ANL/ESD-37

Assessment of PNGV Fuels Infrastructure

Phase 2 Report: Additional Capital Needs and Fuel-Cycle Energy and Emissions Impacts

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Phase 2 Report: Additional Capital Needs and Fuel-Cycle Energy and Emissions Impacts

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Foreword

This report documents the methodologies and results of Argonne National Laboratory's assessment of additional capital needs and fuel-cycle energy and emissions impacts associated with using various fuels in vehicles that are three times as fuel-efficient as today's typical light-duty vehicles. These "3X vehicles" are being developed in the Partnership for a New Generation of Vehicles (PNGV) program. In 1994, the National Research Council's Peer Review Committee on the PNGV program called for an assessment of the potential impacts of 3X vehicles on the fuel infrastructure. In response, the U.S. Department of Energy (DOE) tasked Argonne National Laboratory (ANL) to investigate these impacts. In August 1995, the results of a preliminary analysis were presented to the Peer Review Committee. In January 1997, the results of the first phase of Argonne's analysis were published. The second phase of Argonne's analysis, which covers additional fuels and issues identified during the phase 1 effort, is documented in this report.

Acknowledgments

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Abstract

Argonne National Laboratory assessed the incremental capital needs and fuel-cycle energy and emissions impacts of using each of 11 different fuels in light-duty vehicles with tripled fuel economy (referred to as 3X vehicles). These 3X vehicles are being developed by the Partnership for a New Generation of Vehicles (PNGV). Findings indicate that investments in new fuel-production and -distribution facilities could be relatively modest for alternatives that are relatively similar to conventional fuels (e.g., reformulated gasoline or diesel, or relatively high percentage blends of those fuels). By contrast, alternative fuels with little established infrastructure tend to require far more capital investment. These higher cost alternatives do, however, provide greater energy and environmental benefits.

Summary

This report presents the methodologies and results of Argonne National Laboratory's assessment of the incremental capital needs and fuel-cycle energy and emissions impacts of using each of eleven different fuels in vehicles with tripled fuel economy (3X vehicles). These 3X light-duty vehicles are being developed by the government-industry Partnership for a New Generation of Vehicles (PNGV). Eleven fuels were included in the assessment: reformulated gasoline (RFG), reformulated diesel (RFD), methanol, ethanol, dimethyl ether (DME), liquefied petroleum gas (LPG), compressed natural gas (CNG), liquefied natural gas (LNG), biodiesel, Fischer-Tropsch diesel, and hydrogen. RFG, methanol, ethanol, LPG, CNG, and LNG were assumed to be burned in spark-ignition, direct-injection engines. RFD, Fischer-Tropsch diesel, biodiesel, and dimethyl ether were assumed to be burned in compression-ignition, direct-injection (CIDI) engines. Hydrogen, RFG, and methanol were assumed to be used in fuel-cell vehicles.

Impacts to the infrastructure that produces and distributes each of these fuels were analyzed under high and low scenarios of potential 3X vehicle market penetration. The scenarios established supply requirements (i.e., the volume of each fuel needed to meet the demands of all 3X vehicles likely to be on the road in each year of the analysis), which were used to specify the number and type of new facilities needed in each year. The cost analysis then translated facility requirements into capital costs. Results indicate that substantial capital investment will be needed to build new fuel production plants and to establish distribution infrastructure for methanol, ethanol, dimethyl ether, hydrogen, and CNG. With the exception of CNG and, to a certain extent, LNG, capital needs for production facilities far exceed those for distribution infrastructure for all fuels studied. Among the eleven fuels, hydrogen has the largest capital needs, with DME and, under certain assumptions, CNG distant runners up.

The fuel efficiency gain by 3X vehicles translated directly into reductions in total energy demand, fossil energy demand, and greenhouse gas (primarily CO_2) emissions. The combination of fuel substitution and fuel efficiency resulted in substantial petroleum displacement and large reductions in urban emissions of volatile organic compounds and sulfur oxide for all propulsion system/fuel alternatives considered. Although urban emissions of particulate matter smaller than 10 μm rose for CIDI engines operating on RFD, biodiesel, and Fischer-Tropsch diesel, such increases did not occur for CIDI engines operating on dimethyl ether. Fuel-cell vehicles produced large reductions in urban emissions of nitrogen oxide and carbon monoxide; compression-ignition engines operating on RFD, dimethyl ether, Fischer-Tropsch diesel, or biodiesel were also estimated to produce substantial reductions in urban emissions of carbon monoxide.

Section 1
Introduction

In September 1993, the U.S. government and the U.S. Council for Automotive Research (USCAR), representing Chrysler, Ford, and General Motors, formed the Partnership for a New Generation of Vehicles (PNGV). This joint research and development effort aims to (1) significantly improve national competitiveness in automotive manufacturing; (2) implement commercially viable innovations from ongoing research on conventional vehicles; and (3) develop vehicles that can achieve up to three times the fuel economy of today's vehicles, which would be about 80 miles per gallon (mpg) for six-passenger automobiles. These three-times-efficient (often called 3X) vehicles (goal three) must also meet the safety and emissions requirements expected to be in place when they are introduced, as well as provide the same performance, size, utility, and cost of ownership/operation as the conventional vehicles that they replace.

To develop 3X vehicles, the PNGV program has been focusing on the development and use of advanced automotive technologies and lightweight materials. These technologies could be incorporated into spark-ignition, direct-injection (SIDI) engines, compression-ignition, direct-injection (CIDI) engines, or fuel cells. To meet emissions goals or to provide the optimum fuel for these new propulsion systems, fuels other than gasoline or diesel fuel could be necessary.[1] If development of 3X vehicles is successful, there may be changes in automotive manufacturing, materials production, and fuel production and distribution. Those changes will produce additional perturbations in energy consumption and emissions.

Recently, the PNGV program completed a process to select technology options for further investigation. Four key areas were chosen for intensified R&D efforts: hybrid-electric-vehicle (HEV) drive, direct-injection (DI) engines, fuel cells, and lightweight materials.[2] Research on HEV drive is focusing on energy storage and increasing the efficiency of both power sources. High-power nickel-metal hydride, lithium-ion, and lithium-polymer batteries are particularly promising energy storage technologies that could be used in conjunction with HEV designs. Research on direct-injection engines is also related to HEV applications because efficient compression-ignition direct-injection

[1] In addition to new fuels and/or propulsion systems, a 40% reduction in vehicle weight may be needed. Research on lightweight materials is focusing on increased use of aluminum, magnesium, titanium, and composites.

[2] HEV drivetrain designs incorporate two power sources: one generates energy from fuel stored on board, the other is an electric motor that gets energy from the first source and/or from an advanced energy storage device. HEVs can be designed to operate efficiently on both sources, as well as to capture energy now lost in braking to further improve energy efficiency.

(CIDI) engines are promising candidates for near-term HEV application.[3] Regardless of configuration, engine emissions are perhaps the greatest obstacle to the widespread use of CIDI engines. R&D efforts are now under way to lower CIDI engine emissions. Over the longer term, fuel cells could be used in HEVs to offer near-zero vehicle emissions. Fuel cells can generate electricity from such fuels as hydrogen, compressed natural gas, gasoline, methanol, or ethanol stored on-board the vehicle.

1.1 NRC Peer Review of the PNGV Research Program

The National Research Council (NRC), a part of the National Academy of Sciences, has created a standing committee to provide peer review of the PNGV research program. That Committee has evaluated the progress of the PNGV program each year since 1994. In its first annual report, the NRC Peer Review Committee noted a "very high probability that the PNGV concept vehicle will use technologies that will result in technological discontinuities with many of today's automotive technologies." (NRC 1994) The Committee foresaw the potential for discontinuities in vehicle manufacturing and in the road transportation system as a result of new materials, power trains, or fuels that, in turn, could affect capital requirements, employment, environmental consequences, and the safety and cost of vehicle operations. The Committee cited two examples that could result in such discontinuities: use of hydrogen in place of gasoline as a vehicle fuel and use of advanced, lightweight, nonmetallic materials in place of conventional iron and steel in vehicles. Consequently, the Committee stressed the need for in-depth assessment of changes that could occur in "infrastructure, capital requirements, shifts in employment, total environmental consequences, alternative safety strategies, and total cost of operation associated with each technology being explored in the PNGV program" (NRC 1994).

Responding to the Committee's concerns, Argonne National Laboratory (ANL), together with Oak Ridge National Laboratory (ORNL), conducted a preliminary assessment for the Office of Advanced Automotive Technologies (OAAT) in the U.S. Department of Energy (DOE) to quantify major impacts resulting from the commercialization of 3X vehicles. ANL analyzed fuel-related infrastructure issues, while ORNL was responsible for lightweight-materials-related infrastructure issues. ANL defined first-order effects for advanced automotive technologies, quantified potential demand for PNGV fuels other than gasoline or diesel oil, and explored the importance of the length of the transition period. Results of that preliminary assessment were presented to the NRC Committee and were later published in the proceedings of the 29th International Symposium on Automotive Technology and Automation (ISATA) (Wang and Johnson 1996).

In its second annual review report, the NRC Peer Review Committee emphasized the need for continuing the infrastructure analysis (NRC 1996). The Committee observed

[3] DI engines in stand-alone configuration are subject to the same emissions problems (i.e., high engine-out emissions of NO_x and toxics).

that "modifications to the current vehicle infrastructure associated with changes in safety criteria, automotive service industries, fuel use and vehicle-operator interactions have important implications for market acceptance of a PNGV-type vehicle." The Committee called for "a study to establish the energy balance, in-use environmental effects, and resource requirements, as well as the production and distribution costs, for any fuels other than gasoline or diesel fuel being considered for use in Goal 3 vehicles" and stated that "due attention must be given to the total environmental impacts, including in-use emissions and energy consumption in fuel production and distribution." The Committee stressed that a careful assessment of infrastructure issues associated with alternative technologies should be an essential part of the downselect process scheduled for 1997.

In 1996, with funding from DOE's OAAT, Argonne continued its efforts to analyze issues related to PNGV fuels infrastructure. In particular, ANL estimated capital requirements for the facilities to produce and distribute several candidate fuels to be used in 3X vehicles. Six fuels were included in this so-called Phase 1 analysis: reformulated gasoline (RFG), low-sulfur diesel, dimethyl ether (DME), methanol, ethanol, and hydrogen. Using the GREET (Greenhouse gas emissions, Regulated Emissions, and Energy use in Transportation) and IMPACTT (Integrated Market Penetration and Anticipated Costs of Transportation Technologies) models, both of which were developed at Argonne, ANL estimated the fuel-cycle energy and emissions impacts of introducing 3X vehicles powered with each of the six fuels. The Phase 1 results were presented to the PNGV Review Committee at its third annual review meeting. Details regarding methodologies, assumptions, and results of the Phase 1 effort were documented in a later report (Wang et al. 1997a).

In its third and fourth annual review reports (NRC 1997 and NRC 1998), the PNGV Peer Review Committee reiterated its concern about the environmental and economic impacts of PNGV vehicles and their potential effect on fuel infrastructure. In its third annual review, the Committee stated that "it is important that the power plant configurations and fuel types being considered are accurately represented and evaluated with suitable infrastructure models as an integral part of the downselect process of the PNGV technologies." The Committee further asked that the GREET model be used with specific engine and fuel configurations in various downselect scenarios. Finally, in its fourth annual report, the Committee emphasized the need for extensive investigation of the feasibility, economics, and environmental impacts associated with production and distribution of PNGV fuels.

In 1997, ANL continued to analyze PNGV fuels infrastructure issues. Responding to comments from the automotive and fuels industries (as well as from the Peer Review Committee), ANL included six additional fuels in its so-called Phase 2 effort: reformulated diesel (RFD), compressed natural gas (CNG), liquefied natural gas (LNG), liquefied petroleum gas (LPG), biodiesel, and Fischer-Tropsch (F-T) diesel. ANL delved further into the specific impacts of fuel-cycle energy use and emissions, separating emissions of criteria pollutants into total emissions and urban emissions and estimating emissions of all three main greenhouse gases (CO_2, CH_4, and N_2O). In the area of capital requirements, ANL expanded its initial estimates of total capital needs for fuel production and distribution infrastructure to generate cost estimates for each year between 2007 and 2030 under two potential 3X vehicle market penetration scenarios and estimated each fuel's per-gallon increment associated with those costs. Table 1.1 compares the scope of ANL's Phase 1 and Phase 2 efforts. This report documents the methodologies, assumptions, and results of the Phase 2 effort.

Table 1.1 Scope of ANL's PNGV Fuels Infrastructure Analysis: Phases 1 and 2

	Phase 1 (1996)	Phase 2 (1997)
Fuels	RFG, LSD, MeOH, EtOH, DME, H_2	RFG, RFD, MeOH, EtOH, DME, H_2, CNG, LNG, LPG, biodiesel, F-T diesel
Capital requirements	Two snapshot estimates of total capital requirements	Estimates of annual capital requirements under two market penetration scenarios; $/gal cost estimates
Fuel-cycle energy and emissions estimation	Energy use: total energy, fossil energy, and petroleum	Same
	Criteria pollutants: total emissions	Criteria pollutants: total and urban emissions
	GHGs: CO_2	GHGs: CO_2, CH_4, and N_2O

1.2 Study Scope and Approach

This analysis, sponsored by DOE/OAAT, focused on two infrastructure issues: the cost to build/put into place the fuel production and distribution infrastructure needed for each of the fuels under consideration for 3X vehicles and the fuel-cycle energy and emissions impacts of using each of those candidate fuels. As a point of departure, this study assumed that technological obstacles will be overcome; that is, the PNGV's primary goal of tripling fuel economy will become an engineering reality for all fuel/engine combinations being considered. This is consistent with PNGV goal three. In all likelihood, however, the PNGV program will aid in the development and introduction of some intermediate technologies that, though failing to achieve the 3X goal, will provide significant improvements in vehicle fuel economy (e.g., 2 times fuel economy improvements). A practical issue in analyzing programs like the PNGV is whether to assume that intermediate technologies provide the opportunity for initial market introduction and the basis for incremental improvements to the technology, or whether market introduction must await full achievement of technological goals, which, by definition, limits the analysis to more advanced technologies. There are no easy answers to this issue, but if intermediate technologies are to be considered, the PNGV program will have to rethink its schedule for introducing PNGV technologies.

For this analysis, the two infrastructure issues dictated two largely discrete approaches. To estimate the capital requirements of establishing fuel production and distribution infrastructure, it was first necessary to estimate the annual fuel needs of all 3X vehicles expected to be on the road. To do so, two broadly dissimilar 3X vehicle market penetration scenarios were specified to cover a relatively broad range of potential market acceptance of new 3X vehicles. These scenarios were run through ANL's IMPACTT model to estimate the stock of 3X vehicles and their fuel demand for each year from 2007 through 2030. For each fuel, production technologies and distribution infrastructures were then characterized and appropriate unit costs were developed. Capital requirements for the determined fuel production and distribution infrastructure could then be estimated as a function of unit costs and production/throughput volumes.

To estimate energy and emissions impacts of 3X vehicles, the GREET model was run to generate rates of energy consumption and emissions (i.e., Btu/mi and g/mi) by engine and fuel type, and the IMPACTT model was run to generate estimates of (1) total energy and emissions for a base or reference scenario without 3X vehicles, (2) energy and emissions by conventional vehicles still on the road under the two market penetration scenarios, and (3) energy and emissions by 3X vehicles incorporating each fuel/engine combination under those scenarios. The energy and emissions impact of each fuel/engine combination was then the difference between the reference scenario value and the sum of a conventional vehicle component and a 3X vehicle component corresponding to that fuel/engine alternative.

Note that each candidate PNGV fuel/engine combination was assumed to compete solely with conventional vehicles in the light-duty-vehicle marketplace. This approach was adopted for three reasons. First, if a mix of PNGV fuels and vehicle technologies were to compete with one another, as well as with conventional vehicles, results would show the aggregate effects of the mix, not the effects of each technology. It is the latter that is of interest here. Second, this analysis is intended to identify the maximum infrastructure impacts of introducing a given fuel or technology. By definition, the individual components of a mix are less than the sum. Third, historical precedent suggests that one advanced technology will achieve market dominance after initially vigorous competition. It matters not why dominance occurs — whether because of the superiority of the winning technology itself, the cost to establish and maintain infrastructure for multiple technologies, or simply inefficiencies of scale — only that market penetration assumptions be consistent with its occurrence.

The analytic time frame of this study is between 2007 (three years after completion of the research and development for 3X vehicles) and 2030 (when a significant portion of the light-duty fleet could be expected to be composed of these highly efficient vehicles). The study therefore assumed that 3X vehicles will be introduced beginning in 2007 and that 3X vehicle sales will increase steadily to a defined maximum sales target.

Section 2
Development of 3X Market Share Scenarios and Technology Assumptions

Clearly, the impacts of 3X vehicles depend not only on engine technology and fuel choice, but also on how quickly and completely they penetrate the light-duty-vehicle market. If penetration is rapid and complete, there is little time to make the kinds of infrastructure adjustments needed to accommodate different propulsion systems and fuels. Conversely, if penetration is slower and appears more predictable, deliberate planning is possible. To explore a range of 3X impacts, three market penetration scenarios were postulated. The scenarios include a base or reference scenario depicting a future without 3X vehicles and two market share scenarios bracketing a range of 3X vehicle sales. Thirteen combinations of fuels and propulsion systems were examined in the context of the two market-share scenarios.

2.1 Sales of New Light-Duty Vehicles

The vehicle sales forecast used in all three scenarios was taken from the Energy Information Administration's 1997 forecast of transportation energy demand through the year 2015 and extrapolated to 2030 (EIA 1996a). This forecast assumes 1.9% per year growth in gross domestic product (GDP), relatively low world oil prices (rising from $17.26 in 1995 to only $20.98 per barrel by 2015 [all in 1995 dollars]), continued growth in the number of licensed drivers, and moderate increases in new light-duty-vehicle sales and fuel economy. Under this forecast, new car sales increase from 9.31 million with a rated fuel economy of 28.3 mpg in 1995 to 10.55 million rated at 34.3 mpg in 2030; new light-truck sales increase from 5.88 million rated at 20.4 mpg in 1995 to 7.76 million rated at 26.3 mpg in 2030.

2.2 Market Penetration of 3X Vehicles

The 3X vehicle market share scenarios retain the basic parameters of the reference scenario (e.g., energy prices, economic growth, overall vehicle sales) but allow such market factors as the level of technology maturity and consumer preferences to vary. Since each of these factors is subject to some uncertainty, two extreme sets of conditions could materialize. Under one set, every factor favorable to 3X vehicles' market success could occur, resulting in rapid consumer acceptance and high sales of new 3X vehicles. Alternatively, some factors may not be as favorable to market success, resulting in slower early acceptance and low-to-moderate sales of new 3X vehicles. Historical precedents can be found for extremely rapid market acceptance, relatively slow market acceptance, and for many intermediate levels between these two. For example, the market experience of front-wheel drives and downsizing (i.e., weight reduction) provide some insight into just how rapid market penetration could be. In the United States, the market share of front-wheel drives increased from virtually zero to 80% of new passenger cars between 1976 and 1992, a span of 16 years (Figure 2.1).

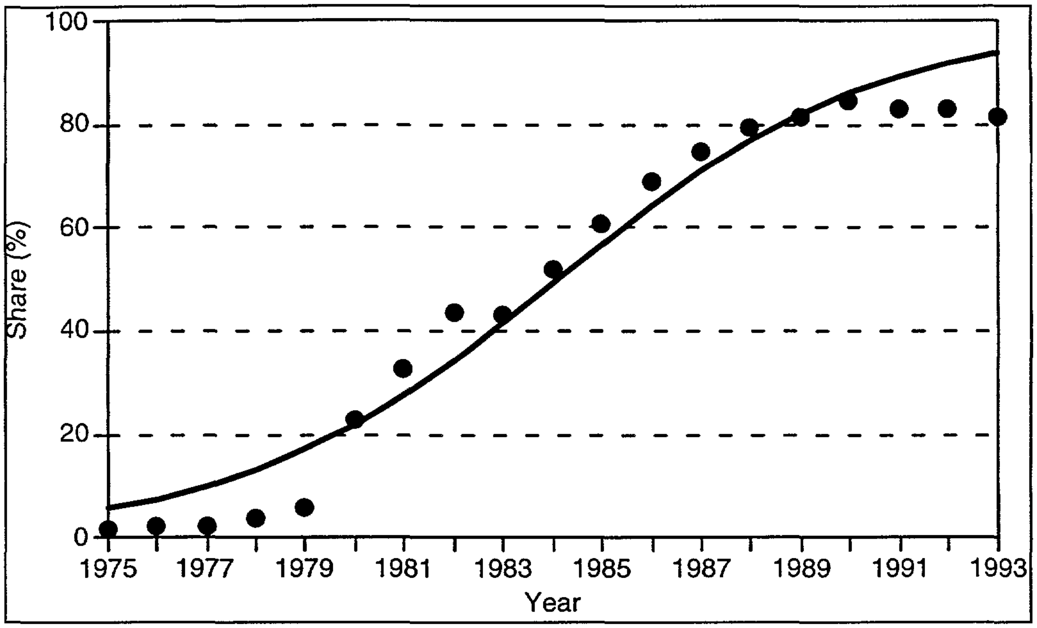

Figure 2.1 Market Share of Front-Wheel-Drive Autos in the United States (based on Murrell et al. 1993)

Light-duty-vehicle (LDV) weight reduction (and the many technologies incorporated therein) has been equally dramatic, with average inertia weight declining by more than 20% between 1976 and 1980 (Figure 2.2). Since a transition to 3X vehicles — involving changes in power systems, materials, and fuels, even as conventional vehicles are produced — is a more complex proposition than introducing either of these technologies, the penetration curves shown in Figures 2.1 and 2.2 provide an indication of the upper limits to market penetration of 3X vehicles.

The mid case for 3X vehicle sales developed by DOE's Policy Office for the Policy Dialogue Advisory Committee (the "Car Talk" Committee) (Resolve, Inc. 1995) is another example of relatively rapid penetration. Under that case, 3X sales achieve a lower ultimate share than front-wheel-drive vehicles or the technologies used to achieve a 20% weight reduction, but penetration is still relatively rapid in terms of the ability of the vehicle manufacturing industry to adapt to such a production shift. For this reason, the mid case was modified slightly for this analysis, extending the timeframe over which the market penetration target is achieved. Thus, the "Car Talk" mid case was modified to produce the high-market-share scenario in which 3X vehicles enter the new light-duty-vehicle market in 2007 and take over 20 years to achieve a 60% market share.

As compared with the high-market-share scenario, the low-market-share scenario assumes a later introduction of 3X vehicles and a slower rate of increase in their sales. Under this scenario, 3X vehicles are assumed to enter the market in 2013, six years later than in the high-market-share scenario, and to capture a 30% share of the new LDV market by 2030. The low-market-share scenario is similar to the market penetration of diesel cars in France in the 16 years between 1973 and 1989 (Figure 2.3). Table 2.1 and

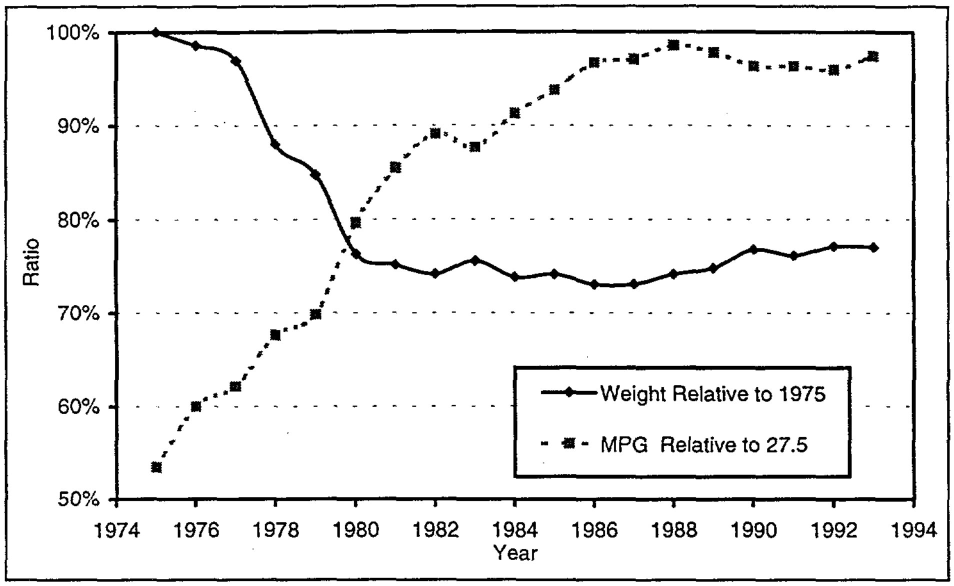

Figure 2.2 Weight Reduction and Fuel Economy Improvement of New Automobiles in the United States (fuel economy relative to 1995 standard of 27.5 mpg) (based on Murrell et al. 1993)

Figure 2.4 illustrate the share of new vehicle sales represented by 3X vehicles under the two scenarios.

For both market share scenarios, each PNGV fuel/engine combination is assumed to have the same market penetration, to compete solely with conventional vehicles (not with one another), and therefore to account for all of the impacts identified. Because competing technologies are set aside for separate fuel/engine comparisons, this assumption provides the basis for analyzing the maximum impact of each technology.

2.3 Sales and Stocks of 3X Vehicles

As stated above, EIA's 1997 forecasts of new car and light-duty-truck (LDT) sales were used to represent total light-duty-vehicle (LDV) sales in the reference scenario and in each of the two market share scenarios. Sales of new 3X vehicles were then estimated as the product of sales and sales shares for cars and LDTs. Note that this implicitly assumes that 3X technologies achieve the same penetration of car and LDT markets, and that 3X LDTs (vans, sport utility vehicles, and pick-ups) achieve the same share of the 3X LDV market as conventional LDTs achieve of the conventional LDV market.

Because of several revisions in input parameters (some of which were offsetting), the number of 3X vehicles expected to be on the road and their fuel use and emissions differ somewhat between Phases 1 and 2 of this study. In Phase 1, total auto and LDT sales were based on EIA's 1996 forecast (Chien 1996, EIA 1996b). For Phase 2, these assumptions were updated with EIA's 1997 forecast (Chien 1997, EIA 1996a), which assumes slightly higher LDV sales in the short term, considerably lower sales in the long term (between 2010 and 2015), and lower conventional vehicle fuel economy. Since new

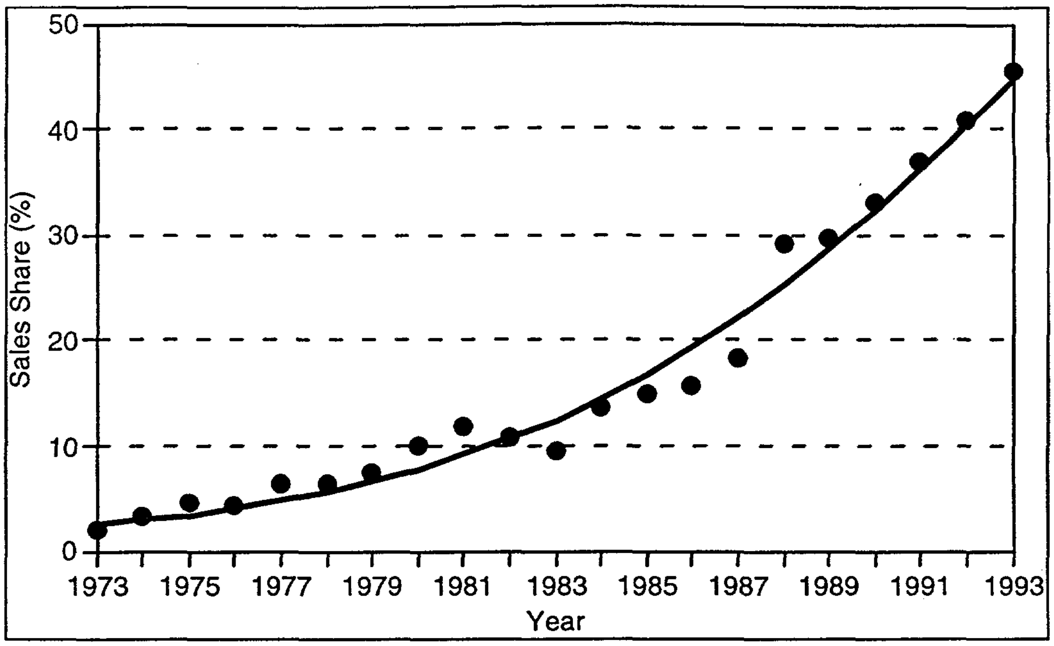

Figure 2.3 Sales Share of New Diesel Cars in France

Table 2.1 3X Share of New Light-Duty Vehicle Sales by Scenario

	High Market Share	Low Market Share
Year	% Share	% Share
2006	0.0	
2007	0.1	
2008	0.3	
2009	0.6	
2010	1.0	
2011	1.6	
2012	2.4	0.0
2013	3.7	0.5
2014	5.8	1.1
2015	9.0	1.7
2016	13.0	2.1
2017	17.0	2.6
2018	21.0	3.2
2019	25.0	3.9
2020	29.0	4.8
2021	33.7	5.8
2022	38.4	7.1
2023	43.1	8.7
2024	47.8	10.6
2025	52.5	12.8
2026	56.6	15.4
2027	58.7	18.4
2028	59.5	21.8
2029	59.8	25.7
2030	60.0	30.0

vehicle sales in the outyears of the EIA forecast were extrapolated to 2030 for this study, the lower long-term sales resulted in approximately 10% fewer 3X vehicle sales in 2030 and approximately 7% fewer 3X sales over the entire forecast period (See Table 2.2).

The procedure used to forecast the fleet of 3X and conventional vehicles expected to be on the road in future years was essentially unchanged in Phase 2. As in the Phase 1 analysis, annual forecasts of 3X market penetration, new LDV sales, and an assumed split between auto and light truck sales were key inputs to the IMPACTT model, which was used to calculate 3X and conventional vehicle stocks and operational energy consumption for each year from 2007 to 2030 (Mintz et al. 1994). Within IMPACTT, a vintaging procedure adjusted a base year vehicle population — adding new vehicles, scrapping or aging others — to produce forecasts of the future light-duty-vehicle fleet by type (auto or light truck), age, and technology (3X or conventional). The resulting estimates of 3X vehicle stocks, expressed as percentages of

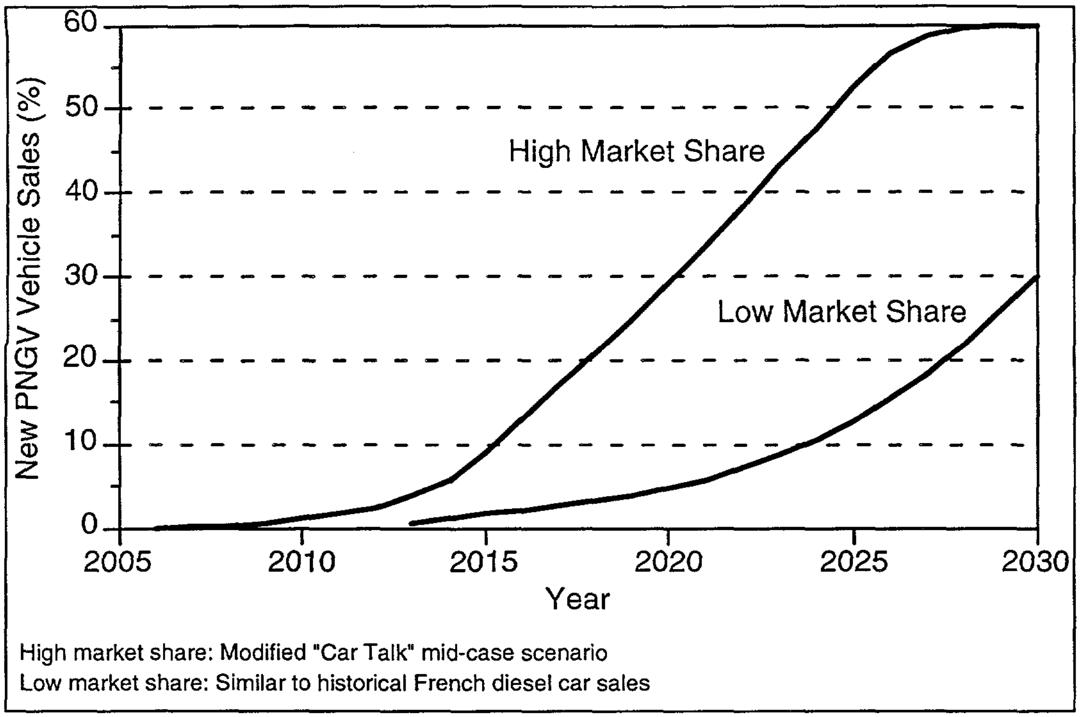

Figure 2.4 Market Share Scenarios for 3X Vehicles

total LDV stocks, are shown in Figure 2.5. Note that even under the high-penetration scenario, 3X vehicles still account for only a little over 40% of total LDV stocks in 2030. This occurs because the turnover of the LDV fleet, which consists of long-lived durable goods (i.e., vehicles), is very slow, typically requiring many years for the characteristics of the vehicle stock to reflect those of new additions to the fleet.

2.4 Fuel Savings Potential

Energy used in the operation of light-duty vehicles was estimated for three scenarios: the reference scenario (without 3X vehicles), the low 3X-market-share scenario, and the high 3X-market-share scenario. As described above, EIA's projections of new LDV fuel economy were used for 1996–2015 and were extrapolated to 2030 using EIA's growth rate between 2010 and 2015. Under the reference scenario, fuel economy for new cars and light trucks thus increases from 27.5 and 20.2 mpg in 1995 to 34.3 and 26.3, respectively, in 2030 (as compared to 35.4 and 26.5 mpg in the earlier EIA forecast used in Phase 1). Because there is no comparable reduction in 3X fuel economy, the percent of operational energy savings attributable to 3X vehicles is thus slightly greater in Phase 2, even though the quantity consumed is less. Estimates of energy use by 3X vehicles, in Phases 1 and 2, are shown in Table 2.3.

Note that energy consumed in the operation of the 3X vehicle fleet is determined not only by the number of 3X autos and light trucks on the road and their fuel economy, but also by annual utilization. Although utilization rates and survival probabilities are assumed to decline with vehicle age, within a particular age range both 3X and

Table 2.2 New 3X Vehicle Sales by Market Share Scenario, Phases 1 and 2 (10^3)

	Phase 1						Phase 2					
	High Market Share			Low Market Share			High Market Share			Low Market Share		
Year	Auto	Light Truck	Total[a]	Auto	Light Truck	Total[a]	Auto	Light Truck	Total[a]	Auto	Light Truck	Total[a]
2007	9	7	17				10	8	18			
2008	29	22	50				30	23	52			
2009	58	45	102				59	45	104			
2010	97	75	172				99	75	174			
2011	151	118	269				159	120	279			
2012	236	184	420				240	181	420			
2013	370	290	659	49	39	88	372	279	651	50	38	88
2014	579	455	1,034	110	86	196	587	439	1,026	111	83	195
2015	904	709	1,613	169	133	302	908	677	1,585	172	128	299
2016	1,325	1,024	2,349	212	164	376	1,316	979	2,295	213	158	371
2017	1,760	1,338	3,098	266	202	467	1,727	1,283	3,009	264	196	460
2018	2,208	1,651	3,859	332	248	581	2,140	1,587	3,727	326	242	568
2019	2,669	1,964	4,633	415	305	720	2,556	1,892	4,448	399	295	694
2020	3,144	2,275	5,419	517	374	892	2,975	2,198	5,173	492	364	856
2021	3,710	2,641	6,351	644	458	1,102	3,467	2,560	6,027	597	441	1,037
2022	4,293	3,005	7,298	799	559	1,358	3,962	2,923	6,885	733	540	1,273
2023	4,893	3,368	8,261	989	680	1,669	4,460	3,288	7,748	900	664	1,564
2024	5,511	3,728	9,239	1,219	825	2,043	4,961	3,654	8,615	1,100	810	1,910
2025	6,146	4,087	10,233	1,496	995	2,491	5,464	4,022	9,486	1,332	981	2,313
2026	6,731	4,398	11,129	1,827	1,194	3,021	5,907	4,346	10,253	1,607	1,183	2,790
2027	7,086	4,550	11,636	2,218	1,424	3,642	6,142	4,519	10,661	1,925	1,416	3,342
2028	7,294	4,601	11,894	2,674	1,686	4,360	6,242	4,592	10,834	2,287	1,682	3,969
2029	7,444	4,611	12,056	3,198	1,981	5,179	6,290	4,626	10,916	2,703	1,988	4,691
2030	7,880	4,318	12,198	3,939	2,159	6,098	6,328	4,653	10,981	2,164	2,327	5,490

[a] The total columns may not reflect exact sums because of rounding.

conventional vehicles are assumed to have the same utilization and survival. As in the Phase 1 analysis, 3X cars are assumed to achieve 81 mpg on the EPA test (3X light trucks are assumed to achieve 63 mpg), and utilization is assumed to decline exponentially with vehicle age. In both phases, in-use fuel economy is assumed to be approximately 20% below EPA-test fuel economy for all vehicles.[4] The light-truck share of LDV sales rises from 35% in EIA's 1996 forecast to 42% in EIA's 1997 forecast. As a

[4] A correction factor of 0.814 was applied to correct for the observed discrepancy or gap between fuel economy as measured on the EPA test cycle and actual or in-use fuel economy. Several studies have confirmed the existence of such a gap and its relative magnitude (McNutt et al. 1978, Westbrook and Patterson 1989, Maples 1992, Mintz et al. 1993). The gap is believed to be due to changes in actual travel conditions since the design of the test cycle and development of averaging procedures, especially increases in the share of travel under urban conditions and increased traffic congestion. Because it is unclear how the fuel economy of 3X vehicles will be affected by these changes, the same correction factor was applied to all vehicle, fuel, and technology types.

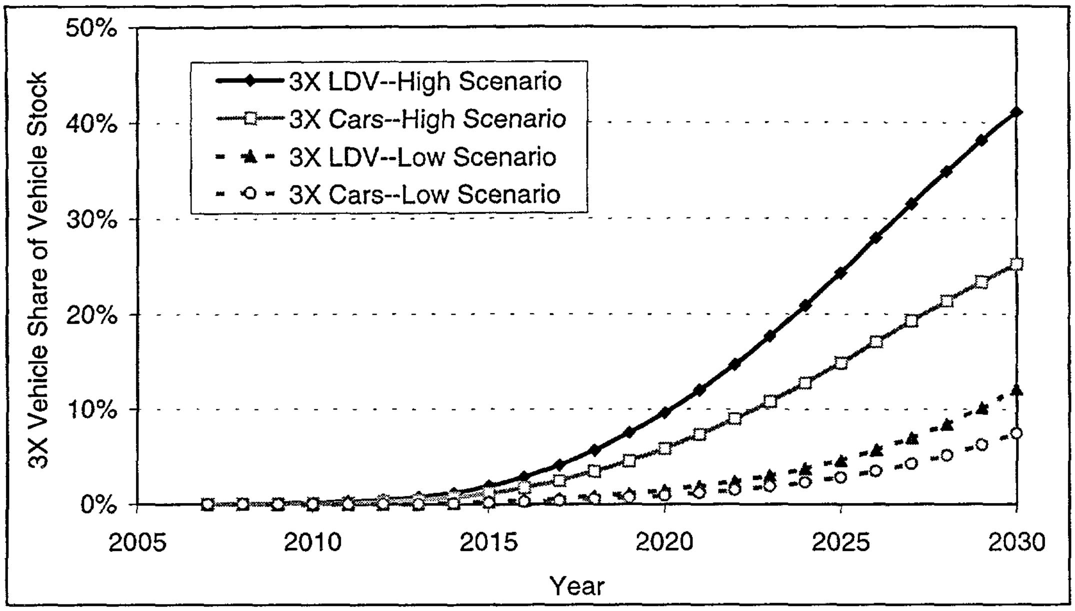

Figure 2.5 3X Cars and Light Trucks as Shares of Total LDV Stocks by Scenario

result, overall fuel use by the 3X fleet drops by 7% in Phase 2 as compared with Phase 1 (tripling the fuel economy of less efficient vehicles saves more fuel).

Figure 2.6 shows the Phase 2 forecast of energy consumption by light-duty vehicles. The figure shows the operational energy savings from introducing 3X vehicles, which is dramatic for the high-market-share scenario and more modest, but still substantial, for the low-market-share scenario. This reduction in energy use is due entirely to improved fuel efficiency. If alternative fuels (such as methanol, ethanol, hydrogen, and DME) are used in 3X vehicles to replace gasoline, additional reductions in petroleum consumption may be expected. The total amount of petroleum reduction from fuel substitution is equal to the amount of energy consumed by 3X vehicles operating on fuels other than gasoline (including the non-gasoline component of blended fuels), plus reductions (if any) in the amount of petroleum consumed in upstream processes.[5] Thus, the effect of both efficiency gain and fuel substitution varies by fuel.

2.5 Candidate 3X Vehicle Technologies

To achieve the goal of tripling fuel economy, the PNGV program has targeted three general areas: converting and using fuel energy more efficiently by eliminating idling at stops and during deceleration; reducing the tractive energy demand of the vehicle by reducing mass, drag, and/or tire rolling resistance; reducing accessory loads of the vehicle; and recapturing some kinetic energy via regenerative braking. To convert and use energy more efficiently in vehicles, two on-board power generation systems have

[5] Note that data presented in Table 2.3 and Figure 2.6 pertain to energy use in vehicle operation only. Fuel consumption for upstream fuel production activities is discussed in Section 4.

Table 2.3 3X Vehicle Operational Energy Use by Market Share Scenario, Phases 1 and 2 (10^6 GGE)

	Phase 1						Phase 2					
	High Market Share			Low Market Share			High Market Share			Low Market Share		
Year	Auto	Light Truck	Total[a]	Auto	Light Truck	Total[a]	Auto	Light Truck	Total[a]	Auto	Light Truck	Total[a]
2007	2	2	4				2	2	5			
2008	9	9	17				9	9	18			
2009	22	22	43				22	22	45			
2010	43	44	87				44	44	88			
2011	76	78	154				78	77	156			
2012	128	130	258				131	129	260			
2013	209	213	421	12	12	23	213	210	423	12	12	23
2014	335	342	677	37	38	75	340	335	675	37	37	74
2015	531	544	1,076	75	77	152	538	527	1,065	76	74	150
2016	818	834	1,652	122	124	246	822	804	1,626	122	119	241
2017	1,195	1,207	2,402	179	181	360	1,191	1,161	2,352	178	173	351
2018	1,659	1,659	3,319	249	249	499	1,639	1,596	3,235	246	239	486
2019	2,210	2,186	4,397	336	332	669	2,164	2,103	4,267	329	319	648
2020	2,846	2,783	5,629	443	433	876	2,762	2,680	5,441	429	416	846
2021	3,583	3,460	7,043	574	554	1,128	3,444	3,337	6,781	551	534	1,085
2022	4,417	4,212	8,629	736	700	1,435	4,205	4,070	8,275	699	676	1,375
2023	5,346	5,031	10,377	933	875	1,809	5,040	4,872	9,912	877	848	1,725
2024	6,365	5,911	12,276	1,175	1,086	2,261	5,941	5,738	11,679	1,092	1,055	2,147
2025	7,471	6,842	14,314	1,469	1,337	2,806	6,903	6,660	13,563	1,351	1,303	2,653
2026	8,643	7,805	16,448	1,827	1,636	3,462	7,904	7,620	15,523	1,660	1,600	3,259
2027	9,816	8,742	18,559	2,257	1,989	4,246	8,886	8,561	17,447	2,027	1,952	3,979
2028	10,951	9,619	20,570	2,773	2,404	5,178	9,815	9,449	19,264	2,461	2,369	4,830
2029	12,029	10,420	22,449	3,387	2,887	6,274	10,674	10,270	20,945	2,970	2,857	5,827
2030	13,118	11,048	24,166	4,145	3,398	7,542	11,461	11,022	22,483	3,560	3,424	6,984

[a] The total columns may not reflect exact sums because of rounding.

been selected by the PNGV program: direct-injection (DI) internal combustion engines and fuel cells. DI engines can be compression ignition (so-called CIDI engines) and be powered with such fuels as diesel, DME, biodiesel, and F-T diesel, all of which have high cetane number. DI engines can also be spark ignition (so-called SIDI engines) and be powered with such fuels as gasoline, methanol, ethanol, natural gas, and LPG, all of which have high octane numbers. Relative to conventional CI engines (diesel engines), CIDI engines can achieve a 30–40% improvement in fuel economy. Relative to conventional SI engines (gasoline engines), SIDI engines can achieve a 20–30% improvement in fuel economy. Fuel cells, which generate electricity from fuels through chemical reactions, are anticipated to achieve twice the fuel economy of conventional SI engines.

SIDI and CIDI engines can be used alone (the engines are the only power source on board the vehicle) or in hybrid configuration. Hybrid configuration achieves additional improvement in fuel economy by eliminating idling and fuel flow during deceleration and by operating engines in a more efficient regime of the engine map. In addition, a

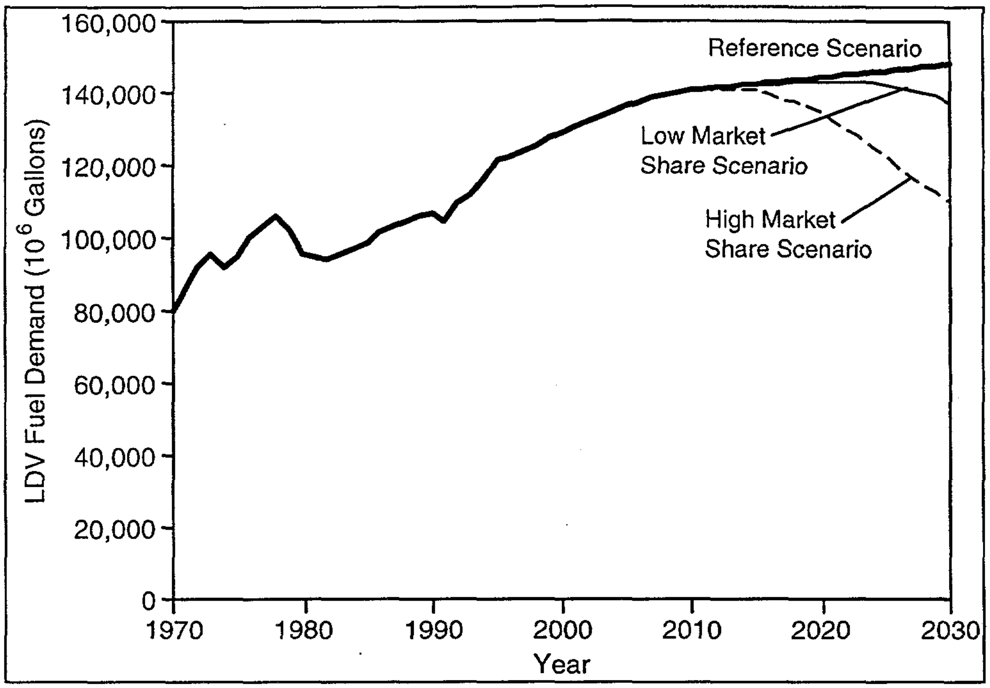

Figure 2.6 Impact of 3X Vehicles on Energy Use by LDVs, Phase 2 Results

hybrid configuration enables use of regenerative braking to recover some of the kinetic energy built up during accelerations, which is otherwise lost. SIDI and CIDI engines in hybrid configuration and fuel cells are presently regarded as reasonable candidates to meet the 3X goal.

However, changes in on-board power units will not be enough. Additional efficiency improvements will be needed to meet the 3X goal. These include reducing vehicle mass (by replacing steel with such lightweight materials as aluminum, magnesium, plastic, and composites); improving drivetrain efficiency, drag coefficients and rolling resistance; and lowering accessory loads. This analysis implicitly assumes that all technical means needed to achieve 3X fuel economy will be utilized. However, it does not address the impacts of developing and deploying the non-fuel technologies. With the exception of the infrastructure impacts of producing and using lightweight materials (which are being analyzed by Oak Ridge National Laboratory), impacts of other unnamed technologies are not addressed in the infrastructure analysis.

To summarize, this analysis includes SIDI engines, CIDI engines, and fuel cells, all in hybrid configuration. Fuel cells are assumed to be proton-exchange membrane (PEM), which is the most promising near-term fuel cell technology for motor vehicle applications. Throughout the analysis, each of the technologies was assumed to meet the 3X goal. However, among the three, SIDI engines currently achieve the least fuel economy improvement, CIDI engines the next, and fuel cells the most. This implies that if all technologies meet the 3X goal, vehicles equipped with SIDI engines will require the most additional effort (in improving drivetrain efficiency and/or reducing mass, drag, accessory loads, or rolling resistance) to reduce vehicle energy demand, vehicles with CIDI engines will require moderate effort, and vehicles with fuel cells will require the least effort. Investigation of the integrated design of each vehicle type to meet the 3X goal is beyond the scope of this study.

2.6 Candidate 3X Fuels

In Phase 2 of this analysis, 11 different PNGV fuels were examined in the context of three propulsion systems. These fuels were selected not only because their properties make them technically feasible candidates, but also because of the broad range of infrastructure impacts that they might produce, the quantification of which could provide important input to the PNGV program for use in its selection of candidate 3X fuels. The fuels are reformulated gasoline, reformulated diesel, dimethyl ether, methanol, ethanol, compressed natural gas, liquefied natural gas, liquefied petroleum gas, biodiesel, Fischer-Tropsch diesel, and hydrogen.

Reformulated gasoline (RFG). RFG is mandated in the nine most severe ozone nonattainment areas of the United States. In California, a more stringent California-specified RFG is required. In addition, many other states that are not required to use RFG under the 1990 Clean Air Act Amendments have opted into the federal program, in effect mandating the use of RFG within their borders. Thus, a sizable portion of the U.S. light-duty-vehicle fleet may be using RFG by the time 3X vehicles are introduced. Phase 1 RFG was introduced in 1995. Phase 2 RFG is required to replace the Phase 1 formulation beginning in 2000. In this analysis, federal Phase 2 RFG was assumed to be used by all conventional LDVs in the reference scenario and by conventional vehicles and 3X SIDI and fuel-cell-powered vehicles in the high- and low-market-share scenarios. The use of light hydrocarbons in fuel-cell-powered vehicles is a relatively recent proposal with its share of technical hurdles. Research is currently under way to develop an efficient, quick-responding reformer to produce hydrogen from light hydrocarbons on board a fuel-cell vehicle using the partial oxidation process. In this study, RFG was assumed to be the hydrocarbon of choice for on-board reforming because it could be readily accommodated by the existing gasoline supply infrastructure.

Reformulated diesel (RFD). The diesel fuel examined in Phase 1 of this analysis was a low-sulfur diesel introduced nationwide in 1993. In the past year, emission targets for CIDI engines have been made more stringent, so stringent in fact that it is debatable whether they can be met with today's low-sulfur diesel fuel. More likely than not, a so-called reformulated diesel (RFD) with low sulfur and aromatic content will be needed. For this analysis, it was assumed that this new diesel fuel will have a sulfur content of 100 ppm by weight. At present, no information on potential aromatic content is available.

Dimethyl ether (DME). DME was included because several recent studies have indicated that this fuel, although expensive and requiring changes in fuel storage and injection systems, may offer significant environmental benefits while exploiting the high thermal efficiency of a CIDI engine. DME's high cetane number (55–60) and inherently low PM emissions make it a particularly attractive replacement for diesel.

Methanol (MeOH). Methanol was considered in pure form (M100) for both *SIDI* engines and fuel-cell vehicles. Methanol has been promoted for LDV applications because it has potentially low VOC and CO emissions while being produced from a non-petroleum source (i.e., natural gas). Methanol fuel cells were assumed to be of the partial oxidation type with on-board reformers.[6]

Ethanol (EtOH). Ethanol was included because it alone, among the fuels considered, is currently made from renewable resources. Ethanol was assumed to be burned in SIDI engines in pure form (E100). Although ethanol in different blend percentages with gasoline (such as 85% ethanol and 15% gasoline [E85] and 10% ethanol and 90% gasoline [E10]) has been used or promoted for LDV applications, pure ethanol better illustrates the fuel's potential impact. Use of ethanol reduces both GHG emissions and fossil fuel use.

Compressed natural gas (CNG) and liquefied natural gas (LNG). CNG and LNG were assumed to be used in SIDI engines. Since they are made from natural gas, which is relatively abundant in the United States and worldwide, CNG and LNG can reduce petroleum use and criteria pollutant emissions.

Liquefied petroleum gas (LPG). LPG was assumed to be used in SIDI engines primarily for its environmental benefits. LPG also offers some petroleum reduction, since approximately 50–60% of the LPG fraction appropriate for motor fuel use (i.e., propane) currently comes from natural gas (EIA 1997a; EIA 1997c). LPG is currently the most widely used alternative fuel in the United States. Consumers are relatively familiar with LPG as a transportation fuel.

Biodiesel. Biodiesel was included because it is produced from renewable sources and has a large potential for reducing transportation GHG emissions and petroleum use. It was assumed to be used in CIDI engines. Because of its high production cost and the desire to use the existing diesel distribution system, it is generally suggested that biodiesel be blended with conventional diesel. Most researchers in the field anticipate that a blend of 20% biodiesel and 80% conventional diesel (B20) will exploit the benefits of biodiesel at a reasonable cost premium. This blend percentage (with RFD as the diesel component) was selected for 3X vehicle applications.

Fischer-Tropsch diesel (F-T diesel). F-T diesel, produced from natural gas, was included because of its zero sulfur content, low aromatic content, and high cetane number. To better utilize F-T diesel's inherent advantages, some suggest that F-T diesel be blended with conventional diesel. In this analysis, a blend of 50% F-T diesel and 50% RFD (F-T50) was assumed for CIDI applications.

Hydrogen (H_2). Gaseous hydrogen was considered for use in fuel-cell vehicles, along with methanol and gasoline.

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[6] Because of on-board reforming, methanol was assumed to be lower quality, which is more or less comparable with the methanol burned by SIDI engines.

The three vehicle technologies and 11 fuels produced a total of 13 vehicle/fuel combinations, which were evaluated in this analysis. Table 2.4 shows the 13 combinations.

Table 2.4 Propulsion Technologies and Fuels Examined in the Phase 2 Analysis

Fuel	Propulsion Technology
RFG	SIDI engines Fuel cells
CNG	SIDI engines
LNG	SIDI engines
LPG	SIDI engines
Methanol	SIDI engines Fuel cells
Ethanol	SIDI engines
RFD	CIDI engines
DME	CIDI engines
Biodiesel	CIDI engines
F-T diesel	CIDI engines
Hydrogen	Fuel cells

Table 2.5 lists the physical and chemical properties of the 11 different fuels. It should be noted that heating value or energy content (Btu/gal) is a particularly important consideration. Though beyond the scope of this analysis, heating value will affect vehicle design and the mix of enabling technologies needed to achieve 3X fuel economy. Vehicles using fuels with heating values lower than RFG will have to provide more on-board fuel storage in order to achieve the PNGV target of a 380-mi driving range, unless some of the difference is compensated by improved efficiencies. Since methanol's heating value is approximately half that of gasoline, methanol tanks will have to be about twice as large as gasoline tanks. Similarly, ethanol tanks will be about one-third larger than gasoline tanks. For other fuels, on-board storage must accommodate both differences in heating value and in the conditions needed to maintain the fuel in a particular (generally liquid) state. LPG tanks will be larger and heavier than gasoline tanks in order to store the fuel at a pressure of about 100 psi; DME tanks will be similar. CNG will be stored in cylinders at about 3000 psi, while LNG will be stored in cryogenic tanks. Gaseous hydrogen (liquid hydrogen was excluded from this analysis) will be stored at approximately 6000 psi. Among the eleven fuels, CNG, LNG, and gaseous hydrogen will incur the most severe weight penalties, which then must be compensated by further mass reductions or efficiency improvements. By contrast, RFD, biodiesel, and F-T diesel have higher energy content than gasoline. On-board storage of these fuels will produce a small weight benefit.

2.7 Fuel Production Pathways

Fuel production pathways for each of the 11 different fuels must be specified in order to estimate capital needs for establishing fuel production and distribution infrastructure and to analyze fuel-cycle energy and emissions impacts. The fuel pathways presented in Figure 2.7 are based on ANL's previous research in this area.

As the figure shows, RFG and RFD are produced from petroleum. LPG is produced from both petroleum and natural gas (NG). CNG, LNG, DME, methanol, and F-T diesel

Table 2.5 Properties of 11 Potential 3X Fuels

Fuel	LHV[a] (Btu/gal)	HHV[a] (Btu/gal)	Density (g/gal)	C ratio[a] (wt)	S ratio[a] (wt)
Reformulated gasoline (RFG)	113,000	122,000	2,749	0.830	0.000100
Reformulated diesel (RFD)	128,500	138,700	3,240	0.870	0.000100
Methanol (MeOH)	57,000	65,000	2,996	0.375	0.000007
Ethanol (EtOH)	76,000	84,500	2,996	0.522	0.000007
Liquefied petroleum gas (LPG)[b]	84,000	91,300	2,000	0.820	0.000000
Liquefied natural gas (LNG)[b]	72,900	80,900	1,589	0.740	0.000000
Dimethyl ether (DME)[b]	68,200	73,600	2,528	0.522	0.000000
Methyl soyate (biodiesel)	117,100	128,500	3,346	0.780	0.000010
Fischer-Tropsch diesel	118,800	128,500	2,915	0.860	0.000010
Natural gas (per SCF)	928	1,031	20.5	0.738	0.000007
Hydrogen (H_2, per SCF)	274	324	2.4	0.000	0.000000

[a] LHV= lower heating value; HHV = higher value; C ratio = carbon ratio; S ratio = sulfur ratio.

[b] Under pressure.

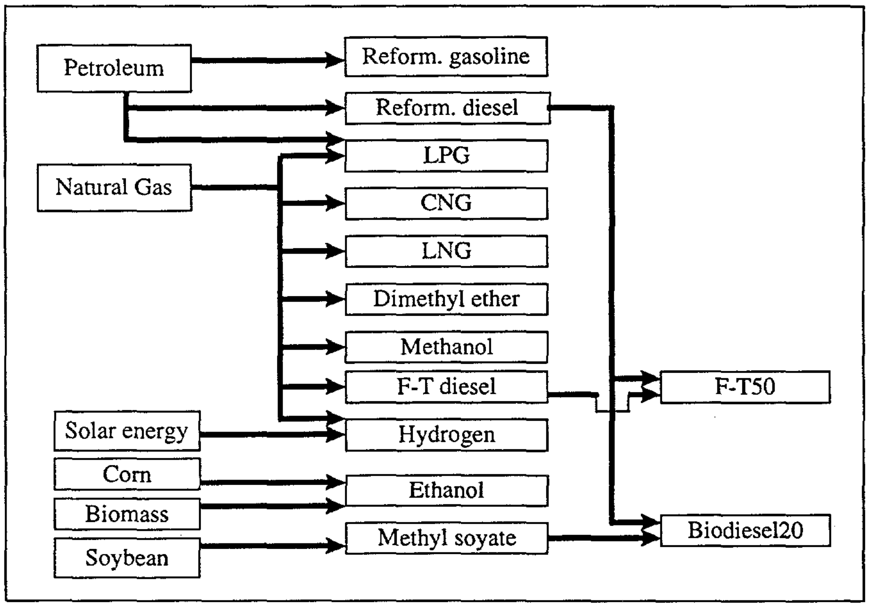

Figure 2.7 Fuel Pathways Considered in this Study

are produced from natural gas. Prior to 2020, all hydrogen was assumed to be produced from NG through steam reforming; beginning in 2020, new hydrogen capacity was assumed to come from solar sources through water electrolysis. Between 2020 and 2030, solar energy thus accounted for an increasing share of hydrogen production. Likewise, ethanol production (initially corn-based) was assumed to shift to cellulosic ethanol plants (using both woody and herbaceous biomass) beginning in 2016. Methyl ester (or soyate) is the oil produced from soy oil through the transesterification process and has properties similar to those of diesel fuel.

Section 3
Capital Requirements of PNGV Fuels Infrastructure

If 3X vehicles require unconventional fuels, a new infrastructure must be developed to supply those fuels in the quantities demanded. That supply infrastructure can be broken down by function: (1) fuel production, which includes the facilities and equipment used to refine and/or process feedstocks into final products, and (2) fuel distribution, which includes the transportation and storage of feedstocks and products at each stage in the production process. Because of the unique characteristics of these two functional areas, estimated capital requirements for PNGV fuels infrastructure have been calculated separately for the two. The methodologies, assumptions, and results of these calculations are discussed below.

3.1 Fuel Production Assumptions

Each fuel evaluated in this study was assumed to supply the energy needs of all 3X vehicles — and only those vehicles — for each year of the analysis.[7] Energy requirements were determined by IMPACTT model runs, which, in turn, were based on vehicle sales and survival modeling and utilization assumptions. These parameters are described in Section 4 of this report. The energy requirement (in gasoline gallon equivalents or GGEs) was then converted into annual demand for each fuel by using the ratio of that fuel's heating value to that of RFG.[8]

An estimate of the physical and capital requirements for production of the requisite volume of fuel was then calculated by determining the scale of production appropriate for the volume demanded and postulating a reasonable timetable for construction of the facilities needed. For each fuel, production was calculated on the basis of a 90% on-stream factor. Production of fuels that also serve as industrial chemicals (e.g., DME) was generally assumed to be incremental to current volumes because motor fuel use will not substantially decrease demand for industrial use. Methanol is a key exception to this, since some reduction in demand for MTBE (as a result of reduced gasoline demand by the non-3X component of the vehicle fleet) can be expected to reduce non-3X demand for methanol, but the impact should not be large given the slow increase in the fleet of 3X vehicles.

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[7] Note that sufficient volumes of fuel had to be supplied for each year of the analysis. Inventories could not be used to balance supply and demand. Note also that the demand forecast did not include the fuel requirements of alternative-fuel vehicles (AFVs) that do not achieve 3X fuel economies. These non-3X AFVs were not considered in this analysis.

[8] Higher heating values were used here to permit comparison with EIA forecasts of fuel demand. In other parts of the analysis, lower heating values were used to account for differences in the water content of combustion products.

Note that for the capital cost analysis, costs were incremental to a base case of 3X vehicles using RFG. Capital and operating costs for production facilities were developed by using data from the literature, supplemented as needed by technical estimates. The capital cost of production includes the capital cost for any necessary feedstock development (e.g., LNG will require additional gas well development, as well as gas processing and liquefaction equipment). In all cases, capital costs were calculated by using a 10-yr payback and a 10% real interest rate. All costs are in 1995 dollars.

3.1.1 Methanol (M100)

Pathway. In this analysis, all methanol was assumed to be imported and to be made from remote, inexpensive natural gas. Capital cost for development of the natural gas feedstock was assumed to be twice as high as for domestic sources to account for the lack of infrastructure in remote foreign fields. All production was assumed to be via steam-reforming, in which a synthesis gas is produced and then catalytically reformed into methanol. Such processing schemes are used in typical low- to intermediate-pressure methanol synthesis, such as those provided by Lurgi; Imperial Chemical Industries, Ltd. (ICI); and M.W. Kellogg. Steam reforming is an efficient, commercial process well-suited to remote gas fields (Chemical Market Associates, Inc. 1996).

Equipment Requirements. Through 2014, new methanol plants were assumed to have a capacity of 2,500 metric tons per day (MTPD) of methanol. This capacity is consistent with that of current world-scale methanol plants. Starting in 2015, new plants were assumed to have a capacity of 10,000 MTPD. This capacity is consistent with the capacity assumptions used in a prior study by the DOE Policy Office and provides significant economies of scale (U.S. DOE 1991).

Cost. Estimates of capital and operating costs for methanol production were derived from various sources. Fixed and working capital costs were developed by using information from DOE (1991) and Chemical Market Associates, Inc. (1996). Foreign remote-gas feedstocks were assumed to be available for $0.80 per million Btu in 2007. This price was assumed to increase (linearly) by 30% through 2015 and to stabilize thereafter. The latter is consistent with assumptions elsewhere in this report regarding EIA-projected domestic gas prices and world crude oil prices. Specifically, since the 1997 Annual Energy Outlook projected flat or declining energy prices from 2010 to 2015, extrapolated prices were assumed to be flat beyond 2015. Non-feedstock operating costs were derived from Chemical Market Associates, Inc. (1996).

3.1.2 Ethanol (E100)

Pathway. Ethanol was assumed to be produced domestically and to be made exclusively from corn through 2015. Over the 2016–2020 period, an increasing share of newly constructed facilities was assumed to use cellulosic biomass in place of corn. This transition applied *only* to new facilities and occurred at 20% per year (that is, in 2015, 100% of ethanol was produced from corn; in 2016, 80% of the ethanol produced in newly constructed facilities was from corn, etc.). By 2020, all *new* facilities were assumed to be based on cellulosic biomass, although older, corn-based plants continued to produce fuel.

Equipment Requirements. New facilities were initially (2007 through 2010) assumed to be of the dry-milling type, with a grind rate of 36,000 bushels of corn per day (to produce 30.9 million gal of ethanol per year). Beginning in 2011, corn-based facilities were assumed to be of the wet-mill type with a grind rate of 108,000 bushels per day (output of 89.1 million gal of ethanol per year).

All cellulosic ethanol plants were assumed to consume 1,000 bone-dry tons (BDT) of cellulosic biomass per day to produce 35.0 million gal of ethanol per year (for an ethanol yield of about 100 gal/dry ton). These plants are approximately five times larger than the capacity of cellulosic ethanol facilities considered in most other analyses. Larger capacity plants are required by the relatively large fuel demand by 3X vehicles in the period beyond 2015. If not for the higher capacity assumption, over 850 cellulosic ethanol plants of the more typical size would be required by 2030 in the high-market-share scenario.

Cost. Costs were developed from several sources. Capital costs of dry-milling plants were obtained from Stanley Consultants (1996), Liegois (1997), and Donnelly (1997). Capital costs of wet-milling plants were from Stanley Consultants (1996). Non-feedstock operating costs for corn facilities were obtained from Stanley Consultants (1996). The price of corn was assumed to be $2.75 per bushel in all years. Co-product prices were from Morris and Ahmed (1992). Capital, operating, and feedstock costs for cellulosic ethanol plants were obtained from Wiselogel (1996).

3.1.3 LPG

Pathway. Liquefied petroleum gas is produced as a by-product of natural-gas processing and crude-oil refining. At present, a bit more than half of the propane produced domestically[9] comes from natural-gas processing plants. Approximately 7% of the current U.S. LPG supply is imported, much of it from Canada (EIA 1997a; EIA 1997c). For this analysis, the imported fraction was assumed to rise to approximately 40% of LPG supply by 2015 on the basis of the findings of the 502(b) study of the U.S. DOE (U.S. DOE 1996; see Section 3.2.3). Imported LPG was assumed to be produced from natural gas.

Equipment Requirements. LPG is likely to be produced by expansion of petroleum refining and gas processing facilities — the current source of LPG — rather than manufactured in new plants. For this analysis, such expansions in the United States and other LPG exporting countries were assumed to be sufficient to supply LPG for 3X vehicles.

[9] Propane is the fraction of LPG used for motor fuel.

Cost. Capital cost estimates for LPG production facilities were derived from True (1996).

3.1.4 DME

Pathway. DME was assumed to be imported and produced from inexpensive, remote natural gas. The use of inexpensive gas and extremely large production facilities is a key factor in the economic viability of DME production (Fleisch and Meurer 1995).

Equipment Requirements. At present, DME is produced from natural gas via a two-step process in which methanol is produced first. In this analysis, DME was assumed to be produced directly from syngas (e.g., via the Haldor Topsøe/Amoco process). Since DME is not currently used as an automotive fuel, there are no full-scale facilities using this process. However, the scant available literature (Fleisch and Meurer 1995; Hansen et al. 1995) indicates that production volumes on the order of 580 million gal per year (42,000 B/D nameplate with an on-stream factor of 90%) would be necessary to make the process economical. This volume is equivalent to 5,600 MTPD, which is about twice the size of current world-scale methanol plants.

Cost. Capital costs for facilities to produce DME have been estimated only approximately in the literature. The published estimate of $1 billion for plant capital was used for this analysis (Fleisch and Meurer 1995).

Feedstock cost should be comparable with that for methanol and Fischer-Tropsch distillate. The literature on DME indicates that inexpensive natural gas is essential for economically supplying DME (Fleisch and Meurer 1995). In this analysis, the cost of remote natural gas was assumed to be $0.80 per million Btu in 2007, to increase linearly (by 30%) through 2015, and to stabilize beyond 2015.

3.1.5 LNG

Pathway. LNG was assumed to be made by cryogenically liquefying domestic natural gas. Though the process is common and large quantities of LNG are produced in this country and abroad (primarily for storage and transportation of gas), LNG is not currently used in significant quantities as an automotive fuel.

For this analysis, capital costs (i.e., for new wells) for the incremental supply of natural gas needed to satisfy 3X vehicle demand were estimated and attributed to transportation use. (In actual practice, however, incremental development of natural gas resources would likely be cross-subsidized by non-transportation users because of the commodity nature of the fuel. This applies to the *price* of gas, but does not reflect the full *cost* of the resource.)

Equipment Requirements. LNG was assumed to be produced from industrial-quality gas in 75,000-gal/day (gpd) liquefiers.

Cost. Cost estimates were developed from several sources. Capital costs of liquefiers and on-site storage tanks were obtained from Acurex Environmental Corporation (1994). Operating costs were obtained from Nepywoda (1997).

3.1.6 CNG

Pathway. Compressed natural gas was assumed to be produced from domestic resources. This pathway will require the development of additional gas supplies.

Equipment Requirements. New wells and gas processing plants will be needed to produce the incremental gas required to supply 3X vehicles.

Cost. The costs of additional wells, processing plants, and connections to major pipelines were estimated. These costs include both non-productive and productive wells. To develop these cost estimates, historical counts of domestic producing wells, new wells drilled, dry and productive wells, and average drilling cost per well were obtained from EIA (1996c) and the American Petroleum Institute (API 1995).

3.1.7 Hydrogen

Pathway. Hydrogen was assumed to be produced domestically, in centralized production facilities, throughout the analysis. From 2007 to 2020, all hydrogen was assumed to be made by steam reforming of natural gas. Beginning in 2021, an increasing share of new production was assumed to use solar-powered electrolysis of water. This process was assumed to be phased in over five years, accounting for an additional 20% of new capacity per year. As a result, 61% of all hydrogen was supplied by solar electrolysis in 2030 under the high-market-share scenario.

Equipment Requirements. Steam reforming of natural gas is a commercial technology. When solar electrolysis is introduced, photo-voltaic (PV) arrays and electrolyzers are the major pieces of capital equipment to be considered. The output of a typical solar hydrogen facility was assumed to be 100 million scf/day. Such a plant would be modular, consisting of several separate electrolyzer units, each rated at 100 MW. Solar arrays sufficient to supply approximately 500 MW of electricity to the electrolyzers have been assumed for each plant. Because of the intermittent nature of the solar resource, PV array capacity for a given plant would depend on location.

Cost. Reformer capital and operating costs were adapted from Blok et al. (1996). Costs for PV arrays and electrolyzers were obtained from Ogden and Delucchi (1993).

3.1.8 Biodiesel

Pathway. Biodiesel was assumed to be produced domestically from soybean oil in this study. Cheaper, higher-oil-content feedstocks (e.g., rapeseed oil) are being investigated in Europe; however, in the United States, the political climate is likely to favor soybean oil.

Soy diesel (methyl ester of soybean oil, or methyl soyate) was assumed to be mixed with 80% reformulated diesel to make a 20% blend of soy diesel fuel (B20). A credit for the by-product glycerine is important in estimating the cost of biodiesel (Flechtner and Gushee 1993). For this analysis, the price of glycerine was assumed to decline to $0.50/lb (about half of the 1997 price) after introduction of biodiesel, significantly reducing the value of the glycerine credit. Because of the limited market for glycerine, such a reduction in value over the course of the analysis is not unreasonable.

Equipment Requirements. Individual plants were assumed to produce approximately 3 million gal of methyl soyate per year (Gavett 1995). This amount is considerably less than the output of corn ethanol plants.

Cost. Capital and operating cost estimates were obtained from Gavett (1995). Feedstock is by far the largest cost component, representing approximately 75% of the cost of methyl ester (Booz-Allen & Hamilton 1994). Thus, little reduction in the cost of biodiesel is likely to come as a result of economies of scale or reductions in processing costs.

3.1.9 Fischer-Tropsch Diesel

Pathway. A 50% blend of Fischer-Tropsch distillate and reformulated diesel (F-T50) was assumed in this analysis. Blending of F-T diesel and petroleum diesel takes advantage of the F-T diesel's inherently low aromatics, low sulfur, and high cetane and reduces the burden on petroleum diesel to achieve mandated reductions in aromatics and sulfur. The reformulated diesel component of FT-50 was assumed to be derived from crude oil. The Fischer-Tropsch component was assumed to be imported and derived from remote natural gas.

Equipment Requirements. A F-T plant using the Shell Middle Distillate Synthesis process (Choi et al. 1996; Kramer 1997) was modeled. Although the process makes significant quantities of high-quality gasoline in addition to distillate, costs were attributed entirely to the desired distillate product. F-T plants were assumed to be built close to large, remote gas fields. As product demand increased, larger plants were assumed to predominate. Thus, by 2030, all plants were assumed to be either 50,000 or 100,000 B/D.

Cost. Costs were developed for three different plant sizes. Costs for a 100,000-B/D plant were from Singleton (1997) and Knott (1997). Costs for a 50,000-B/D plant were from Frank (1997), Singleton (1997), and Choi et al. (1996). Costs for a 5,000-B/D plant were from Singleton (1997) and Choi et al. (1996). Engineering cost estimates were calculated using RS Means Cost Guide (R.S. Means Company, Inc. 1996) and McKetta (1992).

3.1.10 Reformulated Gasoline and Reformulated Diesel

Capital costs of RFG and RFD were not estimated per se. Rather, both were assumed to be conventional fuels for which investment expenditures were already included within the reference case. Industry investment in refining was assumed to remain in its historical range of $3–6 billion per year over the course of the analysis (Energy Statistics Sourcebook 1995). Table 3.1 presents a breakdown of the U.S. petroleum industry's annual capital expenditures for the past 25 years.

Table 3.1 Domestic Capital Expenditures of the U.S. Petroleum Industry ($ billion)

Year	Refining	Exploration & Production	Marketing & Transportation	Other	Total Capital Expenditures
1973	1.104	7.212	1.818	0.916	11.050
1974	2.446	10.889	2.479	2.088	17.902
1975	1.981	9.915	4.576	2.152	18.624
1976	1.819	12.266	4.576	3.162	21.823
1977	1.324	18.400	3.628	3.339	26.691
1978	1.551	19.978	3.248	4.413	29.190
1979	2.735	31.495	4.434	6.055	44.719
1980	3.159	42.185	7.499	7.827	60.670
1981	5.131	57.830	9.513	10.523	82.997
1982	4.710	56.919	9.242	9.378	80.249
1983	4.142	39.473	9.233	5.679	58.527
1984	2.914	36.909	8.267	5.562	53.652
1985	2.992	33.371	6.290	5.199	47.852
1986	2.073	17.904	3.758	4.615	28.350
1987	2.180	14.171	4.409	4.428	25.188
1988	2.874	17.455	5.000	5.419	30.748
1989	3.167	15.481	4.531	6.226	29.405
1990	4.402	16.630	5.831	7.157	34.020
1991	6.741	17.462	6.603	5.922	36.728
1992	6.795	14.681	7.266	5.507	34.249
1993	5.367	13.909	7.191	5.051	31.518
1994	5.082	14.672	5.376	5.413	30.543
1995	4.903	15.775	5.442	6.361	32.481
1996	3.932	18.187	5.331	5.795	33.245
1997	3.907	20.096	5.901	5.899	35.803
Average	3.497	22.931	5.658	5.363	37.449

Sources: 1973–94: Energy Statistics Sourcebook, 1995. 1995-97: Oil and Gas Journal, 1997.

Because feedstock currently represents 70–75% of the price of gasoline and diesel, per-gallon costs of RFG and RFD were estimated as a function of the projected price of crude oil (EIA 1996a), with appropriate adjustments for future investment requirements. Both RFG and RFD were assumed to have a sulfur level of 100 ppm in this analysis. For gasoline, increased desulfurization was assumed to add $0.04/gal; for diesel, meeting this sulfur specification was assumed to add $0.08/gal. The higher diesel desulfurization premium reflects the higher cost (including more capital investment and higher operating pressures) of distillate hydrotreating relative to naphtha hydrotreating.

3.2 Fuel Distribution Assumptions

A five-step process was used to estimate costs associated with establishing PNGV fuels distribution infrastructure. First, the distribution system was characterized from production plant to refueling station for each potential PNGV fuel. This characterization and the known capabilities of the existing gasoline and diesel fuel distribution systems were then used to determine the extent to which existing systems could be modified to accommodate each new fuel. Third, based on estimated fuel demand by 3X vehicles (see Section 2), the requisite number of distribution and storage facilities (such as ocean tankers, storage tanks, trucks, and refueling stations, and pipeline miles) was estimated for each fuel in each year. Fourth, unit costs were estimated for each type of distribution equipment. Finally, annual capital requirements were calculated by assuming a 10-yr payback period and a 10% interest rate (in real-dollar terms). For hydrogen and NG pipelines, a sensitivity case, assuming a 50-yr payback period, was tested.

Tables 3.2–3.6 present the key assumptions used to estimate the size and capital cost of developing distribution systems for each of the candidate 3X fuels. The five tables are organized by stage in the fuel pathway. Assumptions regarding equipment requirements and costs of moving imported liquid fuels from overseas production centers to marine and inland terminals are presented in Table 3.2. Similar assumptions for moving domestically produced liquid fuels from domestic production centers to bulk terminals are presented in Table 3.3. Table 3.4 contains assumptions regarding equipment requirements and costs of moving all these liquid fuels from domestic inland and bulk terminals to service stations, while Table 3.5 contains comparable assumptions for moving gaseous fuels from domestic production centers to service stations. Finally, Table 3.6 presents the costs of adapting service stations to dispense the candidate fuels.

Several assumptions cut across all fuels. First, each service station that dispenses an alternative fuel was assumed to have originally dispensed 150,000 gal gasoline/month. Each such station was assumed to be converted to dispense 100,000 gal gasoline/month and 50,000 gasoline-gallon equivalents (GGE) per month of the alternative fuel. Use of this assumption facilitates comparisons among the fuels.

Second, with the exception of trucks, all equipment was assumed to have a useful life longer than the period of analysis (i.e., 2007–2030 for the high-market-share scenario

Table 3.2 Key Assumptions Relative to Transportation of Imported Fuels

Assumption	Methanol	DME	LPG
Imported ?	Yes	Same	Same
Percent imported	100	100	Varies over time: see text
Ocean Tankers ?	Yes	Same	Same
Capacity (million gallons)	20.4	Same	Same
Round-trips/yr	8	Same	Same
Conversion of existing tankers?	No	Same	Same
New tanker cost ($, millions)	41.2	Same	Same
Marine terminals ?	Yes	Same	Same
No. of marine terminals available	116	Same	Same
Turnover rate of storage tanks (number of times/yr)	18	Same	Same
Cost of converting existing tank ($/bbl)	3	NA	NA
New tank cost ($/bbl)	18	36	36
No. of truck racks/terminal	1	Same	Same
Truck rack cost ($, millions)	1.4	Same	Same
Truck movement from marine terminals ?	Yes	Same	Same
Trucks move first MMBD GGE to service stations?	Yes	Same	Same
Truck capacity (thousand bbls/yr)	240	Same	Same
Cost of converting existing truck ($000)	0	NA	NA
New truck cost ($000)	151	Same	Same
Pipeline movement from marine terminals ?	Yes	Same	Same
Pipelines move all imported fuel above 1 MMBD GGE to inland terminals?	Yes	Same	Same
Throughput volume (million bbls/yr)	80	Same	Same
Cost of converting existing pipeline ($000/mi)	40	NA	NA
New pipeline cost ($000/mi)	396	530	530
Average pipeline distance (mi)	547	Same	Same
Storage at inland terminals ?	See Table 3.4	Same	Same

Same = Used where values/answers for all fuels are the same. NA = Not applicable.

and 2012–2030 for the low-market-share scenario). Trucks, the key exception, were assumed to be replaced every 15 years.[10]

Third, all costs are in 1995 dollars. Costs were converted to 1995 dollars by using either the consumer or producer price index (as appropriate).

[10] Some of the equipment converted to handle the new fuel may be of an age where routine replacement or upgrade would be expected during the period of the analysis. Thus, one might argue that expenditures programmed for replacement or upgrade of gasoline distribution equipment would not be needed if alternative fuels were supplied instead of gasoline. The avoided cost of expanding the gasoline distribution system (to meet the larger demand forecast under a reference scenario without 3X vehicles) could be a legitimate offsetting cost. However, avoided costs were not considered in this analysis.

Table 3.3 **Key Assumptions Relative to Transportation of Domestically Produced Liquid Fuels**

Assumption	Ethanol	Methyl Soyate	LNG	LPG
Movement from domestic production centers to bulk terminals ?	Yes	Same	Same	Same
Percent by pipeline, barge, rail, truck	48/12/40/0	63/8/29/0	Initially all by truck; later rail & truck; see text	60/6/34/0
Movement by pipeline ?	Yes	Yes	No	Yes
Minimum fuel volume required before movement by pipeline begins?	Yes	No	NA	Yes
Minimum volume required (million bbls/yr)	80	NA	NA	80
Alternative mode until minimum met	Truck	NA	NA	Truck
Throughput volume (million bbls/yr)	80	NE	NA	80
Cost of converting existing pipelines ($000/mi)	0	0	NA	NA
New pipeline cost ($000/mi)	396	NA	NA	530
Average pipeline distance (mi)	564	NE	NA	604
Movement by barge ?	Yes	Yes	No	Yes
New tugboats required?	No	No	NA	No
Barge capacity (thousand bbls/yr)	1260	NE	NA	1130
Cost of converting existing barges	0	0	NA	NA
New barge cost ($000)	1260	NA	NA	1260
Movement by rail ?	Yes	Same	Same	Same
New locomotives or track required?	No	Same	Same	Same
Existing excess fuel-specific rail car capacity ?	No	No	No	Yes: see text
Rail car capacity (thousand bbls/yr)	109	129	194	420
New rail car cost ($000)	70	70	324	79
Movement by truck ?	Yes	No	Yes	Yes
Truck capacity (thousand bbls/yr)	240	NA	240	240
Cost of converting existing truck ($000)	0	NA	NA	NA
New truck cost ($000)	151	NA	372	151
Storage at bulk terminals ?	See Table 3.4	Same	Same	Same

Same = Used where values/answers for all fuels are the same. NA = Not applicable. NE = Not estimated because not necessary.

Finally, all costs are incremental to a baseline or business-as-usual level. Specifically, while the capital costs of providing new equipment or converting existing equipment are included, the costs of constructing the original gasoline distribution system are not.

3.2.1 Methanol (M100)

Pathway. Methanol is a liquid at normal temperatures and pressures and thus can be moved through the existing gasoline-distribution system, although some modifications will be required. As stated in Section 3.1, methanol was assumed to be made in foreign,

Table 3.4 Key Assumptions Relative to Storage of Liquid Fuels at Inland and Bulk Terminals and Subsequent Distribution to Service Stations

Assumption	Methanol	DME	LPG	Ethanol	Methyl Soyate	LNG
Storage at inland and bulk terminals ?	Yes	Same	Same	Same	Same	Same
Capacity per terminal (thousand bbls)	300	Same	Same	Same	Same	Same
Turnover rate of storage tanks (number of times/yr)	18	18	18	18	18	24
Cost of converting existing tank ($/bbl)	3	NA	NA	3	3	NA
New tank cost ($/bbl)	18	36	36	18	NA	102
No. of truck racks/terminal	1	1	1	1	NA	1
Truck rack cost ($, millions)	1.4	1.4	1.4	1.4	NA	1.4
Truck movement to service stations ?	Yes	Yes	Yes	Yes	Only as B20	Yes
Truck capacity (thousand bbls/yr)	240	240	240	240	NE	240
Cost of converting existing truck ($000)	0	NA	NA	0	NE	NA
New truck cost ($000)	151	151	151	151	NE	372
Service stations ?	See Table 3.6	Same	Same	Same	Same	Same

Same = Used where values/answers for all fuels are the same. NA = Not applicable. NE = Not estimated because not necessary.

Table 3.5 Key Assumptions Relative to Transportation of Domestically Produced Gaseous Fuels

Assumption	CNG	H_2
Movement to service stations by pipelines ?	Yes	Same
Percent moved by pipeline	100	Same
Can existing natural gas pipeline capacity be used?	Only a limited amount: see text	No
New pipeline capacity required (thousand miles/TCF)	76	Same
New pipeline cost ($/mile, thousands, average for all types)	615	1000
Service stations ?	See Table 3.6	Same

Same = Used where values/answers for all fuels are the same.

Table 3.6 Capital Cost of Adapting Service Stations to Dispense 50,000 GGE of Alternative Fuel per Month (1995$)

Fuel	Cost/Station ($\$10^3$)
Methanol	182
Ethanol	170
DME	261
LPG	204
CNG	928
Hydrogen	1,423
LNG	600
Biodiesel	0

remote areas where inexpensive NG will be available. Methanol would then be transported by ocean tanker to marine terminals in major U.S. ports. Because of unresolved technical problems (e.g., the potential for water pickup by methanol, cross-contamination of products, and materials compatibility), the initially small volumes of methanol shipped from marine terminals to service stations were assumed to be by truck rather than pipeline. Technical problems were assumed to be resolved by the time methanol displaces 1 MMBD of gasoline. At that scale, movement by pipeline from ports to inland bulk terminals should be economical.[11] At both low and high distribution volumes, the final leg in the distribution network, delivery from bulk terminals to service stations, would be by truck. (Some fuel would also be distributed from terminals to smaller bulk plants instead of going directly by truck to service stations. This possibility was not characterized.)

Figure 3.1 shows the methanol distribution system. Tables 3.2, 3.4, and 3.6 presented key assumptions used to characterize that system. Additional assumptions used to estimate equipment requirements and costs of methanol distribution are described below.

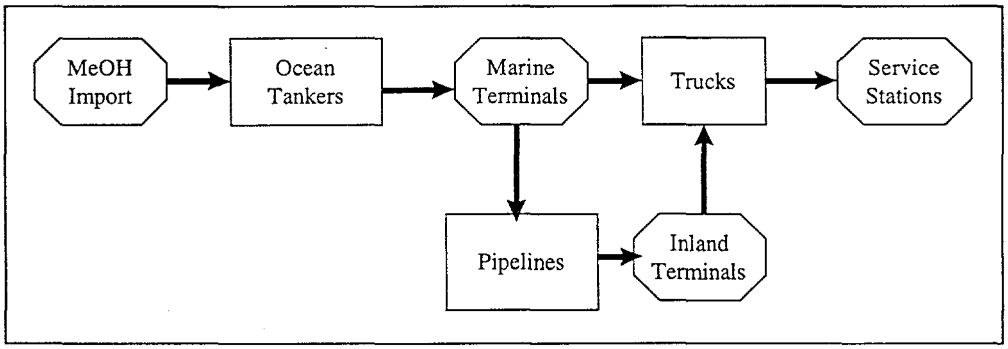

Figure 3.1 Methanol Distribution System

Equipment Requirements. Some gasoline distribution equipment was assumed to be converted to move methanol: trucks, storage tanks at marine and inland terminals, and, eventually, pipelines. This equipment can be converted because use of methanol will reduce gasoline distribution requirements. However, because twice as much (in

[11] Although this threshold may seem high, a prior analysis estimated that 75% of total U.S. travel is within 100 mi of existing marine terminals and can easily be served by truck distribution (U.S. DOE 1990).

physical volume) methanol is required to provide the same energy as gasoline, some new trucks, storage tanks, and pipelines would also be needed.

It was assumed that all ocean tankers used to transport imported methanol would be new (i.e., existing crude carriers would not be modified to ship methanol). This assumption is based on a prior DOE analysis (U.S. DOE 1989) that questioned whether existing tankers could be adequately cleaned, the amount of internal equipment that would need to be replaced, and the age of the tankers available for conversion.

For this analysis, it was assumed that new truck racks would be required at each marine terminal because of the significantly increased methanol fuel volumes that must be handled and to avoid cross-contamination of products. A prior analysis (U.S. DOE 1990) estimated that 116 existing marine terminals could be used for methanol imports. While somewhat dated, this estimate is still reasonable. Similarly, it was assumed that new truck racks would be needed at each inland terminal. An average capacity of 300,000 bbls (EEA 1990) was used to calculate the required number of inland terminals (and thus truck racks) for this analysis.

Existing gasoline service stations were assumed to be adapted to dispense approximately 100,000 gal/month methanol (50,000 GGE) and 100,000 gal/month gasoline. A prior analysis evaluated the service station equipment changes needed to dispense 50,000 GGE of M85/month at a total capacity of 150,000 GGE/month per service station. Equipment changes included, for example, additional refueling positions, new and modified hose dispensers, and new and displaced underground tanks (EEA 1995). Equipment changes estimated for this analysis of M100 fuel were adapted from that earlier analysis.

Cost. Capital cost estimates for the methanol distribution system were derived from several sources. Costs for new ocean tankers, averaging 60,000 dead-weight tons (DWT), were obtained from U.S. DOE (1989) and Zebron (1997). Costs for new and converted tanks at marine and inland bulk terminals were obtained from U.S. DOE (1990), as were costs for new truck racks. Costs for new trucks were from EA Energy Technologies Group (1991). On the basis of this latter study, it was assumed that there are virtually no costs associated with converting existing gasoline trucks to distribute methanol. Costs for new pipelines were from EA Energy Technologies Group (1991), while costs for converting an existing pipeline were assumed to be one-tenth the cost of constructing a new pipeline. Costs for conversion of service stations to dispense 50,000 GGE methanol were from EEA (1995).

3.2.2 Ethanol (E100)

Pathway. Like methanol, ethanol is liquid at normal temperatures and pressures and can be moved through the existing gasoline-distribution system, although some minor modifications may be required. Compared with methanol, ethanol's higher heat content provides an important advantage — approximately one-third less product must be moved to provide the same energy. As stated in Section 3.1, ethanol was assumed to be produced domestically. Movement from production centers to bulk terminals was assumed to be primarily by pipeline and rail. This assumption is consistent with a previous analysis (EA Energy Technologies Group 1991) that estimated that nearly 50% of ethanol distribution could be by pipeline and 40% by rail. In this analysis, trucks were assumed to play a somewhat larger role in ethanol distribution — for bulk movement until volumes reach the levels required to support movement by pipeline, as well as for delivery[12] from bulk terminals to service stations.

Figure 3.2 illustrates the ethanol distribution system. Tables 3.3, 3.4, and 3.6 presented key assumptions used in characterizing that system. The assumptions underlying the equipment requirements and costs of ethanol distribution are described below.

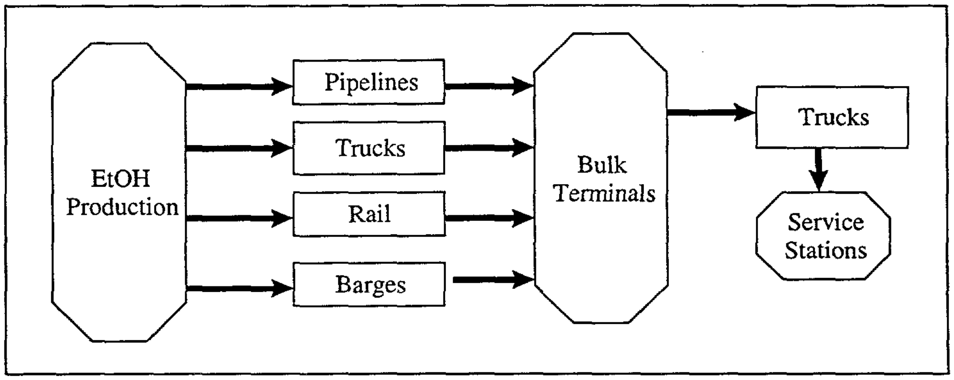

Figure 3.2 Ethanol Distribution System

Equipment Requirements. As with methanol, some gasoline distribution equipment — including pipelines, barges, trucks and storage tanks at bulk terminals — can be converted to move ethanol. This equipment can be converted because ethanol will reduce gasoline distribution requirements. However, because one gallon of ethanol contains about one-third less energy than a gallon of gasoline, 1.5 gal of ethanol is required to replace one gallon of gasoline. So, in addition to the converted equipment, new pipelines, barges, trucks, and storage tanks are also required.

All rail cars were assumed to be new (gasoline is not currently moved by rail; therefore, there are no gasoline rail cars to convert). No new locomotives or track should be needed, but new truck racks were assumed to be required at each bulk terminal. The number of bulk terminals was calculated by assuming an average capacity of 300,000 bbls per terminal (like methanol's inland terminals).

EEA has evaluated the equipment changes needed to permit gasoline service stations to dispense approximately 75,000 gal/month ethanol (50,000 GGE E85) and

[12] Some fuel may be distributed from terminals to smaller bulk plants instead of going directly by truck to service stations. This part of the pathway was not characterized in this analysis.

100,000 gal/month gasoline. Changes included, for example, additional refueling positions, new and modified hose dispensers, and new and displaced underground tanks (Energy and Environmental Analysis 1995). For this study, EEA's analysis was adapted to estimate the equipment changes required for E100.

Cost. Capital cost estimates were derived from several sources. Costs for new pipelines were obtained from EA Energy Technologies Group (1991). Unlike methanol, the cost for converting an existing pipeline was assumed to be zero (likewise for converting an existing barge or truck). Costs for new rail cars and barges were obtained from EA Energy Technologies Group (1991) and Zebron (1997), respectively. Costs for new trucks were from EA Energy Technologies Group (1991). Costs for new and converted tanks and truck racks at bulk terminals were obtained from U.S. DOE (1990). Conversion costs for service stations to dispense 50,000 GGE of ethanol per month were from Energy and Environmental Analysis (1995).

3.2.3 LPG

Pathway. LPG is a gas at normal temperatures and pressures, but it can be stored in liquid form under modest pressure. Although it is possible that some displaced gasoline infrastructure capacity might be converted to LPG use (e.g., pipelines, since gasoline pipelines operate under pressure), prior analyses (e.g., EA Energy Technologies Group 1992) generally have assumed that gasoline facilities will not be converted to LPG. The current LPG distribution system has excess off-peak capacity because of fluctuations in seasonal demand. However, this "excess capacity" is needed to handle peak LPG demand; thus (except where noted below), it was not assumed to be available to move or store LPG for 3X vehicles.

A mix of both imported and domestic LPG was assumed to supply the fuel needs of 3X vehicles. Except for Canadian imports, imported LPG was assumed to be shipped by ocean tanker. EIA's AEO 1997 (EIA 1996a) estimated that in 1996 approximately 3% of all U.S. LPG was from non-Canadian imports. By 2015, EIA forecasts that percentage to triple, to about 9% (under the EIA reference case, that is, no LPG demand by 3X vehicles). In this analysis, EIA's imported and domestic shares were used through 2015. Beyond 2015, imported market shares must include a growing component of transportation sector fuel use. For this analysis, that component was supplied by results of a recent DOE study on the market potential of alternative fuel use by motor vehicles (DOE 1996). In one case of that study, non-Canadian imports accounted for about 40% of the transportation sector's use of LPG (1.7 MMBD LPG) in 2015. Thus, in this analysis, the shares of non-Canadian imports were interpolated between 9% (for volumes of transportation sector LPG use of 159,000 bbl/d, EIA's 2015 estimate) and 40% (for 1.7 MMBD transportation sector LPG use).

As in the methanol analysis, trucks were assumed to move imported LPG from marine terminals to service stations until LPG displaces 1 MMBD of gasoline. At that point, pipelines were assumed to enter the LPG distribution network, moving the fuel to inland terminals from which trucks would deliver it to service stations. In reality, however, even under the high-market-share scenario, the volume of imported LPG never reaches 1 MMBD. Thus, no pipeline movement was assumed for imported LPG.

For domestically produced LPG, 60% was assumed to be moved from production centers to bulk terminals by pipeline, 34% by rail, and the rest by barge. These shares were based on a prior analysis of LPG movement (EA Energy Technologies Group 1992). Trucks were assumed to move LPG until volumes are sufficient to support the construction of one pipeline from domestic production centers. Trucks were also assumed to be used to complete the delivery of LPG from bulk terminals to service stations. As with other fuels, some fuel may also be distributed from terminals to smaller bulk plants instead of going directly by truck to service stations. This part of the pathway was not included in this analysis.

Figure 3.3 illustrates the LPG distribution system. Tables 3.2–3.4 and 3.6 presented key assumptions used to characterize that system. The assumptions underlying the equipment requirements and costs of LPG distribution are described below.

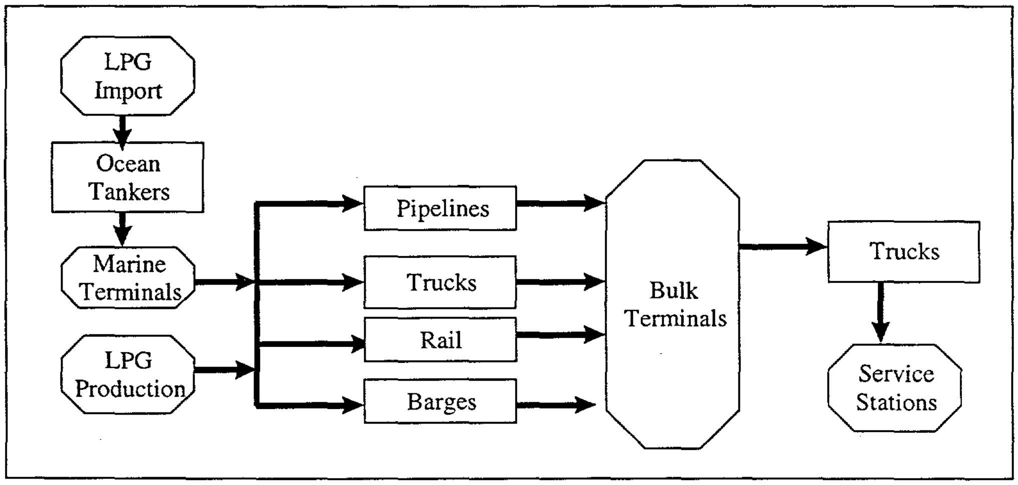

Figure 3.3 LPG Distribution System

Equipment Requirements. With the exception of rail tank cars, the LPG fuel distribution system (from ocean tankers to trucks) was assumed to be entirely new. A prior analysis by EA Engineering (EA Energy Technologies Group 1992) found that the current population of LPG rail tank cars is very large, with sufficient excess capacity to move over 80 million bbl/yr. This excess capacity is well above the volumes of LPG projected to be moved by rail in the low-market-share scenario and until the latter years in the high-market-share scenario. Thus, new rail cars are only required in the outyears of the high-market-share scenario.

Again, service stations were assumed to be converted so that the equivalent of 50,000 GGE of LPG per month could be dispensed. All LPG-specific equipment at service stations was assumed to be new.

Cost. The capital cost estimates for LPG were derived from several sources. The costs of LPG ocean tankers were approximated from the costs of methanol tankers. LPG tankers are likely to be somewhat more expensive (because LPG is stored under pressure), but no information on the cost difference is available. Costs for new and converted tanks at marine, inland and bulk terminals, for new pipelines, and for new rail cars were obtained from EA Energy Technologies Group (1992). Costs for new truck racks and new trucks were from U.S. DOE (1990) and EA Energy Technologies Group (1991), respectively. Costs for new barges were from Zebron (1997). Finally, costs for conversion of service stations to dispense 50,000 GGE of LPG were from EEA (1995).

3.2.4 DME

Pathway. The DME fuel distribution system was assumed to be very similar to that for imported methanol and LPG. Like methanol and LPG, DME was assumed to be shipped on ocean tankers to marine terminals and then transported by truck to service stations until it displaces 1 MMBD gasoline. Beyond this level, DME was assumed to be moved by pipeline to inland terminals and then by truck to service stations. Figure 3.4 illustrates the DME distribution system. Tables 3.2, 3.4, and 3.6 presented key assumptions for the DME pathway. The assumptions underlying the equipment requirements and costs of DME distribution are described below.

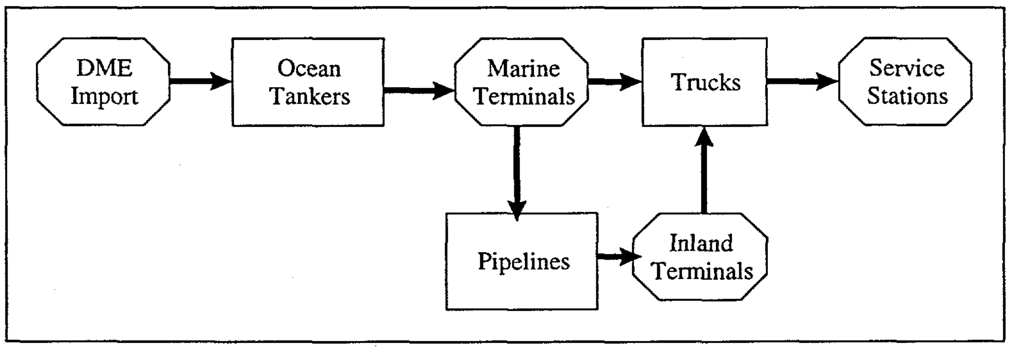

Figure 3.4 DME Distribution System

Equipment Requirements. The physical properties of DME are similar to those of LPG. Like LPG, DME can be stored in liquid form under modest pressure. Because little information exists on DME handling and distribution, DME equipment requirements were approximated on the basis of LPG equipment requirements.

As with LPG, some displaced gasoline infrastructure capacity could be converted to distributing DME. However, as in the LPG analysis, it was assumed that conversion of gasoline infrastructure would not occur. Although DME could make use of converted LPG facilities, this analysis assumed that DME would replace gasoline, not LPG. Thus, all DME fuel distribution requirements (tankers, trucks, pipelines, etc.) were assumed to be new.

Again, gasoline service stations were assumed to be converted to dispense 50,000 GGE of DME per month. All DME-specific equipment at service stations was assumed to be new.

Costs. Except for the cost of converting service stations, capital costs for DME distribution equipment were assumed to equal those for LPG. Because the heating value of DME is approximately 81% that of LPG, nearly 25% more DME must be supplied to equal the energy in 1 gal of LPG (which is roughly equivalent to the energy in 0.75 gal of gasoline). Therefore, the pumps, tanks, and other equipment at service stations dispensing 50,000 GGE DME will require 25% additional capacity, as compared with an energy-equivalent volume of LPG. Thus, EEA's estimate of LPG station conversion cost (EEA 1995) was adapted to develop an estimate for DME station conversions.

3.2.5 LNG

Pathway. LNG was assumed to be produced domestically at centralized production facilities. Because of the need for cryogenic storage, distribution was assumed to be via a separate distribution system (i.e., neither the existing gasoline nor natural gas distribution systems would be used), not unlike the situation today. In the United States, small volumes of LNG are currently moved by truck, and rail shipment to bulk terminals may soon begin. For this analysis, it was assumed that LNG would continue to be moved by these modes from central production facilities to bulk terminals and then to service stations by truck. Because of the lack of prior analyses of the potential mode split of LNG movements, it was assumed that the initial 0.5 MMBD of LNG would be moved solely by truck. When LNG demand exceeds that level, it was assumed that two-thirds of the incremental movement would be by truck and one-third by rail. By using these assumptions, approximately one-fourth of total LNG demand was assumed to be moved by rail in 2030 under the high-market-share scenario.

Figure 3.5 shows the LNG distribution system. Tables 3.3, 3.4, and 3.6 presented key assumptions used to characterize that system. The assumptions underlying the equipment requirements and costs of LNG distribution are described below.

Equipment Requirements. As indicated above, all facilities and equipment required to move LNG were assumed to be new (trucks, rail cars, storage tanks, etc.). Again, service station conversions were assumed to dispense 50,000 GGE of LNG and

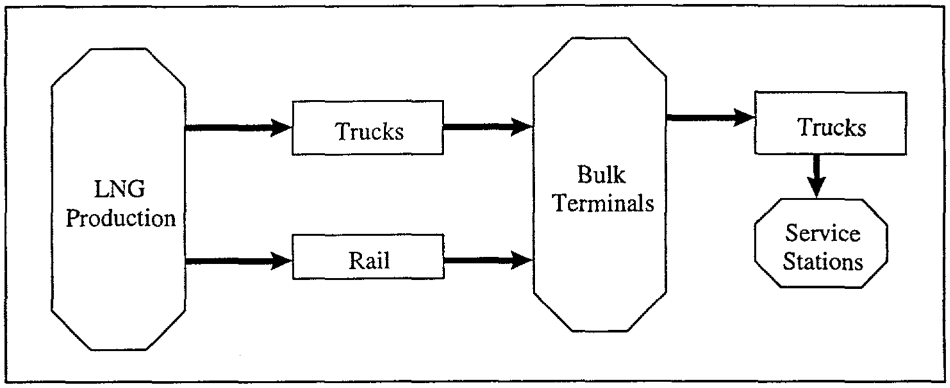

Figure 3.5 LNG Distribution System

100,000 gal of gasoline per month. All LNG-specific equipment at service stations was assumed to be new.

Cost. Capital cost estimates for LNG were derived from several sources. Costs for new trucks and new rail cars were obtained from Acurex (1992 and 1994). Costs for new truck racks were from U.S. DOE (1990). Costs for conversion of service stations to dispense 50,000 GGE of LNG were adapted from estimates developed by Acurex Environmental Corporation for other LNG volumes (1992).

3.2.6 CNG

Pathway. All natural gas was assumed to be produced domestically and moved by pipeline to service stations. The existing natural gas distribution system was assumed to be used, with capacity added to meet demand increases over time. Figure 3.6 illustrates the CNG distribution system. Tables 3.5 and 3.6 presented key assumptions for the CNG pathway. The assumptions underlying the equipment requirements and costs of CNG distribution are described below.

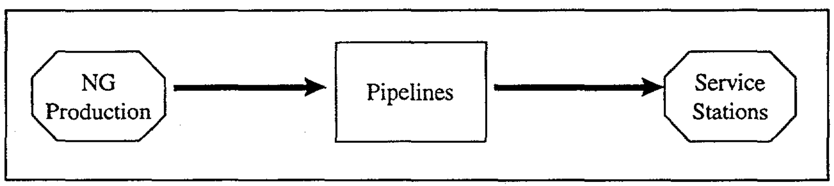

Figure 3.6 Natural-Gas Distribution System

Equipment Requirements. It was assumed that new pipeline capacity would be required once motor-vehicle demand exceeded 0.31 trillion cubic feet (TCF). This threshold was based on EIA's AEO 1997, which forecast 0.31 TCF motor-vehicle use of CNG in 2015 out of total U.S. NG demand of 30 TCF. Because EIA projected capacity additions to the NG pipeline system to meet these demand levels, vehicular demand for CNG above those levels (e.g., all CNG demand by 3X vehicles reaches 2.7 TCF in the high-market-share scenario) was assumed to require even more capacity additions.

In the late 1980s, there were 250,000 mi of transmission lines, 900,000 mi of main distribution lines, and 520,000 mi of service lines capable of moving 22 TCF (EA Mueller 1991; R.F. Webb Corporation 1992). Assuming a linear relationship between pipeline mileage and the volume of NG delivered, new capacity should be required at the rate of 76,000 mi/TCF (1.67 million mi/22 TCF). Although a linear relationship may be overly simplistic, a detailed micro-level analysis would be required to develop a more accurate assessment of the length and size of pipelines required to support the additional natural gas movement. Such analysis is beyond the scope of this effort.

Pipeline expansion typically requires additional storage facilities, which may or may not be included in pipeline cost estimates. Some of the costs cited below for the NG distribution system clearly include expanded storage facilities; for others, it is not clear whether such costs are included. This analysis assumed that pipeline costs included additional storage and thus did not specifically account for expanding storage capacity.

Again, gasoline service stations were assumed to be converted to dispense 50,000 GGE of CNG per month. All CNG-specific equipment at service stations was assumed to be new.

Cost. Capital cost estimates for CNG were derived from several sources. NG pipeline costs vary by size of pipeline, distance, and location. For this analysis, it was assumed that transmission lines would be 32 in. in diameter, distribution lines would be 12 in., and service lines would be 2 in. (Williams 1996). Distance and location were assumed to be comparable to historical patterns. Thus, transmission lines were assumed to cost $900,000/mi, main distribution lines were assumed to cost $780,000/mi, and service pipelines were assumed to cost $190,000/mi (EA Mueller 1991; Williams 1996). Using the historical share of mileage by the three pipeline types, a weighted-average cost of new NG pipeline was calculated at $615,000/mi.

The cost of converting a gasoline service station to dispense 50,000 GGE of CNG was obtained from EEA (1995).

3.2.7 Hydrogen

Pathway. All hydrogen required by 3X vehicles was assumed to be produced in the United States from natural gas and solar electrolysis of water and to be moved in gaseous form (by pipeline) from central production facilities to service stations. An all-new distribution system was assumed; no existing facilities (e.g., no NG distribution facilities) would be converted. Figure 3.7 characterizes the H_2 distribution system. Tables 3.5 and 3.6 presented key assumptions for the pathway. The assumptions underlying the equipment requirements and costs of H_2 distribution are described below.

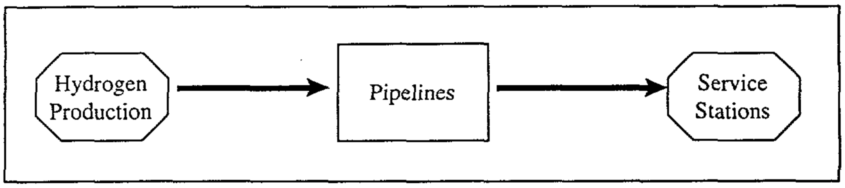

Figure 3.7 Hydrogen Distribution System

Equipment Requirements. As indicated above, the entire pipeline distribution system was assumed to be new. Pipeline miles were assumed to equal the number estimated for the CNG pipeline system, but at increased compression. H_2 pipelines of the same length and size can carry the same amount of energy as NG pipelines, but the required compressor capacity is much greater (3.0–3.5 times as great) because a cubic foot of H_2 contains far less energy than a cubic foot of NG at normal temperature and pressure. H_2 storage requirements were assumed to be much less than those for NG because seasonal demand for hydrogen for transportation use should vary far less than the seasonal demand for NG.

Again, gasoline service stations were assumed to be converted to dispense 50,000 GGE of H_2 per month. All H_2-specific equipment at service stations was assumed to be new.

Cost. Capital cost estimates for H_2 were derived from several sources. The cost of H_2 pipelines (including compressors) was based on work by Williams (1996) and Ogden et al. (1997). According to Williams (1996), H_2 pipelines will be similar to NG pipelines but will cost more, simply because higher pressures are required for H_2 transmission. Williams (1996) indicates that the cost per unit of pipeline will be 50% more and larger compressors will be needed. In this analysis, a cost of $1 million/mi was assumed for H_2 pipelines (Ogden et al. 1997). This cost is consistent with Williams' 50% cost increment vis a vis NG pipelines (using this study's separately derived cost estimate for NG pipeline).

The cost of converting a service station to dispense 50,000 GGE of H_2 was based on Williams (1996) and Berry et al. (1995). Neither reference specifically estimated the conversion cost for dispensing 50,000 GGE of H_2; thus, cost was interpolated from other H_2 dispensing volumes, assuming proportionality to volume throughput. The resulting conversion cost of $1.423 million/station assumed compression of H_2 to above 6000 psi for on-board vehicle storage.

3.2.8 Biodiesel

Pathway. Methyl soyate, produced from the transesterification of soy oil, was assumed to be produced in the United States, specifically in PADD II (the Midwest), and moved from production plants to bulk terminals by pipeline (63%), barge (8%), and rail (29%). Blending with conventional diesel oil, to an 80% diesel and 20% methyl soyate blend (or B20), was assumed to occur at bulk terminals, from which the fuel was assumed to be transported like conventional diesel (Figure 3.8). Mode splits were based on previous analysis of the movement of ethanol from the Midwest (PADD II) to the rest of the United States (EA Energy Technologies Group 1991).

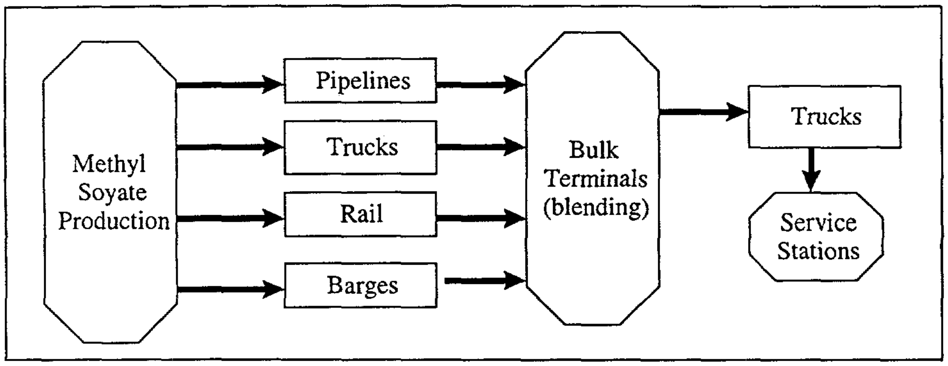

Figure 3.8 Biodiesel Distribution System

Equipment Requirements. For biodiesel, only the movement and storage of methyl soyate was assumed to require new equipment. Once methyl soyate is blended with diesel, the movement of biodiesel was assumed to use the same facilities as gasoline and diesel fuel. Because biodiesel has a higher energy content than the gasoline displaced in the PNGV analysis, no additional distribution capacity (including at service stations) should be required. Likewise, no significant changes in service station equipment should be required.

It was assumed that no additional pipeline or barge capacity would be required to move methyl soyate because there should be less of it moved than the gasoline displaced (methyl soyate has higher energy content than gasoline), and it comprises only 20% (by volume) of the biodiesel blend. Movement by rail was assumed to require new rail cars because gasoline is not currently moved by rail (diesel is moved by rail, but methyl soyate displaces gasoline, not diesel). At bulk terminals, no new storage capacity or truck tracks should be needed because idled gasoline facilities and equipment could be retrofit to store methyl soyate (prior to blending with diesel). Note that cross-contamination of products is less of a concern with biodiesel than with other fuels.

Cost. Distribution of methyl soyate incurs two principal costs: for new rail cars and for retrofitting storage tanks at bulk terminals. This analysis used the same costs for methyl soyate as were estimated for ethanol by the EA Energy Technologies Group (1991).

3.2.9 Reformulated Diesel and Fischer-Tropsch Diesel

The pathways, equipment requirements, and costs to distribute these fuels were assumed to be essentially the same as those for conventional gasoline and diesel fuel. Thus, no incremental capital requirements were assumed. Similarly, no incremental capital requirements were assumed for distributing RFG for 3X vehicles.

3.3 Assumptions and Methodologies Used to Calculate Unit Costs

Estimated unit or per-gallon costs for each fuel are presented in Section 3.4.3. This section presents the methodologies and assumptions used to derive those estimates. Per-gallon costs include capital costs (as estimated in this study), operating costs (including feedstock), and taxes. Capital costs reflect the incremental costs incurred to accommodate fuel demand by 3X vehicles. Converted to a per-gallon basis, these costs were computed as annual capital costs divided by annual fuel production. Operating cost estimates were derived from various sources, as explained below. Operating costs were already on a per-gallon basis. All costs for each fuel were converted to a gasoline-equivalent gallon for comparison purposes.

As one might expect, the way per-gallon costs were calculated in this study may not be the same as the way in which the fuels industry determines a fuel's price. Pricing of fuels is a sophisticated process affected by capital costs, investors' expectations for a return on their capital investments, expected short- and long-term profits, marketing strategies, fuel taxes, and so on. The cost estimation process used in this study was not intended by any means to predict potential prices of candidate 3X fuels. Instead, the intent was to put capital cost estimates for the different fuels into a common unit (a gasoline-gallon equivalent, or GGE) so readers can compare them with other estimates as well as with current prices. This comparison should put the individual estimates into perspective, both relative to one another and to the costs consumers already bear for existing fuels.

3.3.1 Fuel Production Costs

Fuel production costs (in $/GGE) were calculated as the sum of per-gallon capital costs (annual capital cost divided by annual fuel production), feedstock operating costs, and non-feedstock operating costs. For biodiesel and corn-based ethanol, co-products account for a significant cost element. In these cases, the value of co-products was taken as a cost credit and deducted from the per-gallon cost of the fuel.

For the commodity fuels — gasoline, diesel, and CNG — per-gallon prices were estimated by using projected wellhead prices for crude oil and natural gas from the 1997 Annual Energy Outlook (EIA 1996a).

3.3.2 Transportation Costs of Liquid Fuels

Capital Costs of Distribution Equipment. As indicated above, the per-gallon capital cost for the transportation of a given liquid fuel was calculated as total annual capital cost divided by annual fuel use. As stated previously, capital cost was incremental to a reference case, which, in this portion of the analysis, included RFG-fueled 3X vehicles. For liquid fuels that were assumed to use existing gasoline distribution equipment (methanol and ethanol), the cost of converting that equipment was included in the capital cost calculation, but the cost of constructing the original (gasoline distribution) equipment was not. However, capitalization of the original gasoline equipment was included for methanol and ethanol per-gallon cost estimates.

Operating Costs of Ocean Tankers. A DOE report (DOE 1989) estimated the operating cost of a methanol tanker to range from well less than $0.01/gal to $0.04/gal (in 1989 dollars). This analysis assumed a cost of $0.025/gal (1995 dollars), which was applied to all liquid fuels moved by ocean tanker (i.e., methanol, LPG, and DME).

For alternative fuels, the cost attributable to ocean tanker operation is included under fuel distribution in the tables in Section 3.4.3. For gasoline and diesel fuel, this cost was assumed to be part of feedstock cost, because the cost of crude oil acquisition by refiners usually includes ocean transportation.

Operating Costs of Movement to Service Stations. The operating cost associated with moving any liquid fuel from marine terminal or domestic production center to service station was assumed to be similar to that for gasoline, on a volumetric basis. For gasoline, this cost was estimated to be $0.105/gal. This estimate is based on API and EIA data (API 1990; API 1996; EIA 1997b). Of that cost, $0.013/gal was estimated to be for capitalization of the equipment used to move gasoline from marine terminals or domestic production centers to the service stations. Thus, for all liquid fuels, the operating cost for movement from marine terminals or domestic production centers is $0.092/gal. For those liquid fuels that make use of the existing gasoline (or diesel fuel) distribution system, $0.013/gal in capital costs must be added to the above-estimated capital costs. Table 3.7 summarizes these assumptions.

Table 3.7 Per-Gallon Cost of Transporting Liquid Fuels from Marine Terminals or Domestic Production Centers to Service Stations (1995 ¢/physical gal)

Fuel	Capital Cost of Gasoline System (¢/gal)	Incremental Capital Cost of Alternative Fuel Systems (¢/gal)	Operating Cost of All Systems (¢/gal)
Gasoline	1.3	NA	9.2
Methanol	1.3	Varies by year	9.2
Ethanol	1.3	Varies by year	9.2
LPG	NA	Varies by year	9.2
DME	NA	Varies by year	9.2
LNG	NA	Varies by year	9.2
B20	1.3	Varies by year	9.2

NA = Not applicable.

3.3.3 Transportation Costs of Gaseous Fuels

CNG. The cost of moving natural gas from NG processing plants to service stations depends to a significant extent on whether that movement is via an existing or a new distribution system. Using EIA's projections of vehicular natural gas use (0.31 TCF by 2015) as a threshold, CNG demand by 3X vehicles was categorized as either less than or greater than existing system capacity. For demand levels less than or equal to 0.31 TCF, EIA's estimates of the transportation and distribution (T&D) margins for natural gas pipelines were used directly. Those projections can be found in EIA's AEO 1997 (EIA 1996a). For demand levels above 0.31 TCF, transportation costs must also include the capital costs of building new pipelines (see Section 3.2.6), as well as operating costs associated with all distribution facilities and equipment. For this analysis, the capitalization component of new pipeline operating costs was estimated by using historical data on natural gas transportation and distribution (T&D) margins (EIA 1995). Thus, for vehicular CNG use above 0.31 TCF, estimated capital costs were combined with 77% of EIA's natural gas T&D margins to yield total NG transportation costs.

Hydrogen. Because all hydrogen pipelines were assumed to be new, the process used to estimate capital costs was straightforward and uncertainties were kept to a minimum (see Section 3.2.7). Not so for operating costs. Given the greater compression requirements of hydrogen pipelines, operating costs should be greater than those for natural gas pipelines. However, there are no reliable estimates of those costs. For this analysis, the operating costs estimated for new NG pipelines (i.e., EIA's T&D margins less capitalization costs) were used for hydrogen pipelines as well.

3.3.4 Service Station Costs

A gasoline markup of $0.087/gal, reflecting the capital and operating costs of service stations, was calculated from the API and EIA data referenced above. For alternative fuels, capitalization costs for station conversion were added to this figure. All station conversion costs were assigned to alternative fuels (i.e., costs were not spread over the gasoline dispensed at the station).

No incremental operating costs were assumed for any liquid fuel. This assumption is consistent with the findings of prior analyses of methanol, ethanol, LPG (and thus, by extension, DME), and LNG (EEA 1995; Acurex Environmental Corporation 1992).

For CNG, incremental O&M costs of $0.116/GGE were assumed (EEA 1995). For H_2, incremental O&M costs are expected to be somewhat higher than $0.116/GGE because H_2 compressors operate at higher pressure than CNG compressors. This was not confirmed by the literature, however. Williams projected O&M costs of approximately $0.06/GGE (1996), nearly half EEA's estimate for CNG. It is not clear why the two studies differ so markedly. Nevertheless, given the great uncertainty in H_2 estimates in general, this analysis assumed the same incremental service station O&M costs for H_2 as for CNG.

3.3.5 Taxes

According to the American Petroleum Institute, total U.S. gasoline taxes average $0.424/gal (API 1996). Total taxes include federal, state, and local taxes. Federal diesel taxes are \$0.184/gal, and the median value of state diesel taxes is \$0.19/gal (Davis 1997). On a GGE basis, these taxes equate to \$0.391/gal. With the exception of diesel-like fuels, all fuels considered in this analysis were assumed to be taxed like gasoline,[13] and all diesel-like fuels were assumed to be taxed like diesel. All taxes are on a per-Btu basis.

3.4 Capital Requirements

Annual and cumulative capital costs of fuel production and distribution infrastructure and per-gallon costs are presented below. Capital requirements were annualized by using a 10-yr payback and a 10% real-term interest rate. For NG and H_2 pipelines, a 50-yr payback was assumed to better reflect the life expectancy of pipelines as compared with other components of fuel distribution systems.

3.4.1 Facility and System Requirements

Fuel Production Facilities. Table 3.8 summarizes the main components of the physical production systems required to meet the fuel demands of 3X vehicles. Entries are the cumulative numbers of plants/facilities and expected production capacities of each fuel through 2030. On a Btu basis, production capacities are equivalent for all except the two blended fuels — B20 and F-T50 — for which production need cover only the blended fraction.

Fuel Distribution Equipment. Tables 3.9 and 3.10 provide cumulative estimates of the equipment required to distribute the various liquid and gaseous fuels through 2030. Except for trucks, values shown are also estimates of the total equipment required to distribute the various fuels in that year. Annual estimates of equipment requirements were developed, but they are not presented here.

3.4.2 Total Capital Costs

Fuel Production. Table 3.11 presents estimates of the annual cost of phasing in the production facilities described in Table 3.8. Figure 3.9 presents the same data graphically. As shown in the figure, hydrogen is by far the most expensive of the fuels considered, followed by DME and ethanol. At the other end of the spectrum, Fischer-Tropsch diesel, B20, and LPG are the least expensive. In the case of B20, the low percentage of methyl soyate in the biodiesel blend greatly reduces incremental capital costs. As has been noted, all costs are incremental to an RFG-fueled reference case. Thus, 80% of the blended B20 fuel adds no capital cost.

Table 3.12 presents estimates of incremental capital requirements for building fuel production facilities cumulatively through 2015, 2020, 2025, and 2030. Again, hydrogen, DME, and ethanol are the most costly of the alternatives examined, while B20, F-T50, and LPG are the least costly.

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[13] Ethanol tax incentives (currently equivalent to \$0.51/gal in federal tax exceptions) are not included.

Table 3.8 Production Facilities and Capacity Required to Supply Demand for 3X Fuel in 2030

	High-Market-Share Scenario		Low-Market-Share Scenario	
Fuel	Capacity	Facilities	Capacity	Facilities
M100	45.1 x10^9 gal/yr	40 plants @ 10K MTPD 5 Plants @ 2500 MTPD	13.4 x 10^9 gal/yr	11 plants @ 10K MTPD 5 Plants @ 2500 MTPD
E100	32.4 x10^9 gal/yr	1,168 cellulosic plants 21 wet mill plants 5 dry mill plants	10.1 x 10^9 gal/yr	374 cellulosic plants 4 wet-mill plants No dry-mill plants
LPG	30.0 x 10^9 gal/yr	280 domestic projects 40 foreign projects	9.3 x 10^9 gal/yr	117 domestic projects 6 foreign projects
DME	37.6 x 10^9 gal/yr	65 plants	11.6 x 10^9 gal/yr	20 plants
LNG[a]	33.8 x 10^9 gal/yr	1,377 plants	10.5 x 10^9 gal/yr	428 plants
CNG[b]	2.7 tcf/yr	25,385 wells	0.7 tcf/yr	7,878 wells
H_2	8.4 tcf/yr	59 NG plants @1.7 x 10^8 scf/d H_2; 155 solar plants @ 1 x 10^8 scf/d H_2	2.6 tcf/yr	11 NG plants @1.7 x 10^8 scf/d H_2; 60 solar plants @ 1 x 10^8 scf/d H_2
B20	4.1 x 10^9 gal/yr (methyl soyate)	1,359 plants	1.3 x 10^9 gal/yr (methyl soyate)	423 plants
F-T50	10.6 x 10^9 gal/yr (FTD)	1 plant @ 0.7 x 10^9 gal/yr 7 plants @ 1.4 x 10^9 gal/yr	2.9 x 10^9 gal/yr (FTD)	2 plants @ 0.7 x 10^9 gal/yr 1 plant @ 1.4 x 10^9 gal/yr

[a] Requires additional NG processing plants, the costs of which are included in Section 3.4 estimates.
[b] Requires additional NG wells (see CNG), the costs of which are included in Section 3.4 estimates.

Fuel Distribution. Figure 3.10 presents annual capital costs for developing the infrastructure to distribute fuels under the high- and low-market-share scenarios. Table 3.13 presents those costs cumulatively through the years 2015, 2020, 2025, and 2030 for both scenarios.

The cumulative cost of building the infrastructure for biodiesel is insignificant relative to the other fuels: \$32 million vs. \$8 billion for ethanol, the next least expensive alternative under the high scenario. Infrastructure costs for liquid fuels (ranging from \$8 to \$30 billion under the high scenario) are significantly less than those for gaseous fuels (ranging from \$144 to \$268 billion under that scenario). This relationship holds in all years of both scenarios and remains true even when the payback period for natural gas and hydrogen pipelines is raised from 10 to 50 years. With a 50-yr payback, capital costs for CNG and H_2 distribution systems drop (to \$103 and \$187 billion, respectively, under the high scenario), but they are still far higher than those for liquid fuels. The same pattern occurs under the low scenario.

Total Costs. For most of the fuels considered in this analysis, production costs far exceed distribution costs (see Tables 3.12 and 3.13). This phenomenon is particularly true for B20 (where production costs are approximately two orders of magnitude higher

Table 3.9 Distribution Facilities Required to Supply Liquid Fuel Demand of 3X Vehicles in 2030[a]

	Ocean Tankers	Terminal Tankage (10^6 bbl)	Truck Racks	Trucks[b]	Pipelines (mi)	Rail Cars	Barges	Service Stations
Low-Market-Share Scenario								
M100	86	18.4	52	1,410	0	0	0	11,360
E100	0	13.8	46	1,338	846	907	24	11,360
LPG	11	12.4	41	1,290	846	0	10	11,360
DME	74	15.8	52	1,214	0	0	0	11,360
LNG	0	10.4	35	2,042	0	117	0	11,360
B20	0	1.6	0	0	0	67	0	0
High-Market-Share Scenario								
M100	275	77.1	176	4,653	2,188	0	0	36,572
E100	0	44.3	148	3,781	2,707	2,920	76	36,572
LPG	72	40.0	121	3,441	1,993	159	24	36,572
DME	237	66.3	168	4,006	1,914	0	0	36,572
LNG	0	33.6	113	6,189	0	1,063	0	36,572
B20	0	5.1	0	0	0	215	0	0

[a] Physical number of new or converted facilities or equipment.
[b] Including replacements.

Table 3.10 Distribution Facilities Required to Supply Gaseous Fuel Demand of 3X Vehicles in 2030[a]

	Pipelines (mi)	Service Stations
Low-Market-Share Scenario		
CNG	39,247	11,360
H_2	62,807	11,360
High-Market-Share Scenario		
CNG	178,631	36,572
H_2	202,191	36,572

[a] Physical number of new or converted facilities or equipment.

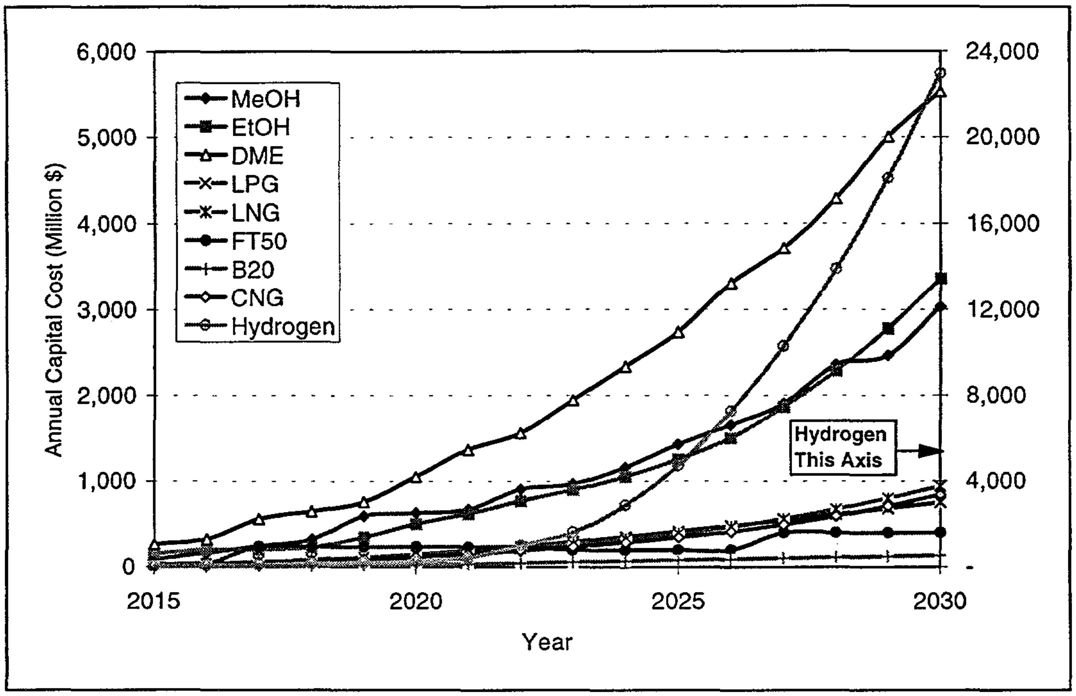
than distribution costs), E100, DME and M100. For LPG, which requires additional pipeline capacity, production costs only slightly exceed distribution costs. The same holds true for hydrogen, but both costs far exceed those of any other alternative examined. CNG (for which additional pipelines account for much of the incremental cost) is the sole exception to this pattern.

3.4.3 Unit Costs

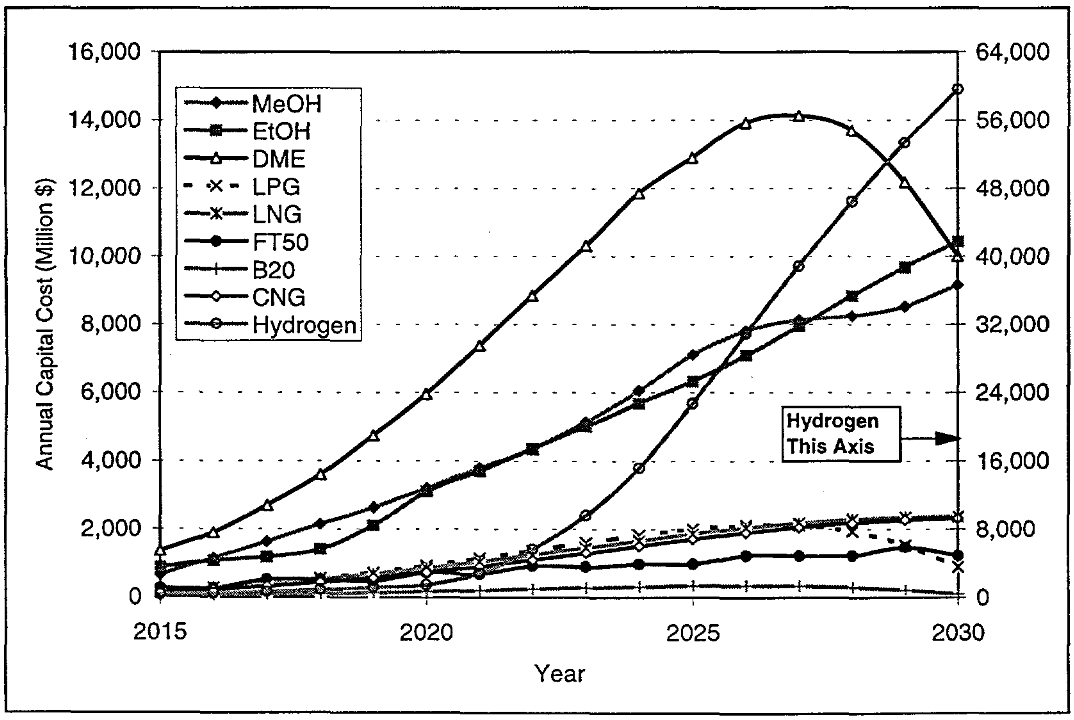
Figure 3.11 illustrates the unit cost (in GGEs) of each fuel over time for both scenarios. As noted above, these costs are based on estimated capital costs, not prices. No attempt has been made to predict pump

Table 3.11 Annual Capital Cost of Building Fuel Production Facilities by Year and Fuel Type ($ million)

	Methanol		Ethanol		Hydrogen		CNG		DME		F-T50		B20		LNG		LPG	
	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low
2007	0.8		0.0		0.2		0.7		3.0		0.0		0.5		0.7		0.8	
2008	3.0		13.6		0.9		2.5		174.7		0.0		1.1		4.3		3.1	
2009	67.7		40.8		2.1		6.2		192.3		40.7		1.6		9.6		7.6	
2010	75.0		68.0		37.6		12.1		221.4		40.7		3.2		17.3		15.0	
2011	86.4		118.3		40.8		21.3		266.2		81.4		5.4		28.2		26.5	
2012	164.1		218.9		79.2		35.6		335.5		81.4		8.6		46.0		44.3	
2013	251.6	3.9	369.9	50.3	120.3	1.1	57.7	3.3	605.9	15.5	122.1	40.7	14.0	1.1	75.1	6.7	71.9	4.0
2014	414.4	72.6	571.1	100.6	199.1	36.9	92.2	10.2	773.5	211.8	275.9	40.7	22.0	2.7	120.0	15.4	115.0	12.6
2015	665.6	85.3	872.9	150.9	284.4	40.5	145.3	20.4	1,357.7	262.1	275.9	40.7	34.9	5.4	187.0	29.1	181.6	25.5
2016	1,131.3	160.9	1,074.1	201.2	444.7	78.3	221.9	32.9	1,892.9	322.7	275.9	40.7	53.2	8.1	280.9	41.6	277.4	41.1
2017	1,624.7	239.6	1,174.7	201.2	646.3	116.9	320.2	48.0	2,697.1	558.8	520.0	235.2	76.3	11.8	396.6	60.2	401.7	60.0
2018	2,144.4	322.4	1,401.7	225.3	888.7	156.7	438.9	66.3	3,596.7	647.8	520.0	235.2	103.7	16.1	530.9	80.2	552.7	82.8
2019	2,629.1	595.7	2,108.4	345.6	1,171.6	197.8	576.2	88.6	4,740.8	755.8	479.3	235.2	135.3	21.5	683.9	105.9	727.3	110.6
2020	3,197.7	628.8	3,091.7	502.0	1,461.2	240.6	730.4	115.4	5,949.6	1,049.6	723.4	235.2	170.2	27.9	850.3	136.2	922.0	144.3
2021	3,794.1	669.0	3,703.0	622.3	2,842.1	435.2	904.0	148.1	7,386.3	1,371.3	682.7	235.2	208.4	35.4	1,039.5	174.1	1,138.3	185.1
2022	4,356.2	903.4	4,348.3	766.6	5,618.2	995.3	1,093.6	187.6	8,856.3	1,563.6	926.8	235.2	248.7	45.1	1,241.2	218.9	1,369.2	234.5
2023	5,128.0	962.2	5,003.4	896.8	9,605.1	1,613.1	1,294.8	232.1	10,313.2	1,943.3	886.1	194.5	287.9	55.3	1,451.1	265.1	1,603.9	290.3
2024	6,047.3	1,158.5	5,680.4	1,051.0	15,206.0	2,864.5	1,501.4	282.8	11,851.6	2,236.9	976.5	194.5	322.8	66.1	1,661.2	322.8	1,826.0	350.4
2025	7,106.6	1,429.3	6,316.9	1,253.3	22,673.2	4,709.3	1,705.4	341.6	12,883.7	2,736.6	976.5	194.5	349.1	77.3	1,865.1	386.8	2,010.9	412.8
2026	7,807.2	1,656.5	7,090.1	1,503.8	30,878.4	7,257.9	1,896.3	411.8	13,919.3	3,304.1	1,220.6	194.5	359.8	88.6	2,045.6	467.4	2,122.7	477.6
2027	8,130.2	1,903.0	7,939.9	1,864.7	38,885.3	10,290.7	2,059.7	495.0	14,126.8	3,711.7	1,220.6	397.9	345.9	100.4	2,186.5	559.3	2,110.6	544.5
2028	8,249.4	2,357.2	8,842.2	2,285.7	46,399.8	13,879.1	2,187.1	592.9	13,688.8	4,279.7	1,220.6	397.9	301.3	111.7	2,287.8	669.3	1,932.0	612.9
2029	8,531.5	2,464.3	9,684.3	2,779.0	53,301.1	18,088.5	2,275.5	706.6	12,179.2	4,999.3	1,464.7	397.9	220.2	123.0	2,343.2	795.2	1,521.4	681.4
2030	9,161.2	3,030.0	10,442.2	3,356.4	59,562.1	22,977.8	2,325.1	837.6	10,017.1	5,531.1	1,220.6	397.9	99.9	132.7	2,363.3	940.1	889.2	747.4



(a) Low-Market-Share Scenario



(b) High-Market-Share Scenario

Figure 3.9 Annual Costs for Building Fuel-Production Facilities

Table 3.12 Incremental Capital Requirements for Building Fuel Production Facilities, Cumulative through 2015, 2020, 2025, and 2030 ($ billion)

Fuel	2015	2020	2025	2030
Low-Market-Share Scenario				
M100	0.2	2.1	7.2	18.6
E100	0.3	1.8	6.4	18.2
LPG	0.04	0.5	2.0	5.0
DME	0.5	3.8	13.8	35.6
LNG	0.1	0.5	1.8	5.3
CNG	0.03	0.4	1.6	4.6
H_2	0.1	0.9	11.5	84.0
B20	0.01	0.1	0.4	0.9
F-T50	0.1	1.1	2.2	3.9
High-Market-Share Scenario				
M100	1.7	12.5	38.9	80.8
E100	2.3	11.1	36.2	80.2
LPG	0.5	3.3	11.3	19.9
DME	3.9	22.8	74.1	138.0
LNG	0.5	3.2	10.5	21.7
CNG	0.4	2.7	9.2	19.9
H_2	0.8	5.4	61.3	290.3
B20	0.1	0.6	2.0	3.4
F-T50	0.9	3.4	7.9	14.2

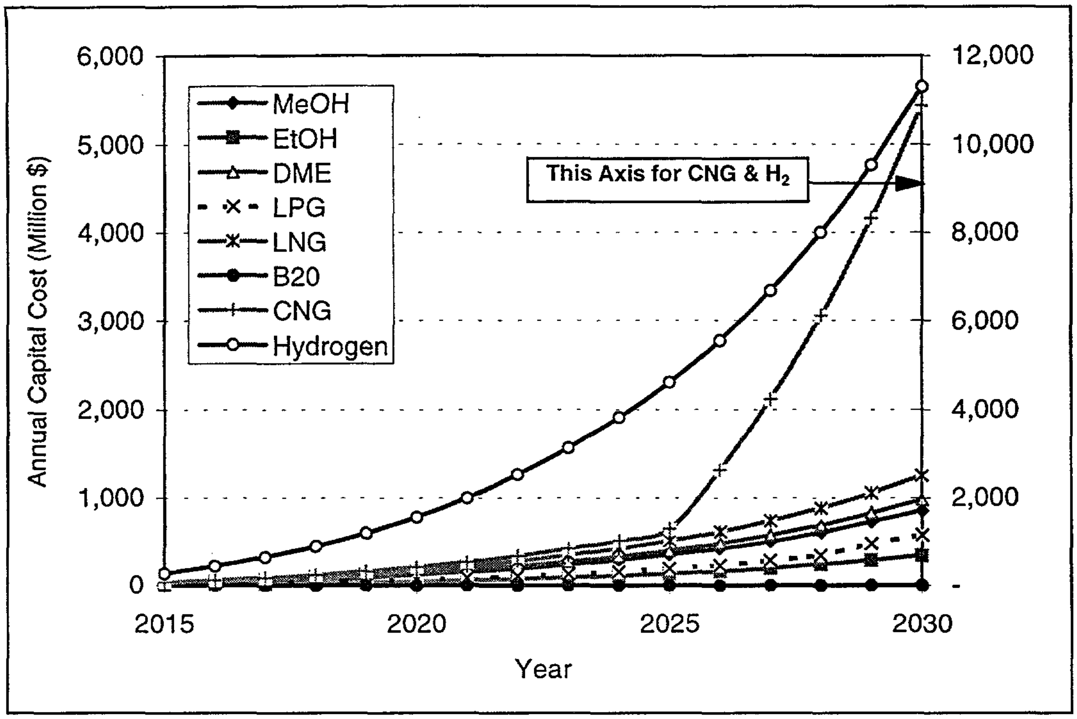
Table 3.13 Incremental Capital Requirements for Building Fuel Distribution Facilities, Cumulative through 2015, 2020, 2025, and 2030 ($ billion)

Fuel	2015	2020	2025	2030
Low-Market-Share Scenario				
M100	0.0	0.4	1.6	4.7
E100	0.0	0.2	0.6	1.8
LPG	0.0	0.3	0.9	2.8
DME	0.0	0.5	1.9	5.4
LNG	0.1	0.6	2.3	6.9
CNG: 10 yr	0.1	0.7	2.9	19.0
CNG: 50 yr	0.1	0.7	2.9	14.9
H_2: 10 yr	0.5	5.2	21.3	62.3
H_2: 50 yr	0.3	3.6	14.8	43.5
B20	0.00	0.00	0.00	0.01
F-T50	0.00	0.00	0.00	0.00
High-Market-Share Scenario				
M100	0.4	2.7	9.3	20.6
E100	0.1	1.1	3.7	8.1
LPG	0.3	1.6	6.1	14.1
DME	0.5	3.1	10.7	23.8
LNG	0.6	4.0	13.6	29.7
CNG: 10 yr	0.7	9.4	54.5	143.6
CNG: 50 yr	0.7	7.6	40.0	102.6
H_2: 10 yr	5.0	35.9	123.5	268.4
H_2: 50 yr	3.5	25.0	86.2	187.3
B20	0.00	0.00	0.01	0.03
F-T50	0.00	0.00	0.00	0.00

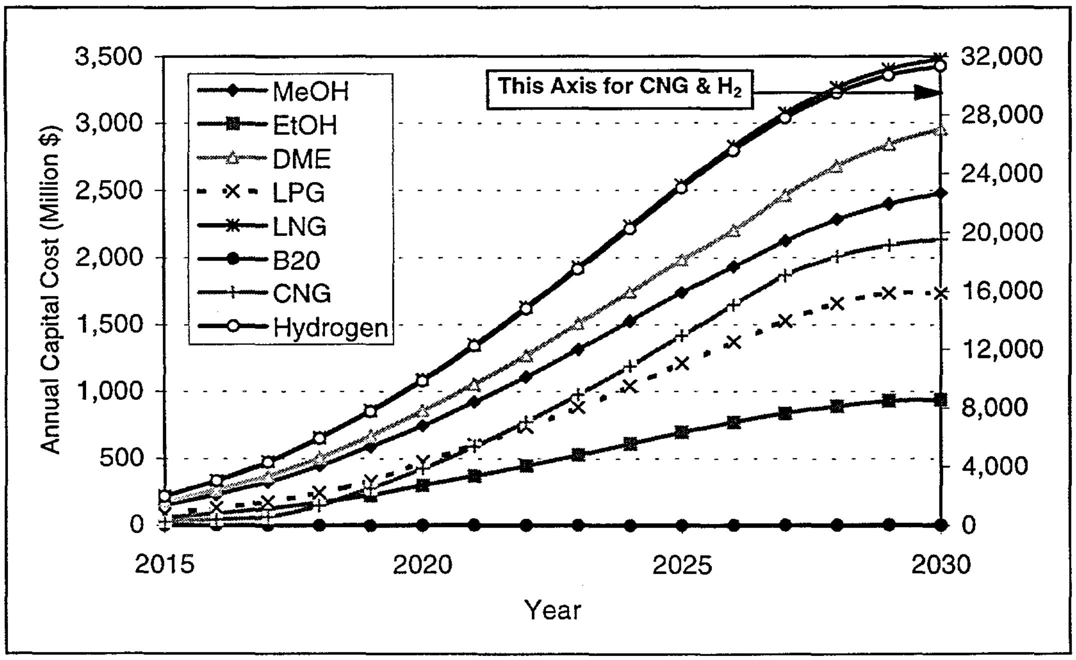
prices. As shown in the figure, unit costs of DME, ethanol, LPG, and, to a certain extent, methanol are quite high in the first year relative to later years. This is one area where the cost of the fuel and the price producers are likely to charge for it may be expected to differ dramatically. High initial costs reflect the need to construct facilities or purchase equipment with capacities far in excess of projected demand volumes for that initial year. As demand increases, economies of scale permit unit costs to decline. This decline does not occur for so-called volume fuels like RFD, RFG, natural gas, and B20,[14,15] which were assumed to be produced in large-scale plants from the outset and thus had already achieved economies of scale by 2007.

[14] Because of economies of scale, LPG cost declines by nearly 50% between 2007 and 2010. This decline is not readily apparent in Figure 3.11b because of the wide range of costs shown.

[15] Because methyl soyate comprises only 20% of the blended B20 fuel, unit cost more closely resembles that of RFD, the 80% component.

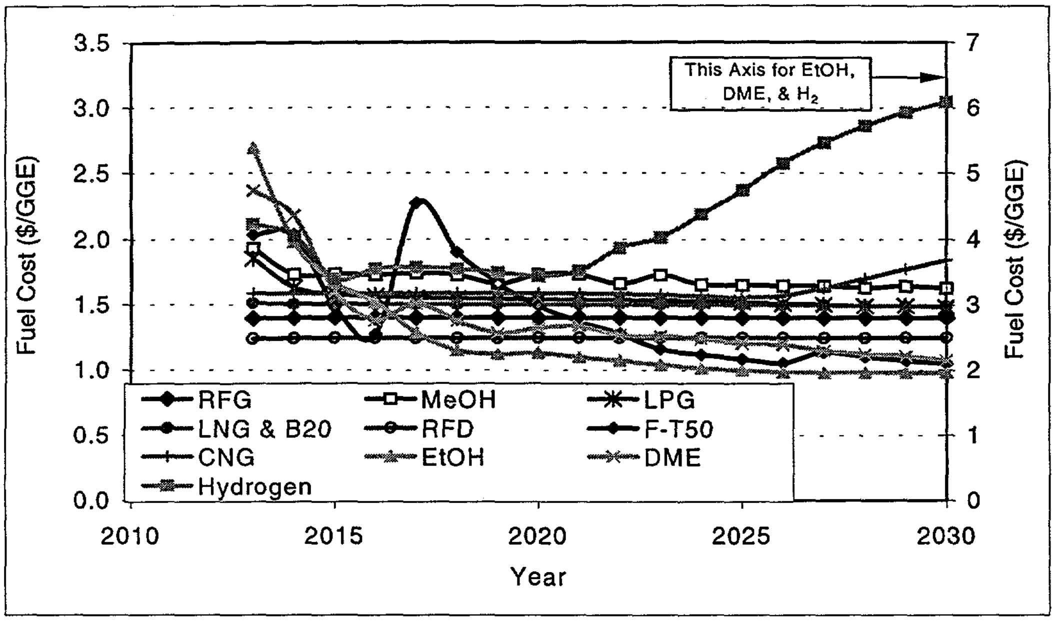


(a) Low-Market-Share Scenario

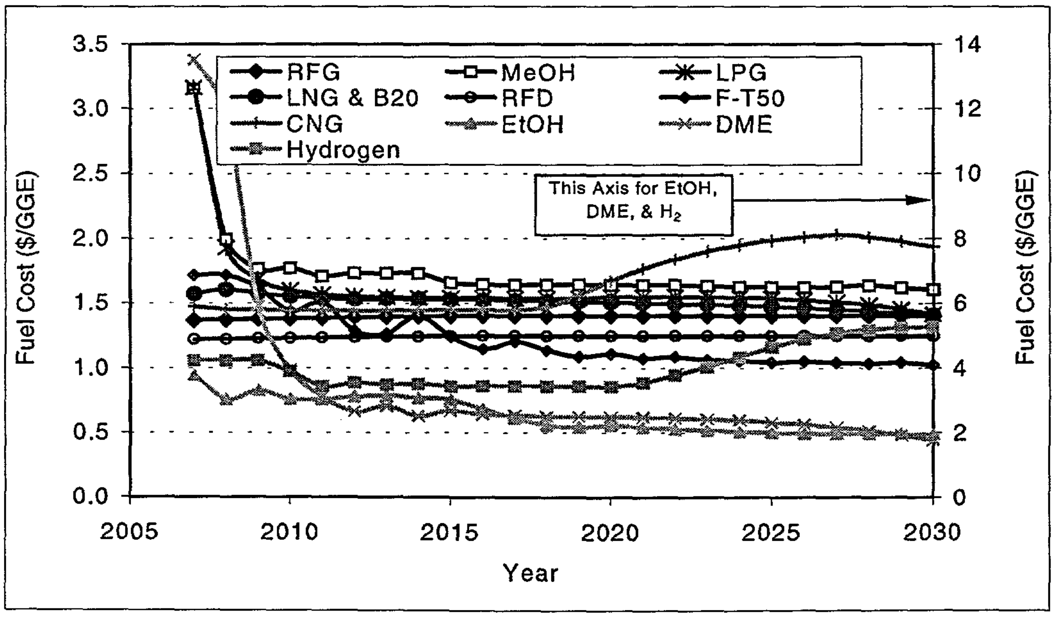


(b) High-Market-Share Scenario

Figure 3.10 Annual Costs for Building Fuel-Distribution Facilities



(a) Low-Market-Share Scenario



(b) High-Market-Share Scenario

Figure 3.11 Unit Costs of Potential 3X Fuels (1995$/GGE)

Hydrogen, which was assumed to be produced in relatively small-scale decentralized facilities (centralized production of hydrogen will be examined in phase 3 of this analysis), never achieves economies of scale. Although scale economies are achieved for CNG production, the need to expand distribution capacity by building new pipelines greatly increases unit costs in the latter years of the analysis.

Similar relationships exist for the low-market-share scenario. However, all of the alternative fuels are more expensive than under the high-market-share scenario. This difference demonstrates the importance of generating sufficient demand for new transportation fuels in order to achieve economies of scale. Again, CNG is an exception in the latter years of the analysis, primarily because of the need for expensive pipeline additions.

Of the 11 fuels examined in this study, the blended Fischer-Tropsch diesel (F-T50) exhibits the most distinctive cost curve, undoubtedly a result of assumptions about facility sizes. As discussed above, FTD was assumed to be produced in three different-sized plants. The smallest, essentially a prototype facility with 5,000-BPD rated capacity, equates to double that capacity (or 130 million GGE per year) when blended with conventional diesel. In the first few years of production at this scale, the capital component of per-gallon cost initially declines because of growth in fuel demand and fairly constant annual capital cost. When the first 50,000 BPD facility (1.3 billion GGE per year blended fuel) comes on-line, per-gallon cost jumps because year-to-year demand increases by approximately 60%, while capital costs of production increase by a factor of five. Unit cost declines in subsequent years as, again, demand grows, while annual capital cost remains constant.

Tables 3.14 and 3.15 disaggregate the unit cost components of the fuels for the years 2015, 2020, 2025, and 2030. Note that changing the payback period for natural gas and hydrogen pipelines has a significant effect on the cost of these two fuels. Under the high-market-share scenario, CNG is about \$0.15/GGE cheaper and H_2 is about \$0.40/GGE cheaper with a 50-yr, as opposed to a 10-yr, payback period.

Table 3.14 Unit Costs of Potential 3X Vehicle Fuels by Component: Low-Market-Share Scenario (1995$/GGE)

	Production Costs					
Fuel	Feedstock	Fuel Production	Distribution	Service Station	Taxes	Total
2015						
RFG	0.540	0.241	0.108	0.087	0.424	1.400
M100	0.214	0.592	0.368	0.137	0.424	1.735
E100	1.678	0.935	0.170	0.133	0.424	3.339
LPG	0.600	0.219	0.196	0.142	0.424	1.582
DME	0.324	1.977	0.318	0.158	0.424	3.202
LNG	0.343	0.345	0.188	0.250	0.424	1.549
CNG: 10 yr	0.258	0.280	0.170	0.455	0.424	1.587
CNG: 50 yr	0.258	0.280	0.170	0.455	0.424	1.587
H_2: 10 yr	0.380	0.370	1.630	0.589	0.424	3.394
H_2: 50 yr	0.380	0.370	1.060	0.589	0.424	2.823
RFD	0.504	0.170	0.095	0.087	0.391	1.246
B20	0.778	0.153	0.096	0.087	0.391	1.505
F-T50	0.362	0.630	0.010	0.087	0.391	1.480
2020						
RFG	0.540	0.241	0.108	0.087	0.424	1.400
M100	0.214	0.592	0.364	0.136	0.424	1.731
E100	0.792	0.745	0.169	0.133	0.424	2.263
LPG	0.600	0.219	0.156	0.142	0.424	1.542
DME	0.324	1.436	0.298	0.158	0.424	2.641
LNG	0.343	0.310	0.188	0.250	0.424	1.514
CNG: 10 yr	0.258	0.277	0.170	0.455	0.424	1.584
CNG: 50 yr	0.258	0.277	0.170	0.455	0.424	1.584
H_2: 10 yr	0.380	0.409	1.630	0.589	0.424	3.433
H_2: 50 yr	0.380	0.409	1.060	0.589	0.424	2.863
RFD	0.504	0.170	0.095	0.087	0.391	1.246
B20	0.778	0.150	0.096	0.087	0.391	1.502
F-T50	0.362	0.640	0.010	0.087	0.391	1.490
2025						
RFG	0.540	0.241	0.108	0.087	0.424	1.400
M100	0.214	0.523	0.354	0.134	0.424	1.649
E100	0.547	0.721	0.168	0.131	0.424	1.991
LPG	0.600	0.204	0.152	0.139	0.424	1.519
DME	0.324	1.214	0.291	0.154	0.424	2.407
LNG	0.343	0.294	0.185	0.241	0.424	1.486
CNG: 10 yr	0.258	0.261	0.170	0.441	0.424	1.553
CNG: 50 yr	0.258	0.261	0.170	0.441	0.424	1.553
H_2: 10 yr	0.298	1.906	1.546	0.567	0.424	4.741
H_2: 50 yr	0.298	1.906	1.008	0.567	0.424	4.203
RFD	0.504	0.170	0.095	0.087	0.391	1.246
B20	0.778	0.146	0.096	0.087	0.391	1.498
F-T50	0.362	0.232	0.010	0.087	0.391	1.082

Continued

Table 3.14 Unit Costs of Potential 3X Vehicle Fuels by Component: Low-Market-Share Scenario (1995$/GGE) (Cont.)

	Production Costs					
Fuel	Feedstock	Fuel Production	Distribution	Service Station	Taxes	Total
2030						
RFG	0.540	0.241	0.108	0.087	0.424	1.400
M100	0.214	0.510	0.347	0.130	0.424	1.625
E100	0.476	0.760	0.170	0.128	0.424	1.957
LPG	0.599	0.155	0.168	0.136	0.424	1.482
DME	0.324	0.961	0.287	0.149	0.424	2.145
LNG	0.343	0.283	0.182	0.230	0.424	1.462
CNG: 10 yr	0.258	0.229	0.506	0.424	0.424	1.841
CNG: 50 yr	0.258	0.229	0.369	0.424	0.424	1.704
H_2: 10 yr	0.153	3.523	1.449	0.542	0.424	6.091
H_2: 50 yr	0.153	3.523	0.948	0.542	0.424	5.590
RFD	0.504	0.170	0.095	0.087	0.391	1.246
B20	0.778	0.136	0.096	0.087	0.391	1.488
F-T50	0.362	0.199	0.010	0.087	0.391	1.049

Table 3.15 Unit Costs of Potential 3X Vehicle Fuels by Component: High-Market-Share Scenario (1995$/GGE)

Fuel	Production Costs: Feedstock	Production Costs: Fuel Production	Distribution	Service Station	Taxes	Total
2015						
RFG	0.540	0.241	0.108	0.087	0.424	1.400
M100	0.214	0.523	0.358	0.136	0.424	1.656
E100	1.671	0.628	0.169	0.133	0.424	3.025
LPG	0.600	0.219	0.154	0.142	0.424	1.540
DME	0.324	1.473	0.303	0.158	0.424	2.681
LNG	0.343	0.325	0.188	0.250	0.424	1.529
CNG: 10 yr	0.258	0.140	0.170	0.455	0.424	1.447
CNG: 50 yr	0.258	0.140	0.170	0.455	0.424	1.447
H_2: 10 yr	0.380	0.408	1.630	0.589	0.424	3.432
H_2: 50 yr	0.380	0.408	1.060	0.589	0.424	2.862
RFD	0.504	0.170	0.095	0.087	0.391	1.246
B20	0.778	0.150	0.096	0.087	0.391	1.502
F-T50	0.385	0.370	0.010	0.087	0.391	1.243
2020						
RFG	0.540	0.241	0.108	0.087	0.424	1.400
M100	0.214	0.510	0.356	0.136	0.424	1.640
E100	0.764	0.730	0.171	0.132	0.424	2.222
LPG	0.599	0.219	0.167	0.142	0.424	1.551
DME	0.324	1.280	0.297	0.157	0.424	2.481
LNG	0.343	0.305	0.187	0.247	0.424	1.506
CNG: 10 yr	0.258	0.138	0.398	0.451	0.424	1.668
CNG: 50 yr	0.258	0.138	0.303	0.451	0.424	1.574
H_2: 10 yr	0.380	0.424	1.606	0.583	0.424	3.417
H_2: 50 yr	0.380	0.424	1.045	0.583	0.424	2.856
RFD	0.504	0.170	0.095	0.087	0.391	1.246
B20	0.778	0.149	0.096	0.087	0.391	1.500
F-T50	0.385	0.234	0.010	0.087	0.391	1.108
2025						
RFG	0.540	0.241	0.108	0.087	0.424	1.400
M100	0.214	0.499	0.351	0.133	0.424	1.620
E100	0.565	0.706	0.170	0.130	0.424	1.995
LPG	0.597	0.199	0.177	0.138	0.424	1.535
DME	0.324	1.128	0.290	0.152	0.424	2.318
LNG	0.343	0.286	0.184	0.237	0.424	1.474
CNG: 10 yr	0.258	0.129	0.739	0.435	0.424	1.985
CNG: 50 yr	0.258	0.129	0.511	0.435	0.424	1.757
H_2: 10 yr	0.295	1.850	1.513	0.559	0.424	4.641
H_2: 50 yr	0.295	1.850	0.987	0.559	0.424	4.115
RFD	0.504	0.170	0.095	0.087	0.391	1.246
B20	0.778	0.143	0.096	0.087	0.391	1.495
F-T50	0.385	0.169	0.010	0.087	0.391	1.042

Continued

Table 3.15 Unit Costs of Potential 3X Vehicle Fuels by Component: High-Market-Share Scenario (1995$/GGE) (Cont.)

Fuel	Production Costs: Feedstock	Production Costs: Fuel Production	Distribution	Service Station	Taxes	Total
2030						
RFG	0.540	0.241	0.108	0.087	0.424	1.400
M100	0.214	0.501	0.341	0.124	0.424	1.604
E100	0.512	0.727	0.168	0.122	0.424	1.953
LPG	0.596	0.089	0.177	0.129	0.424	1.414
DME	0.324	0.593	0.287	0.141	0.424	1.769
LNG	0.343	0.253	0.178	0.210	0.424	1.407
CNG: 10 yr	0.258	0.106	0.753	0.394	0.424	1.935
CNG: 50 yr	0.258	0.106	0.518	0.394	0.424	1.700
H_2: 10 yr	0.174	2.906	1.268	0.496	0.424	5.267
H_2: 50 yr	0.174	2.906	0.835	0.496	0.424	4.835
RFD	0.504	0.170	0.095	0.087	0.391	1.246
B20	0.778	0.121	0.096	0.087	0.391	1.473
F-T50	0.385	0.150	0.010	0.087	0.391	1.023

Section 4
Total Fuel-Cycle Analysis

Petroleum savings by a 3X technology come from two sources: tripling fuel economy and fuel substitution. Tripling fuel economy reduces energy consumption for vehicle operation by 67% and, if the replacement fuel is petroleum-based, results in comparable petroleum displacement (100% if the replacement fuel is not petroleum-based). However, if resource recovery, fuel production, and other upstream processes are highly energy- and/or petroleum-intensive, total energy and petroleum savings could be much less. This reduction in savings is particularly dramatic for nonpetroleum fuels, like hydrogen. Because energy-cycle analysis examines all the stages in the process of vehicle and fuel production and distribution, as well as end-use consumption, it permits a more definitive assessment of energy and petroleum savings (and emissions reductions) than standard end-use analysis, which, by definition, is limited to vehicle operation. For new fuel- and propulsion-system technologies with significantly different energy cycles, the two approaches could produce different conclusions.

Figure 4.1 illustrates the fuel cycle and vehicle cycle,[16] which, together, comprise the total energy cycle. For a given transportation fuel, a fuel cycle includes the following chain of processes: primary energy recovery; primary energy transportation and storage; fuel production; fuel transportation, storage, and distribution; and vehicular fuel combustion. Fuel-cycle activities before vehicular fuel combustion are usually referred to as upstream activities (which result in upstream energy use and upstream emissions). Primary energy resources (e.g., crude oil, natural gas, and coal) are usually referred to as energy feedstocks, and fuels are referred to as, for example, gasoline, diesel, and electricity.

[16] A 3X vehicle is likely to differ from a conventional vehicle in more than just fuel economy. Lightweight materials, such as aluminum, magnesium, plastic, and composites, will probably be used extensively, thus requiring changes in production processes, manufacturing inputs, and suppliers. The powertrain, most likely a hybrid, will be very different from a conventional ICE powertrain, thus requiring additional production changes. All of these variables lead to significantly different energy use and emissions of the vehicle cycle, which includes material recovery and fabrication, vehicle assembly, and vehicle disposal/recycling (see Figure 4.1). The energy and emissions impacts of 3X vehicle manufacturing and material fabrication are addressed in other DOE-sponsored efforts. This study addresses only fuel-cycle (including vehicle operations) energy use and emissions.

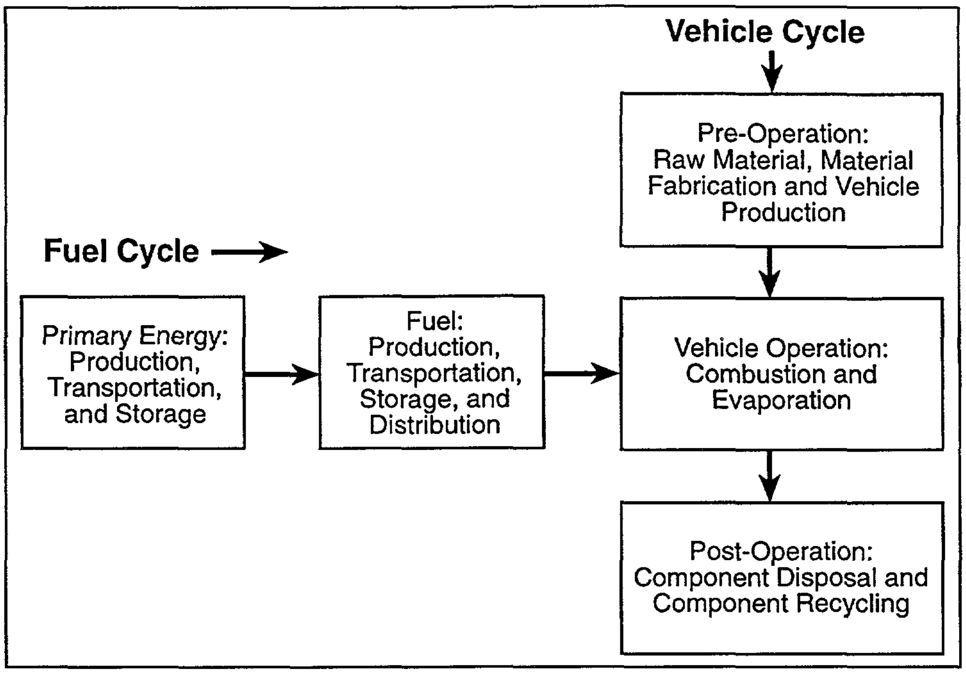


Figure 4.1 Fuel Cycles and Vehicle Cycles for Transportation Energy and Emissions Analysis

In this analysis (as well as in the prior Phase 1 effort), technology-specific rates of energy use and emissions produced were estimated by using the GREET (Greenhouse gases, Regulated Emissions, and Energy use in Transportation) model (Wang 1996). Rates were then applied to forecasts of miles traveled and energy use by 3X and conventional vehicles in the reference, high-, and low-market-share scenarios as produced in the IMPACTT model. The resulting estimates of operational and upstream energy use were then combined to produce annual estimates of total energy (all energy sources), fossil energy (petroleum, natural gas [NG], and coal), and petroleum for each of the candidate 3X technologies. Similarly, estimates of operational and upstream emissions were combined to produce annual estimates of criteria pollutants and greenhouse gases for each of the 3X technologies.

4.1 GREET Analytical Approach

GREET calculates energy use and emissions associated with a variety of alternative transportation fuels and technologies. GREET includes both fuel and vehicle cycles and can calculate energy and emissions for either or both.

For this analysis, GREET was used to calculate energy and emission rates for the fuel cycle only. In this mode, GREET takes into account energy use for primary feedstock recovery and transportation, fuel production, and fuel transportation, storage and distribution. GREET includes emissions caused by process fuel combustion, fuel leakage, and fuel evaporation. Upstream energy use and emissions are calculated in Btu and g/mmBtu of fuel delivered at the pump.

GREET then calculates operational energy use (which is a member of both the vehicle and the fuel cycle, as shown in Figure 4.1) from vehicle fuel economy. Vehicular emissions for conventional ICE vehicles fueled with gasoline and diesel are estimated with EPA's Mobile model.[17] Vehicular emissions for other fuels and propulsion systems are calculated from baseline conventional vehicle emissions and anticipated changes between baseline vehicles (gasoline or diesel) and new technologies. Depending on the application, operational energy use may be assigned to either the vehicle or fuel cycle. In this analysis, it was included in the fuel cycle.

Within GREET, fuel-cycle and vehicle-cycle results are converted into per-mile rates, which may then be reported separately or combined into a total energy-cycle result. Fuel economy is used to convert fuel-cycle energy use and emissions from g/mmBtu to g/mi; lifetime vehicle utilization is used to convert vehicle-cycle energy use and emissions from g/vehicle to g/mi.

The key outputs from the GREET model are gram-per-mile (g/mi) emissions and Btu-per-mile (Btu/mi) energy use for various fuel cycles. GREET includes emissions of volatile organic compounds (VOC), carbon monoxide (CO), nitrogen oxides (NO_x), particulate matter smaller than 10 μm (PM_{10}), sulfur oxides (SO_x), methane (CH_4), nitrous oxide (N_2O), and carbon dioxide (CO_2). The three greenhouse gases (GHGs) (CH_4, N_2O, and CO_2) are then weighted by their global warming potentials to estimate CO_2-equivalent GHG emissions. In this study, the global warming potential factors recommended by the Inter-Governmental Panel on Climate Change (IPCC) were used to calculate CO_2-equivalent GHGs. Those factors are 1 for CO_2, 21 for CH_4, and 310 for N_2O.

Although GREET generates both upstream and operational energy use and emissions, only upstream results are fed into the IMPACTT model. Energy use during vehicle operation is calculated directly in IMPACTT. Emissions from vehicle operations are calculated in IMPACTT in a way similar to that in GREET. In fact, the two models share some of the same assumptions and equations used to calculate emissions from vehicle operations. The notable difference between GREET and IMPACTT is that GREET estimates emission rates, while IMPACTT estimates total emissions for a fleet of vehicles. Thus, while new-vehicle market penetration and stock are not used in GREET, they are crucial elements in IMPACTT (Mintz et al. 1994).

4.1.1 Upstream Calculations

As stated above, only the upstream energy and emission rates generated by GREET are fed into IMPACTT. Upstream calculations follow these steps. For a given stage in the fuel cycle, energy use (in Btu per million Btu of energy throughput) is calculated and allocated to different process fuels (e.g., NG, residual oil, diesel, coal, and electricity).

[17] The current version of EPA's Mobile model is Mobile5b. The next version – Mobile6 – is scheduled to be released in late 1998 or early 1999.

Fuel-specific energy use, together with fuel-specific emission factors (specific to a particular combination of fuel and combustion technology), is then used to calculate combustion emissions for the stage. GREET has an archive of combustion emission factors for various combustion technologies that use different fuels and are equipped with different emission control technologies. Combustion emission factors for VOC, CO, NO_x, PM_{10}, CH_4, and N_2O were derived primarily from data published by the EPA (EPA AP-42 document). For most fuels, emission factors for sulfur oxide are calculated from sulfur content, assuming that all sulfur contained in process fuels is converted into sulfur dioxide (SO_2). Similarly, carbon dioxide emission factors are calculated by a carbon balance approach (i.e., the carbon contained in the fuel burned, minus the carbon contained in combustion emissions of VOC, CO, and CH_4, is assumed to be converted to CO_2). The GREET calculation logic for upstream emissions is presented in Figure 4.2.

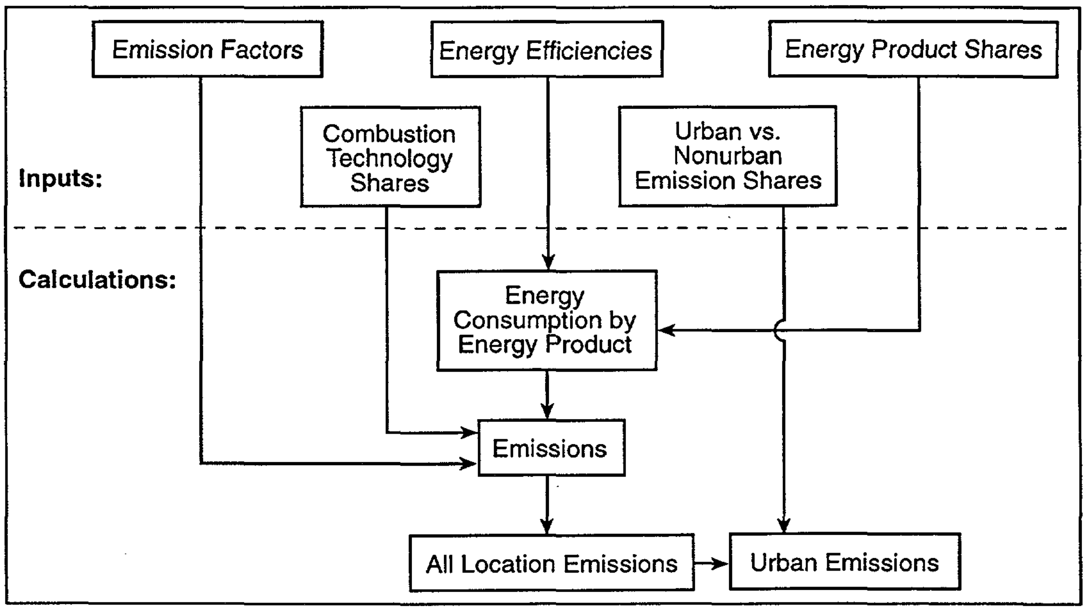


Figure 4.2 GREET Calculation Logic for Upstream Emissions

In the Phase 2 analysis, emissions of the five criteria pollutants were further separated into total emissions and urban emissions. The major concern with respect to emissions is the effect on human health of exposure to air pollution created by these pollutants. Clearly, emissions that occur in remote, sparsely populated areas pose far less of a health threat than those in densely populated urban areas. Although GREET is not a location-specific model, the issue of human exposure warrants some degree of spatial analysis.[18] Thus, emissions are separated into total and urban emissions to provide a better indication of health effects from a given combination of 3X fuel and propulsion system technologies.

GREET uses information on facility locations to separate upstream emissions into the two categories. For facilities located inside urban areas, all emissions are considered urban; emissions from all other facilities are considered to be non-urban. In this analysis, "urban" was defined as the 125 metropolitan areas specified in the 1992 Energy Policy Act. On the basis of a general understanding of the geographic location of fuel production facilities (e.g., petroleum refineries, electric power plants, etc.), a set of ratios was approximated. Corresponding to the share of each facility type located in urban areas, the ratios were then used to allocate emissions from each facility type between urban and non-urban areas.

4.1.2 Fuel-Cycle Paths

To estimate upstream energy and emissions, a fuel-cycle path from primary energy recovery to delivery at the fuel pump must be specified for each technology option. The base case or benchmark fuel-cycle path was defined as petroleum to RFG for conventional vehicles. In this study, 13 fuel-cycle paths were analyzed (see Figure 2.7).

As Figure 2.7 indicates, hydrogen was assumed to be produced from either NG or solar energy, and ethanol was assumed to be produced from either corn or biomass. Prior to 2020, all hydrogen was assumed to be produced from NG via steam reforming; beginning in 2020, some production was assumed to come from solar energy (via water electrolysis). Similarly, all ethanol production was assumed to be from corn until 2016, when production from cellulosic biomass was assumed to begin. Over time, as more new plants begin producing hydrogen from solar energy and ethanol from cellulosic biomass, these technologies' respective shares of total hydrogen and total ethanol production were assumed to rise steadily.

Petroleum to RFG. This path includes crude oil recovery in oil fields; crude oil transportation and storage; crude oil refining; and gasoline (i.e., RFG) transportation, storage, and distribution. Among the upstream processes for this fuel cycle, crude oil refining consumes the most energy (with an energy efficiency of 82.5%, which is slightly below that of refining crude to conventional gasoline). As for GHG emissions, the venting of associated gas in oil fields is a significant source of CH_4 emissions.

Petroleum to Diesel. This path includes crude oil recovery, transportation, and storage; diesel production in crude refineries; and diesel transportation, storage, and

[18] Ideally, results from GREET could be used in an emissions inventory model to generate an emissions distribution by geographic location. The location-specific inventory could then be fed into an air quality model, the results of which could be combined with a population exposure model to assess human health effects of air pollution.

distribution. Again, the largest energy requirement for this cycle occurs at petroleum refineries (with an energy efficiency of 90%).

Petroleum to LPG. This path includes crude oil recovery, transportation, and storage; LPG production in petroleum refineries; and LPG transportation, storage, and distribution. Despite an energy efficiency of 93.5%, LPG production at petroleum refineries consumes the most energy; transportation of imported LPG consumes the next largest share. For this analysis, a constant 40% of LPG supply was assumed to come via this pathway (i.e., from crude oil) under all scenarios. This assumption is based on current U.S. propane production shares (EIA 1997a; EIA 1997c).

NG to CNG. On this path, natural gas is produced in, and processed near, NG fields and transported through pipelines to service stations where it is compressed to about 300 psi. NG pipelines are powered by NG-fueled engines and turbines. Of the stages making up this path, NG compression (by means of electric compressors at dispersed refueling facilities) has the lowest energy efficiency (95%).

NG to LNG. On this path, natural gas is produced in and processed near NG fields, liquefied at LNG plants that are adjacent to NG processing plants, and then transported by rail and truck to LNG service stations. Of the stages making up this path, NG liquefaction uses the most energy (with an energy efficiency of 85%).

NG to LPG. For domestic supplies, this path includes natural gas recovery in NG fields, LPG production at NG processing plants near NG fields, and LPG transportation via rail or truck to LPG service stations. For imports, LPG is assumed to be transported to major U.S. ports via ocean tanker and then transported to LPG refueling stations via truck and pipeline. Though high relative to other fuels, the efficiency of LPG production (96.5%) is the lowest of all the stages in the pathway. In this analysis, NG was assumed to account for 60% of LPG supply under all scenarios.

NG to DME. On this path, natural gas is recovered in and processed near NG fields. DME is then produced at plants that are adjacent to NG processing plants. DME production has the lowest energy efficiency (70%) of these upstream activities. For this analysis, all DME was assumed to be produced overseas from inexpensive NG, shipped by ocean tanker to main U.S. ports, and transported to service stations via pipeline and truck.

NG to Methanol. The upstream stages of this path are similar to those of the NG-to-DME path except that methanol is produced instead of DME. For this analysis, all methanol was assumed to be imported, shipped to main U.S. ports via ocean tanker, and then transported to service stations via pipeline and truck. Methanol production has the lowest energy efficiency (65%) of all the upstream activities in this path.

NG to F-T Diesel. On this path, natural gas is recovered in and processed near NG fields. At F-T plants that are adjacent to NG processing plants, F-T diesel is produced and blended with conventional diesel. F-T diesel blends are then transported to service stations in the same way as conventional diesel. Among the upstream activities of this cycle, F-T diesel production has the lowest energy efficiency (57%).

NG to H_2. Hydrogen can be produced in centralized facilities (like it is now) or in decentralized facilities (like refueling stations using NG). The advantage of decentralized production is its avoidance of expensive H_2 distribution infrastructure. For this analysis, centralized production was assumed because the technology is proven and economies of scale can be realized. Although both liquid and gaseous H_2 can be used for H_2-powered fuel-cell vehicles (FCVs), gaseous H_2 was assumed for this analysis because liquefaction poses additional energy losses and emissions, and the transportation and storage of liquid H_2 can be expensive.

Under this path, NG is recovered in and processed near NG fields, H_2 is produced at centralized plants adjacent to NG processing plants, and gaseous H_2 is transported to service stations via pipeline. In this analysis, H_2 was assumed to be compressed to about 6,000 psi at service stations. With an energy efficiency of 68%, H_2 production consumes the most energy of all the stages in this path. Because H_2 contains no carbon and no carbon sequestration was assumed, the conversion of NG to H_2 produces considerable CO_2 emissions.

Solar Energy to H_2. Production of H_2 from solar energy via water electrolysis offers significant energy and environmental benefits, as well as the possibility of a practically unlimited energy source. In this study, H_2 was assumed to be produced in centralized facilities in such regions as the Southwestern United States where solar energy is abundant. Hydrogen was then assumed to be compressed moderately (to about 100 psi) and transported via pipeline to H_2 refueling stations. There, gaseous H_2 was assumed to be compressed to about 6,000 psi for use by H_2-powered FCVs. Electricity was assumed to be used for compressing H_2 and powering pipeline motors, and parameters typical of U.S. average electric generation were used to estimate emissions of criteria pollutants and GHGs from the electricity used. Note that the same assumptions were applied to H_2 transportation and compression for the above NG-to-H_2 path. Energy efficiencies for gaseous H_2 transportation via pipeline and H_2 compression at service stations were assumed to be 94% and 90%, respectively.

Corn to Ethanol. This path includes corn production and transportation; ethanol production; and ethanol transportation, storage, and distribution. GHG emissions from corn production come from fuels used for farming, harvesting, and corn drying, together with the amount from fertilizers and herbicides used during corn farming. Both wet- and dry-milling technology is currently used in the United States to produce ethanol. Wet-milling plants now account for about two-thirds of ethanol production capacity; dry-milling plants account for the remaining third. Because of tax incentives that are available in certain states and their generally lower capital requirement, most newer ethanol plants are small-scale, dry-milling plants. In this analysis, future corn-to-ethanol plant capacity was assumed to be evenly split between the two technologies (i.e., half wet-milling and the other half dry-milling). Note that this assumption implies that more dry-milling plants will be built in the future than wet-milling plants. For a detailed discussion of the technical assumptions regarding this cycle, see Wang et al. (1997b).

Biomass to Ethanol. This path includes biomass production and transportation; ethanol production; and ethanol transportation, storage, and distribution. Biomass includes both woody and herbaceous feedstocks. In this analysis, the energy and emissions associated with biomass production were calculated in the same way as those for producing ethanol from corn. At cellulosic ethanol plants, the lignin portion of biomass was assumed to be burned to generate steam and electricity in co-generation systems. While combustion of biomass undoubtedly releases CO_2 emissions, this CO_2 came from the atmosphere through photosynthesis. Thus, CO_2 emissions from biomass combustion were treated as a transfer back into the atmosphere with a net effect of zero. For the same reason, CO_2 emissions from ethanol combustion by ethanol-powered vehicles were also assigned a net value of zero.

The electricity generated at ethanol plants was assumed to be exported to the power grid. Emissions credits for the generated electricity were calculated in GREET as a function of the amount of electricity generated and average emissions associated with electricity generation in U.S. electric utility systems.

Soybeans to Biodiesel. This path includes soybean farming; soybean transportation; soy oil extraction and transesterification; biodiesel blending; and biodiesel blend transportation, storage, and distribution. Among the upstream activities for this path, biodiesel production (including extraction and transesterification of soy oil) and soybean farming consume most of the energy and produce most of the emissions.

4.2 IMPACTT Analytical Approach

The IMPACTT model was used to estimate annual energy consumption and emissions production by conventional and 3X vehicles. IMPACTT is a spreadsheet model that simulates the movement of vehicles through the light-duty fleet. IMPACTT incorporates a vehicle stock model that adds new vehicles (3X or conventional) and retires old vehicles from an initial vehicle population profile to produce annual profiles of the auto and light-truck population by age and technology; a usage module to compute vehicle-miles-traveled (VMT), oil displacement, and fuel use by technology; and an emissions module to compute upstream and operational emissions of criteria pollutants and GHGs for autos and light trucks, again by technology. The usage module computes the petroleum that would have been consumed by conventional vehicles in the absence of 3X vehicles, the petroleum equivalent (i.e., GGEs) consumed by 3X vehicles, and the net savings due to the presence of 3X vehicles in the fleet.[19] Upstream energy use is computed post hoc, as a function of operational energy use and a series of GREET-developed rates, which are specific to each potential 3X fuel.

[19] Unlike GREET, IMPACTT's fuel-use module computes only downstream or operational energy use. Upstream energy use is then computed as the product of operational energy use and a GREET-supplied rate.

In IMPACTT, emissions of NO_x, CO, VOC, and PM_{10} are computed separately for autos and light trucks by using age-based tailpipe emission rates obtained from EPA's MOBILE5b and PART5 models for conventional SI and CI engines operating on gasoline and diesel fuel, respectively, and average operational emission rates for nonconventional engines and fuels estimated with assumptions presented in Section 4.2.1. Operational emissions of SO_x and CO_2 are computed as a function of fuel consumption and fuel specifications (see Table 2.5) by using assumptions from GREET. Upstream emission rates for all fuels (conventional as well as potential 3X fuels) are also obtained from GREET.

Version 5.0 of IMPACTT (IMPACTT5) was used for this analysis. Major changes in the emissions module account for most of the difference between this version and the one documented earlier (Mintz et al. 1994). On the emissions side, all emissions are now computed separately for autos and light trucks; emissions of greenhouse gases (CO_2, CH_4 and N_2O) have been added, along with an estimate of total greenhouse gases; and upstream emissions of criteria pollutants and GHGs have been added. On the energy side, operational energy use is now broken down into total energy, fossil fuel, and petroleum; upstream energy has been added (and is broken down into the same categories); and a procedure for estimating urban emissions of criteria pollutants has been developed.

Figure 4.3 illustrates IMPACTT5's structure. Outputs include estimates of the quantity of oil consumed and emissions produced by conventional vehicles, the quantity of alternative fuels consumed and emissions produced by advanced-technology vehicles, and the total quantity of fuel consumed and emissions produced by all vehicles expected to be on the road in a given year under a given scenario.

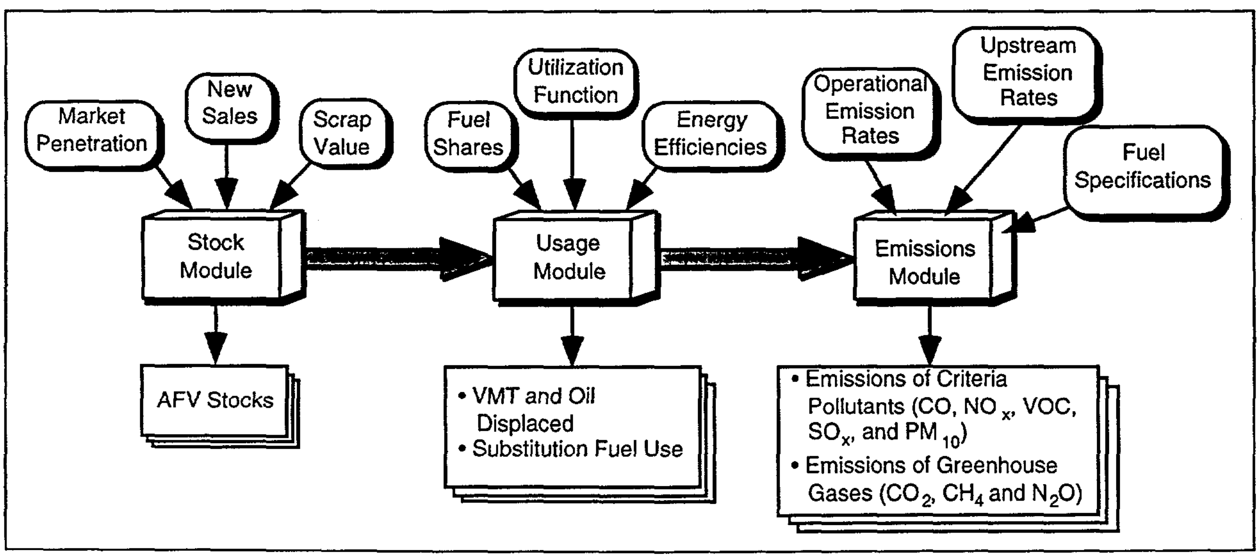


Figure 4.3 Structure of the IMPACTT5 Model

4.2.1 Emissions Calculations

Emission standards are an important reason for considering alternative propulsion systems in the PNGV program. Approximately 40% of model year 1994 (MY94) passenger cars met the Phase 1 (commonly called Tier 1) emission requirements of the Clean Air Act Amendments; by MY96, all passenger cars were required to be in compliance with Tier 1 standards. These standards — for carbon monoxide (CO), oxides of nitrogen (NO_X), non-methane hydrocarbons (NMHC), and particulate matter (PM) — are shown in Table 4.1. Note that the standard for particulate matter (PM) applies only to light-duty diesels. Tier 2 standards that require a further 50% reduction in emissions have been proposed but are not yet mandated. EPA is scheduled to rule on the need for these more stringent standards by December 1999.

Table 4.1 Five-Year or 50,000-mi Emission Standards for Light-Duty Vehicles: 49 States and California (g/mi)

Standard	First MY	NMHC	NMOG	CO	NO_X	PM	HCHO (formaldehyde)
			49 States (mandated)				
Tier 1	1994	0.25	N/A[a]	3.4	0.4	0.08[b]	N/A
Tier 2	2004[c]	0.125	N/A	1.7	0.2	0.08[b]	N/A
			California (mandated)				
TLEV	1994	N/A	0.125	3.4	0.4	0.08[d]	0.015
LEV	1997	N/A	0.075	3.4	0.2	0.08[d]	0.015
ULEV	1997	N/A	0.040	1.7	0.2	0.04[d]	0.008
ZEV	2003	0[e]	0[e]	0[e]	0[e]	0[e]	0[e]
			National LEV Program (voluntary)				
TLEV	2001	N/A	0.125	3.4	0.4	0.08[d]	0.015
LEV	2002	N/A	0.075	3.4	0.2	0.08[d]	0.015
ULEV	2003	N/A	0.040	1.7	0.2	0.04[d]	0.008

[a] Not applicable.

[b] Applies to all 49-state LDVs beginning in MY96.

[c] Need for these standards will be determined by EPA in 1999. They are not yet mandated. Definition of useful life increased to 10 yr or 100,00 mi.

[d] Applies to diesel vehicles only; standards are for 10 yr or 100,000 mi.

[e] Emissions from vehicle itself.

California has defined still stricter vehicle emission standards to be phased in over the next decade. The standards include formaldehyde and replace the non-methane hydrocarbon (NMHC) standard with a non-methane organic gas (NMOG) standard (which includes NMHC and several other organic gases). To meet a fleetwide standard for NMOG, vehicle manufacturers must certify each of their vehicles in one of four emission categories: Transitional-Low-Emission Vehicles (TLEV), Low-Emission Vehicles (LEV), Ultra-Low-Emission Vehicles (ULEV), or Zero-Emission Vehicles (ZEV). A weighted average consisting of the emission standard for the category and the share of each manufacturer's California sales in that category will then be used to determine if manufacturers are meeting the fleetwide NMOG standard.

The California Air Resources Board recently proposed the so-called "LEV II" program (CARB 1997), which extends the already adopted TLEV, LEV, and ULEV standards to 120,000 mi; tightens PM emission standards to 0.04 g/mi for TLEV and 0.01 for LEV and ULEV (applicable at 120,000 mi); and adds a new vehicle category – super-ultra-low-emission vehicle (SULEV). Applicable for 120,000 mi, the proposed SULEV standards are 0.01 g/mi for NMOG, 1.0 for CO, 0.02 for NO_x, and 0.01 for PM.

Recently, EPA adopted a national low-emission-vehicle (NLEV) program to encourage the introduction of LEV types. Forty-five states and the District of Columbia will be covered under this program. The NLEV program is voluntary, and vehicle manufacturers can participate in lieu of complying with the individual requirements of any state except California.[20] The NLEV program begins in MY 2001 and is similar to the California LEV program with one major exception: Zero Emission Vehicles (ZEVs) are not required to be sold (EPA 1998).

It is generally believed that 3X vehicles will be subject to Tier 2 standards for VOC, CO, and NO_x and the ULEV standard for PM. For this analysis, it was assumed that RFG-fueled SIDI engines will meet Tier 2 standards, but no further emissions reductions (e.g., LEV II standards) will occur. All other SIDI engines (fueled with methanol, ethanol, CNG, LNG, and LPG) were assumed to at least meet Tier 2 standards. If an alternative fuel offers inherently lower emissions than RFG, emission reductions were assumed for that fuel. Table 4.2 presents the emission reductions assumed for the five alternative SIDI fuels.

Recently, it has been proposed that CIDI 3X vehicles should be subject to a PM standard of 0.01 g/mi, which is equivalent to the PM emission rate of conventional gasoline SI vehicles. For this analysis, it was assumed that 3X vehicles with CIDI engines will at least meet Tier 2 standards for NO_x, CO, and VOC and current ULEV standards (i.e., 0.04 g/mi) for PM. As with SIDI alternative fuels, CIDI alternative fuels that offer inherently lower emissions were assumed to achieve further reductions relative to RFD. Table 4.3 presents the emission standards that the four CIDI fuels were assumed to meet. Note that the four fuels were assumed to produce no evaporative emissions since all have very low Reid vapor pressure (RVP). RFD, B20, and F-T50 were assumed to

[20] Twenty-three automakers that comprise nearly all of the U.S. LDV market have agreed to participate in the NLEV program. New York, Massachusetts, Maine, and Vermont have decided to pursue ZEV requirements (i.e., the California model) instead of participating in NLEV.

Table 4.2 Relative Emissions of Alternative SIDI Fuels

	Percent Tier 2 RFG-Fueled SIDI Rate				
Pollutant	Methanol	Ethanol	CNG	LNG	LPG
VOC (exhaust)	55	55	15	15	75
VOC (evaporative)	100	100	0	0	0
CO	60	60	40	40	60
NO_x	80	80	60	60	90
PM (exhaust)	10	10	1	1	1
PM (brake and tire)	100	100	100	100	100
CH_4[a]	65	65	1000	1000	100
N_2O[b]	100	100	100	100	100

[a] Gasoline vehicle CH_4 emissions = 0.074 g/mi.

[b] Gasoline vehicle N_2O emissions = 0.005 g/mi.

Table 4.3 Emissions of Alternative CIDI Fuels

	Emissions (g/mi), by Fuel			
Pollutant	RFD[b]	DME	B20	F-T50
VOC (exhaust)	0.125	0.125	0.125	0.125
VOC (evaporative)	0	0	0	0
CO	1.7	1.7	1.7	1.7
NO_x	0.2	0.2	0.2	0.2
PM (exhaust)	0.04	0.01	0.04	0.04
CH_4[a]	0.008	0.008	0.008	0.008
N_2O[b]	0.005	0.005	0.005	0.005

[a] Based on GREET estimates for conventional diesel.

[b] Current California diesel has a sulfur content of about 150 ppm. RFD was assumed to have a sulfur content of 100 ppm in order to meet the 0.04 g/mi PM_{10} emission standard.

meet the current ULEV standard for PM. DME was assumed to meet the tighter LEV II ULEV Standard (0.01 g/mi), which is equivalent to that of an SIDI engine.

It is generally believed that FCVs (using H_2, methanol, or gasoline) will have substantially lower emissions than either SIDI or CIDI engines. Table 4.4 presents the emission assumptions used in this analysis. Note that entries are relative to Tier 2 RFG-fueled vehicles.

4.2.2 Fuel Specifications

In this analysis, diesel fuel specifications were modified to replace the low sulfur California diesel considered in Phase 1 with a lower sulfur, low aromatics

Table 4.4 Relative Emissions of Alternative FCV Fuels

	Percent of Tier 2 RFG-Fueled SIDI Rate		
Pollutant	Hydrogen	Methanol[a] (Partial Oxidation)	Gasoline[a] (Partial Oxidation)
VOC (exhaust)	0	0.5	0.5
VOC (evaporative)	0	20[b]	50[d]
CO	0	1	1
NO_x	0	1	1
PM (exhaust)	0	0	0
PM (brake and tire)	100	100	100
CH_4[c]	0	0	0
N_2O[d]	0	0	0

[a] Based on personal communication with Romesh Kumar of ANL.

[b] Smaller tank size for 3X vehicles helps reduce evaporative emissions.

[c] Gasoline vehicle CH_4 emissions = 0.074 g/mi.

[d] Gasoline vehicle N_2O emissions = 0.005 g/mi.

"reformulated" diesel (RFD). As with gasoline, all diesel was assumed to be reformulated beyond 2000. Specifications for RFD, as well as all other fuels considered in this study, are presented in Table 2.5.

As discussed in Section 2, several fuels that had not been included in the Phase 1 analysis were added to Phase 2. These fuels include a 20% blend of methyl soyate (biodiesel) and conventional diesel (designated as B20), a 50% blend of Fischer-Tropsch diesel and conventional diesel (designated as F-T50), CNG, LNG, and LPG.

4.2.3 Greenhouse Gas Emissions

Operational emissions. As stated above, gasoline-equivalent fuel use by 3X vehicles was calculated simply by assuming that all 3X vehicles meet the PNGV goal (i.e., gasoline-equivalent rated fuel economy of 81 mpg for passenger cars and 63 mpg for light trucks). CO_2 emissions from vehicle operations were then calculated by using a carbon-balance approach (i.e., as a function of the physical quantity of the candidate fuel consumed and its carbon content, less the carbon contained in combustion emissions of VOC, CH_4 and CO).

As part of the Phase 2 analysis, calculations of GHG emissions were expanded to include CH_4 and N_2O and to generate total GHG emissions (in CO_2 equivalents). As with all other pollutants, operational emission rates for CH_4 were assumed to be related to fuel and engine type — CIDI, SIDI, or fuel cell. Operational emission rates for CH_4 and N_2O for each propulsion system-fuel combination were presented in the previous three tables.

Upstream emissions. Upstream emission rates can vary over time as feedstock sources and production processes change. CO_2, CH_4, and N_2O upstream emission rates for each potential 3X fuel were obtained from GREET outputs for 2007 and 2030. Together with rates for the intervening years, estimated by straight-line interpolation, these values were applied to annual estimates of fuel use. For the most part, rates for 2030 are approximately 10% below 2007 values. Key exceptions are ethanol and hydrogen, for which production was assumed to shift from current processes to more advanced, and as yet unproved, processes (i.e., ethanol from biomass as opposed to corn and hydrogen from the electrolysis of water instead of from natural gas). For these fuels, emission rates were assumed constant until introduction of the new process. During the transition to the new process, emission rates were weighted by the share of total capacity represented by each process (see Section 4.3.4).

4.2.4 Urban Emissions

To evaluate the relative damage (in terms of population exposure to criteria pollutants) associated with alternative 3X power system/fuel technologies, the IMPACTT files created for the high- and low-market-share scenarios of Phase 2 were modified to estimate those portions of operational and upstream emissions likely to occur within urban areas. For the estimate, urban vehicle sales, survival and utilization, and urban upstream emission rates had to be estimated.

Both vehicles residing in urban areas ("urban vehicles") and non-resident vehicles being operated within urban areas ("non-urban vehicles") can contribute to urban operational emissions. According to the Nationwide Personal Transportation Survey (NPTS), trips of 75 mi or less account for 82% of total VMT, and trips of 200 mi or less account for 94% of total VMT (Hu 1993). Thus, it may be assumed that approximately 90% of the VMT (and associated emissions) in urban areas is attributable to urban vehicles.[21] Further, it may be assumed that the remaining VMT (and emissions) due to the operation of nonurban vehicles on urban roads is more or less offset by VMT due to the operation of urban vehicles in nonurban areas (or in other, nonresident urban areas). Urban emissions due to vehicle operations may then be estimated as a function of the share of new vehicle sales in urban areas and the survival, urban utilization, and urban emission rates of those vehicles.

For this analysis, "urban" was defined as a metropolitan statistical area (MSA) with a population of 250,000 or more, a definition consistent with the Energy Policy Act of 1992 (EPACT), and an "urban vehicle" was defined as a light-duty vehicle (LDV) residing in such an MSA. According to the 1990 NPTS, "urban vehicles" comprise

[21] Non-urban vehicles could further affect urban air quality if considerable numbers of them are operated near urban area boundaries or atmospheric conditions transport their emissions into urban areas. In the absence of detailed atmospheric modeling, however, it is assumed that this possibility accounts for a negligible share of urban emissions.

70.8% of the LDVs of all ages that households purchased new and 92.7% of the 1990–91 MY LDVs that households purchased new (FHWA 1992). Assuming that vehicles purchased by businesses and other nonhousehold entities follow a similar pattern, it may be assumed that approximately 70% of all the light-duty vehicles sold in the United States remain "urban vehicles".[22]

For this analysis, "urban" and "non-urban" vehicles were assumed to have the same survival and emission rates. Utilization is more problematic. Conventional wisdom suggests that "urban" vehicles may be driven fewer miles because travel destinations are less distant than in rural areas. However, according to the 1990 NPTS, the reverse may be true. "Urban" and "non-urban" automobiles have about the same annual utilization (10,756 mi/yr vs. 10,494 mi/yr), but urban light trucks may travel more miles than nonurban light trucks (11,637 mi/yr vs. 10,766 mi/yr). This surprising pattern was examined further by disaggregating NPTS data by vehicle age or vintage. As shown in Table 4.5, age differences between the urban and nonurban vehicle populations account for virtually all of the difference in light truck utilization (FHWA 1992). Only the newest vehicles continue to show differences in utilization, and these differences may be due to their use on longer trips. Thus, for this analysis, newer vehicles were assumed to travel a slightly higher fraction of miles outside urban areas (to account for their use on longer trips), a fraction that declines with vehicle age. For vehicles aged 0–4 yr, 10% of VMT was assumed to occur outside urban areas; for

Table 4.5 Annual Utilization by Vehicle Type, Location, and Age (VMT/vehicle)

Age (yr)	Automobiles		Light Trucks	
	Urban	Non-Urban	Non-Urban	Urban
0–1	8,294	8,396	8,938	9,885
2	13,517	13,575	14,256	15,237
3	13,312	13,527	14,586	14,285
4	12,634	12,670	12,197	11,975
5	11,692	12,063	13,661	13,103
6–10	10,953	10,964	12,314	12,498
11+	8,000	7,572	7,313	8,687

Source: FHWA 1992.

[22] A higher proportion of late-model LDVs may be "urban." However, because some of these vehicles are eventually resold to non-urban owners, a lower estimate of urban vehicle sales was used in this analysis. Thus, results may be considered conservative estimates of urban vehicle emissions. (For additional discussion, see Section 4.3.3.)

those aged 5–9 yr, 5% of VMT was assumed to occur in non-urban areas; for those 10 yr and older, all VMT was assumed to be urban.[23]

By using these factors, the IMPACTT files created for the high- and low-market-share scenarios were modified to create estimates of the urban vehicle population and the VMT, energy use, and operational emissions of those vehicles under each of the two scenarios. Urban upstream emissions were then added to these values. Urban upstream emissions were calculated as a function of the GREET-estimated upstream urban emissions rate for each pollutant and the IMPACTT estimate of total fuel use (urban and non-urban) under each scenario.

4.3 Key Issues

4.3.1 Utilization and Efficiency of 3X Vehicles

Both conventional and 3X vehicles were assumed to have the same utilization. Because 3X vehicles have triple the fuel economy of conventional vehicles, their per-mile operating cost will be considerably less than that of conventional vehicles operating on the same fuel. This lower operating cost could increase vehicle utilization (as well as energy use and emissions), much like the "rebound effect" that has been documented as a result of CAFE-induced increases in fuel economy (Greene 1992). This analysis does not address the effect of tripled fuel economy on operating cost because it is unclear whether any reduction should be assumed. The PNGV goal is for "comparable" costs. On a lifecycle basis, "comparable" may be achieved in many ways. Alternative fuels with triple the GGE cost of gasoline could result in "comparable" fuel costs. Or, lower fuel costs could offset higher vehicle costs, resulting in "comparable" lifecycle costs. Even more likely is a combination of somewhat higher vehicle costs and GGE equivalent fuel cost. Thus, tripling fuel economy does not necessarily suggest a reduction in operating cost, which might then translate into increased vehicle utilization.

Both 3X and conventional vehicles were assumed to have the same percentage gap between rated and on-road fuel economy. Because the PNGV goal is to triple the fuel economy of conventional vehicles, it was assumed that the appropriate base should be actual, not rated, values. Thus, 81 mpg was reduced to approximately 65 mpg for cars ($27 \times 3 = 81 \times 0.8 = 64.8$), and 63 mpg was reduced to approximately 50 mpg for light trucks ($21 \times 3 = 63 \times 0.8 = 50.4$).

4.3.2 Emission Standards and In-Use Emissions

For this analysis, all vehicles were assumed to achieve at least Tier 2 emission standards by model year 2004. Thus, conventional vehicles meet Tier 2 standards, while 3X vehicles, depending on fuel and technology, achieve either Tier 2 or ULEV

[23] These factors were applied to annual utilization which also declines with vehicle age.

standards. Tables 4.1–4.4 contain the emission standards assumed for 3X vehicles using SIDI and CIDI engines and fuel cells (by fuel type), as well as the emission rates (relative to Tier 2 gasoline vehicles) for 3X vehicles using fuel cells and alternative fuels. Note that the four CIDI engine fuels were assumed to meet the Tier 2 gasoline standards of 0.2 g/mi NO_x and 0.04 g/mi PM. Some type of aftertreatment will be required to meet these standards, and deterioration in the performance of that technology may be anticipated. Thus, it is assumed that NO_x emissions from CIDI engines will be comparable with those of SI engines over all vehicle ages, despite the (uncontrolled) CI engine's historically lower emissions deterioration.[24]

Because many of these vehicles have not been built, let alone been subject to certification testing, assumptions about emission rates are speculative. Clearly, achieving Tier 2 and ULEV standards will be a challenge for vehicle manufacturers. Because one of the goals of the PNGV is to achieve emission levels comparable with those of the conventional vehicles that are being replaced, 3X vehicles were assumed to also achieve Tier 2 and ULEV standards. Unless noted to the contrary, emissions of criteria pollutants by SIDI and CIDI engines were assumed to deteriorate over time at their respective historical deterioration rates as predicted by EPA's MOBILE5b model. Even this is somewhat speculative, however, because EPA is revising the MOBILE model. On the basis of unofficial statements, it appears that the rates at which gasoline vehicles will deteriorate will be considerably lower in the next version of the model. If such is the case, this lower rate of deterioration would reduce the emission benefits of 3X vehicles, particularly those operating on fuel cells or using fuels other than gasoline.

4.3.3 Urban Emissions

A number of simplifying assumptions were needed to permit estimation of the operational portion of urban emissions. Several of these are subject to uncertainty. First, are 70% of all household vehicles sold to urban households, or is it over 90%? According to NPTS, 93% of the model year 1990–91 vehicles that were bought new by households during the timeframe in which NPTS was administered went to urban households (FHWA 1992). Because some of these vehicles may ultimately be resold to nonurban households, it is safe to assume that 93% is a high estimate of vehicles that spend their entire lifetime within urban areas. But, the question is, how high? This analysis used 70%, since it is the share of all vehicles (of all vintages) originally bought new that are currently in urban households. However, if urban households have a lower propensity to retain vehicles purchased new, 70% may be a low estimate.

Second, it is unclear whether the approximately 30% of vehicles assumed to be nonurban generate a significant amount of urban VMT. By using data from NPTS, it appears that approximately 17% of total VMT comes from trips to MSAs with a population of 1,000,000 or more by vehicles from outside MSAs or from MSAs with a

[24] If historical CI emissions deterioration rates were assumed, diesel-like fuels would emit less NO_x than gasoline over a vehicle's lifetime.

population less than 1,000,000 (Hu 1993). Because this study's definition of urban includes MSAs with a population of 250,000 or more, 17% is probably a high estimate of urban VMT by nonurban vehicles. But zero is probably a low estimate.

Third, urban vehicles may contribute more nonurban VMT than assumed. If trips of 75 mi or more account for 18% of total VMT (Hu 1993), one might reasonably assume that no more than 82% of urban vehicle VMT should occur within urban areas. For this analysis, a considerably larger share (90% for newer vehicles, increasing to 100% for vehicles 10 years or older) is assumed. Presumably, the higher share assumed for urban vehicles offsets the lower share assumed for nonurban vehicles.

Fourth, the urban share of upstream emissions is uncertain. Shares were estimated by using the ratio of fuel production to fuel consumption within an urban area. High ratios corresponded to net exporters of energy; low ratios corresponded to net importers. Upstream emissions (and energy use) were then allocated between urban and nonurban areas. In many cases, sparse data necessitated the use of default values that are subject to some uncertainty.

Section 4.5 focuses on urban emission results for the various 3X propulsion system/fuel alternatives. Urban emissions of criteria pollutants are clearly more damaging and of greater interest from a nonattainment perspective. Total emissions of greenhouse gases are also presented in Section 4.5.

4.3.4 Transition in Upstream Production Processes

In the Phase 1 analysis, the transitions from corn to biomass ethanol and from natural gas to solar hydrogen were each assumed to occur over a five-year period, from 2015 to 2020 for ethanol and from 2020 to 2025 for hydrogen. A straight-line interpolation procedure was used to weight the upstream energy and emissions rates associated with each production process in order to estimate total upstream energy and emissions. For the Phase 2 analysis, the 5-yr weighting procedure was replaced with annual estimates of production shares from each process, beginning in the year when the new process was introduced and continuing through 2030. The revised procedure is consistent with the capital cost analysis, which incorporates revised assumptions about investment decisions and plant turnover. Although the cost analysis still assumes a five-year interval for the transition, added capacity, not total production, is assumed to shift to the new production process over that five-year interval. Table 4.6 shows the distribution of both added capacity and production shares by production process for each year from 2007 to 2030. Clearly, the most significant change from the Phase 1 analysis is that solar hydrogen falls far short of full market penetration, achieving only 61% penetration under the high-market-share scenario vs. 76% penetration under the low-market-share scenario by 2030.

Table 4.6 Transition from Natural Gas to Solar Hydrogen and from Corn to Biomass Ethanol

	Hydrogen				Ethanol			
	Added Capacity (%)		Total Production (% solar)		Added Capacity (%)		Total Production (% cellulosic)	
Year	NG	Solar	High Mkt Share	Low Mkt Share	Corn	Cellulosic	High Mkt Share	Low Mkt Share
2007	100	0	0		100	0	0	0
2008	100	0	0		100	0	0	0
2009	100	0	0		100	0	0	0
2010	100	0	0		100	0	0	0
2011	100	0	0		100	0	0	0
2012	100	0	0		100	0	0	0
2013	100	0	0	0	100	0	0	0
2014	100	0	0	0	100	0	0	0
2015	100	0	0	0	100	0	0	0
2016	100	0	0	0	80	20	0	0
2017	100	0	0	0	60	40	0	0
2018	100	0	0	0	40	60	27	6
2019	100	0	0	0	20	80	58	48
2020	100	0	0	0	0	100	74	68
2021	80	20	4	3	0	100	79	75
2022	60	40	10	10	0	100	83	80
2023	40	60	17	16	0	100	86	84
2024	20	80	26	26	0	100	88	87
2025	0	100	35	38	0	100	90	90
2026	0	100	44	49	0	100	91	92
2027	0	100	50	59	0	100	92	93
2028	0	100	55	66	0	100	93	94
2029	0	100	58	72	0	100	93	95
2030	0	100	61	76	0	100	94	96

4.4 Energy and Emissions Estimates

The IMPACTT setup used for this analysis included reference scenario vehicles and 3X vehicles with any of 13 combinations of future propulsion system/fuel technologies. Reference scenario vehicles incorporated RFG-fueled conventional SI engines; 3X vehicles could be powered by the following:

- RFG-fueled SIDI engines,
- Methanol-fueled SIDI engines,

- Ethanol-fueled SIDI engines,
- CNG-fueled SIDI engines,
- LNG-fueled SIDI engines,
- LPG-fueled SIDI engines,
- RFD-fueled CIDI engines,
- F-T50-fueled CIDI engines,
- B20-fueled CIDI engines,
- DME-fueled CIDI engines,
- RFG fuel cells,
- Methanol fuel cells, or
- Hydrogen fuel cells.

For each of these propulsion system/fuel technologies, IMPACTT calculations proceeded in three steps. First, using the reference scenario forecasts of vehicle sales and 3X vehicle market share assumptions described in Sections 2.1 and 2.2, stocks of conventional and 3X vehicles were determined for each year between market introduction (2007 in the high-market-share scenario and 2013 in the low-market-share scenario) and 2030. (Shares of 3X vehicles [out of total LDV stocks]) under the two market penetration scenarios are shown in Figure 2.5). Second, energy use (in gasoline gallon equivalents, or GGEs) was calculated for conventional and 3X vehicles by scenario, year, and vehicle type (auto vs. light truck). Differences in total fuel use between the reference and market share scenarios were then used to calculate fuel savings attributable to fuel efficiency and fuel substitution by 3X vehicles. Third, emissions of criteria pollutants (i.e., CO, VOC, NO_x, PM_{10}, and SO_x) and greenhouse gases (GHGs) were computed by scenario, year, and vehicle type as a function of either fuel use or a combination of VMT and age-based emission factors.[25] Emissions were calculated for conventional vehicles and each of the 13 propulsion system/fuel alternatives under the two market-share scenarios.

[25] Operational emissions of NO_x, CO, VOC, and PM_{10} were computed as a function of VMT and emission rates by vehicle type (auto or light truck) and age (0 to over 20 years), which varied by calendar year; upstream emissions of all pollutants and operational emissions of SO_x and CO_2 were computed as a function of the quantity of fuel used and its composition (i.e., sulfur or carbon content for SO_x and CO_2, which varied by calendar year or as the result of switching from one fuel type to another [e.g., from RFG to methanol]). Fuel specifications are provided in Table 2.5.

As compared with the low-market-share scenario, the high-market-share scenario has nearly three times as many 3X vehicles on the road by 2030. These vehicles produce similar increases in 3X VMT and fuel use.

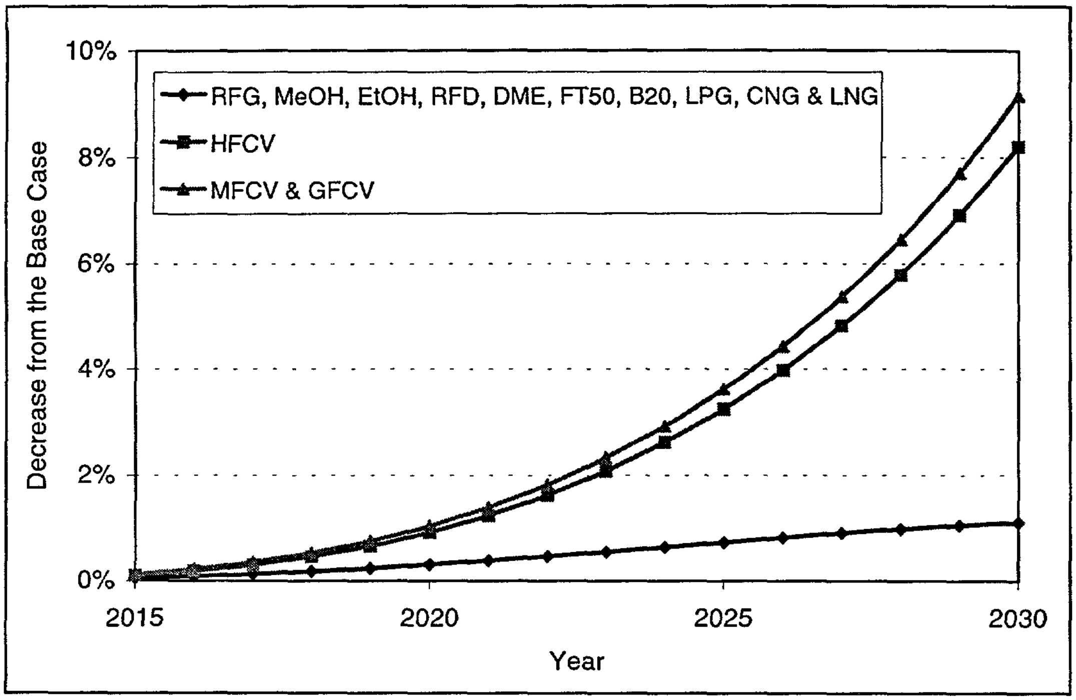
4.4.1 Emissions of Criteria Pollutants

Figures 4.4–4.9 display percent changes in urban emissions of the five criteria pollutants for each of the above propulsion system/fuel combinations. Each figure depicts results for a single pollutant as a series of curves showing annual percentage increases or decreases from the reference scenario forecast for each technology/fuel combination. Curves that are all but indistinguishable are combined to aid interpretation. Upstream and operational emissions are not shown separately (as they were in the Phase 1 report) because virtually all urban emissions are due to vehicle operation. Readers interested in further detail are urged to consult Appendixes A and B, which contain estimates of upstream, operational, and total emissions by propulsion system/fuel combination and scenario.

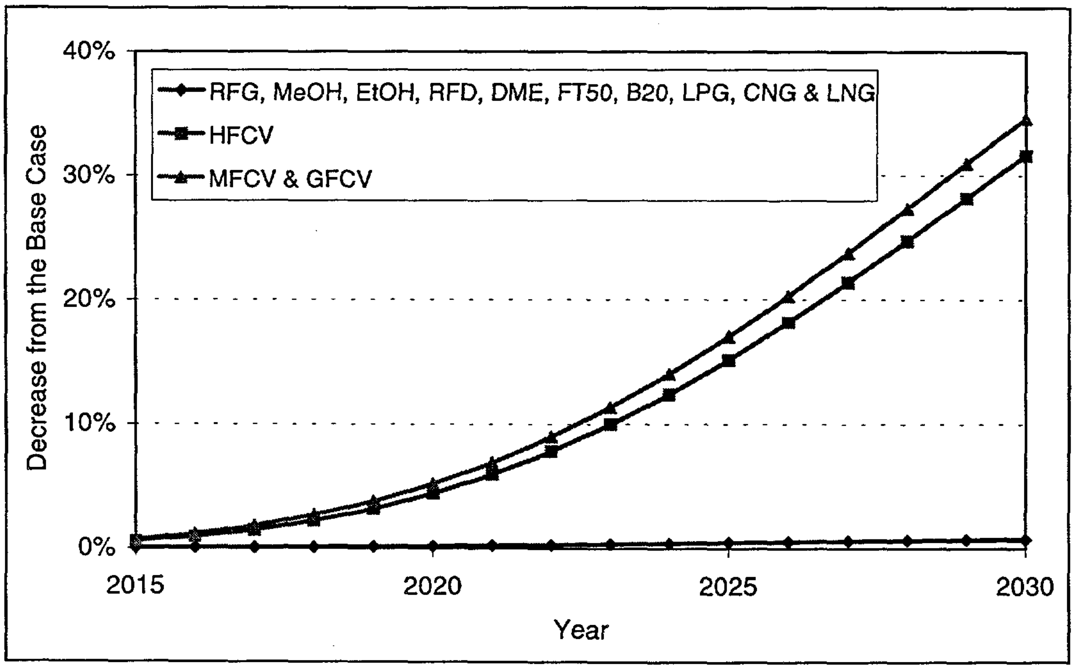
As in the Phase 1 analysis, emissions estimates under both market share scenarios show similar results. However, the patterns are much more striking under the high-market-share scenario (note the different y-axis scales), which, by definition, is a more extreme example of possible market penetration. Thus, the following discussion tends to focus on results from that scenario. Each technology/fuel alternative considered in the analysis was examined in the context of a scenario that contains a significant portion of conventional, as well as 3X, vehicles. Thus, emissions were computed for a combination of conventional and 3X technologies, and results are less striking than would be the case for 3X technologies alone.

Nitrogen Oxides (NO_x). Figure 4.4 illustrates the impact of alternative 3X propulsion system/fuel combinations on urban NO_x emissions under the two scenarios. Because it was assumed that the four CIDI fuels would meet equivalent Tier 2 emission standards, RFD, DME, F-T50, and B20 all fall within a narrow band and are essentially equivalent to RFG, MeOH, EtOH, LPG, and the gaseous-fueled alternatives. Methanol and gasoline fuel cells offer the largest reduction in urban NO_x emissions — 9% under the low-market-share scenario and 35% under the high-market-share scenario. Hydrogen fuel cells achieve somewhat lower NO_x reduction (approximately 8% in the low-market-share scenario vs. 32% in the high-market-share scenario) because of their relatively higher upstream emissions.

Carbon Monoxide (CO). Figure 4.5 shows reductions in CO emissions under the high- and low-market-share scenarios. Again, reductions range up to about 8% under the low-market-share scenario and 35% under the high-market-share scenario, with fuel cells achieving the highest reductions and SIDI engines on any of six fuels achieving the lowest. Between these two clusters, however, the position of the other propulsion system/fuel alternatives differs markedly from NO_x results. Given the CI engine's proven record of relatively low CO emissions, it is not surprising that diesel-like fuels (RFD, DME, F-T50, B20) have the second-best CO reduction.

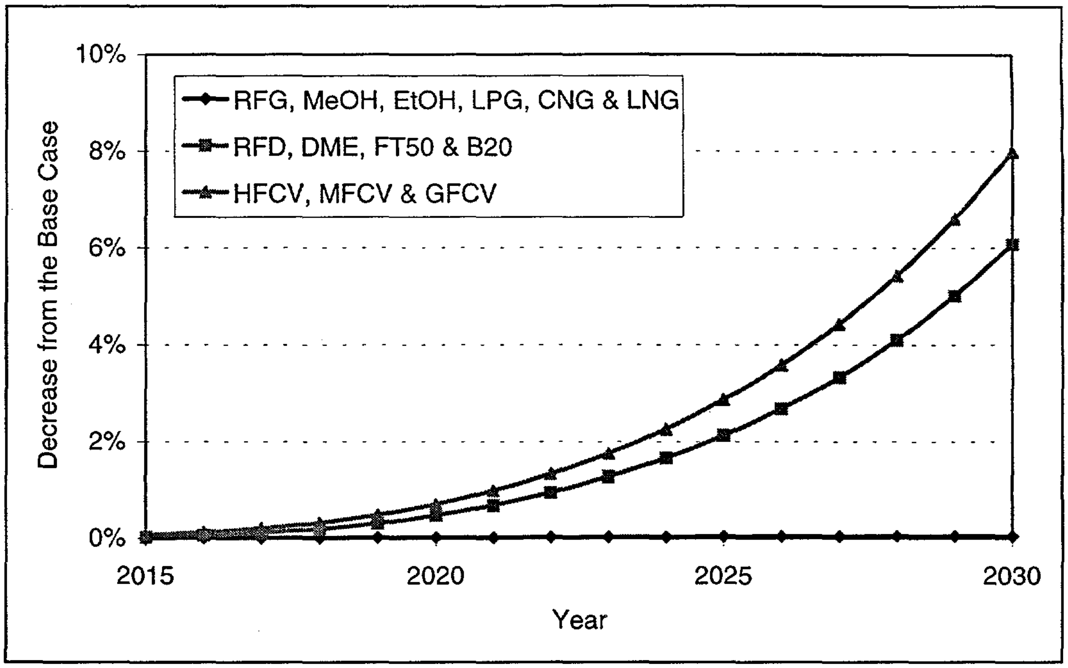


(a) Low-Market-Share Scenario

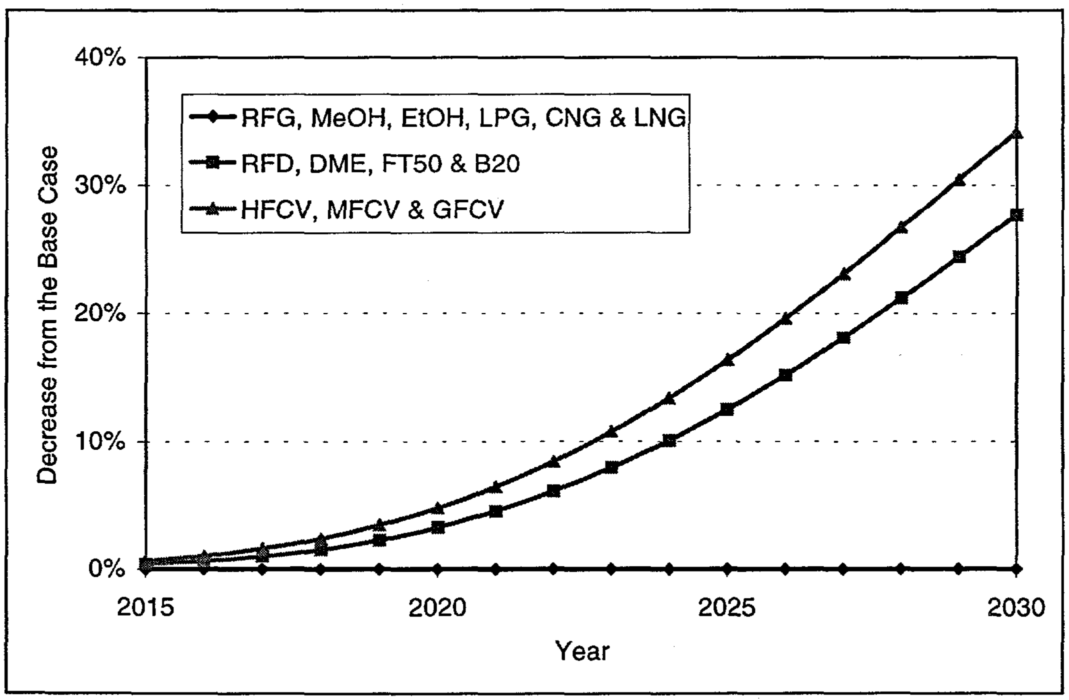


(b) High-Market-Share Scenario

Figure 4.4 Changes in Fuel-Cycle Urban NO_x Emissions by 3X Technology/Fuel Alternative

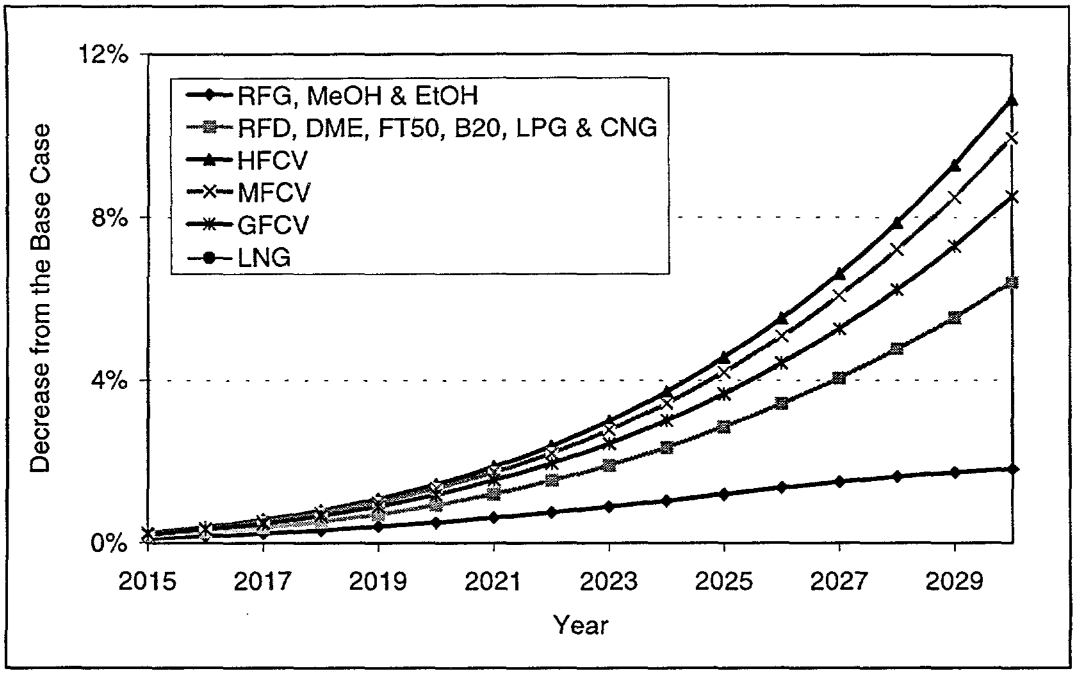


(a) Low-Market-Share Scenario

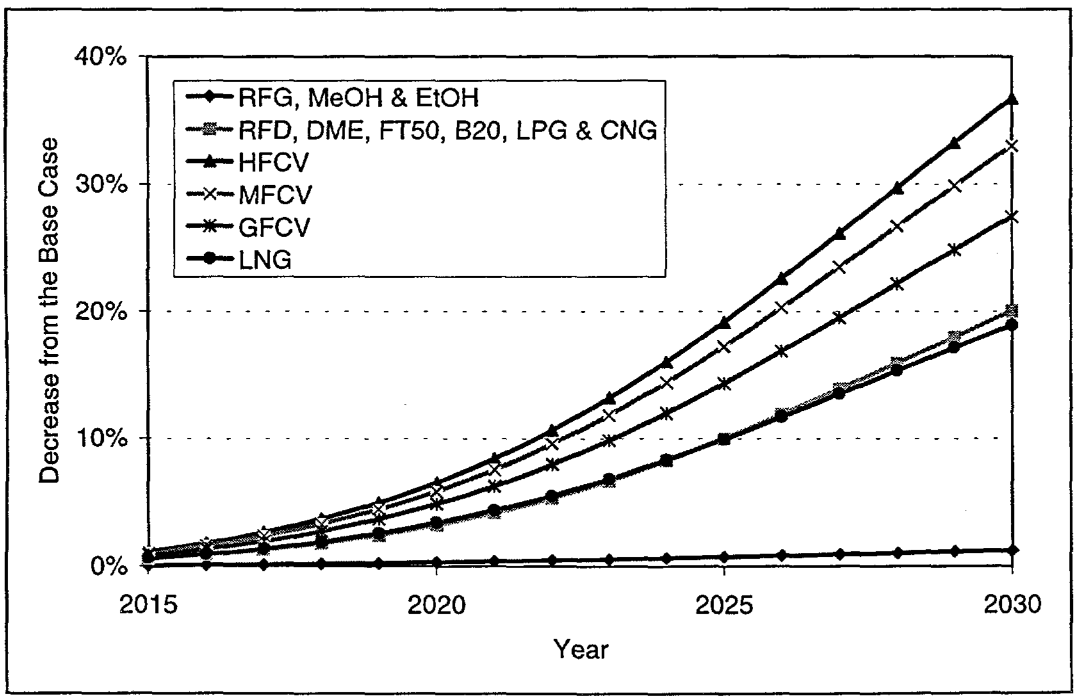


(b) High-Market-Share Scenario

Figure 4.5 Changes in Fuel-Cycle Urban CO Emissions by 3X Technology/Fuel Alternative

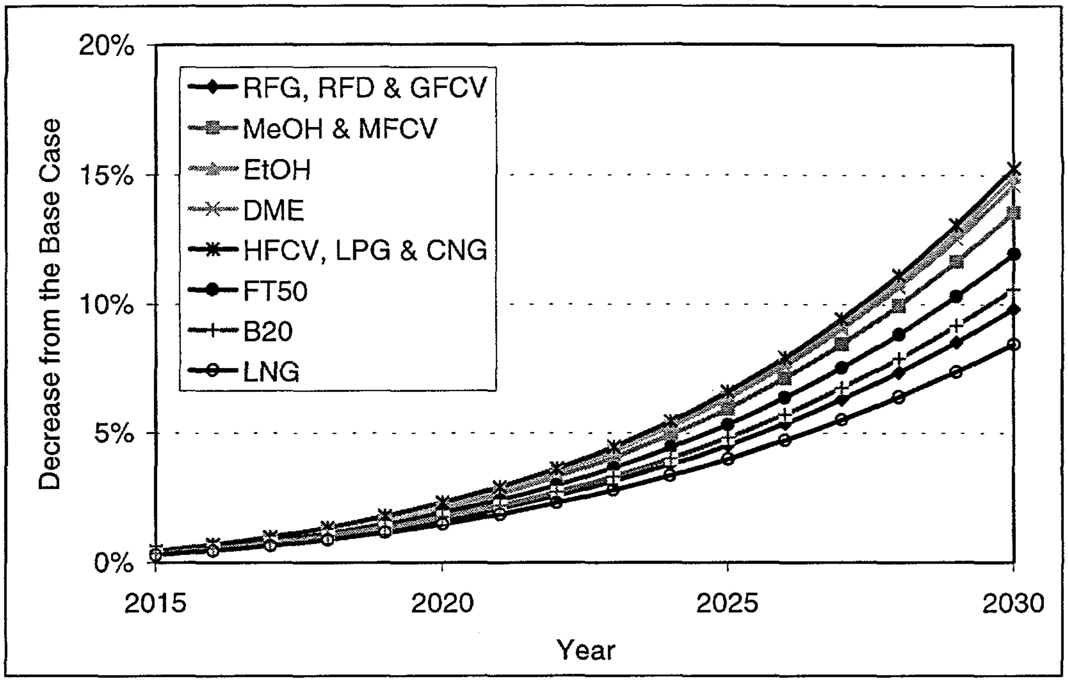


(a) Low-Market-Share Scenario

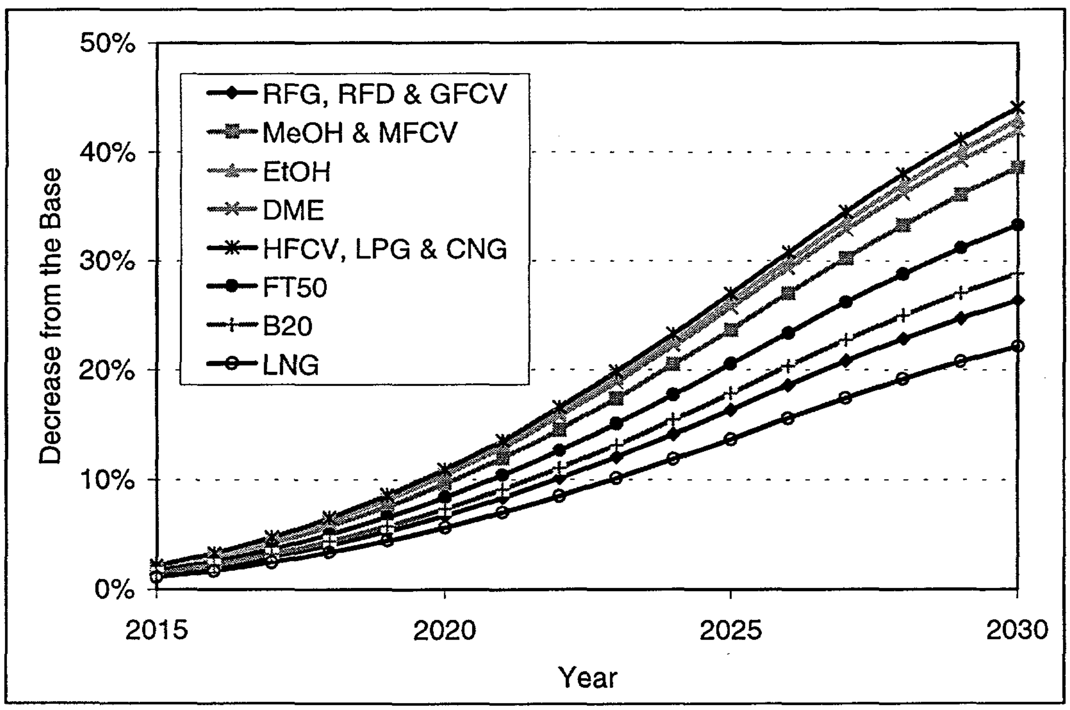


(b) High-Market-Share Scenario

Figure 4.6 Changes in Fuel-Cycle Urban VOC Emissions by 3X Technology/Fuel Alternative

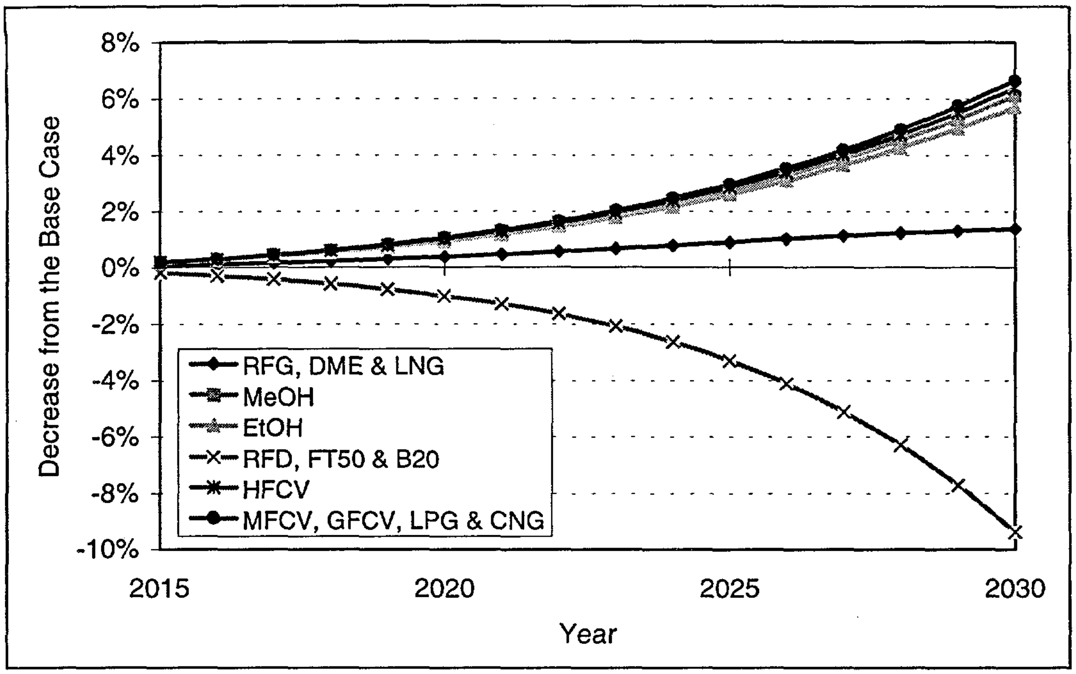


(a) Low-Market-Share Scenario

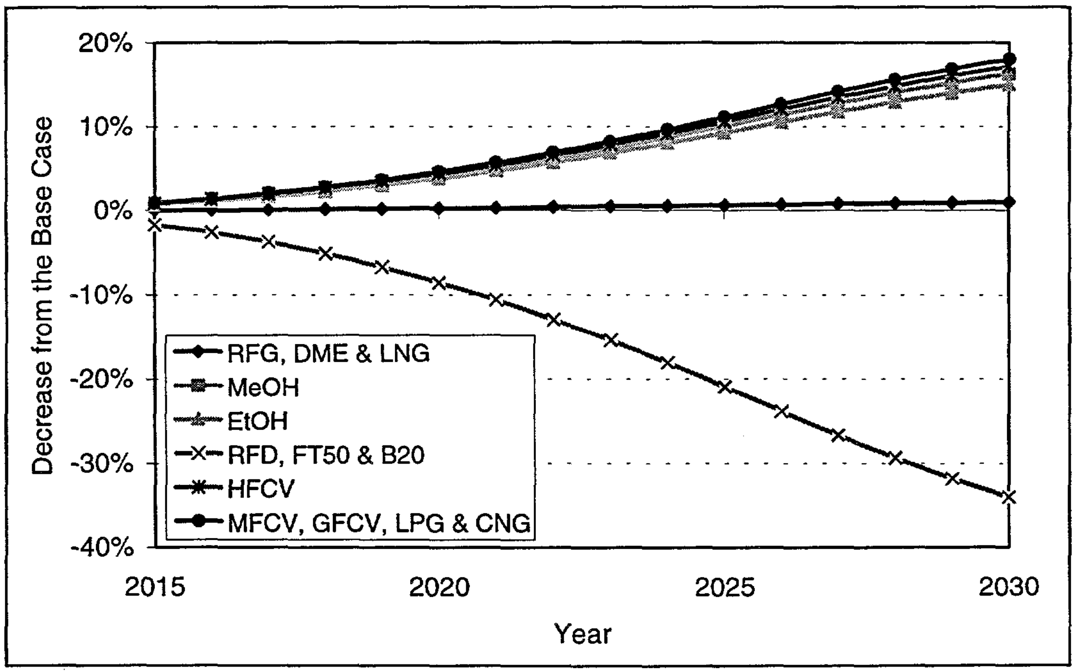


(b) High-Market-Share Scenario

Figure 4.7 Changes in Fuel-Cycle Urban SO_X Emissions by 3X Technology/Fuel Alternative



(a) Low-Market-Share Scenario



(b) High-Market-Share Scenario

Figure 4.8 Changes in Fuel-Cycle Urban PM_{10} Emissions by 3X Technology/Fuel Alternative

Volatile Organic Compounds (VOCs). For VOC, reductions from reference scenario emissions range up to approximately 11% in the low-market-share scenario and 37% in the high-market-share scenario (see Figure 4.6). Hydrogen fuel cells are the clear leader from a VOC reduction standpoint, with methanol fuel cells a close second and gasoline fuel cells third. CIDI engines on RFD, DME F-T50, or B20 and SIDI engines on LPG, CNG, or LNG achieve almost half the reduction of hydrogen fuel cells.

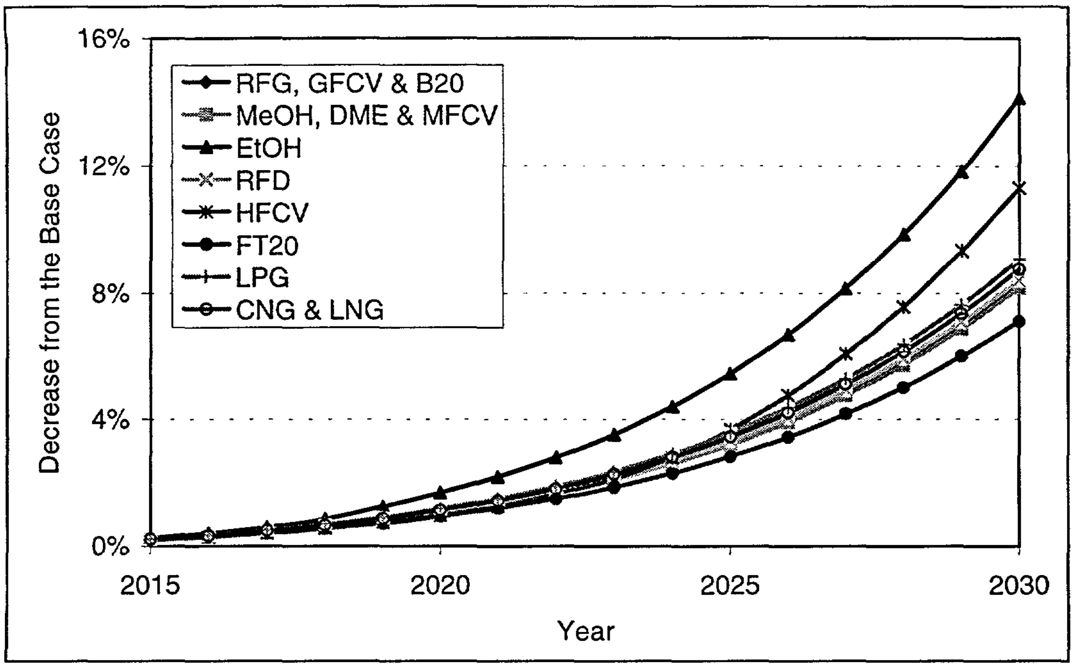
Sulfur Oxides (SO_x). Unlike the other criteria pollutants, urban SO_x emissions are closely related to the volume of fuel used. Thus, relative to the reference scenario, all propulsion system/fuel alternatives reduce urban SO_x emissions because of their tripled fuel efficiency (Figure 4.7). Hydrogen fuel cells, LPG, CNG, ethanol, and DME achieve the biggest reductions, but urban SO_x represents a very small share (on the order of 7–13%) of the total SO_x attributable to light-duty vehicles. Most SO_x emissions come from upstream fuel processing, which tends to be outside urban areas.

Particulate Matter (PM_{10}). Unlike total PM_{10} emissions, nearly half of which occur upstream, urban PM_{10} emissions are dominated by vehicle operations. Thus, with the exception of DME, diesel-like fuels increase PM_{10} emissions (Figure 4.8). Excluding RFG, DME, and LNG, which have little effect on PM, all the other alternatives decrease PM_{10} emissions by approximately 15% under the high-market-share scenario (6% under the low scenario). Note that the increase for diesel-like fuels occurs despite the assumption of a "Tier 2 equivalent" exhaust emission standard of 0.04 g/mi (as compared with the current standard of 0.08 g/mi at 50,000 mi). DME, which produces virtually no particulate matter from fuel combustion, was assumed to achieve the proposed LEV II ULEV standard (including 0.01g/mi PM_{10}). Given that assumption, it comes as no surprise that DME and RFG have comparable urban PM_{10} emissions. For LNG, which produces similar urban PM emissions, upstream processes account for much of urban PM.

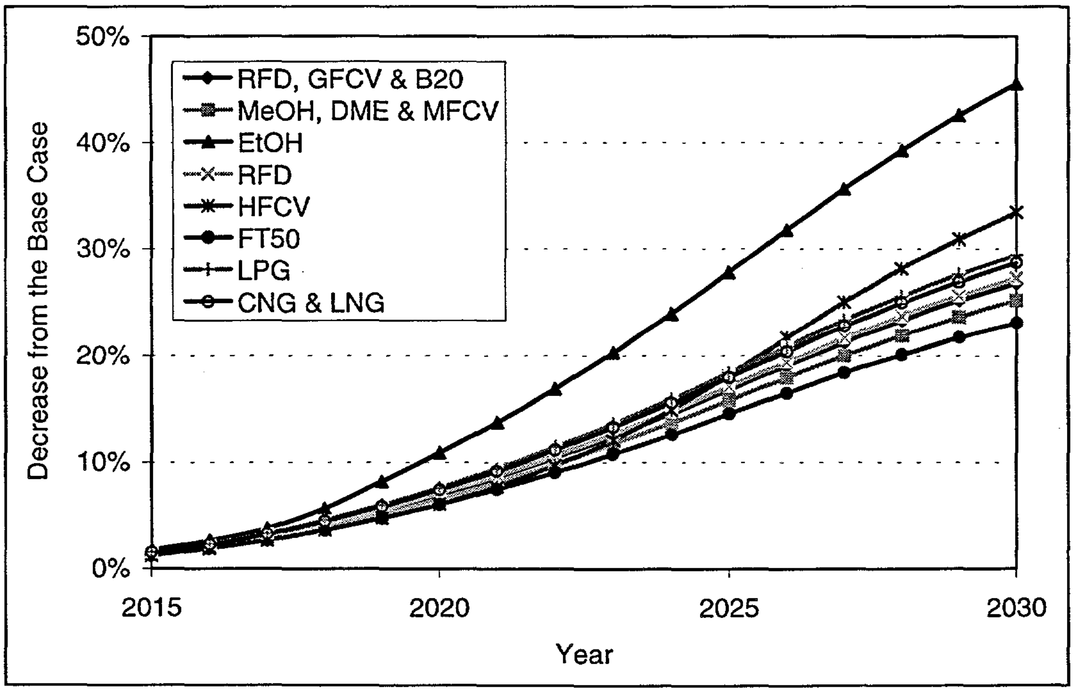
Note also that ethanol is not markedly different from the other SIDI fuel alternatives insofar as urban PM_{10} emissions are concerned. In Phase 1, however, ethanol accounted for the largest increase in total PM_{10} emissions. Virtually all of that increase was due to agricultural processes, making ethanol relatively benign from an urban perspective.

4.4.2 Greenhouse Gas Emissions

Figure 4.12 displays changes in total greenhouse gas (GHG) emissions in the same format as that used for the criteria pollutant graphs. Note that because CO_2 comprises the bulk of GHGs and all propulsion system/fuel alternatives share the same fuel efficiency, emission reductions from non-renewable fuels are clustered. Under the low-market-share scenario, GHG reductions range from 7 to 14%; under the high-market-share scenario, the range is from 23 to 45%. Chief among the low-GHG alternatives are ethanol-fueled SIDI engines and hydrogen fuel cells, both of which generate no CO_2 from vehicle operations. Hydrogen fuel-cell vehicles generate no CO_2 because no carbon is contained in the fuel. Ethanol-fueled SIDI engines are assumed to generate no CO_2 because the carbon in ethanol comes from carbon in the atmosphere via photosynthesis. When



(a) Low-Market-Share Scenario



(b) High-Market-Share Scenario

Figure 4.9 Changes in Fuel-Cycle GHG Emissions by 3X Technology/Fuel Alternative

combined with the conventional vehicles (and their GHG emissions) in the high-market-share scenario, these low-GHG alternatives achieve overall reductions (from all light-duty vehicles, both 3X and conventional) of 46% (for ethanol) and 33% (for hydrogen).

Note also that shifts from current to advanced production technologies cause some GHG reduction curves to shift position relative to the others. Specifically, hydrogen shifts from a position at or near the bottom of the pack to second place by 2025. Ethanol, which is also assumed to shift to a more advanced production technology, has a change in slope, but it is less obvious relative to the other alternatives. After ethanol and hydrogen, the only two renewable fuels examined, LPG and the gaseous fuels, achieve the next-best reduction in GHGs. However, they are only marginally better than the other alternatives.

As compared with Phase 1, Phase 2 estimates of CO_2 emissions reduction are somewhat lower. This result is primarily due to a reduction in projected fuel demand under the reference scenario[26] and a longer transition period from natural gas to solar hydrogen and from corn to cellulosic ethanol.

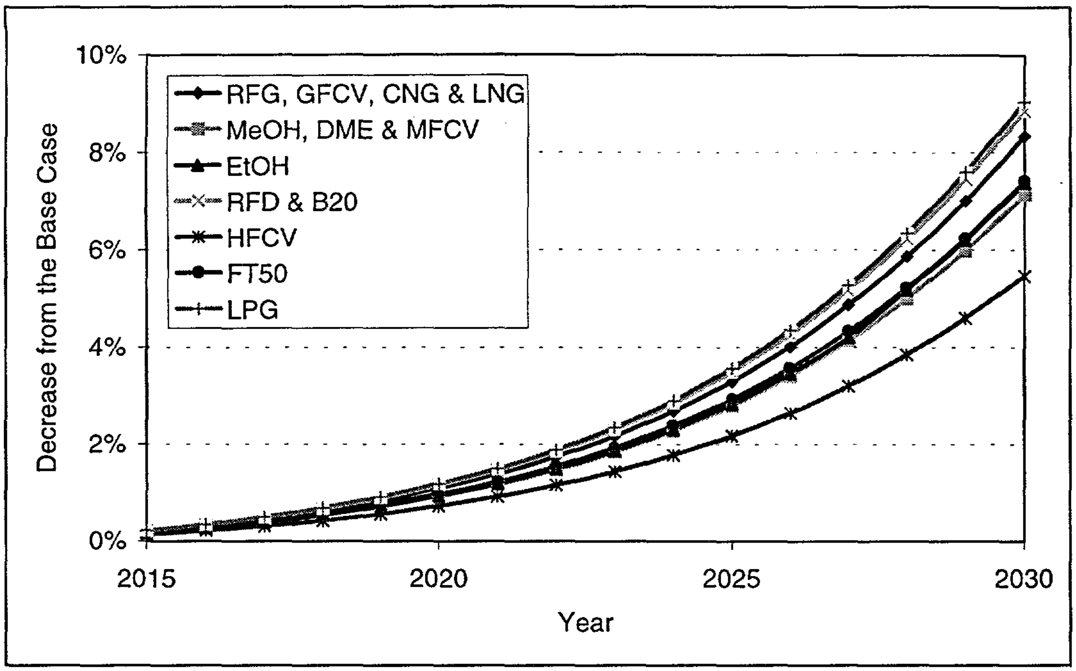
4.4.3 Energy Estimates

Figures 4.10–12 provide estimates of changes in total energy, fossil energy, and petroleum use for the low- and high-market-share scenarios relative to the reference scenario. Again, formats are identical to the above graphs.

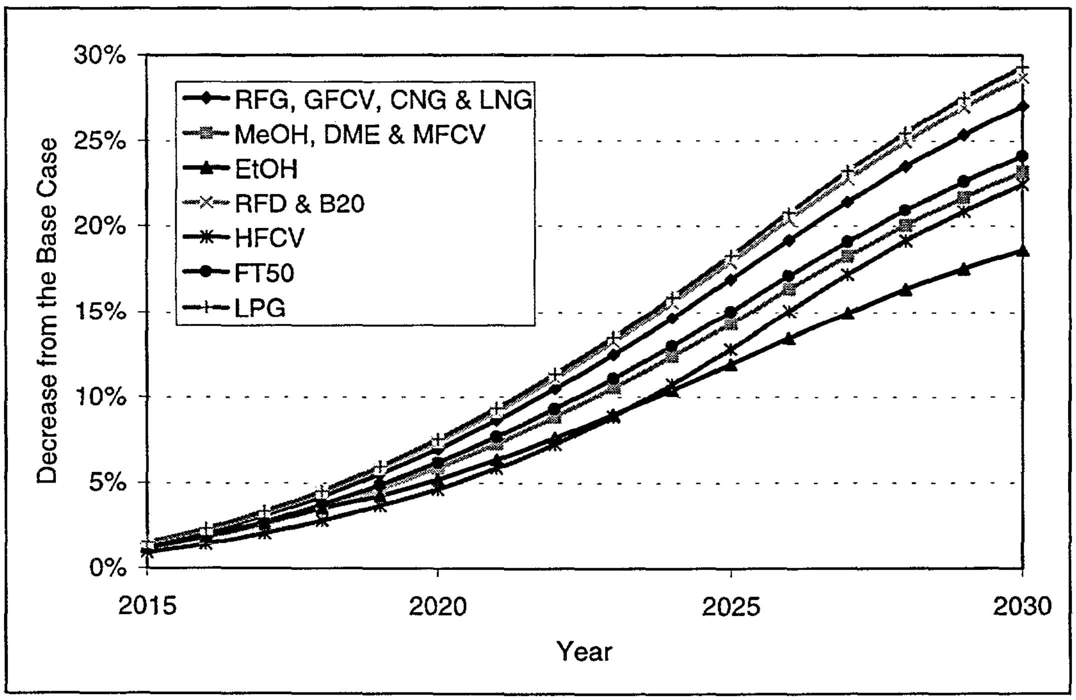
Total Energy. As shown in Figure 4.10, total energy use by light-duty vehicles declines by 18–29% under the high-market-share scenario (5–9% under the low-market-share scenario). By definition, all fuel/technology alternatives achieve 3X fuel economy. Thus, operational energy use declines by 27% in 2030 for all alternatives under the high-market-share scenario (15% in the low-market-share scenario), and the upstream energy requirements of the various fuels account for all the variation in total energy use among the alternatives.

Fossil Fuels. Reductions in fossil energy use by the 13 fuel/technology alternatives under the reference scenario and the high- and low-market-share scenarios are shown in Figure 4.11. The ethanol- and hydrogen-fueled alternatives, both largely nonfossil fuels in 2030, achieve the largest reductions in fossil fuel use in that year (approximately 45% and 38%, respectively, under the high-market-share scenario vs. 11% and 12% under the low-market-share scenario), followed by the biodiesel blend (B20) and RFD, LPG, and CNG, which achieve reductions of nearly 30% under the high-market-share scenario vs. 9% under the low-market-share scenario. The transition from fossil to nonfossil feedstocks is particularly evident in the hydrogen curve, as is a flattening out in all

[26] The lower vehicle sales and fuel economy estimates in AEO-97 result in a 7% reduction in fuel use under the reference scenario as compared with the Phase 1 estimate, which was based on AEO-96 inputs.

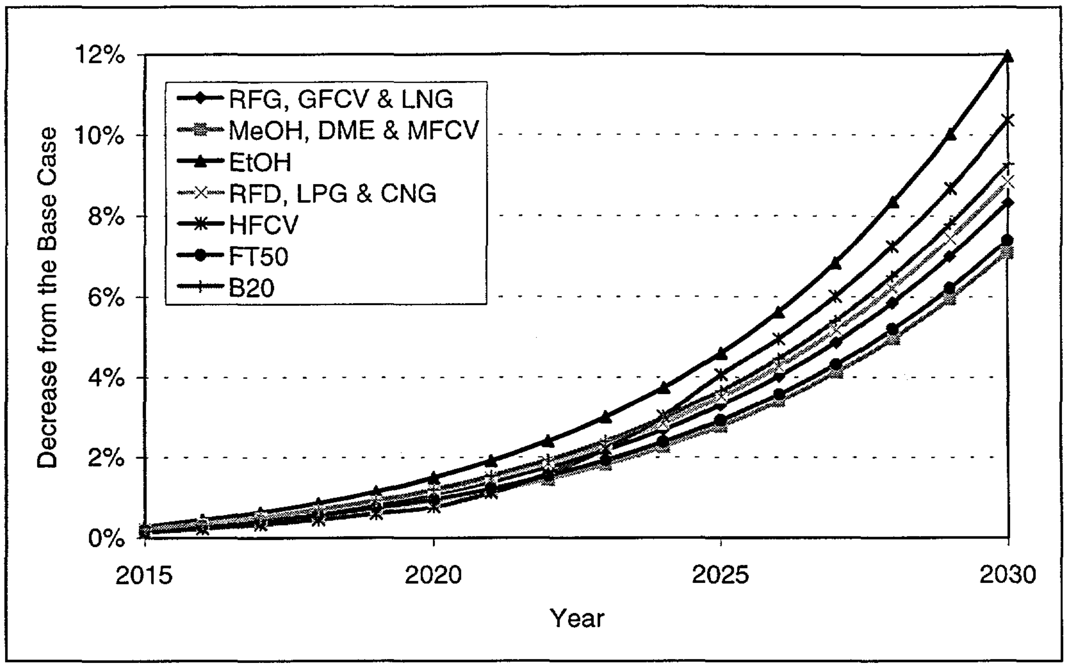


(a) Low-Market-Share Scenario

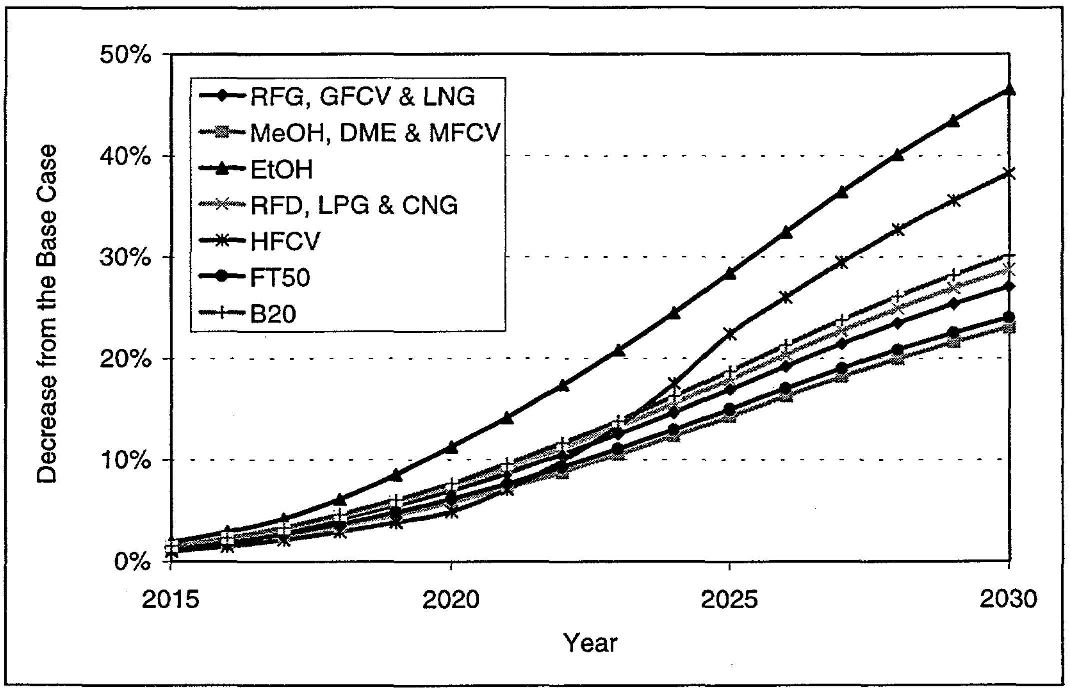


(b) High-Market-Share Scenario

Figure 4.10 Changes in Fuel-Cycle Total Energy Use by 3X Technology/Fuel Alternative

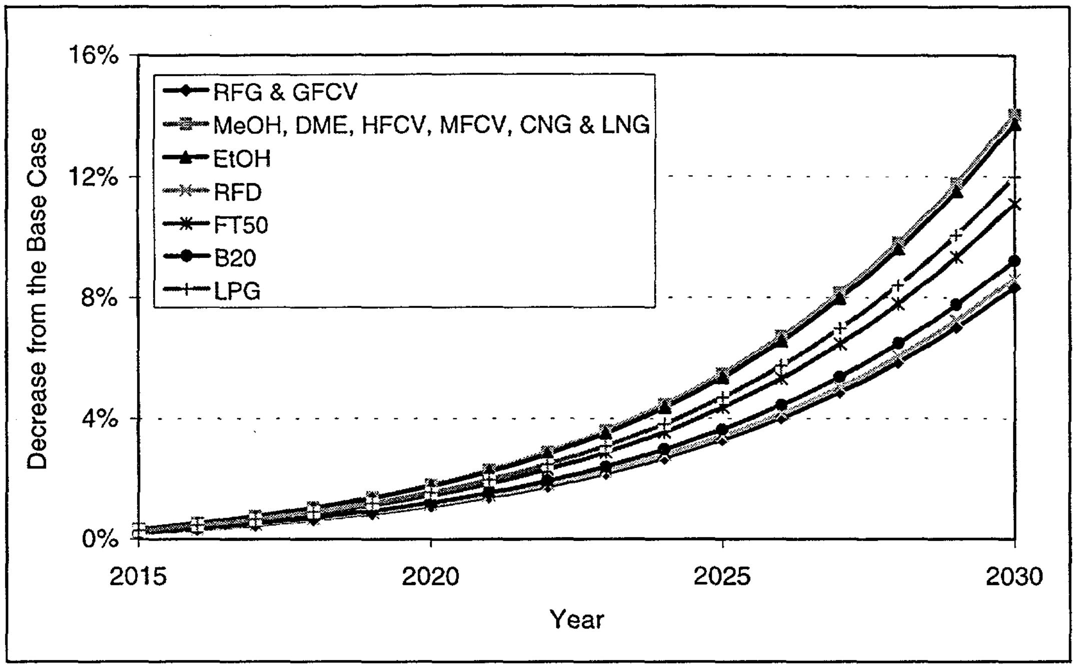


(a) Low-Market-Share Scenario

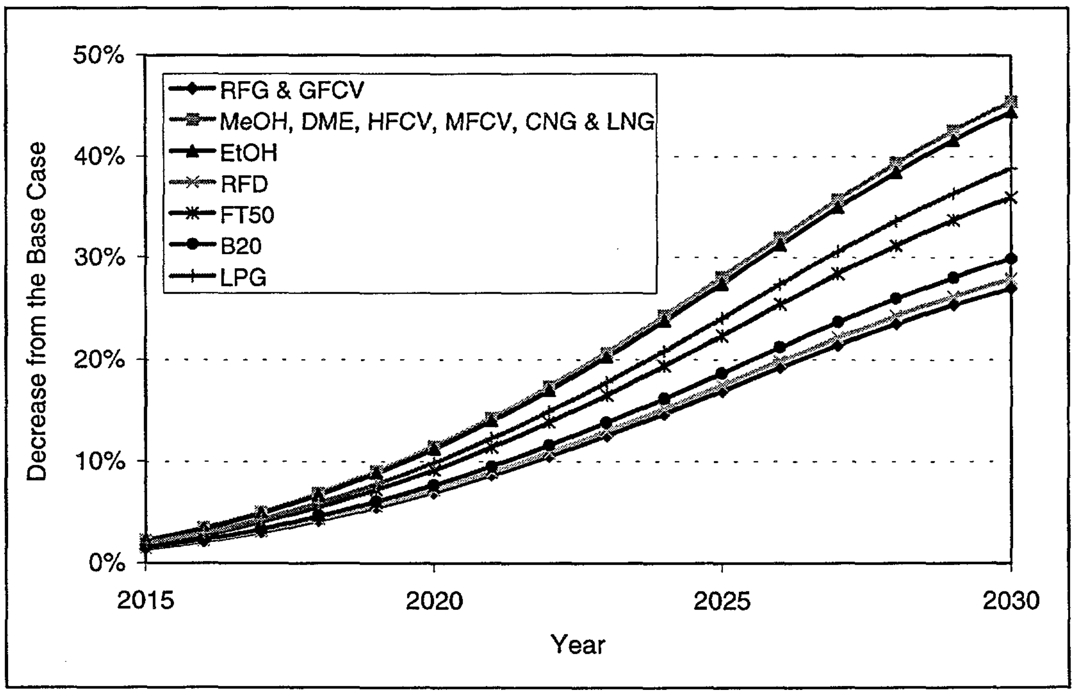


(b) High-Market-Share Scenario

Figure 4.11 Changes in Fuel-Cycle Fossil Energy Use by 3X Technology/Fuel Alternative



(a) Low-Market-Share Scenario



(b) High-Market-Share Scenario

Figure 4.12 Changes in Fuel-Cycle Petroleum Use by 3X Technology/Fuel Alternative

curves for the high-market-share scenario as compared with the low-market-share scenario.

All (completely) fossil-fueled alternatives consume 11.1 quads of fossil fuels because of vehicle *operation* in 2030 under the high-market-share scenario vs. 10.8 quads for B20, 20% of which is nonfossil, and 8.2 quads for the nonfossil alternatives. Again, upstream energy use accounts for the variation in fossil energy use (for the entire fuel cycle) within the two groups of fossil- vs. nonfossil-fueled alternatives.

Petroleum. Several of the fuel/technology alternatives consume nonpetroleum fuels. To the extent that such fuels are derived from fossil sources (e.g., DME or methanol from natural gas), they offer little reduction in greenhouse gas emissions, despite potentially dramatic reductions in petroleum use. Figure 4.12 displays petroleum use by technology/fuel alternative for the reference and low- and high-market-share scenarios. Clearly, the alternatives cluster into three groups: largely petroleum fuels (i.e., RFG, RFD and B20), "part petroleum" fuels (i.e., F-T50 and LPG), and largely nonpetroleum fuels (i.e., hydrogen, methanol, ethanol, DME, CNG, and LNG). By 2030, the nonpetroleum alternatives achieve an approximately 45% reduction in total petroleum use under the high scenario (14% under the low-market-share scenario) relative to the reference scenario. The "part petroleum" alternatives (i.e., LPG and F-T50) achieve the next-best reduction — approximately 35% under the high-market-share scenario and 11% under the low-market-share scenario.

Section 5
Conclusions

In this study, 11 fuels (RFG, RFD, DME, methanol, ethanol, LPG, CNG, LNG, F-T50, B20, and hydrogen) that are candidates for use in 3X vehicles were evaluated in three power system applications (SIDI engine, CIDI engine, or fuel cell) for a total of 13 propulsion system/fuel combinations. Two scenarios depicting alternative levels of 3X market penetration of light-duty-vehicle sales were developed and used to estimate the fuel production and distribution infrastructure needed to satisfy the fuel demands of 3X vehicles and the fuel-cycle energy and emissions impacts of the 13 potential propulsion system/fuel combinations. Capital needs and impacts were generated for each year from market introduction (2007 in the high-market-share scenario and 2013 in the low-market-share scenario) to 2030 for each of the propulsion system/fuel combinations.

As expected, cumulative capital needs were found to vary by technology and scenario. Of particular interest, though, is that supplying the low-market-share scenario's gasoline-equivalent demand requires capital investment of less than $50 billion for all fuels except hydrogen, which is estimated to require a total cumulative investment of $128–146 billion. By contrast, production and distribution facilities with gasoline-equivalent capacity of 1.6 MMBD (which is equivalent to 3X fuel demand in the high-market-share scenario) requires cumulative capital investments of $51 billion for LNG, $88 billion for ethanol, $101 billion for methanol, $123–164 billion for CNG, $162 billion for DME, and $478–559 billion for hydrogen. Although these substantial capital requirements are spread over many years, their sheer magnitude could pose a challenge to the widespread introduction of 3X vehicles.

Petroleum displacement will occur if substantial numbers of 3X vehicles enter the fleet, and adverse impacts on refineries are inevitable. However, the commitment of time and resources to 3X technology development should provide ample economic signals and sufficient lead time for refinery operators to adjust their business to accommodate different fuel demands, including, perhaps, lower gasoline demand. Such an economic restructuring would be considerably less severe than the industry consolidations that occurred during the 1970s and 1980s.

Energy and emissions impacts of 3X vehicles are highly dependent on market penetration and thus differ dramatically between the two scenarios examined in this study. Because impacts are relatively small under the low-market-share scenario, most of the discussion presented here focused on the more significant results obtained for the high-market-share scenario. For all 3X propulsion system/fuel technologies, total energy and fossil fuel use by U.S. light-duty vehicles decline significantly under the high-market-share scenario relative to reference scenario estimates for 2030. Fuel savings occur as a result of fuel-efficiency improvements, which apply to all 3X technologies and reduce LDV energy use by more than 25%, as well as a result of fuel substitution, which applies to the nonpetroleum-fueled alternatives studied. Together, the two effects reduce LDV petroleum use in 2030 by as much as 45% relative to the reference scenario. GHG emissions follow a similar pattern. Total GHG emissions decline by 25–30% with most of the propulsion system/fuel alternatives. For those using renewable fuels (i.e., ethanol from biomass and hydrogen from solar energy), GHG emissions drop by 33% (hydrogen) and 45% (ethanol) relative to the level estimated for the reference scenario.

Among the five criteria pollutants, urban NO_x emissions decline slightly for 3X vehicles using CIDI and SIDI engines and drop substantially for fuel-cell vehicles (FCVs). Urban CO emissions decline for CIDI and FCV alternatives, while VOC emissions drop significantly for all alternatives except RFG-, MeOH- and EtOH-fueled SIDI engines. With the exception of CIDI engines using RFD, F-T50, or B20 (which increase urban PM_{10} emissions by over 30% in the high scenario), all propulsion system/fuel alternatives reduce urban PM_{10} emissions. Reductions are approximately 15–20% for fuel cells and methanol ethanol-, CNG-, or LPG-fueled SIDI engines (RFG- and LNG-fueled SIDI engines and DME-fueled CIDI engines have only very slight reductions). Although urban SO_x emissions declined for all of the alternatives, SO_x emissions resulting from the use of LNG were higher than those resulting from the use of hydrogen, LPG, and CNG.

Table 5.1 qualitatively summarizes impacts of the 13 alternatives on capital requirements and on energy use and emissions relative to the reference scenario. The table clearly shows the trade-off between costs and benefits. For example, while hydrogen FCVs have the greatest incremental capital needs, they offer the largest energy and emissions benefits. On the basis of the cost and benefit changes shown, methanol and gasoline FCVs appear to have particularly promising benefits-to-costs ratios. As stated in the beginning of this report, all 3X technologies were assumed to become an engineering reality. This is speculative, particularly for some less mature technologies, such as fuel cells and DME fuel. By its very nature, the assumption of technological readiness should be a subject of continued reexamination.

The air quality implications of these emissions results should be interpreted cautiously. Changes in emissions of the five criteria pollutants (as presented in Table 5.1) do not necessarily translate into similar changes in air quality, simply because emissions from different fuels and upstream fuel-production activities occur in different locations and at different times and are dependent on atmospheric processes. Generally speaking, upstream emissions occur outside urban areas, while vehicular emissions occur within urban areas. Because of high population exposure (especially where mortality effects exist), emissions in urban areas generate far greater damage than those outside urban areas. That is why urban emissions have been estimated in this analysis. However, as discussed in Section 4.3.3, those estimates are based on broad, categorical data that may not be representative of all urban areas and that do not take into account the effects of varying local climatic conditions. Moreover, because methanol, DME, and much of LPG were assumed to be produced in foreign countries, some of the emissions from their production are not included in the estimates shown here.

Table 5.1 Impacts of Propulsion System/Fuel Alternatives for 3X Vehicles Relative to the Reference Scenario

Parameter	RFG[a]	MeOH[a]	EtOH[a]	LPG[a]	CNG[a]	LNG[a]	RFD[a]	DME[a]	F-T50[a]	B20[a]	GFCV[a]	MFCV[a]	HFCV[a]
Cost of fuel production	0[b]	--	--	-	-	-	0	---	-	0	0	--	---
Cost of fuel distribution	0	-	-	-	---	-	0	-	0	0	0	-	---
Total energy use	+++	++	+	+++	+++	+++	+++	++	++	+++	+++	++	+
Fossil energy use	++	++	+++	++	++	++	++	++	++	++	++	++	+++
Petroleum use	+	+++	+++	++	+++	+++	+	+++	++	+	+	+++	+++
GHG emissions	++	++	+++	++	++	++	++	++	++	++	++	++	+++
VOC emissions[c]	0	0	0	+	+	+	+	+	+	+	++	+++	+++
CO emissions[c]	0	0	0	0	0	0	++	++	++	++	+++	+++	+++
NO_x emissions[c]	0	0	0	0	0	0	0	0	0	0	+++	+++	+++
PM_{10} emissions[c]	0	++	++	++	++	0	---	0	---	---	++	++	++
SO_x emissions[c]	+	+++	+++	+++	+++	+	+	+++	++	+	+	+++	+++

[a] RFG: reformulated gasoline
MeOH: methanol
EtOH: ethanol
LPG: liquefied petroleum gas
CNG: compressed natural gas
LNG: liquefied natural gas
RFD: reformulated diesel
DME: dimethyl ether
F-T50: 50% Fischer-Tropsch diesel and 50% conventional diesel
HFCV: hydrogen fuel-cell vehicles
B20: 20% biodiesel and 80% conventional diesel
GFCV: gasoline fuel-cell vehicles
MFCV: methanol fuel-cell vehicles

[b] Key:
0: no change
-: a little worse
--: worse
---: worst
+: a little better
++: better
+++: best

[c] Urban emissions

As shown in Table 5.1, urban PM_{10} emissions from ethanol-fueled 3X vehicles are less than those from most of the alternatives examined. In marked contrast, the Phase 1 results did not disaggregate criteria emissions into urban and nonurban components. PM_{10} emissions from ethanol occur largely upstream (from farming and ethanol production) and outside urban areas, while PM_{10} emissions from the diesel-like fuels (RFD, F-T50 and B20) occur during vehicle operation, most of which is inside urban areas. Beyond the qualitative comparison of totals shown in Table 5.1, increased urban PM_{10} emissions from RFD and, to a lesser extent, from F-T50 and B20 may also produce worse health effects because diesel PM_{10} emissions, much of which is fine particulate matter of 2.5 μm or less ($PM_{2.5}$), may have much greater damage per unit than ethanol PM_{10} emissions, which tend to be in the 2.5–10 μm range and to be removed from urban populations. Full assessment of the damage caused by emissions from each fuel requires air quality modeling and risk assessment beyond the scope of this analysis.

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Appendix A
Annual Results of Fuel-Cycle Energy and Emissions Analysis: Low-Market-Share Scenario

Table A.1 Energy Use from Vehicle Operation

	Operational Energy Use for the Base Case and for Each PNGV Technology/Fuel Combination (quads)													
	Base Case	CV+RFG	CV+MeOH	CV+EtOH	CV+RFD	CV+DME	CV+HFCV	CV+MFCV	CV+GFC	CV+FTD/RFD	CV+Bio/RFD	CV+LPG	CV+CNG	CV+LNG
2005	14.1	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8
2006	14.2	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0
2007	14.3	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2
2008	14.4	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3
2009	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6
2010	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8
2011	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9
2012	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
2013	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1
2014	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1
2015	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1
2016	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1
2017	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1
2018	15.1	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
2019	15.1	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
2020	15.1	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
2021	15.1	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9
2022	15.1	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9
2023	15.1	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8
2024	15.1	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7
2025	15.1	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6
2026	15.2	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5
2027	15.2	14.4	14.4	14.4	14.4	14.4	14.4	14.4	14.4	14.4	14.4	14.4	14.4	14.4
2028	15.2	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3
2029	15.2	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1
2030	15.2	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0

Table A.2 Fossil Energy Use from Vehicle Operation

	Operational Fossil Energy Use for the Base Case and for Each PNGV Technology/Fuel Combination (quads)													
	Base Case	CV+RFG	CV+MeOH	CV+EtOH	CV+RFD	CV+DME	CV+HFCV	CV+MFCV	CV+GFC	CV+FTD/RFD	CV+Bio/RFD	CV+LPG	CV+CNG	CV+LNG
2005	14.1	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8
2006	14.2	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0
2007	14.3	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2
2008	14.4	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3
2009	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6
2010	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8
2011	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9
2012	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
2013	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1
2014	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1
2015	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1
2016	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1
2017	15.1	15.1	15.1	15.0	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1
2018	15.1	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
2019	15.1	15.0	15.0	14.9	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
2020	15.1	15.0	15.0	14.8	15.0	15.0	15.0	15.0	15.0	15.0	14.9	15.0	15.0	15.0
2021	15.1	14.9	14.9	14.8	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9
2022	15.1	14.9	14.9	14.7	14.9	14.9	14.8	14.9	14.9	14.9	14.8	14.9	14.9	14.9
2023	15.1	14.8	14.8	14.6	14.8	14.8	14.7	14.8	14.8	14.8	14.8	14.8	14.8	14.8
2024	15.1	14.7	14.7	14.4	14.7	14.7	14.5	14.7	14.7	14.7	14.7	14.7	14.7	14.7
2025	15.1	14.6	14.6	14.3	14.6	14.6	14.3	14.6	14.6	14.6	14.6	14.6	14.6	14.6
2026	15.2	14.5	14.5	14.1	14.5	14.5	14.1	14.5	14.5	14.5	14.5	14.5	14.5	14.5
2027	15.2	14.4	14.4	13.9	14.4	14.4	13.9	14.4	14.4	14.4	14.4	14.4	14.4	14.4
2028	15.2	14.3	14.3	13.7	14.3	14.3	13.7	14.3	14.3	14.3	14.2	14.3	14.3	14.3
2029	15.2	14.1	14.1	13.4	14.1	14.1	13.4	14.1	14.1	14.1	14.1	14.1	14.1	14.1
2030	15.2	14.0	14.0	13.1	14.0	14.0	13.1	14.0	14.0	14.0	13.9	14.0	14.0	14.0

Table A.3 Petroleum Use from Vehicle Operation

	Operational Petroleum Use for the Base Case and for Each PNGV Technology/Fuel Combination (quads)													
	Base Case	CV+RFG	CV+MeOH	CV+EtOH	CV+RFD	CV+DME	CV+HFCV	CV+MFCV	CV+GFC	CV+FTD/RFD	CV+Bio/RFD	CV+LPG	CV+CNG	CV+LNG
2005	14.1	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8
2006	14.2	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0
2007	14.3	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2
2008	14.4	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3
2009	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6
2010	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8
2011	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9
2012	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
2013	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1
2014	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1
2015	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1
2016	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1
2017	15.1	15.1	15.0	15.0	15.1	15.0	15.0	15.0	15.1	15.0	15.1	15.0	15.0	15.0
2018	15.1	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
2019	15.1	15.0	14.9	14.9	15.0	14.9	14.9	14.9	15.0	15.0	15.0	15.0	14.9	14.9
2020	15.1	15.0	14.8	14.8	15.0	14.8	14.8	14.8	15.0	14.9	14.9	14.9	14.8	14.8
2021	15.1	14.9	14.8	14.8	14.9	14.8	14.8	14.8	14.9	14.8	14.9	14.8	14.8	14.8
2022	15.1	14.9	14.7	14.7	14.9	14.7	14.7	14.7	14.9	14.8	14.8	14.8	14.7	14.7
2023	15.1	14.8	14.6	14.6	14.8	14.6	14.6	14.6	14.8	14.7	14.8	14.7	14.6	14.6
2024	15.1	14.7	14.4	14.4	14.7	14.4	14.4	14.4	14.7	14.6	14.7	14.6	14.4	14.4
2025	15.1	14.6	14.3	14.3	14.6	14.3	14.3	14.3	14.6	14.5	14.6	14.4	14.3	14.3
2026	15.2	14.5	14.1	14.1	14.5	14.1	14.1	14.1	14.5	14.4	14.5	14.3	14.1	14.1
2027	15.2	14.4	13.9	13.9	14.4	13.9	13.9	13.9	14.4	14.2	14.4	14.1	13.9	13.9
2028	15.2	14.3	13.7	13.7	14.3	13.7	13.7	13.7	14.3	14.0	14.2	13.9	13.7	13.7
2029	15.2	14.1	13.4	13.4	14.1	13.4	13.4	13.4	14.1	13.8	14.1	13.7	13.4	13.4
2030	15.2	14.0	13.1	13.1	14.0	13.1	13.1	13.1	14.0	13.6	13.9	13.4	13.1	13.1

Table A.4 NO_x Emissions from Urban Vehicle Operation

	Operational Emissions of NO_x for the Base Case and for Each PNGV Technology/FuelCombination (10^3 tonnes)													
	Base Case	CV+RFG	CV+MeOH	CV+EtOH	CV+RFD	CV+DME	CV+HFCV	CV+MFCV	CV+GFCV	CV+F-T50	CV+B20	CV+LPG	CV+CNG	CV+LNG
2005	1,712	1,616	1,616	1,616	1,616	1,616	1,616	1,616	1,616	1,616	1,616	1,616	1,616	1,616
2006	1,684	1,626	1,626	1,626	1,626	1,626	1,626	1,626	1,626	1,626	1,626	1,626	1,626	1,626
2007	1,650	1,617	1,617	1,617	1,617	1,617	1,617	1,617	1,617	1,617	1,617	1,617	1,617	1,617
2008	1,600	1,584	1,584	1,584	1,584	1,584	1,584	1,584	1,584	1,584	1,584	1,584	1,584	1,584
2009	1,574	1,568	1,568	1,568	1,568	1,568	1,568	1,568	1,568	1,568	1,568	1,568	1,568	1,568
2010	1,537	1,537	1,537	1,537	1,537	1,537	1,537	1,537	1,537	1,537	1,537	1,537	1,537	1,537
2011	1,493	1,493	1,493	1,493	1,493	1,493	1,493	1,493	1,493	1,493	1,493	1,493	1,493	1,493
2012	1,444	1,444	1,444	1,444	1,444	1,444	1,444	1,444	1,444	1,444	1,444	1,444	1,444	1,444
2013	1,390	1,390	1,390	1,390	1,390	1,390	1,390	1,390	1,390	1,390	1,390	1,390	1,390	1,390
2014	1,340	1,340	1,340	1,340	1,340	1,340	1,339	1,339	1,339	1,340	1,340	1,340	1,340	1,340
2015	1,295	1,295	1,295	1,295	1,295	1,295	1,294	1,294	1,294	1,295	1,295	1,295	1,295	1,295
2016	1,258	1,258	1,258	1,258	1,258	1,258	1,256	1,256	1,256	1,258	1,258	1,258	1,258	1,258
2017	1,229	1,229	1,229	1,229	1,229	1,229	1,226	1,226	1,226	1,229	1,229	1,229	1,229	1,229
2018	1,208	1,208	1,208	1,208	1,208	1,208	1,203	1,204	1,204	1,208	1,208	1,208	1,208	1,208
2019	1,193	1,193	1,193	1,193	1,193	1,193	1,187	1,187	1,187	1,193	1,193	1,193	1,193	1,193
2020	1,185	1,185	1,185	1,185	1,185	1,185	1,176	1,176	1,176	1,185	1,185	1,185	1,185	1,185
2021	1,181	1,181	1,181	1,181	1,181	1,181	1,168	1,168	1,168	1,181	1,181	1,181	1,181	1,181
2022	1,179	1,179	1,179	1,179	1,179	1,179	1,163	1,163	1,163	1,179	1,179	1,179	1,179	1,179
2023	1,181	1,181	1,181	1,181	1,181	1,181	1,159	1,159	1,159	1,181	1,181	1,181	1,181	1,181
2024	1,186	1,186	1,186	1,186	1,186	1,186	1,158	1,158	1,158	1,186	1,186	1,186	1,186	1,186
2025	1,191	1,191	1,191	1,191	1,191	1,191	1,155	1,156	1,156	1,191	1,191	1,191	1,191	1,191
2026	1,196	1,196	1,196	1,196	1,196	1,196	1,152	1,152	1,152	1,196	1,196	1,196	1,196	1,196
2027	1,201	1,201	1,201	1,201	1,201	1,201	1,146	1,146	1,146	1,201	1,201	1,201	1,201	1,201
2028	1,206	1,206	1,206	1,206	1,206	1,206	1,138	1,139	1,139	1,206	1,206	1,206	1,206	1,206
2029	1,212	1,212	1,212	1,212	1,212	1,212	1,128	1,129	1,129	1,212	1,212	1,212	1,212	1,212
2030	1,217	1,217	1,217	1,217	1,217	1,217	1,116	1,117	1,117	1,217	1,217	1,217	1,217	1,217

Table A.5 CO Emissions from Urban Vehicle Operation

	Operational Emissions of CO for the Base Case and for Each PNGV Technology/Fuel Combination (10^3 tonnes)													
	Base Case	CV+RFG	CV+MeOH	CV+EtOH	CV+RFD	CV+DME	CV+HFCV	CV+MFCV	CV+GFC	CV+FTD/RFD	CV+Bio/RFD	CV+LPG	CV+CNG	CV+LNG
2005	26,663	25,093	25,093	25,093	25,093	25,093	25,093	25,093	25,093	25,093	25,093	25,093	25,093	25,093
2006	26,273	25,321	25,321	25,321	25,321	25,321	25,321	25,321	25,321	25,321	25,321	25,321	25,321	25,321
2007	25,797	25,265	25,265	25,265	25,265	25,265	25,265	25,265	25,265	25,265	25,265	25,265	25,265	25,265
2008	25,049	24,787	24,787	24,787	24,787	24,787	24,787	24,787	24,787	24,787	24,787	24,787	24,787	24,787
2009	24,662	24,565	24,565	24,565	24,565	24,565	24,565	24,565	24,565	24,565	24,565	24,565	24,565	24,565
2010	24,099	24,099	24,099	24,099	24,099	24,099	24,099	24,099	24,099	24,099	24,099	24,099	24,099	24,099
2011	23,407	23,407	23,407	23,407	23,407	23,407	23,407	23,407	23,407	23,407	23,407	23,407	23,407	23,407
2012	22,639	22,639	22,639	22,639	22,639	22,639	22,639	22,639	22,639	22,639	22,639	22,639	22,639	22,639
2013	21,787	21,787	21,787	21,787	21,787	21,787	21,785	21,785	21,785	21,787	21,787	21,787	21,787	21,787
2014	20,977	20,977	20,977	20,977	20,975	20,975	20,971	20,971	20,971	20,975	20,975	20,977	20,977	20,977
2015	20,255	20,255	20,255	20,255	20,249	20,249	20,242	20,242	20,242	20,249	20,249	20,255	20,255	20,255
2016	19,651	19,651	19,651	19,651	19,639	19,639	19,627	19,628	19,628	19,639	19,639	19,651	19,651	19,651
2017	19,180	19,180	19,180	19,180	19,160	19,160	19,142	19,142	19,142	19,160	19,160	19,180	19,180	19,180
2018	18,835	18,835	18,835	18,835	18,800	18,800	18,775	18,776	18,776	18,800	18,800	18,835	18,835	18,835
2019	18,597	18,597	18,597	18,597	18,541	18,541	18,508	18,509	18,509	18,541	18,541	18,597	18,597	18,597
2020	18,447	18,447	18,447	18,447	18,361	18,361	18,318	18,319	18,319	18,361	18,361	18,447	18,447	18,447
2021	18,366	18,366	18,366	18,366	18,243	18,243	18,187	18,189	18,189	18,243	18,243	18,366	18,366	18,366
2022	18,343	18,343	18,343	18,343	18,172	18,172	18,101	18,103	18,103	18,172	18,172	18,343	18,343	18,343
2023	18,357	18,357	18,357	18,357	18,128	18,128	18,038	18,041	18,041	18,128	18,128	18,357	18,357	18,357
2024	18,442	18,442	18,442	18,442	18,141	18,141	18,028	18,033	18,033	18,141	18,141	18,442	18,442	18,442
2025	18,524	18,524	18,524	18,524	18,136	18,136	17,997	18,002	18,002	18,136	18,136	18,524	18,524	18,524
2026	18,604	18,604	18,604	18,604	18,113	18,113	17,942	17,949	17,949	18,113	18,113	18,604	18,604	18,604
2027	18,685	18,685	18,685	18,685	18,071	18,071	17,862	17,870	17,870	18,071	18,071	18,685	18,685	18,685
2028	18,767	18,767	18,767	18,767	18,005	18,005	17,752	17,762	17,762	18,005	18,005	18,767	18,767	18,767
2029	18,850	18,850	18,850	18,850	17,913	17,913	17,607	17,620	17,620	17,913	17,913	18,850	18,850	18,850
2030	18,934	18,934	18,934	18,934	17,790	17,790	17,424	17,439	17,439	17,790	17,790	18,934	18,934	18,934

Table A.6 VOC Emissions from Urban Vehicle Operation

	Operational Emissions of VOC for the Base Case and for Each PNGV Technology/Fuel Combination (10^3 tonnes)													
	Base Case	CV+RFG	CV+MeOH	CV+EtOH	CV+RFD	CV+DME	CV+HFCV	CV+MFCV	CV+GFC	CV+FTD/RFD	CV+Bio/RFD	CV+LPG	CV+CNG	CV+LNG
2005	1,174	1,090	1,090	1,090	1,090	1,090	1,090	1,090	1,090	1,090	1,090	1,090	1,090	1,090
2006	1,172	1,127	1,127	1,127	1,127	1,127	1,127	1,127	1,127	1,127	1,127	1,127	1,127	1,127
2007	1,179	1,157	1,157	1,157	1,157	1,157	1,157	1,157	1,157	1,157	1,157	1,157	1,157	1,157
2008	1,192	1,184	1,184	1,184	1,184	1,184	1,184	1,184	1,184	1,184	1,184	1,184	1,184	1,184
2009	1,231	1,228	1,228	1,228	1,228	1,228	1,228	1,228	1,228	1,228	1,228	1,228	1,228	1,228
2010	1,269	1,269	1,269	1,269	1,269	1,269	1,269	1,269	1,269	1,269	1,269	1,269	1,269	1,269
2011	1,304	1,304	1,304	1,304	1,304	1,304	1,304	1,304	1,304	1,304	1,304	1,304	1,304	1,304
2012	1,336	1,336	1,336	1,336	1,336	1,336	1,336	1,336	1,336	1,336	1,336	1,336	1,336	1,336
2013	1,365	1,365	1,365	1,365	1,365	1,365	1,364	1,364	1,364	1,365	1,365	1,365	1,365	1,365
2014	1,390	1,390	1,390	1,390	1,389	1,389	1,389	1,389	1,389	1,389	1,389	1,389	1,389	1,389
2015	1,411	1,411	1,411	1,411	1,410	1,410	1,409	1,409	1,410	1,410	1,410	1,410	1,410	1,410
2016	1,429	1,429	1,429	1,429	1,428	1,428	1,426	1,426	1,427	1,428	1,428	1,428	1,428	1,428
2017	1,444	1,444	1,444	1,444	1,442	1,442	1,439	1,440	1,441	1,442	1,442	1,442	1,442	1,442
2018	1,457	1,457	1,457	1,457	1,454	1,454	1,450	1,451	1,452	1,454	1,454	1,454	1,454	1,454
2019	1,468	1,468	1,468	1,468	1,464	1,464	1,458	1,459	1,460	1,464	1,464	1,463	1,463	1,463
2020	1,477	1,477	1,477	1,477	1,471	1,471	1,463	1,464	1,466	1,471	1,471	1,470	1,470	1,470
2021	1,485	1,485	1,485	1,485	1,476	1,476	1,466	1,468	1,471	1,476	1,476	1,475	1,475	1,475
2022	1,492	1,492	1,492	1,492	1,481	1,481	1,467	1,470	1,473	1,481	1,481	1,480	1,480	1,480
2023	1,499	1,499	1,499	1,499	1,483	1,483	1,466	1,470	1,474	1,483	1,483	1,482	1,482	1,482
2024	1,505	1,505	1,505	1,505	1,485	1,485	1,463	1,468	1,474	1,485	1,485	1,484	1,484	1,484
2025	1,511	1,511	1,511	1,511	1,486	1,486	1,459	1,464	1,472	1,486	1,486	1,485	1,485	1,485
2026	1,517	1,517	1,517	1,517	1,485	1,485	1,452	1,458	1,468	1,485	1,485	1,484	1,484	1,484
2027	1,523	1,523	1,523	1,523	1,484	1,484	1,442	1,451	1,463	1,484	1,484	1,483	1,483	1,483
2028	1,529	1,529	1,529	1,529	1,481	1,481	1,430	1,441	1,455	1,481	1,481	1,480	1,480	1,480
2029	1,535	1,535	1,535	1,535	1,476	1,476	1,415	1,428	1,446	1,476	1,476	1,475	1,475	1,475
2030	1,541	1,541	1,541	1,541	1,470	1,470	1,397	1,412	1,433	1,470	1,470	1,469	1,469	1,469

Table A.7 SO_X Emissions from Urban Vehicle Operation

	Operational Emissions of SO_x for the Base Case and for Each PNGV Technology/FuelCombination (10^3 tonnes)													
	Base Case	CV+RFG	CV+MeOH	CV+EtOH	CV+RFD	CV+DME	CV+HFCV	CV+MFCV	CV+GFC	CV+FTD/RFD	CV+Bio/RFD	CV+LPG	CV+CNG	CV+LNG
2005	42	42	42	42	42	42	42	42	42	42	42	42	42	42
2006	43	42	42	42	42	42	42	42	42	42	42	42	42	42
2007	43	43	43	43	43	43	43	43	43	43	43	43	43	43
2008	43	43	43	43	43	43	43	43	43	43	43	43	43	43
2009	44	44	44	44	44	44	44	44	44	44	44	44	44	44
2010	45	45	45	45	45	45	45	45	45	45	45	45	45	45
2011	45	45	45	45	45	45	45	45	45	45	45	45	45	45
2012	45	45	45	45	45	45	45	45	45	45	45	45	45	45
2013	46	46	46	46	46	46	46	46	46	46	46	46	46	46
2014	46	46	46	46	46	46	46	46	46	46	46	46	46	46
2015	46	46	46	46	46	46	46	46	46	46	46	46	46	46
2016	46	46	46	46	46	46	46	46	46	46	46	46	46	46
2017	46	46	46	46	46	46	46	46	46	46	46	46	46	46
2018	46	46	45	45	46	45	45	45	46	45	46	45	45	45
2019	46	45	45	45	45	45	45	45	45	45	45	45	45	45
2020	46	45	45	45	45	45	45	45	45	45	45	45	45	45
2021	46	45	45	45	45	45	45	45	45	45	45	45	45	45
2022	46	45	45	45	45	45	45	45	45	45	45	45	45	45
2023	46	45	44	44	45	44	44	44	45	45	45	44	44	44
2024	46	45	44	44	45	44	44	44	45	44	45	44	44	44
2025	46	44	44	44	44	43	43	44	44	44	44	43	43	43
2026	46	44	43	43	44	43	43	43	44	44	44	43	43	43
2027	46	44	43	42	44	42	42	43	44	43	44	42	42	42
2028	46	43	42	42	43	42	42	42	43	43	43	42	42	42
2029	46	43	41	41	43	41	41	41	43	42	43	41	41	41
2030	46	42	40	40	43	40	40	40	42	41	42	40	40	40

Table A.8 PM_{10} Emissions from Urban Vehicle Operation

	Operational Emissions of PM_{10} for the Base Case and for Each PNGV Technology/Fuel Combination (10^3 tonnes)													
	Base Case	CV+RFG	CV+MeOH	CV+EtOH	CV+RFD	CV+DME	CV+HFCV	CV+MFCV	CV+GFC	CV+FTD/RFD	CV+Bio/RFD	CV+LPG	CV+CNG	CV+LNG
2005	52	51	51	51	51	51	51	51	51	51	51	51	51	51
2006	52	52	52	52	52	52	52	52	52	52	52	52	52	52
2007	53	53	53	53	53	53	53	53	53	53	53	53	53	53
2008	54	54	54	54	54	54	54	54	54	54	54	54	54	54
2009	55	55	55	55	55	55	55	55	55	55	55	55	55	55
2010	56	56	56	56	56	56	56	56	56	56	56	56	56	56
2011	57	57	57	57	57	57	57	57	57	57	57	57	57	57
2012	58	58	58	58	58	58	58	58	58	58	58	58	58	58
2013	58	58	58	58	58	58	58	58	58	58	58	58	58	58
2014	59	59	59	59	59	59	59	59	59	59	59	59	59	59
2015	59	59	59	59	59	59	59	59	59	59	59	59	59	59
2016	60	60	60	60	60	60	60	60	60	60	60	60	60	60
2017	60	60	60	60	60	60	60	60	60	60	60	60	60	60
2018	60	60	60	60	61	60	60	60	60	61	61	60	60	60
2019	61	61	60	60	61	61	60	60	60	61	61	60	60	60
2020	61	61	61	61	62	61	61	61	61	62	62	61	61	61
2021	61	61	61	61	62	61	61	61	61	62	62	61	61	61
2022	61	61	61	61	63	61	61	61	61	63	63	61	61	61
2023	62	62	61	61	63	62	61	61	61	63	63	61	61	61
2024	62	62	61	61	64	62	61	61	61	64	64	61	61	61
2025	62	62	61	61	65	62	61	61	61	65	65	61	61	61
2026	62	62	61	61	66	62	61	61	61	66	66	61	61	61
2027	63	63	61	61	67	63	61	61	61	67	67	61	61	61
2028	63	63	61	61	68	63	60	60	60	68	68	60	60	60
2029	63	63	60	60	69	63	60	60	60	69	69	60	60	60
2030	63	63	60	60	70	63	60	60	60	70	70	60	60	60

Table A.9 CO_2 Emissions from Urban Vehicle Operation

Operational Emissions of CO_2 for the Base Case and for Each PNGV Technology/Fuel Combination (10^3 tonnes)

	Base Case	CV+RFG	CV+MeOH	CV+EtOH	CV+RFD	CV+DME	CV+HFCV	CV+MFCV	CV+GFC	CV+FTD/RFD	CV+Bio/RFD	CV+LPG	CV+CNG	CV+LNG
2005	1,040,251	1,022,550	1,022,550	1,022,550	1,022,550	1,022,550	1,022,550	1,022,550	1,022,550	1,022,550	1,022,550	1,022,550	1,022,550	1,022,550
2006	1,048,658	1,038,020	1,038,020	1,038,020	1,038,020	1,038,020	1,038,020	1,038,020	1,038,020	1,038,020	1,038,020	1,038,020	1,038,020	1,038,020
2007	1,057,116	1,051,091	1,051,091	1,051,091	1,051,091	1,051,091	1,051,091	1,051,091	1,051,091	1,051,091	1,051,091	1,051,091	1,051,091	1,051,091
2008	1,063,712	1,060,549	1,060,549	1,060,549	1,060,549	1,060,549	1,060,549	1,060,549	1,060,549	1,060,549	1,060,549	1,060,549	1,060,549	1,060,549
2009	1,079,681	1,078,258	1,078,258	1,078,258	1,078,258	1,078,258	1,078,258	1,078,258	1,078,258	1,078,258	1,078,258	1,078,258	1,078,258	1,078,258
2010	1,092,771	1,092,373	1,092,373	1,092,373	1,092,373	1,092,373	1,092,373	1,092,373	1,092,373	1,092,373	1,092,373	1,092,373	1,092,373	1,092,373
2011	1,102,514	1,102,249	1,102,249	1,102,249	1,102,249	1,102,249	1,102,249	1,102,249	1,102,249	1,102,249	1,102,249	1,102,249	1,102,249	1,102,249
2012	1,109,642	1,109,478	1,109,478	1,109,478	1,109,478	1,109,478	1,109,478	1,109,478	1,109,478	1,109,478	1,109,478	1,109,478	1,109,478	1,109,478
2013	1,115,078	1,114,619	1,114,613	1,114,396	1,114,638	1,114,609	1,114,396	1,114,613	1,114,619	1,114,633	1,114,638	1,114,611	1,114,576	1,114,574
2014	1,118,632	1,117,467	1,117,451	1,116,763	1,117,528	1,117,438	1,116,763	1,117,451	1,117,467	1,117,514	1,117,527	1,117,444	1,117,332	1,117,326
2015	1,120,000	1,117,743	1,117,709	1,116,309	1,117,867	1,117,683	1,116,309	1,117,709	1,117,743	1,117,838	1,117,864	1,117,695	1,117,467	1,117,454
2016	1,120,559	1,116,978	1,116,923	1,114,665	1,117,178	1,116,883	1,114,665	1,116,923	1,116,978	1,117,132	1,117,174	1,116,902	1,116,533	1,116,513
2017	1,120,630	1,115,443	1,115,362	1,112,060	1,115,735	1,115,303	1,112,060	1,115,362	1,115,443	1,115,667	1,115,729	1,115,331	1,114,791	1,114,762
2018	1,120,405	1,113,280	1,113,168	1,108,601	1,113,684	1,113,086	1,108,601	1,113,168	1,113,280	1,113,590	1,113,676	1,113,125	1,112,379	1,112,339
2019	1,120,034	1,110,596	1,110,447	1,104,361	1,111,135	1,110,338	1,104,361	1,110,447	1,110,596	1,111,009	1,111,124	1,110,390	1,109,395	1,109,342
2020	1,119,667	1,107,434	1,107,240	1,099,304	1,108,136	1,107,097	1,099,304	1,107,240	1,107,434	1,107,972	1,108,123	1,107,165	1,105,868	1,105,798
2021	1,119,448	1,103,908	1,103,660	1,093,518	1,104,805	1,103,478	1,093,518	1,103,660	1,103,908	1,104,596	1,104,788	1,103,564	1,101,907	1,101,818
2022	1,119,454	1,099,934	1,099,621	1,086,802	1,101,068	1,099,390	1,086,802	1,099,621	1,099,934	1,100,803	1,101,046	1,099,499	1,097,404	1,097,292
2023	1,119,709	1,095,387	1,094,994	1,078,918	1,096,809	1,094,705	1,078,918	1,094,994	1,095,387	1,096,477	1,096,782	1,094,842	1,092,215	1,092,074
2024	1,120,213	1,090,127	1,089,638	1,069,621	1,091,898	1,089,278	1,069,621	1,089,638	1,090,127	1,091,484	1,091,864	1,089,448	1,086,177	1,086,001
2025	1,120,988	1,084,047	1,083,442	1,058,698	1,086,236	1,082,997	1,058,698	1,083,442	1,084,047	1,085,725	1,086,194	1,083,208	1,079,164	1,078,947
2026	1,121,989	1,076,913	1,076,171	1,045,771	1,079,604	1,075,624	1,045,771	1,076,171	1,076,913	1,078,975	1,079,552	1,075,883	1,070,915	1,070,648
2027	1,123,194	1,068,532	1,067,626	1,030,504	1,071,817	1,066,957	1,030,504	1,067,626	1,068,532	1,071,050	1,071,754	1,067,274	1,061,208	1,060,882
2028	1,124,571	1,058,708	1,057,608	1,012,566	1,062,695	1,056,798	1,012,566	1,057,608	1,058,708	1,061,764	1,062,618	1,057,182	1,049,821	1,049,426
2029	1,126,099	1,047,206	1,045,880	991,545	1,052,015	1,044,902	991,545	1,045,880	1,047,206	1,050,892	1,051,923	1,045,365	1,036,486	1,036,009
2030	1,127,736	1,033,855	1,032,265	967,151	1,039,618	1,031,093	967,151	1,032,265	1,033,855	1,038,272	1,039,507	1,031,648	1,021,008	1,020,436

Table A.10 CH_4 Emissions from Urban Vehicle Operation

	Operational Emissions of CH_4 for the Base Case and for Each PNGV Technology/Fuel Combination (10^3 tonnes)													
	Base Case	CV+RFG	CV+MeOH	CV+EtOH	CV+RFD	CV+DME	CV+HFCV	CV+MFCV	CV+GFC	CV+FTD/RFD	CV+Bio/RFD	CV+LPG	CV+CNG	CV+LNG
2005	180	177	177	177	177	177	177	177	177	177	177	177	177	177
2006	183	181	181	181	181	181	181	181	181	181	181	181	181	181
2007	185	184	184	184	184	184	184	184	184	184	184	184	184	184
2008	188	187	187	187	187	187	187	187	187	187	187	187	187	187
2009	192	192	192	192	192	192	192	192	192	192	192	192	192	192
2010	196	196	196	196	196	196	196	196	196	196	196	196	196	196
2011	200	200	200	200	200	200	200	200	200	200	200	200	200	200
2012	203	203	203	203	203	203	203	203	203	203	203	203	203	203
2013	206	206	206	206	205	205	205	205	205	205	205	206	207	207
2014	208	208	208	208	208	208	208	208	208	208	208	208	211	211
2015	210	210	210	210	210	210	210	210	210	210	210	210	217	217
2016	212	212	212	212	211	211	211	211	211	211	211	212	223	223
2017	214	214	213	213	213	213	212	212	212	213	213	214	229	229
2018	216	216	215	215	214	214	213	213	213	214	214	216	237	237
2019	217	217	216	216	214	214	214	214	214	214	214	217	245	245
2020	219	219	217	217	215	215	215	215	215	215	215	219	255	255
2021	220	220	218	218	215	215	215	215	215	215	215	220	267	267
2022	221	221	219	219	216	216	215	215	215	216	216	221	281	281
2023	223	223	220	220	215	215	214	214	214	215	215	223	297	297
2024	224	224	220	220	215	215	214	214	214	215	215	224	317	317
2025	225	225	221	221	214	214	213	213	213	214	214	225	340	340
2026	227	227	221	221	213	213	211	211	211	213	213	227	367	367
2027	228	228	221	221	211	211	209	209	209	211	211	228	400	400
2028	230	230	221	221	209	209	206	206	206	209	209	230	438	438
2029	231	231	221	221	206	206	203	203	203	206	206	231	482	482
2030	232	232	221	221	202	202	199	199	199	202	202	232	534	534

Table A.11 N_2O Emissions from Urban Vehicle Operation

	Operational Emissions of N_2O for the Base Case and for Each PNGV Technology/Fuel Combination (10^3 tonnes)													
	Base Case	CV+RFG	CV+MeOH	CV+EtOH	CV+RFD	CV+DME	CV+HFCV	CV+MFCV	CV+GFC	CV+FTD/RFD	CV+Bio/RFD	CV+LPG	CV+CNG	CV+LNG
2005	12.2	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0
2006	12.3	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2
2007	12.5	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4	12.4
2008	12.7	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6
2009	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0
2010	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2
2011	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5
2012	13.7	13.7	13.7	13.7	13.7	13.7	13.7	13.7	13.7	13.7	13.7	13.7	13.7	13.7
2013	13.9	13.9	13.9	13.9	13.9	13.9	13.9	13.9	13.9	13.9	13.9	13.9	13.9	13.9
2014	14.1	14.1	14.1	14.1	14.1	14.1	14.0	14.0	14.0	14.1	14.1	14.1	14.1	14.1
2015	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2
2016	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3
2017	14.5	14.5	14.5	14.5	14.5	14.5	14.3	14.3	14.3	14.5	14.5	14.5	14.5	14.5
2018	14.6	14.6	14.6	14.6	14.6	14.6	14.4	14.4	14.4	14.6	14.6	14.6	14.6	14.6
2019	14.7	14.7	14.7	14.7	14.7	14.7	14.5	14.5	14.5	14.7	14.7	14.7	14.7	14.7
2020	14.8	14.8	14.8	14.8	14.8	14.8	14.5	14.5	14.5	14.8	14.8	14.8	14.8	14.8
2021	14.9	14.9	14.9	14.9	14.9	14.9	14.5	14.5	14.5	14.9	14.9	14.9	14.9	14.9
2022	15.0	15.0	15.0	15.0	15.0	15.0	14.5	14.5	14.5	15.0	15.0	15.0	15.0	15.0
2023	15.1	15.1	15.1	15.1	15.1	15.1	14.5	14.5	14.5	15.1	15.1	15.1	15.1	15.1
2024	15.1	15.1	15.1	15.1	15.1	15.1	14.4	14.4	14.4	15.1	15.1	15.1	15.1	15.1
2025	15.2	15.2	15.2	15.2	15.2	15.2	14.4	14.4	14.4	15.2	15.2	15.2	15.2	15.2
2026	15.3	15.3	15.3	15.3	15.3	15.3	14.3	14.3	14.3	15.3	15.3	15.3	15.3	15.3
2027	15.4	15.4	15.4	15.4	15.4	15.4	14.1	14.1	14.1	15.4	15.4	15.4	15.4	15.4
2028	15.5	15.5	15.5	15.5	15.5	15.5	13.9	13.9	13.9	15.5	15.5	15.5	15.5	15.5
2029	15.6	15.6	15.6	15.6	15.6	15.6	13.7	13.7	13.7	15.6	15.6	15.6	15.6	15.6
2030	15.7	15.7	15.7	15.7	15.7	15.7	13.4	13.4	13.4	15.7	15.7	15.7	15.7	15.7

Table A.12 Upstream Energy Use (all vehicles)

	Upstream Energy Use for the Base Case and for Each PNGV Technology/Fuel Combination (quads)													
	Base Case	CV+RFG	CV+MeOH	CV+EtOH	CV+RFD	CV+DME	CV+HFCV	CV+MFCV	CV+GFC	CV+FTD/RFD	CV+Bio/RFD	CV+LPG	CV+CNG	CV+LNG
2005	4.2	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1
2006	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2
2007	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3
2008	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3
2009	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4
2010	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4
2011	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
2012	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
2013	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
2014	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
2015	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
2016	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
2017	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
2018	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
2019	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
2020	4.5	4.5	4.5	4.5	4.4	4.5	4.5	4.5	4.5	4.5	4.4	4.4	4.4	4.5
2021	4.5	4.4	4.5	4.5	4.4	4.5	4.5	4.5	4.4	4.5	4.4	4.4	4.4	4.4
2022	4.5	4.4	4.5	4.5	4.4	4.5	4.5	4.5	4.4	4.5	4.4	4.4	4.4	4.4
2023	4.5	4.4	4.5	4.5	4.4	4.5	4.5	4.5	4.4	4.4	4.4	4.4	4.4	4.4
2024	4.5	4.4	4.5	4.4	4.3	4.5	4.6	4.5	4.4	4.4	4.4	4.3	4.4	4.4
2025	4.5	4.3	4.4	4.4	4.3	4.4	4.6	4.4	4.3	4.4	4.3	4.3	4.3	4.4
2026	4.5	4.3	4.4	4.4	4.3	4.4	4.6	4.4	4.3	4.4	4.3	4.3	4.3	4.3
2027	4.5	4.3	4.4	4.4	4.2	4.4	4.6	4.4	4.3	4.4	4.2	4.2	4.3	4.3
2028	4.5	4.2	4.4	4.4	4.2	4.4	4.6	4.4	4.2	4.4	4.2	4.1	4.2	4.3
2029	4.5	4.2	4.4	4.3	4.1	4.4	4.7	4.4	4.2	4.3	4.1	4.1	4.2	4.2
2030	4.5	4.1	4.4	4.3	4.0	4.4	4.7	4.4	4.1	4.3	4.1	4.0	4.1	4.2

Table A.13 Upstream Fossil Energy Use (all vehicles)

	Upstream Fossil Energy Use for the Base Case and for Each PNGV Technology/Fuel Combination (quads)													
	Base Case	CV+RFG	CV+MeOH	CV+EtOH	CV+RFD	CV+DME	CV+HFCV	CV+MFCV	CV+GFC	CV+FTD/RFD	CV+Bio/RFD	CV+LPG	CV+CNG	CV+LNG
2005	4.0	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9
2006	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
2007	4.1	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
2008	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1
2009	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2
2010	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2
2011	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2
2012	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3
2013	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3
2014	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3
2015	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3
2016	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3
2017	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3
2018	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3
2019	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3
2020	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3
2021	4.3	4.3	4.3	4.3	4.2	4.3	4.3	4.3	4.3	4.3	4.2	4.2	4.2	4.3
2022	4.3	4.2	4.3	4.3	4.2	4.3	4.3	4.3	4.2	4.3	4.2	4.2	4.2	4.2
2023	4.3	4.2	4.3	4.3	4.2	4.3	4.4	4.3	4.2	4.3	4.2	4.2	4.2	4.2
2024	4.3	4.2	4.3	4.3	4.2	4.3	4.4	4.3	4.2	4.3	4.2	4.2	4.2	4.2
2025	4.3	4.2	4.3	4.3	4.1	4.3	4.4	4.3	4.2	4.3	4.2	4.1	4.2	4.2
2026	4.3	4.2	4.3	4.3	4.1	4.3	4.4	4.3	4.2	4.2	4.1	4.1	4.1	4.2
2027	4.3	4.1	4.3	4.3	4.1	4.3	4.4	4.3	4.1	4.2	4.1	4.0	4.1	4.1
2028	4.3	4.1	4.3	4.2	4.0	4.3	4.4	4.3	4.1	4.2	4.0	4.0	4.0	4.1
2029	4.3	4.0	4.3	4.2	4.0	4.2	4.5	4.3	4.0	4.2	4.0	3.9	4.0	4.1
2030	4.4	4.0	4.2	4.2	3.9	4.2	4.5	4.2	4.0	4.2	3.9	3.9	3.9	4.0

Table A.14 Upstream Petroleum Use (all vehicles)

	Upstream Petroleum Use for the Base Case and for Each PNGV Technology/Fuel Combination (quads)													
	Base Case	CV+RFG	CV+MeOH	CV+EtOH	CV+RFD	CV+DME	CV+HFCV	CV+MFCV	CV+GFC	CV+FTD/RFD	CV+Bio/RFD	CV+LPG	CV+CNG	CV+LNG
2005	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9
2006	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9
2007	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9
2008	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9
2009	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
2010	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
2011	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
2012	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
2013	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
2014	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
2015	2.1	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
2016	2.1	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
2017	2.1	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
2018	2.1	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
2019	2.1	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
2020	2.1	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
2021	2.1	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
2022	2.1	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
2023	2.1	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
2024	2.1	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
2025	2.1	2.0	2.0	2.0	2.0	1.9	1.9	2.0	2.0	2.0	2.0	1.9	1.9	2.0
2026	2.1	2.0	1.9	2.0	1.9	1.9	1.9	1.9	2.0	1.9	2.0	1.9	1.9	1.9
2027	2.1	2.0	1.9	1.9	1.9	1.9	1.9	1.9	2.0	1.9	1.9	1.9	1.9	1.9
2028	2.1	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9
2029	2.1	1.9	1.8	1.9	1.9	1.8	1.8	1.8	1.9	1.9	1.9	1.8	1.8	1.9
2030	2.1	1.9	1.8	1.9	1.8	1.8	1.8	1.8	1.9	1.8	1.8	1.8	1.8	1.8

Table A.15 Upstream NO_X Emissions (urban locations)

	Upstream Emissions of NO_X for the Base Case and for Each PNGV Technology/Fuel Combination (10^3 tonnes)													
	Base Case	CV+RFG	CV+MeOH	CV+EtOH	CV+RFD	CV+DME	CV+HFCV	CV+MFCV	CV+GFC	CV+FTD/RFD	CV+Bio/RFD	CV+LPG	CV+CNG	CV+LNG
2005	30	30	30	30	30	30	30	30	30	30	30	30	30	30
2006	31	30	30	30	30	30	30	30	30	30	30	30	30	30
2007	31	31	31	31	31	31	31	31	31	31	31	31	31	31
2008	31	31	31	31	31	31	31	31	31	31	31	31	31	31
2009	32	32	32	32	32	32	32	32	32	32	32	32	32	32
2010	32	32	32	32	32	32	32	32	32	32	32	32	32	32
2011	32	32	32	32	32	32	32	32	32	32	32	32	32	32
2012	33	32	32	32	32	32	32	32	32	32	32	32	32	32
2013	33	33	33	33	33	33	33	33	33	33	33	33	33	33
2014	33	33	33	33	33	33	33	33	33	33	33	33	33	33
2015	33	32	32	32	32	32	33	32	32	32	32	32	32	32
2016	33	32	32	32	32	32	32	32	32	32	32	32	32	32
2017	33	32	32	32	32	32	32	32	32	32	32	32	32	32
2018	33	31	31	31	31	31	32	31	31	31	31	31	31	31
2019	33	30	30	31	30	30	32	30	30	30	30	30	31	31
2020	33	30	30	30	30	30	31	30	30	30	30	30	30	30
2021	33	29	29	29	29	29	31	29	29	29	29	29	29	29
2022	33	28	28	29	28	28	30	28	28	28	28	28	28	28
2023	33	27	27	28	27	27	30	27	27	27	27	27	27	27
2024	34	26	26	27	26	26	30	26	26	26	26	26	26	26
2025	34	25	25	26	25	25	30	25	25	25	25	25	25	25
2026	34	24	23	25	24	23	29	23	24	23	24	24	24	25
2027	34	23	22	25	23	22	30	22	23	22	23	23	23	24
2028	34	22	21	24	22	21	30	21	22	21	22	22	22	23
2029	34	21	21	24	21	20	31	21	21	20	21	21	22	22
2030	34	20	20	24	20	20	33	20	20	20	20	21	21	22

Table A.16 Upstream CO Emissions (urban locations)

	Upstream Emissions of CO for the Base Case and for Each PNGV Technology/Fuel Combination (10^3 tonnes)													
	Base Case	CV+RFG	CV+MeOH	CV+EtOH	CV+RFD	CV+DME	CV+HFCV	CV+MFCV	CV+GFC	CV+FTD/RFD	CV+Bio/RFD	CV+LPG	CV+CNG	CV+LNG
2005	21	20	20	20	20	20	20	20	20	20	20	20	20	20
2006	21	21	21	21	21	21	21	21	21	21	21	21	21	21
2007	21	21	21	21	21	21	21	21	21	21	21	21	21	21
2008	21	21	21	21	21	21	21	21	21	21	21	21	21	21
2009	22	21	21	21	21	21	21	21	21	21	21	21	21	21
2010	22	22	22	22	22	22	22	22	22	22	22	22	22	22
2011	22	22	22	22	22	22	22	22	22	22	22	22	22	22
2012	22	22	22	22	22	22	22	22	22	22	22	22	22	22
2013	22	22	22	22	22	22	22	22	22	22	22	22	22	22
2014	22	22	22	22	22	22	22	22	22	22	22	22	22	22
2015	23	22	22	22	22	22	22	22	22	22	22	22	22	22
2016	23	22	22	22	22	22	22	22	22	22	22	22	22	22
2017	23	22	22	22	22	22	22	22	22	22	22	22	22	22
2018	23	21	21	21	21	21	21	21	21	21	21	21	21	21
2019	23	21	21	21	21	21	21	21	21	21	21	21	21	21
2020	23	20	20	20	20	20	21	20	20	20	20	20	20	21
2021	23	20	20	20	20	20	20	20	20	20	20	20	20	20
2022	23	19	19	19	19	19	20	19	19	19	19	19	19	19
2023	23	18	18	19	18	18	19	18	18	18	18	18	18	19
2024	23	18	18	18	18	18	19	18	18	18	18	18	18	18
2025	23	17	17	17	17	17	19	17	17	17	17	17	17	18
2026	23	16	16	17	16	16	18	16	16	16	16	16	16	17
2027	23	15	15	16	15	15	18	15	15	15	16	16	15	17
2028	23	15	15	16	15	15	18	15	15	15	15	15	15	16
2029	23	14	14	15	14	14	18	14	14	14	15	15	14	16
2030	23	14	14	15	14	13	18	14	14	14	14	14	14	16

Table A.17 Upstream VOC Emissions (urban locations)

	Upstream Emissions of VOC for the Base Case and for Each PNGV Technology/Fuel Combination (10^3 tonnes)													
	Base Case	CV+RFG	CV+MeOH	CV+EtOH	CV+RFD	CV+DME	CV+HFCV	CV+MFCV	CV+GFC	CV+FTD/RFD	CV+Bio/RFD	CV+LPG	CV+CNG	CV+LNG
2005	68	67	67	67	67	67	67	67	67	67	67	67	67	67
2006	69	68	68	68	68	68	68	68	68	68	68	68	68	68
2007	70	69	69	69	69	69	69	69	69	69	69	69	69	69
2008	70	70	70	70	70	70	70	70	70	70	70	70	70	70
2009	71	71	71	71	71	71	71	71	71	71	71	71	71	71
2010	72	72	72	72	72	72	72	72	72	72	72	72	72	72
2011	72	72	72	72	72	72	72	72	72	72	72	72	72	72
2012	73	72	72	72	72	72	72	72	72	72	72	72	72	72
2013	73	72	72	72	72	72	72	72	72	72	72	72	72	72
2014	73	72	72	72	72	72	72	72	72	72	72	72	72	72
2015	73	72	72	72	72	72	72	72	72	72	72	72	72	72
2016	73	71	71	71	71	71	71	71	71	71	71	71	71	71
2017	73	70	70	70	70	70	70	70	70	70	70	70	70	70
2018	73	68	68	68	68	68	68	68	68	68	68	68	68	68
2019	73	67	67	67	67	67	67	67	67	67	67	67	67	67
2020	73	65	65	65	65	65	65	65	65	65	65	65	65	65
2021	73	63	63	63	63	63	63	63	63	63	63	63	63	63
2022	73	61	61	61	60	60	61	61	61	60	61	61	60	61
2023	73	59	58	58	58	58	58	58	59	58	58	58	58	59
2024	73	56	56	56	56	55	56	56	56	55	56	56	55	56
2025	73	54	53	53	53	53	53	53	54	53	53	53	52	54
2026	73	51	51	51	50	50	50	51	51	50	50	51	50	51
2027	73	49	48	48	47	47	48	48	49	47	48	48	47	49
2028	73	47	46	46	45	45	45	46	47	45	45	46	44	46
2029	73	45	44	44	43	43	43	44	45	42	43	44	42	45
2030	73	44	42	43	41	41	42	42	44	40	41	42	40	43

Table A.18 Upstream SO_X Emissions (urban locations)

	Upstream Emissions of SO_x for the Base Case and for Each PNGV Technology/Fuel Combination (10^3 tonnes)													
	Base Case	CV+RFG	CV+MeOH	CV+EtOH	CV+RFD	CV+DME	CV+HFCV	CV+MFCV	CV+GFC	CV+FTD/RFD	CV+Bio/RFD	CV+LPG	CV+CNG	CV+LNG
2005	3	3	3	3	3	3	3	3	3	3	3	3	3	3
2006	3	3	3	3	3	3	3	3	3	3	3	3	3	3
2007	3	3	3	3	3	3	3	3	3	3	3	3	3	3
2008	3	3	3	3	3	3	3	3	3	3	3	3	3	3
2009	3	3	3	3	3	3	3	3	3	3	3	3	3	3
2010	3	3	3	3	3	3	3	3	3	3	3	3	3	3
2011	3	3	3	3	3	3	3	3	3	3	3	3	3	3
2012	3	3	3	3	3	3	3	3	3	3	3	3	3	3
2013	3	3	3	3	3	3	3	3	3	3	3	3	3	3
2014	3	3	3	3	3	3	3	3	3	3	3	3	3	3
2015	3	3	3	3	3	3	3	3	3	3	3	3	3	3
2016	3	3	3	3	3	3	3	3	3	3	3	3	3	3
2017	3	3	3	3	3	3	3	3	3	3	3	3	3	3
2018	3	3	3	3	3	3	3	3	3	3	3	3	3	3
2019	3	3	3	3	3	3	3	3	3	3	3	3	3	3
2020	3	3	3	3	3	3	3	3	3	3	3	3	3	3
2021	3	3	3	3	3	3	3	3	3	3	3	3	3	3
2022	3	2	3	2	2	3	2	3	2	3	2	2	2	3
2023	3	2	2	2	2	2	2	2	2	2	2	2	2	3
2024	3	2	2	2	2	2	2	2	2	2	2	2	2	3
2025	3	2	2	2	2	2	2	2	2	2	2	2	2	3
2026	3	2	2	2	2	2	2	2	2	2	2	2	2	4
2027	3	2	2	2	2	2	2	2	2	2	2	2	2	4
2028	3	2	2	2	2	2	2	2	2	2	2	2	2	4
2029	3	2	2	2	2	2	2	2	2	2	2	2	2	5
2030	3	2	2	2	2	2	2	2	2	2	2	2	2	5

Table A.19 Upstream PM_{10} Emissions (urban locations)

	Upstream Emissions of PM_{10} for the Base Case and for Each PNGV Technology/Fuel Combination (10^3 tonnes)													
	Base Case	CV+RFG	CV+MeOH	CV+EtOH	CV+RFD	CV+DME	CV+HFCV	CV+MFCV	CV+GFC	CV+FTD/RFD	CV+Bio/RFD	CV+LPG	CV+CNG	CV+LNG
2005	2	2	2	2	2	2	2	2	2	2	2	2	2	2
2006	2	2	2	2	2	2	2	2	2	2	2	2	2	2
2007	2	2	2	2	2	2	2	2	2	2	2	2	2	2
2008	2	2	2	2	2	2	2	2	2	2	2	2	2	2
2009	2	2	2	2	2	2	2	2	2	2	2	2	2	2
2010	2	2	2	2	2	2	2	2	2	2	2	2	2	2
2011	2	2	2	2	2	2	2	2	2	2	2	2	2	2
2012	2	2	2	2	2	2	2	2	2	2	2	2	2	2
2013	2	2	2	2	2	2	2	2	2	2	2	2	2	2
2014	2	2	2	2	2	2	2	2	2	2	2	2	2	2
2015	2	2	2	2	2	2	2	2	2	2	2	2	2	2
2016	2	2	2	2	2	2	2	2	2	2	2	2	2	2
2017	2	2	2	2	2	2	2	2	2	2	2	2	2	2
2018	2	2	2	2	2	2	2	2	2	2	2	2	2	2
2019	2	2	2	2	2	2	2	2	2	2	2	2	2	2
2020	2	2	2	2	2	2	2	2	2	2	2	2	2	2
2021	2	2	2	2	2	2	2	2	2	2	2	2	2	2
2022	2	2	2	2	2	2	2	2	2	2	2	2	2	3
2023	2	2	2	2	2	2	2	2	2	2	2	2	2	3
2024	2	2	2	2	2	2	2	2	2	2	2	2	2	3
2025	2	2	2	2	2	2	2	2	2	2	2	2	2	3
2026	2	2	2	2	2	2	2	2	2	2	2	2	2	3
2027	2	1	1	2	1	1	2	1	1	1	1	2	1	3
2028	2	1	1	2	1	1	2	1	1	1	1	1	1	4
2029	2	1	1	2	1	1	2	1	1	1	1	1	1	4
2030	2	1	1	2	1	1	1	1	1	1	1	1	1	5

Table A.20 Upstream CO_2 Emissions (all vehicles)

	Upstream Emissions of CO_2 for the Base Case and for Each PNGV Technology/Fuel Combination (10^3 tonnes)													
	Base Case	CV+RFG	CV+MeOH	CV+EtOH	CV+RFD	CV+DME	CV+HFCV	CV+MFCV	CV+GFC	CV+FTD/RFD	CV+Bio/RFD	CV+LPG	CV+CNG	CV+LNG
2005	298,672	293,590	293,590	293,590	293,590	293,590	293,590	293,590	293,590	293,590	293,590	293,590	293,590	293,590
2006	301,086	298,031	298,031	298,031	298,031	298,031	298,031	298,031	298,031	298,031	298,031	298,031	298,031	298,031
2007	303,514	301,784	301,784	301,784	301,784	301,784	301,784	301,784	301,784	301,784	301,784	301,784	301,784	301,784
2008	305,404	304,496	304,496	304,496	304,496	304,496	304,496	304,496	304,496	304,496	304,496	304,496	304,496	304,496
2009	309,985	309,577	309,577	309,577	309,577	309,577	309,577	309,577	309,577	309,577	309,577	309,577	309,577	309,577
2010	313,740	313,625	313,625	313,625	313,625	313,625	313,625	313,625	313,625	313,625	313,625	313,625	313,625	313,625
2011	316,533	316,457	316,457	316,457	316,457	316,457	316,457	316,457	316,457	316,457	316,457	316,457	316,457	316,457
2012	318,575	318,529	318,529	318,529	318,528	318,529	318,529	318,529	318,529	318,529	318,528	318,528	318,528	318,528
2013	320,132	320,000	320,023	320,068	319,977	320,025	320,266	320,023	320,000	320,045	319,981	319,968	319,990	319,989
2014	321,149	320,814	320,883	321,026	320,739	320,891	321,657	320,883	320,814	320,956	320,752	320,711	320,782	320,780
2015	321,537	320,889	321,023	321,312	320,736	321,039	322,601	321,023	320,889	321,178	320,761	320,679	320,823	320,819
2016	321,694	320,666	320,872	321,336	320,419	320,897	323,424	320,872	320,666	321,132	320,458	320,326	320,559	320,553
2017	321,710	320,221	320,509	321,182	319,860	320,546	324,250	320,509	320,221	320,902	319,916	319,724	320,065	320,056
2018	321,642	319,596	319,975	320,396	319,097	320,026	325,161	319,975	319,596	320,538	319,172	318,909	319,380	319,368
2019	321,531	318,822	319,300	318,324	318,156	319,368	326,228	319,300	318,822	320,077	318,253	317,906	318,533	318,517
2020	321,422	317,910	318,500	316,346	317,042	318,589	327,553	318,500	317,910	319,547	317,165	316,716	317,534	317,513
2021	321,355	316,894	317,605	314,449	315,784	317,718	328,854	317,605	316,894	318,986	315,936	315,368	316,413	316,387
2022	321,353	315,750	316,593	312,244	314,347	316,736	329,824	316,593	315,750	318,393	314,532	313,820	315,141	315,108
2023	321,422	314,440	315,430	309,640	312,681	315,609	330,970	315,430	314,440	317,755	312,905	312,021	313,676	313,637
2024	321,563	312,927	314,074	306,582	310,736	314,297	331,209	314,074	312,927	317,054	311,004	309,914	311,975	311,926
2025	321,782	311,177	312,490	302,970	308,470	312,766	330,381	312,490	311,177	316,280	308,789	307,454	310,001	309,942
2026	322,065	309,126	310,609	298,691	305,800	310,949	328,903	310,609	309,126	315,395	306,176	304,552	307,680	307,608
2027	322,407	306,716	308,370	293,630	302,655	308,784	326,639	308,370	306,716	314,372	303,094	301,131	304,951	304,864
2028	322,798	303,893	305,708	287,685	298,965	306,210	324,476	305,708	303,893	313,182	299,475	297,115	301,750	301,646
2029	323,233	300,588	302,546	280,717	294,643	303,152	321,711	302,546	300,588	311,793	295,230	292,412	298,002	297,879
2030	323,699	296,752	298,821	272,628	289,628	299,548	319,103	298,821	296,752	310,181	290,298	286,955	293,652	293,507

Table A.21 Upstream CH_4 Emissions (all vehicles)

	Upstream Emissions of CH_4 for the Base Case and for Each PNGV Technology/Fuel Combination (10^3 tonnes)													
	Base Case	CV+RFG	CV+MeOH	CV+EtOH	CV+RFD	CV+DME	CV+HFCV	CV+MFCV	CV+GFC	CV+FTD/RFD	CV+Bio/RFD	CV+LPG	CV+CNG	CV+LNG
2005	1,259	1,237	1,237	1,237	1,237	1,237	1,237	1,237	1,237	1,237	1,237	1,237	1,237	1,237
2006	1,269	1,256	1,256	1,256	1,256	1,256	1,256	1,256	1,256	1,256	1,256	1,256	1,256	1,256
2007	1,279	1,272	1,272	1,272	1,272	1,272	1,272	1,272	1,272	1,272	1,272	1,272	1,272	1,272
2008	1,287	1,283	1,283	1,283	1,283	1,283	1,283	1,283	1,283	1,283	1,283	1,283	1,283	1,283
2009	1,306	1,305	1,305	1,305	1,305	1,305	1,305	1,305	1,305	1,305	1,305	1,305	1,305	1,305
2010	1,322	1,322	1,322	1,322	1,322	1,322	1,322	1,322	1,322	1,322	1,322	1,322	1,322	1,322
2011	1,334	1,334	1,334	1,334	1,334	1,334	1,334	1,334	1,334	1,334	1,334	1,334	1,334	1,334
2012	1,343	1,343	1,343	1,343	1,343	1,343	1,343	1,343	1,343	1,343	1,343	1,343	1,343	1,343
2013	1,349	1,349	1,349	1,349	1,349	1,349	1,349	1,349	1,349	1,349	1,349	1,349	1,349	1,349
2014	1,354	1,352	1,353	1,352	1,352	1,353	1,353	1,353	1,352	1,352	1,352	1,352	1,354	1,354
2015	1,355	1,353	1,354	1,353	1,352	1,354	1,355	1,354	1,353	1,353	1,352	1,353	1,355	1,355
2016	1,356	1,352	1,354	1,352	1,351	1,354	1,355	1,354	1,352	1,352	1,351	1,352	1,356	1,356
2017	1,356	1,350	1,353	1,351	1,349	1,353	1,355	1,353	1,350	1,350	1,349	1,351	1,356	1,356
2018	1,356	1,347	1,351	1,347	1,347	1,351	1,355	1,351	1,347	1,348	1,346	1,348	1,356	1,356
2019	1,356	1,344	1,349	1,340	1,343	1,349	1,354	1,349	1,344	1,345	1,343	1,345	1,355	1,355
2020	1,355	1,340	1,347	1,332	1,339	1,346	1,353	1,347	1,340	1,341	1,339	1,342	1,355	1,355
2021	1,355	1,336	1,344	1,325	1,335	1,344	1,352	1,344	1,336	1,337	1,334	1,338	1,355	1,355
2022	1,355	1,331	1,341	1,316	1,329	1,341	1,349	1,341	1,331	1,332	1,328	1,334	1,355	1,355
2023	1,355	1,326	1,338	1,306	1,324	1,338	1,347	1,338	1,326	1,327	1,322	1,329	1,355	1,355
2024	1,356	1,320	1,335	1,293	1,317	1,334	1,342	1,335	1,320	1,321	1,315	1,323	1,356	1,356
2025	1,357	1,312	1,331	1,279	1,309	1,331	1,334	1,331	1,312	1,314	1,306	1,317	1,357	1,357
2026	1,358	1,304	1,326	1,262	1,299	1,326	1,324	1,326	1,304	1,306	1,296	1,309	1,359	1,359
2027	1,360	1,294	1,321	1,242	1,288	1,320	1,311	1,321	1,294	1,296	1,285	1,300	1,361	1,361
2028	1,362	1,282	1,314	1,218	1,275	1,314	1,297	1,314	1,282	1,285	1,271	1,290	1,364	1,364
2029	1,363	1,268	1,307	1,190	1,260	1,306	1,279	1,307	1,268	1,272	1,255	1,278	1,367	1,367
2030	1,366	1,252	1,298	1,157	1,242	1,298	1,261	1,298	1,252	1,256	1,236	1,263	1,370	1,371

Table A.22 Upstream N_2O Emissions (all vehicles)

	Upstream Emissions of N_2O for the Base Case and for Each PNGV Technology/Fuel Combination (10^3 tonnes)													
	Base Case	CV+RFG	CV+MeOH	CV+EtOH	CV+RFD	CV+DME	CV+HFCV	CV+MFCV	CV+GFC	CV+FTD/RFD	CV+Bio/RFD	CV+LPG	CV+CNG	CV+LNG
2005	33.7	33.1	33.1	33.1	33.1	33.1	33.1	33.1	33.1	33.1	33.1	33.1	33.1	33.1
2006	33.9	33.6	33.6	33.6	33.6	33.6	33.6	33.6	33.6	33.6	33.6	33.6	33.6	33.6
2007	34.2	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0
2008	31.5	31.4	31.4	31.4	31.4	31.4	31.4	31.4	31.4	31.4	31.4	31.4	31.4	31.4
2009	29.2	29.2	29.2	29.2	29.2	29.2	29.2	29.2	29.2	29.2	29.2	29.2	29.2	29.2
2010	27.1	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0
2011	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
2012	23.0	23.0	23.0	23.0	23.0	23.0	23.0	23.0	23.0	23.0	23.0	23.0	23.0	23.0
2013	21.1	21.1	21.1	21.2	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1	21.1
2014	19.4	19.4	19.4	19.7	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.5
2015	17.8	17.7	17.7	18.5	17.7	17.7	17.8	17.7	17.7	17.7	17.7	17.7	17.7	17.9
2016	16.2	16.2	16.2	17.4	16.2	16.2	16.4	16.2	16.2	16.2	16.2	16.2	16.2	16.5
2017	14.9	14.8	14.8	16.6	14.8	14.8	15.0	14.8	14.8	14.8	14.8	14.8	14.9	15.2
2018	13.6	13.5	13.5	15.7	13.5	13.5	13.8	13.5	13.5	13.5	13.6	13.5	13.6	14.1
2019	12.4	12.4	12.3	14.6	12.3	12.3	12.7	12.3	12.4	12.3	12.4	12.3	12.4	13.1
2020	11.4	11.3	11.2	13.8	11.2	11.2	11.7	11.2	11.3	11.2	11.3	11.2	11.4	12.3
2021	10.4	10.3	10.3	13.4	10.2	10.3	10.8	10.3	10.3	10.2	10.4	10.2	10.4	11.6
2022	9.5	9.4	9.4	13.1	9.3	9.4	9.9	9.4	9.4	9.3	9.5	9.3	9.5	11.1
2023	8.7	8.6	8.6	13.2	8.5	8.5	9.2	8.6	8.6	8.5	8.7	8.5	8.7	10.7
2024	8.0	7.8	7.8	13.5	7.7	7.8	8.5	7.8	7.8	7.7	8.0	7.7	8.0	10.5
2025	7.3	7.1	7.1	14.0	7.0	7.1	7.8	7.1	7.1	7.0	7.3	7.0	7.3	10.4
2026	6.7	6.5	6.5	15.0	6.4	6.5	7.2	6.5	6.5	6.4	6.7	6.3	6.7	10.6
2027	6.1	5.9	6.0	16.3	5.8	5.9	6.6	6.0	5.9	5.8	6.2	5.7	6.1	10.9
2028	5.6	5.3	5.4	18.0	5.2	5.4	6.1	5.4	5.3	5.2	5.7	5.2	5.5	11.4
2029	5.1	4.8	5.0	20.2	4.7	5.0	5.5	5.0	4.8	4.7	5.2	4.7	5.0	12.2
2030	4.7	6.2	5.0	22.9	5.4	5.0	4.9	4.6	4.3	4.2	4.8	4.2	4.4	13.3

Table A.23 Total Energy Use by All Vehicles

	Total Energy Use for the Base Case and for Each PNGV Technology/Fuel Combination (quads)													
	Base Case	CV+RFG	CV+MeOH	CV+EtOH	CV+RFD	CV+DME	CV+HFCV	CV+MFCV	CV+GFC	CV+FTD/RFD	CV+Bio/RFD	CV+LPG	CV+CNG	CV+LNG
2005	18.3	17.9	17.9	17.9	17.9	17.9	17.9	17.9	17.9	17.9	17.9	17.9	17.9	17.9
2006	18.4	18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2
2007	18.6	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4
2008	18.7	18.6	18.6	18.6	18.6	18.6	18.6	18.6	18.6	18.6	18.6	18.6	18.6	18.6
2009	18.9	18.9	18.9	18.9	18.9	18.9	18.9	18.9	18.9	18.9	18.9	18.9	18.9	18.9
2010	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2
2011	19.3	19.3	19.3	19.3	19.3	19.3	19.3	19.3	19.3	19.3	19.3	19.3	19.3	19.3
2012	19.5	19.5	19.5	19.5	19.5	19.5	19.5	19.5	19.5	19.5	19.5	19.5	19.5	19.5
2013	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6
2014	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6
2015	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6
2016	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6
2017	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.6	19.5	19.6	19.6
2018	19.6	19.5	19.5	19.5	19.5	19.5	19.6	19.5	19.5	19.5	19.5	19.5	19.5	19.5
2019	19.6	19.5	19.5	19.5	19.5	19.5	19.5	19.5	19.5	19.5	19.5	19.5	19.5	19.5
2020	19.6	19.4	19.4	19.4	19.4	19.4	19.5	19.4	19.4	19.4	19.4	19.4	19.4	19.4
2021	19.6	19.3	19.4	19.4	19.3	19.4	19.4	19.4	19.3	19.4	19.3	19.3	19.3	19.3
2022	19.6	19.3	19.3	19.3	19.3	19.3	19.4	19.3	19.3	19.3	19.3	19.2	19.3	19.3
2023	19.6	19.2	19.3	19.3	19.2	19.3	19.3	19.3	19.2	19.2	19.2	19.2	19.2	19.2
2024	19.6	19.1	19.2	19.2	19.1	19.2	19.3	19.2	19.1	19.2	19.1	19.1	19.1	19.1
2025	19.6	19.0	19.1	19.1	18.9	19.1	19.2	19.1	19.0	19.1	19.0	18.9	19.0	19.0
2026	19.7	18.9	19.0	19.0	18.8	19.0	19.1	19.0	18.9	18.9	18.8	18.8	18.8	18.9
2027	19.7	18.7	18.9	18.8	18.7	18.9	19.0	18.9	18.7	18.8	18.7	18.6	18.7	18.7
2028	19.7	18.5	18.7	18.7	18.5	18.7	18.9	18.7	18.5	18.7	18.5	18.4	18.5	18.6
2029	19.7	18.3	18.5	18.5	18.2	18.5	18.8	18.5	18.3	18.5	18.3	18.2	18.3	18.4
2030	19.7	18.1	18.3	18.3	18.0	18.3	18.7	18.3	18.1	18.3	18.0	18.0	18.1	18.1

Table A.24 Total Fossil Energy Use by All Vehicles

	Total Fossil Energy Use for the Base Case and for Each PNGV Technology/Fuel Combination (quads)													
	Base Case	CV+RFG	CV+MeOH	CV+EtOH	CV+RFD	CV+DME	CV+HFCV	CV+MFCV	CV+GFC	CV+FTD/RFD	CV+Bio/RFD	CV+LPG	CV+CNG	CV+LNG
2005	18.1	17.8	17.8	17.8	17.8	17.8	17.8	17.8	17.8	17.8	17.8	17.8	17.8	17.8
2006	18.2	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0
2007	18.4	18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2
2008	18.5	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4
2009	18.7	18.7	18.7	18.7	18.7	18.7	18.7	18.7	18.7	18.7	18.7	18.7	18.7	18.7
2010	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0
2011	19.1	19.1	19.1	19.1	19.1	19.1	19.1	19.1	19.1	19.1	19.1	19.1	19.1	19.1
2012	19.3	19.3	19.3	19.3	19.3	19.3	19.3	19.3	19.3	19.3	19.3	19.3	19.3	19.3
2013	19.4	19.4	19.4	19.3	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4
2014	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4
2015	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4
2016	19.5	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4
2017	19.5	19.4	19.4	19.3	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4
2018	19.5	19.3	19.4	19.3	19.3	19.4	19.4	19.4	19.3	19.3	19.3	19.3	19.3	19.3
2019	19.4	19.3	19.3	19.2	19.3	19.3	19.3	19.3	19.3	19.3	19.3	19.3	19.3	19.3
2020	19.4	19.2	19.3	19.2	19.2	19.3	19.3	19.3	19.2	19.3	19.2	19.2	19.2	19.2
2021	19.4	19.2	19.2	19.1	19.2	19.2	19.2	19.2	19.2	19.2	19.1	19.1	19.2	19.2
2022	19.4	19.1	19.2	19.0	19.1	19.2	19.1	19.2	19.1	19.1	19.1	19.1	19.1	19.1
2023	19.4	19.0	19.1	18.9	19.0	19.1	19.0	19.1	19.0	19.1	19.0	19.0	19.0	19.0
2024	19.5	18.9	19.0	18.7	18.9	19.0	18.9	19.0	18.9	19.0	18.9	18.9	18.9	18.9
2025	19.5	18.8	18.9	18.6	18.8	18.9	18.7	18.9	18.8	18.9	18.8	18.8	18.8	18.8
2026	19.5	18.7	18.8	18.4	18.7	18.8	18.5	18.8	18.7	18.8	18.6	18.6	18.7	18.7
2027	19.5	18.6	18.7	18.2	18.5	18.7	18.3	18.7	18.6	18.7	18.5	18.5	18.5	18.6
2028	19.5	18.4	18.6	17.9	18.3	18.6	18.1	18.6	18.4	18.5	18.3	18.3	18.3	18.4
2029	19.6	18.2	18.4	17.6	18.1	18.4	17.9	18.4	18.2	18.3	18.0	18.1	18.1	18.2
2030	19.6	18.0	18.2	17.2	17.9	18.2	17.6	18.2	18.0	18.1	17.8	17.8	17.9	18.0

Table A.25 Total Petroleum Use by All Vehicles

	Total Petroleum Use for the Base Case and for Each PNGV Technology/Fuel Combination (quads)													
	Base Case	CV+RFG	CV+MeOH	CV+EtOH	CV+RFD	CV+DME	CV+HFCV	CV+MFCV	CV+GFC	CV+FTD/RFD	CV+Bio/RFD	CV+LPG	CV+CNG	CV+LNG
2005	16.0	15.7	15.7	15.7	15.7	15.7	15.7	15.7	15.7	15.7	15.7	15.7	15.7	15.7
2006	16.1	15.9	15.9	15.9	15.9	15.9	15.9	15.9	15.9	15.9	15.9	15.9	15.9	15.9
2007	16.2	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1
2008	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3
2009	16.6	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5
2010	16.8	16.8	16.8	16.8	16.8	16.8	16.8	16.8	16.8	16.8	16.8	16.8	16.8	16.8
2011	16.9	16.9	16.9	16.9	16.9	16.9	16.9	16.9	16.9	16.9	16.9	16.9	16.9	16.9
2012	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0
2013	17.1	17.1	17.1	17.1	17.1	17.1	17.1	17.1	17.1	17.1	17.1	17.1	17.1	17.1
2014	17.2	17.1	17.1	17.1	17.1	17.1	17.1	17.1	17.1	17.1	17.1	17.1	17.1	17.1
2015	17.2	17.1	17.1	17.1	17.1	17.1	17.1	17.1	17.1	17.1	17.1	17.1	17.1	17.1
2016	17.2	17.1	17.1	17.1	17.1	17.1	17.1	17.1	17.1	17.1	17.1	17.1	17.1	17.1
2017	17.2	17.1	17.1	17.1	17.1	17.1	17.1	17.1	17.1	17.1	17.1	17.1	17.1	17.1
2018	17.2	17.1	17.0	17.0	17.1	17.0	17.0	17.0	17.1	17.0	17.1	17.0	17.0	17.0
2019	17.2	17.0	16.9	16.9	17.0	16.9	16.9	16.9	17.0	17.0	17.0	17.0	16.9	16.9
2020	17.2	17.0	16.9	16.9	17.0	16.9	16.9	16.9	17.0	16.9	17.0	16.9	16.9	16.9
2021	17.2	16.9	16.8	16.8	16.9	16.8	16.8	16.8	16.9	16.9	16.9	16.8	16.8	16.8
2022	17.2	16.9	16.7	16.7	16.9	16.7	16.7	16.7	16.9	16.8	16.8	16.7	16.7	16.7
2023	17.2	16.8	16.6	16.6	16.8	16.6	16.6	16.6	16.8	16.7	16.8	16.6	16.6	16.6
2024	17.2	16.7	16.4	16.4	16.7	16.4	16.4	16.4	16.7	16.6	16.7	16.5	16.4	16.4
2025	17.2	16.6	16.3	16.3	16.6	16.2	16.2	16.3	16.6	16.4	16.6	16.4	16.2	16.3
2026	17.2	16.5	16.1	16.1	16.5	16.1	16.0	16.1	16.5	16.3	16.4	16.2	16.0	16.1
2027	17.2	16.4	15.8	15.9	16.4	15.8	15.8	15.8	16.4	16.1	16.3	16.0	15.8	15.8
2028	17.2	16.2	15.6	15.6	16.2	15.5	15.5	15.6	16.2	15.9	16.1	15.8	15.5	15.6
2029	17.3	16.1	15.2	15.3	16.0	15.2	15.2	15.2	16.1	15.7	15.9	15.5	15.2	15.3
2030	17.3	15.9	14.9	14.9	15.8	14.9	14.8	14.9	15.9	15.4	15.7	15.2	14.8	14.9

Table A.26 Total NO_X Emissions (urban locations)

	Total Emissions of NO_X for the Base Case and for Each PNGV Technology/Fuel Combination (10^3 tonnes)													
	Base Case	CV+RFG	CV+MeOH	CV+EtOH	CV+RFD	CV+DME	CV+HFCV	CV+MFCV	CV+GFC	CV+FTD/RFD	CV+Bio/RFD	CV+LPG	CV+CNG	CV+LNG
2005	1,742	1,646	1,646	1,646	1,646	1,646	1,646	1,646	1,646	1,646	1,646	1,646	1,646	1,646
2006	1,714	1,656	1,656	1,656	1,656	1,656	1,656	1,656	1,656	1,656	1,656	1,656	1,656	1,656
2007	1,681	1,648	1,648	1,648	1,648	1,648	1,648	1,648	1,648	1,648	1,648	1,648	1,648	1,648
2008	1,631	1,615	1,615	1,615	1,615	1,615	1,615	1,615	1,615	1,615	1,615	1,615	1,615	1,615
2009	1,605	1,599	1,599	1,599	1,599	1,599	1,599	1,599	1,599	1,599	1,599	1,599	1,599	1,599
2010	1,569	1,569	1,569	1,569	1,569	1,569	1,569	1,569	1,569	1,569	1,569	1,569	1,569	1,569
2011	1,525	1,525	1,525	1,525	1,525	1,525	1,525	1,525	1,525	1,525	1,525	1,525	1,525	1,525
2012	1,477	1,476	1,476	1,476	1,476	1,476	1,476	1,476	1,476	1,476	1,476	1,476	1,476	1,476
2013	1,423	1,423	1,423	1,423	1,423	1,423	1,423	1,423	1,423	1,423	1,423	1,423	1,423	1,423
2014	1,373	1,372	1,372	1,372	1,372	1,372	1,372	1,372	1,372	1,372	1,372	1,372	1,372	1,372
2015	1,328	1,327	1,327	1,328	1,327	1,327	1,327	1,327	1,327	1,327	1,327	1,327	1,328	1,328
2016	1,291	1,290	1,290	1,290	1,290	1,290	1,289	1,288	1,288	1,290	1,290	1,290	1,290	1,290
2017	1,262	1,260	1,260	1,261	1,260	1,260	1,258	1,258	1,258	1,260	1,260	1,261	1,261	1,261
2018	1,241	1,239	1,239	1,239	1,239	1,239	1,235	1,235	1,235	1,239	1,239	1,239	1,239	1,239
2019	1,227	1,224	1,224	1,224	1,224	1,224	1,219	1,217	1,218	1,224	1,224	1,224	1,224	1,224
2020	1,218	1,214	1,214	1,215	1,214	1,214	1,207	1,205	1,206	1,214	1,214	1,214	1,215	1,215
2021	1,214	1,209	1,209	1,210	1,209	1,209	1,199	1,197	1,197	1,209	1,209	1,209	1,210	1,210
2022	1,213	1,207	1,207	1,208	1,207	1,207	1,193	1,191	1,191	1,207	1,207	1,207	1,208	1,208
2023	1,214	1,208	1,207	1,208	1,208	1,207	1,189	1,186	1,186	1,207	1,208	1,208	1,208	1,208
2024	1,220	1,212	1,212	1,213	1,212	1,212	1,188	1,184	1,184	1,212	1,212	1,212	1,212	1,212
2025	1,225	1,216	1,216	1,217	1,216	1,216	1,185	1,180	1,181	1,216	1,216	1,216	1,216	1,217
2026	1,230	1,220	1,220	1,221	1,220	1,220	1,181	1,175	1,176	1,220	1,220	1,220	1,220	1,221
2027	1,235	1,224	1,224	1,226	1,224	1,224	1,176	1,169	1,169	1,224	1,224	1,224	1,225	1,225
2028	1,240	1,228	1,228	1,231	1,228	1,228	1,169	1,160	1,161	1,228	1,228	1,228	1,229	1,229
2029	1,246	1,233	1,232	1,235	1,233	1,232	1,160	1,150	1,150	1,232	1,233	1,233	1,234	1,234
2030	1,251	1,237	1,237	1,241	1,237	1,237	1,149	1,137	1,137	1,237	1,238	1,238	1,238	1,239

Table A.27 Total CO Emissions (urban locations)

	Total Emissions of CO for the Base Case and for Each PNGV Technology/Fuel Combination (10^3 tonnes)													
	Base Case	CV+RFG	CV+MeOH	CV+EtOH	CV+RFD	CV+DME	CV+HFCV	CV+MFCV	CV+GFC	CV+FTD/RFD	CV+Bio/RFD	CV+LPG	CV+CNG	CV+LNG
2005	26,683	25,113	25,113	25,113	25,113	25,113	25,113	25,113	25,113	25,113	25,113	25,113	25,113	25,113
2006	26,294	25,341	25,341	25,341	25,341	25,341	25,341	25,341	25,341	25,341	25,341	25,341	25,341	25,341
2007	25,818	25,286	25,286	25,286	25,286	25,286	25,286	25,286	25,286	25,286	25,286	25,286	25,286	25,286
2008	25,070	24,808	24,808	24,808	24,808	24,808	24,808	24,808	24,808	24,808	24,808	24,808	24,808	24,808
2009	24,684	24,586	24,586	24,586	24,586	24,586	24,586	24,586	24,586	24,586	24,586	24,586	24,586	24,586
2010	24,121	24,121	24,121	24,121	24,121	24,121	24,121	24,121	24,121	24,121	24,121	24,121	24,121	24,121
2011	23,429	23,429	23,429	23,429	23,429	23,429	23,429	23,429	23,429	23,429	23,429	23,429	23,429	23,429
2012	22,661	22,661	22,661	22,661	22,661	22,661	22,661	22,661	22,661	22,661	22,661	22,661	22,661	22,661
2013	21,810	21,809	21,809	21,809	21,809	21,809	21,808	21,808	21,808	21,809	21,809	21,809	21,809	21,809
2014	20,999	20,999	20,999	20,999	20,997	20,997	20,993	20,993	20,993	20,997	20,997	20,999	20,999	20,999
2015	20,277	20,277	20,277	20,277	20,271	20,271	20,264	20,264	20,264	20,271	20,271	20,277	20,277	20,277
2016	19,673	19,672	19,672	19,672	19,661	19,661	19,649	19,649	19,649	19,661	19,661	19,672	19,672	19,672
2017	19,203	19,202	19,202	19,202	19,181	19,181	19,164	19,164	19,164	19,181	19,181	19,202	19,202	19,202
2018	18,858	18,856	18,856	18,856	18,821	18,821	18,797	18,797	18,797	18,821	18,821	18,856	18,856	18,856
2019	18,620	18,618	18,618	18,618	18,562	18,562	18,529	18,530	18,530	18,562	18,562	18,618	18,618	18,618
2020	18,469	18,467	18,467	18,467	18,382	18,381	18,338	18,339	18,339	18,382	18,382	18,467	18,467	18,467
2021	18,389	18,386	18,386	18,386	18,263	18,263	18,207	18,208	18,208	18,263	18,263	18,386	18,386	18,386
2022	18,365	18,362	18,362	18,362	18,191	18,191	18,121	18,122	18,122	18,191	18,191	18,362	18,362	18,362
2023	18,380	18,376	18,376	18,376	18,146	18,146	18,057	18,059	18,060	18,146	18,146	18,376	18,376	18,376
2024	18,465	18,460	18,460	18,460	18,158	18,158	18,048	18,050	18,050	18,158	18,159	18,460	18,460	18,460
2025	18,547	18,541	18,540	18,541	18,153	18,153	18,015	18,019	18,019	18,153	18,153	18,541	18,541	18,541
2026	18,627	18,621	18,620	18,621	18,129	18,129	17,960	17,965	17,965	18,129	18,129	18,621	18,621	18,622
2027	18,708	18,701	18,701	18,701	18,086	18,086	17,880	17,885	17,885	18,086	18,086	18,701	18,701	18,702
2028	18,790	18,782	18,781	18,782	18,020	18,020	17,769	17,776	17,777	18,020	18,020	18,782	18,781	18,783
2029	18,873	18,864	18,864	18,865	17,928	17,927	17,625	17,634	17,634	17,927	17,928	18,864	18,864	18,866
2030	18,957	18,948	18,948	18,949	17,804	17,804	17,442	17,453	17,453	17,804	17,805	18,948	18,948	18,950

Table A.28 Total VOC Emissions (urban locations)

	Total Emissions of VOC for the Base Case and for Each PNGV Technology/Fuel Combination (10^3 tonnes)													
	Base Case	CV+RFG	CV+MeOH	CV+EtOH	CV+RFD	CV+DME	CV+HFCV	CV+MFCV	CV+GFC	CV+FTD/RFD	CV+Bio/RFD	CV+LPG	CV+CNG	CV+LNG
2005	1,242	1,158	1,158	1,158	1,158	1,158	1,158	1,158	1,158	1,158	1,158	1,158	1,158	1,158
2006	1,241	1,195	1,195	1,195	1,195	1,195	1,195	1,195	1,195	1,195	1,195	1,195	1,195	1,195
2007	1,249	1,227	1,227	1,227	1,227	1,227	1,227	1,227	1,227	1,227	1,227	1,227	1,227	1,227
2008	1,261	1,253	1,253	1,253	1,253	1,253	1,253	1,253	1,253	1,253	1,253	1,253	1,253	1,253
2009	1,302	1,299	1,299	1,299	1,299	1,299	1,299	1,299	1,299	1,299	1,299	1,299	1,299	1,299
2010	1,340	1,340	1,340	1,340	1,340	1,340	1,340	1,340	1,340	1,340	1,340	1,340	1,340	1,340
2011	1,376	1,376	1,376	1,376	1,376	1,376	1,376	1,376	1,376	1,376	1,376	1,376	1,376	1,376
2012	1,409	1,408	1,408	1,408	1,408	1,408	1,408	1,408	1,408	1,408	1,408	1,408	1,408	1,408
2013	1,438	1,437	1,437	1,437	1,437	1,437	1,437	1,437	1,437	1,437	1,437	1,437	1,437	1,437
2014	1,463	1,462	1,462	1,462	1,462	1,462	1,461	1,461	1,461	1,462	1,462	1,462	1,462	1,462
2015	1,485	1,483	1,483	1,483	1,482	1,482	1,481	1,481	1,481	1,482	1,482	1,482	1,482	1,482
2016	1,503	1,500	1,500	1,500	1,499	1,498	1,497	1,497	1,498	1,498	1,499	1,498	1,498	1,498
2017	1,518	1,514	1,514	1,514	1,512	1,512	1,509	1,510	1,510	1,512	1,512	1,512	1,511	1,512
2018	1,530	1,526	1,526	1,526	1,522	1,522	1,518	1,519	1,520	1,522	1,522	1,522	1,522	1,522
2019	1,541	1,535	1,535	1,535	1,530	1,530	1,524	1,526	1,527	1,530	1,530	1,530	1,529	1,530
2020	1,550	1,542	1,542	1,542	1,536	1,536	1,528	1,529	1,532	1,536	1,536	1,535	1,535	1,535
2021	1,558	1,548	1,548	1,548	1,539	1,539	1,529	1,531	1,534	1,539	1,539	1,538	1,538	1,539
2022	1,565	1,553	1,553	1,553	1,541	1,541	1,528	1,530	1,534	1,541	1,541	1,540	1,540	1,540
2023	1,572	1,557	1,557	1,557	1,542	1,542	1,524	1,528	1,533	1,541	1,542	1,541	1,540	1,541
2024	1,578	1,561	1,561	1,561	1,541	1,541	1,519	1,524	1,530	1,540	1,541	1,540	1,539	1,540
2025	1,584	1,565	1,564	1,564	1,539	1,538	1,512	1,517	1,526	1,538	1,539	1,538	1,537	1,538
2026	1,590	1,568	1,567	1,568	1,535	1,535	1,502	1,509	1,520	1,535	1,535	1,535	1,534	1,535
2027	1,596	1,572	1,571	1,571	1,531	1,531	1,490	1,499	1,512	1,531	1,531	1,531	1,529	1,531
2028	1,602	1,576	1,575	1,575	1,526	1,526	1,476	1,486	1,502	1,525	1,526	1,525	1,524	1,526
2029	1,608	1,580	1,579	1,579	1,519	1,519	1,459	1,472	1,491	1,519	1,519	1,519	1,517	1,520
2030	1,615	1,585	1,584	1,584	1,511	1,511	1,438	1,454	1,477	1,510	1,511	1,511	1,509	1,512

Table A.29 Total SO_x Emissions (urban locations)

	Total Emissions of SO_x for the Base Case and for Each PNGV Technology/Fuel Combination (10^3 tonnes)													
	Base Case	CV+RFG	CV+MeOH	CV+EtOH	CV+RFD	CV+DME	CV+HFCV	CV+MFCV	CV+GFC	CV+FTD/RFD	CV+Bio/RFD	CV+LPG	CV+CNG	CV+LNG
2005	46	45	45	45	45	45	45	45	45	45	45	45	45	45
2006	46	46	46	46	46	46	46	46	46	46	46	46	46	46
2007	46	46	46	46	46	46	46	46	46	46	46	46	46	46
2008	47	47	47	47	47	47	47	47	47	47	47	47	47	47
2009	47	47	47	47	47	47	47	47	47	47	47	47	47	47
2010	48	48	48	48	48	48	48	48	48	48	48	48	48	48
2011	48	48	48	48	48	48	48	48	48	48	48	48	48	48
2012	49	49	49	49	49	49	49	49	49	49	49	49	49	49
2013	49	49	49	49	49	49	49	49	49	49	49	49	49	49
2014	49	49	49	49	49	49	49	49	49	49	49	49	49	49
2015	49	49	49	49	49	49	49	49	49	49	49	49	49	49
2016	49	49	49	49	49	49	49	49	49	49	49	49	49	49
2017	49	49	49	49	49	49	49	49	49	49	49	49	49	49
2018	49	48	48	48	48	48	48	48	48	48	48	48	48	49
2019	49	48	48	48	48	48	48	48	48	48	48	48	48	48
2020	49	48	48	48	48	48	48	48	48	48	48	48	48	48
2021	49	48	48	47	48	47	47	48	48	48	48	47	47	48
2022	49	48	47	47	48	47	47	47	48	47	47	47	47	48
2023	49	47	47	47	47	47	47	47	47	47	47	47	47	47
2024	49	47	46	46	47	46	46	46	47	47	47	46	46	47
2025	49	47	46	46	47	46	46	46	47	46	46	46	46	47
2026	49	46	45	45	46	45	45	45	46	46	46	45	45	46
2027	49	46	45	44	46	44	44	45	46	45	45	44	44	46
2028	49	45	44	43	45	44	43	44	45	45	45	43	43	46
2029	49	45	43	43	45	43	42	43	45	44	44	42	43	45
2030	49	44	42	42	44	42	41	42	44	43	44	41	41	45

Table A.30 Total PM_{10} Emissions (urban locations)

	Total Emissions of PM_{10} for the Base Case and for Each PNGV Technology/Fuel Combination (10^3 tonnes)													
	Base Case	CV+RFG	CV+MeOH	CV+EtOH	CV+RFD	CV+DME	CV+HFCV	CV+MFCV	CV+GFC	CV+FTD/RFD	CV+Bio/RFD	CV+LPG	CV+CNG	CV+LNG
2005	54	53	53	53	53	53	53	53	53	53	53	53	53	53
2006	54	54	54	54	54	54	54	54	54	54	54	54	54	54
2007	55	55	55	55	55	55	55	55	55	55	55	55	55	55
2008	56	56	56	56	56	56	56	56	56	56	56	56	56	56
2009	57	57	57	57	57	57	57	57	57	57	57	57	57	57
2010	58	58	58	58	58	58	58	58	58	58	58	58	58	58
2011	59	59	59	59	59	59	59	59	59	59	59	59	59	59
2012	60	60	60	60	60	60	60	60	60	60	60	60	60	60
2013	60	60	60	60	60	60	60	60	60	60	60	60	60	60
2014	61	61	61	61	61	61	61	61	61	61	61	61	61	61
2015	61	61	61	61	62	61	61	61	61	62	62	61	61	61
2016	62	62	62	62	62	62	62	62	62	62	62	62	62	62
2017	62	62	62	62	63	62	62	62	62	63	63	62	62	62
2018	63	62	62	62	63	62	62	62	62	63	63	62	62	62
2019	63	63	62	62	63	63	62	62	62	63	63	62	62	63
2020	63	63	63	63	64	63	62	62	62	64	64	62	62	63
2021	63	63	63	63	64	63	63	63	63	64	64	63	63	63
2022	64	63	63	63	65	63	63	63	63	65	65	63	63	63
2023	64	63	63	63	65	63	63	63	63	65	65	63	63	63
2024	64	64	63	63	66	64	63	62	62	66	66	63	62	64
2025	64	64	63	63	66	64	62	62	62	66	66	62	62	64
2026	65	64	62	63	67	64	62	62	62	67	67	62	62	64
2027	65	64	62	62	68	64	62	62	62	68	68	62	62	64
2028	65	64	62	62	69	64	62	62	62	69	69	62	62	64
2029	65	64	62	62	70	64	62	61	61	70	70	62	61	64
2030	65	65	61	62	72	65	61	61	61	72	72	61	61	65

Table A.31 Total CO_2 Emissions (all vehicles, all locations)

	Total Emissions of CO_2 for the Base Case and for Each PNGV Technology/Fuel Combination (10^3 tonnes)													
	Base Case	CV+RFG	CV+MeOH	CV+EtOH	CV+RFD	CV+DME	CV+HFCV	CV+MFCV	CV+GFC	CV+FTD/RFD	CV+Bio/RFD	CV+LPG	CV+CNG	CV+LNG
2005	1,338,923	1,316,140	1,316,140	1,316,140	1,316,140	1,316,140	1,316,140	1,316,140	1,316,140	1,316,140	1,316,140	1,316,140	1,316,140	1,316,140
2006	1,349,744	1,336,052	1,336,052	1,336,052	1,336,052	1,336,052	1,336,052	1,336,052	1,336,052	1,336,052	1,336,052	1,336,052	1,336,052	1,336,052
2007	1,360,630	1,352,875	1,352,875	1,352,875	1,352,875	1,352,875	1,352,875	1,352,875	1,352,875	1,352,875	1,352,875	1,352,875	1,352,875	1,352,875
2008	1,369,116	1,365,044	1,365,044	1,365,044	1,365,044	1,365,044	1,365,044	1,365,044	1,365,044	1,365,044	1,365,044	1,365,044	1,365,044	1,365,044
2009	1,389,666	1,387,835	1,387,835	1,387,835	1,387,835	1,387,835	1,387,835	1,387,835	1,387,835	1,387,835	1,387,835	1,387,835	1,387,835	1,387,835
2010	1,406,511	1,405,998	1,405,998	1,405,998	1,405,998	1,405,998	1,405,998	1,405,998	1,405,998	1,405,998	1,405,998	1,405,998	1,405,998	1,405,998
2011	1,419,047	1,418,706	1,418,706	1,418,706	1,418,706	1,418,706	1,418,706	1,418,706	1,418,706	1,418,706	1,418,706	1,418,706	1,418,706	1,418,706
2012	1,428,217	1,428,007	1,428,007	1,428,007	1,428,007	1,428,007	1,428,007	1,428,007	1,428,007	1,428,007	1,428,007	1,428,007	1,428,007	1,428,007
2013	1,435,211	1,434,619	1,434,636	1,434,465	1,434,615	1,434,635	1,434,663	1,434,636	1,434,619	1,434,679	1,434,618	1,434,579	1,434,566	1,434,563
2014	1,439,780	1,438,282	1,438,334	1,437,788	1,438,267	1,438,329	1,438,420	1,438,334	1,438,282	1,438,470	1,438,279	1,438,155	1,438,113	1,438,105
2015	1,441,537	1,438,632	1,438,732	1,437,621	1,438,603	1,438,722	1,438,910	1,438,732	1,438,632	1,439,016	1,438,626	1,438,374	1,438,290	1,438,274
2016	1,442,253	1,437,644	1,437,796	1,436,001	1,437,597	1,437,780	1,438,090	1,437,796	1,437,644	1,438,263	1,437,633	1,437,228	1,437,092	1,437,066
2017	1,442,340	1,435,664	1,435,871	1,433,242	1,435,595	1,435,848	1,436,310	1,435,871	1,435,664	1,436,569	1,435,645	1,435,055	1,434,856	1,434,818
2018	1,442,047	1,432,876	1,433,143	1,428,997	1,432,781	1,433,112	1,433,762	1,433,143	1,432,876	1,434,128	1,432,848	1,432,034	1,431,758	1,431,706
2019	1,441,566	1,429,418	1,429,748	1,422,685	1,429,291	1,429,706	1,430,588	1,429,748	1,429,418	1,431,086	1,429,378	1,428,296	1,427,928	1,427,859
2020	1,441,089	1,425,344	1,425,740	1,415,650	1,425,178	1,425,686	1,426,857	1,425,740	1,425,344	1,427,519	1,425,287	1,423,881	1,423,402	1,423,311
2021	1,440,803	1,420,802	1,421,265	1,407,967	1,420,590	1,421,196	1,422,372	1,421,265	1,420,802	1,423,581	1,420,724	1,418,932	1,418,319	1,418,204
2022	1,440,807	1,415,683	1,416,214	1,399,046	1,415,415	1,416,126	1,416,626	1,416,214	1,415,683	1,419,196	1,415,578	1,413,320	1,412,545	1,412,400
2023	1,441,132	1,409,827	1,410,424	1,388,558	1,409,491	1,410,314	1,409,888	1,410,424	1,409,827	1,414,232	1,409,687	1,406,863	1,405,891	1,405,710
2024	1,441,777	1,403,053	1,403,711	1,376,203	1,402,635	1,403,575	1,400,830	1,403,711	1,403,053	1,408,539	1,402,868	1,399,363	1,398,152	1,397,928
2025	1,442,770	1,395,224	1,395,932	1,361,668	1,394,707	1,395,763	1,389,079	1,395,932	1,395,224	1,402,005	1,394,983	1,390,662	1,389,166	1,388,889
2026	1,444,053	1,386,039	1,386,780	1,344,462	1,385,404	1,386,573	1,374,674	1,386,780	1,386,039	1,394,371	1,385,727	1,380,435	1,378,596	1,378,257
2027	1,445,600	1,375,248	1,375,996	1,324,133	1,374,472	1,375,742	1,357,142	1,375,996	1,375,248	1,385,422	1,374,849	1,368,405	1,366,158	1,365,746
2028	1,447,369	1,362,601	1,363,316	1,300,251	1,361,659	1,363,008	1,337,042	1,363,316	1,362,601	1,374,946	1,362,093	1,354,297	1,351,571	1,351,072
2029	1,449,331	1,347,794	1,348,425	1,272,262	1,346,658	1,348,054	1,313,256	1,348,425	1,347,794	1,362,685	1,347,153	1,337,777	1,334,488	1,333,888
2030	1,451,435	1,330,607	1,331,086	1,239,778	1,329,245	1,330,641	1,286,253	1,331,086	1,330,607	1,348,452	1,329,805	1,318,603	1,314,660	1,313,943

Table A.32 Total CH_4 Emissions (all vehicles, all locations)

	Total Emissions of CH_4 for the Base Case and for Each PNGV Technology/Fuel Combination (10^3 tonnes)													
	Base Case	CV+RFG	CV+MeOH	CV+EtOH	CV+RFD	CV+DME	CV+HFCV	CV+MFCV	CV+GFC	CV+FTD/RFD	CV+Bio/RFD	CV+LPG	CV+CNG	CV+LNG
2005	1,439	1,414	1,414	1,414	1,414	1,414	1,414	1,414	1,414	1,414	1,414	1,414	1,414	1,414
2006	1,451	1,437	1,437	1,437	1,437	1,437	1,437	1,437	1,437	1,437	1,437	1,437	1,437	1,437
2007	1,464	1,456	1,456	1,456	1,456	1,456	1,456	1,456	1,456	1,456	1,456	1,456	1,456	1,456
2008	1,475	1,470	1,470	1,470	1,470	1,470	1,470	1,470	1,470	1,470	1,470	1,470	1,470	1,470
2009	1,498	1,496	1,496	1,496	1,496	1,496	1,496	1,496	1,496	1,496	1,496	1,496	1,496	1,496
2010	1,518	1,518	1,518	1,518	1,518	1,518	1,518	1,518	1,518	1,518	1,518	1,518	1,518	1,518
2011	1,534	1,533	1,533	1,533	1,533	1,533	1,533	1,533	1,533	1,533	1,533	1,533	1,533	1,533
2012	1,545	1,545	1,545	1,545	1,545	1,545	1,545	1,545	1,545	1,545	1,545	1,545	1,545	1,545
2013	1,555	1,554	1,554	1,554	1,554	1,554	1,555	1,554	1,554	1,554	1,554	1,554	1,556	1,556
2014	1,562	1,560	1,561	1,560	1,560	1,561	1,561	1,561	1,560	1,560	1,560	1,561	1,565	1,565
2015	1,566	1,563	1,564	1,563	1,562	1,563	1,565	1,563	1,562	1,562	1,562	1,563	1,572	1,572
2016	1,568	1,564	1,565	1,564	1,563	1,565	1,567	1,565	1,563	1,563	1,563	1,564	1,579	1,579
2017	1,570	1,564	1,566	1,564	1,562	1,565	1,568	1,565	1,562	1,563	1,562	1,565	1,585	1,585
2018	1,572	1,563	1,566	1,562	1,560	1,565	1,568	1,564	1,561	1,561	1,560	1,564	1,593	1,593
2019	1,573	1,561	1,565	1,556	1,558	1,563	1,568	1,563	1,558	1,559	1,557	1,562	1,601	1,601
2020	1,574	1,559	1,564	1,550	1,554	1,562	1,568	1,561	1,555	1,556	1,554	1,560	1,610	1,610
2021	1,575	1,556	1,562	1,543	1,550	1,559	1,567	1,559	1,551	1,552	1,549	1,558	1,622	1,622
2022	1,576	1,553	1,560	1,535	1,545	1,557	1,564	1,556	1,546	1,548	1,544	1,555	1,635	1,635
2023	1,578	1,549	1,558	1,525	1,539	1,553	1,561	1,553	1,540	1,542	1,538	1,552	1,652	1,652
2024	1,580	1,544	1,555	1,514	1,532	1,549	1,555	1,548	1,533	1,536	1,530	1,547	1,673	1,673
2025	1,583	1,538	1,552	1,500	1,523	1,545	1,546	1,543	1,525	1,528	1,520	1,542	1,697	1,697
2026	1,585	1,531	1,547	1,483	1,512	1,539	1,535	1,537	1,515	1,519	1,509	1,536	1,727	1,726
2027	1,588	1,522	1,542	1,463	1,499	1,532	1,520	1,530	1,503	1,507	1,496	1,528	1,761	1,761
2028	1,591	1,511	1,536	1,439	1,484	1,523	1,503	1,521	1,488	1,494	1,480	1,519	1,802	1,802
2029	1,594	1,499	1,528	1,411	1,466	1,512	1,482	1,510	1,471	1,477	1,461	1,508	1,849	1,849
2030	1,598	1,484	1,519	1,378	1,444	1,500	1,459	1,497	1,451	1,459	1,438	1,496	1,904	1,904

Table A.33 Total N_2O Emissions (all vehicles, all locations)

	Total Emissions of N_2O for the Base Case and for Each PNGV Technology/Fuel Combination (10^3 tonnes)													
	Base Case	CV+RFG	CV+MeOH	CV+EtOH	CV+RFD	CV+DME	CV+HFCV	CV+MFCV	CV+GFC	CV+FTD/RFD	CV+Bio/RFD	CV+LPG	CV+CNG	CV+LNG
2005	45.8	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0
2006	46.3	45.8	45.8	45.8	45.8	45.8	45.8	45.8	45.8	45.8	45.8	45.8	45.8	45.8
2007	46.7	46.4	46.4	46.4	46.4	46.4	46.4	46.4	46.4	46.4	46.4	46.4	46.4	46.4
2008	44.2	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0
2009	42.2	42.1	42.1	42.1	42.1	42.1	42.1	42.1	42.1	42.1	42.1	42.1	42.1	42.1
2010	40.3	40.3	40.3	40.3	40.3	40.3	40.3	40.3	40.3	40.3	40.3	40.3	40.3	40.3
2011	38.4	38.4	38.4	38.4	38.4	38.4	38.4	38.4	38.4	38.4	38.4	38.4	38.4	38.4
2012	36.7	36.7	36.7	36.7	36.7	36.7	36.7	36.7	36.7	36.7	36.7	36.7	36.7	36.7
2013	35.0	35.0	35.0	35.1	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0
2014	33.4	33.4	33.4	33.8	33.4	33.4	33.5	33.4	33.4	33.4	33.4	33.4	33.4	33.5
2015	32.0	31.9	31.9	32.7	31.9	31.9	32.0	31.9	31.9	31.9	31.9	31.9	32.0	32.1
2016	30.6	30.6	30.5	31.8	30.5	30.5	30.6	30.5	30.5	30.5	30.6	30.5	30.6	30.8
2017	29.3	29.3	29.3	31.1	29.3	29.2	29.4	29.1	29.2	29.2	29.3	29.2	29.3	29.7
2018	28.2	28.1	28.1	30.3	28.1	28.1	28.2	27.9	27.9	28.1	28.1	28.1	28.2	28.7
2019	27.1	27.0	27.0	29.3	27.0	27.0	27.1	26.8	26.8	27.0	27.1	27.0	27.1	27.8
2020	26.1	26.1	26.0	28.6	26.0	26.0	26.2	25.7	25.8	26.0	26.1	26.0	26.2	27.1
2021	25.3	25.2	25.1	28.2	25.1	25.1	25.3	24.8	24.8	25.1	25.2	25.1	25.3	26.5
2022	24.5	24.4	24.3	28.1	24.3	24.3	24.5	23.9	23.9	24.3	24.4	24.3	24.5	26.0
2023	23.7	23.6	23.6	28.2	23.6	23.6	23.7	23.0	23.1	23.5	23.7	23.5	23.8	25.7
2024	23.1	23.0	22.9	28.6	22.9	22.9	22.9	22.3	22.3	22.9	23.1	22.8	23.1	25.6
2025	22.5	22.4	22.4	29.3	22.3	22.4	22.2	21.5	21.5	22.3	22.5	22.2	22.5	25.7
2026	22.0	21.8	21.8	30.3	21.7	21.8	21.5	20.8	20.8	21.7	22.0	21.7	22.0	25.9
2027	21.5	21.3	21.4	31.7	21.2	21.4	20.8	20.1	20.0	21.2	21.6	21.2	21.5	26.3
2028	21.1	20.8	21.0	33.5	20.7	20.9	20.0	19.4	19.3	20.7	21.2	20.7	21.0	27.0
2029	20.7	20.4	20.6	35.8	20.3	20.6	19.2	18.7	18.5	20.3	20.8	20.3	20.6	27.8
2030	20.4	21.9	20.7	38.6	21.0	20.7	18.3	18.0	17.7	19.9	20.5	19.9	20.1	29.0

Table A.34 Total Greenhouse Gas Emissions (all vehicles)

	Total Greenhouse Gas Emissions for the Base Case and for Each PNGV Technology/Fuel Combination (10^6 tonnes CO_2-equivalent)													
	Base Case	CV+RFG	CV+MeOH	CV+EtOH	CV+RFD	CV+DME	CV+HFCV	CV+MFCV	CV+GFC	CV+FTD/RFD	CV+Bio/RFD	CV+LPG	CV+CNG	CV+LNG
2005	1383	1360	1360	1360	1360	1360	1360	1360	1360	1360	1360	1360	1360	1360
2006	1395	1380	1380	1380	1380	1380	1380	1380	1380	1380	1380	1380	1380	1380
2007	1406	1398	1398	1398	1398	1398	1398	1398	1398	1398	1398	1398	1398	1398
2008	1414	1410	1410	1410	1410	1410	1410	1410	1410	1410	1410	1410	1410	1410
2009	1434	1432	1432	1432	1432	1432	1432	1432	1432	1432	1432	1432	1432	1432
2010	1451	1450	1450	1450	1450	1450	1450	1450	1450	1450	1450	1450	1450	1450
2011	1463	1463	1463	1463	1463	1463	1463	1463	1463	1463	1463	1463	1463	1463
2012	1472	1472	1472	1472	1472	1472	1472	1472	1472	1472	1472	1472	1472	1472
2013	1479	1478	1478	1478	1478	1478	1478	1478	1478	1478	1478	1478	1478	1478
2014	1483	1481	1481	1481	1481	1481	1482	1481	1481	1482	1481	1481	1481	1481
2015	1484	1481	1481	1481	1481	1481	1482	1481	1481	1482	1481	1481	1481	1481
2016	1485	1480	1480	1479	1480	1480	1480	1480	1480	1481	1480	1480	1480	1480
2017	1484	1478	1478	1476	1477	1478	1478	1478	1478	1478	1478	1477	1477	1477
2018	1484	1474	1475	1471	1474	1475	1475	1475	1474	1476	1474	1474	1474	1474
2019	1483	1471	1471	1464	1470	1471	1472	1471	1470	1472	1470	1469	1470	1470
2020	1482	1466	1467	1457	1466	1467	1468	1467	1466	1468	1466	1465	1465	1466
2021	1482	1461	1462	1449	1461	1462	1463	1462	1461	1464	1461	1459	1460	1460
2022	1481	1456	1457	1440	1455	1456	1457	1456	1456	1459	1456	1453	1454	1455
2023	1482	1450	1450	1429	1449	1450	1450	1450	1449	1454	1449	1447	1448	1448
2024	1482	1443	1443	1417	1442	1443	1441	1443	1442	1448	1442	1439	1440	1441
2025	1483	1434	1435	1402	1434	1435	1428	1435	1434	1441	1434	1430	1432	1432
2026	1484	1425	1426	1385	1424	1426	1414	1426	1424	1433	1424	1419	1422	1423
2027	1486	1414	1415	1365	1413	1415	1395	1414	1413	1424	1413	1407	1410	1411
2028	1487	1401	1402	1341	1399	1401	1375	1401	1400	1413	1400	1393	1396	1397
2029	1489	1386	1387	1313	1384	1386	1350	1386	1384	1400	1384	1376	1380	1381
2030	1491	1369	1369	1281	1366	1369	1323	1368	1367	1385	1366	1356	1361	1363

Appendix B

Annual Results of Fuel-Cycle Energy and Emissions Analysis: High-Market-Share Scenario

Table B.1 Energy Use from Vehicle Operation

	Operational Energy Use for the Base Case and for Each PNGV Technology/Fuel Combination (quads)													
	Base Case	CV+RFG	CV+MeOH	CV+EtOH	CV+RFD	CV+DME	CV+HFCV	CV+MFCV	CV+GFC	CV+FTD/RFD	CV+Bio/RFD	CV+LPG	CV+CNG	CV+LNG
2005	14.1	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8
2006	14.2	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0
2007	14.3	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2
2008	14.4	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3
2009	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6
2010	14.8	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7
2011	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9
2012	15.0	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9
2013	15.1	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
2014	15.1	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
2015	15.1	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9
2016	15.1	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8
2017	15.1	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7
2018	15.1	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5
2019	15.1	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3
2020	15.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1
2021	15.1	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8
2022	15.1	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5
2023	15.1	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2
2024	15.1	12.9	12.9	12.9	12.9	12.9	12.9	12.9	12.9	12.9	12.9	12.9	12.9	12.9
2025	15.1	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6
2026	15.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2
2027	15.2	11.9	11.9	11.9	11.9	11.9	11.9	11.9	11.9	11.9	11.9	11.9	11.9	11.9
2028	15.2	11.6	11.6	11.6	11.6	11.6	11.6	11.6	11.6	11.6	11.6	11.6	11.6	11.6
2029	15.2	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4
2030	15.2	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1

Table B.2 Fossil Energy Use from Vehicle Operation

	Operational Fossil Energy Use for the Base Case and for Each PNGV Technology/Fuel Combination (quads)													
	Base Case	CV+RFG	CV+MeOH	CV+EtOH	CV+RFD	CV+DME	CV+HFCV	CV+MFCV	CV+GFC	CV+FTD/RFD	CV+Bio/RFD	CV+LPG	CV+CNG	CV+LNG
2005	14.1	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8
2006	14.2	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0
2007	14.3	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2
2008	14.4	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3
2009	14.6	14.6	14.6	14.5	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6
2010	14.8	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7
2011	14.9	14.9	14.9	14.8	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9
2012	15.0	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9
2013	15.1	15.0	15.0	14.9	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
2014	15.1	15.0	15.0	14.9	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
2015	15.1	14.9	14.9	14.8	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9
2016	15.1	14.8	14.8	14.6	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8
2017	15.1	14.7	14.7	14.4	14.7	14.7	14.7	14.7	14.7	14.7	14.6	14.7	14.7	14.7
2018	15.1	14.5	14.5	14.1	14.5	14.5	14.5	14.5	14.5	14.5	14.4	14.5	14.5	14.5
2019	15.1	14.3	14.3	13.7	14.3	14.3	14.3	14.3	14.3	14.3	14.2	14.3	14.3	14.3
2020	15.1	14.1	14.1	13.4	14.1	14.1	14.1	14.1	14.1	14.1	14.0	14.1	14.1	14.1
2021	15.1	13.8	13.8	12.9	13.8	13.8	13.6	13.8	13.8	13.8	13.7	13.8	13.8	13.8
2022	15.1	13.5	13.5	12.5	13.5	13.5	13.1	13.5	13.5	13.5	13.4	13.5	13.5	13.5
2023	15.1	13.2	13.2	12.0	13.2	13.2	12.5	13.2	13.2	13.2	13.1	13.2	13.2	13.2
2024	15.1	12.9	12.9	11.4	12.9	12.9	11.7	12.9	12.9	12.9	12.7	12.9	12.9	12.9
2025	15.1	12.6	12.6	10.8	12.6	12.6	10.8	12.6	12.6	12.6	12.4	12.6	12.6	12.6
2026	15.2	12.2	12.2	10.2	12.2	12.2	10.2	12.2	12.2	12.2	12.0	12.2	12.2	12.2
2027	15.2	11.9	11.9	9.7	11.9	11.9	9.7	11.9	11.9	11.9	11.6	11.9	11.9	11.9
2028	15.2	11.6	11.6	9.1	11.6	11.6	9.1	11.6	11.6	11.6	11.3	11.6	11.6	11.6
2029	15.2	11.4	11.4	8.7	11.4	11.4	8.7	11.4	11.4	11.4	11.0	11.4	11.4	11.4
2030	15.2	11.1	11.1	8.2	11.1	11.1	8.2	11.1	11.1	11.1	10.8	11.1	11.1	11.1

Table B.3 Petroleum Use from Vehicle Operation

	Operational Petroleum Use for the Base Case and for Each PNGV Technology/Fuel Combination (quads)													
	Base Case	CV+RFG	CV+MeOH	CV+EtOH	CV+RFD	CV+DME	CV+HFCV	CV+MFCV	CV+GFC	CV+FTD/RFD	CV+Bio/RFD	CV+LPG	CV+CNG	CV+LNG
2005	14.1	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8
2006	14.2	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0
2007	14.3	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2
2008	14.4	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3
2009	14.6	14.6	14.5	14.5	14.6	14.5	14.5	14.5	14.6	14.6	14.6	14.6	14.5	14.5
2010	14.8	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7
2011	14.9	14.9	14.8	14.8	14.9	14.8	14.8	14.8	14.9	14.8	14.9	14.8	14.8	14.8
2012	15.0	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9
2013	15.1	15.0	14.9	14.9	15.0	14.9	14.9	14.9	15.0	14.9	15.0	14.9	14.9	14.9
2014	15.1	15.0	14.9	14.9	15.0	14.9	14.9	14.9	15.0	14.9	15.0	14.9	14.9	14.9
2015	15.1	14.9	14.8	14.8	14.9	14.8	14.8	14.8	14.9	14.8	14.9	14.8	14.8	14.8
2016	15.1	14.8	14.6	14.6	14.8	14.6	14.6	14.6	14.8	14.7	14.8	14.7	14.6	14.6
2017	15.1	14.7	14.4	14.4	14.7	14.4	14.4	14.4	14.7	14.5	14.6	14.5	14.4	14.4
2018	15.1	14.5	14.1	14.1	14.5	14.1	14.1	14.1	14.5	14.3	14.4	14.2	14.1	14.1
2019	15.1	14.3	13.7	13.7	14.3	13.7	13.7	13.7	14.3	14.0	14.2	14.0	13.7	13.7
2020	15.1	14.1	13.4	13.4	14.1	13.4	13.4	13.4	14.1	13.7	14.0	13.6	13.4	13.4
2021	15.1	13.8	12.9	12.9	13.8	12.9	12.9	12.9	13.8	13.4	13.7	13.3	12.9	12.9
2022	15.1	13.5	12.5	12.5	13.5	12.5	12.5	12.5	13.5	13.0	13.4	12.9	12.5	12.5
2023	15.1	13.2	12.0	12.0	13.2	12.0	12.0	12.0	13.2	12.6	13.1	12.5	12.0	12.0
2024	15.1	12.9	11.4	11.4	12.9	11.4	11.4	11.4	12.9	12.2	12.7	12.0	11.4	11.4
2025	15.1	12.6	10.8	10.8	12.6	10.8	10.8	10.8	12.6	11.8	12.4	11.5	10.8	10.8
2026	15.2	12.2	10.2	10.2	12.2	10.2	10.2	10.2	12.2	11.3	12.0	11.0	10.2	10.2
2027	15.2	11.9	9.7	9.7	11.9	9.7	9.7	9.7	11.9	10.9	11.6	10.6	9.7	9.7
2028	15.2	11.6	9.1	9.1	11.6	9.1	9.1	9.1	11.6	10.5	11.3	10.1	9.1	9.1
2029	15.2	11.4	8.7	8.7	11.4	8.7	8.7	8.7	11.4	10.1	11.0	9.7	8.7	8.7
2030	15.2	11.1	8.2	8.2	11.1	8.2	8.2	8.2	11.1	9.8	10.8	9.4	8.2	8.2

Table B.4 NO_X Emissions from Urban Vehicle Operation

	Operational Emissions of NO_x for the Base Case and for Each PNGV Technology/FuelCombination (10^3 tonnes)													
	Base Case	CV+RFG	CV+MeOH	CV+EtOH	CV+RFD	CV+DME	CV+HFCV	CV+MFCV	CV+GFCV	CV+FTD/RFD	CV+Bio/RFD	CV+LPG	CV+CNG	CV+LNG
2005	1,712	1,616	1,616	1,616	1,616	1,616	1,616	1,616	1,616	1,616	1,616	1,616	1,616	1,616
2006	1,684	1,626	1,626	1,626	1,626	1,626	1,626	1,626	1,626	1,626	1,626	1,626	1,626	1,626
2007	1,650	1,617	1,617	1,617	1,617	1,617	1,617	1,617	1,617	1,617	1,617	1,617	1,617	1,617
2008	1,600	1,584	1,584	1,584	1,584	1,584	1,584	1,584	1,584	1,584	1,584	1,584	1,584	1,584
2009	1,574	1,568	1,568	1,568	1,568	1,568	1,567	1,567	1,567	1,568	1,568	1,568	1,568	1,568
2010	1,537	1,537	1,537	1,537	1,537	1,537	1,536	1,536	1,536	1,537	1,537	1,537	1,537	1,537
2011	1,493	1,493	1,493	1,493	1,493	1,493	1,491	1,491	1,491	1,493	1,493	1,493	1,493	1,493
2012	1,444	1,444	1,444	1,444	1,444	1,444	1,442	1,442	1,442	1,444	1,444	1,444	1,444	1,444
2013	1,390	1,390	1,390	1,390	1,390	1,390	1,387	1,387	1,387	1,390	1,390	1,390	1,390	1,390
2014	1,340	1,340	1,340	1,340	1,340	1,340	1,334	1,334	1,334	1,340	1,340	1,340	1,340	1,340
2015	1,295	1,295	1,295	1,295	1,295	1,295	1,286	1,286	1,286	1,295	1,295	1,295	1,295	1,295
2016	1,258	1,258	1,258	1,258	1,258	1,258	1,243	1,243	1,243	1,258	1,258	1,258	1,258	1,258
2017	1,229	1,229	1,229	1,229	1,229	1,229	1,207	1,207	1,207	1,229	1,229	1,229	1,229	1,229
2018	1,208	1,208	1,208	1,208	1,208	1,208	1,176	1,176	1,176	1,208	1,208	1,208	1,208	1,208
2019	1,193	1,193	1,193	1,193	1,193	1,193	1,149	1,149	1,149	1,193	1,193	1,193	1,193	1,193
2020	1,185	1,185	1,185	1,185	1,185	1,185	1,124	1,124	1,124	1,185	1,185	1,185	1,185	1,185
2021	1,181	1,181	1,181	1,181	1,181	1,181	1,099	1,100	1,100	1,181	1,181	1,181	1,181	1,181
2022	1,179	1,179	1,179	1,179	1,179	1,179	1,074	1,075	1,075	1,179	1,179	1,179	1,179	1,179
2023	1,181	1,181	1,181	1,181	1,181	1,181	1,047	1,048	1,048	1,181	1,181	1,181	1,181	1,181
2024	1,186	1,186	1,186	1,186	1,186	1,186	1,019	1,021	1,021	1,186	1,186	1,186	1,186	1,186
2025	1,191	1,191	1,191	1,191	1,191	1,191	988	990	990	1,191	1,191	1,191	1,191	1,191
2026	1,196	1,196	1,196	1,196	1,196	1,196	952	955	955	1,196	1,196	1,196	1,196	1,196
2027	1,201	1,201	1,201	1,201	1,201	1,201	914	917	917	1,201	1,201	1,201	1,201	1,201
2028	1,206	1,206	1,206	1,206	1,206	1,206	874	877	877	1,206	1,206	1,206	1,206	1,206
2029	1,212	1,212	1,212	1,212	1,212	1,212	833	836	836	1,212	1,212	1,212	1,212	1,212
2030	1,217	1,217	1,217	1,217	1,217	1,217	791	795	795	1,217	1,217	1,217	1,217	1,217

Table B.5 CO Emissions from Urban Vehicle Operation

	Operational Emissions of CO for the Base Case and for Each PNGV Technology/Fuel Combination (10^3 tonnes)													
	Base Case	CV+RFG	CV+MeOH	CV+EtOH	CV+RFD	CV+DME	CV+HFCV	CV+MFCV	CV+GFC	CV+FTD/RFD	CV+Bio/RFD	CV+LPG	CV+CNG	CV+LNG
2005	26,663	25,093	25,093	25,093	25,093	25,093	25,093	25,093	25,093	25,093	25,093	25,093	25,093	25,093
2006	26,273	25,321	25,321	25,321	25,321	25,321	25,321	25,321	25,321	25,321	25,321	25,321	25,321	25,321
2007	25,797	25,265	25,265	25,265	25,265	25,265	25,264	25,264	25,264	25,265	25,265	25,265	25,265	25,265
2008	25,049	24,787	24,787	24,787	24,787	24,787	24,786	24,786	24,786	24,787	24,787	24,787	24,787	24,787
2009	24,662	24,565	24,565	24,565	24,563	24,563	24,561	24,561	24,561	24,563	24,563	24,565	24,565	24,565
2010	24,099	24,099	24,099	24,099	24,096	24,096	24,091	24,091	24,091	24,096	24,096	24,099	24,099	24,099
2011	23,407	23,407	23,407	23,407	23,400	23,400	23,392	23,392	23,392	23,400	23,400	23,407	23,407	23,407
2012	22,639	22,639	22,639	22,639	22,624	22,624	22,611	22,612	22,612	22,624	22,624	22,639	22,639	22,639
2013	21,787	21,787	21,787	21,787	21,761	21,761	21,740	21,741	21,741	21,761	21,761	21,787	21,787	21,787
2014	20,977	20,977	20,977	20,977	20,931	20,931	20,898	20,899	20,899	20,931	20,931	20,977	20,977	20,977
2015	20,255	20,255	20,255	20,255	20,179	20,179	20,126	20,127	20,127	20,179	20,179	20,255	20,255	20,255
2016	19,651	19,651	19,651	19,651	19,528	19,528	19,446	19,448	19,448	19,528	19,528	19,651	19,651	19,651
2017	19,180	19,180	19,180	19,180	18,988	18,988	18,870	18,873	18,873	18,988	18,988	19,180	19,180	19,180
2018	18,835	18,835	18,835	18,835	18,545	18,545	18,381	18,385	18,385	18,545	18,545	18,835	18,835	18,835
2019	18,597	18,597	18,597	18,597	18,173	18,173	17,955	17,961	17,961	18,173	18,173	18,597	18,597	18,597
2020	18,447	18,447	18,447	18,447	17,845	17,845	17,564	17,573	17,573	17,845	17,845	18,447	18,447	18,447
2021	18,366	18,366	18,366	18,366	17,536	17,536	17,183	17,195	17,195	17,536	17,536	18,366	18,366	18,366
2022	18,343	18,343	18,343	18,343	17,229	17,229	16,796	16,811	16,811	17,229	17,229	18,343	18,343	18,343
2023	18,357	18,357	18,357	18,357	16,903	16,903	16,380	16,399	16,399	16,903	16,903	18,357	18,357	18,357
2024	18,442	18,442	18,442	18,442	16,588	16,588	15,968	15,992	15,992	16,588	16,588	18,442	18,442	18,442
2025	18,524	18,524	18,524	18,524	16,213	16,213	15,488	15,519	15,519	16,213	16,213	18,524	18,524	18,524
2026	18,604	18,604	18,604	18,604	15,783	15,783	14,948	14,985	14,985	15,783	15,783	18,604	18,604	18,604
2027	18,685	18,685	18,685	18,685	15,306	15,306	14,361	14,405	14,405	15,306	15,306	18,685	18,685	18,685
2028	18,767	18,767	18,767	18,767	14,790	14,790	13,740	13,790	13,790	14,790	14,790	18,767	18,767	18,767
2029	18,850	18,850	18,850	18,850	14,248	14,248	13,098	13,155	13,155	14,248	14,248	18,850	18,850	18,850
2030	18,934	18,935	18,935	18,935	13,692	13,692	12,449	12,513	12,513	13,692	13,692	18,935	18,935	18,935

Table B.6 VOC Emissions from Urban Vehicle Operation

	Operational Emissions of VOC for the Base Case and for Each PNGV Technology/Fuel Combination (10^3 tonnes)													
	Base Case	CV+RFG	CV+MeOH	CV+EtOH	CV+RFD	CV+DME	CV+HFCV	CV+MFCV	CV+GFC	CV+FTD/RFD	CV+Bio/RFD	CV+LPG	CV+CNG	CV+LNG
2005	1,174	1,090	1,090	1,090	1,090	1,090	1,090	1,090	1,090	1,090	1,090	1,090	1,090	1,090
2006	1,172	1,127	1,127	1,127	1,127	1,127	1,127	1,127	1,127	1,127	1,127	1,127	1,127	1,127
2007	1,179	1,157	1,157	1,157	1,157	1,157	1,157	1,157	1,157	1,157	1,157	1,157	1,157	1,157
2008	1,192	1,184	1,184	1,184	1,184	1,184	1,183	1,183	1,183	1,184	1,184	1,184	1,184	1,184
2009	1,231	1,228	1,228	1,228	1,228	1,228	1,227	1,227	1,227	1,228	1,228	1,228	1,228	1,228
2010	1,269	1,269	1,269	1,269	1,268	1,268	1,267	1,267	1,268	1,268	1,268	1,268	1,268	1,268
2011	1,304	1,304	1,304	1,304	1,303	1,303	1,301	1,302	1,302	1,303	1,303	1,303	1,303	1,303
2012	1,336	1,336	1,336	1,336	1,334	1,334	1,332	1,332	1,333	1,334	1,334	1,334	1,334	1,334
2013	1,365	1,365	1,365	1,365	1,362	1,362	1,358	1,359	1,360	1,362	1,362	1,362	1,362	1,362
2014	1,390	1,390	1,390	1,390	1,385	1,385	1,380	1,381	1,382	1,385	1,385	1,385	1,385	1,385
2015	1,411	1,411	1,411	1,411	1,404	1,404	1,395	1,397	1,399	1,404	1,404	1,403	1,403	1,403
2016	1,429	1,429	1,429	1,429	1,418	1,418	1,404	1,407	1,410	1,418	1,418	1,417	1,417	1,417
2017	1,444	1,444	1,444	1,444	1,428	1,428	1,407	1,411	1,417	1,428	1,428	1,426	1,426	1,426
2018	1,457	1,457	1,457	1,457	1,434	1,434	1,405	1,410	1,418	1,434	1,434	1,431	1,431	1,431
2019	1,468	1,468	1,468	1,468	1,436	1,436	1,396	1,404	1,414	1,436	1,436	1,432	1,432	1,432
2020	1,477	1,477	1,477	1,477	1,434	1,434	1,382	1,392	1,406	1,434	1,434	1,430	1,430	1,430
2021	1,485	1,485	1,485	1,485	1,429	1,429	1,362	1,375	1,393	1,429	1,429	1,424	1,424	1,424
2022	1,492	1,492	1,492	1,492	1,420	1,420	1,336	1,352	1,375	1,420	1,420	1,414	1,414	1,414
2023	1,499	1,499	1,499	1,499	1,407	1,407	1,304	1,324	1,353	1,407	1,407	1,401	1,401	1,401
2024	1,505	1,505	1,505	1,505	1,390	1,390	1,267	1,291	1,327	1,390	1,390	1,386	1,386	1,386
2025	1,511	1,511	1,511	1,511	1,371	1,371	1,224	1,253	1,296	1,371	1,371	1,367	1,367	1,367
2026	1,517	1,517	1,517	1,517	1,349	1,349	1,177	1,212	1,263	1,349	1,349	1,347	1,347	1,347
2027	1,523	1,523	1,523	1,523	1,325	1,325	1,128	1,168	1,227	1,325	1,325	1,325	1,325	1,325
2028	1,529	1,529	1,529	1,529	1,299	1,299	1,077	1,123	1,191	1,299	1,299	1,303	1,303	1,303
2029	1,535	1,535	1,535	1,535	1,273	1,273	1,026	1,078	1,154	1,273	1,273	1,280	1,280	1,280
2030	1,541	1,541	1,541	1,541	1,247	1,247	976	1,033	1,118	1,247	1,247	1,258	1,258	1,258

Table B.7 SO_x Emissions from Urban Vehicle Operation

	Operational Emissions of SO_x for the Base Case and for Each PNGV Technology/FuelCombination (10^3 tonnes)													
	Base Case	CV+RFG	CV+MeOH	CV+EtOH	CV+RFD	CV+DME	CV+HFCV	CV+MFCV	CV+GFC	CV+FTD/RFD	CV+Bio/RFD	CV+LPG	CV+CNG	CV+LNG
2005	42	42	42	42	42	42	42	42	42	42	42	42	42	42
2006	43	42	42	42	42	42	42	42	42	42	42	42	42	42
2007	43	43	43	43	43	43	43	43	43	43	43	43	43	43
2008	43	43	43	43	43	43	43	43	43	43	43	43	43	43
2009	44	44	44	44	44	44	44	44	44	44	44	44	44	44
2010	45	45	44	44	45	44	44	44	45	44	45	44	44	44
2011	45	45	45	45	45	45	45	45	45	45	45	45	45	45
2012	45	45	45	45	45	45	45	45	45	45	45	45	45	45
2013	46	45	45	45	45	45	45	45	45	45	45	45	45	45
2014	46	45	45	45	45	45	45	45	45	45	45	45	45	45
2015	46	45	45	45	45	45	45	45	45	45	45	45	45	45
2016	46	45	44	44	45	44	44	44	45	45	45	44	44	44
2017	46	44	44	44	45	44	44	44	44	44	44	44	44	44
2018	46	44	43	43	44	43	43	43	44	43	44	43	43	43
2019	46	43	42	42	43	42	42	42	43	43	43	42	42	42
2020	46	43	41	41	43	41	41	41	43	42	42	41	41	41
2021	46	42	40	40	42	39	39	40	42	41	42	39	40	39
2022	46	41	38	38	41	38	38	38	41	40	41	38	38	38
2023	46	40	37	37	40	36	36	37	40	39	40	36	37	36
2024	46	39	36	35	39	35	35	36	39	37	39	35	35	35
2025	46	38	34	34	39	33	33	34	38	36	38	33	33	33
2026	46	37	32	32	38	31	31	32	37	35	37	31	32	31
2027	46	36	31	30	37	30	30	31	36	33	35	30	30	30
2028	46	35	29	29	36	28	28	29	35	32	34	28	28	28
2029	46	35	28	27	35	27	27	28	35	31	34	27	27	27
2030	46	34	27	26	34	25	25	27	34	30	33	25	26	25

Table B.8 PM_{10} Emissions from Urban Vehicle Operation

	Operational Emissions of PM_{10} for the Base Case and for Each PNGV Technology/Fuel Combination (10^3 tonnes)													
	Base Case	CV+RFG	CV+MeOH	CV+EtOH	CV+RFD	CV+DME	CV+HFCV	CV+MFCV	CV+GFC	CV+FTD/RFD	CV+Bio/RFD	CV+LPG	CV+CNG	CV+LNG
2005	52	51	51	51	51	51	51	51	51	51	51	51	51	51
2006	52	52	52	52	52	52	52	52	52	52	52	52	52	52
2007	53	53	53	53	53	53	53	53	53	53	53	53	53	53
2008	54	54	54	54	54	54	54	54	54	54	54	54	54	54
2009	55	55	55	55	55	55	55	55	55	55	55	55	55	55
2010	56	56	56	56	56	56	56	56	56	56	56	56	56	56
2011	57	57	57	57	57	57	57	57	57	57	57	57	57	57
2012	58	58	57	57	58	58	57	57	57	58	58	57	57	57
2013	58	58	58	58	59	58	58	58	58	59	59	58	58	58
2014	59	59	59	59	60	59	58	58	58	60	60	58	58	58
2015	59	59	59	59	60	59	59	59	59	60	60	59	59	59
2016	60	60	59	59	61	60	59	59	59	61	61	59	59	59
2017	60	60	59	59	63	60	59	59	59	63	63	59	59	59
2018	60	60	59	59	64	60	59	59	59	64	64	59	59	59
2019	61	61	59	59	65	61	59	59	59	65	65	59	59	59
2020	61	61	58	58	67	61	58	58	58	67	67	58	58	58
2021	61	61	58	58	68	61	58	58	58	68	68	58	58	58
2022	61	61	58	58	70	61	57	57	57	70	70	57	57	57
2023	62	62	57	57	72	62	57	57	57	72	72	57	57	57
2024	62	62	57	57	74	62	56	56	56	74	74	56	56	56
2025	62	62	56	56	76	62	55	55	55	76	76	55	55	55
2026	62	62	55	55	78	62	55	55	55	78	78	55	55	55
2027	63	63	55	55	80	63	54	54	54	80	80	54	54	54
2028	63	63	54	54	82	63	53	53	53	82	82	53	53	53
2029	63	63	54	54	84	63	53	53	53	84	84	53	53	53
2030	63	63	53	53	86	63	52	52	52	86	86	52	52	52

Table B.9 CO_2 Emissions from Urban Vehicle Operation

	Operational Emissions of CO_2 for the Base Case and for Each PNGV Technology/Fuel Combination (10^3 tonnes)														
	Base Case	CV+RFG	CV+MeOH	CV+EtOH	CV+RFD	CV+DME	CV+HFCV	CV+MFCV	CV+GFC	CV+FTD/RFD	CV+Bio/RFD	CV+LPG	CV+CNG	CV+LNG	
2005	1,040,251	1,022,550	1,022,550	1,022,550	1,022,550	1,022,550	1,022,550	1,022,550	1,022,550	1,022,550	1,022,550	1,022,550	1,022,550	1,022,550	2005
2006	1,048,658	1,038,020	1,038,020	1,038,020	1,038,020	1,038,020	1,038,020	1,038,020	1,038,020	1,038,020	1,038,020	1,038,020	1,038,020	1,038,020	2006
2007	1,057,116	1,051,015	1,051,014	1,050,972	1,051,019	1,051,013	1,050,972	1,051,014	1,051,015	1,051,018	1,051,019	1,051,014	1,051,007	1,051,006	2007
2008	1,063,712	1,060,253	1,060,249	1,060,081	1,060,268	1,060,246	1,060,081	1,060,249	1,060,253	1,060,265	1,060,268	1,060,247	1,060,220	1,060,219	2008
2009	1,079,681	1,077,540	1,077,530	1,077,115	1,077,577	1,077,522	1,077,115	1,077,530	1,077,540	1,077,568	1,077,576	1,077,526	1,077,458	1,077,455	2009
2010	1,092,771	1,090,968	1,090,948	1,090,127	1,091,041	1,090,933	1,090,127	1,090,948	1,090,968	1,091,024	1,091,040	1,090,940	1,090,806	1,090,799	2010
2011	1,102,514	1,099,773	1,099,737	1,098,267	1,099,903	1,099,710	1,098,267	1,099,737	1,099,773	1,099,872	1,099,900	1,099,723	1,099,483	1,099,470	2011
2012	1,109,642	1,105,428	1,105,368	1,102,931	1,105,643	1,105,324	1,102,931	1,105,368	1,105,428	1,105,593	1,105,639	1,105,345	1,104,947	1,104,925	2012
2013	1,115,078	1,108,514	1,108,418	1,104,487	1,108,861	1,108,347	1,104,487	1,108,418	1,108,514	1,108,780	1,108,855	1,108,380	1,107,738	1,107,704	2013
2014	1,118,632	1,108,385	1,108,232	1,101,951	1,108,941	1,108,119	1,101,951	1,108,232	1,108,385	1,108,811	1,108,930	1,108,172	1,107,146	1,107,091	2014
2015	1,120,000	1,104,093	1,103,851	1,093,942	1,104,970	1,103,673	1,093,942	1,103,851	1,104,093	1,104,765	1,104,953	1,103,758	1,102,138	1,102,051	2015
2016	1,120,559	1,096,537	1,096,167	1,081,034	1,097,876	1,095,895	1,081,034	1,096,167	1,096,537	1,097,563	1,097,850	1,096,024	1,093,551	1,093,418	2016
2017	1,120,630	1,086,174	1,085,639	1,063,749	1,088,111	1,085,245	1,063,749	1,085,639	1,086,174	1,087,659	1,088,074	1,085,432	1,081,855	1,081,663	2017
2018	1,120,405	1,073,340	1,072,605	1,042,491	1,076,005	1,072,063	1,042,491	1,072,605	1,073,340	1,075,383	1,075,954	1,072,319	1,067,398	1,067,134	2018
2019	1,120,034	1,058,334	1,057,364	1,017,632	1,061,850	1,056,648	1,017,632	1,057,364	1,058,334	1,061,029	1,061,782	1,056,987	1,050,494	1,050,146	2019
2020	1,119,667	1,041,462	1,040,225	989,559	1,045,946	1,039,313	989,559	1,040,225	1,041,462	1,044,899	1,045,860	1,039,745	1,031,465	1,031,020	2020
2021	1,119,448	1,022,563	1,021,022	957,876	1,028,152	1,019,885	957,876	1,021,022	1,022,563	1,026,847	1,028,044	1,020,424	1,010,105	1,009,550	2021
2022	1,119,454	1,001,915	1,000,033	922,966	1,008,735	998,646	922,966	1,000,033	1,001,915	1,007,143	1,008,604	999,303	986,709	986,033	2022
2023	1,119,709	979,748	977,494	885,175	987,919	975,833	885,175	977,494	979,748	986,011	987,762	976,620	961,533	960,723	2023
2024	1,120,213	956,277	953,621	844,834	965,904	951,662	844,834	953,621	956,277	963,656	965,719	952,590	934,812	933,857	2024
2025	1,120,988	931,736	928,651	802,299	942,918	926,377	802,299	928,651	931,736	940,307	942,703	927,454	906,806	905,697	2025
2026	1,121,989	906,689	903,158	758,538	919,488	900,555	758,538	903,158	906,689	916,499	919,242	901,788	878,155	876,886	2026
2027	1,123,194	882,629	878,660	716,098	897,016	875,734	716,098	878,660	882,629	893,657	896,740	877,120	850,555	849,128	2027
2028	1,124,571	860,490	856,107	676,597	876,377	852,876	676,597	856,107	860,490	872,666	876,071	854,406	825,072	823,496	2028
2029	1,126,099	840,623	835,857	640,664	857,898	832,344	640,664	835,857	840,623	853,864	857,566	834,008	802,111	800,397	2029
2030	1,127,736	823,061	817,945	608,394	841,606	814,173	608,394	817,945	823,061	837,275	841,250	815,960	781,716	779,876	2030

Table B.10 CH_4 Emissions from Urban Vehicle Operation

	Operational Emissions of CH_4 for the Base Case and for Each PNGV Technology/Fuel Combination (10^3 tonnes)													
	Base Case	CV+RFG	CV+MeOH	CV+EtOH	CV+RFD	CV+DME	CV+HFCV	CV+MFCV	CV+GFC	CV+FTD/RFD	CV+Bio/RFD	CV+LPG	CV+CNG	CV+LNG
2005	117	115	115	115	115	115	115	115	115	115	115	115	115	115
2006	119	118	118	118	118	118	118	118	118	118	118	118	118	118
2007	121	120	120	120	120	120	120	120	120	120	120	120	120	120
2008	122	122	122	122	122	122	122	122	122	122	122	122	123	123
2009	125	125	125	125	125	125	125	125	125	125	125	125	126	126
2010	128	128	128	128	128	128	128	128	128	128	128	128	130	130
2011	130	130	130	130	130	130	130	130	130	130	130	130	135	135
2012	132	132	132	132	132	132	132	132	132	132	132	132	140	140
2013	134	134	134	134	133	133	133	133	133	133	133	134	146	146
2014	136	136	135	135	134	134	134	134	134	134	134	136	154	154
2015	138	138	136	136	135	135	134	134	134	135	135	138	167	167
2016	139	139	137	137	135	135	134	134	134	135	135	139	183	183
2017	140	140	138	138	134	134	133	133	133	134	134	140	204	204
2018	141	141	138	138	132	132	131	131	131	132	132	141	229	229
2019	142	142	138	138	131	131	129	129	129	131	131	142	259	259
2020	143	143	137	137	128	128	127	127	127	128	128	143	292	292
2021	144	144	137	137	126	126	123	123	123	126	126	144	330	330
2022	145	145	136	136	122	122	120	120	120	122	122	145	372	372
2023	146	146	135	135	119	119	116	116	116	119	119	146	419	419
2024	147	147	134	134	115	115	111	111	111	115	115	147	469	469
2025	148	148	133	133	111	111	106	106	106	111	111	148	522	522
2026	149	149	132	132	106	106	101	101	101	106	106	149	578	578
2027	149	149	131	131	102	102	96	96	96	102	102	149	633	633
2028	150	150	130	130	97	97	91	91	91	97	97	150	686	686
2029	151	151	129	129	93	93	86	86	86	93	93	151	734	734
2030	152	152	128	128	90	90	83	83	83	90	90	152	779	779

Table B.11 N_2O Emissions from Urban Vehicle Operation

	Operational Emissions of N_2O for the Base Case and for Each PNGV Technology/Fuel Combination (10^3 tonnes)													
	Base Case	CV+RFG	CV+MeOH	CV+EtOH	CV+RFD	CV+DME	CV+HFCV	CV+MFCV	CV+GFC	CV+FTD/RFD	CV+Bio/RFD	CV+LPG	CV+CNG	CV+LNG
2005	7.9	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8
2006	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
2007	8.2	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1
2008	8.3	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2	8.2
2009	8.5	8.5	8.5	8.5	8.5	8.5	8.4	8.4	8.4	8.5	8.5	8.5	8.5	8.5
2010	8.6	8.6	8.6	8.6	8.6	8.6	8.6	8.6	8.6	8.6	8.6	8.6	8.6	8.6
2011	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8
2012	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9
2013	9.1	9.1	9.1	9.1	9.1	9.1	9.0	9.0	9.0	9.1	9.1	9.1	9.1	9.1
2014	9.2	9.2	9.2	9.2	9.2	9.2	9.1	9.1	9.1	9.2	9.2	9.2	9.2	9.2
2015	9.3	9.3	9.3	9.3	9.3	9.3	9.1	9.1	9.1	9.3	9.3	9.3	9.3	9.3
2016	9.4	9.4	9.4	9.4	9.4	9.4	9.1	9.1	9.1	9.4	9.4	9.4	9.4	9.4
2017	9.5	9.5	9.5	9.5	9.5	9.5	9.0	9.0	9.0	9.5	9.5	9.5	9.5	9.5
2018	9.5	9.5	9.5	9.5	9.5	9.5	8.9	8.9	8.9	9.5	9.5	9.5	9.5	9.5
2019	9.6	9.6	9.6	9.6	9.6	9.6	8.7	8.7	8.7	9.6	9.6	9.6	9.6	9.6
2020	9.7	9.7	9.7	9.7	9.7	9.7	8.6	8.6	8.6	9.7	9.7	9.7	9.7	9.7
2021	9.7	9.7	9.7	9.7	9.7	9.7	8.3	8.3	8.3	9.7	9.7	9.7	9.7	9.7
2022	9.8	9.8	9.8	9.8	9.8	9.8	8.1	8.1	8.1	9.8	9.8	9.8	9.8	9.8
2023	9.9	9.9	9.9	9.9	9.9	9.9	7.8	7.8	7.8	9.9	9.9	9.9	9.9	9.9
2024	9.9	9.9	9.9	9.9	9.9	9.9	7.5	7.5	7.5	9.9	9.9	9.9	9.9	9.9
2025	10.0	10.0	10.0	10.0	10.0	10.0	7.2	7.2	7.2	10.0	10.0	10.0	10.0	10.0
2026	10.0	10.0	10.0	10.0	10.0	10.0	6.8	6.8	6.8	10.0	10.0	10.0	10.0	10.0
2027	10.1	10.1	10.1	10.1	10.1	10.1	6.5	6.5	6.5	10.1	10.1	10.1	10.1	10.1
2028	10.2	10.2	10.2	10.2	10.2	10.2	6.1	6.1	6.1	10.2	10.2	10.2	10.2	10.2
2029	10.2	10.2	10.2	10.2	10.2	10.2	5.8	5.8	5.8	10.2	10.2	10.2	10.2	10.2
2030	10.3	10.3	10.3	10.3	10.3	10.3	5.6	5.6	5.6	10.3	10.3	10.3	10.3	10.3

Table B.12 Upstream Energy Use (all vehicles)

	Upstream Energy Use for the Base Case and for Each PNGV Technology/Fuel Combination (quads)													
	Base Case	CV+RFG	CV+MeOH	CV+EtOH	CV+RFD	CV+DME	CV+HFCV	CV+MFCV	CV+GFC	CV+FTD/RFD	CV+Bio/RFD	CV+LPG	CV+CNG	CV+LNG
2005	4.2	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1
2006	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2
2007	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3
2008	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3
2009	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4
2010	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4
2011	4.5	4.4	4.4	4.4	4.4	4.4	4.5	4.4	4.4	4.4	4.4	4.4	4.4	4.4
2012	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
2013	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
2014	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
2015	4.5	4.4	4.5	4.5	4.4	4.5	4.5	4.5	4.4	4.5	4.4	4.4	4.4	4.5
2016	4.5	4.4	4.5	4.5	4.4	4.5	4.6	4.5	4.4	4.5	4.4	4.4	4.4	4.4
2017	4.5	4.4	4.5	4.5	4.3	4.5	4.6	4.5	4.4	4.4	4.3	4.3	4.4	4.4
2018	4.5	4.3	4.5	4.5	4.3	4.5	4.6	4.5	4.3	4.4	4.3	4.3	4.3	4.3
2019	4.5	4.3	4.4	4.5	4.2	4.4	4.6	4.4	4.3	4.4	4.2	4.2	4.2	4.3
2020	4.5	4.2	4.4	4.5	4.1	4.4	4.6	4.4	4.2	4.3	4.1	4.1	4.2	4.2
2021	4.5	4.1	4.4	4.6	4.0	4.4	4.7	4.4	4.1	4.3	4.0	4.0	4.1	4.1
2022	4.5	4.0	4.3	4.6	3.9	4.3	4.7	4.3	4.0	4.3	3.9	3.9	4.0	4.0
2023	4.5	3.9	4.3	4.6	3.8	4.3	4.6	4.3	3.9	4.2	3.8	3.7	3.9	4.0
2024	4.5	3.8	4.3	4.7	3.7	4.3	4.6	4.3	3.8	4.2	3.7	3.6	3.8	3.9
2025	4.5	3.7	4.2	4.7	3.5	4.2	4.5	4.2	3.7	4.1	3.6	3.5	3.7	3.8
2026	4.5	3.6	4.2	4.8	3.4	4.2	4.4	4.2	3.6	4.0	3.5	3.3	3.6	3.7
2027	4.5	3.5	4.2	4.8	3.3	4.1	4.4	4.2	3.5	4.0	3.3	3.2	3.4	3.6
2028	4.5	3.4	4.1	4.9	3.2	4.1	4.3	4.1	3.4	3.9	3.2	3.1	3.3	3.5
2029	4.5	3.4	4.1	4.9	3.1	4.1	4.2	4.1	3.4	3.9	3.1	2.9	3.3	3.4
2030	4.5	3.3	4.1	5.0	3.0	4.0	4.2	4.1	3.3	3.9	3.0	2.8	3.2	3.4

Table B.13 Upstream Fossil Energy Use (all vehicles)

	Upstream Fossil Energy Use for the Base Case and for Each PNGV Technology/Fuel Combination (quads)													
	Base Case	CV+RFG	CV+MeOH	CV+EtOH	CV+RFD	CV+DME	CV+HFCV	CV+MFCV	CV+GFC	CV+FTD/RFD	CV+Bio/RFD	CV+LPG	CV+CNG	CV+LNG
2005	4.0	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9
2006	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
2007	4.1	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
2008	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1
2009	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2
2010	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2
2011	4.2	4.2	4.2	4.2	4.2	4.2	4.3	4.2	4.2	4.2	4.2	4.2	4.2	4.2
2012	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3
2013	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3
2014	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3
2015	4.3	4.3	4.3	4.3	4.2	4.3	4.3	4.3	4.3	4.3	4.2	4.2	4.2	4.3
2016	4.3	4.2	4.3	4.3	4.2	4.3	4.4	4.3	4.2	4.3	4.2	4.2	4.2	4.2
2017	4.3	4.2	4.3	4.3	4.2	4.3	4.4	4.3	4.2	4.3	4.2	4.1	4.2	4.2
2018	4.3	4.1	4.3	4.2	4.1	4.3	4.4	4.3	4.1	4.2	4.1	4.1	4.1	4.2
2019	4.3	4.1	4.3	4.0	4.0	4.3	4.4	4.3	4.1	4.2	4.0	4.0	4.0	4.1
2020	4.3	4.0	4.2	3.9	3.9	4.2	4.4	4.2	4.0	4.2	4.0	3.9	4.0	4.0
2021	4.3	3.9	4.2	3.8	3.8	4.2	4.4	4.2	3.9	4.1	3.9	3.8	3.9	4.0
2022	4.3	3.9	4.2	3.6	3.7	4.2	4.4	4.2	3.9	4.1	3.8	3.7	3.8	3.9
2023	4.3	3.8	4.2	3.4	3.6	4.2	4.4	4.2	3.8	4.1	3.7	3.6	3.7	3.8
2024	4.3	3.7	4.1	3.3	3.5	4.1	4.3	4.1	3.7	4.0	3.6	3.5	3.6	3.7
2025	4.3	3.6	4.1	3.1	3.4	4.1	4.3	4.1	3.6	4.0	3.5	3.3	3.5	3.6
2026	4.3	3.5	4.1	2.9	3.3	4.1	4.2	4.1	3.5	3.9	3.3	3.2	3.4	3.6
2027	4.3	3.4	4.0	2.7	3.2	4.0	4.1	4.0	3.4	3.9	3.2	3.1	3.3	3.5
2028	4.3	3.3	4.0	2.6	3.0	4.0	4.0	4.0	3.3	3.8	3.1	2.9	3.2	3.4
2029	4.3	3.2	4.0	2.4	2.9	4.0	3.9	4.0	3.2	3.8	3.0	2.8	3.1	3.3
2030	4.4	3.2	4.0	2.3	2.9	3.9	3.9	4.0	3.2	3.8	2.9	2.7	3.0	3.3

Table B.14 Upstream Petroleum Use (all vehicles)

	Upstream Petroleum Use for the Base Case and for Each PNGV Technology/Fuel Combination (quads)													
	Base Case	CV+RFG	CV+MeOH	CV+EtOH	CV+RFD	CV+DME	CV+HFCV	CV+MFCV	CV+GFC	CV+FTD/RFD	CV+Bio/RFD	CV+LPG	CV+CNG	CV+LNG
2005	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9
2006	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9
2007	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9
2008	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9
2009	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
2010	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
2011	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
2012	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
2013	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
2014	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
2015	2.1	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
2016	2.1	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
2017	2.1	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
2018	2.1	2.0	1.9	2.0	1.9	1.9	1.9	1.9	2.0	1.9	1.9	1.9	1.9	1.9
2019	2.1	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9
2020	2.1	1.9	1.8	1.9	1.9	1.8	1.8	1.8	1.9	1.9	1.9	1.8	1.8	1.9
2021	2.1	1.9	1.8	1.8	1.8	1.8	1.8	1.8	1.9	1.8	1.8	1.8	1.8	1.8
2022	2.1	1.8	1.7	1.8	1.8	1.7	1.7	1.7	1.8	1.8	1.8	1.7	1.7	1.8
2023	2.1	1.8	1.7	1.7	1.7	1.7	1.6	1.7	1.8	1.7	1.7	1.7	1.6	1.7
2024	2.1	1.8	1.6	1.7	1.7	1.6	1.6	1.6	1.8	1.6	1.7	1.6	1.6	1.6
2025	2.1	1.7	1.5	1.6	1.6	1.5	1.5	1.5	1.7	1.6	1.6	1.5	1.5	1.6
2026	2.1	1.7	1.5	1.6	1.5	1.5	1.4	1.5	1.7	1.5	1.6	1.4	1.4	1.5
2027	2.1	1.6	1.4	1.5	1.5	1.4	1.3	1.4	1.6	1.4	1.5	1.4	1.3	1.5
2028	2.1	1.6	1.3	1.5	1.4	1.3	1.3	1.3	1.6	1.4	1.4	1.3	1.3	1.4
2029	2.1	1.5	1.3	1.4	1.4	1.3	1.2	1.3	1.5	1.3	1.4	1.3	1.2	1.3
2030	2.1	1.5	1.2	1.4	1.3	1.2	1.1	1.2	1.5	1.3	1.4	1.2	1.1	1.3

Table B.15 Upstream NO_X Emissions (urban locations)

	Upstream Emissions of NO_x for the Base Case and for Each PNGV Technology/Fuel Combination (10^3 tonnes)													
	Base Case	CV+RFG	CV+MeOH	CV+EtOH	CV+RFD	CV+DME	CV+HFCV	CV+MFCV	CV+GFC	CV+FTD/RFD	CV+Bio/RFD	CV+LPG	CV+CNG	CV+LNG
2005	30	30	30	30	30	30	30	30	30	30	30	30	30	30
2006	31	30	30	30	30	30	30	30	30	30	30	30	30	30
2007	31	31	31	31	31	31	31	31	31	31	31	31	31	31
2008	31	31	31	31	31	31	31	31	31	31	31	31	31	31
2009	32	32	32	32	32	32	32	32	32	32	32	32	32	32
2010	32	32	32	32	32	32	32	32	32	32	32	32	32	32
2011	32	32	32	32	32	32	33	32	32	32	32	32	32	32
2012	33	32	32	33	32	32	33	32	32	32	32	33	33	33
2013	33	33	33	33	33	33	33	33	33	33	33	33	33	33
2014	33	33	33	33	33	33	34	33	33	33	33	33	33	33
2015	33	33	33	33	33	32	34	33	33	33	33	33	33	33
2016	33	32	32	34	32	32	35	32	32	32	32	32	33	33
2017	33	32	32	34	32	32	36	32	32	32	32	32	33	33
2018	33	32	32	34	32	31	38	32	32	32	32	32	32	33
2019	33	31	31	34	31	31	39	31	31	31	31	32	32	33
2020	33	31	31	34	31	30	41	31	31	31	31	31	32	32
2021	33	30	30	34	30	30	42	30	30	30	31	31	31	32
2022	33	30	29	34	30	29	44	29	30	29	30	30	31	32
2023	33	29	28	34	29	28	47	28	29	28	29	29	31	32
2024	34	29	28	34	28	27	49	28	29	28	29	29	30	32
2025	34	28	27	35	27	26	52	27	28	27	28	28	30	31
2026	34	27	26	35	27	25	55	26	27	26	27	27	29	31
2027	34	26	25	35	26	25	57	25	26	25	27	27	29	31
2028	34	26	24	35	25	24	60	24	26	24	26	26	29	31
2029	34	25	24	35	25	23	62	24	25	23	25	26	28	30
2030	34	25	23	35	24	22	64	23	25	23	25	25	28	30

Table B.16 Upstream CO Emissions (urban locations)

	Upstream Emissions of CO for the Base Case and for Each PNGV Technology/Fuel Combination (10^3 tonnes)													
	Base Case	CV+RFG	CV+MeOH	CV+EtOH	CV+RFD	CV+DME	CV+HFCV	CV+MFCV	CV+GFC	CV+FTD/RFD	CV+Bio/RFD	CV+LPG	CV+CNG	CV+LNG
2005	21	20	20	20	20	20	20	20	20	20	20	20	20	20
2006	21	21	21	21	21	21	21	21	21	21	21	21	21	21
2007	21	21	21	21	21	21	21	21	21	21	21	21	21	21
2008	21	21	21	21	21	21	21	21	21	21	21	21	21	21
2009	22	21	21	21	21	21	22	21	21	21	21	21	21	21
2010	22	22	22	22	22	22	22	22	22	22	22	22	22	22
2011	22	22	22	22	22	22	22	22	22	22	22	22	22	22
2012	22	22	22	22	22	22	22	22	22	22	22	22	22	22
2013	22	22	22	22	22	22	23	22	22	22	22	22	22	22
2014	22	22	22	22	22	22	23	22	22	22	22	22	22	22
2015	23	22	22	23	22	22	23	22	22	22	22	22	22	23
2016	23	22	22	23	22	22	23	22	22	22	22	22	22	23
2017	23	22	22	23	22	22	23	22	22	22	22	22	22	23
2018	23	22	22	23	22	21	24	22	22	22	22	22	22	23
2019	23	21	21	22	21	21	24	21	21	21	22	22	21	23
2020	23	21	21	22	21	21	25	21	21	21	21	21	21	23
2021	23	21	20	22	21	20	25	20	21	20	21	21	21	23
2022	23	20	20	22	20	20	26	20	20	20	21	21	20	23
2023	23	20	20	22	20	19	26	20	20	19	20	20	20	23
2024	23	19	19	22	19	19	27	19	19	19	20	20	19	23
2025	23	19	18	22	19	18	28	18	19	18	20	20	19	23
2026	23	18	18	22	18	18	28	18	18	18	19	19	18	24
2027	23	18	17	21	18	17	29	17	18	17	19	19	18	24
2028	23	18	17	21	17	16	30	17	18	17	19	19	17	24
2029	23	17	16	21	17	16	31	16	17	16	18	18	17	24
2030	23	17	16	21	17	15	31	16	17	16	18	18	17	24

Table B.17 Upstream VOC Emission (urban locations)

	Upstream Emissions of VOC for the Base Case and for Each PNGV Technology/Fuel Combination (10^3 tonnes)													
	Base Case	CV+RFG	CV+MeOH	CV+EtOH	CV+RFD	CV+DME	CV+HFCV	CV+MFCV	CV+GFC	CV+FTD/RFD	CV+Bio/RFD	CV+LPG	CV+CNG	CV+LNG
2005	68	67	67	67	67	67	67	67	67	67	67	67	67	67
2006	69	68	68	68	68	68	68	68	68	68	68	68	68	68
2007	70	69	69	69	69	69	69	69	69	69	69	69	69	69
2008	70	70	70	70	70	70	70	70	70	70	70	70	70	70
2009	71	71	71	71	71	71	71	71	71	71	71	71	71	71
2010	72	72	72	72	72	72	72	72	72	72	72	72	72	72
2011	72	72	72	72	72	72	72	72	72	72	72	72	72	72
2012	73	72	72	72	72	72	72	72	72	72	72	72	72	72
2013	73	73	73	73	72	72	73	73	73	72	72	73	72	73
2014	73	73	72	73	72	72	72	72	73	72	72	72	72	73
2015	73	72	72	72	72	72	72	72	72	72	72	72	72	72
2016	73	72	71	72	71	71	71	71	72	71	71	71	71	72
2017	73	71	71	71	70	70	70	71	71	70	70	70	70	71
2018	73	70	69	70	69	69	69	69	70	69	69	69	68	70
2019	73	69	68	68	67	67	68	68	69	67	67	68	67	69
2020	73	68	67	67	66	66	66	67	68	65	66	67	65	67
2021	73	67	65	66	64	64	65	65	67	63	64	65	63	66
2022	73	65	64	64	62	62	63	64	65	61	62	63	61	64
2023	73	64	62	62	60	60	61	62	64	59	60	61	58	63
2024	73	62	60	60	58	57	59	60	62	56	58	59	56	61
2025	73	61	58	58	55	55	56	58	61	54	55	57	53	59
2026	73	59	56	57	53	52	54	56	59	51	53	55	50	57
2027	73	58	54	55	50	50	52	54	58	49	51	53	48	56
2028	73	56	52	53	48	48	50	52	56	46	49	51	45	54
2029	73	55	50	51	46	46	48	50	55	44	47	49	43	52
2030	73	54	49	50	45	44	46	49	54	42	45	47	41	51

Table B.18 Upstream SO_x Emissions (urban locations)

	Upstream Emissions of SO_x for the Base Case and for Each PNGV Technology/Fuel Combination (10^3 tonnes)													
	Base Case	CV+RFG	CV+MeOH	CV+EtOH	CV+RFD	CV+DME	CV+HFCV	CV+MFCV	CV+GFC	CV+FTD/RFD	CV+Bio/RFD	CV+LPG	CV+CNG	CV+LNG
2005	3	3	3	3	3	3	3	3	3	3	3	3	3	3
2006	3	3	3	3	3	3	3	3	3	3	3	3	3	3
2007	3	3	3	3	3	3	3	3	3	3	3	3	3	3
2008	3	3	3	3	3	3	3	3	3	3	3	3	3	3
2009	3	3	3	3	3	3	3	3	3	3	3	3	3	3
2010	3	3	3	3	3	3	3	3	3	3	3	3	3	3
2011	3	3	3	3	3	3	3	3	3	3	3	3	3	3
2012	3	3	3	3	3	3	3	3	3	3	3	3	3	3
2013	3	3	3	3	3	3	3	3	3	3	3	3	3	3
2014	3	3	3	3	3	3	3	3	3	3	3	3	3	4
2015	3	3	3	3	3	3	3	3	3	3	3	3	3	4
2016	3	3	3	3	3	3	3	3	3	3	3	3	3	4
2017	3	3	3	3	3	3	3	3	3	3	3	3	3	4
2018	3	3	3	3	3	3	3	3	3	3	3	3	3	5
2019	3	3	3	3	3	3	3	3	3	3	3	3	3	5
2020	3	3	3	3	3	3	3	3	3	3	3	3	3	5
2021	3	3	3	3	3	3	3	3	3	3	3	3	3	6
2022	3	3	3	3	3	3	3	3	3	3	3	3	3	7
2023	3	3	3	2	3	3	3	3	3	3	3	3	2	7
2024	3	3	3	2	2	3	3	3	3	3	2	3	2	8
2025	3	2	3	2	2	3	2	3	2	3	2	2	2	9
2026	3	2	3	2	2	3	2	3	2	3	2	2	2	10
2027	3	2	3	2	2	3	2	3	2	3	2	2	2	11
2028	3	2	3	2	2	3	2	3	2	3	2	2	2	11
2029	3	2	3	2	2	3	2	3	2	3	2	2	2	12
2030	3	2	4	2	2	3	2	4	2	3	2	2	2	13

Table B.19 Upstream PM_{10} Emissions (urban locations)

	Upstream Emissions of PM_{10} for the Base Case and for Each PNGV Technology/Fuel Combination (10^3 tonnes)													
	Base Case	CV+RFG	CV+MeOH	CV+EtOH	CV+RFD	CV+DME	CV+HFCV	CV+MFCV	CV+GFC	CV+FTD/RFD	CV+Bio/RFD	CV+LPG	CV+CNG	CV+LNG
2005	2	2	2	2	2	2	2	2	2	2	2	2	2	2
2006	2	2	2	2	2	2	2	2	2	2	2	2	2	2
2007	2	2	2	2	2	2	2	2	2	2	2	2	2	2
2008	2	2	2	2	2	2	2	2	2	2	2	2	2	2
2009	2	2	2	2	2	2	2	2	2	2	2	2	2	2
2010	2	2	2	2	2	2	2	2	2	2	2	2	2	2
2011	2	2	2	2	2	2	2	2	2	2	2	2	2	2
2012	2	2	2	2	2	2	2	2	2	2	2	2	2	2
2013	2	2	2	2	2	2	2	2	2	2	2	2	2	2
2014	2	2	2	2	2	2	2	2	2	2	2	2	2	2
2015	2	2	2	2	2	2	2	2	2	2	2	2	2	3
2016	2	2	2	2	2	2	2	2	2	2	2	2	2	3
2017	2	2	2	2	2	2	2	2	2	2	2	2	2	3
2018	2	2	2	2	2	2	2	2	2	2	2	2	2	4
2019	2	2	2	2	2	2	2	2	2	2	2	2	2	4
2020	2	2	2	2	2	2	2	2	2	2	2	2	2	5
2021	2	2	2	2	2	2	2	2	2	2	2	2	2	5
2022	2	2	2	2	2	2	2	2	2	2	2	2	2	6
2023	2	2	2	2	2	2	2	2	2	2	2	2	2	7
2024	2	2	2	2	2	2	2	2	2	2	2	2	2	8
2025	2	2	2	2	2	2	2	2	2	2	2	2	2	8
2026	2	2	2	2	2	2	2	2	2	2	2	2	2	9
2027	2	2	2	2	2	2	2	2	2	2	2	2	2	10
2028	2	2	2	2	2	2	2	2	2	2	2	2	2	11
2029	2	2	2	2	2	2	2	2	2	2	2	2	1	12
2030	2	2	2	3	2	2	2	2	2	2	2	2	1	13

Table B.20 Upstream CO_2 Emissions (all vehicles)

	Upstream Emissions of CO_2 for the Base Case and for Each PNGV Technology/Fuel Combination (10^3 tonnes)													
	Base Case	CV+RFG	CV+MeOH	CV+EtOH	CV+RFD	CV+DME	CV+HFCV	CV+MFCV	CV+GFC	CV+FTD/RFD	CV+Bio/RFD	CV+LPG	CV+CNG	CV+LNG
2005	298,672	293,590	293,590	293,590	293,590	293,590	293,590	293,590	293,590	293,590	293,590	293,590	293,590	293,590
2006	301,086	298,031	298,031	298,031	298,031	298,031	298,031	298,031	298,031	298,031	298,031	298,031	298,031	298,031
2007	303,514	301,762	301,768	301,779	301,758	301,768	301,815	301,768	301,762	301,771	301,759	301,756	301,760	301,760
2008	305,404	304,411	304,433	304,476	304,393	304,435	304,619	304,433	304,411	304,446	304,396	304,386	304,403	304,403
2009	309,985	309,371	309,424	309,530	309,325	309,429	309,883	309,424	309,371	309,456	309,334	309,308	309,351	309,350
2010	313,740	313,222	313,329	313,539	313,132	313,338	314,238	313,329	313,222	313,391	313,150	313,098	313,183	313,181
2011	316,533	315,746	315,936	316,310	315,585	315,953	317,564	315,936	315,746	316,049	315,618	315,525	315,676	315,672
2012	318,575	317,366	317,681	318,262	317,099	317,709	320,379	317,681	317,366	317,868	317,153	316,999	317,250	317,243
2013	320,132	318,248	318,757	319,659	317,818	318,801	323,107	318,757	318,248	319,058	317,905	317,656	318,062	318,050
2014	321,149	318,207	319,021	320,434	317,520	319,091	325,973	319,021	318,207	319,502	317,659	317,262	317,910	317,891
2015	321,537	316,971	318,255	320,454	315,887	318,366	329,223	318,255	316,971	319,014	316,106	315,479	316,502	316,472
2016	321,694	314,798	316,759	320,101	313,142	316,928	333,510	316,759	314,798	317,918	313,477	312,520	314,082	314,036
2017	321,710	311,820	314,656	319,481	309,424	314,901	338,886	314,656	311,820	316,333	309,909	308,524	310,783	310,717
2018	321,642	308,132	312,034	313,163	304,836	312,371	345,366	312,034	308,132	314,340	305,503	303,598	306,706	306,615
2019	321,531	303,821	308,970	300,985	299,473	309,413	352,946	308,970	303,821	312,012	300,352	297,839	301,940	301,819
2020	321,422	298,974	305,540	289,421	293,430	306,106	361,619	305,540	298,974	309,420	294,551	291,347	296,576	296,422
2021	321,355	293,546	301,729	279,197	286,636	302,435	368,685	301,729	293,546	306,565	288,034	284,040	290,557	290,365
2022	321,353	287,616	297,604	267,890	279,182	298,464	373,945	297,604	287,616	303,505	280,889	276,014	283,968	283,734
2023	321,422	281,251	293,215	255,658	271,148	294,246	377,152	293,215	281,251	300,284	273,192	267,353	276,881	276,600
2024	321,563	274,511	288,609	242,565	262,606	289,824	376,137	288,609	274,511	296,939	265,014	258,134	269,361	269,030
2025	321,782	267,465	283,839	228,739	253,637	285,250	372,280	283,839	267,465	293,514	256,435	248,443	261,484	261,099
2026	322,065	260,273	279,015	214,499	244,447	280,630	365,113	279,015	260,273	290,089	247,649	238,502	253,428	252,988
2027	322,407	253,366	274,433	200,677	235,576	276,248	359,873	274,433	253,366	286,881	239,175	228,893	245,671	245,176
2028	322,798	247,010	270,273	187,782	227,365	272,277	354,187	270,273	247,010	284,018	231,339	219,986	238,512	237,966
2029	323,233	241,306	266,602	176,021	219,945	268,781	351,039	266,602	241,306	281,548	224,267	211,921	232,067	231,472
2030	323,699	236,264	263,420	165,447	213,332	265,760	346,761	263,420	236,264	279,466	217,971	204,718	226,345	225,707

Table B.21 Upstream CH_4 Emissions (all vehicles)

	Upstream Emissions of CH_4 for the Base Case and for Each PNGV Technology/Fuel Combination (10^3 tonnes)													
	Base Case	CV+RFG	CV+MeOH	CV+EtOH	CV+RFD	CV+DME	CV+HFCV	CV+MFCV	CV+GFC	CV+FTD/RFD	CV+Bio/RFD	CV+LPG	CV+CNG	CV+LNG
2005	1,259	1,237	1,237	1,237	1,237	1,237	1,237	1,237	1,237	1,237	1,237	1,237	1,237	1,237
2006	1,269	1,256	1,256	1,256	1,256	1,256	1,256	1,256	1,256	1,256	1,256	1,256	1,256	1,256
2007	1,279	1,272	1,272	1,272	1,272	1,272	1,272	1,272	1,272	1,272	1,272	1,272	1,272	1,272
2008	1,287	1,283	1,283	1,283	1,283	1,283	1,283	1,283	1,283	1,283	1,283	1,283	1,283	1,283
2009	1,306	1,304	1,304	1,304	1,304	1,304	1,304	1,304	1,304	1,304	1,304	1,304	1,304	1,304
2010	1,322	1,320	1,321	1,320	1,320	1,321	1,321	1,321	1,320	1,320	1,320	1,320	1,322	1,322
2011	1,334	1,331	1,332	1,331	1,331	1,332	1,333	1,332	1,331	1,331	1,330	1,331	1,333	1,333
2012	1,343	1,338	1,340	1,338	1,337	1,340	1,342	1,340	1,338	1,338	1,337	1,338	1,342	1,342
2013	1,349	1,341	1,345	1,343	1,341	1,345	1,348	1,345	1,341	1,342	1,341	1,342	1,349	1,349
2014	1,354	1,341	1,347	1,343	1,340	1,347	1,352	1,347	1,341	1,342	1,340	1,342	1,353	1,353
2015	1,355	1,336	1,345	1,339	1,335	1,344	1,352	1,345	1,336	1,337	1,334	1,338	1,354	1,354
2016	1,356	1,327	1,340	1,331	1,325	1,340	1,352	1,340	1,327	1,328	1,324	1,330	1,355	1,355
2017	1,356	1,315	1,333	1,320	1,311	1,333	1,350	1,333	1,315	1,316	1,310	1,318	1,354	1,355
2018	1,356	1,299	1,325	1,294	1,294	1,324	1,348	1,325	1,299	1,301	1,292	1,304	1,354	1,354
2019	1,356	1,281	1,315	1,252	1,275	1,314	1,346	1,315	1,281	1,284	1,272	1,288	1,353	1,353
2020	1,355	1,261	1,304	1,209	1,253	1,303	1,343	1,304	1,261	1,264	1,250	1,270	1,353	1,353
2021	1,355	1,238	1,291	1,168	1,228	1,291	1,336	1,291	1,238	1,242	1,224	1,249	1,352	1,353
2022	1,355	1,213	1,278	1,122	1,201	1,278	1,324	1,278	1,213	1,218	1,196	1,226	1,353	1,353
2023	1,355	1,186	1,264	1,073	1,172	1,264	1,306	1,264	1,186	1,192	1,166	1,202	1,354	1,355
2024	1,356	1,158	1,250	1,020	1,141	1,249	1,280	1,250	1,158	1,165	1,134	1,177	1,355	1,356
2025	1,357	1,128	1,235	965	1,108	1,234	1,248	1,235	1,128	1,137	1,100	1,150	1,357	1,359
2026	1,358	1,098	1,220	907	1,075	1,219	1,209	1,220	1,098	1,108	1,066	1,123	1,360	1,362
2027	1,360	1,068	1,206	852	1,043	1,205	1,175	1,206	1,068	1,080	1,033	1,097	1,364	1,365
2028	1,362	1,042	1,194	800	1,014	1,192	1,141	1,194	1,042	1,054	1,003	1,074	1,367	1,369
2029	1,363	1,018	1,183	753	988	1,182	1,115	1,183	1,018	1,031	975	1,052	1,372	1,374
2030	1,366	996	1,174	710	964	1,172	1,088	1,174	996	1,011	951	1,034	1,377	1,379

Table B.22 Upstream N_2O Emissions (all vehicles)

	Upstream Emissions of N_2O for the Base Case and for Each PNGV Technology/Fuel Combination (10^3 tonnes)													
	Base Case	CV+RFG	CV+MeOH	CV+EtOH	CV+RFD	CV+DME	CV+HFCV	CV+MFCV	CV+GFC	CV+FTD/RFD	CV+Bio/RFD	CV+LPG	CV+CNG	CV+LNG
2005	33.7	33.1	33.1	33.1	33.1	33.1	33.1	33.1	33.1	33.1	33.1	33.1	33.1	33.1
2006	33.9	33.6	33.6	33.6	33.6	33.6	33.6	33.6	33.6	33.6	33.6	33.6	33.6	33.6
2007	34.2	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0
2008	31.5	31.4	31.4	31.5	31.4	31.4	31.4	31.4	31.4	31.4	31.4	31.4	31.4	31.4
2009	29.2	29.2	29.2	29.4	29.2	29.2	29.2	29.2	29.2	29.2	29.2	29.2	29.2	29.2
2010	27.1	27.0	27.0	27.5	27.0	27.0	27.1	27.0	27.0	27.0	27.0	27.0	27.0	27.1
2011	25.0	24.9	24.9	25.8	24.9	24.9	25.1	24.9	24.9	24.9	24.9	24.9	25.0	25.1
2012	23.0	22.9	22.9	24.3	22.9	22.9	23.2	22.9	22.9	22.9	22.9	22.9	23.0	23.2
2013	21.1	21.1	21.0	23.3	21.0	21.0	21.4	21.0	21.1	21.0	21.1	21.0	21.1	21.5
2014	19.4	19.3	19.2	22.9	19.2	19.2	19.9	19.2	19.3	19.2	19.3	19.2	19.5	20.0
2015	17.8	17.7	17.5	23.3	17.5	17.5	18.6	17.5	17.7	17.5	17.7	17.5	17.9	18.8
2016	16.2	16.2	15.9	24.8	16.0	15.9	17.6	15.9	16.2	15.9	16.2	15.9	16.5	17.9
2017	14.9	14.8	14.4	27.3	14.6	14.4	16.9	14.4	14.8	14.4	14.9	14.4	15.4	17.3
2018	13.6	13.6	13.1	27.9	13.3	13.1	16.5	13.1	13.6	13.1	13.7	13.0	14.4	17.1
2019	12.4	12.6	11.9	26.2	12.1	11.9	16.3	11.9	12.6	11.9	12.7	11.8	13.6	17.1
2020	11.4	11.7	10.8	25.9	11.1	10.8	16.5	10.8	11.7	10.8	11.8	10.7	12.9	17.5
2021	10.4	11.0	9.9	27.3	10.2	9.8	16.9	9.9	11.0	9.8	11.1	9.7	12.5	18.2
2022	9.5	10.4	9.0	29.1	9.4	9.0	17.6	9.0	10.4	9.0	10.5	8.8	12.2	19.2
2023	8.7	9.9	8.3	31.3	8.8	8.3	18.4	8.3	9.9	8.2	10.1	8.0	12.1	20.5
2024	8.0	9.6	7.7	33.8	8.2	7.6	19.5	7.7	9.6	7.6	9.8	7.3	12.2	22.0
2025	7.3	9.4	7.2	36.6	7.8	7.1	20.8	7.2	9.4	7.1	9.6	6.7	12.4	23.8
2026	6.7	9.3	6.7	39.7	7.5	6.7	22.2	6.7	9.3	6.6	9.5	6.3	12.8	25.8
2027	6.1	9.3	6.4	42.7	7.2	6.3	23.7	6.4	9.3	6.3	9.5	5.9	13.2	27.8
2028	5.6	9.3	6.1	45.7	7.0	6.1	25.1	6.1	9.3	6.0	9.6	5.5	13.6	29.8
2029	5.1	9.4	5.9	48.5	6.9	5.8	26.5	5.9	9.4	5.8	9.6	5.3	14.1	31.7
2030	4.7	9.5	5.8	51.0	6.8	5.7	27.7	5.8	9.5	5.6	9.8	5.1	14.5	33.4

Table B.23 Total Energy Use by All Vehicles

	Total Energy Use for the Base Case and for Each PNGV Technology/Fuel Combination (quads)													
	Base Case	CV+RFG	CV+MeOH	CV+EtOH	CV+RFD	CV+DME	CV+HFCV	CV+MFCV	CV+GFC	CV+FTD/RFD	CV+Bio/RFD	CV+LPG	CV+CNG	CV+LNG
2005	18.3	17.9	17.9	17.9	17.9	17.9	17.9	17.9	17.9	17.9	17.9	17.9	17.9	17.9
2006	18.4	18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2
2007	18.6	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4
2008	18.7	18.6	18.6	18.6	18.6	18.6	18.6	18.6	18.6	18.6	18.6	18.6	18.6	18.6
2009	18.9	18.9	18.9	18.9	18.9	18.9	18.9	18.9	18.9	18.9	18.9	18.9	18.9	18.9
2010	19.2	19.1	19.1	19.1	19.1	19.1	19.2	19.1	19.1	19.1	19.1	19.1	19.1	19.1
2011	19.3	19.3	19.3	19.3	19.3	19.3	19.3	19.3	19.3	19.3	19.3	19.3	19.3	19.3
2012	19.5	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4
2013	19.6	19.4	19.5	19.5	19.4	19.5	19.5	19.5	19.4	19.5	19.4	19.4	19.4	19.4
2014	19.6	19.4	19.5	19.5	19.4	19.5	19.5	19.5	19.4	19.5	19.4	19.4	19.4	19.4
2015	19.6	19.4	19.4	19.4	19.3	19.4	19.5	19.4	19.4	19.4	19.4	19.3	19.4	19.4
2016	19.6	19.2	19.3	19.3	19.2	19.3	19.4	19.3	19.2	19.3	19.2	19.2	19.2	19.2
2017	19.6	19.0	19.1	19.1	19.0	19.1	19.2	19.1	19.0	19.1	19.0	19.0	19.0	19.1
2018	19.6	18.8	19.0	19.0	18.8	18.9	19.1	19.0	18.8	18.9	18.8	18.8	18.8	18.8
2019	19.6	18.6	18.7	18.8	18.5	18.7	18.9	18.7	18.6	18.7	18.5	18.5	18.5	18.6
2020	19.6	18.3	18.5	18.6	18.2	18.5	18.7	18.5	18.3	18.4	18.2	18.1	18.2	18.3
2021	19.6	17.9	18.2	18.4	17.8	18.2	18.5	18.2	17.9	18.1	17.9	17.8	17.9	17.9
2022	19.6	17.6	17.9	18.1	17.4	17.9	18.2	17.9	17.6	17.8	17.5	17.4	17.5	17.6
2023	19.6	17.2	17.5	17.9	17.0	17.5	17.9	17.5	17.2	17.4	17.1	17.0	17.1	17.2
2024	19.6	16.8	17.2	17.6	16.6	17.2	17.5	17.2	16.8	17.1	16.6	16.5	16.7	16.8
2025	19.6	16.3	16.8	17.3	16.1	16.8	17.1	16.8	16.3	16.7	16.2	16.0	16.3	16.4
2026	19.7	15.9	16.4	17.0	15.6	16.4	16.7	16.4	15.9	16.3	15.7	15.6	15.8	15.9
2027	19.7	15.5	16.1	16.7	15.2	16.1	16.3	16.1	15.5	15.9	15.3	15.1	15.4	15.5
2028	19.7	15.1	15.7	16.5	14.8	15.7	15.9	15.7	15.1	15.6	14.9	14.7	15.0	15.1
2029	19.7	14.7	15.4	16.3	14.4	15.4	15.6	15.4	14.7	15.3	14.5	14.3	14.6	14.8
2030	19.7	14.4	15.2	16.1	14.1	15.2	15.3	15.2	14.4	15.0	14.2	14.0	14.3	14.5

Table B.24 Total Fossil Energy Use by All Vehicles

	Total Fossil Energy Use for the Base Case and for Each PNGV Technology/Fuel Combination (quads)													
	Base Case	CV+RFG	CV+MeOH	CV+EtOH	CV+RFD	CV+DME	CV+HFCV	CV+MFCV	CV+GFC	CV+FTD/RFD	CV+Bio/RFD	CV+LPG	CV+CNG	CV+LNG
2005	18.1	17.8	17.8	17.8	17.8	17.8	17.8	17.8	17.8	17.8	17.8	17.8	17.8	17.8
2006	18.2	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0
2007	18.4	18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2	18.2
2008	18.5	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4	18.4
2009	18.7	18.7	18.7	18.7	18.7	18.7	18.7	18.7	18.7	18.7	18.7	18.7	18.7	18.7
2010	19.0	18.9	18.9	18.9	18.9	18.9	18.9	18.9	18.9	18.9	18.9	18.9	18.9	18.9
2011	19.1	19.1	19.1	19.1	19.1	19.1	19.1	19.1	19.1	19.1	19.1	19.1	19.1	19.1
2012	19.3	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2
2013	19.4	19.2	19.3	19.2	19.2	19.3	19.3	19.3	19.2	19.3	19.2	19.2	19.2	19.2
2014	19.4	19.2	19.3	19.2	19.2	19.3	19.3	19.3	19.2	19.3	19.2	19.2	19.2	19.2
2015	19.4	19.2	19.2	19.1	19.2	19.2	19.2	19.2	19.2	19.2	19.1	19.1	19.2	19.2
2016	19.5	19.0	19.1	18.9	19.0	19.1	19.2	19.1	19.0	19.1	19.0	19.0	19.0	19.0
2017	19.5	18.9	19.0	18.6	18.8	19.0	19.0	19.0	18.9	18.9	18.8	18.8	18.8	18.9
2018	19.5	18.6	18.8	18.3	18.6	18.8	18.9	18.8	18.6	18.7	18.6	18.6	18.6	18.6
2019	19.4	18.4	18.6	17.8	18.3	18.6	18.7	18.6	18.4	18.5	18.3	18.3	18.3	18.4
2020	19.4	18.1	18.3	17.3	18.0	18.3	18.5	18.3	18.1	18.2	17.9	18.0	18.0	18.1
2021	19.4	17.8	18.0	16.7	17.7	18.0	18.1	18.0	17.8	18.0	17.6	17.6	17.7	17.8
2022	19.4	17.4	17.7	16.1	17.3	17.7	17.5	17.7	17.4	17.6	17.2	17.2	17.3	17.4
2023	19.4	17.0	17.4	15.4	16.9	17.4	16.9	17.4	17.0	17.3	16.8	16.8	16.9	17.1
2024	19.5	16.6	17.1	14.7	16.4	17.0	16.1	17.1	16.6	16.9	16.3	16.4	16.5	16.6
2025	19.5	16.2	16.7	13.9	16.0	16.7	15.1	16.7	16.2	16.6	15.8	15.9	16.1	16.2
2026	19.5	15.7	16.3	13.2	15.5	16.3	14.4	16.3	15.7	16.2	15.3	15.4	15.6	15.8
2027	19.5	15.3	16.0	12.4	15.1	16.0	13.8	16.0	15.3	15.8	14.9	15.0	15.2	15.4
2028	19.5	14.9	15.6	11.7	14.7	15.6	13.1	15.6	14.9	15.5	14.4	14.6	14.8	15.0
2029	19.6	14.6	15.3	11.1	14.3	15.3	12.6	15.3	14.6	15.2	14.0	14.2	14.4	14.7
2030	19.6	14.3	15.1	10.5	14.0	15.1	12.1	15.1	14.3	14.9	13.7	13.9	14.1	14.4

Table B.25 Total Petroleum Use by All Vehicles

	Total Petroleum Use for the Base Case and for Each PNGV Technology/Fuel Combination (quads)													
	Base Case	CV+RFG	CV+MeOH	CV+EtOH	CV+RFD	CV+DME	CV+HFCV	CV+MFCV	CV+GFC	CV+FTD/RFD	CV+Bio/RFD	CV+LPG	CV+CNG	CV+LNG
2005	16.0	15.7	15.7	15.7	15.7	15.7	15.7	15.7	15.7	15.7	15.7	15.7	15.7	15.7
2006	16.1	15.9	15.9	15.9	15.9	15.9	15.9	15.9	15.9	15.9	15.9	15.9	15.9	15.9
2007	16.2	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1
2008	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3	16.3
2009	16.6	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5
2010	16.8	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7
2011	16.9	16.9	16.8	16.8	16.9	16.8	16.8	16.8	16.9	16.9	16.9	16.9	16.8	16.8
2012	17.0	17.0	16.9	16.9	17.0	16.9	16.9	16.9	17.0	16.9	17.0	16.9	16.9	16.9
2013	17.1	17.0	16.9	16.9	17.0	16.9	16.9	16.9	17.0	17.0	17.0	17.0	16.9	16.9
2014	17.2	17.0	16.9	16.9	17.0	16.9	16.9	16.9	17.0	17.0	17.0	16.9	16.9	16.9
2015	17.2	16.9	16.8	16.8	16.9	16.8	16.8	16.8	16.9	16.9	16.9	16.8	16.8	16.8
2016	17.2	16.8	16.6	16.6	16.8	16.6	16.6	16.6	16.8	16.7	16.8	16.7	16.6	16.6
2017	17.2	16.7	16.3	16.3	16.6	16.3	16.3	16.3	16.7	16.5	16.6	16.4	16.3	16.3
2018	17.2	16.5	16.0	16.0	16.4	16.0	16.0	16.0	16.5	16.2	16.4	16.2	16.0	16.0
2019	17.2	16.2	15.6	15.7	16.2	15.6	15.6	15.6	16.2	15.9	16.1	15.8	15.6	15.6
2020	17.2	16.0	15.2	15.2	15.9	15.2	15.2	15.2	16.0	15.6	15.9	15.5	15.2	15.2
2021	17.2	15.7	14.7	14.8	15.6	14.7	14.7	14.7	15.7	15.2	15.5	15.1	14.7	14.7
2022	17.2	15.4	14.2	14.3	15.3	14.2	14.2	14.2	15.4	14.8	15.2	14.6	14.2	14.2
2023	17.2	15.0	13.6	13.7	15.0	13.6	13.6	13.6	15.0	14.3	14.8	14.1	13.6	13.7
2024	17.2	14.7	13.0	13.1	14.6	13.0	13.0	13.0	14.7	13.9	14.4	13.6	13.0	13.1
2025	17.2	14.3	12.4	12.5	14.2	12.4	12.3	12.4	14.3	13.4	14.0	13.1	12.3	12.4
2026	17.2	13.9	11.7	11.8	13.8	11.7	11.7	11.7	13.9	12.8	13.6	12.5	11.6	11.8
2027	17.2	13.5	11.1	11.2	13.4	11.1	11.0	11.1	13.5	12.3	13.1	12.0	11.0	11.1
2028	17.2	13.2	10.5	10.6	13.1	10.5	10.4	10.5	13.2	11.9	12.8	11.4	10.4	10.5
2029	17.3	12.9	9.9	10.1	12.7	9.9	9.8	9.9	12.9	11.4	12.4	11.0	9.8	10.0
2030	17.3	12.6	9.4	9.6	12.5	9.4	9.4	9.4	12.6	11.1	12.1	10.6	9.4	9.5

Table B.26 Total NO_x Emissions (urban locations)

	Total Emissions of NO_x for the Base Case and for Each PNGV Technology/Fuel Combination (10^3 tonnes)													
	Base Case	CV+RFG	CV+MeOH	CV+EtOH	CV+RFD	CV+DME	CV+HFCV	CV+MFCV	CV+GFC	CV+FTD/RFD	CV+Bio/RFD	CV+LPG	CV+CNG	CV+LNG
2005	1,742	1,646	1,646	1,646	1,646	1,646	1,646	1,646	1,646	1,646	1,646	1,646	1,646	1,646
2006	1,714	1,656	1,656	1,656	1,656	1,656	1,656	1,656	1,656	1,656	1,656	1,656	1,656	1,656
2007	1,681	1,648	1,648	1,648	1,648	1,648	1,648	1,648	1,648	1,648	1,648	1,648	1,648	1,648
2008	1,631	1,615	1,615	1,615	1,615	1,615	1,615	1,615	1,615	1,615	1,615	1,615	1,615	1,615
2009	1,605	1,599	1,599	1,599	1,599	1,599	1,599	1,599	1,599	1,599	1,599	1,599	1,599	1,599
2010	1,569	1,569	1,569	1,569	1,569	1,569	1,568	1,568	1,568	1,569	1,569	1,569	1,569	1,569
2011	1,525	1,525	1,525	1,525	1,525	1,525	1,524	1,524	1,524	1,525	1,525	1,525	1,525	1,525
2012	1,477	1,476	1,476	1,477	1,476	1,476	1,475	1,474	1,474	1,476	1,476	1,476	1,476	1,476
2013	1,423	1,423	1,423	1,423	1,423	1,423	1,420	1,420	1,420	1,423	1,423	1,423	1,423	1,423
2014	1,373	1,373	1,373	1,373	1,373	1,373	1,368	1,367	1,367	1,373	1,373	1,373	1,373	1,373
2015	1,328	1,328	1,328	1,329	1,328	1,328	1,320	1,319	1,319	1,328	1,328	1,328	1,328	1,328
2016	1,291	1,290	1,290	1,291	1,290	1,290	1,279	1,276	1,276	1,290	1,290	1,290	1,290	1,291
2017	1,262	1,261	1,261	1,263	1,261	1,261	1,243	1,239	1,239	1,261	1,261	1,261	1,261	1,262
2018	1,241	1,240	1,239	1,242	1,240	1,239	1,213	1,208	1,208	1,239	1,240	1,240	1,240	1,240
2019	1,227	1,225	1,224	1,227	1,225	1,224	1,187	1,180	1,180	1,224	1,225	1,225	1,225	1,226
2020	1,218	1,216	1,215	1,219	1,216	1,215	1,164	1,155	1,155	1,215	1,216	1,216	1,216	1,217
2021	1,214	1,211	1,210	1,215	1,211	1,210	1,142	1,130	1,131	1,210	1,211	1,211	1,212	1,213
2022	1,213	1,209	1,209	1,214	1,209	1,208	1,118	1,104	1,105	1,209	1,209	1,210	1,211	1,211
2023	1,214	1,210	1,209	1,215	1,210	1,209	1,093	1,076	1,077	1,209	1,210	1,210	1,211	1,212
2024	1,220	1,215	1,214	1,220	1,214	1,213	1,068	1,049	1,049	1,214	1,215	1,215	1,216	1,217
2025	1,225	1,219	1,218	1,226	1,219	1,218	1,039	1,016	1,018	1,218	1,219	1,219	1,221	1,222
2026	1,230	1,223	1,222	1,231	1,223	1,222	1,007	981	982	1,222	1,224	1,224	1,226	1,227
2027	1,235	1,228	1,226	1,236	1,227	1,226	971	942	943	1,226	1,228	1,228	1,230	1,232
2028	1,240	1,232	1,231	1,242	1,232	1,230	934	901	903	1,231	1,232	1,233	1,235	1,237
2029	1,246	1,237	1,235	1,247	1,236	1,235	895	860	862	1,235	1,237	1,237	1,240	1,242
2030	1,251	1,242	1,240	1,253	1,241	1,239	856	818	820	1,240	1,242	1,242	1,245	1,247

Table B.27 Total CO Emissions (urban locations)

	Total Emissions of CO for the Base Case and for Each PNGV Technology/Fuel Combination (10^3 tonnes)													
	Base Case	CV+RFG	CV+MeOH	CV+EtOH	CV+RFD	CV+DME	CV+HFCV	CV+MFCV	CV+GFC	CV+FTD/RFD	CV+Bio/RFD	CV+LPG	CV+CNG	CV+LNG
2005	26,683	25,113	25,113	25,113	25,113	25,113	25,113	25,113	25,113	25,113	25,113	25,113	25,113	25,113
2006	26,294	25,341	25,341	25,341	25,341	25,341	25,341	25,341	25,341	25,341	25,341	25,341	25,341	25,341
2007	25,818	25,286	25,286	25,286	25,285	25,285	25,285	25,285	25,285	25,285	25,285	25,286	25,286	25,286
2008	25,070	24,808	24,808	24,808	24,808	24,808	24,807	24,807	24,807	24,808	24,808	24,808	24,808	24,808
2009	24,684	24,586	24,586	24,586	24,585	24,585	24,583	24,583	24,583	24,585	24,585	24,586	24,586	24,586
2010	24,121	24,121	24,121	24,121	24,117	24,117	24,113	24,113	24,113	24,117	24,117	24,121	24,121	24,121
2011	23,429	23,429	23,429	23,429	23,422	23,422	23,414	23,414	23,414	23,422	23,422	23,429	23,429	23,429
2012	22,661	22,661	22,661	22,661	22,646	22,646	22,634	22,634	22,634	22,646	22,646	22,661	22,661	22,661
2013	21,810	21,809	21,809	21,810	21,783	21,783	21,763	21,763	21,763	21,783	21,783	21,809	21,809	21,810
2014	20,999	20,999	20,999	20,999	20,954	20,954	20,920	20,921	20,921	20,954	20,954	20,999	20,999	20,999
2015	20,277	20,277	20,277	20,277	20,201	20,201	20,149	20,149	20,149	20,201	20,201	20,277	20,277	20,277
2016	19,673	19,673	19,673	19,673	19,550	19,550	19,469	19,470	19,470	19,550	19,550	19,673	19,673	19,673
2017	19,203	19,202	19,202	19,203	19,010	19,010	18,893	18,895	18,895	19,010	19,010	19,202	19,202	19,203
2018	18,858	18,857	18,857	18,858	18,566	18,566	18,404	18,407	18,407	18,566	18,567	18,857	18,857	18,858
2019	18,620	18,619	18,619	18,620	18,194	18,194	17,979	17,983	17,983	18,194	18,195	18,619	18,619	18,620
2020	18,469	18,468	18,467	18,469	17,866	17,865	17,589	17,594	17,594	17,865	17,866	18,468	18,468	18,469
2021	18,389	18,387	18,386	18,388	17,556	17,556	17,208	17,216	17,216	17,556	17,557	18,387	18,387	18,389
2022	18,365	18,363	18,363	18,365	17,249	17,249	16,821	16,831	16,831	17,249	17,250	18,363	18,363	18,366
2023	18,380	18,377	18,377	18,379	16,923	16,922	16,406	16,419	16,419	16,922	16,923	18,378	18,377	18,381
2024	18,465	18,462	18,461	18,464	16,607	16,607	15,994	16,011	16,012	16,607	16,608	18,462	18,461	18,465
2025	18,547	18,543	18,542	18,545	16,232	16,231	15,516	15,537	15,538	16,232	16,233	18,543	18,543	18,547
2026	18,627	18,623	18,622	18,626	15,802	15,801	14,977	15,003	15,003	15,801	15,803	18,624	18,623	18,628
2027	18,708	18,703	18,703	18,707	15,324	15,323	14,390	14,422	14,422	15,323	15,325	18,704	18,703	18,709
2028	18,790	18,784	18,784	18,788	14,807	14,806	13,770	13,807	13,808	14,807	14,809	18,785	18,784	18,791
2029	18,873	18,867	18,866	18,871	14,265	14,264	13,128	13,172	13,172	14,264	14,266	18,868	18,867	18,874
2030	18,957	18,951	18,951	18,956	13,709	13,708	12,480	12,529	12,530	13,708	13,710	18,953	18,951	18,959

Table B.28 Total VOC Emissions (urban locations)

	Total Emissions of VOC for the Base Case and for Each PNGV Technology/Fuel Combination (10^3 tonnes)													
	Base Case	CV+RFG	CV+MeOH	CV+EtOH	CV+RFD	CV+DME	CV+HFCV	CV+MFCV	CV+GFC	CV+FTD/RFD	CV+Bio/RFD	CV+LPG	CV+CNG	CV+LNG
2005	1,242	1,158	1,158	1,158	1,158	1,158	1,158	1,158	1,158	1,158	1,158	1,158	1,158	1,158
2006	1,241	1,195	1,195	1,195	1,195	1,195	1,195	1,195	1,195	1,195	1,195	1,195	1,195	1,195
2007	1,249	1,227	1,227	1,227	1,227	1,227	1,227	1,227	1,227	1,227	1,227	1,227	1,227	1,227
2008	1,261	1,253	1,253	1,253	1,253	1,253	1,253	1,253	1,253	1,253	1,253	1,253	1,253	1,253
2009	1,302	1,299	1,299	1,299	1,298	1,298	1,298	1,298	1,298	1,298	1,298	1,298	1,298	1,298
2010	1,340	1,340	1,340	1,340	1,340	1,340	1,339	1,339	1,339	1,340	1,340	1,339	1,339	1,340
2011	1,376	1,376	1,376	1,376	1,375	1,375	1,374	1,374	1,374	1,375	1,375	1,375	1,375	1,375
2012	1,409	1,408	1,408	1,408	1,406	1,406	1,404	1,405	1,405	1,406	1,406	1,406	1,406	1,406
2013	1,438	1,437	1,437	1,437	1,434	1,434	1,431	1,432	1,433	1,434	1,434	1,434	1,434	1,434
2014	1,463	1,463	1,462	1,462	1,458	1,458	1,452	1,453	1,455	1,458	1,458	1,457	1,457	1,457
2015	1,485	1,484	1,483	1,483	1,476	1,476	1,467	1,469	1,471	1,476	1,476	1,475	1,475	1,475
2016	1,503	1,501	1,501	1,501	1,489	1,489	1,475	1,478	1,482	1,489	1,489	1,488	1,487	1,488
2017	1,518	1,515	1,515	1,515	1,498	1,498	1,477	1,481	1,488	1,498	1,498	1,496	1,495	1,497
2018	1,530	1,527	1,527	1,527	1,503	1,502	1,474	1,479	1,488	1,502	1,503	1,500	1,499	1,501
2019	1,541	1,537	1,536	1,537	1,503	1,503	1,464	1,472	1,484	1,503	1,503	1,500	1,499	1,501
2020	1,550	1,545	1,544	1,544	1,500	1,500	1,449	1,459	1,474	1,500	1,500	1,496	1,495	1,497
2021	1,558	1,552	1,550	1,551	1,493	1,493	1,427	1,440	1,460	1,492	1,493	1,488	1,486	1,490
2022	1,565	1,558	1,556	1,556	1,482	1,481	1,399	1,416	1,441	1,481	1,482	1,477	1,475	1,479
2023	1,572	1,563	1,560	1,561	1,467	1,466	1,365	1,386	1,417	1,466	1,467	1,463	1,460	1,464
2024	1,578	1,567	1,565	1,565	1,448	1,448	1,325	1,351	1,389	1,447	1,448	1,445	1,441	1,447
2025	1,584	1,572	1,569	1,569	1,426	1,426	1,280	1,311	1,357	1,425	1,426	1,424	1,420	1,427
2026	1,590	1,576	1,572	1,573	1,401	1,401	1,231	1,268	1,322	1,400	1,402	1,402	1,397	1,404
2027	1,596	1,580	1,576	1,577	1,375	1,375	1,179	1,222	1,285	1,373	1,375	1,378	1,373	1,381
2028	1,602	1,585	1,580	1,581	1,348	1,347	1,127	1,175	1,247	1,346	1,348	1,353	1,348	1,357
2029	1,608	1,589	1,585	1,586	1,320	1,319	1,074	1,128	1,209	1,318	1,320	1,329	1,323	1,333
2030	1,615	1,594	1,589	1,590	1,291	1,291	1,022	1,082	1,172	1,289	1,292	1,306	1,299	1,309

Table B.29 Total SO_X Emissions (urban locations)

	Total Emissions of SO_x for the Base Case and for Each PNGV Technology/Fuel Combination (10^3 tonnes)													
	Base Case	CV+RFG	CV+MeOH	CV+EtOH	CV+RFD	CV+DME	CV+HFCV	CV+MFCV	CV+GFC	CV+FTD/RFD	CV+Bio/RFD	CV+LPG	CV+CNG	CV+LNG
2005	46	45	45	45	45	45	45	45	45	45	45	45	45	45
2006	46	46	46	46	46	46	46	46	46	46	46	46	46	46
2007	46	46	46	46	46	46	46	46	46	46	46	46	46	46
2008	47	47	47	47	47	46	46	47	47	47	47	46	46	47
2009	47	47	47	47	47	47	47	47	47	47	47	47	47	47
2010	48	48	48	48	48	48	48	48	48	48	48	48	48	48
2011	48	48	48	48	48	48	48	48	48	48	48	48	48	48
2012	49	48	48	48	48	48	48	48	48	48	48	48	48	48
2013	49	49	48	48	49	48	48	48	49	49	49	48	48	49
2014	49	49	48	48	49	48	48	48	49	48	49	48	48	49
2015	49	48	48	48	48	48	48	48	48	48	48	48	48	48
2016	49	48	48	47	48	47	47	48	48	48	48	47	47	48
2017	49	48	47	47	48	47	47	47	48	47	47	47	47	48
2018	49	47	46	46	47	46	46	46	47	46	47	46	46	47
2019	49	46	45	45	46	45	45	45	46	46	46	45	45	47
2020	49	46	44	44	46	44	44	44	46	45	45	44	44	46
2021	49	45	43	42	45	42	42	43	45	44	44	42	42	45
2022	49	44	42	41	44	41	41	42	44	43	43	41	41	45
2023	49	43	40	39	43	40	39	40	43	41	42	39	39	44
2024	49	42	39	38	42	38	37	39	42	40	41	37	37	43
2025	49	41	37	36	41	36	36	37	41	39	40	36	36	42
2026	49	40	36	34	40	34	34	36	40	37	39	34	34	41
2027	49	39	34	32	39	33	32	34	39	36	38	32	32	40
2028	49	38	33	31	38	31	30	33	38	35	37	30	30	39
2029	49	37	31	29	37	30	29	31	37	34	36	29	29	39
2030	49	36	30	28	36	28	27	30	36	33	35	27	28	38

Table B.30 Total PM_{10} Emissions (urban locations)

	Total Emissions of PM_{10} for the Base Case and for Each PNGV Technology/Fuel Combination (10^3 tonnes)													
	Base Case	CV+RFG	CV+MeOH	CV+EtOH	CV+RFD	CV+DME	CV+HFCV	CV+MFCV	CV+GFC	CV+FTD/RFD	CV+Bio/RFD	CV+LPG	CV+CNG	CV+LNG
2005	54	53	53	53	53	53	53	53	53	53	53	53	53	53
2006	54	54	54	54	54	54	54	54	54	54	54	54	54	54
2007	55	55	55	55	55	55	55	55	55	55	55	55	55	55
2008	56	56	56	56	56	56	56	56	56	56	56	56	56	56
2009	57	57	57	57	57	57	57	57	57	57	57	57	57	57
2010	58	58	58	58	58	58	58	58	58	58	58	58	58	58
2011	59	59	59	59	59	59	59	59	59	59	59	59	59	59
2012	60	60	60	60	60	60	60	60	60	60	60	60	60	60
2013	60	60	60	60	61	60	60	60	60	61	61	60	60	60
2014	61	61	61	61	62	61	61	61	61	62	62	61	61	61
2015	61	61	61	61	63	61	61	61	61	63	63	61	61	61
2016	62	62	61	61	64	62	61	61	61	64	64	61	61	62
2017	62	62	61	61	65	62	61	61	61	65	65	61	61	62
2018	63	63	61	61	66	62	61	61	61	66	66	61	61	62
2019	63	63	61	61	67	63	61	61	61	67	67	61	61	63
2020	63	63	61	61	69	63	60	60	60	69	69	60	60	63
2021	63	63	60	60	70	63	60	60	60	70	70	60	60	63
2022	64	63	60	60	72	63	59	59	59	72	72	59	59	63
2023	64	64	59	59	74	64	59	59	59	74	74	59	59	64
2024	64	64	58	59	76	64	58	58	58	76	76	58	58	64
2025	64	64	58	58	78	64	57	57	57	78	78	57	57	64
2026	65	64	57	58	80	64	57	56	56	80	80	57	56	64
2027	65	64	56	57	82	64	56	56	56	82	82	56	56	64
2028	65	64	56	57	84	64	55	55	55	84	84	55	55	64
2029	65	65	55	56	86	65	55	54	54	86	86	54	54	65
2030	65	65	55	56	88	65	54	54	54	88	88	54	54	65

Table B.31 Total CO_2 Emissions (all vehicles, all locations)

	Total Emissions of CO_2 for the Base Case and for Each PNGV Technology/Fuel Combination (10^3 tonnes)													
	Base Case	CV+RFG	CV+MeOH	CV+EtOH	CV+RFD	CV+DME	CV+HFCV	CV+MFCV	CV+GFC	CV+FTD/RFD	CV+Bio/RFD	CV+LPG	CV+CNG	CV+LNG
2005	1,338,923	1,316,140	1,316,140	1,316,140	1,316,140	1,316,140	1,316,140	1,316,140	1,316,140	1,316,140	1,316,140	1,316,140	1,316,140	1,316,140
2006	1,349,744	1,336,052	1,336,052	1,336,052	1,336,052	1,336,052	1,336,052	1,336,052	1,336,052	1,336,052	1,336,052	1,336,052	1,336,052	1,336,052
2007	1,360,630	1,352,778	1,352,782	1,352,750	1,352,777	1,352,782	1,352,787	1,352,782	1,352,778	1,352,789	1,352,778	1,352,770	1,352,767	1,352,767
2008	1,369,116	1,364,664	1,364,682	1,364,557	1,364,661	1,364,681	1,364,700	1,364,682	1,364,664	1,364,710	1,364,664	1,364,633	1,364,623	1,364,621
2009	1,389,666	1,386,911	1,386,954	1,386,646	1,386,902	1,386,951	1,386,998	1,386,954	1,386,911	1,387,024	1,386,910	1,386,834	1,386,809	1,386,804
2010	1,406,511	1,404,190	1,404,277	1,403,665	1,404,173	1,404,271	1,404,365	1,404,277	1,404,190	1,404,415	1,404,190	1,404,039	1,403,989	1,403,980
2011	1,419,047	1,415,519	1,415,673	1,414,577	1,415,488	1,415,663	1,415,830	1,415,673	1,415,519	1,415,921	1,415,518	1,415,247	1,415,159	1,415,142
2012	1,428,217	1,422,793	1,423,050	1,421,193	1,422,742	1,423,033	1,423,310	1,423,050	1,422,793	1,423,461	1,422,792	1,422,344	1,422,197	1,422,168
2013	1,435,211	1,426,761	1,427,175	1,424,146	1,426,679	1,427,148	1,427,595	1,427,175	1,426,761	1,427,838	1,426,759	1,426,036	1,425,800	1,425,753
2014	1,439,780	1,426,592	1,427,253	1,422,385	1,426,461	1,427,210	1,427,924	1,427,253	1,426,592	1,428,313	1,426,589	1,425,434	1,425,056	1,424,981
2015	1,441,537	1,421,064	1,422,107	1,414,396	1,420,857	1,422,039	1,423,165	1,422,107	1,421,064	1,423,780	1,421,060	1,419,237	1,418,640	1,418,523
2016	1,442,253	1,411,335	1,412,927	1,401,135	1,411,018	1,412,823	1,414,543	1,412,927	1,411,335	1,415,482	1,411,327	1,408,544	1,407,633	1,407,454
2017	1,442,340	1,397,993	1,400,296	1,383,230	1,397,535	1,400,146	1,402,635	1,400,296	1,397,993	1,403,992	1,397,983	1,393,956	1,392,638	1,392,379
2018	1,442,047	1,381,472	1,384,639	1,355,653	1,380,841	1,384,433	1,387,856	1,384,639	1,381,472	1,389,723	1,381,457	1,375,918	1,374,105	1,373,749
2019	1,441,566	1,362,154	1,366,333	1,318,616	1,361,323	1,366,062	1,370,578	1,366,333	1,362,154	1,373,041	1,362,134	1,354,826	1,352,434	1,351,964
2020	1,441,089	1,340,436	1,345,765	1,278,980	1,339,375	1,345,419	1,351,178	1,345,765	1,340,436	1,354,318	1,340,411	1,331,092	1,328,041	1,327,442
2021	1,440,803	1,316,110	1,322,751	1,237,073	1,314,788	1,322,320	1,326,561	1,322,751	1,316,110	1,333,411	1,316,078	1,304,464	1,300,662	1,299,915
2022	1,440,807	1,289,531	1,297,637	1,190,856	1,287,918	1,297,110	1,296,911	1,297,637	1,289,531	1,310,647	1,289,493	1,275,318	1,270,677	1,269,766
2023	1,441,132	1,260,999	1,270,709	1,140,833	1,259,067	1,270,078	1,262,327	1,270,709	1,260,999	1,286,295	1,260,953	1,243,973	1,238,414	1,237,323
2024	1,441,777	1,230,788	1,242,230	1,087,398	1,228,510	1,241,486	1,220,971	1,242,230	1,230,788	1,260,595	1,230,734	1,210,724	1,204,174	1,202,888
2025	1,442,770	1,199,201	1,212,490	1,031,039	1,196,556	1,211,627	1,174,579	1,212,490	1,199,201	1,233,821	1,199,138	1,175,897	1,168,290	1,166,796
2026	1,444,053	1,166,963	1,182,174	973,038	1,163,935	1,181,185	1,123,651	1,182,174	1,166,963	1,206,589	1,166,891	1,140,290	1,131,583	1,129,873
2027	1,445,600	1,135,995	1,153,093	916,774	1,132,592	1,151,982	1,075,971	1,153,093	1,135,995	1,180,537	1,135,915	1,106,014	1,096,226	1,094,304
2028	1,447,369	1,107,499	1,126,380	864,379	1,103,742	1,125,153	1,030,783	1,126,380	1,107,499	1,156,685	1,107,410	1,074,392	1,063,584	1,061,462
2029	1,449,331	1,081,929	1,102,459	816,685	1,077,843	1,101,125	991,704	1,102,459	1,081,929	1,135,412	1,081,832	1,045,929	1,034,177	1,031,869
2030	1,451,435	1,059,325	1,081,365	773,841	1,054,939	1,079,933	955,155	1,081,365	1,059,325	1,116,742	1,059,221	1,020,677	1,008,061	1,005,583

Table B.32 Total CH_4 Emissions (all vehicles, all locations)

	Total Emissions of CH_4 for the Base Case and for Each PNGV Technology/Fuel Combination (10^3 tonnes)													
	Base Case	CV+RFG	CV+MeOH	CV+EtOH	CV+RFD	CV+DME	CV+HFCV	CV+MFCV	CV+GFC	CV+FTD/RFD	CV+Bio/RFD	CV+LPG	CV+CNG	CV+LNG
2005	1,376	1,352	1,352	1,352	1,352	1,352	1,352	1,352	1,352	1,352	1,352	1,352	1,352	1,352
2006	1,388	1,374	1,374	1,374	1,374	1,374	1,374	1,374	1,374	1,374	1,374	1,374	1,374	1,374
2007	1,400	1,392	1,392	1,392	1,392	1,392	1,392	1,392	1,392	1,392	1,392	1,392	1,392	1,392
2008	1,409	1,405	1,405	1,405	1,405	1,405	1,405	1,405	1,405	1,405	1,405	1,405	1,406	1,406
2009	1,432	1,429	1,429	1,429	1,429	1,429	1,429	1,429	1,429	1,429	1,429	1,429	1,431	1,431
2010	1,450	1,448	1,449	1,448	1,448	1,448	1,449	1,448	1,448	1,448	1,448	1,448	1,452	1,452
2011	1,464	1,461	1,462	1,461	1,460	1,462	1,463	1,462	1,461	1,461	1,460	1,461	1,468	1,468
2012	1,475	1,470	1,472	1,471	1,469	1,471	1,473	1,471	1,469	1,470	1,469	1,470	1,482	1,482
2013	1,484	1,476	1,479	1,476	1,474	1,478	1,481	1,478	1,475	1,475	1,474	1,476	1,494	1,494
2014	1,490	1,477	1,482	1,478	1,475	1,481	1,486	1,481	1,475	1,476	1,474	1,479	1,507	1,507
2015	1,493	1,474	1,481	1,475	1,469	1,479	1,487	1,479	1,471	1,472	1,469	1,476	1,521	1,521
2016	1,495	1,466	1,477	1,468	1,459	1,474	1,486	1,474	1,461	1,463	1,458	1,469	1,538	1,538
2017	1,496	1,455	1,471	1,458	1,445	1,467	1,483	1,466	1,448	1,450	1,444	1,459	1,558	1,559
2018	1,497	1,440	1,462	1,432	1,427	1,457	1,480	1,456	1,430	1,434	1,425	1,446	1,583	1,583
2019	1,498	1,423	1,452	1,389	1,406	1,445	1,475	1,444	1,410	1,414	1,403	1,430	1,612	1,612
2020	1,498	1,404	1,441	1,347	1,381	1,432	1,470	1,430	1,387	1,393	1,378	1,413	1,645	1,645
2021	1,499	1,382	1,428	1,305	1,354	1,416	1,459	1,415	1,361	1,368	1,350	1,393	1,682	1,683
2022	1,500	1,358	1,414	1,259	1,323	1,400	1,443	1,398	1,333	1,341	1,318	1,371	1,725	1,726
2023	1,501	1,332	1,400	1,208	1,291	1,382	1,422	1,380	1,302	1,311	1,285	1,348	1,772	1,773
2024	1,503	1,304	1,384	1,155	1,256	1,364	1,391	1,361	1,269	1,280	1,249	1,324	1,824	1,825
2025	1,505	1,276	1,368	1,098	1,219	1,345	1,354	1,341	1,234	1,247	1,211	1,298	1,880	1,881
2026	1,507	1,246	1,352	1,039	1,181	1,325	1,310	1,321	1,198	1,214	1,172	1,272	1,938	1,940
2027	1,509	1,218	1,337	982	1,145	1,307	1,270	1,302	1,164	1,181	1,135	1,247	1,997	1,998
2028	1,512	1,192	1,323	929	1,111	1,290	1,232	1,285	1,133	1,152	1,100	1,224	2,053	2,055
2029	1,515	1,169	1,312	881	1,081	1,275	1,201	1,270	1,104	1,125	1,069	1,204	2,106	2,108
2030	1,518	1,149	1,302	838	1,054	1,262	1,171	1,257	1,079	1,101	1,041	1,186	2,156	2,158

Table B.33 Total N_2O Emissions (all vehicles, all locations)

	Total Emissions of N_2O for the Base Case and for Each PNGV Technology/Fuel Combination (10^3 tonnes)													
	Base Case	CV+RFG	CV+MeOH	CV+EtOH	CV+RFD	CV+DME	CV+HFCV	CV+MFCV	CV+GFC	CV+FTD/RFD	CV+Bio/RFD	CV+LPG	CV+CNG	CV+LNG
2005	41.6	40.9	40.9	40.9	40.9	40.9	40.9	40.9	40.9	40.9	40.9	40.9	40.9	40.9
2006	42.0	41.5	41.5	41.5	41.5	41.5	41.5	41.5	41.5	41.5	41.5	41.5	41.5	41.5
2007	42.4	42.1	42.1	42.1	42.1	42.1	42.1	42.1	42.1	42.1	42.1	42.1	42.1	42.1
2008	39.7	39.6	39.6	39.7	39.6	39.6	39.6	39.6	39.6	39.6	39.6	39.6	39.6	39.6
2009	37.7	37.6	37.6	37.9	37.6	37.6	37.7	37.6	37.6	37.6	37.6	37.6	37.6	37.7
2010	35.7	35.7	35.6	36.1	35.6	35.6	35.7	35.6	35.6	35.6	35.7	35.6	35.7	35.8
2011	33.8	33.7	33.7	34.6	33.7	33.7	33.8	33.7	33.7	33.7	33.7	33.7	33.8	33.9
2012	31.9	31.9	31.8	33.3	31.8	31.8	32.0	31.8	31.8	31.8	31.9	31.8	31.9	32.2
2013	30.2	30.1	30.1	32.4	30.1	30.1	30.4	30.0	30.0	30.1	30.1	30.1	30.2	30.6
2014	28.6	28.5	28.4	32.1	28.4	28.4	29.0	28.3	28.4	28.4	28.5	28.4	28.7	29.2
2015	27.0	27.0	26.8	32.6	26.8	26.8	27.7	26.6	26.7	26.8	27.0	26.8	27.2	28.1
2016	25.6	25.6	25.3	34.2	25.4	25.3	26.7	25.0	25.2	25.3	25.6	25.2	25.9	27.3
2017	24.3	24.3	23.9	36.8	24.0	23.9	25.9	23.4	23.8	23.9	24.3	23.8	24.8	26.8
2018	23.1	23.2	22.7	37.4	22.8	22.6	25.4	22.0	22.5	22.6	23.2	22.6	23.9	26.6
2019	22.0	22.2	21.5	35.8	21.7	21.5	25.1	20.6	21.3	21.5	22.3	21.4	23.2	26.8
2020	21.0	21.4	20.5	35.5	20.8	20.5	25.0	19.4	20.3	20.5	21.5	20.3	22.6	27.2
2021	20.1	20.7	19.6	37.0	19.9	19.6	25.2	18.2	19.3	19.6	20.8	19.4	22.2	27.9
2022	19.3	20.2	18.8	38.9	19.2	18.8	25.6	17.1	18.5	18.8	20.3	18.6	22.0	29.0
2023	18.6	19.8	18.2	41.1	18.6	18.1	26.3	16.1	17.7	18.1	19.9	17.9	22.0	30.3
2024	17.9	19.5	17.6	43.7	18.1	17.6	27.0	15.2	17.1	17.5	19.7	17.2	22.1	31.9
2025	17.3	19.4	17.1	46.6	17.8	17.1	28.0	14.3	16.6	17.0	19.6	16.7	22.4	33.8
2026	16.7	19.3	16.8	49.7	17.5	16.7	29.0	13.6	16.1	16.7	19.5	16.3	22.8	35.8
2027	16.2	19.4	16.5	52.8	17.3	16.4	30.1	12.9	15.7	16.4	19.6	16.0	23.3	37.9
2028	15.8	19.5	16.3	55.9	17.2	16.2	31.2	12.3	15.5	16.1	19.7	15.7	23.8	40.0
2029	15.3	19.6	16.2	58.7	17.1	16.1	32.3	11.8	15.2	16.0	19.9	15.5	24.3	41.9
2030	15.0	19.8	16.1	61.3	17.1	16.0	33.3	11.3	15.1	15.9	20.0	15.4	24.8	43.7

Table B.34 Total Greenhouse Gas Emissions (all vehicles)

	Total Global Warming Potential for the Base Case and for Each PNGV Technology/Fuel Combination (10^6 tonnes CO_2-equivalent)													
	Base Case	CV+RFG	CV+MeOH	CV+EtOH	CV+RFD	CV+DME	CV+HFCV	CV+MFCV	CV+GFC	CV+FTD/RFD	CV+Bio/RFD	CV+LPG	CV+CNG	CV+LNG
2005	1381	1357	1357	1357	1357	1357	1357	1357	1357	1357	1357	1357	1357	1357
2006	1392	1378	1378	1378	1378	1378	1378	1378	1378	1378	1378	1378	1378	1378
2007	1403	1395	1395	1395	1395	1395	1395	1395	1395	1395	1395	1395	1395	1395
2008	1411	1406	1406	1406	1406	1406	1406	1406	1406	1406	1406	1406	1406	1406
2009	1431	1429	1429	1428	1429	1429	1429	1429	1429	1429	1429	1429	1429	1429
2010	1448	1446	1446	1445	1446	1446	1446	1446	1446	1446	1446	1445	1446	1446
2011	1460	1457	1457	1456	1457	1457	1457	1457	1457	1457	1457	1456	1456	1456
2012	1469	1464	1464	1462	1463	1464	1464	1464	1464	1464	1464	1463	1463	1463
2013	1476	1467	1468	1465	1467	1468	1468	1468	1467	1468	1467	1466	1467	1467
2014	1480	1466	1467	1463	1466	1467	1468	1467	1466	1468	1466	1465	1466	1466
2015	1481	1460	1462	1455	1460	1461	1463	1461	1460	1463	1460	1459	1459	1459
2016	1482	1450	1452	1443	1450	1452	1454	1452	1450	1454	1450	1447	1448	1448
2017	1481	1436	1439	1425	1435	1438	1442	1438	1436	1442	1436	1432	1433	1433
2018	1481	1419	1422	1397	1418	1422	1427	1422	1418	1427	1419	1413	1415	1415
2019	1480	1399	1404	1359	1398	1403	1409	1403	1398	1409	1399	1391	1393	1394
2020	1479	1377	1382	1318	1375	1382	1390	1382	1376	1390	1376	1367	1370	1370
2021	1479	1352	1359	1276	1349	1358	1365	1358	1351	1368	1351	1340	1343	1344
2022	1478	1324	1333	1229	1322	1332	1335	1332	1323	1345	1323	1310	1314	1315
2023	1478	1295	1306	1179	1292	1305	1300	1305	1294	1319	1294	1278	1282	1284
2024	1479	1264	1277	1125	1261	1276	1259	1276	1263	1293	1263	1244	1249	1251
2025	1480	1232	1247	1069	1228	1245	1212	1245	1230	1265	1231	1208	1215	1217
2026	1481	1199	1216	1010	1194	1214	1160	1214	1197	1237	1198	1172	1179	1182
2027	1482	1168	1186	954	1162	1185	1112	1184	1165	1210	1166	1137	1145	1148
2028	1484	1139	1159	901	1132	1157	1066	1157	1136	1186	1137	1105	1114	1117
2029	1486	1113	1135	853	1106	1133	1027	1133	1110	1164	1110	1076	1086	1089
2030	1488	1090	1114	810	1082	1111	990	1111	1087	1145	1087	1050	1061	1064

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