ANL/ESD/TM-154

IMPACTT5A Model: Enhancements and Modifications since December 1994

with Special Reference to the Effect
of Tripled-Fuel-Economy Vehicles
on Fuel-Cycle Energy and Emissions

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Notation

3X	tripled fuel economy
B20	biodiesel blend consisting of 20% methyl soyate and 80% conventional diesel
CAFE	Corporate Average Fuel Economy (standard)
CH_4	methane
CI	compression-ignition
CIDI	compression-ignition direct-injection
CNG	compressed natural gas
CO	carbon monoxide
CO_2	carbon dioxide
CTR	Center for Transportation Research
DME	dimethyl ether
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
EtOH	ethanol
F-T50	50% Fischer-Tropsch diesel
FTD	Fischer-Tropsch diesel
GEMPG	gasoline-equivalent miles per gallon
GFC	gasoline fuel cell
GFCV	gasoline fuel cell vehicle
GGE	gallons of gasoline equivalent
GREET	Greenhouse Gas, Emissions, and Energy Use in Transportation (model)
GVW	gross vehicle weight
HDV	heavy-duty vehicle
HFCV	hydrogen fuel cell vehicle
HHV	higher heating value
ICE	internal combustion engine
IMPACTT	Integrated Market Penetration and Anticipated Cost of Transportation Technologies (model)
LDV	light-duty vehicle
LHV	lower heating value
LNG	liquefied natural gas
LPG	liquefied petroleum gas
MeOH	methanol
MFCV	methanol fuel cell vehicle
MMBD	million barrels per day
MPG	miles per gallon
N_2O	nitrous oxide
NO_x	nitrogen oxides

Notation (Cont.)

OTT	Office of Transportation Technologies
$PM_{2.5}$	particulate matter equal to or smaller than 2.5 micrometers (μm) in diameter
PM_{10}	particulate matter equal to or smaller than 10 micrometers (μm) in diameter
R&D	research and development
RFD	reformulated diesel
RFG	reformulated gasoline
SCF	standard cubic foot (feet)
SI	spark-ignition
SIDI	spark-ignition direct-injection
SO_x	sulfur oxides
ULEV	ultra-low-emission vehicle
VMT	vehicle-miles traveled
VOC	volatile organic compounds

IMPACTT5A MODEL: ENHANCEMENTS AND MODIFICATIONS SINCE DECEMBER 1994

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Abstract

Version 5A of the Integrated Market Penetration and Anticipated Cost of Transportation Technologies (IMPACTT5A) model is a spreadsheet-based set of algorithms that calculates the effects of advanced-technology vehicles on baseline fuel use and emissions. Outputs of this Argonne National Laboratory-developed model include estimates of (1) energy use and emissions attributable to conventional-technology vehicles under a baseline scenario and (2) energy use and emissions attributable to advanced- and conventional-technology vehicles under an alternative market-penetration scenario. Enhancements to IMPACTT made after its initial documentation in December 1994 have enabled it to deal with a wide range of fuel and propulsion system technologies included in Argonne's GREET model in a somewhat modified three-phased approach. Vehicle stocks are still projected in the largely unchanged STOCK module. Vehicle-miles traveled, fuel use, and oil displacement by advanced-technology vehicles are projected in an updated USAGE module. Now, both modules can incorporate vehicle efficiency and fuel share profiles consistent with those of the Partnership for a New Generation of Vehicles. Finally, fuel-cycle emissions of carbon monoxide, volatile organic compounds, nitrogen oxides, toxics, and greenhouse gases are computed in the EMISSIONS module via an interface with the GREET model that was developed specifically to perform such calculations. Because of this interface, results are now more broadly informative than were results from earlier versions of IMPACTT.

1 Introduction and Overview

The Center for Transportation Research (CTR) at Argonne National Laboratory developed the Integrated Market Penetration and Anticipated Cost of Transportation Technologies (IMPACTT) model in the early 1990s to assist the U.S. Department of Energy (DOE), Office of Transportation Technologies (OTT), with program planning and development. OTT wanted to assess the likely impacts of vehicle technology advances associated with research and development

(R&D), including work sponsored by the Partnership for a New Generation of Vehicles (PNGV). (PNGV is a cooperative initiative of the U.S. government and the domestic motor vehicle industry designed to triple the fuel economy of light-duty vehicles [LDVs].) IMPACTT is a spreadsheet model, operating in either an Apple™ or PC-compatible environment, that calculates the effect of the characteristics of advanced-technology vehicles and market-penetration assumptions on fuel use and emissions, relative to an accepted baseline.

Outputs of IMPACTT include estimates of (1) baseline energy use and emissions attributable to conventional-technology vehicles and (2) energy use and emissions attributable to conventional- and advanced-technology vehicles under a particular market-penetration scenario. Estimates are based on exogenous projections of conventional-technology vehicle sales, advanced-technology market penetration, and the characteristics of new vehicles — both conventional and advanced technology. Vehicle characteristics include fuel efficiency; operational emission rates for nitrogen oxides (NO_X), carbon monoxide (CO), volatile organic (hydrocarbon) compounds (VOCs), toxic gases (i.e., sulfur oxides [SO_X] and particulate matter equal to or smaller than 10 μm in diameter [PM_{10}]), carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4); and incremental capital cost (i.e., the unit cost of an advanced-technology vehicle minus the unit cost of a conventional-technology vehicle). Annual petroleum displacement and emissions are calculated by projecting the vehicle-miles traveled (VMT), petroleum use, and emissions for each year's conventional-technology and advanced-technology vehicles under a given market-penetration scenario and subtracting those projections from comparable baseline projections for conventional-technology vehicles.

Several worksheets are needed to analyze the impacts of a portfolio of actual or proposed programs. For example, to analyze OTT's Diversified Strategy (DOE 1994), IMPACTT required the use of eight worksheets specific to these technologies: (1) conventional internal combustion engine (ICE), (2) advanced-battery electric, (3) grid-connected hybrid, (4) fuel cell, (5) liquefied petroleum gas (LPG), (6) compressed natural gas (CNG), (7) flexible-fuel ethanol, and (8) dedicated ethanol.[1] Within each of these eight worksheets, IMPACTT operated in a three-module framework. The STOCK module calculated stocks of conventional- and advanced-technology vehicles on the basis of input market penetration, sales, and scrappage rates. The USAGE module estimated petroleum displacement and substitute fuel use on the basis of input fuel shares, utilization functions, and energy efficiencies. The EMISSIONS module estimated gaseous (exhaust and evaporative) residuals from the projected use of conventional and substitute vehicles on the basis of input operational (i.e., tailpipe/evaporative) emission rates and upstream (i.e., energy production and distribution per unit of upstream energy generation) emission rates, both by propulsion system and fuel technology.

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[1] In this version of IMPACTT, each engine/fuel combination was modeled as a composite LDV, the characteristics of which were weighted as approximately 60% auto and 40% light truck. IMPACTT5 contains separate auto and light truck worksheets to better deal with changes in the market shares and emission rates of these two types of vehicles.

IMPACTT5A differs from earlier versions in several ways.[2] First, the eight specific technology worksheets have been consolidated into four worksheets representative of a single market-penetration scenario that *can* (but, for this application, has not been required to) accommodate fractional shares for every candidate technology. This consolidation considerably reduces redundancy in data fields.[3] Second, vehicle turnover in STOCK has been calibrated to reported control totals. Third, fuel shares, utilization functions, and efficiency assumptions in the USAGE module have been revised. Fourth, and most significant, the EMISSIONS module (which formerly applied a single menu of default values for upstream and downstream process and operational emissions) has been augmented by age-specific and model-year-specific inputs from the U.S. Environmental Protection Agency (EPA) MOBILE5b and PART5 emission factor models and by outputs from Argonne's Greenhouse Gas, Regulated Emissions and Energy Use in Transportation (GREET) model. These revisions enable IMPACTT5 to produce highly differentiated, fuel-cycle-specific estimates of residuals for the propulsion systems and fuel alternatives under consideration.

IMPACTT5A has been employed in a wide variety of applications and analyses over the past four years, most notably in the assessment of infrastructure impacts associated with a tripled-fuel-economy (3X) vehicle. That vehicle is currently being developed by the PNGV. The PNGV goal is to produce, shortly after the turn of the century, a market-ready LDV with fuel economy three times that of the 1995 Corporate Average Fuel Economy (CAFE) standard. This report uses the PNGV application to illustrate IMPACTT's current capabilities. Section 2 presents the model methodology. Section 3 describes the content and formats of input data files with special reference to the PNGV application. The sample outputs shown in Section 4 likewise derive from PNGV-related calculations. Appendix A, the updated README file from the model software, describes the contents of each of the worksheets. Appendix B, the SUMMARY worksheet from the PNGV high-market-share scenario, contains detailed estimates of energy and emissions for each of the PNGV propulsion system/fuel candidates.

Additional enhancements are planned for IMPACTT. Chief among them is to create a heavy-duty vehicle (HDV) version of the model. Another enhancement being considered is to convert the structure of the modular components from flat (spreadsheet) files to a database than can operate within the model's shell framework for specific fuels and technologies of interest. This enhancement would enable the model template to be reduced to a single set of worksheets, and data would be pulled into "cells" only when needed. The result would be a significant reduction in storage requirements for the entire model.

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2 IMPACTT5A is the model version used to examine the impacts of tripled-fuel-economy (3X) vehicles. It differs from IMPACTT5B, a sister model, in that it treats technologies as being mutually exclusive; thus, multiple technologies can be accommodated on two advanced-technology worksheets. Both versions have the same internal structure and energy and emission inputs and may be referred to as simply the fifth generation of the IMPACTT model (i.e., IMPACTT5).

3 In other words, the eight technology-specific worksheets in the prior version of the model have been reduced to four — ICE_CAR-(scenario), ICE_LTRK-(scenario), PNGV_CAR-(scenario), and PNGV_LTRK-(scenario) — despite the fact that the total class of LDVs has been disaggregated into autos and light trucks.

2 Methodology

IMPACTT5 is written in Microsoft EXCEL workbook format (compatible with versions 5.0 and above). The version used for the PNGV infrastructure analysis consists of six general worksheets and four vehicle/technology-type worksheets that define the market penetration, energy use, and emission characteristics of the LDV technologies that are included under a scenario. Automobiles and light trucks are considered separately under these scenarios. Table 1 provides a capsule description of several of the worksheets. The model also includes a README file (Appendix A) that provides a condensed description of the model for the user.

Conceptually, each vehicle/technology-type worksheet may be described in terms of three modules, and the model itself may be described as a stack of such worksheets. As shown in Figure 1, the STOCK module estimates the population or stock of advanced- and conventional-technology vehicles when given information on total vehicle sales, advanced-technology marginal cost, market shares, and vehicle depreciation rates. The USAGE module subsequently estimates VMT, fuel use, and CO_2 emissions of advanced- and conventional-technology vehicles. The EMISSIONS module then computes fuel-cycle emissions associated with each propulsion system/fuel combination by using age-specific and model-year-specific VMT and upstream[4] and operational emission rates calculated from the GREET, MOBILE, and PART models (with appropriate modifications to account for in-use deterioration). Finally, results are aggregated across all vehicle/technology-type worksheets to produce total estimates of vehicle stocks, VMT, emissions, and fuel use for each propulsion system/fuel combination.

2.1 General Worksheets

For the PNGV application, IMPACTT5A requires six general worksheets: ICE_CAR-REF, ICE_LTRK-REF, VMT_SUM, CON_SUM, SUMMARY, and SALES-MPG. The ICE_CAR-REF worksheet contains historical estimates of automobile sales; new-car fuel economy in miles per gallon or MPG (by calendar or model year); and age-specific and model-year-specific operational emission rates of criteria pollutants (CO, VOC, NO_x, and PM_{10}) for the years 1970–1996. ICE_CAR-REF is linked to SALES-MPG, which contains forecasts of vehicle sales (100% of which are assumed to be conventional vehicles[5]) and new-car fuel economy for 1997–2030. ICE_CAR-REF contains forecasts of operational emission rates for criteria pollutants (by vehicle age and model year) and for greenhouse gases (by calendar year), and forecasts of upstream emission rates for all pollutants including SO_x (by calendar year) for both conventional

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4 "Upstream" indicates fuel production, processing, and distribution that occur before the fuel is used in vehicles. "Downstream" indicates fuel use in vehicles and vehicle disposal or recycling. "Operational" indicates only fuel use in vehicle operation.

5 In other words, whether or not advanced technologies enter the market, the same number of vehicles is assumed to be sold.

TABLE 1 Workbook Organization

General Worksheet	Cell Range Utilized	Data Content
ICE_CAR-REF	A-1: EY-106	Projected total automobile sales and share of total light-duty vehicle (LDV) sales by year to 2030; new car fuel economy (MPG) by model year; vehicle survival rate by age; age-specific and model-year-specific tailpipe emission rates of criteria pollutants (CO, VOC, NO_x, PM_{10}); upstream process emission rates for these criteria pollutants, SO_x, and attributable greenhouse gases (CO_2, CH_4, N_2O); PM_{10} emissions from tire and brake wear for conventional autos on regular and (as appropriate) reformulated gasoline through 2030.
ICE_LTRK-REF	A-1: EY-106	Same data as those in ICE_CAR-REF, except for light trucks (≤8,500 lb gross vehicle weight) instead of automobiles.
VMT_SUM	A-1: W-52	Fleet average miles per gallon and vehicle-miles displaced by all advanced-technology vehicles (summarized independently, as appropriate).
CON_SUM	A-1: CK-53	Substitution fuel use (in physical units, quads, and million barrels per day) aggregated over all technologies considered in the particular scenario under examination and reported annually for 1990–2030 and cumulatively (as appropriate) for the periods 1990–2000, 1990–2010, 1990–2020, and 1990–2030; count of advanced-technology vehicle stocks by year.
SUMMARY	A-1: EC-242	Emissions of criteria pollutants and greenhouse gases for each technology considered in the scenario under examination, reported annually for 1990–2030 and cumulatively (as appropriate) for the periods 1990–2000, 1990–2010, 1990–2020, and 1990–2030.
SALES-MPG	A-1: N-45	Forecasts of auto and light truck sales and fuel economy (both EPA-rated and on-road) for input into the STOCK and USAGE modules.

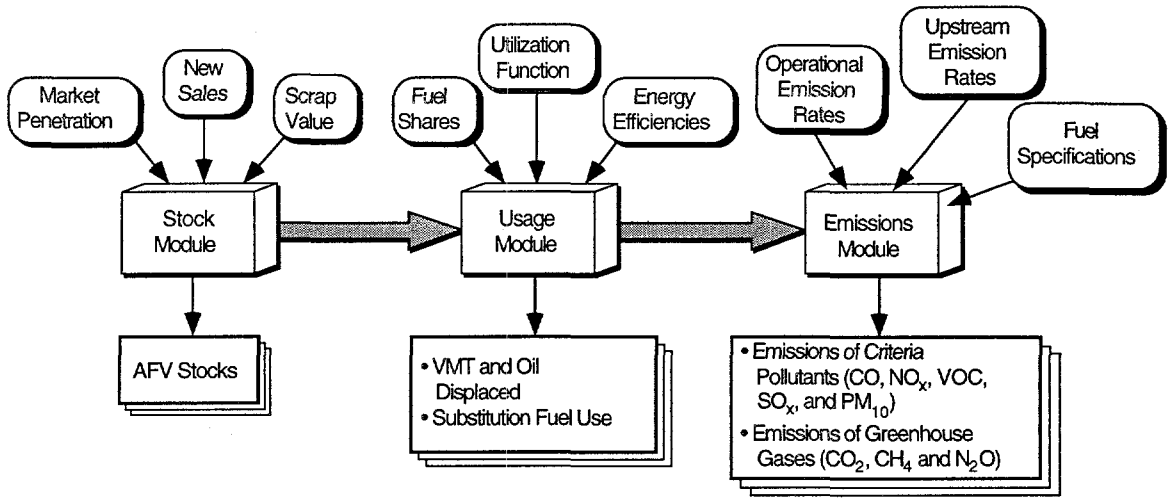

FIGURE 1 Logical Flow of IMPACTT5

gasoline and reformulated gasoline. ICE_LTRK-REF contains basically the same data for light trucks (≤8,500 lb gross vehicle weight [GVW]). Examples of year-specific and vehicle-specific emission rates are shown in Table 2.

Three summary worksheets aggregate results from the vehicle/technology-type worksheets. The VMT_SUM worksheet summarizes fleet average gasoline-equivalent miles per gallon (GEMPG) and vehicle-miles displaced by advanced-technology vehicles. The CON_SUM worksheet summarizes substitution fuel use (in gallons of gasoline-equivalent [GGE], quads, and million barrels per day [MMBD]), vehicle stocks, and CO_2 emissions by propulsion system/fuel combination. SUMMARY summarizes upstream and operational emissions of criteria pollutants and greenhouse gases by propulsion system/fuel combination. For all summary worksheets, results are reported annually for 1990–2030 and cumulatively (as appropriate) for the periods 1990–2000, 1990–2010, 1990–2020, and 1990–2030.

The SALES-MPG worksheet contains reference-case forecasts of auto and light-truck sales and fuel economy, which are input into the STOCK and USAGE modules. Current default values for the reference case are shown in Tables 3 and 4. The default forecasts were derived from *Annual Energy Outlook, 1997* (DOE 1996). Default values assume that EPA test results overestimate actual on-the-road fuel economy by about 20% (Mintz et al. 1993).

2.2 Vehicle/Technology-Type Worksheets

A variable number of vehicle/technology-type worksheets are embedded in each application of the IMPACTT workbook, depending on the specific targets and mission of the application. The

TABLE 2 Default Operational Emission Rates by Vehicle Age for Conventional-Technology Automobiles and Light Trucks Operating on Reformulated Gasoline in 2005

Vehicle Age	Auto Emission Rate (g/mi)				Light Truck Emission Rate (g/mi)			
	NO_x	CO	VOC	PM_{10}	NO_x	CO	VOC	PM_{10}
<1	0.119	1.795	0.320	0.033	0.152	2.041	0.372	0.036
1	0.162	2.098	0.330	0.033	0.201	2.378	0.413	0.036
2	0.233	3.249	0.353	0.033	0.282	3.683	0.478	0.036
3	0.598	8.675	0.376	0.033	0.716	9.820	0.539	0.036
4	0.724	10.736	0.396	0.033	0.906	12.897	0.654	0.036
5	0.997	15.350	0.502	0.033	1.217	18.045	0.931	0.036
6	1.256	19.717	0.604	0.033	1.510	22.882	1.193	0.036
7	1.500	23.848	0.705	0.033	1.786	27.426	1.442	0.036
8	1.732	27.757	0.800	0.033	2.045	31.696	1.680	0.036
9	1.952	31.457	0.891	0.033	2.288	35.708	1.907	0.036
10	2.159	34.957	0.972	0.033	2.517	39.477	2.123	0.035
11	2.355	38.268	1.052	0.033	2.732	43.018	2.264	0.035
12	2.540	41.399	1.128	0.033	2.923	46.256	2.349	0.035
13	2.713	44.318	1.204	0.033	3.084	49.127	2.431	0.035
14	2.875	47.058	1.276	0.033	3.235	51.825	2.515	0.035
15	3.028	49.651	1.348	0.033	3.377	54.359	2.595	0.035
16	3.172	52.103	1.420	0.033	3.510	56.740	2.677	0.035
17	3.309	54.423	1.420	0.033	3.510	56.978	2.677	0.035
18	3.439	56.617	4.893	0.033	3.510	61.080	6.264	0.035
19	3.561	56.617	4.893	0.033	3.510	61.080	6.504	0.035
20	3.677	56.617	4.893	0.033	3.510	61.080	6.736	0.035
20+	3.787	56.617	4.893	0.033	3.510	61.080	7.164	0.035

Source: EPA MOBILE5b model.

default case is based on the high-market-share scenario developed for the PNGV infrastructure analysis. That scenario required four worksheets (PNGV_CAR-HIGH, PNGV_LTRK-HIGH, ICE_CAR-HIGH, ICE_LTRK-HIGH), all of which use a common three-module framework. Because this application did not require the consideration of technologies with different fuel economy, utilization (mi/vehicle), or market-penetration parameters, it was not necessary to construct separate worksheets for each alternative propulsion system/fuel combination. However, since the alternative technologies consume different fuels (with associated differences in upstream and operational emission rates), it was necessary to add fuel-specific emission details to the PNGV_CAR and PNGV_LTRK worksheets. Similarly, because the PNGV propulsion system/fuel combinations are mutually exclusive, it was not necessary to aggregate results for different technologies into single estimates of total VMT, fuel use, or emissions. Thus, not only does this version of the model (i.e., IMPACTT5A) accommodate fewer technologies than the

TABLE 3 Default Sales Forecasts for Light-Duty Vehicles

Year	New Sales (10^3) Auto	Light Truck	Year	New Sales (10^3) Auto	Light Truck
1995	9,314	5,879	2013	10,053	7,544
1996	8,967	5,987	2014	10,114	7,569
1997	9,061	5,866	2015	10,092	7,520
1998	9,270	6,154	2016	10,125	7,532
1999	9,588	6,526	2017	10,158	7,544
2000	9,635	6,723	2018	10,191	7,557
2001	9,556	6,780	2019	10,225	7,569
2002	9,522	6,839	2020	10,258	7,581
2003	9,689	7,075	2021	10,288	7,597
2004	9,778	7,227	2022	10,318	7,613
2005	9,838	7,331	2023	10,348	7,629
2006	9,931	7,432	2024	10,378	7,644
2007	10,004	7,517	2025	10,408	7,660
2008	9,944	7,502	2026	10,436	7,679
2009	9,870	7,476	2027	10,463	7,698
2010	9,894	7,494	2028	10,491	7,717
2011	9,953	7,509	2029	10,518	7,736
2012	9,981	7,530	2030	10,546	7,755

Source: DOE (1996) for 1997–2010; extrapolated for post-2010.

version documented earlier, it also requires less summarizing across worksheets. The following subsections describe the workbook configuration as applied to the fuel economy and market penetration targets of the PNGV.

2.2.1 STOCK Module

The first and largest component of the vehicle/technology-type worksheets is the vehicle STOCK module. The module calculates the stock or population of advanced-technology vehicles by forecast year. New vehicle sales, market-penetration rates for advanced-technology vehicles, and scrap value are the key determinants of conventional- and advanced-technology vehicle stock in each forecast year. Computations are performed for conventional vehicles in the ICE_CAR-REF and ICE_LTRK-REF worksheets and for corresponding advanced/replacement-technology vehicles in a worksheet devoted either to a specific technology *or* to a market penetration case in which several technologies (each with a characteristic emission rate, but with fuel efficiency held constant across technologies) are combined. The PNGV application is an example of the latter

TABLE 4 Default Fuel Economy of New Conventional-Technology Light-Duty Vehicles

	Fuel Economy (MPG)					
	On Road		EPA Test		Total LDV	
Year	Auto	Light Truck	Auto	Light Truck	On Road	EPA Test
1990	22.24	16.56	27.80	20.70	20.15	25.19
1991	22.40	17.04	28.00	21.30	20.34	25.42
1992	22.08	16.64	27.60	20.80	19.91	24.88
1993	22.56	16.80	28.20	21.00	20.08	25.10
1994	22.40	16.64	28.00	20.80	19.71	24.63
1995	22.64	16.32	28.30	20.40	19.69	24.61
1996	22.40	16.32	28.00	20.40	19.49	24.37
1997	22.00	16.40	27.50	20.50	19.40	24.25
1998	22.00	16.40	27.50	20.50	19.36	24.20
1999	22.24	16.40	27.80	20.50	19.44	24.30
2000	22.40	16.40	28.00	20.50	19.47	24.34
2001	22.64	16.40	28.30	20.50	19.55	24.44
2002	23.04	16.64	28.80	20.80	19.85	24.81
2003	23.44	17.04	29.30	21.30	20.23	25.29
2004	23.60	17.04	29.50	21.30	20.28	25.35
2005	23.84	17.28	29.80	21.60	20.51	25.64
2006	24.16	17.44	30.20	21.80	20.74	25.92
2007	24.40	17.68	30.50	22.10	20.98	26.22
2008	24.64	17.84	30.80	22.30	21.17	26.46
2009	24.96	18.08	31.20	22.60	21.44	26.80
2010	25.20	18.32	31.50	22.90	21.69	27.11
2011	25.44	18.56	31.80	23.20	21.94	27.43
2012	25.60	18.80	32.00	23.50	22.15	27.69
2013	25.76	18.96	32.20	23.70	22.32	27.91
2014	25.92	19.20	32.40	24.00	22.54	28.18
2015	26.08	19.36	32.60	24.20	22.71	28.39
2016	26.17	19.47	32.71	24.33	22.82	28.52
2017	26.26	19.57	32.82	24.47	22.92	28.65
2018	26.35	19.68	32.94	24.60	23.03	28.79
2019	26.44	19.79	33.05	24.74	23.13	28.92
2020	26.53	19.90	33.16	24.88	23.24	29.05
2021	26.62	20.01	33.28	25.02	23.35	29.18
2022	26.71	20.12	33.39	25.15	23.45	29.32
2023	26.81	20.23	33.51	25.29	23.56	29.45
2024	26.90	20.35	33.62	25.43	23.67	29.58
2025	26.99	20.46	33.74	25.57	23.77	29.72
2026	27.08	20.57	33.85	25.72	23.88	29.85
2027	27.18	20.69	33.97	25.86	23.99	29.98
2028	27.27	20.80	34.09	26.00	24.09	30.12
2029	27.36	20.92	34.20	26.14	24.20	30.25
2030	27.46	21.03	34.32	26.29	24.31	30.39

Source: DOE (1996).

structure: there are four scenario-specific sheets for the high-market-share scenario from 2007 through 2030, and an equal number for the low-market-share scenario, which is modeled in exactly the same way in a separate workbook. These sheets are therefore called PNGV_CAR-HIGH, ICE_CAR-HIGH, PNGV_LTRK-HIGH, and ICE_LTRK-HIGH. Had the mission of this application been to examine the combined effect of different fuel/technology combinations offering fuel efficiencies and emission characteristics that differ from one another within a single forecast year, there would have been separate worksheets for each combination, with effectively no limit on the potential worksheet count.

In any given year, the equation for new (age = 0) advanced-technology vehicles (cars or light trucks) is based on the market penetration for that technology as a share of total sales of that vehicle class (cars or light trucks). A vintaging stock model (based on Greene and Rathi 1990) is then used to estimate the number of vehicles in a given year by age. For new vehicles:

$$V_{ij} = SALES_i \times P_i \quad . \tag{1}$$

For all other vintages (age = 1, ..., 20+):

$$V_{ij} = V_{i-1,j-1} \times \left(1 - \left[1 + e^{A_0 + MC_i \times A_1 \times (1-DRATE)^j}\right]^{-1}\right) , \tag{2}$$

where

i = year index, 1990, ..., 2030;

j = age index, 0, ..., 20+;

V_{ij} = number of advanced-technology vehicles in year i at age j;

$SALES_i$ = vehicle sales in year i;

P_i = market-penetration rate in year i;

DRATE = price depreciation rate, generally set to 0.15;

MC_{ij} = marginal cost of a new advanced-technology vehicle sold in year i divided by annual miles at age j;

A_0 = asymptotic survival parameter; and

A_1 = new car scrappage parameter, e^{A_1}.

Equation 2 can be algebraically reformulated as:

$$V_{ij} = V_{i-1,j-1} - \frac{V_{i-1,j-1}}{1 + e^{A_0 + MC_i \times A_1 \times (1-DRATE)^j}} \quad . \tag{3}$$

The total number of advanced-technology vehicles in any year is then the summation across all ages of advanced-technology vehicles:

$$V_i = \sum_j V_{ij} \quad . \tag{4}$$

2.2.2 USAGE Module

The major inputs to the USAGE module are the output of the STOCK module (vehicle stock by vintage), an age-dependent utilization rate (annual VMT per vehicle), and energy efficiencies.[6] The major outputs are VMT, VMT-weighted MPG, and substitution fuel use. VMT is computed as the sum of the product of vehicles and vehicle use by vintage. Substitution fuel use is computed as total VMT divided by VMT-weighted GEMPG. Fuel use is reported in GGE and converted into MMBD and quads assuming 42 gal per barrel and either 113,000 or 115,500 Btu per gallon (i.e., the lower heating value of conventional gasoline or reformulated gasoline). No conversion into barrels of imported oil is made within the model.

First, VMT per vehicle is computed as in Equation 5:

$$M_j = M_0 \times e^{(UDRATE \times j)} \quad , \tag{5}$$

where

M_0 = annual miles per vehicle at age 0,

M_j = annual miles per vehicle at age j, and

UDRATE = usage degradation rate.

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[6] Note that age-dependent utilization can be adjusted to account for limited-range vehicles. Thus, for example, battery-powered electric vehicles might travel only two-thirds as many miles per year as conventional-technology vehicles of the same age. Since battery-powered electric vehicles are not under consideration for 3X vehicles, this capability was not used in the PNGV application.

Results from the vehicle stock model (i.e., the number of vehicles at a given age) are then combined with the exogenous variable M_j (miles traveled for a given age) to determine VMT in any given year. The equation is:

$$VMT_i = \sum_j VMT_{ij} = \sum_j V_{ij} \times M_j \ , \qquad (6)$$

where

M_j = annual miles per vehicle at age j and

VMT_{ij} = total VMT in year i at age j.

An advanced-technology vehicle's impact on energy use includes not only the quantity of alternative fuel (if any) consumed by vehicles incorporating that technology but also the quantity of petroleum displaced. In earlier versions of IMPACTT, displacement was computed directly. In IMPACTT5A, displacement is left to the analyst — as baseline fuel use minus PNGV high-(or low-)market-share fuel use. Within the USAGE module, substitution-fuel use (in GGE) is computed as the sum of the product of VMT and advanced-technology fuel efficiency for each vintage.

$$SFUEL_i = \sum_j \left(\frac{V_{ij} \times M_j}{GEMPG_k} + \frac{V_{i,j+1} \times M_{j+1}}{GEMPG_{k-1}} + \ldots \frac{V_{i,j+22} \times M_{j+22}}{GEMPG_{k-22}} \right) \ , \qquad (7)$$

where

$SFUEL_i$ = substitution fuel use (in GGE) in year i and

$GEMPG_k$ = gasoline-equivalent miles per gallon for model year k.

For flexible-fuel vehicles, five additional parameters can be included in the USAGE module. These are alcohol share of reformulated gasoline (RFG), ethanol and methanol shares of alternative fuel use, and ethanol and methanol fuel use. Since flexible-fuel vehicles are not among the technologies being considered by the PNGV, the equations permitting fuel use to be split into two component fuels were deleted from the PNGV application. Readers interested in modeling flexible-fuel vehicles should consult the earlier documentation (Mintz et al. 1994).

Similarly, for electric and grid-connected hybrid vehicles, two additional parameters, transmission and distribution efficiencies, could be used to account for losses between the power

plant and vehicle. They were, in fact, included in earlier versions of the model.[7] However, electric and grid-connected hybrid vehicles are not among the technologies being considered by the PNGV.

2.2.3 EMISSIONS Module

The EMISSIONS module estimates emissions of NO_x, CO, VOCs, SO_x, PM_{10}, CH_4, N_2O, and CO_2. Emissions are estimated for the entire fuel cycle, including upstream fuel production/processing activities and downstream vehicle operations.

2.2.3.1 Operational Emissions

Emissions associated with vehicle operations (i.e., operational emissions) include evaporative emissions, exhaust emissions, and emissions produced by brake and tire wear. NO_x, CO, VOC, and PM_{10} emissions from the operation of conventional- and advanced-technology vehicles are computed as the sum of the product of vehicles, miles per vehicle, and emission rates (in g/mi), all disaggregated by vehicle age (or vintage) and model year. Emission rates are obtained from MOBILE5b for vehicles aged zero to 20+ years and for model years from 1968 to 2003. Tier 2 emission standards are assumed to come into effect in model year 2003. Rates are assumed constant beyond model year 2003.

In the default case, emissions are computed for all vehicle operations. In many cases, however, the portion of emissions that occurs in urban areas is of most concern to analysts and policymakers. Thus, for the PNGV infrastructure analysis, *urban* emissions were estimated on the basis of assumptions about the urban share of vehicle sales and of VMT per vehicle. Only urban emissions are reported in Wang et al. (1998). *Total* emissions are reported in Appendix B of this document.

Operational emissions (in thousands of metric tons) of criteria pollutants (except SO_x) for a given propulsion system/fuel combination are obtained as follows:

$$OPEMIS_{ilm} = \left(\sum_{jk} \frac{V_{ij}}{1{,}000} \times M_j \times OPER_{jklm} \times \frac{CF_i}{1{,}000{,}000} \right) , \qquad (8)$$

[7] However, the accounting for these losses was somewhat inconsistent in earlier applications, since upstream energy use was not calculated for any of the other technologies being modeled. In the PNGV infrastructure application, a series of rates from GREET 1.4 are used to compute upstream emissions and energy use for *all* technologies.

where

$OPEMIS_{ilm}$ = operational emissions in year i of pollutant l from fuel m,

$OPER_{jklm}$ = operational emission rate at vehicle age j for model year k of pollutant l from fuel m,

CF_i = VMT calibration factor in year i.

For conventional gasoline-fueled vehicles, operational emission rates by age, model year, and pollutant ($OPER_{Gasolinejkl}$) are obtained directly from MOBILE5b. For advanced-technology vehicles with spark-ignition direct-injection (SIDI) engines or with fuel cells, two ratios are applied. One reflects the ratio of Tier 2 to Tier 1 standards, and the other reflects the emissions propensity of the propulsion system/fuel combination relative to that of a conventional-technology gasoline vehicle (Table 5). For advanced-technology vehicles with compression-ignition direct-injection (CIDI) engines, Tier 2 equivalent standards are assumed to apply. Table 6 presents the default emission rates assumed for new 3X CIDI engines.

TABLE 5 Default Emission Rates of Advanced-Technology Spark-Ignition Direct-Injection (SIDI) or Fuel Cell Vehicles Relative to Those of Conventional SIDI Vehicles

	Ratio of Emission Rate of Advanced-Technology Vehicle to Tier 2 Emission Rate of RFG-Fueled SIDI (%)							
Pollutant	Methanol SIDI	Ethanol SIDI	CNG SIDI	LNG SIDI	LPG SIDI	Hydrogen Fuel Cell	Methanol[a] Fuel Cell	Gasoline[a] Fuel Cell
VOC (exhaust)	55	55	15	15	75	0	0.5	0.5
VOC (evaporative)	100	100	0	0	0	0	20[b]	50[b]
CO	60	60	40	40	60	0	1	1
NO_x	80	80	60	60	90	0	1	1
PM (exhaust)	10	10	1	1	1	0	0	0
PM (brake and tire)	100	100	100	100	100	100	100	100
CH_4[c]	65	65	1,000	1,000	100	0	0	0
N_2O[d]	100	100	100	100	100	0	0	0

[a] Based on Kumar (1997).

[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.

TABLE 6 Default Emission Rates of Advanced-Technology Compression-Ignition Vehicles Operating on Alternative Fuels

Pollutant	Emission Rate (g/mi) per Fuel[a]			
	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[c]	0.008	0.008	0.008	0.008
N_2O[c]	0.005	0.005	0.005	0.005

[a] RFD = reformulated diesel, DME = dimethyl ether, B20 = 20% methyl soyate blend, and F-T50 = 50% Fischer-Tropsch diesel blend.

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

[c] Based on GREET estimates for conventional diesel.

For all model years beyond 2003, operational emissions are then calculated as:

$$OPER_{jlm} = OPER_{Gasolinejl} \times TIER2_l \times ERATIO_{lm} \ , \qquad (9)$$

where

$OPER_{Gasolinejl}$ = operational emission rate from gasoline-fueled conventional-technology vehicles at age j for pollutant l,

$TIER2_l$ = ratio of Tier 2 to Tier 1 emission standard for pollutant l, and

$ERATIO_{lm}$ = ratio of the emission rate of pollutant l from fuel m to its rate from gasoline.

For SO_X, emission rates are not available from MOBILE5b. Thus, operational emissions are calculated as a function of fuel characteristics (Table 7) by using the following equation:

$$OPSOX_{im} = \frac{FUEL_{im}}{1{,}000{,}000} \times DENSITY_{im} \times \frac{SRATIO_{im}}{1{,}000} \times \frac{64}{32} \quad , \qquad (10)$$

where

$OPSOX_{im}$ = operational emissions of SO_X in year i for fuel m,

$FUEL_{im}$ = fuel use (in GGE) in year i for fuel m,

$DENSITY_{im}$ = fuel density (in g/gal) in year i for fuel m, and

$SRATIO_{im}$ = sulfur ratio (by weight) in year i for fuel m.

2.2.3.2 Upstream Emissions

Emissions are produced by such upstream activities as primary energy recovery; primary energy transportation and storage; fuel production; and fuel transportation, storage, and

TABLE 7 Properties of 11 Potential Fuels for 3X Vehicles[a]

Fuel	LHV (Btu/gal)	HHV (Btu/gal)	Density (g/gal)	Carbon Ratio (wt)	Sulfur Ratio (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 (FTD)	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 heating value, SCF = standard cubic foot.

[b] Under pressure.

distribution. Upstream emissions are estimated as the product of the quantity of fuel consumed in vehicle operation and an upstream emission rate that includes contributions from all these sources. Upstream emission rates (in g/gal) are obtained from GREET 1.4 outputs. Tables 8 and 9 present the emission rates used for the PNGV analysis. Upstream emissions are calculated as:

$$UPEMIS_{ilm} = FUEL_{im} \times UPER_{ilm} \ , \qquad (11)$$

where

$UPEMIS_{ilm}$ = upstream emissions in year i of pollutant l from fuel m and

$UPER_{ilm}$ = upstream emission rate (in g/GGE) in year i of pollutant l from fuel m.

2.2.3.3 Value of Emissions

IMPACTT5 contains damage cost factors for NO_x, CO, and VOC that are based on the cost (in 1992 $/ton) of removing a ton of NO_x, CO, and VOC from stationary sources. Developed by the Congressional Budget Office, the factors can be used to convert physical quantities into dollar values that can then be summed across years and pollutants to produce a single environmental cost associated with each propulsion system/fuel combination. These factors were not used in the PNGV infrastructure analysis. IMPACTT5 does not contain damage cost factors for SO_x and PM_{10}.

TABLE 8 Upstream Emission Rates by Fuel and Pollutant in 2007

Pollutant	RFG	RFD	CNG	LNG	LPG	Methanol	DME	F-T Diesel
	Upstream Emission Rate (g/GGE) per 10^6 Btu of Fuel Produced							
All Locations								
VOC	18.126	9.532	7.222	27.577	8.950	34.569	30.452	6.258
CO	24.133	21.066	27.667	60.077	23.737	80.318	79.750	45.196
NO_x	38.047	26.832	66.086	112.926	32.382	164.641	163.778	63.562
PM_{10}	4.022	2.703	3.618	11.699	1.678	4.072	3.981	2.403
SO_x	27.002	17.219	35.707	16.537	9.848	9.292	8.740	9.266
CH_4	89.572	78.441	220.742	221.533	102.392	150.830	150.295	110.821
N_2O	2.395	1.474	4.126	10.644	0.875	1.118	1.084	0.639
CO_2	21,257	13,348	17,836	17,616	10,377	30,623	31,430	58,966
Urban Locations								
VOC	4.869	1.727	0.426	4.020	2.747	3.187	1.561	0.204
CO	1.471	1.381	1.446	4.047	1.886	1.197	1.007	0.849
NO_x	2.159	1.946	3.281	4.120	2.344	1.576	1.329	1.088
PM_{10}	0.141	0.135	0.082	3.928	0.188	0.163	0.137	0.113
SO_x	0.234	0.207	0.113	3.938	0.244	0.709	0.594	0.530

Pollutant	NG H_2	Solar H_2	Corn Ethanol: Wet	Corn Ethanol: Dry	Cellulosic Ethanol	Biodiesel	F-T50	B20
	Upstream Emission Rate (g/GGE) per 10^6 Btu of Fuel Produced							
All Locations								
VOC	32.667	9.443	29.773	30.276	25.279	93.629	7.895	25.174
CO	94.726	25.911	118.909	121.255	89.152	57.621	33.131	27.865
NO_x	245.018	104.376	175.603	188.932	58.592	102.149	45.197	40.841
PM_{10}	9.834	6.717	51.470	51.470	21.543	4.759	2.553	3.085
SO_x	74.173	68.583	89.158	100.884	-39.819	25.092	13.243	18.684
CH_4	207.696	65.901	107.598	117.235	-17.305	53.535	94.631	73.808
N_2O	9.194	8.380	43.442	46.751	14.850	6.958	1.056	2.494
CO_2	110,616	26,600	46,233	50,599	-6,630	21,948	36,157	14,948
Urban Locations								
VOC	2.390	2.388	3.733	3.759	3.557	2.326	0.965	1.838
CO	6.458	6.448	4.122	4.350	2.910	3.995	1.115	1.867
NO_x	15.869	15.877	7.961	8.365	5.736	3.578	1.517	2.249
PM_{10}	0.318	0.316	0.536	0.554	0.446	0.129	0.124	0.134
So_x	0.243	0.236	0.284	0.326	0.077	0.164	0.369	0.199

TABLE 9 Upstream Emission Rates by Fuel and Pollutant in 2030

	Upstream Emission Rate (g/GGE) per 10^6 Btu of Fuel Produced							
Pollutant	RFG	RFD	CNG	LNG	LPG	Methanol	DME	F-T Diesel
All Locations								
VOC	17.365	8.908	3.439	17.318	6.993	17.059	12.955	3.592
CO	23.374	20.615	26.955	57.645	23.226	64.796	64.231	41.264
NO_x	32.474	23.243	53.706	106.512	29.163	125.823	125.056	55.696
PM_{10}	3.626	2.446	2.624	11.597	1.504	3.352	3.268	2.138
SO_x	20.540	12.889	18.304	14.748	6.731	6.695	6.347	7.030
CH_4	89.646	78.482	221.159	220.866	102.384	140.996	140.459	110.267
N_2O	0.308	0.197	0.444	10.251	0.178	0.619	0.613	0.298
CO_2	21,251	13,344	17,811	17,650	10,377	23,548	24,355	58,969
Urban Locations								
VOC	4.806	1.676	0.209	4.019	2.700	3.161	1.540	0.185
CO	1.525	1.418	1.646	4.069	1.917	1.210	1.019	0.863
NO_x	2.240	1.999	3.612	4.160	2.387	1.568	1.324	1.089
PM_{10}	0.147	0.139	0.104	3.930	0.191	0.165	0.138	0.115
SO_x	0.178	0.160	0.069	3.931	0.194	0.517	0.433	0.386

	Upstream Emission Rate (g/GGE) per 10^6 Btu of Fuel Produced							
Pollutant	NG H_2	Solar H_2	Corn Ethanol: Wet	Corn Ethanol: Dry	Cellulosic Ethanol	Biodiesel	F-T50	B20
All Locations								
VOC	13.194	4.350	23.868	22.244	25.212	73.709	6.250	20.961
CO	86.162	25.085	93.420	76.473	89.041	47.979	30.940	25.705
NO_x	201.146	80.690	152.087	169.920	73.246	76.257	39.469	33.103
PM_{10}	7.494	4.664	47.075	44.451	22.989	3.287	2.292	2.603
SO_x	37.234	32.669	40.460	6.730	-13.686	10.411	9.960	12.428
CH_4	203.894	66.401	95.581	107.360	-19.366	42.337	94.375	71.759
N_2O	1.362	0.781	36.501	35.091	20.399	3.823	0.247	0.872
CO_2	107,876	26,538	37,171	34,173	-7,084	17,344	36,156	14,088
Urban Locations								
VOC	1.006	0.997	3.670	3.686	3.524	2.247	0.931	1.782
CO	6.788	6.769	4.140	4.262	2.555	3.981	1.140	1.895
NO_x	16.191	16.179	8.031	8.357	5.052	3.560	1.544	2.289
PM_{10}	0.364	0.361	0.537	0.542	0.411	0.130	0.127	0.137
So_x	0.149	0.145	0.249	0.248	0.131	0.109	0.273	0.150

3 Input Data

3.1 Vehicle Stock Calculations

IMPACTT5 operates on a set of assumptions that define a particular scenario. Chief among these assumptions are the market-penetration rates for advanced-technology vehicles. The default assumption in IMPACTT5 is that advanced-technology vehicles will replace conventional-technology vehicles on a one-for-one basis. IMPACTT5 can model technologies that do not necessarily replace conventional-technology vehicles (e.g., advanced-battery electric vehicles, which some claim may have a unique, incremental market demand), if appropriate modifications to the sales forecast and conventional-technology market assumptions are made. However, for the PNGV infrastructure analysis, such modifications were not necessary. Market penetration was assumed to be identical for all candidate technologies in the LDV market. The methodology used to develop the PNGV high- and low-market-share scenarios is discussed in Wang et al. (1998). Previous analyses used a vehicle choice model known as AVS (Fulton 1991) to generate the market-penetration rates, although any vehicle choice model or set of assumed penetration rates could provide the required inputs for IMPACTT5. Table 10 presents the market-penetration assumptions of the two scenarios used in the PNGV infrastructure assessment. Note that 3X vehicles are assumed to penetrate car and light truck markets equally.

To estimate the number of new advanced-technology vehicles on the road in a given year, market-penetration rates must be combined with an external forecast of new vehicle sales by vehicle type, and vehicles must be tracked through a survival or vintaging procedure. The default vehicle sales forecast contained in IMPACTT is provided in Table 3. The internal scrappage function uses two basic input parameters, A_0 and A_1, which are set at $A_0 = 0.7355$ and $A_1 = 6.0917$ in the current version of the model.

3.2 Usage Calculations

The USAGE module estimates VMT per year as a function of vehicle age. The key parameters, miles per year for a new vehicle and a degradation rate, are the same for all vehicle technologies examined in the PNGV infrastructure assessment. (Electric vehicles, which might have lower utilization rates than conventional LDVs, were not examined.) Default values (mi/yr by vehicle age) are shown in Table 11.

3.3 Energy Calculations

Energy calculations are very simple in IMPACTT5. The calculation of substitution-fuel use is a function of VMT and new advanced-technology vehicle MPG. For all LDVs, MPG (as

TABLE 10 Market Penetration of 3X Vehicles by Scenario

Year	Percent Share of New LDV Sales	
	High Market Share	Low Market 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

Source: Wang et al. (1998).

TABLE 11 Default Annual Mileage for Autos and Light Trucks by Age

Vehicle Age	Miles per Year
<1	14,523
1–2	13,871
2–3	13,248
3–4	12,653
4–5	12,085
5–6	11,542
6–7	11,024
7–8	10,529
8–9	10,056
9–10	9,605
10–11	9,174
11–12	8,762
12–13	8,368
13–14	7,993
14–15	7,634
15–16	7,291
16–17	6,964
17–18	6,651
18–19	6,352
19–20	6,067
20–21	5,795
21+	5,534

Sources: Greene and Rathi (1990) and U.S. Bureau of the Census (no date).

estimated by the EPA test cycle) is adjusted by a factor of 0.814 to reflect a typical discrepancy (or gap) between test conditions and actual on-road experience. In earlier versions of the model, the Btu content of the candidate fuel was also used in the equation. Now, however, all *quantities* are reported in gallons of gasoline-equivalent.

3.4 Emission Calculations

The EMISSIONS module calculates annual emissions from vehicle operations and upstream activities beginning in the first year for which all parameters are supplied. For both automobiles and light trucks, MOBILE5b reports *operational* emission rates for model years beginning in 1967. Thus, IMPACTT5 calculates baseline operational emissions for model year 1967 and later vehicles beginning in calendar year 1970. Emissions are calculated for conventional-technology vehicles from model year 1990 onward under all other scenarios, and for advanced-technology vehicles from model year 2007 under the PNGV high-market-share scenario and from model year 2013 under the PNGV low-market-share scenario. Note that because calculations are for new vehicles sold in the year of the calculation plus surviving vehicles of older vintages for which all parameters had been supplied, values reported as "total operational emissions" are below true totals for the first 10–15 years of the calculation.

Under all scenarios (baseline, high, and low) Tier 2 emission standards are assumed to go into effect in 2003. No further emission improvements are assumed. Note that MOBILE5 emission rates include the effect of deterioration over time for conventional-technology vehicles. For advanced-technology vehicles, IMPACTT5 can capture deterioration over time via input emission rates by vehicle age. For the PNGV application, emissions of advanced-technology SI and CI engines are assumed to increase over time at the historical rates for conventional-technology SI and CI engines, with one notable exception. Emissions of CI engines tend to increase less rapidly over time than emissions of SI engines, and all CI fuels are assumed to meet the stringent ultra low emission vehicle (ULEV) standard of 0.04 g/mi for PM_{10}. If PM_{10} emissions from advanced-technology CI engines were assumed to increase at the same historical rate as those from conventional-technology CI engines, older CI engines would emit less PM_{10} than SI engines of the same age. Since this is unlikely, PM_{10} emissions from CI engines were assumed to increase over time at the same rate as those from SI engines.[8]

For upstream emissions, input rates (in g/gal) are obtained from GREET 1.4. Further information on the methodology and input assumptions behind those rates may be found in Wang et al. (1998).

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[8] CI engines are likely to require after-treatment to meet Tier 2 standards. Deterioration of after-treatment devices accounts for much of the increase in emissions by older SI engines. Future CI engines equipped with after-treatment devices thus may be expected to experience larger increases in emissions over time than current CI engines.

4 Sample Output

Tables 2–11 contain the key inputs needed to define a full IMPACTT5 scenario. Output values of interest are reported on one or more of the general or scenario-specific worksheets (sometimes both). These are summarized for the PNGV application in Tables 12–13. Tables 14 and 15 contain data transcribed form VMT_SUM, which summarizes results from each of the PNGV and ICE worksheets (in this case, ICE_CAR HIGH, ICE_LTRK HIGH, PNGV_CAR HIGH, and PNGV_LTRK HIGH). Tables 16 and 17 are similarly transcribed from the CON_SUM worksheet, which summarizes operational fuel use from each of the same PNGV and ICE worksheets. Emission results, by pollutant and fuel/technology alternative, cannot be readily summarized in one or two tables. Thus, emissions from vehicle operations are reported in Appendix A.

TABLE 12 Number of Conventional-Technology and 3X Vehicles on the Road under the High-Market-Share Scenario (10^6)

	Conventional Vehicles			3X Vehicles			
Year	Auto	Light Truck	Total	Auto	Light Truck	Total	All LDVs
2005	130	74	204	0	0	0	204
2006	130	76	206	0	0	0	206
2007	129	77	206	0	0	0	206
2008	130	79	209	0	0	0	210
2009	133	82	215	0	0	0	215
2010	135	84	220	0	0	0	220
2011	138	86	224	0	0	1	224
2012	139	88	227	1	0	1	228
2013	141	89	230	1	1	2	232
2014	142	90	232	2	1	3	235
2015	142	91	232	3	2	5	237
2016	141	91	232	4	3	7	239
2017	141	90	231	6	4	10	241
2018	139	89	228	9	6	14	243
2019	137	88	225	12	7	19	244
2020	134	86	221	15	10	25	245
2021	131	84	215	19	12	31	246
2022	128	82	209	23	15	38	247
2023	124	79	203	28	18	46	248
2024	119	76	195	33	21	54	249
2025	114	73	187	39	25	64	250
2026	109	69	178	45	28	73	251
2027	104	66	169	51	32	83	252
2028	98	63	161	57	36	92	253
2029	94	59	153	62	39	101	254
2030	89	57	146	67	42	109	255

TABLE 13 Number of Conventional-Technology and 3X Vehicles on the Road under the Low-Market-Share Scenario (10^6)

	Conventional Vehicles			3X Vehicles			
Year	Auto	Light Truck	Total	Auto	Light Truck	Total	All LDVs
2005	130	74	204	0	0	0	204
2006	130	76	206	0	0	0	206
2007	129	77	206	0	0	0	206
2008	130	79	210	0	0	0	210
2009	133	82	215	0	0	0	215
2010	136	84	220	0	0	0	220
2011	138	86	224	0	0	0	224
2012	140	88	228	0	0	0	228
2013	142	90	232	0	0	0	232
2014	143	91	234	0	0	0	235
2015	144	92	236	0	0	1	237
2016	145	93	238	1	0	1	239
2017	146	93	239	1	1	2	241
2018	147	94	240	1	1	2	243
2019	147	94	241	2	1	3	244
2020	147	94	241	2	1	4	245
2021	147	94	241	3	2	5	246
2022	147	94	241	4	2	6	247
2023	147	94	241	5	3	8	248
2024	146	93	240	6	4	10	249
2025	146	93	238	7	5	12	250
2026	144	92	236	9	6	15	251
2027	143	91	234	11	7	18	252
2028	141	90	231	14	9	22	253
2029	139	88	227	16	10	27	254
2030	137	86	223	20	12	32	255

TABLE 14 Vehicle-Miles Traveled by Conventional-Technology and 3X Vehicles under the High-Market-Share Scenario (10^9)

	Conventional Vehicles			3X Vehicles			
Year	Auto	Light Truck	Total	Auto	Light Truck	Total	All LDVs
2005	0	0	0	1,584	850	2,434	2,434
2006	0	0	0	1,595	872	2,467	2,467
2007	0	0	0	1,599	891	2,489	2,489
2008	1	0	1	1,616	912	2,529	2,530
2009	2	1	3	1,649	941	2,589	2,592
2010	4	2	6	1,677	966	2,643	2,648
2011	6	4	10	1,700	986	2,686	2,696
2012	11	6	17	1,720	1,002	2,722	2,739
2013	17	10	27	1,735	1,015	2,750	2,778
2014	27	16	44	1,745	1,024	2,769	2,813
2015	43	25	69	1,747	1,027	2,773	2,842
2016	66	39	105	1,740	1,024	2,763	2,869
2017	96	56	152	1,725	1,015	2,741	2,892
2018	132	77	209	1,703	1,002	2,706	2,915
2019	174	102	276	1,674	985	2,659	2,935
2020	222	130	352	1,639	963	2,603	2,955
2021	277	162	439	1,597	938	2,535	2,974
2022	338	197	535	1,549	908	2,457	2,992
2023	405	236	641	1,494	875	2,369	3,010
2024	478	278	756	1,434	839	2,273	3,028
2025	555	323	878	1,369	800	2,169	3,046
2026	636	369	1,005	1,301	759	2,060	3,065
2027	715	415	1,129	1,234	719	1,954	3,083
2028	789	458	1,247	1,172	682	1,854	3,101
2029	858	498	1,356	1,115	649	1,764	3,120
2030	922	534	1,456	1,065	618	1,683	3,139
1990–2000	0	0	0	16,915	6,337	23,253	23,253
1990–2010	6	4	10	32,907	14,927	47,834	47,844
1990–2020	801	469	1,270	50,035	24,971	75,006	76,277
1990–2030	6,774	3,938	10,712	63,367	32,757	96,124	106,836

TABLE 15 Vehicle-Miles Traveled by Conventional-Technology and 3X Vehicles under the Low-Market-Share Scenario (10^9)

	Conventional Vehicles			3X Vehicles			
Year	Auto	Light Truck	Total	Auto	Light Truck	Total	All LDVs
2005	0	0	0	1,584	850	2,434	2,434
2006	0	0	0	1,595	872	2,467	2,467
2007	0	0	0	1,599	891	2,489	2,489
2008	0	0	0	1,617	913	2,530	2,530
2009	0	0	0	1,651	942	2,592	2,592
2010	0	0	0	1,681	968	2,648	2,648
2011	0	0	0	1,707	989	2,696	2,696
2012	0	0	0	1,730	1,009	2,739	2,739
2013	1	1	2	1,751	1,025	2,776	2,778
2014	3	2	5	1,769	1,039	2,808	2,813
2015	6	4	10	1,784	1,049	2,832	2,842
2016	10	6	16	1,796	1,057	2,853	2,869
2017	14	8	23	1,806	1,063	2,870	2,892
2018	20	12	32	1,815	1,068	2,883	2,915
2019	27	16	42	1,822	1,071	2,893	2,935
2020	35	20	55	1,827	1,073	2,900	2,955
2021	44	26	70	1,830	1,073	2,903	2,974
2022	56	33	89	1,831	1,072	2,903	2,992
2023	71	41	112	1,829	1,070	2,899	3,010
2024	88	51	139	1,824	1,065	2,889	3,028
2025	109	63	172	1,816	1,059	2,875	3,046
2026	134	78	211	1,803	1,050	2,854	3,065
2027	163	95	258	1,786	1,039	2,825	3,083
2028	198	115	313	1,763	1,025	2,789	3,101
2029	239	138	378	1,735	1,008	2,743	3,120
2030	286	166	452	1,700	987	2,687	3,139

TABLE 16 Fuel Use by Conventional-Technology and 3X Vehicles under the High-Market-Share Scenario (10^6 Gallons of Gasoline Equivalent [GGE])

	Conventional Vehicles			3X Vehicles			
Year	Auto	Light Truck	Total	Auto	Light Truck	Total	All LDVs
2005	68,166	54,059	122,225	0	0	0	122,225
2006	68,694	55,380	124,074	0	0	0	124,074
2007	69,063	56,559	125,622	3	2	5	125,627
2008	69,213	57,498	126,711	11	9	21	126,732
2009	69,963	58,785	128,747	28	23	51	128,798
2010	70,494	59,809	130,302	55	45	101	130,403
2011	70,800	60,476	131,275	99	81	180	131,455
2012	70,946	60,887	131,833	164	134	298	132,131
2013	70,947	61,072	132,019	265	216	481	132,500
2014	70,749	60,967	131,716	424	345	769	132,485
2015	70,242	60,516	130,759	670	544	1,213	131,972
2016	69,445	59,771	129,216	1,024	829	1,853	131,069
2017	68,388	58,761	127,150	1,482	1,198	2,680	129,830
2018	67,092	57,517	124,609	2,041	1,647	3,687	128,296
2019	65,574	56,064	121,637	2,694	2,171	4,865	126,502
2020	63,855	54,426	118,282	3,438	2,766	6,204	124,486
2021	61,905	52,590	114,495	4,287	3,445	7,732	122,227
2022	59,742	50,580	110,322	5,235	4,202	9,437	119,759
2023	57,387	48,418	105,805	6,273	5,031	11,304	117,109
2024	54,858	46,125	100,983	7,395	5,925	13,321	114,303
2025	52,177	43,722	95,899	8,593	6,879	15,472	111,370
2026	49,405	41,263	90,668	9,838	7,870	17,708	108,376
2027	46,709	38,886	85,595	11,061	8,844	19,905	105,500
2028	44,197	36,677	80,873	12,217	9,764	21,981	102,854
2029	41,909	34,669	76,578	13,287	10,614	23,901	100,479
2030	39,855	32,867	72,721	14,266	11,393	25,659	98,380
2005–2010	415,593	342,090	757,683	97	80	177	757,860
2005–2020	1,103,631	932,547	2,036,178	12,397	10,010	22,407	2,058,585
2005–2030	1,611,775	1,358,344	2,970,119	104,850	83,977	188,826	3,158,945

TABLE 17 Fuel Use by Conventional-Technology and 3X Vehicles under the Low-Market-Share Scenario (10^6 Gallons of Gasoline Equivalent [GGE])

	Conventional Vehicles			3X Vehicles			
Year	Auto	Light Truck	Total	Auto	Light Truck	Total	All LDVs
2005	68,166	54,059	122,225	0	0	0	122,225
2006	68,694	55,380	124,074	0	0	0	124,074
2007	69,071	56,566	125,637	0	0	0	125,637
2008	69,243	57,524	126,767	0	0	0	126,767
2009	70,035	58,849	128,884	0	0	0	128,884
2010	70,636	59,935	130,571	0	0	0	130,571
2011	71,053	60,698	131,751	0	0	0	131,751
2012	71,364	61,251	132,615	0	0	0	132,615
2013	71,581	61,622	133,203	15	12	27	133,230
2014	71,700	61,786	133,486	46	38	84	133,570
2015	71,683	61,749	133,432	95	77	172	136,604
2016	71,617	61,619	133,236	153	124	277	133,513
2017	71,515	61,409	132,924	224	181	405	133,329
2018	71,378	61,133	132,511	310	250	560	133,071
2019	71,205	60,798	132,003	413	332	745	132,748
2020	70,992	60,407	131,399	539	433	972	132,371
2021	70,737	59,971	130,708	689	553	1,242	131,950
2022	70,423	59,482	129,905	871	699	1,570	131,475
2023	70,033	58,930	128,963	1,093	876	1,969	130,932
2024	69,548	58,304	127,852	1,361	1,090	2,451	130,303
2025	68,951	57,595	126,546	1,683	1,347	3,030	129,576
2026	68,216	56,784	125,000	2,068	1,654	3,722	128,722
2027	67,320	55,856	123,176	2,527	2,019	4,546	127,722
2028	66,240	54,792	121,032	3,066	2,449	5,515	126,547
2029	64,950	53,569	118,519	3,699	2,954	6,653	125,172
2030	63,430	52,173	115,603	4,434	3,539	7,973	123,576
2005–2010	415,845	342,313	758,158	0	0	0	758,158
2005–2020	1,129,933	954,785	2,084,718	1,795	1,447	3,242	2,087,960
2005–2030	1,809,781	1,522,241	3,332,022	23,286	18,627	41,913	3,373,935

5 Proposed Additional Enhancements

IMPACTT5 will benefit from further improvements to GREET and also from a more efficient manner of processing individual scenarios and technology penetration forecasts. Because there is interest in the constituents of airborne fine particulate matter ($PM_{2.5}$, which has a diameter equal to or smaller than 2.5 μm), especially the formation of secondary nitrates and sulfates from primary nitrogen and sulfur oxide exhaust, GREET will seek to disaggregate its reporting of PM attributable to vehicular activity by species as well as size fraction. Secondary nitrate and sulfate emission factors could then be based on the respective share of nitric and sulfur oxide emissions chemically transformed to ammonium nitrate and similar nitrate compounds. Further, as GREET is expanded to include additional propulsion system/fuel combinations (e.g., ethanol fuel cells) as well as revised/enhanced emission factors (e.g., from EPA's MOBILE6 model), the ability to assess the impact of such revisions will be incorporated into IMPACTT5.

With respect to IMPACTT5's overall structure, its many past applications have been accommodated by simply adding technology-specific or scenario-specific flat files to the workbook. This practice has led, on occasion, to the retention of very large and unwieldy worksheet files that may be incompatible with the memory limits of some older desktop systems. A possible remedy for this shortcoming would be to store all scenario-specific and technology-specific data as more compact external database (.dbf) files that can be invoked sequentially within a basic shell model. Results could then be computed and captured without having to save inputs or intermediate computations as spreadsheets. Since the intent is to make IMPACTT5 more portable, more transferable, and able to deal relatively quickly with any size perturbation in a technology or energy forecast, these enhancements are being seriously considered.

6 References

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Appendix A:

README File

Appendix A:

README File

The Integrated Market Penetration and Anticipated Cost of Transportation Technologies (IMPACTT) model was developed by Argonne National Laboratory's Center for Transportation Research to assist the U.S. Department of Energy (DOE), Office of Transportation Technologies (OTT), with program planning and development. Written in EXCEL 5.0 workbook format, IMPACTT is a spreadsheet model operating in either an Apple or a PC/Windows environment. The version that is the subject of this writeup consists of 10 worksheets. Six of them apply to all technologies (i.e., general worksheets), and the other four are specific to a particular combination of vehicle class and technology type. The general worksheets are called ICE_CAR-REF, ICE_LTRK-REF, SALES-MPG, VMT_SUM, CON_SUM, and SUMMARY.

A.1 General Worksheets

To estimate the number of new advanced-technology vehicles on the road in a given year, market-penetration rates must be combined with an external forecast of new vehicle sales by vehicle type, and vehicles must be tracked through a survival or vintaging procedure. User-supplied forecasts of market penetration and marginal cost for the advanced technology are input to the ICE_CAR-REF and ICE_LTRK-REF worksheets for each year of the analysis. ICE_CAR-REF and ICE_LTRK-REF also contain annual estimates of vehicle sales, fuel economy, and operational emission rates for nitrogen oxides (NO_x), carbon monoxide (CO), volatile organic compounds (VOCs), and particulate matter (PM) by vehicle age or vintage for the years 1970–1995, as well as fuel specifications that are used to calculate emissions of sulfur oxides (SO_x). Expressed in grams per mile (g/mi), emission rates were computed from the U.S. Environmental Protection Agency's (EPA's) MOBILE5b and Part models.

The SALES_MPG worksheet converts user-supplied forecasts of fuel economy into weighted averages for input into the stock model and for calculations of oil displacement and fuel substitution. Users can input either EPA-test or estimated on-road fuel economy. Default forecasts of sales and EPA-test fuel economy were extrapolated from those in the 1997 Annual Energy Outlook (DOE 1996). Default estimates of on-road fuel economy assume a shortfall or gap of about 20% from EPA test results, which are the default inputs (Mintz et al. 1993).

Three of the general worksheets aggregate results from the technology-specific worksheets. Outputs include number of conventional- and advanced-technology vehicles on the road; vehicle-miles traveled (VMT) by conventional and tripled-fuel-economy (3X) vehicles; and emissions of criteria pollutants and greenhouse gases for conventional vehicles and for each 3X propulsion system/fuel combination under consideration by the Partnership for a New Generation of Vehicles (PNGV).

The VMT_SUM worksheet summarizes annual vehicle counts, fleet-average fuel economy (in mi/gallon of gasoline-equivalent or GGE), and VMT by conventional- and advanced-technology vehicles. The CON_SUM worksheet provides an intermediate summary of annual energy consumed in vehicle operation (operational energy) and upstream emissions of criteria pollutants and greenhouse gases by propulsion system/fuel combination. For both CON_SUM and VMT_SUM, results are reported annually for 1990–2030 and cumulatively (as appropriate) for the periods 1990–2000, 1990–2010, 1990–2020, and 1990–2030.

The SUMMARY worksheet is a printer-formatted summary of total energy and emission results from 2005 to 2030 for the sum of conventional-technology vehicles and each candidate 3X propulsion system/fuel combination under the market-penetration scenario being considered.

A.2 Technology-Specific Worksheets

IMPACTT operates on a set of assumptions that define a particular scenario. The high-market-share scenario developed for the assessment of infrastructure impacts of 3X vehicles is the default case contained in the workbook file. That scenario requires the use of four technology-specific worksheets: ICE_CAR-HIGH, ICE_LTRK-HIGH, PNGV_CAR-HIGH, and PNGV_LTRK-HIGH. Because this setup is somewhat different from the typical workbook configuration in which IMPACTT5 operates, it was given the name IMPACTT5A.

Unless advanced technologies are assumed to be mutually exclusive, each advanced technology ordinarily would have a technology-specific worksheet associated with it. This is the typical scenario in which IMPACTT operates. However, for the PNGV infrastructure analysis, a conscious decision was made to develop a worst-case scenario. Since impacts associated with a given fuel are maximized under conditions of very high demand for that fuel, advanced-technology vehicles were limited to sharing the new vehicle market with conventional-technology vehicles, not with each other, in that analysis. Thus, a single advanced-technology worksheet covers all 3X vehicles in the automotive market (PNGV_CAR-HIGH), while another covers all 3X vehicles in the light truck market (PNGV_LTRK-HIGH).

Chief among the parameters used to define a particular scenario are the market-penetration rates for the various advanced technologies. These, in turn, are a key component of the vehicle stock calculation. The default assumption in IMPACTT is that advanced-technology vehicles replace conventional-technology vehicles (and conventional-technology vehicle VMT) on a one-for-one basis.

The USAGE module estimates VMT per year as a function of vehicle age. The key parameters are miles per year for a new vehicle and a deterioration rate. In the high-market-share scenario, advanced- and conventional-technology vehicles are assumed to have the same survival and annual utilization rates, but different fuel economy and emission rates.

Several technology-specific parameters may be user-defined. These include:

- Gasoline-equivalent fuel economy (GEMPG, entered on the worksheet SALES-MPG);

- Upstream energy and emission rates (in Btu/10^6 Btu and g/10^6 Btu) for each propulsion system/fuel combination being examined (entered on ICE_CAR-HIGH and ICE_LTRK-HIGH for conventional-technology vehicles and on CON_SUM for 3X vehicles);

- Operational emission rates (in g/mi) for conventional-technology vehicles (entered directly on ICE_CAR-HIGH and ICE_LTRK-HIGH and entered as ratios relative to Tier 2, spark-ignition, direct-injection [SIDI] engines running on reformulated gasoline for each propulsion system/fuel combination on PNGV_CAR-HIGH and PNGV_LTRK-HIGH); and

- Fuel specifications, such as density, heating value (Btu/gal or other physical unit), sulfur ratio, and carbon ratio (entered on ICE_CAR-HIGH and ICE_LTRK-HIGH for conventional-technology vehicles and on PNGV_CAR-HIGH and PNGV_LTRK-HIGH for 3X vehicles).

A.3 References for Appendix A

DOE, 1996, *Annual Energy Outlook, 1997*, DOE/EIA-0383(97), U.S. Department of Energy, Energy Information Administration, Dec.

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Appendix B:

Estimates of Operational, Upstream, and Total Emissions and Energy Use and of Global Warming Potential under the Baseline Scenario and High-Market-Share Scenario by 3X Technology/Fuel Combination*

* RFG = reformulated gasoline, MeOH = methanol, EtOH = ethanol, RFD = reformulated diesel, DME = dimethyl ether, HFCV = hydrogen fuel cell vehicle, MFCV = methanol fuel cell vehicle, GFCV = gasoline fuel cell vehicle, F-T50 = 50% Fischer-Tropsch diesel, B20 = 20% biodiesel blend, LPG = liquefied petroleum gas, CNG = compressed natural gas, LNG = liquefied natural gas.

TABLE B.1 Operational Emissions of NO_x under the Baseline Scenario and for Conventional-Technology Plus 3X Vehicles under the High-Market-Share Scenario (10^3 metric tons)

Year	Base Case	RFG	MeOH	EtOH	RFD	DME	HFCV	MFCV	GFCV	F-T50	B20	LPG	CNG	LNG
2005	2,550	2,414	2,414	2,414	2,414	2,414	2,414	2,414	2,414	2,414	2,414	2,414	2,414	2,414
2006	2,503	2,421	2,421	2,421	2,421	2,421	2,421	2,421	2,421	2,421	2,421	2,421	2,421	2,421
2007	2,448	2,402	2,402	2,402	2,402	2,402	2,402	2,402	2,402	2,402	2,402	2,402	2,402	2,402
2008	2,373	2,350	2,350	2,350	2,350	2,350	2,350	2,350	2,350	2,350	2,350	2,350	2,350	2,350
2009	2,331	2,322	2,322	2,322	2,322	2,322	2,322	2,322	2,322	2,322	2,322	2,322	2,322	2,322
2010	2,273	2,273	2,273	2,273	2,273	2,273	2,272	2,272	2,272	2,273	2,273	2,273	2,273	2,273
2011	2,204	2,204	2,204	2,204	2,204	2,204	2,202	2,202	2,202	2,204	2,204	2,204	2,204	2,204
2012	2,128	2,128	2,128	2,128	2,128	2,128	2,125	2,125	2,125	2,128	2,128	2,128	2,128	2,128
2013	2,053	2,053	2,053	2,053	2,053	2,053	2,047	2,047	2,047	2,053	2,053	2,053	2,053	2,053
2014	1,981	1,981	1,981	1,981	1,981	1,981	1,972	1,972	1,972	1,981	1,981	1,981	1,981	1,981
2015	1,917	1,917	1,917	1,917	1,917	1,917	1,903	1,903	1,903	1,917	1,917	1,917	1,917	1,917
2016	1,864	1,864	1,864	1,864	1,864	1,864	1,841	1,841	1,841	1,864	1,864	1,864	1,864	1,864
2017	1,823	1,823	1,823	1,823	1,823	1,823	1,788	1,789	1,789	1,823	1,823	1,823	1,823	1,823
2018	1,793	1,793	1,793	1,793	1,793	1,793	1,743	1,743	1,743	1,793	1,793	1,793	1,793	1,793
2019	1,772	1,772	1,772	1,772	1,772	1,772	1,702	1,703	1,703	1,772	1,772	1,772	1,772	1,772
2020	1,760	1,760	1,760	1,760	1,760	1,760	1,665	1,666	1,666	1,760	1,760	1,760	1,760	1,760
2021	1,754	1,754	1,754	1,754	1,754	1,754	1,629	1,630	1,630	1,754	1,754	1,754	1,754	1,754
2022	1,753	1,753	1,753	1,753	1,753	1,753	1,590	1,592	1,592	1,753	1,753	1,753	1,753	1,753
2023	1,755	1,755	1,755	1,755	1,755	1,755	1,549	1,551	1,551	1,755	1,755	1,755	1,755	1,755
2024	1,763	1,763	1,763	1,763	1,763	1,763	1,507	1,509	1,509	1,763	1,763	1,763	1,763	1,763
2025	1,770	1,770	1,770	1,770	1,770	1,770	1,459	1,462	1,462	1,770	1,770	1,770	1,770	1,770
2026	1,778	1,778	1,778	1,778	1,778	1,778	1,405	1,409	1,409	1,778	1,778	1,778	1,778	1,778
2027	1,785	1,785	1,785	1,785	1,785	1,785	1,348	1,352	1,352	1,785	1,785	1,785	1,785	1,785
2028	1,793	1,793	1,793	1,793	1,793	1,793	1,288	1,293	1,293	1,793	1,793	1,793	1,793	1,793
2029	1,801	1,801	1,801	1,801	1,801	1,801	1,226	1,232	1,232	1,801	1,801	1,801	1,801	1,801
2030	1,809	1,809	1,809	1,809	1,809	1,809	1,165	1,172	1,172	1,809	1,809	1,809	1,809	1,809

TABLE B.2 Operational Emissions of CO under the Baseline Scenario and for Conventional-Technology Plus 3X Vehicles under the High-Market-Share Scenario (10^3 metric tons)

Year	Base Case	RFG	MeOH	EtOH	RFD	DME	HFCV	MFCV	GFCV	F-T50	B20	LPG	CNG	LNG
2005	39,651	37,408	37,408	37,408	37,408	37,408	37,408	37,408	37,408	37,408	37,408	37,408	37,408	37,408
2006	39,009	37,649	37,649	37,649	37,649	37,649	37,649	37,649	37,649	37,649	37,649	37,649	37,649	37,649
2007	38,230	37,469	37,469	37,469	37,469	37,469	37,469	37,469	37,469	37,469	37,469	37,469	37,469	37,469
2008	37,098	36,724	36,724	36,724	36,723	36,723	36,721	36,721	36,721	36,723	36,723	36,724	36,724	36,724
2009	36,477	36,338	36,338	36,338	36,336	36,336	36,332	36,332	36,332	36,336	36,336	36,338	36,338	36,338
2010	35,589	35,589	35,589	35,589	35,583	35,583	35,576	35,576	35,576	35,583	35,583	35,589	35,589	35,589
2011	34,507	34,507	34,507	34,507	34,496	34,496	34,483	34,483	34,483	34,496	34,496	34,507	34,507	34,507
2012	33,314	33,314	33,314	33,314	33,292	33,292	33,271	33,271	33,271	33,292	33,292	33,314	33,314	33,314
2013	32,106	32,106	32,106	32,106	32,065	32,065	32,032	32,033	32,033	32,065	32,065	32,106	32,106	32,106
2014	30,955	30,955	30,955	30,955	30,884	30,884	30,831	30,832	30,832	30,884	30,884	30,955	30,955	30,955
2015	29,928	29,928	29,928	29,928	29,810	29,810	29,725	29,727	29,727	29,810	29,810	29,928	29,928	29,928
2016	29,068	29,068	29,068	29,068	28,876	28,876	28,747	28,750	28,750	28,876	28,876	29,068	29,068	29,068
2017	28,397	28,397	28,397	28,397	28,098	28,098	27,911	27,916	27,916	28,098	28,098	28,397	28,397	28,397
2018	27,906	27,906	27,906	27,906	27,455	27,455	27,197	27,204	27,204	27,455	27,455	27,906	27,906	27,906
2019	27,570	27,570	27,570	27,570	26,912	26,912	26,569	26,579	26,579	26,912	26,912	27,570	27,570	27,570
2020	27,358	27,358	27,358	27,358	26,429	26,429	25,988	26,001	26,001	26,429	26,429	27,358	27,358	27,358
2021	27,246	27,246	27,246	27,246	25,969	25,969	25,416	25,434	25,434	25,969	25,969	27,246	27,246	27,246
2022	27,215	27,215	27,215	27,215	25,509	25,509	24,830	24,854	24,854	25,509	25,509	27,215	27,215	27,215
2023	27,239	27,239	27,239	27,239	25,016	25,016	24,199	24,230	24,230	25,016	25,016	27,239	27,239	27,239
2024	27,362	27,362	27,362	27,362	24,538	24,538	23,571	23,608	23,608	24,538	24,538	27,362	27,362	27,362
2025	27,482	27,482	27,482	27,482	23,973	23,973	22,844	22,891	22,891	23,973	23,973	27,482	27,482	27,482
2026	27,601	27,601	27,601	27,601	23,328	23,328	22,031	22,087	22,087	23,328	23,328	27,601	27,601	27,601
2027	27,719	27,719	27,719	27,719	22,615	22,615	21,151	21,216	21,216	22,615	22,615	27,719	27,719	27,719
2028	27,839	27,839	27,839	27,839	21,847	21,847	20,222	20,298	20,298	21,847	21,847	27,839	27,839	27,839
2029	27,961	27,961	27,961	27,961	21,043	21,043	19,267	19,354	19,354	21,043	21,043	27,961	27,961	27,961
2030	28,085	28,085	28,085	28,085	20,221	20,221	18,306	18,404	18,404	20,221	20,221	28,085	28,085	28,085

TABLE B.3 Operational Emissions of VOCs under the Baseline Scenario and for Conventional-Technology Plus 3X Vehicles under the High-Market-Share Scenario (10^3 metric tons)

Year	Base Case	RFG	MeOH	EtOH	RFD	DME	HFCV	MFCV	GFCV	F-T50	B20	LPG	CNG	LNG
2005	1,761	1,642	1,642	1,642	1,642	1,642	1,642	1,642	1,642	1,642	1,642	1,642	1,642	1,642
2006	1,760	1,695	1,695	1,695	1,695	1,695	1,695	1,695	1,695	1,695	1,695	1,695	1,695	1,695
2007	1,771	1,740	1,740	1,740	1,740	1,740	1,740	1,740	1,740	1,740	1,740	1,740	1,740	1,740
2008	1,790	1,779	1,779	1,779	1,779	1,779	1,778	1,778	1,778	1,779	1,779	1,779	1,779	1,779
2009	1,848	1,844	1,844	1,844	1,843	1,843	1,843	1,843	1,843	1,843	1,843	1,843	1,843	1,843
2010	1,903	1,903	1,903	1,903	1,902	1,902	1,901	1,901	1,901	1,902	1,902	1,902	1,902	1,902
2011	1,954	1,954	1,954	1,954	1,953	1,953	1,951	1,951	1,952	1,953	1,953	1,952	1,952	1,952
2012	2,001	2,001	2,001	2,001	1,998	1,998	1,995	1,996	1,997	1,998	1,998	1,998	1,998	1,998
2013	2,043	2,043	2,043	2,043	2,039	2,039	2,033	2,034	2,036	2,039	2,039	2,038	2,038	2,038
2014	2,080	2,080	2,080	2,080	2,073	2,073	2,064	2,065	2,068	2,073	2,073	2,072	2,072	2,072
2015	2,111	2,111	2,111	2,111	2,099	2,099	2,085	2,088	2,091	2,099	2,099	2,098	2,098	2,098
2016	2,136	2,136	2,136	2,136	2,119	2,119	2,097	2,101	2,107	2,119	2,119	2,117	2,117	2,117
2017	2,158	2,158	2,158	2,158	2,132	2,132	2,100	2,106	2,115	2,132	2,132	2,129	2,129	2,129
2018	2,177	2,177	2,177	2,177	2,140	2,140	2,094	2,103	2,115	2,140	2,140	2,136	2,136	2,136
2019	2,193	2,193	2,193	2,193	2,142	2,142	2,080	2,092	2,109	2,142	2,142	2,136	2,136	2,136
2020	2,206	2,206	2,206	2,206	2,139	2,139	2,058	2,073	2,095	2,139	2,139	2,132	2,132	2,132
2021	2,217	2,217	2,217	2,217	2,130	2,130	2,026	2,046	2,074	2,130	2,130	2,122	2,122	2,122
2022	2,228	2,228	2,228	2,228	2,116	2,116	1,985	2,010	2,047	2,116	2,116	2,107	2,107	2,107
2023	2,237	2,237	2,237	2,237	2,096	2,096	1,936	1,967	2,012	2,096	2,096	2,087	2,087	2,087
2024	2,246	2,246	2,246	2,246	2,071	2,071	1,879	1,916	1,971	2,071	2,071	2,063	2,063	2,063
2025	2,255	2,255	2,255	2,255	2,041	2,041	1,814	1,859	1,925	2,041	2,041	2,034	2,034	2,034
2026	2,264	2,264	2,264	2,264	2,007	2,007	1,743	1,796	1,874	2,007	2,007	2,003	2,003	2,003
2027	2,273	2,273	2,273	2,273	1,971	1,971	1,668	1,730	1,821	1,971	1,971	1,970	1,970	1,970
2028	2,282	2,281	2,281	2,281	1,934	1,934	1,592	1,663	1,766	1,934	1,934	1,937	1,937	1,937
2029	2,291	2,290	2,290	2,290	1,895	1,895	1,516	1,596	1,712	1,895	1,895	1,903	1,903	1,903
2030	2,300	2,299	2,299	2,299	1,856	1,856	1,441	1,529	1,658	1,856	1,856	1,870	1,870	1,870

TABLE B.4 Operational Emissions of PM_{10} under the Baseline Scenario and for Conventional-Technology Plus 3X Vehicles under the High-Market-Share Scenario (10^3 metric tons)

Year	Base Case	RFG	MeOH	EtOH	RFD	DME	HFCV	MFCV	GFCV	F-T50	B20	LPG	CNG	LNG
2005	80	78	78	78	78	78	78	78	78	78	78	78	78	78
2006	81	80	80	80	80	80	80	80	80	80	80	80	80	80
2007	82	81	81	81	81	81	81	81	81	81	81	81	81	81
2008	82	82	82	82	82	82	82	82	82	82	82	82	82	82
2009	84	84	84	84	84	84	84	84	84	84	84	84	84	84
2010	86	86	85	85	86	86	85	85	85	86	86	85	85	85
2011	87	87	87	87	87	87	87	87	87	87	87	87	87	87
2012	88	88	88	88	88	88	88	88	88	88	88	88	88	88
2013	89	89	89	89	90	89	89	89	89	90	90	89	89	89
2014	90	90	89	89	91	90	89	89	89	91	91	89	89	89
2015	91	91	90	90	92	91	90	90	90	92	92	90	90	90
2016	91	91	90	90	94	91	90	90	90	94	94	90	90	90
2017	92	92	90	90	96	92	90	90	90	96	96	90	90	90
2018	92	92	90	90	98	92	90	90	90	98	98	90	90	90
2019	93	93	90	90	100	93	89	89	89	100	100	89	89	89
2020	93	93	89	89	102	93	89	89	89	102	102	89	89	89
2021	93	93	89	89	104	93	88	88	88	104	104	88	88	88
2022	94	94	88	88	107	94	87	87	87	107	107	87	87	87
2023	94	94	87	87	110	94	86	86	86	110	110	86	86	86
2024	94	94	86	86	113	94	85	85	85	113	113	85	85	85
2025	95	95	85	85	116	95	84	84	84	116	116	84	84	84
2026	95	95	84	84	120	95	83	83	83	120	120	83	83	83
2027	95	95	83	83	123	95	82	82	82	123	123	82	82	82
2028	96	96	82	82	126	96	81	81	81	126	126	81	81	81
2029	96	96	82	82	129	96	80	80	80	129	129	80	80	80
2030	96	96	81	81	132	96	79	79	79	132	132	79	79	79

TABLE B.5 Operational Emissions of SO_x under the Baseline Scenario and for Conventional-Technology Plus 3X Vehicles under the High-Market-Share Scenario (10^3 metric tons)

Year	Base Case	RFG	MeOH	EtOH	RFD	DME	HFCV	MFCV	GFCV	F-T50	B20	LPG	CNG	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	69	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	73	73	73	73	72	72	73	73	73	73	72	72	72
2013	73	73	73	73	73	73	73	73	73	73	73	73	73	73
2014	74	73	72	72	73	72	72	72	73	73	73	72	72	72
2015	74	73	72	72	73	72	72	72	73	72	72	72	72	72
2016	74	72	71	71	72	71	71	71	72	72	72	71	71	71
2017	74	71	70	70	71	70	70	70	71	71	71	70	70	70
2018	74	71	69	69	71	69	69	69	71	70	70	69	69	69
2019	74	70	67	67	70	67	67	67	70	68	69	67	67	67
2020	74	68	66	65	69	65	65	66	68	67	68	65	65	65
2021	74	67	64	63	67	63	63	64	67	65	67	63	63	63
2022	74	66	61	61	66	61	61	61	66	64	65	61	61	61
2023	74	64	59	59	65	58	58	59	64	62	64	58	59	58
2024	74	63	57	56	63	56	56	57	63	60	62	56	56	56
2025	74	61	54	54	62	53	53	54	61	58	60	53	53	53
2026	74	60	51	51	60	50	50	51	60	55	58	50	50	50
2027	74	58	49	48	58	47	47	49	58	53	57	47	48	47
2028	74	57	46	46	57	44	44	46	57	51	55	44	45	44
2029	74	55	44	44	56	42	42	44	55	49	54	42	43	42
2030	74	54	42	42	55	40	40	42	54	48	52	40	41	40

TABLE B.6 Operational Emissions of CO_2 under the Baseline Scenario and for Conventional-Technology Plus 3X Vehicles under the High-Market-Share Scenario (10^3 metric tons)

Year	Base Case	RFG	MeOH	EtOH	RFD	DME	HFCV	MFCV	GFCV	F-T50	B20	LPG	CNG	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	1,051,015	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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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

TABLE B.7 Operational Emissions of CH_4 under the Baseline Scenario and for Conventional-Technology Plus 3X Vehicles under the High-Market-Share Scenario (10^3 metric tons)

Year	Base Case	RFG	MeOH	EtOH	RFD	DME	HFCV	MFCV	GFCV	F-T50	B20	LPG	CNG	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	188	188
2009	192	192	192	192	192	192	192	192	192	192	192	192	194	194
2010	196	196	196	196	196	196	196	196	196	196	196	196	200	200
2011	200	200	199	199	199	199	199	199	199	199	199	200	206	206
2012	203	203	202	202	202	202	201	201	201	202	202	203	214	214
2013	206	206	205	205	204	204	204	204	204	204	204	206	224	224
2014	208	208	207	207	205	205	205	205	205	205	205	208	237	237
2015	210	210	209	209	206	206	205	205	205	206	206	210	256	256
2016	212	212	210	210	205	205	204	204	204	205	205	212	282	282
2017	214	214	210	210	204	204	203	203	203	204	204	214	315	315
2018	216	216	210	210	202	202	200	200	200	202	202	216	355	355
2019	217	217	210	210	199	199	197	197	197	199	199	217	401	401
2020	219	219	210	210	195	195	193	193	193	195	195	219	453	453
2021	220	220	209	209	191	191	188	188	188	191	191	220	512	512
2022	221	221	208	208	186	186	182	182	182	186	186	221	578	578
2023	223	223	206	206	180	180	175	175	175	180	180	223	650	650
2024	224	224	205	205	174	174	168	168	168	174	174	224	727	727
2025	225	225	203	203	168	168	160	160	160	168	168	225	810	810
2026	227	227	201	201	160	160	152	152	152	160	160	227	896	896
2027	228	228	199	199	154	154	145	145	145	154	154	228	980	980
2028	230	230	197	197	147	147	137	137	137	147	147	230	1,060	1,060
2029	231	231	196	196	141	141	131	131	131	141	141	231	1,134	1,134
2030	232	232	195	195	136	136	125	125	125	136	136	232	1,202	1,202

TABLE B.8 Operational Emissions of N_2O under the Baseline Scenario and for Conventional-Technology Plus 3X Vehicles under the High-Market-Share Scenario (10^3 metric tons)

Year	Base Case	RFG	MeOH	EtOH	RFD	DME	HFCV	MFCV	GFCV	F-T50	B20	LPG	CNG	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	12.9	12.9	12.9	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	13.4	13.4	13.4	13.5	13.5	13.5	13.5	13.5
2012	13.7	13.7	13.7	13.7	13.7	13.7	13.6	13.6	13.6	13.7	13.7	13.7	13.7	13.7
2013	13.9	13.9	13.9	13.9	13.9	13.9	13.8	13.8	13.8	13.9	13.9	13.9	13.9	13.9
2014	14.1	14.1	14.1	14.1	14.1	14.1	13.8	13.8	13.8	14.1	14.1	14.1	14.1	14.1
2015	14.2	14.2	14.2	14.2	14.2	14.2	13.9	13.9	13.9	14.2	14.2	14.2	14.2	14.2
2016	14.3	14.3	14.3	14.3	14.3	14.3	13.8	13.8	13.8	14.3	14.3	14.3	14.3	14.3
2017	14.5	14.5	14.5	14.5	14.5	14.5	13.7	13.7	13.7	14.5	14.5	14.5	14.5	14.5
2018	14.6	14.6	14.6	14.6	14.6	14.6	13.5	13.5	13.5	14.6	14.6	14.6	14.6	14.6
2019	14.7	14.7	14.7	14.7	14.7	14.7	13.3	13.3	13.3	14.7	14.7	14.7	14.7	14.7
2020	14.8	14.8	14.8	14.8	14.8	14.8	13.0	13.0	13.0	14.8	14.8	14.8	14.8	14.8
2021	14.9	14.9	14.9	14.9	14.9	14.9	12.7	12.7	12.7	14.9	14.9	14.9	14.9	14.9
2022	15.0	15.0	15.0	15.0	15.0	15.0	12.3	12.3	12.3	15.0	15.0	15.0	15.0	15.0
2023	15.1	15.1	15.1	15.1	15.1	15.1	11.8	11.8	11.8	15.1	15.1	15.1	15.1	15.1
2024	15.1	15.1	15.1	15.1	15.1	15.1	11.4	11.4	11.4	15.1	15.1	15.1	15.1	15.1
2025	15.2	15.2	15.2	15.2	15.2	15.2	10.8	10.8	10.8	15.2	15.2	15.2	15.2	15.2
2026	15.3	15.3	15.3	15.3	15.3	15.3	10.3	10.3	10.3	15.3	15.3	15.3	15.3	15.3
2027	15.4	15.4	15.4	15.4	15.4	15.4	9.8	9.8	9.8	15.4	15.4	15.4	15.4	15.4
2028	15.5	15.5	15.5	15.5	15.5	15.5	9.3	9.3	9.3	15.5	15.5	15.5	15.5	15.5
2029	15.6	15.6	15.6	15.6	15.6	15.6	8.8	8.8	8.8	15.6	15.6	15.6	15.6	15.6
2030	15.7	15.7	15.7	15.7	15.7	15.7	8.4	8.4	8.4	15.7	15.7	15.7	15.7	15.7

TABLE B.9 Operational Energy Use under the Baseline Scenario and for Conventional-Technology Plus 3X Vehicles under the High-Market-Share Scenario (Quads)

Year	Base Case	RFG	MeOH	EtOH	RFD	DME	HFCV	MFCV	GFCV	F-T50	B20	LPG	CNG	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.10 Operational Fossil Energy Use under the Baseline Scenario and for Conventional-Technology Plus 3X Vehicles under the High-Market-Share Scenario (Quads)

Year	Base Case	RFG	MeOH	EtOH	RFD	DME	HFCV	MFCV	GFCV	F-T50	B20	LPG	CNG	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.11 Operational Petroleum Use under the Baseline Scenario and for Conventional-Technology Plus 3X Vehicles under the High-Market-Share Scenario (Quads)

Year	Base Case	RFG	MeOH	EtOH	RFD	DME	HFCV	MFCV	GFCV	F-T50	B20	LPG	CNG	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.12 Upstream Emissions of NO_x under the Baseline Scenario and for Conventional-Technology Plus 3X Vehicles under the High-Market-Share Scenario (10^3 metric tons)

Year	Base Case	RFG	MeOH	EtOH	RFD	DME	HFCV	MFCV	GFCV	F-T50	B20	LPG	CNG	LNG
2005	535	525	525	525	525	525	525	525	525	525	525	525	525	525
2006	539	533	533	533	533	533	533	533	533	533	533	533	533	533
2007	543	540	540	540	540	540	540	540	540	540	540	540	540	540
2008	543	541	541	541	541	541	542	541	541	541	541	541	541	541
2009	547	546	547	547	546	547	547	547	546	546	546	546	546	547
2010	550	549	551	551	549	551	551	551	549	549	549	549	549	550
2011	551	550	552	553	550	552	554	552	550	550	550	550	550	551
2012	551	549	553	554	548	553	556	553	549	549	549	549	550	551
2013	550	547	553	554	546	553	557	553	547	547	547	546	548	551
2014	548	543	553	554	542	553	560	553	543	543	543	542	545	549
2015	545	537	553	555	536	552	563	553	537	538	537	536	540	547
2016	541	530	553	557	527	553	570	553	530	531	530	529	535	545
2017	538	521	555	561	518	554	578	555	521	523	522	520	529	544
2018	534	512	557	555	507	557	590	557	512	514	512	509	522	542
2019	530	501	560	541	495	560	603	560	501	505	502	498	514	542
2020	526	490	564	530	482	564	619	564	490	494	490	486	506	542
2021	522	478	569	524	468	568	632	569	478	483	478	474	498	542
2022	519	466	574	518	454	574	644	574	466	472	466	460	489	544
2023	515	453	581	512	438	581	653	581	453	460	453	446	481	546
2024	512	439	588	507	423	588	656	588	439	448	439	431	472	549
2025	509	426	596	503	406	596	655	596	426	435	425	416	462	553
2026	506	412	605	499	390	604	650	605	412	423	411	401	453	557
2027	503	399	612	497	374	612	647	612	399	411	397	387	445	562
2028	500	387	619	495	359	619	642	619	387	400	385	374	437	567
2029	497	376	625	494	346	625	641	625	376	390	373	362	429	571
2030	495	367	629	494	334	629	637	629	367	381	363	351	423	576

TABLE B.13 Upstream Emissions of CO under the Baseline Scenario and for Conventional-Technology Plus 3X Vehicles under the High-Market-Share Scenario (10^3 metric tons)

Year	Base Case	RFG	MeOH	EtOH	RFD	DME	HFCV	MFCV	GFCV	F-T50	B20	LPG	CNG	LNG
2005	339	333	333	333	333	333	333	333	333	333	333	333	333	333
2006	342	338	338	338	338	338	338	338	338	338	338	338	338	338
2007	345	343	343	343	343	343	343	343	343	343	343	343	343	343
2008	346	345	345	345	345	345	345	345	345	345	345	345	345	345
2009	351	350	351	351	350	351	351	351	350	350	350	350	350	350
2010	355	354	355	355	354	355	355	355	354	354	354	354	354	355
2011	357	356	358	358	356	358	358	358	356	357	357	356	357	357
2012	359	358	360	361	358	360	360	360	358	358	358	358	358	359
2013	360	358	361	363	358	361	362	361	358	359	359	358	359	360
2014	361	358	362	365	358	362	364	362	358	359	358	358	358	361
2015	361	356	363	368	356	363	365	363	356	357	356	356	356	361
2016	361	353	363	371	352	363	367	363	353	355	354	353	354	360
2017	360	349	364	374	348	364	369	364	349	352	350	349	350	360
2018	360	345	365	377	343	365	372	365	345	348	346	344	346	359
2019	359	339	366	379	338	365	376	366	339	344	341	339	341	359
2020	358	333	367	382	331	366	380	367	333	339	335	333	336	358
2021	358	327	368	386	324	367	382	368	327	334	329	327	330	357
2022	357	320	369	392	317	368	383	369	320	328	323	320	324	357
2023	357	312	371	398	309	370	382	371	312	323	316	312	317	357
2024	357	304	372	405	300	371	377	372	304	316	308	304	310	357
2025	356	296	374	412	291	373	370	374	296	310	301	296	302	357
2026	356	288	375	420	282	374	361	375	288	303	293	287	295	357
2027	356	280	377	429	274	376	353	377	280	297	285	279	288	357
2028	356	272	378	436	266	377	346	378	272	292	278	272	281	358
2029	356	266	379	444	258	378	340	379	266	286	272	265	275	359
2030	356	260	380	451	252	378	334	380	260	282	267	259	270	359

TABLE B.14 Upstream Emissions of VOCs under the Baseline Scenario and for Conventional-Technology Plus 3X Vehicles under the High-Market-Share Scenario (10^3 metric tons)

Year	Base Case	RFG	MeOH	EtOH	RFD	DME	HFCV	MFCV	GFCV	F-T50	B20	LPG	CNG	LNG
2005	255	250	250	250	250	250	250	250	250	250	250	250	250	250
2006	257	254	254	254	254	254	254	254	254	254	254	254	254	254
2007	259	257	257	257	257	257	257	257	257	257	257	257	257	257
2008	260	259	259	259	259	259	259	259	259	259	259	259	259	259
2009	263	263	263	263	263	263	263	263	263	263	263	263	263	263
2010	266	266	266	266	266	266	266	266	266	265	266	266	265	266
2011	268	267	268	267	267	267	267	268	267	267	267	267	267	267
2012	269	268	269	268	268	268	268	269	268	268	268	268	268	268
2013	270	268	269	269	268	269	269	269	268	268	269	268	268	269
2014	270	268	269	269	267	268	268	269	268	267	268	267	267	268
2015	270	266	268	268	265	267	267	268	266	265	267	265	265	267
2016	270	264	266	266	262	265	265	266	264	262	265	262	261	265
2017	269	261	263	264	258	262	262	263	261	258	263	258	257	262
2018	269	257	260	261	254	258	259	260	257	253	260	253	252	259
2019	268	253	257	258	249	254	255	257	253	247	256	248	246	256
2020	268	249	253	254	243	250	250	253	249	241	252	242	240	251
2021	267	244	248	251	236	244	244	248	244	234	248	235	232	247
2022	267	239	243	247	229	238	238	243	239	227	244	228	224	241
2023	266	233	237	243	222	232	230	237	233	219	239	220	216	236
2024	266	227	231	238	214	225	221	231	227	210	233	212	207	230
2025	265	221	225	234	206	217	211	225	221	201	228	203	197	223
2026	265	214	218	230	197	209	201	218	214	192	223	194	187	217
2027	265	208	211	225	189	201	191	211	208	183	217	185	177	210
2028	265	203	204	222	182	194	182	204	203	175	212	177	168	204
2029	265	198	198	218	175	187	173	198	198	168	208	170	160	198
2030	265	193	192	216	169	180	165	192	193	161	203	163	153	193

TABLE B.15 Upstream Emissions of PM_{10} under the Baseline Scenario and for Conventional-Technology Plus 3X Vehicles under the High-Market-Share Scenario (10^3 metric tons)

Year	Base Case	RFG	MeOH	EtOH	RFD	DME	HFCV	MFCV	GFCV	F-T50	B20	LPG	CNG	LNG
2005	57	56	56	56	56	56	56	56	56	56	56	56	56	56
2006	57	56	56	56	56	56	56	56	56	56	56	56	56	56
2007	57	57	57	57	57	57	57	57	57	57	57	57	57	57
2008	58	57	57	57	57	57	57	57	57	57	57	57	57	57
2009	58	58	58	58	58	58	58	58	58	58	58	58	58	58
2010	59	58	58	59	58	58	59	58	58	58	58	58	58	59
2011	59	59	59	60	59	59	59	59	59	59	59	59	59	59
2012	59	59	59	60	59	59	59	59	59	59	59	59	59	59
2013	59	59	59	61	59	59	59	59	59	59	59	58	59	59
2014	59	58	58	62	58	58	59	58	58	58	58	58	58	59
2015	59	58	58	64	58	58	59	58	58	58	58	58	58	59
2016	58	57	57	67	57	57	58	57	57	57	57	57	57	59
2017	58	56	56	70	56	56	58	56	56	56	56	56	56	59
2018	58	55	55	72	55	55	57	55	55	55	55	55	55	59
2019	58	54	54	71	54	54	57	54	54	54	54	53	54	59
2020	57	53	53	71	52	53	57	53	53	52	53	52	53	59
2021	57	52	52	73	51	52	56	52	52	51	51	50	51	59
2022	57	51	51	76	50	51	55	51	51	49	50	49	50	59
2023	57	50	49	78	48	49	55	49	50	48	48	47	48	60
2024	56	48	48	81	46	48	53	48	48	46	47	45	47	60
2025	56	47	46	85	45	46	52	46	47	44	45	43	45	61
2026	56	45	45	88	43	45	51	45	45	42	43	41	43	61
2027	56	44	43	91	41	43	50	43	44	41	42	39	42	62
2028	56	43	42	95	40	42	49	42	43	39	40	37	40	62
2029	55	41	41	98	38	40	48	41	41	38	39	36	39	63
2030	55	40	40	101	37	39	47	40	40	36	37	34	37	63

TABLE B.16 Upstream Emissions of SO_x under the Baseline Scenario and for Conventional-Technology Plus 3X Vehicles under the High-Market-Share Scenario (10^3 metric tons)

Year	Base Case	RFG	MeOH	EtOH	RFD	DME	HFCV	MFCV	GFCV	F-T50	B20	LPG	CNG	LNG
2005	379	373	373	373	373	373	373	373	373	373	373	373	373	373
2006	382	379	379	379	379	379	379	379	379	379	379	379	379	379
2007	386	383	383	383	383	383	383	383	383	383	383	383	383	383
2008	383	382	382	382	382	382	382	382	382	382	382	382	382	382
2009	385	384	384	384	384	384	384	384	384	384	384	384	384	384
2010	385	384	384	384	384	384	384	384	384	384	384	384	384	384
2011	383	382	382	383	382	382	383	382	382	382	382	382	383	382
2012	381	380	379	381	380	379	381	379	380	379	380	379	380	380
2013	379	376	376	379	376	376	378	376	376	376	376	376	377	376
2014	375	372	371	376	371	370	375	371	372	371	371	371	372	371
2015	371	366	364	372	365	364	371	364	366	364	365	364	367	365
2016	367	359	356	367	357	356	366	356	359	357	358	356	360	358
2017	363	352	347	363	349	347	361	347	352	348	349	347	353	349
2018	359	343	337	349	340	337	356	337	343	338	340	337	344	340
2019	354	335	326	328	330	326	350	326	335	328	330	326	336	330
2020	350	325	315	308	319	314	344	315	325	317	320	315	326	320
2021	346	316	302	291	308	302	338	302	316	305	309	303	317	309
2022	342	306	290	274	297	289	332	290	306	293	297	290	306	298
2023	338	295	276	255	285	276	324	276	295	281	285	277	296	286
2024	334	285	263	237	273	262	317	263	285	268	273	263	285	275
2025	330	274	249	218	260	248	309	249	274	255	260	249	273	263
2026	326	264	235	199	248	234	300	235	264	242	247	235	262	251
2027	323	254	222	181	236	221	292	222	254	229	235	222	251	240
2028	320	244	209	165	225	208	284	209	244	218	224	210	240	229
2029	316	236	198	151	215	197	276	198	236	207	214	198	231	220
2030	313	228	188	139	206	187	269	188	228	198	205	188	222	212

TABLE B.17 Upstream Emissions of CO_2 under the Baseline Scenario and for Conventional-Technology Plus 3X Vehicles under the High-Market-Share Scenario (10^3 metric tons)

Year	Base Case	RFG	MeOH	EtOH	RFD	DME	HFCV	MFCV	GFCV	F-T50	B20	LPG	CNG	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	304,432	304,492	304,393	304,434	304,551	304,432	304,411	304,446	304,396	304,386	304,403	304,403
2009	309,985	309,371	309,420	309,569	309,325	309,425	309,717	309,420	309,371	309,456	309,334	309,308	309,351	309,350
2010	313,740	313,222	313,317	313,616	313,132	313,326	313,909	313,317	313,222	313,391	313,149	313,098	313,183	313,181
2011	316,533	315,746	315,909	316,451	315,585	315,925	316,975	315,909	315,746	316,049	315,614	315,525	315,676	315,672
2012	318,575	317,366	317,624	318,535	317,099	317,651	319,402	317,624	317,366	317,868	317,146	316,999	317,250	317,243
2013	320,132	318,248	318,647	320,134	317,818	318,691	321,533	318,647	318,248	319,058	317,892	317,656	318,061	318,050
2014	321,149	318,207	318,816	321,221	317,520	318,887	323,457	318,816	318,207	319,502	317,636	317,262	317,909	317,892
2015	321,537	316,971	317,889	321,726	315,887	318,000	325,253	317,889	316,971	319,014	316,064	315,479	316,501	316,474
2016	321,694	314,798	316,133	322,060	313,142	316,303	327,447	316,133	314,798	317,918	313,405	312,520	314,080	314,038
2017	321,710	311,819	313,655	322,325	309,423	313,902	330,116	313,655	311,819	316,333	309,793	308,524	310,780	310,721
2018	321,642	308,131	310,528	316,514	304,835	310,867	333,302	310,528	308,131	314,340	305,329	303,598	306,701	306,621
2019	321,531	303,819	306,813	304,443	299,471	307,261	337,029	306,813	303,819	312,012	300,102	297,839	301,933	301,829
2020	321,422	298,972	302,578	293,227	293,428	303,148	341,321	302,578	298,972	309,419	294,206	291,347	296,566	296,435
2021	321,355	293,543	297,775	283,692	286,634	298,486	344,325	297,775	293,543	306,564	287,571	284,040	290,544	290,383
2022	321,353	287,612	292,462	273,151	279,180	293,329	345,929	292,462	287,612	303,504	280,284	276,014	283,951	283,757
2023	321,422	281,245	286,681	261,761	271,144	287,719	345,990	286,681	281,245	300,283	272,421	267,353	276,859	276,630
2024	321,563	274,504	280,474	249,574	262,601	281,696	343,048	280,474	274,504	296,938	264,050	258,134	269,334	269,068
2025	321,782	267,456	273,890	236,715	253,632	275,308	338,066	273,890	267,456	293,513	255,251	248,443	261,450	261,146
2026	322,065	260,264	267,061	223,482	244,441	268,683	330,780	267,061	260,264	290,088	246,220	238,502	253,387	253,044
2027	322,407	253,354	260,365	210,647	235,568	262,187	324,899	260,365	253,354	286,879	237,486	228,893	245,622	245,243
2028	322,798	246,996	254,052	198,686	227,356	256,061	318,895	254,052	246,996	284,016	229,384	219,986	238,456	238,043
2029	323,233	241,290	248,224	187,788	219,935	250,407	314,837	248,224	241,290	281,546	222,042	211,921	232,002	231,560
2030	323,699	236,247	242,907	162,404	213,320	245,247	343,553	242,907	236,247	279,463	215,478	204,718	226,272	225,806
2023	338	295	276	255	285	276	324	276	295	281	285	277	296	286
2024	334	285	263	237	273	262	317	263	285	268	273	263	285	275
2025	330	274	249	218	260	248	309	249	274	255	260	249	273	263
2026	326	264	235	199	248	234	300	235	264	242	247	235	262	251
2027	323	254	222	181	236	221	292	222	254	229	235	222	251	240
2028	320	244	209	165	225	208	284	209	244	218	224	210	240	229
2029	316	236	198	151	215	197	276	198	236	207	214	198	231	220
2030	313	228	188	139	206	187	269	188	228	198	205	188	222	212

TABLE B.18 Upstream Emissions of CH_4 under the Baseline Scenario and for Conventional-Technology Plus 3X Vehicles under the High-Market-Share Scenario (10^3 metric tons)

Year	Base Case	RFG	MeOH	EtOH	RFD	DME	HFCV	MFCV	GFCV	F-T50	B20	LPG	CNG	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	1,303	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	1,319	1,320	1,321	1,320	1,321	1,320	1,320	1,320	1,320	1,322	1,322
2011	1,334	1,331	1,332	1,329	1,331	1,332	1,331	1,332	1,331	1,331	1,330	1,331	1,333	1,333
2012	1,343	1,338	1,340	1,335	1,337	1,340	1,337	1,340	1,338	1,338	1,337	1,338	1,342	1,342
2013	1,349	1,341	1,345	1,337	1,341	1,345	1,341	1,345	1,341	1,342	1,341	1,342	1,349	1,349
2014	1,354	1,341	1,346	1,335	1,340	1,346	1,340	1,346	1,341	1,342	1,340	1,342	1,353	1,353
2015	1,355	1,336	1,344	1,326	1,335	1,344	1,335	1,344	1,336	1,337	1,334	1,338	1,354	1,354
2016	1,356	1,327	1,339	1,311	1,325	1,339	1,325	1,339	1,327	1,328	1,324	1,330	1,355	1,355
2017	1,356	1,315	1,332	1,291	1,311	1,332	1,311	1,332	1,315	1,316	1,310	1,318	1,354	1,354
2018	1,356	1,299	1,322	1,266	1,294	1,322	1,295	1,322	1,299	1,301	1,292	1,304	1,354	1,354
2019	1,356	1,281	1,312	1,236	1,275	1,311	1,275	1,312	1,281	1,284	1,272	1,288	1,353	1,353
2020	1,355	1,261	1,299	1,202	1,253	1,299	1,253	1,299	1,261	1,264	1,249	1,270	1,353	1,353
2021	1,355	1,238	1,286	1,164	1,228	1,285	1,227	1,286	1,238	1,242	1,223	1,249	1,353	1,353
2022	1,355	1,213	1,271	1,122	1,201	1,271	1,197	1,271	1,213	1,218	1,195	1,226	1,353	1,353
2023	1,355	1,186	1,255	1,077	1,172	1,255	1,164	1,255	1,186	1,192	1,164	1,202	1,354	1,354
2024	1,356	1,158	1,238	1,029	1,141	1,238	1,126	1,238	1,158	1,165	1,132	1,177	1,355	1,355
2025	1,357	1,128	1,221	978	1,108	1,220	1,084	1,221	1,128	1,136	1,098	1,150	1,358	1,358
2026	1,358	1,098	1,203	926	1,075	1,203	1,040	1,203	1,098	1,107	1,063	1,123	1,361	1,361
2027	1,360	1,069	1,186	876	1,044	1,186	999	1,186	1,069	1,079	1,029	1,097	1,364	1,364
2028	1,362	1,042	1,170	829	1,014	1,170	959	1,170	1,042	1,054	998	1,073	1,368	1,368
2029	1,363	1,018	1,156	786	988	1,156	925	1,156	1,018	1,031	970	1,052	1,373	1,372
2030	1,366	997	1,144	702	964	1,144	1,085	1,144	997	1,010	945	1,034	1,377	1,379

TABLE B.19 Upstream Emissions of N_2O under the Baseline Scenario and for Conventional-Technology Plus 3X Vehicles under the High-Market-Share Scenario (10^3 metric tons)

Year	Base Case	RFG	MeOH	EtOH	RFD	DME	HFCV	MFCV	GFCV	F-T50	B20	LPG	CNG	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	25.0	24.9	24.9	24.9	24.9	24.9	24.9	25.1
2012	23.0	22.9	22.9	24.3	22.9	22.9	23.1	22.9	22.9	22.9	22.9	22.9	22.9	23.2
2013	21.1	21.0	21.0	23.4	21.0	21.0	21.4	21.0	21.0	21.0	21.0	21.0	21.0	21.5
2014	19.4	19.2	19.2	23.0	19.2	19.2	19.8	19.2	19.2	19.2	19.3	19.1	19.3	20.0
2015	17.8	17.5	17.5	23.5	17.4	17.5	18.5	17.5	17.5	17.4	17.6	17.4	17.6	18.8
2016	16.2	15.9	15.9	25.0	15.8	15.9	17.4	15.9	15.9	15.8	16.0	15.8	16.0	17.9
2017	14.9	14.4	14.4	27.6	14.3	14.4	16.6	14.4	14.4	14.3	14.6	14.2	14.6	17.3
2018	13.6	13.0	13.0	27.1	12.9	13.0	16.1	13.0	13.0	12.9	13.3	12.8	13.2	17.0
2019	12.4	11.7	11.7	23.3	11.6	11.7	15.9	11.7	11.7	11.6	12.1	11.5	12.0	17.0
2020	11.4	10.6	10.6	20.9	10.4	10.6	15.9	10.6	10.6	10.4	11.0	10.3	10.9	17.3
2021	10.4	9.5	9.6	20.5	9.3	9.6	16.2	9.6	9.5	9.3	10.0	9.2	9.8	18.0
2022	9.5	8.5	8.6	20.4	8.3	8.6	16.7	8.6	8.5	8.3	9.2	8.2	8.9	18.9
2023	8.7	7.6	7.8	20.4	7.3	7.8	17.4	7.8	7.6	7.4	8.4	7.2	8.0	20.1
2024	8.0	6.8	7.1	20.6	6.5	7.1	18.3	7.1	6.8	6.5	7.7	6.4	7.2	21.6
2025	7.3	6.1	6.4	21.0	5.7	6.4	19.4	6.4	6.1	5.8	7.1	5.7	6.5	23.3
2026	6.7	5.4	5.9	21.5	5.1	5.9	20.7	5.9	5.4	5.1	6.6	5.0	5.8	25.2
2027	6.1	4.8	5.4	22.1	4.5	5.4	22.0	5.4	4.8	4.6	6.1	4.4	5.2	27.1
2028	5.6	4.3	5.0	22.6	3.9	5.0	23.2	5.0	4.3	4.1	5.7	3.9	4.7	28.9
2029	5.1	3.8	4.6	23.2	3.5	4.6	24.5	4.6	3.8	3.6	5.4	3.4	4.2	30.6
2030	4.7	9.5	5.8	64.7	6.8	5.7	5.5	4.3	3.4	3.2	5.1	3.0	3.8	32.3

TABLE B.20 Upstream Energy Use under the Baseline Scenario and for Conventional-Technology Plus 3X Vehicles under the High-Market-Share Scenario (Quads)

Year	Base Case	RFG	MeOH	EtOH	RFD	DME	HFCV	MFCV	GFCV	F-T50	B20	LPG	CNG	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.21 Upstream Fossil Energy Use under the Baseline Scenario and for Conventional-Technology Plus 3X Vehicles under the High-Market-Share Scenario (Quads)

Year	Base Case	RFG	MeOH	EtOH	RFD	DME	HFCV	MFCV	GFCV	F-T50	B20	LPG	CNG	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.22 Upstream Petroleum Use under the Baseline Scenario and for Conventional-Technology Plus 3X Vehicles under the High-Market-Share Scenario (Quads)

Year	Base Case	RFG	MeOH	EtOH	RFD	DME	HFCV	MFCV	GFCV	F-T50	B20	LPG	CNG	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.23 Total Emissions of NO_x under the Baseline Scenario and for Conventional-Technology Plus 3X Vehicles under the High-Market-Share Scenario (10^3 metric tons)

Year	Base Case	RFG	MeOH	EtOH	RFD	DME	HFCV	MFCV	GFCV	F-T50	B20	LPG	CNG	LNG
2005	3,085	2,939	2,939	2,939	2,939	2,939	2,939	2,939	2,939	2,939	2,939	2,939	2,939	2,939
2006	3,042	2,954	2,954	2,954	2,954	2,954	2,954	2,954	2,954	2,954	2,954	2,954	2,954	2,954
2007	2,992	2,942	2,942	2,942	2,942	2,942	2,942	2,942	2,942	2,942	2,942	2,942	2,942	2,942
2008	2,916	2,891	2,891	2,891	2,891	2,891	2,891	2,891	2,891	2,891	2,891	2,891	2,891	2,891
2009	2,878	2,868	2,869	2,869	2,868	2,869	2,869	2,869	2,868	2,868	2,868	2,868	2,869	2,869
2010	2,823	2,822	2,824	2,824	2,822	2,824	2,824	2,823	2,821	2,822	2,822	2,822	2,823	2,823
2011	2,755	2,754	2,756	2,757	2,754	2,756	2,756	2,754	2,752	2,754	2,754	2,754	2,754	2,755
2012	2,679	2,677	2,681	2,683	2,677	2,681	2,681	2,678	2,674	2,678	2,677	2,677	2,678	2,680
2013	2,602	2,599	2,606	2,608	2,599	2,605	2,605	2,600	2,594	2,600	2,599	2,599	2,601	2,603
2014	2,529	2,524	2,534	2,538	2,523	2,534	2,532	2,525	2,515	2,524	2,524	2,523	2,526	2,530
2015	2,462	2,454	2,470	2,477	2,453	2,470	2,468	2,455	2,440	2,455	2,454	2,453	2,458	2,464
2016	2,405	2,394	2,417	2,429	2,391	2,417	2,414	2,395	2,371	2,395	2,394	2,393	2,399	2,409
2017	2,360	2,344	2,377	2,396	2,341	2,377	2,371	2,343	2,310	2,346	2,344	2,342	2,351	2,366
2018	2,327	2,305	2,350	2,361	2,300	2,349	2,339	2,300	2,255	2,307	2,305	2,302	2,314	2,335
2019	2,302	2,274	2,332	2,325	2,268	2,332	2,316	2,263	2,204	2,277	2,274	2,271	2,286	2,314
2020	2,286	2,250	2,324	2,301	2,243	2,324	2,298	2,230	2,156	2,255	2,251	2,247	2,266	2,302
2021	2,277	2,233	2,323	2,290	2,223	2,323	2,280	2,198	2,108	2,238	2,233	2,228	2,252	2,297
2022	2,272	2,219	2,328	2,283	2,207	2,327	2,259	2,166	2,058	2,225	2,219	2,213	2,243	2,297
2023	2,270	2,208	2,336	2,280	2,193	2,336	2,232	2,132	2,003	2,215	2,207	2,201	2,235	2,301
2024	2,275	2,202	2,351	2,283	2,185	2,351	2,199	2,098	1,949	2,210	2,202	2,194	2,234	2,312
2025	2,279	2,196	2,367	2,286	2,176	2,366	2,156	2,058	1,888	2,206	2,195	2,187	2,233	2,323
2026	2,284	2,190	2,382	2,289	2,168	2,382	2,103	2,014	1,821	2,201	2,189	2,179	2,231	2,335
2027	2,288	2,185	2,398	2,293	2,159	2,397	2,050	1,965	1,752	2,196	2,183	2,173	2,230	2,347
2028	2,293	2,180	2,412	2,298	2,152	2,412	1,992	1,912	1,680	2,193	2,178	2,167	2,230	2,360
2029	2,298	2,177	2,425	2,303	2,147	2,425	1,937	1,857	1,609	2,191	2,174	2,163	2,230	2,372
2030	2,303	2,175	2,438	2,303	2,143	2,438	1,802	1,801	1,538	2,190	2,171	2,160	2,231	2,384

TABLE B.24 Total Emissions of CO under the Baseline Scenario and for Conventional-Technology Plus 3X Vehicles under the High-Market-Share Scenario (10^3 metric tons)

Year	Base Case	RFG	MeOH	EtOH	RFD	DME	HFCV	MFCV	GFCV	F-T50	B20	LPG	CNG	LNG
2005	39,990	37,741	37,741	37,741	37,741	37,741	37,741	37,741	37,741	37,741	37,741	37,741	37,741	37,741
2006	39,351	37,987	37,987	37,987	37,987	37,987	37,987	37,987	37,987	37,987	37,987	37,987	37,987	37,987
2007	38,575	37,812	37,812	37,812	37,812	37,812	37,811	37,811	37,811	37,812	37,812	37,812	37,812	37,812
2008	37,444	37,069	37,069	37,069	37,068	37,068	37,067	37,067	37,067	37,068	37,068	37,069	37,069	37,069
2009	36,828	36,688	36,689	36,689	36,686	36,686	36,683	36,683	36,683	36,686	36,686	36,688	36,688	36,689
2010	35,943	35,943	35,943	35,944	35,937	35,938	35,931	35,931	35,930	35,937	35,937	35,943	35,943	35,943
2011	34,865	34,864	34,865	34,866	34,852	34,853	34,841	34,841	34,840	34,852	34,852	34,864	34,864	34,865
2012	33,673	33,672	33,674	33,676	33,649	33,651	33,631	33,631	33,629	33,650	33,650	33,672	33,672	33,673
2013	32,467	32,465	32,467	32,470	32,423	32,426	32,394	32,394	32,391	32,424	32,424	32,465	32,465	32,466
2014	31,316	31,313	31,317	31,322	31,241	31,246	31,194	31,194	31,190	31,242	31,242	31,313	31,313	31,316
2015	30,289	30,284	30,291	30,298	30,165	30,172	30,090	30,090	30,083	30,167	30,166	30,284	30,284	30,289
2016	29,428	29,421	29,431	29,443	29,228	29,239	29,113	29,114	29,103	29,231	29,229	29,420	29,421	29,428
2017	28,757	28,746	28,761	28,779	28,446	28,462	28,279	28,280	28,265	28,450	28,448	28,746	28,747	28,757
2018	28,266	28,251	28,271	28,286	27,799	27,820	27,567	27,569	27,548	27,803	27,801	28,251	28,252	28,265
2019	27,929	27,909	27,935	27,940	27,250	27,278	26,942	26,945	26,918	27,256	27,253	27,909	27,911	27,928
2020	27,716	27,691	27,724	27,721	26,760	26,795	26,365	26,368	26,335	26,768	26,764	27,691	27,694	27,716
2021	27,603	27,573	27,613	27,606	26,293	26,336	25,795	25,802	25,761	26,303	26,298	27,572	27,576	27,603
2022	27,573	27,535	27,584	27,573	25,825	25,877	25,209	25,223	25,174	25,837	25,831	27,535	27,539	27,572
2023	27,596	27,551	27,610	27,594	25,325	25,386	24,577	24,600	24,542	25,339	25,332	27,551	27,556	27,596
2024	27,719	27,667	27,734	27,714	24,838	24,909	23,944	23,981	23,913	24,854	24,846	27,666	27,672	27,719
2025	27,838	27,778	27,856	27,830	24,264	24,345	23,211	23,264	23,187	24,282	24,273	27,778	27,785	27,839
2026	27,957	27,889	27,976	27,946	23,610	23,702	22,388	22,462	22,375	23,631	23,621	27,888	27,896	27,958
2027	28,075	27,999	28,096	28,062	22,888	22,990	21,500	21,593	21,496	22,912	22,900	27,999	28,007	28,077
2028	28,195	28,111	28,217	28,179	22,112	22,224	20,563	20,677	20,571	22,138	22,125	28,111	28,120	28,197
2029	28,317	28,227	28,340	28,299	21,301	21,421	19,603	19,734	19,620	21,329	21,315	28,226	28,236	28,320
2030	28,441	28,345	28,465	28,536	20,473	20,599	18,640	18,784	18,663	20,503	20,488	28,345	28,356	28,445

TABLE B.25 Total Emissions of VOCs under the Baseline Scenario and for Conventional-Technology Plus 3X Vehicles under the High-Market-Share Scenario (10^3 metric tons)

Year	Base Case	RFG	MeOH	EtOH	RFD	DME	HFCV	MFCV	GFCV	F-T50	B20	LPG	CNG	LNG
2005	2,015	1,892	1,892	1,892	1,892	1,892	1,892	1,892	1,892	1,892	1,892	1,892	1,892	1,892
2006	2,016	1,949	1,949	1,949	1,949	1,949	1,949	1,949	1,949	1,949	1,949	1,949	1,949	1,949
2007	2,030	1,998	1,998	1,998	1,997	1,997	1,997	1,997	1,997	1,997	1,997	1,997	1,997	1,997
2008	2,050	2,038	2,038	2,038	2,038	2,038	2,037	2,037	2,038	2,038	2,038	2,038	2,038	2,038
2009	2,111	2,106	2,106	2,106	2,106	2,106	2,106	2,106	2,106	2,106	2,106	2,106	2,106	2,106
2010	2,169	2,168	2,169	2,169	2,167	2,168	2,167	2,167	2,167	2,167	2,168	2,167	2,167	2,168
2011	2,222	2,221	2,222	2,222	2,220	2,220	2,219	2,219	2,219	2,220	2,220	2,220	2,219	2,220
2012	2,270	2,269	2,270	2,270	2,266	2,267	2,264	2,264	2,265	2,266	2,267	2,266	2,266	2,266
2013	2,313	2,311	2,312	2,312	2,307	2,307	2,303	2,303	2,304	2,307	2,307	2,306	2,306	2,307
2014	2,350	2,348	2,348	2,349	2,340	2,341	2,334	2,334	2,336	2,340	2,341	2,339	2,339	2,340
2015	2,381	2,377	2,378	2,379	2,364	2,366	2,355	2,355	2,358	2,364	2,366	2,363	2,362	2,365
2016	2,406	2,400	2,402	2,404	2,381	2,383	2,367	2,367	2,371	2,380	2,384	2,379	2,378	2,382
2017	2,428	2,419	2,422	2,424	2,390	2,394	2,370	2,369	2,376	2,390	2,395	2,387	2,386	2,391
2018	2,446	2,434	2,437	2,439	2,394	2,398	2,364	2,363	2,373	2,393	2,400	2,389	2,388	2,395
2019	2,461	2,446	2,449	2,449	2,391	2,397	2,350	2,349	2,362	2,390	2,398	2,384	2,383	2,392
2020	2,473	2,455	2,458	2,457	2,382	2,389	2,328	2,326	2,344	2,380	2,391	2,374	2,372	2,383
2021	2,484	2,461	2,465	2,463	2,367	2,374	2,295	2,294	2,318	2,365	2,378	2,357	2,354	2,368
2022	2,494	2,466	2,471	2,468	2,345	2,354	2,251	2,253	2,285	2,343	2,359	2,334	2,331	2,348
2023	2,503	2,470	2,475	2,472	2,318	2,328	2,198	2,204	2,245	2,315	2,334	2,307	2,303	2,323
2024	2,512	2,473	2,478	2,475	2,285	2,295	2,134	2,148	2,198	2,281	2,304	2,274	2,269	2,292
2025	2,521	2,476	2,480	2,478	2,247	2,258	2,060	2,084	2,146	2,242	2,269	2,237	2,231	2,258
2026	2,529	2,478	2,482	2,480	2,205	2,217	1,979	2,014	2,088	2,200	2,230	2,197	2,190	2,220
2027	2,538	2,481	2,484	2,482	2,161	2,173	1,895	1,941	2,029	2,155	2,189	2,155	2,148	2,181
2028	2,546	2,484	2,486	2,486	2,115	2,128	1,810	1,867	1,969	2,109	2,146	2,114	2,105	2,141
2029	2,555	2,488	2,488	2,489	2,070	2,082	1,727	1,794	1,909	2,063	2,103	2,073	2,063	2,101
2030	2,565	2,492	2,491	2,515	2,025	2,037	1,607	1,721	1,851	2,017	2,060	2,033	2,023	2,063

TABLE B.26 Total Emissions of PM_{10} under the Baseline Scenario and for Conventional-Technology Plus 3X Vehicles under the High-Market-Share Scenario (10^3 metric tons)

Year	Base Case	RFG	MeOH	EtOH	RFD	DME	HFCV	MFCV	GFCV	F-T50	B20	LPG	CNG	LNG
2005	136	134	134	134	134	134	134	134	134	134	134	134	134	134
2006	138	136	136	136	136	136	136	136	136	136	136	136	136	136
2007	139	138	138	138	138	138	138	138	138	138	138	138	138	138
2008	140	139	139	140	140	139	139	139	139	140	140	139	139	140
2009	142	142	142	142	142	142	142	142	142	142	142	142	142	142
2010	144	144	144	145	144	144	144	144	144	144	144	144	144	144
2011	146	146	145	146	146	146	146	145	145	146	146	145	145	146
2012	147	147	147	148	147	147	147	147	147	147	147	146	147	147
2013	148	148	147	150	148	148	148	147	147	148	148	147	147	148
2014	149	148	148	152	149	148	148	148	148	149	149	148	148	148
2015	149	149	148	155	150	149	148	148	148	150	150	147	148	149
2016	150	148	147	158	151	148	148	147	147	151	151	147	147	149
2017	150	148	147	162	152	148	148	146	146	152	152	146	146	149
2018	150	148	145	172	152	148	147	145	145	152	153	144	145	149
2019	150	147	144	189	153	147	146	144	144	153	154	143	143	148
2020	150	146	142	206	154	146	146	142	142	154	155	141	142	148
2021	151	146	141	222	155	145	144	140	140	155	156	138	140	147
2022	151	145	139	241	157	144	143	138	138	156	157	136	137	147
2023	151	144	136	261	158	143	142	136	136	158	158	133	135	146
2024	151	143	134	282	159	142	140	133	133	159	160	130	132	145
2025	151	141	132	306	161	141	138	131	131	161	161	127	129	145
2026	151	140	129	330	163	140	136	128	128	162	163	124	127	144
2027	151	139	127	354	164	139	134	125	126	164	165	121	124	144
2028	151	138	124	376	166	137	132	123	123	165	166	118	121	143
2029	151	137	122	397	167	137	130	121	121	167	168	116	119	143
2030	152	137	120	182	169	136	126	119	120	168	169	114	117	143

TABLE B.27 Total Emissions of SO_x under the Baseline Scenario and for Conventional-Technology Plus 3X Vehicles under the High-Market-Share Scenario (10^3 metric tons)

Year	Base Case	RFG	MeOH	EtOH	RFD	DME	HFCV	MFCV	GFCV	F-T50	B20	LPG	CNG	LNG
2005	448	440	440	440	440	440	440	440	440	440	440	440	440	440
2006	451	447	447	447	447	447	447	447	447	447	447	447	447	447
2007	455	452	452	452	452	452	452	452	452	452	452	452	452	452
2008	453	452	452	452	452	452	452	452	452	452	452	452	452	452
2009	455	455	454	455	455	454	455	454	455	454	455	454	455	454
2010	456	456	455	457	456	455	456	455	456	455	456	455	456	455
2011	456	455	454	457	455	454	455	454	455	454	455	454	455	454
2012	454	453	452	455	452	452	454	452	453	452	452	452	453	452
2013	452	449	448	454	449	448	451	448	449	448	449	448	449	449
2014	449	445	443	452	444	443	448	443	445	444	444	443	445	444
2015	445	439	436	451	437	436	444	436	439	437	437	436	439	437
2016	441	431	427	450	430	427	439	427	431	428	430	427	431	429
2017	437	423	417	450	420	417	434	417	423	419	420	417	423	419
2018	432	414	406	437	410	405	430	406	414	408	410	406	413	409
2019	428	404	393	411	400	393	425	393	404	396	399	393	403	397
2020	423	394	380	388	388	379	421	380	394	384	388	380	392	385
2021	419	383	366	369	376	365	416	366	383	371	375	366	380	372
2022	415	372	351	349	363	350	412	351	372	357	362	350	367	359
2023	411	360	335	329	349	334	409	335	360	342	348	335	354	345
2024	407	348	319	307	336	318	405	319	348	328	334	318	341	330
2025	404	336	303	285	322	301	402	303	336	312	320	302	326	315
2026	400	323	286	262	308	284	399	286	323	297	306	285	312	301
2027	397	312	270	240	294	268	397	270	312	282	292	269	299	287
2028	393	301	256	220	282	253	396	256	301	269	279	254	286	274
2029	390	291	242	201	271	239	394	242	291	257	268	240	274	262
2030	387	282	230	180	261	227	309	230	282	246	257	228	263	252

TABLE B.28 Total Emissions of CO_2 under the Baseline Scenario and for Conventional-Technology Plus 3X Vehicles under the High-Market-Share Scenario (10^3 metric tons)

Year	Base Case	RFG	MeOH	EtOH	RFD	DME	HFCV	MFCV	GFCV	F-T50	B20	LPG	CNG	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	1,364,681	1,364,573	1,364,661	1,364,680	1,364,633	1,364,681	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	1,386,950	1,386,685	1,386,902	1,386,947	1,386,832	1,386,950	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	1,404,265	1,403,743	1,404,173	1,404,259	1,404,035	1,404,265	1,404,190	1,404,415	1,404,189	1,404,039	1,403,989	1,403,980
2011	1,419,047	1,415,519	1,415,645	1,414,718	1,415,488	1,415,635	1,415,241	1,415,645	1,415,519	1,415,921	1,415,515	1,415,247	1,415,159	1,415,142
2012	1,428,217	1,422,793	1,422,992	1,421,466	1,422,742	1,422,976	1,422,334	1,422,992	1,422,793	1,423,461	1,422,786	1,422,344	1,422,197	1,422,169
2013	1,435,211	1,426,761	1,427,064	1,424,621	1,426,679	1,427,038	1,426,020	1,427,064	1,426,761	1,427,838	1,426,747	1,426,036	1,425,799	1,425,754
2014	1,439,780	1,426,592	1,427,048	1,423,172	1,426,461	1,427,006	1,425,408	1,427,048	1,426,592	1,428,313	1,426,566	1,425,434	1,425,055	1,424,982
2015	1,441,537	1,421,064	1,421,740	1,415,669	1,420,857	1,421,673	1,419,196	1,421,740	1,421,064	1,423,779	1,421,018	1,419,237	1,418,639	1,418,525
2016	1,442,253	1,411,334	1,412,300	1,403,094	1,411,018	1,412,198	1,408,481	1,412,300	1,411,334	1,415,481	1,411,256	1,408,544	1,407,631	1,407,457
2017	1,442,340	1,397,993	1,399,295	1,386,073	1,397,535	1,399,147	1,393,865	1,399,295	1,397,993	1,403,991	1,397,867	1,393,956	1,392,635	1,392,384
2018	1,442,047	1,381,470	1,383,132	1,359,005	1,380,841	1,382,929	1,375,792	1,383,132	1,381,470	1,389,723	1,381,283	1,375,918	1,374,100	1,373,755
2019	1,441,566	1,362,152	1,364,177	1,322,075	1,361,321	1,363,909	1,354,661	1,364,177	1,362,152	1,373,040	1,361,884	1,354,826	1,352,427	1,351,974
2020	1,441,089	1,340,434	1,342,803	1,282,786	1,339,374	1,342,461	1,330,880	1,342,803	1,340,434	1,354,318	1,340,066	1,331,092	1,328,031	1,327,456
2021	1,440,803	1,316,106	1,318,797	1,241,568	1,314,786	1,318,371	1,302,201	1,318,797	1,316,106	1,333,411	1,315,616	1,304,464	1,300,649	1,299,933
2022	1,440,807	1,289,527	1,292,495	1,196,117	1,287,915	1,291,975	1,268,896	1,292,495	1,289,527	1,310,647	1,288,889	1,275,318	1,270,660	1,269,790
2023	1,441,132	1,260,994	1,264,175	1,146,936	1,259,063	1,263,552	1,231,165	1,264,175	1,260,994	1,286,294	1,260,182	1,243,973	1,238,392	1,237,353
2024	1,441,777	1,230,781	1,234,094	1,094,408	1,228,506	1,233,358	1,187,881	1,234,094	1,230,781	1,260,594	1,229,769	1,210,724	1,204,146	1,202,926
2025	1,442,770	1,199,192	1,202,540	1,039,015	1,196,550	1,201,685	1,140,365	1,202,540	1,199,192	1,233,819	1,197,954	1,175,897	1,168,256	1,166,843
2026	1,444,053	1,166,953	1,170,219	982,020	1,163,929	1,169,238	1,089,318	1,170,219	1,166,953	1,206,587	1,165,462	1,140,290	1,131,542	1,129,929
2027	1,445,600	1,135,983	1,139,026	926,745	1,132,585	1,137,921	1,040,996	1,139,026	1,135,983	1,180,535	1,134,226	1,106,014	1,096,177	1,094,371
2028	1,447,369	1,107,486	1,110,158	875,283	1,103,733	1,108,937	995,492	1,110,158	1,107,486	1,156,683	1,105,455	1,074,392	1,063,527	1,061,539
2029	1,449,331	1,081,914	1,084,082	828,452	1,077,833	1,082,750	955,501	1,084,082	1,081,914	1,135,409	1,079,608	1,045,929	1,034,113	1,031,957
2030	1,451,435	1,059,307	1,060,851	770,798	1,054,927	1,059,419	951,947	1,060,851	1,059,307	1,116,739	1,056,727	1,020,677	1,007,988	1,005,682

TABLE B.29 Total Emissions of CH_4 under the Baseline Scenario and for Conventional-Technology Plus 3X Vehicles under the High-Market-Share Scenario (10^3 metric tons)

Year	Base Case	RFG	MeOH	EtOH	RFD	DME	HFCV	MFCV	GFCV	F-T50	B20	LPG	CNG	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	1,471	1,471
2009	1,498	1,496	1,496	1,495	1,495	1,496	1,495	1,496	1,495	1,495	1,495	1,496	1,498	1,498
2010	1,518	1,516	1,517	1,515	1,516	1,516	1,515	1,516	1,516	1,516	1,515	1,516	1,521	1,521
2011	1,534	1,530	1,531	1,528	1,529	1,531	1,529	1,531	1,529	1,530	1,529	1,531	1,540	1,540
2012	1,545	1,540	1,542	1,537	1,539	1,541	1,539	1,541	1,539	1,539	1,539	1,541	1,556	1,556
2013	1,555	1,547	1,549	1,542	1,545	1,548	1,544	1,548	1,545	1,545	1,544	1,548	1,572	1,572
2014	1,562	1,549	1,553	1,542	1,546	1,552	1,545	1,551	1,546	1,547	1,545	1,551	1,590	1,590
2015	1,566	1,546	1,553	1,534	1,540	1,550	1,540	1,549	1,541	1,543	1,540	1,548	1,610	1,610
2016	1,568	1,539	1,549	1,521	1,530	1,544	1,529	1,544	1,532	1,533	1,529	1,542	1,637	1,637
2017	1,570	1,529	1,542	1,502	1,515	1,536	1,514	1,535	1,517	1,520	1,514	1,532	1,670	1,670
2018	1,572	1,515	1,533	1,476	1,496	1,524	1,495	1,523	1,499	1,503	1,494	1,520	1,709	1,709
2019	1,573	1,498	1,522	1,446	1,474	1,510	1,472	1,508	1,478	1,483	1,471	1,505	1,754	1,754
2020	1,574	1,479	1,509	1,411	1,448	1,495	1,446	1,492	1,453	1,459	1,444	1,488	1,806	1,806
2021	1,575	1,458	1,494	1,373	1,419	1,477	1,415	1,473	1,425	1,433	1,414	1,469	1,865	1,865
2022	1,576	1,434	1,478	1,330	1,387	1,457	1,379	1,453	1,395	1,404	1,381	1,448	1,931	1,931
2023	1,578	1,409	1,461	1,283	1,352	1,435	1,339	1,430	1,361	1,373	1,344	1,425	2,004	2,004
2024	1,580	1,382	1,443	1,234	1,315	1,412	1,294	1,406	1,326	1,339	1,306	1,401	2,083	2,083
2025	1,583	1,353	1,423	1,181	1,276	1,388	1,245	1,381	1,288	1,304	1,265	1,376	2,168	2,168
2026	1,585	1,324	1,404	1,127	1,236	1,363	1,193	1,355	1,250	1,268	1,223	1,350	2,257	2,256
2027	1,588	1,297	1,385	1,075	1,197	1,339	1,143	1,330	1,213	1,233	1,183	1,325	2,345	2,344
2028	1,591	1,271	1,367	1,026	1,161	1,317	1,097	1,307	1,179	1,201	1,145	1,303	2,429	2,428
2029	1,594	1,249	1,352	982	1,129	1,298	1,055	1,287	1,148	1,172	1,111	1,283	2,507	2,506
2030	1,598	1,229	1,338	897	1,100	1,280	1,209	1,268	1,121	1,146	1,081	1,266	2,579	2,581

TABLE B.30 Total Emissions of N_2O under the Baseline Scenario and for Conventional-Technology Plus 3X Vehicles under the High-Market-Share Scenario (10^3 metric tons)

Year	Base Case	RFG	MeOH	EtOH	RFD	DME	HFCV	MFCV	GFCV	F-T50	B20	LPG	CNG	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	46.5	46.4	46.4	46.4	46.4	46.4	46.4	46.4	46.4	46.4	46.5
2008	44.2	44.0	44.0	44.1	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	42.4	42.1	42.1	42.1	42.1	42.1	42.1	42.1	42.1	42.1	42.2
2010	40.3	40.2	40.2	40.7	40.2	40.2	40.3	40.2	40.2	40.2	40.3	40.2	40.3	40.3
2011	38.4	38.4	38.4	39.3	38.4	38.4	38.5	38.3	38.3	38.4	38.4	38.4	38.4	38.6
2012	36.7	36.6	36.6	38.0	36.6	36.6	36.7	36.5	36.5	36.6	36.6	36.6	36.6	36.9
2013	35.0	34.9	34.9	37.2	34.9	34.9	35.1	34.7	34.8	34.9	34.9	34.8	34.9	35.4
2014	33.4	33.3	33.2	37.0	33.2	33.2	33.7	33.0	33.1	33.2	33.3	33.2	33.3	34.1
2015	32.0	31.7	31.7	37.7	31.7	31.7	32.4	31.3	31.4	31.6	31.8	31.6	31.8	33.0
2016	30.6	30.2	30.2	39.4	30.2	30.2	31.2	29.7	29.7	30.1	30.4	30.1	30.4	32.2
2017	29.3	28.9	28.8	42.1	28.8	28.8	30.3	28.1	28.1	28.7	29.0	28.7	29.0	31.7
2018	28.2	27.6	27.6	41.7	27.5	27.6	29.7	26.5	26.5	27.4	27.8	27.4	27.8	31.6
2019	27.1	26.4	26.4	37.9	26.2	26.4	29.2	25.0	25.0	26.2	26.8	26.2	26.7	31.7
2020	26.1	25.3	25.4	35.6	25.1	25.4	28.9	23.6	23.6	25.1	25.8	25.1	25.6	32.1
2021	25.3	24.4	24.4	35.4	24.1	24.4	28.9	22.2	22.2	24.1	24.9	24.0	24.7	32.8
2022	24.5	23.5	23.6	35.3	23.2	23.6	29.0	20.9	20.8	23.2	24.1	23.1	23.8	33.9
2023	23.7	22.7	22.9	35.5	22.4	22.9	29.3	19.7	19.5	22.4	23.5	22.3	23.0	35.2
2024	23.1	21.9	22.2	35.8	21.6	22.2	29.7	18.5	18.2	21.7	22.9	21.5	22.3	36.7
2025	22.5	21.3	21.7	36.2	21.0	21.7	30.3	17.3	16.9	21.0	22.4	20.9	21.7	38.5
2026	22.0	20.7	21.2	36.8	20.4	21.2	31.0	16.2	15.7	20.5	21.9	20.3	21.1	40.5
2027	21.5	20.2	20.8	37.5	19.9	20.8	31.7	15.2	14.6	20.0	21.6	19.8	20.6	42.5
2028	21.1	19.8	20.5	38.1	19.5	20.5	32.5	14.3	13.6	19.6	21.2	19.4	20.2	44.4
2029	20.7	19.4	20.2	38.8	19.1	20.2	33.3	13.4	12.6	19.2	21.0	19.0	19.8	46.2
2030	20.4	25.2	21.5	80.4	22.5	21.4	13.9	12.7	11.8	18.9	20.8	18.7	19.5	47.9

TABLE B.31 Total Energy Use under the Baseline Scenario and for Conventional-Technology Plus 3X Vehicles under the High-Market-Share Scenario (Quads)

Year	Base Case	RFG	MeOH	EtOH	RFD	DME	HFCV	MFCV	GFCV	F-T50	B20	LPG	CNG	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	19.3	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	19.0
2018	19.6	18.8	19.0	19.0	18.8	18.9	19.1	19.0	18.8	18.9	18.8	18.7	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	18.4	18.5	18.5
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	18.1	18.1
2021	19.6	17.9	18.2	18.4	17.8	18.2	18.5	18.2	17.9	18.1	17.9	17.7	17.8	17.8
2022	19.6	17.6	17.9	18.1	17.4	17.9	18.2	17.9	17.6	17.8	17.5	17.3	17.3	17.4
2023	19.6	17.2	17.5	17.9	17.0	17.5	17.9	17.5	17.2	17.4	17.1	16.8	16.9	16.9
2024	19.6	16.8	17.2	17.6	16.6	17.2	17.5	17.2	16.8	17.1	16.6	16.4	16.4	16.4
2025	19.6	16.3	16.8	17.3	16.1	16.8	17.1	16.8	16.3	16.7	16.2	15.9	15.9	15.9
2026	19.7	15.9	16.4	17.0	15.6	16.4	16.7	16.4	15.9	16.3	15.7	15.3	15.4	15.4
2027	19.7	15.5	16.1	16.7	15.2	16.1	16.3	16.1	15.5	15.9	15.3	14.8	14.9	14.9
2028	19.7	15.1	15.7	16.5	14.8	15.7	15.9	15.7	15.1	15.6	14.9	14.4	14.4	14.4
2029	19.7	14.7	15.4	16.3	14.4	15.4	15.6	15.4	14.7	15.3	14.5	13.9	13.9	14.0
2030	19.7	14.4	15.2	16.1	14.1	15.2	15.3	15.2	14.4	15.0	14.2	13.6	13.6	13.6

TABLE B.32 Total Fossil Energy Use under the Baseline Scenario and for Conventional-Technology Plus 3X Vehicles under the High-Market-Share Scenario (Quads)

Year	Base Case	RFG	MeOH	EtOH	RFD	DME	HFCV	MFCV	GFCV	F-T50	B20	LPG	CNG	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	17.2	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.33 Total Petroleum Use under the Baseline Scenario and for Conventional-Technology Plus 3X Vehicles under the High-Market-Share Scenario (Quads)

Year	Base Case	RFG	MeOH	EtOH	RFD	DME	HFCV	MFCV	GFCV	F-T50	B20	LPG	CNG	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.34 Total Global Warming Potential under the Baseline Scenario and for Conventional-Technology Plus 3X Vehicles under the High-Market-Share Scenario (10^6 metric tons CO_2 equivalent)

Year	Base Case	RFG	MeOH	EtOH	RFD	DME	HFCV	MFCV	GFCV	F-T50	B20	LPG	CNG	LNG
2005	1,383	1,360	1,360	1,360	1,360	1,360	1,360	1,360	1,360	1,360	1,360	1,360	1,360	1,360
2006	1,395	1,380	1,380	1,380	1,380	1,380	1,380	1,380	1,380	1,380	1,380	1,380	1,380	1,380
2007	1,406	1,398	1,398	1,398	1,398	1,398	1,398	1,398	1,398	1,398	1,398	1,398	1,398	1,398
2008	1,414	1,409	1,409	1,409	1,409	1,409	1,409	1,409	1,409	1,409	1,409	1,409	1,409	1,409
2009	1,434	1,431	1,431	1,431	1,431	1,431	1,431	1,431	1,431	1,431	1,431	1,431	1,431	1,431
2010	1,451	1,449	1,449	1,448	1,448	1,449	1,448	1,449	1,448	1,449	1,448	1,448	1,448	1,448
2011	1,463	1,460	1,460	1,459	1,459	1,460	1,459	1,460	1,460	1,460	1,460	1,459	1,459	1,459
2012	1,472	1,466	1,467	1,466	1,466	1,467	1,466	1,467	1,466	1,467	1,466	1,466	1,466	1,466
2013	1,479	1,470	1,470	1,469	1,470	1,470	1,469	1,470	1,470	1,471	1,470	1,469	1,470	1,470
2014	1,483	1,469	1,470	1,467	1,469	1,470	1,468	1,470	1,469	1,471	1,469	1,468	1,469	1,469
2015	1,484	1,463	1,464	1,460	1,463	1,464	1,462	1,464	1,463	1,466	1,463	1,462	1,462	1,463
2016	1,485	1,453	1,454	1,447	1,452	1,454	1,450	1,454	1,453	1,457	1,453	1,450	1,451	1,452
2017	1,484	1,439	1,441	1,431	1,438	1,440	1,435	1,440	1,439	1,445	1,439	1,435	1,437	1,437
2018	1,484	1,422	1,424	1,403	1,421	1,423	1,416	1,423	1,421	1,430	1,421	1,416	1,419	1,419
2019	1,483	1,402	1,404	1,364	1,400	1,404	1,395	1,404	1,401	1,412	1,401	1,395	1,398	1,399
2020	1,482	1,379	1,382	1,323	1,378	1,382	1,370	1,381	1,378	1,393	1,378	1,370	1,374	1,375
2021	1,482	1,354	1,358	1,281	1,352	1,357	1,341	1,357	1,353	1,371	1,353	1,343	1,347	1,349
2022	1,481	1,327	1,331	1,235	1,324	1,330	1,307	1,329	1,325	1,347	1,325	1,313	1,319	1,321
2023	1,482	1,298	1,302	1,185	1,294	1,301	1,268	1,300	1,296	1,322	1,296	1,281	1,288	1,290
2024	1,482	1,267	1,271	1,131	1,263	1,270	1,224	1,269	1,264	1,295	1,264	1,247	1,255	1,258
2025	1,483	1,234	1,239	1,075	1,230	1,238	1,176	1,237	1,231	1,268	1,231	1,211	1,221	1,224
2026	1,484	1,201	1,206	1,017	1,196	1,204	1,124	1,204	1,198	1,240	1,198	1,175	1,185	1,190
2027	1,486	1,169	1,175	961	1,164	1,172	1,075	1,172	1,166	1,213	1,166	1,140	1,152	1,157
2028	1,487	1,140	1,145	909	1,134	1,143	1,029	1,142	1,136	1,188	1,136	1,108	1,121	1,126
2029	1,489	1,114	1,119	861	1,107	1,116	988	1,115	1,110	1,166	1,109	1,079	1,093	1,099
2030	1,491	1,093	1,096	815	1,085	1,093	982	1,091	1,087	1,147	1,086	1,053	1,068	1,075