Reducing California Petroleum Consumption with Increased Use of High Efficiency Clean Diesel Technology

By
Richard McCann, Ph.D.
Eric Cutter

M.CUBED
POLICY ANALYSIS FOR THE PUBLIC AND PRIVATE SECTORS

Prepared for
The Diesel Technology Forum

Final Report

August 2002

2655 Portage Bay, Suite 3, Davis, CA 95616 (530) 757-6363

1. Executive Summary

California is assessing various options to reduce petroleum consumption over the next several decades. Increased use of diesel vehicles is one such option. Light duty diesel vehicles use on average about 38% less fuel per mile than a comparable gasoline vehicle. However, these vehicles have not been able to meet current California emission standards, and do not represent a significant share of the California passenger vehicle market. On the other hand, light-duty diesel vehicles compose up over 40% of the current market in Western Europe. These cars and light trucks comply with European emission standards, which tend to focus on a different set of pollutants including carbon dioxide. The introduction of ultra low-sulfur diesel fuel in the U.S. market and new emission control technologies may make diesel automobiles a competitive option to reduce fuel use in California by 2007. The potential success of diesel light duty vehicles may depend on the future technology meeting emission standards, policy choices related to future emission standards, compliance options, and the support of advanced clean diesel technology by the State of California through proactive policies.

Under a market scenario allowing for a 25% market penetration rate in diesel automobiles and light trucks, California could save over 530 million gallons of gasoline-equivalent fuel per year by 2030. If diesel passenger vehicle penetration reaches 32%, a level akin to that seen today in Europe, then California could save up over 840 million gallons per year by 2030. Given the state's exposure to market risks with the shift from MTBE to ethanol as the oxygenate additive for reformulated gasoline, diesel delivers an even larger benefit in reducing gasoline consumption directly. Under the price-driven scenario, diesel LDVs could reduce gasoline consumption by 70 million gallons as early as 2010. With early introduction and rapid adoption under the European scenario, savings could rise to 110 million gallons by 2010.

2. Introduction and Summary

Existing and proposed California emission standards effectively discourage the production and sale of current technology light-duty diesel vehicles (LDVs), which have higher tailpipe emissions in oxides of nitrogen (NOx) and particulates (PM), but also achieve greater fuel efficiency relative to gasoline engines, along with lower emission in reactive organic gases (ROG or VOC) and carbon dioxide (CO_2). New technology LDVs are likely to deliver much lower NOx and PM emissions in the near future in a manner that will not compromise air quality goals. State policy makers face important choices for maintaining continuing improvements in air quality while also reducing petroleum consumption by using a proven, low-cost technology. Examining this type of choice is at the core of the Assembly Bill 2076 (Shelley) analysis mandated by the State Legislature.

The analysis presented here finds that encouraging the use of diesel passenger vehicles will yield substantial reductions in fuel consumption, and that advanced clean diesel technology and the policies that affect its availability in California should be included in the state agencies' evaluation mandated in AB 2076, thereby preserving the diesel option. It should be noted that the premise of this analysis is based on fundamental assumptions that new vehicles using advanced clean diesel technology (such as those offered in Europe) will be embraced by U.S. consumers, diesel refueling availability will expand to meet this demand, and that breakthroughs in emission

control technologies will allow advanced clean diesel light-duty cars and trucks the opportunity to exist under the emission requirements.

This analysis relies on publicly available data and forecasts that are consistent with the California Energy Commission's AB2076 report. It uses the CalTrans MVSTAFF forecast for the number of gasoline and diesel autos and light trucks from 2000 through 2020, which is then extrapolated to 2030.[1] The analysis estimates the number of new and retired vehicles in each year to project the potential market for new diesel LDVs. DMV registration data provided by the CEC is used to estimate the vintage of the fleet in 2000, that is the percentage of vehicles produced in each of the previous model years, back through 1970.[2] For example, approximately 0.35% of the vehicles registered in 2000 were produced in the 1970 model year, while 7.4% were produced in 2000. Vehicle scrappage rates from the Oak Ridge National Laboratory were used to estimate how many gasoline and diesel vehicles of each vintage would be scrapped in each subsequent year, from 2001 to 2030.[3] This, combined with the CalTrans vehicle stock forecast, yielded an estimate of the number of new gasoline and diesel vehicles purchased in each year from 2001-2030, giving estimated diesel penetration rates into the future new car market.

The analysis includes two scenarios of increased penetration rates, replacing gasoline vehicles with diesel vehicles, but keeping the total number of vehicles consistent with the CalTrans forecast. The model also keeps the total vehicle miles traveled each year consistent with the CalTrans forecast.[4] Then, using estimates of higher fuel efficiency for diesel vehicles of 38% based on equivalent volumetric energy units (i.e., barrels of crude petroleum consumed), the reduced fuel consumption was estimated based on increased penetration of the more fuel-efficient diesel vehicles.[5] Under a policy scenario allowing for a 25% market penetration rate in diesel automobiles, California could save over 530 million gallons of gasoline-equivalent fuel (i.e., gallons of gasoline) per year by 2030. If diesel automobile and light truck penetration reaches 32%, a level akin to that seen today in Europe, then California could save up over 840 million gallons per year by 2030. The total fuel savings would approach 4% by 2030 and be accelerating as diesel vehicles gain a larger market share in the future

Given the state's exposure to market risks with the shift from MTBE to ethanol as the oxygenate additive for reformulated gasoline (RFG II), diesel delivers an even larger benefit in reducing gasoline consumption directly. Under the price-driven scenario, diesel LDVs could reduce gasoline consumption by 70 million gallons by 2010. With early introduction and rapid adoption under the European scenario, savings could rise to 110 million gallons by 2010.

---

[1] California Department of Transportation, "California Motor Vehicle Stock, Travel and Fuel Forecast", November 2000, www.dot.ca.gov/hq/tsip

[2] Department of Motor Vehicles, Registration data, Source - CEC SUM2000r3.xls (1984-2000 data) and CECREG.xls (1970-1995 data).

[3] Davis, Stacey, "Transportation Energy Data Book 2001", Oak Ridge National Laboratory, Center for Transportation Analysis-Energy Division, Table 6.9, data from Richard Schmoyer, unpublished study from Oak Ridge National Laboratory, TN. www-cta.ornl.gov/data/tedb21/Index.html.

[4] In the CalTrans forecast, the annual miles traveled is lower for diesel vehicles, but the model keeps the total vehicle miles traveled consistent in all scenarios of diesel vehicle penetration for comparison.

[5] This estimate was derived from two sources, the first being the MVSTAFF forecasts and the second being a survey of comparable European automobile models with similar size and performance parameters. Both estimates showed efficiency gains of 38% on average.

3. Current Diesel Fuel Use

We can gain a sense of the potential magnitude of savings in the long run by looking at what diesel fuel use is saving California today. The predominate application of diesel fuel is for truck freight transportation. Trucks larger than 10,000 pounds gross vehicle weight (lbs GVW) consume about 16% of the on-road transportation fuels in California.[6] Of total truck fuel use, diesel represents 90%. Diesel trucks on average are about 20% more fuel efficient than gasoline spark-ignition trucks according to CalTrans data.[7] If this portion of the truck fleet was fueled with gasoline instead, these trucks would consume about 20% more fuel. If all of the diesel-fueled vehicles in California were fueled with gasoline instead, transportation fuel consumption would rise about 4%.

4. Baseline Vehicle Fleet Forecast

The CalTrans forecast projects the number of gasoline and diesel vehicles running in California from 2000 through 2020, as well as vehicle miles traveled, fuel consumed, and fleet average fuel efficiency. We used the CalTrans forecast for Automobiles and Light Duty Trucks (below class GVW 3, or under 10,000 lbs). CalTrans published numbers for 2000-2015 and 2020. For Autos we used straight-line interpolation and projection to provide a forecast for each year from 2000 through 2030. Because existing trends show a declining fleet of diesel automobiles, straight-line interpolation would yield negative numbers prior to 2030. For purposes of this study, we assumed the rate of decline in the number of diesel vehicles would decrease over time. We adjusted the number of gasoline vehicles slightly to ensure that the total number of vehicles was consistent with the CalTrans Forecast. These adjustments are shown in Figure 1 for gasoline LDVs and Figure 2 for diesel LDVs. Note that the because the number of diesel vehicles is quite small relative to gasoline vehicles (i.e., 50,000 diesel versus 25 million gasoline LDVs in 2015) and because the study looks at the change between this base case and increased penetration rates, these adjustments do not significantly affect the results.

[6] CalTrans, MVSTAFF, op. cit.

[7] This efficiency difference is biased downward because larger trucks, which have lower fuel efficiency, tend to be diesel fueled.

Figure 1: CalTrans and Adjusted Gasoline Vehicle Forecast

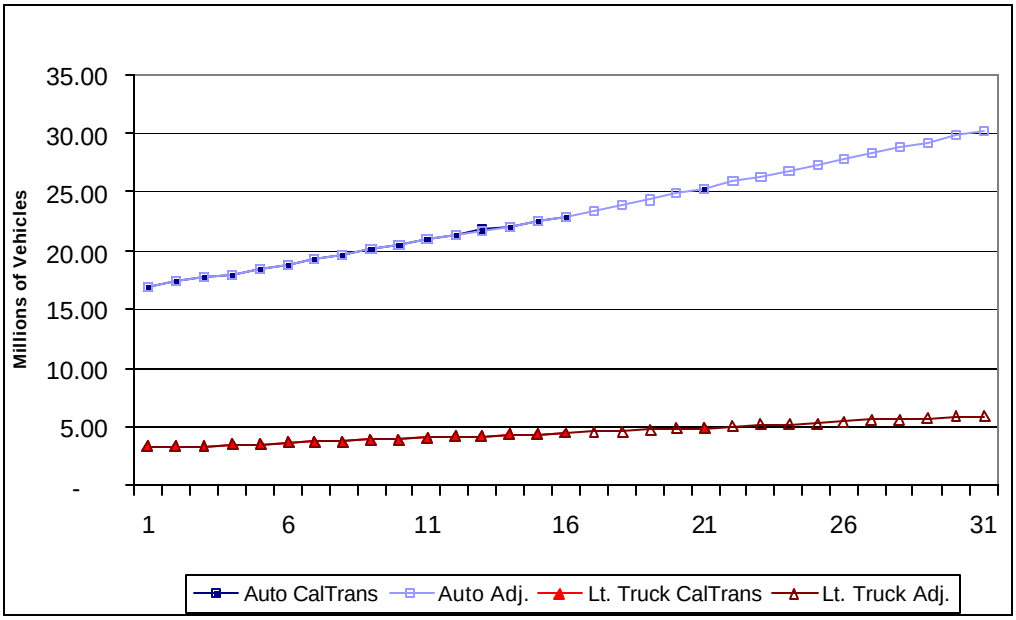
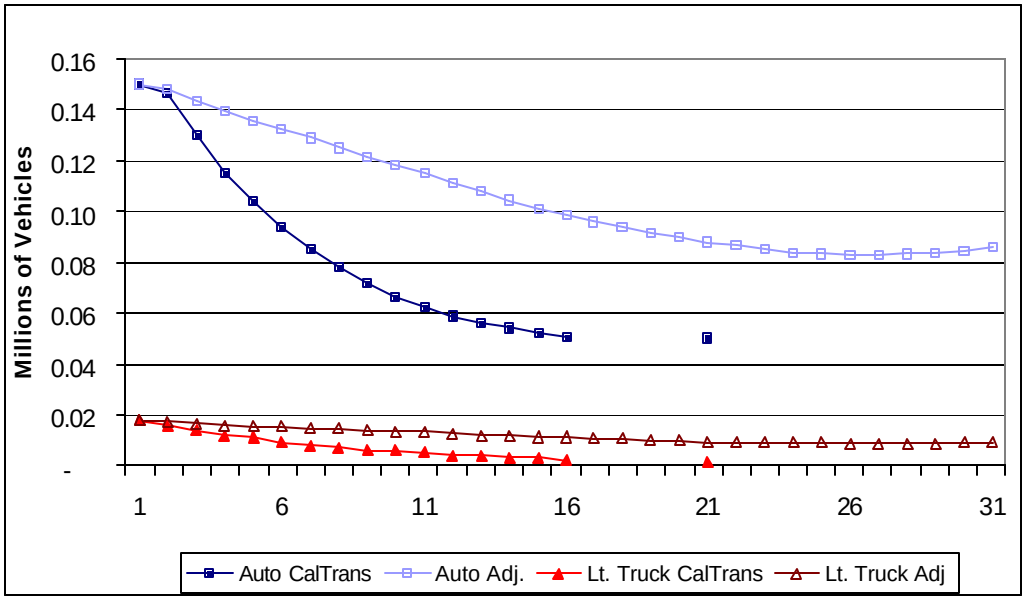


Figure 2: CalTrans and Adjusted Diesel Vehicle Forecast

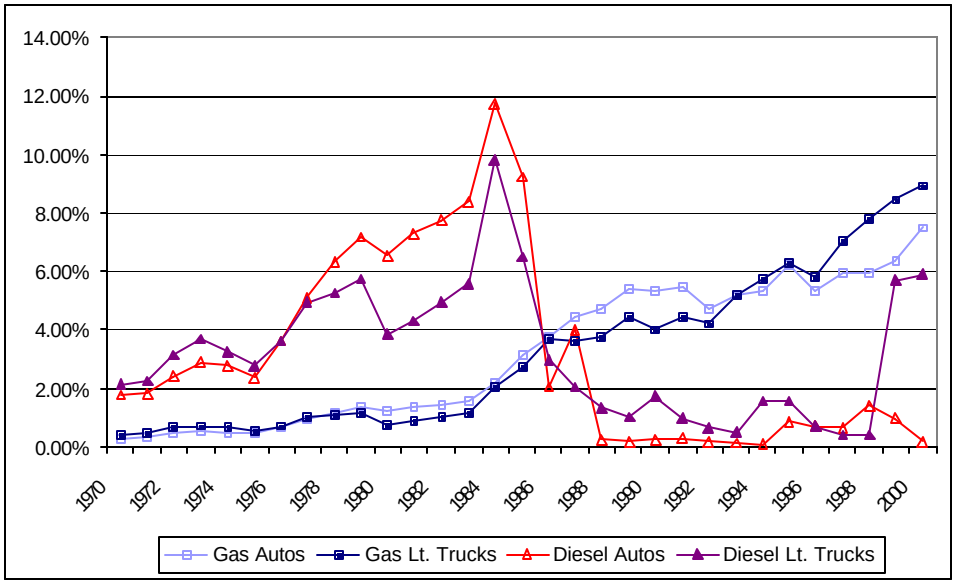


5. Fleet Vintage Distribution

To determine the number of new vehicles purchased and the number of existing vehicles scrapped in each year, we needed to determine the distribution of model vintages in the vehicle fleet for 2000 and for each subsequent year. We used DMV registration data to determine the percentage of vehicles running in 2000 produced in each year from 1970 through 2000. Note the rapid decline in the purchase of diesel autos and light duty trucks after 1984 in Figure 3 below. The largest population of diesel cars are the 1984 models, which compose 12% of the vehicles of

that age. These cars were bought when fuel costs were of paramount interest to consumers. However, increased stringency in federal and state emission standards subsequently limited the potential market for these vehicles.

Figure 3: California 2000 Fleet Vintage



6. Scrappage Rates

Once the distribution of model vintages in the 2000 vehicle fleet was determined, scrappage rates developed by Oak Ridge National Laboratory Center for Transportation Analysis were used to estimate how many vehicles are scrapped each year, as shown in Figure 4. ORNL provided scrappage rates for gasoline autos and light trucks, which were adjusted downward for diesel autos and light trucks to account for the longer expected life of diesel engines. Figure 5 shows the expected life in years and miles for each vehicle type implied by the scrappage rates. The expected life is years is calculated by sum of the survival curve ($Survival\ Curve_n = Survival\ Curve_{n-1} * (1\text{-}Scrap\ Rate_n)$). The expected life in years is calculated using California Air Resources Board EMFAC7 estimates of miles driven in each year of the vehicles life, multiplied by the survival curve for each year.[8]

[8] California Air Resources Board, "EMFAC7F / BURDEN Emission Forecasting Model Documentation," Sacramento, California: Mobile Source Division, 1994.

Figure 4: Automobile Scrappage Rates

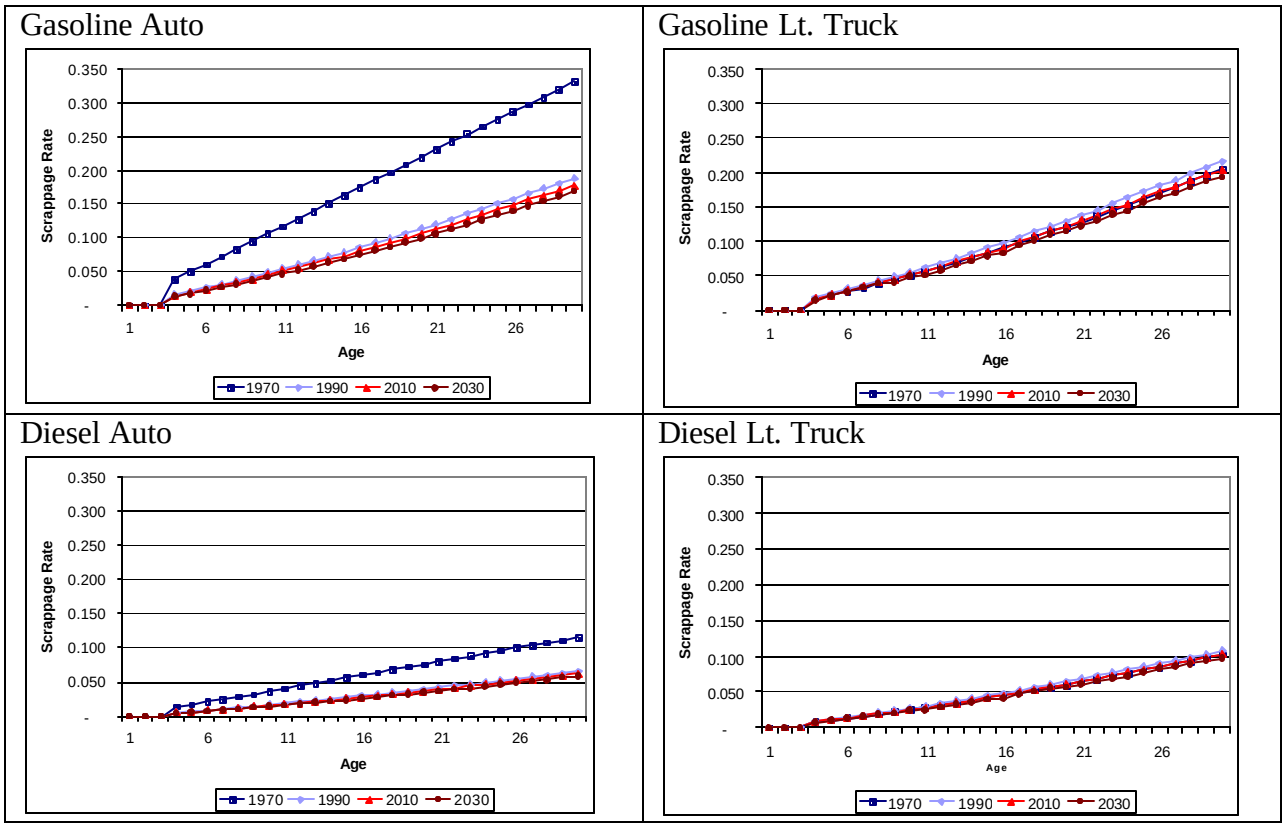


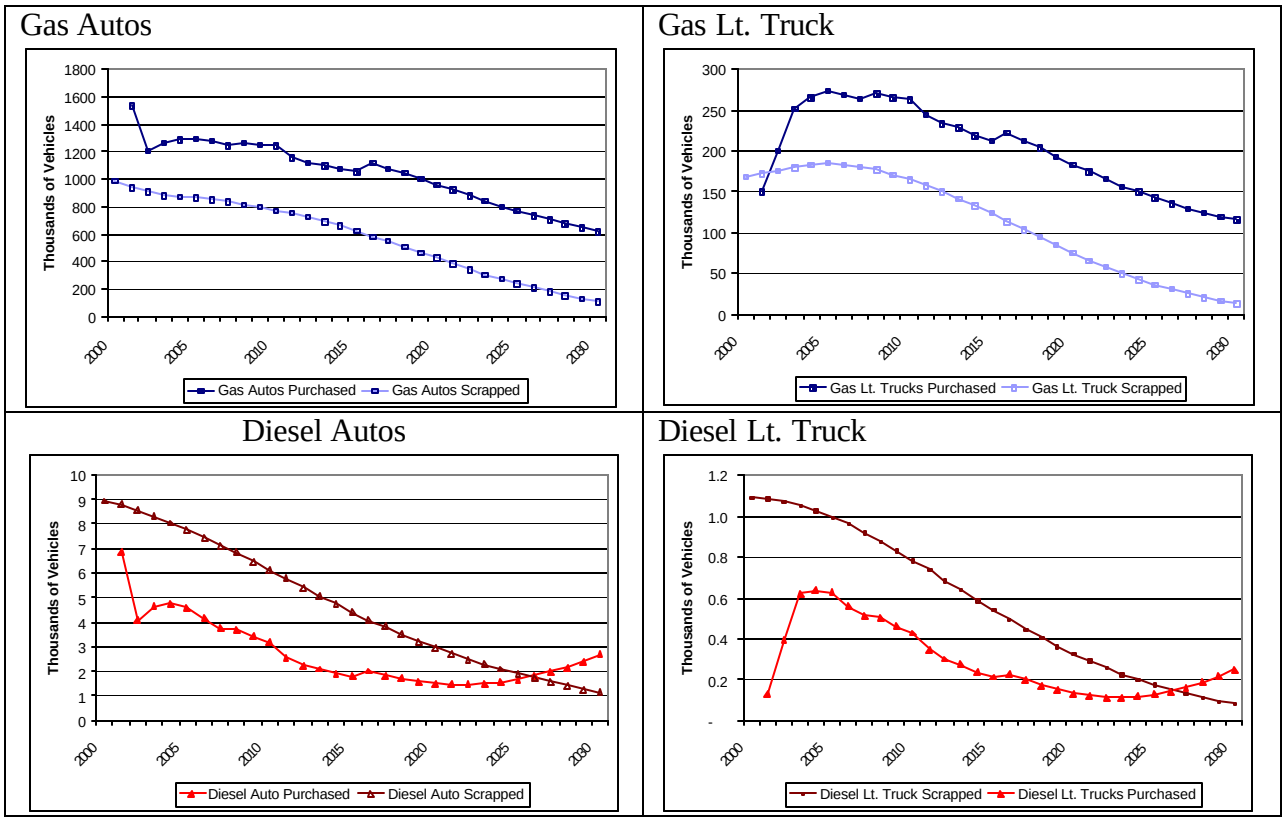
Figure 5: Expected Age and Mileage of Vehicles by Model Year

	Gas Auto		Diesel Auto	
	Age	Mileage	Age	Mileage
1970	11.5	120,335	18.5	190,457
1990	16.3	152,698	23.0	216,127
2010	16.8	155,894	23.4	218,176
2030	17.3	159,045	23.8	220,130
	Gas Lt. Truck		Diesel Lt. Truck	
	Age	Mileage	Age	Mileage
1970	16.0	182,866	20.7	244,148
1990	15.5	178,971	20.2	241,038
2010	15.9	182,192	20.6	243,635
2030	16.4	185,367	21.0	246,137

Applying these scrappage rates to the vehicle population and vintage calculated earlier yields the number of vehicles scrapped each year. Subtracting the vehicles scrapped each year from the population gives the number of vehicles remaining at the end of the year, which, when subtracted from the population in the following year gives the new vehicles purchased that year.[9]

[9] The combination of population forecasts and scrappage rates from different sources results in some in some large changes in the numbers of vehicles purchased in the initial years of the forecast. However, this change has little effect on the overall fuel use forecasts, as the comparison uses an assumption of a large change in new vehicle sales under each of the three scenarios.

Figure 6: Number of Gasoline Autos Scrapped and Purchased Each Year



7. Fuel Use Efficiency Comparisons

We used miles traveled and fuel efficiency forecasts provided by CalTrans to calculate the annual fuel use for gas and diesel vehicles.[10] On average for existing vehicles, the fuel efficiency is 5.6 MPG or 25% greater for diesel autos and 4.9 MPG or 26% greater for diesel light trucks as compared to their gasoline counterparts, as shown in Figure 7. [11] For new diesel vehicles, we assumed a 37.5% gain in fuel efficiency versus gasoline counterparts based on a survey of European car models which offer the choice of diesel or gasoline engines.[12] While CalTrans shows lower vehicle miles traveled for diesel vehicles as seen in Figure 8, we kept the total miles traveled for all vehicles consistent with the CalTrans forecast in order to compare differences in fuel use between the various scenarios for diesel vehicle penetration rates. Figure

[10] CalTrans, MVSTAFF 2000, op. cit.

[11] Both gasoline and diesel are derived from crude petroleum. Because gasoline is more highly refined, it loses more energy content per gallon than diesel during the refining process. Thus, a gallon of petroleum refined into diesel will deliver more energy (or British thermal units (BTUs)) per gallon than gasoline. This higher energy content provides about one-third of the improved fuel economy; the other two-thirds comes from the mechanical efficiency of compression ignition versus spark ignition.

[12] This efficiency gain is probably conservative given the efficiency differences shown in the *2002 Fuel Economy Guide* issues by the U.S. Environmental Protection Agency. That report showed fuel economy gains of 48% to 75% for the two drive cycles for the various Volkswagen diesel models. However, it should also be noted that as manufacturers continue to develop advanced emission control devices in an effort to meet future stringent standards a fuel efficiency penalty will begin to surface due to regeneration cycles associated with those controls.

9 shows the forecasted Base Case total petroleum fuel consumption by the automobiles and light trucks.

Figure 7: Base Case Vehicle Fuel Efficiency

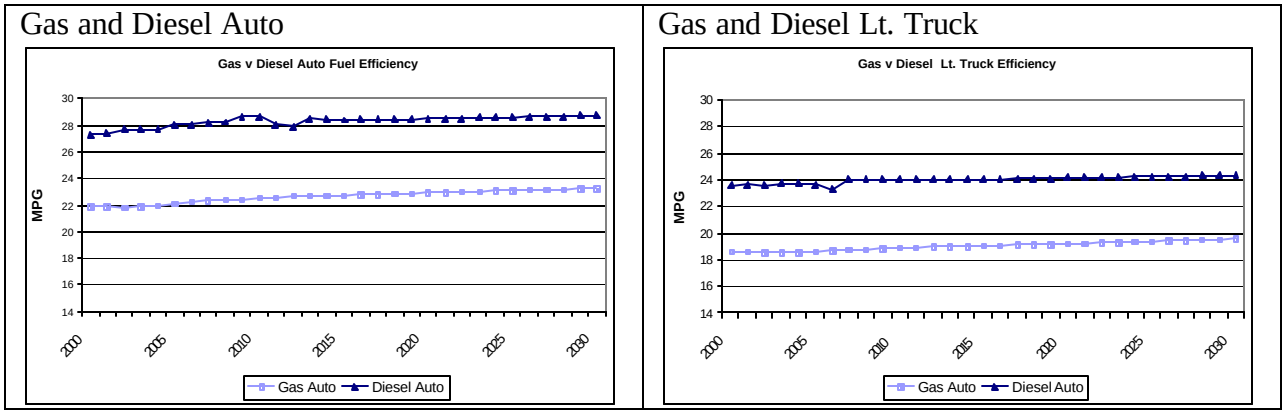


Figure 8: Vehicle Miles Traveled by Type and Fuel

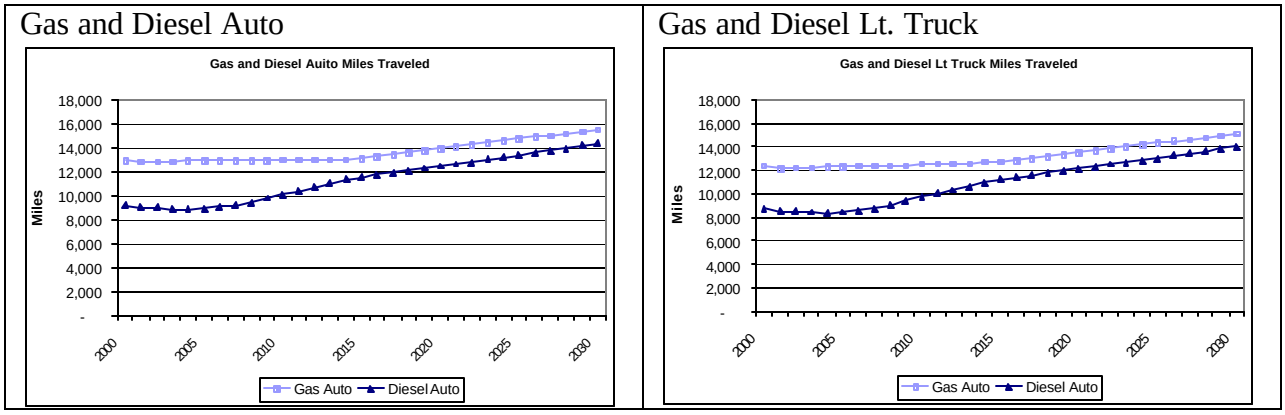
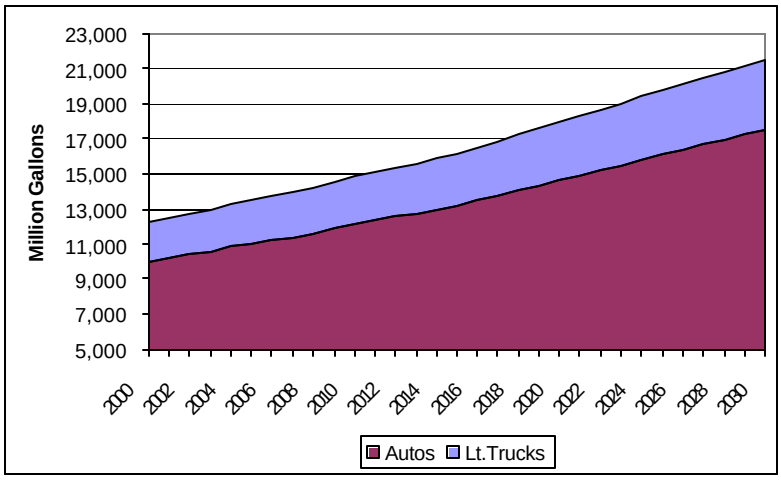


Figure 9: Base Case Fuel Use



8. Increased Diesel Penetration Rate Scenarios

Two potential market development scenarios of increased diesel LDV penetration rates were developed based on penetration rates in Europe and the U.S. experience with new vehicle technologies such as minivans and sport utility vehicles.[13] These scenarios assume increasing rather than declining penetration rates per the base case, assuming that California policies are modified to encourage increasingly advanced, high mileage diesel technology and that those technologies achieve the standards during the projected timeframes. The scenarios also assume increased availability of low sulfur diesel fuel (ULSD). These scenarios provide the policy makers with a range of potential results and impacts to fuel usage in California.

European Diesel/Gas Price Ratio (or Price Driven) Scenario: This forecast is based on the relation of diesel and gas prices to diesel sales in Europe, where diesel LDV sales are higher when diesel prices were lower than gasoline. Based on that relationship, the highest estimated market penetration in California would be about 25% at a one-to-one price ratio (about equivalent to the current price levels).[14] Then using the estimated the increase in the U.S. minivan/SUV market penetration rates for 1980-1996, diesel LDVsales were assumed to increase at a similar rate, capping penetration at 25% by 2030.

European Market Scenario: This forecast uses the 2005 Schroder Salomon Smith Barney market penetration forecast for Europe of 45% as a cap on future penetration in the California new car market. The forecast is insensitive to fuel prices to show an upper bound on the potential market. Sales increase through 2020 (15 years) at the same rate the U.S. minivan/SUV for the 15 years from 1982 to 1996. For the period from 2020 to 2030, diesel sales were set equivalent to the growth in European penetration rates after that market reached a 15% market share in 1995.

The Price Driven scenario projects a penetration in cars from 1% in 2005 to 25% in 2030, and a penetration in trucks from 1% in 2005 to 20% in 2030. The European Market scenario projects a penetration rate in both cars and trucks of 1% in 2005 to 32% in 2030. The increased penetration rates are shown in Figure 10. Figure 11 shows the total vehicle population by fuel and body type.

[13] European market penetration scenarios were developed relying in part on: Adam Collins et al., *Diesel Market Update: Revenge of th Oil Burners*, Industry Report Equity Research: Europe: Auto Manufacturers, (Schroder Salomon Smith Barney, May 3 2002); M Love, *Diesel Passenger Car & Light Commercial Vehicle Markets in Western Europe*, DP 01/0323, (Ricardo, March 2001); and Diesel Technology Forum, *Demand for Diesels: The European Experience* (Washington, D.C., July, 2001). U.S. market penetration for minivans and SUVs was collected from various U.S. Statistical Abstracts for 1987 to 2001 (U.S. Bureau of the Census, *Statistical Abstract of the United States*. (Washington, D.C.: U.S. Government Printing Office, various).

[14] European diesel national market shares appear not to be correlated with overall petroleum fuel price levels, but rather with *relative* prices of diesel and gasoline.

Figure 10: Penetration Rate Scenarios

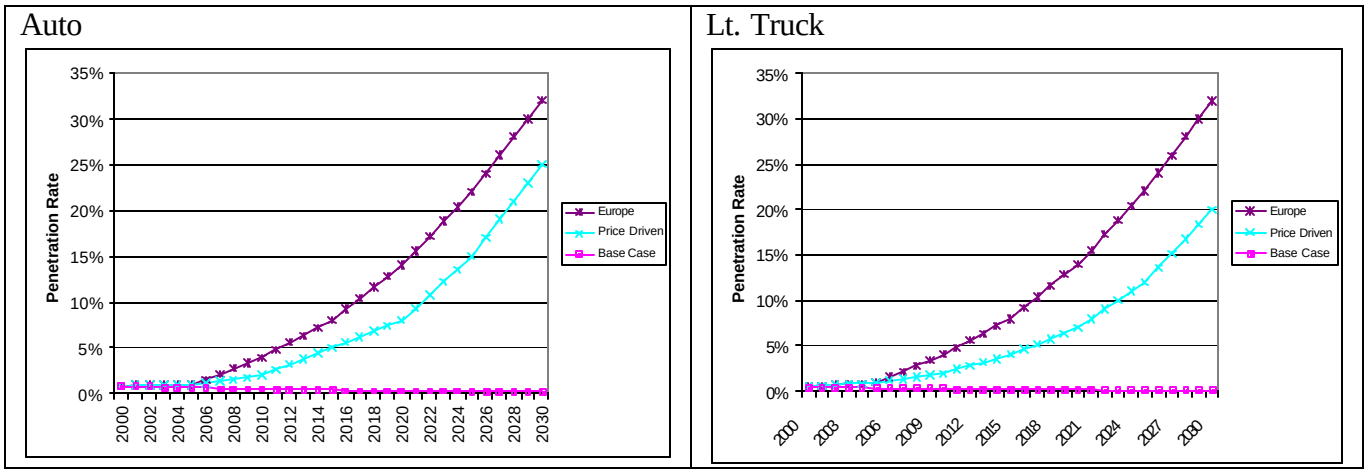
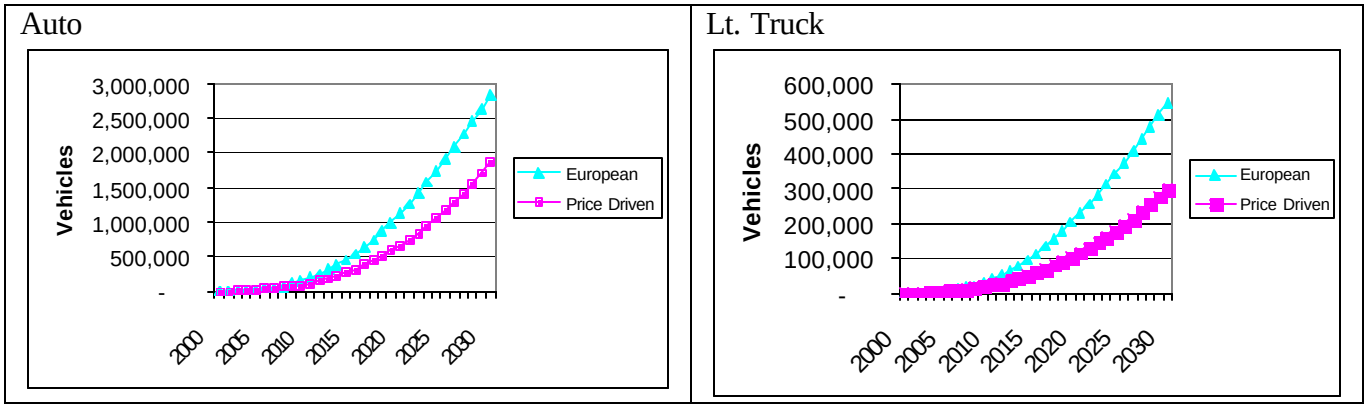


Figure 11: Increase in the Number of Diesel Vehicles



9. Potential Fuel Savings for Each Scenario

Figures 12 and 13 summarize the potential fuel savings under each of the two diesel penetration scenarios. For autos, Price Driven scenario results in an increase of 1.8 million diesel vehicles by 2030 for a savings of 448 million gallons of fuel in that year (or 2.6% of total fuel use).[15] The European scenario increased the number of diesel autos by over 2.8 million, for a fuel savings of 685 million gallons (3.9%).

For light trucks, the Price Driven scenario results in an increase of 299,000 diesel vehicles in 2030 for a savings of nearly 84 million gallons of fuel in that year (2.1%). In the European scenario, the increase in light trucks is 550,000 for a fuel savings of 156 million gallons in 2030 (3.9.

[15] Gallons of diesel fuel converted to gasoline equivalent using ration of 125,000 Btu/gal. for gasoline vs. 138,700 Btu/gal. for diesel

Figure 12: Potential Net Gallons of Petroleum Saved

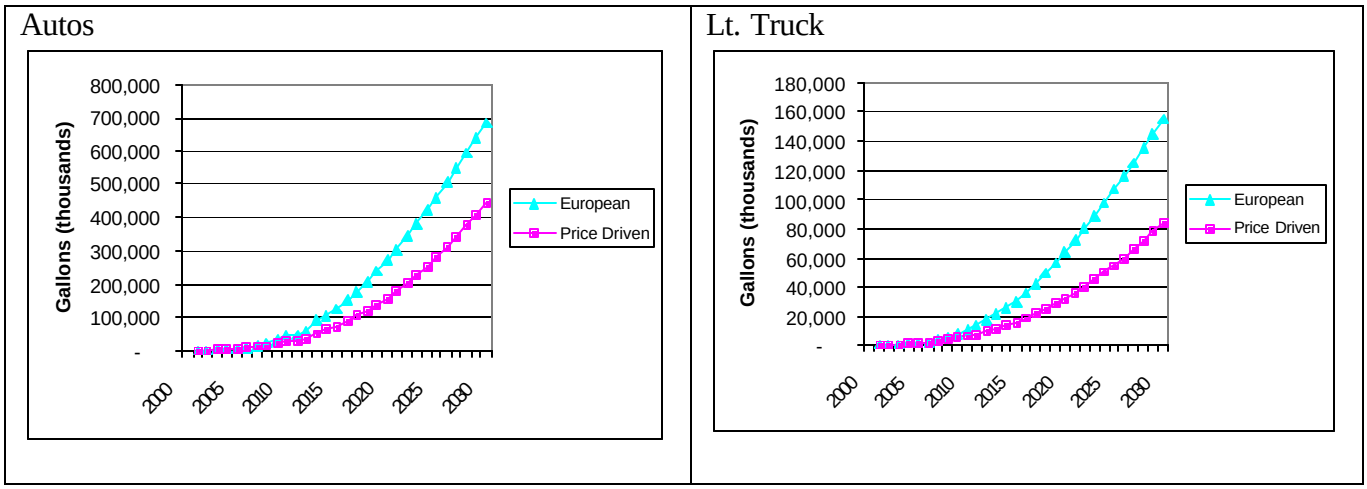


Figure 13: Total Annual Petroleum Saved by Scenario in 2030

Scenario	Increase in Diesel Vehicles	Percent of Total	Gallons of Fuel Saved per Year	Percent of Total
Price Driven Scenario	2.2 Million	7.5%	531 Million	12.5%
European Scenario	3.4 Million	11.2%	841 Million	3.9%

10. Reduction in Oxygenated Gasoline Consumption

California has decided that it must phase out the use of MTBE as an oxygenate for its California-blend reformulated gasoline (RFG II). MTBE has been found contaminating numerous groundwater supplies around the state. The U.S. Environmental Protection Agency is requiring that the state continue to use some form of oxygenate, leaving ethanol as the only alternative.

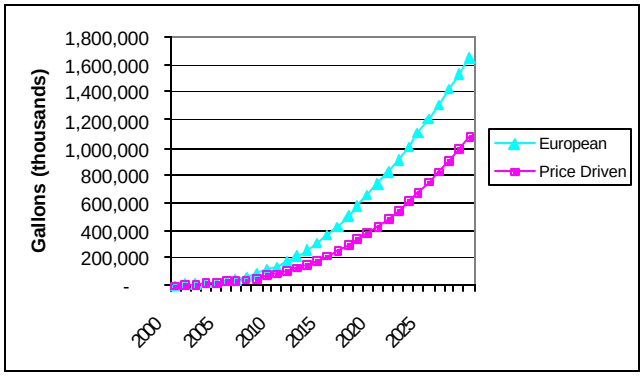
California will not be able to supply a significant share of its own ethanol because (1) the technology to convert California's available biomass to ethanol is still excessively expensive,[16] and (2) the average revenues per acre of $350 for corn is not sufficient to attract energy crop farming in this state, where most crops earn nearly ten times that much per acre.[17] Whether the rest of the U.S. has sufficient infrastructure to supply California's demand in the near term is an open question.[18] The costs and availability of ethanol to replace MTBE are highly uncertain, and contain substantial risks similar to those that California experienced in the recent electricity crisis.

[16] Steven J. Moss et al., *The Economic Impacts of Alternatives to Open-Field Burning of Agricultural Residues*, Contract #A132-121 (San Francisco, California: Prepared for the California Air Resources Board and California Environmental Protection Agency by Foster Associates Inc., November, 1993).
[17] Richard McCann et al., *Analysis of Institutional Issues Affecting the Biomass Industry in California* (Sacramento, California: Prepared for the California Energy Commission Targeted RD&D by Resource Decisions, June, 1994).
[18] Tom MacDonald, Gary Yowell, and Mike McCormack, U.S. Ethanol Industry Production Capacity Outlook: Results of a Survey Conducted by the California Energy Commission, P600-01-017, Staff Report (Sacramento, California: California Energy Commission, Transportation Fuel Supply and Demand Office, August, 2001).

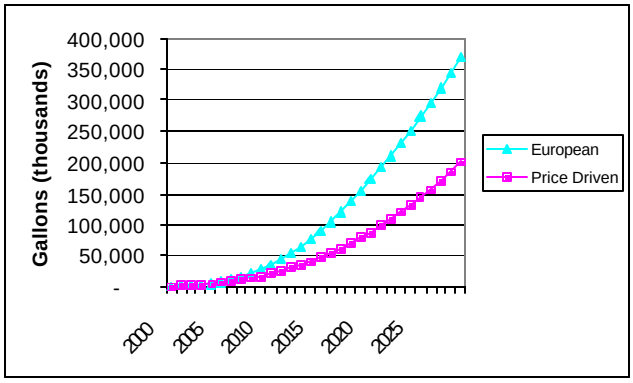
Relying on diesel to replace gasoline can reduce the state's demand for ethanol in the near future as well. Using the same scenarios as describe above, the savings in RFG II were estimated as well. Under the Price Driven scenario, diesel LDVs could reduce gasoline consumption by 86 million gallons by 2010. Under the European scenario, savings rise to 141 million gallons.

Figure 14: Gallons of Gasoline Displaced

Autos



Lt. Truck



Appendix A

Motor Vehicle Baseline Data Sources

1. Motor Vehicle Stock, Travel and Fuel Use Forecast

California Department of Transportation, "California Motor Vehicle Stock, Travel and Fuel Forecast", November 2000, www.dot.ca.gov/hq/tsip. Total Vehicles increased by 2.7% in 2000, continuing to increase at declining rates as population growth slows and vehicle ownership reaches saturation. The forecast was split between diesel and gasoline vehicles based on recent trends in DMV registration data, which shows a declining trend in the percentage of total vehicles that are diesel. Diesel autos decline from 0.88% of all vehicles in 2000 to 0.40% in 2010, while light trucks decline from 0.53% to 0.14% of the vehicle stock over the same time period. Diesel percentages are held constant after 2010.

This forecast also projected total vehicle miles traveled, based on the State Board of Equalization's sales data for gasoline and diesel fuel, and the 1999 on-road vehicle fleet fuel economy forecast from the MVSTAFF Stratified Rate Model. Annual statewide VMT is expected to increase 2.3% in 2000 and 2.1% in 2001. The long-term forecast is for VMT to grow at significantly lower rates than in the past, due to slower population and economic growth.

Fuel consumption is projected based on the MVSTAFF model. Total fuel consumption is expected to increase at declining rates. Diesel fuel consumption is projected to decrease because the number of diesel vehicles is projected to decrease.

Fleet fuel economy is expected to improve slightly throughout the forecast period. Fuel economy is calculated using the Stratified Rate Model, which computes the harmonic average fuel economy by weighting the number of vehicles in each stratum by the annual miles and travel and fuel economy of that stratum.

2. Motor Vehicle Stock Vintage

Department of Motor Vehicles, Registration data, Source - CEC SUM2000r3.xls (1984-2000 data) and CECREG.xls (1970-1995 data).

3. Scrappage Rates

Davis, Stacey, "Transportation Energy Data Book 2001", Oak Ridge National Laboratory, Center for Transportation Analysis-Energy Division, Table 6.9, data from Richard Schmoyer, unpublished study from Oak Ridge National Laboratory, TN. www-cta.ornl.gov/data/tedb21/Index.html. The expected median lifetime for automobiles in 1970, 1980 and 1990 are 11.5, 12.5 and 16.1 years respectively. For light trucks the expected median lifetimes are 16.8, 15.7 and 15.5 respectively. Scrappage rates for intervening years and for 1990-2030 were interpolated and projected using straight-line linear formulas.