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CALIFORNIA ALTERNATIVE FUELS MARKET ASSESSMENT 2006

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Prepared By:
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Prepared By:
TIAX, LLC
Larry Waterland
Cupertino, California
Contract No. 600-02-003

Prepared For:
California Energy Commission

M. Lorraine White,
AB 1007 Project Manager

James J. Folkman,
Contract Project Manager

Sherry Stoner,
Contract Manager

Ray Tuvell,
Manager
EMERGING FUELS & TECHNOLOGY OFFICE

Rosella Shapiro,
Deputy Director
FUELS AND TRANSPORTATION DIVISION

B.B Blevins
Executive Director

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Consultant
Larry Waterland, Stefan Unnasch, Michael Jackson
Cupertino Office, TIAX LLC

AB 1007 Project Manager
M. Lorraine White

Contract Project Manager
James M. Folkman

Contract Manager
Sherry Stoner

The authors wish to acknowledge the contributions to this report by the following:

Energy Commission

McKinley Addy
Asish Gautam
Tom Macdonald
Mike McCormack
Tim Olson
Peter Quinliven
Rosella Shapiro
Jason Sterling
Mike Trujillo
Ray Tuvell
Jerry Wiens
Gary Yowell

Air Resources Board

Gehardt Achtelik
Analisa Bevan
Steve Brisby
Richard Corey
Ben Deal
Bill Dean
Robert Fletcher
Barbara Fry
Jose Gomez
Narci Gonzalez
Mike Scheible
Dean Simeroth
Peter Venturini
Gary Yee

ABSTRACT

Since 2001, the *California Alternative Fuels Market Assessment* (formerly the *California Clean Fuels Market Assessment*) has been an essential element of the Energy Commission's alternative fuels programs. It has been designed to provide a dynamic process for periodic reviews and updates that can be used by the Commission to set alternative fuels infrastructure goals, use objectives, and development priorities; and help design potential incentives programs to encourage the expanded use of alternative fuels in the state's transportation fuels marketplace. The initial market assessment was prepared in 2001 and updated in 2003. This report is the further update of the assessment, designed to provide a current snapshot of the alternative fuel development and commercial vehicle status. This current update is intended to be the foundation to support the development of the state's plan to increase the use of alternative transportation fuels required by AB 1007 (Pavley). Thus, this Market Assessment 2006 describes the baseline of alternative fuel development and use in California by identifying vehicles, market niche consumers, fueling locations, and fuel throughput. The alternative fuel markets discussed include natural gas, propane, ethanol, electricity, alternative diesel fuels such as biodiesel and Fischer Tropsch liquid fuels, and hydrogen. For each fuel, the report outlines the current quantities of use, vehicle availability, fueling infrastructure and special needs, barriers and opportunities for expansion, and an overall assessment for each of these fuels. Market projections for future use of each fuel under business as usual scenarios out to 2030 are also discussed.

KEYWORDS

Alternative fuels, transportation fuels, natural gas vehicles, propane vehicles, electric vehicles, ethanol fuel, E-85, biodiesel, Fischer-Tropsch liquid fuel, gas to liquid fuel, hydrogen fuel.

REPORT ORGANIZATION

This report is structured as follows. Section 1 provides an overview of the current California transportation fuel marketplace by discussing market trends, government actions, and recent developments influencing the supply, distribution, and use of alternative fuels in the transportation sector. Section 2 introduces natural gas vehicles, describing their current population, availability, needs in terms of fueling infrastructure, and barriers to and opportunities for expansion. Section 3 provides a similar analysis for liquefied petroleum gas (propane). Electric-drive vehicles are the subject of Section 4; full function battery electric vehicle (EV) without internal combustion engines, neighborhood electric vehicles (NEV), and plug-in hybrid electric vehicle (PHEV) are all discussed. Section 5 turns to ethanol, currently the most important and fastest growing alternative fuel used in transport. Alternative diesel fuels – bio, gas-to-liquid (GTL) and ethanol-diesel – are discussed in Section 6. Section 7 analyzes the role that hydrogen-fueled may play in transport in the future, discusses expected values for vehicle range, fuel economy, and requirements for fueling infrastructure for those vehicles. The final section of this report, Section 8, discusses dimethyl ether (DME), an LPG-like synthetic fuel produced through synthesis of carbon monoxide with hydrogen.

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SECTION 1. CALIFORNIA'S TRANSPORTATION SYSTEM

California faces a number of issues related to public health, environment, climate change, economy, and energy diversity. To a large extent, California's transportation system directly impacts each of these issues. California's economy will depend on how well these issues are managed to accommodate substantial population increases and associated demands for transportation fuels, as well as high prices for gasoline and diesel fuels, emissions from cars, trucks, and off-road equipment, climate change emissions, and the growth of goods movement. State and Federal agencies have developed regulations and incentives to address many of these issues but the future is still unclear as to how effective those efforts will be.

Along with the rest of the world, California's consumption of petroleum fuels, especially in the transportation sector, is expected to continue increasing into the foreseeable future. Since domestic crude oil production cannot fully support this continued growth, foreign sources of crude oil will be increasingly important. At the same time, the ability of the state's refining industry to expand crude oil refining is limited, forcing it to import more finished transportation fuels and blending components. These trends will add costs to finished fuels while in some instances, supply disruptions will result in episodic price shocks. There may be measures that the state can take to reduce demand and augment supply in order to mitigate the economic risks associated with these uncertainties.

Most Californians live in regions that do not meet either the state or federal ambient air quality standards. Both ozone and $PM_{2.5}$ standards are exceeded in most regions of California. Substantial progress has been made in reducing precursors of ozone and $PM_{2.5}$ over the past several decades, but more reduction is needed to reduce emissions of hydrocarbons (HC), carbon monoxide (CO), oxides of nitrogen (NO_x), and particulate manner (PM). Most of the reductions will have to come from on- and off-road vehicles, although stationary sources also provide opportunities to reduce emissions. Local air quality districts are tasked with developing ambient air quality attainment plans to achieve the standards. The California Air Resources Board (ARB) was given authority by the 1970 Clean Air Act to regulate the emissions of on- and off-road vehicles and has set some of the most stringent exhaust emission standards in the world.

Through the leadership of California's governor and legislature, California has concluded that climate change will have many negative consequences on regional economic goals. Emissions of greenhouse gases will result in higher surface temperatures, increased sea level, and altered and/or extreme precipitation patterns. Higher temperatures, for example, result in higher ozone levels and threaten human health. California has passed regulations to limit greenhouse gas (GHG) emissions from light-duty vehicles and is working on legislation to cap GHG emissions statewide. GHG emissions standards will help reduce the demand for gasoline in California as well as other fuels and could provide future growth in the use of alternative and renewable fuels.

The increasing integration of the world economy is easily observed in the impact of goods movement in California. Goods from around the world and particularly from China are shipped into several ports in California. The largest are the Ports of Los Angeles and Long Beach, with a substantial volume also shipped into Oakland. Emissions from ships, dockside handling equipment, trains, and trucks all add up to some of the largest sources of emissions in the South Coast or Bay Area. Ports are also a major cause of congestion and PM emissions in the neighboring communities.

Although most experts believe there are enough fossil fuel sources to supply the world's demands for gasoline and diesel well into the 21^{st} century, there is a growing consensus that biofuels and other alternative fuels have an important role to play in displacing petroleum and in lowering the climate change impact of transportation systems in the future.

Table 1-1 summarizes these issues, with following sections addressing each in more details.

Table 1-1. California's transportation system faces a number of issues.

Transport Energy Use
California's transport sector uses huge amounts of energy, almost all of it provided by petroleum. The inherent and structural advantages of petroleum fuels will be difficult to overcome in the near future.
Internationalization of Transport Fuel Market
Growing demand for energy in transportation, combined with a lack of planned new refineries, suggests that California will become increasingly dependent upon the import of refined petroleum products.
Economic Viability
Continued growth and prosperity in California will require substantial increases in fuel production.
Costly Oil Causes High Gasoline Prices
High gasoline prices in 2006 were caused by increases in the cost of crude oil.
World Oil Prices Will Remain High
Increasing demand for oil, particularly from developing economies in East Asia, along with limits on productive capacity suggest that oil prices will remain high for the foreseeable future.
Unhealthy Air Quality
Most Californians breathe unhealthy air. Substantial reductions of emissions are needed from cars and trucks as well as power generation and industrial sources.
Global Warming
California is taking a leadership position to reduce greenhouse gas emissions from industrial and mobile sources.
Goods Movement
Movement of goods in California contributes to our economy but also affects congestion and air quality in and around ports.
Alternative Fuels Can Displace Petroleum
Alternative fuels have the potential to reduce petroleum consumption, as well as to force improvements in traditional conversion technologies.
Biofuels
Ethanol is now blended in California gasoline and demonstrations are underway to test ethanol use in fuel flexible vehicles. Biodiesel and other alternative diesel formulations are also being tested.
State and Federal Measures
A variety of state and federal regulatory efforts have aimed to promote alternative fuels, to varying degrees of success.

Source: Energy Commission

Profile of Transportation-Sector Energy Use in California

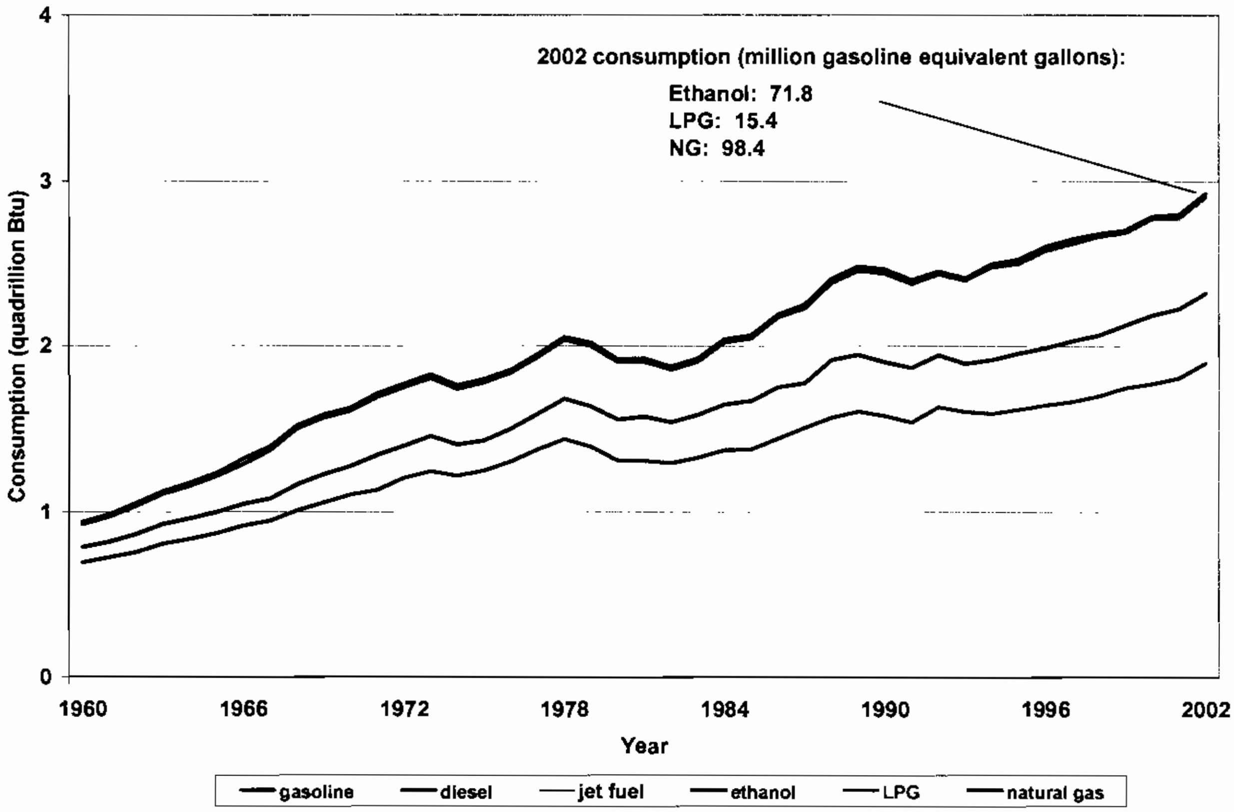
California's large and diverse economy is supported by a vast transportation infrastructure, particularly that supporting the private automobile. Transport energy use has grown steadily in the past fifty years, with the vast majority of that energy provided by refined petroleum products. Petroleum-powered internal combustion engines continue to enjoy innate and structural advantages over alternative fuel vehicles that will be difficult to overcome.

Californians are well-known for their love affair with the automobile. There were more than 24 million motor vehicles registered in California in 2004, more than one per licensed driver. Statewide gasoline consumption was 14.8 billion gallons that year, second only to the U.S. total in consumption and slightly more than that of Japan, a country with four times the population. California's 750,000 medium and heavy-duty diesel vehicles consumed 4.1 billion gallons of diesel fuel in 2004, or more than 6200 Olympic-sized swimming pools. All this is provided to customers by almost 10,000 public retail gas stations at a cost lower than most pay for bottled water.

Figure 1-1 shows California's transport energy use consumption by fuel from 1960 to 2002, measured in terms of quadrillion Btu. As the figure demonstrates, energy use in the transportation sector has increased steadily over that time, with total use more than tripling at an annual increase of almost 3 percent. Moreover, transport energy use continues to be dominated by refined petroleum products, particularly by gasoline, jet, and diesel fuel. Recent changes in transport technologies and environmental regulations promoting the use of alternative transport fuels, including ethanol and natural gas, have failed to alter this basic dynamic.

The importance of petroleum in California's transport sector has been supported by the large number of refineries located within the state, shown in Table 1-2. As that table demonstrates, a significant proportion of the US (12.2 percent) and international (2.4 percent) crude oil refining capacity is located in California. Table 1-3 shows the breakdown of gasoline refineries by company in California and the rest of North America, showing that refineries specializing in gasoline are even more heavily concentrated in California. Chevron-Texaco, Philips, and Shell Oil have particularly strong presence in the state. The ability of these refineries to meet internal demand for transportation fuels has been one of the major drivers of the success of those technologies in the marketplace.

Of course, California's residents have paid a price for the ease and convenience of the private automobile. California's Air Resources Board estimates that 90 percent of California's residents breathe unhealthy air. As a result, both federal and state regulators have worked to promote alternative fuel vehicles through regulation and incentives. Gasoline and diesel-powered internal combustion engines continue to enjoy significant advantages over alternative fuel vehicles, owing to the high energy density of petroleum, hidden and explicit subsidies the oil industry, and the extensive infrastructure that has developed around the production, refining, and distribution of transportation fuels. As a result, gasoline and diesel-powered vehicles have developed into a powerful incumbent technology that is not easily displaced, even as alternative fuel vehicles become increasingly competitive.



Source: EIA State Energy Data
Natural gas includes consumption in pipeline operation

Figure 1-1. California transport energy consumption dominated by petroleum.

Table 1-2. Proportion of U.S. and world refining capacity located in California in 2006.

	Number of Refineries	Capacity (mill bpd)
California	20	2.0
US	149	16.4
% CA of US	13.4%	12.2%
% CA of World	Not available	2.4%[a]

[a]2005

Sources: EIA Refinery Capacity 2006; EIA Annual Energy Review 2005

Table 1-3. Gasoline refineries by company in CA and North America.

Company	CA	Rest of North America
BP	1	4
Chevron Texaco	2	8
ExxonMobil	1	13
Philips	2	8
Shell	3	6
Tesoro	1	5
Valero	2	10
Kern Oil	1	0
Total	**13**	**54**

Source: "The California Reformulated Gasoline Phase 3 Program, ARB, 7 November 2002

California's Transport Fuel Market Expected to Internationalize in Coming Years

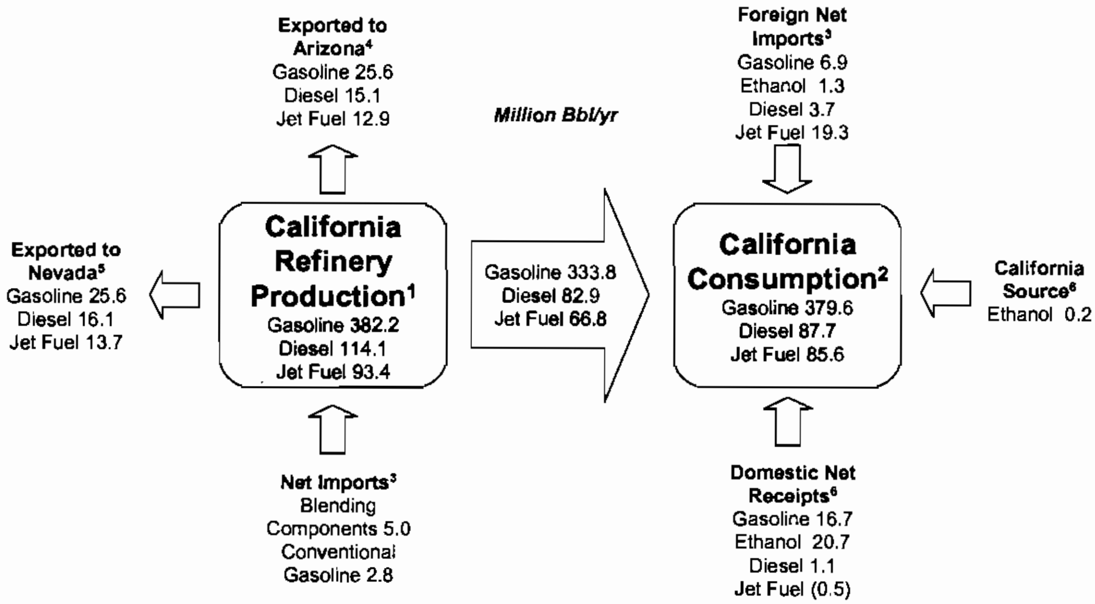
While heavily reliant upon imports of crude oil, California currently possesses sufficient refining capacity to meet today's demand for transport fuels. With most new refineries expected to be built in developing countries with high demand growth for energy, California will increasingly become dependent on imports of refined petroleum products to meet its internal demand.

California's crude oil production, while the third largest of any state in the U.S., is sufficient to meet only one-third of statewide demand. As a result, California is heavily dependent upon sources of crude oil from outside of the state – approximately one-third from Alaska, and the balance from overseas. In contrast, California has the potential to be largely self-sufficient in supplying refined petroleum products for use in the transport sector today (Figure 1-2). Productivity improvements at newer California refineries during the 1980s have allowed it to keep pace with internal demand, despite the closing of older, inefficient refineries. As a result, the relatively small amounts of transport fuels imported or received from other states largely offset fuels California provides to surrounding states or the lower quality fuels California exports to foreign markets. One important, and growing, exception to this trend is ethanol, which has become important as an oxygenate under federal requirements for reformulated gasoline in recent years.

Most new refinery capacity is expected to be constructed overseas in countries where the growth in energy demand is fastest. As Figure 1-3 demonstrates, incremental growth in petroleum demand is expected to be concentrated in non-OECD countries until 2030. Demand for oil will increase particularly quickly in Asia, as the use of the private automobile becomes more common in China and India. Energy companies prefer to site new refining capacity as close to demand as possible: as a result, most if not all, of new refining capacity will be constructed outside of the U.S. and other developed countries.

As a result of these two trends, California is expected to become increasingly dependent upon foreign sources of refined petroleum products. The internationalization of the market for transportation fuels will be facilitated by the unification of fuel quality requirements internationally and regionally, as more governments take steps to alleviate local air pollution problems. Examples of convergence in fuel quality include moves to require the sale of ethanol blends of gasoline throughout the U.S., as well as the almost synchronized transition to low and ultra-low sulfur fuel in Europe, the U.S., and Japan.

While allowing California to meet its demand for transport fuels, there are potential downsides to importing larger quantities of refined petroleum products. Two possible negative consequences of California's increasing dependence upon international transportation fuels are cost – a premium will be required to pay for the transportation of refined products from overseas – as well as the possibility that foreign political or economic unrest might lead to immediate disruption in supplies of gasoline and diesel and jet fuels.

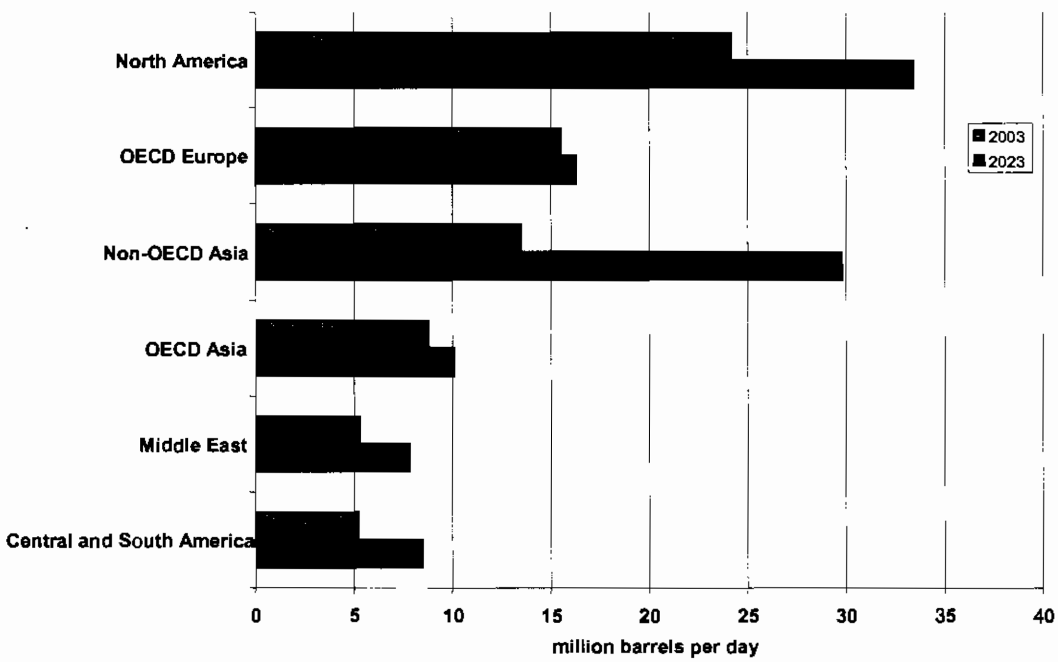


All data from 2004 unless otherwise noted.

1. Energy Commission "Weekly Fuels Watch Report"
2. California Board of Equalization for Gasoline Demand, CEC Estimates for Diesel and Jet Fuel
3. PIERS Gasoline Blendstocks & Various Conventional Gasoline Sources
4. Kinder Morgan Pipeline Shipments and Trucking Exports
5. Kinder Morgan Pipeline Shipments
6. CEC Estimates Based on Multiple Sources

Source: Energy Commission

Figure 1-2. California largely self-sufficient in transport fuels in 2004.



Source: EIA International Energy Outlook 2006

Figure 1-3. Most oil consumption growth expected to be in non-OECD countries.

Continued Economic Viability in California Will Require an Efficient and Cost Effective Transportation System

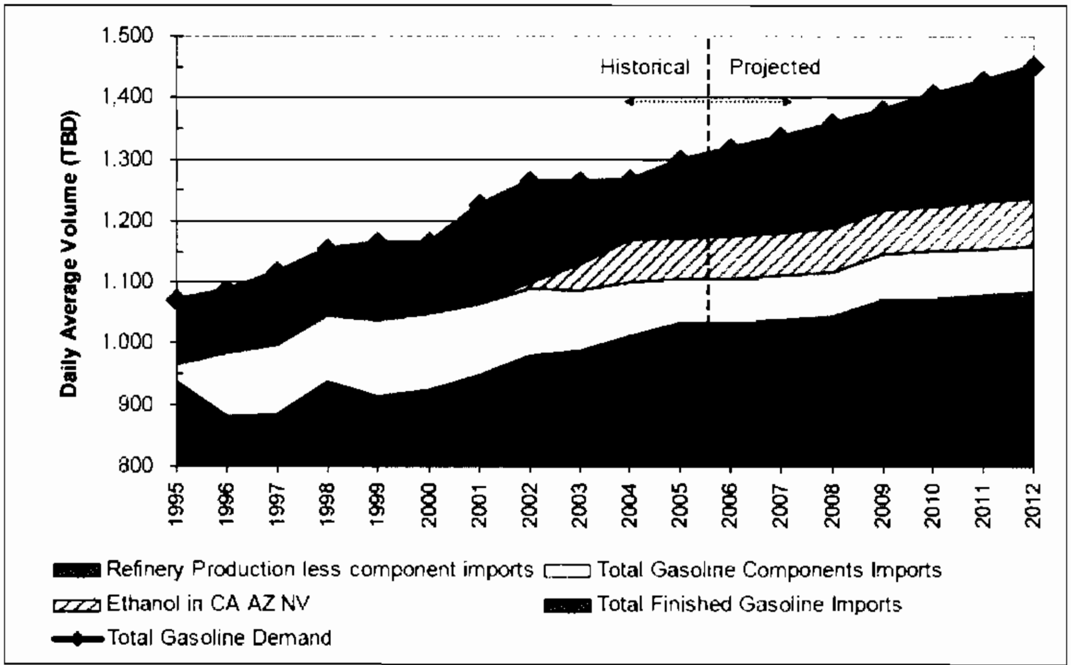
Population and economic growth in California will pressure existing petroleum/refining infrastructure. Managing this challenge will require a combination of increased crude oil and refined product imports and more efficient as well as alternative fuel vehicles.

California is home to one of the world's most viable economy with a mix of agriculture, construction, petroleum, high technology, service, and entertainment industries. California is ranked as the 7th largest economy in the world with a gross state product of $1.5 trillion. The viability of California's economy attracts a talented work force. The California Department of Finance projects that population growth will average 1.15 percent annually per capita over the next 20 years. With this increased population will come added numbers of light- and heavy-duty vehicles. Average miles driven will also increase as more and more of our population moves out of the major city centers to find affordable housing. The result for the transportation system will be increasing demand for gasoline and diesel fuels. Figure 1-4 shows a projection of the demand for gasoline in California and in Arizona and Nevada, two states supplied by California's refineries. Also shown is the expected California refining capacity capable of meeting this demand.

Figure 1-4 clearly shows that California's in-state refining capacity will not be able to keep up with the projected economic growth. The refining industry will be required to rely more on imported refined products and on more imported blend components to make up for the shortfall in in-state gasoline and diesel production. Except for product imports from Washington state, California refiners and the associate petroleum distribution system of pipelines, terminals, and storage tanks meet the state's fuel demands. In 2004 California refineries processed 1.8 million barrels per day (bpd) of crude oil—42 percent or 750 bpd were from crude produced in California, 22 percent or 388 bpd from Alaska, and 36 percent or 652 bpd from foreign sources. Figure 1-5 shows crude oil sources for California refineries from 1995 to 2005. This figure also shows the growing share of imported crude oil as California and Alaskan crude oil production decline. This will mean more foreign crude oil will be imported into California.

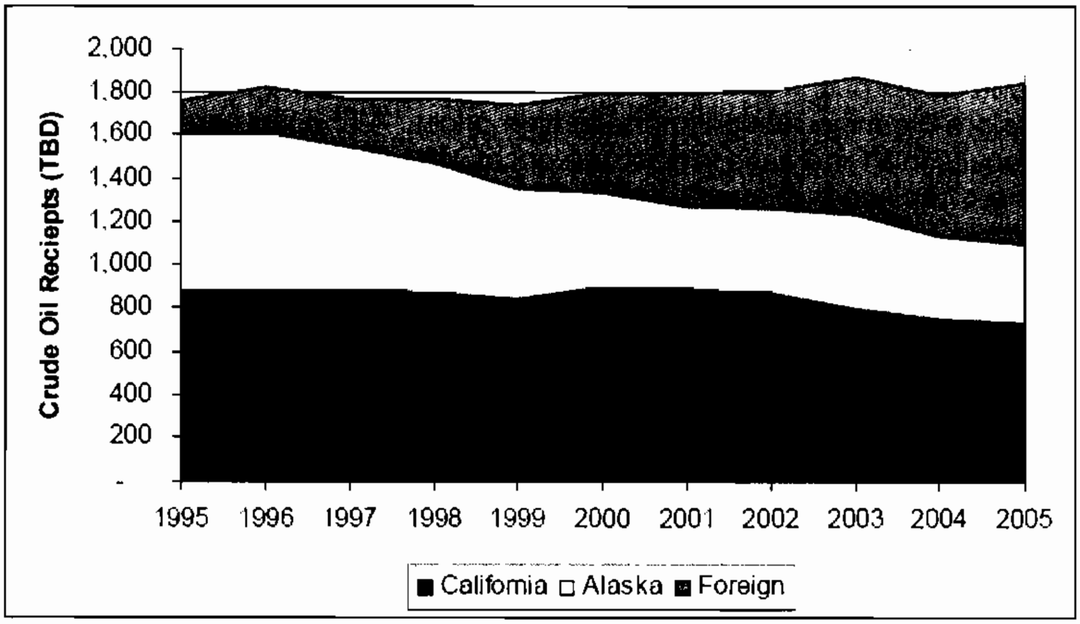
California's refining capacity decreased in the 1990's as older, less efficient, facilities were retired. Capacity is increasing as refiners modernize to produce newer gasoline and diesel fuels. This slow growth since 1989 is expected to help meet near term demand but is not a long term solution.

California, then, is faced with either having to import refined products to meet the growing demand or to reduce demand either by improving vehicle efficiency and/or promoting alternative fuels. Increased efficiency and alternative fuel use could also help reduce emissions of greenhouse gas emissions. There are, however, many hurdles to implementing these options. It is clear that without these options to reduce or displace the demand for gasoline and diesel fuels that California refineries will become more dependent on foreign sources of crude oil, including from geopolitically unstable regions like the Middle East. Such reliance could have a very negative effect on California's future economic viability.



Source: Spring 2006 Petroleum Fuels Price Spike – Report to the Governor, CEC, 2006.

Figure 1-4. Projected demand for gasoline in California, Arizona, and Nevada expected to exceed refinery capacity.



Source: Spring 2006 Petroleum Fuels Price Spike – Report to the Governor, CEC, 2006.

Figure 1-5. California increasingly reliant on import crude as California and Alaska production decline.

California's High Gasoline Prices in 2006 are Caused by High Oil Prices

California and the rest of the U.S. have experienced all time high prices for gasoline and diesel fuels. These high prices are caused by the increase in demand from countries like India and China. The economic growth of these countries will continue to put upward pressure on oil demand and price in the foreseeable future.

The 1990's were characterized by reasonably behaved energy prices for petroleum and natural gas. Oil nominally sold for $20 per barrel with most experts, including those in the oil and auto industries, projecting similar prices in the future. The incredible expansion of the economies in India and China, however, increased the demand for oil much faster than anticipated. Production increased to meet the demand but without any margin. This created a very tight supply and resulted in higher oil prices. Furthermore, several other factors constrained production in the last several years: hurricanes in the U.S. Gulf region and U.S. invasion of Iraq and subsequent occupation. Market speculation on price increases has also supported higher prices. All of these factors contribute to higher oil prices.

Figure 1-6 shows the history of oil prices from 1983 through August 2006 (NYMEX Futures[1]). Also shown is the timing of several selected world events: first Iraq war, 9-11, invasion of Iraq, and Hurricane Katrina. The first Iraqi war caused a run up in oil prices that were eased when fears of production shortages did not materialize. 9-11 resulted in a substantial downturn in world economies with associated reduction in oil demand and price. Oil prices since the invasion of Iraq have moved strongly upward compounded by the effects of the Gulf hurricanes. Oil prices in the summer of 2006 have consistently topped $70 per barrel—an increase of some $50 per barrel compared to the 1990s.

Gasoline and diesel prices in California are at all time highs in 2006. Crude oil costs to the refiners are the main reason for these high prices. A $50 per barrel increase in crude oil results in $1 increase in gasoline prices. The California refining industry's ability to meet consumer demands—which fluctuate from summertime highs to winter lows is another factor influencing gasoline and diesel prices. California refineries are operating near capability so any outages either planned (such as routine maintenance) or unplanned (such as equipment failures) can cause price spikes as has been experienced. Figure 1-7 illustrates the fluctuations in gasoline prices over the last several years. Clearly shown are the price differences between summer and winter driving seasons. Also visible is the influence of crude oil prices which increased from roughly $60 per barrel in 2005 to $70 per barrel in 2006. Gasoline prices increased about 25 cents proportional to the increase in crude oil prices.

The future outlook of gasoline and diesel prices in California will be influenced by world oil prices, California's economic growth, environmental regulations, and the oil industry's ability to meet the demand for petroleum products. High gasoline prices in 2005 held

[1] EIA, Crushing, OK Crude Oil Future Contract 1, [http://tonto.eia.doe.gov/dnav/pet/hist/rclc1M.htm].

growth in gasoline demand in California to 0.48 percent compared to an average annual increase of 1.8 percent from 1995 to 2005. In addition, the regulation of greenhouse gas emissions from light-duty vehicles under AB 1493 has the potential to further reduce fuel consumption after 2010. At the same time, population growth in California is projected at 1.15 percent annually for the next 20 years.[2] This will translate to annual demand growth rates ranging from 0.7 to 1.0 percent for gasoline through 2010 and around 2.6 percent for diesel through 2025.[3] It is likely that California refineries will become increasingly dependent on imports of refined products to meet demand.

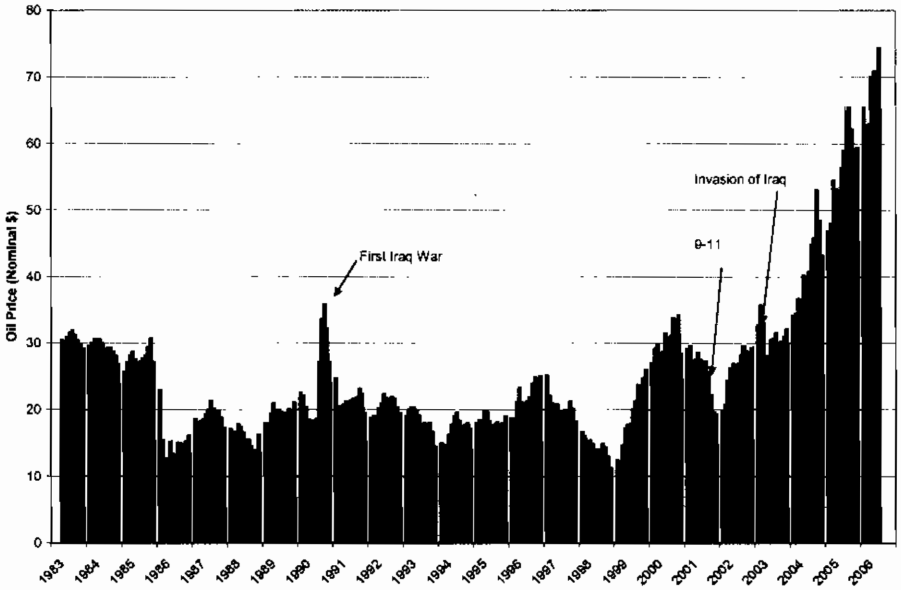


Figure 1-6. World oil price history 1983 to 2006.

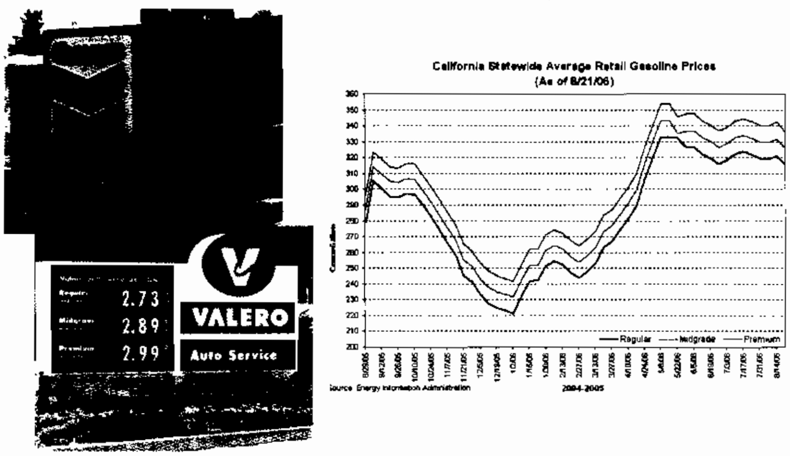


Figure 1-7. Gasoline price fluctuations in California

[2] CEC, "Forecasts of California Transportation Energy Demand 2005-2025, In Support of the 2005 Integrated Energy Policy Report, CEC Staff Report, April 2005, CEC-600-2005-008.

[3] CEC, "Renewable Diesel Analysis", 2006.

World Oil Prices Will Remain High

The Energy Information Administration's Annual Energy Outlook 2006 projects world oil prices to remain $50 to $60 through 2030. Although these high prices will reduce demand in the transportation sector, EIA still projects substantial demand increases, with U.S. reliance on imported oil growing from 52 percent in 2006 to 62 percent in 2030.

EIA substantially revised its estimate of energy prices, supplies, and demands for the U.S. in its Annual Energy Outlook (AEO) 2006.[4] The key revision reflected higher world oil prices as a result of increased demand and also supply constraints due to disruptions and inadequate investments in production capacity. AEO 2006 assumes oil-rich producing regions will invest less in production than previously predicted, due to the strong, continued growth in the world's economy even in the face of high oil prices. Energy costs continue to be a smaller percentage of GNP than in past years when high energy prices preceded economic recessions in 1972-73, 1979-80, and 1991. The U.S. and world economy appear more resilient to higher energy prices today. EIA also considered high and low oil price scenarios to their reference projection. Figure 1-8 shows these estimates.

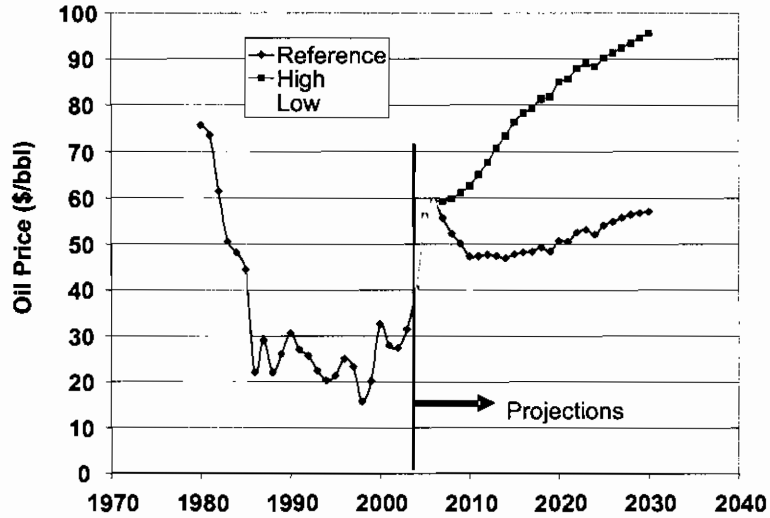
ExxonMobil predicts world energy demand will grow by 1.6 percent between now and 2030.[5] Regional demand in North America and Europe is projected to grow at 0.6 and 0.8 percent respectively. Non OECD Asia Pacific growth is projected to be 3.2 percent, Latin America 2.2 percent, Africa 2 percent, Middle East 1.9 percent, Russia 1.3 percent, and Asia Pacific (OECD) 0.9 percent . So, developing countries will have the largest demand growth with total demand exceeding OECD countries by 2020. ExxonMobil projects there will be abundant oil resources to meet world demands--using both conventional and heavy oil/tar sands and shale oil. It is anticipated that refining capacity will expand but mostly in areas near oil production and in areas of largest growth. U.S. refining capacity will increase but at much lower rates than the rest of the world. U.S. will also become more dependent on imports of refined products from offshore refineries. It is also expected that refineries sited in locations in Eastern Europe and Asia will produced similar quality fuels as used in the U.S.

The Organization of Petroleum Exporting Countries (OPEC) controls a majority of the world's proven oil reserves, with OPEC currently supplying some 40 percent of the oil produced today. OPEC has attempted in the past to control oil prices by limiting supply. Current demand compared to supply has the same effect as OPEC limiting supply. There is not much OPEC or other producers can do to increase near term supply and this has resulted in a very tight oil market. Figure 1-9 shows how tight this market is and the relative influence of OEDC and non OEDC countries. Also shown is the growing China demand for oil.

4 EIA, "Annual Energy Outlook 2006 with Projections to 2030", DOE/EIA-0383(2006), February 2006 [http://www.eia.doe.gov/oiaf/aeo/index.html].

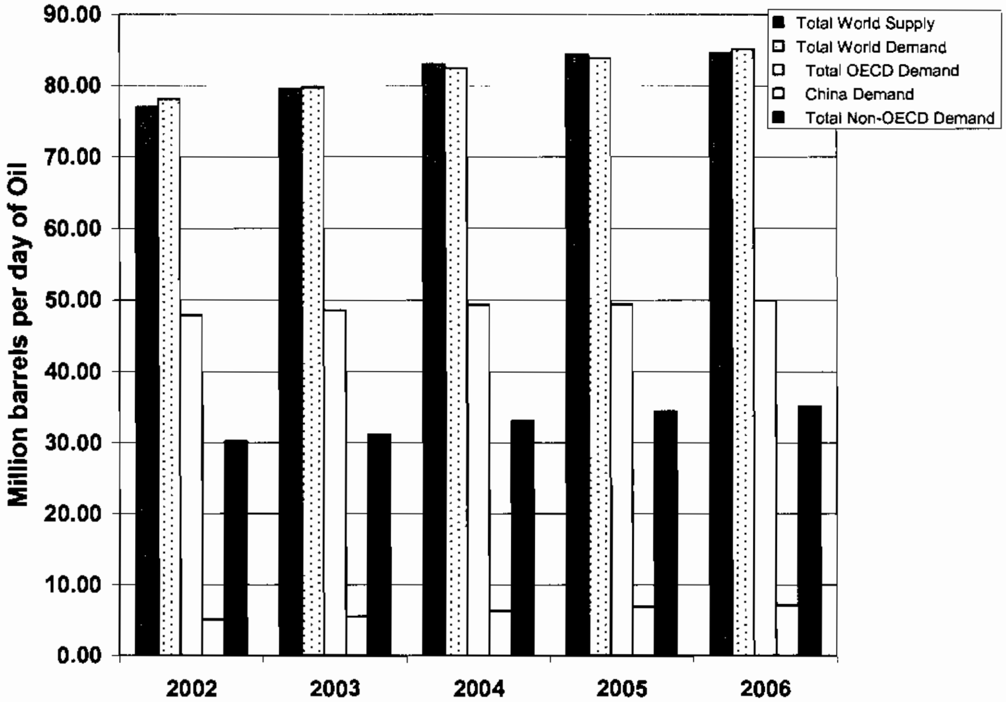
5 Cohen, Kenneth P., "The Energy Outlook for the Global Transportation Sector", Presented at California Air Resources Board Haagen-Smit Symposium, Monterey, California, May 9 2006.

There is a lot of consensus among experts that oil prices will remain high in the $50 to $60 per barrel range and not return to the $20 levels seen in the 1990's. This price will depend upon how the world's economies react to more expensive oil—an economic downturn would likely moderate prices, while robust growth would support them. Higher prices are also possible, but this would allow for more alternative sources of energy to enter into the market place.



Source: DOE EIA Annual Energy Outlook 2006

Figure 1-8. EIA world oil price scenarios.



Source: DOE EIA

Figure 1-9. Oil market is very tight with demand exceeding supply in some instances.

Transportation Technologies Now Available to Meet Air Quality Standards

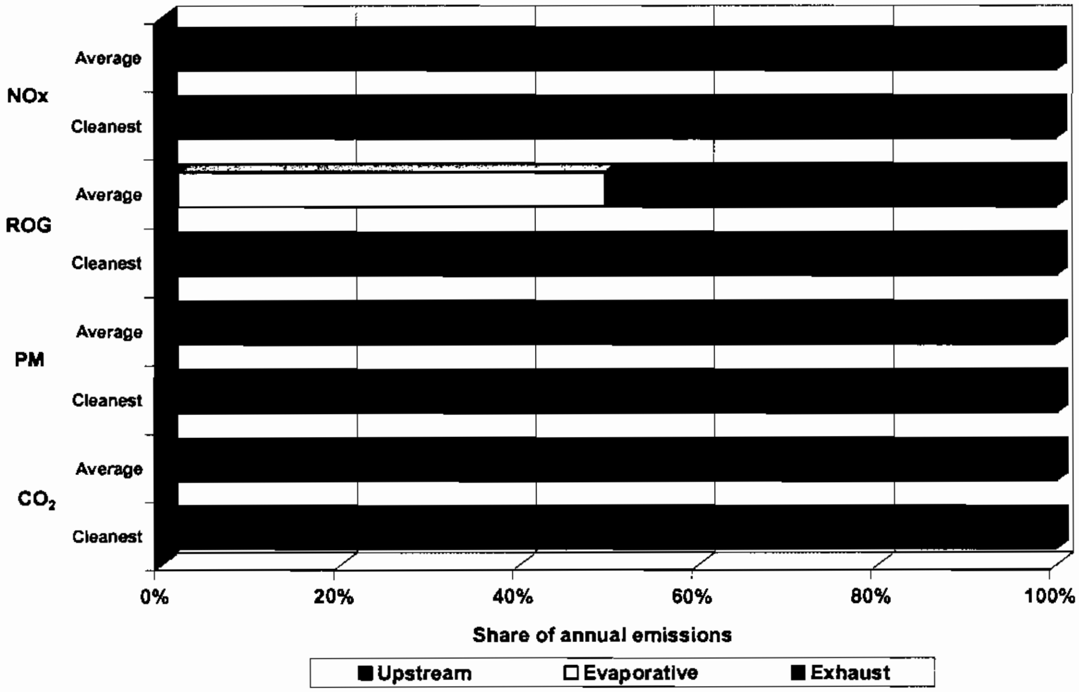
Both light- and heavy-duty engine and vehicle emissions technologies are now developed or near to being developed that once implemented will help regions in California meet national ambient air quality standards for ozone and $PM_{2.5}$.

Today most Californians still work and live in areas of the state that do not meet national or state ambient air quality standards for ozone and $PM_{2.5}$. Exposure to elevated levels of ozone and $PM_{2.5}$ (particulate manner less than 2.5 microns) leads to substantial health care costs and premature deaths. The California Air Resources Board (ARB) and local air quality management (or pollution control) districts have worked to implement emission standards on stationary and mobile equipment to meet air quality standards. Much progress has been made in reducing harmful levels of ozone, although further reductions of hydrocarbon (HC) and NO_x emissions will be necessary to meet the new federal and state 8-hour ozone standards, set at 0.08 ppm and 0.07 ppm, respectively.

Table 1-4 compares the emissions of the cleanest passenger car technologies to the current California fleet average in 2005. This table also shows a projection of the cleanest heavy-duty vehicles (meeting 2010 emission standards) compared to the current California fleet average in 2005. Rolling in vehicles meeting these standards will help local districts reduce emission inventories from on-road mobile sources. Similar reductions will be needed in non-road applications, with standards mirroring those for heavy-duty vehicles to be enforced from 2013. Districts and ARB will also need to develop innovative control strategies such as indirect source rules to help control emissions in existing and future residential and commercial developments. Incentive programs like the state run Carl Moyer Program or local programs like SECAT or the Gateway Cities Program will also be needed to reduce emissions enough to meet attainment.

As individual vehicles become cleaner, controlling upstream emissions associated with the refining and distribution of transportation fuels will become increasingly important to efforts to improve local air quality. Figure 1-10 demonstrates a "well to wheel" analysis of annual emissions of NO_x, ROG, PM, and CO_2 from an average and cleanest (PZEV) light-duty vehicle in California, broken down by upstream, evaporative, and exhaust emissions. As that figure shows, with the exception of carbon dioxide, upstream emissions become a relatively greater fraction of total emissions as vehicles become cleaner. Policymakers hoping to meet state and federal air quality standards will likely shift their attention to energy production in the years to come.

Figure 1-11 shows the contribution of the mobile (on and non road) sector to the overall statewide inventory for ozone precursors. Mobile sources contribute 66 percent of the total inventory and have been the target of a variety of emission control measures to reduce these emissions. The same trend holds for $PM_{2.5}$ where mobile sources contribute 56 percent of the inventory (from combustion sources), with stationary sources contributing the balance. Further technological advances to reduce those emissions, along with concerted efforts on the part of regulators, will be required to meet increasingly strict state and federal air quality standards.



Source: TIAX AB 1493 analysis, EMFAC2002

Figure 1-10. Well-to-Wheel emissions for average and cleanest California light-duty vehicles in 2005.

Table 1-4. Newest vehicle technologies are 8 to 23 times cleaner than average vehicles on the road today.

Vehicle Class	Passenger Cars				Heavy-Heavy Duty Trucks			
	HC	CO	NO_x	$PM_{2.5}$	HC	CO	NO_x	$PM_{2.5}$
Average 2005 Fleet Vehicle	0.66	6.26	0.57	0.03	0.68	3.09	16.91	0.37
Cleanest Technology[1]	0.03	0.40	0.024	0.003	0.22	2.10	0.89	0.04

1. Partial Zero Emissions Vehicle (PZEV) estimate of on-road emissions g/mi for Passenger Cars
2. 2010 Heavy-duty engine standards in g/bhp-hr convert to g/mi with 3.0 g bhp-hr/mi factor.

Source: TIAX AB 1493 analysis, EMFAC2002

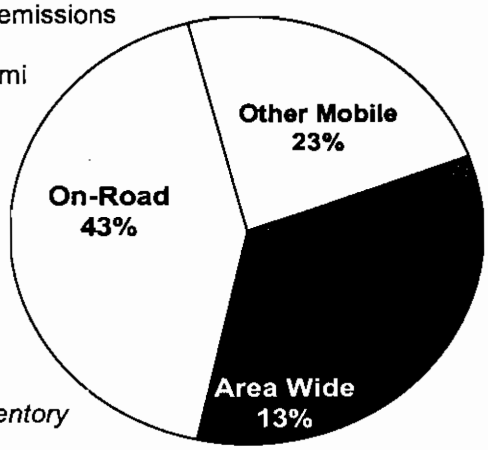


Figure 1-11. Statewide emission inventory of ozone precursors (NOx+ROG) by major source category.

Source: ARB 2002 emission inventory

Climate Change Could Adversely Affect California's Economy and the Health of its Citizens

Climate change is a threat to California's agriculture, land, air quality, and the health of its citizens. The negative impacts of climate change could severely impact California's economy due to any one of these threats.

Most scientists now acknowledge that global warming results from manmade emissions of greenhouse gases. The primary greenhouse gases include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons, and sulfur hexafluoride (SF_6).[6] Other greenhouse gases include ozone precursors and particulate matter. Figure 1-12 shows manmade emissions of the different greenhouse gases in California for 1999. Total emissions were 417 million metric tons of CO_2 equivalent. Carbon dioxide is the largest contributor to total greenhouse gas emissions with fossil fuel combustion responsible for 98 percent of California's total CO_2 emissions in 1999. Figure 1-12 also shows that transportation is the largest source of fossil fuel related CO_2 emissions. California measures aimed at reducing transportation related greenhouse gas emissions will have a significant impact on California's greenhouse gas emissions.

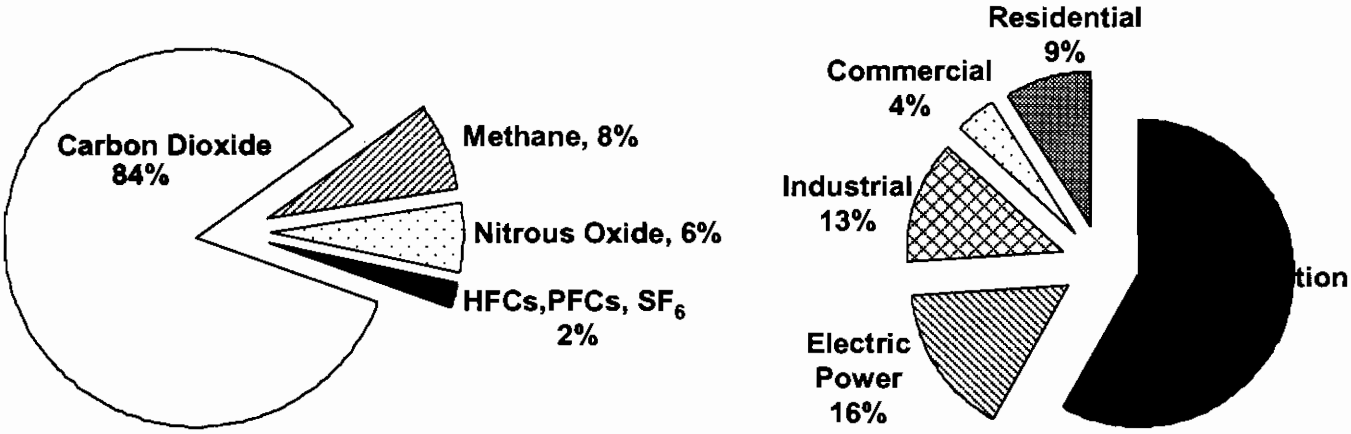
The potential impacts of climate change are well documented and include increased surface temperature, rising sea levels, and altered/extreme precipitation patterns. There are many wide-ranging impacts of these effects, but of particular interest to California are coastal impacts and the effect on the Sierra snowpack. Figure 1-13 shows the San Francisco yearly mean sea level, obtained from the Golden Gate tide gauge. The data show an average rate of increase of 0.5 ft/century from 1885 to 1997. From 1925 to 1997, the rate of change was 50 percent higher or 0.75 ft/century. Rising sea levels can lead to erosion of beaches, flooding of coastal wetlands and significant costs to protect coastal communities.

California, to a large extent, depends on the runoff from the Sierra snow pack for water. In warm winters, precipitation falls as rain rather than snow, with lower volumes of spring snowmelt runoff. Figure 1-13 also shows the percent of spring runoff compared to annual runoff. Spring runoff has decreased over the last century, especially after 1950. This implies that California may not be able to depend on the snow pack to store water for summer irrigation of crops in the future. A significant economic investment will be required to provide an alternative water capture and storage method.

California has taken a world leadership role by developing regulations to limit GHG emissions from vehicles and industry. The standards are designed to stimulate the commercialization and diffusion of existing clean energy technologies that currently face barriers to market development. It is anticipated that these technologies will create jobs and save consumers money over the life of a vehicle or piece of equipment, and also

[6] Black carbon aerosols, primarily emitted from combustion processes, are also believed to have a significant climate impact.

reduce "upstream" emissions of HC, CO, NO_x and PM as less fuel is transported through the fuel distribution system.



Source: TIAX LLC report to the Energy Commission

Figure 1-12. CO_2 emissions from transportation make up majority of GHG emission in California.

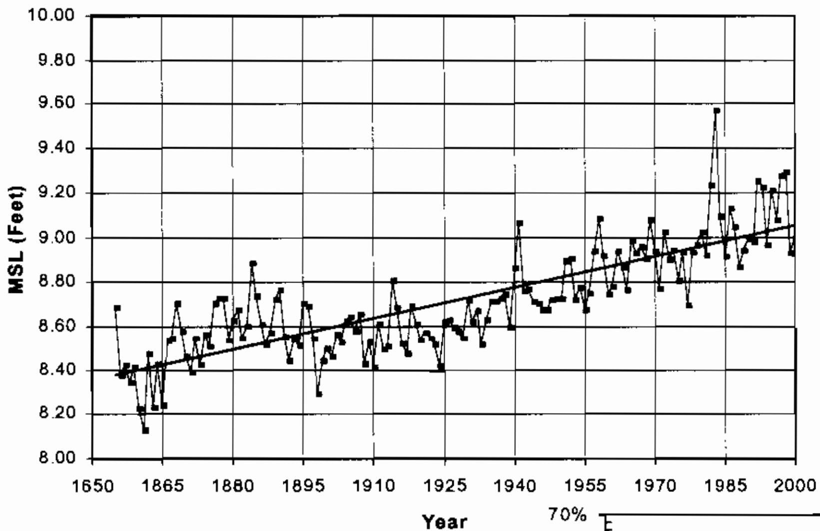
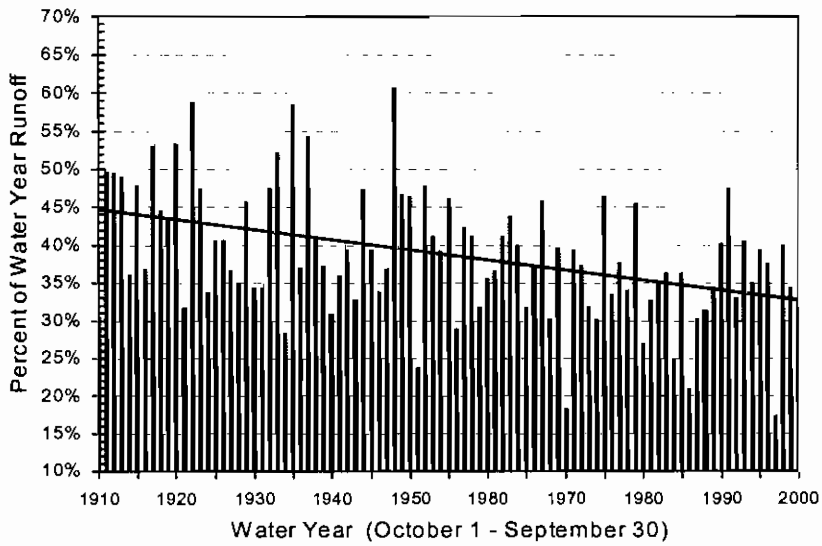


Figure 1-13. San Francisco sea level raise (left) and Sacramento River runoff (lower).

Source: TIAX LLC report to the Energy Commission



Increased Goods Movement Creates Environmental Challenges

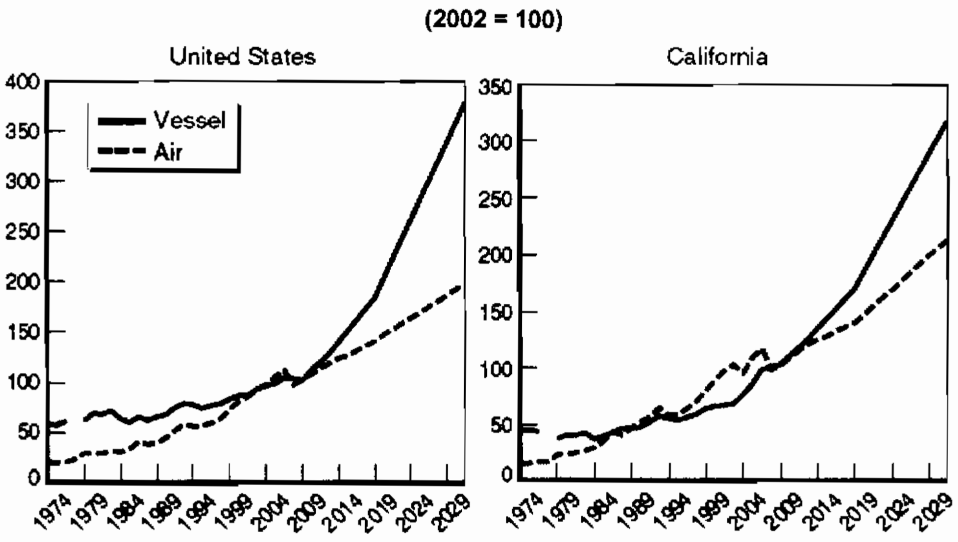
Increased goods movement in California, while contributing to and supporting economic growth, also threatens to increase air emissions. Recent efforts to manage those impacts, while notable, face significant economic and regulatory barriers.

Approximately two-thirds of U.S. petroleum consumption is linked to transportation – as a result, changes in the overall magnitude and relative share of different transport modes hold important implications for patterns of energy use. In particular, recent and projected trends in goods movement promise to impact how and where energy is consumed in California. Decades of robust domestic economic growth has translated into increased demand for goods movement. Several related trends have contributed to further influence the volume and pace of goods movement in California: the growing importance of Asian countries, particularly China, as exporters to the U.S.; efforts to promote international trade through deregulation under the World Trade Organization; and the growth of just-in-time manufacturing techniques, to name but a few.

These trends, along with expected strong national and regional economic growth, are predicted to generate increased demand for goods movement in both the U.S. and California. As Figure-1-14 demonstrates, ship-borne traffic is expected to more than triple in California by 2030, with even larger increases anticipated for the nation as a whole. How the impacts of this growth – increasing congestion on highways, at ports, and on rail lines, and air pollution associated with expanded energy use – are managed will be an important issue for California in the coming decades.

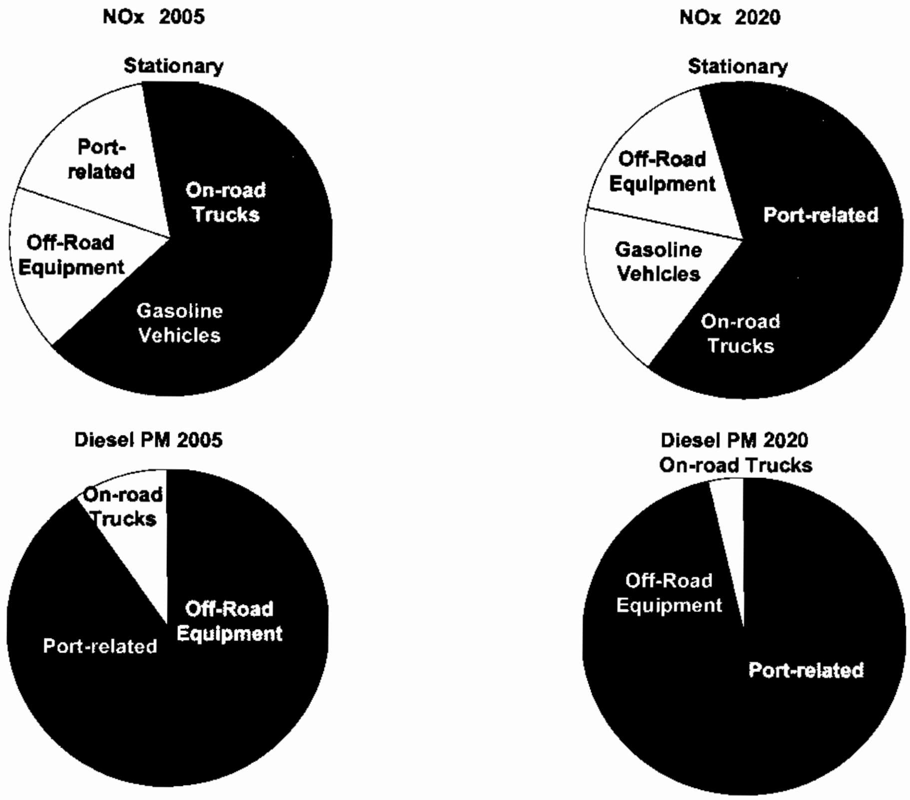
Of particular relevance to the state's economy and environment is the anticipated growth in goods movement through the Ports of Long Beach and Los Angeles, collectively known as the San Pedro Bay Ports. Those two ports account for more than 40 percent of all U.S. container traffic, and contribute heavily to both the California economy and local environmental concerns. Port-related activity is already a significant source of air pollution in the South Coast region, and its importance is projected to increase dramatically in the coming decades as other sources of pollution come under tighter regulatory control (Figure 1-15). With the announcement of its Clean Air Action Plan, the San Pedro Bay Ports have demonstrated a willingness to address current and future air pollution problems – at the same time, several issues, including how to manage emissions from late model heavy-duty diesel trucks (the so called "legacy" fleet) and foreign-registered ocean-born vessels not covered by federal and local environmental regulations, will present significant obstacles to controlling emissions from their activities.

It will be important to incorporate the significant activity associated with the movement of goods in any strategy that reduces petroleum use and addresses reduced GHG emissions as well as emissions of criteria pollutants.



Source: "U.S. Census Bureau, U.S. Exports/Imports of Merchandise", in "California's Global Gateways: Trends and Issues", PPIC, 2004.

Figure 1-14. U.S. and California trade volume projected to increase.



Source: "Goods Movement Action Plan, Phase I: Foundations", BHTA and CalEPA, 2005.

Figure 1-15. Port related activity expected to dominate emissions in the South Coast Air Basin.

Alternative Fuels are Effective Strategies to Displace Petroleum

About 900 million gallons of ethanol are blended into gasoline in Califomia. Over 240,000 FFVs are currently operating in California.

California has a long history promoting alternative fuels to reduce emissions from vehicles and other stationary combustion equipment and to decrease petroleum consumption and petroleum imports. The California Energy Commission (CEC) has been the lead agency in developing and demonstrating technology as well as developing incentive programs to promote the use of alternative fuels in the market place. Much of this work started in the early 1980's and focused on alcohol fuels in both vehicle and stationary applications. This was followed by developments in natural gas (compressed and liquefied) and propane in vehicle applications and a substantial development of electric drive technologies for vehicle technologies in the 1990s. More recently work has focused on the use of hydrogen in fuel cell vehicles.

The CEC methanol program lead to the development of flexible fuel vehicles (or FFVs) that could operate on gasoline or any mixture of gasoline and M85 (85 percent methanol mixed with gasoline). In the late 1980s methanol provided better emissions performance than gasoline since methanol as a HC is much less reactive than gasoline, and because lower NO_x emissions were possible in light-duty vehicle applications. Used in heavy-duty vehicles, methanol produced 50 percent less NO_x and eliminated PM emissions with sufficient engine oil control. Providing cleaner light- and heavy-duty emissions performance and promoting energy security were the primary drivers of interest in methanol. Natural gas and LPG (propane) technologies also had similar emissions benefits and were also considered viable options for reducing emissions from vehicles. The use of LPG in particular became increasingly common in the 1980s, with transportation sector consumption reaching 1.7 million barrels equivalent in California in 1984.

The oil industry responded to the threat of methanol potentially displacing petroleum by developing cleaner formulations of gasoline (so-called reformulated gasoline or RFG). This was achieved by removing some of the lighter ends of gasoline like benzene and by adding oxygenate like MTBE (which coincidently was also produced from methanol). With further development and substantial vehicle testing in the cooperative "Auto-Oil" study, RFG became an enabling technology allowing substantial improvements in catalyst technology so that partial zero emission vehicles (PZEVs) were possible. This development effectively removed the need for alternative fuels to improve ambient air quality. Similar technology improvements have occurred in heavy-duty engines and diesel technologies will meet very stringent exhaust standards in 2010 (which are even considerably lower than uncontrolled alternative fuel engines). The lessons learned from the roughly two decades of alternative fuel commercialization efforts are summarized in Table 1-5.

Although most experts still believed that alternative fuels are needed to protect against petroleum supply disruptions and our reliance on regions geopolitically unstable, the low costs of oil in the 1990s stymied any widespread development of alternative fuels except in specific instances. First the technology success of FFVs encouraged congress to pass the

Alternative Motor Fuels Act (AMFA) which included CAFE incentives for auto makers to produce these vehicles. Second, the Clean Air Act Amendments of 1990 required the use of reformulated gasoline in areas of ozone nonattainment. Further, Congress provided a substantial tax break for ethanol when blended with gasoline.

As interest in methanol waned, the auto makers continued to produce FFVs but changed compatibility to ethanol (E85) and any mixtures of E85 and gasoline. Groundwater contamination by MTBE led to it being banned in California and other states. Ethanol is now widely used in California to meet California RFG requirements.

Table 1-5. Commercialization lessons learned from the California experience with alternative fuels.

Critical Factor	Comments
Low Level Blends	Blending ethanol or other oxygenates into gasoline has been the most successful strategy for getting alternative fuels into the market place since blends can be used in existing vehicles without modification and since little or small changes have to be made to the fueling infrastructure. MTBE and ethanol have been the most successful components, but both have negative environmental tradeoffs that were subsequently discovered—groundwater contamination in the case of MTBE and permeation emissions in the case of ethanol
Fueling Infrastructure	Vehicle users expect widespread availability of fuels. CEC demonstration programs occasionally had dedicated alternative fuel vehicles abandoned due to low fuel—drivers were too nervous to continue and arranged for alternative transportation modes. Even drivers of FFVs complained that it was difficult to find alternative fuel stations. Fuel stations need sufficient throughput to pay for the alternative fuel station investment. Building stations in anticipation of demand was a financial failure. Station's need to be carefully matched to vehicles.
End Users Vehicle Purchases	Fleets are not necessarily the best users to introduce higher priced alternative fuel vehicles even if the life cycle costs are lower. Fleets are low cost vehicle buyers. Alternative fueled vehicle price premiums reduced the number of vehicles that could be purchased.
CAFE Incentives	Vehicle manufacturers needed incentives to produce vehicles that have higher costs but same or nearly the same functionally as conventional fueled vehicles. The CAFE incentives have been very effective at increasing production of FFVs.
End Users Fuel Purchases	Users needed either an economic or performance reason for purchasing alternative fuels. Secondary, but limiting, reasons are users beliefs in helping to provide societal benefits (such as lower emissions) or in reducing petroleum consumption.
Blended Fuels	Blending alternative fuels into conventional gasoline or diesel is usually a higher value proposition for fuel suppliers. Fuel additives such as octane or cetane improvers generally are higher priced than the fuel itself. Alternative fuels therefore can command a higher price as a blend component.
Societal Benefits	Air emissions (criteria pollutants) were a compelling driver for alternative fuels until gasoline and diesel technologies achieved very low emission standards. Energy security or petroleum displacement, although important, has not carried the same importance as reducing criteria pollutant emissions.
Global Warming	Reducing carbon emissions from vehicles and other combustion equipment is now the primary driver for use of alternative fuels or other technologies to reduce GHG emissions.

Source: TIAX and Energy Commission

Biofuels Will Become a Viable Strategy to Supplement Fossil Energy Supplies

Biofuels can be used to displace petroleum use in both the light- and heavy-duty sectors. Biofuels strategies are compatible with measures to limit ambient air emissions and have lower GHG emissions.

All major energy companies are currently evaluating the use of biofuels as a viable strategy to augment gasoline and diesel supplies. Biofuel pathways include, for example, producing ethanol from starches or sugars as well as from cellulosic materials. Thermal processes using gasification and the Fischer-Tropsch synthesis to produced synthetic diesel and gasoline are alternate paths. Biodiesel is another possible biofuel; biodiesel can be produced from oils such as soybean oil, recycled cooking oils, or animal fats.

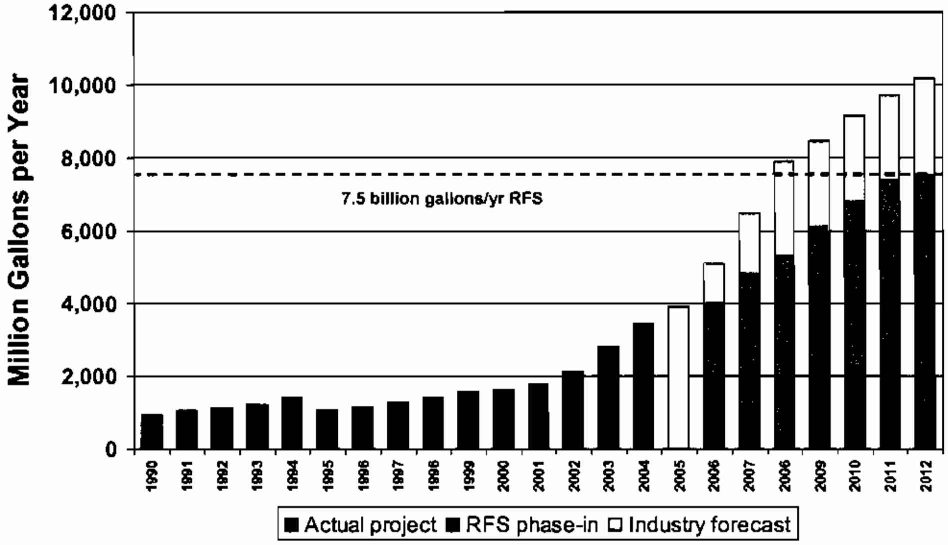
Currently, ethanol produced from corn is the largest volume alternative fuel produced in the U.S. Figure 1-16 shows the current production and projections for the future (compared to the renewable fuels standard RFS in the 2005 Energy Policy Act). California currently blends 900 million gallons of ethanol into gasoline (5.7 percent by volume). This displaces gasoline, effectively increases refinery output, and extends crude oil supplies. When formulated to meet California RFG standards, low level ethanol-gasoline blends – used in the mix of older and newer vehicles – reduce the impact of exhaust emissions on ambient air quality (reduced ozone forming potential, lower CO emissions, and lower toxic emissions). In addition, ethanol blends produce lower GHG emissions than conventional gasoline, because some of ethanol's carbon is recycled in the corn growing process.

Although there are a significant number of FFVs in the current California vehicle fleet, there are only three stations that dispense high level blends of ethanol and gasoline or E85, and only one is truly public access. The primary emphasis by ethanol producers is the gasoline blend market, where up to 10 percent ethanol is added. Use as E85 would require ethanol to be sold as an energy equivalent to gasoline or at 72 percent of the gasoline price. Currently, ethanol is selling at prices greater than gasoline in the blend market.

Figure 1-17 shows the potential GHG emission reductions possible with alternative fuels. As shown, ethanol from corn is comparable to other alternative fuels such as compressed natural gas. The greatest possible reductions are from bio-sources that do not require as much energy to produce. Cellulosic feedstocks have large advantages as shown; however, additional development will be needed to make these processes economic in the U.S.

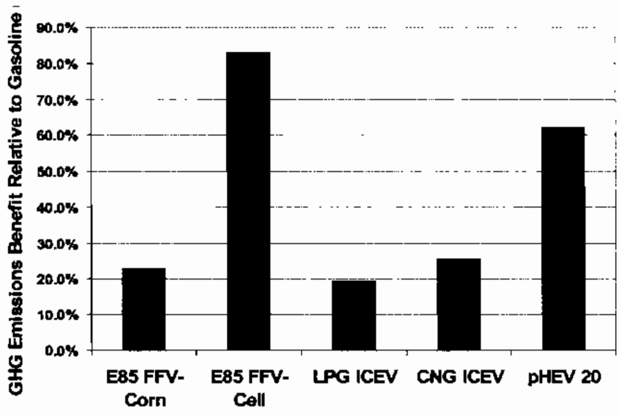
Total production of biofuels is limited by land and water resources. Food and fiber production also competes for these resources. Estimates of the potential size of the biofuels resource compared to other fossil and non fossil resources are shown in Figure 1-18. Biofuels are not expected to be a total replacement for conventional fuels but more of a displacement strategy aimed at extending fossil fuel use. This is clear based on the size of the potential resource. Whether biofuels will be used primarily as a blend in conventional fuels or as "neat" fuel is still unclear, at least for ethanol.

Other alternative fuels are already in the California market. Propane continues to be used but at a declining share. Natural gas is used in transit buses (primarily as CNG) and in some heavy-duty applications like refuse haulers (primarily as LNG), and in light-duty vehicles. Honda manufactures a natural gas version of the Civic, the GX. Synthetic diesel produced from natural gas (via the Fischer-Tropsch synthesis) is also being blended with diesel fuel in California. With the exception of natural gas derived diesel fuels, these various alternative fuels provide GHG benefits of about 25 percent depending on the amount of carbon in the fuel and the possible fuel economy impacts.



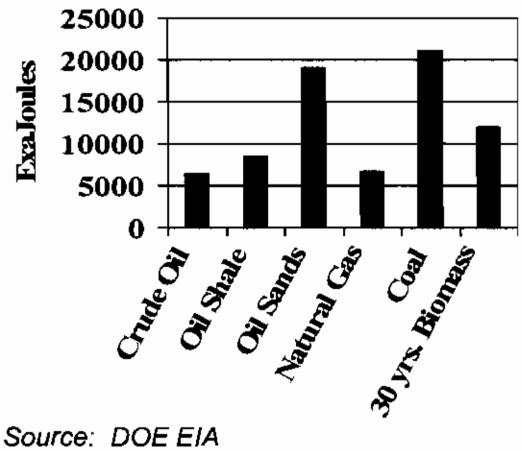
Source: Renewable Fuels Association

Figure 1-16. Ethanol production projected to exceed federal RFS.



Source: TIAX Well to Wheel Fuel Cycle Analysis Report

Figure 1-17. GHG benefit of alternative fuels compared to gasoline.



Source: DOE EIA

Figure 1-18. Size of world's energy resources.

Regulations and Incentives Have Had Limited Success in Promoting Alternative Fuels

Despite considerable efforts both nationally and in California to implement regulations and incentives to promote alternative fuel vehicles, alternative fuels continue to play a limited role in the transport sector. Public policy has been more effective at forcing changes in conventional gasoline formulations and gasoline engines than a fundamental shift to alternate fuels or technologies.

Since 1988, numerous attempts have been made to promote alternative fuels at both the national and local levels (Table 1-6). Two major periods of policy activity occurred – the first at the national level during the late 1980s and 1990s, the second at the state level since 2000, primarily in California. Early national efforts attempted to promote the use of alternative fuels in transportation, primarily as a means of meeting local air quality objectives. In contrast, efforts in California in recent years have focused upon an expanded set of technologies, including electric drive vehicles, in hopes of also controlling greenhouse gas emissions and reducing petroleum dependence.

Table 1-6 demonstrates some of the more important national efforts to promote alternative fuels. Particularly important were the Alternative Motor Fuel Act of 1988, which established CAFE credits for alternative fuel vehicles, and the 1990 Clean Air Act Amendments, which mandated the use of reformulated gasoline (RFG) in non-attainment areas. Those efforts, while boosting the sale of flexible fuel vehicles and the use of MTBE and ethanol as oxygenates, have been criticized for increasing, rather than reducing, petroleum dependence due the lack of widespread access to higher content ethanol blends such as E85 (85 percent ethanol/15 percent gasoline; see Figure 1-19). Also notable were the two federal Energy Policy Acts: the first in 1992, which promoted the use of alternative fuel vehicles in public fleets; the second in 2005, which established or extended a variety of tax credits, including a $0.50 per gallon credit for fuel, a 30 percent credit for fueling infrastructure, and a credit to cover 50 percent of the incremental cost of the vehicles themselves.

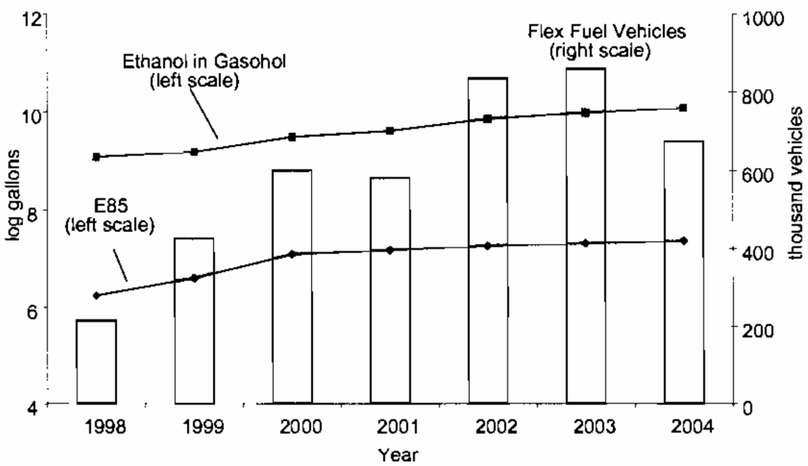
State initiatives in California include the Air Resources Board's Low Emission Vehicle (LEV) Program of 1990, as well as more recent efforts to establish standards for and caps on greenhouse gas emissions in California. The LEV program, which established regulatory links between fuel quality and engine technology, was largely successful at promoting cleaner gasoline vehicles. In contrast, requirements for the sale of electric vehicles failed in implementation when auto manufacturers successfully argued that barriers to commercializing battery electric vehicles made them impossible to market to consumers. More recent state regulatory efforts potentially impacting alternative fuels include AB 1493, under which California established GHG emission standards for light-duty vehicles, and AB 32, wherein California will set legally binding caps on emissions statewide.

As these examples demonstrate, the record of government in drafting regulations and incentives to promote alternative fuel vehicles over the past 20 years has been mixed. National and state policy action has been better at promoting marginal shifts in existing technology rather than the wholesale introduction of alternative fuel vehicles. Future effort is needed to improve the market attractiveness of alternative fuels compared to gasoline and diesel.

Table 1-6. Selected regulations and incentives promoting alternative fuel vehicles.

Level	Year	Legislation or Regulation	Action	Achievements	Limitations
Federal	1988	Alternative Motor Fuel Act	CAFE credits for alternative-fueled vehicles	4 million FFVs on-road	Limited E85 distribution infrastructure
	1990	Clean Air Act Amendments	RFG requirements for non-attainment areas	Enabled much cleaner gasoline technologies; 900 million gallons of ethanol blended in CA	Troubles with MTBE contamination
	1992	Energy Policy Act	Fleet rules requiring use of alternative fuel vehicles	Promoted FFVs in public fleets	Private fleets unaffected
	1991 and 1998	Intermodal Surface Transportation Efficiency Act	Required conformity between transport planning and air quality goals	Allowed flexible use of transportation funds	Most funds devoted to congestion management
	2005	Energy Policy Act	Many incentives for alternative fuels, including $0.50 per gallon equivalent	—	—
CA	1990	Low Emission Vehicle Program	Required sale of zero emission vehicles in CA	Dramatic improvements in gasoline ICEs	Failed to promote BEVs
	2000	AB 2076	Established petroleum reduction goals	—	—
	2002	AB 1493	Established GHG emission standards for LD vehicles	—	—
	2005	AB 1007	Requires development of alternative fuels plan	—	—
	2006	AB 32	Directs ARB to set cap on greenhouse gas emissions	—	—

Source: TIAX evaluation 2006.



Source: "Estimated Number of Alternative-Fueled Vehicles", EIA, 2004.

Figure 1-19. Flex-fuel vehicles made available and ethanol consumption by fuel, 1998-2004.

SECTION 2. NATURAL GAS

Quantities of Use

Natural gas vehicle (NGV) technology is relatively well-proven. Compared to counterpart gasoline and diesel vehicles, NGVs reduce petroleum consumption and usually have lower criteria pollutant emissions. Still, while NGVs have been commercialized and in common use in the U.S. for over a decade, their total number is still quite small relative to gasoline and diesel vehicles. Table 2-1 summarizes the state of natural gas transportation fuel use in California based on the most recent information available (which often is as of 2004 as noted in the table).

Table 2-1. Natural gas fuel use in California.

Number of NGVs (2004)	26,700[7]
Fraction of on-road population, %	0.11
OEM LDV models offered (2006)	3[8]
LDV engines certified (2006)	7[9]
HDV engines certified (2006)	6
CNG stations, total (2004)	365[10]
public access	148
LNG, L/CNG stations, total (2006)	41
public access	—[a]
CNG dispensed, billion scf (2004)	3.84
million gge	31
Fraction of petroleum fuel, %	0.16
LNG dispensed, million gal (2006)	36
million gge	23
Fraction of petroleum fuel, %	0.12

[a] Some offer access with advance arrangements, rarely used

Source: As noted in the table references.

Estimates of the total number of NGVs in the U.S. can be obtained from a number of sources which differ slightly in the population estimates. Data from the Natural Gas Vehicle Coalition (NGVC) and the International Association for Natural Gas Vehicles

[7] California DMV data contained in a personal communication, J. Folkman of the Commission to L. Waterland of TIAX, August 2, 2006.

[8] [www.eere.energy.gov/afdc/].

[9] ARB certification database, [www.arb.ca.gov/msprog/cert.htm].

[10] 2005 Integrated Energy Policy Report, CEC-100-2005-007-CMF, November 2005.

(IANGV) indicate there are about 130,000 NGVs in the U.S. in 2006 and over 5 million NGVs worldwide.[11,12] Argentina, Brazil, and Pakistan are each reported to have over one million NGVs. The number of NGVs in California can be estimated from California Department of Motor Vehicles (DMV) data. These data indicate that there were a total of 26,670 NGVs in California in 2004, as shown in Table 2-2,[13] although the DMV registration data for heavy duty NGVs may not reflect vehicles sold and registered as diesel or gasoline vehicles prior to conversion to CNG or LNG.

Table 2-2. Numbers of natural gas vehicles by vehicle type registered.

Vehicle Category	Number of Natural Gas Vehicles
Light Duty	21,269
Heavy Duty	5,401
Total	26,670

Source: DMV Database 2004

The total number of NGVs registered in California grew steadily in the 1990s and then quite rapidly (approximately tripling) from 1999 through 2001, as shown in Figure 2-1. From 2001 through 2004, the total number of NGVs in California has fluctuated as the (smaller) number of heavy duty NGVs have increased while the (larger) number of light duty NGVs has generally decreased. This declining number of light duty NGVs is most often attributed to the decreased number of new NGV product offerings, although other factors such as vehicle range, vehicle incremental cost, and fueling station availability are sometimes cited.

California has consumed just over two trillion standard cubic feet ($2x10^6$ mmscf) of natural gas per year for all uses for each of the last eight years.[14,15] California consumption by customers has been about 11 percent of the U.S. consumption by customers over this time period. Approximately 16 percent of the natural gas consumed in California is produced within the state, and the remaining 84 percent is supplied from outside the state. Most of the natural gas imported from outside California is produced from gas fields in the southwest (San Juan and Permian basins), Rocky Mountain basins, and Western Canada basins. Of the natural gas that is produced and consumed in California, roughly 75 percent is associated gas, which is a byproduct of petroleum production, and roughly 25 percent is produced from gas wells that are not associated with oil wells. Most of the associated gas comes from the south-central part of the state

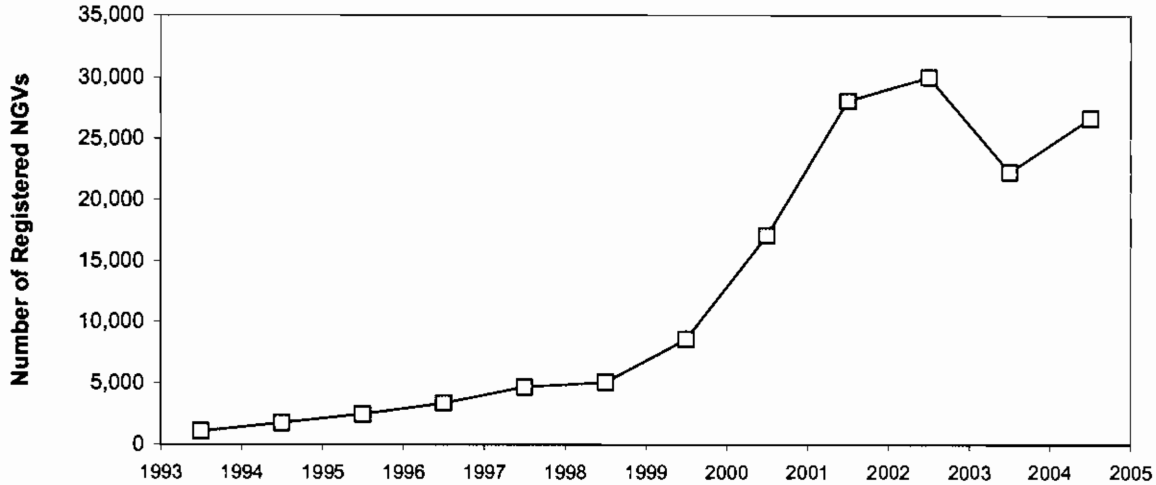
[11] [www.ngvc.org].

[12] [www.iangv.org/content/view/17/35].

[13] California DMV data contained in a personal communication, J. Folkman of CEC to L. Waterland of TIAX, August 2, 2006.

[14] [www.energy.ca.gov/naturalgas/natural_gas_facts.htm].

[15] [www.eia.doe.gov/oil_gas/natural_gas/info_glance/natural_gas.html].



Source: DMV Database 2004

Figure 2-1. Natural gas vehicle growth in California.

(in and near Kern County) and essentially all the non-associated gas comes from Northern California.[16,17] California natural gas production, at 323 billion scf represented roughly 1.2 percent of the 27 trillion scf dry gas production in North America in 2003, the most recent data available.[18,19]

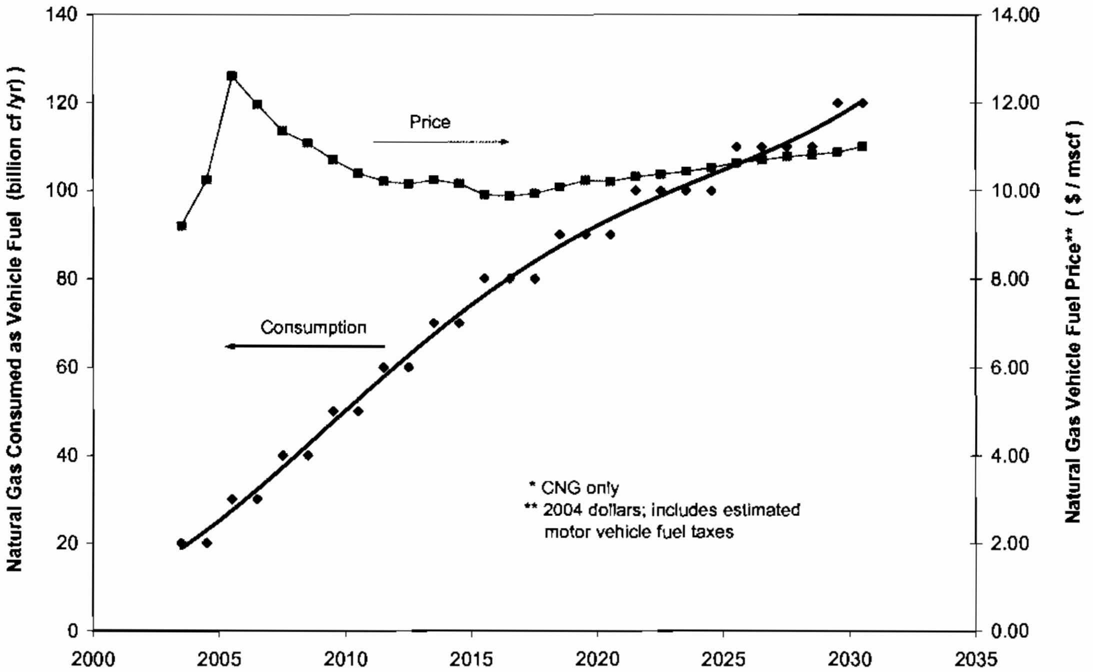
Figure 2-2 shows the quantities of natural gas used annually by various types of California consumers since 1997. Note that these quantities are plotted using a logarithmic scale so that the amount of natural gas that the DOE EIA reports as used for vehicle fuel is discernable. Figure 2-2 shows that California natural gas consumption for the categories other than vehicle fuel has remained relatively constant for the last eight years. But natural gas for vehicle fuel use has steadily grown to where it totaled 3.84 billion scf (31 million gge) in 2004 (the most recent year with vehicle fuel use data in the EIA database). Still, this quantity was only 0.17 percent of total 2.4 trillion scf of statewide natural gas use for the year. The 31 million gge of CNG combined with the estimated 23 million gge of LNG represents 0.28 percent of total petroleum transportation fuel use of 19.9 billion gal in 2004.

[16] Marks, M., and DiGiovanna, M., *Natural Gas Assessment Update,* CEC-600-2005-003, February 2005

[17] Maul, D., *California's Natural Gas Context,* CEC presentation dated December, 2004 (available at: [www.energy.ca.gov/papers/2004-12-14_MAUL_NATGAS.PDF)].

[18] [www.eia.doe.gov/oil_gas/natural_gas/info_glance/natural_gas.html].

[19] [www.eia.doe.gov/pub/international/iea2004/table41.xls].



Source: DOE EIA Annual Energy Outlook 2006.

Figure 2-4. Projections of future U.S. natural gas vehicle fuel consumption and prices.

Table 2-4. Projected estimated petroleum fuel displacement in California.

	2012	2017	2022	2030
Natural gas vehicle fuel consumption, bcf				
U.S.	60	80	100	120
California	11	15	19	22
Petroleum fuel displaced, mmgge				
California	88	120	152	176

Source: DOE EIA Annual Energy Outlook 2006.

petroleum fuel displaced equal to the California vehicle fuel use quantities are also given. The table indicates that by 2030, the petroleum fuel displaced by natural gas fuel will total 176 million gge. This quantity is in the range of that estimated in the supporting documentation for the 2005 IEPR for CNG use in light duty vehicles, 82 million gge in 2025, but is less than the total displacement of 1.2 billion gge in 2025 (0.08 bgge CNG in LDVs plus 1.1 bgge for CNG/LNG use in HDVs) for a business as usual scenario.[23]

[23] Fong, D., *et al.*, "Options to Reduce California's Petroleum Fuel Use — In Support of 2005 Integrated Energy Policy Report," CEC-600-2005-024-ED2, July, 2005

The 88 mmgge projected displacement in 2012 is consistent with a 6 percent annual increase from the 53 mmgge total natural gas use in 2004 to 2012.

Availability of Vehicles

Light Duty Natural Gas Vehicles

General Motors and Honda offer 2006 model year OEM light duty NGVs. Their specific offerings are listed in Table 2-5. In the last column in Table 2-5, "dedicated" denotes vehicles that operate only on natural gas, and "bi-fuel" denotes vehicles that can operate on either natural gas or gasoline (not to be confused with dual-fuel natural gas engines, which are discussed subsequently). All commercially available light duty NGVs store natural gas fuel as compressed natural gas (CNG), typically at a maximum pressure of 3,600 psi. Bi-fuel NGVs have both CNG and gasoline fuel tanks. More detailed NGV specifications such as fuel tank capacity and vehicle range are available from the DOE Alternative Fuels Data Center website.[24]

Table 2-5. 2006 model year original equipment manufacturer light duty NGVs available in the U.S.

Manufacturer	Brand	Model	Powertrain	Emissions Cert.	CNG Fuel Sys.
General Motors	Chevrolet	Silverado Pickup Truck	6.0-L V8	ULEV & CA SULEV	Dedicated
General Motors	Chevrolet	Silverado Pickup Truck	6.0-L V8	ULEV	Bi-Fuel
General Motors	GMC	Sierra Pickup Truck	6.0-L V8	ULEV & CA SULEV	Dedicated
General Motors	GMC	Sierra Pickup Truck	6.0-L V8	ULEV	Bi-Fuel
Honda	Civic	GX Sedan	1.7-L I4	SULEV Tier 2, Bin II	Dedicated

Source: DOE Alternative Fuels Data Center[24] and manufacturers' web sites

OEM NGVs qualify for various tax credits. Moreover, Honda has teamed with the FuelMaker Corporation to market the "Phill" CNG home fueling appliance with the Civic GX shown in Figure 2-5. This home refueling appliance also qualifies for various discounts, tax credits, and (in the South Coast Air Quality Management District) copayments.

[24] [www.eere.energy.gov/afdc/].

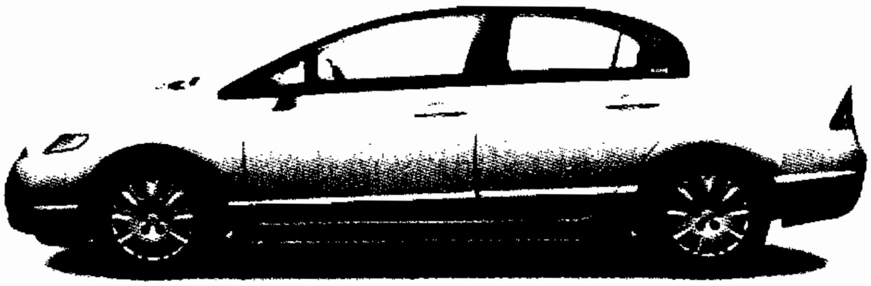


Figure 2-5. The 2006 Honda GX NGV is certified to EPA's ultra-low Tier 2, Bin II exhaust emissions category.

Other OEMs that formerly offered light duty NGVs, including Ford, Daimler-Chrysler, and Toyota, have recently discontinued all NGV product offerings in the U.S. For example, the Ford CNG Crown Victoria, which was a popular choice for fleets ranging from taxi cabs to police cruisers that needed a full-size sedan, was discontinued by Ford in 2004. Only a BAF conversion (see below) can be used in this market niche. The reduced number of light-duty CNG vehicles marketed by OEMs in the U.S. has been a disappointment to NGV advocates such as the California Natural Gas Vehicle Coalition (CNGVC). Interestingly, OEM's such as Ford, Daimler-Chrysler (Mercedes), Volvo, Volkswagen, Toyota, Nissan, Peugeot, and Fiat offer many light-duty NGV products in European and Asian markets that are not available for sale in the U.S. This has variously been attributed to factors including the investment needed for emissions and crashworthiness certification and the relatively low cost of gasoline in the U.S.

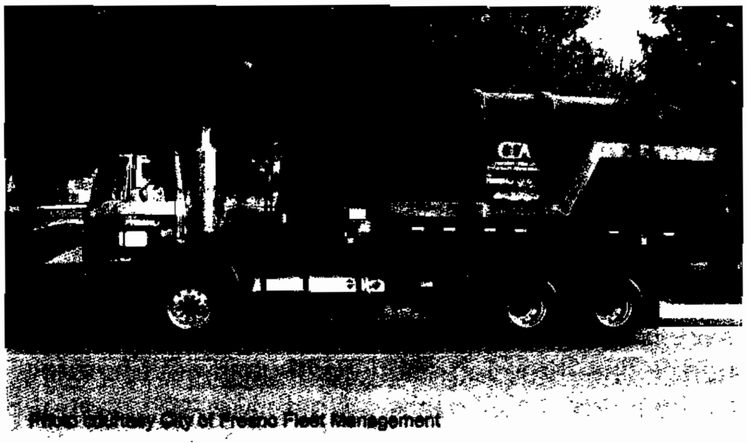
Many of the approximately five million NGVs in the rest of the world are gasoline vehicles that have been modified or retrofitted to operate on natural gas. The retrofit equipment includes natural gas injectors or mixers, CNG fuel tank(s), and various safety and control systems. In the U.S., EPA-approved equipment must be used for NGV conversion. In addition, in California, the equipment must be certified by ARB. Technically, since 2003, ARB no longer certifies natural gas retrofit equipment. Engines or vehicles with this equipment are ARB-certified as such. Companies such as Baytech and BAF have obtained EPA and ARB certifications in the past. The only MY 2006 engine conversion that has an ARB certification is BAF conversion of the Ford 4.6-L engine which can be used in the Ford Crown Victoria, Mercury Grand Marquis, and Lincoln Town Car.

Heavy Duty Natural Gas Vehicles and Engines

Nearly all heavy duty NGVs in California are in one of the following categories: buses, refuse trucks, and Class 8 tractors (that pull semi-trailers). Figures 2-6, 2-7, and 2-8 show examples of heavy duty NGVs in each of these categories. While light duty NGVs almost always utilize CNG fuel tanks and fueling stations, many heavy duty NGVs have liquefied natural gas (LNG) fuel tanks and are refueled at LNG fueling stations. LNG, which must be maintained at cryogenic temperatures as low as -260°F, is much denser

Source: Los Angeles Metropolitan Transit Authority

Figure 2-6. Many transit agencies in California operate natural gas transit buses. This is one of the 2,200 CNG buses operated by the Los Angeles Metropolitan Transit Authority.



Source: City of Fresno

Figure 2-7. Approximately 1,270 refuse trucks in California are natural gas fueled, such as this City of Fresno LNG truck.

Source: Harris Ranch

Figure 2-8. This Harris Ranch LNG-fueled Class 8 tractor is an example of the various natural gas fueled tractor-trailer rigs operating in California.

than CNG. Therefore, LNG fuel tanks are smaller and lighter than CNG tanks providing the same vehicle range.

Natural gas fueled buses in the California population include transit buses, school buses, airport and other special shuttle buses, and small buses such as used for paratransit service. As of the beginning of 2006, there were approximately 4,965 natural gas transit buses operating in California, which represents 44 percent of the total of 11,285 transit buses in the state. Approximately 4,629 of these were CNG fueled and 336 were LNG fueled.[25] The growth in the number of natural gas transit buses to the fraction achieved in California to date has been influenced by the ARB transit rule and the South Coast Air Quality Management District (SCAQMD) Fleet Rule 1192. Recent changes by ARB to the transit rule relaxed the strict emission requirements applicable to agencies that had elected the diesel path, and this may slow the growth of natural gas transit buses in California.[26] Transit buses and school buses make up most of California's natural gas fueled bus population. However, various other bus fleets are natural gas fueled. For example, Los Angeles World Airports has operated several LNG fueled 40-foot airport shuttle buses since 1994.

Refuse trucks include refuse collection trucks, recyclable material collection trucks, and refuse transfer trucks. Refuse transfer trucks, which are substantially fewer in number than collection trucks, are basically Class 8 semi tractor-trailer trucks. Refuse collection trucks are the fastest growing heavy duty NGV application in California. The rapid growth of natural gas fueled refuse collection trucks in California is largely the result of SCAQMD Fleet Rule 1193 and the Carl Moyer Program. It has recently been reported that, as of 2005, there were 1,268 natural gas refuse trucks operating in California: 699 of these were LNG fueled, 131 were CNG fueled, the specific fuel type for the remaining 266 trucks could not be determined.[27] The three largest natural gas fleet operators in California were the City of Los Angeles (252 LNG trucks), Waste Management of San Diego (126 LNG trucks), and the County of Sacramento (105 LNG trucks).

Heavy duty natural gas engines are quieter than diesel engines, and this has been a significant factor for refuse collection applications. Customers also appreciate the green image associated with natural gas refuse trucks.

Other on-road heavy duty NGV applications are primarily tractors that pull semi-trailers. Most of these are Class 8 tractors, which are the largest and most powerful tractors that (when combined with a fully loaded trailer) can have a GVW as high as 80,000 lb. These tractor-trailer trucks are used for various applications such as warehouse-to-retailer delivery of grocery and other products, refuse transfer (from receiving stations to landfills), and agriculture operations (e.g., Figure 2-8). All of these are return-to-base fleet operations. Early natural gas truck analyses suggested that the most economical applications would be line-haul trucks because their very high annual mileage and fuel

[25] 2006 Transit Vehicle Database, American Public Transportation Association, May 2006.

[26] [www.arb.ca.gov/regact/sctransit/sctransit.htm].

[27] Cannon, J., *Greening Garbage Trucks: Trends in Alternative Fuel Use, 2002-2005*, Inform, Inc., report, ISBN #0-918780-84-5, 2006.

consumption would enable the fuel cost savings to offset the incremental capital costs.[28] In fact, this expectation was the impetus for the Interstate Clean Transportation Corridor (ICTC) concept.[29] However, the challenge associated with a natural gas refueling infrastructure for line-haul interstate trucking has been formidable, and the ICTC project has focused primarily on return-to-base fleets. Even though these trucks usually have significantly lower annual fuel consumption, refueling is much more straightforward.

Almost all natural gas large tractor-trailer trucks are LNG fueled because range is usually important, the space available for fuel tank(s) on the tractor is limited, and the incremental weight of the fuel tank(s) affects payload capacity and therefore economics. Smaller trucks, many of which are more properly classed as medium duty, are more likely to be equipped with CNG fuel tanks.

There are also various natural gas fueled off-road vehicles in California. For example, the City of Long Beach and other municipalities operate natural gas fueled street sweepers auxiliary power units, which are encouraged by SCAQMD Fleet Rule 1186.1. LNG-fueled yard tractors are used by the Port of Los Angeles and Von's grocery stores. Los Angeles City Sanitation operates a few LNG-fueled implements such as landfill graders.

Nearly all heavy duty vehicles were originally designed to use diesel fuel. Even though heavy duty vehicles are usually considered to be a better natural gas application than light duty vehicles, replacement of a diesel engine with an equivalent natural gas engine is not as straightforward as replacing a gasoline engine. This is primarily because diesel engines are compression-ignition (as opposed to gasoline engines and most heavy duty natural gas engines, which are spark-ignition) due to the better fuel efficiency and durability of compression-ignition engines. Compression-ignition engines require fuels that, when mixed with air, will ignite when compressed to a high pressure and temperature (in technical terms, this fuel characteristic is measured by the cetane number). Natural gas doesn't have suitable compression-ignition characteristics, so some other means must be provided to ignite the natural gas mixture. All natural gas engines utilize either spark ignition or diesel pilot ignition.

Unlike the ARB certification process for light duty applications in which the entire engine-vehicle combination is certified via chassis dynamometer testing, in heavy duty applications only the engine is certified via engine dynamometer testing. Available MY 2005 and 2006 heavy duty natural gas engines that are certified to ARB's exhaust emission standards are listed in Table 2-6.

[28] Powars, C., Moyer, C., and Lowell, D., *LNG Vehicle Technology, Economics, and Safety Assessment*, GRI-94/0051, February, 1994.

[29] [www.gladstein.org/ictc/index.php].

Table 2-6. Recent ARB-certified heavy duty natural gas engines. Includes heavy-heavy and medium-heavy duty diesel and urban bus test procedure certifications. Does not include Otto engine test procedure certifications.

Model Year	Manufacturer	Engine Model[1], Displacement (L)	Power Rating (hp)	Fuel Type	Service Class[2]	Certif. Std.[3] (g/hp-hr) NO_x+NMHC, PM	CARB EO Date
2006	Cummins	BG, 5.9	195, 200, 230	CNG&LNG	MHD	1.8, 0.01	9/2/05
2006	Cummins	CG, 8.3	250, 275, 280	CNG&LNG	MHD	1.8, 0.01	9/2/05
2006	Cummins	LG, 8.9	320	CNG&LNG	MHD	1.5, 0.01	9/2/05
2006	Deere	8.1	275, 280	CNG&LNG	HHD	1.2, 0.01	9/21/05
2006	Deere	8.1	250	CNG&LNG	MHD	1.2, 0.01	9/21/05
2006	Deere	8.1	250, 275, 280	CNG&LNG	UB	1.2, 0.01	9/21/05
2006	Mack	E7G, 11.9	325, 425	CNG&LNG	HHD	2.4, 0.10	10/18/05
2006	Westport	ISXG, 14.9	425, 464	LNG; DF[4]	HHD	1.2, 0.02	3/2/06
2005	Cummins	CG, 8.3	250, 275, 280	CNG&LNG	UB	1.8[5], 0.01[5]	12/20/04
2005	Cummins	LG, 8.9	320	CNG&LNG	UB	1.4[5], 0.01[5]	8/4/04
2005	Cummins	LG, 8.9	320	CNG&LNG	MHD	1.4[5], 0.01[5]	8/4/04
2005	Detroit Diesel	50G[6], 8.5	275	CNG&LNG	UB	1.2, 0.01	12/2/04
2005	Detroit Diesel	50G[6], 8.5	275	CNG&LNG	UB	1.2[5], 0.01[5]	12/2/04

Notes:

1 - Only most recent shown for same engine manufacturer, model, ratings, and service class

2 - MHD = medium heavy duty under diesel test procedure, HHD = heavy heavy duty under diesel test procedure, UB = urban bus (EOs for NG engines certified under Otto test procedure are not listed here)

3 - Note that certification test emissions are usually < standard (see CARB EO database)

4 - EO is for "BF (CNG/diesel)" but this is believed to be in error because ISXG is dual-fuel (DF) with only LNG to date

5 - Certification is for "Family Emission Limits" and not "Standards"

6 - Detroit Diesel ceased production of Series 50 and 50G engines in September, 2004

Source: ARB Certification Database

Vehicle Range and Fuel Economy

The range of NGVs is usually less than that of counterpart gasoline and diesel vehicles because the volumetric energy densities (e.g., Btu/ft^3 or J/L) of CNG and LNG are approximately 30 percent and 55 percent, respectively, of gasoline or diesel fuel. Moreover, owing to their need to either contain high pressures or provide thermal insulation, CNG and LNG fuel tanks are significantly heavier than gasoline or diesel tanks. NGV range is often an important issue for many light duty and heavy duty vehicle applications. NGV fuel economy is also an important consideration, primarily because it affects vehicle operating costs, and secondarily because it affects range. The following paragraphs discuss fuel economy and range data for light duty and heavy duty vehicles.

Light duty vehicles in the U.S. almost always have spark ignition gasoline engines, and the efficiency of gasoline and natural gas spark ignition engines is usually very similar. Factors such as higher compression ratios enabled by the high knock resistance (i.e., octane rating) of natural gas, which increase power and efficiency, are offset by other factors such as the air displaced by natural gas, which decreases power and efficiency.

Also, current natural gas engine designs are not as highly optimized for maximum efficiency as gasoline engines. Therefore, vehicle fuel economy, as measured by miles per gallon (mpg) for gasoline vehicles and miles per gasoline gallon equivalent (mpgge) for NGVs, is generally similar for light duty NGVs and gasoline vehicles. Obviously, real-world fuel economy depends on specific driving profiles as well as other factors such as passenger or cargo load, air conditioner usage, and driving terrain.

Vehicle driving range is equal to the product of fuel economy (discussed above) times the usable fuel in the fuel tank. The usable fuel in the fuel tank is a subtle issue for both CNG and LNG vehicles. The usable fuel volume is always less than the tank internal volume. For CNG, this is because various effects such as heat-of-compression and temperature-compensation often cause slightly less than a full quantity (mass) of fuel to be delivered into the tank during refueling. Fuel cannot be consumed beyond the point where the tank pressure has decreased to the minimum engine fuel supply pressure requirement. For LNG, a small vapor space (ullage) must be left in the tank during refueling to allow for liquid phase expansion. Even if all the liquid in the tank could be consumed, some vapor-phase natural gas remains in the tank.

Table 2-7 summarizes the fuel economy ratings, fuel tank capacity, and approximate driving range for the previously considered 2006 model year OEM light duty CNG vehicles: the Honda Civic GX sedan and Chevrolet Silverado pickup truck (which has the same basic power train and chassis as the GMC Sierra pickup truck). For the Civic GX, these quantities are compared to corresponding quantities for the 2006 Civic gasoline-fueled sedan. For the Chevrolet/GMC pickup trucks, the counterpart gasoline pickup truck is the 2006 Silverado 1500 2WD model.

Most currently operating heavy duty NGVs have spark-ignition natural gas engines that operate in the lean-burn mode. These engines have generally been able to meet applicable diesel engine emission standards without substantial exhaust gas recirculation (EGR), NO_x-reduction aftertreatment devices, or particulate traps. This situation will change, however, as the 2007-2010 emissions standards phase in. Due to throttling losses and other factors, spark-ignition lean-burn natural gas engines are not as efficient as their counterpart diesels. Their efficiency is typically reported to be in the range of approximately 77 to 83 percent of diesel engine efficiency.[30,31,32,33,34,35,36,37] Precise natural gas to diesel relative fuel economy data are not easy to obtain from

[30] *Liquefied Natural Gas for Heavy-Duty Transportation*, Arthur D. Little, Final Report No. FR-01-101 for GTI and Brookhaven National Laboratory, May, 2001.

[31] Royer, R., *Baytech Light-, Medium-, and Heavy-Duty Gaseous fuel Systems*, presented at the 2005 Natural Gas Vehicle Technology Forum Meeting, Washington, DC, August 2-4, 2005.

[32] Calvert, B. *BAF Technologies*, presented at the 2005 Natural Gas Vehicle Technology Forum Meeting, Washington, DC, August 2-4, 2005.

[33] Schneider, J., *Evaluation of Fueling Performance Targets for Onboard 70 MPa Gaseous Hydrogen Storage Containers*, paper presented at the 2006 National Hydrogen Association Conference, Long Beach, CA, March 13-16, 2006.

[34] Mulligan, N. *Hydrogen and Natural Gas Blends: Converting light and Heavy Duty Vehicles*, Collier Technologies presentation at DOE 2005 Hydrogen Program review, Washington, DC, May 25, 2005.

Table 2-7. Fuel economy and range data for the 2006 OEM light-duty NGVs considered here.

NGV	Dedicated NGV			Gasoline Counterpart		
	Fuel Economy (City/Hwy)	Fuel Tank Capacity	Est. Typ. Range[2]	Fuel Economy (City/Hwy)	Fuel Tank Capacity	Est. Typ. Range[2]
2006 Honda Civic GX	28/39 mpgge[1]	8.03 gge	200-250 mi.	30/38 mpg[1]	13.2 gal	390-528mi
2006 Chevrolet Silverado & GMC Sierra Pickup Trucks (9200 lb.GVWR)	9/12 mpgge[3]	21.3 gge	170-210 mi.	14/19[1,4]	34 gal	470-640 mi

Notes:
1 - EPA rating (gge = gasoline gallon equivalent), from [http://www.fueleconomy.gov/]
2 - Max. possible based on EPA FE and tank capacity
3 - From [http://www.eere.energy.gov/afdc/]
4 - For a Silverado 1500 2WD

Source: References noted

actual replicated field experience. Factors that thwart straightforward comparisons include: counterpart diesel vehicles have substantially different routes or duty cycles, natural gas or diesel refueling data are suspect or not recorded, or vehicles are sometimes defueled for maintenance. Organizations such as the National Renewable Energy Laboratory (NREL) collect, analyze, and report performance data from selected heavy duty NGV fleet demonstrations and deployments. Table 2-8 summarizes average natural gas to diesel relative fuel economy results for some example fleets. It is important to recognize that most of the data listed in this table resulted from demonstrations of old-model or developmental natural gas engines, and the fuel economy is inferior to that of current-generation engines such as those listed in Table 2-6. Figure 2-9 shows the general progression of increasing fuel economy with time. Many of the spark-ignition natural gas engines that are now being developed to meet the 2007-2010 heavy duty emission standards are stoichiometric (e.g., chemically correct air-fuel ratio) combustion instead of lean burn, and these are reported to have superior fuel economy.

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35 Munshi, S., *Hydrogen ICEs: Technology and its Potential*, Westport presentation at the California Hydrogen Business Council Meeting, Diamond Bar, CA, May 19, 2006.

36 [www.nrel.gov/vehiclesandfuels/ngvtf/engines/htm].

37 [www.nrel.gov/vehiclesandfuels/ngvtf/engines/html].

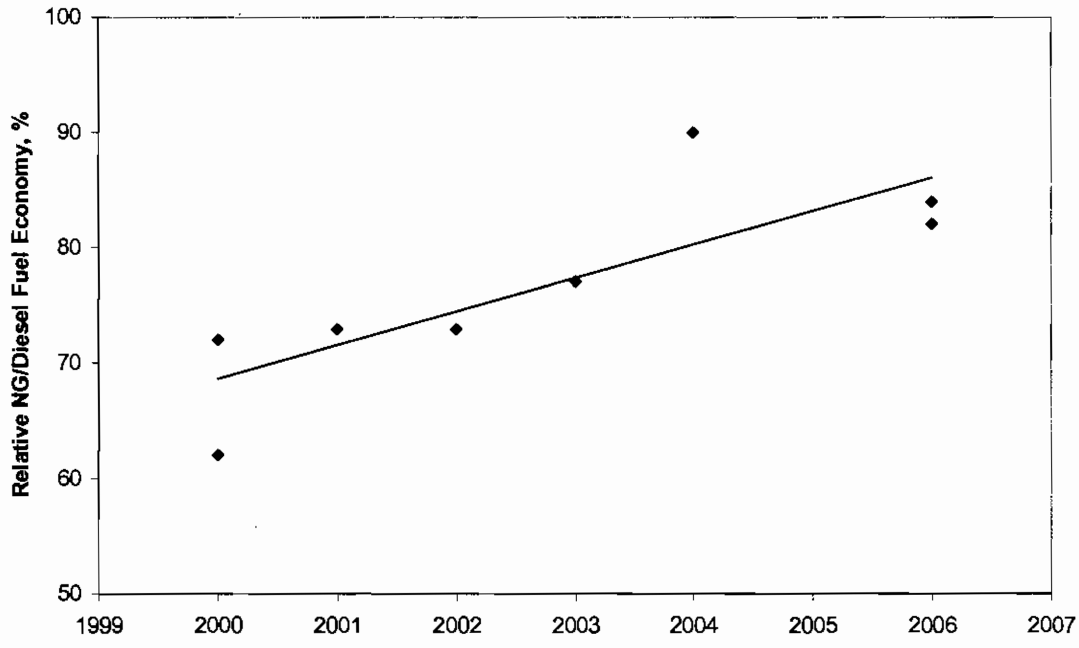
Table 2-8. Example heavy duty NGV fleet average fuel economy results relative to diesel. Note that most of the reported results are for prior-generation or developmental natural gas engines.

Application & Fleet	NG Engine Type[1]	Engine Mfgr. & Model	Avg. or Typ. NG/Diesel Fuel Economy	Report Ref. No. (Date)
Transit Bus, Washington Metro	SI, LB	CWI[4] CG+ (8.3 L) Deere 6081H (8.1 L)	82% 84%	17 (2006)
Transit Bus, DART[2]	SI, LB	Cummins L-10 280G (10 L)	72%	18 (2000)
Refuse Collection, Waste Management[3]	SI, LB	Mack E-7G (11.9 L)	73%[5]	19 (2001)
Class 8 Tractor, Refuse Transfer, Norcal	DF, HPDI	Westport ISXG (14.9 L)	90%	20 (2004)
Class 8 Tractor, Freight, Viking	SI, LB	CWI[4] CG+ (8.3 L)	77%	21 (2003)
Class 8 Tractor, Grocery Dist., Raley's	SI, LB	Cummins L-10 300G (10 L)	62%	22 (2000)
Package Delivery Truck, UPS	SI, LB	Cummins BG (5.9L)	73%	23 (2002)

Notes:

1 - SI = Spark Ignition, DF = Dual Fuel, LB = Lean Burn, HPDI = high pressure Direct Injection
2 - DART = Dallas Area Rapid Transit
3 - Washington, PA
4 - CWI = Cummins Westport Inc.
5 - 88-91% indicated during chassis dynamometer emissions testing

Source: Various [30, 31, 32, 33, 34, 35, 36, 37]



Source: Data in Table 2-8

Figure 2-9. Fleet average heavy duty NGV relative fuel economy has improved over time.

The range of heavy duty NGVs depends on the engine fuel consumption rate (which is affected by the driving pattern), the capacity of the fuel tank(s), and other secondary factors mentioned previously. Both the natural gas fuel tank capacities and in-service fuel consumption rates of heavy duty NGVs vary considerably depending on the application, CNG or LNG fueling, and the specific vehicle configuration.

Table 2-9 lists typical in-service fuel consumption rates, fuel tank capacities, and resultant driving ranges, for natural gas transit buses, refuse collection trucks, and other Class 8 truck applications. There are substantial variations in these quantities depending in the specific fleet application and vehicle equipment, and some heavy duty NGVs may have characteristics significantly different from those in Table 2-9.

In general, it is not practical to equip a heavy duty NGV with enough CNG or LNG capacity so that it's driving range equals that of a comparable diesel vehicle with maximum diesel fuel capacity. This is a problem for a few applications, but in most cases it is not.

Table 2-9. Heavy duty NGV typical in-service average fuel consumption rates, fuel tank capacities, and resultant driving ranges.

NGV Application	Typical Fuel Consumption Rate (mpdge[1])	CNG			LNG		
		Typical Usable Fuel Capacity		Typical Range	Typical Usable Fuel Capacity		Typical Range
		(scf)	(dge)	(miles)	(LNG gal)	(dge)	(miles)
Transit buses	2 - 4.5	20,000	150	450	250	150	450
Refuse Collection Trucks	2 - 3	7,000	50	130	150	90	220
Class 8 Tractors	4 - 8	–[2]	–[2]	–[2]	170	100	600

Notes:
1 - mpdge = miles per diesel gallon energy equivalent
2 - Most natural gas Class 8 tractor trailers are LNG
Source: Various

Vehicle and Engine Costs

NGVs currently cost significantly more than their gasoline or diesel counterparts. This is true for both light duty and heavy duty NGVs. Table 2-10 lists the retail price (MSRP) of the manufacturer's suggested 2006 model year light duty NGVs, the specifications of which were summarized in Table 2-5. Table 2-10 also lists the MSRP of similarly equipped gasoline vehicles, and the resultant incremental price of the NGV. While the incremental price of light duty NGVs is significant, available government programs provide various financial incentives such as tax credits, which can affect most of the incremental costs.

Table 2-10. Retail price of light duty NGVs and counterpart gasoline vehicles.

NGV	Vehicle Type	Dedicated NGV MSRP[1]	Gasoline Counterpart MSRP[1]	Incremental Price
2006 Honda Civic GX	4-door sedan, AT[2]	$24,440	$19,260[3]	$5,180
Chevrolet Silverado 2500HD[4]	Pickup Truck, Reg. Cab, 2-Whl. Dr., AT[2]	$33,345	$23,795	$9,550
GMC Sierra 2500HD[4]	Pickup Truck, Reg. Cab, 2-Whl. Dr., AT[2]	$33,345	$23,795	$9,550

Notes:

1 - MSRP = manufacturer's suggested retail price (from manufacturers' web sites, June, 2006)
2 - AT = automatic transmission
3 - MSRP for gasoline Civic EX is $19,260. GX is not a precise counterpart of any gasoline model.
4 - Silverado and Sierra in various configurations are available with dedicated CNG. Incremental price = $9,550 in all cases

Source: Manufacturers websites, June 2006.

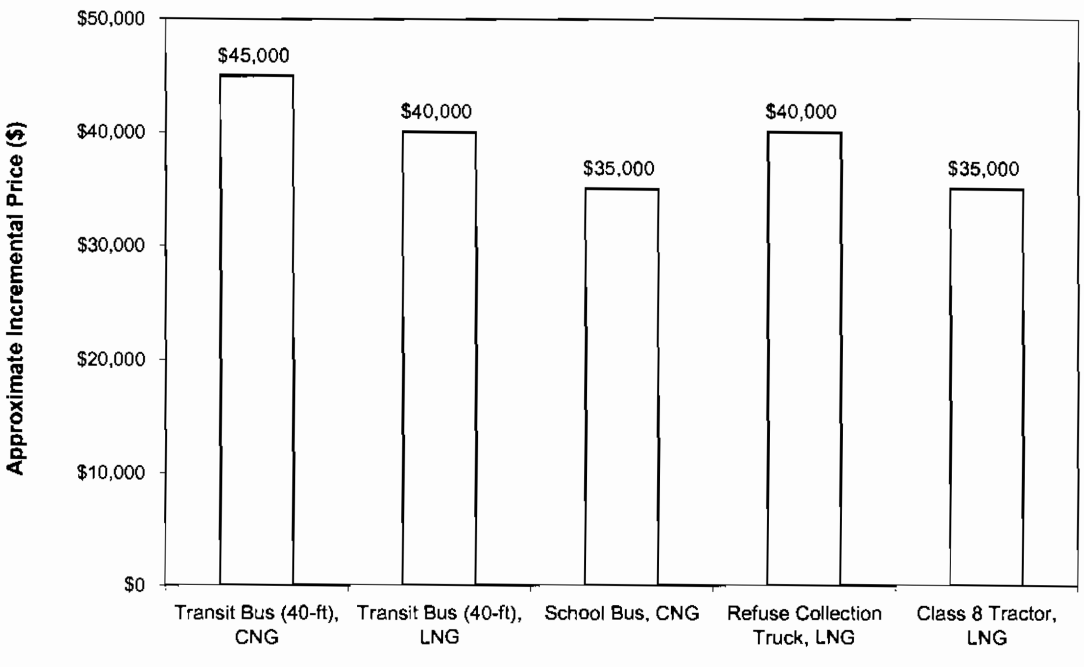
Heavy duty NGVs can be either CNG or LNG fueled. Most natural gas transit buses in California are CNG fueled (roughly 90 percent), and all natural gas school buses are CNG fueled. Based on data cited above, approximately 12 percent of California's natural gas refuse trucks are CNG and 88 percent are LNG. Most natural gas fueled Class 8 tractors are LNG because LNG provides more compact storage to support longer range operations, the tractor chassis space available for fuel tanks is limited, and LNG fuel tanks have the same general shape and aspect ratio as diesel tractor fuel tanks.

Heavy duty NGVs are currently assembled and sold in two ways, which affects how they are purchased and their price. Nearly all full-size natural gas transit buses are manufactured and sold on a bid basis by transit bus OEMs such as Gillig, New Flyer, North American Bus Industries, and Orion. Most natural gas school buses are manufactured and sold in the same fashion. These OEMs assemble buses by manufacturing parts (e.g., chassis, body) and procuring other parts (e.g., natural gas engines, CNG and LNG fuel tanks). In a few cases, bus OEMs subcontract to specialists to install natural gas fuel systems. Overall, most natural gas buses are manufactured and sold by OEMs in a fashion analogous to diesel buses.

Some natural gas refuse trucks are manufactured by OEMs (e.g., Mack), and others are assembled by firms or truck dealers that specialize in installing natural gas engines, tanks, and fuel systems. These firms or dealers are often referred to as "upfitters." In some cases, upfitters basically convert a new diesel truck or new partial truck by adding the natural gas engine, CNG or LNG fuel tanks, and associated systems. At this time, no natural gas fueled Class 8 tractors are manufactured in truck OEM factories and sold as standard OEM truck models. Currently operating natural gas Class 8 tractors (nearly all of which are LNG) are diesel trucks converted by dealers or other upfitters, though a few have been assembled during special one-time factory runs.

The purchasing and pricing of natural gas trucks converted by upfitters is more complicated than a straight purchase from the OEM or through a dealer. In many studies, heavy duty NGV prices have been estimated by adding the incremental natural gas engine cost, the LNG or CNG fuel tank and system cost, and the upfitting cost, to the new diesel truck or tractor cost. However, there is no simple MSRP for natural gas trucks and buses, and there is no published MSRP for heavy-duty natural gas engines. Therefore, the question, "How much does a NGV cost?" is more difficult to answer for heavy duty NGVs than for light duty NGVs. This variability in the process for building heavy duty NGVs is reflected in the DMV data, which tends to undercount the actual number of NGVs in service.

Perhaps the best way to characterize the incremental price of heavy duty NGVs is from previous purchase information. Figure 2-10 summarizes representative incremental prices (i.e., relative to equivalent diesel) for various types of heavy duty NGVs. These price differentials are based on various reports from fleets and studies, and from applications for financial incentives such as the Carl Moyer Program. The representative price increments shown in Figure 2-10 are very approximate, and there are substantial higher and lower variations. These apply to prior NGV purchases. Future heavy duty NGV purchases may involve substantially different economics. Applications for grant funding may represent the high end of the actual range of incremental price.



Source: Various reports and Carl Moyer Program funding applications

Figure 2-10. Representative incremental prices of heavy duty NGVs relative to comparable diesel vehicles.

Fueling Infrastructure and Specific Needs

Fueling station designs and fuel supply infrastructures are well developed but quite different for CNG and LNG. To complicate matters further, some CNG vehicles are refueled at stations that receive and store natural gas as LNG; these stations are referred to as L/CNG stations. CNG and LNG fueling infrastructure supports a variety of applications and circumstances. Essentially all light duty NGVs, including some individually owned non-fleet NGVs, are CNG fueled. Heavy duty NGVs, such as buses (transit, shuttle, and school buses), refuse collection trucks, Class 8 tractors, and a few other types of trucks and non-highway vehicles, may be either CNG or LNG fueled. All heavy duty NGVs are part of a vehicle fleet and none are individually owned.
Figures 2-11 through 2-13 show examples of California-located fueling stations of each type. Because CNG, LNG, and L/CNG station designs and fuel supply infrastructures are different from each other, each is discussed separately in the following subsections.

CNG Fueling Stations and Fuel Supply

There are many CNG fueling station types, capacities, and applications. Some, such as the example shown in Figure 2-11, are public access stations that accept credit cards just like most gasoline stations. Others, such as most CNG transit bus stations, are not accessible by the general public. CNG station refueling rate capabilities vary by orders of magnitude, from well over 1,000 scfm (which is approximately 8 gge/min) per dispenser for some CNG transit bus stations to less than 1 scfm for the Phill home fueling appliance.

The most common type of CNG station is the cascaded fast-fill configuration. Natural gas from a pipeline is metered, dried, and compressed. The compressed gas is stored in a bank of pressure vessels, which are filled and drawn from in a cascaded sequence in order to provide the maximum number of vehicles with full fills in the shortest time.

The two main variations on the CNG station configuration described above are direct fast-fill and time-fill stations. For many high-throughput stations, such as used at some transit bus facilities, it is more practical to directly match the compressor capacity to the desired refueling rate, in which case the pressure vessel cascade can be replaced with a smaller capacity buffer vessel or vessels. At the other extreme, if slower refueling rates are acceptable (e.g., CNG vehicles refueled while they are parked overnight), then time-fill CNG refueling can be employed. Time-fill facilities have much smaller compressors (or one compressor simultaneously filling multiple vehicles) and no pressure vessel cascade or individual vehicle metering. Small time-fill CNG fueling equipment includes the FuelMaker vehicle refueling appliance (VRA), which is installed outside many small businesses and private homes, and the Phill appliance, which is installed inside residential garages.[38] Phill, which is being marketed in conjunction with the Honda Civic GX with various financial incentives, is regarded by many NGV

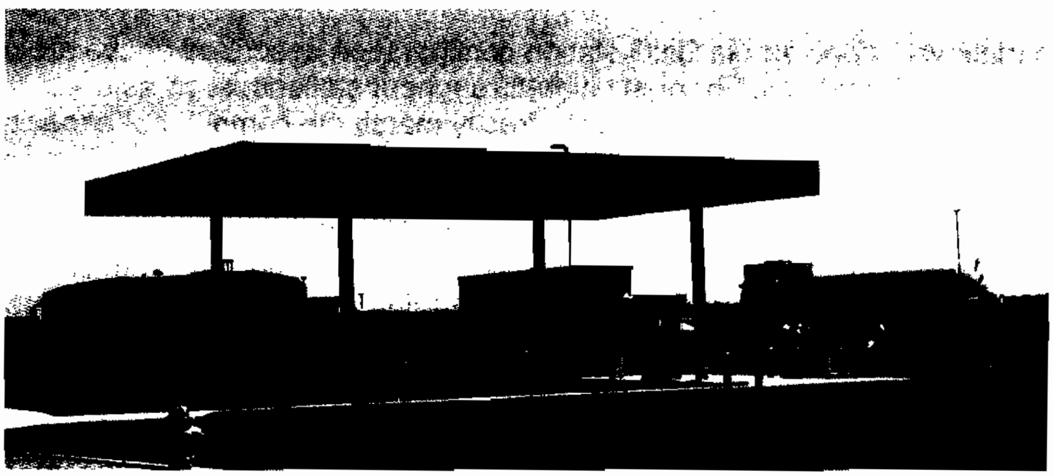
[38] [www.fuelmaker.com].

Figure 2-11. CNG fueling station example: This public-access station at the San Francisco Airport is used by airport shuttles and taxis.

Source: Clean Energy

Figure 2-12. LNG fueling station example: This Waste Management station in Corona is a typical LNG refuse truck fleet station

Source: Waste Management, Inc.



Source: Southwest Transportation Agency

Figure 2-13. L/CNG fueling station example: This Southwest Transportation Agency station in Caruthers (near Fresno) dispenses CNG from the island on the left and LNG from the island on the right.

stakeholders as a potential solution to the vehicle- infrastructure "chicken-or-egg" dilemma that has inhibited individually owned light-duty CNG vehicle market growth.

How many CNG fueling stations are there in California? This simple question doesn't have a precise answer because nobody keeps an exact count and there is some ambiguity regarding which types of CNG stations to count, i.e., public access stations, private fleet stations, home fueling appliances? A variety of recent references have reported the number of CNG stations in California, which are counted or referenced in different ways.

The CEC 2005 Integrated Energy Policy Report (IEPR) states that there are 365 CNG stations in California, 40 percent of which are public access.[39] The California Natural Gas Vehicle Coalition (NGVC) presentation to the CEC Non-Petroleum Fuels Working Group in 2004 indicated that, at that time, there were 300+ natural gas fueling stations in California, 50 percent of which were public access (CNG and LNG stations were not considered separately).[40] The 2005/2006 California NGVC Natural Gas Fueling Station Directory lists 118 CNG stations in California that are more-or-less public access (although many of these do not accept conventional credit cards such as MasterCard and Visa, some require special call-ahead arrangements for public access, and a few are actually L/CNG stations).[41] The Clean Car Maps website maintained by WestStart/Calstart lists 165 California CNG stations, although a few of these are noted as "private," and some are noted as "not operating" (typically because equipment is out of order).[42] A 2003 California NGVC presentation tabulated 206 California CNG stations, 81 of which were cited as being public access.[43] This table was reproduced in the 2003 California Clean Fuels Market Assessment report.[44] The number cited in Table 2-1 of this report is consistent with the 2005 IEPR.

The economics of CNG fueling stations are a direct function of their natural gas throughput. In simple terms, the capital and operating costs must be amortized by the fuel sold (in the case of a public access station) or dispensed (in the case of a private fleet station). An unfortunate paradox is that the CNG stations that dispense the least amount of fuel are the 100 percent public access stations that are not associated with any particular fleet. For this reason, the numbers of these types of stations have been decreasing in California. At present, less than ten CNG stations are integrated with retail gasoline stations, and no California CNG stations are operated as joint ventures with major petroleum companies. Previously, companies such as Shell Oil dispensed CNG at a few of their California gasoline stations.

[39] *2005 Integrated Energy Policy Report*, CEC-100-2005-007 CMF, November, 2005.

[40] Eaves, M., *Natural Gas Vehicle Role in Fuel Diversity for California*, presentation to CEC Non-Petroleum Fuel Working Group, October 17, 2004.

[41] [www.cnvc.org/ngv/cngvc.nsf/attached/directory_05-6-20.pdf/$FILE/directory_05-6-20.pdf].

[42] [www.cleancarmaps.com/home/sitelistsearchcng.php?type=CNG].

[43] Eaves, M., *The California Program*, presentation to the Natural Gas Vehicle Technology Forum meeting, Albany, NY, September 9, 2003.

[44] Leonard, J., *California Clean Fuels Market Assessment 2003*, CEC-600-03-015C, August, 2003.

A related challenge that inhibits public use of CNG fueling stations is the fact that most "public access" stations do not accept conventional credit cards such as MasterCard or Visa. This is mainly because the potential revenue from non-fleet users of these stations does not justify the hardware, software, and contractual expense associated with conventional credit card reading and accounting.

Certain transit bus fueling facilities are the CNG stations that have the most fuel throughput and therefore the best economics. Transit buses are usually refueled in rapid succession in the evening by trained technicians using high-capacity fast-fill equipment. For example, the new CNG fueling facility being installed at the Orange County Transit Authority Santa Ana base will dispense almost 40,000 mscf per month (i.e., about 320,000 gge/month).[45]

Nearly all of the CNG stations in California are "anchored" by user fleets. Example CNG vehicle fleets that anchor these stations include government agency light-duty vehicle fleets, school buses, refuse collection trucks, airport shuttle buses and vans, taxi cabs, delivery trucks, and natural gas utility service vehicles. Some of these CNG stations are private, but many are open for public-access CNG vehicle fueling. However, some of these stations are located in industrial areas or large fleet service yards and are not as convenient as conventional retail gasoline stations.

In the California post-deregulation era, CNG fueling station ownership and operation is shifting from the gas utilities to private companies such as Clean Energy, Trillium, Pinnacle, and others. There are many options and business models involving different CNG station financing, construction, ownership, operation, and maintenance. Different companies specialize in different business arrangements and services. Some companies have purchased CNG stations from gas utilities; some will build and operate stations (including natural gas purchase contracting) for fleets on a take-or-pay arrangement, where the fleet agrees to a minimum fuel throughput; and some prefer to sell what is basically a compression service to fleets that do their own gas purchase contracting. As pointed out in many NGV stakeholders' meetings, what no companies will do at this time is construct and operate CNG fueling stations based on a "build it and they will come" expectation.

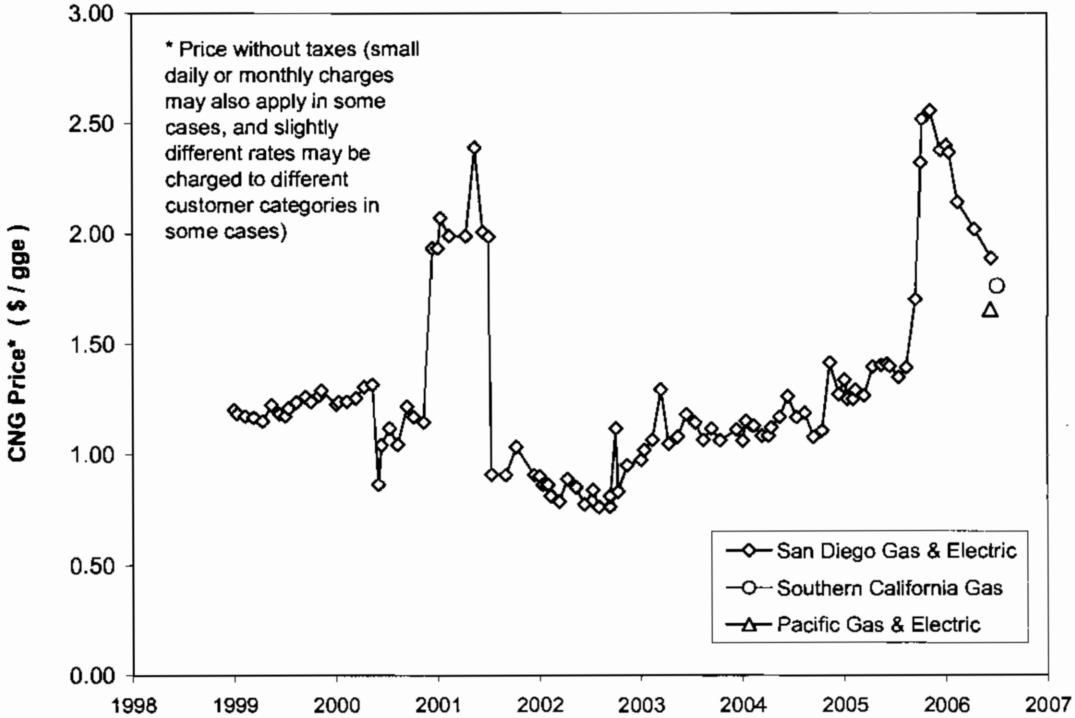
The "price" paid for CNG at any given time depends on the type of sale. In general, there are three broad categories of CNG sales:

1. Retail CNG sales at public-access fueling stations operated and/or owned by natural gas utilities
2. Retail CNG sales at public-access fueling stations operated and/or owned by private companies
3. Fleet vehicle refueling at public-access or private CNG stations that may be operated and/or owned by the fleets themselves

[45] Ryan Erickson, Orange County Transportation Authority, personal communication, June 1, 2005.

The vast majority of California CNG sales are in Category 3. However, CNG prices for Category 1 sales are the most straightforward to characterize. This is because the natural gas utility owners of these stations must file tariff advise letters with the California Public Utilities Commission (PUC). Figure 2-14 shows the CNG prices, in dollars per gasoline gallon equivalent ($/gge), at stations operated by California natural gas utilities since 1999. In their California PUC filings, the utilities break out these prices in terms of their components. For example, Table 2-11 shows these components and corresponding prices for the Southern California Gas Company filing that took effect on July 1, 2006.

The CNG retail price at Category 2 public-access stations is the posted price, which is set by the station owners, just like retail gasoline stations. Clean Energy owns and operates more public-access CNG stations in California than any other private company, and their website lists their retail CNG price for their Southern California stations. For June of 2006, this price was $2.399/gge.[46]



Source: Natural gas utilities' tariff advice letters filed with the California PUC

Figure 2-14. Prices for CNG dispensed at public access stations owned and operated by natural gas utilities.

46 [www.cleanenergyfuels.com/main.html].

Table 2-11. Example price breakout for CNG sold at stations owned and operated by California natural gas utilities

Component	Price
Gas procurement	$0.692/gge
Gas transmission	$0.117/gge
Gas compression	$0.948/gge
Total	$1.757/gge

Source: Natural gas utilities' tariff advice letters filed with the California PUC

Far more CNG is dispensed from Category 3 stations which service NGV fleets than Category 1 and 2 stations, and the cost of CNG to fleets using these stations is generally much less than the posted price at retail CNG stations. Therefore, the most visible CNG price, the posted price, creates the misimpression that CNG is more expensive than it really is. The actual "price" of CNG at Category 3 stations is, however, difficult or impossible to quantify because most of the information relating to this price is private business information. Nevertheless, while the details of contracts between CNG station operators and NGV fleets are usually confidential, Clean Energy computed and disclosed the average selling price of CNG (which includes both retail and contract fueling) from their company-owned stations in Southern California for the month of June, 2006.[47] Table 2-10 compares this price to the previously cited posted retail price for the same time period. The fact that the average CNG selling price shown in Table 2-12 is 31 percent lower than the posted retail price illustrates the misimpression created by using posted retail prices at public-access stations as a reference for actual CNG vehicle fuel prices.

Table 2-12. Average price of CNG sold from Clean Energy CNG stations in Southern California during June, 2006, compared to posted retail price.

Average CNG price paid by retail and contract customers	$1.65/gge
Posted CNG retail price	$2.40/gge

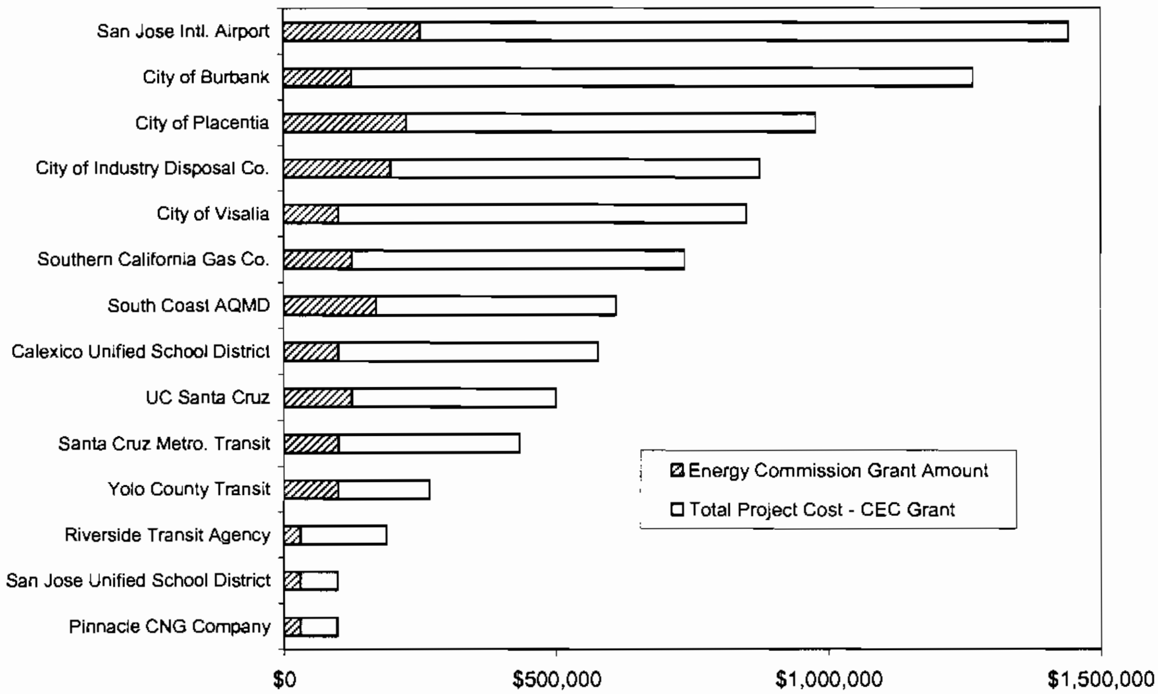
Source: Clean Energy[10]

The capital cost of CNG fueling stations depends on many factors, but the maximum dispensing rate and how long that rate must be maintained are the main cost-determining specifications. On the "high" end of this scale are large heavy duty CNG vehicle fleet (e.g., transit bus) stations that desire to refuel in rapid sequence (or simultaneously) within a given time window. This typically requires a substantial

[47] Brian Powers, Clean Energy, personal communication, June 30, 2006.

compressor capacity (e.g., a few thousand scfm), and such stations can cost several million dollars. Stations with refueling requirements that are more evenly distributed throughout the day can use lower-capacity compressors with a pressure vessel cascade, which reduces the capital cost. At the "low" end of the cost scale are low-capacity fast-fill CNG stations and time-fill stations.

Many CNG fueling stations have been partially funded by government agencies such as the U.S. Department of Transportation (for transit bus stations), California air quality management districts, and the Energy Commission, including Clean Cities grants funded by DOE and managed by the Energy Commission. Figure 2-15 shows the total costs and Commission-cofunded amounts for 14 California CNG fueling stations.[48] This chart also illustrates the substantial variations in CNG station capital costs.



Source: California Energy Commission[48]

Figure 2-15. California CNG fueling stations recently supported by CEC showing total cost and CEC-funded amount.

[48] Progress report on the Clean Fueling Station Infrastructure Program, January 9, 2006; in personal communication from J. Wiens, Energy Commission, July 31, 2006.

The primary operating cost of CNG stations is the cost of compression, i.e., the cost of energy to drive the compressor(s). Most compressors are powered by electric motors, but a few are powered by natural gas fueled internal combustion engines. Although gas engines are usually less expensive to operate, they are sometimes problem prone and difficult to permit. Compressor drive motor electric power requirements are often approximately 0.4 kW/scfm, but there are substantial variations associated with different gas supply pressures, compressor types, and other variables. The daily cost of compression is the product of the kW/scfm rate, compressor capacity in scfm, hours per day of compressor operation, and electricity cost.

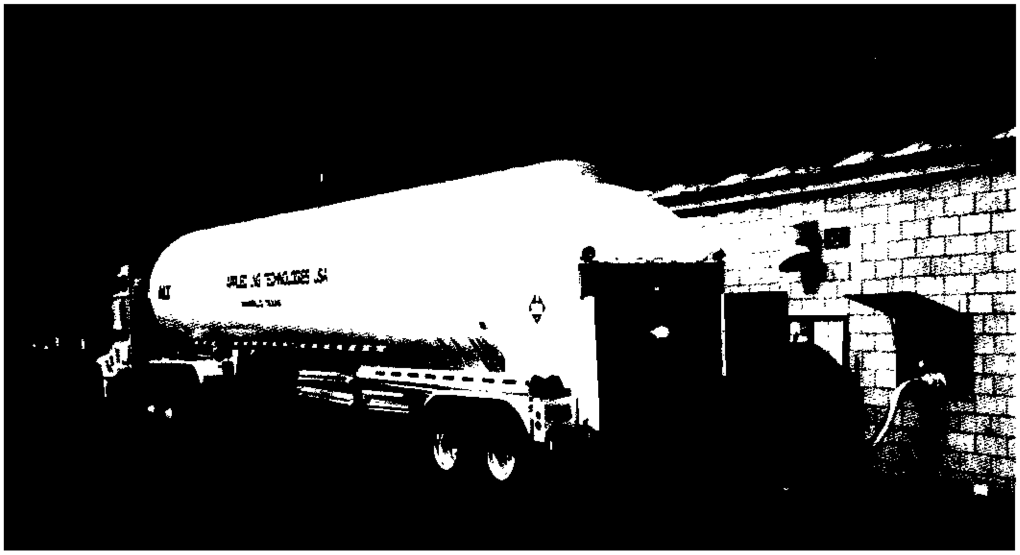
Other station operation and maintenance expenses are primarily personnel, service, and equipment costs. Compressors and dryers are not usually low-maintenance components, and special skills are often required for problem diagnosis and repairs. For these reasons, fleets sometimes elect to contract for CNG station operation and/or maintenance services. Some fleets prefer not to own the station but to purchase the CNG refueling service on a contract basis. Various companies have made it a business to provide CNG station services tailored to fleet customers' needs. In some cases, this involves building and operating a station at the customer's site. The contractor may also purchase the natural gas, in which case the customer pays an agreed-on amount for CNG dispensed into their vehicles over a given time period. An example of this type of arrangement in California is Trillium's ownership and management of the Los Angeles County Metropolitan Transportation Authority (LACMTA) CNG fueling facilities.

The current program to provide a discounted Phill CNG home fueling appliance with Honda Civic GX purchases was mentioned above. FuelMaker reports that, as of mid-July, 2006, 107 Phill units have been installed in California and orders have been received for 26 additional units.[49] Phill units have been installed throughout California, but the heaviest concentration is in the Southern California area.

LNG Fueling Stations and Fuel Supply

The infrastructure supporting LNG-fueled vehicles is quite different from the pipeline-to-station infrastructure supporting CNG-fueled vehicles. LNG is transported from natural gas liquefaction plants to LNG fueling stations in cryogenic tank trucks like that shown in Figure 2-16. In that regard, the LNG fuel infrastructure more closely resembles the gasoline and diesel fuel delivery infrastructure. LNG delivered by the cryogenic tank trucks is stored in insulated tanks at the station. The tank liquid capacity is selected based on the anticipated station dispensing rate and the desire to receive deliveries frequent enough so that heat leaks don't cause product venting (by raising the LNG saturation pressure to the tank pressure relief device set point). It is most economical to accept a full rather than partial LNG tank truck load, so most LNG station storage tanks are at least 13,000-15,000 gallons.

[49] Jeff Harju, FuelMaker Corporation, personal communication, July 24, 2006.



Source: ALT USA

Figure 2-16. LNG is transported from natural gas liquefaction plants to LNG fueling stations in cryogenic tank trucks, which hold 10,000 to 12,000 gallons.

From the storage tank, LNG is pumped through the dispenser and into the vehicle tank during refueling operations.[50] Because of the higher density of LNG compared to CNG, and because pumps are less expensive and have lower power requirements than compressors, it is more straightforward to provide high refueling rates (e.g., gge/min) with LNG stations than with CNG stations.

Recall from the above discussion that essentially all LNG vehicles in California are heavy-duty, return-to-base fleet vehicles such as large trucks and transit buses. Therefore, at this time, there is little need for public access LNG stations. This situation may change in the future if LNG line-haul trucks (i.e., trucks that refuel at various stations along interstate or intrastate routes) become a reality as envisioned by the original ICTC.

There are approximately 41 LNG and L/CNG fueling stations operating in California as of mid-2006. These stations and their locations are listed in Table 2-11. No official tabulation of California LNG, L/CNG, or CNG stations is maintained. Table 2-11 was constructed from information obtained from various press releases, board meeting minutes, reports, and websites. A source of frequent station name ambiguity is the fact that refuse truck LNG stations are sometimes listed by the municipality name and sometimes by the name of the current refuse contractor. LNG stations maybe equipped to also dispense CNG using L/CNG systems, because it is relatively straightforward and

[50] A few early-generation LNG fueling stations used a pressure-transfer process instead of a pump, but all full-scale permanent LNG stations currently operating in California employ a cryogenic pump for fuel transfer.

economical to add this capability. Of the 41 stations listed in Table 2-13, 28 are LNG only, 10 are LNG and L/CNG, and 3 are L/CNG only. Some of the LNG stations listed in Table 2-11 are available for access by other LNG vehicles through advance arrangements, but this is done very infrequently. As indicated in the table, there are clusters of stations in the population centers of the state: Los Angeles, San Francisco, San Diego, Sacramento, and Fresno.

There is no official monitoring of the quantity of LNG consumed by LNG vehicles in California. In principle, this quantity could be evaluated by summing the quantity of LNG sold as a transportation fuel, or summing the quantity of LNG purchased by station owners/operators, or by computing the total consumed by all vehicles. Essentially, all LNG transportation fuel in California is sold by one of two companies: Applied LNG Technologies USA (ALT USA, which is now owned by Apollo Resources) and Clean Energy. Both companies consider the quantity of LNG they sell to be private business information. In theory, the quantities of LNG purchased by user fleets could be surveyed and summed, but this has not been done. Researchers have estimated and summed the average daily mileage of all California LNG vehicles divided by their respective miles per LNG gallon fuel consumption, but the most recent documented calculation of this type was in 2001.[51] While there has been no rigorous survey or calculation in this regard, the LNG transportation fuel consumption in California in mid-2006 is estimated to be slightly less than 100,000 LNG gallons per day, and this magnitude range estimate has been confirmed by companies that sell LNG.

The cost of LNG delivered to fueling stations has three main components:

$$\text{Delivered LNG cost} = \text{Feed gas cost} + \text{Liquefaction Cost} + \text{Transportation cost}$$

The liquefaction cost includes amortization of the liquefier and gas pretreatment equipment capital cost, as well as their operating and maintenance cost. The power needed to drive the compressors that are part of most liquefaction cycles is significant.[52] LNG tank truck transportation costs are usually estimated to be approximately $0.0004 per LNG gallon-mile.[53] In most cases, pipeline gas is supplied to the liquefaction plant, and so the feed gas cost relates to the natural gas commodity prices. The price of LNG delivered to customers includes the above-described cost elements plus a profit or return-on-investment for the LNG fuel supply business and their investors. A variety of

[51] Powars, C., and Pope, G., *California LNG Transportation Fuel Supply and Demand Assessment*, CEC P600-02-002F, January, 2002.

[52] For example, if the compressors are driven by natural gas engines, roughly 10 to 20% (depending on the plant size, liquefaction cycle, feed gas pressure, etc.) of the feed gas flow is needed to drive the compressors.

[53] *Liquefied Natural Gas for Heavy-Duty Transportation*, Arthur D. Little Final Report FR-01-101, prepared for Brookhaven National Laboratory and Gas Technology Institute, May, 2001.

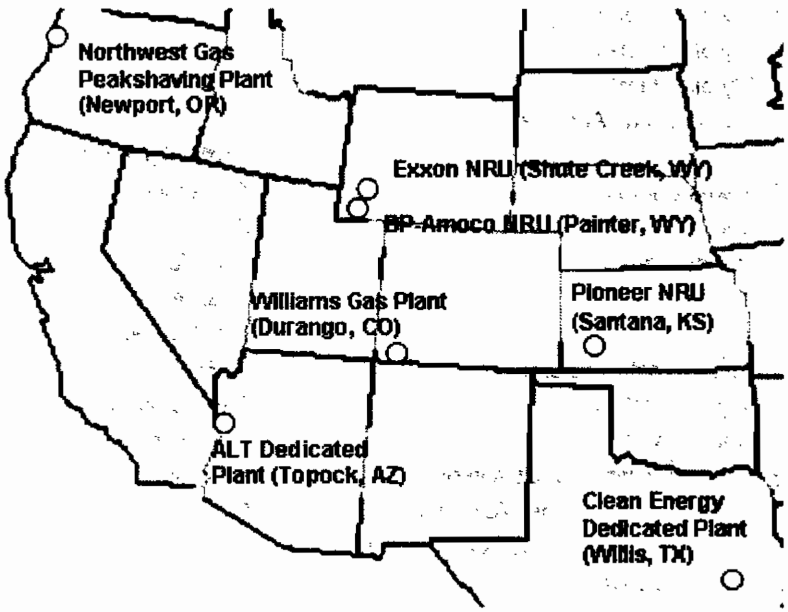
Table 2-13. LNG and L/CNG fueling stations operating in California as of mid-2006.

Station Operator / Name	Location
Anaheim Disposal	Anaheim
City of Bakersfield	Bakersfield
City of Barstow*	Barstow
City of Carson	Carson
City of Fresno	Fresno
City of Long Beach	Long Beach
City of Redlands*	Redlands
City of Los Angeles	Los Angeles (East)
City of Los Angeles	Los Angeles (West)
City of Sacramento*	Sacramento
City of San Diego	San Diego
City of Tulare*	Tulare
County of Los Angeles	Whittier
County of Sacramento*	North Highlands
Downs Energy*	Temecula
FreeStar / UPS*	Ontario
GI Industries	Simi Valley
Harris Ranch	Coalinga
L. A. World Airports	Los Angeles
Norcal Waste Systems	S. San Francisco
OmniTrans**	San Bernardino
OmniTrans**	Montclair
Orange County Transit Authority	Anaheim
Orange County Transit Authority	Garden Grove
Riverside County Waste Management*	Riverside
Santa Cruz Transit**	Santa Cruz
Santa Monica Big Blue Bus*	Santa Monica
Solano Garbage	Fairfield
Southwest Transportation*	Caruthers
Sysco Food Services	Walnut
Taormina Industries	Anaheim
The Vons Companies	Santa Fe Springs
USA Waste (Waste Management)	Fresno
Vons Groceries	Santa Fe Springs
Waste Management	Baldwin Park
Waste Management	Palmdale
Waste Management	El Cajon
Waste Management	Corona
Waste Management	Oakland
Waste Management	Irvine
Waste Management / SunLine Transit	Thousand Palms

* LNG & L/CNG ** L/CNG only

Source: Various press releases, board meeting minutes, reports, and websites strategies is being used or investigated to minimize one or more of the cost elements LNG cost equation, and these are briefly described in the following paragraphs.

Figure 2-17 is a map showing the primary sources of the LNG transportation fuel delivered to California. Most of the LNG comes from the purpose-built liquefaction plant in Topock, Arizona, owned by ALT USA. This 86,000-gpd capacity plant receives gas from the large interstate pipeline that enters California at that location. Much of the LNG delivered to California by Clean Energy is produced at one of the two large nitrogen rejection unit (NRU) facilities in Wyoming. It is reasonable to surmise that the "plant gate" price of LNG at these facilities (which were built and financed for other purposes) is relatively low, but the transportation cost to California is relatively high. Clean Energy also owns the purpose-built 108,000-gpd capacity plant in Willis, Texas, which was previously owned by ALT USA.



Source: CEC P600-02-002F[51]

Figure 2-17. Sources of California LNG transportation fuel.

Because California is dependent on so few sources of LNG, with all sources being located outside of the state, and some quite distant, LNG supply disruptions have occurred, which are a major inconvenience to LNG vehicle fleets. There have also been concerns that LNG supplies are not growing as fast as the demand. To address these concerns, the Commission and SCAQMD have sponsored LNG supply/demand projections, new liquefier technology R&D, and new LNG plant installations. To date, none of these projects has produced a significant increase in California's LNG supply.

The capital cost of LNG fueling stations depends on many factors, but the most critical factor is usually the capacity of the LNG storage tank(s). Other important cost-influencing factors include the specific site conditions, number of dispensers, desired dispensing rate, storage tank number and installation (e.g., aboveground or underground), and various special features (e.g., inclusion of L/CNG capability, "on-thefly" conditioning, separate LNG tank truck offloading pump, weights-and-measures certified dispensers, special vapor-management capabilities).

As noted above, LNG fueling stations should be able to accept full LNG tank truck loads of approximately 10,000 gallons, while maintaining some additional capacity to accommodate realistic variations in usage rates and delivery schedules. Therefore, minimum-capacity stations with about 15,000 gallons of storage are commonly specified for truck fleets acquiring LNG trucks. Most LNG station design and installation companies such as Chart, General Physics, and Northstar have developed what are often called "cookie-cutter" designs for these small-capacity LNG stations. They usually include one vertical 15,000-gallon LNG tank, one dispenser (which is usually a dispenser panel integrated into the code-required impoundment wall), a transfer pump submerged in an LNG-filled vessel, a conditioning circuit (to raise the LNG saturation pressure to match engine fuel pressure requirements), and various safety features. For ideal site conditions, the installed cost of these basic stations can be as low as about $700,000, but specific site challenges and/or desired extra features often increase the price.

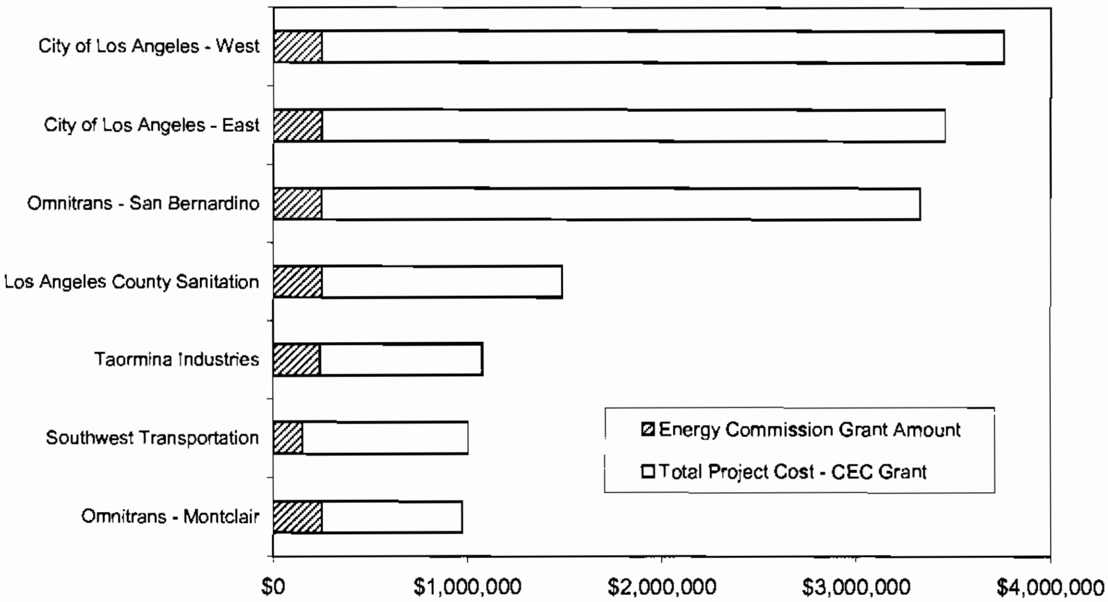
At the other end of the scale are some high-capacity LNG fueling stations for large transit bus or truck fleets, which may have 60,000 gal of LNG storage capacity, multiple dispensers, dispensing rates as high as 50 LNG gal/min (which is equivalent to 4,200 scfm and is more than any CNG station dispensing rate), and various special features. The cost of high-capacity LNG stations of this type can be as high as the $2 to $3 million range.

Figure 2-18 shows the total costs and Commission-cofunded amounts for seven California LNG and L/CNG stations. The figure illustrates the substantial variation in LNG and L/CNG station prices.

Various skid-mounted, portable, and mobile LNG fueling equipment is also available to support temporary refueling needs. These systems utilize relatively small-capacity LNG tanks; 6,000 gal is typical. Cryogenics companies offer standard design temporary (e.g., skid-mounted) and mobile (e.g., truck-mounted) LNG fueling equipment.[54] While this equipment can provide a low initial-cost solution for temporary LNG fueling requirements, permitting issues sometimes delay utilization because most of the same codes and standards for permanent LNG stations also apply to temporary and mobile LNG fueling facilities.

The operating costs of LNG stations are generally less than those of CNG stations because the power required to drive LNG pumps is substantially less than the power required to drive CNG compressors. Other operating cost elements are usually regarded as being similar for LNG and CNG stations, although there has been no published data collection and analysis study to confirm this.

[54] [www.nexgenfueling.com/p_fs_selectionguide.html].



Source: California Energy Commission[48]

Figure 2-18. California LNG and L/CNG fueling stations recently supported by CEC showing total costs and CEC-funded amount.

The main differences between LNG and CNG stations are obviously the completely different natural gas supply infrastructures and station components. The fact that natural gas is stored at LNG stations and not at CNG stations is sometimes considered an advantage (i.e., in the event of a pipeline supply disruption). However, to date there have been more supply problems with LNG than with pipeline natural gas. Another practical LNG - CNG station difference is the fact that, while some LNG stations have "limited public access," none are truly public access in the conventional sense.

As with CNG stations, LNG station operation and maintenance training is usually provided as part of the station design and construction contract. Various firms offer LNG station maintenance service contracts for fleets that prefer this option. At least one company, Clean Energy, is prepared to offer a "take-or-pay" contract service where they would dispense LNG at an agreed-on price from a station that they would install and own at the fleet's site, if the fleet agrees to purchase a minimum quantity of fuel over a specified time period. While this type of fueling contract has been used for CNG, no such contracts are in place for LNG.

An important characteristic that is unique to LNG (and L/CNG) is the "use it or lose it" aspect. That is, if no fuel is consumed from LNG vehicle or station fuel tanks, heat leaks will increase the LNG saturation pressure until that pressure is equal to the pressure relief device (PRD) set point. Additional heat leak produces venting to the atmosphere.[55] Venting can occur from LNG vehicles that are not driven for periods of roughly five days (or vehicles with higher than normal fuel tank heat-leak rates, e.g., due to a "soft vacuum"), or from stations that dispense very small quantities of LNG. LNG vaporization losses as high as 10 percent have been estimated,[56] although there have been no methodological measurements to confirm this estimate. There have also been various attempts and suggestions aimed at eliminating or reducing venting,[57] but most experts agree that frequent LNG vehicle usage and adequate LNG station throughput are the ultimate solutions. Significant LNG venting compromises economics, increases greenhouse gas emissions, and may create a safety hazard.

L/CNG Fueling Stations and Fuel Supply

LNG-to-CNG (L/CNG) fueling stations are an option that enables CNG vehicles to be refueled using an LNG fuel delivery infrastructure. A key advantage relative to a conventional CNG station is that a relatively low-cost and low-power-consumption, high-pressure cryogenic liquid pump replaces the gas compressor. Secondary advantages are that no dryer is needed and a lower capacity pressure vessel cascade or buffer can be used. These advantages are at least partially offset by the need for an LNG storage tank and heat exchanger.

Two types of L/CNG fueling stations have been installed in California (see also Table 2 13).

1. L/CNG stations combined with LNG stations — There are approximately ten of these LNG-plus-L/CNG, stations in California. An example is the Southwest Transportation Agency station, which is shown in Figure 2-13. If an LNG station is available or planned, the addition of a CNG fueling capability by adding L/CNG components is a relatively low-cost option.

2. L/CNG-only stations — This type of station has been built for CNG fleets that prefer an L/CNG station over a conventional compressor station and have no need for LNG fueling. The Omnitrans station shown in Figure 2-19 is an example of an L/CNG-only station.

[55] The vapor venting rate is very approximately equal to the heat leak rate divided by the LNG heat of vaporization (which is approximately 156 Btu/lb at a typical PRD set point of 230 psi).

[56] Wegrzyn, J., *Energy, Efficiency, and Economics of LNG & L/CNG*, presentation to Natural Gas Vehicle Technology Forum meeting, Dallas, Texas, January 28, 2003.

[57] Techniques for eliminating LNG vehicle and/or fueling station venting include reliquefaction, vent gas utilization for purposes such as electric power generation, and refueling strategies that do not require fuel to be conditioned (saturation pressure increased) in the storage tank. None of these are in common use as of mid-2006.

Source: Omnitrans

Figure 2-19. This Omnitrans station in Montclair, California, is an example of an L/CNG-only station. The LNG storage tank, vaporizer, and gas pressure vessel cascade are seen here. The pumps are behind the retaining wall and the CNG dispensers are about 50 yards away.

The Omnitrans stations dispense more fuel than any other L/CNG stations in California, and these stations are a good case study regarding L/CNG applications. Omnitrans is the transit agency serving the San Bernardino Valley area, and their two L/CNG stations are located in San Bernardino ("East Valley") and Montclair ("West Valley,"). Omnitrans previously used pipeline-supplied compressor-type CNG fueling equipment, which experienced significant problems including poor reliability of the natural gas engine drives, neighborhood complaints regarding odors (associated with residual odorant in the dryer effluent) and compressor noise, and slow refueling rates. All of these problems were solved after replacing the compressor stations with L/CNG stations.[58] While Omnitrans clearly prefers L/CNG systems for refueling their CNG buses, the tradeoffs are subtle and not all CNG fleets share this preference. For example, Orange County Transit Authority (OCTA) carefully evaluated both pipeline-compressor and L/CNG options for their new Santa Ana CNG station, and they elected to install a pipeline-compressor station.

Another aspect of using L/CNG technology for CNG vehicle fleet refueling is cited as advantage by some users: current LNG supplied to California is generally purer (i.e., has higher methane content) than typical pipeline natural gas. Even though the pipeline gas meets, and usually exceeds, the gas purity specifications for all current-generation natural gas engines, some fleets with older-generation engines prefer the higher purity

[58] Bach, R., *LNG-to-CNG Transit Bus Refueling Station Success*, presentation to APTA Bus and Paratransit Conference, Milwaukee, Wisconsin, May, 2003.

L/CNG fuel. Some fleets that must forward budget for fuel purchases prefer the "guaranteed" price type of LNG supply contracts, although other fleets point out that the same benefit can be achieved with hedged pipeline natural gas contracts.

L/CNG stations cost slightly more than LNG stations because a high-pressure (e.g., 4,000+ psi capability) pump and vaporizer are required. The cost for adding L/CNG capability to an LNG station is $150,000 to $250,000.[59] Issues involving LNG fuel sourcing and costs, potential supply disruptions, station operation and maintenance, and training programs for L/CNG stations are similar to the previously described issues for LNG stations.

Barriers and Opportunities for Expansion

Future prospects for NGVs in California are uncertain. Some industry representatives or stakeholders suggest that a tipping point has been reached and light duty and/or heavy duty NGV populations will grow rapidly in the future, while others speculate that this will not be the case. Some previous goals discussed for California NGV growth may have been overly optimistic. As documented in the CEC 2003 California Clean Fuels Market Assessment,[59] NGV industry stakeholders joined with the SCAQMD and other government agencies to form the California Natural Gas Vehicle Partnership (CNGVP) in 2002. Goals established by the CNGVP in 2002 include.[60]

- 33,000 and 90,000 new light duty NGVs in California within 3 and 5 years, respectively
- 10,000 and 25,000 new heavy duty NGVs in California within 3 and 5 years, respectively

These goals have not been met. What is the outlook for NGVs in California going forward from mid-2006? Future NGV growth is difficult to predict. While there are compelling factors that indicate substantial growth potential, there are also many factors that indicate otherwise. Some of these positive and negative factors are listed in Table 2-14. Two of the most important factors are recent Federal tax credit legislation and the 2007 – 2010 EPA and ARB heavy duty emission standards.

The Energy Policy Act of 2005 (EPact), provides significant tax credits to buyers of new dedicated NGVs and installers of CNG and LNG fueling stations (including home fueling appliances). The 2005 Highway Bill contains an important $0.50 per gallon excise tax credit paid to sellers of CNG and LNG. These and other new financial incentives substantially enhance the economic proposition of NGV ownership and operation.

[59] Leonard, J., *California Clean Fuels Market Assessment 2003*, CEC-600-03-015C, August, 2003.

[60] [www.cngvp.org/news_press_8.html].

Table 2-14. Recent factors potentially affecting future NGV growth in California.

Factors that may encourage substantial future light duty and/or heavy duty NGV growth in California	Factors that may discourage substantial future light duty and/or heavy duty NGV growth in California
NGV economic incentives in the 2005 Energy Policy Act and Highway Bill	Limited variety of OEM light duty NGV offerings
Heavy duty natural gas engines meeting 2007-2010 emission standards likely to be cost competitive with diesel engines	Decreased emissions advantage of heavy duty NGVs relative to diesel vehicles that attain near zero 2007-2010 emission standards
Availability of "Phill" home fueling appliance for light duty NGVs	Limited selection of certified heavy duty natural gas engines and few OEM factory-produced natural gas trucks
Public outrage regarding gasoline prices	Concerns regarding potential LNG fuel supply disruptions
Public concerns about global warming	Public interest in NGVs dwarfed by interest in hybrids, biofuels, and hydrogen fuel cell vehicles
Public desire to reduce petroleum imports	Government funding for NGV RD&D orders of magnitude less than funding for hydrogen fuel cell vehicles
Availability of ARB-certified NGV aftermarket equipment and upfitted engines/vehicles	Possible continued "cheating" on EPAct compliance by fueling bi-fuel vehicles with gasoline
NGVs recognized as a practical step toward hydrogen vehicles	
Possible increased scrutiny to correct "cheating" on EPAct compliance by fueling bi-fuel vehicles with gasoline	

Source: This analysis

The implications of near zero 2007 – 2010 EPA and ARB heavy duty emission standards are subtle. On the one hand, it is unlikely that natural gas engines will have a substantial regulated pollutant emission advantage over new compliant diesel engines by 2010. This will decrease some financial incentives such as those currently available under the Carl Moyer Program. On the other hand, diesel engines meeting the 2010 standards will be significantly more expensive (and probably slightly less efficient). It is anticipated that heavy duty natural gas engines can be certified to the 2010 standards with less complicated and expensive exhaust aftertreatment systems than those required for certified diesel engines. How will these factors play out? The CNGVP, SCAQMD, and Southern California Gas Company commissioned TIAX to analyze and compare the life cycle costs of natural gas and diesel transit buses, refuse collection trucks, and short-haul trucks in 2010 and beyond.[61] This comprehensive analysis predicts that, by 2010, neither fuel choice (natural gas or diesel) will have a clear life cycle cost advantage. In particular, after 2010, natural gas trucks and buses will have lower life cycle costs depending on future price ratios of LNG and CNG relative to diesel

[61] Schubert, R., and Fable, S., *Comparative Costs of 2010 Heavy-Duty Diesel and Natural Gas Technologies*, TIAX Final Report for Case No. D020286/D020288, July, 2005.

fuel, the level of NGV market penetration, and the costs of emission control technologies for heavy duty natural gas and diesel engines.

What are the prospects for future growth specific to the LNG vehicle marketplace and fueling infrastructure in California? Some factors indicate a potential for substantial growth while other factors present obstacles. Three positive factors and two negative factors that may affect future LNG vehicle and infrastructure growth in California are:

- Positive: The economic case and societal benefits of LNG-fueled return-to-base heavy-duty vehicle fleets is relatively sound compared with many other alternative transportation fuel options. Recent studies indicate that the economics may be even better in the future when diesel engine and fuel costs increase in order to meet the 2007-2010 emission standards.

- Negative: Many of the heavy-duty vehicle applications that are good candidates for LNG fueling are Class 8 trucks that require engines in the 400+ horsepower range (which usually have displacements of 11 liters or more). As of mid-2006, there is a dearth of certified natural gas engines in this category (see Table 2-4). The Mack E7G engine is only available in Mack trucks. The Westport ISXG engine is just now transitioning from the demonstration phase to a commercial product. The lack of high-horsepower natural gas engine products has motivated government agencies such as SCAQMD to cofund development programs. If current efforts to develop new high horsepower natural gas engines to meet the 2007-2010 emission standards are not successful, the lack of high-horsepower natural gas engine choices will make it difficult to achieve significant growth in the important high fuel consuming goods movement market sector.

- Positive: It is more straightforward to apply fleet rules (and financial incentives, in many cases) that encourage alternative fuel use to certain classes of heavy duty fleet vehicles, relative to other classes of vehicles. Moreover, LNG is often the alternative fuel of choice for many heavy duty vehicle fleets. Recent settlement of disputes regarding the SCAQMD 1190 series of fleet rules, combined with new tax credits, may stimulate continued growth of LNG vehicles and infrastructure in California.

- Negative: Concerns remain regarding the adequacy of LNG transportation fuel supplies in California. In spite of funding from the Commission and SCAQMD, there have been no new significant-capacity LNG sources added to the market in the last six years. The current California LNG transportation fuel supply is vulnerable, and supply disruptions have briefly idled LNG vehicle fleets. The LNG import terminal project outlook is moving in a direction that has no relevance to California LNG transportation fuel demand (except, perhaps, to moderate natural gas commodity prices).

- Positive: As of mid-2006, there is optimism that the Clean Air Action Plan development by the Ports of Los Angeles and Long Beach will result in substantial numbers of LNG-fueled trucks, yard equipment, and possibly railroad locomotives operating within the ports and/or transporting goods to and from the ports. Important future decisions will include choices between LNG and "clean diesel," funding development, and compromises among various stakeholders. Details are provided in a comprehensive set of draft documents including the draft San Pedro Bay Ports Clean Air Action Plan.[62]

Overall Assessment

As noted above, the future of natural gas as a transportation fuel is uncertain. Unless the automobile OEMs expand their offering of CNG light duty vehicles for sale in California, as many do in European and Asian markets, the population of light duty NGVs is likely to decline. Honda appears to be committed to its NGV offering, and is attempting to enter the general population marketplace teamed with the FuelMaker Phill home refueling appliance. However, despite this, sales of LDVs to the general population will likely remain a niche marketplace. Even such traditional fleet uses of light duty NGVs, such as taxicab fleets, are likely to decline. With no vehicle offerings, such fleets cannot grow in number. OEMs complain that the expense of the ARB certification process is a barrier to increased market penetration. However, the OEMs go through the same certification of their gasoline vehicle offerings. They just have a large enough gasoline vehicle sales base over which to distribute certification costs. Individual consumers are generally not willing to pay the price premium for an NGV, even in the face of fuel cost savings. It can be argued that a sufficient number of public access fueling stations exists to support a general population of NGVs in major California urban regions. Nevertheless, government and fuel provider fleet use of light duty NGVs will likely continue as long as there are vehicle offerings. As discussed in this section, the Honda GX and two GM pickup truck models were certified in 2006. As long as these remain available, their use will continue. Such fleets have ready access to (often fleet-owned) fueling stations. Fuel accessibility is not a problem for return to base fleets. Moreover, many government entities are required to maintain certain percentages of their fleets as alternative fuel vehicles. Continuing availability of at least some light duty NGV offerings gives these entities a means to meet such requirements without having to rely solely on heavy duty NGVs to meet AFV mandates.

In contrast, the heavy duty NGV marketplace is likely to remain active. Most of the natural gas fuel use in the state is in the heavy duty sector (i.e., displaces diesel), and this is projected to remain the case. Many transit agencies in the state committed to the alternative fuel path, and are satisfying their commitment largely via the purchase and use of CNG buses. The number of agencies moving to this path will increase in the near future to satisfy the requirement that all agencies within SCAQMD embrace the alternative fuel path. School districts will continue to purchase CNG school buses with incentive funding from state and federal sources. Government agency-run shuttle bus fleets will remain under pressure to employ AFVs, and natural gas use in refuse trucks will continue to see increased NGV penetration. All of these are return to base fleets that are best suited for natural gas use.

[62] [www.portoflosangeles.org/environment_studies.htm#air].

Most of the NGV research and development work is being done as part of the DOE-funded Next Generation Natural Gas Vehicle (NGNGV) program managed by NREL. This R&D work is focused on developing heavy duty NGV engines with the objective of meeting the 2007 through 2010 EPA and ARB heavy duty vehicle emission standards. If successful, heavy duty NGVs will be able to economically compete with diesel fueled vehicles under a variety of potentially likely scenarios.

In summary, natural gas transportation fuel can be considered a success in many applications in the heavy duty sector. This has been largely driven by air quality mandates in the past, along with several incentive programs like the Carl Moyer Program. While the air quality drivers for NGV use have and will continue to diminish, an economic case can be made for NGV use in many applications, which is largely possible because of the infrastructure development programs of the past.

SECTION 3. LIQUEFIED PETROLEUM GAS

Quantities of Use

Liquefied petroleum gas (LPG, also known as "propane," in reference to its primary constituent) has long been a widely used alternative fuel, including use in the transportation sector. In the U.S., propane vehicles are most commonly found in commercial fleet in applications such as pickup trucks, taxis, buses, and airport shuttles. Worldwide, the number of LPG fueled vehicles has steadily increased, to over 8 million vehicles in 2004[63]. LPG fuel consumption has seen a corresponding global increase to more than 18 billion gal/year. In contrast, the U.S. LPG vehicle population has decreased from about 141,000 on road vehicles in 1997 to about 115,000 in 2002[64]. This declining population exists because the number of vehicles made available for sale has fallen from a peak of nearly 6,000 in 1999 to a low of about 1,700 in 2002, before increasing to about 2,100 in 2003 and 2004,[65] as shown in Figure 3-1. Despite this decline in the nationwide number of LPG vehicles, U.S. LPG fuel use increased from 210 million gge in 1999 to 242 million gge in 2004. Still, the use of LPG as a motor vehicle fuel remains an insignificant 1.7 percent of the 13 billion gallons of LPG sold in the U.S. in 2004. The remaining 98.3 percent of the U.S. LPG demand is for non vehicle applications.

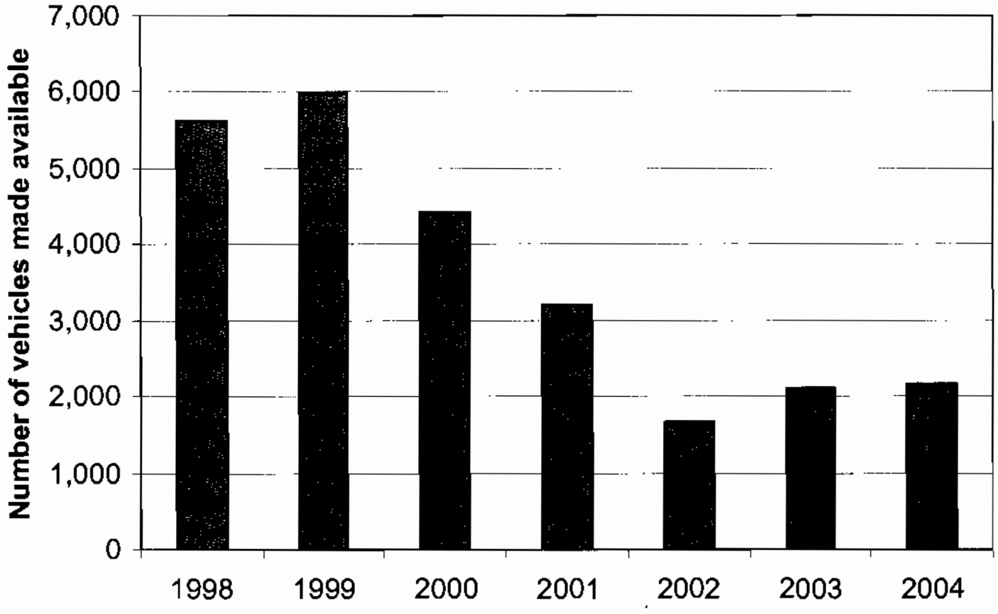
The declining U.S. LPG vehicle population is reflected in the California population, which declined from 33,000 vehicles in 1999 to 22,000 vehicles in 2004. The declining vehicle population accounts for the decline in LPG use as a transportation fuel in California from 40 million gallons in 1999 to 26 million gallons in 2004.[66] Table 3-1 summarizes the state of LPG a transportation fuel use in California based on the most recent information available.

[63] *Making the Case for Propane Motor Fuel*, presentation by J. Van Bogart, Clean Fuel USA, to the California Energy Commission Workshop on Proposed Transportation Energy Efficiency and Alternative Fuels Analyses, December 20, 2004, [http://www.energy.ca.gov/2005_energypolicy/documents/2004_index.html#122004], viewed August 2006.

[64] *Propane Industry Issues and Trends*, Propane Education & Research Council, June 2004, [http://www.propanecouncil.org/industry/issues.htm], viewed August, 2006.

[65] Energy Information Administration, *Annual Survey of Alternative Fuel Vehicles and Users*, [http://www.eia.doe.gov/fuelrenewable.html], viewed August 2006.

[66] *Making the Case for Propane Motor Fuel*, presentation by J. Van Bogart, Clean Fuel USA, to the California Energy Commission Workshop on Proposed Transportation Energy Efficiency and Alternative Fuels Analyses, December 20, 2004, [http://www.energy.ca.gov/2005_energypolicy/documents/2004_index.html#122004], viewed August 2006.



Source: DOE EIA[65]

Figure 3-1. On road LPG vehicles made available in the U.S.

Table 3-1. LPG transportation fuel use in California.

Number of LPG vehicles(2004)	22,000
Fraction of on-road population, %	0.091
OEM LDV models offered (2006)	0
LDV engines certified (2006)	0
HDV engines certified (2006)	4
LPG stations, total	235
public assess	234
LPG dispensed, million gal	26
million gge	19
petroleum fuel fraction, %	0.098

Source: Clean Fuel USA[66]

The outlook for LPG use as a transportation fuel to displace petroleum fuel consumption is not bright. DOE EIA forecasts an annual growth rate in the use of LPG in the transportation sector in the U.S. of 5.0 percent . This is slightly greater than the 3 percent growth experienced between 1999 and 2004 noted above. However, California use of LPG vehicle fuel decreased over the same time period. In addition, there has been no light duty LPG vehicle (dedicated or bi fuel) offered for sale by automobile OEMs since 2004, as discussed below. And the number of heavy duty engine models certified for sale in California is quite limited. LPG stakeholders contend that the expense of certifying a new vehicle or heavy duty engine would lead to a decline in the number of vehicles offered for sale in the state. This, in turn would lead to the declining use of LPG as a vehicle fuel in California, despite increasing sales nationwide. Still, unless the transportation fuel landscape in the state changes significantly (a business as usual scenario), annual sales of vehicle fuel LPG through 2030 will likely do no better than stay the same as it is currently (or was in 2004).

Availability of Vehicles

Commercial offerings of LPG-fueled cars and light trucks have been predominantly bi-fuel vehicles, which can run on either LPG or gasoline using the same engine but separate fuel systems. As is the case with similar natural gas engines, bi-fuel propane engines are convenient to the fleet operator, but they don't allow optimization for the low-emissions combustion characteristics of LPG. The California Department of Transportation (Caltrans) operates a large fleet (over 1,300) of Ford F-150 bi-fuel LPG pickup trucks that until recently had operated exclusively on gasoline. Caltrans has agreed to operate these vehicles on LPG fuel as much as possible. And, under the Energy Commission's Alternative Fuel Infrastructure Program, 12 new propane stations were installed to help Caltrans achieve this goal.[67] Installation of these stations was completed in September 2005, as discussed below.

In the light duty sector, the absence of LPG engines and vehicles offered by major vehicle manufacturers continues to be an impediment to the further development of propane as a major transportation fuel. In the light-duty sector, no propane vehicles have been offered for sale by the vehicle OEMs since 2004, and only the Ford F-150 was available in 2003 and 2004. Moreover, no aftermarket LPG or bi-fuel conversion kit has been certified for use by ARB in California since 2002.

For heavy-duty applications, a few both dedicated LPG and bi-fuel (LPG or gasoline) model year 2006 engines have been certified for sale in California. These are listed in Table 3-2. These engines find specific use in a variety of medium-heavy duty applications, both on-road and off-road. For example, the Cummins B5.9 LPG Plus engine is a versatile powerplant that can be used in large pickups, small school buses, vehicles operated by transit properties including shuttle buses, step vans, delivery trucks, and sweepers, and port vehicles such as yard hostlers. The BAF dedicated LPG Ford 6.8 L, V10 engine can be found in Ford E-450 truck applications. The Baytech dedicated LPG and bi-fuel GM 8.1 L V8 engines can be used in Chevrolet Kodiak and GMC Topkick C4500, C5500, C6500, C7500, and C8500 vehicles.

[67] Details about these propane stations are described in *California Alternative Fuels Infrastructure Program Evaluation 2003*, California Energy Commission Consultant's Report 600-03-018, October 2003.

Table 3-2. Model year 2006 heavy duty LPG engines certified for Use in California.[68]

Manufacturer	Model	Service Type[a]	Fuel System	Displace-ment (L)	NO_x+NMHC (g/bhp-hr)	Cert. Std. NO_x+NMHC
BAF Technologies	V-10	HDO	Dedicated	6.8	0.4	1.0
Baytech	L18	HDO	Dedicated	8.1	0.4	1.0
	L18	HDO	Bi-fuel	8.1	0.3-0.9	1.0
Cummins	B5.9 LPG	MHD	Dedicated	5.9	2.1	2.2

[a] HDO: Heavy Duty Otto, MHD: Medium Heavy Duty

Source: ARB Certification Database[68]

A gallon of propane contains about 71 percent and 65 percent respectively, of the energy found in a gallon of gasoline and diesel. Like their natural gas counterparts, dedicated propane engines use spark ignition and can achieve similar fuel efficiency to gasoline engines. However, spark-ignited alternative fuel engines are significantly less fuel efficient than diesel engines, which use compression ignition under a leaner combustion process.

Like the light duty NGV and gasoline vehicle comparison, fuel economy for the BAF and Baytech HDO applications as measured by miles per gallon (mpg) for gasoline counterparts of the vehicles and miles per gasoline gallon equivalent (mpgge) are generally comparable. So a vehicle with the comparably sized LPG fuel tank as the gasoline tank for bi-fuel vehicles or the gasoline tank of the equivalent gasoline vehicle will have roughly 71 percent of the range as with LPG. However, vehicles using both the BAF and Baytech engine noted in Table 3-2 offer a range of LPG fuel tank capacities (as well as gasoline fuel tank capacities for bi-fuel vehicles), so the user can choose an LPG fuel tank capacity that meets their useable range requirements. Heavy-duty vehicles that use the Cummins dedicated LPG engines are often used in shorter-haul, on-road applications (e.g., school buses) or off-road applications (e.g., yard hostlers); in part, this is due to their diminished driving range compared to comparable diesel vehicles. But, their range with the fuel tanks supplied with these vehicles is sufficient to meet the application.

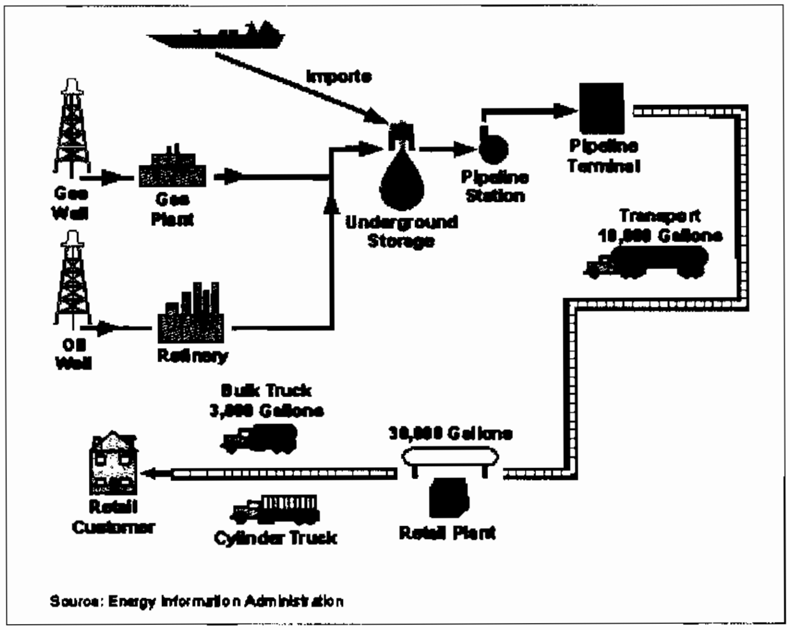
The costs and prices of LPG vehicles are similar to those of CNG vehicles, although onboard LPG fuel tanks are less expensive than CNG tanks. The dedicated LPG and bi-fuel vehicles in the HDO applications noted in Table 3-2 are typically priced about $4,000 to $5,000 more than the gasoline vehicles from which they are derived. The cost for a shuttle bus with the Cummins B5.9LPG engine is approximately $15,000 higher than its diesel fueled counterpart. The additional costs associated with LPG capable vehicles can be attributed to (1) the extra cost of the LPG fuel tank and fuel system (for

[68] ARB certification database website, [http://www.arb.ca.gov/msprog/onroad/cert/mdehdehdv/2006/2006.php], viewed August 2006.

bi-fuel vehicles), (2) the extra cost of LPG capable engines due to their low production volumes, and (3) the cost of engineering, testing, and certifying the vehicle and/or engine. In fact, some propane stakeholders believe it is the high cost of obtaining ARB certification of either vehicles or engine families (cited to be $500,000 to $1 million[69]) that has caused the vehicle OEMs, engine providers, and conversion kit vendors to exit the LPG market.[69,70]

Fueling Infrastructure and Specific Needs

As Figure 3-2 shows, propane is produced through both natural gas processing and petroleum refining. Worldwide, about 60 percent of the LPG supply comes from natural gas production with 40 percent from oil refining.[71] In the U.S. the opposite holds,



Source: http://www.npga.com

Figure 3-2. Production chain for propane.

[69] *Making the Case for Propane Motor Fuel*, presentation by J. Van Bogart, Clean Fuel USA, to the California Energy Commission Workshop on Proposed Transportation Energy Efficiency and Alternative Fuels Analyses, December 20, 2004, [http://www.energy.ca.gov/2005_energypolicy/documents/2004_index.html#122004], viewed August 2006.

[70] *Air Quality and Opportunities to Expand Alternative Transportation Fuels*, presentation by J. Van Bogart, Clean Fuel USA, to the California Energy Commission Workshop on Air Quality and Opportunities to Expand Alternative Transportation Fuels, July 8, 2005, [http://www.energy.ca.gov/2005_energypolicy/documents/2005_index.html#070805], viewed August 2006.

[71] *Propane Infrastructure*, Clean Fuel Energy presentation to the Workshop on Transportation Energy Demand Forecasts and Options to Reduce Petroleum Fuel Use, May 17, 2005, can be obtained from http://www.energy.ca.gov/2005_energypolicy/documents/2005_index.html#051705

40 percent comes from natural gas processing and 60 percent from oil refining. These same approximate ratios hold for LPG production in PADD 5, which comprises the West Coast and includes California.[72] The distinction about feedstock can be important when considering propane's status as a "non-petroleum" alternative fuel that "displaces" gasoline and diesel. However this debate aside, from a practical standpoint propane has become firmly established in California as a certified, low-emission alternative fuel. Feedstock also affects fuel quality: refinery production results in LPG that includes propylene (also known as propene), which is an undesirable component for motor vehicle fuel due to its high photochemical reactivity (smog-forming potential). Finally, because refinery expansions may be limited in the future, and given that a large portion of California's propane comes from refineries, the question has been raised as to how California would meet a major increase in propane demand (as might occur for motor vehicle fuel applications).

Propane is shipped to retail storage sites through pipelines as well as on railcars, transport trucks, and barges. For safety purposes (similar to the case with CNG), ethyl mercaptan is added to propane as an odorant when it is loaded into transport trucks or onto railcars. Bulk trucks typically make the final delivery in 1,800- to 5,000-gallon cylinder trucks. In this regard the LPG fuel infrastructure resembles the gasoline fuel delivery infrastructure. In fact, many propane dispensers are located at gasoline stations. These dispensers are oftentimes used only to refill small tanks for home barbeque and other uses. However many are equipped for routine vehicle refueling.

How many LPG fueling stations are there in California? This simple question doesn't have a precise answer because various references cite different numbers. The CEC 2005 Integrated Energy Policy Report (IEPR) states that there are 1,500 LPG service stations in California, 900 of which are "motor vehicle friendly" and dispense LPG to motor vehicles.[73] The numbers in the IEPR apparently came from a presentation by Clean Fuel USA to the May 17, 2005, Commission workshop on transportation energy as the same numbers are cited.[74] The Clean Car Maps website maintained by WestStart/Calstart lists 533 California LPG stations.[75] The DOE Alternative Fuels Data Center, maintained by NREL, lists 235 stations, all but one are cited as being public access. The Caltrans website lists 172 stations.[76] The AFDC numbers are the ones cited in Table 3-1.

LPG has long been used as a mainstream fuel for barbecues, outdoor heaters, forklifts and recreational vehicles. California's existing LPG stations, which primarily serve these markets, are well-dispersed in key locations. These stations are generally owned and utilized differently than natural gas fueling stations (CNG or LNG). LPG fleet end users

[72] [www.eia.doe.gov/oil_gas/petroleum/info_glance/petroleum.html].

[73] *2005 Integrated Energy Policy Report*, CEC-100-2005-007 CMF, November, 2005.

[74] *Propane Infrastructure*, Clean Fuel Energy presentation to the Workshop on Transportation Energy Demand Forecasts and Options to Reduce Petroleum Fuel Use, May 17, 2005, can be obtained from [http://www.energy.ca.gov/2005_energypolicy/documents/2005_index.html#051705].

[75] [http://www.cleancarmaps.com/home/sitelistsearchcng.php?type=CNG].

[76] [http://www.dot.ca.gov/hq/eqsc/altfuel/FuelingPropane.htm].

often own and operate their own fueling stations, because they are inexpensive to install and have relatively low life-cycle costs.[77] As a result, the LPG infrastructure is commercially self-sustaining today.

The network of fueling stations with characteristics the general population has come to expect for their gasoline and diesel vehicles would need to be significantly expanded before propane could become a mainstream transportation fuel. Such motor vehicle fuel propane stations offering cardreader-equipped island dispensers and full public access are more expensive to build than those used to fill portable five gallon tanks and recreation vehicles, although they are less expensive than comparable natural gas stations. To the fuel provider, the added cost of building an vehicle fuel propane station can sometimes be justified by the higher throughput that is likely to result. This in turn could result in a lower price at the pump per gallon of propane.

In an attempt to alleviate the shortage of convenient public access LPG dispensing stations in California, in 2001 the Energy Commission allocated funding to help build or upgrade 13 propane stations in California for motor vehicle fuel dispensing. One of these stations was completed in 2004, the other 12 in 2005.[78] All are self-serve stations that are significantly more sophisticated and user friendly compared to those that dispense propane for the portable container market. They were all located on typical fueling islands and equipped with gasoline-style dispensers that meet weights and measures requirements, complete with cardreader systems that can accept typical fuel-purchase cards used by fleets (e.g., Voyager). They were intentionally strategically located near fleets that operate bi-fuel pickup trucks, such as Caltrans' various facilities throughout the state. All dispensers are operated by Clean Fuels USA, which will operate a total of 26 conveniently located open public access 24 hour/day stations throughout the state by 2007.[79]

The LPG industry has stated that the U.S. LPG supply is currently sufficient to operate millions of vehicles per year. Worldwide, there is ample LPG supply, but prices drive product distribution. Propane is traded on the commodities market; consequently, the price of LPG changes daily. LPG prices are subject to a number of influences; some are common to all petroleum products, and others are unique to LPG. Because LPG is essentially the most portable gaseous fuel, it is typically used for home heating in regions where natural gas pipelines don't exist. It can also serve many other different markets, from fueling barbecue grills to producing petrochemicals. The price of LPG in these markets is influenced by many factors, including the prices of its feedstocks (natural gas and crude oil), prices of competing fuels in each market, the distance LPG has to travel to reach

[77] For example, LPG stations have no maintenance associated with gas compression and drying.

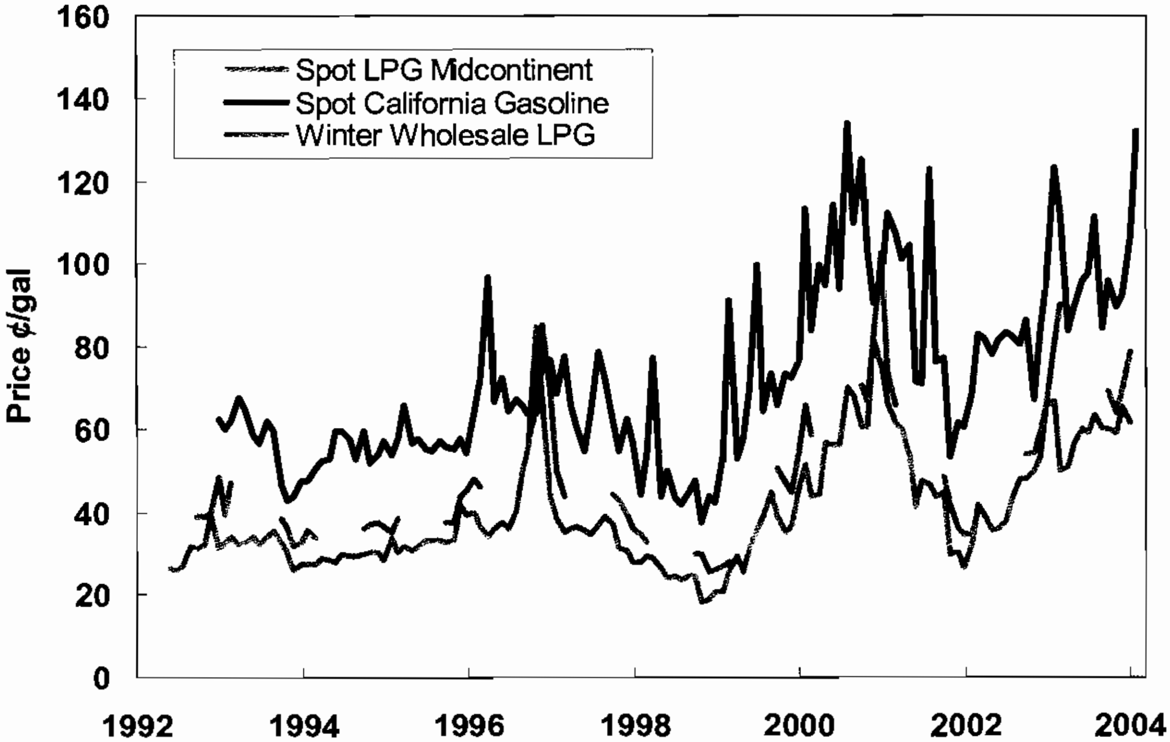
[78] Progress report on the Clean Fueling Station Infrastructure Program, January 9, 2006; in personal communication from J. Wiens, Energy Commission, July 31, 2006.

[79] *Propane Infrastructure*, Clean Fuel Energy presentation to the Workshop on Transportation Energy Demand Forecasts and Options to Reduce Petroleum Fuel Use, May 17, 2005, can be obtained from [http://www.energy.ca.gov/2005_energypolicy/documents/2005_index.html#051705].

a customer, and specific issues within individual markets served (e.g., residential, fork lifts, etc.).

As Figure 3-3 shows, the spot price of propane has closely tracked the spot price of gasoline in California over the last 12 years. When high gasoline prices occurred in late 2000 and early 2001, the midcontinent market price of propane also exhibited significant increases. A similar run up in the prices of both fuels began in 2004. The federal Energy Information Administration only tracks residential and wholesale propane prices during the winter heating season, which is why the winter wholesale LPG price curve in Figure 3-3 is a broken line. Presumably, if propane becomes a major transportation fuel, prices by individual states would be reported on a year-round basis.

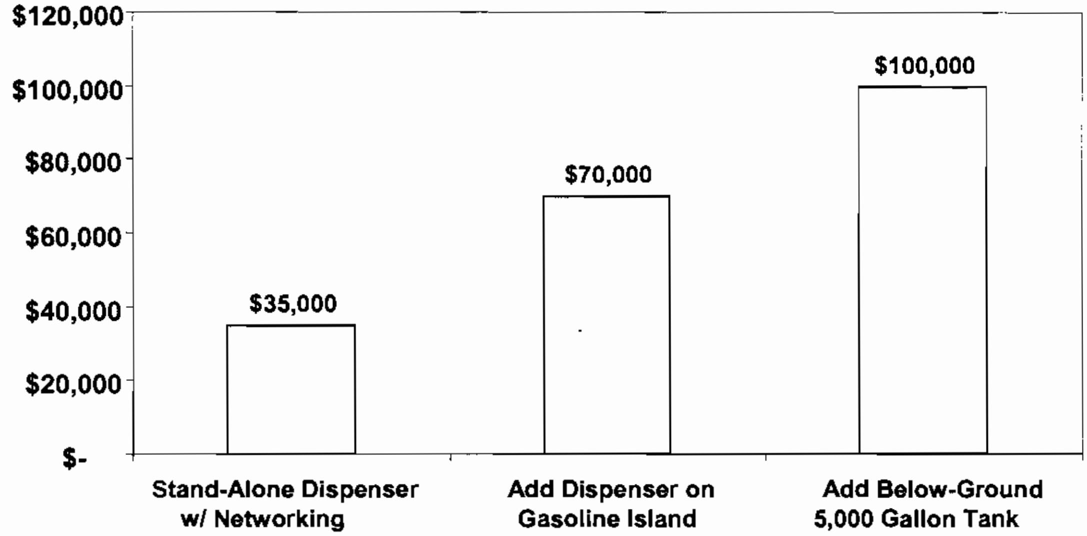
The midcontinent spot price for LPG averaged 56 percent of the California gasoline price in the data shown in Figure 3-3. For the winter wholesale LPG price, this average was 70 percent . As LPG contains 71 percent of the energy content of an equal volume of gasoline, anytime this price ratio is less than 71 percent, LPG fuel is the less expensive fuel on a $/mile basis. This is the same as stating that 1 gal of LPG equals 0.71 gge, or that the substitution ratio of LPG relative to gasoline is 1.40.



Source: EIA

Figure 3-3. Spot and winter wholesale LPG prices generally track those of gasoline (¢/actual gallon).

Figure 3-4 compares the costs of building three types of public-access LPG stations for vehicle fuel applications. These costs have not been updated since the 2003 Clean Fuels Market Assessment, but are still considered realistic. It shows that a stand-alone dispenser with point-of-sale networking costs about $30,000. If the LPG dispenser is built onto the gasoline island at a typical station, the cost is about $70,000. The same station with a 6,000-gallon, below-ground LPG tank would cost about $100,000. For comparison, the costs of the Commission supported fueling stations ranged from an average about $30,000 for two stations funded, to an average of about $90,000 for 10 stations supported, and to a single station cost of just over $210,000.[80]



Source: Delta Liquid Energy Company, October 2000

Figure 3-4. Estimated costs to build various types of LPG stations.

LPG stations are relatively simple systems compared to CNG or LNG stations. A typical station consists of an aboveground storage tank, a two to four horsepower transfer pump, and a meter and hose dispensing system. Unlike CNG stations, there is no need for a gas compressor or dryer. This makes an LPG station relatively easy to operate and maintain. The estimated cost per year to maintain a station is $1,000, according to Delta Liquid Energy Company.[81]

LPG comes in three different commercial grades, with varying compositions of propane other hydrocarbons, and miscellaneous other constituents. A minimum propane content of 90 percent by liquid volume is necessary for vehicle fuel applications, to ensure sufficient vapor pressure for delivery of the fuel to the engine, even at very low

80 Progress report on the Clean Fueling Station Infrastructure Program, January 9, 2006; in personal communication from J. Wiens, Energy Commission, July 31, 2006.

81 Survey input received from Bill Platz, Delta Liquid Energy Company.

temperatures.[82] From an emission standpoint, the propylene (also known as propene) content of LPG is of concern because it has high photochemical reactivity. In addition, propylene and higher molecular weight hydrocarbons can adversely affect fuel system components. Propylene does not occur in LPG obtained from natural gas processing plants, but it does in the LPG resulting from petroleum refinery operations. Primarily to control propylene content, the U.S. propane industry and regulatory agencies have developed an automotive propane standard known as HD-5. Most LPG fuel for vehicle use meets this HD-5 specification, which is summarized in Table 3-3. However, the California motor vehicle LPG fuel specifications are not as restrictive. These are also given in Table 3-3. ARB is currently investigating motor vehicle LPG fuel quality.

Table 3-3. HD-5 Specification for Automotive LPG.

Parameter	HD-5 Propane Specification	California Motor Vehicle Fuel Specification[83]
Propane Content	90% liquid volume (min)	85% liquid volume (min)
Propylene Content	5% liquid volume (max)	10% liquid volume (max)
Butane and Heavier HCs Content	2.5% liquid	5.0% liquid
Moisture Content	Dryness test of NGPA	Dryness test of NGPA
Residual Matter Content	0.05 ml	0.05 ml
Total Sulfur Content	123 ppm by weight fraction	120 ppm by weight fraction

Source: ASTM specification, ARB specification[83]

LPG stations must meet a variety of building codes and standards, including but not limited to UPC, UFC, UBC, and NFPA 58. In addition, there may be varying requirements from local fire authorities.

Barriers and Opportunities for Expansion

Since the 2003 Market Assessment, the interest level in further developing LPG alternative fueled vehicle has waned considerably. As noted above, there have been no light-duty either dedicated or bi-fuel LPG vehicles produced since 2004. In heavy duty applications Baytech continues to certify its GM 8.1 L engine and several vehicle applications in both dedicated and bi-fuel versions. BAF continues to certify its Ford 6.8 L dedicated LPG engine and vehicle applications. And, Cummins still certifies the B5.9 LPG engine for use by several medium duty "specialty" applications. However, the overall population of these vehicles in which these engines are used continues to decline both in the U.S. and California.

Nevertheless, the propane industry, in many cases with the support of DOE, continues to fund propane technology development and demonstration efforts, in part to maintain

[82] Source: Website of the National Alternative Fuel Training Consortium [http://naftp.nrcce.wvu.edu/technical/indepth/LPG/LPG.html].

[83] Title 13 CCR, Section 2292.6.

propane's status as a viable clean fuel alternative.[84] Several of the projects currently ongoing include:

- Development, certification, and sale of an LPG heavy duty truck and bus engine that will comply with the EPA 2010 heavy duty engine standards. If successful, Hino Motor Sales USA Inc has committed to commercializing the engine.
- Design and develop a modified production low emission, light duty truck based on the Ford F-150 pickup truck platform
- Develop, test, and market a dedicated propane version of the Blue Bird Vision series school bus

In addition, in October 2005 the Propane Education & Research Council (PERC) announced a propane engine development program as part of DOE's Clean Cities program. Six projects will be supported to:

- Install new propane stations in select Clean Cities participant locations.
- Expand local government fleets to include LPG fueled trucks
- Develop a propane fueled commercial mower
- Develop propane fueled auxiliary power units for long haul trucks
- Add propane fueled urban buses to local transit systems
- Install selective catalytic reduction systems on propane fueled vehicles

Success in these ongoing efforts can only help to spur demand for LPG vehicle fuel use. The project to produce an LPG engine that will comply with the 2010 heavy duty engine standard is of particular importance if LPG is going to play any role in the heavy duty sector.

The propane infrastructure has essentially already reached sustainable commercial status due to the fuel's use in non-vehicle applications. Vehicle fueling stations are more complex and costly than propane stations designed simply to fuel barbecue cylinders or forklifts, but they can be built at lower costs than natural gas stations (CNG or LNG). The biggest challenges to expanding the motor vehicle fuel propane infrastructure in California are related to vehicle and fuel issues more than the fueling stations themselves. Specific impediments include the following:

- High fuel prices and volatility due to distribution bottlenecks, storage imbalances, natural gas market dynamics, and other factors,
- Low demand for propane as a motor vehicle fuel, due to lack of commercially available dedicated propane vehicles, and the absence of fuel-use requirements for bi-fuel vehicles, and
- High incremental cost (especially in the heavy-duty sector) of propane-fueled vehicles and engines.

[84] *Propane Technology Review*, Propane Education and Research Council, April 2006, [http://www.propanecouncil.org/industry/activities.cfm?id=92], viewed August 2006.

These barriers have persisted for years, yet they still remain. Similar barriers apply to NGVs as well. However, the NGV stakeholders have been much more proactive than the LPG stakeholders, despite the fact that vehicle fuel use of both fuels represents such a small fraction of total petroleum fuel consumption.

Overall Assessment

Beyond its use in bi-fuel vehicles – which often end up being operated mostly on gasoline – LPG continues to have some potential to become a more mainstream low-emission transportation fuel offering certain societal benefits. It has proven to be a clean-burning fuel in dedicated heavy-duty engines, and greater deployment could yield major displacement of gasoline and diesel fuels. A significant challenge involves getting major vehicle and engine manufacturers to build dedicated LPG, or even bi-fuel platforms that are affordable and optimized for the fuel's combustion characteristics.

It's difficult to estimate the number of LPG vehicles that are likely to be on the road in California in any future year. In part, this depends on what role bi-fuel vehicles will continue to play. There are no strong energy-related drivers that make use of AFVs like propane vehicles compelling to fleet operators, as a general rule, and the effect of the AFV incentives have yet to play a part in vehicle choice. Like with natural gas fuel, air-quality drivers are going to become steadily less important as conventional fueled vehicles are meeting some very restrictive emissions standards, and are projected to continue to meet standards that become more restrictive. The prospects for LPG vehicle population growth in California are not promising given that no light duty OEM vehicle platform has been available since 2004. LPG is likely to fill only a niche role in federal, state, and local government fleets where AFV use can be mandated, and in fuel provider fleets with ready access to the fuel at attractive cost.

SECTION 4. ELECTRICITY

In the context of this report, using electricity as an alternative fuel can only be done in a vehicle that has some significant operating range that can be totally serviced via a battery-powered electric motor that has taken a significant portion of its charge from the electric power grid. Thus, an electric vehicle for the present purposes is a traditional battery electric vehicle (BEV) that has no internal combustion engine, a neighborhood electric vehicles (NEV), or a plug-in hybrid electric vehicle (PHEV). A BEV is a certified, on road vehicle that could replace a gasoline or diesel fueled vehicle and requires a special charger to be recharged. A PHEV (also termed a grid connected HEV) would also be a full function on road vehicle that has an electric only range that will allow most everyday functions, and that can be recharged using standard 110-V household service. A NEV is a vehicle with a top speed of 25 mph, so that its use would be limited to roads with a posted speed limit of 35 mph or lower. A NEV can also be recharged using standard 110-V household service. Table 4-1 summarizes the state of electric vehicle use in California based on the most recent information available as noted in the table.

Table 4-1. EV use in California.

Number of on road EVs (2006)	500-1,000[85]
Number of NEVs (2006)	15,000[86]
OEM on road EV models offered (2006)	0
OEM NEV models offered (2006)	5[87]
EV charging stations, total	400[88]
public assess	340

Source: References noted

The prospects for electricity as a fuel to offer significant displacement of petroleum transportation fuels are not bright. BEV technology even today is too expensive and too constraining with respect to vehicle range to allow commercial success in the marketplace. And the needed developments in improving battery technologies are too long range and uncertain to alter this conclusion. PHEV technology offers another means of using grid electricity as a transportation fuel, but development prospects and the potential successful commercialization of this technology are too uncertain with respect to basing future fuel displacement predictions.

85 Personal communication with ARB staff, June 2006.

86 *The Impact of Neighborhood Electric Vehicles in California*, presentation at the Commission hearing on Transportation Fuels, September 29, 2005, available at [http://www.energy.ca.gov/2005_energypolicy/documents/2005_index.html#092905].

87 Driveclean.ca.gov website [http://www.driveclean.ca.gov/en/gv/vsearch/cleansearch_result.asp?vehicletypeid=37].

88 Alternative Fuels Data Center, [http://afdcmap2.nrel.gov/locator/FindNearResult.asp].

Quantities of Use

Battery electric vehicle technology is well proven. In fact, the first production vehicles in the U.S. were BEVs. The BEV's greatest feature is that has zero direct emissions. It is this characteristic that led to the ARB zero emission vehicle program that was adopted in 1990. The regulations adopted under this program led to the production and use of several thousand BEVs[89] in the mid to late 1990's. Six OEM automakers had BEV offerings for sale or lease to the general public, in addition to government agency fleets. For reasons that are discussed below, all six stopped production of BEVs by 2004, and leased vehicles were reclaimed. As a consequence, in 2006 there were no OEM BEV offerings, as indicated in Table 4-1. The table also indicates that there were an estimated 500 to 1,000 existing EVs still in operation.[90] This number is going to continue to dwindle, at least for the foreseeable future, as vehicles reach their useful service life and are retired (but not replaced).

There has been some production of NEVs continuing to today. These vehicles have found, and continue to find use in a number of applications where extended range and highway speed capabilities are not needed. These applications could be performed by gasoline fueled vehicles. But the operation of a NEV reduces emissions, displaces petroleum, and has advantages over gasoline vehicles in the applications they serve. These applications include gated community neighborhood use, military bases, and commercial and government fleets in which short distance travel in confined residential and city areas is the norm. Table 4-1 notes that five NEV models were certified for sale as ZEVs in 2006.[91] The table also shows that there are an estimated 15,000 NEVs currently operating in California.[92]

Availability of Vehicles

The requirements and credits established in the California ZEV program provided an impetus for the development of current BEV technologies, as well as alternative, very low emission gasoline vehicle technologies. Because the program, as well as the market and market potential it stimulated, have changed over time, it is worth reviewing the history of the program and how it has impacted electric vehicles in California.

[89] The term BEV refers to an on road vehicle that can be registered to operate on any public roadway in the state, relying only on battery power to an electric motor for propulsion. A PHEV is a full function on road vehicle that has some minimum operation time using only its electric drive system. A NEV is an on road vehicle with a limited top speed, so its use is restricted to operation on city streets with maximum posted speed limit of 45 mph.

[90] Personal communication with ARB staff, June 2006.

[91] Driveclean.ca.gov website [http://www.driveclean.ca.gov/en/gv/vsearch/cleansearch_result.asp?vehicletypeid=37].

[92] *The Impact of Neighborhood Electric Vehicles in California*, presentation at the Commission hearing on Transportation Fuels, September 29, 2005, available at [http://www.energy.ca.gov/2005_energypolicy/documents/2005_index.html#092905].

In 1990, ARB adopted the ZEV program, which effectively required that 10 percent of all new cars offered for sale in California by 2003 would be powered by battery-electric propulsion systems.[93] Over the last decade and a half, ARB has conducted biennial reviews of the program, resulting in significant evolution of the program's original "ZEV mandate." In 1996, ARB agreed to eliminate the 1998-2002 ZEV requirements in exchange for agreements with the six largest automakers to produce a very limited number of "demonstration" electric vehicles in California. All automakers complied with this demonstration agreement. Afterward, some refused to continue producing EVs, while others produced small numbers to earn ZEV "credits" against their 2003 obligations. Although the production numbers for these BEVs were small, all vehicles produced were successfully leased or sold to consumers and fleets. Demand for BEVs exceeded supply, though the $20,000 cost subsidy for a vehicle no doubt influenced demand.

In January 2001, ARB adopted major amendments that were designed to "maintain progress towards commercialization of ZEVs while recognizing the market constraints created primarily by the cost of battery technology." Essentially, these amendments reduced the numbers of ZEVs to be required in the near term, and broadened the scope of alternative vehicle technologies that manufacturers could utilize in meeting their ZEV obligations.[94]

In April 2003, ARB again decided to modify the ZEV regulation. Acknowledging that the ZEV regulations were "on hold for 2003-2004 because of automaker lawsuits," ARB adopted changes designed to go into full effect in 2005.[95] The most significant change was the creation of "a new ZEV pathway" that offered manufacturers a choice of two options for meeting ZEV requirements. The first option was for automakers to meet standards similar to the ZEV rule as it existed in 2001. This meant producing a vehicle mix that included 2 percent pure ZEVs, 2 percent "advanced-technology" partial ZEVs (ATPZEVs) a category that included hybrid-electric and CNG vehicles, and 6 percent partial ZEVs (PZEVs), which are very low emission gasoline vehicles that meet the most stringent exhaust emission standard, have no evaporative emissions, and have a 150,000 mile emission warranty. The second option was for automakers to accept a new "alternative" ZEV compliance strategy. On the alternative path, BEVs may be used to meet up to 50 percent of the new ZEV production requirement. The remaining portion must be met with Type III ZEVs (fuel cells) Low-speed neighborhood electric vehicles (NEVs) were also eligible for generating ZEV credits under the 2003 modifications. NEVs are street-legal vehicles that operate at up to 25 mph, with approximately 30 mile range per charge. They can be used in a variety of locations and applications including housing developments, campuses, public agency fleets, and golf courses.

[93] ARB recognized that other zero-emission technologies might eventually emerge, such as direct-hydrogen fuel cell vehicles, to enable automakers to meet their ZEV obligations. However, "ZEV" and "battery EV" have been essentially synonymous in the early years of the program.

[94] ARB, 2003 ZEV Program Rulemaking, March 25, 2003.

[95] However, automakers would be able to receive credit for qualifying vehicles (e.g., ZEVs) that they sold or leased in 2003-04.

In addition to the program changes in 2003, ARB committed to regular review of the program and ZEV technology. ARB appointed "an independent review panel of technology/industry experts with no financial ties to motor vehicle manufacturers" chartered with reporting on "ZEV technology progress, costs and consumer acceptance." The ZEV Expert Review Panel was to commence its work in June 2006 and report its findings to ARB in early 2007. In addition, ARB held a ZEV Technology Symposium in September 2006 with overall findings summarized in a ZEV Technology Review staff report to be presented to the Board in 2007.

In adopting the April 2003 amendments and continuing the review process, ARB reiterated the need to "maintain pressure on the commercialization of ZEV technologies," while essentially acknowledging the industry's position that current-technology battery EVs are still too expensive and have insufficient range. As in previous amendments, ARB attempted to give automakers greater flexibility in meeting individual requirements, while still requiring that equivalent overall emission reductions be achieved.

In these most recent amendments to the ZEV regulations, ARB did provide substantial regulatory incentives for PHEVs. Such vehicles will operate like today's gasoline electric hybrids, except they will be equipped with a somewhat larger battery pack and the ability to recharge the batteries from a standard 110 volt household outlet. PHEVs will likely have an all-electric driving range of at least 10 or 20 miles or more (60 miles is common evaluation option) with a control strategy that turns on and off the gasoline or diesel internal combustion engine for optimal operation. The PHEV will use electricity from the grid to recharge the vehicles' batteries, reducing greenhouse gases and petroleum consumption and potentially criteria pollutants. Research and demonstrations of PHEVs are currently ongoing and as discussed below.

It is noteworthy that significant numbers of non-road electrodrive technologies are being operated in California, including forklifts, golf carts, tow tractors, airport ground support equipment, burden and personnel carriers, turf trucks, sweepers, scrubbers, and varnishers. In addition there are truck-stop electrification facilities for use by trucks when stopped, and electric shore-power for marine vessels. Electro-drive non-road equipment are not part of the ZEV program but are an important component in reducing on-site emissions of diesel PM and other pollutants and have been encouraged through a variety of air quality regulations and incentive programs. The non-road electric equipment is also one pathway towards greater petroleum displacement.

Light Duty Vehicles

As noted above, there are currently no light-duty on-road EV models available for lease or sale by major manufacturers. Six major automakers (General Motors, Ford, Daimler Chrysler, Toyota, Nissan, and Honda) had produced several thousand of these "pure ZEVs" for the California market but all stopped production by 2004. Vehicle conversions are still available in California from a variety of companies, however. In fact, these are in high, and increasing demand. However, being conversions instead of an OEM production model probably relegates these vehicles to niche market status.

The major manufacturers have cited high manufacturing costs, limited performance of storage batteries (limited life and range), and limited market as reasons for discontinuing their EV programs. Despite focused programs to develop and demonstrate advanced battery technologies over the last few years, ARB staff reported at the March 2003 biennial review that "no significant reductions in the cost of battery EVs" had been realized with the small numbers of vehicles produced by that date. The staff report further noted that "the marketing of battery EVs has been met with only modest success," citing only neighborhood electric vehicles (NEVs) as achieving "limited usage" commercialization.[96] By the end of 2003, no major automobile OEM was producing BEVs.

Between 500 and 1,000 major automaker-produced BEVs still remain in California. ARB estimates are at the lower end of the range while the utilities estimate the higher number.[97] According to the utilities, approximately half are Toyota RAV4s operated by Los Angeles Department of Water and Power and Southern California Edison. There are also approximately 200 EV Ford Ranger trucks in operation. The remaining vehicles are mainly privately owned or government RAV4s. In addition, there are several thousand hobbyist electric vehicles (vehicle conversions) that were not part of the ZEV program.

Due to ZEV credits being available for NEVs in a variety of applications and environments, manufacturers have produced and sold many of these vehicles. It is estimated that there are in the range of 15,000 NEVs currently operating in California,[98] although ARB estimates that 33,000 NEVs were placed into service between 2001 and 2003.[99] There have been several manufacturers in the market including Global Electric Motorcars (GEM), a division of Daimler Chrysler, Ford Think, Club Car, a division of GM, Dynasty, and others. The majority of NEVs currently in California are GEM vehicles. Mightycomm reports that sales of the GEMs began in 1998 and spiked in 2001-2003 when they received maximum ZEV credits. Multiple manufacturers actually gave away or leased and sold NEVs far below retail price in order to generate credits. Although some of these vehicles are still in operation, many were reclaimed by the manufacturers. GEM has five certified NEV models currently (2006) being offered for sale or lease.[100] Configurations with varying passenger capacity (2 to 6) and cargo capabilities are offered.

[96] ARB, 2003 ZEV Program Rulemaking, March 25, 2003.

[97] Personal communication with ARB staff. June 2006.

[98] *The Impact of Neighborhood Electric Vehicles in California*, presentation at the Commission hearing on Transportation Fuels, September 29, 2005, available at]http://www.energy.ca.gov/2005_energypolicy/documents/2005_index.html#092905].

[99] Personal communication with ARB staff. June 2006.

[100] Driveclean.com website, [http://www.driveclean.ca.gov/en/gv/vsearch/cleansearch_result.asp?vehicletypeid=37].

Off road Vehicles and Equipment

The overall population of off road electro-drive equipment in California has not been updated since the 2003 Clean Fuel Market Assessment in which it was estimated that there were approximately 300,000 off road electric vehicles, with a combined electrical load of more than 800 megawatts operating in California in 2002.

Heavy Duty Vehicles

Many heavy-duty electric vehicles in the form of electric transit and shuttle buses have been installed in California but have not experienced significant growth. The City of Santa Barbara has been the focal point in use of battery electric vehicles in California with its fleet of 20 buses and shuttles. In fact, the Santa Barbara Metropolitan Transit District operates more battery electric vehicles than any other agency in the nation.[101] Its most recent purchases of electric shuttles and buses were in 2000. It bears noting that the Santa Barbara buses are not classified as urban transit buses because they are too small. Nevertheless, the agency is committed to continuing its use of battery electric vehicles by replacing existing vehicles at end of life but has experienced difficulty in procuring new electric vehicles matching its specifications.

Although a motivating factor in the greater use of electric buses could have been the 2000 ARB Zero Emission Bus (ZBus) Regulation that required reductions in NO_x and PM through the use of advanced vehicle technologies, the regulation has not played a role in electric bus advancement. As part of the regulation, larger transit agencies were required to participate in the demonstration of zero-emission buses, such as electric buses or fuel cell buses. Five transit agencies fit the eligibility requirements for demonstrating zero-emission buses. One, the San Francisco Municipal Railway, complied with its existing electric trolley fleet. The perceived benefits of the fuel cell propulsion system led the majority of these transit agencies to focus their efforts on fuel cell and fuel cell/hybrid electric buses bus demonstrations rather than electric buses.[102] Thus, potential growth in electric bus operation in California has not materialized due to greater focus on zero-emission fuel cell technologies.

Plug-in Hybrid Electric Vehicles

PHEV research and demonstration efforts are ongoing for all of light-duty, medium duty, heavy-duty, and bus applications. The Electric Power Research Institute (EPRI) is heavily invested in all of these areas, helping to advance the technology and establish the environmental and performance benefits.

[101] Santa Barbara Metropolitan Transit District. Request for Information – Electric Vehicles. March 2006.

[102] ARB. Staff Report: *Initial Statement of Reasons. Proposed modifications to the exhaust emission standards and test procedures - 1985 and subsequent model year heavy-duty urban bus engines and vehicles, the fleet rule for transit agencies, and zero emission bus requirements*. May 2004.

There is currently no major manufacturer producing light-duty PHEVs for sale or use in California. Several companies are offering conversions for gasoline hybrid vehicles and research vehicles have been built for demonstration and testing purposes. None of the major automakers are producing PHEVs.

In the medium-duty applications, PHEVs are being tested through a partnership between EPRI, DaimlerChrysler, and others. The consortium is testing a DaimlerChrysler prototype Sprinter van. Currently one van is being tested in California by Southern California Edison. Another 30 vans are being manufactured by DaimlerChrysler with plans for 18 to be tested in the U.S. and the rest in Germany. EPRI expects to test some of these vehicles in other applications as part of their PHEV research and demonstration program. One aspect of the effort is to determine the optimal control strategies for vehicle performance, efficiency, and emissions minimization for both criteria pollutants and greenhouse gases.

PHEV proof-of-concept is being explored for heavy-duty vehicle applications. WestStart/Calstart is leading a consortium of three utilities, EPRI, and a hybrid powertrain provider, Eaton Corp, to produce a PHEV trouble truck in the 24,500-33,000 GVWR range.[103] By applying PHEV technology to utility truck operations, the Hybrid Truck Users Forum (HTUF) Utility Working Group is hoping to maximize efficiency and performance while reducing emissions, noise, and costs. A vehicle has not yet been produced but one proof-of-concept vehicles is expected to be built in 2006.

Vehicle Cost

Currently, vehicle costs are certainly a barrier for EVs. Automobile OEMs are not producing BEVs primarily because of their costs. The costs of PHEVs are expected to be significantly lower than BEVs because hybridization allows the batteries to be smaller. According to EPRI research, plug-in hybrids could be less expensive than conventional gasoline vehicles on a life-cycle cost basis, if produced in traditional automotive-scale volumes.

NEV costs are generally between $5,000 and $10,000 depending on such features as number of passengers and cargo load capabilities. The five GEM vehicles listed in on the Driveclean.com website have MSRP ranging from $7,000 to $12,000.[19] The costs are not easily comparable with conventional vehicles because they operate on a different operating paradigm. Non-road electric vehicles (e.g., forklifts) are generally priced comparably, or less than, similar vehicles using combustion engines.[104] Some of these vehicles operate in enclosed areas not suited for combustion engines.

[103] *PG&E. Plug-in Hybrid Electric Trouble Truck Project.* Presented at the Heavy Duty Hybrid Workshop in Sacramento. September, 2005.
[http://www.airquality.org/mobile/cff/CleanCities/20050922PGandE.pdf] viewed June 2006.

[104] Personal communication with David Modisette, Executive Director of the California Electric Vehicle Transportation Coalition, August 2003.

Vehicle Population Growth Projections

The on-road electric vehicle population in California is currently declining due to absence of new products. However, the population could likely again grow rapidly if PHEVs are commercialized. The current interest in gasoline hybrid vehicles indicates significant interest by consumers in higher efficiency vehicles. California now has in the range of 75,000 – 100,000 hybrid vehicles based on the DMV's expected distribution of 75,000 HOV lane stickers by the end of Summer, 2006. Whether this interest in gasoline hybrids translates to interest in even higher efficiency vehicles that plug-in and use relatively inexpensive electricity is not yet fully known. For 2012 -2022, the potential population of PHEVs is probably a function of several factors: 1) relative costs and benefits of PHEVs versus other powertrain and alternative fuel technologies, 2) advancements in battery and electric drive components, 3) market interest in PHEVs and their unique attributes, and 4) level of continued automaker focus on hydrogen fuel cell and ICE technologies. In addition, with each change of the ZEV and ZBus regulations over the last decade, automakers have gained increased flexibility to comply through the use of a variety of advanced vehicle technologies. Thus it is very difficult to forecast the number of PHEVs that will be on the road in California in the next two decades.

Fueling Infrastructure and Specific Needs

Public electric vehicle charging stations are infrastructure specifically designed and installed for full battery electric vehicle or equipment charging that augments home or base recharging by vehicle operators. Charging stations have been installed throughout the state by private and public owners to make electric vehicle use possible. Some of the stations are designed to be used by vehicles when they are parked overnight. Due to the large battery storage requirements, overnight or other relatively long charging periods using 220/240V power can be necessary. ARB estimates that it takes two to five hours to charge vehicles that are one-quarter to one-half charged and up to eight hours to recharge from an "empty" state.[105] In addition to overnight charging stations, many stations are located in public areas to allow for opportunity recharging away from home.

Two standards were defined for vehicle charging: conductive, originally supported by Ford, Daimler-Chrysler, and Honda, and inductive, supported by GM, Nissen, and Toyota. Thus, chargers to support both types of systems have been installed throughout the state.[106] The inductive charger is essentially a paddle that uses magnetic fields to charge the battery and transmit charging data to the vehicle's computer. The conductive charger is a metal-on-metal plug connector that interfaces with the batteries and vehicle

[105] ARB. *Zero and Near Zero Emission Vehicle Guide: Electric Vehicles.* [http://www.driveclean.ca.gov/en/gv/driveclean/vtype_electric.asp#Charging]. Viewed July 2006.

[106] Alt Fuels.Org. *Electric Vehicle Refueling Connectors.* http://www.altfuels.org/backgrnd/condind.html. Viewed July 2006.

computer by wire. The data transfer between the charger and the vehicle computer is necessary to ensure full charging.

Despite far fewer BEVs operation currently than at the height of the market in the early 2000s, both public and private EV recharging stations continue to be operational in the state. Existing charging stations may continue to operate for some time but will eventually be retired as the current fleet of BEVs reaches its useful life.

Because the much diminished role that on-road BEVs are expected to play in California over the next two decades, (likely limited to NEVs and potentially PHEVs in the light- and heavy-duty markets, as discussed above) the existing charging infrastructure will not be expanded or likely even maintained in the long term. NEVs and PHEVs will instead charge their batteries using standard 110V home or business outlets.

Number of Electric Charging Stations

Since early in the decade, the number of EV chargers in the state has declined.[107] Survey responses received from two alternative fuel technical advisory group members in 2001 regarding the EV charging infrastructure indicated that there were nearly 3,300 EV chargers in California in mid 2001. About 59 percent were inductive chargers and 41 percent were conductive. Checks in mid-2006 of web-based AFV fueling station locators listed on ARB's Driveclean.ca.gov website (e.g., evchargernews.com, cleancarmaps.com and afdc.doe.gov/refueling) indicate estimates between 400 and 750 for the number of chargers currently operational in the state. For example, evchargenews.com, updated in January 2006, lists 600 public-access charging stations in the state. Cleancarmaps.com lists approximately 750 operational chargers, though this site would double count stations that had more than one type charger on site. DOE's Alternative Fuel Data Center (AFDC) lists 400 EV charging stations, 340 of which are public-access. The numbers cited in Table 4-1 were based on the AFDC estimate. Interestingly, the number of chargers by all counts has only declined moderately since the 2003 Clean Fuel Market Assessment, indicating that, despite fewer vehicles on the road, many station owners still have their chargers.

Based on the website data, the stations still in operation are concentrated in three major areas of the state: the Los Angeles Basin, the San Francisco Bay Area, and the Sacramento/San Joaquin Valleys. Within these regions, charging sites are generally located in municipal parking lots, airports, malls, libraries, sports complexes and other locations where people spend time. The basic strategy has been to install chargers at key locations within metropolitan areas, allowing BEV users to extend vehicle range through "opportunity" charging while working, attending events, shopping, etc. Although one cannot completely recharge a low-charge battery during a few hours shopping, it is enough to recharge a partially charged battery or to "top off" the charge. In addition to

[107] The decline is mainly due to the reduction of vehicles in the fleet but it may have also been influenced by the Energy Commission's discontinuation of its infrastructure match program that provided $750 in matching funds to automakers to install infrastructure for each vehicle sold or leased.

the BEV chargers that are located throughout California at public agencies and private businesses, private owners "refuel" their BEVs at home with their own 220/240V chargers installed in a garage or parking space.

For NEVs, charging stations are not necessary because the vehicles can be plugged into standard 110V outlets at the home or business terminal. Off road equipment is also charged directly at the business operations base and does not face the battery range challenges that lead to the need for public charging stations for on-road BEVs.

It is important to note that due to the potential growth for off road electro-drive equipment in the state, the number of chargers for this equipment category could continue to grow in California even though the number of chargers for on-road vehicles is declining.

Little information is publicly available on the quantities of electricity currently "dispensed" at California's on-road EV chargers (per station and collectively), or the quantity needed to justify installation and operational costs. At this stage of EV deployment, public stations do not receive enough use to consume large quantities of electricity. Fleets with large numbers of EVs, such as Southern California Edison's Toyota RAV EV fleet, have experienced high electricity consumption per charger, and substantial quantities of gasoline fuel have been displaced. But data on exact quantities displaced are hard to come by.

As noted above, there were approximately 300,000 non-road EVs (not including lawn & garden equipment) operating in California in 2003 with a total connected load of 835-840 MW (i.e. if all equipment were charging at the same time, the load would be 835-840MW). This could grow to 585,000-620,000 pieces of equipment and 1,530-2,230 MW by 2020 (with summer peak load of 540-775MW). The utilities estimate that the summer peaks can be substantially lowered through time-of-use pricing, interruptible rates, and energy efficiency efforts.[108]

Cost of Electricity

The cost of electricity in California depends on local utility rates and other factors. For EV charging, there are a variety of rate structures. Residential EV charging rates range from $0.04 to $0.13 per kWh for off-peak charging, with on-peak charging in the summer costing substantially more. Also, electricity prices and charging rates change with the seasons and additional time-of-use and demand charges may be applied. To take full advantage of special off-peak EV charging rates, residential customers may need to install a second meter or a dual-meter adapter. As an example, the Sacramento Municipal Utility District (SMUD) has offered an EV charging cost that is approximately half the regular residential rate.[109] To take advantage of the EV charging rate, SMUD

[108] TIAX. *Electric Transportation and Goods-Movement Technologies in California: Technical Brief.* Report for California Electric Transportation Coalition. October 2005.

[109] [http://www.smud.org/about/evs/index.html]. Viewed June, 2006.

requires that an additional meter with a dedicated EV charging outlet be installed at the residence. Southern California Edison offers its residential customers two "time of use" EV charging rates, depending on their individual charging needs and habits.[110]

Some utilities offer an EV mileage credit on the electric bill as an alternative to installing a second meter or dual-meter adapter. The City of Burbank municipal utility, for example, offers a $0.013 per mile credit but charges the normal residential rate of $0.013/kWh to $0.045/kWh.[111] to EV users, the same rates as for "normal" customers.

To place recharging costs in to perspective, past commercially available BEV fuel economy ranged from 0.28 to 0.70 kWh/mile.[112] In fact, this fuel economy, and the associated lowered operating cost represents a major benefit offered by BEVs. The 0.28 to 0.70 kWh/mi translates directly to 53 to 130 mi/gge, certainly in the HEV and projected PHEV range.

Capital Cost of EV Charging Stations

It is not expected that any further on-road EV charging stations will be installed in California due to the absence of an on-road EV product that requires special charging infrastructure. Therefore, these costs are not reported. Battery chargers for off-road equipment, such as those for electric forklifts, generally cost in the range of $1,000-$2,000 per forklift although chargers can usually recharge multiple forklift batteries simultaneously.[113]

Charging Station Public Access: Hours and Accommodations

Hours of access to public charging stations vary. As a general rule, stations are available during the operating hours of the host site. Most public EV charging stations found in parking lots are available around the clock. In the case of office garages, operating hours are usually linked to working hours, e.g., 6:00 a.m. until 8:00 p.m. Presently, EV charging is free to the user at public stations because the public host site pays for the electricity. Thus, cardreader access and point-of-sale billing are not issues. Some billing system and card system mechanisms have been tested, e.g., the Bay Area Rapid Transit's kiosk charging system. Development of user-friendly and cost-effective cardreader systems for EV charging have not been a priority because of the decreasing number of on road vehicles and the absence of growth potential.

[110] [http://www.sce.com/PowerandEnvironment/ElectricTransportation/Tips/Savings.htm]. Viewed June, 2006.

[111] [http://www.burbankwaterandpower.com/res_el_rates.html]. Viewed June, 2006.

[112] Personal communication from P. Quinliven, CEC, September 13, 2006

[113] AQMD has funded forklift charging infrastructure through its Clean Fuels Program Fund. The infrastructure funding was provided for fleets of forklifts rather than individual forklifts and average approximately $1000-$2000 per forklift.

Barriers and Opportunities for Expansion

Vehicle range and vehicle battery life have been the significant barriers to wider adoption and production of BEVs. Reduced range compared with petroleum-based vehicles is a direct function of the batteries' relatively low energy density (energy stored per volume or weight). Reduced battery life is associated with the number of charge/discharge cycles the battery can sustain while operating efficiently. The need to keep the average state of charge low enough to be able to absorb energy recovered through regenerative braking is a limiting factor in battery life. Advancements in lithium based batteries, either lithium ion (LiL) or lithium polymer (LiP) technologies, are showing promise for long-term use either in pure BEVs or PHEVs. The lithium energy storage technologies have the highest energy density and power to weight ratio of technologies considered today, and they have potential for higher cycle lives.

Although there is little indication that pure BEVs will reenter the marketplace, research to lower the costs of conventional gasoline- and diesel-hybrids as well as potential PHEV applications is pushing the envelope in battery development. Toyota has indicated that it plans to offer all of its vehicle models with hybrid powertrain options by the end of the decade and will likely use lithium technologies for energy storage.

The chief barrier preventing expansion of the BEV and BEV charging infrastructure is competition from other developing vehicle technologies that can meet or nearly achieve ZEV standards (e.g. fuel cell technologies, hybrids including fuel-only and plug-in types). At this time, no specific recommendations regarding battery EVs and their charging infrastructure are made due to the uncertainty in the future needs for special BEV infrastructure.

Overall Assessment

As indicated many times in the discussion in this section, the potential for the use of grid supplied electricity as a true alternative fuel that can offset petroleum transportation fuel dependence lies with the continued development of the PHEV. The OEM automobile manufacturers have made clear their aversion to selling vehicles to the public that have their range limited by the distance to the nearest refueling outlet (i.e. charging station). Currently available battery electric technologies do not allow a vehicle "fuel tank" (i.e., the batteries) with enough capacity to offer the range between refueling requirement the public demands and has become used to. And it remains doubtful that battery technology that has sufficient capacity can be developed in the foreseeable future. Moreover, automobile OEMs have invested in other technologies that offer near zero emissions without constraining vehicle range to something the public will not tolerate. The PHEV is likely the next near zero emission technology that could serve as a bridge to other zero emission vehicle technologies such as the fuel cell vehicle. In summary, grid-supplied electricity does not currently, and is not forecast to reduce significant petroleum transportation fuel use in California.

SECTION 5. ETHANOL

Quantities of Use

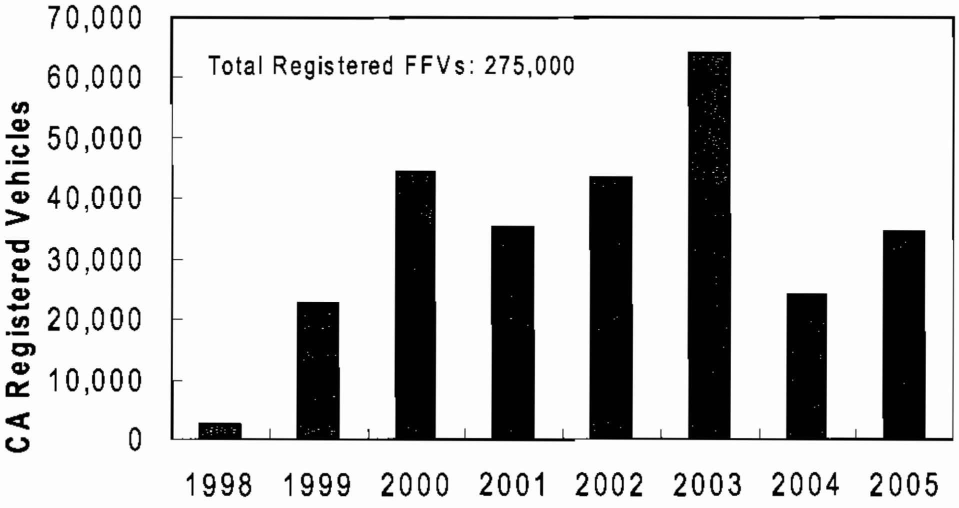
In California the ethanol is sold as a 5.7 percent blend in all gasoline sold in California (some refiners blend at 7.7 percent ethanol, but the blend is rare in the marketplace. Total ethanol consumption for this blend is 900 million gallons sold per year. The use of ethanol as a blending component was prompted by the phase out of MTBE. The E5.7 blend corresponds to a 2 percent oxygen content used to meet the federal oxygenate requirement for air quality reasons. The high octane number of ethanol is also needed to make up for the contribution to the octane rating provided by MTBE. In order to meet volumetric output, octane, and emission requirements, the fraction of ethanol blending in the gasoline pool is expected to remain constant over the next few years.[114]

E85, a blend of 85 percent ethanol and 15 percent gasoline by volume, is sold at four California refueling stations, making up a small fraction of the demand for ethanol. Flexible fueled vehicles (FFVs) are on the road in California that could use E85 if it were made available at more sites. With current in-state production levels, California is many years away from producing enough ethanol to meet its own gasoline blending requirements. The advantages of E85 fueling, emissions impacts, petroleum displacement, and impacts on the gasoline pool need to be better understood. Selling ethanol as E85 would offer ethanol producers another channel to market and would provide a different set of financial risk factors and pricing options than selling ethanol as a gasoline blending component.

Figure 5-1 shows the number E85 FFVs registered in California by model year, with a total of nearly 250,000 vehicles reported registered through October 2005. The varying population by year reflects the number of FFVs that were sold in a year, market preferences for the vehicles, and vehicle retirement. FFV sales increased through 2003 and then dropped significantly. The decline in subsequent year FFV populations is due largely to Ford and Daimler-Chrysler reducing the number of their models that were offered as FFVs.

Table 5-1 summarizes the state of ethanol fuel use in California. E85 sales are based on the most recent information for vehicle registrations. E85 fuel usage is very low and a throughput per station was estimated. The contribution of ethanol as a blending component is also given.

[114] Kennedy, R., Schremp, G., et al. *Ethanol Market Outlook for California*, CEC Report CEC-600-2005-037, November 2005.



Source: DMV database

Figure 5-1. E85 FFVs registered in California in October 2005, by model year.

Table 5-1. Ethanol transportation fuel use in California.

Number of E85 vehicles(2005)	250,000
Fraction of on-road population, %	1.0
OEM LDV FFV models offered (2006)	21
LDV FFV engines certified (2006)	10
HDV engines certified (2006)	0
E85 stations, total	4
public assess	1
E85 dispensed, million gal (2005)	0.1
million gge	0.07
petroleum fuel fraction, %	0.0005
Ethanol blended in gasoline, million gal (2005)	900
million gge	648
petroleum fuel fraction, %	4.4

Source: Various

Availability of Vehicles

Flexible-fuel vehicles (FFVs) powered by ethanol[115] have been offered in the United States by major manufacturers for several years. As Table 5-2 shows, a variety of 2005 and 2006 model year makes and models are currently offered as FFVs that can run on E85. Similar offerings have been available over the last few model years. Some FFV offerings are available only for certain vehicle configurations. A more detailed list of ethanol FFVs is available from the National Ethanol Coalition or the EPA Fuel Economy Guide. The Vehicle Identification Number (VIN) can also be used to determine if the car is an FFV, as many do not otherwise identify or advertise that they can operate on E85.

Table 5-2. 2005 and 2006 model year E85 FFVs

Manufacturer	Available Models as E85 FFVs	2006 Offerings
GMC / Chevrolet	Various SUVs (Chevy Tahoe, GMC Yukon, Chevy Suburban) and pickups (Chevy Silverado, GMC Sierra), Chevy Impala, Monte Carlo	10
Chrysler / Dodge	Various minivans; Chrysler Sebring and Dodge Stratus sedans / convertibles, Dodge Ram Pickup, Dodge Durango SUV	5
Ford / Mercury	Taurus sedans and wagons; selected Sables; Explorer and Mountaineer SUVs; F150 pickups, Lincoln Town Car, Crown Victoria (excluding police and taxi), Mercury Grand Marquis	5
Mercedes-Benz	C320 sedan and coupe, C240 sedan and wagon	0
Nissan	Titan King and Crew Cab	1

Source: National Ethanol Vehicle Coalition website [www. E85fuel.com/ffvs.htm]

EPA Fuel Economy Guide [www.fueleconomy.gov]

Automakers offer FFVs as part of their strategy to comply with Federal Corporate Average Fuel Economy (CAFE) standards. E85 FFVs improve the fuel economy rating for automakers[116] even if they are not fueled on E85. The CAFE incentive for FFVs has resulted in millions of vehicles being built in the U.S., which could provide an immediate customer base for E85 stations if they are built.

[115] Ethanol FFVs are capable of running on a blend of 15 percent gasoline and 85 percent ethanol (E85), or any mixture of E85 and gasoline. Essentially the same engine technology is used in FFVs that operate on methanol (M85).

[116] An automaker's overall CAFE score essentially corresponds to the inverse of all of the fuel used by the cars sold in a year. The CAFE calculation is based on a vehicle operating on E85 half of the time, regardless of what the vehicle will do in customer service. The ethanol component of E85 does not count towards the fuel calculation. Thus an E85 FFV with a fuel economy rating of 16 mpg on E85 and 21 mpg on gasoline would effectively have a fuel economy of 35 mpg for CAFE calculations. Note that the fuel economy calculation is weighted by the gallons per mile of fuel consumption or the harmonic average of the mpg values.

The major automakers are beginning to actively promote their FFVs. In February of 2006, GM started an ad campaign to promote awareness of E85 in the general public and its own flex-fuel vehicles called "Live Green, Go Yellow". The campaign seeks to make consumers aware of the 1.5 million GM vehicles that are E85-capable as well as encourage customers to push for E85 stations in their neighborhoods. GM, Chevron, Pacific Ethanol, and the State of California have announced a joint effort to demonstrate E85 FFVs. Plans for this program include the operation of 1500 GM Impalas and Silverado pickup trucks with the California Department of Transportation (Caltrans) in Northern California and the Central Valley. Chevron would provide the necessary fueling stations for the project and the ethanol would be provided by Pacific Ethanol.

Ford is partnering with the ethanol company, VeraSun Energy to add E85 stations in the Midwest by creating an "Ethanol Corridor" between Chicago and Kansas City. Ford has local ad campaigns for the areas with high concentrations of E85 stations. Their ad campaign uses an interstate highway sign with and E-85 in the route designation. Ford, GM and Daimler-Chrysler plan to sell 1 million new FFVs (total U.S.) in 2006 and double that production by 2010.

It appears that the CAFE incentive has been a key driver for the production of FFVs. Carmakers now appear to be embracing E85 as an option to displace petroleum, so the outlook for the continued production of FFVs appears promising. Growth in E85 fueling infrastructure and greater use of E85 would create a continued customer demand for FFVs in the Midwest. Therefore, a continued growth of the FFV population in California might be expected. However, the recent drop on FFV offerings suggests that there will be uncertainties in the California FFV population unless either the use of E85 increases or strategies are developed to assure the continued sales in California.

Range and Fuel Economy

E85 is a relatively high-octane (rating of 105) fuel that contains about 72 percent of the energy in gasoline on a volumetric basis (approx. 82,000 Btu per gallon, compared to 114,000 Btu/gal for gasoline)[117]. When driven on E85, this translates to a proportional reduction in driving range (assuming the same size fuel tank) for FFVs compared to similar gasoline-powered vehicles. Estimates for mid-sized vehicles indicate that more than 350 miles can be driven on an 18-gallon tank of fuel. FFVs operating on E85 get a horsepower boost of approximately 5-7 percent.[118] The improvement in performance has been attributed to a variety of factors including charge air cooling and higher octane

[117] The energy content for fuels are compared on a lower heating value basis. The lower heating value is considered more representative of the maximum energy that could be recovered in an internal combustion engine. The LHV of E85 blends can vary with the properties of the gasoline blending component and the actual level of ethanol in the E85. Furthermore, the heating value in Btu/gal is not necessarily the weighted average of the heating values of the ethanol and gasoline blending components because the density of the resultant mixture may not correspond to the weighted average of the components.

[118] National Renewable Energy Laboratory, Alternative Fuels Data Center website [http://www.afdc.nrel.gov/altfuel/eth_general.html].

number than gasoline. The latent heat of vaporization of ethanol is about six times as high as that of gasoline. This fuel property results in increased cooling of air entering the cylinder as well as during the compression stroke. The decrease in air temperature increases the density of the air charge and results in less work required by the piston. Newer engines with knock detectors can take advantage of the higher octane number of E85. Timing can be advanced to the onset of knock, which results in more efficient engine operation. The energy consumption is also improved for FFVs operating on E85 for similar reasons.

The fuel economy data for E85 passenger cars are reported in the EPA Fuel Economy Guide. For E85 FFVs, the data are reported for the vehicle operating on gasoline as well as the vehicle operating on E85. Results are presented in miles per actual gallon. Fuel economy data for all of the FFVs in the 2006 Fuel Economy Guide shows that on average an FFV traveling on E85 requires 1.34 gallons of ethanol or 1 gallon of gasoline to drive the same distance. This value is referred to as the fuel substitution ratio. This figure is based on the average fuel substitution ratio for 31 FFVs and agrees with similar calculations performed for prior model years. When compared on an energy equivalent basis, the energy consumption on E85 is 3 percent lower than that of FFVs operating on gasoline[119]. Comparisons of the fuel economy from prior EPA Fuel Economy Guides also show a fuel substitution ration of 1.34.

While the fuel economy of E85 and gasoline vehicles is published in the fuel economy guide, there is no consistent guide to customers on what E85 price represents a comparable comparison with gasoline. Customers might choose to prefer E85 because it is domestically produced, has high octane number, or other factors.

The FFV feature comes standard on the vehicles shown in the table above. Since all models have this feature, no incremental cost for FFV operation is apparent to the consumer. The cost to the manufacturer is often cited as being less than $100. Because E85 FFVs are part of automakers compliance strategy for meeting Corporate Average Fuel Economy requirements, it is in the manufacturer's best interests to not have an FFV price differential that is easy to determine.

FFVs that are designed for operation on E85 are already commercially available, as noted above. Thousands (about 250,000) are currently on the road in California, and growth in these numbers is expected to continue as long as automakers offer the FFV feature as standard equipment on popular models.

[119] The energy content of gasoline is higher than E85 by a factor of 1.39 (1/0.72). The accuracy of the 3 percent improvement is about 1 percent (likely fuel efficiency improvement is 2 to 4 percent) due to uncertainties in the test fuel's exact composition, heating value, variations in vehicle performance, and reporting of fuel economy with only 2 significant figures of precision.

Emissions

E85 vehicles must be certified to operate on E85 and any mixture of ethanol and gasoline. No issues with exhaust emissions have developed regarding E85 issues. However, low levels of alcohol appear to result in an increase in evaporative emissions. The increased evaporative emissions are due to the alcohol permeation in fuel system components enabling the transport of hydrocarbons through the hose material. This hose permeation effect appears to be an issue with conventional vehicle operation on California RFG with 5.7 percent ethanol. The hose permeation effect does not appear to increase if the ethanol content is increased to 10 percent .

Fueling Infrastructure and Specific Needs

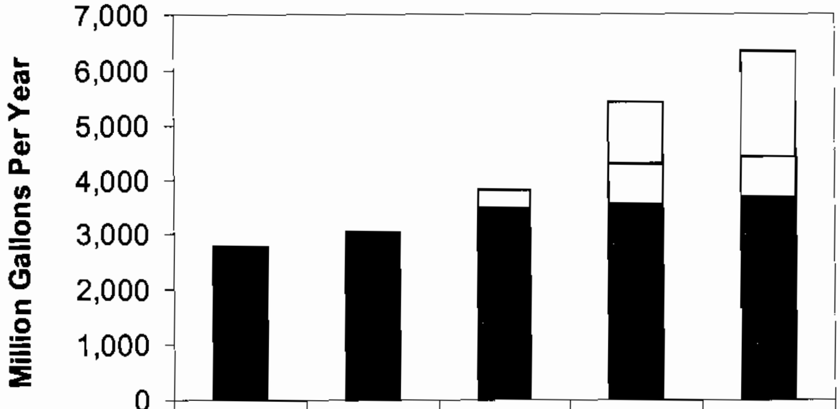
The success of an E85 infrastructure depends on the price and availability of ethanol as well as an FFV population to support E85 sales. At this time, ethanol prices are driven by its value as a low level blending component for gasoline coupled with requirements for gasoline formulation. Therefore, opportunities for E85 sales are limited until ethanol supply exceeds the demand from low level blends. Technical requirements for E85 delivery and fueling infrastructure are not a significant barrier.

Demand for ethanol in California (for all transportation applications) would include the sum of E5.7 and E85 sales. E5.7 currently accounts for 900 millions gallons per year. If the same quantity of gasoline were sold as E10, and additional 700 million gallons per year would be required. 250,000 E85 FFVs operating on E85 half of the time would consume 200 million gallons of ethanol.

Ethanol Production

U.S. fuel grade ethanol production reached 3.5 billion gallons in 2005, with corn serving as the primary feedstock. Most of this was consumed in the transportation market through ethanol's use as a blending agent with gasoline; either to extend the available volume of gasoline, or increase oxygenate levels to reduce wintertime carbon monoxide emissions from vehicles. Used in these ways, ethanol is considered a "replacement" fuel instead of an alternative fuel (per the U.S. Energy Policy Act). Thirty-nine new ethanol plants are expected to be completed over the next year in the U.S., which will result in an additional 1.4 to 2 billion gallons of ethanol production capacity.

The Energy Bill of 2005 requires 7 billion gallons of ethanol to be used for transportation fuel by 2020. Provisions in the Energy Policy Act of 2005 include a nationwide renewable fuels standard (RFS) that will double the use of ethanol and biodiesel by 2012. The bulk of the renewable fuels are expected to be ethanol blended with gasoline, and biodiesel blended with petroleum diesel fuel. Renewable fuel use requirements start at 4 billion gallons in 2006 and increase to 7.5 billion gallons in 2012. By 2013, a minimum of 250 million gallons a year of cellulosic derived ethanol will be required. Figure 5-2 shows the current U.S. ethanol production capacity and projections for growth.



	2002	2003	2004	2005	2006
□ Planned			0	1150.5	1904
□ Under Construction			330	730	730
■ Existing Expansions			0	62	201
■ Existing	2773	3041	3486	3486	3486

Source: Energy Commission[120]

Figure 5-2. U.S. Ethanol Production Capacity[120]

Forty million gallons of ethanol are currently produced in California[121] with the potential to expand production significantly from in state and imported feedstocks. The Commission's Bioenergy Plan indicates a theoretical production potential of 3 billion gallons per year from cellulosic resources. This theoretical value includes feedstock resources that could be grown or collected from residue. However, the economics of production, competing uses for biomass resources, delivery costs and constraints, have not been extensively studied.

A 2001 Consultant Report for the Energy Commission evaluated the costs and benefits of using biomass-based ethanol production in California to meet this oxygenate demand for California gasoline. The analysis assessed the economics of using cellulose residue to produce 200 to 400 million gallons per year of ethanol production in California. This level of production is a conservative estimate used to assess near term policy options and is well within the 3 billion gallon theoretical value in the Bioenergy Plan. The 400 million gallon per year analysis does not include cellulose or sugar/starch based energy crops. Many positive attributes were identified from establishing a biomass-to-ethanol

[120] McCormack, M., *The Outlook for Ethanol Use in California*, CEC Presentation 2005-02-08.pdf, February 2005.

[121] California, demand for ethanol in California (for all transportation applications) could exceed 700 millions gallons a year, or about 40 percent of the nation's current total output.

industry in California, including a finding that the economic benefits are potentially greater than the costs.[122]

Three ethanol production facilities are currently operating in California with a combined capacity of 33 million gallons per year (mgpy). Parallel Products Inc. operates a 3 mgpy facility in Rancho Cucamonga using beverage wastes. The Golden Cheese Company in Corona, CA uses waste cheese whey to produce 5 mgpy of ethanol. California's first corn grain ethanol plant opened in August 2005 in Goshen built by Phoenix Bio Industries and Western Milling. The facility uses corn imported from the Midwest to produce 25 mgpy of ethanol and 265,000 tons of wet distillers grain that is sold to the local cattle industry. Ownership is under negotiation.

Expansion of the California Ethanol industry is under way. Pacific Ethanol is nearing completion of its 35 mgpy plant in Madera which is scheduled to begin production in the Fall of 2006. The Commission's Bioenergy Plan indicates a theoretical production potential of 3 billion gallons per year from cellulosic resources.[123] This theoretical value includes feedstock resources that could be grown or collected from residue. Corn and sugar crop based facilities would add to the total production potential.

Plans for new ethanol plants are being floated by many groups. The City of Gridley is working on a decade old plan to produce ethanol from rice straw. Developers are investigating the conversion of municipal waste in Santa Maria, Riverside and Santa Barbara into ethanol. In Imperial County, a group is proposing a sugar/ethanol facility using sugar cane and sugar beets with the bagasse used to make ethanol.

The success these of ethanol plants will depend on many factors. New technologies, such as cellulosic conversion, will need to be proven at a commercial scale. The price of ethanol needed to support the rapid growth in plant construction is an important uncertainty. In the event of an oversupply of ethanol or change in gasoline or ethanol prices, the willingness of the investment community to sustain continued funding of ethanol plants may be challenged.

Distribution Infrastructure

The ethanol delivery infrastructure is currently handling the demand from E5.7 of 900 million gallons per year. Most ethanol is imported to California by railcar from the Midwest with some product imported from the Caribbean or Brazil by tanker ship. The ethanol is stored in bulk terminals in southern California and in the San Francisco Bay area.

[122] California Energy Commission, *Costs and Benefits of a Biomass-to-Ethanol Production Industry in California*, Final Consultants Report P500-01-002, by Arthur D. Little, March 2001, at [http://www.energy.ca.gov/mtbe/ethanol/index.html].

[123] *Recommendations for a Bioenergy Plan for California*, CEC 600-2006-004-F, April 2006.

Ethanol and gasoline blending components follow separate delivery routes to gasoline blending terminals. Gasoline is transported by pipeline, typically at a cost of 1 to 2 cents per gallon while ethanol is transported by tanker truck at a cost of 4 to 5 cents per gallon[124]. Currently, ethanol products are not shipped in petroleum product pipelines due to the risk of either absorbing water and sediment into the ethanol product or affecting the life of the pipeline by dissolving corroded components. Regardless of the rationale for segregated infrastructure, the truck delivery mode will likely remain in use in the near term.

The established ethanol distribution infrastructure would play an important role in the expanded use of ethanol in California either as higher level blends or as E85. Practices for blending and hauling ethanol have been established and bulk storage facilities are available for the expanded use of ethanol fuels. Ethanol could also be directly distributed as E85 from in-state production facilities if California production capacity were to expand.

Fuel Station Infrastructure

E85 stations are currently commercial, as evidenced by the many states with many dispensing stations. Equipment requirements for E85 fueling stations are similar to those for gasoline stations. The fuel is stored in an underground tank and dispensed through a conventional gasoline dispenser. The requirements for E85 fueling stations are documented in a DOE report[125]. ARB provides a list of E85 compatible vapor recovery components and requires that the fueling system be tested for compliance with vapor recovery regulations. At this time, an enhanced vapor recovery system has not been certified by ARB, but meeting this requirement should be possible with existing commercially available equipment. [126] Certification of a fueling station design can cost over $10,000 because the equipment configuration needs to be tested in-use at a service station according to ARB rykes. The testing requires emission monitoring equipment and involves monitoring station performance as a representative population of vehicles is fueled.

About 700 E85 stations operate in the U.S. with 508 E85 stations listed in the National Ethanol Vehicle Coalition (NEVC) FFV Purchasing Guide. Over 100 stations are in Minnesota with large station concentrations in other ethanol producing states. Since corn is a primary feedstock for ethanol, it's not surprising that America's highest concentration of E85 use and fueling stations is in the Midwest. Incentives such as producer payments have resulted in a large number of ethanol plants being built there. The higher concentration of fueling stations in Minnesota is certainly due to the large

[124] Personal communication, R. Reynolds, Downstream Alternatives, August 2006.

[125] *Guidebook for Handling, Storing and Dispensing Fuel Ethanol*, prepared by the U.S. Department of Energy (see [http://www.afdc.nrel.gov/pdfs/ethguide.pdf]).

[126] Lew, G., ARB Letter, E85 Compatible Vapor Recovery Equipment, June 5, 2006.

number of ethanol plants in the state. As illustrated in Figure 5-3, four E85 stations are located in California with three of these stations identified as private access stations.

Fueling Station Constraints

The number of E85 stations required in California depends on the strategies for E85 sales. With the relatively large FFV population, existing publicly owned vehicles could provide sufficient demand to support public stations. A marketing campaign would be needed to make customers aware of their vehicle's E85 capability and the location of stations. Fleet strategies for E85 use are also possible.

Source: This analysis

Figure 5-3. Planned and Existing California E85 Fueling Stations.

Fueling stations need to provide sufficient throughput capacity and customer access. Seasonal ethanol availability, ethanol price, availability of FFVs, and fraction of fillings on E85 will affect the potential sales of E85. Because FFVs can operate on gasoline, customers would presumably not fuel with E85 all of the time. The requirements for E85 fueling stations were examined in terms of potential FFV demand, ethanol throughput constraints, and fuel station coverage.

A typical large gasoline station sells 250,000 gallons per month or 50,000 gallons per month per dual hose dispenser. Volumes of diesel are lower at retail stations and premium gasoline sales are significantly lower than regular grade sales. If a throughput of 20,000 gallons of E85 were sufficient to support the use of an underground tank and dispenser, about 240 FFVs would be required operating on E85 100 percent of the time[127] or 480 vehicles per station fueling on E85 half of the time.

With an in-state FFV population of 250,000, at an average on-road fuel economy of 14 mpg (E85 gal), annual fuel consumption would be 930 gal/vehicle/year. 230 million gallons of E85 (196 million gallons of ethanol) would be consumed if these vehicles fueled on E85 half of the time. The actual percentage of time fueling would depend on the price of fuel, fuel availability, and station access. The 50 percent E85 usage is intended to illustrate the infrastructure requirement. Assuming that vehicle queuing and fuel payment is as important a constraint as fuel flow from the dispenser, an E85 station may be able to deliver 70,000 gallons per dispenser per month[128]. Approximately 275 fueling stations would be required to dispense this quantity of fuel based on the typical vehicle throughput of gasoline stations. However, a larger FFV population may be needed to market this fuel effectively.

The distribution of the vehicles may also be a challenging factor in making a business case for E85. The State's 9,400 retail gasoline stations support a vehicle population of 2,500 vehicles per station. With a scenario for 250,000 FFVs with 275 stations, the vehicle to station density is 900. Unless FFVs and drivers motivated to use E85 were closely located to E85 stations, the existing FFV population would likely underutilize 275 E85 stations.

The E85 dispensers in Minnesota are operating at significant lower throughput compared to this queuing constraint. The highest reported throughput was 26,820 gallons per month, about 400 vehicles operating on E85 full time. The average is 7,420 gallons per month, with just over 100 full time E85 vehicles per station.

Access to fueling stations is an important factor for alternative fueled vehicles. For an introduction of vehicles to the public, 5 to10 percent of retail stations are considered necessary to minimize the impact on the customer and enable driving in a wide region. In the case of FFVs, presumably fewer stations would be required for customers to fuel on E85 a significant portion of the time. 280 retail stations in California would provide 3 percent retail coverage and provide sufficient throughput capacity to serve

[127] 14,000 miles/year, 19.4 miles per gallon gasoline (larger than average car), 1.39 gallons E85/gal gasoline 83 gal E85/vehicle/month.

[128] The average fill volume for gasoline is 8 gallons. The fill volume for E85 would need to be 11 gallons, adding less than 1 minute to the actual fueling event with a 5 gal/minute pump.

250,000 FFVs as discussed previously. For comparison in Minnesota, 6 percent of gasoline stations offer E85.[129]

If E85 fuel is made available, the existing stock of E85 FFVs provides a customer base that would eliminate some of the early underutilization of infrastructure associated with other alternative fuel options. The ability to market fuel to over 200,000 vehicles in a potentially growing population will be an important factor in aiding in the development of an E85 infrastructure.

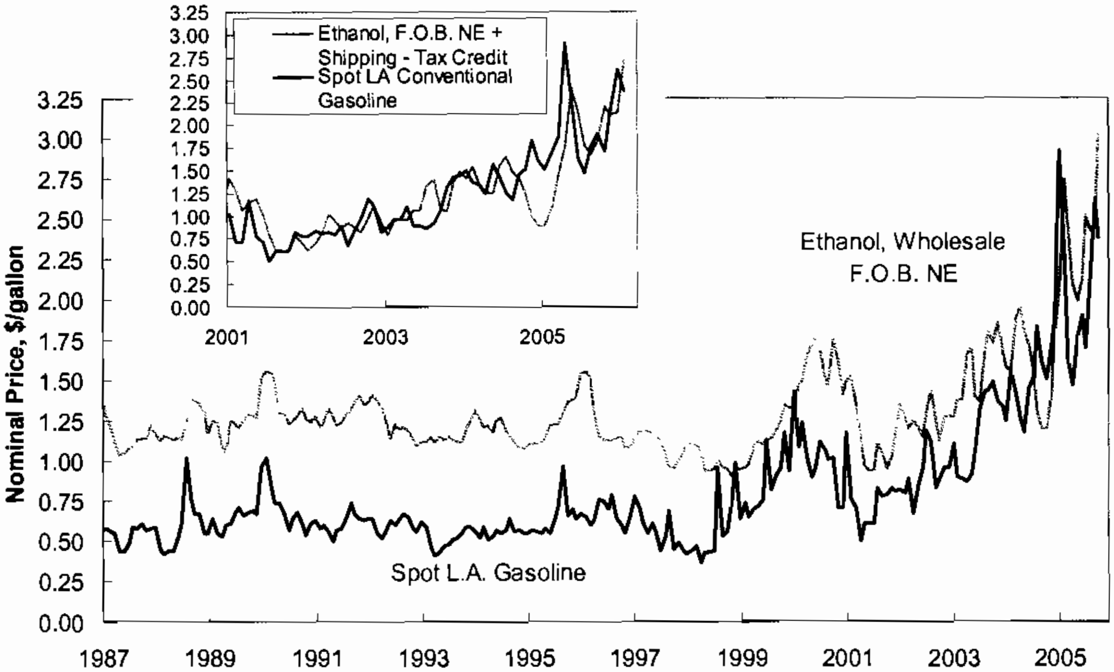
Fuel Supply, Demand and Price

From the current in-state production capacity of 33 million gallons per year, it is clear that almost all the ethanol currently blended into gasoline in the state is imported from out-of-state. Most of the ethanol used in fuel in California has been from conventional feedstocks such as corn. Factors such as the distance and cost of ethanol transport to gasoline blending markets versus local E85 sales, other costs in the retail supply chain, customers' willingness to purchase ethanol, and other factors would affect the economic viability of selling E85.

Historically, the wholesale price of ethanol has tracked the price of gasoline. Prior to 1999, wholesale ethanol prices were about 50 cents per gallon higher than that of wholesale gasoline. This difference reflected the $0.54 per gallon tax credit available for blending ethanol with gasoline. This trend continued after 2000 with the phase out of MTBE and expanded use of ethanol. The volatility in both gasoline and ethanol prices increased. The prices in Figure 5-4 are based on ethanol delivery to Nebraska, so, the price delivered to California would be about $0.20 per gallon higher. After 2004 ethanol prices minus the tax credit ($0.51) plus shipping costs were often below the price of gasoline (see insert in Figure 5-4)[130]. Supply and demand factors influenced the price of ethanol as much as the blending value in gasoline.

[129] 227 E85 stations in MN pumping an estimated average of 7,423 gallons per month per station (26,821 is the high) –MN Department of Commerce. [http://www.state.mn.us/mn/externalDocs/Commerce/E-85_Fuel_Use_Data_041703045254_E85FueUse.pdf]. MN has 3656 retail gasoline stations -National Petroleum News [http://12.9.210.65/uploads/researchdata/2006/USAnnualStationCount/06-stationcount.pdf].

[130] McDonald, T., *Alcohol Fuel Flexibility, Progress and Prospects*, XV International Symposium on Alcohol Fuels, September 2005, Also CEC Presentation 999-2005-024.pdf.



Source: DOE EIA

Figure 5-4. Ethanol and Gasoline Wholesale Price ($/actual gallon)

Marketing E85 is challenging because the customer is aware of its lower energy content and would expect the price to be approximately 72 percent of the gasoline price. As a gasoline blending component, ethanol has value as a high octane component, meeting oxygenate requirements or renewables content needs. Also the resultant E5.7 gasoline blend has a much smaller change in energy content compared with non oxygenated gasoline or reformulated gasoline with MTBE. Ethanol prices may not always consistent with competitive pricing as E85.

With current demand for ethanol as a gasoline blending component and existing ethanol supplies, the price relationship between ethanol and gasoline might be expected to persist. However, expanded supplies of ethanol in California and the U.S. would put pressure on ethanol prices. Growing E10 and E85 markets would absorb some of the growth in production capacity. If ethanol supplies grow significantly, the price of ethanol could approach the cost of production, which is $1.20 to $1.70 per gallon.

Currently, in those states where it can be purchased, E85 is typically more expensive than gasoline on an energy-content basis in most retail locations. Aggregate E85 prices are not reported by DOE and most frequently cited source of E85 prices is provided by the American Lung Association[131]. Spot checks of E85 prices are reported by customers and posted on the website. In 2006, the E85 prices at the pump range between $2.60 and $2.90 per gallon when gasoline is about $3.00 per gallon, although some stations have offered E85 at prices at energy equivalent prices. The EPA uses an ethanol price of $1.98 in its fuel calculator and a gasoline price of $2.87/gal. These values are consistent with EIA projections of fuel prices and do not reflect the recent market activity.

With gasoline at $3.00/gal, an energy equivalent price for ethanol would be $2.16 per gallon[132] of E85 or $2.24 per gallon on a per mile equivalent basis (3/1.34). It appears that prices were somewhat higher than these levels at many E85 stations. Fuel sales averaged over 7,400 gal per month per dispenser.

Ethanol Retailing Options

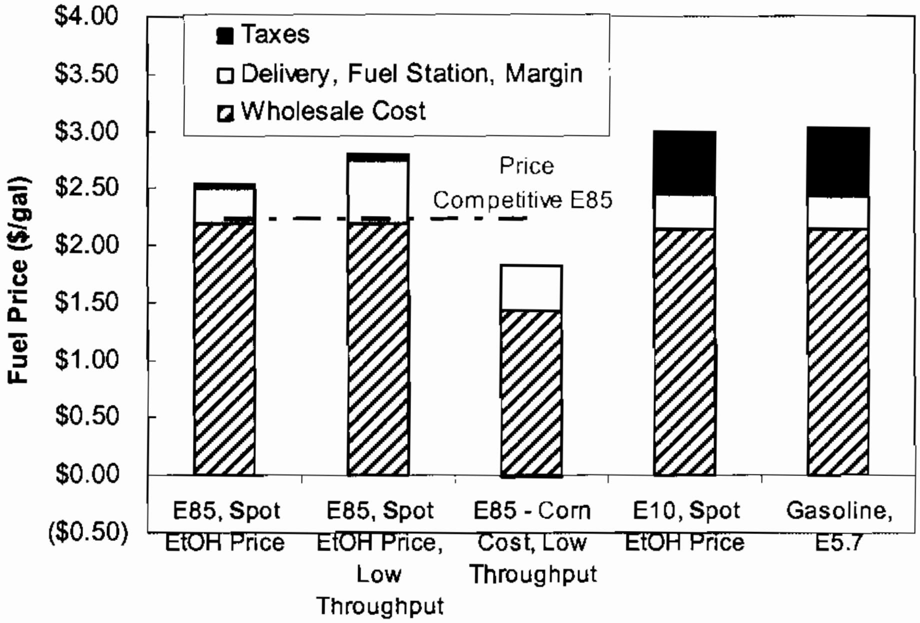
Several ethanol marketing options were examined in order to assess the potential for selling ethanol as E85 or as a blending component to gasoline. The following factors were considered in the analysis:

- Fuel price is built up based on fueling station capital, operating costs, fuel throughput, road taxes, sales tax, and ethanol tax credit.
- Fuel price built up with spot ethanol at $2.20/gal and gasoline blending component at $2.14/gal. The scenario with ethanol production cost is $1.31/gal with corn at $2.18/bushel
- Costs for low throughput stations are based on 13,000 gal/month from a single dispenser and assume direct delivery and no bulk terminal costs for ethanol.

Figure 5-5 shows the equivalent retail price of gasoline and ethanol blends with different marketing scenarios. The price point where E85 is competitive with gasoline is also shown. For wholesale ethanol at the spot price, E85 prices would need to be higher than $2.26 per gallon ($3.03/1.34), which would make it more expensive than gasoline per mile. The price of E10 would be slightly lower than that of gasoline and the retailer could sell the product at the same price as gasoline or slightly lower (the energy content will be slightly lower). However, selling E10 in California would require demonstrating that the fuel blend has no net impact on vehicle exhaust and evaporative emissions.

[131] American Lung Association, *E85 Price Forum*, [http://www.cleanairchoice.org/outdoor/PriceForum.asp].

[132] A gallon of E85 contains about 72 percent of the energy found in a gasoline gallon. The fuel substation ratio, which takes into account fuel economy, is 1/1.03/0.72 =1.34



Source: This analysis

Figure 5-5. Ethanol Fuel Prices for Different Sales Strategies.

If the price of E85 is built up from the cost of corn based ethanol from a large plant ($1.31/gal), then the resultant E85 price is well below $2.26/gal. The net back price to the ethanol plant would be $1.79/gal for an E85 price of $2.26/gal.

These pricing scenarios illustrate the potential marketing options for ethanol in California. E85 provides another market for ethanol which would help maintain price stability if the blend market is saturated. With gasoline prices at $3/gal, E85 sales provide an opportunity for fuel sales that are higher than the cost of production including capital recovery. Furthermore, vehicle operators appear to be willing to pay the mileage equivalent price for E85 or slightly higher. Market risk through the E85 pathway would be tied to the price of gasoline and customer preference rather than the ethanol market.

Several marketing models have been implemented for the E85 stations in the Midwest. About 300 stations are supplied by ethanol directly from the plant. The gasoline blending component is added at gasoline terminals. This option takes advantage of lower transportation costs to fueling stations in close proximity to ethanol plants. About 100 stations are operated through strategic alliances with state energy agencies, fuel marketers, and ethanol plants[133]. Marketing ethanol as E85 appears to provide a lower net back price to the ethanol producer.

[133] Personal communication, R. Reynolds, Downstream Alternatives, August 2006.

In the near term, California ethanol production will not even approach demand for E5.7. However, with continued growth in ethanol production capacity, E85 may prove to be an attractive avenue to market, especially where direct sales from the ethanol plant can cut transportation costs. Selling E85 reduces ethanol supply from blending markets and producers may find the combination of market paths helps maintain stability in ethanol prices.

Many of the E85 stations in the Midwest are supplied by ethanol directly from an ethanol plant. The gasoline blending component is obtained from a nearby terminal. Available gasoline is blended with the ethanol to achieve the required vapor pressure depending on the time of year and season. This splash blending approach effectively results in E75, E80, and E85 sold at different times of the year. For example, E85 sold during colder months often contains 70 percent ethanol and 30 percent petroleum to produce the necessary vapor pressure for starting in cold temperatures. An E85 fueling site operator typically cannot carry over summer-blend E85, but rather must "blend down" any remaining summer fuel to make an E70 mixture134. This may be done with relative ease by adding additional gasoline to the storage tank. There is no concern with carrying over winter-blend E70 into warmer months as FFVs operate on any blend of E85 and gasoline in during warmer times. For retail service stations, seasonal fuel adjustments are handled automatically at the wholesale fuel terminal. Similar blending strategies may be needed in California if E85 is going to be blended with gasoline blending stock at terminals.

Barriers and Opportunities for Expansion

The market for ethanol has grown significantly as a blending component to gasoline, and recent interest from automakers and fuel producers in the Midwest indicate that an E85 strategy might also provide a significant market in California. The population of FFVs has reached over 200,000 vehicles which could consume well over 200 million gallons of E85, even if operating on the fuel half of the time. E85 could provide a channel to market that would provide fuel producers with a different price/risk relationship than selling ethanol to the gasoline blending pool. However, several barriers would appear to slow the growth of E85 as a fuel in California.

California ethanol production capacity is less than 40 million gallons per year, far below the 900 million gallons currently blended into gasoline. Any growth in ethanol production capacity might first be used to displace imported ethanol in the gasoline pool. While a business case might exist for E85 in the Midwest where producers make more ethanol than can be blended into gasoline locally, the same situation is not likely to exist in California for many years. However, as ethanol production capacity grows in California, some plant operators might identify local E85 strategies.

[134] U.S. DOE, *E85 Tool Kit*, [http://www.eere.energy.gov/afdc/e85toolkit/e85_specs.html].

E85 stations have not yet been certified for ARB vapor recovery requirements. Achieving this certification requires an investment in time and other resources from station operators, though this does not pose a substantial technical challenge.

Hose permeation emissions from low level blends of ethanol may limit the use of E10 in California. The emission impacts of the commingled fuel products in E85 vehicles have not been assessed.

Automakers have built E85 vehicles as part of a CAFE compliance strategy. The continued sale of the vehicles in California is not assured as the CAFE incentive does not require sales in the state. Similarly, many E85 vehicles have been purchased by fleets to meet EPact requirements. If EPact requirements change to require the use of alterative fuels, the choice of E85 FFVs many not be assured.

SECTION 6. ALTERNATIVE DIESEL FUELS

Alternative diesel fuels as defined in this report are fuels with a non-petroleum component (even completely non-petroleum) that can be used in an unmodified or slightly modified diesel engine. This report will concentrate on the forms of alternative diesel fuels that are available to vehicles on the road today, either commercially or in demonstration fleets. These three alternatives are biodiesel, Fischer-Tropsch diesel (referred to gas to liquid, or GTL diesel), and E diesel. All of the alternative diesel fuels offer the benefits of reduced petroleum dependency and increased renewable fuels use; some also give reduced vehicle emissions.

Biodiesel, refers to any diesel fuel substitute derived from renewable biomass. It is currently produced in the U.S. and elsewhere from vegetable oil, animal fat, or waste vegetable oil. Pure biodiesel (B100) is available in the marketplace and can be used in some engines without modification, though biodiesel blends of up to 20 percent (B20) are more common and can be used safely in most diesel engines. Blends using 5 percent biodiesel (B5) can be used in any diesel engine without modification.

Gas-to-liquid (GTL) diesel is a synthetic diesel fuel that uses Fischer-Tropsch technology to convert natural gas or the syngas from the gasification of coal, petroleum coke, or biomass into an ultra-clean fuel for diesel engines. These fuels have been termed GTL from natural gas, CTL from gasified coal, PTL from gasified petroleum coke, and BTL from gasified biomass. They have also been termed XTL to denote that they can be produced from a number of feedstocks. They will all be referred to here as Fischer-Tropsch (FT) diesel. The resulting product has virtually no sulfur, extremely high cetane, low density, and very good cold flow properties. Reduced lubricity is the only downside from a performance perspective. This fuel can be blended in any proportion with conventional diesel fuel and used in existing engines without modification.

Ethanol-diesel fuel blends (E-diesel) contain typically between 5 to 15 percent ethanol and a fatty acid-based stabilizing additive. Additives must be added to E diesel to overcome inherent problems such as separation of the ethanol and diesel fuel, reduced lubricity and increased fuel pump wear, loss of cetane number, and increased corrosion of fuel system components. The additives are marketed by several companies, each of which consider their formulation proprietary.

Quantities of Use

Table 6-1 summarizes the state of the alternative diesel fuel marketplace in 2005. Only biodiesel and FT diesel fuel data are given in the table. As E-diesel is an emerging experimental fuel, the quantities produced and used would be insignificant. California's diesel transportation fuel consumption in 2004 was 4.1 billion gal/year.[135] California in

[135] Energy Information Administration, [www.eia.doe.gov].

state production of both alternative diesel fuels given in Table 6-1 account for no more 0.1 percent of this diesel fuel consumption. California would need to import a significant fraction of the worldwide production of FT diesel fuels to displace a correspondingly significant fraction of its annual diesel fuel use.

Table 6-1. Alternative diesel fuel production in 2005.

	Biodiesel (B100)[a]	FT diesel
Production capacity, million gal/yr		
Global	1,800[136]	3,000[137]
U.S.	395[138]	Neg[b]
California	11.6	Neg
Production, million gal/yr		
Global	955[3]	3,000[2]
U.S.	75[139]	Neg
California	4[140]	Neg

[a] Biodiesel production capacity and production are for the European Union (EU). The combination of the U.S. and E.U. production accounts for most of the global levels.
[b] Neg = negligible

Source: References noted

Availability of Vehicles

In contrast to other alternative fuels, alternative diesel fuels require no fuel specific vehicle to become incorporated into the market. The alternative diesel fuels discussed in this report can be used in virtually all conventional diesel fueled engines and vehicles. Thus, any limitations in the fuel's use is not constrained by the available of vehicles; essentially all diesel fueled vehicles in the population can utilize the fuels or blends of the alternative diesel fuel with current petroleum based diesels in the marketplace.

For biodiesel, B5 can be used in any vehicle in the population. B20 can be used with most (almost all) vehicles. Most engine manufacturers recognize their engine warranties when fueled with biodiesel bends up to B20. B100 can be used in many vehicles without engine modifications, though engine warranty provisions may not be honored for some engines. Older engines can be made compatible with B100 at a parts cost of $30 to $50

[136] European Biodiesel Board data, [http://www.ebb-eu.org/stats.php].

[137] Sasol, *Sasol Coal-to-Liquids Developments*, presentation to the Gasification Technologies Council Conference, 10-12 October 2005, San Francisco.

[138] National Biodiesel Board, *Commercial Biodiesel Production Plants*, [http://www.biodiesel.org/buyingbiodiesel/producers_marketers/ProducersMap-Existing.pdf].

[139] National Biodiesel Board, *Estimated U.S. Biodiesel Production*, [http://www.nbb.org/pdf_files/fuelfactsheets/Production_Graph_Slide.pdf].

[140] K. Koyama, *Alternative Fuels Commercialization*, CEC-600-2005-020, May 2005.

per vehicle. It is ARB's policy that biodiesel blends up to B20 comply with the diesel fuel regulations provided the biodiesel portion of the blend complies with ASTM 6715 (including the 15 ppm sulfur limitation) and the diesel portion of the blend complies with the California diesel fuel regulations.[141] Biodiesel blends of greater than B50 (including B100) are not regulated and blends between B20 and B50 are not prohibited but are not recommended. Biodiesel blends do not offer comparable cold weather performance to petroleum diesel (cloud point and pour point temperatures are higher than for petroleum diesel). Therefore, block heaters may be required in cold climates for biodiesel blend use. Biodiesel acts as a solvent and can release deposits from within the fuel system of the engine, which can clog fuel filters. More frequent filter changes (especially early on in using biodiesel) may be needed.

B100 has an energy content about 7 percent below No. 2 diesel. Thus, biodiesel blends would reduce fuel economy on a mpg basis. Vehicle range would be decreased as well. However, for B20, the most common blend, these decreases would be 1.4 percent . This decrease would not be noticed except over an extended time period. Biodiesel use reduces vehicle emissions of diesel PM, hydrocarbon (HC) and CO. Biodiesel use can cause a small in increase NO_x emissions, though more recent data show little effect on NO_x.[142]

Fischer-Tropsch (FT) diesel fuels can be used when blended in any mixture fraction with petroleum based diesel fuels. In fact, blends of FT diesel with petroleum diesel are considered premium diesel fuel in Europe, and are sold at a premium price. Use of FT diesel blends have not affected engine performance or maintenance requirements. The energy content of FT diesel on a Btu/gal basis is comparable to No. 2 diesel. So, vehicle fuel economy and range would not be affected with the use of FT blends, although small losses in fuel economy (3.3 percent) have been experienced. Emissions of all criteria pollutants, PM, HC, CO, and NO_x are decreased to varying degrees with FT diesel use, with the diesel PM emissions most notably reduced.

E-diesel blends up to 15 percent ethanol can be used in most (almost all) vehicles. However, for safety reasons to prevent vapor explosions, the vehicle's fuel tank should be retrofitted with a flame arrester. Like biodiesel blends, E-diesel acts as a solvent and can release deposits from the vehicle fuel system, as well as fueling station tanks and transfer lines. Extra fuel filter changes are recommended with initial E-diesel use. As ethanol has 60 percent of the energy content of No. 2 diesel (Btu/gal), use of E-diesel blends will reduce fuel economy and vehicle range on a tankfull of fuel a proportionate amount depending on the fraction of ethanol contained in the blend. For example an E-diesel blend containing 10 percent ethanol (ED-10) would contain about 4 percent less energy than the parent diesel, and fuel economy and vehicle range would be decreased accordingly. However, the E-diesel stabilizing additives are formulated to raise the

[141] Suggested ARB Policy, presentation to the ARB Fuels Workshop, May 24, 2006, [http://www.arb.ca.gov/fuels/diesel/altdiesel/altdiesel.htm].

[142] R. McCormick, *Effect of Biodiesel on NO_x Emissions*, presentation the ARB Biodiesel Workshop, July 5, 2005, [http://www.arb.ca.gov/fuels/diesel/altdiesel/altdiesel.htm].

energy content of the blend to minimize the negative effect. E-diesel use reduces PM and CO emissions compared to No. 2 diesel; effects on NO_x emissions have been insignificant.[143]

E-diesel blends have the vapor pressure and flammability limits of ethanol. This means that ethanol concentrations in enclosed spaces such as fuel storage and vehicle fuel tanks are flammable at typical ambient temperatures. For this reason, an NREL report recommended a number of actions to reduce safety risks.[144] These were:

- Limiting the use of E-diesel to centrally-fueled vehicle fleets;
- Equipping all fuel storage tank vents and the vehicle tank vent and fill openings with flame arresters designed for use with ethanol;
- Establishing an electrical ground connection between the vehicle and the fueling station fuel dispenser; and
- Ensuring that vehicle fuel tank level detectors are of an intrinsically safe design.

As a consequence of these recommendations, E-diesel use will likely occur only in niche fleet applications.

Fueling Infrastructure and Specific Needs

There are two aspects of the alternative diesel fuel infrastructure that need to be considered: fuel production and fuel distribution and use. These differ some among the three generic alternative diesel fuels under consideration, so each fuel will be discussed separately.

Biodiesel

Biodiesel is a clean burning alternative fuel produced from renewable resources, such as vegetable oil, animal fats, or waste vegetable oil. The official definition of biodiesel is "a fuel comprised of mono-alkyl esters of long chain fatty acids derived from vegetable oils or animal fats which conform to ASTM D6751 specifications for use in diesel engines."[145] As noted above pure biodiesel (B100) is available and can be used in many engines without modification, though biodiesel blends of up to 20 percent (B20) are more common and can be used safely in almost all engines. Lower biodiesel blends such as B5 and even B2 are sold, but the emission reduction and petroleum displacement benefits of these blends are proportionately decreased.

[143] N. Marek and J. Evanoff, *Pre-Commercialization of E-diesel Fuels in Off-Road Applications*, Proceedings of the A&WMA 2002 Annual Conference, paper No. 42740, June, 2002

[144] L.R. Waterland, S. Venkatesh, and S. Unnasch, *Safety and Performance Assessment of Ethanol/Diesel Blends (E-Diesel)*, NREL/SR-540.34817, September 2003.

[145] National Biodiesel Board, [www.biodiesel.org].

In the United States (U.S.), biodiesel is typically made from soybean oil, recycled cooking oils, and animal fats; palm and rapeseed oils are used in other countries. Biodiesel is made by a process termed transesterification in which the oil feedstock is combined with an alcohol (usually methanol) and caustic (NaOH). This transesterification process is required to produce a biodiesel with viscosity characteristics compatible with diesel engines.

In 2004, 27 commercial biodiesel plants in the U.S produced over 33 million gallons.[146] These plants can use as their feedstock either waste vegetable oil (WVO) or straight vegetable oil (SVO). The volume of WVO available for use as a feedstock is limited by the amount of waste cooking oil that is generated each year. This has been estimated at a maximum of 150 – 250 million gallons. The limit of SVO available is currently limited by the agricultural output of soybeans, tempered by other demands on the crop. Ostensibly, the soybean oil production is only limited by the agricultural acreage devoted to growing soybeans (or other oil bearing crops). With enough feedstock, biodiesel production becomes limited by the production plant capacity.

The National Biodiesel Board lists 34 biodiesel retail fueling sites located throughout California that sell either B20 or B100 to the public.[147] Most are open convenient hours during the week and most accept all major credit cards. The Alternative Fuels Data Center (AFDC) lists 30 biodiesel stations in California, 25 stations open to the public.[148] All but eight of these stations are open at convenient times; the eight request a call ahead. The five private stations listed by the AFDC are controlled federal government sites (e.g. an Air Force Base) that fuel the site's fleet. Not surprisingly, the greatest concentration of biodiesel retailers and distributors is in the Midwest. No special infrastructure is needed to support biodiesel blend distribution. The fuels can be easily accommodated by the current petroleum product distribution and dispensing system.

The average price for B100 in the United States during January and February 2006 was $3.23/gal, while B20 averaged $2.64gal.[149] Diesel prices average $2.56/gal over the same time period, so B20 was selling at a $0.08/gal premium at the time. During mid 2005, B20 sold at a $0.13 to $0.22/gal premium in California.[150] Biodiesel may be sold at a premium in some locations because of the emissions reductions that can be achieved by using B20 or B100 fuels. Nevertheless, biodiesel would be a more attractive fuel at more price equity with No. 2 diesel. This is forecast to become more easily done as biodiesel feedstock prices decline relative to crude oil prices. Figure 6-1 shows the recent convergence of soybean oil and petroleum prices.

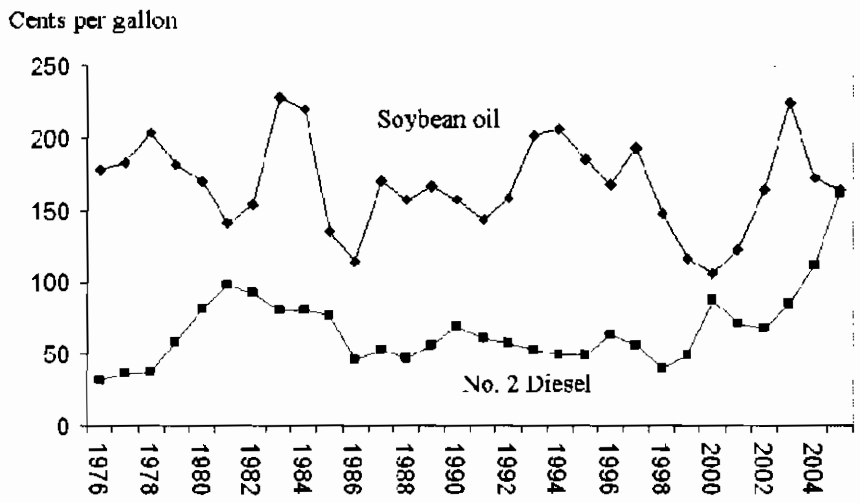
[146] D. Fong, *Addendum to Options to Reduce Petroleum Fuel Use*, 2nd edition, CEC-600-2005-024-ED2-AD, revised June 2005.

[147] National Biodiesel Board, [http://www.biodiesel.org/buyingbiodiesel/retailfuelingsites/showstate.asp?st=CA].

[148] Alternative Fuels Data Center, [http://afdcmap2.nrel.gov/locator/].

[149] *Clean Cities Alternative Fuel Price Report*, Feb. 2006, U.S. Department of Energy, Energy Efficiency and Renewable Energy.

[150] K. Koyama, *Alternative Fuels Commercialization*, CEC-600-2005-020, May 2005.



Source: USDA and Energy Information Administration[151]

Figure 6-1. Soybean Oil Feedstock vs. Diesel Prices

Minnesota became the first state to enact a biofuels requirement with a B2 bill that became effective in September, 2005. The bill requires that all diesel sold in Minnesota contain 2 percent biodiesel. The March 2002 legislation went into effect 2005 after two new 30 million gallon per year facilities came online in Minnesota. California has a similar B2 bill progressing through the legislative process, SB1675 (Kehoe).

FT Diesel

As noted above, FT diesel is a synthetic diesel fuel that uses Fischer-Tropsch technology to convert natural gas or syngas into an ultra-clean fuel for diesel engines. The resulting product has virtually no sulfur, extremely high cetane, low density, and very good cold flow properties. This fuel can be blended in any proportion with conventional diesel fuel and used in existing engines without modification. In this sense, FT diesels can be thought of as a one-to-one replacement for conventional diesel. In fact, at times FT fuels are economically blended with conventional petroleum diesel fuels to extend California's diesel fuel supplies, and improve refinery capacity of cleaner diesel fuels. FT diesel offers good emissions performance at high aromatic levels and its use can have emissions benefits. Thus, when used as a high quality blendstock, GTL diesel allows refinery to meet current diesel specifications with lower quality distillates.

The FT process starting with natural gas needs large volumes of low-cost gas (less than $1.00 per million Btu) to compete with diesel fuel. Natural gas at this price, and in these volumes, does not currently exist within California natural gas suppliers. As a

[151] James Duffield, U.S. Department of Agriculture, Clean Cities Congress Presentation, May 2006.

consequence, most current and planned FT diesel plants are overseas. Two options exist for capturing the natural gas deposits overseas, especially stranded gas deposits for which transport to a consumer via pipeline is impractical or too expensive. These are producing FT diesel fuel and transporting this within the international crude oil transportation infrastructure, or producing LNG and transporting this liquid fuel. Relative economics generally dictates which of these competing fuels is chosen.

Four currently operational FT diesel produce liquids from natural gas and coal using 1980s technology, and are located in the U.S., Malaysia, South Africa, and Qatar (open in June 2006).[152] The four new FT diesel (GTL) plants under construction or planned are located in Qatar. This total new construction will add about 300,000 bbl/day of worldwide FT diesel production capacity.

Like biodiesel, no special infrastructure is needed to support FT blend distribution. These blends can be easily accommodated by the current petroleum product distribution and dispensing system. In fact, FT diesels are considered blendstocks for currently distributed diesel. As such, their cost is no different than petroleum diesels. Their use as blendstocks is decided upon considering their cost to a refinery compared to the other products coming out of a refinery.

E-diesel

As noted above, ethanol-diesel fuel blends (E-diesel) contain typically between 5 to 15 percent ethanol and a fatty acid-based stabilizing additive. The additive must be added to E-diesel to overcome inherent problems such as separation of the ethanol and diesel fuel, reduced lubricity and increased fuel pump wear, decrease in cetane number, and increased corrosion of fuel system components. The additives are marketed by several companies each of which consider their formulation proprietary. E-diesel is more effective than biodiesel in reducing diesel engine particulate emissions and in most markets it is currently less expensive than biodiesel.

Currently, E-diesel fuels are considered experimental for use in on road diesel applications. While they are currently used in off road applications, for on road use special permission must be obtained from the U.S. EPA for their use as experimental fuels. The fuel is, therefore not publicly available through retail locations.

E-diesel has been successfully demonstrated in several California fleets. E.J. Harrison & Sons, a refuse truck fleet operator based in California, was launched in November, 2004, and is the longest-running, continuous O_2Diesel (a blend additive supplier) fleet operation. The year-long program was funded under the terms of an O_2Diesel's subcontract with the NREL. O_2Diesel currently has three other demonstration fleets in the U.S.

[152] K. Koyama, *Alternative Fuels Commercialization*, CEC-600-2005-020, May 2005.

As noted above, special precautions must be taken in the transportation, dispensing, and use of the fuel owing to its enclosed space flammability properties. For this reason alone, E-diesels will only find limited use in niche fleet applications. Its benefits in these applications are the improved emission performance the fuel offers and its petroleum displacement properties. Like ethanol gasoline blends discussed in Section 5, its cost benefits depend on ethanol prices relative to diesel fuel prices. In favorable situations, these cost benefits can be attractive.

Barriers and Opportunities for Expansion

There are a number of key issues that need to be addressed that could become barriers to the widespread adoption of biodiesel into the alternative diesel fuel pool in the state. Most of these are really concerns expressed in the alternative fuel community that need experience or data to confirm that the concern is valid so that remedies to alleviate the concern can be defined as needed. These include the following:

1) **Fuel Stability.** Engine and fuel injection equipment manufacturers are concerned that biodiesel may undergo oxidation during storage, handing, and use and form fuel system deposits. These deposits could cause plugging and damage to engine fuel system components. NREL is examining biodiesel stability as part of a nationwide fuel quality surveys. In addition, efforts directed at understanding the fundamental chemistry of biodiesel oxidative degradation are underway. This work is directed toward developing a practical test for assessing fuel stability, and should eventually lead to including an oxidation stability requirement in the standard specifications for biodiesel and biodiesel blends. In addition, being a vegetable oil product, long term storage can result in mold growth

2) **Engine Long Term Durability.** Engine manufacturers and fuel users have concerns relating to potential biodiesel effects on the durability of engine and fuel system components. NREL is currently assessing the impact on durability with fuel pump and fuel injector wear tests, and with materials compatibility tests.

3) **Increased NO_x Emissions.** Some studies have shown that biodiesel blends increase engine NO_x emissions. Recent work at NREL suggests that there are insufficient data, and insufficiently representative data, to draw any conclusions regarding the average effect of biodiesel on NO_x emissions, even directionally.[153] A second issue revolves around the different trends observed for NO_x measurements on engine and chassis dynamometers where engine dynamometers tend to show higher increases in NO_x emissions with increasing blend levels.

[153] R. McCormick, *Effect of Biodiesel on NO_x Emissions,* presentation the ARB Biodiesel Workshop, July 5, 2005, [http://www.arb.ca.gov/fuels/diesel/altdiesel/altdiesel.htm].

4) **Compatibility with 2007 and 2010 Emission Control Systems.** B20 and lower blends are likely to be considered verified California diesel fuel,[154] but the effect on advanced emission control systems, particularly exhaust aftertreatment systems, is yet to be determined.

5) **Cold Weather Performance.** Both the cloud point and pour point of biodiesel are at higher temperatures than for No. 2 diesel. Diesel engines will likely require block-heaters in cold climates.

6) **Protective Fuel Specifications and Fuel Specifications for Finished Fuels.** There are ongoing discussions on whether existing fuel specifications are protective enough. In addition there is a need to have finished fuel specifications for different blend levels of biodiesel such as for B5, B20, and B100 finished biodiesel fuels.
7) **Quality Control of the Fuel.** Implementation of a quality control program such as ISO 9000 is needed to monitor the quality of biodiesel so that incidences like the Minnesota experience are minimized. Negative experiences with biodiesel make it more difficult to gain acceptance.
8) **Effect of Feedstock on Criteria Pollutant and Air Toxic Emissions.** There are still data gaps in toxic emissions from bioidiesel as it compares to cleaner CARB diesel fuel and there is a need to gain a more accurate measurements of the toxic emission benefits and disbenefits of biodiesel.
9) **Multimedia Evaluation.** Development of specifications requires biodiesel to undergo a multimedia evaluation.
10) **Pipeline Issues Transport of Biodiesel through Pipelines.** Because of the ability of biodiesel to absorb moisture and the chance of carryover of biodiesel in the pipeline which can contaminate jet fuel there is a need to address the transport of biodiesel in the existing pipeline infrastructure.

As FT diesels are already in the transportation fuel marketplace, there are no barriers preventing its even more widespread use. The quantity of FT diesel incorporated into transportation fuels marketplace will be limited by the amount produced, which in turn will be determined by the economics of the market. GTL fuels, of course, are limited by the quantity of stranded natural gas in the world. CTL would not face such limits, but instead will be restricted by the costs of production.

E-diesel fuels face the same set of concerns as biodiesel fuels. Thus, there are unresolved concerns relating to long term engine durability and compatibility with 2007 and 2010 heavy duty engine emissions control systems. These will be resolved as the fuel sees additional use. The safety issues surrounding the transportation and use of this fuel remain potential barriers, though barriers that can be addressed.

[154] Suggested ARB Policy, presentation to the ARB Fuels Workshop, May 24, 2006, [http://www.arb.ca.gov/fuels/diesel/altdiesel/altdiesel.htm].

Overall Assessment

FT diesel fuels are already in the marketplace, though the extent to which these blendstocks reduce petroleum consumption in California has not been measured. Currently planned production capacity is expected to grow to 250,000 bbl/day by 2011.[155] This corresponds to 3.8 billion gal/year. The extent to which this non-petroleum fuel can reduce California's current 4.1 billion gal/year diesel fuel demand is only a function of how much worldwide production can be economically absorbed.

Similarly, biodiesel fuels are already in the marketplace worldwide, in the U.S., and even in California. While a few technical issues regarding the effects of their use on infrastructure components and engine systems, the amount of biodiesel fuel can be used in California to displace petroleum fuel is more limited by production capacity and cost. So, even if California B100 production was 10 million gal/year (current plant capacity of 11.6 million gal/year), and another 40 million gal/year could be imported into the state from elsewhere in the U.S., 50 million gal/year of biodiesel could only displace about 1 percent of the 4.1 billion gal of diesel fuel used in the state in 2004.

Finally, as noted above, there will likely be niche fleet uses that can and would use E-diesel, the total petroleum fuel displacement by the ethanol in E-diesel would be insignificant.

[155] K. Koyama, *Alternative Fuels Commercialization*, CEC-600-2005-020, May 2005.

SECTION 7. HYDROGEN

Quantities of Use

The extent of current hydrogen use as transportation fuel in California is summarized in Table 7-1. Hydrogen vehicles in California consist of demonstration fuel cell passenger cars, internal combustion engine passenger cars, fuel cell buses, and hybrid fuel cell buses. Automakers place vehicles in outreach, government and various fleets for multiple purposes. Mileage accumulation varies among the different applications.

Table 7-1. Hydrogen transportation fuel use in California.

Number of Hydrogen vehicles (2006)[a]	160
Fraction of on-road population, %	0
OEM LDV models offered (2006)	1
LDV engines certified (2006)	1
HDV engines certified (2006)	0
Hydrogen stations, total	33
public assess	5
Hydrogen dispensed, million kg	0.02
million gge	0.02
petroleum fuel fraction, %	0.0001
Based on 9 hydrogen buses, 10,000 mi/yr 6 mi/kg 60 cars, 4000 mi/yr, 50 mi/kg	

[a] Estimate includes vehicles from fuel cell car, ICE car, and bus programs.

Source: This analysis

While a variety of hydrogen vehicles have been built for demonstration programs, only one passenger car has been certified by the EPA. The fuel economy and configuration of the Honda FCX can be found in the EPA Fuel Economy Guide. None of the hydrogen vehicles are offered in a commercial sense at prices that would be near competitive with conventional vehicles. The quantities of fuel used for hydrogen vehicles shown in Table 7-1 was based on assumed mileage accumulation and fuel economy.

Availability of Vehicles

Hydrogen is a fuel option for both fuel cell and internal combustion engine (ICE) powered vehicles. Fuel cell powered vehicles are being developed because of their potential for high fuel efficiency and zero emissions. Hydrogen ICE vehicles are presented as an option with fewer developmental challenges that is available today. Some developers also attribute a potential for increased fuel efficiency to hydrogen ICE vehicles, with a wide range of estimates. Some developers claim that a fuel economy improvement of a hybrid hydrogen ICE vehicle with a factor of 1.7 over conventional gasoline vehicles should be attributed to hydrogen ICE vehicles. Others argue that the improvement from a comparable vehicle is only 1.1 over gasoline because hydrogen vehicles would require larger engines and fuel tanks to achieve the same performance and range as gasoline vehicles. Modeling estimates for fuel economy data for both hydrogen IC engine vehicles and fuel cell vehicles are summarized in the Hydrogen Highway Network Societal Benefits Report.[156]. A 1.3 x improvement in fuel economy for hydrogen ICE vehicles and 2.0 x improvement for fuel cell vehicles was used as a baseline value for the analysis in the report.

Offerings of hydrogen vehicles have been limited to demonstration vehicles for government programs. While none of the current fuel cell vehicles are available as commercial offerings, they represent a refinement in fuel cell stack technology and vehicle integration.

In recent years, fuel cell vehicles have received considerable attention and funding through state and Federal programs. The California Fuel Cell Partnership (CaFCP), a public-private partnership between interested industry and state and local government agencies, has been leading the coordination of fuel cell vehicle (FCV) demonstrations in California. To date, the CaFCP members have placed 134 light-duty fuel cell vehicles on California's roads in demonstration projects. These vehicles have logged around 473,000 vehicle-miles on California's streets, proving that FCVs are more than a showroom attraction[157].

Fuel cell vehicles are many years away from a commercial introduction. DOE anticipates a technology validation demonstration program with a commercial launch after 2015.[158] Persistent problems of fuel cell stack durability and cost as well as onboard hydrogen storage need to be addressed. The current demonstration vehicles have limited range, generally around 100 to 220 miles.[159] Currently, the vehicles are built in small volumes with prototype components. Even at high volumes, the vehicles are expected to cost over $5000 more than a comparable gasoline vehicle.[160] However, fuel economy from fuel cell vehicles is expected to be over 2 times that of a comparable gasoline vehicle on an energy equivalent basis.

An alternative to fuel cell vehicles is hydrogen ICE powered vehicles in either conventional or hybrid drivetrains. BMW has developed conventional hydrogen ICE prototypes. Ford has developed prototypes of hydrogen ICEs and hydrogen hybrid

[156] Unnasch, S., et al., *Societal Benefits Topic Team Report, California 2010 Hydrogen Highway Network*, for Blueprint Plan,]http://www.hydrogenhighway.ca.gov/plan/reports/**sbreport**.pdf], March 2005.

[157] Personal communication with Nico Bouwkamp, California FuelCell Partnership

[158] Gronich, S., *Transition Strategies*, Presentation at DOE Transition Workshop, January 26, 2006.

[159] Wipke, K., et al., *Controlled Hydrogen Fleet Infrastructure Demonstration Validation Project, Project Overview and Fall 2006 Results*, ARB ZEV Technology Symposium, September 2006.

[160] Wipke, K., et al., *Controlled Hydrogen Fleet Infrastructure Demonstration Validation Project, Project Overview and Fall 2006 Results*, ARB ZEV Technology Symposium, September 2006.

ICEs. Quantum Technologies converts Toyota's Prius gasoline hybrid vehicles to operate on hydrogen. They have delivered 30 hydrogen hybrid Prius to the South Coast Air Quality Management District. Quantum has also provided vehicles outside of California in other parts of the U.S. and in Norway.

Demonstrations of hydrogen vehicles are expected to be ramped up in the near future as automakers and energy companies fulfill 5 year grants with the Department of Energy through DOE's Controlled Hydrogen Fleet and Infrastructure Demonstration and Validation Project and other government supported projects. From this project automakers have stated plans to deploy over 100 fuel cell vehicles nationwide before 2009. A large fraction of those vehicles will be deployed in California. California ARB recently announced the award of the Hydrogen Vehicle RFP 05-610 providing funding for the demonstration of one PEM FCV from GM, four hydrogen ICE hybrids (Prius) from Quantum Technologies, and two hydrogen ICE E450 shuttle buses from Ford.

Heavy-duty applications, such as buses, are attractive first adopters of hydrogen technology due to their fleet refueling situation and fewer constraints for onboard storage. SunLine Transit has led the way with one fuel cell bus, one hydrogen hybrid ICE bus, and one bus operating on a mix of hydrogen and CNG in an ICE[161]. Santa Clara Valley Transit Authority operates three fuel cell buses[162]. AC Transit recently added three fuel cell buses to its fleet[163].

Several manufacturers have produced hydrogen fuel cell and hydrogen ICE demonstration vehicles. Such vehicles have potential to provide the highest efficiency and fuel economy of any currently known, practicable propulsion technology – while delivering zero-emissions and avoiding some of the multi media impacts associated with gasoline vehicles. Engine oil leaks are eliminated from fuel cell vehicles and hydrogen production infrastructure does not bear the risk of petroleum spills. Hydrogen is therefore expected to be the long-term fuel for fuel cell vehicles. On strictly a demonstration scale, in certain niche applications such as transit buses, direct-hydrogen fuel cell vehicles are already displacing conventionally fueled vehicles. Much of this work is being sponsored by the California Fuel Cell Partnership, of which the Energy Commission is a member.

Fuel cell developers recognize both heavy-duty (transit) and light-duty fuel cell vehicles will probably be deployed initially in fleet applications to accommodate higher vehicle costs as well as fueling, operation, and maintenance requirements. For example, in 2004, California Fuel Cell Partnership transit agency associate partners began operation of 40-foot fuel cell buses. To date, the members of the California Fuel Cell Partnership have successfully placed 143 fuel cell vehicles (134 light-duty vehicles and 9 buses) in California.

[161] From SunLine Transit website [http://www.sunline.org/home/index.asp?page=114].

[162] From VTA website [http://www.vta.org/projects/ZEBs.html].

[163] [http://www.actransit.org/environment/hyroad.main.wu].

For heavy-duty applications, hydrogen-fueled buses will be deployed initially at progressive transit agencies already having CNG fueling facilities that can make the transition to hydrogen. In 2003, larger transit districts (>200 buses) that have opted for the "diesel path" under ARB's transit bus fleet regulation were to have begun demonstrating three of these Zero-Emission Buses (ZEBs). By 2008, they will be required to begin purchasing ZEBs (two years sooner than if they had selected the "alternative fuels" path). Diesel fuel path transit agencies will be the first transit agencies required to purchase zero emission buses. Hydrogen fueled fuel cell buses appear to the be technology of choice at this time.

The Energy Commission supports this effort through the California Energy Commission Fuel Cell/Hydrogen Program. This program is a collaborative effort between the Energy Commission and the 30 partnership members to demonstrate fuel cell vehicles under real-world conditions. Work under the Fuel Cell/Hydrogen Program includes:

- Provide funding to support hydrogen fuel infrastructure demonstrations, and fund studies that that can provide guidance for planning, designing, siting, permitting, and procuring facilities to refuel hydrogen-powered vehicles in San Jose (Santa Clara VTA), Oakland (AC Transit), and Chula Vista (City).

- Explore the path to fuel cell commercialization, from identifying potential problems associated with codes and standards, siting, safety, infrastructure, and fuel choice, to developing solutions to these problems.

- Increase public awareness and enhance public opinion about fuel cell vehicles and hydrogen to prepare the market for commercialization.

To date, SunLine Transit has been California's most aggressive agency in demonstrating hydrogen buses, placing a hybrid hydrogen fuel cell bus into revenue service in November 2002.[164] SunLine Transit acquired another fuel cell bus in 2004. AC Transit has obtained 3 hybrid hydrogen fuel cell buses. Having chosen the "diesel path" for compliance with ARB's transit bus fleet rule, AC Transit procured government grants amounting to more than $14 million that were used to procure three fuel cell buses in addition to a state-of-the-art fueling and maintenance facility. If these fuel cell bus demonstrations prove successful, AC Transit plans to make fuel cell buses comprise 15 percent of their acquisitions in 2008[165]. NREL is working with the University of California, Davis to assist these agencies in the transition to hydrogen, and provide data collection activities.

Demonstrations aside, achieving widespread use of direct-hydrogen fuel cell vehicles will require vehicle, fuel-production, and infrastructure investments of very large proportions. On the vehicle side alone, major efforts are needed to develop affordable

[164] SunLine website [www.sunline.org].

[165] AC Transit website [www.ACTransit.org].

and workable on-board hydrogen storage systems. Even as fuel cell vehicles begin to achieve commercial status, much work needs to be done to educate permitting officials, the general public, and business communities about hydrogen fuel and fuel cell technologies. According to "early adopters" of hydrogen-fueled vehicles and fueling stations, the largest barrier may be the current lack of hydrogen-specific codes and standards that provide for safe use of this unique fuel without being overly burdensome or costly to meet.[166]

Vehicle Range and Fuel Economy

Hydrogen holds more energy per unit mass than other fuels. One kg of hydrogen contains as much energy (114,000 Btu, LHV) as a gallon of gasoline, which weighs 2.7 kg. However, hydrogen is stored as a compressed gas at 5,000 psi on most vehicles. Space considerations limit how much fuel can be stored on a vehicle. Many passenger cars hold 3 kg of hydrogen with the goal of storing up to 5 kg with advances in tank configuration or higher storage pressure.

ICE vehicles that use CNG or LNG currently deliver significantly reduced range compared to similar conventional vehicles. Fuel cell engines operate more efficiently than internal combustion engines (ICEs), enabling fuel cell vehicles to get more miles from a given volume of the same fuel. Direct-hydrogen fuel cell vehicles are especially efficient, because no on-board fuel reformation process is needed. Also, electric drive systems offer significant efficiency gains over conventional drive systems, as demonstrated by the Toyota Prius and Honda Insight and Civic hybrid EVs. Putting these factors together, the improved energy-conversion efficiency of fuel cell vehicles can have a dramatic impact on reducing the weight and size of the fuel storage system. A direct result is that fuel cell vehicles can provide greater vehicle range than would be available from an ICE vehicle using hydrogen. On the negative side, any type of hydrogen-fueled vehicle faces the range constraint of reduced energy content per volume and/or mass of fuel (depending on which form of on-board hydrogen storage method is used).

Most of the major automobile manufacturers are involved in fuel cell vehicle research. The most prominent manufacturers working on ICE concepts include Ford and BMW. GM has also built some prototype hydrogen ICE vehicles. With the exception of the Quantum retrofit vehicles, all of the other automakers appear to be focusing their hydrogen efforts on fuel cell vehicles.

One hydrogen vehicle, the Honda FCX, has been certified and its fuel economy published in the EPA fuel economy guide. With an EPA city/highway rating of 62/51 mpkg (57 mpkg combined) and an EPA-rated driving range of 210 miles, the hydrogen-powered FCX delivers nearly a 20-percent improvement in fuel efficiency and 30 percent improvement in range versus the 2004 model with an EPA rating of 51/46 mpkg

[166] For example, this is a top concern of SunLine Transit Agency's management concerning expansion of its hydrogen fuel cell bus program.

(48 mpkg combined) and a range of 160 miles. In terms of energy efficiency, one mile per kilogram (mpkg) of hydrogen is almost equivalent to one mile per gallon (mpg) of gasoline[167].

Assessing the fuel economy improvement for hydrogen vehicles is challenging due to the limited number of vehicles with detailed fuel economy data as well as the challenge in finding a comparable baseline vehicle. For example, Honda does not produce a vehicle that is exactly comparable to the FCX. A variety of efforts have been undertaken to assess the potential fuel economy of hydrogen vehicles including both modeling studies and comparisons of in-use data. A review of these fuel economy projections is published in the Hydrogen Highway Societal Benefits report[168]. Projected fuel economy improvements for hydrogen fuel cell vehicles ranged from 1.7 to 2.5 times that of gasoline with a value of 2.0 being used for analysis purposes. Even with improved fuel economy it will be challenging for hydrogen vehicles to achieve the same (350 mile) range that gasoline vehicles have provided.

Vehicle Cost

Direct hydrogen fuel cell vehicles are powered by an electric motor with electricity generated from a fuel cell. Vehicle modifications include adding on-board storage of hydrogen and replacing the conventional engine and transmission with a fuel cell engine and electric-drive system. Fuel storage is a particularly challenging and costly issue for hydrogen vehicles. While compressed hydrogen is typically used in today's prototype vehicles, at least four additional methods are being considered: 1) liquefied hydrogen, 2) selected metal hydrides, 3) refrigerated superactive carbon, and 4) carbon or graphite nanostructure.

Some manufacturers are building fuel cell electric drive systems that are powered solely by a fuel cell engine, while others are building hybrid drive systems that include a battery pack or some other source for peak power requirements. In part, this choice depends on what vehicle application is desired, e.g., passenger cars or a transit buses. Regardless, fuel cell vehicles are virtually "hand built" today and their current incremental cost significantly exceeds that of any other mainstream clean-vehicle alternative. With continued progress in building low-cost, high-power-density fuel cell engines, production costs for fuel cell vehicles can be dramatically reduced. However, a number of major challenges remain before hydrogen fuel cell vehicles can become cost comparable with conventional vehicles.[169]

[167] [http://corporate.honda.com/environment/fuel_cells.aspx?id=fuel_cells_fcx].

[168] Unnasch, S., et al., *Societal Benefits Topic Team Report, California 2010 Hydrogen Highway Network*, for Blueprint Plan March 2005.

[169] Challenges include cost and supply issues for precious metals and other materials making up membrane-electrode assemblies; the need for advanced, lower-cost hydrogen storage technology; tradeoffs associated with on-board air compression versus using ambient pressure stacks; and difficulties with delivery of constant power during transient operation.

Estimates of the long term cost of hydrogen fuel cell vehicles are frequently investigated by the DOE and others. The key parameters affecting hydrogen fuel cell vehicle cost are the hydrogen storage tanks and fuel cell stack. The precious metals loading (platinum) on the fuel cell membrane and the cost of the membrane result in over half of the cost of the fuel cell stack. Fuel cell stack costs are projected in the $50 to $100/kW range for large volume production compared with $10 to $30/kW for internal combustion engines. The net effect of the fuel cell stack and hydrogen storage is a $10,000 to $15,000 increase in the price of the vehicle with current fuel cell technology with longer term vehicle costs being several thousand dollars higher than gasoline ICE vehicles.[170]

Vehicle Population Projections

Given the current barriers and uncertainty on how manufacturers will meet certain regulatory drivers, it's difficult to assess the number of fuel cell vehicles that will actually be on the road in California over the next 5 to 10 years. The California Hydrogen Blueprint Plan presents a scenarios for 2,000 LDV and 10 HDVs. This estimate is in line with expected FCV deployments by the CaFCP and hydrogen ICE vehicles from other companies. Larger introductions of hydrogen vehicles are discussed in the Blueprint Plan for the longer term.[171]

Fueling Infrastructure and Special Needs

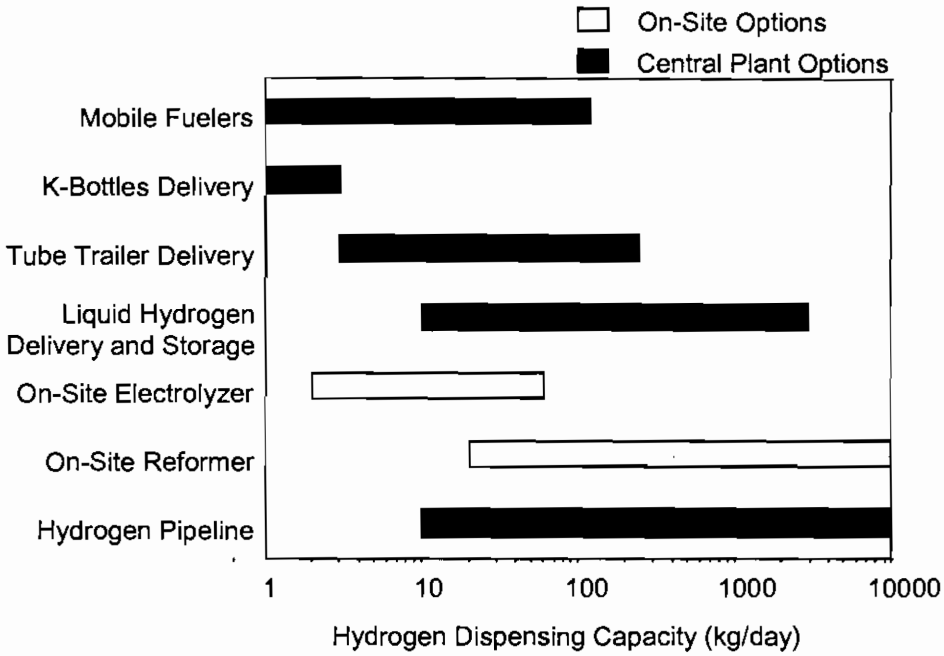
Various supply options can provide fuel for hydrogen vehicles. An integrated approach to developing hydrogen infrastructure needs to consider these options in a manner that addresses a variety of constraints involving the following fuel supply issues:

- Fuel availability for non-fleet vehicles (station coverage)
- Stationary and distributed production capacity
- Fueling station capital and operating cost
- Transition from small vehicle demonstrations to large volume operation

Figure 7-1 shows a variety of supply options, which could provide hydrogen for vehicle fueling. Central plant options take advantage of existing infrastructure. Capital costs of small-scale options such as mobile fuelers and tube trailer delivery are relatively low, but delivery costs result in a higher cost per kg than higher capacity options. On-site production options can support the growth in fueling capacity and provide fuel at distributed locations. Hydrogen can also be delivered by pipeline from central plants. In the near term, integration with existing pipelines is an option for fueling facilities located near pipelines.

[170] Lasher, S., J. Thijssen, S. Unnasch, *Guidance for Transportation Technologies: Fuel Choice for Fuel Cell Vehicles, Phase II Final Report*, February 2002, available at [http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/fuel_choice_fcvs.pdf].

[171] California Environmental Protection Agency, *California Hydrogen Blueprint Plan: Volume I,* May 2005.



Source: TIAX report[170]

Figure 7-1. Hydrogen supply options

Because hydrogen is in a gaseous state at atmospheric pressure and ambient temperatures, its use as a transportation fuel presents greater transportation and storage challenges than liquid fuels. Similar to the case with natural gas fuel, there are a variety of approaches used to produce hydrogen and store it onboard vehicles. These include the following:

- Off-site steam methane reforming of natural gas, with tanker-truck delivery of liquid hydrogen to the refueling station, and on-site storage of liquid and gaseous hydrogen
- On-site natural gas reforming, with on-site compression and storage of gaseous hydrogen
- On-site electrolysis (splitting of water into hydrogen and oxygen), with on-site compression and storage of gaseous hydrogen

The "best" method for vehicle applications is yet to be determined and depends on the intended application, as well as many other factors. The merits of different supply options are described in a Commission report.[172]

[172] Powars, C., S. Unnasch, B. Blackburn, Powars, et al., *Hydrogen Fueling Station Guidelines*, California Energy Commission, Consultant Report, 600-04-002V1, September 2004.

A second alternative would be to follow British Columbia Transit's model, and use on-site electrolysis to produce hydrogen. This option makes most sense if there is an abundance of renewable energy to power the electrolysis process, as is the case in British Columbia (hydro-electric power) and the Coachella Valley of Southern California (wind and solar power). For the electrolysis option, as the hydrogen is generated it is compressed and pumped into storage tanks on each fuel cell bus. Another possibility would be to use on-site generation of hydrogen using a small-scale methane reformer. Both of these latter methods for generating hydrogen are being demonstrated at SunLine Transit in Palm Desert, California, in conjunction with the California Fuel Cell Partnership.

Regardless of how it is produced, hydrogen for fuel cell applications needs to be free of impurities (e.g., sulfur). Fuel standards will need to be adopted before significant numbers of fuel cell vehicles are deployed.

Number of Stations

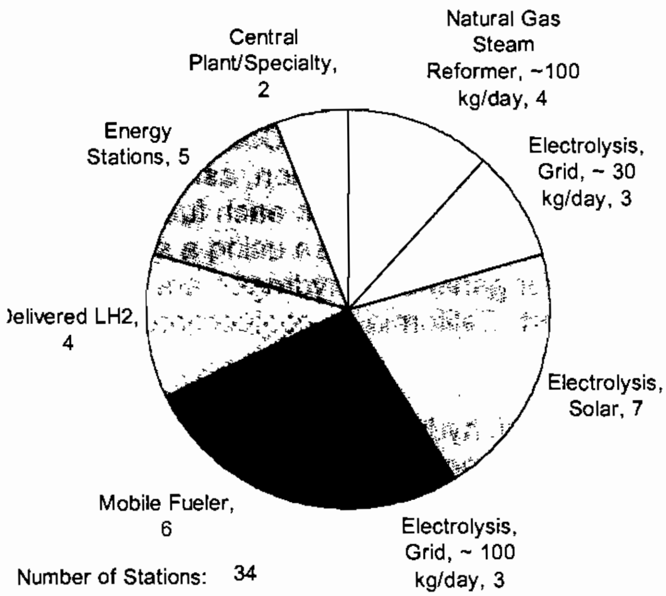
As of June 2006, there are 22 facilities in California that are specifically designed to dispense hydrogen as a motor vehicle fuel, with several planned stations in the planning stages[173]. The existing stations include a variety of supply and delivery options such as on-site electrolysis, on-site steam reforming, liquid hydrogen delivery, tube trailer delivery, and integrated mobile fuelers. A mix of hydrogen station options was evaluated as part of the blueprint plan. A scenario for the near term stations that are planned, grouped by delivery option is shown in Figure 7-2. The production capacity for these stations would be about 2,000 tonnes per year[174]. Figure 7-3 shows the location of hydrogen fueling stations in California.

Today's hydrogen stations for vehicle applications are essentially hand-built, first-generation prototypes. Most likely, they bear little resemblance to how optimized, cost-competitive hydrogen stations of the future may perhaps operate.

The Blueprint plan also addresses the stations that would be required for a large scale introduction of hydrogen vehicles. An analysis of the driving time to fueling stations was performed for Southern California. The collection of 250 stations resulted in an average driving time of about 3 minutes, which was deemed sufficient for a commercial introduction.

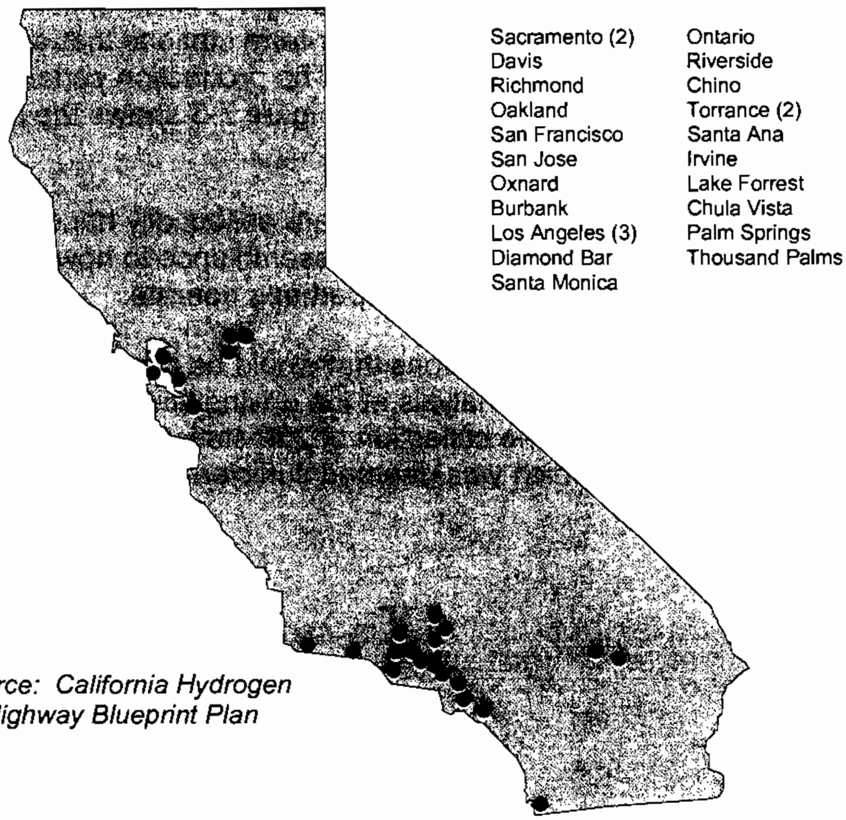
[173] [http://www.cafcp.org/fuel-vehl_map.html].

[174] *California Hydrogen Highway Network, Blueprint Plan*, March 2005.



Source: California Hydrogen Highway Blueprint Plan

Figure 7-2. Existing and planned hydrogen fueling stations in California grouped by supply option.



Source: California Hydrogen Highway Blueprint Plan

Figure 7-3. Location of hydrogen fueling stations in California.

Station Capital and Operational Costs

Preliminary results show that hydrogen production costs could ultimately be low (<$2/kg), with delivery and fueling station costs resulting in hydrogen in the $3 to $6 per kg range. This price would be competitive with gasoline at $2 to $3 per gallon depending on the hydrogen vehicle fuel economy. Near term costs are high due to high capital cost per station and low capacity factors (i.e. utilization), because regional coverage dictates the number of hydrogen station installations rather than calculated demand. Minimizing risks will require managing capacity factors, FCV and hydrogen infrastructure introduction scenarios, and reducing the capital cost of the hydrogen infrastructure. The capital, operating, and per kg costs of hydrogen are evaluated in the Hydrogen Highway Blueprint Plan Economy Team report for near term hydrogen stations. Longer term systems are analyzed with DOE's H2A effort.

Building Codes and Standards

Few standards and codes have been established specifically for hydrogen vehicle fueling stations. It is expected that certain existing standards for other compressed or liquefied fuels will be adapted for hydrogen; however, entirely new standards and codes will be needed as well. This is one of the most challenging existing barriers to using hydrogen as a mainstream transportation fuel. A plan for developing codes and standards for hydrogen fueling stations was included as a Hydrogen Highway topic team report. [175]

It was recommended that various federal agencies establish a national entity to prepare and promulgate uniform codes and standards for hydrogen use as a fuel for light-duty vehicles and transit buses. Some of these efforts are under way today through the International Standards Organization's (ISO) Technical Committee (TC197), in conjunction with DOE and the National Hydrogen Association. DOE is also supporting a comprehensive effort to incorporate codes for hydrogen applications through the International Code Council (ICC) process. In addition, this work on hydrogen codes and standards will be coordinated with similar activities sponsored by the European Union. The National Fire Protection Agency has also issued a revised set of standards for hydrogen fueling stations (NFPA55). These standards identify the equipment, ventilation, and setback requirements for hydrogen equipment. The implementation of this standard at fueling stations will still require considerable field experience as the interpretation of the standards by local fire officials must be worked out on a case by case basis.

[175] California Hydrogen Highway Network, Blueprint Plan *Implementation Topic Team Report, Codes $ Standards, Insurance & Liability*, January 2005.

Example of Future Development

A variety of studies have been undertaken to assess the build up of hydrogen vehicles and associated infrastructure requirements. Table 7-2 shows some of the more prominent recent efforts.

Table 7-2. Studies on Transition to Commercial Hydrogen Infrastructure

Organization	Resource	Scope
UCD ITS	The Hydrogen Transition[176]	Assemble stakeholders to discuss energy and environmental impacts, infrastructure requirements, and policy options for hydrogen economy.
CA H2 Highway	Blueprint Plan[177]	Define requirements for near term introduction of vehicles.
DOE	Transition Workshop[178]	Analyze transition requirements for build up to full scale fuel cell vehicle commercialization (millions/year).

Source: References noted

Barriers and Opportunities for Expansion

Hydrogen vehicles have received considerable interest from automakers, fuel cell developers, energy companies and a wide range of government stakeholders. In the past two years efforts to address the introduction of hydrogen vehicles have been initiated with the California Hydrogen Highway Network and DOE Technology Validation Program as well as other programs in the U.S. DOE has also developed scenarios for an extensive expansion of fuel cell vehicles with the potential for very high levels of market penetration by 2030. However, the success of hydrogen vehicle technology in the long term will depend on the ability to solve many technical challenges with the vehicles and fuel infrastructure. Barriers to wide-scale commercialization of hydrogen-fueled vehicles include the following:

- Storing and delivering hydrogen are very costly. Hydrogen is currently delivered by pipeline, tube trailer and cryogenic truck. Even at large scale, the delivery costs can be over $1.00 per kg of hydrogen.[179]

[176] Sperling, D and J. Cannon (editors), *The Hydrogen Energy Transition, Moving toward the post petroleum age in transportation*, Elsevier Press, 2004.

[177] *California Hydrogen Highway Network*, "Blueprint Plan," March 2005

[178] Gronich, S., *Transition Strategies*, Presentation at DOE Transition Workshop, January 26, 2006.

[179] DOE H2A Analysis, [http://www.hydrogen.energy.gov/h2a_analysis.html].

- High capital investment for fueling stations and underutilized capital during the build up of vehicle population results in greater investment risk than other fuel technologies. Hydrogen fueling stations will need to operate at the throughput of today's gasoline fueling stations in order to achieve a fuel cost that is comparable to gasoline prices today. Because the fueling stations will include compression, storage, and in some cases on site production equipment, the initial capital investment will be higher than that of a comparable gasoline station and the costs will need to be managed during the transition.
- Vehicles must achieve performance, durability, and cost comparable to conventional vehicles. The lifetime of fuel cell stacks and integration with the fuel and water management system needs to be developed so fuel cells can achieve lifetimes comparable to gasoline engines. Also, breakthroughs in hydrogen storage need to be developed in order to store about 5 kg of hydrogen on board the vehicle. Today's 5,000 psi system allows for about 2 to 5 kg of storage in a passenger car.
- Codes, standards, and permitting requirements need to accommodate hydrogen in urban areas and hydrogen fueling technologies may need to adapt to these requirements.

Overall Assessment

Hydrogen vehicles have the potential to provide the majority of all vehicle transportation fuel use with no emissions from the vehicle and the opportunity to capture CO_2 or produce the hydrogen from renewable sources. There is little consensus on the exact timeframe, but many public- and private-sector experts believe that direct-hydrogen fuel cell vehicles will gradually replace internal combustion engine vehicles as the predominant mode of transportation in metropolitan areas throughout California and the United States.

SECTION 8. DME (DIMETHYL ETHER)

Quantities of Use

DME is an LPG-like synthetic fuel that is produced through synthesis of carbon monoxide with hydrogen. The synthesis gas can be derived from natural gas, coal, biomass, or other resources. Today DME is produced from natural gas and used in the chemical industry and as a propellant for hairspray. The production route and costs are similar to that of methanol.

Like LPG, DME is a liquid at 150 psi and ambient temperature. DME has no carbon to carbon bonds, so no particulate is formed from combustion. Its high cetane number makes it a suitable fuel for diesel engines. However, DME would require a new infrastructure, which suggests that it would be best suited for fleet applications. No vehicles operate on DME in California as indicated in Table 8-1.

Table 8-1. DME transportation fuel use in California

Number of DME vehicles(2004)	0
Fraction of on-road population, %	0
OEM LDV models offered (2006)	0
LDV engines certified (2006)	0
HDV engines certified (2006)	0
DME stations, total	0
public assess	0
DME dispensed, million gal	0
million gge	0
petroleum fuel fraction, %	0

Source: This analysis

Availability of Vehicles

DME has been investigated as a fuel for heavy duty diesel engines for many years with promising results from laboratory tests. The most extensive developments with vehicles include demonstrations in Sweden and China. The Swedish Energy awarded AB Volvo grant to support the technical development of a third-generation DME engine for heavy vehicles. The project's goal is to deliver technology for a major field test with 30 third-generation DME-powered trucks planned for the years 2009 and 2010. Volvo's second-generation DME engine uses a low-pressure, common rail system, with an injection pressure less than 20 percent that of an equivalent diesel engine. A special fuel pump and sealing materials are designed to work with the DME. DME trucks are also being developed and tested in China by the National Traffic Safety and Environment Laboratory and Nissan Diesel Motor Co. DME engines have also been tested by engine manufacturers and developers in the U.S.; however, no vehicle demonstration projects are planned in the near term.

The costs and prices of DME vehicles would likely be less than those of CNG vehicles, as on board DME fuel tanks would be similar to LPG tanks and less expensive than CNG tanks. DME would be injected into the engine as a liquid using equipment similar to that in existing diesel engines. DME engines would also require less extensive particulate control because no soot is formed during combustion.

Fueling Infrastructure and Specific Needs

DME is could be shipped to storage sites on railcars, transport trucks, and barges Tanker trucks would make the final delivery. In this regard the DME fuel infrastructure resembles the LPG and gasoline fuel delivery infrastructure. DME infrastructure would need to focus initially on fleets with central refueling capabilities.

Because DME is produced in a similar manner to methanol, the cost of production would be similar. Methanol prices have ranged from $0.40 /gal to over $1.40/gal during the initial introduction of MTBE or $0.30 to $0.70 per gge. The cost of methanol production is about $0.40/gal based on stranded natural gas valued at $1.00/MMBtu. The cost per unit of energy would be comparable for DME ($1.00/MMBtu).

Barriers and Opportunities for Expansion

For DME to be successful as an alternative fuel, both a vehicle technology would need to be developed and DME supplies would need to be expanded beyond the existing chemical markets. Near term steps to advance the commercialization of DME include:

- Continue DME truck demonstrations
- Develop a DME engine that meets California emission requirements
- Identify sources of fuel grade DME supply that would result in cost competitive fuel including remote natural gas resources and feedstocks indigenous to California such as stranded natural gas and biomass
- Develop standards to prevent misfueling of LPG and DME vehicles

The biggest challenge to expanding the use of DME as a motor fuel is identifying a clear source of DME supplies that would result in a secure low cost source of fuel. A roadmap for DME supplies and infrastructure development is needed to give stakeholders the confidence to go forward with engine, vehicle, and infrastructure investments. Developments with DME vehicles overseas may prompt further interest in DME in the future.

Overall Assessment

Developments in DME engine technology could result in vehicles with low emissions and relatively low costs. However, a clear path for the development of engines and fuel supplies needs to be developed.