NATURAL GAS SCENARIO

AB 1007 STATE PLAN TO INCREASE THE USE OF ALTERNATIVE FUELS

5/31/07 DRAFT

[TEXT AND METHODOLOGY IS RELATIVELY COMPLETE, BUT QUANTITATIVE RESULTS ARE PRELIMINARY AND SUBJECT TO CHANGE]

California Energy Commission and California Air Resources Board

1. Executive Summary

Compressed natural gas (CNG) and liquefied natural gas (LNG) vehicle and fueling infrastructure technologies are relatively well developed and there is negligible risk associated with technical feasibility uncertainties. Natural gas vehicles (NGVs) have been proven to be commercially viable, most definitely in other countries (there are over 5 million NGVs worldwide) and marginally in the U.S. (where there are about 130,000 NGVs). Private companies are engaged in natural gas engine, vehicle, fueling station, and fuel supply businesses. However, some original equipment manufacturers (OEMs) have recently discontinued their natural gas engine and vehicle products.

Natural gas use as a transportation fuel obviously displaces gasoline and diesel fuel consumption, and it also provides environmental benefits. For any credible set of assumptions, CNG and LNG use reduces greenhouse gas emissions. While nearly all currently consumed natural gas is a fossil fuel, it can also be a biofuel when sourced from landfills, sewage, or agriculture waste.

CNG and LNG are and generally have been less expensive than gasoline and diesel fuel on an energy-equivalent basis. However, natural gas vehicles and fueling stations are more expensive. Therefore, the overall economics are favorable if the fuel cost savings can amortize the additional equipment costs. This equation favors high fuel use applications, and that is one reason why heavy duty vehicles are the fastest growing NGV segment in California.

In California, approximately 125 million gasoline gallons equivalent (gge) of CNG and LNG were consumed in 2006, and consumption has increased at an average rate of about 14% annually over the past five years. This provides a rational point-of-departure for forecasting future natural gas transportation fuel use. Forecasts of CNG and LNG use in heavy duty vehicles (HDVs) and CNG use in light duty vehicles (LDVs) are shown in Figures 1 and 2, respectively. Relative to historical growth, initial future growth is considered to decrease, remain about the same, and increase for the conservative, moderate, and aggressive scenarios, respectively. The CNG and LNG growth rates are modulated to be consistent with the anticipated growth rate for all transportation fuels in the long term, and special situations such as California port plans for LNG trucks are accounted for. The forecast percentages of petroleum fuel displacement are summarized in Table 1 for AB1007 milestone dates.

The environmental impacts of natural gas transportation fuel use are estimated by applying the factors quantified in the AB1007 well-to-wheels analyses to the CNG and LNG consumption forecasts. These impacts are summarized in Table 2, where negative numbers indicate emission reductions. Natural gas fuel use is anticipated to provide significant reductions of greenhouse gas, hydrocarbon, and toxic emissions.

Numbers of vehicles, fueling stations, and their costs are estimated from the CNG and LNG fuel use forecasts by assuming representative fuel consumption rates, R&D expenses, and capital costs. This provides the basis for the life cycle cost analyses and cost effectiveness assessment. The cost effectiveness is defined as the sum of all expenses (R&D, incremental capital and incentive costs, fuel cost savings) divided by the CNG and/or LNG fuel consumption in gge.

Therefore, the cost effectiveness is the real cost, in $/gge, of using natural gas instead of petroleum fuels, on a per-year or life cycle basis. The cost effectiveness will be negative when the lower fuel costs offset other expenses, and this implies savings or profits for all participants. Table 3 summarizes forecast investment expenses and cost effectiveness for the three scenarios.

It is concluded that increased CNG and LNG use in California can economically contribute to AB1007 goals for petroleum fuel displacement and "no net material increase in emissions." Details of this storyline and associated analyses are provided in subsequent sections. Please note that, while the methodology is reasonably well established, the analyses are still being refined and the quantitative results in this document are subject to change.

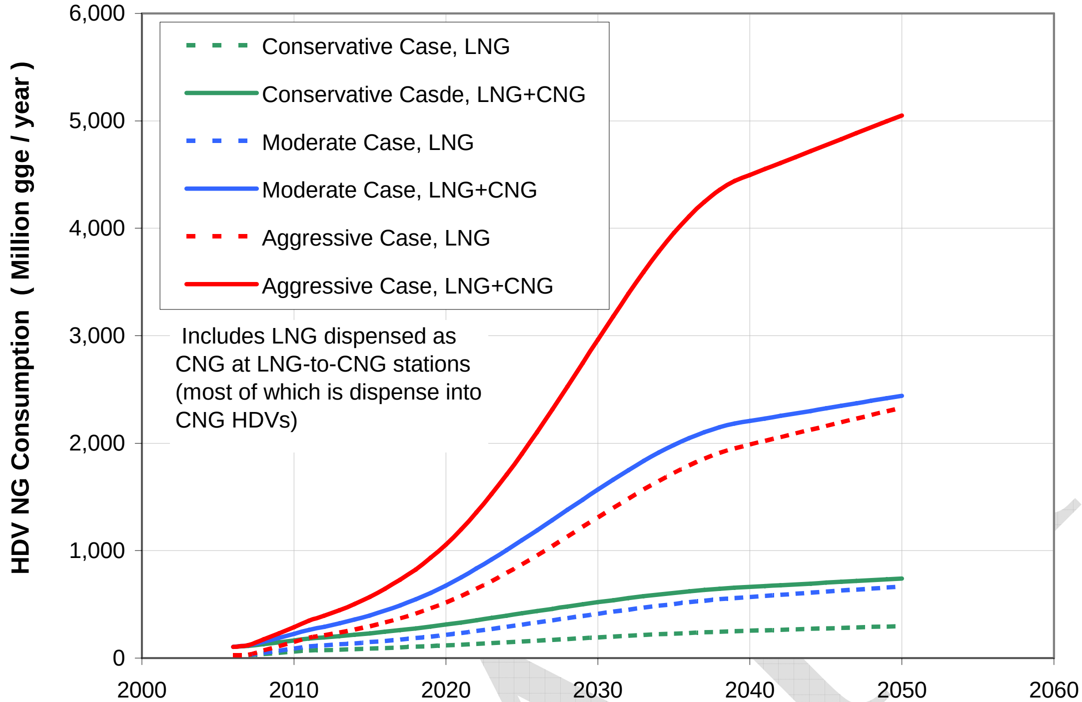

Figure 1. Heavy Duty Natural Gas Vehicle Fuel Use Forecasts

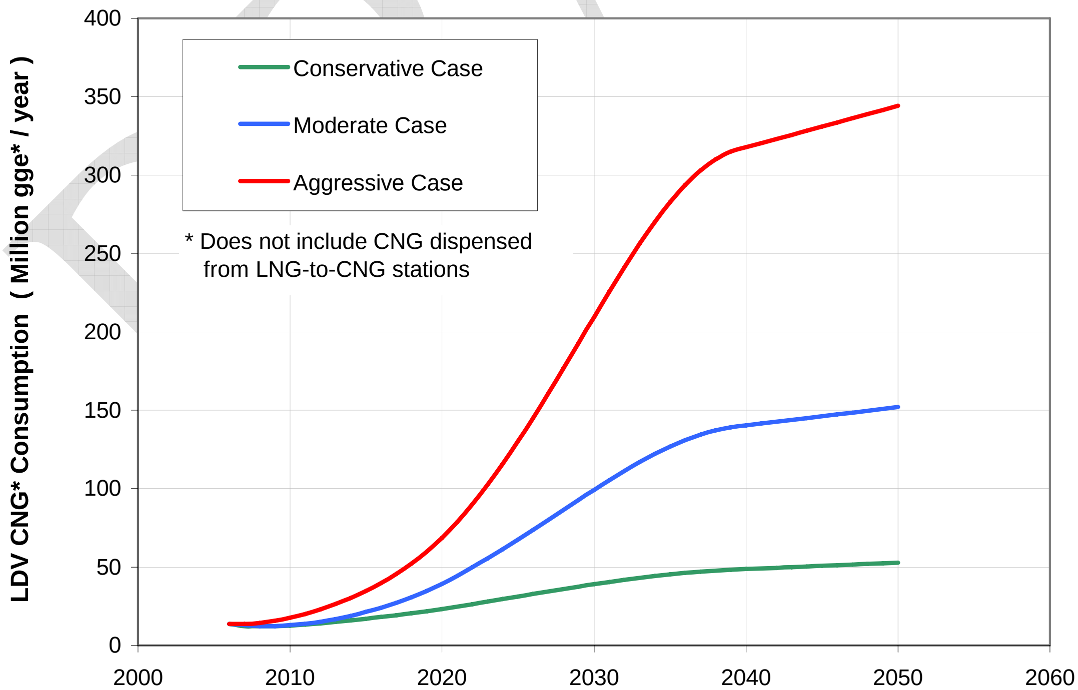

Figure 2. Light Duty Natural Gas Vehicle Fuel Use Forecasts

Table 1. Natural Gas Fuel Use Forecast Summary

		Total LDV+HDV NG Fuel Use, million gge/yr & (% of Total CA Vehicle Fuel Use)					
Case	**Year**	**2006**	**2012**	**2017**	**2022**	**2030**	**2050**
Conservative		125 (0.6%)	218 (1%)	294 (1.2%)	399 (1.7%)	589 (2.3%)	839 (2.8%)
Moderate		125 (0.6%)	319 (1.4%)	536 (2.3%)	912 (3.8%)	1721(6.8%)	2666 (8.9%)
Aggressive		125 (0.6%)	433 (1.9%)	803 (3.4%)	1494 (6.2%)	3271 (13%)	5570 (19%)

Table 2. Environmental Benefits Forecast Summary

		Approximate Reduction Relative to Baseline, 212 through 2050					
Case	**Type**	**GHG**	**PM**	**NOx**	**HC**	**Toxics**	**Water Impact**
Conservative		(all TBD)					
Moderate		LDV: -20% HDV: -5% to -20%	negligible	negligible	-40% to -70%	LDV: -80% HDV: -20% to -40%	none
Aggressive		(all TBD)					

Table 3. Estimated Cost and Cost Effectiveness Forecast Summary

[numbers will probably be revised]

		Estimated Investment* Requirement, then-yr million$ & (Cost Effectiveness**)					
Case	**Year**	**2006**	**2012**	**2017**	**2022**	**2030**	**2050**
Conservative		-- (--)	1490 (-0.10)	1070 (0.71	990 (0.64)	1400 (-0.08)	323? (-0.10)
Moderate		-- (--)	2560 (-0.22)	2250 (0.38)	2600 (0.34)	2280 (-0.19)	110? (-0.16)
Aggressive		-- (--)	2900 (-0.54)	2710 (0.09)	3340 (0.16)	3900 (-0.29)	2200? (-0.21)

* For vehicle & infrastructure R&D + incentives (not including fuel savings or tax revenue impacts)

** 2007$/gge, negative indicates savings or profits for participants (see text for detailed definition)

2. Natural gas Vehicle Technology Status Summary

CNG and LNG vehicle and fuel-supply infrastructure technologies are relatively low risk, and no technical breakthroughs are required for deployment. CNG-fueled light-duty vehicles and CNG- and LNG-fueled heavy-duty trucks and buses have been operating in California for over 40 years.

CNG and LNG use as a vehicle fuel reduces petroleum consumption. CNG and LNG use also provides significant benefits in terms of reduced greenhouse gas emissions, criteria pollutants, and toxics, compared to gasoline and diesel fuel on a well-to-wheels basis.[1] While natural gas is generally regarded as a non-renewable fossil fuel, biogas is a renewable CNG and LNG source and the technical feasibility of deriving both CNG and LNG from landfill gas has been successfully demonstrated.

Two broad classes of NGVs are light-duty vehicles (LDVs, e.g., passenger cars, light trucks and vans) and heavy-duty vehicles (HDVs, e.g., transit and school buses, large trucks)[2]. The technologies, economics, and markets for these two NGV classes are significantly different, and so they are usually considered separately. Another important distinction is the method used to store natural gas on the vehicles. Because the density of natural gas is very low at ambient conditions, it is either compressed or liquefied and stored on vehicles as CNG or LNG, respectively. The vehicle and infrastructure technologies are quite different for CNG and LNG. For equal gas mass and energy content, LNG tanks are smaller, lighter, and less expensive than CNG tanks, and so LNG is favored for many HDV applications. On the other hand, LNG will eventually boil off if vehicles are parked for long periods, and so CNG is used for essentially all LDV applications. The choice of LNG or CNG will often reflect local availability.

The economics of CNG and LNG vehicles benefits from the fact that, even without any special financial incentives, natural gas is less expensive than refined petroleum products on a unit energy basis (e.g., $/Btu or $/J). Natural gas, crude oil, and diesel fuel are all commodity products, and their relative prices are discussed in more detail in subsequent sections. However, CNG and LNG vehicles and fueling facilities are more expensive than counterpart gasoline and diesel vehicles and facilities. Therefore, the key to favorable NGV economics is to identify situations for which the fuel cost savings can amortize the extra capital costs, i.e., vehicles with high fuel consumption. This favors various heavy-duty applications because, even though the capital cost of HDVs is much greater than that of LDVs, the ratio of fuel consumption to capital cost is usually also greater.

Line-haul trucks consume more fuel (up to approximately 30,000 diesel gallons per year) than most other on-highway vehicle types, and this may eventually be a very economical natural gas application. However, experience has shown that centrally fueled return-to-base truck and bus operations are more practical near-term HDV natural gas applications, though their annual fuel

[1] "Full Fuel Cycle Assessment: Well-to-Wheels Energy Inputs, Emissions, and Water Impacts," CEC-600-2007-004D, February 2007.

[2] NGV classification (and vehicle classification in general) can include these two classes, or three classes (including medium duty vehicles, MDVs, or many more classes and subclasses. Different classification systems often account for seemingly different numbers in different analyses.

consumption is often less than half that of line-haul trucks. This is primarily because there is not yet a U.S. or California natural gas fueling infrastructure for line-haul trucks, and return-to-base fleets can be refueled at one dedicated station.

In California, most natural gas transportation fuel is consumed by transit buses and refuse trucks. Both of these applications are partially driven by fleet rules (such as the CARB Transit Rule and SCAQMD Fleet Rules 1192 and 1193), and they also benefit from financial incentives (such as the Carl Moyer Program, and Energy Policy Act, and Federal Highway Bill provisions). These incentives and mandates are discussed in more detail in subsequent sections. Other common heavy-duty natural gas applications include Class 8 tractor-trailer operations such as warehouse-to-retail distribution of grocery and other products. Natural gas also fuels various off-highway vehicles such as yard tractors, but these do not yet account for a significant portion of California natural gas transportation fuel use.

As of 2006, there were about 5,000 natural gas transit buses operating in California. Roughly 90% of these were CNG fueled and 10% were LNG fueled. In addition to these buses operated by transit agencies, other natural gas buses of various sizes are operated as school buses, airport shuttle buses, and similar applications. The most recent count of natural gas refuse trucks indicates that, in 2005, there were approximately 1,300 natural gas refuse trucks in California.[3] Most of these (approximately 85%) were reported to be LNG fueled.

Heavy-duty vehicles such as trucks and buses usually have engines manufactured by one company installed in a chassis manufactured by a different company. Original equipment manufacturers' (OEMs') commitment to heavy-duty natural gas engine commercialization has fluctuated. Currently, CARB-certified natural gas engines are offered for sale by three engine OEMs: Cummins Westport, Westport, and Deere. Mack-Volvo recently discontinued their natural gas engine products and Deere is anticipated to soon discontinue theirs. In addition, a few non-OEM companies offer diesel-to-natural gas converted engines that fall into the CARB heavy-duty category.

A number of U.S. and Canadian OEMs manufacture natural gas transit and school buses on their assembly lines. Natural gas trucks are usually manufactured as diesel trucks by the OEMs and converted to natural gas by dealers or "upfitters," although Kenworth has recently indicated that they may manufacture trucks with Westport engines and LNG fuel systems on their assembly line. NGV proponents cite the lack of OEM commitment as a major challenge, and this is usually blamed on factors such as onerous and expensive certification requirements and government agency vehicle purchases that do not comply with established goals.

Light-duty NGVs (which include light trucks and other vehicles up to 8,500 lb GVW) include dedicated and bi-fuel vehicles that are sold as NGVs by OEMs, as well as gasoline vehicles that have been converted to CNG operation. It is difficult to quantify the exact number of light-duty

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

NGVs currently operating in California because no one organization is currently responsible for tracking and reporting this number[4].

As recent as a decade ago, nearly all major domestic and foreign OEMs offered dedicated and/or bi-fuel CNG vehicles as part of their product line. All but one OEM (Honda, see below) have dropped their NGVs from the U.S. market. Interestingly, almost all OEMs manufacture NGVs for non-U.S. markets. Over 99.5% of light-duty NGVs operating in the world today are in locations other than California.[5]

The only OEM light-duty NGV currently offered for sale in the U.S. is the Honda Civic GX, which is certified to EPA's ultra-low Tier 2, Bin II exhaust emissions standards. Through an agreement between Honda and FuelMaker, Civic GX purchasers are offered a discount on a "Phill" CNG home fueling appliance. They also qualify for California HOV lane access without any quotas (such as apply to hybrid vehicles). NGV proponents have high hopes that these benefits combined with recent gasoline prices will vitalize Civic GX sales and motivate other OEM's to re-enter the light-duty NGV market.

Most OEMs represent that, currently, light-duty NGV sales volumes do not justify the required development, manufacturing, and especially the certification expenses. The expense associated with CARB certification has also discouraged most CNG conversion equipment manufacturers from marketing their products in California. Only two firms (Baytech and BAF) have current CARB certification for converted LDVs.[6] Interestingly, California-based Impco sells approximately 13,000 natural gas and propane conversion kits per month to the world market, but none in California (primarily because of the expense required to comply with current CARB OBD II requirements[7]).

All light-duty NGV engines are basically converted gasoline engines. Even the engines in OEM NGVs are based on previously existing gasoline engine families that have been redesigned or simply modified for natural gas operation. All current heavy-duty natural gas engines are basically converted diesel engines. While a variety of heavy-duty natural gas engine technologies are being used or developed (e.g., lean-burn or stoichiometric spark ignition, various dual-fuel technologies including high pressure direct injection), all of these are applied to existing diesel engine product lines. Designing a light-duty or heavy-duty "clean sheet of paper" natural gas engine may result in performance (e.g., fuel economy), emission, and/or cost reduction improvements, but no programs of this type are known to be underway at this time.

[4] For example, there are substantial uncertainties associated with estimating the number of CNG LDVs from the DMV database due to factors such as vehicles converted to CNG that are not reflected in the vehicle identification number (VIN) and vehicles that are no longer operational but still in the DMV database.

[5] "Natural gas for Vehicles (NGV), Global Opportunities for natural gas as a Transportation fuel for Today and Tomorrow," International gas Union Study Group 5.3 Final Report, December, 2005

[6] CARB no longer certifies conversion equipment, but they do certify converted vehicles and engines.

[7] Mike Eaves, California Natural Gas Vehicle Coalition, presentation to CEC, March 23, 2007.

3. Natural Gas Transportation Fuel Storyline Forecast Overview

A California natural gas transportation fuel "storyline" has been developed as part of the State's plan to increase the use of alternative transportation fuels, which is required by AB 1007 (Pavley). This storyline is based on an assessment of the current technology and market status, well-to-wheels analyses to quantify important energy metrics and environmental effects, and meetings with NGV stakeholders to take full advantage of their activities, plans, and recommendations.

A key component of the natural gas storyline is forecast of future California natural gas transportation fuel use, economics, and benefits. Forecasts represent three scenarios: conservative, moderate, and aggressive growth. The assumptions that define these three scenarios are discussed subsequent sections. Forecasts for the three scenarios are made from the present (considered to be 2006, which is the latest year for which some actual data is available) through all years specified in the AB 1007 legislation (2012, 2017, and 2022) plus the additional years considered by CEC and CARB staff (2030 and 2050). These forecasts are summarized in the graphs and table in Section 1 and discussed in the following sections.

The California natural gas storyline scenario forecast methodology consisted of five basic steps, which are summarized below and explained in more detail in subsequent sections:

- Natural gas transportation fuel use is forecast based on an adjusted extrapolation of historical CNG and LNG use by LDVs and HDVs in early years and modulated to an equilibrium rate in later years. The extrapolation adjustments for the three scenarios accounts for factors such as the different light-duty and heavy-duty market outlooks, California port project effects, the potential for increased use of CNG home fueling appliances, and possible new natural gas sources in the future. The long-term modulations bring the forecasts into equilibrium with existing CEC forecasts for all California highway and off-road transportation fuel use (primarily gasoline and diesel fuel). Representative fuel energy content and fuel efficiency data are employed to express the CNG and LNG forecasts in terms of gasoline gallon equivalent (gge) volumes.

- Vehicle numbers and growth rates are forecast from the fuel use forecasts by considering representative fuel economy data (e.g., mi/gge) and annual mileage accumulation (e.g., VMT) for the different classes of CNG and LNG vehicles.

- The numbers and sizes of CNG and LNG fueling stations are estimated by analyzing the potential station throughput as a function of type and size (e.g., small to large fleet or public station, home fueling appliance), allocating these station types and sizes to appropriate segments of the vehicle number forecasts, and calculating the resulting number of each station type and size by year for each scenario.

- Life cycle cost analyses were carried out for each scenario based on the forecast fuel quantities, vehicle populations, and numbers of stations. These economic analyses incorporate estimates for inflation and the cost of money, vehicle costs, station costs, fuel cost differentials, required R&D investments, and current and future financial incentives.

- Figures-of-merit such as environmental benefits, required investments, and cost effectiveness are calculated from the forecasted quantities for each scenario. Compliance with the important AB 1007 "No Net Material Increase in Emissions" criterion is verified.

The forecast methodologies and results for the conservative, moderate, and aggressive growth scenarios are discussed in more detail in Sections 4, 5, and 6, respectively.

4. Conservative Growth Scenario

The conservative growth scenario presumes that the future will unfold as a conservative extrapolation of the past. This scenario includes a conservative interpretation of possible future changes in market conditions and government interventions that affect NGV growth. For example, the conservative scenario assumes that some of the current government incentives and mandates that affect natural gas vehicles and infrastructure (such as the Energy Policy Act and Federal Highway Bill provisions at the federal level, and the Carl Moyer Program and CARB and SCAQMD fleet rules at the California level) remain in place in the future. In addition, the conservative scenario assumes that programs such as those being developed by the Ports of Los Angeles and Long Beach go forward, but the impact on heavy-duty NGVs will be somewhat less than the baseline plan. As summarized in Section 1, the conservative scenario forecast predicts that CNG and LNG will displace approximately 1%, 1.7%, and 2.8% of California's petroleum-based fuel consumption in 2012, 2022, and 2050, respectively

The conservative growth scenario CNG and LNG fuel use forecast discussion below is followed by a summary of the vehicle and station number estimation and life cycle cost analysis. This provides the basis for environmental benefits and cost effectiveness discussion.

<u>CNG and LNG Fuel Use Forecast</u>

The quantitative California CNG and LNG transportation fuel consumption forecast is based on a detailed estimation of historical California CNG and LNG transportation fuel consumption. The estimation of historical California CNG and LNG transportation fuel consumption combined data from many sources because there is currently no official quantification of this metric. The primary sources of CNG data are California's major natural gas utilities,[8] which are required by the California Public Utilities Commission (CPUC) to report natural gas that is transported to natural gas fueling stations[9]. The primary sources of LNG data are delivery data provided by the two primary suppliers of California LNG transportation fuel[10]. Approximations are applied to account for the relative amounts of CNG dispensed into light-duty and heavy-duty vehicles,

[8] Pacific Gas & Electric (PG&E), Southern California Gas Company (SoCalGas), and San Diego Gas & Electric (SDG&E).
[9] Separate data quantifying natural gas dispensed into vehicles through home fueling appliances is not yet available, but this is a negligible fraction of the total CNG dispensed prior to 2007.
[10] Applied LNG Technologies USA (ALT, which is now a subsidiary of Earth Biofuels) and Clean Energy.

because there is no current system for tracking these data. These approximations recognize that substantially more CNG is consumed by heavy-duty than light-duty vehicles. The total California annual light-duty CNG vehicle fuel consumption is estimated by multiplying the approximate number of light-duty CNG vehicles operating in California (estimated from the DMV database and other sources) by the estimated average VMT and dividing by the estimated average fuel economy in mi/gge). The California annual heavy-duty CNG vehicle fuel consumption is then assumed to be the total CNG consumption (reported by California natural gas utilities) minus the light-duty CNG vehicle consumption. Also, natural gas dispensed from LNG-to-CNG stations is counted as LNG because, while overall LNG delivery data are collected, these data are aggregated and do not reflect relative quantities of LNG delivered to LNG and LNG-to-CNG stations (some of which dispense both LNG and CNG). Other approximations include application of typical lower heating values to convert natural gas quantities to gge, and typical LNG saturation pressures to convert LNG gallons to mass and energy units.

The conservative scenario CNG and LNG fuel use forecast shown in Figures 1 and 2 and summarized Table 1 is based on the following specific assumptions:

- The 5-year average historical growth rates of CNG and LNG consumption are calculated from the previously discussed historical data. For the conservative scenario, the initial growth rate (i.e., going forward from 2007) for total CNG consumption is assumed to be 50% of the historical average total CNG consumption growth rate. The initial LNG consumption growth rate is assumed to be 75% of the historical average LNG consumption growth rate.

- In recognition of the previously discussed exit of most OEMs from the light-duty CNG vehicle market, light-duty CNG vehicle fuel consumption growth for the conservative scenario is assumed to be slightly negative in 2007, zero in 2008 and 2009, and grow to equal 50% of the historical total CNG consumption growth rate for 2010 through 2022. As the market matures, the light-duty CNG vehicle fuel consumption growth rate is assumed to approach the growth rate projected by the CalCars Model[11] for total California transportation fuel demand for 2023 through 2040, and continue at the CalCars Model projected growth rate for 2041 through 2050.

- A potentially significant but uncertain factor affecting the future growth of LNG trucks in California is the San Pedro Bay Ports Clean Air Action Plan (SPBPCAAP), which may result in 5,000 or more new LNG trucks over the next 5 years. An amount of LNG consumption is added to the above discussed heavy-duty LNG vehicle consumption growth rate to account for the SPBPCAAP. For the conservative scenario, this additional amount is assumed to be 50% of the LNG fuel consumption estimated for the SPBPCAAP[12] for 2007 through 2011.

- The heavy-duty CNG vehicle fuel consumption growth rate is adjusted to maintain a constant total CNG consumption growth rate (i.e., compensate for the slightly negative and then zero

[11] Kavalec, C., "CalCars: The California Conventional and Alternative Fuel Response Simulator," CEC paper available at: www.energy.ca.gov/papers/CEC-999-1996-007.pdf
[12] Estimated by multiplying the planned (cumulative) number of trucks each year by typical miles/year and dividing by anticipated average miles/LNG gallon.

light-duty CNG vehicle conservative scenario fuel consumption growth rate forecast) for 2007 through 2011. It is forecast to remain constant at the forecasted total CNG consumption growth rate (estimated as 50% of the historical growth rate, as previously discussed) for 2012 through 2022, gradually approach the CalCars Model projected consumption growth rate for all fuels during 2023 through 2040, and continue at the CalCars Model projected growth rate for 2041 through 2050.

- After the previously discussed SPBPCAAP additions, the heavy-duty LNG vehicle fuel consumption growth rate for the conservative scenario is assumed to remain at the previously discussed rate of 75% of the historical rate, through 2022. For 2023 through 2040, the LNG consumption growth rate is assumed to gradually approach the CalCars Model projected growth rate for all diesel fuel, and the LNG consumption growth rate is assumed to be equal to the CalCars Model projected diesel fuel growth rate for 2041 through 2050.

Vehicle and Station Numbers and Life Cycle Cost Analysis

The methodology employed to forecast the number of natural gas vehicles, estimate various expenses and savings, and analyze the life cycle costs, is described here for the conservative scenario. Subsequent discussions for the moderate and aggressive scenarios in Sections 5 and 6 are much briefer because the same basic methodology is applied for all scenarios.

Vehicle populations are projected for each milestone year based on the previously discussed natural gas fuel use forecasts. Projections were carried out for CNG LDVs, CNG HDVs, and LNG HDVs. The basic approach is to multiply the forecasted annual fuel use (gge/yr) by the ratio of the representative average annual vehicle miles traveled (VMT, in mi/yr-veh) to the representative average fuel economy (FE, in mi/gge), for the three categories of NGVs considered. These vehicle numbers are summarized in Table 4. As previously discussed, there are actually many more classes of NGVs, such as small shuttle buses and mid-size trucks, which are normally regarded as medium duty vehicles (MDVs) or medium-heavy duty vehicles (MHDVs). The simplification of capturing all of these vehicle classes in three categories accounts for the fact that that the average VMT and FE numbers in Table 4 may not be the same as other estimates for similar-sounding vehicle classes.

The natural gas fueling infrastructure analysis considere six types of fueling facilities:

1. CNG home refueling appliances (HRAs)
2. Small-capacity CNG stations
3. Medium-capacity CNG stations
4. Large-capacity CNG stations
5. Large-capacity LNG stations
6. CNG dispensers added to existing gasoline stations

The numbers of each type of natural gas fueling facility are forecast by considering their approximate capacities (e.g., number of vehicles fueled simultaneously, fueling times, utilization windows) and estimating what percentage of each of the three vehicle categories would be fueled at each of the six station types. These station number forecasts are also summarized in Table 4.

Table 4. Forecast Numbers of Vehicles and Stations: Conservative Scenario

		2012	2017	2022	2030	2050
Vehicles	CNG LDV	7050	9600	13150	19500	26350
	CNG HDV	10851	14805	20322	30069	40644
	LNG HDV	5931	7862	10483	15379	23724
Stations	HRA	2115	2880	3945	5850	7905
	Sml. CNG	69	93	128	190	256
	Med. CNG	34	47	64	95	128
	Lrg. CNG	452	617	847	1253	1693
	Lrg. LNG	124	164	218	320	494
	CNG Disp.	137	187	256	379	512

This analysis considers the likely natural gas vehicle, engine, station, and infrastructure R&D that would be needed to support the forecast growth. The R&D costs must be paid by some combination of government and private entities, and these costs are an important life cycle cost expense. Vehicle and engine R&D costs are forecast based on estimates of the number of new CNG and LNG vehicles and engines[13] that would be introduced and their likely R&D costs[14] between milestone years 2012 and 2022. The market is assumed to mature by 2030 so that as further R&D investments (over and above those normally include in the vehicle cost) will be unnecessary. Natural gas fueling station and infrastructure R&D costs[15] are estimated in a similar fashion, and these are assumed to apply in the milestone years 2012 through 2030.

The ranges of NGV purchase incremental prices (i.e., NGV price - counterpart gasoline or diesel vehicle price) are estimated from historical data, anticipated future R&D benefits, learning curve effects, and production scale economies. Incremental purchase price ranges are developed for each class of vehicle for near-term (2008-2017), mid-term (2018-2030), and mature market (2030-2050) time frames. These estimates (using price range averages) are multiplied by vehicle number forecasts to forecast the total incremental vehicle purchase expenses for each milestone year. Fueling station costs are also assumed to decrease in the future as a result of R&D, learning curve effects, and scale economies. The cost ranges for the six station types are estimated for similar near-term, mid-term, and mature-market time frames. The numbers of each type of station to be built in each milestone year are multiplied by the respective range-average cost estimates and summed to forecast the total station capital cost requirements.

13 Assumed development of: 3 new CNG LDV models at $450 million each, 3 new CNG MDV models at $150 million each, 4 new CNG HD engines/vehicles at $300 million each, and 4 new LNG HD engines/vehicles at $300 million each.

14 New commercial product vehicle and engine development costs are estimated from various sources including the NREL New Generation Natural Gas Vehicle (NGNGV) program.

15 Estimated station/infrastructure R&D costs are $20 million, $50 million, $50 million, $100 million, and $200 million for HRAs, small CNG, medium CNG, large CNG, and large LNG stations, respectively, in each of the milestone years.

The future prices of natural gas and refined petroleum products, and future relations between dispensed CNG and LNG prices and natural gas commodity prices, are quite uncertain. There is not good agreement among analysts and stakeholders in this regard, and past forecasts of future fuel prices have been notoriously inaccurate. Given this future fuel price uncertainty, this analysis is based on an assessment of current fuel price differences and the assumption that these price differences are more predictable going forward than the absolute prices of CNG, LNG, gasoline, and diesel fuel. Based on a review of historical CNG and LNG prices affecting various NGV types,[16] and corresponding historical gasoline and diesel fuel prices, the following fuel price differences are applied for this initial analysis:

- Incremental CNG price (LDVs fueled with HRAs): -$2.00/gge
- Incremental CNG price (retail CNG stations): -$0.75/gge
- Incremental CNG price (fleet CNG stations): -$1.25/gge
- Incremental LNG price (fleet LNG stations): -$1.25/gge

Note that these incremental natural gas fuel prices are all negative, i.e., natural gas is less expensive than gasoline (and diesel fuel) on an energy-equivalent basis. This has been the case historically, and this is the case at present. This price differential is assumed to remain constant into the future, with no optimistic increase, in this analysis. A more refined analysis would also consider vehicle fuel efficiency differences 2007-2050, but these differences and their uncertainties are small relative to future fuel price differential uncertainties.

As previously discussed, all R&D expenses, capital costs, and operating costs must be paid by some entity, whether it is the vehicle owner, station operator, fuel supplier, their investors, or the government. An objective of this analysis is to capture all these costs and to subsequently estimate the portions that derive from government incentives, private investors, etc. In that regard, this initial analysis assumes that government incentives cover 100% of the vehicle purchase incremental costs and 50% of the fueling station and infrastructure capital costs. An additional cost to the government, when alternative fuels are taxed at a rate less than gasoline and diesel fuel, is the tax revenue loss. This impact is forecast based on the estimated sales of CNG and LNG for each milestone year and the effective tax rate difference[17] (which are based on current fuel tax rates).

The forecasts described above provide all the quantities needed for NGV life cycle cost analyses. Discounted cash flow analyses are applied to express cash flows and future capital costs in terms of now-year dollars. The discount rate is assumed to be 5% for public funds and 12% for private investments.

Cost Effectiveness and Environmental Benefits

[16] CNG and LNG fuel incremental price estimates are based on input from SoCalGas, SDG&E, and PG&E for HRA fueling; data from DOE Clean Cities Program for retail CNG; data from Clean Energy and Trillium for fleet CNG; and data from ALT and Clean Energy for fleet LNG.

[17] The different way that CNG dispensed from HRAs is considered in the analysis, although the future tax treatment of HRA CNG is quite uncertain.

The cost effectiveness figure-of-merit is defined as the sum of all pertinent incremental costs and savings associated with natural gas fuel use, divided by the total natural gas fuel consumption (in gge). The numerator includes the vehicle and station R&D expenses, vehicle and station incremental costs, fuel cost savings, and fuel tax revenue loss. Cost effectiveness can be calculated on a single milestone year basis or a life cycle (e.g., over the useful life of an NGV) basis. When calculated on a single year basis, the cost effectiveness is essentially the incremental cost (or savings) associated with one gge of additional natural gas fuel use in that year. Note that, because the incremental fuel cost in the numerator is CNG or LNG cost (in gge) minus gasoline or diesel fuel cost, this quantity is negative. Therefore, a negative cost effectiveness indicates a savings for fuel users and/or profits for participating companies and/or the possibility of reducing government incentives. A positive cost effectiveness indicates the opposite. Table 5 summarizes the forecast cost effectiveness for CNG LDVs, CNG HDVs, and LNG HDVs in each milestone year for the conservative scenario.

Table 5. Forecast Cost Effectiveness, Life Cycle Basis ($/gge): Conservative Scenario

		2012	2017	2022	2030	2050
Vehicle Category	CNG LDV	1.38	2.03	1.54	0.17	0.12
	CNG HDV	-0.98	-0.05	0.13	-0.22	-0.14
	LNG HDV	-0.72	0.14	0.25	-0.19	-0.27

The environmental benefits associated with the conservative NGV scenario are forecast by combining the fuel use forecasts with the factors developed in the AB1007 well-to-wheels analysis of energy inputs, emissions, and water impacts.[18] These benefits are forecast via the following process:

- Calculate the relevant emissions for counterpart gasoline or diesel vehicles for the fuel quantities corresponding to each vehicle class
- Calculate the relevant emissions for the NGVs in each class consuming the forecast quantities of CNG and LNG
- Subtract the NGV emissions from the counterpart gasoline or diesel emissions for each vehicle class, and sum these differences over all classes

Table 6 summarizes the environmental benefits for the conservative scenario for each vehicle class and milestone year in terms of greenhouse gases (GHG), particulate matter (PM), oxides of nitrogen (NO_x), toxics, and water impacts. These environmental effects are negative when the NGV emissions are less than counterpart gasoline and diesel fuel cycle emissions.

A key objective of the AB1007 assessment is to determine the magnitude of the government incentives required to achieve the forecast petroleum fuel consumption reduction and environmental benefits. This analysis facilitates quantification of these government interventions, which consisted of incentive funding of 100% of NGV purchase prices, incentive

[18] "Full Fuel Cycle Assessment: Well-to-Wheels Energy Inputs, Emissions, and Water Impacts," CEC-600-2007-004D, February 2007.

funding of 50% of CNG and LNG fueling facility capital costs, and loss of tax revenue associated with the lower energy-equivalent tax rates for CNG and LNG. These government intervention costs (in then-year dollars) are summarizes in Table 7 for the conservative scenario and each milestone year.

Table 6. Forecast Environmental Benefits: Conservative Scenario [to be provided]

Table 7. Forecast Government intervention Costs: Conservative Scenario [to be provided]

5. Moderate Growth Scenario

The moderate growth scenario presumes that market conditions for NGVs will improve in the future because concerns about issues such as global warming and petroleum imports will motivate some new government incentives and mandates that benefit NGVs. For example, the California LCFS will produce programs that stimulate natural gas vehicle and infrastructure growth. Current programs, such as the SPBPCAAP, will go forward as planned without reductions or delays. NGV OEMs will find market conditions to be moderately attractive, and so there will be some new LDV and HDV product offerings. The moderate scenario assumes that these events cause light-duty and heavy-duty NGV growth rates to continue to substantially exceed gasoline and diesel vehicle growth rates in the near future, but NGV growth rates stabilize to be consistent with currently projected growth rates for all vehicles in the distant future. As summarized in Section 1, the moderate scenario forecast predicts that CNG and LNG will displace approximately 1.4%, 3.8%, and 8.9% of California's petroleum-based fuel consumption in 2012, 2022, and 2050, respectively.

The moderate growth scenario CNG and LNG fuel use forecast discussion below is followed by a summary of the vehicle and station number estimation and life cycle cost analysis. This provides the basis for environmental benefits and cost effectiveness discussion.

CNG and LNG Fuel Use Forecast

As with the conservative scenario, the moderate scenario forecast utilizes quantification of historical California CNG and LNG transportation fuel consumption growth rates as a point-of-departure. The moderate scenario CNG and LNG fuel use forecast shown in Figures 1 and 2 and summarized in Table 1 is based on the following specific assumptions:

- The 5-year average historical growth rates of CNG and LNG consumption are calculated as discussed in Section 4. For the moderate scenario, the initial growth rate (i.e., going forward from 2007) for total CNG consumption is assumed to be equal to the average historical CNG growth rate, and he initial growth rate for heavy-duty vehicle LNG consumption is assumed to be equal to the average historical LNG growth rate.

- The moderate scenario also recognizes that near-term light-duty CNG vehicle growth will be affected by the dearth of OEM products. Light-duty vehicle CNG consumption growth rates are assumed to be -5%, -5%, and 0% in 2007, 2008, and 2009, respectively. Between 2010 and 2016, in response to new incentives and market forces (such as might result from the LCFS), the light-duty vehicle CNG fuel consumption growth rate is assumed to increase so that it is equal to the previously discussed total CNG plus LNG consumption growth rate average over the past 5 years. Light-duty CNG fuel consumption is assumed to continue at this growth rate between 2017 and 2022. Past 2022, the growth rate is assumed to gradually decrease until, in 2040, it is equal to the average growth rate for all California transportation fuels predicted by the previously discussed CalCars Model. For 2041 through 2050, the light-duty vehicle CNG fuel consumption growth rate is assumed to be equal to the growth rate predicted for all California transportation fuels by the CalCars Model.

- For the moderate scenario, the previously discussed SPBPCAAP is assumed to go forward with LNG truck deployment consistent with current plans. The LNG fuel consumption for these LNG port trucks is estimated and added to the previously discussed baseline LNG consumption growth rate for the CEG scenario between 2007 and 2012.

- The heavy-duty CNG vehicle fuel consumption increase rate is adjusted to maintain a constant total CNG consumption increase rate (i.e., compensate for the slightly negative and then zero light-duty CNG vehicle moderate scenario fuel consumption growth rate forecast) for 2007 through 2012. It is forecast to remain constant at the previously discussed total CNG plus LNG fuel consumption growth rate average over the past 5 years for the 2013 through 2022 time increment. Past 2022, the heavy-duty CNG vehicle fuel consumption growth rate is assumed to gradually decrease until, in 2040, it is equal to the average growth rate for all California transportation fuels predicted by the CalCars Model. For 2041 through 2050, the heavy-duty vehicle CNG fuel consumption growth rate is assumed to equal the growth rate predicted for all California transportation fuels by the CalCars Model.

- After the previously discussed SPBPCAAP additions for the moderate scenario, the heavy-duty LNG vehicle fuel consumption growth rate is assumed to continue at the previously discussed total CNG plus LNG fuel consumption growth rate historical average over the past 5 years for 2013 through 2022. After 2022, the LNG fuel consumption growth rate is assumed to decline gradually until it is equal to the CalCars Model predicted California total diesel fuel consumption growth rate in 2040. For 2041 through 2050, the LNG fuel consumption growth rate is assumed to be equal to the total California diesel fuel consumption growth rate predicted by the CalCars Model.

Vehicle and Station Numbers and Life Cycle Cost Analysis

The methodology used to apply the fuel use projections to forecast the number of vehicles (CNG LDVs, CNG HDVs, and LNG HDVs) and numbers of fueling stations for the moderate scenario is exactly the same as described in Section 4 for the conservative scenario. The same VMT, FE, and vehicle-station type allocation factors are used. The resulting numbers of vehicles and stations forecast for the moderate scenario are summarized in Table 8.

Table 8. Forecast Numbers of Vehicles and Stations: Moderate Scenario

		2012	2017	2022	2030	2050
Vehicles	CNG LDV	7550	13500	25000	54000	76000
	CNG HDV	15908	29241	53609	106391	163126
	LNG HDV	9034	13172	19241	31448	51034
Stations	HRA	2265	4050	7500	16200	22800
	Sml. CNG	73	131	243	525	739
	Med. CNG	37	66	122	263	369
	Lrg. CNG	663	1218	2234	4433	6797
	Lrg. LNG	188	274	401	655	1063
	CNG Disp.	147	263	486	1050	1478

The estimated natural gas vehicle, engine, fueling station, and infrastructure R&D costs for the moderate scenario are forecast to be the same as those for the conservative scenario (Section 4) based on the rationale that the numbers of new products will be the same and the cost to develop new products will be the same, but the numbers of new products sold will be greater.

The moderate scenario assumes the same per-vehicle incremental costs as the conservative scenario, and these incremental costs depended on the vehicle type and market maturity (purchase date) as described in Section 4. Similarly, the moderate scenario assumes the same time-dependent and type-dependent CNG and LNG fueling station capital costs.

The moderate scenario assumes that the natural gas price difference (per gge) relative to gasoline and diesel fuel is the same as for the conservative scenario, for both CNG and LNG and all considered fuel sales methods. The per gge fuel tax government revenue impact is also the same. Therefore, the total fuel cost savings and tax impacts increased in proportion to the forecast fuel use for this scenario.

Cost Effectiveness and Environmental Benefits

The cost effectiveness figure-of-merit is defined in Section 4. The moderate scenario cost effectiveness forecasts for CNG LDVs, CNG HDVs, and LNG HDVs in each milestone year is indicated in Table 9.

Table 9. Forecast Cost Effectiveness, Life Cycle Basis ($/gge): Moderate Scenario

		2012	2017	2022	2030	2050
Vehicle Category	CNG LDV	1.21	1.49	0.89	0.14	0.10
	CNG HDV	-1.03	-0.35	-0.05	-0.45	-0.26
	LNG HDV	-0.83	-0.02	0.17	-0.27	-0.31

The environmental benefits associated with the moderate scenario, which are calculated as described in Section 4 for the conservative scenario, are summarized in Table 10. The government intervention costs for the moderate scenario are shown in Table 11.

Table 10. Forecast Environmental Benefits: Moderate Scenario [to be provided]

Table 11. Forecast Government Intervention Costs: Moderate Scenario [to be provided]

6. Aggressive Growth Scenario

The aggressive growth scenario presumes that the California commitment to deal with issues such as greenhouse gas emissions and petroleum imports will promptly produce additional incentives, regulations, and other government actions that significantly enhance the business prospects for light-duty CNG vehicles and heavy-duty CNG and LNG vehicles. Vehicle OEMs (and perhaps natural gas conversion equipment manufacturers and installers), CNG and LNG fuel providers, and companies that build and/or operate CNG and LNG fueling stations will respond to these new incentives and attractive market conditions. The new government interventions that could facilitate the aggressive scenario include not only extensions of existing incentives such as tax credits and partial-funding grants, but they may also include initiatives such as special rule exceptions for low carbon fuel and vehicle technologies, prioritization of home fueling appliance installations, expedited vehicle and engine certifications, and PUC re-engagement of natural gas utility NGV programs. As summarized in Section 1, the aggressive scenario forecast predicts that CNG and LNG will displace approximately 1.9%, 6.2%, and 19% of California's petroleum-based fuel consumption in 2012, 2022, and 2050, respectively.

The aggressive growth scenario CNG and LNG fuel use forecast discussion below is followed by a summary of the vehicle and station number estimation and life cycle cost analysis. This provides the basis for environmental benefits and cost effectiveness discussion.

<u>CNG and LNG Fuel Use Forecast</u>

As with the conservative and moderate scenario forecasts, the initial aggressive scenario forecast utilizes the previously discussed quantification of historical California CNG and LNG transportation fuel consumption growth rates. The aggressive scenario CNG and LNG fuel use forecast shown in Figures 1 and 2 and summarized in Table 1 is based on the following specific assumptions:

- For the aggressive scenario, the initial growth rate (i.e., going forward from 2007) for <u>total</u> CNG consumption is assumed to be equal to 125% of the average historical CNG consumption growth rate. The initial growth rate for heavy-duty LNG vehicle fuel consumption is also assumed to be equal to 150% of the average historical LNG growth rate.

- The aggressive scenario assumes that due to the current dearth of OEM products, the light-duty CNG vehicle fuel consumption growth rate is zero in 2007, but it continuously increases each year until, in 2014, it is equal to the aggressive scenario growth rate of total CNG fuel consumption (which was assumed to be 125% of the historical CNG consumption growth rate as discussed above). The light-duty CNG vehicle fuel consumption is assumed to increase at this same growth rate for years 2015 through 2022. After 2022, the growth rate is assumed to gradually decrease until, in 2040, it is equal to the average growth rate for all California transportation fuels predicted by the CalCars Model. For 2041 through 2050, the aggressive scenario light-duty CNG vehicle fuel consumption growth rate is assumed to be equal to the growth rate predicted for all transportation fuels by the CalCars Model.

- For the aggressive scenario, the SPBPCAAP is assumed to be highly successful so that, starting in 2008 and continuing through 2011, the incremental LNG port truck LNG fuel consumption is double the amount estimated as corresponding to the baseline SPBPCAAP (i.e., due to augmentation of the SPBPCAAP, adoption of similar plans by other California ports, or both).

- The aggressive scenario heavy-duty CNG vehicle fuel consumption increase rate is adjusted to maintain a constant total CNG consumption growth rate (i.e., compensate for the slightly lower light-duty CNG vehicle fuel consumption growth rate forecast) for 2007 through 2012. For 2013 through 2022, it is forecast to remain constant at the previously discussed aggressive total CNG plus LNG consumption growth rate. After 2022, the heavy-duty CNG vehicle fuel consumption growth rate is assumed to gradually decline until, in 2040, it equals the CalCars Model predicted growth rate for California diesel fuel (on-road and off-road). For 2041 through 2050, the aggressive scenario heavy-duty CNG fuel consumption growth rate is assumed to continue at the growth rate predicted for California diesel fuel by the CalCars Model.

- After the previously discussed port project additions, the aggressive scenario heavy-duty LNG vehicle fuel consumption rate growth rate is assumed to continue at the previously discussed LNG fuel consumption growth rate (which is 150% of the historical average), and this growth rate continues for 2012 through 2022. Between 2023 and 2040, the LNG fuel consumption growth rate gradually declines to the rate predicted by the CalCars Model for California diesel fuel. The LNG vehicle fuel consumption growth rate is assumed to be equal to the California diesel fuel consumption growth rate predicted by the CalCars Model for 2041 through 2050..

Vehicle and Station Numbers and Life Cycle Cost Analysis

The methodology used to apply the fuel use projections to forecast the number of vehicles (CNG LDVs, CNG HDVs, and LNG HDVs) and numbers of fueling stations for the agressive scenario is exactly the same as described in Section 4 for the conservative scenario. The same VMT, FE, and vehicle-station type allocation factors are used. The resulting numbers of vehicles and stations forecast for the aggressive scenario are summarized in Table 12.

Table 12. Forecast Numbers of Vehicles and Stations: Aggressive Scenario

		2012	2017	2022	2030	2050
Vehicles	CNG LDV	11550	22800	45000	104700	172050
	CNG HDV	16754	33103	65379	152184	250023
	LNG HDV	15724	27379	47793	97034	172897
Stations	HRA	3465	6840	13500	31410	51615
	Sml. CNG	112	222	438	1018	1673
	Med. CNG	56	111	219	509	836
	Lrg. CNG	698	1379	2724	6341	10418
	Lrg. LNG	328	570	996	2022	3602
	CNG Disp.	225	443	875	2036	3345

The estimated natural gas vehicle, engine, fueling station, and infrastructure R&D costs for the aggressive scenario are forecast to be the same as those for the conservative scenario (Section 4) based on the rationale that the numbers of new products will be the same and the cost to develop new products will be the same, but the numbers of new products sold will be greater.

The aggressive scenario assumes the same per-vehicle incremental costs as the conservative scenario, and these incremental costs depended on the vehicle type and market maturity (purchase date) as described in Section 4. Similarly, the aggressive scenario assumes the same time-dependent and type-dependent CNG and LNG fueling station capital costs.

The aggressive scenario assumes that the natural gas price difference (per gge) relative to gasoline and diesel fuel is the same as for the conservative scenario, for both CNG and LNG and all considered fuel sales methods. The per gge fuel tax government revenue impact is also the same. Therefore, the total fuel cost savings and tax impacts increased in proportion to the forecast fuel use for this scenario.

Cost Effectiveness and Environmental Benefits

The cost effectiveness figure-of-merit is defined in Section 4. The aggressive scenario cost effectiveness forecasts for CNG LDVs, CNG HDVs, and LNG HDVs in each milestone year is indicated in Table 13.

Table 13. Forecast Cost Effectiveness, Life Cycle Basis ($/gge): Aggressive Scenario

		2012	2017	2022	2030	2050
Vehicle Category	CNG LDV	0.37	0.95	0.56	0.13	0.09
	CNG HDV	-1.03	-0.40	-0.08	-0.55	-0.32
	LNG HDV	-0.96	-0.27	0.00	-0.46	-0.39

The environmental benefits associated with the aggressive scenario, which are calculated as described in Section 4 for the conservative scenario, are summarized in Table 14. The government intervention costs for the aggressive scenario are shown in Table 15.

Table 14. Forecast Environmental Benefits: Aggressive Scenario [to be provided]

Table 15. Forecast Government Intervention Costs: Aggressive Scenario [to be provided]

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