SUM(J,SAM('ENGIN',J)) + .1*4.698 + .125)/SUM(J,SAM('ENGIN',J));
[35] REG16(I,'CFUEL') = (SUM(J, SAM(J,'CFUEL')) - .9*9.284 )/SUM(J, SAM(J,'CFUEL'));
[36] REG1('PETRO',I) = (SUM(J,SAM('PETRO',J)) - .1*9.284)/SUM(J,SAM('PETRO',J));

| | 2020 | | 2050 | |
|---|---|---|---|---|
| | BASE MODEL | SCNRIO2 | BASE MODEL | SCNRIO2 |
| CA OUTPUT ($BILLION) | 3078.0223 | 3070.0183 | 6568.5732 | 6553.2078 |
| % CHANGE CA OUTPUT | 0.10% | -0.26% | 0.11% | -0.23% |
| CA PERSONAL INCOME ($BILLION) | 2009.5373 | 2010.4295 | 4325.2331 | 4330.7327 |
| % CHANGE CA PERS. INC. | 0.11% | 0.04% | 0.12% | 0.13% |
| LABOR DEMAND (MILLIONS) | 18.6605 | 18.7119 | 27.9673 | 28.0539 |
| % CHNGE LABOR DEMAND | 0.03% | 0.28% | 0.04% | 0.31% |
| PRICE OF CFOOD | 1.0001 | 1.0002 | 1.0001 | 1.0000 |
| PRICE OF CHOME | 1.0000 | 1.0001 | 1.0001 | 0.9999 |
| PRICE OF CFUEL | 1.0000 | 0.9111 | 1.0000 | 0.9088 |
| PRICE OF CFURN | 1.0001 | 1.0002 | 1.0001 | 1.0000 |
| PRICE OF CCLOTH | 1.0001 | 1.0002 | 1.0001 | 1.0001 |
| PRICE OF CTRANS | 1.0000 | 1.0171 | 1.0001 | 1.0126 |
| PRICE OF CMED | 1.0001 | 1.0006 | 1.0001 | 1.0004 |
| PRICE OF CAMUS | 1.0000 | 1.0002 | 1.0001 | 1.0000 |
| PRICE OF COTHR | 1.0000 | 1.0001 | 1.0001 | 1.0000 |
| ENMIN | | | | |
| OUTPUT ($BILLION) | 6.2086 | 5.7836 | 7.6887 | 7.0685 |
| % CHANGE OUTPUT | 0.08% | -6.84% | 0.07% | -8.07% |
| IMPORTS ($BILLION) | 36.0105 | 32.6693 | 57.4093 | 50.5293 |
| % CHANGE IMPORTS | 0.07% | -9.28% | 0.08% | -11.98% |
| EXPORTS ($BILLION) | 1.0965 | 1.1419 | 2.6396 | 2.7839 |
| % CHANGE EXPORTS | -0.07% | 4.15% | -0.09% | 5.47% |
| PETRO | | | | |
| OUTPUT ($BILLION) | 39.3048 | 34.7300 | 39.2540 | 30.4067 |
| % CHANGE OUTPUT | 0.07% | -11.64% | 0.11% | -22.54% |
| IMPORTS ($BILLION) | 15.6834 | 15.3455 | 63.6368 | 61.6306 |
| % CHANGE IMPORTS | 0.01% | -2.15% | 0.02% | -3.15% |
| EXPORTS ($BILLION) | 11.9979 | 12.2159 | 19.1419 | 19.6556 |
| % CHANGE EXPORTS | -0.02% | 1.82% | -0.02% | 2.68% |
| ENGIN | | | | |
| OUTPUT ($BILLION) | 40.4675 | 40.6323 | 87.0335 | 87.2374 |
| % CHANGE OUTPUT | 0.05% | 0.41% | 0.05% | 0.23% |
| IMPORTS ($BILLION) | 9.0494 | 9.1111 | 19.4495 | 19.5371 |
| % CHANGE IMPORTS | 0.02% | 0.68% | 0.04% | 0.45% |
| EXPORTS ($BILLION) | 13.8359 | 13.7330 | 29.7408 | 29.5942 |
| % CHANGE EXPORTS | -0.03% | -0.74% | -0.05% | -0.49% |
| CHEMS | | | | |
| OUTPUT ($BILLION) | 30.2836 | 31.3101 | 64.9941 | 67.2368 |
| % CHANGE OUTPUT | 0.22% | 3.39% | 0.24% | 3.45% |
| IMPORTS ($BILLION) | 39.3028 | 39.2798 | 84.2137 | 84.1389 |
| % CHANGE IMPORTS | 0.01% | -0.06% | 0.02% | -0.09% |
| EXPORTS ($BILLION) | 2.0905 | 2.0918 | 4.6502 | 4.6547 |
| % CHANGE EXPORTS | -0.01% | 0.06% | -0.02% | 0.10% |
| FOODS | | | | |
| OUTPUT ($BILLION) | 92.9579 | 99.2793 | 200.2299 | 214.2155 |
| % CHANGE OUTPUT | 0.14% | 6.80% | 0.17% | 6.98% |
| APPAR | | | | |
| OUTPUT ($BILLION) | 25.9513 | 27.6314 | 55.8814 | 59.8357 |
| % CHANGE OUTPUT | 0.20% | 6.47% | 0.25% | 7.08% |
| MOTOR | | | | |
| OUTPUT ($BILLION) | 18.2243 | 18.0770 | 39.3478 | 39.0798 |
| % CHANGE OUTPUT | 0.23% | -0.81% | 0.24% | -0.68% |

transportation rises 0.17 percent and 0.13 percent in 2020 and 2050, respectively, while motor vehicle sector output falls 0.81 percent and 0.68 percent in those same times.

### 6.4.3 Scenario 3: ACEE-Moderate + Fuel Cell Vehicles

Scenario 3 incorporates fuel efficiency improvements in light-duty vehicles, substantial penetration of light-duty fuel cell vehicles, and again diesel blends of GTL or FTD fuels. This scenario was constructed to level demand for gasoline and diesel fuels to 2002 levels (about 17.3 billion g.g.e). As in Scenario 2, all new LDVs starting in 2008 would have ACEEE advanced fuel economy technologies. FTD would also be blended into all diesel fuels.

Fuel cell vehicles using compressed hydrogen were then introduced to maintain and level out gasoline and diesel demand to 2002 levels. In other words, the reduction in demand from ACEEE technologies, plus the displacement of diesel from FTD blends, plus the displacement of gasoline from hydrogen fuel cells completely offsets the growth in demand from 2002 to 2050. Obviously, this is a very aggressive scenario and was selected as one of the upper bounding cases.

Table 6-4 shows our estimates of the economic inputs to the modeling. Costs to households are 3 to 4 times higher than in the previous scenarios; a hydrogen industry develops; and the refining industry loses revenue to foreign suppliers of FTD (could be the same energy company), customers with more efficient gasoline vehicles, and new hydrogen industry (also could be the same energy companies).

Scenario 3 code is similar to the previous ones, but with additional lines to model hydrogen displacing gasoline.

The cost of consumer transportation (CTRNS) increases by 90 percent of projected consumer cost. These additional costs are inserted such that the new, higher amount of consumer transportation spending is expressed as the appropriate multiple of old spending.[37]

The cost of industrial engines increases by 10 percent of the projected consumer cost, plus the commercial costs. These additional costs are inserted such that the new, higher amount of industrial spending on engines is expressed as the appropriate multiple of old spending.[38]

90 percent of the projected savings from increased fuel efficiency accrue to consumers. These savings are inserted such that the new, lower amount of consumer fuel spending is expressed as the appropriate fraction of old spending.[39]

[37] REG16(I,'CTRNS') = (SUM(J, SAM(J,'CTRNS')) + .9*7.193)/SUM(J, SAM(J,'CTRNS'));
[38] REG1('ENGIN',I) = (SUM(J,SAM('ENGIN',J)) + .1*7.193 + .125)/SUM(J,SAM('ENGIN',J));
[39] REG16(I,'CFUEL') = (SUM(J, SAM(J,'CFUEL')) - .9*8.269 )/SUM(J, SAM(J,'CFUEL'));

**Table 6-4. Estimated Economic Inputs for Scenario 3: ACEE-Moderate + Fuel Cell Vehicles (Reducing Fuel Use to 2002 Levels)**

| Changes in Consumer Expenditures | Million 2002 $ | | Changes in Sector Revenue | Million 2002 $ | |
|---|---|---|---|---|---|
| | 2020 | 2050 | | 2020 | 2050 |
| Cost | | | Benefit | | |
| Household (inc. vehicle cost) | 5,680 | 10,463 | Vehicle Mfg. (inc. vehicle revenue) | 5,680 | 10,463 |
| Household (inc. FCV cost | 945 | 1,133 | Vehicle Mfg. (inc. FCV revenue) | 945 | 1,133 |
| Household (inc. PZEV cost) | 443 | 322 | Vehicle Mfg. (inc. PZEV revenue) | 443 | 322 |
| Commercial (inc. GTL-diesel cost) | 125 | 146 | Foreign GTL Producer (inc. revenue) | 125 | 146 |
| Household (inc. $H_2$ cost) | 776 | 8,718 | Hydrogen industry (inc. revenue) | 673 | 7,609 |
| | | | California Excise Tax (inc. $H_2$ revenue) | 52 | 554 |
| | | | Federal Excise Tax (inc. $H_2$ revenue) | 52 | 554 |
| Total Cost | 7,970 | 20,782 | Total Benefits | 7,970 | 20,782 |
| Benefits | | | Cost | | |
| Household (dec. gasoline expenditure | 8,269 | 26,170 | Refiners (decrease in revenue) | 6,454 | 20,425 |
| | | | California Excise Tax (dec. revenue) | 908 | 2,872 |
| | | | Federal Excise Tax (dec. revenue) | 908 | 2,872 |
| Total Benefits | 8,269 | 26,170 | Total Costs | 8,269 | 26,170 |

10 percent of the projected savings from increased fuel efficiency accrue to industry. These savings are inserted such that the new, lower amount of industrial spending on fuel is expressed as the appropriate multiple of old spending.[40]

This scenario, unlike the others, includes expenditures on hydrogen fuel via the chemical (CHEM) sector that displaces money previously spent on the fossil fuels provided by the energy and mining (ENMIN) sector.[41]

[40] REG1('PETRO',I) = (SUM(J,SAM('PETRO',J)) - .1*8.269)/SUM(J,SAM('PETRO',J));

[41] REG1('CHEMS','PETRO') = (SAM('CHEMS','PETRO') + .776) / SAM('CHEMS','PETRO');
REG1('ENMIN','PETRO') = (SAM('ENMIN','PETRO') - .776) / SAM('ENMIN','PETRO');

The table below compares selected results for base model and Scenario 3 runs of E-DRAM in both 2020 and 2050. Results show that Scenario 3 slightly reduces state output (by 0.28 percent in 2020 and 0.26 percent in 2050) while leaving state personal income roughly within the bounds of model calibration. *Real* personal income remains essentially constant while output falls because of increased consumer purchasing power due to improved fuel efficiency. Results indicate that the price of consumer fuel – interpreted as the price of vehicle miles traveled – is roughly 8 percent lower in 2020 and 12 percent lower 2050 under Scenario 3 than in base.

Increased fuel efficiency reduces demand for refined petroleum products. E-DRAM predicts petroleum sector output being 10 percent lower in 2020 and roughly 30 percent lower in 2050 under Scenario 4 *vs.* base. Decreased petroleum sector output – plus fuel displacement – adversely affects upstream crude oil suppliers. The model predicts energy and mining sector output being roughly 7 percent lower in 2020 and 18 percent lower in 2050 under Scenario 3 than base.

Money freed from fuel expenditure is spent in other sectors. Scenario 3 raises food sector output by 6 and 9 percent over base in 2020 and 2050, respectively, while raising apparel sector output by roughly 5 and 9 percent over base in 2020 and 2050, respectively.

Sectors such as motor vehicle manufacturing that rely heavily on combustion engine inputs, see costs rise; thus their prices rise and output falls. The price of consumer transportation rises 2.7 and 2.1 percent in 2020 and 2050, respectively, while motor vehicle sector output falls 1.1-1.2 percent.

| | 2020 | | 2050 | |
|---|---|---|---|---|
| | BASE MODEL | SCNRIO3 | BASE MODEL | SCNRIO3 |
| CA OUTPUT ($BILLION) | 3078.0223 | 3069.4120 | 6568.5732 | 6551.2810 |
| % CHANGE CA OUTPUT | 0.10% | -0.28% | 0.11% | -0.26% |
| CA PERSONAL INCOME ($BILLION) | 2009.5373 | 2006.5412 | 4325.2331 | 4330.4291 |
| % CHANGE CA PERS. INC. | 0.11% | -0.15% | 0.12% | 0.12% |
| LABOR DEMAND (MILLIONS) | 18.6605 | 18.6841 | 27.9673 | 28.0763 |
| % CHNGE LABOR DEMAND | 0.03% | 0.13% | 0.04% | 0.39% |
| PRICE OF CFOOD | 1.0001 | 1.0013 | 1.0001 | 1.0013 |
| PRICE OF CHOME | 1.0000 | 1.0008 | 1.0001 | 1.0008 |
| PRICE OF CFUEL | 1.0000 | 0.9215 | 1.0000 | 0.8801 |
| PRICE OF CFURN | 1.0001 | 1.0011 | 1.0001 | 1.0011 |
| PRICE OF CCLOTH | 1.0001 | 1.0011 | 1.0001 | 1.0011 |
| PRICE OF CTRANS | 1.0000 | 1.0271 | 1.0001 | 1.0208 |
| PRICE OF CMED | 1.0001 | 1.0020 | 1.0001 | 1.0021 |
| PRICE OF CAMUS | 1.0000 | 1.0013 | 1.0001 | 1.0012 |
| PRICE OF COTHR | 1.0000 | 1.0008 | 1.0001 | 1.0008 |
| ENMIN | | | | |
| OUTPUT ($BILLION) | 6.2086 | 5.7448 | 7.6887 | 6.3197 |
| % CHANGE OUTPUT | 0.08% | -7.47% | 0.07% | -17.81% |
| IMPORTS ($BILLION) | 36.0105 | 32.5922 | 57.4093 | 43.5417 |
| % CHANGE IMPORTS | 0.07% | -9.49% | 0.08% | -24.16% |
| EXPORTS ($BILLION) | 1.0965 | 1.1430 | 2.6396 | 2.9601 |
| % CHANGE EXPORTS | -0.07% | 4.25% | -0.09% | 12.14% |
| PETRO | | | | |
| OUTPUT ($BILLION) | 39.3048 | 35.3868 | 39.2540 | 27.6640 |
| % CHANGE OUTPUT | 0.07% | -9.97% | 0.11% | -29.53% |
| IMPORTS ($BILLION) | 15.6834 | 15.3992 | 63.6368 | 61.1013 |
| % CHANGE IMPORTS | 0.01% | -1.81% | 0.02% | -3.98% |
| EXPORTS ($BILLION) | 11.9979 | 12.1807 | 19.1419 | 19.7960 |
| % CHANGE EXPORTS | -0.02% | 1.52% | -0.02% | 3.42% |
| ENGIN | | | | |
| OUTPUT ($BILLION) | 40.4675 | 40.6730 | 87.0335 | 87.1527 |
| % CHANGE OUTPUT | 0.05% | 0.51% | 0.05% | 0.14% |
| IMPORTS ($BILLION) | 9.0494 | 9.1578 | 19.4495 | 19.6373 |
| % CHANGE IMPORTS | 0.02% | 1.20% | 0.04% | 0.97% |
| EXPORTS ($BILLION) | 13.8359 | 13.6559 | 29.7408 | 29.4282 |
| % CHANGE EXPORTS | -0.03% | -1.30% | -0.05% | -1.05% |
| CHEMS | | | | |
| OUTPUT ($BILLION) | 30.2836 | 32.0653 | 64.9941 | 75.5236 |
| % CHANGE OUTPUT | 0.22% | 5.88% | 0.24% | 16.20% |
| IMPORTS ($BILLION) | 39.3028 | 39.3585 | 84.2137 | 84.3541 |
| % CHANGE IMPORTS | 0.01% | 0.14% | 0.02% | 0.17% |
| EXPORTS ($BILLION) | 2.0905 | 2.0872 | 4.6502 | 4.6417 |
| % CHANGE EXPORTS | -0.01% | -0.16% | -0.02% | -0.18% |
| FOODS | | | | |
| OUTPUT ($BILLION) | 92.9579 | 98.4497 | 200.2299 | 218.8242 |
| % CHANGE OUTPUT | 0.14% | 5.91% | 0.17% | 9.29% |
| APPAR | | | | |
| OUTPUT ($BILLION) | 25.9513 | 27.1334 | 55.8814 | 61.0011 |
| % CHANGE OUTPUT | 0.20% | 4.55% | 0.25% | 9.16% |
| MOTOR | | | | |
| OUTPUT ($BILLION) | 18.2243 | 18.0142 | 39.3478 | 38.8744 |
| % CHANGE OUTPUT | 0.23% | -1.15% | 0.24% | -1.20% |

### 6.4.4 Scenario 4: ACEE-Full Hybrid Vehicles

Scenario 4 is similar to 3 but even more aggressive with the introduction of all hybrid technologies starting in all light-duty vehicles in 2008. This case is based on ACEEE — full hybrid technologies and costs. The scenario also includes FTD blends.

Table 6-5 presents our estimates of the costs and benefits for this scenario in 2002 and 2050. Here the reduction in fuel costs offset the higher vehicle costs.

**Table 6-5. Estimated Economic Inputs for Scenario 4: ACEE-Full Hybrid Vehicles**

| Changes in Consumer Expenditures | Million 2002 $ | | Changes in Sector Revenue | Million 2002 $ | |
|---|---|---|---|---|---|
| | 2020 | 2050 | | 2020 | 2050 |
| Cost | | | Benefit | | |
| Household (inc. vehicle cost) | 13,033 | 21,096 | Vehicle Mfg. (inc. vehicle revenue) | 13,033 | 21,096 |
| Household (inc. PZEV cost) | 501 | 812 | Vehicle Mfg. (inc. PZEV revenue) | 501 | 812 |
| Commercial (inc. GTL-diesel cost) | 125 | 146 | Foreign GTL Producer (inc. revenue) | 125 | 146 |
| Total Cost | 13,660 | 22,054 | Total Benefits | 13,660 | 22,054 |
| Benefits | | | Cost | | |
| Consumer (dec. gasoline expenditure | 12,533 | 29,896 | Refiners (decrease in revenue) | 9,782 | 23,333 |
| | | | California Excise Tax (dec. revenue) | 1,376 | 3,281 |
| | | | Federal Excise Tax (dec. revenue) | 1,376 | 3,281 |
| Total Benefits | 12,533 | 29,896 | Total Costs | 12,533 | 29,896 |

Scenario 3 code is similar to the previous ones, but with additional lines to model hydrogen displacing gasoline.

The cost of consumer transportation (CTRNS) increases by 90 percent of projected consumer cost. These additional costs are inserted such that the new, higher amount of consumer transportation spending is expressed as the appropriate multiple of old spending.[42]

The cost of industrial engines increases by 10 percent of the projected consumer cost, plus the commercial costs. These additional costs are inserted such that the new, higher

[42] REG16(I,'CTRNS') = (SUM(J, SAM(J,'CTRNS')) + .9*13.534)/SUM(J, SAM(J,'CTRNS'));

amount of industrial spending on engines is expressed as the appropriate multiple of old spending.[43]

90 percent of the projected savings from increased fuel efficiency accrue to consumers. These savings are inserted such that the new, lower amount of consumer fuel spending is expressed as the appropriate fraction of old spending.[44]

10 percent of the projected savings from increased fuel efficiency accrue to industry. These savings are inserted such that the new, lower amount of industrial spending on fuel is expressed as the appropriate multiple of old spending.[45]

On a more technical note, since any model changes not overwritten from one scenario loop to the next remain in effect, fuel displacement code from Scenario 3 must be replaced with code restoring the appropriate parameters to their default settings.[46]

The table below compares selected results for base model and Scenario 4 runs of E-DRAM in both 2020 and 2050. Results show that Scenario 4 slightly reduces state output (by 0.50 percent in 2020 and 0.46 percent in 2050). State personal income also falls slightly *vs.* the base cases, by 0.42 percent in 2020 and 0.16 percent in 2050. Results indicate that the price of consumer fuel – interpreted as the price of vehicle miles traveled – is roughly 12 percent lower in 2020 and 14 percent lower in 2050 under Scenario 4 than base.

Increased fuel efficiency reduces the demand for refined petroleum products. E-DRAM predicts petroleum sector output being 15 percent lower in 2020 and 33 percent lower in 2050 under Scenario 4 *vs.* base. Decreased petroleum sector output adversely affects upstream crude oil suppliers. The model predicts energy and mining sector output being 10 percent lower in 2020 and 13 percent lower in 2050 under scenario four than base.

Money freed from fuel expenditure is spent in other sectors. Scenario 4 raises food sector output by 9 and 11 percent over base in 2020 and 2050, respectively, while raising apparel sector output by 6 and 9 percent over base in 2020 and 2050, respectively.

Sectors such as motor vehicle manufacturing that rely heavily on combustion engine inputs, see costs rise; thus their prices rise and output falls. The price of consumer transportation rises roughly 5 and 4 percent in 2020 and 2050, respectively, while motor vehicle sector output falls roughly 2 and 1.7 percent in those same times.

[43] REG1('ENGIN',I) = (SUM(J,SAM('ENGIN',J)) + .1*13.534 + .125)/SUM(J,SAM('ENGIN',J));
[44] REG16(I,'CFUEL') = (SUM(J, SAM(J,'CFUEL')) - .9*12.533 )/SUM(J, SAM(J,'CFUEL'));
[45] REG1('PETRO',I) = (SUM(J,SAM('PETRO',J)) - .1*12.533)/SUM(J,SAM('PETRO',J));
[46] REG1('PETRO',I) = (SUM(J,SAM('PETRO',J)) - .1*12.533)/SUM(J,SAM('PETRO',J));

| | 2020 | | 2050 | |
|---|---|---|---|---|
| | TODAY | SCNRIO4 | TODAY | SCNRIO4 |
| CA OUTPUT ($BILLION) | 3078.0223 | 3062.4866 | 6568.5732 | 6538.4894 |
| % CHANGE CA OUTPUT | 0.10% | -0.50% | 0.11% | -0.46% |
| CA PERSONAL INCOME ($BILLION) | 2009.5373 | 2001.0251 | 4325.2331 | 4318.1160 |
| % CHANGE CA PERS. INC. | 0.11% | -0.42% | 0.12% | -0.16% |
| LABOR DEMAND (MILLIONS) | 18.6605 | 18.6726 | 27.9673 | 28.0382 |
| % CHNGE LABOR DEMAND | 0.03% | 0.06% | 0.04% | 0.25% |
| PRICE OF CFOOD | 1.0001 | 1.0026 | 1.0001 | 1.0018 |
| PRICE OF CHOME | 1.0000 | 1.0018 | 1.0001 | 1.0012 |
| PRICE OF CFUEL | 1.0000 | 0.8818 | 1.0000 | 0.8636 |
| PRICE OF CFURN | 1.0001 | 1.0022 | 1.0001 | 1.0015 |
| PRICE OF CCLOTH | 1.0001 | 1.0023 | 1.0001 | 1.0016 |
| PRICE OF CTRANS | 1.0000 | 1.0513 | 1.0001 | 1.0382 |
| PRICE OF CMED | 1.0001 | 1.0038 | 1.0001 | 1.0029 |
| PRICE OF CAMUS | 1.0000 | 1.0027 | 1.0001 | 1.0018 |
| PRICE OF COTHR | 1.0000 | 1.0017 | 1.0001 | 1.0012 |
| ENMIN | | | | |
| OUTPUT ($BILLION) | 6.2086 | 5.6084 | 7.6887 | 6.7220 |
| % CHANGE OUTPUT | 0.08% | -9.67% | 0.07% | -12.57% |
| IMPORTS ($BILLION) | 36.0105 | 31.8337 | 57.4093 | 47.5359 |
| % CHANGE IMPORTS | 0.07% | -11.60% | 0.08% | -17.20% |
| EXPORTS ($BILLION) | 1.0965 | 1.1542 | 2.6396 | 2.8549 |
| % CHANGE EXPORTS | -0.07% | 5.27% | -0.09% | 8.16% |
| PETRO | | | | |
| OUTPUT ($BILLION) | 39.3048 | 33.5161 | 39.2540 | 26.4558 |
| % CHANGE OUTPUT | 0.07% | -14.73% | 0.11% | -32.60% |
| IMPORTS ($BILLION) | 15.6834 | 15.2814 | 63.6368 | 60.7897 |
| % CHANGE IMPORTS | 0.01% | -2.56% | 0.02% | -4.47% |
| EXPORTS ($BILLION) | 11.9979 | 12.2582 | 19.1419 | 19.8796 |
| % CHANGE EXPORTS | -0.02% | 2.17% | -0.02% | 3.85% |
| ENGIN | | | | |
| OUTPUT ($BILLION) | 40.4675 | 40.8046 | 87.0335 | 87.4671 |
| % CHANGE OUTPUT | 0.05% | 0.83% | 0.05% | 0.50% |
| IMPORTS ($BILLION) | 9.0494 | 9.2482 | 19.4495 | 19.7580 |
| % CHANGE IMPORTS | 0.02% | 2.20% | 0.04% | 1.59% |
| EXPORTS ($BILLION) | 13.8359 | 13.5091 | 29.7408 | 29.2304 |
| % CHANGE EXPORTS | -0.03% | -2.36% | -0.05% | -1.72% |
| CHEMS | | | | |
| OUTPUT ($BILLION) | 30.2836 | 31.6679 | 64.9941 | 68.3594 |
| % CHANGE OUTPUT | 0.22% | 4.57% | 0.24% | 5.18% |
| IMPORTS ($BILLION) | 39.3028 | 39.4178 | 84.2137 | 84.3420 |
| % CHANGE IMPORTS | 0.01% | 0.29% | 0.02% | 0.15% |
| EXPORTS ($BILLION) | 2.0905 | 2.0838 | 4.6502 | 4.6424 |
| % CHANGE EXPORTS | -0.01% | -0.32% | -0.02% | -0.17% |
| FOODS | | | | |
| OUTPUT ($BILLION) | 92.9579 | 101.3527 | 200.2299 | 221.4745 |
| % CHANGE OUTPUT | 0.14% | 9.03% | 0.17% | 10.61% |
| APPAR | | | | |
| OUTPUT ($BILLION) | 25.9513 | 27.5086 | 55.8814 | 60.8908 |
| % CHANGE OUTPUT | 0.20% | 6.00% | 0.25% | 8.96% |
| MOTOR | | | | |
| OUTPUT ($BILLION) | 18.2243 | 17.8553 | 39.3478 | 38.6851 |
| % CHANGE OUTPUT | 0.23% | -2.02% | 0.24% | -1.68% |

### 6.4.5 Scenario Comparisons

Comparing effects across scenarios in 2020 and 2050 reveals the following. First, gains in fuel efficiency reduce the price of vehicle miles traveled. Scenarios 1, 2, and 4 reflect progressively more fuel efficient technologies. The scenarios implement static fuel cost saving of roughly $3.3 billion, $9.3 billion, and $12.5 billion, respectively and E-DRAM predicts the price of CFUEL falling sequentially by scenario to 97, 91, and 88 percent of its base level. Second, while gains in fuel efficiency, which translate into lower petroleum consumption and production, appear to reduce *nominal* state output by 0.1 to 0.5 percent depending on the scenario, *real* state income remains nearly constant because of aggregate price level deflation due lower fuel costs. Real SPI falls by more than calibration error only under Scenario 4 / 2020 – the only permutation in which projected engine costs outweigh fuel savings.

None of the strategies appears to have significant negative impacts on the state economy as a whole. The cost of building and buying more efficient engines is generally offset by their cheaper operating costs. This said, however, adjustments in the energy related sectors are significant. In 2020, ENMIN and PETRO sector output fall 2-10 and 4-15 percent below base, respectively, depending on the scenario.

| 2020 | BASE MODEL | SCNRIO1 | SCNRIO2 | SCNRIO3 | SCNRIO4 |
|---|---|---|---|---|---|
| CA OUTPUT ($BILLION) | 3078.0223 | 3074.9243 | 3070.0183 | 3069.4120 | 3062.4866 |
| % CHANGE CA OUTPUT | 0.10% | -0.10% | -0.26% | -0.28% | -0.50% |
| CA PERSONAL INCOME ($BILLION) | 2009.5373 | 2009.5213 | 2010.4295 | 2006.5412 | 2001.0251 |
| % CHANGE CA PERS. INC. | 0.11% | 0.00% | 0.04% | -0.15% | -0.42% |
| LABOR DEMAND (MILLIONS) | 18.6605 | 18.6767 | 18.7119 | 18.6841 | 18.6726 |
| % CHNGE LABOR DEMAND | 0.03% | 0.09% | 0.28% | 0.13% | 0.06% |
| PRICE OF CFOOD | 1.0001 | 1.0001 | 1.0002 | 1.0013 | 1.0026 |
| PRICE OF CHOME | 1.0000 | 1.0000 | 1.0001 | 1.0008 | 1.0018 |
| PRICE OF CFUEL | 1.0000 | 0.9687 | 0.9111 | 0.9215 | 0.8818 |
| PRICE OF CFURN | 1.0001 | 1.0001 | 1.0002 | 1.0011 | 1.0022 |
| PRICE OF CCLOTH | 1.0001 | 1.0001 | 1.0002 | 1.0011 | 1.0023 |
| PRICE OF CTRANS | 1.0000 | 1.0072 | 1.0171 | 1.0271 | 1.0513 |
| PRICE OF CMED | 1.0001 | 1.0002 | 1.0006 | 1.0020 | 1.0038 |
| PRICE OF CAMUS | 1.0000 | 1.0001 | 1.0002 | 1.0013 | 1.0027 |
| PRICE OF COTHR | 1.0000 | 1.0000 | 1.0001 | 1.0008 | 1.0017 |
| ENMIN | | | | | |
| OUTPUT ($BILLION) | 6.2086 | 6.0575 | 5.7836 | 5.7448 | 5.6084 |
| % CHANGE OUTPUT | 0.08% | -2.43% | -6.84% | -7.47% | -9.67% |
| IMPORTS ($BILLION) | 36.0105 | 34.8290 | 32.6693 | 32.5922 | 31.8337 |
| % CHANGE IMPORTS | 0.07% | -3.28% | -9.28% | -9.49% | -11.60% |
| EXPORTS ($BILLION) | 1.0965 | 1.1122 | 1.1419 | 1.1430 | 1.1542 |
| % CHANGE EXPORTS | -0.07% | 1.43% | 4.15% | 4.25% | 5.27% |
| PETRO | | | | | |
| OUTPUT ($BILLION) | 39.3048 | 37.6902 | 34.7300 | 35.3868 | 33.5161 |
| % CHANGE OUTPUT | 0.07% | -4.11% | -11.64% | -9.97% | -14.73% |
| IMPORTS ($BILLION) | 15.6834 | 15.5646 | 15.3455 | 15.3992 | 15.2814 |
| % CHANGE IMPORTS | 0.01% | -0.76% | -2.15% | -1.81% | -2.56% |
| EXPORTS ($BILLION) | 11.9979 | 12.0739 | 12.2159 | 12.1807 | 12.2582 |
| % CHANGE EXPORTS | -0.02% | 0.63% | 1.82% | 1.52% | 2.17% |
| ENGIN | | | | | |
| OUTPUT ($BILLION) | 40.4675 | 40.5818 | 40.6323 | 40.6730 | 40.8046 |
| % CHANGE OUTPUT | 0.05% | 0.28% | 0.41% | 0.51% | 0.83% |
| IMPORTS ($BILLION) | 9.0494 | 9.0815 | 9.1111 | 9.1578 | 9.2482 |
| % CHANGE IMPORTS | 0.02% | 0.35% | 0.68% | 1.20% | 2.20% |
| EXPORTS ($BILLION) | 13.8359 | 13.7822 | 13.7330 | 13.6559 | 13.5091 |
| % CHANGE EXPORTS | -0.03% | -0.39% | -0.74% | -1.30% | -2.36% |
| CHEMS | | | | | |
| OUTPUT ($BILLION) | 30.2836 | 30.6482 | 31.3101 | 32.0653 | 31.6679 |
| % CHANGE OUTPUT | 0.22% | 1.20% | 3.39% | 5.88% | 4.57% |
| IMPORTS ($BILLION) | 39.3028 | 39.2943 | 39.2798 | 39.3585 | 39.4178 |
| % CHANGE IMPORTS | 0.01% | -0.02% | -0.06% | 0.14% | 0.29% |
| EXPORTS ($BILLION) | 2.0905 | 2.0910 | 2.0918 | 2.0872 | 2.0838 |
| % CHANGE EXPORTS | -0.01% | 0.02% | 0.06% | -0.16% | -0.32% |
| FOODS | | | | | |
| OUTPUT ($BILLION) | 92.9579 | 95.1127 | 99.2793 | 98.4497 | 101.3527 |
| % CHANGE OUTPUT | 0.14% | 2.32% | 6.80% | 5.91% | 9.03% |
| APPAR | | | | | |
| OUTPUT ($BILLION) | 25.9513 | 26.4969 | 27.6314 | 27.1334 | 27.5086 |
| % CHANGE OUTPUT | 0.20% | 2.10% | 6.47% | 4.55% | 6.00% |
| MOTOR | | | | | |
| OUTPUT ($BILLION) | 18.2243 | 18.1613 | 18.0770 | 18.0142 | 17.8553 |
| % CHANGE OUTPUT | 0.23% | -0.35% | -0.81% | -1.15% | -2.02% |

| 2050 | BASE MODEL | SCNRIO1 | SCNRIO2 | SCNRIO3 | SCNRIO4 |
|---|---|---|---|---|---|
| CA OUTPUT ($BILLION) | 6568.5732 | 6557.2797 | 6553.2078 | 6551.2810 | 6538.4894 |
| % CHANGE CA OUTPUT | 0.11% | -0.17% | -0.23% | -0.26% | -0.46% |
| CA PERSONAL INCOME ($BILLION) | 4325.2331 | 4329.6794 | 4330.7327 | 4330.4291 | 4318.1160 |
| % CHANGE CA PERS. INC. | 0.12% | 0.10% | 0.13% | 0.12% | -0.16% |
| LABOR DEMAND (MILLIONS) | 27.9673 | 28.0326 | 28.0539 | 28.0763 | 28.0382 |
| % CHNGE LABOR DEMAND | 0.04% | 0.23% | 0.31% | 0.39% | 0.25% |
| PRICE OF CFOOD | 1.0001 | 1.0000 | 1.0000 | 1.0013 | 1.0018 |
| PRICE OF CHOME | 1.0001 | 0.9999 | 0.9999 | 1.0008 | 1.0012 |
| PRICE OF CFUEL | 1.0000 | 0.9324 | 0.9088 | 0.8801 | 0.8636 |
| PRICE OF CFURN | 1.0001 | 1.0000 | 1.0000 | 1.0011 | 1.0015 |
| PRICE OF CCLOTH | 1.0001 | 1.0000 | 1.0001 | 1.0011 | 1.0016 |
| PRICE OF CTRANS | 1.0001 | 1.0095 | 1.0126 | 1.0208 | 1.0382 |
| PRICE OF CMED | 1.0001 | 1.0003 | 1.0004 | 1.0021 | 1.0029 |
| PRICE OF CAMUS | 1.0001 | 0.9999 | 1.0000 | 1.0012 | 1.0018 |
| PRICE OF COTHR | 1.0001 | 0.9999 | 1.0000 | 1.0008 | 1.0012 |
| ENMIN | | | | | |
| OUTPUT ($BILLION) | 7.6887 | 7.2328 | 7.0685 | 6.3197 | 6.7220 |
| % CHANGE OUTPUT | 0.07% | -5.93% | -8.07% | -17.81% | -12.57% |
| IMPORTS ($BILLION) | 57.4093 | 52.2725 | 50.5293 | 43.5417 | 47.5359 |
| % CHANGE IMPORTS | 0.08% | -8.95% | -11.98% | -24.16% | -17.20% |
| EXPORTS ($BILLION) | 2.6396 | 2.7452 | 2.7839 | 2.9601 | 2.8549 |
| % CHANGE EXPORTS | -0.09% | 4.00% | 5.47% | 12.14% | 8.16% |
| PETRO | | | | | |
| OUTPUT ($BILLION) | 39.2540 | 32.6620 | 30.4067 | 27.6640 | 26.4558 |
| % CHANGE OUTPUT | 0.11% | -16.79% | -22.54% | -29.53% | -32.60% |
| IMPORTS ($BILLION) | 63.6368 | 62.1426 | 61.6306 | 61.1013 | 60.7897 |
| % CHANGE IMPORTS | 0.02% | -2.35% | -3.15% | -3.98% | -4.47% |
| EXPORTS ($BILLION) | 19.1419 | 19.5219 | 19.6556 | 19.7960 | 19.8796 |
| % CHANGE EXPORTS | -0.02% | 1.99% | 2.68% | 3.42% | 3.85% |
| ENGIN | | | | | |
| OUTPUT ($BILLION) | 87.0335 | 87.2217 | 87.2374 | 87.1527 | 87.4671 |
| % CHANGE OUTPUT | 0.05% | 0.22% | 0.23% | 0.14% | 0.50% |
| IMPORTS ($BILLION) | 19.4495 | 19.5153 | 19.5371 | 19.6373 | 19.7580 |
| % CHANGE IMPORTS | 0.04% | 0.34% | 0.45% | 0.97% | 1.59% |
| EXPORTS ($BILLION) | 29.7408 | 29.6307 | 29.5942 | 29.4282 | 29.2304 |
| % CHANGE EXPORTS | -0.05% | -0.37% | -0.49% | -1.05% | -1.72% |
| CHEMS | | | | | |
| OUTPUT ($BILLION) | 64.9941 | 66.6697 | 67.2368 | 75.5236 | 68.3594 |
| % CHANGE OUTPUT | 0.24% | 2.58% | 3.45% | 16.20% | 5.18% |
| IMPORTS ($BILLION) | 84.2137 | 84.1483 | 84.1389 | 84.3541 | 84.3420 |
| % CHANGE IMPORTS | 0.02% | -0.08% | -0.09% | 0.17% | 0.15% |
| EXPORTS ($BILLION) | 4.6502 | 4.6542 | 4.6547 | 4.6417 | 4.6424 |
| % CHANGE EXPORTS | -0.02% | 0.09% | 0.10% | -0.18% | -0.17% |
| FOODS | | | | | |
| OUTPUT ($BILLION) | 200.2299 | 210.4874 | 214.2155 | 218.8242 | 221.4745 |
| % CHANGE OUTPUT | 0.17% | 5.12% | 6.98% | 9.29% | 10.61% |
| APPAR | | | | | |
| OUTPUT ($BILLION) | 55.8814 | 58.7842 | 59.8357 | 61.0011 | 60.8908 |
| % CHANGE OUTPUT | 0.25% | 5.19% | 7.08% | 9.16% | 8.96% |
| MOTOR | | | | | |
| OUTPUT ($BILLION) | 39.3478 | 39.1508 | 39.0798 | 38.8744 | 38.6851 |
| % CHANGE OUTPUT | 0.24% | -0.50% | -0.68% | -1.20% | -1.68% |

### 6.5 Sensitivity Analysis

Sensitivity analysis – examining the behavior of a model in response to key input changes – is a good way to assess a model's properties and bolster confidence in its results. E-DRAM's predecessor, DRAM, has undergone extensive sensitivity analysis, as documented in Berck, *et. al.* (Summer 1996). For purposes of this project, it is useful to examine E-DRAM's when parameters governing consumers' sensitivity to fuel prices, petroleum imports as a function of domestic price, and overall economic performance as a function of energy prices are changed. To this end, the following experiments are performed.

#### 6.5.1 Consumers' Response to Fuel Price Changes

Changing the own-price elasticity of demand CFUEL changes consumers' sensitivity to fuel price changes. More specifically, lowering this parameter to -0.77 (from its default setting of -0.2) makes consumers respond to a 1.0 percent decrease in the price of fuel price by demanding 0.77 percent (rather than 0.2 percent) more fuel. Economists describe the elasticity of -.77 as more elastic than the elasticity of -.2.

Running the 2020 version of E-DRAM with this new (*vs.* old) elasiticity imposed yields results listed in the gray (*vs.* white) columns. The contrast is as expected. The more sensitive consumers are to fuel price changes, the less they cut back fuel consumption in response to increased fuel efficiency. This is because fuel efficiency gains trigger two opposing effects. One is a decreased demand for fuel since less is needed to produce the same number of vehicle miles traveled. The other is an increased demand for vehicle miles traveled because they're cheaper. It's the low-price elasticity of demand that governs the size of this second response, i.e., raising this parameter's (absolute) value means a greater increase in the quantity demanded per any given price decrease.

With more elastic of demand for CFUEL, statewide impacts of the scenarios being considered are dampened slightly. In Scenario 4, for example, state output declines by 0.2 percent rather than 0.5 percent and real personal income falls by 0.1 percent rather than 0.4 percent. With consumers buying relatively more fuel, ENMIN and PETRO sector output decline by only 4.6 percent and 7.4 percent, respectively, rather than by 9.7 percent and 14.7 percent, respectively. Demand for complimentary products thus rises relative to the base model, *e.g.*, ENGIN sector output increases 1.3 percent rather than 0.8 percent. Relatively less spending is shifted to fuel substitutes like food and apparel, *e.g.*, FOODS and APPPAR sector output increase by 8.3 percent (*vs.* 9.0 percent in base) and 3.6 percent (*vs.* 6.0 percent in base), respectively.

| 2020 | BASE MODEL | SCNRIO1 | SCNRIO1 | SCNRIO2 | SCNRIO2 | SCNRIO3 | SCNRIO3 | SCNRIO4 | SCNRIO4 |
|---|---|---|---|---|---|---|---|---|---|
| CA OUTPUT ($BILLION) | 3078.022 | 3074.924 | 3076.657 | 3070.018 | 3075.484 | 3069.412 | 3074.329 | 3062.487 | 3070.572 |
| % CHANGE CA OUTPUT | 0.10% | -0.10% | -0.04% | -0.26% | -0.08% | -0.28% | -0.12% | -0.50% | -0.24% |
| CA PERS. INC. ($BIL.) | 2009.537 | 2009.521 | 2010.283 | 2010.429 | 2013.756 | 2006.541 | 2009.407 | 2001.025 | 2006.661 |
| % CHNGE CA PERS. INC. | 0.11% | 0.00% | 0.04% | 0.04% | 0.21% | -0.15% | -0.01% | -0.42% | -0.14% |
| LAB. DEMAND (MIL.) | 18.661 | 18.677 | 18.677 | 18.712 | 18.719 | 18.684 | 18.690 | 18.673 | 18.688 |
| % CHNGE LAB. DEMAND | 0.03% | 0.09% | 0.09% | 0.28% | 0.31% | 0.13% | 0.16% | 0.06% | 0.15% |
| PRICE OF CFOOD | 1.000 | 1.000 | 1.000 | 1.000 | 0.999 | 1.001 | 1.000 | 1.003 | 1.001 |
| PRICE OF CHOME | 1.000 | 1.000 | 1.000 | 1.000 | 0.999 | 1.001 | 1.000 | 1.002 | 1.001 |
| PRICE OF CFUEL | 1.000 | 0.969 | 0.969 | 0.911 | 0.911 | 0.922 | 0.922 | 0.882 | 0.882 |
| PRICE OF CFURN | 1.000 | 1.000 | 1.000 | 1.000 | 0.999 | 1.001 | 1.000 | 1.002 | 1.001 |
| PRICE OF CCLOTH | 1.000 | 1.000 | 1.000 | 1.000 | 0.999 | 1.001 | 1.000 | 1.002 | 1.001 |
| PRICE OF CTRANS | 1.000 | 1.007 | 1.007 | 1.017 | 1.016 | 1.027 | 1.026 | 1.051 | 1.050 |
| PRICE OF CMED | 1.000 | 1.000 | 1.000 | 1.001 | 0.999 | 1.002 | 1.001 | 1.004 | 1.002 |
| PRICE OF CAMUS | 1.000 | 1.000 | 1.000 | 1.000 | 0.999 | 1.001 | 1.000 | 1.003 | 1.001 |
| PRICE OF COTHR | 1.000 | 1.000 | 1.000 | 1.000 | 0.999 | 1.001 | 1.000 | 1.002 | 1.000 |
| ENMIN | | | | | | | | | |
| OUTPUT ($BILLION) | 6.209 | 6.058 | 6.134 | 5.784 | 6.008 | 5.745 | 5.945 | 5.608 | 5.921 |
| % CHANGE OUTPUT | 0.08% | -2.43% | -1.19% | -6.84% | -3.24% | -7.47% | -4.25% | -9.67% | -4.64% |
| IMPORTS ($BILLION) | 36.011 | 34.829 | 35.418 | 32.669 | 34.270 | 32.592 | 34.022 | 31.834 | 34.000 |
| % CHANGE IMPORTS | 0.07% | -3.28% | -1.65% | -9.28% | -4.83% | -9.49% | -5.52% | -11.60% | -5.58% |
| EXPORTS ($BILLION) | 1.096 | 1.112 | 1.104 | 1.142 | 1.120 | 1.143 | 1.123 | 1.154 | 1.123 |
| % CHANGE EXPORTS | -0.07% | 1.43% | 0.73% | 4.15% | 2.11% | 4.25% | 2.42% | 5.27% | 2.45% |
| PETRO | | | | | | | | | |
| OUTPUT ($BILLION) | 39.305 | 37.690 | 38.466 | 34.730 | 36.855 | 35.387 | 37.328 | 33.516 | 36.401 |
| % CHANGE OUTPUT | 0.07% | -4.11% | -2.14% | -11.64% | -6.23% | -9.97% | -5.03% | -14.73% | -7.39% |
| IMPORTS ($BILLION) | 15.683 | 15.565 | 15.597 | 15.345 | 15.431 | 15.399 | 15.476 | 15.281 | 15.394 |
| % CHANGE IMPORTS | 0.01% | -0.76% | -0.55% | -2.15% | -1.61% | -1.81% | -1.32% | -2.56% | -1.85% |
| EXPORTS ($BILLION) | 11.998 | 12.074 | 12.053 | 12.216 | 12.160 | 12.181 | 12.131 | 12.258 | 12.184 |
| % CHANGE EXPORTS | -0.02% | 0.63% | 0.46% | 1.82% | 1.35% | 1.52% | 1.11% | 2.17% | 1.55% |
| ENGIN | | | | | | | | | |
| OUTPUT ($BILLION) | 40.468 | 40.582 | 40.619 | 40.632 | 40.761 | 40.673 | 40.786 | 40.805 | 41.005 |
| % CHANGE OUTPUT | 0.05% | 0.28% | 0.37% | 0.41% | 0.72% | 0.51% | 0.79% | 0.83% | 1.33% |
| IMPORTS ($BILLION) | 9.049 | 9.081 | 9.076 | 9.111 | 9.089 | 9.158 | 9.139 | 9.248 | 9.213 |
| % CHANGE IMPORTS | 0.02% | 0.35% | 0.29% | 0.68% | 0.44% | 1.20% | 0.99% | 2.20% | 1.81% |
| EXPORTS ($BILLION) | 13.836 | 13.782 | 13.792 | 13.733 | 13.770 | 13.656 | 13.687 | 13.509 | 13.566 |
| % CHANGE EXPORTS | -0.03% | -0.39% | -0.32% | -0.74% | -0.48% | -1.30% | -1.07% | -2.36% | -1.95% |
| CHEMS | | | | | | | | | |
| OUTPUT ($BILLION) | 30.284 | 30.648 | 30.602 | 31.310 | 31.221 | 32.065 | 32.027 | 31.668 | 31.581 |
| % CHANGE OUTPUT | 0.22% | 1.20% | 1.05% | 3.39% | 3.09% | 5.88% | 5.76% | 4.57% | 4.28% |
| IMPORTS ($BILLION) | 39.303 | 39.294 | 39.278 | 39.280 | 39.219 | 39.358 | 39.307 | 39.418 | 39.321 |
| % CHANGE IMPORTS | 0.01% | -0.02% | -0.06% | -0.06% | -0.21% | 0.14% | 0.01% | 0.29% | 0.05% |
| EXPORTS ($BILLION) | 2.090 | 2.091 | 2.092 | 2.092 | 2.095 | 2.087 | 2.090 | 2.084 | 2.089 |
| % CHANGE EXPORTS | -0.01% | 0.02% | 0.07% | 0.06% | 0.23% | -0.16% | -0.01% | -0.32% | -0.05% |
| FOODS | | | | | | | | | |
| OUTPUT ($BILLION) | 92.958 | 95.113 | 94.919 | 99.279 | 98.760 | 98.450 | 97.975 | 101.353 | 100.663 |
| % CHANGE OUTPUT | 0.14% | 2.32% | 2.11% | 6.80% | 6.24% | 5.91% | 5.40% | 9.03% | 8.29% |
| APPAR | | | | | | | | | |
| OUTPUT ($BILLION) | 25.951 | 26.497 | 26.323 | 27.631 | 27.163 | 27.133 | 26.707 | 27.509 | 26.885 |
| % CHANGE OUTPUT | 0.20% | 2.10% | 1.43% | 6.47% | 4.67% | 4.55% | 2.91% | 6.00% | 3.60% |
| MOTOR | | | | | | | | | |
| OUTPUT ($BILLION) | 18.224 | 18.161 | 18.190 | 18.077 | 18.168 | 18.014 | 18.095 | 17.855 | 17.991 |
| % CHANGE OUTPUT | 0.23% | -0.35% | -0.19% | -0.81% | -0.31% | -1.15% | -0.71% | -2.02% | -1.28% |

### 6.5.2 Elasticity of Imports with respect to Domestic Price

Lowering the elasticity of imports with respect to domestic price (ETAM) makes the quantity of goods imported less sensitive to domestic price changes. Changing ETAM for the petroleum sector to 0.1 (from its default setting of 2) means that a 1.0 percent decrease in the domestic price of petroleum decreases imports of refined petroleum by 0.1 percent (rather than 2.0 percent).and from 4.0 to 1.0 for the energy and mining sector With these parameter changes, Similarly, changing ETAM for the ENMIN sector to 1 (from its default setting of 4) means that a 1 percent decrease in the domestic price of crude oil will decrease imports of crude oil by 1.0 percent (rather than 4.0 percent).

The parameter changes outlined above cause some domestic PETRO and ENMIN sector production to be being supplanted by imports, as expected. The table below shows results from running the 2020 version of E-DRAM with new (*vs.* old) elasticities listed in the gray (*vs.* white) columns. While statewide effects aren't appreciably different with these new parameter settings, adverse impacts on the ENMIN and PETRO sectors are amplified as falling demand is compounded by rising imports. This compounding is greatest in the ENMIN sector where domestic output falls 7.3 percent (*vs.* 2.4 percent) in Scenario 1, 21.1 percent (*vs*. 6.8 percent) in Scenario 2, 21.9 percent (*vs.* 7.5 percent) in Scenario 3, and 27.6 percent (*vs.* 9.7 percent) in Scenario 4.

Conversely, if the elasticities of trade were increased, or the domestic elasticity of supply were decreased, domestic output would be less sensitive to the scenarios and state output and personal income would be higher.

| 2020 | BASE MODEL | SCNRIO1 | SCNRIO1 | SCNRIO2 | SCNRIO2 | SCNRIO3 | SCNRIO3 | SCNRIO4 | SCNRIO4 |
|---|---|---|---|---|---|---|---|---|---|
| CA OUTPUT ($BILLION) | 3078.022 | 3074.924 | 3074.649 | 3070.018 | 3069.005 | 3069.412 | 3068.447 | 3062.487 | 3061.123 |
| % CHANGE CA OUTPUT | 0.10% | -0.10% | -0.11% | -0.26% | -0.29% | -0.28% | -0.31% | -0.50% | -0.55% |
| CA PERS. INC. ($BIL.) | 2009.537 | 2009.521 | 2009.361 | 2010.429 | 2009.858 | 2006.541 | 2005.985 | 2001.025 | 2000.271 |
| % CHNGE CA PERS. INC. | 0.11% | 0.00% | -0.01% | 0.04% | 0.02% | -0.15% | -0.18% | -0.42% | -0.46% |
| LAB. DEMAND (MIL.) | 18.661 | 18.677 | 18.677 | 18.712 | 18.711 | 18.684 | 18.684 | 18.673 | 18.67164 |
| % CHNGE LAB. DEMAND | 0.03% | 0.09% | 0.09% | 0.28% | 0.27% | 0.13% | 0.12% | 0.06% | 0.06% |
| PRICE OF CFOOD | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.001 | 1.001 | 1.003 | 1.002197 |
| PRICE OF CHOME | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.001 | 1.001 | 1.002 | 1.001495 |
| PRICE OF CFUEL | 1.000 | 0.969 | 0.968 | 0.911 | 0.910 | 0.922 | 0.921 | 0.882 | 0.880875 |
| PRICE OF CFURN | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.001 | 1.001 | 1.002 | 1.001886 |
| PRICE OF CCLOTH | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.001 | 1.001 | 1.002 | 1.00194 |
| PRICE OF CTRANS | 1.000 | 1.007 | 1.007 | 1.017 | 1.017 | 1.027 | 1.027 | 1.051 | 1.051033 |
| PRICE OF CMED | 1.000 | 1.000 | 1.000 | 1.001 | 1.000 | 1.002 | 1.002 | 1.004 | 1.003364 |
| PRICE OF CAMUS | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.001 | 1.001 | 1.003 | 1.002307 |
| PRICE OF COTHR | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.001 | 1.001 | 1.002 | 1.001442 |
| ENMIN | | | | | | | | | |
| OUTPUT ($BILLION) | 6.209 | 6.058 | 5.754 | 5.784 | 4.897 | 5.745 | 4.849 | 5.608 | 4.494602 |
| % CHANGE OUTPUT | 0.08% | -2.43% | -7.32% | -6.84% | -21.13% | -7.47% | -21.90% | -9.67% | -27.61% |
| IMPORTS ($BILLION) | 36.011 | 34.829 | 35.060 | 32.669 | 33.336 | 32.592 | 33.298 | 31.834 | 32.67667 |
| % CHANGE IMPORTS | 0.07% | -3.28% | -2.64% | -9.28% | -7.43% | -9.49% | -7.53% | -11.60% | -9.26% |
| EXPORTS ($BILLION) | 1.096 | 1.112 | 1.146 | 1.142 | 1.245 | 1.143 | 1.247 | 1.154 | 1.286606 |
| % CHANGE EXPORTS | -0.07% | 1.43% | 4.47% | 4.15% | 13.54% | 4.25% | 13.75% | 5.27% | 17.34% |
| PETRO | | | | | | | | | |
| OUTPUT ($BILLION) | 39.305 | 37.690 | 37.608 | 34.730 | 34.466 | 35.387 | 35.173 | 33.516 | 33.19064 |
| % CHANGE OUTPUT | 0.07% | -4.11% | -4.32% | -11.64% | -12.31% | -9.97% | -10.51% | -14.73% | -15.56% |
| IMPORTS ($BILLION) | 15.683 | 15.565 | 15.673 | 15.345 | 15.659 | 15.399 | 15.662 | 15.281 | 15.6558 |
| % CHANGE IMPORTS | 0.01% | -0.76% | -0.07% | -2.15% | -0.15% | -1.81% | -0.13% | -2.56% | -0.18% |
| EXPORTS ($BILLION) | 11.998 | 12.074 | 12.100 | 12.216 | 12.277 | 12.181 | 12.238 | 12.258 | 12.32398 |
| % CHANGE EXPORTS | -0.02% | 0.63% | 0.85% | 1.82% | 2.32% | 1.52% | 2.00% | 2.17% | 2.72% |
| ENGIN | | | | | | | | | |
| OUTPUT ($BILLION) | 40.468 | 40.582 | 40.587 | 40.632 | 40.645 | 40.673 | 40.685 | 40.805 | 40.81842 |
| % CHANGE OUTPUT | 0.05% | 0.28% | 0.29% | 0.41% | 0.44% | 0.51% | 0.54% | 0.83% | 0.87% |
| IMPORTS ($BILLION) | 9.049 | 9.081 | 9.079 | 9.111 | 9.105 | 9.158 | 9.152 | 9.248 | 9.240452 |
| % CHANGE IMPORTS | 0.02% | 0.35% | 0.33% | 0.68% | 0.61% | 1.20% | 1.13% | 2.20% | 2.11% |
| EXPORTS ($BILLION) | 13.836 | 13.782 | 13.786 | 13.733 | 13.743 | 13.656 | 13.666 | 13.509 | 13.52159 |
| % CHANGE EXPORTS | -0.03% | -0.39% | -0.36% | -0.74% | -0.67% | -1.30% | -1.23% | -2.36% | -2.27% |
| CHEMS | | | | | | | | | |
| OUTPUT ($BILLION) | 30.284 | 30.648 | 30.661 | 31.310 | 31.336 | 32.065 | 32.087 | 31.668 | 31.69406 |
| % CHANGE OUTPUT | 0.22% | 1.20% | 1.25% | 3.39% | 3.48% | 5.88% | 5.96% | 4.57% | 4.66% |
| IMPORTS ($BILLION) | 39.303 | 39.294 | 39.285 | 39.280 | 39.255 | 39.358 | 39.334 | 39.418 | 39.38798 |
| % CHANGE IMPORTS | 0.01% | -0.02% | -0.05% | -0.06% | -0.12% | 0.14% | 0.08% | 0.29% | 0.22% |
| EXPORTS ($BILLION) | 2.090 | 2.091 | 2.092 | 2.092 | 2.093 | 2.087 | 2.089 | 2.084 | 2.08549 |
| % CHANGE EXPORTS | -0.01% | 0.02% | 0.05% | 0.06% | 0.13% | -0.16% | -0.09% | -0.32% | -0.24% |
| FOODS | | | | | | | | | |
| OUTPUT ($BILLION) | 92.958 | 95.113 | 95.145 | 99.279 | 99.343 | 98.450 | 98.512 | 101.353 | 101.4153 |
| % CHANGE OUTPUT | 0.14% | 2.32% | 2.35% | 6.80% | 6.87% | 5.91% | 5.98% | 9.03% | 9.10% |
| APPAR | | | | | | | | | |
| OUTPUT ($BILLION) | 25.951 | 26.497 | 26.507 | 27.631 | 27.650 | 27.133 | 27.152 | 27.509 | 27.52633 |
| % CHANGE OUTPUT | 0.20% | 2.10% | 2.14% | 6.47% | 6.55% | 4.55% | 4.63% | 6.00% | 6.07% |
| MOTOR | | | | | | | | | |
| OUTPUT ($BILLION) | 18.224 | 18.161 | 18.165 | 18.077 | 18.084 | 18.014 | 18.021 | 17.855 | 17.86203 |
| % CHANGE OUTPUT | 0.23% | -0.35% | -0.33% | -0.81% | -0.77% | -1.15% | -1.12% | -2.02% | -1.99% |

### 6.5.3 Higher World Energy Prices

A primary motivation for decreasing petroleum dependency is limiting vulnerability to supply shocks that cause price spikes. Examining how E-DRAM assesses the impact of such spikes on the state economy – and predicting the extent to which the scenarios under consideration these impacts – is thus critical.

The table below compares runs given 20 percent higher world ENMIN and PETRO prices (gray columns) with runs at original world prices (white columns) . Comparing "NEW MODEL" to "BASE MODEL" columns shows that E-DRAM predicts 2020 California state product being roughly $21 billion (0.7 percent) lower and state personal income being $22 billion (1.1 percent) lower when both world PETRO and ENMIN prices are 20 percent higher. These higher world prices nudge the price of consumer fuel (CFUEL) up 6.2 percent, while the price of other consumer goods remain constant or fall slightly (0.1-0.2 percent).[47] Domestic output in the energy and mining sector rises nearly $2.2 billion (35 percent) while domestic output in the petroleum sector rises $1.0 billion (2.6 percent) as higher world prices drive down imports in those sectors.[48] Other sectors contract in the face of world energy price inflation, *e.g.*, output of the FOODS and APPAR sectors falls by 5.6 and 7.2 percent, respectively.

Comparing the gray and white "SCENARIO#" columns confirms the intuition that strategies to improve fuel efficiency reap greater rewards in a world with higher energy prices. Higher world prices induce greater domestic production that offsets declines in California's ENMIN and PETRO sector production triggered by demand reduction due to efficiency gains. In Scenario 4 with high world prices (*vs.* base model prices), for example, state output falls 0.4 percent (vs. 0.5 percent) and personal income falls 0.2 percent (*vs.* 0.4 percent); domestic ENMIN output falls 4.4 percent (*vs.* 9.7 percent) and PETRO production falls 12.3 percent (*vs.* 14.7 percent).

[47] The price of CFUEL rises by significantly less than 20% because the CFUEL sector also includes utilities.
[48] The domestic production as a share of imports is much lower in the ENMIN than in the PETRO sector.

| 2020 | BASE MODEL | NEW MODEL | SCNRIO1 | SCNRIO1 | SCNRIO2 | SCNRIO2 | SCNRIO3 | SCNRIO3 | SCNRIO4 | SCNRIO4 |
|---|---|---|---|---|---|---|---|---|---|---|
| CA OUTPUT ($BIL.) | 3078.022 | 3057.149 | 3074.924 | 3055.703 | 3070.018 | 3052.939 | 3069.412 | 3052.433 | 3062.487 | 3046.364 |
| % CHNGE OUTPUT | 0.10% | -0.58% | -0.10% | -0.05% | -0.26% | -0.14% | -0.28% | -0.15% | -0.50% | -0.35% |
| PERS. INC. ($BIL.) | 2009.537 | 1987.684 | 2009.521 | 1989.172 | 2010.429 | 1992.458 | 2006.541 | 1988.392 | 2001.025 | 1984.108 |
| % CHNGE PERS. INC. | 0.11% | -0.98% | 0.00% | 0.07% | 0.04% | 0.24% | -0.15% | 0.04% | -0.42% | -0.18% |
| JOBS (MIL.) | 18.661 | 18.536 | 18.677 | 18.558 | 18.712 | 18.605 | 18.684 | 18.577 | 18.673 | 18.571 |
| % CHNGE JOBS | 0.03% | -0.64% | 0.09% | 0.12% | 0.28% | 0.37% | 0.13% | 0.22% | 0.06% | 0.19% |
| PRICE OF CFOOD | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.001 | 1.001 | 1.003 | 1.002 |
| PRICE OF CHOME | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.001 | 1.000 | 1.002 | 1.001 |
| PRICE OF CFUEL | 1.000 | 1.062 | 0.969 | 1.030 | 0.911 | 0.969 | 0.922 | 0.979 | 0.882 | 0.938 |
| PRICE OF CFURN | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.001 | 1.001 | 1.002 | 1.002 |
| PRICE OF CCLOTH | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.001 | 1.001 | 1.002 | 1.002 |
| PRICE OF CTRANS | 1.000 | 1.000 | 1.007 | 1.008 | 1.017 | 1.017 | 1.027 | 1.027 | 1.051 | 1.052 |
| PRICE OF CMED | 1.000 | 0.998 | 1.000 | 0.998 | 1.001 | 0.999 | 1.002 | 1.000 | 1.004 | 1.002 |
| PRICE OF CAMUS | 1.000 | 0.999 | 1.000 | 0.999 | 1.000 | 0.999 | 1.001 | 1.000 | 1.003 | 1.002 |
| PRICE OF COTHR | 1.000 | 0.999 | 1.000 | 0.999 | 1.000 | 0.999 | 1.001 | 1.000 | 1.002 | 1.001 |
| ENMIN | | | | | | | | | | |
| OUTPUT ($BILLION) | 6.209 | 8.394 | 6.058 | 8.477 | 5.784 | 8.205 | 5.745 | 8.168 | 5.608 | 8.027 |
| % CHANGE OUTPUT | 0.08% | 35.31% | -2.43% | 0.99% | -6.84% | -2.25% | -7.47% | -2.69% | -9.67% | -4.37% |
| IMPORTS ($BILLION) | 36.011 | 34.875 | 34.829 | 33.762 | 32.669 | 31.738 | 32.592 | 31.701 | 31.834 | 30.946 |
| % CHANGE IMPORTS | 0.07% | -3.09% | -3.28% | -3.19% | -9.28% | -9.00% | -9.49% | -9.10% | -11.60% | -11.27% |
| EXPORTS ($BILLION) | 1.096 | 1.136 | 1.112 | 1.127 | 1.142 | 1.156 | 1.143 | 1.156 | 1.154 | 1.168 |
| % CHANGE EXPORTS | -0.07% | 3.51% | 1.43% | -0.82% | 4.15% | 1.75% | 4.25% | 1.79% | 5.27% | 2.81% |
| PETRO | | | | | | | | | | |
| OUTPUT ($BILLION) | 39.305 | 40.335 | 37.690 | 39.238 | 34.730 | 36.508 | 35.387 | 37.331 | 33.516 | 35.370 |
| % CHANGE OUTPUT | 0.07% | 2.69% | -4.11% | -2.72% | -11.64% | -9.49% | -9.97% | -7.45% | -14.73% | -12.31% |
| IMPORTS ($BILLION) | 15.683 | 14.222 | 15.565 | 13.711 | 15.345 | 13.519 | 15.399 | 13.468 | 15.281 | 13.459 |
| % CHANGE IMPORTS | 0.01% | -9.30% | -0.76% | -3.59% | -2.15% | -4.95% | -1.81% | -5.30% | -2.56% | -5.37% |
| EXPORTS ($BILLION) | 11.998 | 13.361 | 12.074 | 13.405 | 12.216 | 13.562 | 12.181 | 13.604 | 12.258 | 13.612 |
| % CHANGE EXPORTS | -0.02% | 11.34% | 0.63% | 0.33% | 1.82% | 1.51% | 1.52% | 1.82% | 2.17% | 1.88% |
| ENGIN | | | | | | | | | | |
| OUTPUT ($BILLION) | 40.468 | 40.443 | 40.582 | 40.563 | 40.632 | 40.643 | 40.673 | 40.674 | 40.805 | 40.828 |
| % CHANGE OUTPUT | 0.05% | -0.01% | 0.28% | 0.30% | 0.41% | 0.50% | 0.51% | 0.57% | 0.83% | 0.95% |
| IMPORTS ($BILLION) | 9.049 | 9.009 | 9.081 | 9.043 | 9.111 | 9.069 | 9.158 | 9.118 | 9.248 | 9.205 |
| % CHANGE IMPORTS | 0.02% | -0.42% | 0.35% | 0.37% | 0.68% | 0.67% | 1.20% | 1.21% | 2.20% | 2.17% |
| EXPORTS ($BILLION) | 13.836 | 13.904 | 13.782 | 13.847 | 13.733 | 13.802 | 13.656 | 13.721 | 13.509 | 13.579 |
| % CHANGE EXPORTS | -0.03% | 0.46% | -0.39% | -0.41% | -0.74% | -0.73% | -1.30% | -1.31% | -2.36% | -2.33% |
| CHEMS | | | | | | | | | | |
| OUTPUT ($BILLION) | 30.284 | 28.636 | 30.648 | 29.029 | 31.310 | 29.766 | 32.065 | 30.572 | 31.668 | 30.161 |
| % CHANGE OUTPUT | 0.22% | -5.23% | 1.20% | 1.37% | 3.39% | 3.95% | 5.88% | 6.76% | 4.57% | 5.32% |
| IMPORTS ($BILLION) | 39.303 | 39.601 | 39.294 | 39.599 | 39.280 | 39.573 | 39.358 | 39.657 | 39.418 | 39.705 |
| % CHANGE IMPORTS | 0.01% | 0.77% | -0.02% | 0.00% | -0.06% | -0.07% | 0.14% | 0.14% | 0.29% | 0.26% |
| EXPORTS ($BILLION) | 2.090 | 2.073 | 2.091 | 2.073 | 2.092 | 2.075 | 2.087 | 2.070 | 2.084 | 2.067 |
| % CHANGE EXPORTS | -0.01% | -0.84% | 0.02% | 0.00% | 0.06% | 0.08% | -0.16% | -0.16% | -0.32% | -0.29% |
| FOODS | | | | | | | | | | |
| OUTPUT ($BILLION) | 92.958 | 87.663 | 95.113 | 89.805 | 99.279 | 93.999 | 98.450 | 93.241 | 101.353 | 96.095 |
| % CHANGE OUTPUT | 0.14% | -5.56% | 2.32% | 2.44% | 6.80% | 7.23% | 5.91% | 6.36% | 9.03% | 9.62% |
| APPAR | | | | | | | | | | |
| OUTPUT ($BILLION) | 25.951 | 24.030 | 26.497 | 24.595 | 27.631 | 25.781 | 27.133 | 25.302 | 27.509 | 25.690 |
| % CHANGE OUTPUT | 0.20% | -7.22% | 2.10% | 2.35% | 6.47% | 7.28% | 4.55% | 5.29% | 6.00% | 6.91% |
| MOTOR | | | | | | | | | | |
| OUTPUT ($BILLION) | 18.224 | 17.880 | 18.161 | 17.829 | 18.077 | 17.772 | 18.014 | 17.707 | 17.855 | 17.565 |
| % CHANGE OUTPUT | 0.23% | -1.67% | -0.35% | -0.29% | -0.81% | -0.61% | -1.15% | -0.97% | -2.02% | -1.76% |

In experiments where the world price of only *refined* petroleum rises by 20 percent (*e.g.*, if refining capacity were the pressing constraint), E-DRAM behaves in much the same way as discussed above, only to a lesser degree. Comparing "BASE MODEL" and "NEW MODEL" columns shows that E-DRAM predicts 2020 California state product actually increasing slightly, as the rise in state ENMIN production triggered by a higher world crude oil price offsets declines in demand triggered by fuel efficiency gains. Other sectors contract in the face of world refined petroleum price inflation, *e.g.*, output of the FOODS and APPAR sectors falls by 1.9 and 2.3 percent, respectively.

Comparing "SCNENARIO#" columns again indicates that strategies to improve fuel efficiency reap greater rewards when world energy prices are relatively high. With 20 percent higher world petroleum prices, declines in state output and employment due to the various scenarios are generally 20 to 50 percent less than they would be with lower world prices. The higher world PETRO prices bring forth greater domestic PETRO production, thus offsetting declines in California's PETRO, and by extension, ENMIN, sectors that demand reduction due to efficiency gains would otherwise have triggered. In Scenario 4 with high world prices (*vs.* base model prices), for example, state output falls 0.4 percent (vs. 0.5 percent) and state personal income falls 0.3 percent (*vs.* 0.4 percent), as domestic PETRO production falls only 9.9 percent (*vs.* 14.7 percent).

| 2020 | BASE MODEL | NEW MODEL | SCNRIO1 | SCNRIO1 | SCNRIO2 | SCNRIO2 | SCNRIO3 | SCNRIO3 | SCNRIO4 | SCNRIO4 |
|---|---|---|---|---|---|---|---|---|---|---|
| CA OUTPUT ($BIL.) | 3078.022 | 3081.352 | 3074.924 | 3080.196 | 3070.018 | 3075.686 | 3069.412 | 3075.117 | 3062.487 | 3068.329 |
| % CHNGE OUTPUT | 0.10% | 0.20% | -0.10% | -0.04% | -0.26% | -0.18% | -0.28% | -0.20% | -0.50% | -0.42% |
| PERS. INC. ($BIL.) | 2009.537 | 2006.100 | 2009.521 | 2007.093 | 2010.429 | 2008.506 | 2006.541 | 2004.541 | 2001.025 | 1999.308 |
| % CHNGE PERS. INC. | 0.11% | -0.06% | 0.00% | 0.05% | 0.04% | 0.12% | -0.15% | -0.08% | -0.42% | -0.34% |
| JOBS (MIL.) | 18.661 | 18.629 | 18.677 | 18.651 | 18.712 | 18.688 | 18.684 | 18.660 | 18.673 | 18.650 |
| % CHNGE JOBS | 0.03% | -0.14% | 0.09% | 0.12% | 0.28% | 0.32% | 0.13% | 0.17% | 0.06% | 0.11% |
| PRICE OF CFOOD | 1.000 | 1.001 | 1.000 | 1.001 | 1.000 | 1.001 | 1.001 | 1.002 | 1.003 | 1.003 |
| PRICE OF CHOME | 1.000 | 1.001 | 1.000 | 1.001 | 1.000 | 1.001 | 1.001 | 1.001 | 1.002 | 1.002 |
| PRICE OF CFUEL | 1.000 | 1.024 | 0.969 | 0.991 | 0.911 | 0.933 | 0.922 | 0.943 | 0.882 | 0.903 |
| PRICE OF CFURN | 1.000 | 1.001 | 1.000 | 1.001 | 1.000 | 1.001 | 1.001 | 1.002 | 1.002 | 1.003 |
| PRICE OF CCLOTH | 1.000 | 1.001 | 1.000 | 1.001 | 1.000 | 1.001 | 1.001 | 1.002 | 1.002 | 1.003 |
| PRICE OF CTRANS | 1.000 | 1.001 | 1.007 | 1.008 | 1.017 | 1.018 | 1.027 | 1.028 | 1.051 | 1.052 |
| PRICE OF CMED | 1.000 | 1.001 | 1.000 | 1.001 | 1.001 | 1.001 | 1.002 | 1.003 | 1.004 | 1.004 |
| PRICE OF CAMUS | 1.000 | 1.001 | 1.000 | 1.001 | 1.000 | 1.001 | 1.001 | 1.002 | 1.003 | 1.003 |
| PRICE OF COTHR | 1.000 | 1.001 | 1.000 | 1.001 | 1.000 | 1.001 | 1.001 | 1.001 | 1.002 | 1.002 |
| ENMIN | | | | | | | | | | |
| OUTPUT ($BILLION) | 6.209 | 7.069 | 6.058 | 6.488 | 5.784 | 6.241 | 5.745 | 6.186 | 5.608 | 6.076 |
| % CHANGE OUTPUT | 0.08% | 13.95% | -2.43% | -8.22% | -6.84% | -11.71% | -7.47% | -12.48% | -9.67% | -14.05% |
| IMPORTS ($BILLION) | 36.011 | 38.931 | 34.829 | 38.768 | 32.669 | 36.595 | 32.592 | 36.388 | 31.834 | 35.749 |
| % CHANGE IMPORTS | 0.07% | 8.18% | -3.28% | -0.42% | -9.28% | -6.00% | -9.49% | -6.53% | -11.60% | -8.18% |
| EXPORTS ($BILLION) | 1.096 | 1.006 | 1.112 | 1.064 | 1.142 | 1.090 | 1.143 | 1.092 | 1.154 | 1.100 |
| % CHANGE EXPORTS | -0.07% | -8.29% | 1.43% | 5.74% | 4.15% | 8.29% | 4.25% | 8.54% | 5.27% | 9.34% |
| PETRO | | | | | | | | | | |
| OUTPUT ($BILLION) | 39.305 | 45.924 | 37.690 | 45.525 | 34.730 | 42.595 | 35.387 | 43.246 | 33.516 | 41.383 |
| % CHANGE OUTPUT | 0.07% | 16.92% | -4.11% | -0.87% | -11.64% | -7.25% | -9.97% | -5.83% | -14.73% | -9.89% |
| IMPORTS ($BILLION) | 15.683 | 12.239 | 15.565 | 11.154 | 15.345 | 11.006 | 15.399 | 11.041 | 15.281 | 10.964 |
| % CHANGE IMPORTS | 0.01% | -21.95% | -0.76% | -8.87% | -2.15% | -10.07% | -1.81% | -9.79% | -2.56% | -10.42% |
| EXPORTS ($BILLION) | 11.998 | 15.760 | 12.074 | 15.894 | 12.216 | 16.070 | 12.181 | 16.028 | 12.258 | 16.121 |
| % CHANGE EXPORTS | -0.02% | 31.34% | 0.63% | 0.85% | 1.82% | 1.96% | 1.52% | 1.70% | 2.17% | 2.29% |
| ENGIN | | | | | | | | | | |
| OUTPUT ($BILLION) | 40.468 | 40.422 | 40.582 | 40.538 | 40.632 | 40.599 | 40.673 | 40.634 | 40.805 | 40.775 |
| % CHANGE OUTPUT | 0.05% | -0.06% | 0.28% | 0.29% | 0.41% | 0.44% | 0.51% | 0.52% | 0.83% | 0.87% |
| IMPORTS ($BILLION) | 9.049 | 9.062 | 9.081 | 9.096 | 9.111 | 9.123 | 9.158 | 9.172 | 9.248 | 9.260 |
| % CHANGE IMPORTS | 0.02% | 0.16% | 0.35% | 0.37% | 0.68% | 0.67% | 1.20% | 1.21% | 2.20% | 2.18% |
| EXPORTS ($BILLION) | 13.836 | 13.815 | 13.782 | 13.759 | 13.733 | 13.713 | 13.656 | 13.633 | 13.509 | 13.490 |
| % CHANGE EXPORTS | -0.03% | -0.18% | -0.39% | -0.40% | -0.74% | -0.74% | -1.30% | -1.31% | -2.36% | -2.35% |
| CHEMS | | | | | | | | | | |
| OUTPUT ($BILLION) | 30.284 | 29.951 | 30.648 | 30.394 | 31.310 | 31.066 | 32.065 | 32.010 | 31.668 | 31.429 |
| % CHANGE OUTPUT | 0.22% | -0.88% | 1.20% | 1.48% | 3.39% | 3.72% | 5.88% | 6.88% | 4.57% | 4.93% |
| IMPORTS ($BILLION) | 39.303 | 39.408 | 39.294 | 39.393 | 39.280 | 39.375 | 39.358 | 39.460 | 39.418 | 39.512 |
| % CHANGE IMPORTS | 0.01% | 0.28% | -0.02% | -0.04% | -0.06% | -0.08% | 0.14% | 0.13% | 0.29% | 0.26% |
| EXPORTS ($BILLION) | 2.090 | 2.084 | 2.091 | 2.085 | 2.092 | 2.086 | 2.087 | 2.081 | 2.084 | 2.078 |
| % CHANGE EXPORTS | -0.01% | -0.30% | 0.02% | 0.04% | 0.06% | 0.09% | -0.16% | -0.14% | -0.32% | -0.29% |
| FOODS | | | | | | | | | | |
| OUTPUT ($BILLION) | 92.958 | 91.080 | 95.113 | 93.388 | 99.279 | 97.496 | 98.450 | 96.681 | 101.353 | 99.545 |
| % CHANGE OUTPUT | 0.14% | -1.88% | 2.32% | 2.53% | 6.80% | 7.04% | 5.91% | 6.15% | 9.03% | 9.29% |
| APPAR | | | | | | | | | | |
| OUTPUT ($BILLION) | 25.951 | 25.313 | 26.497 | 25.919 | 27.631 | 27.045 | 27.133 | 26.551 | 27.509 | 26.920 |
| % CHANGE OUTPUT | 0.20% | -2.27% | 2.10% | 2.39% | 6.47% | 6.85% | 4.55% | 4.89% | 6.00% | 6.35% |
| MOTOR | | | | | | | | | | |
| OUTPUT ($BILLION) | 18.224 | 18.151 | 18.161 | 18.103 | 18.077 | 18.024 | 18.014 | 17.959 | 17.855 | 17.805 |
| % CHANGE OUTPUT | 0.23% | -0.18% | -0.35% | -0.26% | -0.81% | -0.70% | -1.15% | -1.06% | -2.02% | -1.90% |

### 6.5.4 An Energy Taxes

Another way to reduce petroleum use, and thus energy dependence, is to raise the price of petroleum. The table below compares select output for runs with an additional 20 percent state sales tax on PETRO (gray columns) with base runs (white columns) of E-DRAM.

Imposing such a tax reduces state output by 0.6 to 0.7 percent and state income by 0.4 to 0.6 percent. It increases the price of CFUEL 4.7 to 6.0 percent while reducing domestic PETRO production 4.9 to 17.0 percent and domestic ENMIN production 3.7 to 6.7 percent. Unlike fuel efficiency strategies, the tax raises the price of vehicle miles traveled and thus does not generate cost savings that can be shifted to other sectors. Output across all sectors thus contracts slightly as the tax is basically inflationary.

| | 1999 | | 2020 | | 2050 | |
|---|---|---|---|---|---|---|
| | BASE MODEL | TAX | BASE MODEL | TAX | BASE MODEL | TAX |
| CA OUTPUT ($BIL.) | 1378.090 | 1367.183 | 3078.022 | 3057.935 | 6568.573 | 6532.449 |
| % CHNGE OUTPUT | 0.08% | -0.71% | 0.10% | -0.65% | 0.11% | -0.55% |
| PERS. INC. ($BIL.) | 892.489 | 886.188 | 2009.537 | 1998.180 | 4325.233 | 4306.451 |
| % CHNGE PERS. INC. | 0.09% | -0.62% | 0.11% | -0.57% | 0.12% | -0.43% |
| PRICE OF CFOOD | 1.000 | 1.001 | 1.000 | 1.001 | 1.000 | 1.001 |
| PRICE OF CHOME | 1.000 | 1.001 | 1.000 | 1.001 | 1.000 | 1.001 |
| PRICE OF CFUEL | 1.000 | 1.060 | 1.000 | 1.054 | 1.000 | 1.047 |
| PRICE OF CFURN | 1.000 | 1.001 | 1.000 | 1.001 | 1.000 | 1.001 |
| PRICE OF CCLOTH | 1.000 | 1.001 | 1.000 | 1.001 | 1.000 | 1.001 |
| PRICE OF CTRANS | 1.000 | 1.002 | 1.000 | 1.002 | 1.000 | 1.002 |
| PRICE OF CMED | 1.000 | 1.001 | 1.000 | 1.001 | 1.000 | 1.001 |
| PRICE OF CAMUS | 1.000 | 1.001 | 1.000 | 1.001 | 1.000 | 1.001 |
| PRICE OF COTHR | 1.000 | 1.001 | 1.000 | 1.001 | 1.000 | 1.001 |
| ENMIN | | | | | | |
| OUTPUT ($BILLION) | 5.879 | 5.659 | 6.209 | 5.912 | 7.689 | 7.174 |
| % CHANGE OUTPUT | 0.09% | -3.66% | 0.08% | -4.78% | 0.07% | -6.69% |
| IMPORTS ($BILLION) | 17.540 | 17.283 | 36.011 | 35.243 | 57.409 | 55.420 |
| % CHANGE IMPORTS | 0.05% | -1.42% | 0.07% | -2.13% | 0.08% | -3.47% |
| EXPORTS ($BILLION) | 0.437 | 0.445 | 1.096 | 1.123 | 2.640 | 2.744 |
| % CHANGE EXPORTS | -0.06% | 1.58% | -0.07% | 2.40% | -0.09% | 3.96% |
| PETRO | | | | | | |
| OUTPUT ($BILLION) | 24.816 | 23.594 | 39.305 | 36.471 | 39.254 | 32.592 |
| % CHANGE OUTPUT | 0.06% | -4.87% | 0.07% | -7.21% | 0.11% | -16.97% |
| IMPORTS ($BILLION) | 2.806 | 2.854 | 15.683 | 15.942 | 63.637 | 64.399 |
| % CHANGE IMPORTS | 0.01% | 1.74% | 0.01% | 1.65% | 0.02% | 1.20% |
| EXPORTS ($BILLION) | 6.475 | 6.354 | 11.998 | 11.784 | 19.142 | 18.893 |
| % CHANGE EXPORTS | -0.01% | -1.88% | -0.02% | -1.79% | -0.02% | -1.30% |
| ENGIN | | | | | | |
| OUTPUT ($BILLION) | 17.984 | 17.900 | 40.468 | 40.313 | 87.033 | 86.761 |
| % CHANGE OUTPUT | 0.06% | -0.41% | 0.05% | -0.38% | 0.05% | -0.31% |
| IMPORTS ($BILLION) | 4.028 | 4.036 | 9.049 | 9.068 | 19.450 | 19.486 |
| % CHANGE IMPORTS | 0.01% | 0.21% | 0.02% | 0.20% | 0.04% | 0.19% |
| EXPORTS ($BILLION) | 6.145 | 6.131 | 13.836 | 13.805 | 29.741 | 29.679 |
| % CHANGE EXPORTS | -0.01% | -0.23% | -0.03% | -0.22% | -0.05% | -0.21% |
| CHEMS | | | | | | |
| OUTPUT ($BILLION) | 13.479 | 12.875 | 30.284 | 29.100 | 64.994 | 62.797 |
| % CHANGE OUTPUT | 0.19% | -4.30% | 0.22% | -3.91% | 0.24% | -3.38% |
| IMPORTS ($BILLION) | 17.534 | 17.618 | 39.303 | 39.477 | 84.214 | 84.553 |
| % CHANGE IMPORTS | 0.00% | 0.48% | 0.01% | 0.44% | 0.02% | 0.40% |
| EXPORTS ($BILLION) | 0.899 | 0.894 | 2.090 | 2.080 | 4.650 | 4.630 |
| % CHANGE EXPORTS | 0.00% | -0.53% | -0.01% | -0.49% | -0.02% | -0.44% |
| FOODS | | | | | | |
| OUTPUT ($BILLION) | 41.240 | 39.120 | 92.958 | 88.711 | 200.230 | 192.362 |
| % CHANGE OUTPUT | 0.11% | -5.04% | 0.14% | -4.57% | 0.17% | -3.93% |
| APPAR | | | | | | |
| OUTPUT ($BILLION) | 11.517 | 10.757 | 25.951 | 24.451 | 55.881 | 53.134 |
| % CHANGE OUTPUT | 0.14% | -6.47% | 0.20% | -5.78% | 0.25% | -4.92% |
| MOTOR | | | | | | |
| OUTPUT ($BILLION) | 8.051 | 7.921 | 18.224 | 17.985 | 39.348 | 38.929 |
| % CHANGE OUTPUT | 0.20% | -1.42% | 0.23% | -1.31% | 0.24% | -1.07% |

### 6.5.5 A Pollution Tax

For comparison's sake, a Pigouvian tax levied on industries in proportion to their nitrogen oxide (NOX) emissions is briefly considered. Summary results of experiments run using the 1999 model with taxes set such that economy-wide $NO_x$ emissions are reduced by 5, 10, and 15 percent are reported below. The table indicates that achieving 5, 10, and 15 percent reductions via such taxation scheme would cause state product to drop 0.9, 2.0, and 3.2 percent, respectively while shrinking state personal income by 0.7, 1.6, and 2.6 percent, respectively.

| 1999 | BASE MODEL | 5% NOX CUT | 10% NOX CUT | 15% NOX CUT |
|---|---|---|---|---|
| CA OUTPUT ($BILLION) | 1378.0905 | 1364.4467 | 1349.8422 | 1333.2856 |
| % CHANGE CA OUTPUT | 0.08% | -0.91% | -1.97% | -3.18% |
| CA PERSONAL INCOME ($BILLION) | 892.4894 | 885.4017 | 877.4866 | 868.1903 |
| % CHANGE CA PERS. INC. | 0.09% | -0.71% | -1.59% | -2.64% |
| GENERAL FUND REVENUE ($BILLION) | 56.7748 | 60.5554 | 64.3181 | 68.2828 |

## 6.6 Conclusions

The UC Berkeley team analyzed the economic impacts of four alternate strategies for reducing California's petroleum dependence. The strategies (summarized in Appendix C) were developed in a collaborative process between ARB, CEC, and ADL. Each scenario is built around two elements: (1) reduced gasoline demand from improved light-duty vehicle fuel economy, and (2) diesel fuel displacement from gas-to-liquid (GTL) or Fischer Tropsch diesel fuels. The scenarios were constructed to try to “bound” the possible impacts to the California economy. Scenario 1 combines off-the-shelf fuel efficiency improvements in light-duty vehicles with a 33 percent blend of FTD in diesel fuel to meet ARB’s future ULSD specification. Scenarios 2 through 4 incorporate progressively aggressive and therefore more costly fuel efficiency and/or displacement options.

The analysis uses E-DRAM, a modified version of the Dynamic Revenue Analysis Model used by the California Department of Finance. The analysis concludes that the statewide economic impacts of the strategies being considered are small. This is not surprising, given that static costs estimates of the most aggressive scenario under consideration are $14.4 billion in 2020, a time when gross state product (GSP) is projected to be nearly $3.1 trillion, and $23.3 billion in 2050, when GSP is projected to be nearly $6.6 trillion. The highest static cost estimates are thus only 0.35 to 0.47 percent of projected GSP.

Results for the most modest and aggressive scenarios are summarized below as bounding cases. As indicated above, E-DRAM predicts that general equilibrium effects on state output and income are small. Predicted impacts on petroleum refining and crude oil production sectors are much larger, and should be interpreted as worst-case effects given the E-DRAM's weakness in allocating domestic demand reductions between domestic and imported products.

Scenario 1, which embodies the most modest fuel economy improvements, may cause state gross product (GSP) and state personal income (SPI) to be slightly lower than would otherwise be the case. E-DRAM predicts Scenario 1 lowering 2020 GSP by 0.10 percent – a magnitude within the bounds of model calibration error, and 2050 GSP by 0.17 percent. The scenario's predicted effect on state personal income is essentially zero in 2020 and 0.10 percent (again, a magnitude within the bounds of calibration error) in 2050. Impacts on the directly effected sectors – crude oil producers (ENMIN) and petroleum refiners (PETRO) – are significant. E-DRAM predicts ENMIN and PETRO output falling 5.9 and 16.8 percent, respectively, (Berck and Hess, Feb. 2000). Declines in these sectors, triggered by fuel efficiency gains, are offset by fuel cost savings being spent in other sectors.

Scenario 4, which embodies the most aggressive change, has a modest impact on GSP and a marginal effect on SPI. E-DRAM predicts Scenario 4 lowering 2020 GSP by roughly 0.50 percent, and 2050 GSP by 0.46 percent. The scenario's predicted effects on SPI are -0.42 percent in 2020 and –0.46 percent in 2050. As expected, the predicted impacts of this scenario on energy related sectors are large. E-DRAM predicts ENMIN output falling 9.67 percent in 2020 and 12.57 percent in 2050. PETRO output is projected to fall 14.73 percent in 2020 and 32.6 percent in 2050. Again, reduced spending in these sectors is displaced to others.

The above results are robust to the sensitivity analyses performed. The model responds as expected to changes in the own-price elasticity of consumer demand for fuel, import elasticity, and prices. Sensitivity analysis confirms intuition that the scenarios under consideration become more attractive as world energy prices rise. Higher world energy prices simultaneous raise the consumer benefits of fuel efficiency while offsetting domestic energy producer costs by favoring domestic over imported fuel products.

## 7. Summary of Economic Benefits

Dependence on imported petroleum products result in a significant impact on the California economy. As population grows, the States reliance on imported sources will continue to rise while in-state refining capacity is limited. Fuel shortages and price impacts have the potential to adversely impact the State economy which raises the need for the State to find a solution. A variety of strategies are being analyzed by State policy makers to reduce California's dependency on petroleum. These strategies will be comprised of options such as improving vehicle fuel economy, using alternative fuels, and reducing miles traveled.

This study, which is Task 1 of the Evaluation of Petroleum Replacement Options, provides an evaluation of the indirect impacts of reducing statewide gasoline consumption. These indirect impacts, or externalities, include air emissions and petroleum spill or multi media impacts. The extent of reductions in air emissions and multi media impacts were determined for the petroleum reduction options identified by the Energy Commission in the Task 3 report. This report also includes an assessment of the impacts of reducing gasoline usage on the State economy.

## 8. Indirect Impacts

Gasoline consumption results in air emissions and multimedia impacts. The extent of these emissions and spills was determined for various options by quantifying the emissions that correspond to each petroleum displacement option based on changes in the gallons of fuel used and miles driven.

Emissions impacts include fuel cycle and vehicle emissions. Fuel cycle emissions are the result of the production, transportation, and distribution of fuels. Vehicle emissions include those from the exhaust as well as evaporative or fuel system losses. Emissions from the fuel cycle and the vehicle include the criteria pollutants Nox, PM, CO, and NMOG. Both diesel particulate and some components of the NMOG are toxic air contaminants.

In order to determine fuel cycle emissions, all of the steps associated with producing and distributing fuels in California were identified. Reducing gasoline demand in California would primarily result in a reduction in imported gasoline. Consequently, the fuel cycle emissions associated with reduced gasoline consumption correspond to a reduction in tanker ship and local delivery truck emissions as well as fugitive NMOG losses from fuel transfers, bulk terminals, and vehicle refueling. These emissions were determined based on emission standards that would be in effect beyond 2010.

Hydrocarbon emissions are a source of toxics. The extent of toxic emissions depends upon the composition of the hydrocarbons or NMOG emissions. These vary with vehicle exhaust, fuel vapors, and spilled fuel.

For gasoline as well as a variety of alternative fuels, the fuel cycle and toxic emissions were determined on a g/gallon (or unit fuel) basis. These emission factors were then used to determine the tons per year of emission reduction for each petroleum displacement option.

The emissions from vehicles were also determined. A baseline gasoline PZEV was assumed and emission rates were based on in-use emission factors determined by the ARB. As the PZEV standard represents a very low level of emissions, alternative fueled vehicles were assumed to emit at the standard with the exception of technologies with inherently zero emissions such as Nox from fuel cell powered vehicles. Emission rates were also determined for heavy duty vehicles.

In summary, reducing a gallon of gasoline consumption results in the reduction of approximately 0.5 grams of criteria pollutants and 11 kg of GHG emissions (from both the vehicle and fuel cycle). Additionally, reducing a mile of driving results in the reduction of approximately 0.03 grams of criteria pollutants.

The value of emission reductions was then determined. Several approaches have been identified for determining the value of emission reductions including the cost of health impacts, alternative cost of controlling emissions, and market prices for emission reductions. A variety of methods was used to assess the costs for different classes of pollutants as different pollutants have different health and regulatory consequences.

The value of PM and toxic emissions was determined based on an assessment of their health impacts. The cost of criteria pollutants was based on the cost or trading emissions which is motivated by compliance with ozone reduction goals. The costs of GHG emissions is also based on emission trades with the rational the GHG emission reductions are necessary in order to mitigate unknown and potentially very costly climate impacts.

Multi media impacts were also analyzed on a per gallon of gasoline basis. Spill rates were identified from a variety of sources including marine vessels, underground tanks, and pipelines. The cost of reducing spills (beyond those costs included in the price of gasoline) was used to value their impacts as large fuel spills are generally cleaned up as required by law.

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