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The IMPACTT Model: Structure and Technical Description

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The IMPACTT Model: Structure and Technical Description

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AVAILABILITY OF COMPUTER SOFTWARE

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THE IMPACTT MODEL: STRUCTURE AND TECHNICAL DESCRIPTION

by

M.M. Mintz, M.M. Tompkins, and J. Camp

ABSTRACT

The Integrated Market Penetration and Anticipated Cost of Transportation Technologies model, or IMPACTT, is a spreadsheet model that calculates the effect of advanced-technology vehicles and market penetration on baseline fuel use and emissions. Outputs include estimates of the quantity and value of oil displaced and emissions reduced by advanced-technology vehicles, the quantity of alternative fuels they consume, and the total incremental costs borne by purchasers of advanced-technology vehicles. In the current version of IMPACTT, up to eight fuel or engine technologies applicable to light-duty vehicles can be modeled by using a three-phase approach. First, the vehicle stock and miles traveled by the advanced-technology vehicle are determined. Second, assumptions about efficiency and fuel shares are used to estimate substitution-fuel use and oil displacement. Third, changes in emissions of carbon monoxide, nonmethane hydrocarbons, nitrogen oxides, and carbon dioxide are computed.

1 INTRODUCTION AND OVERVIEW

Argonne National Laboratory's (ANL's) Center for Transportation Research (CTR) developed the Integrated Market Penetration and Anticipated Cost of Transportation Technologies model (IMPACTT) to assist the U.S. Department of Energy's (DOE's) Office of Transportation Technologies (OTT) with program planning and development. IMPACTT is a spreadsheet model, operating in either an Apple™ or PC-compatible environment, that calculates the effect of advanced-technology vehicles and market penetration on baseline fuel use and emissions.

Outputs include estimates of the quantity and value of oil displaced and emissions reduced by advanced-technology vehicles, the quantity of alternative fuels they consume, and the total incremental costs borne by purchasers of advanced-technology vehicles. Estimates are based on exogenous projections of conventional vehicle sales, advanced-technology market penetration, and the characteristics of new conventional and advanced-technology vehicles. Vehicle characteristics include fuel efficiency; tailpipe emissions of nitrogen oxides (NO_x), carbon monoxide (CO), and nonmethane hydrocarbons (NMHCs); and incremental capital cost (i.e., the unit cost of a conventional vehicle less the unit cost of an advanced-technology vehicle). Annual petroleum displacement and emissions reduction are calculated by projecting the miles traveled by each model year's conventional vehicles, their petroleum use, and their emissions and then subtracting those projections from comparable projections for advanced-technology vehicles.

2 METHODOLOGY

Written in Microsoft EXCEL 5.0 workbook format, IMPACTT is a spreadsheet model consisting of eight general worksheets and an equal number of technology-specific worksheets, each of which represents a fuel or technology alternative.[1] In addition to the 16 worksheets, a "Read Me" file (essentially an on-line, condensed version of this document; see Appendix A) is attached. The names and dimensions of the 16 worksheets are listed in Table 1.

As shown in Figure 1, IMPACTT's technology-specific worksheets contain three modules. The **STOCK** module projects the population or stock of an advanced- or conventional-technology vehicle from estimates of total vehicle sales, advanced-technology marginal cost and market penetration, and vehicle depreciation rates. The **USAGE** module then estimates the amount of substitution fuel consumed by the advanced-technology vehicle, as well as the vehicle-miles traveled (VMT), oil displaced, and carbon dioxide (CO_2) reduction achieved by that vehicle relative to a conventional-technology vehicle of the same age or model year. The **EMISSIONS** module then computes the quantity and dollar value of reductions in tailpipe and refinery emissions attributable to the advanced-technology vehicle. Finally, results are summarized across all technology-specific worksheets to yield total estimates of advanced-technology stocks, VMT, oil displacement, emissions reduction, and substitution-fuel use.

Several worksheets are needed to analyze the impacts of a portfolio of actual or proposed programs. For example, analyses of the DOE/OTT Diversified Strategy (U.S. DOE 1994a) required the use of eight technology-specific worksheets (corresponding to the following technologies and fuels: conventional internal-combustion engines [ICEs], advanced-battery electric, grid-connected hybrid, fuel cell, liquid petroleum gas (LPG), compressed natural gas (CNG), flexible-fuel ("flex-fuel") ethanol, and dedicated ethanol). Analyses of OTT's Advanced Hybrid Vehicle, Electric/Fuel Cell Vehicle, and Natural Gas Then Alcohol strategies required one, two, and three technology-specific worksheets, respectively.

2.1 GENERAL WORKSHEETS

The current version of IMPACTT contains eight general worksheets: INPUTS, SALES-MPG, EMIS INPUTS, VMT SUM, OIL SUM, EMIS SUM, CON SUM, and EMIS RED SUM. The INPUTS worksheet contains user-supplied forecasts of market penetration and marginal cost per vehicle for each advanced technology and an emissions rate for each of three criteria pollutants. The SALES-MPG worksheet contains forecasts of auto and light truck sales and fuel economy that are converted into weighted averages for input into the STOCK and USAGE modules. Default values from the SALES-MPG worksheet are listed in

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1 Although all of the technologies included on the default file are targeted toward the class of total light-duty vehicles, separate analyses of autos and light-duty trucks may be performed by modifying internal pointers and output headings.

TABLE 1 Workbook Organization

Worksheet	Beginning Cell Location	Ending Cell Location
INPUTS	A-1	S-54
ICE	A-1	BJ-75
CNG	A-1	BT-55
LPG	A-1	BT-55
FLEX (ETOH)	A-1	BT-62
HYB (HYBRID)	A-1	BT-60
ELEC (EV)	A-1	BT-62
FCV (FUEL CELL)	A-1	BT-60
DED ETOH	A-1	BT-60
VMT SUM	A-1	U-52
CON SUM	A-1	AW-53
EMIS RED SUM	A-1	AX-100
EMIS INPUTS	A-1	V-118D
EMIS SUM	A-1	BO-100
OIL SUM	A-1	BK-53
SALES-MPG	A-1	M-45

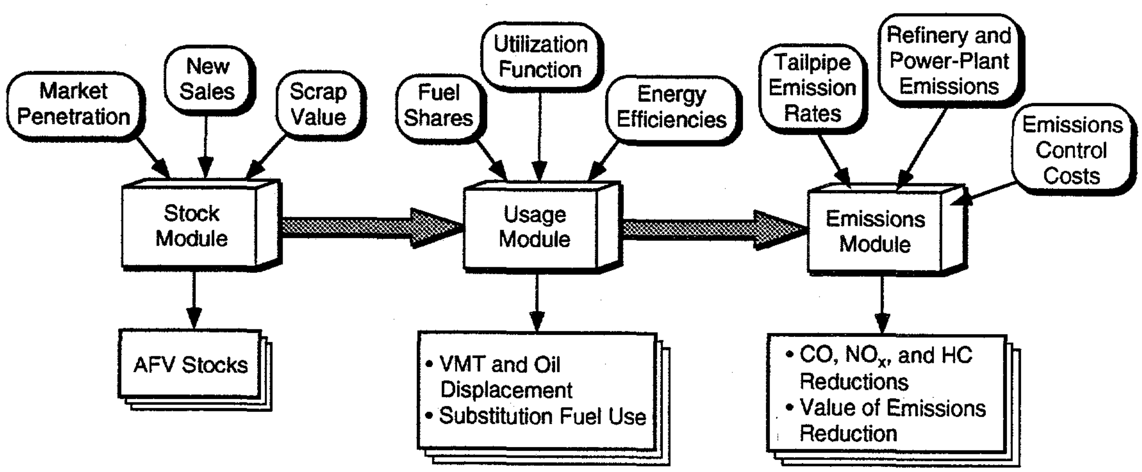

FIGURE 1 Structure of IMPACTT Technology-Specific Worksheets

Tables 2 and 3. These forecasts were derived from the *1994 Annual Energy Outlook* (DOE 1994b). Default values assume a 20% shortfall or gap between the U.S. Environmental Protection Agency's (EPA's) test results and on-the-road fuel economy (Mintz, Vyas, and Conley 1993).

The EMIS INPUTS worksheet contains (1) default rates of tailpipe emissions by vehicle type and vintage and (2) rates of refinery and power-plant emissions by fuel type. Expressed in grams per mile, rates were computed from the EPA's MOBILE5a model. Within EMIS INPUTS, values for total light-duty vehicles are weighted as 60% autos and 40% light trucks. Default values for power-plant emissions are based on the year 2000 electricity generation mix for New York City and southern California, the two locations likely to have the earliest market penetration of electric vehicles (EVs). Default values are weighted by the relative share of VMT contributed by each of these two markets (Wang and Santini 1994). Default values are provided in Tables 4–6.

Five summary worksheets aggregate results from the technology-specific worksheets. The VMT SUM worksheet summarizes fleet average miles-per-gallon (mpg) and vehicle-miles displaced by all advanced-technology vehicles, while OIL SUM and EMIS RED SUM summarize total oil displacement and emissions reduction. CON SUM summarizes substitution-fuel use (in physical units, quads[2] and millions of barrels per day) and advanced-technology vehicle stocks, while EMIS SUM summarizes emissions of criteria pollutants. Note that in both CON SUM and EMIS SUM, entries are aggregated over all technologies considered in the particular scenario under examination. Summary worksheets report annual results for 1990–2030 and cumulatively (as appropriate) for the periods 1990–2000, 1990–2010, 1990–2020, and 1990–2030.

2.2 TECHNOLOGY-SPECIFIC WORKSHEETS

The default case is based on the diversified scenario developed by the DOE's OTT for its five-year program plan. That scenario required the use of eight technology-specific worksheets. Thus, by using a common three-module framework, the default version of the model can accommodate up to seven advanced (and one conventional) technologies.

2.2.1 STOCK Module

The first and largest component of the technology-specific worksheets is the vehicle **STOCK** module. On the basis of a capital vintaging model developed by Greene and Rathi (1990), the module calculates the stock or population of conventional- or advanced-technology light-duty vehicles by forecast year. New-vehicle sales, market-penetration rates for advanced-technology vehicles, and scrap value are the key determinants of conventional- and

[2] 10^{15} (one quadrillion) Btu = 1 quad.

TABLE 2 Default New-Vehicle Sales by Vehicle Type

	Sales (10^3) by Vehicle Type			
Year	Autos	Light Trucks	Medium Trucks	Heavy Trucks
1990	9,580	4,390	160	110
1991	8,450	3,930	130	90
1992	8,420	4,500	140	100
1993	9,060	5,110	170	120
1994	9,420	5,310	190	140
1995	9,290	5,330	210	150
1996	9,540	5,180	216	154
1997	9,740	5,300	222	158
1998	9,790	5,450	228	162
1999	9,780	5,550	234	166
2000	9,780	5,660	240	170
2001	9,760	5,770	248	174
2002	9,780	5,920	256	178
2003	9,840	6,120	264	182
2004	9,990	6,230	272	186
2005	10,120	6,270	280	190
2006	10,230	6,260	288	192
2007	10,480	6,360	296	194
2008	10,490	6,390	304	196
2009	10,410	6,410	312	198
2010	10,370	6,520	320	200
2011	10,421	6,572	328	202
2012	10,524	6,676	336	204
2013	10,575	6,728	344	206
2014	10,626	6,780	352	208
2015	10,677	6,832	360	210
2016	10,729	6,884	368	212
2017	10,780	6,936	376	214
2018	10,831	6,988	384	216
2019	10,882	7,040	392	218
2020	10,934	7,092	400	220
2021	10,985	7,144	400	220
2022	11,036	7,196	400	220
2023	11,087	7,248	400	220
2024	11,139	7,300	400	220
2025	11,190	7,352	400	220
2026	11,241	7,404	400	220
2027	11,292	7,456	400	220
2028	11,343	7,508	400	220
2029	11,395	7,560	400	220
2030	11,446	7,612	400	220

Sources: 1994–2010: DOE 1994b; post-2010: extrapolated.

TABLE 3 Default On-Road and EPA-Test Fuel Economy of New Light-Duty Vehicles (mpg)

	On-Road		EPA Test		Total Light Duty	
Year	Auto	Light Truck	Auto	Light Truck	On-Road	EPA-Test
1990	22.56	16.73	28.20	20.91	20.33	25.42
1991	22.50	16.76	28.13	20.95	20.29	25.36
1992	22.44	16.78	28.05	20.98	20.08	25.10
1993	22.59	16.93	28.23	21.16	20.16	25.19
1994	22.73	17.07	28.41	21.34	20.30	25.38
1995	22.88	17.21	28.59	21.52	20.43	25.53
1996	23.02	17.36	28.78	21.70	20.65	25.81
1997	23.17	17.50	28.96	21.87	20.79	25.99
1998	23.31	17.64	29.14	22.05	20.91	26.13
1999	23.46	17.79	29.32	22.23	21.03	26.28
2000	23.60	17.93	29.50	22.41	21.15	26.43
2001	23.78	18.08	29.72	22.60	21.29	26.61
2002	23.95	18.24	29.94	22.80	21.42	26.78
2003	24.13	18.39	30.16	22.99	21.55	26.94
2004	24.30	18.55	30.38	23.19	21.72	27.15
2005	24.48	18.70	30.60	23.38	21.89	27.37
2006	24.61	18.83	30.76	23.54	22.04	27.55
2007	24.74	18.95	30.92	23.69	22.18	27.73
2008	24.87	19.08	31.09	23.85	22.31	27.88
2009	25.00	19.20	31.25	24.00	22.42	28.02
2010	25.13	25.13	31.41	24.16	22.52	28.15
2011	25.13	19.33	31.41	24.16	22.52	28.14
2012	25.13	19.33	31.41	24.16	22.51	28.13
2013	25.13	19.33	31.41	24.16	22.50	28.13
2014	25.13	19.33	31.41	24.16	22.50	28.12
2015	25.13	19.33	31.41	24.16	22.49	28.12
2016	25.13	19.33	31.41	24.16	22.49	28.11
2017	25.13	19.33	31.41	24.16	22.49	28.11
2018	25.13	19.33	31.41	24.16	22.48	28.10
2019	25.13	19.33	31.41	24.16	22.48	28.10
2020	25.13	19.33	31.41	24.16	22.47	28.09
2021	25.13	19.33	31.41	24.16	22.47	28.09
2022	25.13	19.33	31.41	24.16	22.47	28.08
2023	25.13	19.33	31.41	24.16	22.46	28.08
2024	25.13	19.33	31.41	24.16	22.46	28.07
2025	25.13	19.33	31.41	24.16	22.46	28.07
2026	25.13	19.33	31.41	24.16	22.45	28.07
2027	25.13	19.33	31.41	24.16	22.45	28.06
2028	25.13	19.33	31.41	24.16	22.45	28.06
2029	25.13	19.33	31.41	24.16	22.44	28.05
2030	25.13	19.33	31.41	24.16	22.44	28.05

Sources: 1994–2010: DOE 1994b; post-2010: assumed constant.

TABLE 4 Default Emission Rates of Automobiles by Age and Pollutant

Age (in years)	Emission Rate by Pollutant (g/mi)			
			NMHCs	
	NO_x	CO	Exhaust	Evaporative
<1	0.23	5.28	0.21	0.26
1	0.31	7.00	0.28	0.26
2	0.45	9.41	0.38	0.27
3	0.58	11.63	0.48	0.28
4	0.70	13.65	0.56	0.28
5	0.97	18.24	0.88	0.39
6	1.22	22.43	1.16	0.49
7	0.05	26.36	1.43	0.58
8	1.69	30.09	1.68	0.67
9	1.91	33.42	1.91	0.76
10	2.12	36.25	2.09	0.85
11	2.31	39.47	2.31	0.93
12	2.49	42.54	2.52	1.02
13	2.66	45.43	2.72	1.10
14	2.82	48.13	2.91	1.18
15	2.98	50.71	3.09	1.30
16	3.12	53.11	3.27	1.62
17	3.26	55.35	3.45	1.79

Source: EPA, MOBILE5a for post-2003 new vehicles. Because LPG, CNG, flex-fuel, and dedicated ethanol vehicles begin to appear before 2004, emission savings for those vehicles are somewhat understated.

advanced-technology vehicle stock in each forecast year. Comparable projections for heavy-duty vehicles are produced within an earlier version of the model by applying historical survival and usage rates. Those calculations and inputs are not reported here.

In any given year, the equation for new (i.e., age = 0) advanced-technology-vehicle stock is based on the market penetration for that technology as a share of total sales for light-duty vehicles (automobiles and light-duty trucks). A vintaging stock model is then used to estimate the number of vehicles in a given year by age.

For age = 0,

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

TABLE 5 Default Emission Rates of Light Trucks by Age and Pollutant

Age (in years)	Emission Rate by Pollutant (g/mi)			
			NMHCs	
	NO_x	CO	Exhaust	Evaporative
<1	0.44	8.25	0.28	0.24
1	0.53	10.01	0.35	0.24
2	0.68	12.61	0.45	0.25
3	0.82	15.05	0.56	0.25
4	0.98	18.02	0.71	0.28
5	1.27	23.40	1.07	0.39
6	1.55	28.41	1.39	0.50
7	1.82	33.21	1.71	0.61
8	2.09	37.85	2.01	0.71
9	2.34	72.09	2.28	0.81
10	2.59	45.83	2.52	0.91
11	2.82	50.07	2.80	1.01
12	3.03	54.10	3.07	1.10
13	3.24	57.98	3.32	1.19
14	3.44	61.69	3.57	1.28
15	3.68	66.58	3.84	1.40
16	3.93	69.47	4.10	1.67
17	4.21	74.97	4.40	1.83

Source: EPA, MOBILE5a.

For age = 2,..., 17,

$$V_{ij} = V_{i-1,j-1} \times \left(1-\left[1+e^{A0 + MC_i \times A_1 \times (1-DRATE)^j}\right]^{-1}\right), \qquad (2)$$

where:

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

j = age index, 0,...,17;

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

$SALES_i$ = vehicle sales, year i;

P_i = market-penetration rate;

DRATE = price-depreciation rate, generally set to 0.15;

TABLE 6 Default Emission Rates of Total Light-Duty Vehicles by Age and Pollutant

Age (in years)	Emission Rate by Pollutant (g/mi)			
			NMHCs	
	NO_x	CO	Exhaust	Evaporative
<1	0.31	6.46	0.24	0.25
1	0.40	8.20	0.31	0.25
2	0.54	10.69	0.41	0.26
3	0.67	13.00	0.51	0.27
4	0.81	15.40	0.62	0.28
5	1.09	20.30	0.95	0.39
6	1.36	24.82	1.26	0.49
7	0.76	29.10	1.54	0.59
8	1.85	33.19	1.81	0.69
9	2.08	48.89	2.06	0.78
10	2.30	40.08	2.26	0.88
11	2.51	43.71	2.51	0.97
12	2.71	47.16	2.74	1.05
13	2.89	50.45	2.96	1.14
14	3.07	53.56	3.18	1.22
15	3.26	57.06	3.39	1.34
16	3.44	59.65	3.60	1.64
17	3.64	63.20	3.83	1.81

MC_{ij} = marginal cost of a new advanced-technology vehicle divided by annual miles;

A_0 = asymptotic survival parameter; and

A_1 = new-car scrappage parameter, e^{A1}.

Equation 2 can be algebraically reformulated as:

$$V_{ij} = V_{i-1,j-1} - \frac{V_{i-1,j-1}}{1 + e^{A0 + MC_i \times A_1 \times (1-DRATE)^j}} . \tag{3}$$

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

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

2.2.2 USAGE Module

The output of the **STOCK** module (vehicle stock by vintage for each advanced technology), an age-dependent utilization rate (annual VMT per vehicle), fuel shares, and energy efficiencies are the major inputs to the **USAGE** module. Vehicle-miles traveled, oil displacement, and substitution-fuel use for each advanced technology are the major outputs.[3] Vehicle-miles traveled is computed as the sum of the product of total new-vehicle sales, advanced-technology market penetration, survival, and vehicle use by vintage. Potential oil displacement is computed as the sum of the product of VMT and conventional-vehicle mpg for each vintage.[4] Displacement is reported in gallons and converted into millions of barrels per day (MMBD) and quads by using the assumptions of 42 gal/bbl and 115,400 Btu/gal (i.e., the lower heating value of gasoline). No conversion into barrels of imported oil is made within the model.

An advanced technology's impact on energy use includes both (1) the quantity of petroleum displaced by the use of the advanced-technology vehicle and (2) the quantity of the alternative fuel (if any) consumed by that vehicle (e.g., kWh used by electric vehicles). Within the USAGE module, the latter (known as substitution-fuel use) is computed as the sum of the product of VMT and advanced-technology GEMPG (the product of gasoline-equivalent mpg and the Btu content of the fuel relative to gasoline) for each vintage.

First, VMT must be computed, as in Equation 5:

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

where:

M_0 = annual miles per vehicle, age 0;

M_j = annual miles per vehicle, age j; and

UDRATE = usage depreciation rate.

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[3] Note that age-dependent utilization can be adjusted to account for limited range. Thus, for example, EVs might travel only two-thirds as many miles per year as conventional vehicles.

[4] For bi-fuel technologies in which petroleum is not totally displaced (e.g., dedicated ethanol vehicles running on an 85% ethanol fuel or flex-fuel vehicles), potential oil displacement is multiplied by the share of VMT run on alternative fuel for each vintage. Total displacement is then the sum of these products.

Results from the vehicle stock model, which yields the number of vehicles of a given age, are then combined with the exogenous variable V_j (the miles traveled for a given age) to determine VMT in any given year. The equation specification is given below:

$$\mathrm{VMT}_i = \sum_j VMT_{ij} = \sum_j V_{ij} \times M_j \,, \tag{6}$$

where:

M_j = annual miles per vehicle, age j, and

VMT_{ij} = total vehicle-miles traveled, year i and age j.

Potential gasoline displacement is calculated from miles traveled by the advanced-technology vehicles and miles per gallon of the new conventional vehicles that are being displaced, as shown in Equation 7:

$$\mathrm{PGD}_i = \sum_j \frac{VMT_{ij}}{NMPG_k} \,, \tag{7}$$

where:

$NMPG_k$ = miles per gallon of the new conventional vehicle replaced by the advanced-technology vehicle, model year k, and

PGD_i = potential gasoline displaced (gallons), year i.

Several technology-specific parameters are used to compute fuel substitution (i.e., alternative-fuel consumption):

$$\mathrm{AFUSE}_i = \sum_j \left(\frac{VMT_{ij} \times AFSHARE_i}{GEMPG_k \times BRATE \times ERATE} \right) , \tag{8}$$

where:

$GEMPG_k$ = gasoline-equivalent mpg, model year k;

BRATE = Btu per equivalent volume of fuel relative to gasoline;

ERATE = efficiency relative to conventional vehicle;

$AFUSE_i$ = alternative fuel use, year i; and

$AFSHARE_i$ = share of VMT on alternative fuel, year i.

For flexibly fueled vehicles, five additional parameters are included in the fuel-substitution module: (1) alcohol share of gasoline, (2) ethanol and (3) methanol shares of fuel-alcohol use, and (4) ethanol and (5) methanol-fuel use. In the current version of the model, the share of methanol is not estimated, and the share of ethanol is estimated from an exogenous forecast of biofuels production. The default production forecast (contained in the FLEX worksheet) was developed by the DOE/OTT (U.S. DOE 1994a). The default forecast assumes that real prices for biofuels decline and bioethanol accounts for 100% of biofuels production.[5] Thus, ethanol shares are supply-constrained to the sum of current and new production capacity.

For electric and grid-connected hybrid vehicles, two additional parameters, transmission and distribution efficiencies, are used to account for losses between the power plant and vehicle. Fuel conversion efficiencies (e.g., to produce electricity or fuel-grade alcohol, or to compress natural gas) are not included in the fuel substitution calculation.

2.2.3 EMISSIONS Module

The **EMISSIONS** module estimates reductions in NO_x, CO, and NMHC emissions associated with advanced-technology vehicles. Although SO_x emissions are not estimated in the current version of the model, the worksheets have been designed so that users can add SO_x emission rates and thus compute SO_x emissions. All emission rates (in grams per mile) are modeled as a function of vehicle age or vintage. Emission reduction rates (in grams per mile by vintage) are obtained by subtracting the projected values from the conventional-vehicle values contained in the EMIS INPUTS worksheet. Within the **EMISSIONS** module, emissions reductions are computed as the sum of the product of VMT and the emissions reduction rate by vintage and are then converted to short tons. Because most of the technologies considered in IMPACTT are introduced after 2003, the conventional vehicles displaced by those technologies are assumed to meet Tier 2 emission standards, which are 50% of current Tier I standards. No conventional-technology improvements beyond Tier 2 standards are assumed. Thus, reductions in g/mi emissions between conventional- and advanced-technology vehicles vary only with vehicle vintage, not future year.

As vehicles age, emissions from vehicles with heat engines are assumed to rise at the same rate as those from the conventional vehicles modeled in Mobile 5A. In other words, emission controls for advanced heat engines are assumed to degrade at the same rate as those for conventional internal-combustion engines because of a combination of aging equipment and inadequate operating conditions. Moveover, as the fleet of advanced-technology vehicles ages and becomes as old as the fleet of conventional-technology vehicles that it is replacing, emissions reductions will become somewhat less for heat engines. For

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[5] An improved procedure for estimating fuel shares is currently under development. That procedure is expected to be based on algorithms developed for the Alternative Fuels Trade Model (AFTM) (Greene, *Choice of Alternative Fuels and Alternative Fuel Vehicles in the AFTM*, Oak Ridge National Laboratory, Aug. 1993).

fuel-cell, electric, and hybrid vehicles operating in the electric mode, degradation is not expected to occur; therefore, emissions reductions increase as the advanced-technology fleet ages.

The emission reduction rates for NO_x, CO, and exhaust NMHC (in grams per mile) for a given year are calculated as follows:

$$ERRATE_{jl} = (TEMISC_{jl} + REMISC_{jl}) - (TEMISA_{jl} + REMISA_{jl}) , \quad (9)$$

where:

$TEMISC_{jl}$ = tailpipe emission rate; conventional-technology vehicle, age j; pollutant l;

$EMISA_{jl}$ = tailpipe emission rate; advanced-technology vehicle, age j; pollutant l;

$REMISC_{l}$ = refinery (or power-plant) emission rate, conventional fuel, pollutant l;

$REMISA_{l}$ = refinery (or power-plant) emission rate, alternative fuel, pollutant l; and

$ERRATE_{jl}$ = emission reduction rate in g/mi, age j, pollutant l for an advanced-technology vehicle.

Emission reductions for each pollutant are calculated according to Equation 10. The factor 907,200 is used to convert grams into the reported unit of thousands of short tons.

$$EMRED_{il} = \frac{\sum_{j} ERRATE_{jl} \times VMT_{ij}}{(907{,}200)} , \quad (10)$$

where:

$EMRED_{il}$ = Emissions reduction for all advanced-technology vehicles in short tons, year i, pollutant l;

$ERRATE_{jl}$ = Emissions reduction rate in g/mi, age j, pollutant l; and

VMT_{ij} = Vehicle-miles traveled, year i, age j.

Emissions reductions are reported in short tons per year, as well as by dollar value. A series of damage cost factors, developed by the Congressional Budget Office, is used to convert physical quantities into dollar values, which are summed across years and pollutants to produce a single environmental benefit associated with each advanced technology. Damage cost factors are based on the cost (in 1992 \$/ton) of removing one ton of NO_x, CO, and NMHC emissions from stationary sources.

3 INPUT DATA

3.1 VEHICLE STOCK CALCULATIONS

IMPACTT operates on a set of assumptions that define a particular scenario. Chief among these assumptions are market-penetration rates for the various advanced technologies, which are a key component of the vehicle stock calculation. The default assumption in IMPACTT is that advanced-technology vehicles replace conventional vehicles on a one-for-one basis. The only exception is for advanced-battery electric vehicles, which are assumed to have a small, unique market demand (i.e., 10% of all electric vehicle sales).[6] For the OTT program plan, market-penetration assumptions for the candidate OTT-supported technologies in the light-duty-vehicle (LDV) market were produced by the Alternative Vehicle Sales (AVS) vehicle-choice model (Fulton 1991). Any vehicle-choice model (or set of assumed penetration rates) could provide the required market-penetration inputs for IMPACTT. Tables 7 and 8 present default market-penetration assumptions for light- and heavy-duty-vehicle markets, respectively.

To estimate the number of new advanced-technology vehicles on the road in any 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 forecast of vehicle sales contained in IMPACTT is provided in Table 2. 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.

In IMPACTT, heavy-duty-vehicle stocks are calculated by applying survival rates reported in Davis and Strang (1993). Rates represent the probability of all classes of trucks of a given vintage surviving to a particular age. To reflect the assumed longer life expectancy of medium trucks, the survival function corresponding to data from 1966–1973 was used for that size class, while the function corresponding to 1978–1989 was used for heavy trucks.

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 most light-duty-vehicle technologies. The key exception is advanced-battery electric vehicles, the usage of which is assumed to be two-thirds that of conventional light-duty vehicles. The reduced miles-per-year assumption by vehicle age is embedded into the usage module calculation for electric vehicles. The standard, default numbers of miles per year by vehicle age are listed in Table 9.

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[6] This assumption is scenario-specific and can be modified by changing the market-penetration assumptions in the INPUTS worksheet and by inserting appropriate factors to adjust substitution-fuel use.

TABLE 7 Default Market Penetration of Total Light-Duty Vehicles

	Share of Sales of New Light-Duty Vehicles by Technology or Fuel						
Year	Hybrid	Electric Vehicle	Fuel Cell	Flex ETOH[a]	Ded. ETOH[b]	CNG[c]	LPG[d]
1995	0	0	0	0.009	0	0.005	0.005
1996	0	0	0	0.019	0	0.006	0.008
1997	0	0.001	0	0.030	0	0.008	0.012
1998	0	0.002	0	0.040	0	0.010	0.015
1999	0	0.003	0	0.050	0	0.012	0.019
2000	0	0.004	0	0.061	0	0.014	0.022
2001	0	0.007	0	0.071	0	0.017	0.024
2002	0	0.010	0	0.081	0	0.019	0.025
2003	0.010	0.013	0	0.091	0.010	0.022	0.027
2004	0.033	0.016	0	0.102	0.015	0.024	0.028
2005	0.057	0.019	0	0.112	0.019	0.027	0.030
2006	0.080	0.019	0	0.113	0.022	0.033	0.032
2007	0.103	0.020	0.011	0.115	0.024	0.038	0.035
2008	0.126	0.020	0.016	0.116	0.027	0.044	0.037
2009	0.150	0.020	0.021	0.118	0.029	0.049	0.040
2010	0.173	0.021	0.026	0.119	0.032	0.055	0.042
2011	0.181	0.021	0.030	0.124	0.036	0.057	0.044
2012	0.188	0.021	0.035	0.129	0.040	0.059	0.045
2013	0.196	0.021	0.039	0.134	0.044	0.061	0.047
2014	0.203	0.021	0.044	0.139	0.048	0.063	0.048
2015	0.211	0.022	0.048	0.145	0.052	0.065	0.050
2016	0.219	0.024	0.059	0.150	0.055	0.066	0.052
2017	0.226	0.026	0.070	0.155	0.059	0.068	0.053
2018	0.234	0.028	0.081	0.160	0.063	0.070	0.055
2019	0.241	0.030	0.092	0.165	0.067	0.072	0.056
2020	0.249	0.032	0.103	0.170	0.071	0.074	0.058
2021	0.248	0.032	0.106	0.169	0.074	0.073	0.058
2022	0.247	0.032	0.110	0.168	0.076	0.072	0.057
2023	0.245	0.032	0.113	0.168	0.079	0.071	0.057
2024	0.244	0.032	0.117	0.167	0.081	0.070	0.056
2025	0.243	0.032	0.120	0.166	0.084	0.069	0.056
2026	0.242	0.033	0.123	0.165	0.087	0.068	0.055
2027	0.240	0.033	0.127	0.165	0.090	0.067	0.055
2028	0.239	0.033	0.130	0.164	0.092	0.065	0.054
2029	0.237	0.033	0.134	0.164	0.095	0.064	0.054
2030	0.236	0.033	0.137	0.163	0.098	0.063	0.053

[a] Flex ETOH = Flexible-fuel ethanol.

[b] Ded. ETOH = Dedicated ethanol.

[c] CNG = Compressed natural gas.

[d] LPG = Liquid petroleum gas (propane).

Source: AVS model, Feb. 8, 1994, run.

TABLE 8 Default Market Penetration of Medium and Heavy Trucks

	Share of Sales of New Heavy-Duty Vehicles by Technology or Fuel				
	Medium Trucks			Heavy Trucks	
Year	Fuel Cell	CNG[a]	LPG[b]	Fuel Cell	LE55[c]
1995	–	0.01	0	–	–
1996	–	0.02	0.01	–	0
1997	–	0.05	0.02	–	0
1998	–	0.07	0.03	–	0
1999	–	0.08	0.05	–	0
2000	–	0.10	0.05	–	0
2001	–	0.13	0.08	–	0.01
2002	–	0.16	0.08	–	0.04
2003	–	0.19	0.10	–	0.08
2004	–	0.22	0.11	–	0.12
2005	–	0.24	0.12	–	0.16
2006	–	0.25	0.13	–	0.20
2007	–	0.27	0.14	–	0.24
2008	–	0.29	0.15	–	0.28
2009	0	0.31	0.16	–	0.32
2010	0.01	0.33	0.17	0	0.36
2011	0.03	0.34	0.17	0.01	0.40
2012	0.07	0.35	0.18	0.03	0.42
2013	0.11	0.35	0.18	0.07	0.44
2014	0.16	0.36	0.18	0.11	0.46
2015	0.21	0.37	0.19	0.16	0.48
2016	0.27	0.38	0.19	0.21	0.50
2017	0.32	0.38	0.19	0.27	0.53
2018	0.36	0.39	0.20	0.32	0.55
2019	0.38	0.40	0.20	0.36	0.58
2020	0.40	0.40	0.20	0.38	0.59
2021	0.40	0.40	0.20	0.40	0.60
2022	0.40	0.40	0.20	0.40	0.60
2023	0.40	0.40	0.20	0.40	0.60
2024	0.40	0.40	0.20	0.40	0.60
2025	0.40	0.40	0.20	0.40	0.60
2026	0.40	0.40	0.20	0.40	0.60
2027	0.40	0.40	0.20	0.40	0.60
2028	0.40	0.40	0.20	0.40	0.60
2029	0.40	0.40	0.20	0.40	0.60
2030	0.40	0.40	0.20	0.40	0.60

[a] CNG = Compressed natural gas.

[b] LPG = Liquid petroleum gas (propane).

[c] LE55 = Low-emission, 55% thermal-efficiency diesel engines.

Source: OTT 1994.

TABLE 9 Default Annual Miles by Age and Vehicle Type

Age (in years)	Annual Miles Traveled by Vehicle Type		
	Light-Duty Vehicles	Medium Trucks	Heavy Trucks
<1	14,523	18,154	100,000
1–2	13,871	17,339	86,071
2–3	13,248	16,560	74,082
3–4	12,653	15,817	63,763
4–5	12,085	15,106	54,881
5–6	11,542	14,428	47,237
6–7	11,024	13,780	40,657
7–8	10,529	3,162	34,994
8–9	10,056	12,571	30,119
9–10	9,605	12,006	25,924
10–11	9,174	1,467	22,313
11–12	8,762	10,952	19,205
12–13	8,368	10,460	16,530
13–14	7,993	9,991	14,227
14–15	7,634	9,542	12,246
15–16	7,291	9,114	10,540
16–17	6,964	8,704	9,072
17–18	6,651 [a]	8,314	7,808
18–19	N/A	7,940	6,721
19–20	N/A	7,584	5,784
20–21	N/A	7,243	4,979
21–22	N/A	6,918	4,285
22–23	N/A	6,607	3,688
23–24	N/A	6,311	3,175
24–25	N/A	6,027	2,732
25–26	N/A	5,757	2,352

Model Parameters:

DRATE = 0.0459	M_0 = 14,523
DRATE = 0.0459	M_0 = 18,154
DRATE = 0.1500	M_0 = 100,000

[a] Ages 17 and over.

Sources: Greene and Rathi (1990) and U.S. DOC (1990).

3.3 ENERGY CALCULATIONS

Energy consumption/savings estimates are based on a number of technology-specific assumptions. The calculation of oil displacement is a function of miles traveled and the efficiency (mpg) of new conventional vehicles (see Table 3). For light-duty vehicles, the EPA test mpg was adjusted by a factor of 0.8 to reflect a typical shortfall or gap between test conditions and actual on-road experience. The Btu and efficiency rates are used to estimate substitution effects (i.e., consumption of alternative fuels in lieu of conventional fuels). The Btu rate is the ratio of the lower heating value for the alternative fuel to the lower heating value for the conventional fuel.

Fuel efficiency is represented by two variables, GEMPG and ERATE. When the user wishes to specify a general improvement, ERATE should be set to the desired value. When specific improvements are known or the rate of improvement is assumed to vary over time, values of advanced-technology fuel efficiency (GEMPG) should be entered directly by year, and the default value of ERATE should be set at 1.0. Alternatively, the user can specify an efficiency rate (ERATE) different from 1.0 (as well as GEMPG values by year) to simulate a scenario in which both general improvements occur and the engine is optimized to take full advantage of an alternative fuel's properties. The default value for ERATE is 1.0; default values for GEMPG are those assumed for DOE/OTT 1994 and are shown in Table 10.

3.4 EMISSIONS CALCULATIONS

The **EMISSIONS** module first determines the difference in emission rates between a conventional vehicle and an advanced-technology vehicle. For light-duty vehicles, input parameters are Tier 2 emissions standards (degraded to estimated on-road performance by vehicle age by using MOBILE5a degradation factors for autos and light-duty trucks), estimated emissions from advanced-technology vehicles (also by age), and refinery and power-plant emission rates. In the default case, advanced technologies are assumed to degrade at the same rate as conventional vehicles, dedicated-alcohol and flexible-fueled vehicles are assumed to have essentially the same tailpipe emissions as gasoline-fueled vehicles, and CNG vehicles are assumed to achieve a 7% reduction in CO emissions relative to gasoline vehicles. Hybrids are assumed to achieve Tier 2 emissions standards when operating on a heat engine. Advanced-battery electric vehicles, hybrids operating on grid-supplied electricity, and fuel-cell-powered vehicles are assumed to be zero-emission vehicles (0.2 g/mi NO_x, 0.04 g/mi CO, 0.01 g/mi NMHCs, and 0.46 g/mi SO_x for electric vehicles and 0.001 g/mi NO_x, essentially zero CO, 0.002 g/mi NMHCs, and essentially zero SO_x for fuel-cell vehicles).

Both tailpipe and refinery (or power-plant) values are included in the default calculation. Users can exclude refinery (or power-plant) values by eliminating those terms from the formula.

TABLE 10 Default Gasoline-Equivalent Miles per Gallon of New Advanced-Technology, Light-Duty Vehicles

	Fuel or Technology[a]						
Year	CNG	LPG	Flex ETOH	Hybrid	EV	Fuel Cell	Ded. ETOH
1990	20.3	20.3	20.3	–	–	–	20.3
1991	20.3	20.3	20.3	–	–	–	20.3
1992	20.1	20.1	20.1	–	–	–	20.1
1993	20.2	20.2	20.2	–	–	–	20.2
1994	20.3	20.3	20.3	–	–	–	20.3
1995	20.4	20.4	20.4	–	–	–	20.4
1996	20.6	20.6	20.6	–	–	–	20.6
1997	20.8	20.8	20.8	–	48.9	–	20.8
1998	20.9	20.9	20.9	–	52.7	–	20.9
1999	21.0	21.0	21.0	–	56.6	–	21.0
2000	21.1	21.1	21.1	–	60.6	–	21.1
2001	21.3	21.3	21.3	–	64.6	–	21.3
2002	21.4	21.4	21.4	–	68.7	–	21.4
2003	21.6	21.6	21.6	30.6	72.8	–	21.6
2004	21.7	21.7	21.7	35.2	77.1	–	21.7
2005	21.9	21.9	21.9	39.6	81.4	–	21.9
2006	22.0	22.0	22.0	44.3	82.0	–	22.0
2007	22.2	22.2	22.2	48.8	82.5	42.6	22.2
2008	22.3	22.3	22.3	53.5	83.0	45.6	22.3
2009	22.4	22.4	22.4	53.8	83.4	48.7	22.4
2010	22.5	22.5	22.5	54.0	83.8	51.7	22.5
2011	22.5	22.5	22.5	54.0	83.8	54.6	22.5
2012	22.5	22.5	22.5	54.0	83.7	57.4	22.5
2013	22.5	22.5	22.5	54.0	83.7	60.2	22.5
2014	22.5	22.5	22.5	54.0	83.7	63.0	22.5
2015	22.5	22.5	22.5	54.0	83.7	65.9	22.5
2016	22.5	22.5	22.5	54.0	83.7	68.7	22.5
2017	22.5	22.5	22.5	54.0	83.6	71.5	22.5
2018	22.5	22.5	22.5	54.0	83.6	71.5	22.5
2019	22.5	22.5	22.5	53.9	83.6	71.5	22.5
2020	22.5	22.5	22.5	53.9	83.6	71.5	22.5
2021	22.5	22.5	22.5	53.9	83.6	71.5	22.5
2022	22.5	22.5	22.5	53.9	83.6	71.4	22.5
2023	22.5	22.5	22.5	53.9	83.6	71.4	22.5
2024	22.5	22.5	22.5	53.9	83.6	71.4	22.5
2025	22.5	22.5	22.5	53.9	83.5	71.4	22.5
2026	22.5	22.5	22.5	53.9	83.5	71.4	22.5
2027	22.4	22.4	22.4	53.9	83.5	71.4	22.4
2028	22.4	22.4	22.4	53.9	83.5	71.4	22.4
2029	22.4	22.4	22.4	53.9	83.5	71.4	22.4
2030	22.4	22.4	22.4	53.9	83.5	71.4	22.4

[a] CNG = compressed natural gas, LPG = liquid petroleum gas (propane), Flex ETOH = flexible-fuel ethanol, EV = electric vehicle, and Ded. ETOH = dedicated ethanol.

4 SAMPLE OUTPUT

Tables 2–10 contain the key inputs needed to define a full eight-technology (seven advanced and one conventional) IMPACTT scenario. Rather than reproducing the full workbook for that run (hardcopies of all 16 worksheets would occupy 62 pages), only portions of the five output worksheets are shown in Tables 11–17. Table 11 is from the VMT SUM worksheet, Tables 12 and 13 are from CON SUM, Tables 14 and 15 are from RED SUM and EMIS SUM, and Tables 16 and 17 are from OIL SUM.

TABLE 11 Vehicle Miles Traveled by Advanced-Technology, Light-Duty Vehicles

	Vehicle-Miles Traveled (10^9) by Technology								
Year	Hybrid	Electric Vehicle	Fuel Cell	Flex ETOH[a]	Ded. ETOH[b]	CNG[c]	LPG[d]	ICE[e]	Total
1990	0	0	0	0	0	0	0	1,983	1,983
1991	0	0	0	0	0	0	0	1,993	1,993
1992	0	0	0	0	0	0	0	2,008	2,008
1993	0	0	0	0	0	0	0	2,040	2,040
1994	0	0	0	0	0	0	0	2,078	2,078
1995	0	0	0	2	0	1	1	2,106	2,110
1996	0	0	0	6	0	2	3	2,128	2,139
1997	0	0	0	12	0	4	5	2,148	2,169
1998	0	0	0	20	0	6	8	2,164	2,199
1999	0	1	0	30	0	8	12	2,176	2,227
2000	0	1	0	42	0	11	16	2,184	2,255
2001	0	2	0	56	0	14	21	2,188	2,281
2002	0	4	0	71	0	18	25	2,186	2,305
2003	2	6	0	88	2	22	30	2,178	2,329
2004	10	8	0	107	6	26	34	2,162	2,353
2005	23	11	0	126	10	31	39	2,135	2,376
2006	41	14	0	145	15	36	44	2,103	2,398
2007	64	17	3	162	20	43	49	2,064	2,422
2008	93	19	6	178	25	51	54	2,015	2,443
2009	125	22	11	193	31	59	60	1,958	2,459
2010	161	24	17	206	37	68	65	1,895	2,473
2011	197	26	24	219	43	77	70	1,829	2,485
2012	233	28	31	232	50	85	75	1,762	2,498
2013	268	30	40	245	58	94	80	1,694	2,508
2014	303	32	49	257	65	102	85	1,624	2,518
2015	337	33	58	269	73	110	90	1,555	2,526
2016	370	35	70	282	82	117	95	1,483	2,533
2017	402	37	84	294	90	124	99	1,408	2,538
2018	432	39	99	306	99	131	104	1,332	2,543
2019	461	41	117	319	108	138	109	1,254	2,546
2020	489	43	136	332	118	144	113	1,174	2,549
2021	514	46	155	343	127	149	117	1,102	2,552
2022	535	48	173	353	135	154	121	1,037	2,556
2023	553	50	191	362	144	158	124	979	2,560
2024	569	52	208	370	153	161	126	928	2,566
2025	582	53	224	377	161	163	129	882	2,571
2026	592	55	240	383	170	164	130	843	2,577
2027	601	56	256	388	178	165	132	810	2,584
2028	608	58	270	392	186	165	132	781	2,592
2029	613	59	284	395	194	165	133	757	2,601
2030	618	60	298	398	202	164	133	737	2,611
Period	Cumulative Totals								
1990–2000	0	3	0	113	0	33	45	23,010	23,203
1990–2010	519	131	38	1,446	145	400	466	43,895	47,041
1990–2020	4,012	476	746	4,200	933	1,521	1,388	59,009	72,284
1990–2030	9,796	1,013	3,045	7,962	2,583	3,129	2,665	67,864	98,056

[a] Flex ETOH = flexible-fuel ethanol.

[b] Ded. ETOH = dedicated ethanol.

[c] CNG = Compressed natural gas.

[d] LPG = Liquid petroleum gas (propane).

[e] ICE = Internal combustion engine.

TABLE 12 Fuel Consumption of Light-Duty Vehicles by Fuel Type

	Fuel Consumption (10^9 bbl/day) by Fuel Type						
Year	ETOH[a]	MEOH[b]	CNG[c]	LPG[d]	Electricity	Gasoline	Total
1990	0	0	0	0	0	6.11	6.11
1991	0	0	0	0	0	6.07	6.07
1992	0	0	0	0	0	6.07	6.07
1993	0	0	0	0	0	6.12	6.12
1994	0	0	0	0	0	6.20	6.20
1995	0	0	0	0	0	6.25	6.25
1996	0	0	0	0.01	0	6.29	6.31
1997	0	0	0.01	0.01	0	6.34	6.36
1998	0	0	0.02	0.02	0	6.38	6.42
1999	0	0	0.02	0.03	0	6.41	6.47
2000	0	0	0.03	0.05	0	6.43	6.50
2001	0	0	0.04	0.06	0	6.44	6.54
2002	0	0	0.05	0.07	0	6.45	6.57
2003	0.01	0	0.06	0.08	0.01	6.44	6.60
2004	0.02	0	0.07	0.10	0.02	6.41	6.61
2005	0.05	0	0.08	0.11	0.03	6.35	6.61
2006	0.07	0	0.09	0.12	0.04	6.27	6.60
2007	0.11	0	0.11	0.14	0.06	6.16	6.58
2008	0.17	0.01	0.13	0.15	0.08	6.01	6.54
2009	0.29	0.02	0.15	0.16	0.10	5.78	6.49
2010	0.53	0.02	0.17	0.18	0.12	5.40	6.42
2011	0.62	0.03	0.19	0.19	0.14	5.18	6.35
2012	0.70	0.04	0.21	0.20	0.17	4.96	6.28
2013	0.79	0.05	0.23	0.22	0.19	4.74	6.21
2014	0.89	0.06	0.25	0.23	0.21	4.51	6.14
2015	0.99	0.06	0.27	0.24	0.23	4.28	6.06
2016	1.08	0.07	0.28	0.25	0.25	4.05	5.99
2017	1.16	0.08	0.30	0.26	0.27	3.83	5.91
2018	1.22	0.10	0.32	0.28	0.29	3.62	5.83
2019	1.29	0.11	0.33	0.29	0.31	3.41	5.74
2020	1.36	0.13	0.34	0.30	0.32	3.20	5.66
2021	1.41	0.14	0.36	0.31	0.34	3.02	5.58
2022	1.47	0.16	0.37	0.32	0.35	2.85	5.52
2023	1.52	0.17	0.38	0.33	0.37	2.69	5.46
2024	1.57	0.19	0.39	0.34	0.38	2.56	5.41
2025	1.62	0.20	0.39	0.34	0.38	2.43	5.37
2026	1.66	0.21	0.40	0.35	0.39	2.33	5.34
2027	1.70	0.23	0.40	0.35	0.40	2.24	5.31
2028	1.73	0.24	0.40	0.35	0.40	2.17	5.29
2029	1.76	0.25	0.40	0.35	0.41	2.10	5.27
2030	1.79	0.26	0.40	0.35	0.41	2.05	5.27
Period	Cumulative Totals						
1990–2000	0	0	0.09	0.13	0	68.67	68.88
1990–2010	1.24	0.05	1.01	1.29	0.47	130.40	134.40
1990–2020	11.33	0.77	3.74	3.75	2.85	172.20	194.60
1990–2030	27.55	2.81	7.64	7.14	6.68	196.60	248.40

[a] ETOH = Ethanol.

[b] MEOH = Methanol.

[c] CNG = Compressed natural gas.

[d] LPG = Liquid petroleum gas (propane).

TABLE 13 Stocks of Light-Duty Vehicles and Share of Alternative-Fuel Vehicles

	Vehicle Stocks (10^6) by Technology								
Year	Hybrid	Electric Vehicle	Fuel Cell	FFV[a]	Ded. ETOH[b]	LPG[c]	CNG[d]	Conventional ICE	Share of AFVs[e] (%)
1990	0	0	0	0	0	0	0	184.46	0
1991	0	0	0	0	0	0	0	186.10	0
1992	0	0	0	0	0	0	0	187.71	0
1993	0	0	0	0	0	0	0	190.54	0
1994	0	0	0	0	0	0	0	193.72	0
1995	0	0	0	0.13	0	0.07	0.07	196.20	0.13
1996	0	0	0	0.42	0	0.18	0.16	198.17	0.38
1997	0	0.01	0	0.86	0	0.36	0.28	199.83	0.75
1998	0	0.05	0	1.46	0	0.58	0.44	201.11	1.24
1999	0	0.09	0	2.22	0	0.86	0.62	201.97	1.85
2000	0	0.15	0	3.14	0	1.20	0.83	202.49	2.56
2001	0	0.27	0	4.20	0	1.55	1.08	202.72	3.38
2002	0	0.43	0	5.41	0	1.92	1.36	202.71	4.31
2003	0.16	0.66	0	6.77	0.16	2.31	1.68	202.19	5.49
2004	0.70	0.94	0	8.28	0.39	2.72	2.04	200.96	6.97
2005	1.63	1.27	0	9.90	0.70	3.13	2.42	198.93	8.74
2006	2.94	1.61	0	11.49	1.06	3.56	2.89	196.31	10.71
2007	4.67	1.95	0.19	13.04	1.46	4.01	3.43	193.09	12.96
2008	6.82	2.29	0.46	14.53	1.89	4.47	4.05	189.14	15.43
2009	9.30	2.62	0.81	15.91	2.36	4.94	4.73	184.45	18.07
2010	12.16	2.95	1.25	17.19	2.86	5.41	5.47	179.13	20.88
2011	15.11	3.26	1.76	18.45	3.40	5.88	6.22	173.48	23.76
2012	18.15	3.55	2.36	19.69	3.99	6.34	6.97	167.65	26.69
2013	21.24	3.83	3.03	20.88	4.62	6.79	7.70	161.55	29.65
2014	24.35	4.08	3.77	22.04	5.29	7.24	8.43	155.26	32.63
2015	27.46	4.30	4.57	23.16	5.98	7.67	9.14	148.84	35.60
2016	30.52	4.54	5.54	24.27	6.70	8.10	9.83	142.20	38.63
2017	33.52	4.80	6.66	25.37	7.45	8.52	10.50	135.36	41.70
2018	36.44	5.08	7.95	26.47	8.22	8.94	11.14	128.36	44.81
2019	39.26	5.37	9.40	27.57	9.02	9.35	11.76	121.21	47.96
2020	41.98	5.68	10.99	28.69	9.83	9.76	12.36	113.94	51.15
2021	44.43	5.98	12.59	29.71	10.63	10.14	12.88	107.21	54.10
2022	46.58	6.25	14.19	30.65	11.42	10.47	13.33	101.01	56.82
2023	48.45	6.51	15.78	31.49	12.20	10.77	13.72	95.33	59.30
2024	50.07	6.76	17.35	32.26	12.97	11.04	14.03	90.19	61.57
2025	51.46	7.00	18.87	32.95	13.73	11.26	14.28	85.56	63.61
2026	52.62	7.23	20.36	33.56	14.49	11.45	14.46	81.44	65.43
2027	53.58	7.45	21.80	34.10	15.24	11.60	14.59	77.81	67.05
2028	54.36	7.65	23.19	34.57	15.98	11.71	14.66	74.67	68.47
2029	55.01	7.84	24.54	34.96	16.72	11.80	14.68	71.98	69.70
2030	55.54	8.02	25.83	35.28	17.46	11.85	14.67	69.72	70.75
Period	Cumulative Totals								
1990–2000	0	0.30	0	8.23	0	3.25	2.40	2,142.3	
1990–2010	38.38	15.28	2.70	115.00	10.88	37.27	31.56	4,091.9	
1990–2020	326.41	59.77	58.72	351.50	75.39	115.90	125.60	5,539.8	
1990–2030	838.50	130.50	253.20	681.10	216.20	228.00	266.90	6,394.7	

[a] FFV = Flexible-fuel vehicle.

[b] Ded. ETOH = Dedicated ethanol.

[c] LPG = Liquid petroleum gas (propane).

[d] CNG = Compressed natural gas.

[e] AFVs = Alternative-fuel vehicles.

TABLE 14 Total Emissions Reduction from Seven Advanced Technologies

	Total Emissions Reduction (10^6 tons)			CO_2		Monetary Value ($$10^9$, 1992 dollars)[a]			
Year	NO_x	CO	NMHC	Tailpipe	Upstream	NO_x	CO	NMHC	Total
						0	0	0	0
1991	0	0	0	0	0	0	0	0	0
1992	0	0	0	0	0	0	0	0	0
1993	0	0	0	0	0	0	0	0	0
1994	0	0	0	0	0	0	0	0	0
1995	0	0	0	0.77	0.38	0	0	0	0
1996	0	0	0	1.97	0.97	0	0	0	0
1997	0	0	0	3.65	1.80	0	0	0	0
1998	0	0.01	0	5.80	2.85	0	0	0	0.01
1999	0	0.01	0	8.36	4.12	0	0	0	0.01
2000	0	0.02	0	11.31	5.57	0	0.01	0	0.01
2001	0	0.03	0	14.64	7.21	0.01	0.01	0.01	0.02
2002	0	0.05	0	18.33	9.02	0.01	0.01	0.01	0.03
2003	0	0.07	0	24.01	11.82	0.01	0.02	0.01	0.04
2004	0.01	0.11	0.01	32.36	15.93	0.02	0.03	0.02	0.07
2005	0.01	0.17	0.01	43.59	21.46	0.02	0.05	0.03	0.11
2006	0.01	0.25	0.02	57.05	28.09	0.03	0.07	0.05	0.16
2007	0.02	0.36	0.02	75.12	36.98	0.05	0.11	0.07	0.23
2008	0.03	0.51	0.03	98.74	48.61	0.07	0.15	0.10	0.33
2009	0.04	0.69	0.05	131.50	64.74	0.11	0.21	0.15	0.46
2010	0.06	0.93	0.07	183.79	90.48	0.15	0.28	0.20	0.63
2011	0.07	1.19	0.09	213.68	105.20	0.19	0.36	0.26	0.81
2012	0.09	1.49	0.11	244.33	120.29	0.24	0.45	0.33	1.01
2013	0.10	1.84	0.13	275.77	135.77	0.29	0.55	0.40	1.24
2014	0.12	2.21	0.16	307.12	151.20	0.34	0.66	0.48	1.48
2015	0.14	2.60	0.19	338.80	166.79	0.40	0.78	0.57	1.75
2016	0.17	3.03	0.22	370.12	182.21	0.46	0.91	0.66	2.03
2017	0.19	3.47	0.25	400.38	197.11	0.53	1.04	0.76	2.33
2018	0.22	3.92	0.28	428.97	211.19	0.59	1.17	0.86	2.63
2019	0.24	4.38	0.32	457.94	225.44	0.66	1.31	0.96	2.94
2020	0.27	4.84	0.35	487.26	239.88	0.73	1.45	1.07	3.25
2021	0.29	5.29	0.38	512.80	252.46	0.80	1.59	1.17	3.56
2022	0.32	5.74	0.42	536.88	264.31	0.87	1.72	1.27	3.86
2023	0.34	6.17	0.45	559.21	275.30	0.94	1.85	1.37	4.16
2024	0.36	6.60	0.48	579.74	285.41	1.00	1.98	1.46	4.44
2025	0.39	7.02	0.51	598.54	294.67	1.06	2.10	1.56	4.72
2026	0.41	7.41	0.54	614.67	302.61	1.12	2.22	1.65	4.99
2027	0.43	7.79	0.57	629.13	309.73	1.17	2.34	1.73	5.25
2028	0.45	8.14	0.60	642.04	316.08	1.23	2.44	1.82	5.49
2029	0.47	8.47	0.62	653.63	321.79	1.28	2.54	1.89	5.71
2030	0.48	8.76	0.64	664.05	326.92	1.33	2.63	1.96	5.92
Period	**Cumulative Totals**								
1990–2000	0	0.05	0	31.87	15.69	0.01	0.02	0.01	0.04
1990–2010	0.18	3.21	0.22	710.99	350.02	0.49	0.96	0.66	2.11
1990–2020	1.79	32.17	2.30	4,235.36	2,085.10	4.91	9.65	7.01	21.58
1990–2030	5.71	103.56	7.51	10,226.07	5,034.37	15.71	31.07	22.89	69.68

[a] NO_x, CO, and NMHC only.

TABLE 15 Total Light-Duty Vehicle Emissions from All Advanced and Conventional Technologies

	Emissions (10^6 tons) by Type				
				CO_2	
Year	NO_x	CO	NMHC	Tailpipe	Upstream
1990	1.21	21.30	2.24	855.65	421.24
1991	1.22	21.67	2.28	850.51	418.71
1992	1.24	22.20	2.33	849.52	418.22
1993	1.26	22.81	2.39	857.49	422.15
1994	1.30	23.30	2.45	868.32	427.48
1995	1.32	23.74	2.49	875.46	431.00
1996	1.34	23.98	2.52	881.92	434.18
1997	1.36	24.30	2.55	888.81	437.57
1998	1.38	24.55	2.58	895.34	440.78
1999	1.39	24.83	2.61	901.37	443.75
2000	1.40	25.02	2.64	904.12	445.10
2001	1.42	25.28	2.66	907.52	446.78
2002	1.43	25.55	2.68	909.76	447.88
2003	1.44	25.79	2.69	910.41	448.20
2004	1.45	25.99	2.70	907.96	447.00
2005	1.46	26.23	2.72	901.40	443.77
2006	1.48	26.46	2.73	892.28	439.27
2007	1.49	26.68	2.74	879.66	433.06
2008	1.50	26.87	2.75	860.70	423.73
2009	1.51	27.03	2.76	831.33	409.27
2010	1.51	27.12	2.75	781.62	384.80
2011	1.51	27.13	2.74	754.17	371.28
2012	1.51	27.09	2.72	726.60	357.71
2013	1.51	27.00	2.69	697.83	343.55
2014	1.50	26.87	2.66	668.94	329.32
2015	1.50	26.69	2.62	639.55	314.85
2016	1.49	26.48	2.58	610.54	300.57
2017	1.48	26.24	2.54	582.34	286.69
2018	1.46	25.97	2.49	555.75	273.60
2019	1.45	25.69	2.45	528.70	260.28
2020	1.43	25.41	2.40	501.18	246.74
2021	1.42	25.13	2.35	477.56	235.11
2022	1.40	24.85	2.30	455.48	224.24
2023	1.39	24.58	2.26	435.22	214.26
2024	1.37	24.31	2.21	416.87	205.23
2025	1.36	24.05	2.17	400.30	197.07
2026	1.35	23.80	2.13	386.49	190.27
2027	1.33	23.57	2.10	374.48	184.36
2028	1.32	23.37	2.06	364.14	179.27
2029	1.31	23.20	2.03	355.36	174.95
2030	1.31	23.07	2.01	347.95	171.30
Period	Cumulative Totals				
1990–2000	14.42	257.70	27.09	9,628.52	4,740.19
1990–2010	29.09	520.69	54.27	18,411.16	9,063.95
1990–2020	43.93	785.28	80.16	24,676.75	12,148.56
1990–2030	57.48	1025.2	101.79	28,690.61	14,124.61

TABLE 16 Oil Displacement by Light-Duty Vehicle Technology

	Oil Displacement (10^6 bbl/day)						
Year	FFV[a]	Hybrid	Electric Vehicle	CNG/[b] LPG	Alcohols	Fuel Cell	Total
1990	0	0	0	0	0	0	0
1991	0	0	0	0	0	0	0
1992	0	0	0	0	0	0	0
1993	0	0	0	0	0	0	0
1994	0	0	0	0	0	0	0
1995	0	0	0	0.01	0	0	0.01
1996	0	0	0	0.01	0	0	0.01
1997	0	0	0	0.03	0	0	0.03
1998	0	0	0	0.04	0	0	0.04
1999	0	0	0	0.06	0	0	0.06
2000	0	0	0	0.08	0	0	0.08
2001	0	0	0.01	0.10	0	0	0.10
2002	0	0	0.01	0.12	0	0	0.13
2003	0	0.01	0.02	0.14	0.01	0	0.17
2004	0	0.03	0.02	0.17	0.01	0	0.23
2005	0	0.06	0.03	0.19	0.03	0	0.31
2006	0	0.11	0.04	0.22	0.04	0	0.41
2007	0.01	0.17	0.05	0.25	0.06	0.01	0.55
2008	0.05	0.25	0.05	0.28	0.10	0.02	0.75
2009	0.13	0.33	0.06	0.32	0.20	0.03	1.07
2010	0.34	0.43	0.06	0.36	0.42	0.05	1.65
2011	0.38	0.52	0.07	0.39	0.48	0.06	1.91
2012	0.43	0.61	0.08	0.43	0.55	0.08	2.18
2013	0.49	0.71	0.08	0.46	0.62	0.10	2.46
2014	0.54	0.80	0.08	0.49	0.69	0.13	2.74
2015	0.60	0.89	0.09	0.53	0.77	0.15	3.02
2016	0.65	0.97	0.09	0.56	0.84	0.18	3.30
2017	0.70	1.06	0.10	0.59	0.90	0.22	3.56
2018	0.73	1.13	0.10	0.62	0.95	0.26	3.79
2019	0.75	1.21	0.11	0.65	1.00	0.31	4.02
2020	0.78	1.29	0.11	0.68	1.05	0.36	4.26
2021	0.80	1.35	0.12	0.70	1.08	0.41	4.46
2022	0.82	1.41	0.13	0.72	1.13	0.45	4.66
2023	0.85	1.45	0.13	0.74	1.17	0.50	4.84
2024	0.87	1.49	0.14	0.75	1.21	0.55	5.01
2025	0.89	1.53	0.14	0.77	1.25	0.59	5.17
2026	0.91	1.56	0.14	0.77	1.28	0.63	5.29
2027	0.92	1.58	0.15	0.78	1.31	0.67	5.41
2028	0.93	1.60	0.15	0.78	1.34	0.71	5.51
2029	0.94	1.61	0.16	0.78	1.37	0.75	5.60
2030	0.94	1.62	0.16	0.78	1.39	0.78	5.68
Period	Cumulative Totals						
1990–2000	0.00	0.00	0.01	0.22	0.00	0.00	0.23
1990–2010	0.54	1.39	0.36	2.37	0.87	0.10	5.61
1990–2020	6.60	10.57	1.27	7.76	8.69	1.96	36.84
1990–2030	15.46	25.77	2.68	15.34	21.24	8.00	88.48

[a] FFV = Flexible-fuel vehicle.

[b] CNG/LPG = Compressed natural gas and liquid petroleum gas (propane).

TABLE 17 Baseline Oil Consumed and Displaced by All Advanced Technologies

	Baseline Forecasts[a]					Percent Displaced by Advanced Technologies	
	Gasoline Consumption						
Year	Quads	10^6 bbl/day	Transportation Oil (10^6 bbl/day)	U.S. Oil (10^6 bbl/day)	Highway Oil (10^6 bbl/day)	Gasoline	Transport-ation Oil
1990	13.59	6.42	11.04	16.99	7.78	4.0	2.2
1991	13.65	6.45	11.03	25.32	7.78	3.5	2.3
1992	13.70	6.47	11.02	33.65	7.79	3.8	2.4
1993	13.90	6.56	11.25	31.86	7.95	4.1	2.4
1994	14.09	6.66	11.49	30.08	8.10	4.3	2.5
1995	14.29	6.75	11.72	28.29	8.25	4.6	2.6
1996	14.48	6.84	11.95	26.50	8.41	5.0	2.8
1997	14.68	6.93	12.19	24.72	8.56	5.4	3.0
1998	14.87	7.02	12.42	22.93	8.71	5.9	3.2
1999	15.07	7.12	12.66	21.14	8.86	6.4	3.5
2000	15.26	7.21	12.89	19.36	9.02	6.9	3.7
2001	15.39	7.27	13.07	19.57	9.12	7.4	4.1
2002	15.53	7.33	13.24	19.77	9.23	8.0	4.6
2003	15.66	7.40	13.41	19.98	9.33	8.8	5.0
2004	15.80	7.46	13.59	20.19	9.44	9.7	5.4
2005	15.93	7.52	13.76	20.40	9.54	11.0	5.8
2006	16.03	7.57	13.92	20.57	9.64	12.1	7.1
2007	16.13	7.62	14.08	20.75	9.73	13.6	8.3
2008	16.24	7.67	14.24	20.92	9.83	15.6	9.5
2009	16.34	7.72	14.40	21.09	9.92	18.4	10.8
2010	16.44	7.77	14.56	21.27	10.02	22.8	12.0
2011	16.55	7.82	14.73	21.45	10.12	25.2	13.3
2012	16.76	7.91	15.07	21.81	10.32	27.6	14.5
2013	16.86	7.96	15.24	21.99	10.42	30.1	15.9
2014	16.97	8.01	15.41	22.17	10.52	32.5	17.1
2015	17.07	8.06	15.58	22.35	10.62	35.0	18.4
2016	17.18	8.11	15.75	22.53	10.72	37.4	19.7
2017	17.28	8.16	15.92	22.71	10.82	39.6	20.9
2018	17.39	8.21	16.09	22.89	10.92	41.8	22.0
2019	17.49	8.26	16.25	23.07	11.02	43.9	23.1
2020	17.60	8.31	16.42	23.25	11.12	46.0	24.2
2021	17.70	8.37	16.59	23.43	11.22	47.8	25.2
2022	17.81	8.42	16.76	23.61	11.32	49.4	26.1
2023	17.91	8.48	16.93	23.79	11.42	50.9	26.8
2024	18.02	8.53	17.10	23.97	11.52	52.3	27.6
2025	18.12	8.59	17.27	24.15	11.62	53.5	28.2
2026	18.23	8.64	17.44	24.33	11.72	54.5	28.7
2027	18.33	8.70	17.61	24.51	11.82	55.3	29.1
2028	18.44	8.75	17.78	24.70	11.92	56.0	29.5
2029	18.55	8.80	17.95	24.88	12.02	56.6	29.8
2030	18.65	8.86	18.12	25.06	12.12	57.1	30.1
Period	Cumulative Totals						
1990–2000	157.56	74.42	129.66	280.84	91.21		
1990–2010	317.05	149.76	267.94	485.35	187.01		
1990–2020	488.18	230.60	424.39	709.56	293.61		
1990–2030	669.95	316.74	597.95	952.00	410.33		

[a] Baseline consumption before the introduction of advanced technologies. Derived from DOE/EIA 1994.

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APPENDIX: "READ ME" FILE

IMPACTT (Integrated Market Penetration and Anticipated Cost of Transportation Technologies) was developed by Argonne National Laboratory's Center for Transportation Research to assist the U.S. Department of Energy's 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 PC/Windows environment. The current version consists of 16 worksheets — eight of them apply to all technologies (i.e., general worksheets); the other eight are specific to a particular technology or fuel alternative. The general worksheets are called INPUTS, SALES-MPG, EMIS INPUTS, VMT SUM, OIL SUM, EMIS SUM, EMIS RED SUM, and CON SUM.

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. The INPUTs worksheet contains user-supplied forecasts of market penetration and marginal cost for each advanced technology under examination and an emissions reduction value for each of three criteria pollutants (NO_x, CO, and NMHC). Each advanced technology contained on the INPUTS worksheet must have a technology-specific worksheet associated with it.

The SALES-MPG worksheet converts user-supplied forecasts of auto and light-truck sales and fuel economy into weighted averages for input into the stock model and calculations of oil displacement and fuel substitution. Note that users can input either EPA-test or estimated on-the-road fuel economy. Default forecasts of sales and EPA-test fuel economy were extrapolated from those in the *1994 Annual Energy Outlook* (DOE/EIA 1994). Default estimates of on-the-road fuel economy assume a 20% shortfall or gap from EPA test results, which are the default inputs (Mintz, Vyas, and Conley 1993).

The EMIS INPUTS worksheet contains default tailpipe emission rates by engine type and vintage and refinery and power-plant emission rates by fuel type. Expressed in g/mi, rates were computed from the EPA's MOBILE5a model. Within EMIS INPUTS, values for total light-duty vehicles are weighted as 60% autos and 40% light trucks. Default values for power-plant emissions are based on the year 2000 generation mix for New York City and southern California, the two locations likely to see the earliest EV market penetration. Default values are weighted by the relative share of VMT contributed by each of these two markets (Wang and Santini 1994).

Four of the general worksheets aggregate results across the technology-specific worksheets. The VMT SUM worksheet summarizes stocks and vehicle-miles displaced by all advanced-technology vehicles, while OIL SUM and EMIS RED SUM summarize total oil displacement and emissions reduction. Substitution-fuel use, again aggregated over all technologies considered in the particular scenario under examination, is summarized in the

CON SUM worksheet. For all four of these worksheets, results are reported annually for 1990–2030 and cumulatively (as appropriate) for 1990–2000, 1990–2010, 1990–2020 and 1990–2030. Outputs include advanced-technology vehicles on the road, oil displacement, VMT displacement, emissions reduction, value of emissions reduction, substitution-fuel use, and fleet-average fuel economy (miles/gallon gasoline equivalent) for the fleet of advanced-technology vehicles on the road.

Technology-Specific Worksheets

IMPACTT operates on a set of assumptions that define a particular scenario. The diversified scenario developed by DOE's Office of Transportation Technologies for its five-year program plan is the default case contained in the workbook file. That scenario required the use of eight technology-specific worksheets: HYBRID, ELECTRIC, FUEL CELL, FLEX ETHANOL, DED ETHANOL, CNG, LPG, and ICE. Thus, the default version of the model can accommodate up to eight different technologies.

Chief among the parameters used to define a particular scenario is the market penetration of the various advanced technologies — these rates are, in turn, a key component of the vehicle stock calculation. The default assumption in IMPACTT is that advanced-technology vehicles replace conventional vehicles on a one-for-one basis. The only exception is for advanced-battery electric vehicles, which are assumed to have a small (i.e., 10% of all electric vehicle sales), unique market demand. Thus, EV market penetration is multiplied by 0.9 in the default case, and EV electricity use is divided by 0.9 to account for unique or nonreplacement market demand.

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 most light-duty-vehicle technologies. The key exception is the assumption of reduced miles-per-year by vehicle age for electric vehicles, which is embedded into the usage model calculation.

Several technology-specific parameters may be user-defined. These include gasoline-equivalent fuel economy, Btu content of the alternative fuel relative to gasoline, and efficiency relative to a conventionally fueled vehicle, all of which are used to compute fuel substitution (i.e., alternative-fuel use). For flex-fueled vehicles, five additional parameters are included in the calculation: alcohol share of reformulated gasoline, ethanol and methanol shares of fuel use, and ethanol and methanol fuel use. In the current version of IMPACTT, ethanol and methanol shares are estimated from an exogenous biofuels production forecast and an assumed split between bioethanol and biomethanol production. The default production forecast (contained in cells AO-13 through AV-57 of the DED ETOH worksheet) was developed by the Office of Transportation Technologies for its draft program plan. It assumes declining real prices for biofuels along with ethanol accounting for 100% of biofuels production. Thus, the default forecast assumes that ethanol shares are supply-constrained to the sum of current and new production capacity. Because the Office of Transportation Technologies has no ongoing methanol program, flex-fuel methanol and dedicated methanol vehicles are not modeled on the default file.

For electric vehicles, three additional parameters may be user defined. Annual usage may be set equal to that of conventional vehicles or modified to account for range limitations and differences in life expectancy. In the default case, electric vehicles are assumed to experience two-thirds the usage of conventional vehicles at all ages. Distribution and transmission efficiencies (cells Z12 and AA12 of the ELEC worksheet), which are used to account for losses between the power plant and vehicle, may also be user-defined. In the default case, 90% is assumed for distribution efficiency, and 95% is assumed for transmission efficiency. Note that calculations go back no further in the fuel cycle than the plant gate. In other words, fuel conversion efficiencies (e.g., to produce electricity or fuel-grade alcohol, or to compress natural gas) are not included in the current fuel substitution calculation. Total fuel-cycle energy use and emissions will be added to a subsequent version of IMPACTT.