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TRANSPORTATION SECTOR MODEL OF THE NATIONAL ENERGY MODELING SYSTEM

Volume II--Appendices

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Appendix F. Attachments to the Transportation Model

The attachments contained within this appendix provide additional details about the model development and estimation process which do not easily lend themselves to incorporation in the main body of the model documentation report. The information provided in these attachments is not integral to the understanding of the model's operation, but provides the reader with to opportunity to gain a deeper understanding of some of the model's underlying assumptions. There will be a slight degree of replication of materials found elsewhere in the documentation, made unavoidable by the dictates of internal consistency. Each attachment is associated with a specific component of the transportation model; the presentation follows the same sequence of modules employed in Volume I.

The following attachments are contained in Appendix F:

Attachment 1: Fuel Economy Model (FEM): Provides a discussion of the FEM vehicle demand and performance by size class models.

Attachment 2: Alternative Fuel Vehicle (AFV) Model: Describes data input sources and extrapolation methodologies.

Attachment 3: Light-Duty Vehicle (LDV) Stock Model: Discusses the fuel economy gap estimation methodology.

Attachment 4: Light Duty Vehicle Fleet Model: Presents the data development for business, utility, and government fleet vehicles.

Attachment 5: Light Commercial Truck Model: Describes the stratification methodology and data sources employed in estimating the stock and performance of LCT's.

Attachment 6: Air Travel Demand Model: Presents the derivation of the demographic index, used to modify estimates of personal travel demand.

Attachment 7: Airborne Emissions Model: Describes the derivation of emissions factors used to associate transportation measures to levels of airborne emissions of several pollutants.

Attachment 1: Fuel Economy Model

Demand Models for Vehicle Size Class Mix
and Performance by Size Class

INTRODUCTION

Estimates of the future mix of vehicle classes sold and the performance level by size class requires a detailed econometric demand model of vehicle choice by size class and vehicle performance within size class. There are a few publicly available models that forecast vehicle demand by size class, but those models have proved inaccurate in the past, and do not use a class structure that is compatible with the one used in the FEM. Demand for performance has not been assessed to date in any publicly available study. Both the size mix and performance levels are difficult to estimate because the car purchase decision is complex and consumer choice depends not only on the macroeconomic conditions but also on the attributes of individual products in the marketplace. Some of these attributes are based on the styling of the car, its perceived quality, the manufacturer's image and the status conveyed by owning a specific model, and cannot be easily quantified. Although these variables affect choice of individual models, they can also affect the choice of vehicle sizes or performance levels. For example, many consumers appeared to willing to buy a Japanese car for its quality and reliability even if it's size was smaller than the size actually desired by consumers. There have also been changes in consumer performance that may be linked to demographic variables, e.g., older consumers prefer larger cars.

These factors have made the automotive market notoriously difficult to forecast. The models incorporated in the FEM do <u>not</u> represent an attempt to provide a comprehensive forecast of future shifts in size class mix or performance levels by size class in response to the potentially large range of influencing or causal variables. Rather, the models attempt to capture the response to broad macroeconomic forces or behavioral (time) trends based on the experience of the last 15 years. It is recognized that these models are relatively simplistic, and it is anticipated that future versions of the FEM will incorporate more advanced models.

METHODOLOGY

The methodology employed to assess the influence of macroeconomic and time dependent variables on the mix of size classes and performance was by regression analysis of historical data.

EEA has compiled a very large data base on car and light truck sales over the 1979-1990 period. These data are based on the official CAFE files from EPA, augmented by the addition of vehicle and engine descriptor variables. All of the vehicles were classified by market class according to the scheme utilized in the FEM. Vehicle performance levels were measured by the horsepower to weight ratio (HP/WT) that is well correlated to objective measures such as the 0 to 60 mph acceleration time. Detailed weight data was unavailable for light trucks, and horsepower alone was used as a surrogate for performance. (Fortunately, truck weight within market class did not change significantly in the 12 year period analyzed).

The models for size class mix and performance utilized the same set of independent variables

- Disposable income per capita (in 1990 dollars)
- Price of gasoline (1990 dollars)
- Vehicle price average by class
- Vehicle fuel economy
- Rate of change of gas price over two years
- Cost of driving per mile
- Number of nameplates (models) in a class

The last variable is really a composite of fuel cost/fuel economy and not a new independent variable.

Performance was defined as the average HP/WT ratio by class for cars, and the average HP by class for trucks. Market share was defined as the sales fraction of the class relative to <u>entire car and light truck</u> market. This definition was chosen to incorporate the effects of consumers switching from cars to light trucks.

In general, the models were linear regressions of the logarithm of all variables, so that the co-efficients represented "elasticity" estimates. However, the market share model was modified to utilize the variable (m/1-m) as the independent variable in the regression, for two reasons. First, the elasticity of market share appears to be dependent on how large a share of the market a size class has. This reflects the fact that at very low market shares, buyers of a particular class are reduced to the diehard consumers who are less likely to switch due to macroeconomic forces, and the market is inelastic. Second the log(m/1-m) form converts a 0 to 1 variable to one that spans the -infinity to +infinity range. As a result of this variable change the model cannot be driven to m=1 for any input set, so that no one market class takes over the entire market for any combination of inputs. Such a variable form has been utilized in prior analysis by Wheaton Econometric Forecasting Associates (WEFA).

RESULTS

A stepwise linear regression of performance by market class and of class market share was performed to aid in the selection of independent variables with the greatest statistical significance. In addition, the co-efficients were required to be

- directionally consistent with intuitive expectations
- consistent in absolute magnitude across market classes that are similar

For the market share regressions, the variables that were statistically significant included: model year (time), price of gasoline, disposable income, number of nameplates (in some classes). In particular, number of nameplates was significant in those classes where only one or two makes existed in the early 1980's but new makes were introduced in the mid-to-late 1980's; compact vans are a good example of this phenomenon.

Table F-1 shows the results of the regressions of (m_i/1-m_i) against the variables MDLY (model year), LPGAS (price of gasoline), LYD (per capita disposable income), and LNPLT (number of nameplates). The following conclusions are appropriate:

- Subcompact and minicompact market share benefits from a time trend towards smaller cars. Market share increases with increasing gasoline prices (1.33 co-efficient) but decreases with increasing income.
- Sports cars market share appears to be declining with time but is insensitive to price of gasoline or income.
- Compact car market share increase with time and increasing price of gasoline, but is insensitive to income trends.

Table F-1. Regression Results From LDV Market Share Model

Group	F Val	R^2	Intercept	MDLY	LPGAS	LYD	LNPLT
Mini and Subcompact	14.359	0.891	-5.428	0.056 (1.761)	1.33 (1.828)	-0.169 (-1.524)	1.136 (2.288)
Sports	11.193	0.808	-2.475	-0.049 (-1.903)	0.26 (.466)	.0068 (.059)	
Compact	5.533	0.76	-5.021	0.111 (2.117)	1.332 (1.35)	0.107 (.52)	0.383 (.825)
Intermediate	3.084	0.536	-1.01	-0.051 (-1.742)	-0.213 (-.335)	-0.0017 (-.013)	
Large	16.880	0.864	-3.312	-0.119 (-4.754)	0.042 (.077)	0.231 (2.018)	
Luxury	18.458	0.939	-3.1	0.126 (2.336)	1.166 (2.704)	0.169 (1.441)	-0.435 (-.699)
Mini Truck	1.378	0.341	2.268	-0.018 (-.168)	-3.648 (-1.6)	-0.968 (-2.027)	
Compact Pickup	19.183	0.916	-8.749	-0.042 (-1.238)	-0.811 (-1.48)	0.174 (1.247)	1.91 (5.122)
Compact Van	804.167	0.998	-9.3	0.01 (.352)	0.832 (1.727)	0.307 (3.045)	1.466 (16.421)
Compact Utility	274.104	0.994	-7.36	-0.042 (-1.447)	-0.2 (-.396)	0.366 (2.933)	0.763 (8.474)
Standard Size Trucks	1.582	0.475	-2.779	-0.056 (-1.523)	0.252 (.307)	0.144 (.846)	

- Intermediate car market share is decreasing with time but is largely insensitive to either the price of gasoline or income.
- Large car market share decreases with time, but increases with income.
- Luxury car market share increases with time, income and the price of gasoline.
- Minitruck market share is very sensitive to the price of gasoline, and decreases with increasing gasoline prices and income.
- Compact trucks and utilities market share are negatively influenced by time trends and price of gas, but positively by income.
- Compact vans have a unique trend relative to all trucks in showing increasing market share with increasing gasoline prices. It is also positively influenced by increasing income.
- Full size trucks (pickup, van and utility) show relatively stable market shares, with a modestly declining time trend. Only utility vehicles' market share appear to be

sensitive to income, while market shares of all full size trucks are insensitive to the price of gasoline.

Some of these trends initially appear to be counterintuitive, but one must consider the impact of a particular variable on sales of the class as well as the total fleet sales. For example, while sales of luxury cars decreases with increasing gasoline prices, the market share increases since sales of all other cars decline by a greater amount for the same change in the price of gasoline. Sales of minitrucks and compact pickup and utility vehicles, most of which are used for personal transportation or recreation, are also more strongly affected by increasing price of gasoline, and their market share drops. On the other hand, standard size vehicles are used more commonly in the light commercial sector or for hauling rather than personal transportation and their market shares are relatively stable in response to gasoline prices.

It should be noted that the co-efficients in Table F-1 are not elasticities as the dependent variable is $m_i/1-m_i$, not m_i alone. In general, the values of m_i range from 0.05 to 0.20. The correct "elasticity" co-efficient is the actual co-efficient times $1-m_i/2$, so that multiplying the co-efficients in Table F-1 by 0.4 ~ 0.475 will provide an estimate of elasticity.

The performance model utilized a similar procedure, but the dependent variable was average HP/WT (or HP for trucks) by class. The most significant variables were found to be LFC (fuel consumption), personal income (LYD) and price of gas (LPGAS) in most cases. In some cases, cost per mile (LCPM) provided a better regression when substituted for LFC and LPGAS. The results of the regression are shown in Table F-2. In general, the regressions yield the elasticities presented in Table F-3.

The results indicate that virtually all classes respond similarly to the cost of driving, although for small cars (mini-, sub-, and compact cars) an equivalent result was obtained for fuel economy rather than cost per mile. Performance demand is more sensitive to disposable income, with the large trucks showing very high sensitivity. This particular finding is suspect and may be due to the fact that significant engine improvements in the late 1980's (which increased rated HP) occurred in the same time frame when incomes were rising.

Table F-2. Regression Results From LDV Performance Model

Group	F Val	R^2	Intercept	LFC	LYD	LPGAS
Mini and Subcompact	14.819	0.848	13.893	-0.238 (1.706)	1.012 (-2.270)	0.11 (-.811)
Sports	7.675	0.742	-1.104	-0.311 (1.299)	-0.533 (.666)	-0.364 (1.616)
Compact	11.613	0.813	20.709	-0.252 (3.094)	1.721 (-3.308)	0.403 (-2.679)
Intermediate	57.101	0.956	14.252	-0.099 (.845)	1.114 (-3.296)	-0.0051 (.050)
Large	72.509	0.964	10.429	-0.168 (1.380)	0.704 (-1.902)	-0.171 (1.535)
Luxury	151.145	0.983	11.085	-0.124 (1.859)	0.79 (-2.704)	-0.248 (2.912)
Mini Truck	0.219	0.076	0.88	0.378 (.550)	0.483 (.230)	0.035 (.056)
Compact Pickup	35.043	0.929	-9.264	-0.119 (-.646)	1.409 (3.045)	0.03 (.228)
Compact Van	57.789	0.956	-33.712	-0.853 (-2.375)	3.722 (2.960)	-0.0044 (-.012)
Compact Utility	21.804	0.891	-10.507	0.586 (2.824)	1.785 (2.149)	-0.063 (-.264)
Standard Pickup	16.854	0.863	-17.358	0.276 (1.315)	2.41 (3.182)	0.271 (1.257)
Standard Van	37.117	0.933	-14.171	0.142 (1.061)	2.038 (4.393)	0.195 (1.72)
Standard Utility	21.177	0.888	-19.425	0.331 (2.144)	2.54 (3.398)	0.253 (1.176)

Table F-3: LDV Performance Model Elasticities

	LFC	LYD	LPGAS	LCPM
Small Cars	-0.23 ~ -0.30	+1 to +1.7	N.S.	--
Large Cars	-0.10 ~ -0.17	0.7 to 1.0	Variable	-0.1 to -0.20
Small Trucks	N.S.	+1.4 to +1.7	N.S.	-0.24 to -0.33
Standard Trucks	N.S.	-2.0 to 2.5	N.S.	-0.23 to -0.35

N.S. - Not Specified

VALUE OF PERFORMANCE AND FUEL ECONOMY ADJUSTMENT

The value of performance is defined as the dollar amount that consumers are willing to pay for horsepower. This value was estimated from the actual list price for the vehicles in the 1988-1990 period and was based on the engine option prices. This method assumes that the manufacturers are pricing horsepower at levels that consumers are willing to pay. Most domestic models offer an optional engine with higher HP, while several import models offer optional turbocharged engines or 4-valve engine versions. In each case the cost of the engine option alone was identified from manufacturer price lists for 1989/1990 models (very often, the engine option is available with other features such as performance tires, aerodynamic devices etc. so that the vehicle price is higher than the cost of the engine option). Based on the prices of engine options, the following averages are applicable for all cars except sports and luxury cars:

Table F-4. LDV Performance and Price Options

Engine Option	HP Gain (%)	Price	Price/% HP
4-Valve vs. 2-Valve	30 to 35	$400 to 500	13.30 to 16.66
V-6 vs. I-4	25 to 30	$300 to 400	12 to 16
V-8 vs. V-6	30 to 35	$400 to 500	13.30 to 16.66
Turbo vs. Nat Aspirated	45 to 60	$650 to 850	14.44 to 18.88

Based on these data, an approximate average value of performance is $15 per percent increase in HP. Most sports and several luxury cars charge prices that are 15 to 25 percent higher than the values quoted above (although some very high priced luxury cars such as Mercedes, Porsche, and BMW charge more than twice the values quoted above). Accordingly, the value of performance for these classes has been set to $18 per percent increase in HP.

Increasing performance also decreases fuel economy and this relationship is derived from a regression analysis of fuel economy data that provides the sensitivity of fuel economy to factors that increase performance. In general, performance can be increased by four methods:

- by increasing the axle ratio
- by installing a larger engine with the same number of cylinders
- by installing a larger engine with more cylinders

- by utilizing 4-valve heads or turbocharging

The first method is suitable only for small changes in performance (less than 10 percent). The second method is useful for changes in the range of 10 to 25 percent. The use of engines with more cylinders can result in HP gains of 30 to 60 percent (4 cylinder to 6 cylinder, or 6 cylinder to 8 cylinder). 4-valve engines generally provide HP gains of 20 to 25 percent relative to a 2-valve engine of equal displacement, while turbocharging can provide an HP increase of 40 to 45 percent relative to a naturally aspirated engine of equal displacement. These technologies can be combined with displacement increases or decreases to achieve any desired result.

Based on engineering and regression analysis (see Appendix G, Supplement 1), the fuel economy sensitivity for axles ratio changes is -0.22 (i.e., a 10 percent axle ratio increase decreases fuel economy by 2.2 percent). The fuel economy sensitivity for displacement changes without changing the number of cylinders is -0.35 (i.e. a 25 percent change in displacement decreases fuel economy by nine percent, including the effect of increased engine weight). Substituting a V-6 for a 4-cylinder or a V-8 for a V-8 significantly increases the vehicle weight, and a fifty percent HP increase decreases fuel economy by about 25 percent.

A non-linear equation that captures these effects is given by

$$\Delta FE = -0.22\,\Delta HP - 0.56\,\Delta HP^2 \;; \quad \Delta HP > 0$$
$$= -0.22\,\Delta HP + 0.56\,\Delta HP^2 \;; \quad \Delta HP < 0$$

where both ΔHP and ΔFE are expressed as *percent changes*. The equation is valid for ΔHP values between 0 and 60 percent.

TECHNOLOGY IMPROVEMENTS FOR AUTOMOBILES

The characteristics of the automotive technologies considered in the LDV module have been developed by Energy and Environmental Analysis, Inc. of Arlington Virginia, and are tabulated on the following pages in Tables F-6 to F-9.[1] Much of this research has been derived from an earlier study of technological change and its potential application to fuel economy improvements.[2] In this study, numerous automotive technologies have been evaluated in regard to both their estimated impacts on vehicle performance and their cost-effectiveness from a producer's standpoint. Individual technologies or groups of technologies have been assigned to one of three "certainty levels", defined below, which indicates the likelihood of their incorporation in the near-term.

The Standard Technology Matrices for cars and light trucks (Tables F-6 and F-7) represent a relatively conservative estimation of technology cost, availability, and impact over the course of the forecast. The corresponding High Technology Matrices (Tables F-8 and F-9) reflect a more optimistic assessment of the potentials of selected technologies. In order to permit a ready comparison of technology characteristics, those elements in the High Technology Matrices which differ from their Standard Technology counterparts are shaded.

Table F-5: Certainty Levels of Near-Term Technologies for Improving Fuel Economy[3]

Level	Technology Characteristics
1	Technologies currently in production in at least one mass market vehicle worldwide and which have no technical risk in the sense that they are fully demonstrated and are available to all manufacturers through either direct production or licensing. Level 1 improvements are therefore available for production use within one product cycle.
2	Technologies ready for commercialization and for which there are no engineering constraints (such as emissions control considerations) which would inhibit their use in production vehicles. Technologies assessed at Level 2 are considered to have low technical risk in the sense that some "debugging" effort may be required because of a lack of on-road experience
3	Technologies in advanced stages of development but which may face some technical constraints before they can be used in production vehicles. Because Level 3 technologies bear some uncertainty as to when they will be fully available for use in production, it is not possible to presently establish with certainty that they are available for incorporation into new vehicles over the course of a complete product cycle.

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[1] *NEMS Fuel Economy Model: LDV High Technology Update,* Decision Analysis Corporation of Virginia, DE-AC01-92EI21946, Task 95124, Subtask 9-2, 6/17/96.

[2] DeCicco, J., and Ross, M., *An Updated Assessment of the Near-Term Potential for Improving Automotive Fuel Economy,* American Council for an Energy-Efficient Economy, Washington DC, 11/93.

[3] *Ibid.* p. 12.

Table F-6: Standard Technology Matrix For Cars

	Fractional Fuel Efficiency Change	Incremental Cost (1990 $)	Incremental Cost ($/Unit Wt.)	Incremental Weight (Lbs.)	Incremental Weight (Lbs./Unit Wt.)	First Year Introduced	Fractional Horsepower Change
Front Wheel Drive	0.060	150	0.00	0	-0.08	1980	0
Unit Body	0.040	80	0.00	0	-0.05	1980	0
Material Substitution II	0.033	0	0.60	0	-0.05	1987	0
Material Substitution III	0.066	0	0.80	0	-0.10	1997	0
Material Substitution IV	0.099	0	1.00	0	-0.15	2007	0
Material Substitution V	0.132	0	1.50	0	-0.20	2017	0
Drag Reduction II	0.023	32	0.00	0	0.00	1985	0
Drag Reduction III	0.046	64	0.00	0	0.05	1991	0
Drag Reduction IV	0.069	112	0.00	0	0.01	2004	0
Drag Reduction V	0.092	176	0.00	0	0.02	2014	0
TCLU	0.030	40	0.00	0	0.00	1980	0
4-Speed Automatic	0.045	225	0.00	30	0.00	1980	0.05
5-Speed Automatic	0.065	325	0.00	40	0.00	1995	0.07
CVT	0.100	250	0.00	20	0.00	1995	0.07
6-Speed Manual	0.020	100	0.00	30	0.00	1991	0.05
Electronic Transmission I	0.005	20	0.00	5	0.00	1988	0
Electronic Transmission II	0.015	40	0.00	5	0.00	1998	0
Roller Cam	0.020	16	0.00	0	0.00	1987	0
OHC 4	0.030	100	0.00	0	0.00	1980	0.2
OHC 6	0.030	140	0.00	0	0.00	1980	0.2
OHC 8	0.030	170	0.00	0	0.00	1980	0.2
4C/4V	0.080	240	0.00	30	0.00	1988	0.45
6C/4V	0.080	320	0.00	45	0.00	1991	0.45
8C/4V	0.080	400	0.00	60	0.00	1991	0.45
Cylinder Reduction	0.030	-100	0.00	-150	0.00	1988	-0.1
4C/5V	0.100	300	0.00	45	0.00	1998	0.55
Turbo	0.050	800	0.00	80	0.00	1980	0.45
Engine Friction Reduction I	0.020	20	0.00	0	0.00	1987	0
Engine Friction Reduction II	0.035	50	0.00	0	0.00	1996	0
Engine Friction Reduction III	0.050	90	0.00	0	0.00	2006	0
Engine Friction Reduction IV	0.065	140	0.00	0	0.00	2016	0
VVT I	0.080	140	0.00	40	0.00	1998	0.1
VVT II	0.100	180	0.00	40	0.00	2008	0.15
Lean Burn	0.100	150	0.00	0	0.00	2012	0
Two Stroke	0.150	150	0.00	-150	0.00	2004	0
TBI	0.020	40	0.00	0	0.00	1982	0.05
MPI	0.035	80	0.00	0	0.00	1987	0.1
Air Pump	0.010	0	0.00	-10	0.00	1982	0
DFS	0.015	15	0.00	0	0.00	1987	0.1
Oil 5W-30	0.005	2	0.00	0	0.00	1987	0
Oil Synthetic	0.015	5	0.00	0	0.00	1997	0
Tires I	0.010	16	0.00	0	0.00	1992	0
Tires II	0.020	32	0.00	0	0.00	2002	0
Tires III	0.030	48	0.00	0	0.00	2012	0
Tires IV	0.040	64	0.00	0	0.00	2018	0
ACC I	0.005	15	0.00	0	0.00	1992	0
ACC II	0.010	30	0.00	0	0.00	1997	0
EPS	0.015	40	0.00	0	0.00	2002	0
4WD Improvements	0.030	100	0.00	0	-0.05	2002	0
Air Bags	-0.010	300	0.00	35	0.00	1987	0
Emissions Tier I	-0.010	150	0.00	10	0.00	1994	0
Emissions Tier II	-0.010	300	0.00	20	0.00	2003	0
ABS	-0.005	300	0.00	10	0.00	1987	0
Side Impact	-0.005	100	0.00	20	0.00	1996	0
Roof Crush	-0.003	100	0.00	5	0.00	2001	0
Increased Size/Wt.	-0.033	0	0.00	0	0.05	1991	0
Compression Ratio Increase	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Idle Off	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Optimized Manual Transmission	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Variable Displacement	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Electric Hybrid	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Table F-7: Standard Technology Matrix For Trucks

	Fractional Fuel Efficiency Change	Incremental Cost (1990 $)	Incremental Cost ($/Unit Wt.)	Incremental Weight (Lbs.)	Incremental Weight (Lbs./Unit Wt.)	First Year Introduced	Fractional Horsepower Change
Front Wheel Drive	0.020	160	0.00	0	-0.08	1985	0
Unit Body	0.060	80	0.00	0	-0.05	1995	0
Material Substitution II	0.033	0	0.60	0	-0.05	1996	0
Material Substitution III	0.066	0	0.80	0	-0.10	2006	0
Material Substitution IV	0.099	0	1.00	0	-0.15	2016	0
Material Substitution V	0.132	0	1.50	0	-0.20	2026	0
Drag Reduction II	0.023	32	0.00	0	0.00	1990	0
Drag Reduction III	0.046	64	0.00	0	0.05	1997	0
Drag Reduction IV	0.069	112	0.00	0	0.01	2007	0
Drag Reduction V	0.092	176	0.00	0	0.02	2017	0
TCLU	0.030	40	0.00	0	0.00	1980	0
4-Speed Automatic	0.045	225	0.00	30	0.00	1980	0.05
5-Speed Automatic	0.065	325	0.00	40	0.00	1997	0.07
CVT	0.100	250	0.00	20	0.00	2005	0.07
6-Speed Manual	0.020	100	0.00	30	0.00	1997	0.05
Electronic Transmission I	0.005	20	0.00	5	0.00	1991	0
Electronic Transmission II	0.015	40	0.00	5	0.00	2006	0
Roller Cam	0.020	16	0.00	0	0.00	1986	0
OHC 4	0.030	100	0.00	0	0.00	1980	0.15
OHC 6	0.030	140	0.00	0	0.00	1985	0.15
OHC 8	0.030	170	0.00	0	0.00	1995	0.15
4C/4V	0.060	240	0.00	30	0.00	1990	0.30
6C/4V	0.060	320	0.00	45	0.00	1990	0.30
8C/4V	0.060	400	0.00	60	0.00	2002	0.30
Cylinder Reduction	0.030	-100	0.00	-150	0.00	1990	-0.1
4C/5V	0.080	300	0.00	45	0.00	1997	0.55
Turbo	0.050	800	0.00	80	0.00	1980	0.45
Engine Friction Reduction I	0.020	20	0.00	0	0.00	1991	0
Engine Friction Reduction II	0.035	50	0.00	0	0.00	2002	0
Engine Friction Reduction III	0.050	90	0.00	0	0.00	2012	0
Engine Friction Reduction IV	0.065	140	0.00	0	0.00	2022	0
VVT I	0.080	140	0.00	40	0.00	2006	0.1
VVT II	0.100	180	0.00	40	0.00	2016	0.15
Lean Burn	0.100	150	0.00	0	0.00	2018	0
Two Stroke	0.150	150	0.00	-150	0.00	2008	0
TBI	0.020	40	0.00	0	0.00	1985	0.05
MPI	0.035	80	0.00	0	0.00	1985	0.1
Air Pump	0.010	0	0.00	-10	0.00	1985	0
DFS	0.015	15	0.00	0	0.00	1985	0.1
Oil %w-30	0.005	2	0.00	0	0.00	1987	0
Oil Synthetic	0.015	5	0.00	0	0.00	1997	0
Tires I	0.010	16	0.00	0	0.00	1992	0
Tires II	0.020	32	0.00	0	0.00	2002	0
Tires III	0.030	48	0.00	0	0.00	2012	0
Tires IV	0.040	64	0.00	0	0.00	2018	0
ACC I	0.005	15	0.00	0	0.00	1997	0
ACC II	0.010	30	0.00	0	0.00	2007	0
EPS	0.015	40	0.00	0	0.00	2002	0
4WD Improvements	0.030	100	0.00	0	-0.05	2002	0
Air Bags	-0.010	300	0.00	35	0.00	1992	0
Emissions Tier I	-0.010	150	0.00	10	0.00	1996	0
Emissions Tier II	-0.010	300	0.00	20	0.00	2004	0
ABS	-0.005	300	0.00	10	0.00	1990	0
Side Impact	-0.005	100	0.00	20	0.00	1996	0
Roof Crush	-0.003	100	0.00	5	0.00	2001	0
Increased Size/Wt.	-0.033	0	0.00	0	0.05	1991	0
Compression Ratio Increase	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Idle Off	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Optimized Manual Transmission	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Variable Displacement	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Electric Hybrid	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Table F-8: High Technology Matrix For Cars

	Fractional Fuel Efficiency Change	Incremental Cost (1990 $)	Incremental Cost ($/Unit Wt.)	Incremental Weight (Lbs.)	Incremental Weight (Lbs./Unit Wt.)	First Year Introduced	Fractional Horsepower Change
Front Wheel Drive	0.060	160	0.00	0	-0.08	1980	0
Unit Body	0.040	80	0.00	0	-0.05	1980	0
Material Substitution II	0.033	0	0.30	0	-0.05	1987	0
Material Substitution III	0.066	0	0.40	0	-0.10	1997	0
Material Substitution IV	0.099	0	0.50	0	-0.15	2003	0
Material Substitution V	0.132	0	0.75	0	-0.20	2007	0
Drag Reduction II	0.023	32	0.00	0	0.00	1985	0
Drag Reduction III	0.046	64	0.00	0	0.05	1991	0
Drag Reduction IV	0.069	112	0.00	0	0.01	1997	0
Drag Reduction V	0.092	176	0.00	0	0.02	2003	0
TCLU	0.030	40	0.00	0	0.00	1980	0
4-Speed Automatic	0.045	225	0.00	30	0.00	1980	0.05
5-Speed Automatic	0.065	325	0.00	40	0.00	1995	0.07
CVT	0.100	250	0.00	20	0.00	1995	0.07
6-Speed Manual	0.020	100	0.00	30	0.00	1991	0.05
Electronic Transmission I	0.005	20	0.00	5	0.00	1988	0
Electronic Transmission II	[illegible]	60	0.00	5	0.00	1998	0
Roller Cam	0.020	16	0.00	0	0.00	1987	0
OHC 4	0.030	45	0.00	0	0.00	1980	0.2
OHC 6	0.030	55	0.00	0	0.00	1980	0.2
OHC 8	0.030	65	0.00	0	0.00	1980	0.2
4C/4V	0.080	125	0.00	30	0.00	1988	0.45
6C/4V	0.080	165	0.00	45	0.00	1991	0.45
8C/4V	0.080	205	0.00	60	0.00	1991	0.45
Cylinder Reduction	0.030	-100	0.00	-150	0.00	1988	-0.1
4C/5V	0.100	300	0.00	45	0.00	1998	0.55
Turbo	[illegible]	300	0.00	80	0.00	1980	0.45
Engine Friction Reduction I	0.020	20	0.00	0	0.00	1987	0
Engine Friction Reduction II	0.035	50	0.00	0	0.00	1996	0
Engine Friction Reduction III	0.050	90	0.00	0	0.00	2006	0
Engine Friction Reduction IV	0.065	120	0.00	0	0.00	2016	0
VVT I	0.080	100	0.00	40	0.00	1998	0.1
VVT II	0.100	150	0.00	40	0.00	2008	0.15
Lean Burn	0.120	75	0.00	0	0.00	2012	0
Two Stroke	0.150	0	0.00	-150	0.00	2004	0
TBI	0.020	40	0.00	0	0.00	1982	0.05
MPI	0.035	80	0.00	0	0.00	1987	0.1
Air Pump	0.010	0	0.00	-10	0.00	1982	0
DFS	0.015	15	0.00	0	0.00	1987	0.1
Oil %w-30	0.005	2	0.00	0	0.00	1987	0
Oil Synthetic	0.015	5	0.00	0	0.00	1997	0
Tires I	0.010	5	0.00	0	0.00	1992	0
Tires II	0.033	10	0.00	0	0.00	2002	0
Tires III	0.048	15	0.00	0	0.00	2012	0
Tires IV	[illegible]	20	0.00	0	0.00	2018	0
ACC I	0.010	[illegible]	0.00	0	0.00	1992	0
ACC II	0.017	13	0.00	0	0.00	1997	0
EPS	0.015	40	0.00	0	0.00	2002	0
4WD Improvements	0.030	100	0.00	0	-0.05	2002	0
Air Bags	-0.010	300	0.00	35	0.00	1987	0
Emissions Tier I	-0.010	150	0.00	10	0.00	1994	0
Emissions Tier II	-0.010	300	0.00	20	0.00	2003	0
ABS	-0.005	300	0.00	10	0.00	1987	0
Side Impact	-0.005	100	0.00	20	0.00	1996	0
Roof Crush	-0.003	100	0.00	5	0.00	2001	0
Increased Size/Wt.	-0.033	0	0.00	0	0.05	1991	0
Compression Ratio Increase	*0.010*	*0*	*0.00*	*0*	*0.00*	*1995*	*0.02*
Idle Off	*0.110*	*260*	*0.00*	*0*	*0.00*	*1997*	*0*
Optimized Manual Transmission	*0.120*	*60*	*0.00*	*0*	*0.00*	*1997*	*0*
Variable Displacement	*0.030*	*65*	*0.00*	*0*	*0.00*	*1999*	*0*
Electric Hybrid	*0.660*	*1785*	*0.00*	*0*	*0.00*	*2001*	*0*

Table F-9: High Technology Matrix For Trucks

	Fractional Fuel Efficiency Change	Incremental Cost (1990 $)	Incremental Cost ($/Unit Wt.)	Incremental Weight (Lbs.)	Incremental Weight (Lbs./Unit Wt.)	First Year Introduced	Fractional Horsepower Change
Front Wheel Drive	0.020	160	0.00	0	-0.08	1985	0
Unit Body	0.060	80	0.00	0	-0.05	1995	0
Material Substitution II	0.033	0	0.30	0	-0.05	1987	0
Material Substitution III	0.066	0	0.40	0	-0.10	1997	0
Material Substitution IV	0.099	0	0.50	0	-0.15	2003	0
Material Substitution V	0.132	0	0.75	0	-0.20	2007	0
Drag Reduction II	0.023	32	0.00	0	0.00	1985	0
Drag Reduction III	0.046	64	0.00	0	0.05	1991	0
Drag Reduction IV	0.069	112	0.00	0	0.01	1997	0
Drag Reduction V	0.092	176	0.00	0	0.02	2003	0
TCLU	0.030	40	0.00	0	0.00	1980	0
4-Speed Automatic	0.045	225	0.00	30	0.00	1980	0.05
5-Speed Automatic	0.065	325	0.00	40	0.00	1995	0.07
CVT	0.100	250	0.00	20	0.00	1995	0.07
6-Speed Manual	0.020	100	0.00	30	0.00	1991	0.05
Electronic Transmission I	0.005	20	0.00	5	0.00	1988	0
Electronic Transmission II	0.080	50	0.00	5	0.00	1998	0
Roller Cam	0.020	16	0.00	0	0.00	1987	0
OHC 4	0.030	45	0.00	0	0.00	1980	0.2
OHC 6	0.030	55	0.00	0	0.00	1980	0.2
OHC 8	0.030	65	0.00	0	0.00	1989	0.2
4C/4V	0.030	125	0.00	30	0.00	1988	0.45
6C/4V	0.080	165	0.00	45	0.00	1991	0.45
8C/4V	0.080	205	0.00	60	0.00	1997	0.45
Cylinder Reduction	0.030	-100	0.00	-150	0.00	1995	-0.1
4C/5V	0.100	300	0.00	45	0.00	1994	0.55
Turbo	0.080	300	0.00	80	0.00	1980	0.45
Engine Friction Reduction I	0.020	20	0.00	0	0.00	1987	0
Engine Friction Reduction II	0.035	50	0.00	0	0.00	1996	0
Engine Friction Reduction III	0.050	90	0.00	0	0.00	2006	0
Engine Friction Reduction IV	0.065	120	0.00	0	0.00	2016	0
VVT I	0.080	100	0.00	40	0.00	1995	0.1
VVT II	0.120	130	0.00	40	0.00	2008	0.15
Lean Burn	0.100	75	0.00	0	0.00	2012	0
Two Stroke	0.150	0	0.00	-150	0.00	2004	0
TBI	0.020	40	0.00	0	0.00	1982	0.05
MPI	0.035	80	0.00	0	0.00	1987	0.1
Air Pump	0.010	0	0.00	-10	0.00	1982	0
DFS	0.015	15	0.00	0	0.00	1987	0.1
Oil 5W-30	0.005	2	0.00	0	0.00	1987	0
Oil Synthetic	0.015	5	0.00	0	0.00	1997	0
Tires I	0.010	5	0.00	0	0.00	1992	0
Tires II	0.033	10	0.00	0	0.00	2002	0
Tires III	0.048	15	0.00	0	0.00	2012	0
Tires IV	0.053	20	0.00	0	0.00	2018	0
ACC I	0.040	5	0.00	0	0.00	1992	0
ACC II	0.017	13	0.00	0	0.00	1997	0
EPS	0.015	40	0.00	0	0.00	2002	0
4WD Improvements	0.030	100	0.00	0	-0.05	2002	0
Air Bags	-0.010	300	0.00	35	0.00	1987	0
Emissions Tier I	-0.010	150	0.00	10	0.00	1994	0
Emissions Tier II	-0.010	300	0.00	20	0.00	2003	0
ABS	-0.005	300	0.00	10	0.00	1987	0
Side Impact	-0.005	100	0.00	20	0.00	1996	0
Roof Crush	-0.003	100	0.00	5	0.00	2001	0
Increased Size/Wt.	-0.033	0	0.00	0	0.05	1991	0
Compression Ratio Increase	*0.010*	*0*	*0.00*	*0*	*0.00*	*1995*	*0.02*
Idle Off	*0.110*	*260*	*0.00*	*0*	*0.00*	*1997*	*0*
Optimized Manual Transmission	*0.120*	*60*	*0.00*	*0*	*0.00*	*1997*	*0*
Variable Displacement	*0.030*	*65*	*0.00*	*0*	*0.00*	*1999*	*0*
Electric Hybrid	*0.660*	*1785*	*0.00*	*0*	*0.00*	*2001*	*0*

CHARACTERISTICS OF ALTERNATIVE FUEL VEHICLES

This section provides a documentation of the updated Fuel Economy Model that also forecasts attributes of Alternative Fuel Vehicles (AFVs) for incorporation into the NEMS transportation model. The NEMS model requires a forecast of vehicle attributes consistent with those provided for conventional gasoline powered vehicles. The existing AFV module considers only three size classes, and requires five attributes by size class, which includes vehicle price and fuel efficiency as well as range, fuel availability and an estimate of emissions relative to gasoline. In general, fuel availability is specified exogenously, while the Fuel Economy Model (FEM) is expected to supply other attributes. The updated FEM provides attributes for AFVs in up to 12 market classes and five fuel types.

Other than gasoline and diesel powered vehicles, the model considers a variety of alternative fuel vehicles that are of both the dedicated and bi-fuel (alternative fuel/gasoline) type. The fuels considered include methanol, ethanol, electricity, compressed natural gas and liquified petroleum gas for a matrix of 10 alternative fuel vehicle types. The existing AFV module contains two other AFV types that are engine technology based classifications (assuming that the 10 described above use piston i.c. engine based technology). The two others are turbine powered using gasoline or CNG, and fuel cell powered using methanol or pure hydrogen, for an additional four AFV classes.

Available data for the manufacturers suggest that turbine powered vehicles are most unlikely to be produced as they have significantly higher costs and lower fuel economy than i.c. engines of equal power. Fuel cell powered vehicles using either methanol or pure hydrogen are unlikely to see commercial production before 2010. Attributes of all other vehicle types are summarized in this report, and a preliminary estimate of fuel cell vehicle attributes is also provided. Most of the data provided are drawn from ongoing work by EEA for the DOE's Alternative Fuel Transition Model, or from a recently completed EEA analysis for the Office of Technology Assessment.

The specification of AFV attributes requires a series of supply side issues to be resolved largely based on the judgement of EEA. Essentially, manufacturers can choose to tradeoff first cost against vehicle range, performance and even emissions. The choice of such parameters should ideally be made by the demand forecasting model, but such capabilities are not yet available in demand forecasting models.

The first consideration in forecasting AFV demand is that all fuels are not well suited to all vehicle size classes. For example, the size and weight of CNG tanks make it a poor choice for small cars.

Based on engineering considerations, EEA has estimated the likely combinations of fuel types and vehicle types that will be available in cars and light trucks. These combinations are shown in Table F-10 and F11, respectively. It should be noted that are no technical barriers to any particular combination of fuel type and size class, and these favored combinations are based on EEA's judgement about market acceptability and economic barriers facing AFVs in each class.

A second and more important consideration is that vehicle price is a strong function of sales volume. There are significant fixed costs associated with the design, tooling and certification of an AFV model, and if a model has a sales volume of only a few hundred units per year, the fixed costs allocations to each unit are quite large. A typical (non-luxury) gasoline car model is produced at annual volumes of 100,000 to 200,000 units, while most current AFV model sales are only in the range of a few tens to hundreds of units per year. Since the supply and demand models are not interactive, the pre-specification of vehicle price involves estimating sales volumes. Other analysis by EEA suggests that economies of scale result in similar percentage price reduction for every order of magnitude increase in production volume. In this analysis, EEA has assumed that AFV's will be derived from gasoline vehicles and sales volume per model will be in the 2,000 to 3,000 range so that modest economy of scale is achieved, but the full extent is not, for the near term. Pricing at volumes of 20,000 to 30,000 units per year is also considered. Based on other analysis for DOE, EEA recommends that prices at intermediate volumes be scaled in proportion to the logarithm of sales.

EEA analysis for the DOE indicates that auto-manufacturers must anticipate a sales volume of about 2500 units per year of a given AFV model in order to enter the market. At much lower sales volumes in the range of a few tens of vehicles to a few hundred vehicles per year, automanufacturers have typically subcontracted the work to small conversion shops, or else these AFVs have been aftermarket conversions of existing gasoline vehicles. In general, manufacturers believe that most aftermarket conversions are not well engineered in terms of emissions, fuel economy, and safety, and often have poor performance at high or low ambient temperatures. However, these conversions are much cheaper than automanufacturer designed products at the same sales volume, so that an aftermarket conversion is usually sold at 250 units/yr at the same price as an OEM conversion sold at 2500 units/year. The poor quality is a deterrent to consumer purchase.

Table F-10: Alternative Fuel Type Potential Application by Size Class (Cars)						
	Mini/Sub Compact	Compact	Midsize	Large	Luxury	Sport
Alcohol Flex[4]	✗	✗	✗	✗	✗	✗
Methanol Neat	✗	✗	✗	✗		✗
Ethanol Neat		✗	✗	✗		
CNG Dedicated				✗		
CNG Bifuel				✗		
LPG Dedicated			✗	✗		
LPG Bifuel			✗	✗		
Electric	✗	✗				
EV/Hybrid		✗	✗			
Fuel Cell Methanol			✗	✗		
Fuel Cell Hydrogen			✗	✗		

The following sections summarize the changes required to develop each particular AFV type from a gasoline based car, which EEA believes will serve as the base design, since developing a unique "ground up" AFV design is not likely as long as AFV sales volumes per model are less than 10 percent of similar gasoline engine model sales. Manufactu-rer's may contemplate offering a unique "ground up" design only for EVs, if a specific model can be sold in volumes of 50,000 units per year or more, which appears unlikely to this time. In addition, only OEM products are considered so that quality issues do not influence purchase considerations.

As a result, future model specific improvements for all AFV types will follow those for gasoline vehicles, except for inapplicable technologies for a specific AFV type. These inapplicable technologies are recognized in the descriptions that follow. In addition, it should be emphasized that there is a sales volume based price affect, but there is no "learning curve" effect for all engine technologies that are very similar to gasoline engine technologies, namely engines for alcohol fuels, CNG and LPG. Learning curve effects for EVs and hybrid vehicles are primarily associated with future cost reductions in energy storage media, either batteries or ultracapacitors, and in power electronics. Learning curves also exist for CNG fuel tanks, but the cost reductions will be less

[4] Includes methanol/ethanol.

dramatic than for EVs and hybrids.

Table F-11: Alternative Fuel Type Potential Application by Size Class (Light Trucks)							
	Mini-Utility	Compact Pickup	Compact Van	Compact Utility	Standard Pickup	Standard Van	Standard Utility
Alcohol Flex[5]	✗	✗	✗	✗	✗	✗	✗
Methanol Neat		✗	✗				
Ethanol Neat			✗				
CNG Dedicated		✗			✗	✗	
CNG Bifuel			✗		✗	✗	
LPG Dedicated		✗	✗		✗	✗	
LPG Bifuel		✗	✗		✗	✗	
Electric		✗	✗				
EV/Hybrid			✗	✗			✗
Fuel Cell Methanol		✗				✗	
Fuel Cell Hydrogen			?			?	

Each AFV type will require additional or specialized parts that result in variable cost increases, as well as fixed costs associated with:

- engineering
- tooling
- certification
- marketing

To the extent possible, total incremental AFV fixed costs per model have been identified. Table F-12 shows how the variable and fixed costs can be translated into a incremental retail price equivalent (IRPE) given a certain anticipated sales (or production) volume per model. These formulas have been used to develop retail price estimates. Ideally, the NEMS model should assume low sales volume prices, compute the actual sales, and iteratively check if the sales volumes

[5] Includes ethanol/methanol.

predicted are in line with pricing assumptions.

Table F-12: Conversion of Variable and Fixed Costs to IRPE	
Supplier costs to manufacturer	A
Total manufacturer investments	B
Unit cost of investment, C per production volume V	$\frac{B \times 1.358}{V \times 4.487}$
Automanufacturer Cost	A x 1.4 + C = D
IRPE	D x 1.25

FLEXIBLE FUEL AND DEDICATED ALCOHOL VEHICLES

These vehicles closely resemble the gasoline engine powered vehicle, and the modifications of a conventional vehicle to be either a flexible fuel vehicle (FFV) or dedicated alcohol fuel vehicle are relatively minor. At present, all alcohol vehicles are OEM products and no aftermarket conversions are expected. The most significant modifications are:

- Upgrade of the fuel tank and fuel lines materials to be corrosion resistant to alcohol
- New high flow fuel pump that can provide up to twice the flow rate of conventional pumps
- Modified fuel injectors and a new fuel/spark calibration for alcohol fuel
- Modifications to the evaporative emission control system to handle alcohol gasoline blends (FFV only)

The FFV also has a unique component, the fuel alcohol sensor that signals the engine electronic control system on the alcohol gasoline blend being used. The variable cost of all of the above parts is typically about $300 to $500 at low sales volume, with much of the cost associated with the fuel pump and fuel sensor. The high end of the range of costs is associated with converting a vehicle whose current fuel system requires significant materials changes, whereas the lower end would be for a vehicle whose current fuel system is corrosion resistant to alcohol.

Dedicated alcohol vehicles require similar changes but do not need the fuel sensor. If the engine is optimized for alcohol, it needs a new high compression ratio cylinder head, which partly offsets the cost of the sensor. Dedicated alcohol vehicle will have a simpler evaporative emission control system, although cost savings here are expected to be small. The net variable cost of a dedicated alcohol vehicle will be only slightly lower than that of an FFV and is estimated at $250 to 350 at low sales volume. Variable costs (which include supplier fixed costs) are expected to be reduced to half the low volume levels, i.e. $150 to 250, due to reduced per unit supplier costs, if volumes increase to 25,000 units/year.

Fixed costs for the automanufacturer are estimated at $7 to $8 million per model line, based on input from the manufacturers, for an assumed sales volume of 2500 units/year. However, significantly higher sales volume does not require much higher investment, and it is estimated that 25,000 units/year sales capability would require only an additional $2 million more to expand assembly capacity and enhance the marketing network.

Attributes of flexible fuel and dedicated vehicles are shown in Table F-13, relative to gasoline vehicle attributes. Prices are shown as if manufactures are pricing these vehicles as a standard product, (which they are clearly not) and EIA may wish to modify the prices to reflect current pricing. All of the improvements possible for conventional vehicles are applicable to FFV's and dedicated alcohol vehicles. At present, EEA believes that dedicated vehicles and FFVs operated on alcohol fuel may have small benefits in reactivity adjusted HC emissions (in the range of -10 to -20 percent) relative to an equal technology gasoline vehicle, but other emission benefits are negligible. In general, the range of prices shown at each sales volume are associated with vehicle size changes, with smaller cars at the low end of the price range, large trucks at the high end of the range, and mid-sized/large cars and compact trucks at the middle of the range.

Table F-13: Characteristics of Alcohol Fuel Vehicles Relative to Gasoline ICE's

	Methanol FFV	Ethanol FFV	Methanol Dedicated	Ethanol Dedicated
Horsepower	+4	+3	+8	+6
Range on M85/E85	-43	-27	-37	-24
Fuel Economy	+2	+1	+8	+4
Incremental Price ($)[6]				
@ 2,500 units/yr	1650-2000	1650-2000	1560-1820	1560-1820
@ 25,000 units/yr	410-500	410-500	370-425	370-425

CNG/LPG VEHICLES

CNG/LPG vehicles are the next step in complexity from an alcohol fueled vehicle for conversion

[6] Assumes manufacturer makes normal return on investment.

from a conventional gasoline vehicle. The major difference is that the fuel tanks are more complex, heavy and expensive, especially for CNG. Currently, most CNG and LPG vehicles are aftermarket conversions, but the OEMs have recently entered this market with a range of new products.

Outside of the fuel tanks, engine and fuel conversion costs are quite similar to these for a dedicated alcohol fuel vehicle. These include more expensive fuel lines, new fuel injectors and more expensive fuel injector drivers. The pump in an alcohol fuel vehicle is replaced by a pressure regulator, which can be a relatively expensive piece of equipment for a CNG vehicle that is certified to a stringent emission standard. Low pressure LPG pressure regulators are less expensive, but some manufacturers are experimenting with liquid LPG injection for optimal emission control. Engine improvements for both CNG and LPG systems are also similar, requiring revisions to the valve seats, pistons and rings and head gasket.

For dedicated systems, increases to the engine compression ratio (CR) by 0.5 to 1 point for LPG and 1.5 to 2 points for CNG are optimal. Such increases may, in turn, lead to revisions to the cooling system and air intake system. The increases in CR lead to a fuel economy benefit of and 4 and 8 percent for LPG and CNG, respectively.

Engine components and costs for a dual fuel system of high quality that is emission certified is estimated at $350 to 450. Engine improvements for dedicated CNG/LPG engines that are optimized will increase these costs to $500 to $600. However, there will be a cost savings of $350 associated with the elimination of the gasoline fuel system and evaporative system, for a net cost of $150 to 250. The costs are for volumes of 2,500 units/year and could decrease by 50 percent at 25,000 units/year, based on interviews with CNG system manufacturers.

Costs of fuel tanks are significant. For CNG, the incremental costs of tanks are estimated at $100-125 per gasoline equivalent gallon, and a typical tank for cars is about 9 gallons, while one for trucks is 12 gallons. Hence, CNG tank costs are $900 to 1125 for cars, and $1200 to 1500 for trucks at low volume. The tanks add about 150 lbs weight for cars and 200 lbs for trucks. LPG tanks cost approximately one-third as much as CNG tanks. One significant uncertainty is how much the cost of CNG/LPG tanks can decline as a function of volume. It has been estimated that costs will decline by 33% as sales volume increases from 2500 units/year to 25,000 units/year, but this figure may indicate benefits from "learning" as well.

Engineering and tooling costs for CNG and LPG vehicles are significantly higher than for alcohol fueled vehicles, because of the need to modify the body and chassis to accommodate the tanks, and the need to upgrade suspension tires and brakes to accommodate the increased weight. In addition, the vehicle will have to be crash tested due to the extensive changes to the fuel system, to verify system integrity. At low volume it has been estimated that engineering, tooling and certification costs per model for dual fuel vehicle are about $15 million. Additional engine engineering costs for a dedicated CNG/LPG vehicle are estimated at $3 million. Expansion of special assembly facilities to accommodate a volume of 25,000 units per year is estimated to cost an additional $5 million for facilities.

Costs and vehicle attributes for CNG/LPG vehicles are shown in Table F-14. In addition, it is assumed that future CNG/LPG vehicles will be certified as ILEVs for emissions to meet Clean Fleet and California requirements. As before, the range of costs span the size range of vehicles from small cars to large trucks. At sales volumes of a few hundred units per year, only aftermarket conversions are expected to be available at approximately the same price is OEM products at a sales volume of 2500 units/year.

Future improvements to CNG/LPG vehicles will not differ from those for gasoline vehicles, with the sole of exception of VVT (Variable Valve Timing). Pumping losses in CNG/LPG engines are lower because of the air displacement effect of gaseous fuels. EEA estimates that VVT benefits will be reduced to half its gasoline benefit when used in conjunction with these fuels.

ELECTRIC, FUEL CELL AND HYBRID VEHICLES

These vehicles are a significant departure from conventional vehicles in that their drivetrain and fuel system is very different from a gasoline engine and its fuel tank/fuel system. The pricing analysis of these vehicles reflects the fact that there are no electric vehicles (EVs) or Hybrid Electric Vehicles (HEVs) in production and that data must be extrapolated from current prototypes and pre-production vehicle models. Fuel cell powered vehicles are still at least a decade or two away from commercialization.

Electric Vehicles

In the electric vehicle, the engine is replaced by an electric motor and controller, while the gasoline tank is replaced by a battery. EEA analysis for the OTA for an EV with a production volume of 25,000 units/yr revealed a range of attributes that depend on battery technology. Table F-15 provides the data for four vehicle classes for several different batteries for the year 2005, which is believed to be the earliest point where relatively high EV production volume can be realized. However, the table assumes that a relatively high technology body would be used.

Table F-14: Attributes of CNG/LPG Vehicles Relative to Gasoline Vehicles				
	CNG Bi-fuel	LPG Bi-fuel	CNG Dedicated	LPG Dedicated
Horsepower	-15	-8	-5	0
Range	-50	-20	-40	-15
Fuel Economy (BTU equivalent)	-0	-0	+8	+4
Incremental Price[7] @ 2,500 units/yr	4750/5350	3550/3950	4840/5440	3670/3860
@ 25,000 units/yr	1825/2225	1085/1175	1695/2100	920/985

Note that range is based on an assumed tank size that holds approximately half the gasoline energy equivalent for CNG vehicles and 80 percent of the gasoline energy equivalent for LPG. Other tank sizes could be incorporated at different costs.

EEA believes that the Lead Acid battery is potentially the only viable near term solution. Some analysts claim that the Nickel Metal Hydride battery (Ni-MH) can became cost competitive at $200/kwh relative to a lead-acid battery at $125/kwh by the year 2002, but others believe that the Ni-MH batteries are more likely to cost $400/kwh initially. A range of 80 to 100 miles is the best that can be considered in the entire time frame to 2015, given the steep increase in costs to obtain a 200 mile range. Beyond 2005, the Ni-MH battery could be dominant, although it is very speculative to make such a prediction. Of course, all EVs are zero emission vehicles.

Electric vehicles can be conversions of existing gasoline vehicles, but the conversion is rather extensive. Essentially, the entire drivetrain must be replaced, necessitating removal of the gasoline engine and transmission. In addition, the fuel tank must be removed, and the vehicle equipped with batteries. The EV motor/controllers and batteries have very different characteristics of weight and size relative to the components displaced in a conventional gasoline car, so that the repackaging of these components, especially the battery, requires significant engineering and design effort. The conversion process typically utilizes a vehicle built without any of the gasoline vehicle's drivetrain and fuel systems, and such vehicles are referred to as gliders.

7 Cars/Light Trucks.

Table F-16: EV Characteristics in 2005					
Battery (Scenario)	Range	Battery Weight (kg)	Total Weight (kg)	Energy Eff. (kwh/km)	Incr. Price (1994)
Subcompact					
Lead Acid (m)	80	612	1540	0.190	8,030
Ni-MH (m)	100	283	1010	0.116	13,575 (6631)*
Ni-MH (o)	200	823	1850	0.201	42,500
Na-S (o)	200	263	943	0.106	27,050
Intermediate					
Lead Acid (m)	80	830	2,031	0.250	10,900
Ni-MH (m)	100	370	1,335	0.153	17,900 (8835)[8]
Ni-MH (o)	200	1,075	2,430	0.265	55,675
Na-S (o)	200	343	1,250	0.141	35,500
Compact Van					
Lead Acid (m)	80	918	2,336	0.288	12,700
Ni-MH (m)	100	425	1,540	0.177	21,000 (10,600)*
Ni-MH (o)	200	1,234	2,800	0.305	64,400
Na-S (o)	200	394	1,440	0.162	41,220
Standard Pickup					
Lead Acid (m)	80	1,186	2,918	0.360	16,760
Ni-MH (m)	100	550	1,887	0.217	27,520 (14,070)*
Ni-MH (o)	200	1,598	3,527	0.384	83,820
Na-S (o)	200	510	1,764	0.199	53,800

Energy Efficiency is based on electrical consumption at wall plug. Price increment is relative to advanced conventional vehicle for the same scenario.

Purpose designed EVs have been displayed by some automanufacturers such as GM and BMW, but most industry analysts doubt that such vehicles will be produced at a production capacity level of less than 100,000 units/year because of the very high investment in the design, tooling and certification for a unique design. Indeed, GM officials have stated that they can never recover the $260 million invested in the design and engineering for the purpose-built "Impact" EV. Even at 100,000 units/year, media reports suggest that a purpose built EV would require investments similar to that for a conventional car (about $1 billion per model) but the incremental investment for a glider derived EV would be about one-tenth that amount.

[8] Price if Ni-mH battery can be manufactured at $200/kwh.

For electric vehicles derived from a glider, investment costs have had to estimated since none of the manufacturers provided this information. Approximate estimates from published magazine articles and other anecdotal information support an estimate of $50 million in engineering, tooling, certification and launch cost for a production capacity of 2,500 units per year. This investment increases to $80 million for 25,000 units per year and $100 million for 100,000 units/year, based on the media reports discussed, as well as anecdotal information from the automanufacturers. However, the major capital expense is the construction of a battery plant, which is not treated here, since the battery is a "variable cost" to the automanufacturer. In addition, the same battery type or model can be used across different vehicle series and different automanufacturers.

In the near term (certainly to 2000 and perhaps to 2005), EEA believes that the only realistic battery option is the Advanced Lead Acid Battery. EEA interviewed the only manufacturer (Horizon) of such a battery that is nearing commercial production, and obtained costs at low volume production (of approximately 5000 vehicle battery packs per year) and at high volume (50,000 per year). Horizon's estimates for the high volume production rate battery was for a future unspecified date and may involve economies of both scale and learning, since such a battery has never been produced before.

The post-2002 estimate assumes emergence of the Nickel Metal Hydride battery, and its attributes have been estimated from current prototype performance. Although there is considerable uncertainty about its costs, it is assumed that the resulting EV will be cost competitive with a 2010 lead-acid battery powered EV, given a learning cost reduction schedule for the lead-acid battery. Although it is not necessary to specify the battery under this assumption to derive IRPE, it is necessary to do so to derive the characteristics of the EV in terms of weight, size and performance. EVs will also benefit from future improvements to weight, drag and rolling resistance.

For the computer model, it is assumed that all EV production will be based on a "glider" derived from a conventional gasoline car. The weight of the glider with no electrical components is estimated at 54 percent of the weight of the gasoline car. For an EV with performance levels equivalent to a gasoline car, battery weight (W_{Batt}) is given by:

$$W_{Batt} = \left[\frac{0.1 \frac{R}{S_3}}{0.9 - 0.15 \frac{R}{S_E}} \right] \cdot W_{Glider}$$

where R is the EV range (in km), S_E is the battery specific energy in watt hours per kilogram, and W_{GLIDER} is glider weight in kg. An advanced lead acid battery has a specific energy of 40 wh/kg, while the Nickel Metal Hydride battery has an S_E of 72. These equations are used to estimate battery weight.

The IRPE of the EV at 25,000 units/year is estimated based on the assumption that the cost of the electric motor and electronic controller will offset the cost of the gasoline engine, fuel system and emission control system while the cost of the battery will be the most significant cost increment to the EV. In volume production, Lead Acid batteries are expected to cost (the automanufacturer) $125 per kwh or $5 per kg. The Nickel Metal Hydride battery is initially expected to cost $400 per kwh or $28.80 per kg. These costs apply in 1998, but Ni-MH batteries in 2002 should decrease to about $250 per kwh.

Costs are expected to go down significantly with experience, but the "learning curve" is difficult to quantify objectively. Costs are expected to decline by 25 percent per decade based on interviews with battery manufacturers so that, for example, lead-acid batteries will sell for $94 per kwh in 2008. The IRPE calculation amortizes the $80 million in fixed costs as per the formula in Table F-12. Costs at low sales volumes of 2,500 units/year have been calculated externally, and in general, it has been found that an offset of $10,000 in IRPE provides a reasonable representation of the low volume sales price relative to the calculated high volume sales price.

Fuel-Cell Vehicles

In a full cell vehicle, the fuel cell is similar to the EV battery in that it supplies motive power to the motors. The sizing of the fuel cell is based on the continuous power requirement of the vehicle, but all other factors will be quite similar to those for an EV. However, the present state of development of fuel cells is in its infancy, and considerable development is required before the fuel cell can be commercialized. Fuel cell powered vehicles are also zero emission vehicles.

PEM Fuel cells can use only hydrogen as fuel, and hence, hydrogen must be either carried on board in liquid form in a cryogenic tank, or manufactured on board with a methanol reformer. The DOE is researching the PEM fuel cell and reformer, and the costs and weights of these components are based on very aggressive targets set by DOE, not on current costs which are two orders of magnitude above the targets. The DOE targets may be appropriate for fuel cells in the 2020 time frame.

Calculations by EEA for OTA, based on DOE cost and performance targets, indicate that fuel cell vehicles of either type will have weights approximately similar to these of conventional gasoline vehicles, so that the FEM utilizes a short-cut approach to fuel cell IRPE determination. It starts with the finding that weights are similar to derive the required power output of a fuel cell, which is 30 kw per ton of vehicle weight. Peak output requirements are assumed to be met by a high power lead acid battery with peak power capacity of 2/3 of the fuel cell output, and a specific power capability of 500 w/kg.

Costs are based on these power output estimates and it is assumed that fuel cells will be initially available at the cost of $450 per kw with a methanol reformer costing an additional $200 per kw in 2003. The costs are one order of magnitude higher than DOE targets but may be representative of prices that can be achieved in the short-term. The cost of a cryogenic hydrogen tank is estimated at about $3000, with only a weak dependence on size, at a sales volume of 25,000 unit/year. Costs of batteries are computed using the same methodology used to calculate EV battery costs.

Fixed cost amortization and low volume cost increases are assumed to be identical to those derived for EVs. However, the learning curve is expected to be very steep so that fuel cell/reformer costs decline 14 percent per year, to reach DOE targets by 2020. Fuel economy calculations are based on the details developed the OTA report, and are simply weight based for the purposes of the FEM.

Electric Hybrid Vehicles

Electric Hybrid Vehicles feature both an engine and an electric motor as part of the drivetrain, but there can be a wide variety of designs that allow for large variations in the relative sizes of the electric motor, i.c. engine, and electric storage capacity. Hybrids are often classified as series or parallel, and also as charge depleting or charge sustaining. Even within these four categories, manufacturers disagree about the optimal relative size of the engine versus the electric motor. Due to these uncertainties, EEA has selected one promising approach which is a series, charge sustaining hybrid, with an engine sized to be able to produce the continuous power requirement of 30 kilowatts per ton of loaded vehicle weight, as an example for determining the IRPE.

Since the calculations to derive hybrid vehicle characteristics are relatively complex, a reduced form based on EEA's work for OTA has been used. Most of the costs of the vehicles scale in approximate proportion to vehicle weight, so that the gasoline vehicle weight is used as an indicator, and the calculated midsized hybrid vehicle costs and fuel economy are used as a reference point for scaling. The IRPE of hybrid vehicles are scaled based on an expected midsized vehicle IRPE of $4400 in 2002 under a production rate of 25,000 units/year. A learning curve reduces these costs at 25 percent per decade, while low volume production at 2,500 units/year imposes an IRPE penalty of $10,000.

Series hybrid vehicles are expected to have 30 percent better composite fuel economy than current conventional gasoline cars. However, future engine improvements to reduce pumping loss and drivetrain improvements are not applicable to such vehicles, due to the electric drivetrain used. Emissions of these vehicles are expected to conform to California ULEV regulations, much like CNG vehicle emissions.

Attachment 2: Alternative Fuel Vehicle Model

Data Input Sources and Extrapolation Methodology

INTRODUCTION

This Attachment documents the AFV database used in the National Energy Modeling System Transportation Sector Model. The database includes the present values and forecast methodologies of six attributes for three classes of light-duty vehicles. These attributes apply to sixteen vehicle-technology types and three scenarios for nine regions of the United States.

DEFINITIONS

The vehicle classes are:

1. Small light-duty
2. Medium light-duty
3. Large light-duty

The attributes are:

1. Purchase price (1990$, including the NPV of periodic battery and fuel cell replacements)
2. Fuel Operating Cost (1990$/MMBtu)
3. Fuel Availability (Fraction of stations)
4. Vehicle Efficiency (Miles/MMBtu)
5. Emissions (impact-weighted index to gasoline in each year)
6. Vehicle Range (miles between refueling)

The vehicle-technology types are:

1. Gasoline
2. Methanol Flex
3. Methanol Neat
4. Ethanol Flex
5. Ethanol Neat
6. CNG
7. LPG
8. Electric
9. Electric Hybrid - Large ICE
10. Electric Hybrid - Small ICE
11. Electric Hybrid Gas Turbine
12. Gas Turbine Gasoline
13. Gas Turbine CNG
14. Fuel Cell Methanol
15. Fuel Cell Hydrogen
16. Diesel

OTHER TECHNOLOGIES

There are two limitations in the database in terms of other technologies. The technologies that could have been included in the database but were not are:

- hydrogen i.c.e.-- near-conventional engines that burn hydrogen as opposed to electrochemical generation of power in fuel cells (as was considered in the database). Hydrogen-burning engines have been manufactured for some time and outperform gasoline engines in terms of emissions. As with fuel cells, their main drawback is fuel price, as tremendous amounts of energy are needed for the production of hydrogen from water.

- hydrogen-CNG mix (hythane)-- also burned in i.c.e.'s and already in use. Offers great advantages in terms of emissions at a more reasonable price than pure hydrogen.

The technologies in the database that are misspecified are:

- Fuel cells/hydrogen & methanol-- at this early stage of development it would be more practical to consider these two as one technology. Each rely on essentially the same power train and electrochemical energy conversion technology, the only difference being the way the fuel is stored. Hydrogen is extremely unwieldy due to its low mass, which means that to fit in a fuel tank of manageable size it must be liquified or bonded to other substances. Methanol, with its high hydrogen content, falls within the latter category as the hydrogen in it is the only participant in the electrochemical conversion.

APPROACH

The approach to the database development is as follows:

1. Identify data sources in the open literature and through industry contacts.

2. Obtain the data and organize it for use in the database.

3. Define and design the database to characterize the data usefully.

FORECASTING METHOD

The data base is provided in a spreadsheet format. The basic forecasting method is to identify current values for fuel prices, vehicle prices, fuel availability, etc. and one or more forecast values. The current data are entered in the 1990 column of cells for each attribute and extrapolated exponentially to and through the other data points. (In some cases, the 1990 values are assigned so that the curve fit through the 1992 values is based on 1992 actual data.) Each of the eight sections for vehicle attributes contains a detailed log of relationships and data sources.

DATABASE LIMITATIONS

Three main types of limitations apply to the database and to its usage within a transportation choice model. They are discussed below.

GENERAL DATA AND MODELING ISSUES

- Model and data do not distinguish fleet and non-fleet users. Fleet criteria include the availability of a central station, set and known use patterns, large cargo requirements (taxi, delivery, etc.), longer permissible refueling times, and limited luxury features. Non-fleet users need public stations, much longer range, luggage space, luxury features, better performance, and higher reliability. These markets are on different legislative paths and ATF adoption schedules. They cannot be mixed and cannot be modeled using the Bunch approach.

- Model and data do not recognize non-economic forces currently distorting markets. In 1991, SAIC contacted the owners of every CNG vehicle refueling station in the country. We found that the number and use of CNG vehicles is exaggerated by about 200% and that current usage patterns and interests by non-utility users are biased by artificially low-cost CNG (e.g., no compression costs). Moreover, many of the public refueling stations have very limited refueling capability. These stations are operated mostly as demonstrations rather than as commercial stations. A similar deficiency exists at the LPG outlets, most of which are not equipped to refuel vehicles. The

Bunch approach, which is geared to open-market, non-fleet purchase decisions, requires an accurate and economic (i.e., non-interventionist) baseline tied specifically to private vehicles. This baseline does not exist.

- Model specifies six decision variables cited in Bunch. SAIC work suggests that actual technology choice depends on additional variables. The following variables omitted from the model significantly affect consumer choice: reliability, maintenance cost, certainty of maintenance availability, salvage or resale value, performance, utility (trunk space in CNG vehicles, A/C in electric vehicles, etc.), safety issues (real or perceived), ease of refueling, and refueling time. A few of these omitted variables appear in other work by the Transportation Modeling committee but were not requested of SAIC. The omission of these variables is highly significant when large differences exist but are not well-understood by survey participants (e.g., 5-minute refueling for gasoline vs. 8-hour refueling for electric).

MACROECONOMIC ISSUES

The database model is generally optimistic about the current rate of technological progress and innovation and assumes it will continue to grow progressively faster. Limitations in the database suggest that these forecasts may be overly optimistic in a macroeconomic sense.

- Diversion of Resources — the diversion of government and private sector resources toward alternative investments is not considered, i.e., large sums could go into infrastructure and mass transportation systems that are more efficient than any passenger vehicle alternative.

- Institutional Barriers — the created interests of significant economic or political actors, or groups of actors, could override market considerations for the benefit or detriment of any alternative technology or fuel.

- Environmental Barriers — one or more AFVs may receive significant opposition or backing purely for its environmental impact; moreover, public opinion as well as the environmental movement's preferences may shift in the near future, i.e., the environmental movement currently supports methanol-fueled vehicles, but that could change if a cleaner way to produce hydrogen for hydrogen-burning vehicles was found.

- Psychological Barriers — acceptance by the public is also a function of misperceptions and psychological factors, e.g., CNG, LNG, LPG and hydrogen may be perceived as dangerous to handle and thus avoided even if their safety records are objectively similar to that of gasoline.

- Information Barriers — accurate data do not exist for most of the exotic vehicle-fuel combinations (fuel cells, hybrid electric, etc.). Also cost and performance estimates for many of the emerging alternatives, especially electric vehicles, differ by a factor of 2-10 from source to source. In many cases, there is no clear basis for distinguishing among such inconsistencies.

DESCRIPTION OF VEHICLE TECHNOLOGIES

The AFV module currently analyzes 15 alternative-fuel technologies against a single conventional gasoline powered vehicle[9] in the spreadsheet analysis. Additional conventional and non-conventional technologies can be added to the analysis; however, for simplicity, conventional technologies are represented as a single category. This section of the report describes the characteristics of the alternative-fuel technologies as well as the criteria used in selection of alternative fuel-vehicle types.

[9]. This study assumes all gasoline powered internal combustion engines under a single technology category even though there is significant variation within gasoline fueled engines.

Four primary technology selection criteria are employed for this study. The four criteria are the following:

- Vehicle operates utilizing a non-gasoline fuel or a significantly new engine technology.
- Technology holds the potential to penetrate the light-duty vehicle market by the year 2030.
- Technology possesses distinct fuel use, performance and/or cost characteristics relative to all other technologies considered.
- Data is available on important attributes for the vehicle technology.

Variations within each technology class based on vehicle subclass are not being analyzed as a distinct category but are incorporated into the collective category for the technology[10]. Future work in estimating market share growth for alternative-fuel technology may breakdown technology classes by engine and combustion technology; however, the complexity of such an analysis is unwarranted at the present time.

This study has identified 15 alternative-fuel technologies which have met the four criteria previously stated. Conventional gasoline technology has been grouped into one single category using average vehicle attributes taken across all conventional vehicles. Following is a list of the sixteen vehicle technologies incorporated in this study. The advantages and disadvantages of each of the individual technologies will be briefly described in the following sections.

Gasoline Internal Combustion Engine Vehicles

Presently, the vast majority of transportation vehicles utilize an internal combustion engine (ICE) which was first patented in 1876 by Nikolaus Otto. The ICE is a heat driven engine which operates by mixing air and fuel vapor together, compressing the fuel mix in a cylinder, and igniting the fuel mix by means of an electric spark. The ignited fuel mix pushes a piston which in turn drives the vehicle[11]. Since the invention of the internal combustion engine the primary power source has been

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[10] Significant variations exist in the gasoline powered technology such as fuel injected engines versus carbureting engines; however, for simplicity all technologies utilizing a single fuel mix will be categorized together.

[11] Glasstone, S., *Energy Deskbook*, Van Nostrand Reinhold Company, New York, 1983, pp. 364-368.

gasoline, although, many other fuels such as alcohols, natural gas and diesel can be utilized. It is speculated that if the discoveries of enormous petroleum deposits in Texas had not occurred during the early development years, the automobile would have developed as an alcohol vehicle rather than gasoline.

One of the primary advantages of conventional ICE vehicles is that economically these vehicles are inexpensive to operate due to the large development and refining infrastructure established for petroleum products. An abundance of petroleum deposits occur throughout the world and transportation of petroleum is not difficult in comparison to methanol and natural gas.

The conventional gasoline ICE vehicles are more harmful to the environment than the majority of alternative-fuel vehicles. Environmental concerns is one of the leading incentives for the development of alternative-fuel vehicles due to the problems associated with greenhouse gasses and urban ozone formation problems.

Diesel Vehicles

The diesel engine, like the gasoline engine, is an internal combustion engine which is heat driven from the ignition of diesel fuel in the cylinder which in turn drives the pistons. Unlike the gasoline ICE, a spark plug is not used to ignite the fuel mix but rather the combination of the compression and heat of the cylinder causes ignition of the fuel mix.

Ethanol Vehicles

Ethanol is a fuel which is currently being used to supply ethanol powered vehicles in a ratio of approximately 85 percent ethanol to 15 percent gasoline as well as a gasoline supply extender for conventional gasoline powered engines in a ratio of approximately 5 percent ethanol and 95 percent gasoline. This study is considering only ethanol vehicles (vehicles using the 85/15 percent mix) as a category separate from conventional vehicles. Two technology categories exist under the ethanol fuel heading. Ethanol Neat Vehicles which use only ethanol fuel and Ethanol Flex Vehicles which have the ability to switch between gasoline and ethanol fuels.

Ethanol can be produced from food sources such as corn and sugar cane or from non-food biomass such as trees, grass, waste paper, and cardboard. Presently, approximately 95 percent of ethanol fuel being produced in the United States comes from corn. Neat ethanol engines are expected to produce a 30 percent increase in efficiency over conventional gasoline engines; however, ethanol fuel has a lower energy content of only 67 percent of gasoline. A variation in cost estimates for ethanol fuel production exist depending on the source material and the distillation process. The EPA estimates that the "gasoline equivalent" ethanol price using corn stock is between $1.47 and $2.07 per gallon[12].

Ethanol fuel provides several important environmental benefits over gasoline in both the consumption and production stages. Ethanol is produced from a renewable energy source such as corn or sugar cane, where as petroleum is a non-renewable energy source which could be depleted in the future. Ethanol fueled vehicles emit a lower amount of carbon dioxide, nitrogen oxide and hydrocarbons than gasoline[13]. The Environmental Protection Agency estimates that carbon dioxide emissions, the major component of "greenhouse gases", are reduced to zero using ethanol produced from corn or sugar cane when considering the carbon reabsorption factor of corn during the growing stage[14].

Methanol Vehicles

Methanol fuel is similar in some respects to ethanol since it also is used as a gasoline extender in conventional gasoline engines and as a fuel in methanol engines. Presently methanol is mixed with gasoline in an 85 percent methanol/ 15 percent gasoline (M85) ratio and is consumed in a methanol engine. Two technologies exist for this analysis under the methanol heading; Methanol Neat which

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[12] Environmental Protection Agency, *Analysis of the Economic and Environmental Effects of Ethanol as an Automobile Fuel*, April, 1990, pp. 15-22.

[13] The Gas Research Institute, The Energy Information Administration, and Science Applications International Corporation, *Identification and Analysis of Factors Affecting the Adoption of Alternative Transportation Fuels*, 1991, pp. 20-21.

[14] Environmental Protection Agency, *Analysis of the Economic and Environmental Effects of Ethanol as an Automobile Fuel*, April, 1990, pp. 49-50.

operates on M85 and Methanol Flex which has the ability to switch between M85 and gasoline depending on economic and availability factors.

Currently natural gas is the primary source of methanol although other materials such as coal, biomass and cellulose can be used. Methanol allows countries with excess natural gas supplies to export fuel without the expense of pipelines and LNG process. It is estimated that the wholesale price of methanol produced from natural gas is approximately $.40/gallon. However, because methanol has only about one half of the energy per gallon of gasoline, the cost per gasoline equivalent gallon is estimated at $.75[15].

Environmental advantages of methanol fueled vehicles are reductions in ozone formation, volatile organic compounds (VOC) and "greenhouse gas" emissions[16]. Ozone formation is a significant problem in urban areas linked to the emission of gasoline vehicles. Methanol emissions produce a lower photochemical reactivity than gasoline emissions; therefore, reducing the urban ozone formation problem. It is estimated that methanol vehicles emit 80 percent less VOC emissions than gasoline vehicles. Methanol vehicles emit increased volumes of formaldehyde and methanol gas which can be harmful in concentrated amounts. Further research is being conducted on the health risks associated with methanol and formaldehyde emissions.

Electric Vehicles

Extensive alternative fuel vehicle research is now being done to improve electric vehicle performance. The primary obstacle of electric car development is battery technology. Various automobile manufacturers and research groups are concentrating on improving battery capabilities; however, at the present time battery technology limits electric vehicle range and performance attributes. For this reason electric vehicle motors have been combined with other conventional and

[15] The Gas Research Institute, The Energy Information Administration, and Science Applications International Corporation, *Identification and Analysis of Factors Affecting the Adoption of Alternative Transportation Fuels*, 1991, p. 28.

[16] Energy Protection Agency, *Analysis of the Economic and Environmental Effects of Methanol as an Automobile Fuel*, April, 1990, pp. 15-18.

non-conventional technologies in order to enhance vehicle performance. Technologies combined with electric motors include the internal combustion engine and gas turbine engine. This study will consider four technologies under the electric vehicle heading; electric, electric hybrid, electric hybrid/small ICE, and electric hybrid/gas turbine.

The primary advantage of electric-powered vehicles is that they produce virtually no direct emissions at the point of consumption. Direct emissions produced by electric vehicles are largely hydrogen emissions released during the battery recharging stage. Although hydrogen is an explosive emission in high concentration, hydrogen poses no problem to atmospheric air pollution[17]. While electric vehicles produce almost no direct emissions there are emissions associated with the electricity production stage depending on the power source of the electricity generation. Centralized power plants located away from urban centers eliminate urban ozone formation problems and can effectively control emissions associated with fossil fuel consumption. Electric motors have the advantage over internal combustion engines (ICE) because electric motors do not idle when the motion is stopped as ICEs do thus eliminating the idling power loss which can be significant in urban transportation settings.

Considering present electricity prices, exclusive electric vehicles as an alternative to gasoline vehicles are not as cost effective as ethanol, methanol, and natural gas vehicles. Even though electricity as a transportation fuel delivers 50 percent more miles per Btu than other fuels, the current price of electricity makes electric fuel transportation notably more expensive than conventional vehicles[18].

Compressed Natural Gas/Liquid Petroleum Gas Vehicles

Compressed Natural Gas (CNG) and Liquid Petroleum Gas (LPG) vehicles are grouped together in this summary because the engine technology is similar for the two vehicles utilizing different fuel sources. CNG vehicles have been in use for several decades in the United States while in other parts

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[17] The Gas Research Institute, The Energy Information Administration, and Science Applications International Corporation, *Identification and Analysis of Factors Affecting the Adoption of Alternative Transportation Fuels*, 1991, p. 21.

[18] Ibid, p.30.

of the world they have been in operation since the 1930's[19]. The largest application of CNG vehicles has been in heavy-duty fleet vehicles because of the bulky natural gas storage tanks.

The CNG/LPG technology consists of a modified internal combustion engine connected to the fuel source in a closed system[20]. Because the fuel supply is in a gaseous state the entire storage engine system must be a closed system which eliminates the emissions problem of evaporating fuel during storage and refueling. The CNG/LPG engine produces higher thermal efficiencies than conventional gasoline engines; however, because of the additional weight involved with the fuel storage tanks the additional energy efficiencies are almost negated[21]. However; presently it is reported that natural gas vehicle operation is less expensive than conventional gasoline vehicles. A survey of gas utilities taken by the Gas Research Institute indicated that the CNG price per gallon-equivalent of gasoline is $.85-$1.10. GRI reports that it's analysis indicates that CNG prices including compression costs and fuel taxes are 13 percent lower than gasoline cost for conventional vehicles[22].

Compressed natural gas and liquid petroleum gas vehicles are considered clean fuel vehicles because the fuel burns cleaner than conventional gasoline vehicles. Natural gas vehicles do not emit ozone formation emissions, however, these vehicles do emit a high amount of NO_x and methane which is an important contributor to greenhouse gases.

Gas Turbine Vehicles

Gas turbine engines have been in existence for several decades and presently have several significant applications such as aircraft engines and electricity generation. Gas turbine technology is a

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[19] Environmental Protection Agency, *Analysis of the Economic and Environmental Effects of Compressed Natural Gas as a Vehicle Fuel*, Volume II Heavy-Duty Vehicles, April 1990, pp. 1-2.4.

[20] Energy Information Administration, *Energy Consumption and Conservation Potential: Supporting Analysis for National Energy Strategy*, December 21, 1990, pp. 90-91.

[21] Energy Information Administration, *Energy Consumption and Conservation Potential: Supporting Analysis for National Energy Strategy*, December 21, 1990, pp. 90-91.

[22] The Gas Research Institute, The Energy Information Administration, and Science Applications International Corporation, *Identification and Analysis of Factors Affecting the Adoption of Alternative Transportation Fuels*, 1991, p. 29.

significant variation from ICE technology. A gas turbine engine consists of three principle components; a compressor which compresses outside air to be mixed with fuel, a combustion chamber where the compressed air and fuel are ignited, and turbine which is turned by the exhaust of the ignited fuel mix[23].

Gas turbine vehicles potentially could be up to 50 percent more efficient than conventional internal combustion engine vehicles[24]. The increased efficiency is due to the fact that a turbine engine utilizes a larger percentage of the work being performed by the fuel than ICE's. Small turbine engines suitable for use in transportation vehicles are not being produced now on a large scale; therefore, the current cost of turbine engines are prohibitive for vehicle use.

Gas turbine engines could be designed to burn different fuels ranging from alcohols to diesel fuel. This study will consider two technologies under the gas turbine engine, compressed natural gas and conventional gasoline.

Fuel Cell Vehicles

The concept of fuel cells as a power source for transportation vehicles is similar to electric vehicle technology because an electric current powers a motor which drives the vehicle. The difference is that an electric vehicle runs off of a battery which is recharged periodically while a fuel cell is charged by a separate power source such as methanol or hydrogen. The first large scale applications of fuel cell technology were the Apollo and Gemini space missions which sparked interest in fuel cell technology in vehicle transportation.

Fuel cell technology has the advantage of higher conversion efficiency from the fuel source into electricity than a combustion engine. A large portion of the energy derived in a heat driven internal combustion engine is lost in the form of external heat which does not occur in the fuel cell

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[23] Glasstone, S. *Energy Deskbook*, Van Nostrand Reinhold Company, New York, 1983, pp. 152-156.

[24] Energy Information Administration, *Energy Consumption and Conservation Potential: Supporting Analysis for National Energy Strategy*, December 21, 1990, pp. 90-91.

technology. Fuel cell technology remains in the development stage and cost projections of transportation vehicles are extremely high. Further research may lower the costs of fuel cell technology; however, for now fuel cell technology seems unrealistic for large scale adoption.

VEHICLE PRICES

This section documents vehicle purchase prices in the database. The output of the database is a vehicle price for sixteen technologies for three vehicle sizes and three penetration scenarios, from 1990 through 2030, in thousands of 1990 dollars.

The general approach is to establish current and ultimate price premia for AFV's (alternative fuel vehicles) over the price of a gasoline I.C.E. (internal combustion engine) vehicle, and to use an exponential decay function (expressed as a compound percentage decline rate) to project each price premium towards its ultimate value. The shape of the curve implied by the price decay is based on forecasted future price levels or SAIC's judgment where no data are available. A non-fuel escalation rate was used to establish future prices of gasoline vehicles for each of three vehicle sizes (small, medium, and large)[25] through the year 2030.

Vehicle prices were obtained from the following inputs:

- Current price of gasoline vehicles by size (S, M, L).
- Current price premia for 15 other vehicle types independent of size (i.e., fuel-related premium or discount to base gasoline vehicle).

[25] Size categories are defined primarily by weight, and secondarily by passenger cabin volume. These definitions are consistent with usage in all of the literature, and in terms of weight are: below 2600 lbs for small vehicles, between 2600 and 3200 lbs for mid size, and above 3200 for large.

- Ultimate long-run price premia for 15 other vehicle types independent of size.

- Non-fuel escalation rate independent of vehicle type.

- Annual, compound percentage decline in current premium towards ultimate premium, or premium decay, for 15 vehicle types for three scenarios (B, H, L).

The approach has the following advantages:

- Projected AFV prices should be relatively consistent vis a vis conventional gasoline and other AFV prices.

- Incorporating the price of gasoline vehicles into AFV prices ensures that the non-fuel escalation rate is taken into account for all technologies.

- Updating and revising figures based on future developments are facilitated.

CURRENT VEHICLE PRICES

Determining current vehicle prices required two steps: finding the price for gasoline vehicles of three sizes (small, medium, and large), and obtaining current AFV purchase prices by adding a premium to the gasoline vehicle price for each technology.

GASOLINE VEHICLE PRICES

Prices for gasoline vehicles were established by averaging the prices of three representative vehicles for each size category. The vehicles were selected on the basis of market share[26]. All prices are

[26] Market share source: NADA, August 1992, p.32.

manufacturer's suggested retail prices obtained from the National Automobile Dealers Association (NADA) used vehicle price guide. Table F-17 below provides detailed information on the selected gasoline vehicles.

Table F-17. Gasoline Vehicle Characteristics (1990)

SIZE	VEHICLE MAKE, MODEL, BODY & STYLE	PRICE (1990 $)	WEIGHT (LBS)
LARGE	Ford Ltd Crown Victoria V8/ 4D Sedan	$17,257	3821 lbs
	Cadillac DeVille/ 4D Sedan	$27,540	3546 lbs
	Dodge B250/ Van	$12,575	NA
MID-SIZE	Beretta Corsica/ 2D coupe GT2	$13,750	2839 lbs
	Ford Taurus/ 4D sedan, GL	$13,834	3089 lbs
	Honda Accord/ 4D sedan LX	$14,895	2857 lbs
SMALL	Honda Civic/ 3D hatchback DX	$8695	2165 lbs
	Chevrolet Cavalier L4/ 4D sedan	$8820	2471 lbs
	Ford Escort/ 2D hatchback LX	$7806	c2312 lbs

Sources for price and weight:

Large:	(NADA, July-August, 1992, ps.23, 75, 271)
Mid-sized:	(NADA, July-August, 1992, ps.29, 74, 174)
Small:	(NADA, July-August, 1992, ps.29, 73, 173)

CURRENT PRICE PREMIA FOR AFV'S

Current price premia are the premia paid in the market today over conventional gasoline vehicle prices for each technology in the database. All current AFV prices are calculated by adding these premia to the current gasoline vehicle price values for each category. The premia are added to the current gasoline vehicle price to obtain the current AFV prices for each vehicle size, type, or scenario. All premia and SAIC's assumptions, rationales, and comments for each technology are provided below. Each entry also contains the citations consulted by SAIC; abbreviations are more fully defined at the end of this report.

- **Diesel — $1000.** Average premia for representative diesel passenger vehicles; figure was slightly higher in the past.
  Sources: (NADA, July-August, 1992 & SAIC).

- **Ethanol Flex — $4,500.** Figure was set at the upper end of the range in the literature because of recent DOE data that places a much higher premium on flexible fuel vehicles.
  Sources: FFV range $2000-5000 (Cogan, August 1992, p.94); average of $6,400 for DOE AFV's (including ethanol, methanol and CNG) procured in 1990 (G.A.O, May 1991, p.20).

- **Ethanol Neat — $2000.** As is the case with ethanol flex, estimate is at the upper end of the range to make it more consistent with recent DOE data.
  Sources: $300-2000 (Cogan, August 1992, p.94), DOE AFV's data (G.A.O., May 1991, p.20).

- **Methanol Flex — $4,700.** Premium is equal to that of ethanol flex plus $200 for higher manufacturing costs due the corrosive nature of the fuel, i.e., stainless steel or specially treated materials are needed for the engine. Figure is consistent with the literature consensus and recent DOE data.
  Sources: Fully optimized vehicle not engineered yet (CRS, 1989, p.17); higher corrosiveness (Rouse, 1991).

- **Methanol Neat — $2,200.** Premium is equal to that of ethanol neat plus $200 for higher manufacturing costs due the corrosive nature of the fuel, i.e., stainless steel or specially treated materials are needed for the engine. Figure is consistent with the literature consensus and recent DOE data.
  Sources: $2000 1992 Ford econoline van (NREL, 1992); FFV range $2000-5000 (Cogan, August 1992, p.94); average of $6,400 for DOE AFV's (includes ethanol, methanol and CNG) procured in 1990 (G.A.O, May 1991, p.20); $210-340 by 1995 (D.O.E., August 1990, p.ix); higher corrosiveness (Rouse, 1991).

- **Electric — $45,000.** This figure includes an estimate of the net present value of battery replacements. It is consistent with most recent sources and manufacturer-quoted prices of soon-to-be released vehicles.
  Sources: 1989 GM G vans priced at $32,500 in 1989 (SAIC/report, 1991, p.25); 1993 Ford small van priced at $100,000 (NREL, 1992, on-line); batteries premium $6,000 by 1995; 1993 GM Impact production cost range $15-20,000 (O.T.A., 1990, p.119); GM Impact price range $20,000-30,000 (Woodruff, 1991, p.58); batteries premium $2,600-8,200 for advanced lead-acid battery (ICAMF, 1990, 1.16); Fiat Electra priced

at $22,000 or twice the price of its I.C.E. twin (Woodruff, 1991, p.57); current battery price $1,500, replaced every 20,000 miles (Woodruff, 1991, p.58).

- **Electric Hybrid/Large I.C.E. — $50,000.** Figure includes the price of a regular electric vehicle (EV) plus a premium for the large I.C.E. The premium accounts for the fact that two engines would be costly and inefficient in terms of maintenance and use of space. A large I.C.E. acts as a range extender in the same way as a conventional gasoline I.C.E. The difference in price between a small and large I.C.E. is deemed to be insignificant at any stage. The figure is consistent with manufacturer prices of soon-to-be released vehicles and the consensus of the literature.
  Sources:1993 Ford small hybrid van priced at $100,000 (NREL, 1992, on-line); high cost of adding batteries and electric motors to the engine of an I.C.E. (Woodruff, 1991, p.59).

- **Electric Hybrid/Small I.C.E. — $50,000.** See Electric Hybrid/Large I.C.E. above. A small I.C.E. only serves as a generator to recharge the batteries for the electric engine to operate. The difference in price between a small and large I.C.E. is insignificant at any stage.
  Sources:1993 Ford small hybrid van priced at $100,000 (NREL, 1992, on-line); high cost of adding batteries and electric motors to the engine of an I.C.E. (Woodruff, 1991, p.59).

- **Electric Hybrid/Turbine — $125,000.** Figure includes the price of an electric hybrid/I.C.E. plus a high premium that reflects the absence of a viable prototype at this time. Gas turbine vehicles were manufactured in the fifties without success due to lack of competitively-priced, heat-resistant materials; however, new developments may solve such obstacles and a prototype vehicle may be successfully produced by 1998.

  Source: (The Economist, September 28, 1991).

- **CNG — $2,750.** Although some economies of scale are already present, all CNG vehicles are essentially retrofitted rather than optimized, therefore a significant premium (and potential for improvement) remains. The selected figure is consistent with the middle to the higher end of the 1992 literature ranges.
  Sources: Range of $2000-5000 (Cogan, August 1992, p.94); 1992 Chrysler Dodge B-Series Van Wagon $5000 (NREL, 1992, on-line); $2,550-3,250 (EPA, 1990, p.10);

$2550-3250 for light-duty automobile (large), $1650-2250 (small-medium), $2350-3050 light duty truck; mass-produced dual-fuel $1600 (ICAMF, 1990, p.5.7); average of $6,400 for DOE AFV's (includes ethanol, methanol and CNG) procured in 1990 (G.A.O, May 1991, p.20); $800 by 1995 (D.O.E., August 1990, p.ix).

- **LPG — $1,500.** Although some economies of scale are already present, all LPG vehicles are essentially retrofitted rather than optimized, therefore a significant premium (and potential for improvement) remains. The selected figure is consistent with the middle to the higher end of the 1992 literature ranges.
  Sources: $1,200-2,200, (ICAMF, 1990, p.1.15.); 1992 Ford F-700 medium duty truck conversion option at $800 (NREL, 1992, on-line).

- **Turbine/Gasoline — $125,000.** Figure includes a high premium that reflects the absence of a viable prototype at this time. Gas turbine vehicles were manufactured in the fifties without success due to lack of competitively-priced, heat-resistant materials; however, new developments may solve such obstacles and a prototype vehicle may be successfully produced by 1998. The figure is consistent with the electric hybrid/turbine vehicle premium. No significant estimated price differential between CNG and gasoline technologies at this time.
  Source: (The Economist, September 28, 1991).

- **Turbine/CNG — $125,000.** See Turbine/Gasoline above. No significant estimated price differential between CNG and gasoline technologies at this time.
  Source: (The Economist, September 28, 1991).

- **Fuel Cell/Hydrogen — $150,000.** Figure includes a high premium for fuel cells because they are far more expensive than conventional batteries; there is also a premium included for fuel storage. Production prices in the literature diverge widely. Both hydrogen and methanol technologies rely on hydrogen for their electrochemical reactions and differ only in the way it is stored, i.e., as a component of methanol, or independently; therefore, no significant difference between them exists at this stage. Hydrogen-burning (as opposed to fuel cell) vehicles are far more feasible and less costly at this time.
  Sources: Fuel cells cost and premium for fuel storage (McCosh, 1992, p.29); 1995 prototype's price: drive system and engine $225,000, plus a fuel storage tank with a price range of $2,253 to $7,709, for a subtotal of $225,203 to $232,659 not including

chassis (C.E.C., June 1991, pp.25-30).

Hydrogen I.C.E. Sources: feasibility; prototypes in Japan, i.e., Nissan's joint effort with Musashi Institute of Technology (Maruyama, 1991); Mazda hopes to sell a few hydrogen-burning cars in California within ten years; current models are not optimized; premium for hydrogen tank is $26,000 (Templeman, 1991, p.59).

- **Fuel Cell/Methanol — $150,000.** See Fuel Cell/Hydrogen above. Both hydrogen and methanol technologies rely on hydrogen for their electrochemical reactions and differ only in the way it is stored, i.e., as a component of methanol, or independently; therefore, no significant difference between them exists at this stage.
  Sources: See Fuel Cell/Hydrogen.

FUTURE VEHICLE PRICES

Ultimate price premia are defined as the minimum future price differentials between gasoline and ATF vehicles. An extensive literature search and SAIC's own resources yielded forecast future prices, which were used to set ultimate price premia and the approximate expected year they will be reached. All ATF vehicle prices falling between the ultimate and the current price premia are calculated by using the price premia decay rate described in the subsequent section.

FUTURE GASOLINE VEHICLE PRICES

For all gasoline models, the prices beyond 1992 escalated at 2% per year. Non-fuel escalation factors include:

- The historical tendency of options to become standard equipment through time.

- Progressively higher additional costs for emissions controls and efficiency requirements. These are estimated to be $70 for a TLEV and $170 for LEV/ULEV (CARB, August 1990, p.IX.13).

- Increased investment in more efficient, lighter engines such as the 2-stoke engine (The Economist, September 28, 1991) and higher cost super-light body materials such as carbon composites (GM, 1992, pp.14,15).

DEVELOPMENT OF ULTIMATE PRICE PREMIA

Minimum price differentials are reached once all criteria for improvement relative to conventional prices have been met. The criteria include the maximization of well-known economic principles such as economies of scale, returns to scale, and learning curves. The future year and value assigned to AFV premia were found by applying the above criteria to the current status of the technology, the short-term and future projected gains, and relevant theoretical limitations.

Once values for ultimate cost and associated year were calculated, the premia were added to the corresponding year's conventional gasoline price. After an AFV has reached its ultimate premium, price differentials between that AFV and a conventional vehicle remain constant except for non-fuel escalation. Assumptions, rationales and comments for each technology are provided below.

- **Diesel — $1,000.** Average premia for representative diesel passenger vehicles; figure was slightly higher in the past, but is not expected to decline further.
  Sources: (NADA, July-August, 1992 & SAIC).

- **Ethanol Flex — $0.** Near-zero ultimate price premium assumes economies of scale and optimization achieved prior to switch to ethanol neat vehicles. Figure consistent with EPA and most recent literature.
  Source: (EPA/ethanol, 1990, Appendix C, p.2).

- **Ethanol Neat — $0.** Near-zero ultimate price premium assumes economies of scale and optimization of both ethanol types. Prior development of flex vehicle would provide learning curve feedback. Figure consistent with EPA and most recent literature.
  Source: (EPA/ethanol, 1990, Appendix C, p.2).

- **Methanol Flex — $200.** Premium is equal to that of ethanol flex plus $200 for higher manufacturing costs due the corrosive nature of the fuel, i.e., stainless steel or specially treated materials are needed for the engine.
  Sources: Premia for corrosion-resistant materials, fuel sensing and control systems, and larger fuel tank for a total range of $150-500 in the late nineties, down to near-zero premium after that (CRS,1989,p.17); $150-300 at high volume production (EPA, April

1990, p.35); $300 with large scale production (ICAMF, 1990, p.1.14).

- **Methanol Flex — $100.** Premium is equal to that of ethanol neat plus $100 for higher manufacturing costs due the corrosive nature of the fuel, i.e., stainless steel or specially treated materials are needed for the engine. Such a premium would be smaller for a dedicated neat vehicle due to greater economies of scale, optimization, and transfer of knowledge from flexible fuel vehicles.
Sources: (EPA, 1990, Appendix C, p.2, & CRS, 1989, p.17).

- **Electric — $6,500.** Figure includes an estimate of the ultimate price premium of a battery, assuming steady improvements in battery technology and mass production taking place as zero-emission vehicle laws take effect. Advanced batteries now in an infant stage of development could considerably extend the range of the vehicle without the need for replacement. Differences between EV and EH vehicles are unimportant, as their most expensive component, the batteries, is the same. The figure is consistent with the consensus of the literature.
Sources: Premium for ZEV $1350 (SAIC/report, 1991, p.35); advanced batteries, such as sodium-sulfur, with a 100,000-mile life may be available by 1994 (Woodruff, 1991, p.58).

- **Electric Hybrid/Large I.C.E. — $6,500.** See Electric above. Differences between EV and EH vehicles are unimportant, as their most expensive component, the batteries, is the same. The additional cost of a range-extender I.C.E. (regardless of size) ultimately approaches zero as economies of scale, transfer of knowledge and innovation arrive. The figure is consistent with the consensus of the literature.
Sources: See Electric above.

- **Electric Hybrid/Small I.C.E. — $6,500.** See Electric and Electric Hybrid/Large I.C.E. above. The additional cost of a range-extender I.C.E. (regardless of size) ultimately approaches zero as economies of scale, transfer of knowledge, and innovation arrive. The figure is consistent with the consensus of the literature.
Sources: See Electric Hybrid/Large I.C.E. above.

- **Electric Hybrid/Turbine — $6,500.** See Electric above. Differences between EV and EH vehicles are unimportant, as their most expensive component, the batteries, is the same. The additional cost of a range-extender turbine ultimately approaches zero

as economies of scale, transfer of knowledge, and innovation arrive. The figure is consistent with the consensus of the literature.
Sources: See Electric Vehicle above, and Turbine/Gasoline & CNG below.

- **CNG — $750.** Assumes mass-production of optimized dedicated vehicle. The figure is consistent with the consensus of the literature.
  Sources: $700-800 for optimized and dedicated vehicle (O.T.A., 1990, p.101); $800 for optimized large-scale production, less for dedicated vehicle (ICAMF, 1990, p.1.14).

- **LPG — $500.** Assumes mass-production of optimized dedicated vehicle. The figure is consistent with current price differences between LPG and CNG vehicles, and assumes such differences will persist.
  Source: $500 (SAIC judgment).

- **Turbines/Gasoline — $1,500.** Assumes likely advances in high temperature ceramics and electronic combustion controls will take place by the end of the decade and eventually make this technology cost-competitive with conventional technology.
  Source: (The Economist, September 28, 1991, p.95).

- **Turbines/CNG — $1,500.** See Turbine/Gasoline above. Assumes there will be no significant price differential between CNG and gasoline technologies.
  Source: (The Economist, September 28, 1991, p.95).

- **Fuel Cell/Hydrogen — $6,500.** Assumes significant advances in storage technology and fuel cell manufacturing are accomplished due to high demand.
  Sources: storage technique breakthroughs: liquid hydrogen, or hydrogen bonded with powdered metals or stored in metal alloy balls may render it as safe as gasoline (Templeman, 1991, pp.59, 60); by 2010 the fuel cell hybrid will be $6,562 plus chassis (C.E.C., June 1991, pp.25-30).

- **Fuel Cell/Methanol — $6,500.** Assumes significant advances in storage technology and fuel cell manufacturing are accomplished due to high demand.
  Sources: Hydrogen-rich methanol would allow a fuel cell vehicle to refuel as rapidly as an I.C.E. vehicle (Economist, September 1991, p.75); storage technique breakthroughs: liquid hydrogen, or hydrogen bonded with powdered metals or stored in metal alloy balls may render it as safe as gasoline (Templeman, 1991, pp.59, 60);

by 2010 the fuel cell hybrid will be $6,562 plus chassis (C.E.C., June 1991, pp.25-30).

A comparison of the current and ultimate price premia discussed above is provided in the following table.

Table F-18. AFV Price Premia by Technology

TECHNOLOGY	PRICE PREMIA	
	CURRENT	ULTIMATE
Diesel	1,000	1,000
Ethanol Flex	4,500	0
Ethanol Neat	2,000	0
Methanol Flex	4,700	200
Methanol Neat	2,200	100
Electric	45,000	6,500
Electric Hybrid/Large ICE	50,000	6,500
Electric Hybrid/Small ICE	50,000	6,500
Electric Hybrid/Turbine	50,000	6,500
CNG	2,750	750
LPG	1,500	500
Turbine/Gasoline	125,000	1,500
Turbine/CNG	125,000	1,500
Fuel Cell/Methanol	150,000	6,500
Fuel Cell/Hydrogen	150,000	6,500

APPLICATION OF THE DECAY FUNCTION

This rate is the annual, compound percentage decline in the current premium towards the ultimate premium for all AFV technologies. AFV prices are assumed to fall along a curve between the current and the ultimate price premia. The curve's shape is determined by the decay rate. If the exponential decay rate is rapid, the vehicle price reached its ultimate price well before 2030 (e.g., ethanol and methanol). If the decay rate is slow, the ultimate price may not be reached in the 40-year period.

Table F-19. LDV and AFV Cost Decay Rates

FUEL TYPE	LOW	BASE	HIGH	EXPLANATION
Diesel ICE	10%	1%	1%	Diesel engines are advantageous only for medium and heavy-duty vehicles. Unsuccessful previous attempt to penetrate the passenger car market.
Ethanol & Methanol Flex	5%	10%	15%	Similar technologies are assumed to have near identical decay rates and constitute the alcohols flexible fuel market segment. Because of initial fuel availability advantages over neat vehicles and already existing technology (retrofitted gasoline engines), flex ones are expected to be mass-produced much sooner than optimized neat vehicles. Consistent with the consensus of the literature.
Ethanol & Methanol Neat	2.5%	5%	7.5%	Because optimized neat vehicles necessitate more engineering, they will take longer to develop and be mass-produced than flex vehicles. It is assumed that there will be a trend towards optimization and that flex vehicles will not be available in significant numbers by the end of the next decade. The rates were rounded off to figures equal to half of those for flex vehicles and are consistent with the consensus of the literature.
Electric & Electric Hybrids (ICE & Turbine)	7.5%	12.5%	15%	Assuming steady improvements in battery technology and the expansion of zero emissions state limit programs, the overall advantages of electric and hybrid vehicles will translate into the fastest annual increase in production for any AFV. The rates seem even faster because initial production is much lower than other competing technologies, i.e., CNG, LPG, and alcohol flex.
CNG	5%	10%	15%	Assuming retrofit conversion through 2000; dedicated mass-produced optimized vehicle after that year.
LPG	2%	4%	6%	Dedicated mass-production will come later than CNG vehicles, due to the latter's greater advantages vis a vis the non-fleet passenger vehicle market segment.
Turbines: Gasoline & CNG	5%	10%	15%	Rates consistent with, and slightly lower than, those for electrical vehicles. Both technologies are in their infancy but are also very promising. Assuming technology is operational by the end of the century, costs should decrease rapidly after that due to high initial learning curve position (e.g., turbine technology) and use of conventional fuel.
Fuel Cells: Methanol & Hydrogen	5%	10%	15%	Rates are consistent with electrical vehicles and rounded off to equal those of turbine vehicles. The development of this technology presents more obstacles than turbines but offers more potential rewards, i.e., lower emissions and seemingly limitless fuel supply.

SOURCES:

- **Diesel** — Rate tied to gasoline rate; the price premium is assumed to remain constant through time. The usefulness of this technology is limited to large vehicles.

- **Ethanol Flex** — $300 premium with large production in the future (EPA, April 1990, p.2); limited production by 1993, full by 2000 (C.E.C., 1989, p.7).

- **Methanol Flex** — Costs dropping since Chrysler began selling its Dodge Spirit and Plymouth Acclaim without a price premium, other auto makers will presumably follow (Cogan, August 1992, p.94); limited production by 1993, full by 2000 (C.E.C., August 1989, p.6); Federal fleet assumptions for cost premia: 1993=$2,500, 1994=$1500, 1995=$1000, 1996=$275, 2001=$150 (D.O.E., May 1992, p.26).

- **Methanol Neat** — No significant production for dedicated vehicles before 2007-2010 (CRS, 1989, p.17-18).

- **Electric** — Large resources from Detroit's consortium going into EV research (Woodruff, 1991); estimated manufacturing cost versus annual production volume (no. of vehicles manufactured/EV cost in 1988$): 30/$48,200, 100/$40,000, 1000/$29,500, 10,000/$21,000, 50,000/$18,100 (C.E.C., August 1989, p.6); limited production 1993-2000 (C.E.C., 1989, p.7); economies of scale after 1998 (60,000-100,000 units) and replacement of DCEV (direct current electric vehicle) by ACEV (alternating current e.v.); NiFe batteries and advanced battery use beginning 2003 and 2005 respectively, by 2009 1/2 of the EV and EV/hybrid market captured (A.F., 1990, p.18-22); GM Impact plant production will be 25,000/year (Woodruff, 1991, p.54, p.58); it takes production runs of at least 50,000/year to make a profit on a reasonably priced vehicle (Woodruff, 1991, p.59).

- **Electric Hybrid/Large I.C.E.** — NiFe battery car by 2003; by 2010 half of the EV's may be EV/hybrid (A.F., 1990, p.18-22). See other applicable references above under Electric.

- **Electric Hybrid/Small I.C.E.** — NiFe battery car by 2003; by 2010 half of the EV's may be EV/hybrid (A.F., 1990, p.18-22). See other applicable references above under Electric.

- **Electric Hybrid/Turbine** — NiFe battery car by 2003; by 2010 half of the EV's may be EV/hybrid (A.F., 1990, p.18-22). See other applicable references above under Electric, and under Turbine.

- **CNG** — Retrofit conversion 1993-2000 (C.E.C., 1989, p.7).

- **LPG** — Retrofit conversion 1993-2000 (C.E.C., 1989, p.7).

- **Turbine/Gasoline** — (The Economist, September 28, 1991, p.95).

- **Turbine/CNG** — (The Economist, September 28, 1991, p.95).

- **Fuel Cell/Hydrogen** — Prototype vehicle by 1993, demonstration vehicle by 2000 (C.E.C., 1989, p.7); prototype by 1995 possible, limited production 1000 to 10,000 units/year by 2002 (C.E.C., June 1991, p.20); main current obstacles are safety, compact storage, and competitive production costs; factory site vehicles by 2000, road vehicles beyond that (Tyler, 1990, p.20).

- **Fuel Cell/Methanol** — See references for Fuel Cell/Hydrogen above.

VEHICLE EFFICIENCY

This section documents vehicle efficiency in the database. The output of the database is the efficiency rate for sixteen technologies for three vehicle sizes, from 1990 to 2030. The rate is given in miles per MMBtu.

The general approach consists of establishing the current mid-size vehicle mileage per MMBtu for each fuel. The mileage figures are then adjusted for differences in vehicle size (e.g., small and large) using an index of mileage by size, as a function of mid-size mileage, while holding fuel constant. A fuel-use adjustment is needed to correct the miles/MMBtu estimates for pure fuel use vs. hybrid fuel use (e.g., electric vs. electric hybrid).

To obtain future vehicle efficiency, an annual simple percentage efficiency gain by vehicle type was developed. Fuels with greater potential for engine efficiency improvements were assigned greater estimated efficiency gains over time (e.g., gasoline I.C.E. vs. EV.).

Thus, the vehicle efficiency inputs are:

- Current mileage per MMBtu for each fuel.
- Mileage by vehicle size (small, large) as a function of mid-size vehicle mileage.
- A fuel-use efficiency adjustment to correct the miles/MMBtu estimates for pure fuel use vs. hybrid fuel use.
- Annual simple percentage efficiency gain by vehicle type for all vehicle types.

The approach has the following advantages:

- Projected efficiency rates should be relatively consistent vis a vis conventional gasoline I.C.E. and other technology efficiency rates.
- Updating and revising figures based on future developments are facilitated.

CURRENT VEHICLE EFFICIENCY

This section describes the process of obtaining current efficiency rates and adjusting for size and fuel use. As explained in the previous section, current mileages per MMBtu for each vehicle technology were initially obtained for a mid-size vehicle only. The following table shows these current efficiency rates. The sources consulted and the specific references and/or figures used are given immediately after the table.[27] Efficiencies for the other two vehicle sizes were obtained by applying an adjustment factor of +10% for small, and -10% for large, to the base mid-size vehicle efficiency rate shown in the following table.

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[27] Some improvements in the efficiency of gasoline vehicles also apply to AFV's, i.e., super-light materials and on-board computers, while others do not, i.e., two-stroke engines. Those that do apply do so differently from one technology to another, i.e., it will be easier to reduce air drag in a vehicle that has a small, powerful engine and does not require large fuel storage capacity.

Table F-20. Current Mid-Sized Vehicle Fuel Efficiencies

FUEL TYPE	Miles/MMBtu
Gasoline	265
Diesel	280
Ethanol	190
Methanol	270
CNG	230
LPG	405
Electricity	695
Hydrogen	250

SOURCES AND REFERENCES:

- **Gasoline** — Efficiency rates of 24 MPG for Buick Park Avenue V6; 25 MPG for a Buick LeSabre; 24 MPG for Toyota Camry (G.M.,1992, pp.14, 15, 36); Clean, highly efficient engines already developed in Japan, i.e., M-Miller cycle engine (Japan 21st, 1992); recent impressive gains in mileage, i.e., 65 MPG for a 1992 Honda Civic hatchback VX (Woodruff, 1991, p.56).

- **Ethanol Flex** — Efficiency of 0.0505 ethanol gallons per mile (EPA, April 1990, p.53).

- **Ethanol Neat** — Efficiency of 0.0418 ethanol gallons per mile (EPA, April 1990, p.53).

- **Methanol Flex** — Efficiency of 11.4 MPG for 1992 Ford Econoline Van (NREL, 1992, On line).

- **Methanol Neat** — Dedicated vehicle improvement over gasoline vehicle (CRS, 1989, p.18); dedicated vehicle is 4-15% better in energy input due to higher compression ratios (Oil & Gas, Dec 1991, p.59).

- **Electric** — SAIC data.

- **Electric Hybrid** — SAIC data.

- **CNG** — SAIC data.

- **LPG** — Efficiency for a 1992-1993 Ford F-700 Medium Duty Truck is 15 to 20% less than its gasoline equivalent (N.R.E.L., 1992, On-line).

- **Turbine/Gasoline** — SAIC data.

- **Turbine/CNG** — SAIC data.

- **Fuel Cell/Hydrogen** — Energy density is about 3.8 watts per pound, or less than that of an EV's lead-acid batteries (McCosh, August 1992, p.29); the theoretical limit to energy conversion is 80-85% (Templeman, 1991, p.59).

- **Fuel Cell/Methanol** — See Fuel Cell/Hydrogen above. Both hydrogen and methanol technologies consume hydrogen as a fuel; so they are essentially the same technology, differing only in the way the fuel is stored.

FUTURE EFFICIENCY RATES

Future efficiency rates were obtained by applying an annual percentage gain by technology type, for each of the three penetration scenarios. This section describes how the gain rates were determined and provides the sources used.

ANNUAL PERCENTAGE GAIN IN EFFICIENCY

The following table shows the efficiency gain rates by vehicle technology for three penetration scenarios. Each vehicle technology entry is accompanied by comments or an explanation of assumptions where applicable.

Table F-21. Annual LDV & AFV Efficiency Gain, by Technology (Three Scenarios)

TECHNOLOGY	SCENARIO BASE	SCENARIO HIGH	SCENARIO LOW	EXPLANATION
Gasoline & Diesel	1.00%	0.00%	2.00%	Based on historical rate, i.e., since 1974 GM vehicles have improved efficiency by 125%, and assuming current trends continue, i.e., increased investment in order to meet policy goals and competitive challenges of AFV's. The efficiency escalation rate cannot remain constant, because the easier gains have been already achieved. Nevertheless, even the automakers themselves have set ambitious goals, i.e., Chrysler's 29 MPG by 1996. Diesel rate parallels gasoline's and is consistent with the historical record.[28]
Alcohol Fuels	1.00%	2.00%	0.50%	5-10% operation efficiency increase through technological improvements in the near future. Since ethanol and methanol have higher heat content than gasoline or diesel, higher efficiency can be expected from a vehicle that runs on neat fuel, but the annual gains in efficiency would be almost the same for both neat and flex fuels.
Electric & Electric Hybrids	0.50%	0.75%	0.00%	Much higher initial efficiency, but fast improvements in battery and/or engine technology are unlikely, resulting in a relatively low efficiency gains rate. Note that this technology is not affected by the Carnot cycle's theoretical limit. Similar rates are projected for all types of hybrids, as their respective complementary technologies are secondary to the electric technology.
CNG & LPG	1.00%	2.00%	0.50%	Gain rates equivalent to those of alcohol fuels assumed.
Turbine/ Gasoline	1.25%	0.00%	2.00%	Based on existing technology applied to other types of vehicles, i.e., Abrahms M1 tank, hovercraft, and assuming the technology will fulfill its theoretical expectations once applied to passenger vehicles. Efficiency gains should parallel those of conventional gasoline vehicles to a large extent.
Turbine/CNG	1.25%	2.00%	0.50%	See TURBINE/GASOLINE entry above. Efficiency gains should parallel those of conventional CNG vehicles to a large extent.
Fuel Cell/ Methanol & Hydrogen	1.25%	2.00%	0.00%	Although the technology is in its infancy, because of its vast potential a fast gain rate similar to that of turbines is expected, i.e., it has a theoretical efficiency of 80 to 85% when the heat of the process is recovered for use elsewhere. It is assumed that there will be continuous technical breakthroughs as projected today, i.e., proton exchange membrane, or other advanced systems fully developed.

SOURCES AND REFERENCES:

- **Gasoline** — Carnot cycle's theoretical maximum (Romano, 1989, p.75); 2-stroke engine (The Economist, September 28, 1991 & Scientific American, October 1992, pp.

[28] Regardless of fuel choice, all ICE's are limited by the Carnot cycle's theoretical maximum of 40 to 50%.

112-113); super-light materials (GM, 1992, p.14, 15); reduced air drag, upgraded on-board computers (Woodruff, 1991, p.56); reformulation (Unzelman, 1991,p.64). Since 1974 GM vehicles have improved efficiency by 125% (GM, 1992, p.14, 15); Chrysler's efficiency goal is to achieve an average 29 MPG by 1996 (Woodruff, 1991, p.54).

Already existing promising prototypes (Maruyama, 1991); policy and industry goals in the U.S. and elsewhere (Woodruff, 1991, p.54); CAFE's standards by 2001; the historical efficiency escalation rate, defined as a reduction in gallons/year per vehicle, is 4.95% (Oil & Gas, Dec 1991, p.58).

- **Diesel** — Carnot cycle's theoretical maximum (Romano, 1989, p.75); super-light materials (GM, 1992, p.14, 15); reduced air drag, upgraded on-board computers (Woodruff, 1991, p.56); reformulation (Unzelman, 1991,p.64).

- **Ethanol Flex** — 5-10% operational efficiency increase (Oil & Gas, Dec 1991, p.59); Carnot cycle's theoretical maximum (Romano, 1989, p.75).

- **Ethanol Neat** — Higher heat content and efficiency rates; learning curve gains of 20 to 30% over gasoline by the time dedicated vehicles enter the market (CRS, 1989, p.18); Carnot cycle's theoretical maximum (Romano, 1989, p.75).

- **Methanol Flex** — 5-10% operational efficiency increase over gasoline (Oil & Gas, Dec 1991, p.59); Carnot cycle's theoretical maximum (Romano, 1989, p.75); improvement over gasoline: low case 4%, base 6%, and high 13% (CRS, 1989, p.18).

- **Methanol Neat** — Higher heat content and efficiency rate; learning curve gains of 20 to 30% over gasoline by the time dedicated vehicles enter the market (CRS, 1989, p.18); Carnot cycle's theoretical maximum (Romano, 1989, p.75).

- **Electric** — SAIC data.

- **Electric Hybrid/Large I.C.E.** — Efficiency rates of 36 MPG for an average passenger vehicle, and 21 MPG for a light truck (A.F., 1990, p.18-22).

- **Electric Hybrid/Small I.C.E.** — Efficiency rates of 36 MPG for an average passenger vehicle, and 21 MPG for a light truck (A.F., 1990, p.18-22).

- **Electric Hybrid/Turbine** — (The Economist, September 28, 1991, p.95).
- **CNG** — Carnot cycle's theoretical maximum (Romano, 1989, p.75).
- **LPG** — Carnot cycle's theoretical maximum (Romano, 1989, p.75).
- **Turbine/Gasoline** — (The Economist, September 28, 1991, p.95).
- **Turbine/CNG** — (The Economist, September 28, 1991, p.95).
- **Fuel Cell/Hydrogen** — (Templeman, 1991, pp.59-60).
- **Fuel Cell/Methanol** — (Templeman, 1991, pp.59-60).

VEHICLE EMISSIONS

This section describes vehicle emissions from conventional and ATF vehicles over time.

INDEX APPROACH

The general approach uses an index value tied to the impact-weighted emissions from mid-size gasoline vehicles. In each year from 1990-2030, the emissions impact from the base-case gasoline vehicle is estimated. As gasoline vehicle emissions decline (e.g., due to reformulation), the absolute emissions level declines but the index value remains constant (at 1.0). The emissions impact of the alternative fuels is benchmarked against the absolute level to create the index value for the alternatives. If the emissions of an AFV declines faster than that of the gasoline vehicle, the emissions index for that AFV will decline. If the emissions of an AFV increases or declines less rapidly than that of the gasoline vehicle, the emissions index for that AFV will increase. The technology choice module can make use of this relative indexing in annually selecting vehicle types.

The weight given to emissions and emissions indexing in the technology choice module is outside the scope of this database. Whether decisions will ultimately be made with respect to some threshold emissions level is also not considered.

The emissions index is constructed from the following inputs:

- Current emissions from a mid-size car for five pollutants (CO, CO_2, NO_x, methane, and NMHC) in grams/mile for 16 vehicle types. See Table F-22.
- Minimum possible emissions by 2030 for the same pollutants for the same vehicle types. See Table F-23.
- Annual simple percentage decline in emissions towards the minima, same vehicle types.
- Impact-weighting of the five pollutants on health and environmental criteria.

The index constructed from these data is necessary because the impact on human health and the environment from a gram of one pollutant is not equivalent to the impact of another pollutant. This non-equivalence is particularly apparent when one compares the typical emissions of NO_x (about 1 gram/mile) to that of CO_2 (about 450 grams/mile). Clearly, CO_2 is not 450 times more hazardous to health or the environment than NO_x. Thus, a weighting scheme (i.e., an index) must be constructed to properly compare the overall emissions index.

Table F-22. Base Mid-Sized Vehicle Emissions (Grams/Mile, 1990)

TECHNOLOGY	CO	NMHC	MET	NO_x	CO_2	ASSUMPTIONS AND EXPLANATIONS
Gasoline	9.00	1.00	0.00	1.03	452	Representative vehicle for size category. Standard catalytic converter.[29]
Diesel	3.40	0.41	0.00	1.00	450	Representative vehicle for size category. Consistent with data entered under gasoline. Standard catalytic converter.
Ethanol Flex	2.00	0.60	0.00	1.10	435	Consistent with data entered under gasoline and diesel. Retrofitted representative vehicle for size category. Generally higher NO_x than gasoline and diesel due to higher combustion temperature. Formaldehyde not included for methanol emissions.
Ethanol Neat	1.57	0.36	0.00	1.10	429	
Methanol Flex	1.75	0.29	0.00	1.10	447	
Methanol Neat	1.50	0.20	0.00	1.10	450	
Electric	0.00	0.00	0.00	0.00	0.00	Near zero emissions. Rounded off for manageability.
Electric Hybrid/ Large ICE	2.00	0.10	0.00	0.20	90	Due to smaller size and less use, i.c.e.'s emissions are ¼ or less of a conventional engine.
Electric Hybrid/ Small ICE	1.00	0.05	0.00	0.10	45	Due to smaller size and less use, i.c.e's emissions are ½ of large i.c.e.'s
Electric Hybrid/ Gasoline Turbine	0.50	0.03	0.00	0.06	25	Near zero for electric part. See TURBINE entry below. Due to less use and smaller size emission's are about ¼ of conventional turbine's.
CNG	0.30	0.23	1.20	0.97	419	Representative vehicle, consistent with alcohol and gasoline vehicles selected above.
LPG	0.28	0.29	0.00	0.59	437	
Turbine/Gasoline	2.00	0.10	0.00	0.25	100	Theoretically very low emissions, around ¼ of conventional fuel (gasoline or CNG respectively) vehicle.
Turbine/CNG	0.08	0.06	0.35	0.40	95	
Fuel Cell/Methanol	0.00	0.00	0.20	0.01	0.01	Near zero emissions. Small methane figure for methanol vehicle.
Fuel Cell/Hydrogen	0.00	0.00	0.00	0.01	0.01	

[29] For all technologies, pollution produced by the power source or fuel production process is not included.

Table F-23. Minimum Possible Emissions, Mid-Size Vehicle (Grams/Mile, 2030)

TECHNOLOGY	CO	NMHC	MET	NO_x	CO_2	ASSUMPTIONS
Gasoline	1.70	0.04	0.00	0.20	250	Advanced catalytic converters and reformulation.[30]
Diesel	1.25	0.04	0.00	0.20	250	
Alcohol Fuels: Flex & Neat	1.00	0.04	0.00	0.20	250	Advanced catalytic converters.[31]
Electric	0.00	0.00	0.00	0.00	0.00	Power source and accidental leakage not included.
Electric Hybrid/ Large ICE	0.40	0.01	0.00	0.04	60	Due to less use and smaller size, ICE's emissions are ¼ or less of conventional engine.
Electric Hybrid/ Small ICE	0.20	0.01	0.00	0.02	30	Due to smaller size, ICE's emissions are ½ of large ICE hybrid.
Electric Hybrid/ Gasoline Turbine	0.01	0.00	0.00	0.01	12	Advanced catalytic converter and reformulation.
CNG	0.20	0.01	0.20	0.20	250	Advanced catalytic converter.
LPG	0.10	0.04	0.00	0.20	250	
Turbine/Gasoline	0.50	0.02	0.00	0.05	25	Advanced catalytic converter and reformulation.
Turbine/CNG	0.05	0.00	0.05	0.05	25	Advanced catalytic converter.
Fuel Cell/Methanol & Hydrogen	0.00	0.00	0.00	0.01	0.01	Negligible emissions.

[30] For all technologies, emissions from fuel source and accidental leakage is not included.

[31] For ethanol, the 30 to 50% emissions reduction must be weighed against the considerable CO, CO_2 and nitrogen compounds produced by growing, fertilizing, harvesting, drying and transporting the crops to produce the fuel. EPA estimates the pollution created by producing and burning a gallon of ethanol is up to six times as much as producing and burning a gallon of gasoline. However, aldehydes are not produced (Frank, August 1992, p.106).

IMPACT WEIGHTING

The weighting scheme assumes that all impacts will be in the area of health (85% of the decision) or environment (15%) and will be based on each pollutant's contribution to impacts in those areas. For example, CO_2 has an impact on the environment but little or no impact on health. For CO, the reverse is true. Note that we are not considering health impacts derived from environmental impacts as health impacts. We are using the more conventional understanding that, for example, CO_2 is not considered a respiratory hazard (health) but is a greenhouse gas (environment).

In general, the reasoning behind the weightings is as follows:

- **Carbon Monoxide (CO)** — A moderate health hazard for its role in surface-level ozone creation; its environmental effect is negligible.

- **Non-Methane Hydrocarbons (NMHC)** — Serious health hazard for its significant role in surface-level ozone creation; its environmental effect is negligible.

- **Methane (Met)** — Important greenhouse gas; negligible health threat.

- **Nitrogen Oxides (NO_x)** — Serious health hazard for their role in surface-level ozone creation; also a significant greenhouse gas.

- **Carbon Dioxide (CO_2)** — Statistically insignificant health impact but some greenhouse impact.

The choice of the five pollutants (CO, CO_2, NO_x, methane, and NMHC) was based partly on the availability of detailed technical literature and partly on SAIC's judgment about the pollutants likely to affect vehicle choice and public policy in the coming decades. Additional pollutants, notably aldehydes and particulates, could have been added. The ultimate selection of five pollutants was based on computational tractability. The specific inclusion of methane and non-methane hydrocarbons was based on the need to distinguish natural gas-fueled vehicles based on smog-related and non-smog-related emissions. The impact of the various pollutants per unit emitted is assumed not to change over time.

Table F-24. Pollutant Impact Weighting Factors (Health vs. Environment)

IMPACT	WEIGHT	CO	NMHC	MET	NO_x	CO_2
Health	0.85	0.02	0.44	0.00	0.39	0.00
Environment	0.15	0.00	0.00	0.09	0.06	0.0005

The database treats electric vehicles as zero-emissions vehicles (ZEVs) in accordance with California regulations and shows them with zero emissions. Powerplant emissions are not included in the database. Emissions for the gas turbine engines are generally guesses. Emissions levels for the fuel cells are approximately zero, except for NO_x. The emissions for converting coal or natural gas to methanol or hydrogen for use in the fuel cells are not included. Similarly, emissions from ethanol exclude the CO, CO_2, and nitrogen compounds emitted during growing, fertilizing, harvesting, drying, and transporting the crops. Emissions and leakage from tanks (e.g., CNG and hydrogen releases) are also not considered.

DECLINES IN EMISSIONS OVER TIME

The simple annual percentage rate at which the vehicle emissions decline is based on an extensive review of the literature for both the vehicles and the fuels. The decay rates are provided in the following table.

Table F-25. LDV & AFV Emissions Decay Rates

TECHNOLOGY	CO	NMHC	MET	NO_x	CO_2
Gasoline & Diesel	10.0%	10.0%	0.0%	5.0%	0.0%
Alcohol Fuels/Neat & Flex	5.0%	10.0%	0.0%	5.0%	0.0%
Electric Hybrids/ICE & Turbine	0.0%	0.0%	0.0%	0.0%	0.0%
CNG	5.0%	10.0%	10.0%	5.0%	3.0%
LPG	5.0%	10.0%	0.0%	5.0%	3.0%
Turbine/Gasoline	10.0%	10.0%	0.0%	5.0%	0.0%
Turbine/CNG	5.0%	10.0%	10.0%	5.0%	3.0%
Fuel Cell/Methanol & Hydrogen	0.1%	0.1%	0.1%	0.1%	0.1%

In general, the following factors were considered.

- **Gasoline** — Development of upgraded on-board computers for more precise spark timing and fuel injection (so gasoline burns more completely and less HC's escape); widespread use of catalytic converters that will eliminate up to 99% of CO and NO_x pollution by electronically preheating before a car starts; consequent increase in CO2.

- **Electric** — Assigned zero emissions in isolation of power source, therefore decay function is also zero. Even if power source is included there will be dramatic reductions compared to gasoline emissions, depending on fuel burned (natural gas or coal) to generate power. Improvements in emission controls at the source are expected to keep electricity ahead of gasoline.

- **Electric Hybrid/Gas Turbine** — Gas turbine would emit insignificant amounts of pollutants, so they may not need a catalytic converter. Without including power source, the electric part would have zero emissions (see above paragraph.) Although not yet engineered as such, turbine technology has been fully developed.

- **Turbine/CNG** — Widely used in other applications, with well-known emissions. For passenger vehicle applications this technology will emit insignificant amounts of pollutants and may not need catalytic converters.

SOURCES AND REFERENCES:

- **Gasoline** — Clean, highly efficient vehicles such as the M-Miller Cycle engine vehicle are being developed in Japan (Japan 21st, 1992).

- **Methanol Neat** — A dedicated vehicle has higher compression ratios, thus higher heat and NO_x than gasoline I.C.E.; high level of formaldehyde (Oil & Gas, Dec 1991, p.59); high level of carcinogen formaldehyde (Oil & Gas, Dec 1991, p.59).

- **CNG** — The cleanest running nonelectric production vehicle available today full-size Dodge van (Frank, August 1992, p.105). CO level is 1/2 to 1/10 lower, but NO_x is higher due to higher peak combustion temperature in the presence of excess oxygen (Oil & Gas, Dec 1991, p.59).

- **LPG** — Low CO and HC, higher NO (Oil & Gas, Dec 1991, p.60). In the 1992 Ford F-700 Medium Duty Truck, HC and NO_x are significantly lower than their conventional equivalent, while CO emissions are comparable (NREL, 1992, On line).

- **Fuel Cell/Hydrogen and Methanol** — Would meet California's no-emissions requirements for 1994 (McCosh, 1992, p.29); cleanest emissions of any fuel; emissions are water and a low quantity of NO_x (SAIC/report, 1991, p.22); temperature of the electrochemical reaction is low enough to keep NO_x from being a problem (Romano, 1989, p.75).

  Production process reverses gains in emissions; CO2 & NO_x are byproducts of hydrogen production (Ondrey, 1992, p.30).

  Japan in investing in hydrogen-burning vehicles that are far cleaner than any other AFV (Maruyama, 1991); environmentally-friendly HR-X by Mazda, a prototype with a hydrogen-burning rotary engine developed already (Japan 21st, 1992).

- **Gasoline** — Upgraded on-board computers for more precise spark timing and fuel injection; future catalytic converters may eliminate 99% of pollution by electronically preheating before a car starts (Woodruff, 1991, p.56).

  Possibilities of catalytic converters: Ford's 1993 Escort/Mercury Tracer models pass California's 1994 TLEV standard; Corning's EHC prototype passes 1997 ULEV standard (Cogan, September 1992, ps.35); 96% HC and 76% NO_x reduction comparing 1992 to 1960's vehicles (Frank, August 1992, p.103); improvements in refueling connection (Oil & Gas, Dec 1991, p.38). By 2003 the CAA could require 25% of all US cars to cut HC by 40%, and NO_x by 50%. By 2006 100% of US cars must meet that standard (Woodruff, 1991, p.59).

- **Electric** — Dramatic reductions compared to gasoline emissions depending on fuel burned (natural gas or coal), emissions controls at the power plant and type of generating equipment (Frank, August 1992, p.105).

- **Electric Hybrid/Turbine** — No direct reference. See relevant entries ELECTRIC above and TURBINE below.

- **CNG** — Considerable improvement potential for emissions in three areas: fuel metering and mixing, lean/dilute combustion systems, catalytic converters (Weaver, 1991, ps.4-7).

- **Turbine/Gasoline** — Gas turbine would emit insignificant amounts of pollutants, may not need a catalytic converter (The Economist, September 28, 1991, p.95).

- **Fuel Cell/Hydrogen** — Hydrogen already is the cleanest fuel available; only emissions are water and small quantities of NO_x (SAIC/report, 1991, p.22).

FUEL OPERATING COST

This section documents fuel operating cost in the database. The output of the database is operating cost for eight fuels, for nine regions, through three penetration scenarios (base, high, and low), from 1990 to 2030. The results are expressed in constant 1990 $/MMBtu.

The general approach is to establish the current national average fuel operating cost for each fuel. Regional differences are obtained using a percentage deviation from the minimum regional price and are assumed to remain constant over time. The sustainability of any such regional price deviations absent government intervention (or unusually skewed tax policies) is questionable. This issue is raised in Section 2 of the report.

Projected operating costs are found using a compound annual percentage fuel price escalation rate for each individual fuel, for each scenario (base, high, low).

The inputs used to forecast fuel costs are:

- Fuel operating cost in 1990 $/MMBtu.
- Regional fuel price differences, as a percentage deviation from the minimum regional prices, by region, by fuel.
- Fuel price escalation, compound annual percentage, all fuels individually, by scenario.

The approach has the following advantages:

- Projected fuel prices should be relatively consistent vis a vis conventional gasoline and other fuel prices.
- Updating and revising figures based on future developments are facilitated.

CURRENT AVERAGE FUEL OPERATING COST

Operating cost is derived from the current national average retail price usually given in $/gallon or similar measure. To allow comparisons between fuels, retail price was converted into dollars per energy content ($/MMBtu). Retail prices by fuel are tabulated below.

Table F-26. Average Fuel Prices, $1990

FUEL TYPE	RETAIL PRICE ($/MMBtu)
Gasoline	$9.70
Diesel	$7.69
Ethanol	$14.55
Methanol	$19.23
CNG	$8.50
LPG	$7.83
Electricity	$23.53
Hydrogen	$30.00

REGIONAL DIFFERENCES, ASSUMPTIONS, AND CRITERIA

Regional fuel prices are calculated by adding a percentage price differential to the national average retail prices found in the preceding table. The price differentials for each region shown in Table F-27 are based on factors such as proximity or access to major ports, production fields, refineries, state/regional consumer price index, adequate infrastructure, local producer and government support.

These factors, assumptions and caveats are discussed after the table. The subsequent notes raise questions about the sustainability of these differences in a national market.

Table F-27. Regional Fuel Price Differences

FUEL TYPE	PERCENTAGE DIFFERENCE BY REGION								
	NE	MA	SA	ENC	ESC	WSC	WNC	MTN	PAC
Gasoline	0.05	0.025	0.025	0.01	0.025	0	0.05	0.025	0.01
Diesel	0.05	0.025	0.025	0.01	0.025	0	0.05	0.025	0.01
Ethanol	0.075	0.0375	0.037	0	0	0.01	0	0.0375	0.05
Methanol	0.05	0.025	0.025	0.01	0.025	0	0.05	0.025	0.01
CNG	0.05	0.025	0.0375	0.025	0.025	0	- 0.025	0	0.025
LPG	0.05	0.025	0.025	0.01	0.025	0	0.05	0.025	0.01
Electricity	0.1	0.05	0.025	0.01	0.025	0.01	0	0	0.0375
Hydrogen	0.05	0.025	0.025	0.01	0.025	0	0.05	0.025	0.01

Abbreviations:

NE	New England
MA	Mid Atlantic
SA	South Atlantic
ENC	East North Central
WSC	West South Central
WNC	West North Central
MTN	Mountain
PAC	Pacific

EXPLANATIONS

- **Gasoline** — In the U.S. national market gasoline prices are essentially the same.
- **Diesel** — In the U.S. national market diesel prices are essentially the same.
- **Ethanol** — Mainly produced from corn in Midwest states; the regions that are part of it, or closest to it, enjoy lower prices due to advantages such as access, convenient transportation, and local support (i.e., state subsidies, farmers interests).
- **Methanol** — Mostly imported, therefore regions enjoying proximity and easy access

to major ports and processing infrastructure, i.e., Los Angeles and New Orleans, would have a price advantage. The Pacific region also benefits from California's acute interest in this fuel, i.e., special incentives from the state. Inflexible infrastructure and the high cost of living in NE and WNC explain higher prices in those regions.

- **Electricity** — Regions with access to relatively abundant and cheap power produced by hydroelectric and coal-fired power plants benefit, e.g., WNC, WSC, MTN, and ENC. More expensive power from regions without low-cost fossil fuels drives prices up in NE and MA.

- **CNG** — Proximity to the rich fields in WSC and MTN benefits those regions and ESC, WNC, ENC and PAC. Competing imports benefit areas near major ports, i.e., PAC, ESC. The high cost of living and inaccessibility to fields drive prices up in NE.

- **LPG** — Access to competitive imports and refineries benefits PAC, ESC and ENC. Local production and support would benefit ENC and PAC. Higher transportation costs, infrastructure inflexibility and higher cost of living puts NE at a disadvantage.

- **Hydrogen** — Access to abundant raw materials, i.e., especially low-cost electricity benefits such regions as PAC, ENC, SA, WSC. Infrastructure and local support also push prices down in PAC. WSC, and MTN.

IMPORTANT ASSUMPTIONS AND CAVEATS

- Regional fuel price differences may persist due to transportation costs from producing or importing regions. These differences, however, are likely to be no more than $.05/gallon equivalent and are generally less than differences in state excise taxes.

- Differences in state excise taxes within a region can easily exceed differences in transportation costs from region to region.

- Electricity is shown at an average price. Off-peak electricity will cost less and on-peak electricity will cost much more. If EV sales are induced with the promise of daytime refueling at the office, much higher charges than those shown on the table will apply.

PROJECTED FUEL OPERATING COSTS

Projected fuel operating costs are found using a fuel price escalation rate. This section describes the escalation rate in more detail, and provides a representative sample of the output.

FUEL PRICE ESCALATION RATE

The escalation rate is a compound annual percentage, applied to each fuel individually. The rates for each fuel and the assumptions behind them are shown below.

Table F-28. Fuel Price Escalation Rates

FUEL	RATE	EXPLANATION AND ASSUMPTIONS
Gasoline Diesel	2%	Rate consistent with projections of oil prices based on current and future demand, output, refining capacity, etc.
Ethanol	3%	Mostly from domestic production, ethanol is a net energy loser (which implies the need of subsidies to make it competitive.) Assuming the cost of subsidies is incorporated, and due to the cyclical nature of the corn crops, the escalation rate would be the highest for all ATFs.
Methanol	1%	Assuming it is produced mostly from cheap imports without significant supply disruptions.
Electricity	1%	Assuming most power is used during off-peak hours when power plants have excess capacity. Also assuming regions with excess capacity will compensate for areas where increasing capacity would be prohibitive.
CNG	1%	Mostly from cheap, large fields in the U.S.
LPG	1%	Mostly from domestic production.
Hydrogen	1%	Assuming the current trend in production costs reduction continues, and assuming that sufficient power for production process is obtained from a reliable source.

SOURCES OF ESTIMATES:

- **Gasoline** — Escalation rates for periods: 1990-95 = 1.3%, 1995-2000 = 3.18%, 2000-2005 = 1.63%, 2005-2010 = 1.24 (D.O.E., July 1991, p.25); escalation rates due to reformulation: from 1990 to 2010 a 13.53% increase every five years (SAIC & Oil & Gas, Dec 1991, p.61). Fuel prices will go up as oxygenate-hydrocarbon shift takes place by replacing aromatics with ethers (Unzelman, 1991).

- **Diesel** — SAIC.

- **Ethanol** — Current production is 1 billion gallons per year; 3 to 8 billion gallons possible by 2010 without exerting strong upward pressure on feedstock prices.

- **Methanol** — Increase of 19.31% every ten years (SAIC & Oil & Gas, Dec 1991, p.60).

- **Electricity** — SAIC.

- **CNG** — Increase of 29.18% every ten years (SAIC & Oil & Gas, Dec 1991, p.60).

- **LPG** — Increase of 27.94% every ten years (SAIC & Oil & Gas, Dec 1991, p.60).

- **Hydrogen** — Projected operating costs for five-year intervals: $0.69 per mile by year 2000, down to $0.18 by 2005, $0.15 by 2015, and $0.12 by 2020 (SAIC/report, 1990); the fuel is projected to be cost equivalent with $1/gallon of diesel in the near future (SAIC/Ballard, 1992, p.1-22); demand stimulated by the Clean Air Act (CAA) of 1994; already there is new related investment; new production processes could cut costs by 5-10% and increase capacity by 50% (i.e., high temperature steam electrolizer); 80% of production costs are electricity-related (Ondrey, 1992, pp.31-35).

FUTURE FUEL PRICES IN THE LITERATURE
(In Gasoline-Gallon-Equivalent Unless Specified)

- **Gasoline** — $11.00 per MMBtu (reformulated) By the year 2000 (SAIC /report, 1991, p.26). $1.25-1.39 by the year 2000 (C.E.C., 1989, p.11). $1.58 (D.O.E., July 1991, p.25). $0.20 per gallon rise for reformulated gasoline (Woodruff, 1991, p.56). $0.32 per gallon (1990$) for gasoline reformulation for $2.08 pump price in the year 2010; 26 cents for $1.70 by 2005 (Oil & Gas, Dec 1991, p.59).

- **Ethanol Flex** — $1-1.50 per gallon under expanded fuel ethanol program; produced from corn (EPA, April 1990, p.i).

- **Ethanol Neat** — $17.70 per MMBtu by year 2000 (SAIC /report, p.26).$2.33 by year 2000 (C.E.C., 1989, p.11).

- **Methanol Flex** — $1.01-1.14 established market with guarantees. $1.14-1.35 with few guarantees (O.T.A., 1990, p.76). $1.39 by year 2000 (C.E.C., 1989, p.11). $2.79 (Oil & Gas, Dec 1991, p.60).

- **Methanol Neat** — $0.55-0.83 wholesale per gallons of methanol, by years 2004-2007 (CRS,1989,p.16). $1.35-1.75 by 2007 (A.P.I., August 1989, p.10). $14.50 MMBtu by year 2000 (SAIC /report, 1991, p.26). $1.29-1.37 during a transition phase, with strong market guarantees,$1.61-1.81 with few guarantees. $0.89-1.09 for an established market, with strong guarantees. $1.02-1.27 with few guarantees (O.T.A.,1990, pp.75-6).

- **Electric** — $18.00 MMBtu by year 2000 (SAIC/report, 1991, p.26). $1.31 by year 2000 (C.E.C., 1989, p.11). $5.28 or 15 cents kw/hr if produced with nuclear power (Oil & Gas, Dec 1991, p.61).

- **CNG** — $9.60 MMBtu by year 2000 (SAIC/report, 1991, p.26).$0.84 by year 2000 (C.E.C., 1989, p.11). $2.16 (Oil & Gas, Dec 1991, p.60).

- **LPG** — $0.98 by year 2000 (C.E.C., 1989, p.11). $1.29 (Oil & Gas, Dec 1991, p.60).

- **Fuel Cell/Hydrogen** — $0.18 per mile (SAIC/report, 1990); below $2.00 if substantial improvements can be made in photovoltaic technology (O.T.A.,1990, p.129). $3.50 if nuclear power costs 15 cents kw/hr (Oil & Gas, Dec 1991, p.61). $0.10 per mile year 2030 (SAIC/report, 1990) More efficient solar energy technology (substantially above 30% today) is needed to produce hydrogen by electrolysis (Tyler, 1990, p.20); research into photochemical and photovoltaic conversion (Gross, 1992, p.74; & Hodgson, 1991, p.58); pre and post-reformers to increase capacity of existing hydrogen plants, boost yields, no major changes in existing basic technology (Ondrey, 1992, pp.31-35). Efficiency improvements in the production of hydrogen can be expect to reach 70 to 90% once improved electrolysis methods are developed (Tyler, 1990, p.20). Promising production methods may bring hydrogen closer to gasoline's production cost, e.g., photobiological and photochemical conversions (though the latter's theoretical maximum efficiency is 32%)(Hodgson, 1991, p.58); hydrogen is the most likely main energy source replacing oil in all applications in the 21st century (Templeman, 1991, pp.60-61).

FUEL AVAILABILITY

This section documents fuel availability in the database. The output is fuel availability as a percent of gasoline availability for eight fuels, for nine regions, from 1990 through 2030, through three penetration scenarios (base, high, low).

The general approach is to determine current and ultimate fuel availability as a percentage of gasoline availability (assumed to be 1). A number of current fuel availability factors were considered in creating a percentage index for each fuel. Projected availability is determined by changes in these factors over time, which are represented by an exponential rate of closure in the current availability gap between gasoline and each of seven alternative fuels. The rate of closure changes for each of three penetration scenarios (base, high, low).

The data reported in this section are uncertain and of questionable usefulness due to the uncertain specification of availability in the model. The values reported in this section must be read in the light of the subsequent extended comments on modeling problems related to fuel availability.

The inputs used to forecast fuel availability are:

- Current regional fuel availability factors, as a percentage of gasoline availability, for all fuels.
- Fuel availability growth factors, represented as an exponential rate of closure in the availability gap.

The approach has the following advantages:

- Projected alternative fuel availability index values should be relatively consistent vis a vis gasoline and other ATF availability indices.
- Updating and revising figures based on future developments are facilitated.

CURRENT FUEL AVAILABILITY

Current alternative fuel availability regional differences are expressed as a percentage of gasoline availability in the base year 1990 as shown in the following table. Important limitations on these values and their usage are subsequently discussed.

Table F-29. Base Year (1990) Fuel Availability, by Region

FUEL TYPE	NE	MA	SA	ENC	ESC	WNC	WSC	MTN	PAC
GASOLINE & DIESEL	1	1	1	1	1	1	1	1	1
ETHANOL	0.01	0.02	0.02	0.1	0.02	0.02	0.02	0.05	0.05
METHANOL	0.01	0.05	0.02	0.02	0.02	0.02	0.01	0.05	0.1
CNG	0.01	0.02	0.02	0.05	0.02	0.02	0.05	0.05	0.05
LPG	0.01	0.02	0.02	0.05	0.02	0.02	0.1	0.05	0.1
ELECTRICITY	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
HYDROGEN	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01

FUTURE AVAILABILITY

Changes in infrastructure and other growth factors that are demanded by an economically significant ATF are discussed in this section, along with pertinent assumptions and caveats.

Future availability is determined by changes in the regional availability factors outlined in the previous section. Such changes affect the differences between gasoline and each ATF, so they are represented by an exponential rate of closure of the availability gap between gasoline and each ATF.

GASOLINE INFRASTRUCTURE AND OTHER GROWTH FACTORS.

There are roughly a million gasoline stations in the United States at the present time. For any ATF to be accepted by the public a certain threshold of availability must be reached (aside from economic and other considerations). Attaining the threshold level would require government and private investments in infrastructure in the order of tens of billions of dollars in a very short time. It would also exclude the possibility of having more than one or two competitive different fuels at one time. The infrastructure required would vary considerably from fuel to fuel. The implications are explored for each fuel below.

- **Ethanol and methanol** — a large proportion of the existing equipment could be easily adapted as these two fuels have obvious physical similarities to gasoline, i.e., use same pumps and dispensing equipment. However in the case of methanol, its corrosive nature would demand upgrading the system's reservoirs and pipes. There are additional expenses associated with differences in water tolerance and fuel contamination, fire, and explosion hazards.

- **CNG and LPG** — there is a small infrastructure capable of handling vehicle fleets successfully. Both fuels are, and will continue to be, attractive for the vehicle fleet subset, because a central refueling site can service the entire fleet. However, for private passenger cars, adapting a single existing gasoline service station would require a minimum of $250,000 for a compressor. Such a price tag would rule out a wide distribution network for passenger vehicles unless there is some government subsidy.

- **Electricity** — the extensive existing electricity infrastructure should be capable of servicing a large number of vehicles in terms of megawatts of off-peak capacity. On-peak demand would cause massive cost and availability problems. Moreover, since long refueling time would make service station refueling impossible, costly adapters would have to find a place in every user's household.

- **Hydrogen** — although there is an almost limitless supply of raw materials (e.g., water), there is no existing infrastructure for the distribution of hydrogen. Hydrogen's low mass makes it expensive to store since it must be liquified or bound to other substances. For these reasons reaching the necessary threshold level would involve a much higher price tag than for other ATFs.

<u>EXPONENTIAL RATE OF CLOSURE</u>

The growth factors described above were used to determine the exponential rate of closure in the availability gap between gasoline and each ATF, for each penetration scenario. Assumptions and caveats in addition to the ones outlined above are provided after the table.

Table F-30. Availability Gap Closure Rates, By Scenario

FUEL TYPE	PENETRATION SCENARIO		
	BASE	HIGH	LOW
Diesel	99%	99%	99%
Ethanol	10%	20%	2%
Methanol	10%	20%	2%
CNG	10%	20%	2%
LPG	10%	20%	2%
Electricity	10%	40%	2%
Hydrogen	10%	10%	2%

ASSUMPTIONS AND CAVEATS

- Accelerated exponential rates in all penetration cases, especially in the high case, such that a common market would appear in the United States within ten to twenty years. The market arrival time span for each fuel was calculated based on each fuel individually without any other ATF challenger. Such a individual competition approach is inconsistent with the model specifications.

- Regional differences in availability are highly unlikely in any national market, though they can exist initially.

- Even though regional fuel price differences may persist due to transportation costs from producing or importing regions, availability differences cannot, and will not persist if a national market develops.

- It is not clear what constitutes availability for EV's, i.e., whether refueling time refers to recharging batteries as opposed to switching them. Therefore arbitrary assumptions have been made for this category.

SPECIFIC REFERENCES AND SOURCES

- **Gasoline** — Reformulated gasoline may require $20 to $40 billion in upgraded refineries (Woodruff, 1991, p.56).

- **Methanol** — Cannot be integrated into current distribution system without modifying the system: water tolerance and fuel contamination, materials compatibility in storage and distribution systems, fire and explosion hazards (A.P.I., September 1990, p.27).

- **CNG** — High pressure compressors cost $250,000 each (Woodruff, 1991, p.57).

- **LPG** — There are 10,000 propane refueling stations in the United States (Frank, 1992, p.106).

- **Hydrogen** — Supply of Hydrogen (Frank, August 1992, p.106).

VEHICLE RANGE

This section documents vehicle range in the database. The output of the database is vehicle range in miles for sixteen technologies for three vehicle sizes, through three penetration scenarios (high, low and base) from 1990 through 2030.

The general approach is to establish range (defined as average current miles between refueling) for a small vehicle, through an extensive literature search. The findings are used as base range figures to derive the other two vehicle sizes (e.g., large and medium) using a range credit or penalty. The credit/penalty is expressed as a percentage that lowers the base small vehicle range. Projected range is found by applying an annual simple percentage gain on the base current figures for each technology.

Thus, the inputs used to forecast vehicle range are:

- Miles between refueling for small cars in 1990, for all technologies.

- Range credit or penalty for mid-size and large cars in 1990, all fuels.
- Annual simple percentage gain in range, by vehicle type to 2030.

The results are displayed in miles for all vehicle-fuel types from 1990 to 2030.

CURRENT VEHICLE RANGE

This section describes current vehicle range. For each technology, the base small vehicle range in 1990 is based on the average number of miles between refueling found in the literature. These figures are shown in the following table, which also features the range credit or penalty for vehicle size. The credit is expressed as a percentage ranging from -10% to -15%, for mid and large size vehicles respectively. Sources for these figures are provided at the end of this section.

Table F-31. Current Small Vehicle Range and Size Range Credit

TECHNOLOGY	RANGE IN MILES (SMALL VEHICLE, 1990)	SIZE RANGE CREDIT	
		MID-SIZE	LARGE SIZE
Gasoline	350	-10.00%	-15.00%
Diesel	400	-10.00%	-15.00%
Ethanol Flex	260	-10.00%	-15.00%
Ethanol Neat	235	-10.00%	-15.00%
Methanol Flex	220	-10.00%	-15.00%
Methanol Neat	196	-10.00%	-15.00%
Electric	120	-10.00%	-15.00%
Electric Hyb/Large ICE	250	-10.00%	-15.00%
Electric Hyb/Small ICE	200	-10.00%	-15.00%
Electric Hybrid/Turbine	300	-10.00%	-15.00%
CNG	225	-10.00%	-15.00%
LPG	300	-10.00%	-15.00%
Turbine/CNG & Gasoline	100	-10.00%	-15.00%
Fuel Cell/Methanol & Hydrogen	100	-10.00%	-15.00%

SPECIFIC REFERENCES AND SOURCES: (Range in Miles)

- **Gasoline** — 424 (U.C.E.T.F., 1990, p.40).
- **Diesel** — 488 (U.C.E.T.F., 1990, p.40).
- **Ethanol Flex** — 331 (U.C.E.T.F., 1990, p.40).
- **Methanol Flex** — 350 for 1991 Ford Taurus 4D sedan; 400 for 1992 Ford Econoline van (NREL, 1992, on line); lower range than gasoline's by 40-43%, by 1995 38-41% (D.O.E., August 1990, p.13); 292 (U.C.E.T.F., 1990, p.40).
- **Methanol Neat** — 265 (U.C.E.T.F., 1990, p.40).
- **Electric** — 120 for 1992 GM Impact (G.M. Impact, 1992); 100 for Ford small van (NREL, 1992, on line); Pb-acid battery = 44, NiFe = 90, NaS = 207 (D.O.E.,August 1990, p.13);100 (U.C.E.T.F., 1990, p.40); 340 at 25 mph for Tokyo Electric Power prototype (Gross, 1992, p.74).
- **Electric Hybrid/Large I.C.E.** — 250 for 1993 Ford small Van (NREL, 1992, on line); 40 for electric engine extended range gasoline i.c.e. for the LA301 by International Automotive Design's (The Economist, September 28, 1991, pp.95,96).
- **Electric Hybrid/Small I.C.E.** — 300 for GM's HX3 gasoline prototype; 40 kilowatt generator to recharge its own batteries (Woodruff, 1991, p.59).
- **CNG** — 200 for 1992 GMC medium-duty truck (GM Natural Gas Powered, 1992); 200 for 1992 Chrysler Dodge B-series van/wagon NREL, 1992, on line); 1990-95 lower than gasoline by 61% (D.O.E.,August 1990, p.13); 106 (U.C.E.T.F., 1990, p.40).
- **LPG** — 34 (U.C.E.T.F., 1990, p.40).
- **Fuel Cell/Hydrogen** — 300-500 with electric engine and improved storage, i.e. liquid or absorption process (Rouse, 1991, p.15); 190 for BMW's liquid-hydrogen storage vehicle; 75 for Mercedes hydracide vehicle (Romano, 1989, pp.60, 61).

PROJECTED VEHICLE RANGE

Projected vehicle range for all technologies is found by applying an annual simple percentage gain to the current base for each technology. The annual gain is assumed to be 1% because most improvements in technology apply equally to all fuels, i.e., reduce air drag, advanced body materials. It is also assumed that there will be similar advances in areas that are not shared because the rationale for investment in R & D is the same regardless of fuel technology, i.e., fuel reformulation, engine enhancements. Market penetration does not affect the annual gain; therefore, the rate of 1% is valid for all penetration scenarios.

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Attachment 3: LDV Stock Module

Fuel Economy Gap Estimation

INTRODUCTION

This attachment presents long-term projections of the fuel efficiency degradation factor for automobiles and light-duty trucks. The projections are based on the analysis of important trends in driving patterns that affect fuel economy. These trends include the increase in urban share driving, urban congestion, and highway speeds. The projections are developed for the period 1990 through 2030. This appendix also outlines other efforts to project fuel economy degradation factors.[32]

BACKGROUND

A discrepancy exists between automotive fuel economy as measured by the Environmental Protection Agency (EPA) under controlled laboratory conditions and the actual fuel efficiency observed under real "on road" conditions. Public and private organizations such as the Department of Energy (DOE), the Environmental Protection Agency (EPA), Ford Motor Company, General Motors Corporation, and Mitsubitshi Motors Corporation have conducted independent research on fuel economy, in the past, confirming this discrepancy.[33] The fuel efficiency degradation factor (also known as "the gap") measures this discrepancy and is defined as the difference between on-road fuel economy and EPA tested fuel economy.[34] When fuel economy is expressed in terms of miles per gallons (MPG), the degradation factor or gap is formulated as:

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[32] This appendix is taken from a report which was prepared by Decision Analysis Corporation of Virginia (DAC) for the Energy Demand Analysis Branch of the Energy Information Administration (EIA), under Task No. 92010, Subtask 1, Contract No. DE-AC01-92EI21946.

[33] Davis, S. and Morris, M., Oak Ridge National Laboratory, Transportation Energy Data Book: Edition 12, ORNL-6710, (Edition 12 of ORNL-5198), p.3-9, March 1992.

[34] Westbrook, F. and Patterson, P., "Changing Driving Patterns and Their Effect on Fuel Economy," presented May 2, 1989 at the 1989 SAE Government/Industry Meeting, Washington, D.C.

$$GAP = \frac{EPA\ Test\ MPG\ -\ On\text{-}Road\ MPG}{EPA\ Test\ MPG}$$

On-road fuel efficiency depends on several determinants which can be classified into technological factors, driver behavior and habits, driving trends, and road and climate conditions. Furthermore, the magnitude of the gap between tested fuel efficiency and on-road fuel efficiency depends on the specific procedures and conditions used during the test and the closeness of the formulations used to represent real driving conditions.

EPA fuel economy estimates for city and highway driving are published every year for each new model available in the U.S.[35] These MPG estimates are obtained based on vehicle tests performed under controlled laboratory conditions and then adjusted downwards to reflect actual driving conditions. Separate tests are used to generate the city and highway MPG estimates.

The EPA city fuel economy estimates are based on a test that simulates a 7.5 mile, stop-and-go trip with an average speed of 20 mph. The trip lasts 23 minutes and has 18 stops. About 18 percent of the time is spent idling, such as waiting for traffic lights or in rush hour traffic. Two types of engine starts are used: a cold start and a hot start. The cold start is similar to starting the car in the morning after it has been parked all night. The hot start is similar to restarting a vehicle after it has been warmed up, driven and stopped for a short time.

The EPA highway fuel economy estimates represent a mixture of "non-city" driving. Segments corresponding to different kinds of rural roads and interstate highways are included. The test simulates a 10-mile trip and averages 48 mph. The test is run from hot start and has little idling time and no stops.

EPA adjusts these laboratory fuel economy estimates downwards to reflect actual driving on the road conditions. In the 1992 Gas Mileage Guide: EPA Fuel Economy Estimates the city estimates are lowered by 10 percent and the highway estimates by 22 percent from the laboratory test results. These adjustment factors represent the EPA estimates of the fuel efficiency gap for both city and highway driving.

Fuel economy can also be represented by a composite number that combines city and highway fuel

[35] DOE/EPA, Gas Mileage Guide: EPA Fuel Economy Estimates, DOE/CE-0019/10.

economies. EPA computes composite fuel economies using the following formulation:

$$EPA\ Composite\ MPG = \left[\frac{0.55}{MPG_c} + \frac{0.45}{MPG_h}\right]^{-1}$$

where:

MPG_c = Miles per gallon for city driving
MPG_h = Miles per gallon for highway driving

EPA's composite formulation is developed based on 55% city driving and 45% highway driving. This formulation, combined with the EPA city and highway fuel efficiency gaps, leads to a base composite MPG gap for all new vehicles of 15 percent.

Previous attempts at estimating the base fuel efficiency gap have been made. In 1978, McNutt et al., measured the gap for model year 1974 through model year 1977 cars. The resulting estimates of the gap were between 6 and 9 percent.[36] In 1984, Hellman and Murrel estimated a composite MPG gap of 15 percent.[37] More recently in 1992, Oak Ridge National Laboratory (ORNL) reported composite gap estimates that apply to all automobiles and light trucks in operation.[38] The ORNL base composite gap estimate for all automobiles in operation pre-1974 to 1989 was 15.2 percent. The ORNL gap estimate for light trucks in operation pre-1976 to 1989 was 28.3 percent. For this analysis, ORNL used EPA tested fuel economy data which was verified by the National Highway Safety Administration (NHTSA). These data were compared against on-road fuel economy data from (1) the Federal Highway Administration (FHWA) Highway Statistics 1989, (2) the Department of Energy, Energy Information Administration, 1988 Residential Transportation Energy Consumption Survey (RTECS), and (3) the Bureau of the Census, 1987 Census of Transportation, Truck Inventory and Use Survey (TIUS).

Very few attempts to forecast trends in the fuel economy gap are available. In 1989, Westbrook and

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[36] SAE 780037

[37] SAE 840496

[38] Davis, S. and Morris, M., Oak Ridge National Laboratory, Transportation Energy Data Book: Edition 12, ORNL-6710, (Edition 12 of ORNL-5198), p.3-9, March 1992.

Maples, John D., and Philip D. Patterson, "The Fuel Economy Gap for All Automobiles and Light Trucks in Operation," Draft, Washington, DC, 1991.

Patterson analyzed trends in driving patterns and produced forecasts of the fuel economy gap for the year 2010.[39] Their results indicated a composite gap of 29.7 percent for automobiles for the year 2010. This combined fuel efficient gap corresponded to a city fuel efficiency gap of 23.5 percent and a highway fuel efficiency gap of 30.5 percent. Organizations such as Data Resources Incorporated (DRI) and Wharton Econometrics Forecasting Associates (WEFA) use values for the degradation factors that remain constant over their forecasting horizon. The Department of Energy (DOE) and the Energy Information Administration (EIA) in the 1990 National Energy Strategy (NES) projected the fuel efficiency gap to reach 30 percent by 2030 in the NES reference case.[40] The projected gap for the High Conservation and the Very High Conservation cases of NES were 25 and 20 percent respectively. Also, EIA in the Annual Energy Outlook 1992 (AEO) projected the fuel efficiency gap to increase from 20 percent in 1990 to 25 percent in 2010.

An ongoing effort by DOE's Office of Transportation Technologies in conjunction with the University of Tennessee is focused on forecasting the fuel efficiency gap for automobiles and light duty trucks through 2010. This work considers three scenarios based on differing assumptions about urban shares, highway speed, and congestion trends.

This attachment presents independent projections of the fuel efficiency gap to the year 2030 for two vehicle types:

1) Automobiles, and
2) Light Duty Trucks.

The projections are generated based on the analysis of three important trends in driving patterns that affect fuel efficiency. These factors are:

1) increasing urban share of vehicle miles traveled,
2) increasing average highway speed, and
3) increasing level of urban highway congestion.

[39] Westbrook, F. and Patterson, P., "Changing Driving Patterns and Their Effect on Fuel Economy," presented May 2, 1989 at the 1989 SAE Government/Industry Meeting, Washington, D.C.

[40] EIA, Energy Consumption and Conservation Potential: Supporting Analysis for the National Energy Strategy, SR/NES/90-02, Service Report, p. 89, Washington, D.C., December 1990.

Initially, forecasts for each of these factors were developed based on two different growth scenarios:

1) Logistic Growth, and
2) Linear Growth

These scenarios are fully described as follows, using urban share growth as an example:

Logistic Approach

Figure F-1 shows the historical urban share of automobile VMT driving from 1972 through 1990 and a logistic curve fitted to the historical period and extended through the year 2030. The logistic share values are developed based on a logistic functional form originally formulated by Fisher and Pry [41] and defined by:

$$f_t^U = \frac{f_\infty^U}{1 + e^{-(\alpha+\beta t)}}$$

where:

f_t^U is the urban share in year t,

f_∞^U, is the urban share asymptotic limit, α and β are parameters of the logistic curve defined by:

$$\alpha = \ln[f_0^U / (f_\infty^U - f_0^U)],$$

$$\beta = (1/h^U)\ln[(f_\infty^U + f_0^U) / f_0^U],$$

where:

f_0^U is the base year urban share, and

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[41] Fisher, J.G. and Pry, R.M., "A Simple Substitution Model of Technology Change." Technological Forecasting and Social Change, Vol.3, pp.75-88, 1971.

h^u is the halving factor for the logistic curve. The halving factor is the time required from the base year for the urban share to reach the midpoint between its base year value and its asymptotic limit.

The logistic curve in Figure F-1 represents the curve that best fits the historical data on urban share for the 1972-1990 period. This curve is generated by assuming two logistic parameters and by selecting a base share year. These two parameters are the asymptotic limit and the halving factor. The asymptotic limit represents an upper limit to the growth of the urban share. The halving factor is a measurement of the time needed for the share to reach this upper limit. The values for both parameters are specific to the best fit curve and they are determined using an iterative approach which minimizes the sum of the squares of the difference between the historical shares and the logistic estimated shares.

Linear Approach

If it is assumed that the urban share will continue growing linearly, the impact on the fuel efficiency gap differs. Figure F-2 shows the historical urban share of automobile VMT driving from 1972 through 1990 and both a logistic curve and a straight line, fitted to the historical period and extended through the year 2030. The linear share forecasts developed by simple regression are considerably larger than those resulting from the logistic functional form.

The conclusions of the report noted that the logistic approach seemed to yield a more realistic projection of the gap. This was based largely on intuition, as the logistic approach can account for constraints which the linear approach cannot. As a result, logistic data were used in forming the model and are presented herein.

A total of two sets of projections were generated for each of the vehicle types, factors, and scenarios. The first was based on the assumption that all urban driving is city driving and all rural driving is highway driving. Fuel economy gap projections generated in the past are based on such an assumption, as it makes the gap calculations considerably easier. However, the assumption oversimplifies reality since some of the urban driving is on interstate highways and other freeways located in urban areas, and some of the rural driving includes stop-and-go city type of driving. The second set of projections were generated taking into consideration the decomposition of urban and rural driving into city and highway driving according to road types. This adjusted city/highway driving share approach was deemed more realistic. This is due to the fact that such an approach more closely resembles actual driving behaviour and consequently avoids the restricting assumption that urban driving is equal to city driving and rural driving is equal to highway driving. As such, only these calculations are included in this attachment.

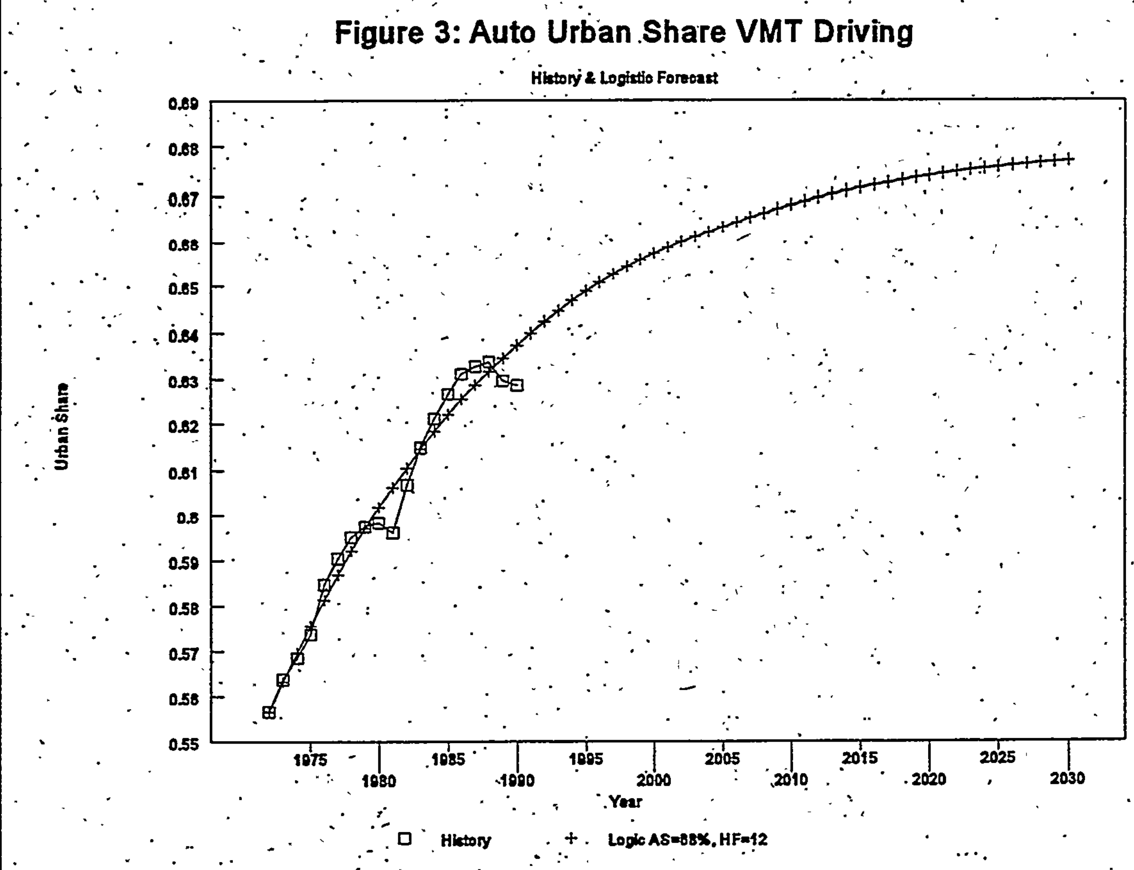
The decomposition is based on road types. Thus, VMT driving on roads identified as "interstate" and "other freeways and expressways" in urban areas are considered part of the highway driving share. Other road types located in urban areas are considered part of the city driving share. In addition, VMT driving on roads defined as "minor collectors" and "local" in rural areas are classified as city driving while the rest of the road types in rural area are considered highway driving. Although this road classification does not exactly replicate reality, it is a closer representation of the actual city/highway driving composition.

Approximately 63 percent of total 1990 VMT consisted of driving in urban areas and 37 percent in rural areas. 68 percent of the urban VMT is considered city driving and 32 percent highway driving. In rural areas, 17 percent is considered city driving and 83 percent highway driving. This composition represents overall city and highway driving shares for 1990 of:

City Share:	49.1 %
Highway Share:	50.9 %

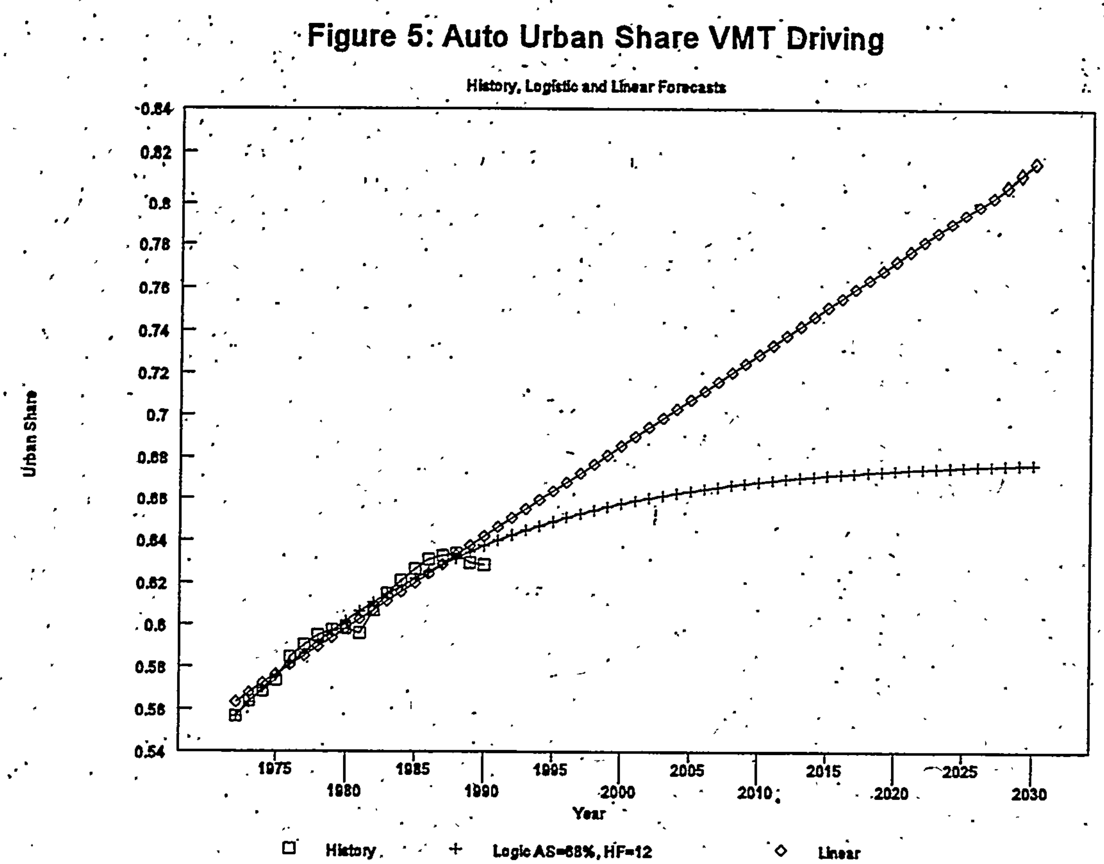
These adjusted city and highway shares are the bases for the calculations of the fuel efficiency gap projections in this chapter. The impact on fuel efficiency, from each of the three factors considered in this study, is affected by these adjusted shares. The impact from the increasing urban share trend is diminished since only part of the urban share (68% in 1990) is considered city share. The impact from increasing highway speeds is amplified since highway driving in both urban and rural areas is considered. Finally, the impact from increasing urban highway congestion is diminished since only part of the urban share is considered highway driving. The resulting fuel efficiency gap projections for automobiles and light duty trucks using the logistic approach based on these adjusted shares will be presented.

Figure F-1. Urban Share of Automobile VMT: Logistic Forecast



Source: Historical Values from U.S. DoT, FHWA, Highway Statistics, different yearly issues.

Figure F-2. Urban Share of Automobile VMT: Logistic and Linear Forecasts



Source: Historical Values from U.S. DoT, FHWA, Highway Statistics, different yearly issues.

FUEL EFFICIENCY GAP PROJECTIONS

This section outlines the three trends which are assumed to affect the fuel efficiency gap estimates of the EPA. It then presents the projections of the fuel efficiency gap which have been utilized in the NEMS Transportation Sector Model.

Increasing Urban Share Driving

A review of the data from the last few decades on VMT for both automobiles and light duty trucks reflects a continuous increase in the share of urban driving.[42] For automobiles the urban share increased from 45.4 percent in 1953 to 62.9 in 1990. Figure F-3 shows the historical urban share of VMT for automobiles. This represents a 38.5 percent increase in 37 years, or an average annual rate of increase of 0.88 percent. For light duty trucks the urban share increased from 39.5 percent in 1966 to 55.4 in 1990. Figure F-4 shows the historical urban share of VMT for light duty trucks. This represents a 40.3 percent increase in 24 years, or an average annual rate of increase of 1.42 percent.

Westbrook and Patterson investigated the reasons for this increase in urban share by analyzing the data for the period from 1975 through 1985.[43] Their results indicated that the major reasons for this increase are the larger fraction of travel in urban roads and a larger fraction of roads being classified as urban. Population shifts to urban areas and driving shifts within metropolitan areas account for the larger fraction in urban driving which was estimated to be the cause for 58 percent of the increase in urban share. The other 42 percent increase was determined to be the consequence of the reclassification of roads from rural to urban. Any area reclassified by the U.S. Bureau of the Census from rural to urban results in the reclassification of all roads (regardless of the type) as urban.

Forecasts of the shares of urban and highway driving are necessary in order to forecast the change in the fuel efficiency gap due to changes in driving shares. It is very difficult to draw conclusions about the increasing trend in urban driving. Nevertheless, it can be expected that population shifts to urban areas will continue and that future land developments will force

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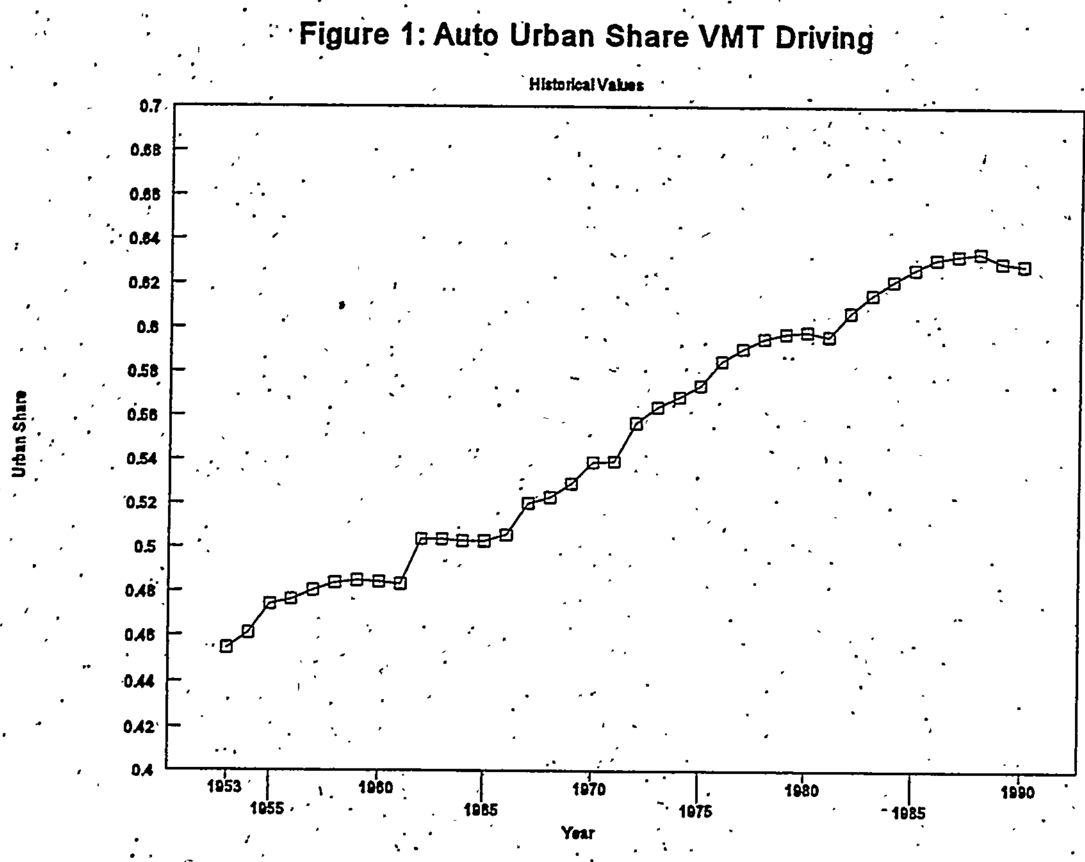
[42] Data on VMT is published annually by the U.S. Department of Transportation, Federal Highway Administration, in Highway Statistics.

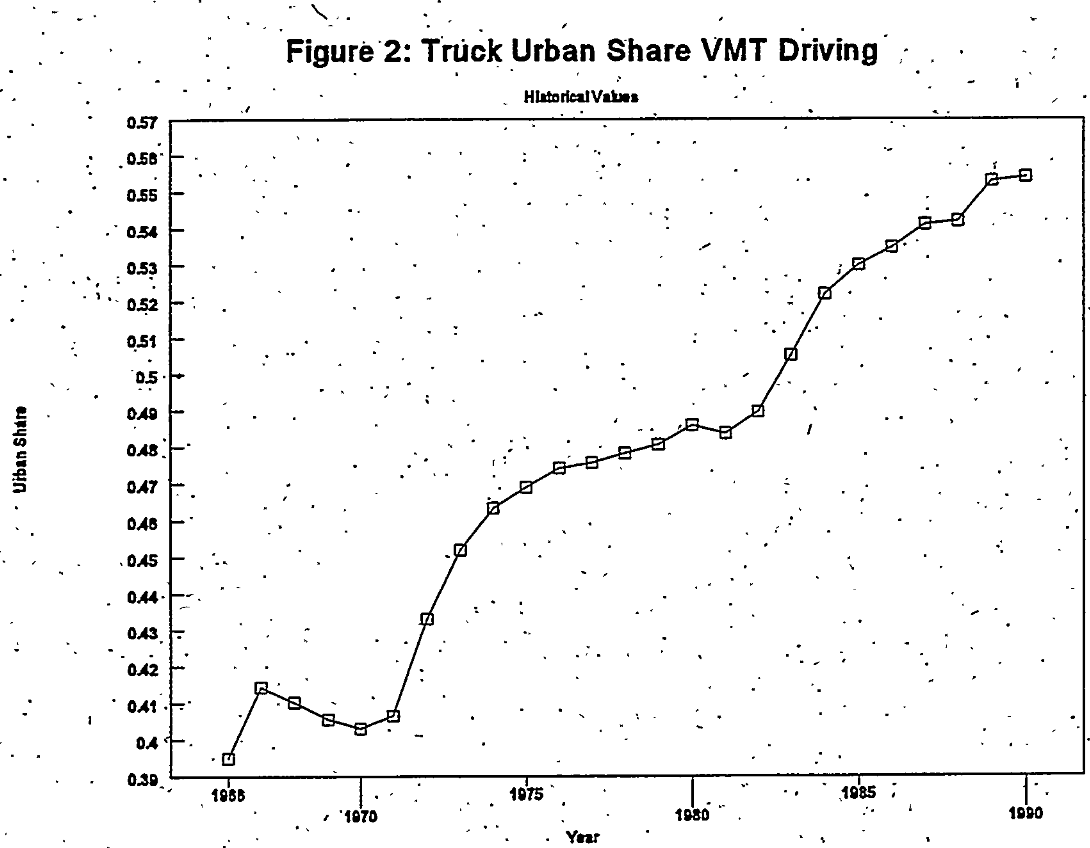
[43] Westbrook, F. and Patterson, P., "Changing Driving Patterns and Their Effect on Fuel Economy," presented May 2, 1989 at the 1989 SAE Government/Industry Meeting, Washington, D.C.

Figure F-3. Urban Share of Automobile VMT: 1953-1990



Source: Historical Values from U.S. DoT, FHWA, Highway Statistics, different yearly issues.

Figure F-4. Urban Share of Light Truck VMT: 1966-1990



Source: Historical Values from U.S. DoT, FHWA, Highway Statistics, different yearly issues.

the reclassification of rural areas into urban areas. If we assume that this rate of increase in urban share will gradually diminish and level off, the logistic path applies (see Figure F-1). The calculations for logistic growth of increased urban share for automobiles and light trucks follow.

Automobiles:

Table F-32 summarizes the impact of the adjusted logistic city share growth on the composite fuel efficiency gap for automobiles. The adjusted logistic city share projection for the year 2010 becomes 51.1 percent as compared to the unadjusted logistic share of 66.8 percent; in the year 2030, the projection levels off at 51.5 percent as compared to an unadjusted 67.7 percent projected logistically. The adjusted logistic forecasts of city share increase are translated into a fuel efficiency gap of 16.05 percent by the year 2030. This represents an increase of only 0.85 percentage points over the base gap of 15.2 percent.

Light Duty Trucks:

The influence of the adjusted logistic urban share growth on the composite fuel efficiency gap for light duty trucks is presented in Table F-33. For the year 2010 the adjusted logistic city share projection becomes 48.8 percent as compared to an unadjusted logistic share of 62.3 percent. For the year 2030, the projection begins to level off at 50.3 percent as compared to an unadjusted 65.2 percent projected logistically. The adjusted logistic forecasts of urban share increase are translated into a fuel efficiency gap of 29.73 percent by the year 2030. This represents an increase of only 1.43 percentage points over the base gap of 28.3 percent.

Table F-32. Automobile Fuel Efficiency Gap Projections: Logistic Growth of City Driving Share (with Adjusted City Driving Share)

	1988	1990	1995	2000	2005	2010	2015	2020	2025	2030
City Share	49.3%	49.1%	50.1%	50.5%	50.8%	51.1%	51.2%	51.4%	51.5%	51.5%
Base Gap	15.20	15.20	15.20	15.20	15.20	15.20	15.20	15.20	15.20	15.20
Gap Forecast	15.27	15.19	15.56	15.73	15.82	15.90	15.97	16.02	16.04	16.05
Change	0.07	-0.01	0.36	0.53	0.62	0.70	0.77	0.82	0.84	0.85

Sources: Base Gap from ORNL 1992, Urban Share Forecasts based on Fisher & Pry Logistic Function.

Table F-33. Light Truck Fuel Efficiency Gap Projections: Logistic Growth of City Driving Share (with Adjusted City Driving Share)

	1988	1990	1995	2000	2005	2010	2015	2020	2025	2030
City Share	44.6%	45.3%	46.3%	47.3%	48.1%	48.8%	49.3%	49.7%	50.0%	50.3%
Base Gap	28.30	28.30	28.30	28.30	28.30	28.30	28.30	28.30	28.30	28.30
Gap Forecast	28.30	28.48	28.72	28.98	29.21	29.35	29.50	29.60	29.66	29.73
Change	0.00	0.18	0.42	0.68	0.91	1.05	1.20	1.30	1.36	1.43

Sources: Base Gap from ORNL 1992, Urban Share Forecasts based on Fisher & Pry Logistic Function.

Increasing Highway Speeds

The level of speed of a vehicle is one of the relevant factors that affects its fuel efficiency. Specifically, it has been determined that speeds over 45 mph decrease fuel efficiency for most vehicles. Furthermore, EPA estimates that traveling at 65 mph as compared to 55 mph lowers fuel economy over 15 percent.[44] ORNL's 1992 Transportation Energy Data Book presents the findings of a fuel economy study performed by the Federal Highway Administration in 1984.[45] This study concluded that, on average, vehicles experience fuel efficiency losses of about 17.8 percent when their speed is increased from 55 mph to 65 mph. This is equivalent to a reduction of 1.78 percent for each mile per hour increase over speed ranging from 55 mph to 65 mph.

Average highway speeds in the United States have shown an increasing trend for several years with few exceptions. Figure F-5 presents average highway speeds in mph for the last 45 years. The data in this figure indicate two different increasing trend periods. The first period from 1945 through 1973 corresponds to the largest rate of increase on highway speeds. During these years, highway speed increased at an annual rate of 1.13 percent. In 1973, average highway speed suddenly dropped from about 66 mph to about 55 mph. This sudden drop corresponds to the implementation of the nationwide 55 mph speed limit. After 1974, the increasing trend has continued at a more moderate rate. In the 1974-1990 period the annual rate of speed increase has been 0.15 percent. A closer look at the post-1973 period indicates that through the rest of the 1970s, the average speed remained fairly constant between 55 and 56 mph; and, through the 1980s, the annual rate of increase was 0.34 percent.

The increase in highway speed can also be illustrated by considering the percentage of rural and urban VMT driving over 55 mph on highways with posted speed limits of 55 mph. Figure F-6 presents these data for the 1981-1990 period. In only 9 years, the percent of rural VMT driving over the 55 mph speed limit rose from 46.4 percent to 58.7 percent for a total of 12.3 percentage points. The percentage increase in urban VMT driving was even more dramatic, from 37.6 percent to 53.8 percent for a total of 16.2 percentage points. The percentage exceeding the speed limit is far from homogeneous. Significant differences exist across states, highway types, and location for rural or urban areas. For instance, in 1990 the percentage of vehicles exceeding the 55 mph limit in urban interstate highways in New York was 82.5 as compared to 68.2 in California and only 33.7 in South

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[44] DOE/EPA, 1992 Gas Milage: EPA Fuel Economy Estimates, DOE/CE-019/10, October 1991.

[45] Davis, S. and Morris, M., Oak Ridge National Laboratory, Transportation Energy Data Book: Edition 12, ORNL-6710, (Edition 12 of ORNL-5198), Table 3.42, p.3-66, March 1992. 1984 data from U.S. Department of Transportation, Federal Highway Administration, Fuel Consumption and Emission Values for Traffic Models, Washington, D.C., May 1985.

Dakota.

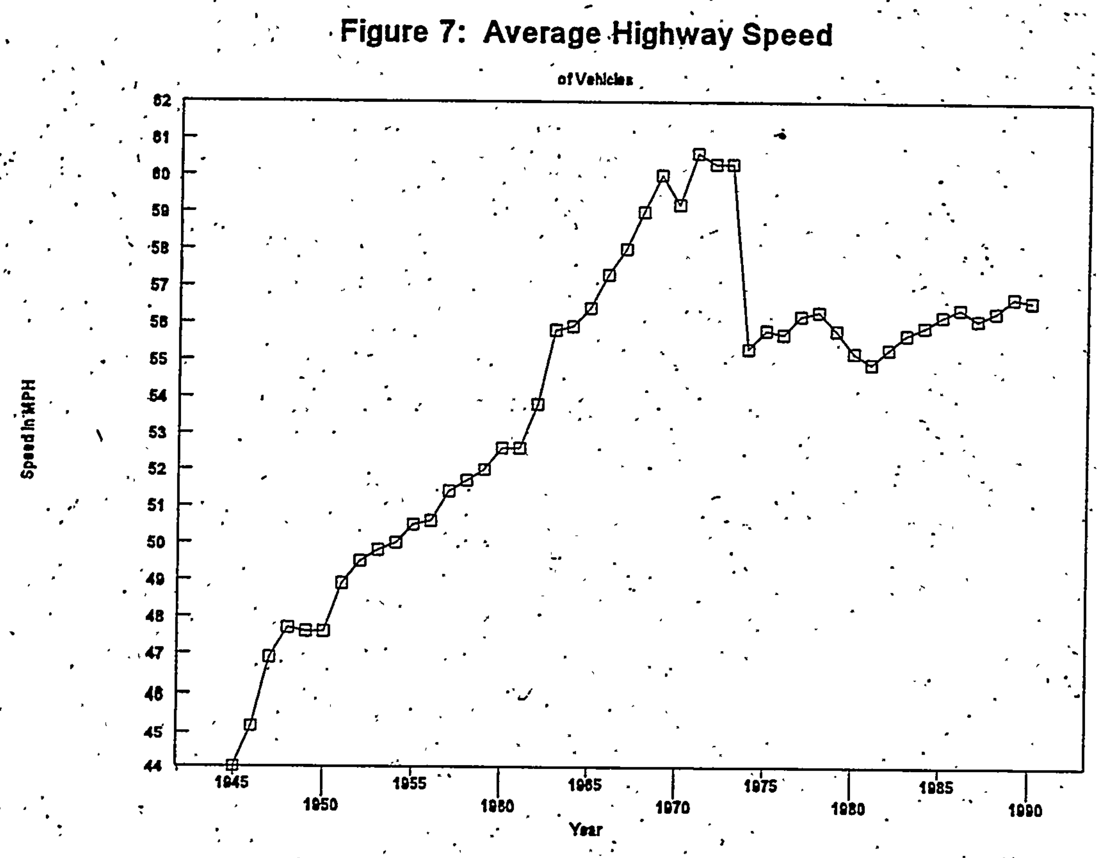
The estimation of the overall impact of speed trends in fuel economy is dependent on the specific data type selected to measure this trend and on the methodology used to forecast this trend. One could choose a disaggregated approach in which speed trend forecasts are developed by urban and rural driving, highway type, and vehicle type, for each state. Given the time limitations, the current study utilizes the nationwide average highway speed for all vehicles and highway types. Average speeds post-1980 are used as the basis to generate forecasts.

As Figure F-5 illustrates, average highway speed is influenced by regulatory policies such as the implementation of the nationwide speed limit in 1973-1974. Other factors affecting speed might include safety and environmental regulations, gasoline prices, oil shortages, income fluctuations, etc. Although a methodology to forecast speed trends which includes all relevant factors is desirable, a logistic approach based on historical trends has been applied.

Automobiles:

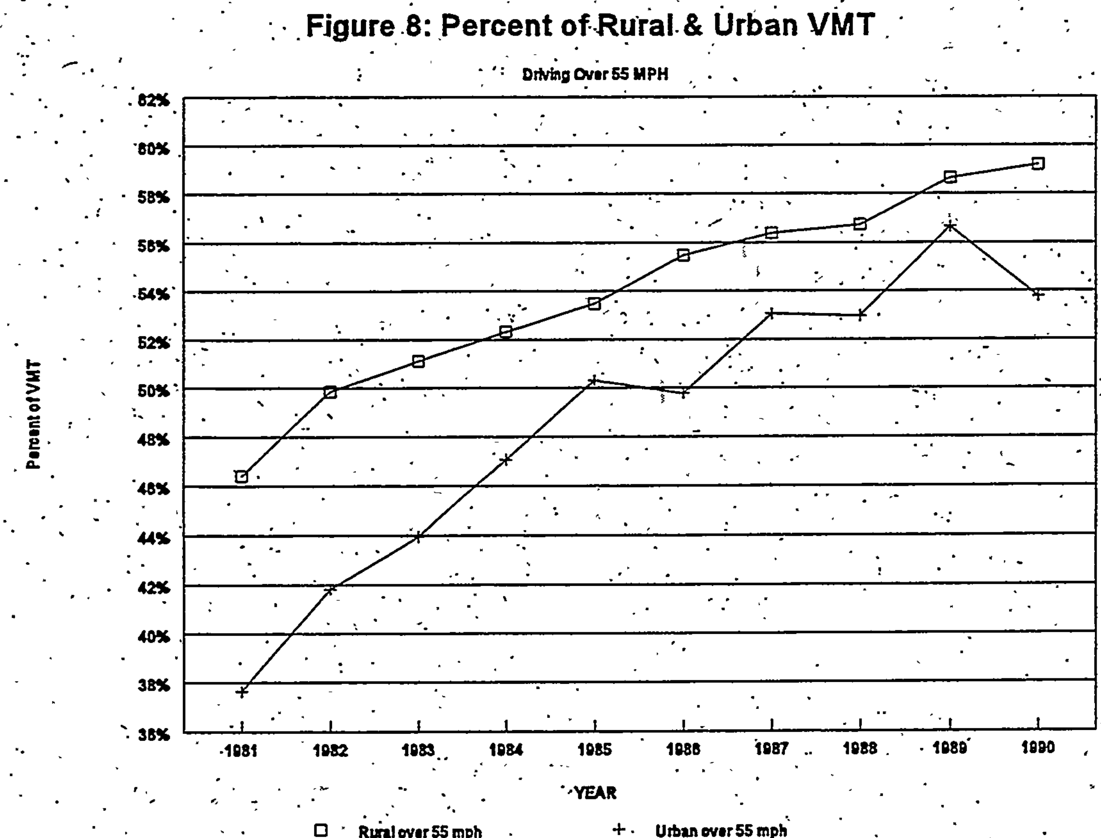
Table F-34 summarizes the impact of the adjusted highway share speeds on the composite fuel efficiency gap for automobiles using the logistic approach. Unlike the adjusted results for the urban driving share, the fuel efficiency gap forecasts indicate that in 2010 the gap has increased to 17.02 percent, which is greater than the unadjusted logistic forecast of 16.58 percent. By the year 2030, the adjusted forecast is 18.27 percent, which is above the unadjusted logistic forecast of 17.47. By the year 2030, the adjusted gap is 3.07 percent above the base gap of 15.2 percent.

Figure F-5. Average Vehicle Highway Speed: 1945-1990



Source: Historical Values from U.S. DoT, FHWA, Highway Statistics, different yearly issues.

Figure F-6. Percent of Highway VMT over 55 MPH: 1981-1990



Note: Based on data for roads with posted speed limit of 55 mph.

Source: Historical values from U.S. DoT, FHWA, Highway Statistics, different yearly issues.

Table F-34. Automobile Fuel Efficiency Gap Projections: Logistic Growth of Average Highway Speed (with Adjusted Highway Driving Shares)

	1988	1990	1995	2000	2005	2010	2015	2020	2025	2030
Highway Speed,mph	56.30	56.60	57.41	58.06	58.66	59.22	59.75	60.23	60.69	61.11
Base Gap	15.20	15.20	15.20	15.20	15.20	15.20	15.20	15.20	15.20	15.20
Gap Forecast	15.19	15.39	15.89	16.31	16.67	17.02	17.38	17.70	18.00	18.27
Change	-0.01	0.19	0.69	1.11	1.47	1.82	2.18	2.50	2.80	3.07

Sources: Base Gap from ORNL 1992, Highway Speed Forecasts based on Fisher & Pry Logistic Function.

Table F-35. Light Truck Fuel Efficiency Gap Projection: Logistic Growth of Average Highway Speed (with Adjusted Highway Driving Share)

	1988	1990	1995	2000	2005	2010	2015	2020	2025	2030
Highway Speed,mph	56.30	56.60	57.41	58.06	58.66	59.22	59.75	60.23	60.69	61.11
Base Gap	28.30	28.30	28.30	28.30	28.30	28.30	28.30	28.30	28.30	28.30
Gap Forecast	28.29	28.49	28.95	29.35	29.74	30.07	30.43	30.73	31.01	31.29
Change	-0.01	0.19	0.65	1.05	1.44	1.77	2.13	2.43	2.71	2.99

Sources: Base Gap from ORNL 1992, Highway Speed Forecasts based on Fisher & Pry Logistic Function.

Light Duty Trucks:
Table F-35 displays the fuel efficiency gap projections for light duty trucks assuming logistic growth for average highway speed and an adjusted driving share to reflect the city to highway driving proportion. The adjusted logistic projections imply that the fuel efficiency gap for light duty trucks will be 30.07 percent for an increase of 1.77 percentage points over the base gap in the year 2010. The gap forecast is larger than the unadjusted logistic projection of 29.74 percent. By 2030 the adjusted logistic forecast is 2.99 percent above the base gap of 28.30 percent, while the unadjusted logistic is 2.39 percent above the base gap. This implies a fuel efficiency gap of 31.29 percent in 2030.

Increasing Urban Highway Congestion

Congestion is a primary issue of the domestic transportation system. Urban congestion has increased in the last decades in most metropolitan areas as expansion and improvement of the transportation system lagged behind the rapid growth of travel demand.

The Federal Highway Administration (FHWA) classifies the two major causes of urban road congestion as recurring congestion and non-recurring congestion. Recurring congestion is that congestion which is the consequence of inadequate road capacity, reduction of through-put lanes, narrowing of lane widths, physical barriers, inadequate traffic light synchronization, and other similar causes. FHWA estimates that recurrent congestion accounts for 40 percent of all urban road congestion. Non-recurring congestion is that congestion resulting from disabled vehicles and accidents. FHWA estimates that disablement account for 55 percent of overall urban congestion, with the remaining 5 percent due to accidents.

One of the most important road types within urban areas in which congestion takes place is urban freeways. In 1990, 32 percent of the total vehicle miles of travel in urban areas corresponded to freeways, while freeways comprised only 5.7 percent of the urban roadway mileage.[46] The increase in urban congestion can be further analyzed by considering the increase in urban VMT as compared to the increase in urban lane miles. Data corresponding to the period 1975-1987 indicate that urban VMT demand growth rate is over 4 times the rate of new urban lane capacity growth. This corresponds to an increase in the average urban through-put (urban VMT per mile) of 38.9 percent.

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[46] U.S. DOT, FHA, Highway Statistics 1990.

Differing methodologies have been developed recently to measure the extent and duration of freeway congestion in urban areas.[47][48] Hanks and Lomax of the Texas Transportation Institute (TTI) have developed congestion indices for 39 urban areas. Table F-36 lists VMT, VMT per lane-mile, congestion indices, and rankings for each of the urban areas analyzed by TTI. Table F-37 lists, in addition to the congestion indices, estimates of the congestion cost per capita for each of these urban areas. Few attempts to forecast urban congestion and its effect on fuel economy are available.[49]

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[47] Cottrell, P., "Measurement of the Extent and Duration of Freeway Congestion in Urbanized Areas,"ITE 61st Annual Meeting, Milwaukee, Wisconsin, Sept. 1991.

[48] Hanks, J., and Lomax, T., Roadway Congestion in Major Urban Areas: 1982 to 1987, Texas Transportation Institute, Research Report 1131-2, College Station, Texas, Oct. 1989.

[49] Lindley, J., "Urban Freeway Congestion Problems and Solutions: An Update," ITE Journal, Dec. 1989, pp. 21-23. Feng, An, "Automobile Fuel Economy and Traffic Congestion," Dissertation for PhD in Applied Physics, University of Michigan, 1992. Westbrook, F. and Patterson, P., "Changing Driving Patterns and Their Effect on Fuel Economy," presented May 2, 1989 at the 1989 SAE Government/Industry Meeting, Washington, D.C.

Table F-36. Congestion Index Value for Selected Cities

Urban Area	Freeway/Expressway Streets DVMT[1]	Freeway/Expressway Streets DVMT[2]	Principal Arterial DVMT[1]	Principal Arterial DVMT[2]	Congestion[3] Index	Rank
Western & Southern Cities	4,580	295	16,475	2610	1.23	4
Phoenix AZ	96,890	4,880	73,810	11,780	1.47	1
Los Angeles CA	8,055	660	6,135	1,000	1.00	17
Sacramento CA	23,155	1,640	8,180	1,560	1.08	12
San Diego CA	39,580	2,305	12,670	2,005	1.31	2
Denver CO	9,550	830	10,600	1,930	0.95	22
Miami FL	7,420	555	13,000	2,000	1.14	7
Tampa FL	3,300	280	3,880	610	1.02	16
Atlanta GA	23,940	1,600	9,350	1,500	1.16	6
Indianapolis IN	7,640	710	4,100	835	0.85	32
Louisville KY	5,380	515	2,975	520	0.86	30
Kansas City MO	11,920	1,410	4,350	910	0.69	39
St. Louis MO	16,290	1,430	11,215	1,745	0.96	20
Albuquerque NM	2,025	200	3,550	650	0.91	26
Oklahoma City OK	6,330	700	3,465	655	0.76	36
Portland OR	6,700	540	3,200	525	1.00	17
Memphis TN	3,730	375	3,930	760	0.84	34
Nashville TN	5,000	430	4,915	905	0.95	22
Salt Lake City UT	3,810	410	1,865	340	0.78	35
Seattle-Everett WA	16,600	1,140	8,950	1,475	1.14	7
Northeast & Midwest Cities						
Washington DC	22,910	1,555	18,400	2,240	1.25	3
Chicago IL	30,945	2,260	24,965	3,870	1.11	9
Baltimore MD	13,735	1,200	9,020	1,680	0.92	25
Boston MA	20,205	1,490	13,700	2,675	1.04	14
Detroit MI	21,800	1,610	21,545	3,450	1.10	11
Minn-St. Paul MN	15,620	1,230	5,200	1,160	0.97	19
New York NY	73,615	5,385	46,490	6,930	1.11	9
Cincinnati OH	9,560	845	3,315	790	0.87	29
Cleveland OH	11,185	960	4,840	1,100	0.89	27
Philadelphia PA	15,125	1,370	22,550	3,150	1.06	13
Pittsburgh PA	7,190	925	9,905	1,510	0.85	32
Milwaukee WI	6,820	570	4,640	930	0.94	24
Major Texas Cities						
Austin TX	5,150	420	2,150	415	0.96	20
Corpus Christi TX	1,500	180	1,490	320	0.72	37
Dallas TX	22,100	1,640	8,200	1,690	1.03	15
El Paso TX	3,200	345	3,000	805	0.72	37
Fort Worth TX	11,000	990	4,250	840	0.88	28
Houston TX	25,800	1,640	10,500	1,970	1.19	5
San Antonio TX	8,800	810	4,800	1,050	0.86	30
West/South Avg	15,095	1,045	9,750	1,715	1.01	
North/Midwest Avg	20,725	1,615	15,380	2,455	1.01	
Outside TX Avg	17,205	1,260	11,860	1,995	1.01	
Texas Avg	11,080	860	4,910	1,015	0.91	
Congested TX Avg	14,570	1,100	5,980	1,195	0.98	
Total Avg	16,105	1,190	10,610	1,820	0.99	
Maximum Value	96,890	5,385	73,810	11,780	1.47	
Minimum Value	1,500	180	1,490	320	0.69	

Note: Congested Texas cities average includes Austin, Dallas, Fort Worth, Houston, and San Antonio.

[1]Daily vehicle-miles of travel

[2]Daily vehicle-miles of travel per lane-mile

[3]See Equation s-1

Table F-37. 1987 Urban Area Rankings by Congestion Index and Cost per Capita

Urban Area	Congestion Index		Congestion Cost per Capita	
	Value	Rank	Value (Dollars)	Rank
Western & Southern Cities				
Phoenix AZ	1.23	4	510	10
Los Angeles CA	1.47	1	730	2
Sacramento CA	1.00	17	360	19
San Diego CA	1.08	12	280	25
San Fran-Oakland CA	1.31	2	670	3
Denver CO	0.95	22	420	14
Miami FL	1.14	7	670	4
Tampa FL	1.02	16	340	22
Atlanta GA	1.16	6	650	5
Indianapolis IN	0.85	32	100	38
Louisville KY	0.86	29	180	31
Kansas City MO	0.69	39	130	35
St. Louis MO	0.96	20	380	17
Albuquerque NM	0.91	26	250	27
Oklahoma City OK	0.76	36	170	34
Portland OR	1.00	18	300	24
Memphis TN	0.84	34	210	29
Nashville TN	0.95	23	380	18
Salt Lake City UT	0.78	35	120	36
Seattle-Everett WA	1.14	8	580	6
Northeast & Midwest Cities				
Washington DC	1.25	3	740	1
Chicago IL	1.11	9	340	21
Baltimore MD	0.92	25	340	23
Boston MA	1.04	14	400	16
Detroit MI	1.10	11	480	11
Minn-St. Paul MN	0.97	19	240	28
New York NY	1.11	9	430	12
Cincinnati OH	0.87	29	180	32
Cleveland OH	0.89	27	170	33
Philadelphia PA	1.06	13	520	9
Pittsburgh PA	0.85	32	410	15
Milwaukee WI	0.94	24	190	30
Major Texas Cities				
Austin TX	0.96	21	420	13
Corpus Christi TX	0.72	37	80	39
Dallas TX	1.03	15	530	8
El Paso TX	0.72	37	110	37
Fort Worth TX	0.88	27	360	20
Houston TX	1.19	5	550	7
San Antonio TX	0.86	30	260	26

Source: Hanks, J., and Lomax, T., Roadway Congestion in Major Urban Areas: 1982 to 1987, TTI, Research Report 1131-2, College Station, TX, Oct. 1989.

Lindley's projections of consumption statistics for the year 2005 take into account factors including time delays, wasted fuel, and user cost. The urban freeway congestion statistic projections developed by Lindley are presented in Table F-38.

The projections generated in this study utilize the wasted fuel values developed by Lindley as the basis to measure the impact of urban congestion on the fuel efficiency gap. The study further assumes that the amount of wasted fuel due to congestion will increase following a logistic trend.

The amount of wasted fuel is divided between automobiles and light duty trucks assuming that the light duty trucks VMT driving share will increase from 23.4 percent in 1989 to 33 percent in 2010, and will remain constant at 33 percent through 2030.

Automobiles:
The wasted fuel forecast due to traffic delays for the year 2010 is 9,164 mil.gal. and for the year 2030 it is 11,426 mil.gal. as summarized in Table F-39. This implies that the fuel efficiency gap will be 18.66 percent in 2010 and 23.08 percent in 2030. These are lower projections as compared to the unadjusted figures of 21.53 percent and 26.32 percent corresponding to the same years.

Light Duty Trucks:
Table F-40 presents the fuel efficiency gap projections for light duty trucks based on adjusted city/highway shares and assuming logistic growth of wasted fuel due to congestion. The wasted fuel forecast for light duty trucks for the year 2010 is 4,513 mil.gal. and for the year 2030 it is 5,628 mil.gal. This implies that the fuel efficiency gap will be 32.77 percent in 2010 and 33.43 percent in 2030 as compared to the unadjusted figures of 32.91 percent and 34.09 percent.

Overall Degradation Factor Forecast

Figures F-7 and F-8 summarize the projections of the fuel efficiency gap using assumptions of logistic growth and adjusted city/highway shares for automobiles and light duty trucks, respectively. The overall results are listed in Table F-41.

As illustrated in Table F-41, the logistic approach generates lower forecasts for the overall fuel efficiency gap for both automobiles and light duty trucks as compared to the ones generated using the linear approach. The overall fuel efficiency gap for automobiles is expected to increase from a base of 15.2 to 27.00 by the year 2030 assuming a logistic trend. The fuel efficiency gap will increase further to 34.07 if a linear trend is assumed instead. The overall fuel efficiency gap for light duty trucks is expected to increase from a base of 28.3 to 37.85 or 42.91 by the year 2030 assuming logistic and linear growth respectively.

Table F-38. Urban Freeway Congestion Statistics

	1984	1987	(1984 data) 2005	(1987 data) 2005
Freeway Miles	15335	16097	15335	16097
Vehicle-Miles of Travel (billions)	277	337	411.0	493
Recurring delay (million vehicle-hours)	485	728	2049	3030
Delay due to incidents (million vehicle-hours)	767	1287	4858	7978
Total delay (million vehicle-hours)	1252	2015	6907	11008
Total wasted fuel (million gallons)	1378	2206	7317	11638
Total user costs (billion dollars)	9	16	51	88

Source: Lindley, J., "Urban Freeway Congestion Problems and Solutions: An Update," ITE Journal, December 1989, pages 21-23.

Table F-39. Automobile Fuel Efficiency Gap Projections: Logistic Increasing Congestion Trend (with Adjusted City/Highway Driving Share)

	1990	1995	2000	2005	2010	2015	2020	2025	2030
Wasted Fuel (Million Gallons)	2252	3865	5788	7764	9164	10284	10924	11259	11426
Base Gap	15	15	15	15	15	15	15	15	15
Gap Forecast	15.69	16.37	17.34	18.20	18.66	22.08	22.50	22.79	23.08
Change	0.49	1.17	2.14	3.00	3.46	6.88	7.30	7.59	7.88

Figure F-7. Fuel Efficiency Gap for Automobiles (with Adjusted Driving Share)

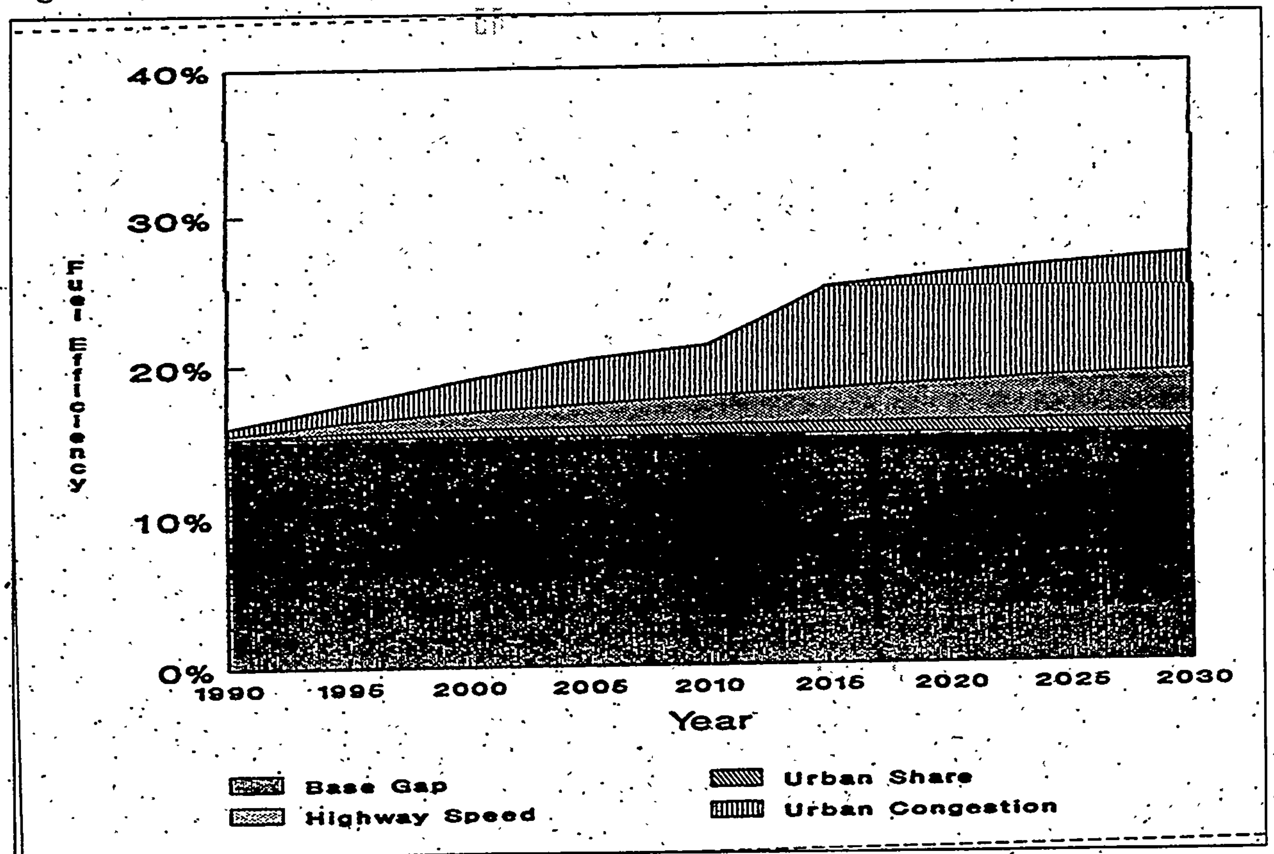


Figure F-8. Fuel Efficiency Gap for Light Duty Trucks (Logistic Forecast)

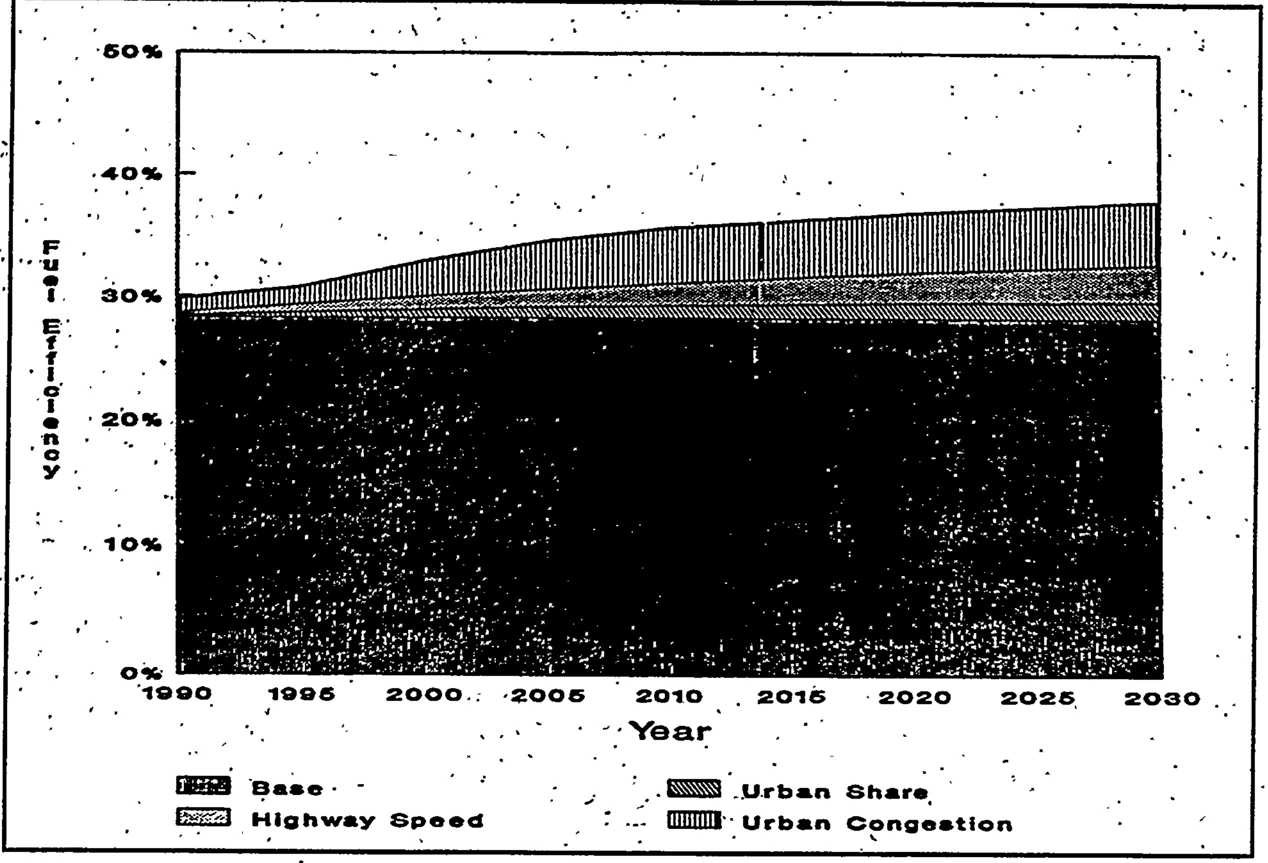


Table F-40. Light Truck Fuel Efficiency Gap Projections: Logistic Increasing Congestion Trend (with Adjusted City/Highway Driving Share)

	1990	1995	2000	2005	2010	2015	2020	2025	2030
Wasted Fuel (Million Gallons)	611	1203	2240	3375	4513	5065	5380	5545	5628
Base Gap	28.3	28.3	28.3	28.3	28.3	28.3	28.3	28.3	28.3
Gap Forecast	29.41	29.76	31.17	32.17	32.77	32.89	33.14	33.28	33.43
Change	1.11	1.46	2.87	3.87	4.47	4.59	4.84	4.98	5.13

Table F-41. Total Fuel Efficiency Gap Projections for Automobiles and Light Duty Trucks with Adjusted City/Highway Driving Share

	1990	1995	2000	2005	2010	2015	2020	2025	2030
AUTOMOBILES									
Base Gap	15.20	15.20	15.20	15.20	15.20	15.20	15.20	15.20	15.20
Gap Forecast	15.87	17.42	18.98	20.29	21.18	25.03	25.82	26.43	27.00
Change	0.67	2.22	3.78	5.09	5.98	9.83	10.62	11.23	11.80
L. D. TRUCKS									
Base Gap	28.30	28.30	28.30	28.30	28.30	28.30	28.30	28.30	28.30
Gap Forecast	29.78	30.83	32.90	34.52	35.59	36.22	36.87	37.35	37.85
Change	1.48	2.53	4.60	6.22	7.29	7.92	8.57	9.05	9.55

Characteristics of Fleet Vehicles

Aggregation of EPACT Requirements

Under the provisions of EPACT, purchases of vehicles by fleets meeting certain criteria are affected by the requirement that a proportion be alternatively fueled. The specific conditions under which these provisions are in effect, and the fleet sizes which are affected are not static, but are subject to revision. The impact of the current legislation on different fleet types is tabulated below.[50]

Table F42: Federal Mandates for Alternative-Fueled Vehicles

Year	Percent of Total Light Duty Vehicle Acquisitions				
	Federal	State	Fuel Providers	Electric Utilities	Municipal & Private
1996	25	10	30	—	—
1997	33	15	50	—	—
1998	50	25	70	30	—
1999	75	50	90	50	20
2000	75	75	90	70	20
2001	75	75	90	90	20
2002	75	75	90	90	30
2003	75	75	90	90	40
2004	75	75	90	90	50
2005	75	75	90	90	60
Thereafter	75	75	90	90	70

Affected fleets are also distinguished by geographical location: fleets of 50 or more of which 20 or more are located in metropolitan areas with a population over 250,000 with the capability of central refueling.[51] Federal mandates for the three fleet types considered by the model are estimated using a stock-weighted average of the relevant categories above, and identified as $EPACT3_{ITY,T}$ in the code.

[50]The table has been reproduced from *Alternatives To Traditional Transportation Fuels 1994, Volume 1,* U.S. Department of Energy, Energy Information Administration, DOE/EIA-0585(94)1, February 1996, Table 1.

[51]PL 102-486 §301(5)(A)&(B), and §301(9), 10 CFR 106 STAT. 2866, et. seq.

Business fleets are directly mapped to the "Municipal and Private" column above, government fleets combine "Federal" and "State" requirements, and Utility fleets combine the "Fuel Providers" and "Electric Utilities" mandates. Weighting factors are derived from recent stock estimates, and are subject to periodic revision.

Business Fleet Stratification for Automobiles

Vehicles which are categorized under the somewhat broad definition of business fleets include automobiles used for daily rental and long term leasing--vehicles not intended to be covered under the alternative fuel provisions of EPACT. As the AEO95 model was structured, all business fleet vehicles were considered to be covered by the legislation, resulting in an elevated estimate of the consequent sales of alternative fuel vehicles. A time series of the number of automobiles in each category is tabulated in the table below. The fraction of business fleet vehicles which would be subject to EPACT shows a distinct downward trend over the past twenty years, as depicted below, reaching approximately 50 percent in 1990.

Table F-43: Business Fleet Distribution of Vehicles

	Business Fleets			Percent Covered
	Total	Covered	Uncovered	
1971	3,900	2,336	1,564	59.90%
1972	4,107	2,449	1,658	59.63%
1973	4,430	2,691	1,739	60.74%
1974	4,482	2,740	1,742	61.13%
1975	4,553	2,763	1,790	60.69%
1976	4,858	2,911	1,947	59.92%
1977	5,075	2,952	2,123	58.17%
1978	5,411	3,003	2,408	55.50%
1979	5,554	3,054	2,500	54.99%
1980	5,692	3,139	2,553	55.15%
1981	5,679	3,163	2,516	55.70%
1982	5,567	3,125	2,442	56.13%
1983	5,641	3,182	2,459	56.41%
1984	5,972	3,216	2,756	53.85%
1985	6,184	3,276	2,908	52.98%
1986	6,438	3,163	3,275	49.13%
1987	6,606	3,298	3,308	49.92%
1988	6,869	3,414	3,455	49.70%
1989	6,978	3,413	3,565	48.91%
1990	6,974	3,455	3,519	49.54%

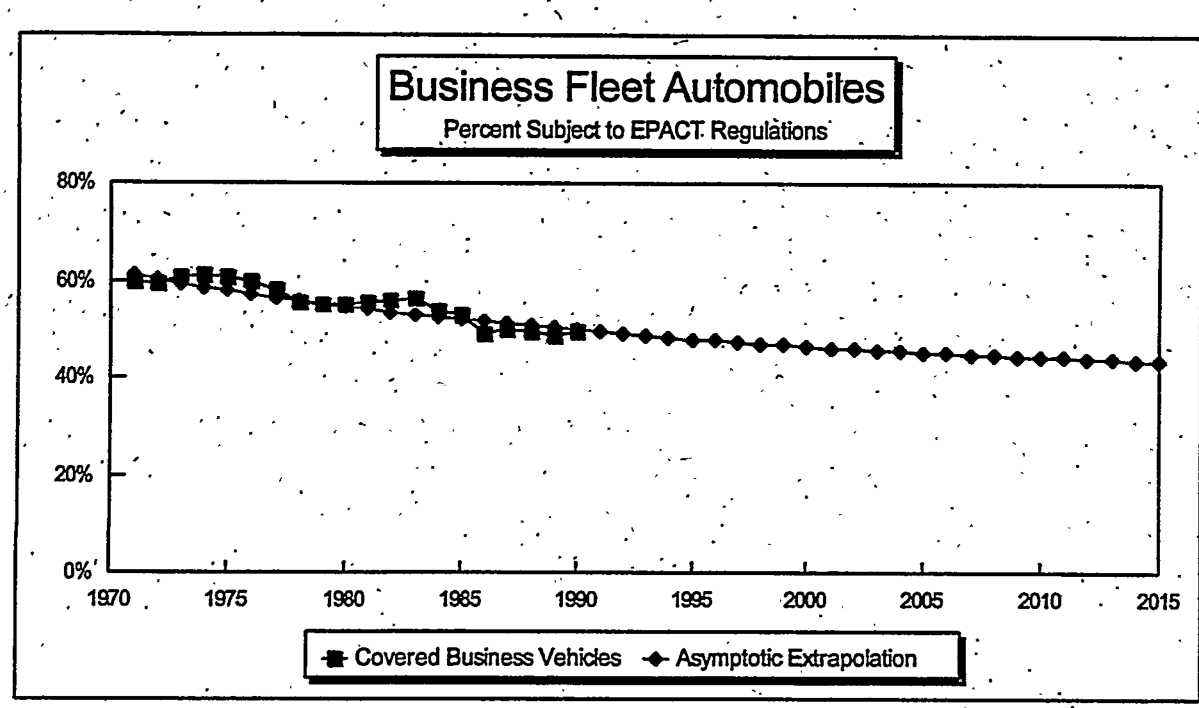
A new variable, BFLTFRAC, has been established to further stratify the stock of business fleet cars, with only the "covered" vehicles being used to estimate AFV purchases under EPACT. This variable is estimated using an asymptotic extrapolation of the historical trend, using an assumed lower limit of 40 percent, and a functional form as follows:

$$BFLTFRAC_{T-1971} = BFLTFRAC_{MIN} + (BFLTFRAC_{MAX} - BFLTFRAC_{MIN}) \cdot EXP^{(K_2 \cdot (T-1971))}$$

The input assumptions, estimated coefficients, and extrapolated values of BFLTFRAC are provided below.

Covered Business Fleet Extrapolation	
Input Assumptions	
$BFLTFRAC_{MIN}$	40%
$BFLTFRAC_{MAX}$	61.2%
Base Year	1971
Regression Output	
k_2	-0.0404
R^2	0.839

Figure F-9: EPACT Effects on Business Fleet Automobiles



Distribution of Fleet Light Trucks

As noted in the amended documentation, the Light Duty Vehicle Fleet Module first estimates the sales of light trucks to fleets as follows:

$$FLTSAL_{VT=2,ITY,T} = FLTTRAT \cdot SQDTRUCKSL_{T} \cdot FLTSHR_{ITY}$$

where:

FLTSAL = Sales to fleets by vehicle and fleet type
FLTTRAT = Fraction of total truck sales attributed to fleets
SQDTRUCKSL = Total light truck sales in a given year, obtained from the NEMS Macroeconomic Module
FLTSHR = Fraction of fleet trucks purchased by a given fleet type
VT = Index of vehicle type: 1 = cars, 2 = light trucks
ITY = Index of fleet type: 1 = business, 2 = government, 3 = utility

The fleet allocation factor, FLTTRAT, has been previously extracted from data provided in the Transportation Energy Data Book,[52] which provides and estimate of the fraction of light trucks sold for personal use, and a survey of fleet vehicles,[53] which provides a mechanism for further stratifying non-personal sales into fleet/non-fleet categories. Under the current revision, only the personal/non-personal distinction is used, with all non-personal sales of light trucks being allocated to the fleet module. There are two reasons to re-estimate the value of FLTTRAT rather than merely redefining it as the percentage of trucks sold for non-personal use: first, the value of the personal-use sales share reported by ORNL is derived from the 1987 TIUS, which has been superseded by the recently published 1992 survey; and second, because TIUS does not survey government and publicly-owned vehicles, the sales share derived from its summary tends to overestimate the fraction of LDT's sold for personal use. A derivation of the updated value for FLTTRAT follows.

In estimating this factor, it is necessary to combine elements of two different data samples: the relevant components of TIUS,[54] and the annual data collected by FHWA.[55] Although these surveys are drawn from different populations and are not directly comparable, it is assumed that the

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[52]*Transportation Energy Data Book: Edition 12,* Oak Ridge National Laboratory, ORNL-6710, March 1992, Page A-12.

[53]*Fleet Vehicles in the United States: Composition, Operating Characteristics, and Fueling Practices,* Oak Ridge National Laboratory, ORNL-6717, May 1992.

[54]*1992 Census of Transportation: Truck Inventory and Use Survey,* U.S. Department of Commerce, Bureau of the Census, TC92-T-52, May 1995.

[55]*Highway Statistics 1992,* U.S. Department of Transportation, Federal Highway Administration, FHWA-PL-93-023.

relationships among elements of one data set are also valid in the other. Vehicle characteristics from the 1992 FHWA survey are tabulated below:

Table F-44: FHWA Highway Statistics 1992		
Total Number of Trucks (All Types)	45,504,067	Table VM-1
Total Light Duty Trucks (2-Axle, 4-Tire)	39,533,142	
Total Federally-Owned Trucks	281,623	Table MV-1
Total State & Municipal Trucks	1,547,020	

1) First, the FHWA data is used to estimate the fraction of two-axle, four tire trucks in the truck population:

$$\text{Percent LDT} = \frac{\text{Total LDT}}{\text{Total Trucks}} = \frac{39{,}533{,}142}{45{,}504{,}067} = 86.88\%$$

2). Assuming that the distribution of trucks is uniform across sectors, the number of LDT's owned by federal, state, and municipal agencies can be estimated:

$$\text{Public LDT} = (\text{Federal Trucks} + \text{State \& Municipal Trucks}) \cdot \text{Percent LDT} = 1{,}588{,}693$$

3) Using the numbers above, the fraction of LDT's owned by public agencies is estimated:

$$\text{Percent Public LDT} = \frac{\text{Public LDT}}{\text{Total LDT}} = 4.02\%$$

It is assumed that this figure represents the degree of underestimation of LDT stock in the TIUS survey, which does not include publicly-owned vehicles.

4) To reconcile this discrepancy, the total number of privately-owned LDT's from the TIUS microdata file (on CD-ROM) is subsequently adjusted:

$$Implied\ TIUS\ LDT\ Population = \frac{Total\ TIUS\ LDT}{1 - Percent\ Public\ LDT}$$

5) Using TIUS estimates of the number of LDT's employed for personal use, the percentage of personal-use trucks can then be calculated:

$$Percent\ Personal\ LDT = \frac{Total\ TIUS\ Personal\ LDT}{Implied\ TiuIUS\ LDT}$$

6) Finally, the percentage of LDT's assigned to the Fleet Module is simply calculated:

$$Fleet\ Percent = FLTTRAT = (1 - Percent\ Personal\ LDT)$$

The results are tabulated below.

Table F-45: TIUS LDT Data and Distributions	
Total LDT's, from TIUS	53,435,873
Implied Total LDT's	55,673,175
Total Personal-Use LDT's, from TIUS	39,766,945
Percent Personal-Use	71.43%
Percent Fleet (FLTTRAT)	28.57%

The use of this revised allocation factor will result in a more accurate distribution of light-duty trucks in both the personal-use and fleet modules.

Fleet Share Distribution

The above information, combined with vehicle-use information from TIUS can be used to re-estimate the allocation of trucks among fleet types. This parameter, FLTTSHR, allocates total fleet LDT purchases among business, government, and utility fleets according to a fixed ratio, the derivation of which has not been previously documented. Using the implied estimate of the number of publicly-owned LDT's, presented above, and TIUS estimates of the number of utility and commercial LDT's (excluding those used for personal transport), the following distribution has been incorporated into the LDV Fleet Model.

Table F-46: Current and Previous Fleet LDT Allocation			
Fleet Type	Number	Current NEMS FLTTSHR	Previous NEMS FLTTSHR
Business	13,285,511	83.5%	73.6%
Government	2,237,302	14.1%	17.8%
Utility	383,421	2.4%	8.8%

Vehicle Distribution Within Fleets

Under the provisions of EPACT, purchases of vehicles by fleets meeting certain criteria are affected by the requirement that a proportion be alternatively fueled. The specific conditions under which these provisions are in effect, and the fleet sizes which are affected are not static, but are subject to revision. Obtaining an accurate estimate of the number of automobiles in fleet service is necessary in order to derive a forecast of the purchase of alternative fuel vehicles mandated under EPACT, and the consequent demand for petroleum, electricity, and alternative fuels used for transportation. Under the previous model, a fixed proportion of annual automobile and light truck sales (which were exogenously obtained) were assigned to business, utility, and government fleets. As the alternative fuel provisions of EPACT attach to fleets at or above a given size, it is important to develop a means of estimating the affected population of vehicles under the current, or any future definition of a "fleet". Due to the dissimilarities of the data available, separate approaches have been developed for light trucks and automobiles, as described below.

Trucks

The proposed approach uses the fleet-size data from the TIUS survey to derive a functional form for estimating the affected population of LDT's in fleets. The applicability of this approach is constrained by the aggregate nature of the survey, but should serve as a good first approximation. The first step is to look at the distribution of trucks by fleet type; only business and utility fleets are considered as all government vehicles are assumed to be affected by the legislation (and are not represented in TIUS). The number of trucks within each considered fleet type, stratified by fleet size, are tabulated below. These distributions are also graphically depicted on the following pages. It is clear from these figures that business and utility fleets have significantly different size characteristics, as is to be expected. Most commercial light trucks exist in fleets of less than 20 vehicles, and are therefore unaffected by EPACT legislation, while the overwhelming majority of utility vehicles are in large fleets.

Table F-47: Light Truck Distribution in Business Fleets

Fleet Size	Number	Percent of Total Defined	Cumulative Percentage: P(n)	Reverse Cumulative: Q(n)
1	5,422,935	43.7%	43.7%	100.0%
2 to 5	4,261,155	34.3%	78.0%	56.3%
6 to 9	799,876	6.4%	84.5%	22.0%
10 to 24	843,262	6.8%	91.3%	15.5%
25 to 99	613,610	4.9%	96.2%	8.7%
100 to 499	295,196	2.4%	98.6%	3.8%
500 or More	176,383	1.4%	100.0%	1.4%
Undefined	873,094			
Total Defined	12,412,417			

Table F-48: Light Truck Distribution in Utility Fleets

Fleet Size	Number	Percent of Total Defined	Cumulative Percentage: P(n)	Reverse Cumulative: Q(n)
1	25,677	6.8%	6.8%	100.0%
2 to 5	18,573	4.9%	11.8%	93.2%
6 to 9	24,296	6.5%	18.2%	88.2%
10 to 24	38,717	10.3%	28.6%	81.8%
25 to 99	59,301	15.8%	44.3%	71.4%
100 to 499	49,294	13.1%	57.5%	55.7%
500 or More	159,804	42.5%	100.0%	42.5%
Undefined	7,759			
Total Defined	375,662			

Figure F-10: Business Fleet LDT Distribution

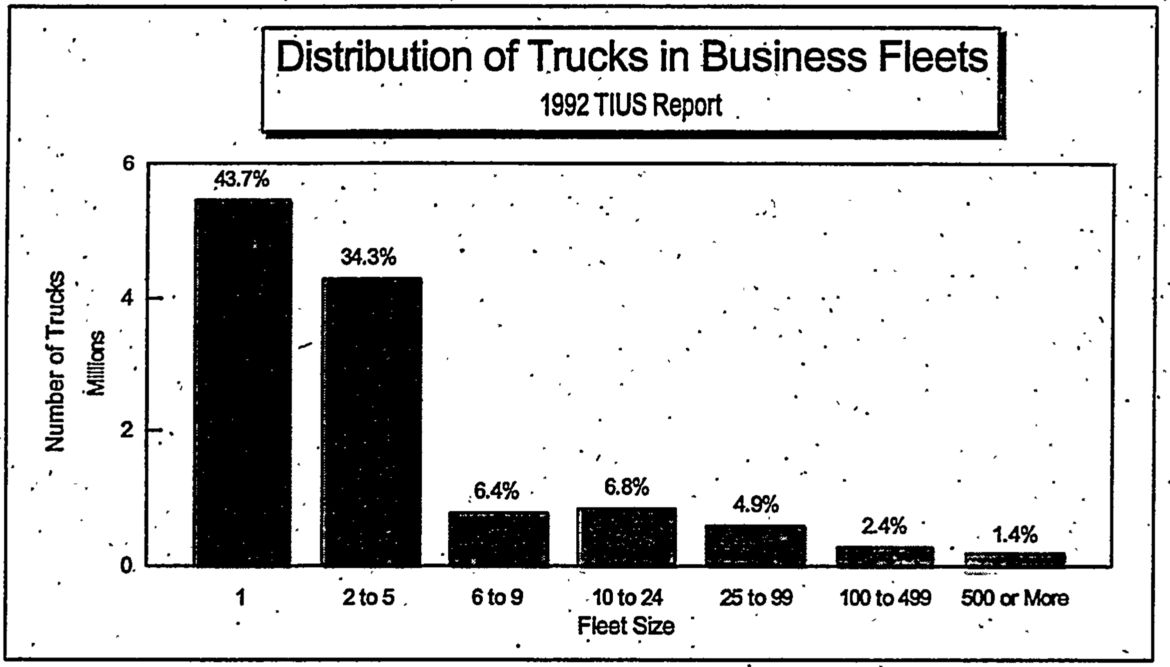
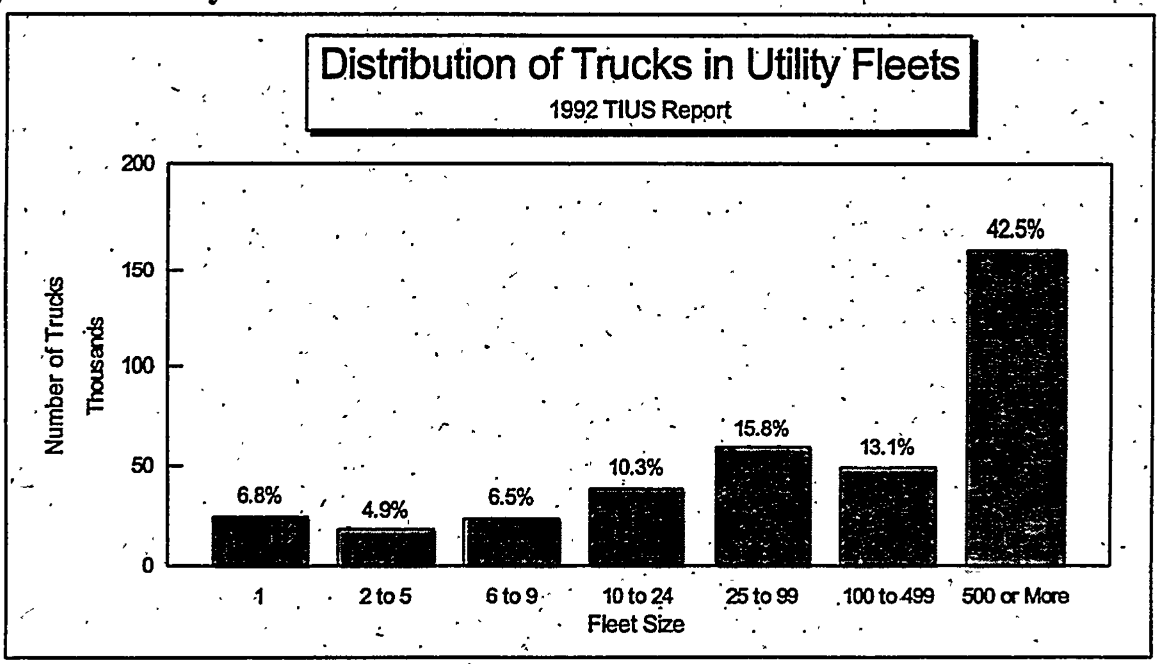


Figure F-11: Utility Fleet LDT Distribution



As the strata defined in the TIUS survey do not correspond to the fleet sizes addressed in EPACT, it is necessary to derive a functional form for each distribution. This is accomplished by considering the cumulative distribution of fleet trucks P(n), or, more accurately, its complement: Q(n), referred to, for lack of a better term, as the reverse cumulative distribution. This distribution describes the number of trucks in fleet sizes greater than or equal to *n*, as depicted below.

Figure F-12: Distribution of LDT's, by Fleet Size

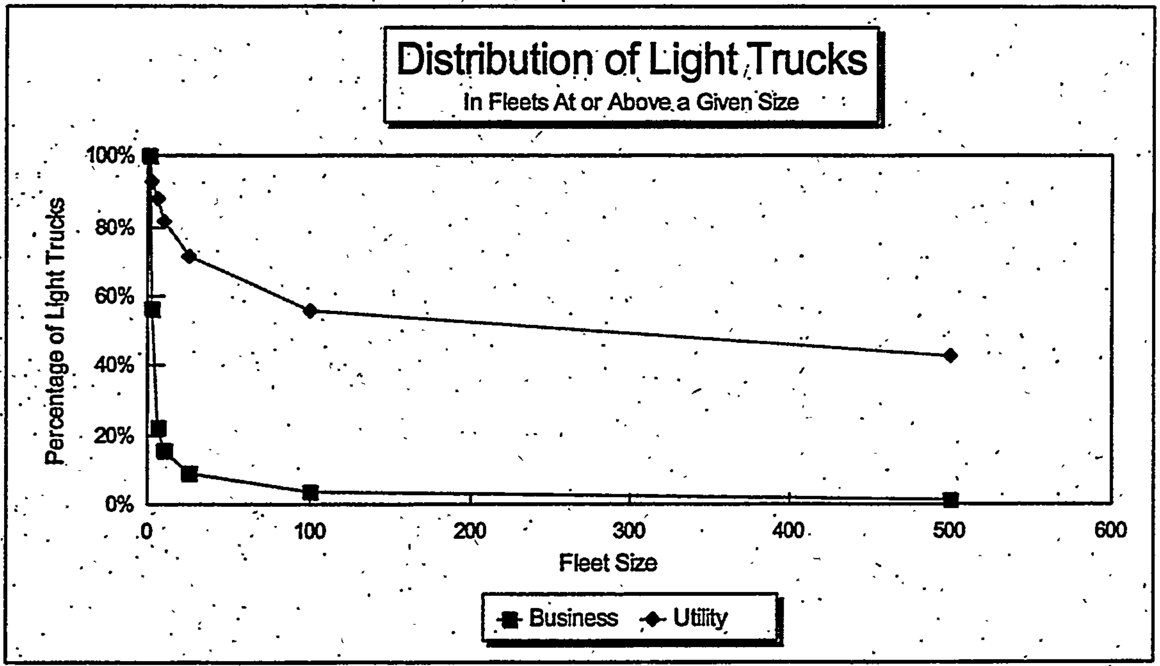
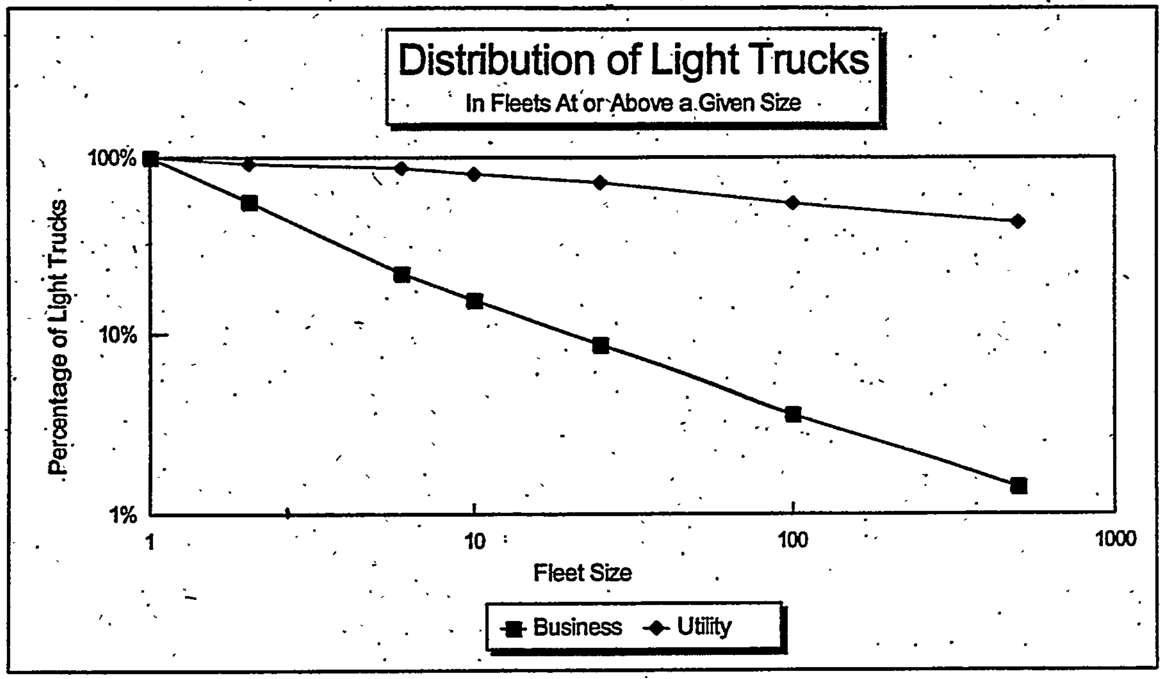


Figure F-13: Distribution of LDT's, by Fleet Size (Logarithmic Scale)



The most straightforward method of estimating a functional form is to transform the data so that it approximates a linear relationship, then use OLS to estimate the coefficients. As the figure above shows, plotting both axes logarithmically produces a reasonable approximation of linearity. This suggests the following form:

$$Ln\,Q(n) = k\,Ln\,(n)$$

or

$$Q(n) = n^{k}$$

where:

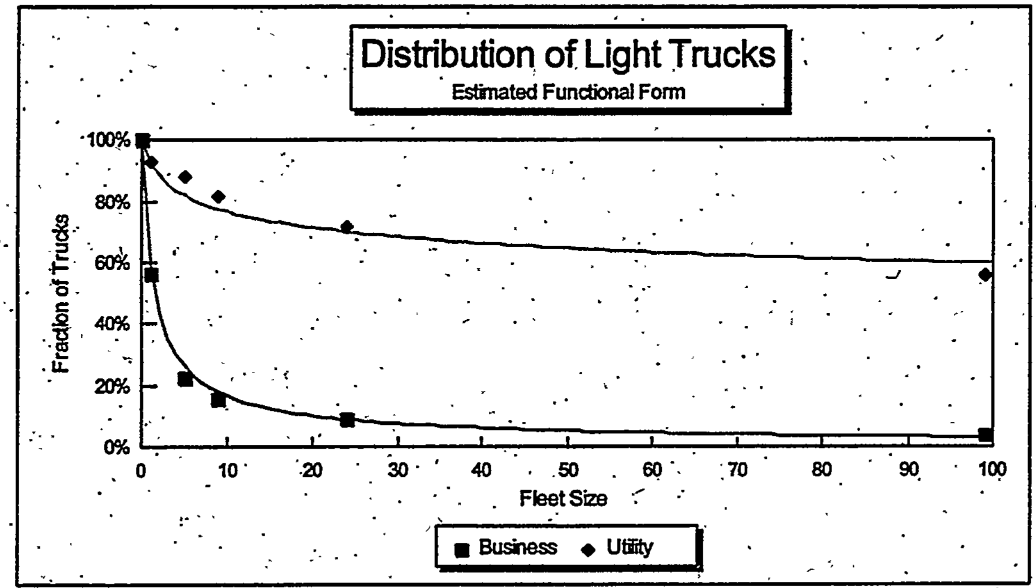
Q(n) = The reverse cumulative distribution: the percentage of trucks in fleets of size greater than or equal to *n*.

Testing this approach with the data described above provides the results tabulated below. The significance of the coefficients and the high R-squared gives confidence that this formulation will provide a satisfactory means of estimating the affected light truck population in business and utility fleets. A plot of these functions over TIUS data is provided below.

Table F-49: Regression Output

	Business	Utility
Constant	0	0
Coefficient (k)	-0.747	-0.111
Standard Error	0.020	0.008
T-Statistic	-36.63	-13.22
R Squared	0.988	0.937

Figure F-14: Distribution of LDT's (Estimated Functional Form)



Applying this function permits a stratification of light trucks into three groups: non-fleet (<20 vehicles), small fleet (20-50 vehicles) and large fleet (>50 vehicles). The distribution of these percentages, by fleet type, are tabulated below. It should be noted, once again, that publicly-owned vehicles (federal, state, and municipal) are not subject to the fleet-size constraints, and are therefore not similarly stratified. Insofar as different components of the publicly-owned fleet of LTD's have different acquisition requirements under EPACT, it is suggested that a sales-weighted average of the requirements be used.

Table F-50: Distribution of LDT's, by Fleet Type and Size (FLTSIZE)

Fleet Size	Index (IFS)	Calculation	Fleet Type	
			Business	Utility
Non-Fleet (<20 LDT's)	1	Q(1) - Q(20)	89.3%	28.4%
Small Fleet (20-50 LDT's)	2	Q(20) - Q(50)	5.3%	6.9%
Large Fleet (>50 LDT's)	3	Q(50)	5.4%	64.7%
Total			100%	100%

Automobiles

In a report on the characteristics of fleet vehicles in the United States,[56] Oak Ridge Natiional Laboratory notes that no comprehensive nationwide automobile fleet vehicle survey is currently available. This stands in contrast to the abundance of census data available for the analysis of U.S. truck populations, and inhibits the development of a methodology to estimate the number of fleet vehicles covered by EPACT regulations. The *1992 Automotive Fleet Fact Book*,[57] which provides summary characteristics of fleet vehicles, represents the sole source of data used in constructing the following distribution.

Given the limitations of the data, several assumptions and manipulations are necessary to transform the published data into a form commensurate with the needs of the model. It is first assumed that both Government and Utility fleets are large enough to be affected by EPACT regulations, obviating the need for further analysis of their distributions. It is also assumed that the number of vehicles in business fleets should not include employee-owned, daily rental, or individually-leased vehicles, as these are outside the purview of the legislation. This exclusion is accomplished through the use of the function BFLTFRAC, described above. Aggregating business fleet data and subtracting excluded vehicles results in the distribution provided in the table below. As there are only three data points, this effectively precludes the use of regression analysis to estimate a distribution function for business fleet vehicles. The alternative is to assume the simplest functional form which can be adjusted to approximate the desired distribution. After testing a variety of specifications, the form selected is as follows:

$$Q(n) = \frac{k_3}{Ln(n)}$$

where:

$Q(n)$ = The percentage of vehicles in fleets of size greater than or equal to n

k_3 = The constant of proportionality, chosen by normalizing the function to 1.0 when $n = 4$; estimated to be 1.386.

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[56] *Fleet Vehicles in the United States: Composition, Operating Characteristics, and Fueling Practices*, Oak Ridge National Laboratory, ORNL-6717, May 1992.

[57] *Automotive Fleet Fact Book, 1992.* Bobit Publishing Company, pp. 16, 20.

Table F-51: 1992 Bobit Fleet Data	
Fleet Type	Number of Vehicles (Thousands)
Business Fleets (by Size)	
>= 4 Vehicles	5,261
>= 10 Vehicles	2,820
>= 25 Vehicles	2,323
Government Fleets	504
Utility Fleets	544

This function is graphically displayed below, along with the original data. Applying this function permits a stratification of business fleet automobiles into three groups: non-fleet (<20 vehicles), small fleet (20-50 vehicles) and large fleet (>50 vehicles). The distribution of these percentages is tabulated below.

Figure F-15: Distribution of Business Fleet Vehicles

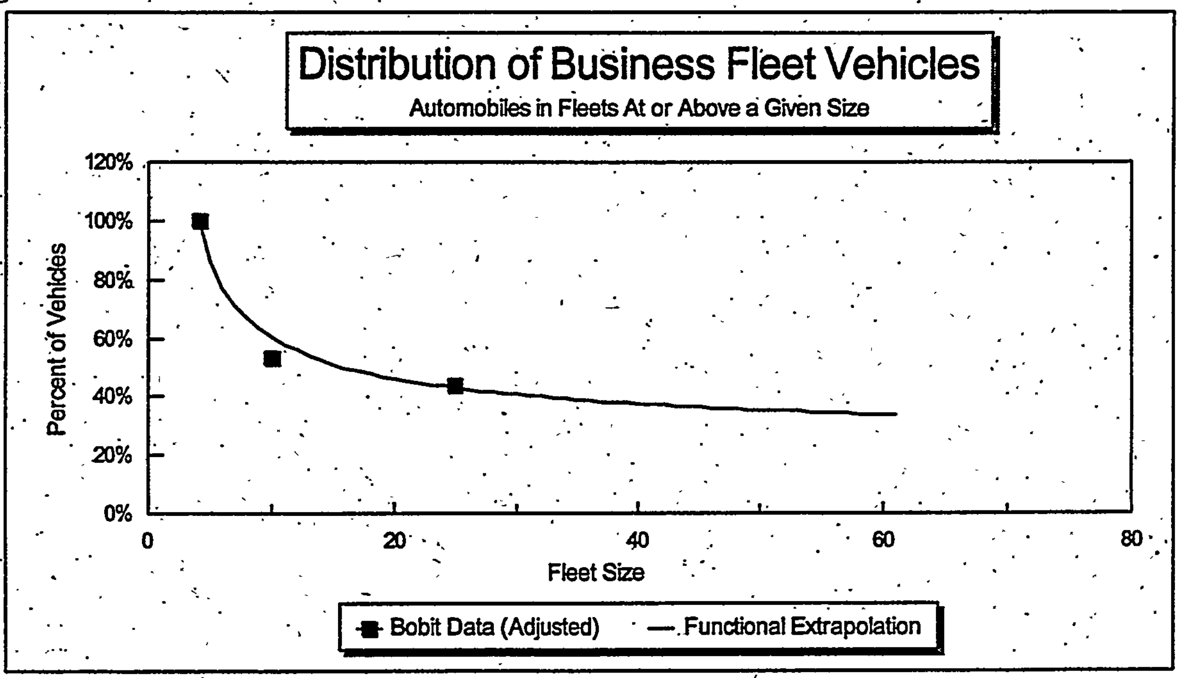


Table F-52: Percentage of Business Fleet Automobiles (FLTSIZE)			
Fleet Size	Index (IFS)	Calculation	Percent
Non-Fleet (<20 Cars)	1	Q(1) - Q(20)	53.7%
Small Fleet (20-50 Cars)	2	Q(20) - Q(50)	10.8%
Large Fleet (>50 Cars)	3	Q(50)	35.4%
Total			100%

The incorporation of these modifications will, in all likelihood, not result in significant changes in the output of the NEMS Transportation Model, but will more easily permit the inclusion of users' assumptions and will be able to withstand a higher level of scrutiny of the methodology.

Attachment 5: Light Commercial Truck Model

Data Development for the LCT Model

The primary source of data for this model is the microdata file of the 1992 Truck Inventory and Use Survey (TIUS), which provides numerous details on truck stock and usage patterns at a high level of disaggregation. The data derived from this source are used to allocate and sort the summary truck data presented in the Federal Highway Administration's annual publication of highway statistics, which constitute the baseline from which the NEMS forecast is made. TIUS data are also used to distribute estimated sales of trucks, obtained from the Macroeconomic Model, among the affected models according to their weight class. Finally, the TIUS microdata set is used to construct a characterization of these Light Commercial Trucks, comprising their average annual miles of travel, fuel economy, and distribution among several aggregate industrial groupings chosen for their correspondence with output measures currently being forecast by NEMS. It is expected that projected growth in industrial output will provide a useful proxy for the growth in demand for the services of light commercial trucks. This issue will be addressed later in this section.

Distribution of Truck Stock

The principal source of confusion and double-counting encountered in the truck models stems from differing definitions of what constitutes a light truck among the data sources used by NEMS. In the past, FHWA's estimate of 2-axle, 4-tire trucks have been interpreted as representing light-duty trucks, less than 8,500 lbs, and therefore properly within the purview of the LDV Module. Likewise, sales estimates from the Macro Model have been assumed to represent only LDT's, and have been similarly assigned. On closer examination, neither of these assumptions can be shown to have been justified.

Using the information derived from TIUS, it is estimated that of the 2-axle, 4-tire trucks, approximately 88 percent of the pickup trucks and 85 percent of the other trucks (vans, panel trucks, etc.) fall into that weight range. The remainder properly belong in the newly-established LCT category. Similarly, sales estimates from the Macro Model have been shown to represent sales of trucks under 14,000 lbs., indicating a significant overlap across the LCT weight range and into the medium freight truck category. Using the weight distributions by truck type available from TIUS, a suggested stratification scheme may be proposed. Table F-53, below, presents the TIUS estimates of single-unit truck stock, stratified by axle configuration, body type, and weight. While there are significant discrepancies between FHWA's summary stock figures and those presented below (see Table F-65), it is assumed that the relative distribution of trucks within each grouping is constant, and transferrable between samples.

Table F-53: Distribution of Single-Unit Trucks, From TIUS

	Total	Pickup	Van	SU Light	SU Heavy
2 AX, 2 TIRES EA					
6,000 OR LESS	36,682,877	22,085,491	14,499,647	97,739	0
6 ,001- 10,000	16,476,534	10,195,368	5,909,766	371,400	0
10 ,001- 14,000	95,522	0	0	95,522	0
14 ,001- 16,000	37,980	0	0	37,980	0
16 ,001- 19,500	53,606	0	0	53,606	0
19,501-26,000	434,632	0	0	434,632	0
26 ,001- 33,000	27,359	0	0	0	27,359
33,001 OR MORE	244,863	0	0	0	244,863
Total	54,053,373	32,280,859	20,409,413	1,090,879	272,222
2 AX, 2&4 TIRES					
6,000 OR LESS	374,070	290,142	74,031	9,897	0
6 ,001- 10,000	1,035,862	536,274	89,182	410,406	0
10 ,001- 14,000	246,374	0	0	246,374	0
14 ,001- 16,000	81,897	0	0	81,897	0
16 ,001- 19,500	141,746	0	0	141,746	0
19,501-26,000	1,219,550	0	0	1,219,550	0
26 ,001- 33,000	72,072	0	0	0	72,072
33,001 OR MORE	169,942	0	0	0	169,942
Total	3,341,513	826,416	163,213	2,109,870	242,014
3 AXLES					
6,000 OR LESS	731	0	0	731	0
6 ,001- 10,000	2,123	0	0	2,123	0
10 ,001- 14,000	3,970	0	0	3,970	0
14 ,001- 16,000	2,478	0	0	2,478	0
16 ,001- 19,500	5,342	0	0	5,342	0
19,501-26,000	94,064	0	0	94,064	0
26 ,001- 33,000	7,446	0	0	0	7,446
33,001 OR MORE	329,043	0	0	0	329,043
Total	445,197	0	0	108,708	336,489
4 AXLES OR MORE					
6,000 OR LESS	0	0	0	0	0
6 ,001- 10,000	1,351	0	0	1,351	0
10 ,001- 14,000	1,807	0	0	1,807	0
14 ,001- 16,000	0	0	0	0	0
16 ,001- 19,500	291	0	0	291	0
19,501-26,000	3,024	0	0	3,024	0
26 ,001- 33,000	151	0	0	0	151
33,001 OR MORE	62,084	0	0	0	62,084
Total	68,708	0	0	6,473	62,235

The data above can be used to estimate the fraction of single-unit trucks in the FHWA sample which are less than or equal 10,000 lbs., the upper bound of the LCT weight class. Aggregating the sample numbers and calculating the percentages in the relevant groups provides the winnowing factors in the table below.

Table F-54: Stock Estimates: All Single-Unit Trucks						
Number	All Trucks		Trucks<=10,000 Lbs		%<=10k lbs	
	2A4T	Other	2A4T	Other	2A4T	Other
Pickups	32,280,859	826,416	32,280,859	826,416	100%	100%
Other	21,772,514	3,029,002	20,878,552	587,721	95.89%	19.40%
Total	*54,053,373*	*3,855,418*	*53,159,411*	*1,414,137*		
Percent	All Trucks		Trucks<=10,000 Lbs			
	2A4T	Other	2A4T	Other		
Pickups	59.72%	21.44%	60.72%	58.44%		
Other	40.28%	78.56%	39.28%	41.56%		

Similarly, the distributions in Table F-53 can be aggregated to determine the allocation of truck sales obtained from the Macro Model, first splitting off that fraction between 10,000 and 14,000 lbs., and then distributing the remainder between 2-axle, 4-tire trucks and trucks with other axle configurations, as shown below.

Table F-55: Distribution of Light Truck Sales from Macro Model		
	Total	Percent
Total SU Trucks <= 14,000 lbs	54,921,221	
Of Which: SU Trucks <= 10,000 lbs.	54,573,548	99.37%
Of Which: 2A4T Trucks <= 10,000 lbs	53,159,411	97.41%
Other SU Trucks <= 10,000 lbs.	1,414,137	2.59%

The next step is to determine the fraction of trucks which exceed the 8,500 lb. lower bound of the LCT weight category. TIUS, unfortunately, does not provide a breakdown of truck stock along those lines, thus requiring the imputing of the appropriate fractions. After consideration of several options, it has been decided to use a simple linear interpolation of the cumulative share of each truck type between 6,000 and 10,000 lbs. The data and resulting shares are provided in Table F-56, below.

Table F-56: Linear Interpolation: Fraction Between 8.5 and 10k lbs

Axle Configuration	Pickups		Other	
2A4T				
	Total	**Percent**	**Total**	**Percent**
<= 6k	22,085,491	68.42%	14,597,386	67.05%
<= 10k	32,280,859	100.00%	20,878,552	95.89%
Total	32,280,859	100.00%	21,772,514	100.00%
Interpolation				
<= 8.5	28,457,596	88.16%	17,762,570	85.08%
8.5-10k	3,823,263	11.84%	3,115,982 *	14.92%
Other				
	Total	**Percent**	**Total**	**Percent**
<= 6k	290,142	35.11%	84,659	14.40%
<= 10k	826,416	100.00%	587,721	100.00%
Total	826,416	100.00%	587,721	100.00%
Interpolation				
<= 8.5	625,313	75.67%	399,073	67.90%
8.5-10k	201,103	24.33%	188,648	32.10%

* The weight range for 2-axle, 4-tire non-pickup trucks is defined to be everything >= 8,500 lbs. This is done to simplify the accounting of the model, due to the small number of these trucks which exceed 10,000 lbs., and to recognize that the purposes to which most of these vans and small panel truck are put would most appropriately be addressed within the Light Commercial Truck Model, rather than in the Highway Freight Model.

In order to simplify the allocation scheme described above, the distribution of stock and sales are presented graphically, in Figures F-16 and F-17, below.

Figure F-16: Distribution of FHWA Single-Unit Truck Stocks

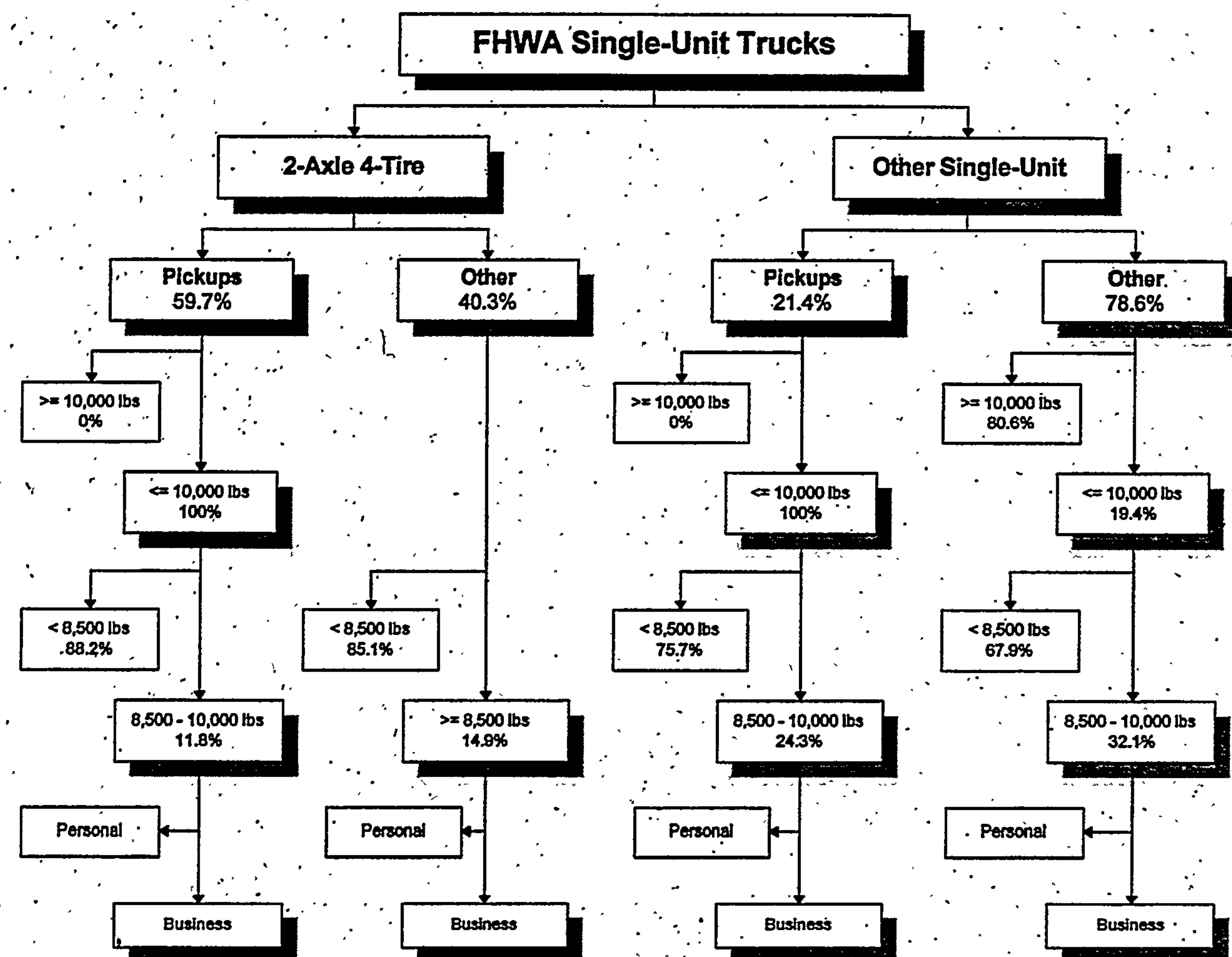
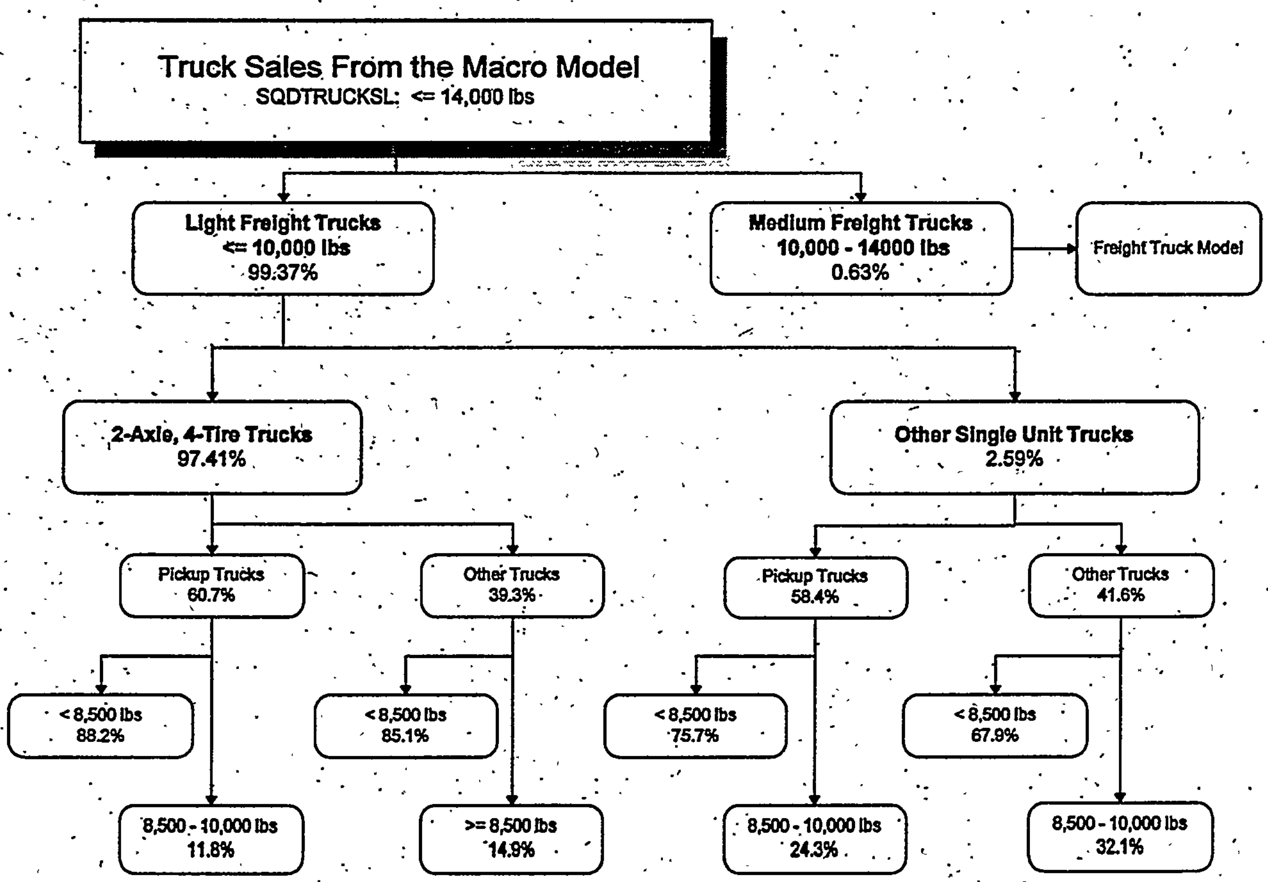


Figure F-17: Distribution of Light Truck Sales



Allocation of Truck Stock Among Industrial Groups

In order to develop a forecast of LCT use which is sensitive to economic activity, it is necessary to allocate the trucks according to their major use. TIUS provides an accounting of trucks within sixteen major use categories, not all of which correspond directly with measures of industrial output generated by NEMS. These categories are therefore aggregated into measures which can be addressed within the NEMS structure, as defined below.

Table F-57: Correspondence of Major Use Categories

TIUS Categories	Aggregate LCT Model Categories
Agriculture or Farm Activities Forestry or Lumber	Agriculture
Mining or Quarry	Mining
Construction Work Contractor Activities	Construction
Manufacturing Wholesale Trade Retail Trade Business Daily Rental Not In Use For Hire Transportation Other One-Way Rental	Manufacturing & Trade
Utilities	Utilities
Personal Transportation	Personal

Detailed tables of the distribution of single-unit trucks among both major-use categories are provided in subsequent tables. These data are used to share-out the four types of truck considered by this model. It is assumed that the relative shares of trucks in the 6 to 10 thousand pound weight range is an acceptable proxy for the relative populations of the 8.5 to 10 thousand pound vehicles. The aggregate numbers and the resulting percentages are provided in the following table. It is further assumed that the percentage figures used to allocate the LCT's remain constant, at least until the publication of the next TIUS. These are rather strong assumptions, but appear justified by the paucity of other sources of detailed information about the population and operating characteristics of Light Commercial Trucks.

Table F-58: Number of Trucks, 6,000-10,000 lbs GVW				
Major Use	2 Axle, 4 Tire		Other Single-Unit	
	Pickup	Other	Pickup	Other
Agriculture	1,419,306	316,281	104,408	66,853
Mining	79,925	40,414	5,664	3,278
Construction	1,197,648	800,004	78,721	120,343
Trade	1,064,497	1,592,306	113,801	231,008
Utilities	84,334	127,476	3,378	9,334
Personal	6,349,658	4,298,573	230,302	72,246
Total	10,195,368	7,175,054	536,274	503,062
Percent	2 Axle, 4 Tire		Other Single-Unit	
	Pickup	Other	Pickup	Other
Agriculture	13.9%	4.4%	19.5%	13.3%
Mining	0.8%	0.6%	1.1%	0.7%
Construction	11.7%	11.1%	14.7%	23.9%
Trade	10.4%	22.2%	21.2%	45.9%
Utilities	0.8%	1.8%	0.6%	1.9%
Personal	62.3%	59.9%	42.9%	14.4%

Operating Characteristics

The operating characteristics of LCT's relevant to forecasting energy demand are the average annual miles per truck driven within each major use category and the corresponding average fuel economy. An extensive sequence of sorting and tabulating procedures has resulted in Table F-59, which provides an estimate of average travel demand for trucks between 6 and 10 thousand pounds. As is done in apportioning trucks among use categories, it is assumed that these driving characteristics are uniform across the weight class, and therefore accurately represent the more narrow LCT category.

Table F-59: Average Annual Miles, by Major Use (1992 TIUS) Aggregated for NEMS				
Major Use	Single-Unit Trucks, 6,000 - 10,000 Lbs.			
	2 Axle, 4 Tire		Other Single-Unit	
	Pickup	Other	Pickup	Other
Agriculture	11,920	8,569	15,197	7,054
Mining	20,231	24,871	18,520	17,786
Construction	15,909	15,195	13,043	10,074
Trade	13,313	15,394	10,009	11,832
Utilities	13,023	13,776	9,947	9,996
Personal	9,980	10,148	8,429	5,852

Estimating the average fuel economy of these trucks is considerably more problematic, and requires additional assumptions and calculations. While TIUS requires the operators of larger trucks to explicitly state their average fuel economy, the census form for smaller trucks requires only that operators identify an MPG range in which their trucks operated in the prior year. It is therefore necessary to combine these two sets of survey responses on the most aggregate level, and then use more robust estimation methods to determine the mean characteristics of each group. The aggregate tabulation of trucks according to major use, vehicle type, and fuel economy is provided in tables below. Again, the attributes of 6 to 10 thousand pound trucks are assumed to represent those of the 8.5 to 10 thousand pound group.

Estimating the average characteristics of these grouped data involves the use of a trimmed mean: first determining the quartiles of each distribution, calculating the interquartile range (IQR), and then estimating the biweighted harmonic mean of the sample. These quartiles are presented in Table F-60. Determining the biweighted mean involves calculating a weighting factor which is a function of an observation's deviation from the median of the sample $\hat{X}$, as shown below.

$$w(X) = (1 - Z^2)^2 \qquad |Z| \leq 1$$

$$w(X) = 0 \qquad |Z| > 1$$

$$\text{where:} \qquad Z = \frac{X - \hat{X}}{3(IQR)}$$

where w is the weighting factor, and X represents the midpoint of each MPG range. The biweighted mean is then calculated as follows:

$$\tilde{X} = \left[\frac{\sum_k N_k \left(\frac{1}{X_k} \right) w(X_k)}{\sum_k N_k w(X_k)} \right]^{-1}$$

where N_k is the population of MPG range k. The inverting of the MPG value in the equation, and subsequent inversion of the result is intended to provide an estimate of the harmonic mean of the sample. This results in a first approximation of the fuel economy of LCT's, and is tabulated in Table F-60. These values are subsequently used to replace the value of the sample median in the calculation of Z, above, and the procedure is iterated until the MPG estimates converge. The results of this iterative procedure are presented in Table F-61.

Table F-60: MPG Distributions, By Quartile				
	2 Axle, 4 Tire		Other	
	Pickup	Other	Pickup	Other
Agriculture				
Q25	10.9	8.0	10.0	8.0
Median	13.1	10.8	12.3	10.0
Q75	16.5	13.6	17.4	12.5
IQR	5.6	5.6	7.3	4.4
Mean	12.83	9.26	11.87	9.02
Mining				
Q25	11.5	11.1	11.5	9.2
Median	13.5	12.5	12.0	10.7
Q75	16.2	14.2	12.6	13.0
IQR	4.7	3.1	1.1	3.8
Mean	13.18	12.15	12.00	10.25
Construction				
Q25	11.7	10.6	10.5	8.0
Median	13.8	12.5	13.4	9.8
Q75	16.9	15.7	15.4	11.7
IQR	5.2	5.1	4.9	3.7
Mean	13.50	11.96	12.74	9.12
Trade				
Q25	11.8	10.4	10.2	8.1
Median	14.0	12.7	12.6	10.1
Q75	17.3	15.8	21.0	12.5
IQR	5.6	5.4	10.9	4.3
Mean	13.63	11.84	12.70	9.28
Utilities				
Q25	11.8	9.6	11.7	7.3
Median	14.1	12.0	12.7	9.8
Q75	16.8	14.4	17.4	11.9
IQR	4.9	4.8	5.7	4.6
Mean	13.49	10.86	13.46	8.84
Personal				
Q25	11.8	12.1	10.2	9.6
Median	14.1	14.4	12.4	11.5
Q75	17.4	17.7	16.8	13.9
IQR	5.7	5.6	6.6	4.2
Mean	13.73	14.05	12.31	10.95

Table F-61: Average MPG: Biweighted Mean Iterated				
Major Use	2 Axle, 4 Tire			
	Pickup	Other	Pickup	Other
Agriculture	12.77	8.75	11.79	8.66
Mining	13.12	11.92	12.00	10.10
Construction	13.45	11.79	12.58	8.92
Trade	13.55	11.57	12.71	8.98
Utilities	13.33	10.25	13.57	8.65
Personal	13.67	13.99	12.29	10.78

The above tables effectively describe Light Commercial Trucks for the purpose of forecasting their demand for travel and consumption of fuel. In the following section, the FHWA stock numbers will be incorporated, and measures of industrial output will be used to test the responsiveness of the proposed model to variations in economic conditions.

Incorporation of FHWA Baseline Data

In order to track the activities of LCT's, and derive an estimate of scrappage rates, historical figures from FHWA have been considered. The stock of trucks and their annual miles of travel are presented below. It should be noted that, beginning with the 1994 edition of FHWA's *Highway Statistics*, a revised definition of 2-axle, 4-tire trucks has been implemented, removing such vehicles as vans and sport-utility vehicles from the "automobile" category and placing them in the "single-

Table F-62: Single-Unit Truck Characteristics, from FHWA						
	Stock		VMT (Millions)		VMT per Truck	
	2A4T	Other	2A4T	Other	2A4T	Other
1985	46,125,097	3,927,412	490,274	46,980	10,629	11,962
1986	47,319,902	4,024,842	510,178	48,413	10,781	12,029
1987	48,816,260	3,883,694	543,615	49,537	11,136	12,755
1988	50,524,830	3,957,319	575,411	51,239	11,389	12,948
1989	51,644,255	4,102,863	596,024	52,969	11,541	12,910
1990	52,932,510	4,243,044	614,491	53,443	11,609	12,595
1991	53,210,253	4,265,307	624,982	53,787	11,746	12,610
1992	53,844,501	4,316,148	637,049	53,691	11,831	12,440
1993	55,710,076	4,526,004	661,546	56,781	11,875	12,546
1994	57,141,967	4,724,608	669,321	61,284	11,713	12,971
1995	57,897,398	5,203,810	686,977	62,706	11,865	12,050

unit truck" category.

This change in definition has required making incremental adjustments to 2A4T truck stocks in the preceding years. This has been accomplished by considering the change in 2A4T populations for the year 1993--the only overlapping year in which stock numbers under both sets of definitions are provided. The current definition increases truck population by 36.2 percent over the prior tabulation; this is therefore considered to be uniform across time, and previous years' stocks have been similarly augmented. The number of miles traveled is also adjusted, through the expedient of assuming that every vehicle transferred from the automobile category travels an average number of miles defined by the overall average for automobiles. The above table represents single-unit trucks of all weight classes. The stratification procedures described in the previous section is subsequently imposed in order to derive an estimate of Light Commercial Truck stock within each truck type and major-use category. The distribution among truck types is presented below, in Table F-63.

Table F-63: Number of Light Commercial Trucks (by Type)

	2A4T		Other	
	Pickup	Other	Pickup	Other
1985	3,262,486	2,658,945	204,858	192,171
1986	3,346,996	2,727,821	209,940	196,938
1987	3,452,835	2,814,081	202,578	190,032
1988	3,573,685	2,912,574	206,418	193,634
1989	3,652,863	2,977,105	214,010	200,756
1990	3,743,983	3,051,368	221,322	207,615
1991	3,763,628	3,067,379	222,483	208,704
1992	3,808,489	3,103,941	225,135	211,192
1993	3,940,444	3,211,484	236,081	221,460
1994	4,041,723	3,294,028	246,441	231,178
1995	4,095,156	3,337,576	271,436	254,626

The number of trucks in each year is assumed to represent the net effect of a fixed scrappage rate applied to the previous year's stock, and the allocation of new purchases from the Macro Model. Because light truck purchases are exogenously supplied, the scrappage rate must be inferred. The table below represents the allocation of new LCT stock by vehicle type. Allocation among major-use groups is detailed in subsequent tables. A fixed scrappage rate is then calculated for the two classes of single-unit trucks, combining pickups and others, and averaging across the years 1986 to 1994. This results in an average annual scrappage rate of 6.77 percent for 2-axle 4-tire trucks, and

6.54 percent for other single-unit trucks. This percentage is applied uniformly across the forecast years. The purpose of this exercise is to enable the model to accommodate the incorporation of more fuel-efficient trucks over the course of the forecast.

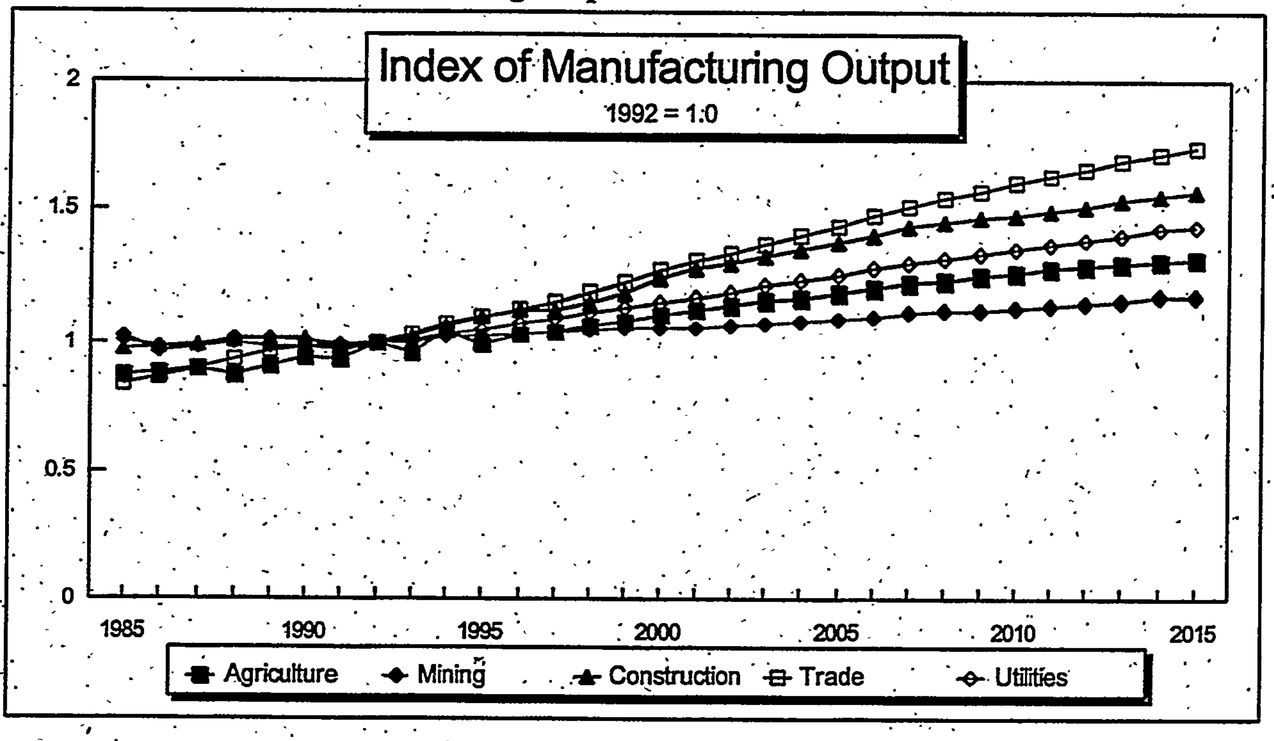
Table F-64: New Purchases of Light Commercial Trucks (by Type)

	2A4T		Other	
	Pickup	Other	Pickup	Other
1985	307,831	250,884	16,192	15,189
1986	320,501	261,210	16,858	15,814
1987	323,634	263,763	17,023	15,969
1988	337,556	275,110	17,755	16,656
1989	326,905	266,430	17,195	16,130
1990	305,929	249,334	16,092	15,095
1991	287,665	234,449	15,131	14,194
1992	324,257	264,272	17,056	16,000
1993	374,857	305,511	19,717	18,496
1994	421,693	343,682	22,181	20,807
1995	424,944	346,331	22,352	20,968

Forecasting VMT and MPG

In order to estimate fuel demand by LCT's, it is necessary to develop a forecast of two elements: the total travel demanded within each major-use group, and the average fuel economy of the trucks. Again, the FHWA data provides little guidance in the allocation of VMT and MPG among light commercial trucks; assumptions based on TIUS stratifications are therefore used.

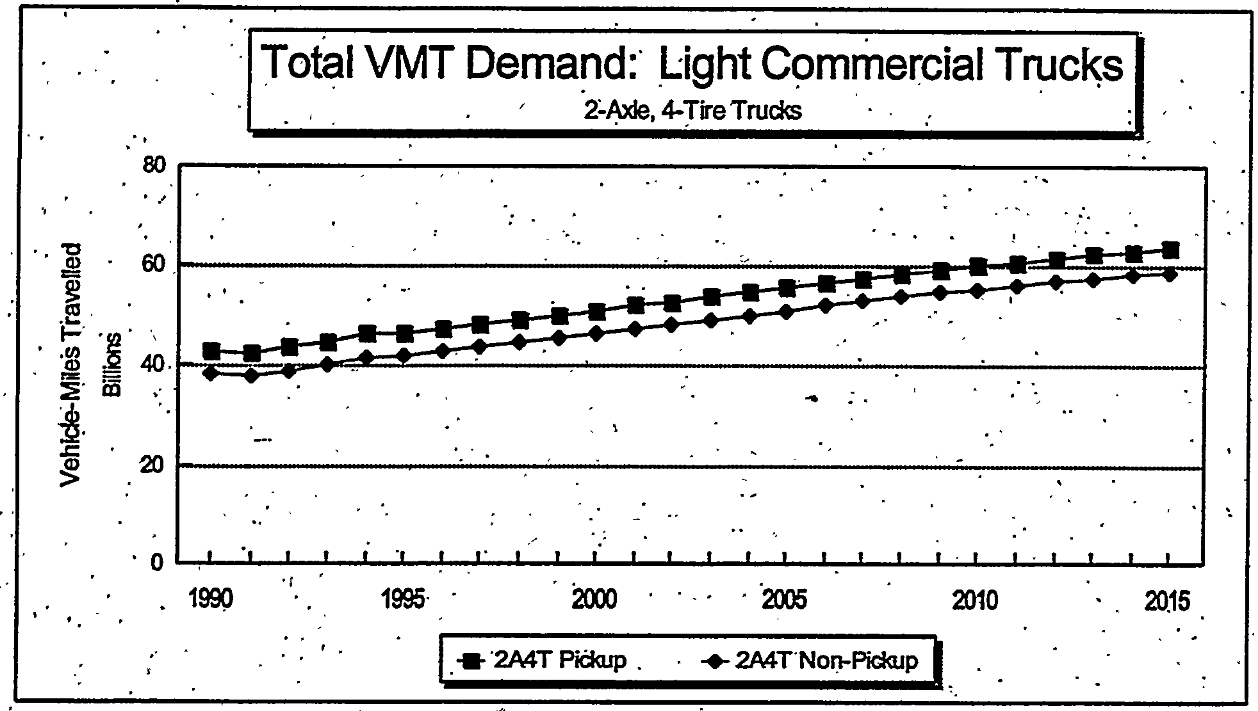
Figure F-18: Index of Manufacturing Output



Using the disaggregated FHWA data on the number of LCT's in 1992, and the TIUS data on the average number of miles per truck in the same year, a baseline VMT demand for 1992 may be constructed for each industrial group. Each baseline figure is then multiplied by an index of corresponding macroeconomic output (1992 = 1.0), to estimate the growth in VMT for each group. Personal travel is the exception, being adjusted by an index of personal travel from the LDV Model. The indexed growth in industrial output is depicted in the figure above. The figure on the following page depicts total VMT forecasts by truck type.

Estimates of fuel economy for trucks in each sector are obtained in a similar manner. Absent disaggregate time-trend data on LCT fuel economy, it is assumed that the 1992 TIUS values derived above satisfactorily describe each class of truck. It is further assumed that new trucks acquired after 1992 experience the same proportional change in MPG as do the light-duty trucks as represented in the LDV Model. Each MPG within the LCT Model is therefore adjusted by an index of LDT fuel economy, with 1992 = 1.0. These new, more efficient trucks are incorporated into the previous year's scrappage-adjusted stock using a stock-weighted harmonic average of fuel economies. This is depicted in the aggregate, below, where a VMT-weighted harmonic average was used to combine industrial groups, resulting in a forecast of stock MPG by truck type.

Figure F-19: Total VMT Demand for LCT's



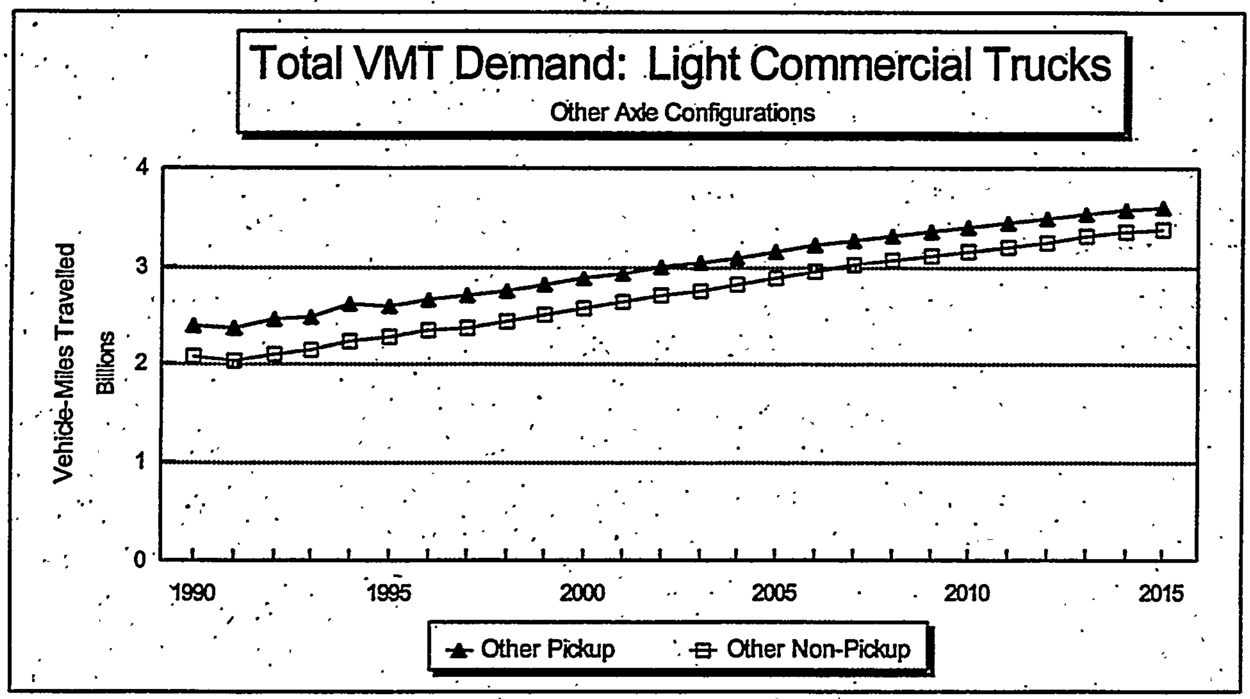
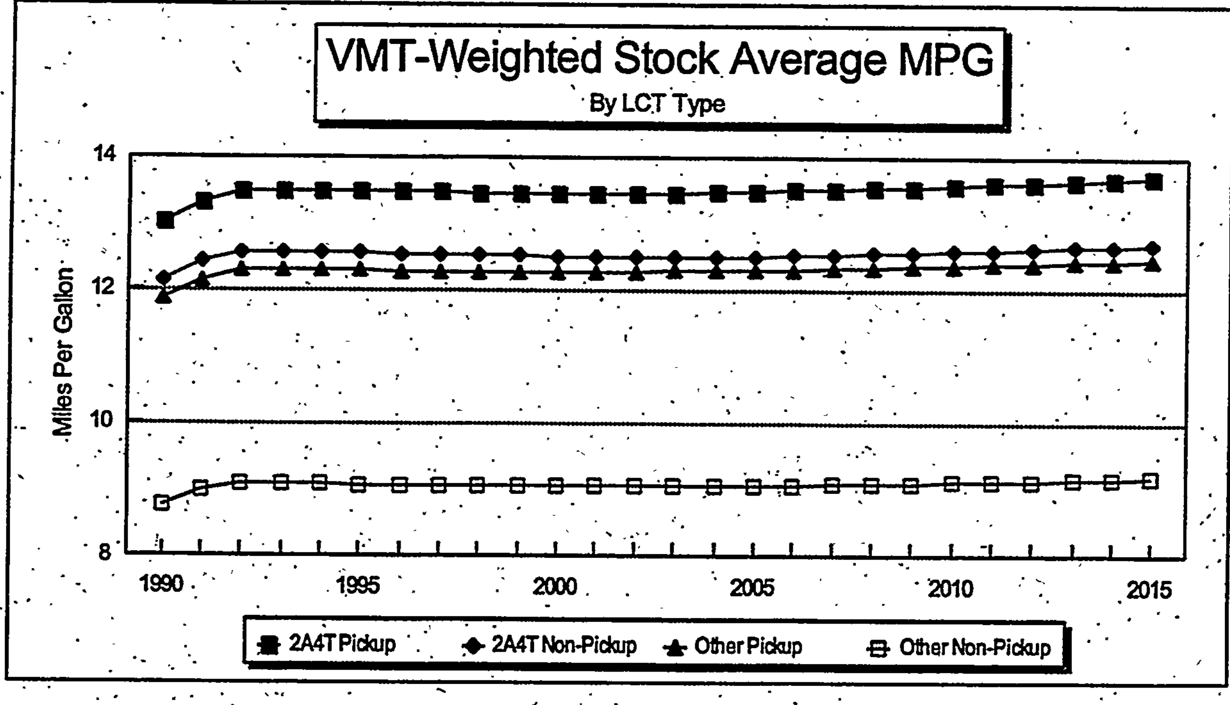


Figure F-20: Stock Average MPG for Light Commercial Trucks

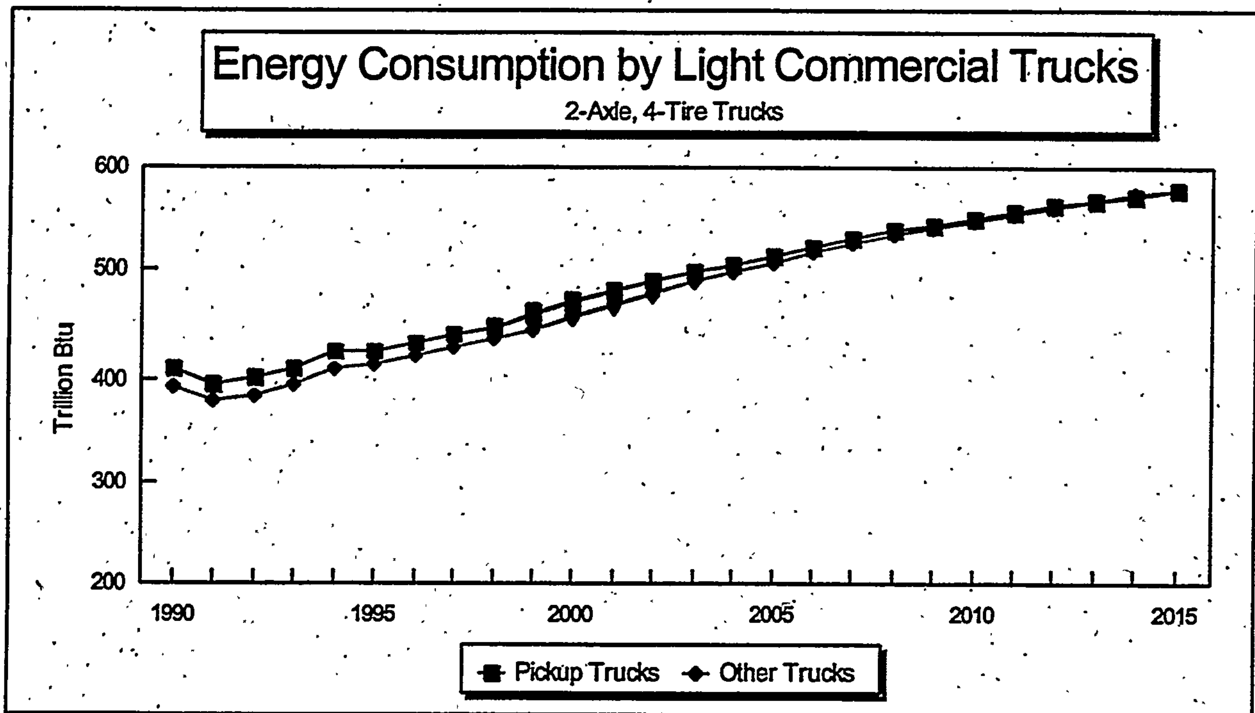


Energy Demand

Having an estimate of travel demand and fuel economy for each truck type and industrial group, it is a simple step to calculate the energy required to meet this demand. The figures below represent the aggregate demand for energy, by truck type, for LCT's. It is a relatively small, but not negligible, amount; rising from approximately 1 quad in 1990 to near 2 quads in 2015. The figures on the following page show how this energy demand is distributed among the major-use groups. Personal travel represents roughly half of all energy demand within this class of truck, with much of the remainder being allocated between Construction and Manufacturing & Trade.

This proposed model provides, by necessity, a rough approximation of the characteristics and performance of a relatively small category of trucks. Improvements in the model and the narrowing of assumptions will probably have to wait until the issuance of the next Truck Inventory and Use Survey, or the provision of more detailed statistics by FHWA.

Figure F-21: Energy Consumption by Light Commercial Trucks



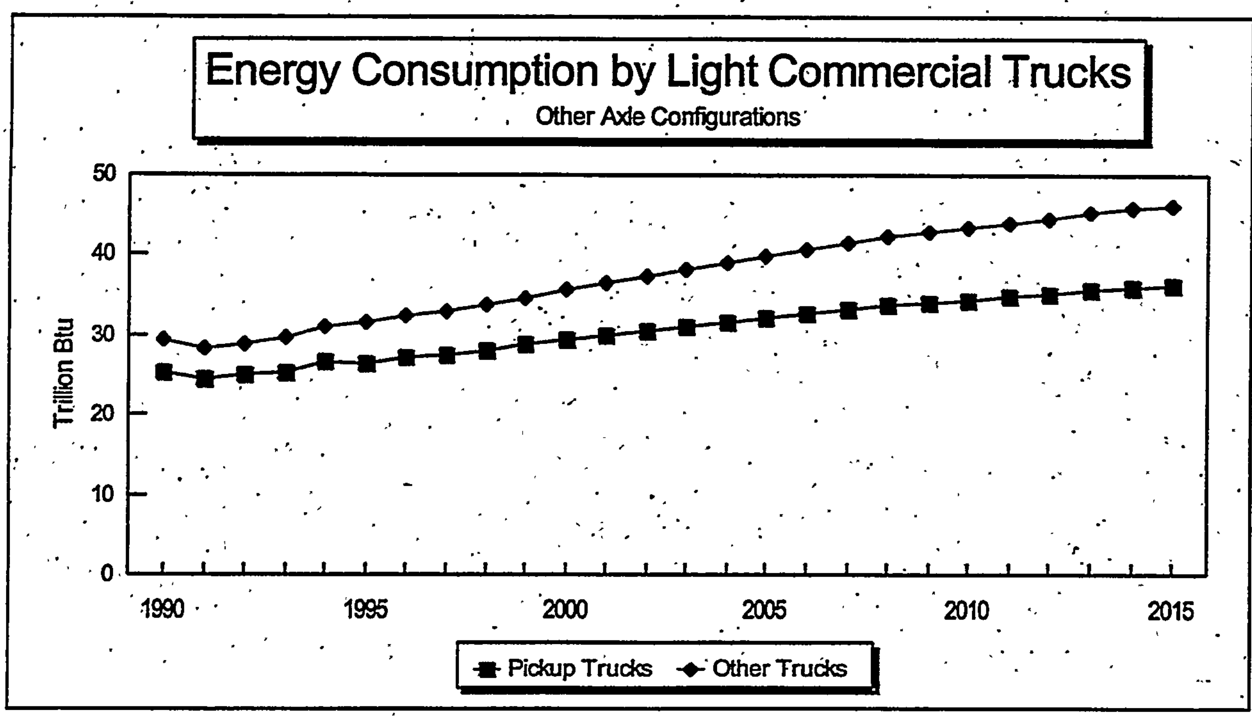
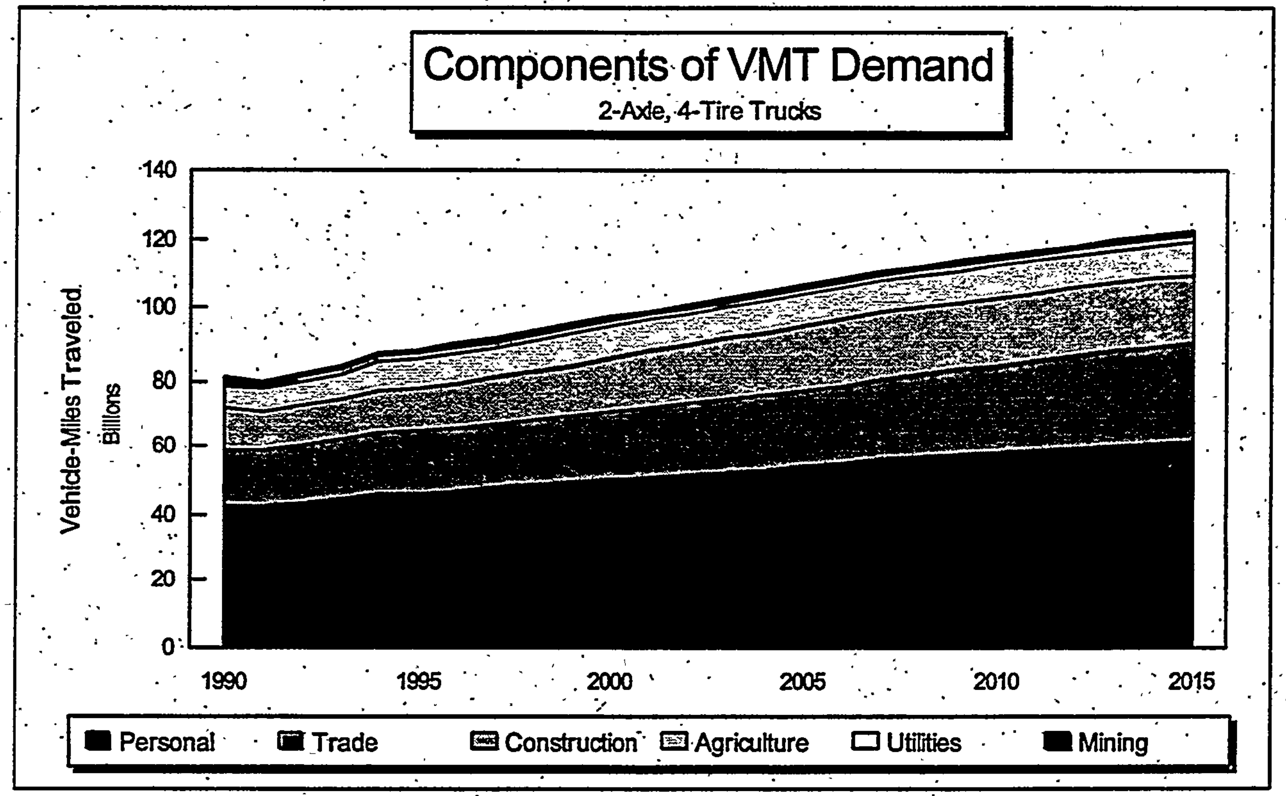
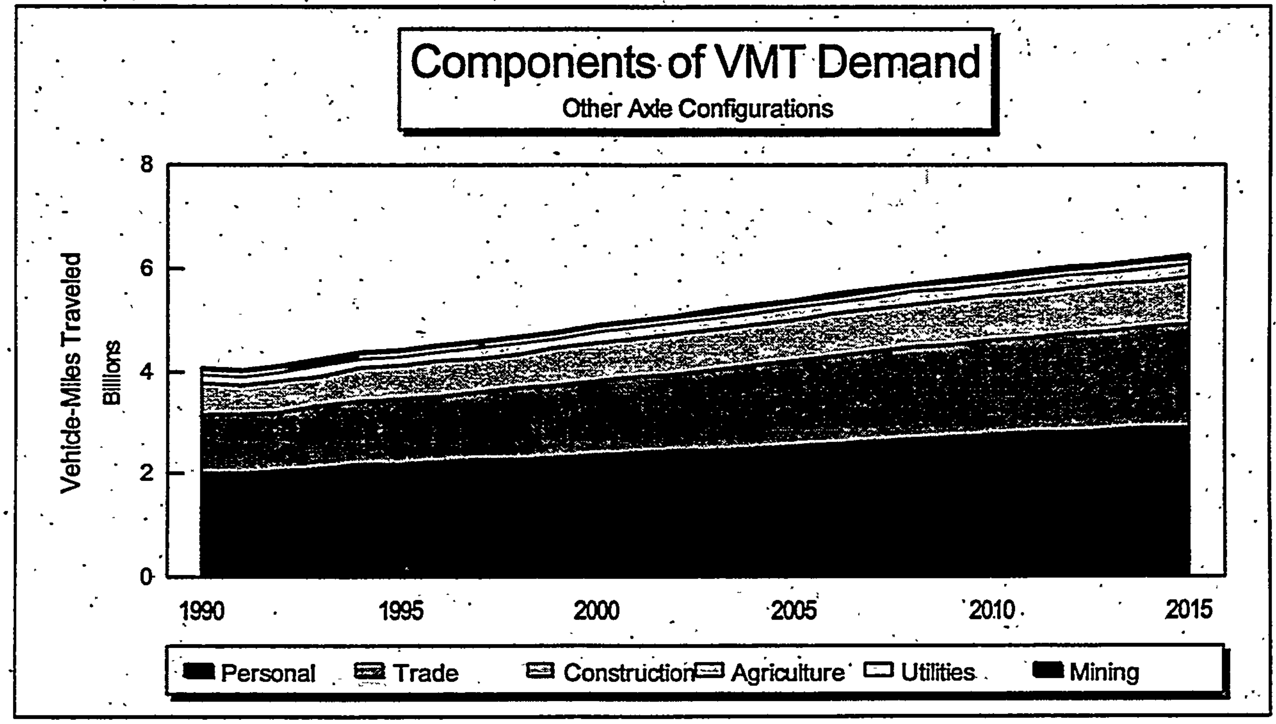


Figure F-22: Components of VMT Demand for LCT's





1992 TIUS Estimated Truck Registration Comparison with Federal Highway Administration Truck Registration

The Federal Highway Administration (FHWA) estimate of the number of private and commercial trucks registered is based on a calendar year summary report from each state. It reflects differences in truck definitions used by each state for vehicle registration from those used in TIUS.

Table F-65: 1992 TIUS vs. FHWA			
State	TIUS	FHWA	Difference
	(Numbers in Thousands)		
US	59,201	43,675	15,525
AL	1,167	1,075	92
AK	201	169	31
AZ	1,000	787	213
AR	749	512	237
CA	7,150	4,718	2,433
CO	1,093	722	371
CT	544	109	435
DE	173	121	52
DC	29	11	19
FL	2,673	1,938	735
GA	1,644	1,709	(65)
HI	280	95	185
ID	467	401	66
IL	2,272	1,325	947
IN	1,414	1,159	256
IA	931	741	190
KS	1,002	642	360
KY	1,016	984	32
LA	1,124	1,050	74
ME	339	211	127
MD	941	583	358
MA	879	467	412
MI	2,166	1,538	628
MN	1,156	708	448
MS	648	433	215
MO	1,357	1,156	201
MT	372	348	24

Table F-65: 1992 TIUS vs. FHWA			
State	TIUS	FHWA	Difference
	(Numbers in Thousands)		
NE	534	442	92
NV	388	286	102
NH	306	189	118
NJ	1,099	353	746
NM	581	492	89
NY	2,000	1,191	809
NC	1,760	1,439	321
ND	291	251	39
OH	2,189	1,635	554
OK	1,080	927	153
OR	1,059	592	467
PA	2,368	1,558	809
RI	159	98	61
SC	841	617	224
SD	295	279	16
TN	1,463	857	605
TX	4,373	3,803	570
UT	510	429	81
VT	157	112	46
VA	1,517	1,230	286
WA	1,542	1,288	254
WV	477	456	21
WI	1,197	1,221	(24)
WY	235	222	13

Table F-66: Distribution of 2-Axle, 4-Tire Trucks by Major Use and Weight									
Pickup Trucks, by Major Use	Total	Gross Vehicle Weight (Lbs.)							
		6,000 or Less	6,001 - 10,000	10,001 - 14,000	14,001 -16,000	16,001 -19,500	19,501 - 26,000	26,001 - 33,000	33,001 or More
Total	32,280,857	22,085,490	10,195,367	0	0	0	0	0	0
Agriculture or Farm Activities	2,267,891	937,018	1,330,873	0	0	0	0	0	0
Forestry or Lumber	150,014	61,581	88,433	0	0	0	0	0	0
Construction Work	1,049,648	520,703	528,945	0	0	0	0	0	0
Contractor Activities	1,623,799	955,096	668,703	0	0	0	0	0	0
Manufacturing	338,911	189,362	149,549	0	0	0	0	0	0
Wholesale Trade	269,741	190,115	79,626	0	0	0	0	0	0
Retail Trade	692,200	461,164	231,036	0	0	0	0	0	0
Business Use	1,186,238	795,568	390,670	0	0	0	0	0	0
Utilities	209,452	125,118	84,334	0	0	0	0	0	0
Mining or Quarry	92,084	12,159	79,925	0	0	0	0	0	0
Daily Rental	34,916	3,507	31,409	0	0	0	0	0	0
Not In Use	551,553	383,412	168,141	0	0	0	0	0	0
For Hire Transportation	52,733	38,668	14,065	0	0	0	0	0	0
Other	0	0	0	0	0	0	0	0	0
One-Way Rental	1,792	1,792	0	0	0	0	0	0	0
Personal Transportation	23,759,885	17,410,227	6,349,658	0	0	0	0	0	0

Table F-67: Distribution of 2-Axle, 4-Tire Trucks by Major Use and Weight

Other Single-Unit Trucks, by Major Use	Total	Gross Vehicle Weight (Lbs.)							
		6,000 or Less	6,001 - 10,000	10,001 - 14,000	14,001 -16,000	16,001 - 19,500	19,501 - 26,000	26,001 - 33,000	33,001 or More
Total	21,772,510	14,597,388	6,281,165	95,520	37,979	53,606	434,631	27,359	244,862
Agriculture or Farm Activities	410,505	109,687	141,046	5,464	5,134	23,838	96,743	2,304	26,289
Forestry or Lumber	22,915	7,451	4,707	454	192	749	8,528	225	609
Construction Work	390,414	144,592	164,320	12,054	2,309	6,716	49,089	3,488	7,846
Contractor Activities	976,763	422,582	491,968	9,323	2,832	1,929	38,510	744	8,875
Manufacturing	205,174	100,217	73,168	3,750	2,262	1,476	19,751	2,565	1,985
Wholesale Trade	480,380	217,272	194,978	6,914	1,094	3,183	44,847	5,342	6,750
Retail Trade	895,807	521,579	302,067	11,725	3,421	908	44,372	1,852	9,883
Business Use	1,497,535	917,823	512,825	14,580	7,264	2,565	29,280	2,288	10,910
Utilities	195,288	67,812	99,889	7,886	4,465	1,193	12,440	495	1,108
Mining or Quarry	52,521	12,106	32,726	147	488	139	5,575	89	1,251
Daily Rental	195,002	141,659	39,550	2,024	363	0	9,049	1,338	1,019
Not In Use	277,168	129,822	87,921	3,513	2,543	3,372	25,300	2,298	22,399
For Hire Transportation	112,495	45,299	23,077	8,046	2,724	3,877	21,023	3,875	4,574
Other	0	0	0	0	0	0	0	0	0
One-Way Rental	2,485	0	2,234	17	0	0	0	0	234
Personal Transportation	16,058,058	11,759,487	4,110,689	9,623	2,888	3,661	30,124	456	141,130

Table F-68: Distribution of Other Trucks by Major Use and Weight

Pickup Trucks, by Major Use	Total	Gross Vehicle Weight (Lbs.)							
		6,000 or Less	6,001 - 10,000	10,001 - 14,000	14,001 -16,000	16,001 -19,500	19,501 - 26,000	26,001 - 33,000	33,001 or More
Total	829,477	293,203	536,274	0	0	0	0	0	0
Agriculture or Farm Activities	136,899	32,686	104,213	0	0	0	0	0	0
Forestry or Lumber	4,064	3,869	195	0	0	0	0	0	0
Construction Work	40,665	13,032	27,633	0	0	0	0	0	0
Contractor Activities	67,095	16,007	51,088	0	0	0	0	0	0
Manufacturing	15,046	10,250	4,796	0	0	0	0	0	0
Wholesale Trade	10,971	4,532	6,439	0	0	0	0	0	0
Retail Trade	26,109	1,881	24,228	0	0	0	0	0	0
Business Use	104,232	33,933	70,299	0	0	0	0	0	0
Utilities	5,612	2,234	3,378	0	0	0	0	0	0
Mining or Quarry	6,348	684	5,664	0	0	0	0	0	0
Daily Rental	2,821	2,821	0	0	0	0	0	0	0
Not In Use	25,814	17,775	8,039	0	0	0	0	0	0
For Hire Transportation	1,528	1,528	0	0	0	0	0	0	0
Other	0	0	0	0	0	0	0	0	0
One-Way Rental	0	0	0	0	0	0	0	0	0
Personal Transportation	382,273	151,971	230,302	0	0	0	0	0	0

Table F-69: Distribution of Other Trucks by Major Use and Weight

Other Single-Unit Trucks, by Major Use	Total	Gross Vehicle Weight (Lbs.)							
		6,000 or Less	6,001 - 10,000	10,001 - 14,000	14,001 -16,000	16,001 -19,500	19,501 - 26,000	26,001 - 33,000	33,001 or More
Total	3,033,101	88,758	503,062	252,150	84,377	147,378	1,316,638	79,669	561,069
Agriculture or Farm Activities	607,046	4,052	63,688	25,315	14,877	66,596	328,713	11,008	92,797
Forestry or Lumber	48,625	0	3,165	4,331	1,148	3,065	22,467	568	13,881
Construction Work	415,318	2,187	55,000	24,817	11,383	10,320	165,356	7,355	138,900
Contractor Activities	260,603	1,709	65,343	37,739	8,011	10,768	108,512	5,668	22,853
Manufacturing	133,231	0	27,007	11,376	1,591	2,965	54,014	6,262	30,016
Wholesale Trade	268,484	11,975	45,929	18,980	6,274	4,551	134,448	13,275	33,052
Retail Trade	281,472	3,266	58,877	29,972	8,997	6,303	129,628	11,475	32,954
Business Use	286,903	3,198	70,163	37,765	12,388	8,469	91,839	5,689	57,392
Utilities	120,447	0	9,334	21,719	4,490	4,017	69,957	3,064	7,866
Mining or Quarry	43,562	376	3,278	3,100	1,738	1,153	15,313	661	17,943
Daily Rental	48,880	1,005	811	12,203	0	4,859	22,551	2,450	5,001
Not In Use	94,829	5,428	18,852	2,082	3,488	7,346	38,659	3,078	15,896
For Hire Transportation	204,859	0	8,923	10,525	5,808	8,345	89,051	8,112	74,095
Other	0	0	0	0	0	0	0	0	0
One-Way Rental	7,043	0	446	1,787	96	28	4,359	0	327
Personal Transportation	211,799	-55,562	72,246	10,439	4,088	8,593	41,771	1,004	18,096

Table F-70: Distribution of 2-Axle, 4-Tire Trucks by Major Use and Weight

Major Use	Total	Gross Vehicle Weight (Lbs.)							
		6,000 or Less	6,001 - 10,000	10,001 - 14,000	14,001 - 16,000	16,001 - 19,500	19,501 - 26,000	26,001 - 33,000	33,001 or More
Pickup Trucks									
Agriculture	2,417,905	998,599	1,419,306	0	0	0	0	0	0
Mining	92,084	12,159	79,925	0	0	0	0	0	0
Construction	2,673,447	1,475,799	1,197,648	0	0	0	0	0	0
Trade	3,128,084	2,063,588	1,064,496	0	0	0	0	0	0
Utilities	209,452	125,118	84,334	0	0	0	0	0	0
Personal	23,759,885	17,410,227	6,349,658	0	0	0	0	0	0
Other Single-Unit Trucks									
Agriculture	433,420	117,138	145,753	5,918	5,326	24,587	105,271	2,529	26,898
Mining	52,521	12,106	32,726	147	488	139	5,575	89	1,251
Construction	1,367,177	567,174	656,288	21,377	5,141	8,645	87,599	4,232	16,721
Trade	3,666,046	2,073,671	1,235,820	50,569	19,671	15,381	193,622	19,558	57,754
Utilities	195,288	67,812	99,889	7,886	4,465	1,193	12,440	495	1,108
Personal	16,058,058	11,759,487	4,110,689	9,623	2,888	3,661	30,124	456	141,130

Table F-71: Distribution of Other Trucks by Major Use and Weight

Major Use	Total	Gross Vehicle Weight (Lbs.)							
		6,000 or Less	6,001 - 10,000	10,001 - 14,000	14,001 - 16,000	16,001 - 19,500	19,501 - 26,000	26,001 - 33,000	33,001 or More
Pickups									
Agriculture	140,963	36,555	104,408	0	0	0	0	0	0
Mining	6,348	684	5,664	0	0	0	0	0	0
Construction	107,760	29,039	78,721	0	0	0	0	0	0
Trade	186,521	72,720	113,801	0	0	0	0	0	0
Utilities	5,612	2,234	3,378	0	0	0	0	0	0
Personal	382,273	151,971	230,302	0	0	0	0	0	0
Other Single-Unit									
Agriculture	655,671	4,052	66,853	29,646	16,025	69,661	351,180	11,576	106,678
Mining	43,562	376	3,278	3,100	1,738	1,153	15,313	661	17,943
Construction	675,921	3,896	120,343	62,556	19,394	21,088	273,868	13,023	161,753
Trade	1,325,701	24,872	231,008	124,690	38,642	42,866	564,549	50,341	248,733
Utilities	120,447	0	9,334	21,719	4,490	4,017	69,957	3,064	7,866
Personal	211,799	55,562	72,246	10,439	4,088	8,593	41,771	1,004	18,096

Fuel Economy of Light Commercial Trucks

Table F-72: Distribution of Light Commercial Trucks by MPG												
Miles per Gallon	AGRICULTURE				MINING				CONSTRUCTION			
	2 Axle, 4-Tire		Other Axle Configurations		2 Axle, 4-Tire		Other Axle Configurations		2 Axle, 4-Tire		Other Axle Configurations	
	Pickup	Other	Pickup	Other	Pickup	Other	Pickup	Other	Pickup	Other	Pickup	Other
Less Than 5	0	11,586	0	2,157	0	1,304	0	40	0	6,009	0	1,695
6.0 - 6.9	2,249	37,908	6,233	6,559	0	1,258	0	42	0	22,340	493	10,669
7.0 - 7.9	47,422	41,985	4,863	14,519	1,566	3,491	0	629	17,069	44,871	1,520	32,174
9.0 - 10.9	319,048	54,325	28,961	19,405	13,148	2,970	271	1,110	171,259	150,295	23,296	34,899
11.0 - 12.9	321,488	54,229	18,398	8,554	20,774	13,312	5,041	632	302,322	221,162	10,420	20,910
13.0 - 14.9	266,650	33,385	7,596	4,900	19,671	10,986	351	309	280,306	116,567	19,477	5,652
15.0 - 20.9	436,552	45,033	31,111	8,924	24,496	5,073	0	514	392,149	189,693	23,516	9,598
21.0 - 24.9	20,643	1,557	7,246	0	271	0	0	0	25,983	22,077	0	0
25.0 - 29.9	4,195	150	0	174	0	0	0	0	2,343	2,849	0	0
30 Or More	1,060	666	0	0	0	0	0	0	6,218	1,914	0	0

Table F-73: Distribution of Light Commercial Trucks by MPG

Miles per Gallon	TRADE				UTILITIES				PERSONAL			
	2 Axle, 4-Tire		Other Axle Configurations		2 Axle, 4-Tire		Other Axle Configurations		2 Axle, 4-Tire		Other Axle Configurations	
	Pickup	Other	Pickup	Other	Pickup	Other	Pickup	Other	Pickup	Other	Pickup	Other
Less Than 5	1,327	12,125	0	3,676	0	3,946	0	79	579	2,852	0	294
6.0 - 6.9	0	61,177	0	25,386	0	6,984	0	2,007	1,969	9,642	1,566	2,286
7.0 - 7.9	31,564	117,844	10,543	43,261	6,072	13,822	0	1,595	61,712	23,772	8,881	8,507
9,0 - 10.9	131,515	256,935	29,328	61,669	10,249	20,388	266	2,553	993,076	518,874	75,913	19,783
11.0 - 12.9	241,581	341,049	19,775	37,485	11,357	33,365	1,692	1,702	1,380,887	890,383	40,580	16,678
13.0 - 14.9	219,022	262,500	10,410	11,880	27,177	20,653	0	1,038	1,387,827	1,015,041	23,548	10,683
15.0 - 20.9	381,479	351,819	13,460	31,591	28,437	22,706	1,420	215	2,317,935	1,636,196	73,846	11,313
21.0 - 24.9	21,295	57,959	28,193	177	771	1,800	0	145	178,123	138,696	4,662	45
25.0 - 29.9	3,118	2,288	0	163	271	45	0	0	18,133	27,188	0	0
30 Or More	0	884	0	0	0	236	0	0	9,418	4,133	1,305	0

Major-Use Distribution of LCT's

Table F-74: Light Commercial Truck Stock: Stratification by Major Use Group

	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
2A4T Pickup											
Agricultures	454,174	465,938	480,672	497,496	508,518	521,203	523,938	530,183	548,553	562,652	570,090
Mining	25,576	26,238	27,068	28,015	28,636	29,350	29,504	29,856	30,890	31,684	32,103
Construction	383,244	393,171	405,604	419,800	429,101	439,805	442,113	447,383	462,883	474,780	481,057
Trade	340,636	349,459	360,510	373,128	381,395	390,909	392,960	397,644	411,421	421,996	427,575
Utilities	26,987	27,686	28,561	29,561	30,216	30,969	31,132	31,503	32,595	33,432	33,874
Personal	2,031,871	2,084,504	2,150,420	2,225,685	2,274,997	2,331,746	2,343,981	2,371,921	2,454,102	2,517,178	2,550,456
Total	*3,262,486*	*3,346,996*	*3,452,835*	*3,573,685*	*3,652,883*	*3,743,983*	*3,763,628*	*3,808,489*	*3,940,444*	*4,041,723*	*4,095,156*
2A4T Non-Pickup											
Agriculture	117,208	120,244	124,046	128,388	131,233	134,506	135,212	136,824	141,564	145,203	147,122
Mining	14,977	15,365	15,851	16,405	16,769	17,187	17,277	17,483	18,089	18,554	18,799
Construction	296,467	304,147	313,764	324,746	331,941	340,221	342,007	346,083	358,074	367,277	372,133
Trade	590,080	605,365	624,508	646,366	660,687	677,167	680,720	688,834	712,701	731,019	740,683
Utilities	47,240	48,464	49,997	51,746	52,893	54,212	54,497	55,146	57,057	58,524	59,297
Personal	1,592,973	1,634,237	1,685,915	1,744,922	1,783,583	1,828,074	1,837,666	1,859,570	1,924,000	1,973,451	1,999,541
Total	*2,658,945*	*2,727,821*	*2,814,081*	*2,912,574*	*2,977,105*	*3,051,368*	*3,067,379*	*3,103,941*	*3,211,484*	*3,294,028*	*3,337,576*
Other Pickup											
Agriculture	39,884	40,874	39,440	40,188	41,666	43,089	43,316	43,832	45,963	47,980	52,846
Mining	2,164	2,217	2,140	2,180	2,260	2,338	2,350	2,378	2,493	2,603	2,867
Construction	30,072	30,818	29,737	30,301	31,415	32,488	32,659	33,048	34,655	36,176	39,845
Trade	43,472	44,551	42,988	43,803	45,414	46,966	47,212	47,775	50,098	52,296	57,601
Utilities	1,290	1,322	1,276	1,300	1,348	1,394	1,401	1,418	1,487	1,552	1,710
Personal	87,976	90,158	86,997	88,646	91,906	95,046	95,545	96,684	101,385	105,834	116,568
Total	*204,858*	*209,940*	*202,578*	*206,418*	*214,010*	*221,322*	*222,483*	*225,135*	*236,081*	*246,441*	*271,436*
Other Non-Pickup											
Agriculture	25,538	26,172	25,254	25,732	26,679	27,590	27,735	28,066	29,430	30,722	33,838
Mining	1,252	1,283	1,238	1,262	1,308	1,353	1,360	1,376	1,443	1,506	1,659
Construction	45,971	47,112	45,460	46,321	48,025	49,666	49,926	50,522	52,978	55,303	60,912
Trade	88,246	90,435	87,263	88,918	92,188	95,338	95,838	96,980	101,696	106,158	116,925
Utilities	3,566	3,654	3,526	3,593	3,725	3,852	3,872	3,919	4,109	4,289	4,724
Personal	27,598	28,283	27,291	27,808	28,831	29,816	29,973	30,330	31,804	33,200	36,567
Total	*192,171*	*196,938*	*190,032*	*193,634*	*200,756*	*207,616*	*208,704*	*211,192*	*221,460*	*231,178*	*254,626*

Table F-75: LCT Sales: Stratification by Major Use Group

	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
2A4T Pickup											
Agriculture	42,853	44,617	45,053	46,991	45,509	42,589	40,046	45,140	52,184	58,704	59,157
Mining	2,413	2,513	2,537	2,646	2,563	2,398	2,255	2,542	2,939	3,306	3,331
Construction	36,161	37,649	38,017	39,653	38,402	35,937	33,792	38,090	44,034	49,536	49,918
Trade	32,141	33,463	33,791	35,244	34,132	31,942	30,035	33,856	39,139	44,029	44,368
Utilities	2,546	2,651	2,677	2,792	2,704	2,531	2,380	2,682	3,101	3,488	3,516
Personal	191,717	199,607	201,558	210,229	203,596	190,532	179,157	201,947	233,461	262,629	264,654
Total	307,831	320,501	323,634	337,556	326,905	305,929	287,665	324,257	374,857	421,693	424,944
2A4T Non-Pickup											
Agriculture	11,059	11,514	11,627	12,127	11,744	10,991	10,335	11,649	13,467	15,150	15,267
Mining	1,413	1,471	1,486	1,550	1,501	1,404	1,321	1,489	1,721	1,936	1,951
Construction	27,973	29,124	29,409	30,674	29,706	27,800	26,141	29,466	34,064	38,320	38,615
Trade	55,677	57,968	58,535	61,053	59,127	55,333	52,029	58,648	67,800	76,271	76,859
Utilities	4,457	4,641	4,686	4,888	4,734	4,430	4,165	4,695	5,428	6,106	6,153
Personal	150,305	156,491	158,020	164,819	159,618	149,376	140,458	158,325	183,031	205,900	207,487
Total	250,884	261,210	263,763	275,110	266,430	249,334	234,449	264,272	305,511	343,682	346,331
Other Pickup											
Agriculture	3,152	3,282	3,314	3,457	3,348	3,133	2,946	3,321	3,839	4,318	4,352
Mining	171	178	180	188	182	170	160	180	208	234	236
Construction	2,377	2,475	2,499	2,606	2,524	2,362	2,221	2,504	2,894	3,256	3,281
Trade	3,436	3,577	3,612	3,768	3,649	3,415	3,211	3,619	4,184	4,707	4,743
Utilities	102	106	107	112	108	101	95	107	124	140	141
Personal	6,954	7,240	7,311	7,625	7,384	6,911	6,498	7,325	8,468	9,526	9,599
Total	16,192	16,858	17,023	17,755	17,195	16,092	15,131	17,056	19,717	22,181	22,352
Other Non-Pickup											
Agriculture	2,019	2,102	2,122	2,213	2,144	2,006	1,886	2,126	2,458	2,765	2,786
Mining	99	103	104	109	105	98	92	104	121	136	137
Construction	3,634	3,783	3,820	3,984	3,859	3,611	3,396	3,827	4,425	4,978	5,016
Trade	6,975	7,262	7,333	7,648	7,407	6,932	6,518	7,347	8,494	9,555	9,628
Utilities	282	293	296	309	299	280	263	297	343	386	389
Personal	2,181	2,271	2,293	2,392	2,317	2,168	2,038	2,298	2,656	2,988	3,011
Total	15,189	15,814	15,969	16,656	16,130	15,095	14,194	16,000	18,496	20,807	20,968

Attachment 6: Air Travel Module

Derivation of Demographic Adjustment Factors

It is expected that the "personal travel" segment of commercial passenger traffic will be more sensitive to air fares than the "business travel" segment. It is also likely that the volume of discretionary travel will be more influenced by public perceptions of airline safety, convenience, and quality of service. One way of quantifying this effect is in a stratified measure of the "propensity to fly" which, in its most rudimentary form, associates with each age group and gender a static value obtained from a survey of travelers.[58] The propensity to fly is considered to be the product of the percentage of a given population segment to have flown in the previous year, and the average number of flights taken by the travelers. This translates into the number of trips per capita associated with that population cohort. These values are subsequently used to modulate forecasts produced by the conventional model as follows:

$$ARPM_T = DI_T \cdot RPM_{D,P,T}$$

where:

$ARPM_T$ = Adjusted personal-travel revenue passenger miles in year t.
DI_T = Demographic index in year t.
$RPM_{D,P,T}$ = Unadjusted forecast of domestic personal RPM in year t.

and:

$$DI_T = \left[\frac{\sum_I POP_{I,T} \cdot PROFLY_{I,T}}{\sum_I POP_{I,T}}\right] \div \left[\frac{\sum_I POP_{I,0} \cdot PROFLY_{I,0}}{\sum_I POP_{I,0}}\right]$$

where:

$POP_{I,T}$ = The population of the I^{th} cohort in year T.
$POP_{I,0}$ = The population of the I^{th} cohort in the base year.
$PROFLY_{I,T}$ = The propensity to fly for the I^{th} cohort.

The following describes the assumptions and data manipulations undertaken to develop age- and

[58] This adjustment algorithm has been adapted from that provided in Appendix A of *Forecasting Civil Aviation Activity: Methods and Approaches,* Transportation Research Circular Number 372, Transportation Research Board, June 1991.

gender-specific demographic adjustments to forecasts of personal travel. The use of these factors is predicated on the static nature of the public's propensity to fly ($PROFLY_{I,T} = PROFLY_{I,0}$), absent sufficient time series data to reflect and predict changing trends.

■ The ATA travel survey provides the percentage of each age group which has flown in the previous year (π_A), as well as the fraction of men and women of all age groups who have flown (π_M, π_W). The first step is to derive an estimate of the percentage of each age group and sex which has flown.

■ Given that N_M and N_W represent the total number of men and women, respectively, the percent of the flying population that are of each gender can be represented as follows:

$$P_M = \frac{\pi_M N_M}{\pi_M N_M + \pi_W N_W} \quad ; \quad P_W = 1 - P_M$$

Using the 1990 Census numbers, $P_M = 0.53$ and $P_W = 0.47$. In other words, 53 percent of people who took at least one air trip in the previous year were male.

■ It is assumed that this gender ratio is constant across age groups and time. This ratio is used to estimate the percentage of the population by gender and age group which has flown in the previous year. The equation for males is as follows:

$$\pi_{M,A} = \frac{P_M \pi_A N_A}{N_{M,A}}$$

In order to determine the number of trips per capita for male and female cohorts, further assumptions are necessary.

■ According to the ATA survey, male travelers flew more than female travelers; the ratio of male to female trips per capita is 1.72, i.e.:

$$\frac{T_M}{N_M} = 1.72 \frac{T_W}{N_W}$$

where T_M and T_W represent the total number of trips by male and female travellers, respectively.

■ In each age group, the number of average trips per capita is reported. It is assumed that the male/female travel ratio holds across age groups, which enables the subsequent division of each figure into two gender-specific figures.

For each age group, the number of trips per capita (TPC) is expressed as:

$$\frac{T_{M,A} + T_{W,A}}{N_{M,A} + N_{W,A}} = TPC_A$$

From above:

$$T_{M,A} = 1.72\left(\frac{T_{W,A}\,N_{M,A}}{N_{W,A}}\right)$$

Substituting, and rearranging:

$$T_{W,A}\left(1 + 1.72\left(\frac{N_{M,A}}{N_{W,A}}\right)\right) = TPC_A\,(N_{M,A} + N_{W,A})$$

which leads to the trips per capita for women, by age group:

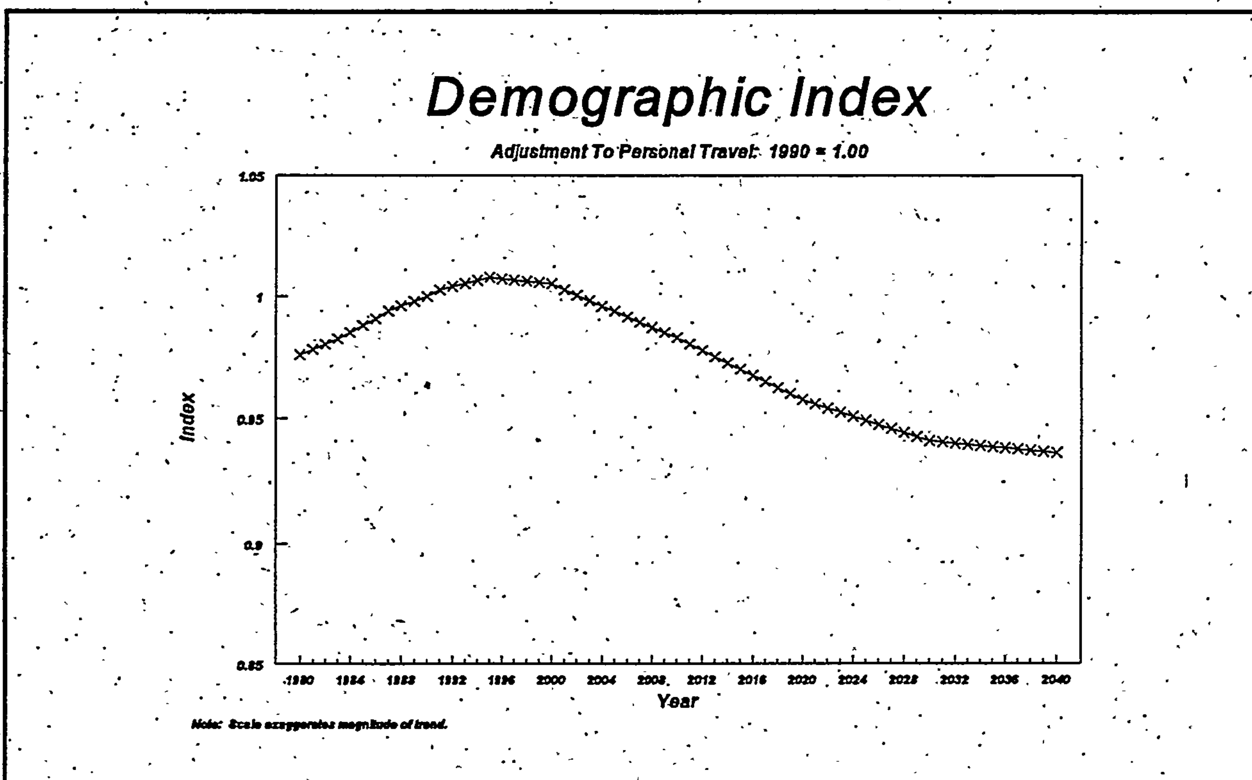
$$\frac{T_{W,A}}{N_{W,A}} = TPC_A\left[\frac{N_{M,A} + N_{W,A}}{N_{W,A} + 1.72\,N_{M,A}}\right]$$

The resulting figures are tabulated, and a graph of the demographic index through the year 2040 is provided on the following page.

Table F-76. ATA 1990 Air Travel Survey Data

Age Group	1990 Population ('000)		Percentage Flown		Average Trips per Capita		Propensity to Fly ($PROFLY_{I,T}$)	
	Male	Female	Male	Female	Male	Female	Male	Female
18-24	13,215	12,925	0.31	0.29	3.29	1.91	1.03	0.55
25-34	22,078	21,848	0.37	0.33	4.88	2.83	1.80	0.94
35-44	18,193	19,112	0.38	0.32	5.18	3.03	1.97	0.97
45-54	12,406	13,081	0.39	0.33	4.82	2.81	1.89	0.93
55-64	10,103	11,260	0.33	0.26	4.17	2.45	1.36	0.63
65+	12,853	18,706	0.31	0.19	4.28	2.52	1.34	0.48

Figure F-23. Demographic Adjustment Index for Personal Air Travel: 1980-2040



Sources:

Population Data: U.S. Department of Commerce, Bureau of the Census, *Projections of the Population of the United States by Age, Sex, and Race: 1988 to 2080*, Population Estimates and Projections, Series P-25, No. 1018.

Percentage Flown & Trips per Capita: ATA, *Air Travel Survey, 1990.*

Attachment 7: Vehicle Emissions Module

Derivation of Emission Factors

INTRODUCTION

This report provides EPA emission factors to be used in the transportation vehicle emission solution algorithm, which is outlined in the *Transportation Sector Component Design Report* (TSCDR) section on emissions. This algorithm is as follows:

$$EMISS_{IE,IM,IR,T} = EFACT_{IE,IM,IR,T} * U_{IM,IR,T}$$

where *EMISS* is total emissions of pollutant IP by mode IM, in region IR, and time T, *EFACT* is an emission factor based on technology, fuel and vintage weights, and *U* is a measure of annual vehicle activity (vehicle-miles-traveled or fuel consumption in gallons).

The TSCDR specifies modal emission factors for SO_x, NO_x, carbon, CO, CO_2 and VOCs, and calls for emissions to be calculated for the following six transportation modes:

Highway	Non-Highway
Light-Duty Vehicles	Rail
Freight Trucks	Air
Buses	Water

A number of these transportation modes have subcomponent modes that are to be handled in a separate TERF "Miscellaneous End-Use Component" module. These subcomponent modes include military aircraft, recreational boating, passenger rail, and buses. This report also provides the emission factors for these miscellaneous transportation energy end-use categories, as well as for alternative fuel vehicles (AFVs).

Pollutant emission factors are not reported for certain transportation vehicles. Reasons for the exclusion of these emission factors include one or more of the following:

- the lack of adequate EPA emissions testing results for the production of reliable fleet-average emission rates,

- the quantities of a pollutant generated a vehicle type are not significant,

- the pollutant is not regulated by the EPA (for example, only aircraft HC and smoke emissions are currently regulated).

Such instances of nonreported emission factors are documented in the relevant transportation mode sections of this report.

HIGHWAY MOBILE SOURCE EMISSION FACTORS

Highway Source Emission Factor Information Sources

Emission factors and the accompanying calculation procedures used for virtually all federal and state mobile source emission inventory studies come from the following EPA source documents:

- *Compilation of Air Pollutant Emission Factors - Volume II: Mobile Sources* (AP-42, Fourth Edition, September 1985)

- *Supplement A to AP-42 Volume II*, January 1991.

- *User's Guide to MOBILE4.1*, EPA-AA-TEB-91-01 (EPA Office of Mobile Sources, Emission Control Technology Division, July 1991).

- *Interim Guidance for the Preparation of Mobile Source Emission Inventories*, Attachments A through J (This EPA memorandum supersedes the mobile source emission inventory preparation instructions contained in *Procedures for Emission Inventory Preparation — Volume IV, Mobile Sources*, which is currently being revised)

- *Procedures for Emission Inventory Preparation — Volume IV, Mobile Sources*, EPA-450/4-81-26d (revised), (July 1992).

The document, *Compilation of Air Pollutant Emission Factors - Volume II*, reports all data and emission factor calculation algorithms for both highway and off-highway emission sources. Supplement A to AP-42 presents updated emissions factor information for highway sources based on the results of additional vehicle test data obtained subsequent to the publication of the original AP-42 Air Pollutant Emission Factor compilation document, as well as methodological modifications reflecting calculation refinements and new emission regulations. Both EPA data source documents categorize highway mobile sources into eight types: light-duty gasoline vehicles (LDGVs), light-duty gasoline-powered trucks with a gross vehicle weight rating of less than or equal to 6,000 lbs (LDGT1s), light-duty gasoline-powered trucks with a gross vehicle weight rating greater than 6,000 lbs (LDGT2s), heavy-duty gasoline-powered vehicles (HDGVs), light-duty diesel-powered vehicles (LDDVs), light-duty diesel-powered trucks (LDDTs), heavy-duty diesel-powered vehicles (HDDVs), and motorcycles. The EPA document, *Procedures for Emission Inventory Preparation — Volume IV, Mobile Sources*, provides the most up-to-date instructions for all state and local agencies involved in the preparation of mobile source inventories. The EPA makes frequent mention of the fact that a number of emission rate studies are ongoing. Therefore, frequent monitoring of the status of EPA analytical studies is suggested in order to ensure that TERF emission factors reflect the latest available emission testing and methodological information.

Highway mobile source emission factor calculation routines, outlined in the above EPA documents, are incorporated into EPA's MOBILE model, which estimates hydrocarbon, carbon monoxide, and oxides of nitrogen emission factors for gasoline and diesel-powered vehicles. The most recent version of the mobile emissions model, MOBILE4.1, was released in 1991 for the express purpose of preparing all 1990 base year emission inventories mandated by the CAAA for all areas exclusive of California, and to prepare CAAA-mandated carbon monoxide emissions inventory projections. However, MOBILE4.1 does not incorporate the effects of other CAAA provisions, such as the Tier I exhaust emissions standards for light-duty vehicles and light-duty trucks. Revisions to the MOBILE4.1 model to reflect CAAA provisions for NMHC and NO_x and additional test data are being discussed and planned for incorporation into the new MOBILE5 model. The EPA is currently seeking recommendations through a series of public workshops, and expects to release MOBILE5 in the fall of 1992. Appendix E.EM.B provides an excerpt from an EPA letter handout (dated March 5, 1992) that outlines potential MOBILE5 revisions.

Highway source emission factors for California are calculated through the use of the California Air Resources Board's own emission factor model, EMFAC. The most recent version of this model is EMFAC7EP, which incorporates the most recent California vehicle and fuel standards. All EMFAC model versions are variants of EPA's MOBILE model, and have been customized to serve the emission calculation needs of the CARB. EPA's Office of Mobile Sources is currently examining CARB in-use test data for vehicles certified to meet California's 0.7 gpm NO_x emission standard. Emission rate equations for reflecting the effects of California's low-emitting vehicle (LEV) program and inspection/maintenance credits are also being considered for inclusion in MOBILE model updates.

The California Air Resources Board uses a separate computer model to assimilate emission test data and calculate basic emission rates. This model, CALIFAC, uses the CARB's In-Use Surveillance Program and the Inspection/Maintenance Project databases (along with EPA data) to derive the basic emission factors. The basic emission factors serve as the inputs to EMFAC, which subsequently applies emission correction factors to produce final emission factors. This report lists the California highway emission factors along with the EPA national emission factors.

The EPA Procedure for Calculating Mobile Source Emissions Factors

Methodology Overview

Federal and state agency-developed emission factors for each vehicle type are derived from a four-step process[59]:

First, "basic exhaust emission factors", or BEFs, are estimated according to rigid federal testing procedures[60].

Second, the BEFs are adjusted with a series of multiplicative and additive correction factors that account for testing condition variances in ambient temperature and operating mode, as well as expected emission contxl device tampering rates.

Third, the BEFs are further adjusted with a composite correction factor that reflects actual vehicle characteristics and driver operating practices (For the hydrocarbon BEF, separate emission factors for evaporative and running losses are added. In addition, the hydrocarbon

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[59] All emission rate equations and data referenced in this section come from EPA's AP-42 document and accompanying supplements, or the MOBILE4.1 model documentation, unless otherwise noted.

[60] Exhaust and evaporative emissions testing procedures for light-duty gasoline and diesel-powered vehicles are stipulated in the Code of Federal Regulations, 40 CFR Part 86, Subpart B, July 1, 1989. Testing procedures for heavy-duty gasoline and diesel-powered vehicles are stipulated in 40 CFR Part 86, Subpart N, July 1, 1989.

and carbon monoxide BEFs are adjusted for fuel volatility.). A number of these correction factors are not included in the emission factor calculations for diesel-powered vehicles and trucks due primarily to a lack of reliable data.

Fourth, consolidated BEFs are derived by weighting the adjusted BEFs according to the fraction of total miles driven for each model year, and then summing over the 25 historical model years that constitute the in-use vehicle fleet for each calendar year.[61] The equations for the consolidated emission factors are as follows:

$$EFHC = \Sigma TF * [(ADJBEF * SALHCF * RVPCF) + REFUEL + RNGLOS + CCEVRT]$$
$$EFCO = \Sigma TF * (ADJBEF * SALHCF * RVPCF)$$
$$EFNO_x = \Sigma TF * (ADJBEF * SALHCF)$$

where:

ADJBEF =	Adjusted basic exhaust emission factor in grams per mile,
SALHCF =	Composite speed, air conditioning, extra load, and trailer towing correction factor,
RVPCF =	Fuel volatility correction factor,
REFUEL =	Refueling hydrocarbon emission factor (g/mile),
RNGLOS =	Running loss hydrocarbon emission factor (g/mile),
CCERVT =	Crankcase and evaporative hydrocarbon emission factor (g/mile),
TF =	Fraction of total miles driven

(Summation occurs over 25 model years *i*, from n-24 to n, where *n* is the calendar year)

Methodology Details

Federal Test Procedures. The federal test procedures calculate basic exhaust and evaporative emissions for each vehicle model under specified ambient temperature and humidity levels, average speed and idle time, vehicle-miles-traveled (VMT), percent of VMT in cold-start, hot-start, and stabilized operations, trip length, and fuel volatility.[62] The gathering of exhaust emissions data is accomplished with three test segments. For Segment No. 1 (cold-start test), emissions for the first

[61] The number of model years for the in-use fleet was expanded from 20 to 25 with the release of MOBILE4.1 (see User's Guide to MOBILE4.1, Sec. 1.1.4.).

[62] The measure of volatility is *Reid Vapor Pressure*. Vapor pressure measures the level of surface pressure in pounds per square inch (psi) required to keep a liquid from vaporizing. Vehicles are tested at a certified RVP of 9.0 psi.

505 seconds after engine start-up are collected. For Segment No. 2 (stabilized test), emissions are collected for the next 870 seconds. Finally, for Segment No. 3 (hot-start test), the engine is turned off for a ten-minute duration, and is restarted and run for an additional 505 seconds with emissions being collected. The EPA conducts the test cycles at both low and high altitude locations.

Basic Emission Rates. The basic emission rate is calculated by a two-step formula based on the assumption that emission rates increase linearly with respect to accumulated vehicle mileage. First, a zero-mile emission level is obtained from the in-use vehicle testing results for a specific model year and pollutant. Added to this basic emission rate is an adjustment that reflects the culmulative mileage for the model year vehicle and a per-10,000 mile emission deterioration rate. The two step formula accounts for vehicles with cumulative mileage of less than 50,000, and vehicles with mileage in excess of 50,000. The following example shows the equations and calculations used to obtain basic carbon monoxide emission rates for light-duty vehicles with a 1990 model year.

Example 1: Calculating Carbon Monoxide Base Emission Rates

<u>BER Two-Step Formula</u>

$$BER = ZML + (DR1 * M), \qquad \text{for } M \leq 50{,}000 \text{ Miles}$$
$$\quad = ZML + (DR1 * 5) + (DR2 * (M - 5)), \qquad \text{for } M \leq 50{,}000 \text{ Miles}$$

where

ZML =	Zero-mile emission level in gpm
DR1 =	Emission deterioration rate for vehicles with less than or equal to 50,000 miles, in gpm per 10,000 miles
DR2 =	Emission deterioration rate for vehicles with more than 50,000 miles, in gpm per 10,000 miles
M =	Model year cumulative mileage divided by 10,000 miles

<u>Assumptions:</u>

(1) CO emissions are for light-duty gasoline-powered vehicles with a 1990 model year
(2) Tests conducted at low altitude
(3) Calculate emission levels at cumulative mileage intervals of 50,000 and 100,000 miles.

<u>50,000 Mile Emission Level:</u>

$$BER = 2.813 + (0.769 * 5) = 6.658 \text{ grams per mile CO}$$

<u>100,000 Mile Emission Level:</u>

$$BER = 2.813 + (0.769 * 5) + (0.961 * (10 - 5)) = 11.463 \text{ grams per mile CO}$$

Data Source: U.S. Environmental Protection Agency Office of Mobile Sources, *Supplement A, Compilation of Air Pollutant Emission Factors, Volume II - Mobile Sources* (AP-42), January 1991.

Basic Emission Factor Adjustments. The basic emission factors are adjusted with a series of general and pollutant-specific correction factors to account for ambient and vehicle operation characteristics that differ from the standardized federal testing conditions. The adjusted BER equations are as follows:

$$ADJBEF_{HC} = \{[(BER * OMTCF) - OFFMTH] * PCLEFT\} + OMTTAM$$

$$ADJBEF_{CO} = (BER * OMTCF * PCLEFT) + OFFCO + OMTTAM$$

$$ADJBEF_{NOx} = (BER * OMTCF) + OMTTAM$$

The equation terms are described below:

Temperature/Operating-Mode Correction Factor (OMTCF) — This multiplicative correction factor accounts for the observation that vehicles produce a smaller quantity of emissions as they move from cold-start to stabilized and hot-start operating modes. The OMTCF is expressed as a sum of VMT-weighted linear functions of the fleet cumulative mileage for each model year, adjusted for (1) the emissions contribution attributable to each operating mode (represented as intercept and slope coefficients of the linear functions), and (2) a previously estimated temperature correction factor for each model year, pollutant, test segment, and ambient temperature (not applicable to diesel-powered vehicles and trucks). As with the basic emission rate formula, OMTCFs are calculated with a two-stage formula to reflect emissions deterioration for vehicles with cumulative mileage greater than 50,000 miles:

$$OMTCF = (TERM1 + TERM2 + TERM3) / DENOM$$

	Cumulative Mileage ≤ 50,000	Cumulative Mileage > 50,000
TERM1 =	$W * TCF_1 * [B_1 + (D_{11} * M)]$	$W * TCF_1 * [B_1 + (D_{11} * 5)] + [D_{12} * (M - 5)]$
TERM2 =	$(1-W-X) * TCF_2 * [B_2 + (D_{21} * M)]$	$(1-W-X) * TCF_2 * [B_2 + (D_{21} * 5)] + [D_{22} * (M - 5)]$
TERM3 =	$X * TCF_3 * [B_3 + (D_{31} * M)]$	$W * TCF_3 * [B_3 + (D_{31} * 5)] + [D_{32} * (M - 5)]$
DENOM =	$B_0 + (D_{0i} * M)$	$B_0 + (D_{0i} * 5) + [D_{02} * (M - 5)]$

where:

W =	fraction of vehicle-miles-traveled in the cold start mode
X =	fraction of vehicle-miles-traveled in the hot start mode
TCF_i =	high or low temperature correction factor (depending on ambient testing temperature) for pollutant, model year, and test segment "i"
B_i =	normalized intercept coefficient for pollutant, model year, and test segment "i"
D_{ij} =	normalized slope coefficient for pollutant, model year, test segment "i" and culmulative mileage level "j" (1 if $M \leq 5$; 2 if $M > 5$)
M =	cumulative mileage divided by 10,000 miles for each model year

The low temperature correction factor is applied when the ambient temperature is lower than the reference test temperature of 75°F. For all pollutants, test segments, and model years, *except* segment 1 (cold start) CO emissions for model years from 1980 and later, a simple exponential model is used.[63] In the case of cold start carbon monoxide OMTCFs for model years 1980 and later, two additional calculation steps are necessary. First, TCF_1 is removed from the TERM1 equation in order to eliminate the temperature correction related to the cold start mode. Second, an alternative additive version of the low temperature correction factor is calculated, the "CO offset" (**OFFCO**), which adjusts the cold start emissions for higher CO produced during the cold start mode. The CO offset is multiplied by the percent of VMT in the cold start mode (the "W" term) and adjusted for fuel volatility if the temperature is greater than 40°F. The CO offset term is then added to the basic CO exhaust emission rate factor.

The high temperature correction factor equation for pre-1980 model years, applied when the ambient temperature is higher than 75°F, is similar to that of the low temperature correction factor. For post-1979 model years, an alternative correction factor is used that incorporates a fuel volatility correction component. The combined high temperature/fuel volatility correction factor model is:

$$TRCF = e^{\{[A * (RVP - 9.0)] + [B * (T - 75.0)] + [C * (RVP - 9.0)] * (T - 75.0)\}}$$

where RVP is the fuel volatility level in psi RVP, T is the ambient temperature, and A, B, and C are estimated coefficients.

Tampering Offset (TAMPOFF) — A tampering and misfueling offset (in grams per mile) is added to the basic emission rate to reflect the assumption that a certain fraction of flHxt vehicles have had emission control components disabled or fueling components damaged. Such tampering and misfueling occurrences increase exhaust and evaporative emissions. Tampering/misfueling types tracked by the EPA include air pump disablement, catalyst removal, EGR system disablement, filler neck damage, fuel tank misfueled, combined filler neck damage and fuel tank misfueled, PCV system disablement, canister disconnection, and combined canister and fuel cap removal.

The EPA has conducted nationwide tampering/misfueling surveys since 1978, and data for surveys completed in 1984, 1985, and 1986 have been incorporated into the Tampering

[63] The equation is: $TCF_{low} = EXP\ [TC_{ibp} * (T - 75.0)]$, where TC_{ibp} is a coefficient for model year *i*, pollutant *p*, and test segment *b*, at the ambient reference temperature of 75 degrees Fahrenheit; and T is the ambient temperature.

Offset calculation methodology.[64] The TAMPOFF is applied to only four vehicle types due to the lack of comprehensive data: light-duty gas-powered vehicles, light-duty gas-powered trucks (both weight categories I and II), and heavy-duty gas-powered vehicles. The TAMPOFFs for each tampering type are calculated with the following equation for calendar year $_n$:

$$TAMPOFF = TAMP_{ipm} * PEQUIP_{im} * RATE_{im}$$

where:

$TAMP_{ipm}$ =	incremental increase in emissions from tampered vehicles for model year *i*, pollutant *p*, and tampering type *m*,
$PEQUIP_{im}$ =	percent of the model-year *i* vehicles that are equipped with item *m* that can be tampered,
$RATE_{im}$ =	percent of model-year *i* vehicles with equipment *m* that has been tampered with.

The term, TAMP, is derived from linear regression equations with cumulative mileage in 10,000-mile increments serving as the regressor or explanatory variable (the regression intercept is interpreted as the zero-mileage emission rate). The regressions yield deterioration rates up to 50,000 cumulative mileage, with mileage in the 50,000 to 130,000 range handled with an additional adjustment factor representing each tampering-type/vehicle-type combination.

The tampering-type emissions offsets are combined to form an overall composite offset with each tampering-type offset adjusted with the applicable temperature correction factor (TCF), and weighted according to the percent of accumulated vehicle-miles-traveled in cold start, stabilized, and hot start modes. The tampering offset is not applicable to diesel-powered vehicles and trucks.

Inspection and Maintenance (I/M) Program Exhaust Emission Benefit (PCLEFT) — This optional emissions rate adjustment factor accounts for the hydrocarbon and CO emissions reduction benefits attributable to inspection/maintenance programs. The emission rate I/M credits are estimated using a separate EPA model, TECH IV+, which is currently

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[64] Source: *Compilation of Air Pollutant Emission Factors, Volume 2 — Mobile Sources, Supplement A*, Appendix E, p. E-1. Additional survey results gathered after the publication of this document are also included in the offset estimation equations.

being updated into a TECH 5 version that will include a NO_x benefit submodel and other revisions reflecting new I/M program data.[65] I/M program parameters for the TECH model include program start year, stringency level, first/last model years of vehicle subject to program requirements, waiver rates, compliance rates, program type, inspection frequency, vehicle type, test type, and availability of alternative I/M credits for certain technology groups. The I/M program emissions benefit is not applicable to diesel-powered vehicles and all truck types.

Methane Offset (OFFMTH) — This grams-per-mile offset is used to adjust the hydrocarbon basic emission rate when nonmethane HC emissions are estimated. Model-year offsets are calculated for each of the three test segments.

The BEFs are further adjusted by a *composite speed, air conditioning, extra load, and trailer towing correction factor* (**SALHCF**), with the following form:

$$SALHCF_{HC,CO} = SCF * ACCF * XLCF * TWCF$$

and

$$SALHCF_{NOx} = SCF * ACCF * XLCF * TWCF * HCF$$

Each of the equation terms are described below.

Speed Correction Factor (SCF) — Federal test procedures call for the collection of basic exhaust emissions at an average speed of 19.6 miles per hour. To account for higher and lower average speeds exhibited by in-use vehicles, correction factors for three speed ranges were calculated using linear regression.[66] The ranges are low speeds (2.5 to 19.6 mph), moderate speeds (19.6 to 48 mph), and high speeds (48 to 65 mph). The speed correction factors are delineated by model year group, technology, pollutant, and emission level (i.e., normal vs high emitters), but are weighted and combined into one basic speed correction factor applied to base emission rates.

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[65] The only NO_x reduction benefit currently modeled is from a reduction in tampering rates resulting from I/M programs. EPA analysis of transient I/M test (IM240) data indicates that additional emissions reductions result from NO_x cutpoint I/M programs. (See Appendix E.EM.C, List of Potential Revisions for MOBILE5, Item No. 3-5.)

[66] The speed correction factors are normalized to the speed associated with a weighted sum of the cold start and hot start mode VMT fractions. The SCFs were derived from multiplicative linear regression equations.

Air Conditioning Correction Factor (ACCF) — The air conditioning correction accounts for the impact of air conditioner operations on pollutant emission types at various ambient temperatures for each model year (This factor is not applicable to heavy-duty gas-powered vehicles, light-duty diesel-powered vehicles, light-duty diesel-powered trucks, and heavy-duty diesel-powered vehicles). The correction factor is expressed as a linear relationship to temperature, adjusted with a multiplicative factor that reflects the fraction of AC units in use. The air conditioning correction factor equation has the following form:

$$ACCF = V * U * [A + (B * (T - 75) - 1)] + 1$$

where:

V =	fraction of vehicles equipped with AC,
U =	faction of AC units in use = (DI - 70)/10, where DI is the temperature discomfort index,
DI =	((DB + WB)*0.4) + 15,
DB =	dry bulb temperature,
WB =	wet bulb temperature,
A =	intercept coefficient,
B =	slope coefficient,
T =	ambient temperature.

Extra Load Correction Factor (XLCF) — This correction factor incorporates the impacts on emissions of an increase of 500 pounds to the test standard vehicle weight, which includes a driver and one passenger. (This factor is not applicable to heavy-duty gas-powered vehicles, light-duty diesel-powered vehicles, light-duty diesel-powered trucks, and heavy-duty diesel-powered vehicles). The extra load correction factor equation is:

$$XLCF = [(XLC - 1.0) * U] + 1.0$$

where XLC is a factor coefficient for each model year and pollutant,[67] and U is the fraction of vehicle-miles-traveled with the extra load.

Trailer Towing Correction Factor (TWCF) — The trailer towing correction factor, which accounts for the effect on emissions of an extra trailer weight of 1,000 pounds, is calculated with an equation that is identical in structure to that used for calculating the extra load

[67] For example, XLC varies from 1.0786 to 1.0455 for low altitude light-duty gas-powered vehicles, depending on the model year. The XLC range for CO is 1.3058 to 1.1347, and the range for NO_x is 1.0719 to 0.9535.

correction factor:

$$TTCF = [(TTC - 1.0) * U] + 1.0$$

where TTC is a factor coefficient for each model year and pollutant,[68] and U is the fraction of vehicle-miles-traveled with the extra trailer load.

This factor is not applicable to heavy-duty gas-powered vehicles, light-duty diesel-powered vehicles, light-duty diesel-powered trucks, and heavy-duty diesel-powered vehicles.

NO_x Humidity Correction Factor (HCF) — NO_x emission factors are normalized to 75 grains of water per pound of dry air. To achieve this normalization given various humidity levels, a multiplicative correction factor is applied to the composite NO_x SALHCF. The following HCF equation is applicable for all model years:

$$HCF = 1.0 - 0.0038 * (H - 75.0)$$

where H = humidity level in grains of water/lb. dry air. This humidity correction factor is not applicable to heavy-duty diesel-powered trucks.

Data obtained from monitoring emissions at different Reid Vapor Pressure levels shows that hydrocarbon and CO emissions increase as volatility increases. For exhaust emissions at fuel volatility levels different from the test certification RVP of 9.0 psi, and when the ambient temperature is greater than 40°F, a *fuel volatility correction factor* (**RVPCF**) is applied to the basic hydrocarbon and CO emission factors.

There are three fuel volatility correction factor equations, with the selection based on vehicle model year and ambient temperature. For model years 1971 through 1979 (and at all temperatures), the RVPCFs for hydrocarbons and CO are based on a simple linear extrapolation model[69]:

$$RVPCF_{HC} = (0.56222 + 0.012512 * RVP) / 0.67483$$
$$RVPCF_{CO} = (7.1656 + 0.33413 * RVP) / 10.17277$$

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[68] For example, TTC varies from 1.7288 to 1.2614 for low altitude light-duty gas-powered vehicles, depending on the model year. The TTC range for CO is 1.8940 to 3.9722, and the range for NO_x is 1.1184 to 1.3875.

[69] The denominator value represents the numerator evaluated at the certification Reid Vapor Pressure of 9 psi.

For post-1979 model years and at a temperature greater than 75°F, the RVPCF is incorporated with the high temperature correction factor discussed in the Temperature/Operating-Mode Correction Factor (OMTCF) section.

For post-1979 model years and at a temperature in the 40°F to 75°F range, a two-step correction procedure is used. First, a RVP correction factor evaluated at 75°F is obtained using the combined high temperature/fuel volatility model. The resulting RVPCF is then used as an input to the following equation:

$$RVPCF == 1.0 + \{[(RVPCF_{75°F} - 1.0) * [(T - 40.0) / 35.0)]\}$$

where T is the ambient temperature in the range of 40°F to 75°F.

The post-1979 model year fuel volatility correction factors are also disaggregated based on test segment and fuel delivery system (carbureted, throttle-body fuel injection, and multi-point fuel injection).

Evaporative Emissions Factors. In addition to the basic exhaust emission factors for hydrocarbons, evaporative emissions from carburetion and fuel tank systems must be included in the consolidated hydrocarbon emission factors. The EPA models five types of HC evaporative emissions: *crankcase*, *hot soak* (evaporative emissions occurring after a trip), *diurnal* (release of fuel vapors due to an expansion of the air-fuel mixture in a partially filled fuel tank when the ambient temperature increases), *running loss* (emission generated during vehicle operation), and *refueling* (displacement of fuel vapor from the tank during refueling, and spillage). Evaporative emission factors are not applicable to diesel-powered vehicles and trucks.

Crankcase, hot soak, and diurnal emissions (CCERVT) are calculated with one equation:

$$CCERVT = [(HS + TAMPHS) * TPD_j] + [(DI + TAMPDI) / MPD_j] + (CC + TAMPCC)$$

where:

HS =	Hot soak emission rates in grams per trip, corrected for temperature and RVP fuel volatility,
TAMPHS =	Excess hot soak emission rates due to tampering, corrected for RVP fuel volatility,
TPD_j =	Trips per day for age *j* vehicles,
DI =	Diurnal emission rates in grams, corrected for temperature and fuel volatility,

TAMPDI =	Excess diurnal emission rates due to tampering, corrected for temperature and RVP fuel volatility,
MPD_j =	Miles-per-day values for age *j* vehicles,
CC =	Crankcase emissions in grams per mile,
TAMPCC =	Excess crankcase emissions due to tampering.

Running loss emissions (RNGLOS) are calculated in a similar manner: loss emission rates in grams per mile are corrected for temperature and RVP fuel volatility (RULOSS), and then are added to the excess running loss emissions ascribed to tampering (TAMPRL).

Refueling loss emissions (REFUEL) are calculated by adding together the displacement fueling losses corrected for RVP fuel volatility (DISP) and an average spillage rate (SPILL), both measured in grams per gallon. This figure is divided by the road fuel economy rate (ROADFE), measured in gallons per mile.

All evaporative emission factor components are modeled as a function of the ambient temperature and fuel volatility. Running losses are modeled with two additional variables — average speed and trip duration. Refueling losses are modeled with one additional variable, defined as the temperature difference between the dispensed fuel and the residual tank fuel. EPA has also recently incorporated into its modeling the results of inspection/maintenance program testing for fuel/evaporative control system leaks and the capability of the carbon canister to properly purge vapors. The impact of "pressure and purge" problems on hot soak, diurnal, and running loss emission rates are reflected in MOBILE4.1.[70]

Calculation of Travel Weighting Fractions. After emission factor corrections have been applied to the basic exhaust emission factors, and hydrocarbon evaporative and exhaust emission factor components have been added together, travel weighting fractions (TFs) are applied for deriving the final consolidated emission factors.

The TFs represent model-year proportions of total vehicle-miles-traveled for each vehicle type. They are calculated with the use of an annual mileage accumulation rate distribution, a registration distribution[71], and a diesel sales distribution (applicable to all vehicle types *except* heavy-duty gas-

[70] User's Guide to MOBILE4.1, Sec. 1.1.6, p. 1-12.

[71] The EPA collects July 1 registration data, which is adjusted to reflect registration activity as of January 1. Vehicle sales are assumed to be uniform throughout the year.

powered vehicles and heavy-duty gas-powered trucks).

Example 2 shows the calculation of a consolidated hydrocarbon emission factor for model-year 1988 light-duty gasoline-powered vehicles.

Example 2: Calculating a Consolidated Hydrocarbon Emission Factor for
Light-Duty Gasoline Powered Vehicles

Assumptions:

(1) HC emissions are for light-duty gasoline-powered vehicles with a 1988 evaluation calendar year, 20-model-year vehicle window, with testing conducted at low altitude.
(2) Daily minimum and maximum ambient temperatures are 60°F and 80°F, respectively.
(3) All conditions match the basic federal test conditions (i.e., air conditioning, extra load, trailer towing, humidity levels, and other basic exhaust emission correction factors have no affect on the calculations, and are therefore set to 1.0).
(4) No inspection/maintenance or anti-tampering programs are assumed.
(5) Certification fuel volatility of 9.0 psi is assumed.
(6) Total HC emissions are calculated at an average speed of 30 miles per hour.
(7) Percentages of vehicle-miles-traveled in the cold start, stabilized, and hot start operating modes are 40%, 30%, and 30%, respectively.
(8) Basic HC emission factors are adjusted for the effects of tampering.
(9) Methane is included in HC calculations.

Consolidated Emission Factor Equation

$$CONBEFHC_n = \sum TF_i * [(BEF * SALHCF) + REFUEL + RNGLOS + CCEVERT]$$

where:

$CONBEFHC_n$ = Consolidated Hydrocarbon Emission Factor for calendar year n,
TF_i = Travel Weighting Fraction for Model Year i,
BEF = Adjusted Hydrocarbon Exhaust Emission Factor,
SALHCF = Speed Correction Factor,
REFUEL = Refueling HC Emission Factor,
RNGLOS = Running Loss HC Emission Factor,
CCEVERT = Crankcase and Evaporative HC Emission Factor.

Data Table

Model Year (i)	TF	BEF (gpm)	SALHCF (gpm)	REFUEL (gpm)	RNGLOS (gpm)	CCEVERT (gpm)	CONBEFHC$_n$: TF*(BEF*SALHCF)+ REFUEL+RNGLOS+C CEVERT
1988*	0.0307	0.415	0.730	0.243	0.254	0.147	0.029
1987	0.1209	0.472	0.730	0.244	0.254	0.155	0.121
1986	0.1102	0.577	0.730	0.248	0.264	0.177	0.122
1985	0.0985	0.688	0.730	0.255	0.275	0.215	0.123
1984	0.0879	0.808	0.730	0.262	0.285	0.258	0.123
1983	0.0783	0.938	0.730	0.266	0.294	0.300	0.121
1982	0.0679	1.257	0.730	0.263	0.303	0.345	0.124
1981	0.0598	1.480	0.730	0.272	0.311	0.390	0.123
1980	0.0537	2.507	0.730	0.291	0.551	0.576	0.174
1979	0.0481	4.941	0.730	0.335	0.559	0.620	0.246
1978	0.0427	5.253	0.730	0.339	0.566	0.665	0.231
1977	0.0381	5.505	0.730	0.370	0.650	1.515	0.250
1976	0.0328	5.807	0.717	0.387	0.656	1.593	0.223
1975	0.0280	6.043	0.717	0.427	0.662	1.674	0.199
1974	0.0237	5.844	0.706	0.473	0.668	1.759	0.167
1973	0.0197	5.945	0.706	0.473	0.673	1.846	0.142
1972	0.0167	5.906	0.795	0.465	0.679	1.937	0.130
1971	0.0134	9.089	0.798	0.469	0.683	2.726	0.149
1970	0.0104	9.296	0.811	0.451	0.715	3.556	0.128
1969	0.0185	8.856	0.781	0.454	0.684	3.660	0.217

$$\sum_{=1}^{n} = 3.142$$

Data Source: U.S. Environmental Protection Agency Office of Mobile Sources, *Supplement A, Compilation of Air Pollutant Emission Factors, Volume II - Mobile Sources* (AP-42), January 1991, Appendix G.

DAC Highway Mobile Source Emissions Factor Methodology

Carbon Monoxide, Volatile Organic Compound, and Nitrogen Oxide Emission Factors: Conventional Vehicles

DAC calculated VOC, CO, and NO_x emission factors for highway sources using a two-step methodology. First, MOBILE4.1 model runs were conducted to obtain baseline emission factor forecasts. Second, off-line adjustments to the baseline emission factor forecasts were made to reflect the new CAAA regulations that have not been incorporated into the MOBILE4.1 solution algorithms. Table F-77 provides the adjusted MOBILE4.1 emission factors for conventional vehicle types.[72] The vehicle types consist of LDGVs, LDGTs (combined Class 1 and 2), HDGVs, LDDVs, LDDTs, and HDDVs. Table F-78 provides the EPA definitions for each of the vehicle-type categories.

Emission factors for heavy-duty diesel-powered vehicles (HDDVs) should be used for diesel-powered buses. This is recommended by the EPA, which cites the similarities between the two vehicles types as well as the lack of comprehensive emission testing for buses (note that the EPA bus emission factors are reported in grams per mile as opposed to the TERF lbs./1,000 gal. specification). Efforts at improving the EPA bus emission data base are ongoing because of concern that the HDDV emission factors do not accurately reflect in-use characteristics of buses in urban areas.

A complication results in trying to combine the EPA vehicle-type emission factors into the freight truck category designated in the TSCDR. As shown in Table F-78, the EPA vehicle-type categories for heavy-duty vehicles and trucks do not correspond to the weight categories used by either the TIUS or the FHWA Highway statistics report. The EPA uses a weight cut-off of 8,500 pounds GVW for its heavy-duty classifications. Trucks with an average weight greater than 10,000 pounds are classified as medium, light-heavy, or heavy-heavy by the TIUS. There is no weighting method that proves satisfactory for normalizing the EPA emission factors to the FHWA weight categories. Therefore, we recommend that the EPA emission factors for gasoline and diesel heavy-duty vehicles (HDGVs and HDDVs) be used as the TERF freight truck emission factors.

[72] Five-year interval forecasts were interpolated to produce year-to-year emission factors.

Table F-77. Adjusted MOBILE4.1 Emission Factors

YEAR	LDGV			LDGT			HDGV		
	VOC	CO	NOx	VOC	CO	NOx	VOC	CO	NOx
1990	2.09	20.63	1.43	4.20	29.16	1.93	10.84	101.36	5.82
1991	2.33	18.67	1.16	3.84	26.16	1.81	9.90	90.91	5.61
1992	2.59	16.89	0.94	3.51	23.47	1.70	9.05	81.53	5.41
1993	2.89	15.28	0.76	3.21	21.06	1.59	8.27	73.12	5.21
1994	3.22	13.83	0.62	2.93	18.89	1.49	7.55	65.58	5.02
1995	3.59	12.51	0.50	2.68	16.95	1.40	6.90	58.82	4.84
1996	2.98	11.88	0.50	2.54	15.72	1.35	6.45	52.74	4.73
1997	2.47	11.29	0.50	2.41	14.58	1.29	6.04	47.28	4.63
1998	2.05	10.72	0.50	2.28	13.53	1.24	5.65	42.39	4.53
1999	1.70	10.18	0.50	2.16	12.55	1.20	5.28	38.01	4.43
2000	1.41	9.67	0.50	2.05	11.64	1.15	4.94	34.08	4.33
2001	1.34	9.27	0.50	1.96	11.01	1.13	4.66	31.50	4.29
2002	1.27	8.88	0.50	1.87	10.41	1.10	4.40	29.11	4.26
2003	1.21	8.51	0.50	1.79	9.85	1.08	4.15	26.90	4.22
2004	1.15	8.15	0.50	1.71	9.31	1.06	3.92	24.86	4.19
2005	1.09	7.81	0.50	1.63	8.81	1.04	3.70	22.98	4.15
2006	1.09	7.78	0.50	1.62	8.75	1.04	3.66	22.33	4.13
2007	1.09	7.76	0.50	1.62	8.69	1.03	3.61	21.71	4.11
2008	1.08	7.73	0.50	1.61	8.63	1.03	3.57	21.10	4.10
2009	1.08	7.71	0.50	1.61	8.58	1.02	3.53	20.51	4.08
2010	1.08	7.68	0.50	1.60	8.52	1.02	3.49	19.93	4.06
2011	1.08	7.67	0.50	1.60	8.52	1.02	3.49	19.87	4.05
2012	1.08	7.67	0.50	1.60	8.52	1.02	3.49	19.81	4.04
2013	1.08	7.66	0.50	1.60	8.52	1.01	3.48	19.76	4.04
2014	1.08	7.66	0.50	1.60	8.52	1.01	3.48	19.70	4.03
2015	1.08	7.65	0.50	1.60	8.52	1.01	3.48	19.64	4.02
2016	1.08	7.65	0.50	1.60	8.52	1.01	3.48	19.64	4.02
2017	1.08	7.65	0.50	1.60	8.51	1.01	3.48	19.64	4.02
2018	1.08	7.65	0.50	1.60	8.51	1.01	3.48	19.63	4.02
2019	1.08	7.65	0.50	1.60	8.50	1.01	3.48	19.63	4.02
2020	1.08	7.65	0.50	1.60	8.50	1.01	3.48	19.63	4.02
2025	1.08	7.65	0.50	1.60	8.50	1.01	3.48	19.63	4.02
2030	1.08	7.65	0.50	1.60	8.50	1.01	3.48	19.63	4.02

Adjustment notation:

(1) LDGV's: Adjust VOC downward by 0.14 gpm for 1995 through 2030 to reflect decrease in exhause emission standard from 0.39 gpm to 0.25 gpm.

(2) LDGV'S: Assume NO_x emissions of 0.50 gpm beginning in 1995 and forward to reflect new/in-use standard fo 0.40 gpm and 0.6 gpm 100,000-mile certification standard.

(3) LDGV's: CO emission factors include new cold temperature standards.

(4) LDDV's: MOBILE4.1 emission factors are below standards; therefore no adjustments to LDDV emission factors are necessary.

(5) HDDV's: MOBILE4.1 incorporates 1994 HC and CO standards. NO_x standard was lowered, but MOBILE4.1 produces forcast emission factors at about the same level as the standards.

Table F-77 (Continued)

YEAR	LDDV			LDDT			HDDV		
	VOC	CO	NOx	VOC	CO	NOx	VOC	CO	NOx
1990	0.71	1.67	1.63	0.96	1.90	1.87	2.84	13.03	19.45
1991	0.72	1.68	1.63	0.97	1.91	1.86	2.73	12.75	17.72
1992	0.73	1.70	1.64	0.98	1.91	1.85	2.62	12.49	16.14
1993	0.74	1.71	1.64	1.00	1.92	1.85	2.52	12.22	14.70
1994	0.75	1.73	1.65	1.01	1.92	1.84	2.42	11.96	13.39
1995	0.76	1.74	1.65	1.02	1.93	1.83	2.32	11.71	12.20
1996	0.74	1.71	1.59	0.98	1.89	1.76	2.28	11.61	11.56
1997	0.71	1.68	1.53	0.94	1.85	1.69	2.25	11.51	10.94
1998	0.69	1.65	1.48	0.91	1.81	1.62	2.22	11.41	10.37
1999	0.67	1.63	1.42	0.87	1.78	1.56	2.18	11.31	9.82
2000	0.65	1.60	1.37	0.84	1.74	1.50	2.15	11.21	9.30
2001	0.62	1.57	1.32	0.80	1.70	1.44	2.14	11.18	9.11
2002	0.59	1.53	1.27	0.76	1.66	1.39	2.13	11.16	8.92
2003	0.57	1.50	1.22	0.73	1.62	1.33	2.13	11.13	8.73
2004	0.54	1.47	1.17	0.69	1.59	1.28	2.12	11.11	8.55
2005	0.52	1.44	1.13	0.66	1.55	1.23	2.11	11.08	8.37
2006	0.52	1.44	1.12	0.66	1.55	1.22	2.11	11.07	8.32
2007	0.51	1.43	1.11	0.66	1.55	1.21	2.11	11.07	8.27
2008	0.51	1.43	1.09	0.65	1.54	1.21	2.10	11.06	8.21
2009	0.50	1.42	1.08	0.65	1.54	1.20	2.10	11.06	8.16
2010	0.50	1.42	1.07	0.65	1.54	1.19	2.10	11.05	8.11
2011	0.50	1.42	1.07	0.65	1.54	1.19	2.10	11.05	8.10
2012	0.51	1.43	1.08	0.65	1.54	1.19	2.10	11.05	8.09
2013	0.51	1.43	1.08	0.66	1.54	1.19	2.10	11.04	8.07
2014	0.52	1.44	1.09	0.66	1.54	1.19	2.10	11.04	8.06
2015	0.52	1.44	1.09	0.66	1.54	1.19	2.10	11.04	8.05
2016	0.52	1.44	1.09	0.66	1.54	1.19	2.10	11.04	8.05
2017	0.52	1.44	1.09	0.67	1.55	1.20	2.10	11.04	8.05
2018	0.52	1.44	1.09	0.67	1.55	1.20	2.10	11.04	8.05
2019	0.52	1.44	1.09	0.68	1.56	1.21	2.10	11.04	8.05
2020	0.52	1.44	1.09	0.68	1.56	1.21	2.10	11.04	8.05
2025	0.52	1.44	1.09	0.68	1.56	1.21	2.10	11.04	8.05
2030	0.52	1.44	1.09	0.68	1.56	1.21	2.10	11.04	8.05

Adjustment notation:

(1) LDGV's: Adjust VOC downward by 0.14 gpm for 1995 through 2030 to reflect decrease in exhause emission standard from 0.39 gpm to 0.25 gpm.

(2) LDGV'S: Assume NO_x emissions of 0.50 gpm beginning in 1995 and forward to reflect new/in-use standard fo 0.40 gpm and 0.6 gpm 100,000-mile certification standard.

(3) LDGV's: CO emission factors include new cold temperature standards.

(4) LDDV's: MOBILE4.1 emission factors are below standards; therefore no adjustments to LDDV emission factors are necessary.

(5) HDDV's: MOBILE4.1 incorporates 1994 HC and CO standards. NO_x standard was lowered, but MOBILE4.1 produces forcast emission factors at about the same level as the standards.

Table F-78: EPA Highway Vehicle Classification Categories and Definitions

Vehicle Type Classification Category	EPA Category Definition
Light-duty gasoline-powered vehicles (LDGVs)	Gas-fueled vehicle primarily designed for passenger transportation with a design capacity of 12 persons or less.
Light-duty gasoline-powered trucks, Class 1 (LDGT1s)	Diesel-fueled vehicle primarily designed for passenger transportation with a design capacity of 12 persons or less.
Light-duty gasoline-powered trucks, Class 2 (LDGT2s)	Gas-fueled vehicle with a Gross Vehicle Weight (GVW) between 6,001 and 8,500 pounds.
Heavy-duty gasoline-powered vehicles (HDGVs)	Gas-fueled vehicle designed to carry property, with a Gross Vehicle Weight (GVW) over 8,500 pounds, or; any vehicle designated for passenger transportation having a design capacity of more than 12 persons.
Light-duty diesel-powered vehicles (LDDVs)	Any diesel-fueled vehicle designated primarily for passenger transportation and having a design capacity of 12 persons or less.
Light-duty diesel-powered trucks (LDDTs)	Any diesel-fueled vehicle designed primarily for property transportation, and rated at 8,500 lbs. GVW or less.
Heavy-duty diesel-powered vehicles (HDDVs)	Any diesel-fueled vehicle designed primarily for property transportation, and rated at more than 8,500 lbs. GVW.

Source: U.S. Environmental Protection Agency, *Supplement A to AP-42 Volume II*, January 1991.

DAC obtained the MOBILE4.1 model from the EPA, and used the model to calculate national CO, NO_x, and VOC emission factors to the year 2020 (the last MOBILE4.1 forecast year) using a scenario-based input data set. EPA staff make the assumption that emission factors remain relatively stable after 2010.[73] Therefore, emission factors for 2020 are used for the subsequent forecast years. As already noted, the MOBILE4.1 emission factors do not reflect many new CAAA standards that should affect emission rates after 1993. Post hoc adjustments need to be made to account for new vehicle standards, in-use standards, and other CAAA emission control requirements if the forecasted emission factors exceed the standards in any year. It is important to note that any emission factor adjustments are based on gross assumptions, with the resulting emission factors considered to be interim in nature.

The MOBILE4.1 input data set consists of a series of user-specified control flags, data inputs common to all emission scenarios, and data inputs specific to an individual scenario. In addition to regulating program execution and input/output stream formatting, the control flags determine model actions such as the use of emission control device tampering rates, average vehicle speed selection, mileage accumulation rate selection, VMT mix selection, I/M program impact, ambient temperature selection, and many other factors. Control flags specifying EPA default values and national averages were included to the maximum extent.

[73] Personal communication with Lois Platte, EPA Motor Vehicle Emission Laboratory, Ann Arbor, Michigan, June 26, 1992.

The greatest difficulty in developing the MOBILE4.1 data set was accounting for the impact of inspection/maintenance programs. MOBILE4.1 was not designed with the capability for estimating national average I/M program impacts. The I/M program data set record must be specified according to local I/M program attributes. Such program attributes are highly customized to met locale-specific implementation needs, and therefore cannot be formulated into a national average I/M program. Further complications result from the fact that I/M programs are not required nor implemented in many areas of the country, and new EPA regulations have resulted in greater complexity for existing and planned programs.

To account for the effects of I/M and anti-tampering programs on emission factors, a model-run interpolation method was used. Inspection and maintenance programs are required for 162 ozone areas based on CAAA regulations. A data set was created that included parameters and data for an "enhanced" I/M model program (required for serious, severe, and extreme ozone nonattainment areas) as outlined in the EPA's Notice of Proposed Rulemaking.[74] An enhanced I/M program includes annual centralized testing for light-duty vehicles and trucks, and include such tests as the transient IM240 exhaust emission test, the transient purge test, the pressure test, the two-speed exhaust test, and the idle exhaust test. The EPA estimates that such an I/M program could reduce vehicle VOC emissions by 28 percent, CO emissions by 30 percent, and NO_x emissions by 9 percent.[75]

A MOBILE4.1 emission factor based on national imposition of enhanced I/M programs is assumed to represent an upper bound for vehicle emissions. To account for areas that have no I/M and anti-tampering programs, a MOBILE4.1 data set was created that excluded operating I/M and anti-tampering programs. Separate sets of emission factors were generated from MOBILE4.1 model runs employing each data set. Composite emission factors were derived by taking the arithmetic average of the two emission factor sets. Ideally, the composite emission factor set should be calculated as a weighted average, using vehicle mileage data for each type of ozone nonattainment area and I/M program type. Such a procedure is complex and time-consuming (and perhaps not doable because of the flexibility afforded to the states for choosing I/M program elements), and could not be attempted given the resources available for this subtask. The simple arithmetic average approach, while producing somewhat arbitrary results, is superior to assuming a universally-applied I/M program for all areas of the country. Such an assumption yields overly-optimistic emission factor

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[74] EPA Notice of Proposed Rulemaking, "Vehicle Inspection and Maintenance Requirements for State Implementation Plans," 40 CFR Part 51, July 9, 1992.

[75] Ibid., section II.

reductions.

Sulfur Dioxide and Carbon Dioxide Emission Factors: Conventional Vehicles

The EPA does not regularly monitor and report carbon dioxide and sulfur dioxide emissions for highway mobile sources. The relatively small amounts of SO_2 emitted by trucks and cars are quickly converted to sulfuric acid; and therefore do not represent a significant air pollution hazard. Although the EPA produced SO_2 measurement procedures in the early 1980's, the Agency has not published SO_2 emission factors.[76]

The SO_2 and CO_2 emission factors to be used in TERF come from the Argonne National Laboratory's Transportation Energy and Emissions model (TEEMS). Table F-79 provides the emission factors produced for the DOE Office of Environmental Analysis as part of data input to the NESEAM model.[77] These emission factors include the effects of CAAA emission standards, and are forecasted to the year 2030.

The TEEMS/NEASAM emission factors were reported in pounds of emissions per million Btu. To convert the emission factors to a grams-per-mile equivalent, the following formula was used:

$$EF_{gpm} = EF_{ppBtu} \times 57.9549 / MPG_c$$

where:

EF_{gpm} = Emission factor in grams per mile,
EF_{ppBtu} = TEEMS emission factor in pounds per million Btu,
MPG = TEEMS forecasted fuel economy for category c vehicles in gallons per mile,

The TEEMS model does not report CO_2 emission factors for heavy-duty diesel trucks and heavy-duty gasoline vehicles.

[76] Personal communication with Penny Carey, EPA Motor Vehicle Emissions Laboratory, Ann Arbor, Michigan, August 4, 1992.

[77] See, *Decision Analysis Corporation, Mobile Source Air Emissions Regulations and Inventories, Draft Report,* (Prepared for the EIA Energy Demand Analysis Branch under Contract No. DE-AC01-92EI21946, July 15, 1992).

Table F-79. LDV Sulfur Dioxide and Carbon Dioxide Emission Factors (Grams/Mile)

YEAR	SO2					CO2		
	HDDT	HDGV	LDDT	LDGT	LDGV	LDDT	LDGT	LDGV
1990	1.3892	0.3890	0.5156	0.0968	0.0846	178.2613	178.2613	98.0075
1991	1.0592	0.3913	0.3898	0.0957	0.0827	176.1273	176.1273	96.8204
1992	0.8075	0.3937	0.2947	0.0947	0.0809	174.0188	174.0188	95.6477
1993	0.6157	0.3961	0.2228	0.0937	0.0791	171.9355	171.9355	94.4891
1994	0.4694	0.3985	0.1685	0.0927	0.0773	169.8771	169.8771	93.3446
1995	0.3579	0.4009	0.1274	0.0917	0.0756	167.8435	167.8435	92.2140
1996	0.3586	0.3987	0.1263	0.0913	0.0747	167.1971	167.1971	91.5909
1997	0.3593	0.3966	0.1253	0.0910	0.0738	166.5531	166.5531	90.9719
1998	0.3600	0.3945	0.1243	0.0906	0.0729	165.9117	165.9117	90.3572
1999	0.3607	0.3924	0.1233	0.0902	0.0721	165.2728	165.2728	89.7466
2000	0.3615	0.3904	0.1222	0.0898	0.0712	164.6363	164.6363	89.1402
2001	0.3540	0.3895	0.1206	0.0887	0.0705	162.6740	162.6740	87.8486
2002	0.3467	0.3886	0.1190	0.0875	0.0698	160.7351	160.7351	86.5757
2003	0.3396	0.3877	0.1174	0.0863	0.0691	158.8193	158.8193	85.3213
2004	0.3326	0.3869	0.1158	0.0852	0.0684	156.9264	156.9264	84.0850
2005	0.3258	0.3860	0.1143	0.0841	0.0678	155.0560	155.0560	82.8667
2006	0.3191	0.3851	0.1127	0.0830	0.0671	153.2080	153.2080	81.6660
2007	0.3125	0.3843	0.1112	0.0819	0.0664	151.3819	151.3819	80.4827
2008	0.3061	0.3834	0.1097	0.0808	0.0658	149.5776	149.5776	79.3166
2009	0.2998	0.3825	0.1082	0.0797	0.0651	147.7948	147.7948	78.1673
2010	0.2936	0.3817	0.1068	0.0787	0.0645	146.0333	146.0333	77.0347
2020	0.31806	0.413476	0.10608	0.076857	0.063419	146.0333	146.0333	77.03472
2030	0.31806	0.413476	0.10608	0.076857	0.063419	146.0333	146.0333	77.03472

Source: Argonne National Laboratory Transportation Energy and Emissions Modeling System (TEEMS), Model run ANL-90N.

Total Carbon Emission Factors: Conventional Vehicles

The calculation of total carbon emission factors for gasoline and diesel fuels is straightforward. The following formulae are used to produce carbon emission factors in grams per mile:

$$CarbonEF_{gas} = 0.866 * (2791.0/MPG)$$
$$CarbonEF_{diesel} = 0.858 * (3192.0/MPG)$$

The constant values of 0.886 and 0.858 are the carbon mass fractions of gasoline and diesel, respectively.[78] The constant values of 2791 and 3192 are the densities for gasoline and diesel fuel, and were obtained from EIA's *1989 International Energy Annual* (February 1991).[79] To obtain the carbon emission factors, the endogenously calculated TERF miles-per-gallon estimates (MPG) will need to be passed to the emissions module. As currently configured, MPG forecasts will be determined using the Argonne National Laboratory TEEMS methodology, which uses lagged MPG and other economic variables.

Using Argonne's ANL-90N TEEMS run as an example, automobile and diesel freight truck carbon emission factors for 1990, 1995, 2005 and 2010 are shown below (MPG figures are in parentheses).

Year	Emission Factor, g/mile (MPG)	
	Automobiles	Light Trucks
1990	120.8 (20.0)	464.2 (5.9)
1995	119.5 (20.7)	449.0 (6.1)
2000	116.1 (21.3)	427.9 (6.4)
2005	107.5 (23.0)	421.3 (6.5)
2010	89.3 (27.7)	415.0 (6.6)

[78] This value is reported by the EPA. See, Frank Black, 3rd U.S. - Dutch International Symposium, "Atmospheric Ozone Research and Its Policy Implications" (May 9-13, 1988, Nijmegen, the Netherlands), or the DeLuchi/Argonne greenhouse gas study.

[79] Appendix F, Volume, Weight, and Monetary Conversions, p. 149.

Emission Factors: Alternative Fuel Vehicles

The calculation of emission factors for alternative fuel vehicles (AFVs) is subjective in nature, and depends on emissions data from test vehicles and the likely capability of AFVs to meet new CAAA clean-fuel vehicle emission standards. Emission factors for NMHC, CO, NO_x, and CO_2 were provided to Argonne National Laboratory in a greenhouse gas emission study conducted jointly by the Institute of Transportation Studies at the University of California-Davis, and the Center for Energy and Environmental Studies at Princeton University.[80] Table F-80 lists these AFV emission factors for light-duty vehicles (LDV's) and heavy-duty vehicles, such as freight trucks and buses (HDV's), powered by the following fuels: methanol (100%), compressed natural gas, hydrogen, ethanol (100%), and liquid petroleum gas (LPG). Electric vehicles are considered to emit no pollutants other than a small quantity of chlorofluorocarbons (CFCs).

Table F-80. Lifetime Average Emission Factors for Alternative Fuel Vehicles (Grams per Mile)

	Methanol*		Natural Gas		Hydrogen		Ethanol*		LPG	
	LDV	HDV	LDV	HDV	LDV	HDV	LDV	HDV	LDV	HDV
NMHC	0.56	4.86	0.22	0.60	0.04	0.04	0.38	4.42	0.22	1.80
CO	7.21	13.00	3.60	7.00	0.70	0.10	7.21	13.00	5.50	9.00
NO_x	0.45	8.05	0.45	8.05	0.45	8.05	0.45	8.05	0.45	8.05
CO_2	214.64	1495.41	195.51	1463.94	0.00	0.00	0.00	0.00	226.72	1695.56

*Emission factors are for M100 (100% methanol) and 100% ethanol fuels.

[80] Mark A. DeLuchi, University of California Institute of Transportation Studies, *Emissions of Greenhouse Gases From the Use of Transportation Fuels and Electricity* (for the Argonne National Laboratory Center for Transportation Research, June 26, 1991).

OFF-HIGHWAY SOURCES EMISSIONS FACTORS

Off-Highway Mobile Source Emission Factor Information Sources

The following documents were used to compile off-highway emission factors or supply background information on emission factor calculation methods:

- *Compilation of Air Pollutant Emission Factors - Volume II: Mobile Sources* (AP-42, Fourth Edition, September 1985)
- *Nonroad Engine and Vehicle Emission Study—Report*, EPA 460/3-91-02 (November 1991)
- *Interim Guidance for the Preparation of Mobile Source Emission Inventories*, Attachments A through J (This EPA memorandum supersedes the mobile source emission inventory preparation instructions contained in *Procedures for Emission Inventory Preparation — Volume IV, Mobile Sources*, which is currently being revised)
- *Procedures for Emission Inventory Preparation — Volume IV, Mobile Sources*, EPA-450/4-81-026d (revised), (July 1992).

The document, *Compilation of Air Pollutant Emission Factors - Volume II*, reports all data and emission factor calculation algorithms for both highway and off-highway emission sources. Section II outlines the emission calculation methodologies for off-highway mobile sources, including aircraft, railroad locomotives, inboard-powered vessels, outboard-powered vessels, small general utility engines, agricultural equipment, heavy duty construction equipment, and snowmobiles. The EPA is planning to issue an updated version of the AP-42 document, although no estimate has been given as to the release date. The EPA's *Nonroad Engine and Vehicle Emission Study*, which was mandated as part of CAAA Section 213(a), provides new or updated emission inventory data and emission factors for ten nonroad equipment categories including commercial marine vessels, which is one of the transport modes to be modeled in TERF.[81] The Nonroad Emission study targeted 24 nonattainment areas as well as national totals. The document, *Procedures for Emission Inventory Preparation — Volume IV, Mobile Sources,* provides state and local agencies with detailed guidance on the preparation of highway and off-highway mobile source emission inventories. The off-highway emission factors contained in this section were derived either directly from the inventory preparation procedure report, or were calculated using data tables contained therein.

Railroad Locomotive Emission Factors

Table F-81 lists the railroad locomotive emission factors to be incorporated into the TERF model. Emission factors for CO, NO_x, SO_2 and HC are included.[82] Note that the EPA does not measure separately the volatile component of total hydrocarbons. Also, no distinction is made between freight and passenger locomotives because both travel modes use the same locomotive technology types. These emission factors are reported in the July 1992 edition of *Procedures for Emission Inventory Preparation — Volume IV, Mobile Sources*. They are considered default values for fleet-average line haul locomotives.[83] Line haul locomotives represent the largest segment of the locomotive population, and include all locomotives used for freight and passenger service. As of mid-1991, 9,708 line haul locomotives were in service.[84] Yard locomotives are used for moving railcars within a rail switchyard, and are considered a negligible source of emissions. As of mid-1991, 4,589 yard locomotives were in service.[85]

The emission factors represent an average of emission factors for five diesel engine configuration types: 2-stroke supercharged switch locomotive, 4-stroke switch locomotive, 2-stoke super-charged road service locomotive, 2-stroke turbocharged road service locomotive, and 4-stroke road service locomotive. The emission factors are based on duty cycle testing and average fuel consumption

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[81] The other nine equipment categories are lawn and garden equipment, airport service equipment, recreational vehicles, recreational marine equipment, light commercial equipment, industrial equipment, construction equipment, agricultural equipment, and logging equipment.

[82] Source: EPA Office of Mobile Sources, *Locomotive Emission Factors for Inventory Guidance Document* (June 1991).

[83] The EPA also outlines a methodology for calculating more detailed locomotive emissions for areas that are expected to deviate significantly from the national average. The methodology is called the *roster tailoring method,* and uses emissions data from individual locomotive makes and models.

[84] *Interim Guidance for the Preparation of Mobile Source Emission Inventories,* Attachment J, Emissions from Railroads (EPA Office of Mobile Sources, February 15, 1992), Appendix 6-5, p. 6-23.

[85] Ibid, p. 6-23.

rates. A duty cycle consists of the operating time in eight throttle notch settings plus idle and dynamic braking. The fuel consumption rate of a locomotive is determined by the throttle notch position — the higher the notch, the higher the fuel consumption, and vice versa. Therefore, fuel consumption is proportional to the amount of time the locomotive spends in each throttle notch position.[86] The locomotive emission factors apply to all three Interstate Commerce Commission (ICC) railroad classes: Class I — annual revenues greater than $93.5 million; Class II — annual revenues greater than $18.7 million but less than $93.5 million; Class III — annual revenues less than $18.7 million.

Table F-81. TRAN Locomotive Emission Factors

Pollutant	Emission Factor (lbs./1,000 gal of fuel)
HC	21.10
CO	6.26
NO_x	493.10
SO_2*	36.00
PM	11.60

*Based on fuel sulfur content of 0.25 percent by weight.

Look-Ahead Issues Concerning Locomotive Emission Factors

In terms of specifying future-year locomotive emission factors given CAAA requirements, the emission factors in Table F-81 are to be used for all forecast years. Section 213 of the Amended Act requires the EPA to promulgate emission standards for new locomotives by November 1995. These new standards are to be designed to obtain the greatest degree of emission reduction achievable, with due consideration given to compliance cost, energy consumption, safety and noise.[87] New emission factors would be based on testing of the applicable locomotive emission reduction technologies that would be manufactured to comply with new standards. Given the large uncertainty over the prospective emission standards and technologies, as well as the low stock turnover of locomotive

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[86] Ibid, p. 6-13.

[87] CAAA, sec. 213 (a)(5), 104 STAT 2501.

engines, there is no justification for assigning alternative emission factors to the forecast interval.

Aircraft Emission Factors

Overview of the EPA Aircraft Emissions Inventory Methodology

The EPA bases its aircraft emission factors on five operating modes that together consist of the landing and takeoff (LTO) cycle. The first operating mode is the approach, in which the aircraft makes its airport approach after the descent from cruising altitude. The second operating mode is taxi/idle-in, where the aircraft lands and taxis to the gate. The third mode is taxi/idle-out, in which the aircraft taxis back out to the runway for subsequent takeoff.[88] The fourth mode is takeoff, in which the aircraft attains liftoff speed and becomes airborne. The fifth mode is termed the climbout, and represents the aircraft's accent to cruising altitude. Most aircraft go through a similar sequence during an LTO cycle.

During each operation mode the aircraft engines operate at a fairly standard power setting for a given aircraft category. The power setting results in a certain rate of fuel flow (expressed in pounds per minute) for the operating mode. Total emissions from the aircraft engine are thus determined by the amount of time that an aircraft engine spends in each operation mode (termed the "Time-in Mode"), the fuel consumption rate, and the engine-specific emission factors for each operating mode, expressed in pounds of emissions per 1,000 pounds of fuel consumed.

The EPA aircraft emission factors and inventory preparation procedures are site-specific; they are highly dependent on local airport and aircraft population data. Generally, the emissions inventory is prepared using the following steps: (1) identify airports to be included in the inventory area, (2) determine the mixing height[89] to be applied to the LTO cycle (a standard default value of 3,000 feet is assumed), (3) define the aircraft fleet population for each aircraft category across all airports, (4) determine the number of LTOs for each aircraft category, (5) select emission factors for each aircraft category, (6) estimate a time-in-mode for each aircraft category at each airport, and (7) calculate an inventory based on the airport activity, time-in-mode, and emission factors.

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[88] Both Taxi/idle operating modes are highly variable, and depend on such factors as airport size and layout, the amount of ground congestion, airport-specific operational procedures, time of day, and seasonal travel activity.

[89] The height of the mixing zone — that portion of the atmosphere where aircraft emissions affect ground level pollutant concentrations — influences the time-in-mode for approach and climbout operation modes, and is particularly significant when calculating NO_x emissions.

EPA Aircraft Categorization

The EPA categorizes aircraft by the type of use: commercial, general aviation, and military. Commercial aircraft include those used for scheduled service transporting passengers, freight, or both. Air taxis also fly scheduled service carrying passengers and/or freight, but usually are smaller aircraft and operate on a more limited basis than the commercial carriers. Business aircraft support business travel, usually on an unscheduled basis, and general aviation includes most other non-military aircraft used for recreational flying, personal transportation, and various other activities.

The EPA combines business aircraft with general aviation aircraft because of their similar size, use frequency, and operating profiles. Similarly, air taxis are treated much like the general aviation category because they are typically the same types of aircraft. Military aircraft cover a wide range of sizes, uses, and operating missions. While they often are similar to civil aircraft, they are handled separately because they typically operate exclusively out of military air bases and frequently have distinctive flight profiles. Helicopters, or rotary wing aircraft, can be found in each of the categories. Their operation is distinct because they do not always operate from an airport but may land and takeoff from a heliport at a hospital, police station, or similarly dispersed location. Military rotorcraft are included in the military category and non-military rotorcraft are included in the general aviation category since information on size and number are usually found in common sources. However, they are combined into a single group for calculating emissions since their flight profiles are similar.

Commercial aircraft typically are the largest source of aircraft emissions. Although they make up less than half of all aircraft in operation around a metropolitan area, their emissions usually represent a large fraction of the total because of their size and operating frequency. This would not hold true for a city with a disproportionate amount of military activity, or a city with no major civil airports.

Aircraft Emissions Characteristics

The EPA views HC, CO, NO_x, SO_2, and PM_{10} as the significant aircraft pollutants. However, only

HC emissions and smoke production are currently regulated.[90] For a single LTO cycle, aircraft emissions vary considerably depending on the category of aircraft and the aircraft's flight profile. Emission rates for HC and CO are high during the taxi/idle phases when aircraft engines are at low power and operate at suboptimum efficiency. The emission rates fall as the aircraft moves into the higher power operating modes of the LTO cycle. Conversely, NO_x emissions are low when engine power and combustion temperature are low, but increase as the power level is increased and combustion temperature rises. Therefore the takeoff and climbout modes have the highest NO_x emission rates.

Sulfur dioxide emission rates are highest during the takeoff and climbout operation modes when fuel consumption rates are high. Sulfur emissions typically are not measured when aircraft engines are tested. Therefore, the EPA uses a default emission factor of 0.54 pounds SO_2 per 1,000 pounds of fuel for all engine types. (EPA assumes that all sulfur in the fuel combines with oxygen during combustion to form SO_2. Nationally, the sulfur content of fuel remains fairly constant from year to year at about 0.05% by weight for commercial jet fuel, 0.025% by weight for military fuel, and 0.006% by weight for aviation gasoline. These national sulfur content figures are used by the EPA for estimating the SO_2 default emission factors.

Particulate emission characteristics are similar to that of HC and CO in that emission rates are higher at low power rates than at high power rates because of greater combustion efficiency at a higher engine power. However, particulate emissions are highest during takeoff and climbout due to the greater fuel flow rate. The EPA does not report emission factors for particulates except for a small number of engine models, citing the difficulty in estimating PM emissions.[91] Direct measurement of particulate emissions from aircraft engines typically are not available from manufacturers, although emission of visible smoke is reported as part of the engine certification procedure.[92] The inventory preparation procedure document reports emission factors for only one civil aircraft engine model. This engine model is used in a number of European-built aircraft, and is not representative of the total aircraft fleet.

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[90] EPA established standards for aircraft HC emissions in 1984, which included the establishment of standard procedures for engine certification and emissions testing. The standard applies to jet engines with an engine thrust of over 6,000 pounds. The EPA reports that many older in-service engines exceed the standards. New engine designs produced since the standards went into effect have HC emissions lower than the standards, but the design changes made to reduce the HC emissions resulted in small increases in NO_x emissions.

[91] *Procedures for Emission Inventory Preparation, Vol IV*, page 149.

[92] Ibid., p. 149.

DAC Methodology for Calculating Aircraft Emission Factors

As mentioned above, the EPA aircraft emission factors are reported for individual engine models (currently 88 civil aircraft engines and 54 military engines) by LTO operation mode. Consequently, the emission factors apply to activity levels measured in full LTO cycles, not fuel consumption as specified in the TSCDR. DAC developed a methodology for converting the EPA operating-mode emission factors into a fleet average emission factor based on total gallons of fuel consumed. The data used to construct the fuel-based emission factors are presented in Appendix E.EM.C.

The first step of the conversion methodology involves the derivation of fleet-average time-in-mode figures. The EPA reports default TIM values in minutes for each civil and military aircraft category. Since commercial aircraft accounted for 93.6 percent of civil aircraft energy consumption in 1989, the TIM values for jumbo, long, and medium range jet commercial carriers were used as proxies for the entire civil aircraft population.[93] These TIM figures are as follows: Takeoff — 0.7 minutes, Climbout — 2.2 minutes, Approach — 4.0 minutes, Taxi/Idle — 26.0 minutes. Military aircraft TIM's are highly variable. Therefore, the arithmetic averages of TIMs for combat, trainer, and transport aircraft were used as proxies for the fleet TIMs. Helicopter TIMs were excluded from the calculations due to LTO incompatibility with the other aircraft categories.

The second step of the conversion methodology is to determine the fuel use for each operating mode using the EPA's fuel flow data, and to construct fuel consumption shares. The LTO time-in-mode amounts (in minutes) were multiplied by the fuel flow amounts (in pounds per minute) to obtain fuel consumption in pounds for each operating mode. The modal fuel consumption figures were then divided by total LTO fuel consumption to derive the fuel consumption shares (see Appendix E.EM.C, pages E.EM.C-3 and E.EM.C-6).

The third step is to calculate average emission factors by pollutant type for the population of engine models reported by the EPA. Separate samples of 46 civil and 15 military aircraft engine models were created from the EPA's list.[94] The selection was based on reported engine market shares for

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[93] Aircraft Btu energy consumption figures come from Oak Ridge National Laboratory, *Transportation Energy Data Book, Edition 12*, ORNL-6710 (Oak Ridge, Tennessee, March 1992).

[94] *Procedures for Emission Inventory Preparation*, Table 5-4, "Commercial Aircraft types and Engine Models," and Table 5-6, "Military Aircraft types and Engine Models."

each aircraft model, with aircraft models chosen based on a proportional representation of the commercial, general and military aircraft categories. The sample engine-model emission factors were aggregated by calculating the arithmetic average of reported pollutant emission factors.[95] (see Appendix E.EM.C, pages E.EM.C-1, E.EM.C-2, E.EM.C-4, and E.EM.C-5). Since the SO_2 emission factor is the same for each operation mode, this methodology is not applicable for SO_2 emission rate estimation.

The fourth step is to calculate the weighted fleet-average emission factors for HC, CO, and NO_x by multiplying the aggregated engine sample emission factors by the fuel consumption shares calculated in step 2. Two further calculations are necessary to produce emission factors that correspond to TSCDR specifications. First, the emission factors must be converted into gallons-of-fuel equivalents. A conversion factor of 6.2 pounds per gallon was used. Second, the total HC emission factors must be adjusted to produce volatile organic compound (VOC) emission factors. The following EPA adjustment factors, applicable to turbine engines, were used:

$$VOC_{COMMERCIAL} = THC_{COMMERCIAL} \times 1.0947$$
$$VOC_{MILITARY} = THC_{MILITARY} \times 1.1046$$

Table F-82 presents the aircraft emissions factors for HC, VOC, CO, NO_x, and SO_2.[96]

Table F-82. Aircraft Emission Factors

Pollutant	Emission Factors (lbs./1000 gal. of fuel)	
	Commercial Aircraft	Military Aircraft
HC	37.82	75.54
VOC	41.40	83.44
CO	101.97	330.17
NO_x	79.04	58.15
SO_2	3.35	3.35

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[95] Ibid., Table 5-4, "Modal Emission Rates."

[96] Source: Appendix E.EM.C, page E.EM.C-3;

Notes: Commercial and military VOC emission factors calculated by multiplying Appendix E.EM.C HC values by 1.0947 and 1.1046, respectively.

SO_2 emission factors calculated by dividing the EPA standard value of 0.54 pounds per 1,000 gallons by 6.2.

Look-Ahead Issues Concerning Aircraft Emission Factors

Among the factors expected to influence aircraft emission rates in a forecasting context are the following:

- new aircraft engine designs,
- airport noise regulations,
- an increase in airport congestion problems

Aircraft with cleaner and more energy-efficient engine designs are expected to continue to slowly penetrate the world aircraft fleet population. Since there is a significant engineering and development leadtime for producing new aircraft engines, most of the commercial aircraft to be added to the fleet in the next five to seven years will be powered by engines currently monitored by the EPA.[97] Given the 12-year average service life for commercial aircraft engines, the newer generation of aircraft engines are not expected to make a significant impact on national emission levels until 2010. However, a possible catalyst for an increased rate of new aircraft engine market penetration is the recent enactment of national airport noise regulations, which require the phase-out of loud aircraft by 2000. Airlines are expected to upgrade their fleets with quieter and cleaner engines once the industry formulates compliance plans. The extent of the emission rate impact of such fleet upgrading is unknown at this time.

Acting as a counterweight on the downward pressure on emission rates caused by stock turnover and new regulations is the growth in air travel combined with limited excess capacity at many airports. Air travel has experienced strong growth over the past several years, and this growth is expected to continue for the foreseeable future. The primary capacity squeeze will be felt at small feeder airports and regional hubs. Increased congestion at capacity-constrained airports will increase taxi/idle times, resulting in increased emissions per LTO.

Given these offsetting impacts on aircraft emissions, the emission factors listed in Table F-82 should be satisfactory for estimating future aircraft emission levels.

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[97] Ibid., p. 208.

Waterborne Vessel Emission Factors

Commercial Vessels

Table F-83 provides the EPA emission factors for domestic commercial motorships. These emission factors are reported in the AP-42 document. The emission factors are based on Army Corps of Engineers waterway classification categories, which are defined as follows:

- **River** — All waterborne traffic between ports or landings wherein the entire movement takes place on inland waterways.
- **Great Lakes** — All waterborne traffic between United States ports on the Great Lakes.
- **Coastal** — All domestic traffic receiving a carriage over the ocean or between the Great Lakes ports and seacoast ports when having a carriage over the ocean.

To derived an average emission factor for all three waterway category vessels, a weighted-average methodology was applied whereby shipment tonnage and average length-of-haul data from the Army Corps of Engineers were used to construct emission factor weights.[98] Table F-83 provides more details on the weighting methodology.

The EPA *Nonroad Engine and Vehicle Emission Study Report* provides emission factors for two additional vessel categories: ocean-going steamships and harbor/fishing vessels.[99] These emission factors are based on engine sizes and operating mode (hoteling, cruise, and full power), and are not compatible with the emission factors provided in Table F-83. Because of the small emissions contribution of these vessels to the overall waterborne vessel total, they are not included in the composite waterborne vessel emission factors. For reference purposes, Appendix E.EM.D provides the ocean-going and harbor/fishing vessel emission factor tables from the Nonroad Engine and Vehicle report.

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[98] U.S. Army Corps of Engineers, *Waterborne Commerce of the United States, Calendar Year 1989* (Waterborne Statistics Center, New Orleans, LA, 1991), Part 5: National Summaries, pp. 32, 93.

[99] These emission factors were compiled and provided to the EPA in a Booz Allen & Hamilton report, *Commercial Marine Vessel Contributions to Emission Inventories* (Los Angeles, CA, October 7, 1991).

Table F-83. Commercial Vessel Emission Factors[100] (Pounds per 1,000 gallons of fuel)

Pollutant	Waterway Class			Weighted Average*
	River	Great Lakes	Coastal	
HC	50	59	50	51
CO	100	110	110	107
NO_x	280	260	270	273
SO_2	27	27	27	27

* Average emission factors calculated by multiplying pollutant emission factors for each waterway class by shipment mileage weights and then summing the weighted emission factor values. The shipment weights are as follows: River — 0.34, Great Lakes — 0.07, Coastal — 0.59. Shipment mileage weights were derived by multiplying tons shipped by the average length-of-haul per ton shipped for each waterway class.

Recreational Vessels

Table F-84 provides HC, CO, and NO_x emission factors for recreational marine vessels. These emission factors come from the EPA *Nonroad Engine and Vehicle Emission Study Report*. The EPA classifies and reports emission factors for the following vehicle/engine types:

- vessels with inboard engines (4-stroke)
- vessels with outboard engines (2-stroke)
- vessels with sterndrive engines (4-stroke)
- sailboats with auxiliary outboard engines (diesel)
- sailboats with auxiliary inboard engines (diesel)

When the AP-42 document was compiled, emission testing data was not available for recreational marine vessels. The EPA used coast guard diesel engine and automotive engine emission data to compute in-board emission factors based on the duty-cycle for engines classified as large out-boards. Out-board emission factors were derived from data supplied to the EPA by the Southwest Research Institute.

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[100] U.S. Environmental Protection Agency, *Compilation of Air Pollutant Emission Factors, Volume II: Mobile Sources*, AP-42, PB-87-205266 (EPA Office of Mobile Sources, September 1985), Part II, Off-Highway Mobile Sources, Table II-3.1.

U.S. Army Corps of Engineers, *Waterborne Commerce of the United States, Calendar Year 1989* (Waterborne Statistics Center, New Orleans, LA, 1991), Part 5: National Summaries, pp. 32, 93.

For the Nonroad Engine and Vehicle report, outboard engine emission factors were derived from test data supplied to EPA by the National Marine Manufacturers Association, which tested 25 two-stroke and three four-stroke outboard engines. For four-stroke outboards, emission factors recommended by the Southwest Research Institute were used for particulate matter emissions.[101] Since no data were available for 2-stroke outboard engine particulate matter emissions, EPA used emission factors from the CARB Technical Support Document for utility and lawn/garden equipment as approximations. For inboard/sterndrive gasoline engines, the EPA derived emission factors on the basis of test data on three 4-stroke gasoline marine inboard/sterndrive engines supplied by NMMA. The particulate emission factor used was 1.64 pounds per 1,000 gallons of fuel. The EPA used NMMA test data for a small diesel sailboat inboard and three large diesel inboard engines as the basis for calculating emission factors for inboard diesel engines.

As with the commercial marine vessels, vessel/engine-type emission factors must be weighted according to an activity or population level indicator and summed to obtain an average emission factor for the total recreational marine vessel population. Engine population data for each vessel/engine-type class was used to construct the weights. Boat population figures were gathered from local boat registration data bases, and were subsequently adjusted to obtain engine population estimates. Energy and Environmental Analysis developed the engine number derivation methodology for the EPA.

Table F-84. Recreational Marine Vessel Emission Factors[102] (Pounds per 1,000 gallons of fuel)

Pollutant	Vessel/Engine Type				Weighted Average*
	Outboard/ 2-Stroke	Outboard/ 4-Stroke	Sterndrive/ 4-Stroke	Sailboard/ Diesel Aux.	
HC	1610	190	160	50	1233
CO	2990	3130	2680	80	2884
NO_x	20	150	100	380	44

* Weights for each vessel/engine-type category were constructed from the following engine population figures: Outboard/2-Stroke — 8,204,304, Outboard/4-Stroke — 41,228, Sterndrive/4-Stroke — 2,713,420, Sailboat/Diesel-Aux. — 114,502.

[101] U.S. Environmental Protection Agency, *Designation of Areas for Air Quality Planning Purposes*, 40 CFR Part 81, Final Rule, Washington, D.C., Office of Air and Radiation, November 6, 1991.

[102] U.S. Environmental Protection Agency, *Nonroad Engine and Vehicle Emission Study — Report*, EPA 460/3-91-02 (EPA Office of Mobile Sources, November 1991), Table 2-03, Appendix I, Table I-11.

Table F-85. Ocean-Going Commercial Vessel Emission Factors

OPERATING PLANT Operating Mode/Rated Output	POLLUTANT				
	NO_x	HC	CO	SO_x	PM
STEAM PROPULSION					
Full Power	63.6	1.72	7.27	159x(%S)	56.5
Maneuver/Cruise	55.8	0.682	3.45	159x(%S)	20
Hotelling					
- Burning residual bunker fuel	36.4	3.2	*	159x(%S)	10
- Burning distillate oil	22.2	3	4	142x(%S)	15
MOTOR PROPULSION					
All underway operating modes	550	24	61	157x(%S)	33
AUXILLARY DIESEL GENERATORS					
- 20 KW (50% Load)	477	144	53.4	27	17
- 40 KW (50% Load)	226	285	67.6	27	17
- 200 KW (50% Load)	140	17.8	62.3	27	17
- 500 KW (50% Load)	293	81.9	48.1	27	17

Notes:
1) Emissions factors showing an asterisk (*) are considered negligible for these operating modes.
2) Average sulfur concentrations used are 0.8 percent for marine diesel, and 2.0 percent for bunker fuel oil.

Sources:
1) U.S. Environmental Protection Agency. Compilation of Air Pollutant Emission Factors, 1985.
2) U.S. Department of Transportation, Port Vessel Emissions Model, 1986.
3) California Air Resources Board, Report to the California Legislature on Air pollutant Emissions from Marine Vessels.

Table F-86. Harbor and Fishing Vessel Emission Factors

OPERATING PLANT Operating Mode/Rated Output	POLLUTANT				
	NO_x	HC	CO	SO_x	PM
DIESEL ENGINES	Pounds per Thousand Gallons of Fuel Consumed				
< 500 Horsepower					
Full	275.1	21	58.5	157x(%S)	17
Cruise	389.3	51.1	47.3	157x(%S)	17
Slow	337.5	56.7	59	157x(%S)	17
500 - 1000 Horsepower					
Full	300	24	61	157x(%S)	17
Cruise	300	17.1	80.9	157x(%S)	17
Slow	167.2	16.8	62.2	157x(%S)	17
1000 - 1500 Horsepower					
Full	300	24	61	157x(%S)	17
Cruise	300	24	61	157x(%S)	17
Slow	300	24	61	157x(%S)	17
1500 - 2000 Horsepower					
Full	472	16.8	237.7	157x(%S)	17
Cruise	623.1	24	44.6	157x(%S)	17
Slow	371.3	24	122.4	157x(%S)	17
2000+ Horsepower					
Full	399.6	21.3	95.9	157x(%S)	17
Cruise	391.7	16.8	78.3	157x(%S)	17
Slow	419.6	22.6	59.8	157x(%S)	17
GASOLINE ENGINES	Grams per Brake Horsepower Hour				
Exhaust Emissions - All HP Ratings	5.16	6.68	199	0.268	0.327
Evaporative Emissions		62.0	Grams/Hr		
Crankcase Blowby		38.3	Grams/Hr		

Notes: 1) Average sulfur concentration for marine diesel fuel = 0.8 percent.

Sources:
1) U.S. Environmental Protection Agency. Compilation of Air Pollutant Emission Factors, 1985.
2) U.S. Department of Transportation, Port Vessel Emissions Model, 1986.
3) California Air Resources Board, Report to the California Legislature on Air pollutant Emissions from Marine Vessels.

Attachment 8: LDV Stock Model

Fuel Economy, Vehicle Choice, and Changing Demographics

This attachment documents the methodology used to forecast the light truck (e.g. pickup trucks, sport utility vehicles) share of total light duty vehicle sales in the NEMS Transportation model. Given the marked difference in fuel economy standards for cars and light trucks this share directly affects both the forecast level of oil consumption and the level of carbon emissions. More generally, the presentation highlights the importance of considering structural shifts in developing long-term energy forecasts.

Background

Short-term (one to two years) forecasts assume that past trends in energy use and past relationships between economic and demographic factors and energy use will continue in the near term. They implicitly assume that structural changes are relatively unimportant as a cause of forecast error compared to errors introduced by uncertainty in estimates of forecasts of variables such as economic growth and energy prices. Those who tinker with long-term energy forecasts don't have this luxury. Certain physical assumptions may be accepted without further consideration (e.g. first law of thermodynamics, heating-degree days in a "normal" year in Southwest Census region). However, the longer the time horizon of the forecast is the more important it is to scrutinize assumptions that remain implicit in short-term forecasting. For example, to develop short-term forecasts of electricity use in buildings it isn't necessary to disaggregate this use by type and efficiency of equipment; it is reasonable to assume that changes in these factors are not an important source of uncertainty. This same assumption would be entirely inappropriate in a methodology used to forecast long-term building sector electricity use. The Energy Information Administration's *Annual Energy Outlook 1996* provides energy forecasts through 2015. Within this time frame most of the electricity-using equipment now in buildings will be replaced and even the currently known menu of replacement choices vary considerably in energy efficiency.

This attachment scrutinizes a single variable in the NEMS Transportation model--the share of light trucks relative to total light-duty vehicle annual sales. It compares estimates of the light truck sales share based on extrapolating past trends to an approach that makes explicit assumptions concerning the impact future demographic changes will have on vehicle choice decisions. We know with a fair degree of certainty that as the generation of "baby boomers" reach age 55, the share of the population under the age of 55 will decrease sharply from the share maintained for many decades. We also know the age distribution of current truck purchasers. The methodology described provides forecasts of the light truck share based on knowledge of an aging population. The methodology does not address the question raised in the subtitle of this paper. To the extent that the population over age 55 in 2015 behave differently from the current over 55 population in terms of their vehicle purchases, the forecasts either under or over estimate the level of new light truck sales.

Methodology

Information on the characteristics of light truck buyers were obtained from the *1989 Buyers of New Compact Trucks, Summary Report,* published by Newsweek. Light trucks are divided into two types, pickup and sport utility.

Table F-87: Truck Buyer Characteristics

	Pickup	Sport Utility
Total	53%	47%
Male	88%	73%
Female	12%	27%
<19	3%	1%
20-24	13%	7%
25-29	13%	15%
30-34	11%	15%
35-39	13%	17%
40-44	12%	16%
45-49	9%	11%
50-54	7%	8%
55-59	6%	5%
60-64	5%	3%
>65	8%	2%

The first step in the methodology used was to aggregate the data across the type of truck, in order to determine a combined age and sex distribution among truck purchasers.

Let: P_{Type} = the percentage of total light truck purchases of a given type.
$P_{Sex,Type}$ = the percentage of each type purchased by a given sex.
$P_{Age,Type}$ = the percentage of each type purchased by a given age group.

Then, aggregating across truck types:

$$P_{Sex,Age} = \sum_{Type} P_{Type} \cdot P_{Sex,Type} \cdot P_{Age,Type}$$

as displayed below. A summation across sex within each age group provides the age distribution of light truck purchasers, depicted in the chart below, and in Figure F-24.

Table F-88: Light Duty Vehicle Purchases by Age and Sex, 1989

Overall LDT Purchases				
Age Group	Male	Female	Total	Cumulative
<19	1.7%	0.3%	2.1%	2.1%
20-24	8.5%	1.7%	10.2%	12.2%
25-29	11.2%	2.7%	13.9%	26.2%
30-34	10.3%	2.6%	12.9%	39.1%
35-39	11.9%	3.0%	14.9%	53.9%
40-44	11.1%	2.8%	13.9%	67.8%
45-49	8.0%	2.0%	9.9%	77.8%
50-54	6.0%	1.5%	7.5%	85.2%
55-59	4.5%	1.0%	5.5%	90.8%
60-64	3.4%	0.7%	4.1%	94.8%
>65	4.4%	0.8%	5.2%	100.0%
Total	81.0%	19.1%	100.0%	

Looking at the cumulative percentages (Figure F-25), approximately 85 percent of all light truck purchases are made by people under 55 years old. Of this group approximately 81 percent are men and 19 percent are women (Table F-88). The historical and projected proportion of the population under 55 years is subsequently graphed in Figure F-26.

Figure F-24: Age Distribution of Truck Purchasers

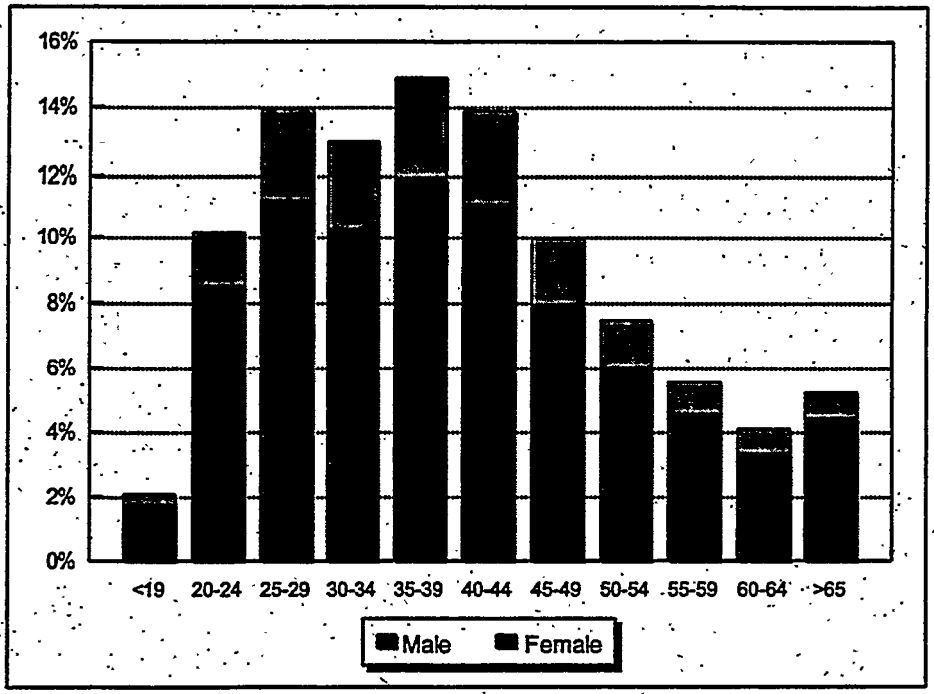
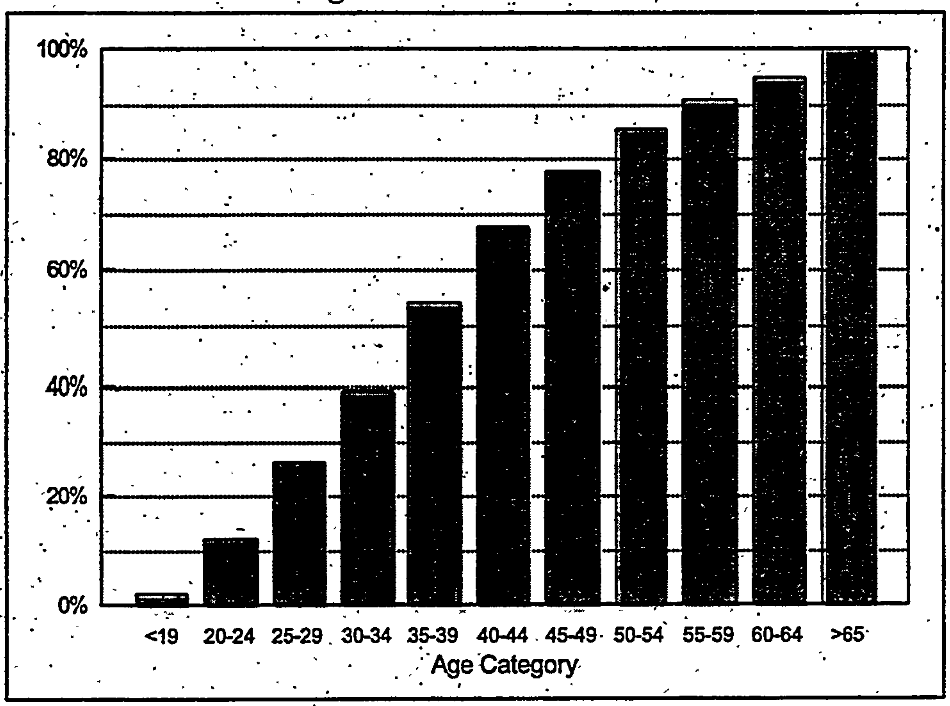
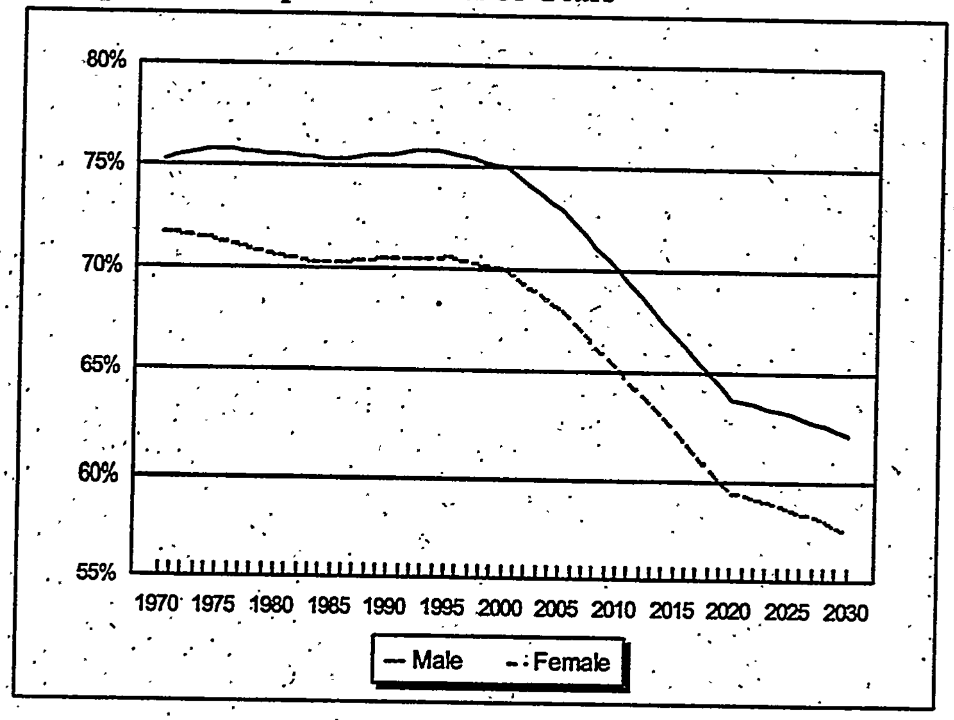


Figure F-25: Cumulative Percentage of Truck Purchasers



A weighted average of the share of the driving age population under 55 years is used as a proxy to measure the demographic impact of an aging population on future truck purchase trends. Note the methodology developed here assumes that people over age 55 will continue to represent only about 15 percent of the light truck purchasing market (Table F-88). Given this assumption, as the proportion of the population under age 55 falls after 2000 (Figure F-26), truck sales will as a proportion of light-duty vehicle sales will stabilize (Figure F-28). In 2015, the unadjusted light truck market share is 49 percent compared to a population-adjusted share of 43 percent.

Figure F-26: Proportion of Population Under 55 Years



The specific methodology used in *AEO96* to develop a demographic index to dampen future truck sales is detailed below. It is certainly not the only index that could have been developed, however, under the assumption that "Grandma will not choose to drive a pick up truck" any approach would dampen light truck sales beyond 2000.

Weighted Population Index

Since the cumulative total (Table F-88) indicates that people under the age of 55 are responsible for 85 percent of all light truck purchases, declines in this share of the population is used as a moderating influence relative to a trend based estimate of light truck sales based on extrapolating recent history. The population index is weighted by the male/female distribution (Table F-88) of truck buyers, as follows:

Let $P_{Sex, Age}$ = the fraction of all LDT buyers of a given sex and age group

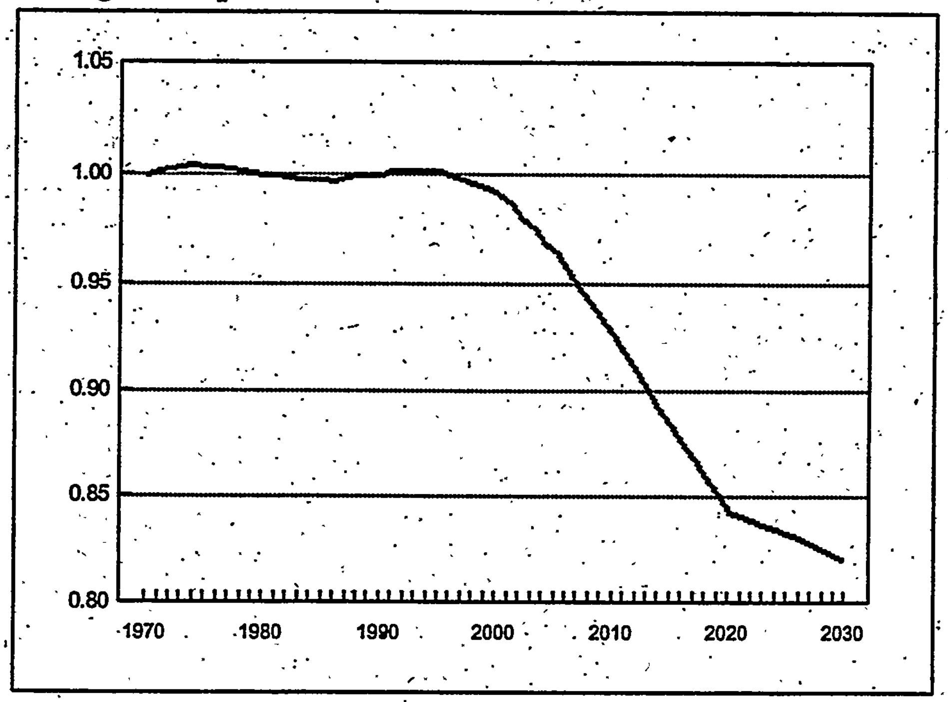
$\Pi_{Sex, Age<55, T}$ = the percentage of the population under the age of 55, by sex, in year T

The weighted share of the population under the age of 55 is then:

$$P{<}55_T = \sum_{Sex} \left[\Pi_{Sex,Age<55,T} \cdot \left(\sum_{Age} P_{Sex,Age} \right) \right]$$

This share is subsequently indexed (1990 = 1.0). Index values are included in the data provided with this paper. The effect of the aging of the "baby boomers" is dramatic (Figure F-27). The aging population has nearly a 15 percent dampening effect on new truck sales relative to a straightforward extrapolation estimate based on recent trends.

Figure F-27: Weighted Population Index



Extrapolation of Recent Trends

The unadjusted share of total LDV purchases accounted for by trucks is extrapolated using the 1982 and 1992 values as anchor points, and an assumed maximum value. The functional form of the curve is as follows:

$$LTS_T = LTS_{1982} + (LTS_{Max} - LTS_{1982}) \cdot (1 - \exp^{-k(T - 1982T_0)})$$

where LTS indicates the Light Truck Share of total LDV sales (referred to in the model code by the variable name CARLTSHR), and the constant, k, is determined as follows:

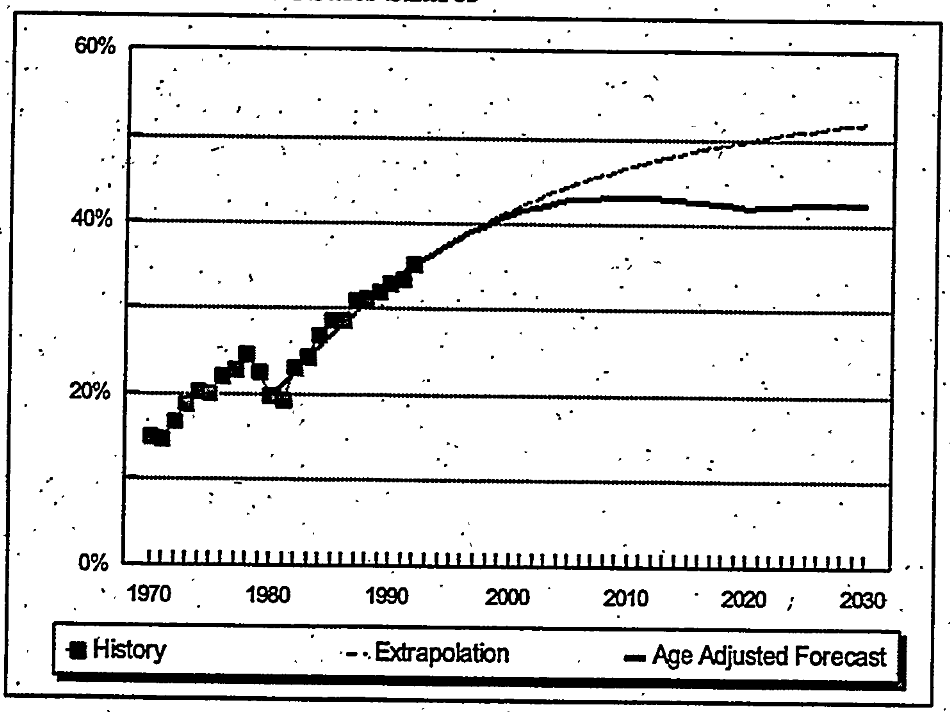
$$k = \frac{-Ln\left[1 - \frac{(LTS_{1992} - LTS_{1982})}{(LTS_{Max} - LTS_{1982})}\right]}{10}$$

Using the data in the table below, k is calculated and the curve is explicitly defined.

Extrapolation Inputs	
LTS_{1982}	0.230
LTS_{1992}	0.353
LTS_{Max}	0.550
k	0.049

The value of k was chosen so that the truck market share of light duty vehicles in 2015 is comparable to the share projected in a recent report.

Figure F-28: Forecasts of Truck Sales Shares



For any forecast year, the population-adjusted estimate is calculated simply by multiplying the extrapolated estimates by the demographic index described above.