OPTION 2H
LNG AND CNG FOR
MEDIUM- AND HEAVY-DUTY VEHICLES

Description

This paper updates the prior analysis contained in the *California Strategies to Reduce Petroleum Dependency (AB 2076)* report.[1] This paper explores a regulatory or incentive-based strategy intended to increase the use of natural gas in medium- and heavy-duty on-road vehicles. The analysis also assumes, based on staff monitoring of research and development activity by government and industry, negligible change in the status, implementation rate, and cost to implement advanced natural gas engine technologies onto heavy-duty vehicle platforms, since the prior analysis. The analysis period ends in 2025 rather than 2030 as in the previous analysis.

Background

On-road medium- and heavy-duty vehicles are defined as vehicles weighing greater than 8,500 pounds of gross vehicle weight. Expanded use of alternative fuels in medium-duty and heavy-duty trucks using more efficient, advanced natural gas engine technologies can reduce projected diesel fuel use from this sector. This Option explores the use of compressed natural gas (CNG) in medium-duty vehicles and liquefied natural gas (LNG) or CNG in heavy-duty vehicles. Each would replace a vehicle normally fueled with diesel.

Medium-duty and heavy-duty trucks move much of the nation's goods and are considered vital to the economy. Medium-duty trucks tend to be used in shorter trips with central refueling and hence are more likely to use CNG than LNG. Heavy-duty vehicles are used both for shorter trips and longer trips. They are more suited for LNG than CNG, because LNG has a volumetric energy content closer to diesel than does CNG. Much more diesel fuel is used by heavy-duty vehicles in long trips where central fueling is not an option.

Natural gas medium- and heavy-duty vehicles are an attractive environmental option to diesel fueled vehicles because they emit fewer criteria pollutants and toxic components. However, the limited availability of refueling facilities and typically higher vehicle purchase prices have affected the sale of this fuel option in these applications.

Staff limited this option to dedicated CNG and LNG vehicles in order to evaluate maximum diesel displacement. Dual fueled and bi-fueled vehicles would cost more to purchase as they have both a diesel and a CNG or LNG fueling system. Since they would use diesel, they would displace less diesel fuel. Furthermore, staff assumed that in a mature market condition, as discussed below, the cost of using natural gas would be significantly less than the cost of using diesel.

Status of Natural Gas Medium- and Heavy-Duty Vehicles

Some medium- and heavy-duty trucks use natural gas instead of diesel fuel. A small amount of pilot diesel fuel is used to initiate the combustion. Efforts are under way to limit the amount of pilot diesel fuel needed, and to minimize emissions. Today's economics tend to favor diesel fuel and opportunities to use natural gas are limited. Municipal vehicles, including trash haul applications, street sweepers and utility trucks have all been demonstrated. Heavy-duty applications of natural gas include grocery stores such as Raley's and Von's using CNG, and line-haul trucking such as Harris Ranch with LNG.

Staff determined weighted-averages of the year 2000 vehicle fuel economies for the existing relevant diesel vehicle classes using several sources. In the analysis, staff began with base case vehicles that achieve12.7miles per gallon of diesel in Class 3-6 vehicles and 6.5 miles per gallon of diesel in Class 7-8 vehicles.[2]

Natural gas and natural gas vehicle stake holders have joined forces to establish two working groups to advance the state of natural gas heavy-duty vehicles. One is working to improve the vehicles, and the other is working to improve fueling infrastructure.

The U. S. Department of Energy and other stake holders are working jointly to improve the performance of medium-duty and heavy-duty natural gas vehicle technologies.[3] Their near-term objective was to deploy one Class 3-6 by 2004 and one Class 7-8 vehicle by 2007, both will be designed to be commercially viable and meet year 2007 emissions targets while significantly advancing the performance capability of natural gas in these applications. Funding needs to continue this effort is $7 million in 2006 and 2007. They do not specifically identify efficiency targets. However, the performance goal is to match the efficiency of comparable diesel engines. If funded, they expect that vehicles developed under this program will lead to commercial offerings to achieve limited market scope with current incentive programs aimed at reducing emissions or displacing petroleum fuels.

Many of the stakeholders are also involved in improving the refueling infrastructure in an effort to build the market for natural gas vehicles.[4] This effort focuses upon improved gas compression methods and component integration for CNG and lowering the cost of LNG production by developing small-scale LNG production technology and lower cost equipment. Ensuring safety and reliability are important aspects of this work.

Assumptions and Methodology

Diesel demand reductions in 2010, 2020, and 2025 from on-road heavy-duty vehicles are estimated based on projected sales of natural gas heavy-duty vehicles, associated improvements in advanced natural gas engine fuel economy, existing and projected vehicle populations, infrastructure costs and other assumptions. Key assumptions and common methodology are summarized below.

- Fuel economies and vehicle miles traveled are weighted across vehicle classes.

- All new natural gas vehicles sold by 2020 are fully competitive with conventional diesel vehicles on performance, reliability and durability bases, and meet prevailing emission standards. Compression ignition-based LNG vehicles meet prevailing fuel economy performance of diesel engines. Spark ignition-based CNG engine platforms meet 95 percent of prevailing diesel engine fuel economy performance, due to heavier on-board fuel tanks and throttling losses associated with spark ignition.

- All new vehicles sold replace diesel-fueled vehicles because diesels dominate the vehicle population segment considered.

- Variable penetration rates in all vehicle classes with higher rates in some classes and time periods than others.[5]

- Certain costs are associated with achieving the assumed penetration rates and estimated petroleum displacements for NGVs. These include incremental capital cost, incremental fuel cost, incremental operation and maintenance costs and an incremental infrastructure cost. These costs vary among vehicle classes.

Near-Term Market or Business-As-Usual (BAU) Scenario

We define a near term market to account for current penetrations of natural gas vehicles through the year 2010, which is also the transition year to the matured market discussed later. These commercially available vehicles meet the prevailing emission standards and satisfy the demand in several niche and emerging applications. In a near term market, staff assumed that 2005 incremental capital costs of medium-duty CNG vehicles averaging $9,000 prevail through 2010. Similarly, it is assumed that the incremental cost of CNG and LNG Class 7-8 heavy-duty vehicles averaging $28,767, prevail through 2010. These costs are expressed in 2004 dollars.

We also assume that the sales of natural gas vehicles through 2010 is a nominal 2 percent of the vehicle population as these products benefit from several favorable factors. These factors include local and state government incentives, fuel cost advantage and $9,000 to $18,000 in reduced incremental cost compared to competing diesel products. The incremental price reduction comes from the corresponding price increase for competing medium- and heavy-duty diesel vehicles to meet the prevailing emission standards.

Mature Market or Aggressive Scenario

In a mature market, staff assumed that research and development (R&D) successfully reduces incremental capital costs of medium-duty CNG vehicles from a high of $11,000 in 1997 to $2,000 by 2025. Likewise, staff assumed that R&D successfully reduces incremental capital cost of CNG Class 7-8 heavy-duty vehicles from a high of $45,000 in 1997 to $11,000 by 2025. Similarly, the incremental capital cost of LNG Class 7-8 heavy-duty vehicles decreases from $28,767 in 1997 to $4,700 by 2025. All are expressed in 2004 dollars.

Staff developed compressed natural gas fuel costs using the same approach described in Option 2D, CNG for Light-Duty Vehicles. First, we used the Energy Commission's commercial end-use price forecast from 2004 to 2022, adjusted with plus and minus one standard deviation (scaled to gasoline price variability) to determine a range of natural gas commodity prices, assuming commercial operation of public refueling facilities. These were $0.53 to $0.77 per therm of gas. Next, we added expected capital recovery for station upgrades (estimated from current natural gas utility tariffs for CNG at utility-owned public refueling stations, with scaling to account for larger volume throughput) and added expected electricity and maintenance charges, based upon existing natural gas utility tariffs. This added another $1.03 to $1.13 per therm of gas. Next, we added state and federal fuel excise taxes, sales tax and natural gas regulatory fees to arrive at a final CNG price range of $1.56 to $1.90 per therm (equivalent to $2.14 to $2.61 per gallon of diesel on an energy content basis, expressed "DGE" or $1.88 to $2.29 per gallon gasoline equivalent).

For LNG staff developed the fuel price estimate for in-state production and out-of-state supplies for the California market.

For in-state production, we used the Energy Commission's commercial end-use price forecast from 2004 to 2022, adjusted with plus or minus one standard deviation (scaled to gasoline price variability) to determine a range of natural gas commodity prices, assuming commercial operation of public refueling facilities. These were $0.53 to $0.77 per therm of gas. We then converted this cost per therm to the cost per LNG gallon. Next, we added expected liquefaction and delivery cost of $0.23 to $0.39 per LNG gallon. We then added state and federal fuel excise taxes, sales tax and a retail markup of $0.119, $0.06 and $0.09 to arrive at final LNG per gallon price range of $1.01 to $1.39. This is equivalent to $1.55 to $2.17 per gallon of DGE without the markup. With the markup, the price on a diesel gallon equivalent basis ranges from $1.64 to $2.29.

For out-of-state production, we used the Energy Commission's commercial end-use price forecast from 2005 to 2025 for core gas cost, adjusted with plus and minus one standard deviation (scaled to gasoline price variability) to determine a range of natural gas commodity prices, assuming commercial operation of public refueling facilities. The core gas cost is on an LNG gallon basis. These were $0.45 to $0.76 per LNG gallon. Next, we added expected liquefaction and delivery cost of $0.45 to $0.76 per LNG gallon. We then added state and federal fuel excise taxes, sales tax and a retail markup of $0.119 and $0.06 to arrive at final LNG per gallon price range of $1.25 to $1.64. This is equivalent to $1.92 to $2.57 per gallon of DGE without the markup. With the markup, the price on a diesel gallon equivalent basis ranges from $2.09 to $2.73.

Penetration Rates and Scenarios

Developing a future vehicle penetration scenario for advanced, medium- and heavy-duty natural gas vehicle technologies is complex and challenging due to the number of factors that influence the penetrations and the overall scenario period. We used a simplified approach by limiting the total natural gas vehicle penetration to a maximum of 15 to 25 percent of the total vehicle population in the year 2025 for the BAU and Aggressive cases respectively. These maximum penetrations are historical values observed in the transit bus segment where natural gas vehicle technologies have been most successful. An average ramp up schedule of 2 percent of the existing vehicle population is used to estimate the penetration rates from 2008 to 2025 to achieve the new natural gas vehicle population. This period is divided further into three segments: 2008 to 2010; 2011 to 2020; 2021 to 2025. The 2005 to 2007 period penetrations are negligible (<1 percent of the existing vehicle population) as they are limited to prototype, demonstrations and field trials.

The penetration period is divided into segments based on clearly defined factors. A minimum penetration rate of 1 percent of the vehicle population is assumed. This minimum rate is taken as half of the 2 percent nominal historical vehicle population growth rate reported in the 1996 World Vehicle Forecast and Strategies.[6] This rate corresponds to 14.3 percent of the new vehicle sales.

The penetration periods are defined based on regulatory milestone events, technology phase-in, maturation and availability, and alternative fuel infrastructure deployment. A more detailed description of the rationale used to formulate these penetration periods is provided below.

Superimposed onto the penetration period determinants are two key factors that interact to define the likely penetration scenarios for the analysis: Cost to meet the emission standards and consumer hesitation due to uncertainty about reliability, durability and expected performance in the early years.

Cost to Meet Emission Standards

Based on published industry information and analysis of costs to comply with emission standards by the U.S. Environmental Protection Agency (EPA),[7] the supporting analysis found that advanced natural gas vehicles in the matured market are likely to cost up to $15,000 more than natural gas vehicles manufactured before 2010. The post 2010 incremental cost is in addition to today's declining incremental vehicle costs of $11,000 (Class 3-6 vehicles) to $28,000 (Class 7-8 vehicles) for fuel system and on-board storage compared to conventional diesel vehicles. These higher but declining incremental costs are assumed to influence consumer purchase decisions and therefore modulate advanced vehicle penetrations. Comparably higher costs for diesel engines to meet the 2007 emission standards suggest price parity and even price advantage may materialize for medium- and heavy-duty natural gas vehicles in a range of applications. Literature reviews and industry data suggest that by the year 2010, Class 3-6 heavy-duty natural gas vehicles are likely to achieve price parity with comparable diesel engines.[8] Similarly, by 2010, available data suggest Class 7 and 8 natural gas vehicles are likely to achieve price parity or enjoy a price advantage over comparable diesel vehicles.[9] By 2025, natural gas vehicles in the full range of medium- and heavy-duty vehicle classes 3 through 8 are price competitive with their diesel counterparts.[10] The narrowing costs between the natural gas vehicles and competing diesel vehicles make the natural gas vehicles relatively attractive.

Consumer Hesitation

Historically, consumers hesitate to embrace a new technology until its reliability, durability and performance expectations are proven. This is even more so for heavy-duty natural gas vehicles that are employed in mission-driven applications. This market reality is expected to constrain the penetration of the advanced natural gas vehicles for up to the first three years after each product introduction.

These factors influenced the penetration rates in the three penetration periods. The following penetration scenarios are likely to emerge as a result of these factors individually and combined, during the three penetration periods the 2002 to 2025 planning period is divided into.

1. In the 2005-2007 time frame sales of advanced new natural gas vehicles are negligible, limited to prototypes, field trials and demonstrations. This penetration period is negligible for purposes of this analysis.

2. In the 2008-2010 period, we assumed the penetration rate of 1 percent and 2 percent of the vehicle population in the target year or 14.3 percent to 28.6 percent of the new vehicle sales for the BAU and Aggressive cases respectively. During this period, consumers buy 2.0 gm NOx per brake-horsepower-hr natural gas (NG) and diesel products, now in the market for 5 years, to hedge against the higher priced 0.2 gm NOx engines entering the market. As a consequence, sales of 0.2 gm NOx NG and competing diesel vehicles decline sharply due to product performance uncertainties and customer purchase hesitations.

3. In the 2011-2020 period, we also assumed a penetration rate of 1 percent and 2 percent or 14.3 to 28.6 percent of new vehicle sales for the BAU and Aggressive cases respectively. During this period, vehicle sales are driven by fleets replacing aging 4.0 gm and 2.5 gm NOx natural gas and diesel engines.

4. In the 2021-2025 period, the nominal penetration rate continues as more fleets purchase newer vehicles to replace aging vehicles and to take advantage of the potential fuel savings from potential efficiency improvements and fuel costs (i.e., natural gas vs diesel fuel).

Results

The general impact on California's diesel and gasoline demand from using medium- and heavy-duty natural gas vehicles is summarized in Tables 1-4. Net-Direct benefits to the state are characterized by Direct-Non-Environmental Benefits, a Change in Government Revenue due to reduced fuel taxes, Direct Environmental Net Benefits and the External Cost of Petroleum Dependency.

Table 1. Petroleum Reduction and Benefits for Medium- and Heavy-Duty Natural Gas Vehicles for Low Fuel Price and 5 Percent Discount Rate

Alternative Fuel Option or Scenario	Displacement in 2025, billion gallon gasoline equivalent	Reduction from Base Case Demand, percent	Highest Cumulative Benefit or Change, Present Value, 2005-2025, 5% discount rate, Billion $2005				
			A	B	C	D	A+B+C+D
			Direct Non-Environmental Benefit	Change in Government Revenue	Direct Environmental Net Benefit	External Cost of Petroleum Dependency	Direct Net Benefit
Business As Usual	1.1	5.3	1.4	(1.3)	0.22	0.76	1.08
Aggressive	1.72	8.3	2.65	(2.48)	0.36	1.24	1.77

Table 2. Petroleum Reduction and Benefits for Medium- and Heavy-Duty Natural Gas Vehicles for Low Fuel Price and 12 Percent Discount Rate

Alternative Fuel Option or Scenario	Displacement in 2025, billion gallon gasoline equivalent	Reduction from Base Case Demand, percent	Highest Cumulative Benefit or Change, Present Value, 2005-2025, 12% discount rate, Billion $2005				
			A	B	C	D	A+B+C+D
			Direct Non-Environmental Benefit	Change in Government Revenue	Direct Environmental Net Benefit	External Cost of Petroleum Dependency	Direct Net Benefit
Business As Usual	1.1	5.3	0.47	(0.66)	0.22	0.76	0.79
Aggressive	1.72	8.3	1.0	(1.2)	0.36	1.24	1.4

Table 3. Petroleum Reduction and Benefits for Medium- and Heavy-Duty Natural Gas Vehicles for High Fuel Price and 5 Percent Discount Rate

Alternative Fuel Option or Scenario	Displacement in 2025, billion gallon gasoline equivalent	Reduction from Base Case Demand, percent	Highest Cumulative Benefit or Change, Present Value, 2005-2025, 5% discount rate, Billion $2005				
			A	B	C	D	A+B+C+D
			Direct Non-Environmental Benefit	Change in Government Revenue	Direct Environmental Net Benefit	External Cost of Petroleum Dependency	Direct Net Benefit
Business As Usual	1.1	5.3	0.27	(1.33)	0.22	0.76	(0.08)
Aggressive	1.72	8.3	0.59	(2.48)	0.36	1.24	(0.29)

Table 4. Petroleum Reduction and Benefits for Medium- and Heavy-Duty Natural Gas Vehicles for High Fuel Price and 12 Percent Discount Rate

Alternative Fuel Option or Scenario	Displacement in 2025, billion gallon gasoline equivalent	Reduction from Base Case Demand, percent	Highest Cumulative Benefit or Change, Present Value, 2005-2025, 12% discount rate, Billion $2005				
			A	B	C	D	A+B+C+D
			Direct Non-Environmental Benefit	Change in Government Revenue	Direct Environmental Net Benefit	External Cost of Petroleum Dependency	Direct Net Benefit
Business As Usual	1.1	5.3	0.02	(0.6)	0.22	0.76	(0.3)
Aggressive	1.72	8.3	0.01	(1.2)	0.36	1.24	(0.4)

Business-as-Usual Scenario

For the Business as Usual Scenario, medium and heavy-duty CNG and LNG vehicles reduce California's on-road diesel demand by 1.25 billion gallons or about 5.3 percent of the state's on-road gasoline and diesel demand in 2025.

Under this scenario, a 5 percent discount rate and low diesel fuel price of $1.82 per gallon, consumers are estimated to save $1.37 billion in 2025. The corresponding outcomes under this scenario, a 5 percent discount rate and high diesel fuel price of $2.18 per gallon, consumers save an estimated $0.27 billion in 2025. There is a loss in government revenue of $1.33 billion for both.

Under this scenario, a 12 percent discount rate and low diesel fuel price of $1.82 per gallon, consumers are estimated to save $0.53 billion in 2025. The corresponding outcomes under this scenario, a 12 percent discount rate and high diesel fuel price of $2.18 per gallon are estimated to be a $0.02 billion loss to consumers and $0.66 billion loss to government in 2025.

Aggressive Scenario

For the Aggressive Scenario, medium and heavy-duty CNG and LNG vehicles reduce California's on-road diesel demand by 1.72 billion gallons or about 8.3 percent of the state's on-road gasoline and diesel demand in 2025.

Under the scenario of a 5 percent discount rate and low diesel fuel price of $1.82 per gallon, consumers are estimated to save $2.7 billion in 2025. There is a loss in government revenue of $2.48 billion. The corresponding outcomes, under the scenario of a 5 percent discount rate and high diesel fuel price of $2.18 per gallon, are estimated to be $0.59 billion in consumer savings in 2025. There is a loss in government revenue of $2.48 billion.

Under the scenario of a 12 percent discount rate and low diesel fuel price of $1.82 per gallon, consumers are estimated to save $1.02 billion in 2025. The government loses $1.2 billion in 2025. The corresponding outcomes, under the scenario of a 12 percent discount rate and high diesel fuel price of $2.18 per gallon, are estimated to be $0.014 billion in consumer savings and a $1.2 billion loss to government in 2025.

Key Drivers and Uncertainties

1. Assuming fuel economy of natural gas vehicles approaches that of diesel fueled vehicles.
2. Assuming NGVs are as fuel efficient as corresponding diesel vehicles.

3. Assuming Vehicle class distribution does not change.
4. Assuming vehicle miles traveled are the same for diesel and natural gas vehicles (affects demand reduction and incremental operating costs).
5. Assuming a more rapid fleet turnover in the years 2015-2025 as vehicle fleet ages and replacement is justified by lower operating cost from more fuel-efficient vehicles.

Endnotes

[1] "California Strategies to Reduce Petroleum Dependency (AB 2076), California Energy Commission and the California Air Resources Board, December, 2001.

[2] These are the weighted average fleet vehicle fuel economies determined in several analysis including the report "Profile and Segmentation of Medium and Heavy Vehicle Purchase Patterns and Current and Projected Populations", MacKay & Company, February 1995.

[3] Next-Generation Natural Gas Vehicle Program, Vehicle Working Group Workshop and Meeting, October, 2001.

[4] Natural Gas Vehicle Infrastructure Working Group and Vehicle Working Group, Summary of Recommendations to Overcome Natural Gas Vehicle Infrastructure Technology Obstacles, September 2001.

[5] As used in this analysis, vehicle penetration rate means a percentage of new vehicles entering the existing fleet population. For this scenario, 100 percent of new vehicles sold meet the assumed fuel economy targets used in the analysis. It is estimated that new vehicle sales are fewer than 10 percent of the existing population in any given year. The penetration rate is varied to reflect rapid turnover of the vehicle population. A higher penetration rate is assumed to occur in the years 2015-2025 from aging and the availability of more fuel-efficient vehicles. A composite vehicle class distribution is used in estimating the vehicle penetrations.

[6] Pemberton, Max. 1996 World Vehicle Forecasts and Strategies: The Next 20 years: A Special Report Covering the Period from 1960-2015. Ward's Communications. Pemberton Associates, Warwickshire, UK, 1996.

[7] "Regulatory Impact Analysis: Control of Emissions of Air Pollution from Highway Heavy-duty Engines", U.S. Environmental Protection Agency, document EPA 420-R-00-10, July 2000.

[8] "California Strategies to Reduce Petroleum Dependency (AB2076), California Energy Commission and the California Air Resources Board, December, 2001.

[9] Ibid.

[10] Ibid.