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Model Documentation Report: Transportation Sector Model of the National Energy Modeling System

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Appendix A. Input Data and Parameters

LIST OF TABLES

The following table itemizes the variables, data inputs, parameters, and indices employed in each of the Transportation Model's constituent components. These variables are grouped by module, and are identified by the equation number in Appendix B in which they are first encountered. The sources of parameters and data inputs are provided immediately following this table.

Table A-1. List of Transportation Sector Model Variables

LIGHT DUTY VEHICLE MODULE: Fuel Economy Model					
ITEM	**CLASS. (Source)**	**DESCRIPTION**	**UNITS**	**SUBROUTINE**	**EQ #**
ACTUAL$MKT	Variable	The economic share of technology *itc*, prior to consideration of engineering or regulatory constraints.	Percent	FEMCALC	7
ADJFE	Variable	The fuel economy adjustment factor	Percent	FEMCALC	21
ADJHP	Variable	The fractional change in horspower from the previous year within a given vehicle class	Percent	FEMCALC	19
BENCHMPG	Input Data (B)	MPG benchmark factors to ensure congruence with most recent data from ORNL	—	FEMSIZE	39
CAFE	Variable	Actual CAFE values by group	Miles per Gallon	CAFECALC	34
CLASS$SHARE	Variable	Relative market share for each class. Basis for CAFE calculations	Percent	CAFECALC	31
CMKS	Variable	Class market share, subsequently reassigned to the appropriate vehicle class and group, $\text{CLASS\$SHARE}_{icl,igp}$	Percent	CMKSCALC	32
COSTEFFECT	Variable	A unitless measure of cost effectiveness	—	FEMCALC	6
DEL$COSTABS	Variable	Change in cost associated with technology *itc*	Percent	FEMCALC	4
DEL$COSTWGT	Variable	The weight-based change in cost of technology *itc*	$ per lb	FEMCALC	4
DEL$FE	Variable	The fractional change in fuel economy associated with technology *itc*	Percent	FEMCALC	3
DEL$HP	Variable	The fractional change in horsepower of technology *itc*	Percent	FEMCALC	5
DEL$MKT	Variable	The amount of the superseded technology's market share to be removed	Percent	NOTE$SUPER	26
DEL$WGTABS	Variable	The change in weight associated with technology *itc*	lbs	FEMCALC	16
DEL$WGTWGT	Variable	The fractional change in weight associated with technology *itc*	Percent	FEMCALC	4
DELTA$MKT	Variable	The change in market share for technology *itc*	Percent	FEMCALC	14
DIFF$LN	Variable	The increment from the base year (1990) of the log of the market share ratio	—	CMKSCALC	29
DISCOUNT	Parameter (A)	Discount rate used in payback calculation	Percent	FEMCALC	3

LIGHT DUTY VEHICLE MODULE: Fuel Economy Model

ITEM	CLASS. (Source)	DESCRIPTION	UNITS	SUBROUTINE	EQ #
FE	Variable	Fuel economy of technology *itc*, within seven size classes	Miles per Gallon	FEMCALC	3
FEMPG	Variable	Average fuel economy by six ORNL size classes	MPG	FEMSIZE	38
FESIXC	Variable	Fuel economy for cars within six size classes	MPG	FEMSIZE	40
FESIXT	Variable	Fuel economy for light trucks within six size classes	MPG	FEMSIZE	40
FUELCOST	Variable	Projected fuel cost	$ per MMBtu	FEMCALC	1
FUELSAVE	Variable	The expected present value of fuel savings over the payback period	$	FEMCALC	3
HP	Variable	Horsepower	HP	FEMCALC	18
icl	Index	FEM vehicle size class index (7)	—	FEMSIZE	—
igp	Index	CAFE group index: 1 = domestic car, 2 = import car, 3 = domestic light truck, 4 = import light truck	—	FEMSIZE	—
INCOME	Variable	Household income	$ per year	FEMCALC	198
ino	Index	The index identifying the technologies in the superseding group	—	NOTE$SUPER	—
isno	Index	An index indicating the superseded technology	—	NOTE$SUPER	—
itc	Index	The index representing the technology under consideration	—	FEMCALC	3
MANDMKSH	Input Data (A)	Mandatory market share	Percent	FEMCALC	9
MAP	Input Data (A)	Array of mapping constants, which converts FEM to ORNL size classes	—	FEMSIZE	35
MAPSALE	Variable	Disaggregate vehicle sales	Units	FEMSIZE	35
MAPSHR	Variable	Sales shares within the disaggregate array	Percent	FEMSIZE	37
MAX$SHARE	Input Data (A)	The maximum market share of the group, *ino*	Percent	NOTE$SUPER	25
MKT$MAX	Input Data (A)	Maximum market share of technology in given class	Percent	NOTE$SUPER	25
MKT$PEN	Variable	Market share of technology in given class and year	Percent	FEMCALC	8
MMAX	Variable	The maximum market share for technology *itc*, obtained from MKT$MAX	Percent	FEMCALC	7
N	Index	Time period index (1990 = 1)	—	FEMSIZE	—
num$sup	Index	The number of technologies in the superseding group	—	NOTE$SUPER	—
NVS7SC	Variable	New vehicle sales within the seven FEM size classes	Units	TSIZE	41
ORNLMPG	Input Data (B)	Most recent (1992) fuel economy data from ORNL	MPG	FEMSIZE	39
osc	Index	ORNL size class index (6)	—	FEMSIZE	—
PAYBACK	Input Data (A)	The user-specified payback period	Years	FEMCALC	3

LIGHT DUTY VEHICLE MODULE: Fuel Economy Model					
ITEM	**CLASS. (Source)**	**DESCRIPTION**	**UNITS**	**SUBROUTINE**	**EQ #**
PERFFACT	Input Data (A)	Performance factor (multiplier for horsepower adjustment)	—	FEMCALC	19
PMAX	Parameter (A)	The institutional maximum market share, which models tooling constraints on the part of the manufacturers	Percent	FEMCALC	7
PRICE	Variable	Vehicle price	$	FEMCALC	17
PRICE$EX	Variable	The expected price of fuel	$	FEMCALC	2
PSLOPE	Variable	The fuel cost slope	—	FEMCALC	1
RATIO$LN	Variable	Log of the market share ratio of the considered vehicle class	—	CMKSCALC	31
REGCOST	Variable	A factor representing regulatory pressure to increase fuel economy	$ per MPG	FEMCALC	6
REQ$MKT	Input Data (A)	The total market share of those technologies which are required for the implementation of technology *itc*, indicating that technology's maximum share	Percent	FEMCALC	10
SYNR$DEL	Input Data (A)	The synergistic effect of two technologies on fuel economy	—	FEMCALC	13
TECHCOST	Input Data (A)	The cost of technology *itc*	$	FEMCALC	4
TOT$MKT	Variable	The total market share of the considered group of technologies	Percent	NOTE$SUPER	27
TOTNVS7	Variable	Total new vehicle sales within the six ORNL size classes	Units	FEMSIZE	36
VAL$PERF	Input Data (A)	The dollar value of performance of technology *itc*	$	FEMCALC	5
VALUEPERF	Variable	The value associated with an incremental change in performance	$	FEMCALC	5
WEIGHT	Variable	The base year vehicle weight, absent the considered technology	lbs	FEMCALC	4
YEAR	Index	Year index (*YEAR* = *N*+1)	—	FEMSIZE	—

LIGHT DUTY VEHICLE MODULE: Regional Sales Model					
ITEM	**CLASS.**	**DESCRIPTION**	**UNITS**	**SUBROUTINE**	**EQ #**
AHPCAR	Variable	Average automobile horsepower	HP	TSIZE	49
AHPTRUCK	Variable	Average light truck horsepower	HP	TSIZE	50
COMTSHR	Data Input (B)	Fraction of new light trucks dedicated to commercial freight	Percent	TSIZE	42
COSTMIR	Variable	The cost of driving in region *REG*	$ per Mile	TREG	52
DAF	Paramete r (C)	A demographic adjustment factor, to reflect different age groups' driving patterns	—	TEXOG	55
FLTCRAT	Paramete r (B)	Fraction of new cars purchased by fleets	Percent	TSIZE	41
FLTTRAT	Paramete r (B)	Fraction of new light trucks purchased by fleets	Percent	TSIZE	42
GROUP	Index	Index indicating domestic or imported vehicles	—	TSIZE	—
HP	Variable	Vehicle horsepower by FEM size class, group	HP	TSIZE	47
HPCAR	Variable	Average horsepower of new automobiles, by size class *SC*	HP	TSIZE	47
HPTRUCK	Variable	Average horsepower of new light trucks, by size class *SC*	HP	TSIZE	48
INCOMER	Variable	Regional per capita disposable income	$	TREG	53
LTSHRR	Variable	Non-fleet market shares of light trucks, by size class *SC*	Percent	TSIZE	46
NCS	Variable	New car sales, by size class and region	Units	TREG	57
NCSTSCC	Variable	New car sales in the modified six size classes, *SC*	Units	TSIZE	43
NLTS	Variable	New light truck sales, by size class and region	Units	TREG	58
NLTSTSCC	Variable	New light truck sales in six size classes *SC*	Units	TSIZE	44
NVS7SC	Variable	New vehicle sales in the original seven FEM size classes	Units	TSIZE	43
PASSHRR	Variable	Non-fleet market shares of automobiles, by size class *SC*	Percent	TSIZE	45

LIGHT DUTY VEHICLE MODULE: Regional Sales Model					
ITEM	**CLASS.**	**DESCRIPTION**	**UNITS**	**SUBROUTINE**	**EQ #**
PRFEM	Data Input (D)	Ratio of female to male driving rates	—	TVMT	54
RHO	Paramete r (C)	Lag factor for the VMT difference equation	—	TVMT	54
RSHR	Variable	Regional VMT shares	Percent	TREG	57
SALESHR	Data Input (B)	Fraction of vehicle sales which are domestic/imported	Percent	TSIZE	41
SEDSHR	Variable	Regional share of the consumption of a given fuel in period *T*	Percent	TREG	51
TMC_POP16	Variable	Total regional population over the age of 16	—	TMAC	55
TMC_POPAFO	Variable	Total population in region *REG*	—	TMAC	53
TMC_SQDTRU CKSL	Variable	Total light truck sales (supplied by the MACRO module)	Units	TMAC	42
TMC_SQTRCA RS	Variable	Total new car sales (supplied by the MACRO module)	Units	TSIZE	41
TMC_YD	Variable	Estimated disposable personal income by region, *REG*	$	TMAC	51
VMT16R	Variable	Vehicle-miles traveled per population over 16 years of age	—	TREG	54
VMTEER	Variable	Total VMT in region *REG*	—	TREG	55

LIGHT DUTY VEHICLE MODULE: Alternative Fuel Vehicle Model					
ITEM	**CLASS.**	**DESCRIPTION**	**UNITS**	**SUBROUTINE**	**EQ #**
AFCOST	Variable	Alternative vehicle fuel price	$ per MMBtu	TALT3	60
APSHR11	Variable	Relative market shares of each aggregate technology	Percent	TALT1	76
APSHR22	Variable	Relative market shares of each AFV technology	Percent	TALT2	72
APSHR33	Variable	Relative market shares of each EV technology	Percent	TALT3	68
APSHR44	Variable	Absolute market shares of each technology	Percent	TALT1	79
BETACONST	Parameter (F)	Constant associated with each considered technology *IT*	—	TALT3	66
BETACONST1	Parameter (F)	Constant associated with each considered technology	—	TALT1	74
BETACONST2	Parameter (F)	Constant associated with each considered AFV technology	_	TALT2	70
BETAEM	Parameter (F)	Coefficient associated with vehicle emissions	—	TALT3	66
BETAEM2	Parameter (F)	Coefficient associated with the square of vehicle emissions	—	TALT3	66
BETAFA	Parameter (F)	Coefficient associated with fuel availability	—	TALT3	66
BETAFA2	Parameter (F)	Coefficient associated with the square of fuel availability	—	TALT3	66
BETAFC	Parameter (F)	Coefficient associated with fuel cost	$(\$)^{-1}$	TALT3	66
BETAVP	Parameter (F)	Coefficient associated with vehicle price	$(\$)^{-1}$	TALT3	66
BETAVR	Parameter (F)	Coefficient associated with vehicle range	$(\text{Miles})^{-1}$	TALT3	66
BETAVR2	Parameter (F)	Coefficient associated with the square of vehicle range	$(\text{Miles})^{-2}$	TALT3	66
COMAV	Input Data (E)	Commercial availability of each AFV technology	—	TALT3	59
COPCOST	Variable	Fuel operating costs for each AFV technology	Cents per Mile	TALT3	65
COPCOST1	Variable	Fuel operating costs for conventional and alternative vehicles	Cents per mile	TALT1	74
COPCOST2	Variable	Fuel operating costs for alternative vehicles	Cents per mile	TALT2	70
EMISS1	Input Data (E)	Emissions levels relative to gasoline ICE's	—	TALT1	74
EMISS2	Input Data (E)	AFV emissions levels relative to gasoline ICE's	—	TALT2	70
EMISS3	Input Data (E)	EV emissions levels relative to gasoline ICE's	Percent	TALT3	66
EVC1	Variable	Exponentiated value of vehicle utility vector	—	TALT1	75
EVC2	Variable	Exponentiated value of alternative vehicle utility vector	—	TALT2	71
EVC3	Variable	Exponentiated value of electric vehicle utility vector	—	TALT3	67

LIGHT DUTY VEHICLE MODULE: Alternative Fuel Vehicle Model					
ITEM	**CLASS.**	**DESCRIPTION**	**UNITS**	**SUBROUTINE**	**EQ #**
FAVAIL	Input Data (E)	Availability of each alternative fuel relative to gasoline	Percent	TALT3	60
FAVAIL11	Input Data (E)	Fuel availability for conventional and alternative technologies	Percent	TALT1	74
FAVAIL22	Input Data (E)	Alternative technology fuel availability	Percent	TALT2	70
FAVAIL33	Input Data (E)	Fuel availability for EV technologies	Percent	TALT3	66
FEC3SC	Variable	Automobile fuel economy within the three reduced size classes	MPG	TALT3	61
FET3SC	Variable	Light truck fuel economy within the three reduced size classes	MPG	TALT3	62
IT	Index	Index of the sixteen engine technologies considered by the model	—	TALT3	—
RFP	Variable	Regional fuel price	Dollars per MMBtu	TALT3	50
TT50	Input Data (X)	The exogenously specified year in which 50% of the demand for technology *IT* can be met	Year	TALT3	59
VC1	Variable	Utility vector for conventional and alternative vehicles	—	TALT1	74
VC1	Variable	Utility vector for conventional and alternative vehicles	—	TALT1	74
VC2	Variable	Utility vector for alternative vehicles	—	TALT2	70
VC3	Variable	Utility vector for electric vehicles	—	TALT3	66
VEFF	Input Data (E)	Fuel economy of technology *IT*, relative to gasoline baseline	—	TALT3	64
VEFFACT	Variable	Baseline efficiency of gasoline ICE's, in MPG	Miles per MMBtu	TALT3	63
VPRICE1	Input Data (E)	Price of each considered technology in 1990$	1990 $	TALT1	74
VPRICE2	Input Data (E)	Price of each considered AFV technology in 1990$	1990 $	TALT2	70
VPRICE3	Input Data (E)	Price of each considered EV technology in 1990$	1990 $	TALT3	66
VRANGE1	Input Data (E)	Vehicle range of the considered technology	Miles	TALT1	74
VRANGE2	Input Data (E)	Vehicle range of the considered AFV technology	Miles	TALT2	70
VRANGE3	Input Data (E)	Vehicle range of the considered EV technology	Miles	TALT3	66

LIGHT DUTY VEHICLE STOCK MODULE					
ITEM	**CLASS.**	**DESCRIPTION**	**UNITS**	**SUBROUTINE**	**EQ #**
ADJVMTPC	Variable	Demographically-adjusted per capita VMT	Vehicle-miles	TVMT	142
AMPGC	Variable	The average MPG of cars within the reduced AFV size class	Miles per gallon	TMPGSTK	129
AMPGT	Variable	The average MPG of trucks within the reduced AFV size class	Miles per gallon	TMPGSTK	129
ANCMPG	Variable	Average new car MPG	Miles per gallon	TMPGSTK	133
ANTMPG	Variable	Average new light truck MPG	Miles per gallon	TMPGSTK	133
APSHRNC	Variable	Absolute market share of new cars, by technology, from the AFV model	Percent	TMPGSTK	133
APSHRNT	Variable	Absolute market share of new light trucks, by technology, from the AFV model	Percent	TMPGSTK	133
ASC	Index	The three AFV size classes, onto which the six primary size classes are mapped	—		—
CCMPGLDV	Variable	New car MPG, by technology *IT*	MPG	TMPGAG	156
CMPGSTK	Variable	Automobile stock MPG, by vintage and technology	Miles per gallon	TMPGSTK	135
CMPGT	Variable	Automobile stock MPG	Miles per gallon	TMPGSTK	135
COSTMI	Variable	Cost of driving per mile	$ per mile	TVMT	139
DAF	Input Data (C)	Demographic adjustment factor	—	TVMT	142
FLTECHSAL	Variable	Fleet sales by size, technology, and fleet type	Units	TMPGAG	153
FLTECHSALT	Variable	Vehicle purchases by fleet type and technolgy	Units	TMPGAG	153
FLTECHSTK	Variable	Total fleet vehicle stock, by technology and fleet type	Units	TMPGAG	155
FLTMPG	Variable	Fleet vehicle MPG by vehicle type, size class, and technology	MPG	TMPGAG	154
FLTMPGNEW	Variable	New fleet vehicle MPG, by vehicle type and technology *ITECH*	MPG	TMPGAG	156
FLTSTOCK	Variable	New fleet stock, by vehicle type and technology *ITECH*	Units	TMPGAG	155
FLTVMT	Variable	Fleet VMT	Vehicle-miles	TVMT	144
FLVMTSHR	Variable	VMT-weighted shares by size class and technology	Percent	TFREISMOD	148
FVMTSC	Variable	Freight VMT by size class	Vehicle-miles	TVMT	144
INCOME	Variable	Per capita disposable personal income	$	TVMT	140
IS	Index	Index of size class (1-3)	—	TMPGAG	—
IT	Index	Index of vehicle technology (1-16)	—	TMPGAG	—
IT2	Index	Reassigned indices of vehicle technology *IT2* = 1-16; *IT* = 16,15,1-14	—	TMPGAG	—

LIGHT DUTY VEHICLE STOCK MODULE					
ITEM	**CLASS.**	**DESCRIPTION**	**UNITS**	**SUBROUTINE**	**EQ #**
ITECH	Index	Index of fleet vehicle technologies which correspond to the *IT* index	—	TMPGAG	—
ITY	Index	Index of fleet type: Business, Government, Utility	—	TMPGAG	—
LTSTK	Variable	Surviving light truck stock, by technology and vintage	Units	TSMOD	120
LVMT	Variable	Average light truck VMT, by vintage, from RTECS	Vehicle miles traveled	TEXOG	134
MPGC	Variable	New car fuel efficiency, by engine technology	Miles per gallon	TMPGSTK	131
MPGC	Variable	New car MPG, by technology *IT*	MPG	TMPGAG	156
MPGFLT	Variable	Stock MPG for all light duty vehicles	Miles per gallon	TMPGSTK	137
MPGT	Variable	New light truck fuel efficiency, by engine technology	Miles per gallon	TMPGSTK	131
MPGTECH	Variable	Average stock MPG by technology	MPG	TMPGSTK	138
NCMPG	Variable	New car MPG, from the FEM model	Miles per gallon	TMPGSTK	132
NCS3A	Variable	New car sales by reduced size class and engine technology: *IS* = 1, *OSC* = 1,6; *IS* = 2, *OSC* = 2,3; *IS* = 3, *OSC* = 4,5	Units	TMPGSTK	125
NCS3SC	Variable	Total new car sales by reduced size class	Units	TMPGSTK	127
NCSR	Variable	Regional new car sales by reduced size class	Units	TMPGSTK	126
NCSTECH	Variable	New car sales, by region, size class, and technology, from the AFV Module	Units	TSMOD	119
NLT3A	Variable	New light truck sales by reduced size class and technolgy: *IS* = 1, *OSC* = 1,3; *IS* = 2, *OSC* = 2,5; *IS* = 3, *OSC* = 4,6	Units	TMPGSTK	125
NLTECH	Variable	New light truck sales, by region, size class, and technology	Units	TSMOD	119
NLTMPG	Variable	New light truck MPG, from the FEM model	Miles per gallon	TMPGSTK	132
NLTS3SC	Variable	Total new light truck sales by reduced size class	Units	TMPGSTK	127
NLTSR	Variable	Regional new light truck sales by reduced size class	Units	TMPGSTK	126
NNCSCA	Variable	New conventional car sales by six size classes	Units	TMPGSTK	128
NNLTCA	Variable	New conventional light truck sales by six size classes	Units	TMPGSTK	128
OLDFSTK	Variable	Number of fleet vehicles rolled over into corresponding private categories	Units	TSMOD	122
PASSTK	Variable	Surviving automobile stock, by technology and vintage	Units	TSMOD	120
PrFem	Data Input (C)	The ratio of per capita female driving to per capita male driving.	—	TVMT	141

LIGHT DUTY VEHICLE STOCK MODULE					
ITEM	**CLASS.**	**DESCRIPTION**	**UNITS**	**SUBROUTINE**	**EQ #**
PVMT	Variable	Average automobile VMT, by vintage, from RTECS	Vehicle miles traveled	TEXOG	134
RATIO	Variable	Light truck MPG adjustment factor	—	TMPGSTK	130
RHO	Parameter (C)	Difference equation lag factor, estimated, using the Cochrane-Orcutt iterative procedure, to be 0.72	—	TVMT	141
SCMPG	Variable	Stock MPG for automibles	Miles per gallon	TMPGSTK	136
SSURVLT	Input Data (B)	Fraction of a given vintage's light trucks which survive	Percent	TSMOD	120
SSURVP	Input Data (B)	Fraction of a given vintage's automobiles which survive	Percent	TSMOD	120
STKCAR	Variable	Total stock of non-fleet automobiles in year *T*	Units	TSMOD	123
STKCT	Variable	Stock of non-fleet vehicles, by technology	Units	TMPGAG	158
STKTR	Variable	Total stock of non-fleet light trucks in year *T*	Units	TSMOD	123
STMPG	Variable	Stock MPG for light trucks	Miles per gallon	TMPGSTK	136
STOCKLDV	Variable	Total stock of fleet and non-fleet vehicles, by technology	Units	TMPGAG	158
TECHNCS	Variable	Non-fleet new car sales, by technology *IT*	Units	TMPGAG	156
TECHNCS	Variable	Total new car sales, by technology	Units	TSMOD	119
TECHNLT	Variable	Total new light truck sales, by technology	Units	TSMOD	119
TECHNLT	Variable	Non-fleet new light truck sales, by technology *IT*	Units	TMPGAG	157
TLDVMPG	Variable	Average fuel economy of light-duty vehicles	MPG	TMPGAG	161
TMC_POPAFO	Variable	Total population, from MACRO module	Units	TVMT	140
TMC_SQDTRUCKSL	Variable	Total light truck sales, from MACRO module	Units	TFREISMOD	147
TMC_YD	Variable	Total disposable personal income, from MACRO module	$	TVMT	140
TMPGLDVSTK	Variable	Average MPG by vehicle type *VT*	MPG	TMPGAG	160
TMPGT	Variable	Light truck stock MPG	Miles per gallon	TMPGSTK	135
TOTMICT	Variable	Total miles driven by cars	Miles	TMPGSTK	134
TOTMITT	Variable	Total miles driven by light trucks	Miles	TMPGSTK	134
TPMGTR	Variable	Price of motor gasoline	$ per gallon	TVMT	139
TRFLTMPG	Variable	Average light truck MPG	MPG	TFREISMOD	152
TRSAL	Variable	Light truck sales for freight	Units	TFREISMOD	147
TRSALTECH	Variable	Light truck sales by technology	Units	TFREISMOD	148
TRSTK	Variable	Total light truck stock	Units	TFREISMOD	151
TRSTKTECH	Variable	Light truck stock by technology	Units	TFREISMOD	149
TRSTKTOT	Variable	Total light truck stock by technology	Units	TFREISMOD	150

LIGHT DUTY VEHICLE STOCK MODULE					
ITEM	**CLASS.**	**DESCRIPTION**	**UNITS**	**SUBROUTINE**	**EQ #**
TSTOCKLDV	Variable	Total stock by vehicle type *VT*	Units	TMPGAG	159
TTMPGLDV	Variable	New light truck MPG, by technology *IT*	MPG	TMPGAG	157
TTMPGSTK	Variable	Light truck stock MPG, by vintage and technology	Miles per gallon	TMPGSTK	135
VDF	Input Data (N)	Vehicle fuel efficiency degradation factor	Percent	TMPGSTK	135
VMTECH	Variable	Personal travel VMT by technology	Vehicle-miles	TVMT	145
VMTEE	Variable	VMT for personal travel	Vehicle-miles	TVMT	144
VMTLDV	Variable	Total VMT for light duty vehicles	Vehicle-miles	TVMT	143
VSPLDV	Variable	The light duty vehicle shares of each of the sixteen vehicle technologies	Percent	TSMOD	124
VT	Index	Index of vehicle type: 1 = cars, 2 = light trucks	—	TMPGAG	—
XLDVMT	Variable	Fractional change of VMT over base year (1990)	Percent	TVMT	146

LIGHT DUTY VEHICLE FLEET MODULE					
ITEM	**CLASS.**	**DESCRIPTION**	**UNITS**	**SUBROUTINE**	**EQ #**
APSHR55	Variable	Absolute regional market shares of adjusted vehicle sales	Percent	TLEGIS	102
APSHRFLTB	Variable	Market shares of business fleet by vehicle type and technology	Percent	TLEGIS	106
APSHRFLTB	Variable	Alternative technology shares for the business fleet	Percent	TLEGIS	84
APSHRFLTOT	Variable	Aggregate market shares of fleet vehicle technologies	Percent	TLEGIS	105
APSHRNC	Variable	Market shares of new cars by technology	Percent	TLEGIS	104
APSHRNT	Variable	Market shares of new light trucks by technology	Percent	TLEGIS	104
AVSALES	Variable	Regional adjusted vehicle sales by size class	Units	TLEGIS	97
AVSALEST	Variable	Total regional adjusted vehicle sales by size class	Units	TLEGIS	100
ELECVSAL	Variable	Regional electric vehicle sales	Units	TLEGIS	92
ELECVSALSC	Variable	Regional ZEV sales within corresponding regions	Units	TLEGIS	96
EPACT	Parameter (H)	Legislative mandates for AFV purchases, by fleet type	Percent	TEXOG	81
FLTALT	Variable	Number of AFV's purchased by each fleet type in a given year	Units	TFLTSTKS	81
FLTAPSHR1	Input Data (G)	Fraction of each fleets' purchases which are AFV's, from historical data	Percent	TEXOG	81
FLTCONV	Variable	Fleet purchases of conventional vehicles	Units	TFLTSTKS	82
FLTCRAT	Input Data (G)	Fraction of total car sales attributed to fleets	Percent	TEXOG	80
FLTCSHR	Input Data (G)	Fraction of fleet cars purchased by a given fleet type	Percent	TEXOG	80
FLTECH	Variable	Vehicle purchases by fleet type and technology	Units	TFLTSTKS	85
FLTECHSAL	Variable	Fleet sales by size, technology, and fleet type	unts	TFLTSTKS	84
FLTECHSHR	Input Data (G)	Alternative technology shares for the government and utility fleets	Percent	TEXOG	84
FLTFCLDVBTU	Variable	Fuel consumption by vehicle type and technology	MMBtu	TFLTCONS	117
FLTFCLDVBTUR	Variable	Regional fuel consumption by fleet vehicles, by technology	MMBtu	TFLTCONS	118
FLTLDVC	Variable	Fuel consumption by technology, vehicle and fleet type	MMBtu	TFLTCONS	116
FLTMPG	Variable	New fleet vehicle fuel efficiency, by fleet type and engine technology	Miles per Gallon	TFLTMPG	110
FLTMPGTOT	Variable	Overall fuel efficiency of new fleet cars and light trucks	MPG	TFLTMPG	112
FLTSAL	Variable	Sales to fleets by vehicle and fleet type	Units	TFLTSTKS	80
FLTSLSCA	Variable	Fleet purchases of AFV's, by size class	Units	TFLTSTKS	83
FLTSLSCC	Variable	Fleet purchases of conventional vehicles, by size class	Units	TFLTSTKS	83

LIGHT DUTY VEHICLE FLEET MODULE					
ITEM	**CLASS.**	**DESCRIPTION**	**UNITS**	**SUBROUTINE**	**EQ #**
FLTSSHR	Input Data (G)	Percentage of fleet vehicles in each size class, from historical data	Percent	TEXOG	83
FLTSTKVN	Variable	Fleet stock by fleet type, technology, and vintage	Units	TFLTSTKS	86
FLTTOTMPG	Variable	Fleet vehicle average fuel efficiency for cars and light trucks	Miles per Gallon	TFLTMPG	115
FLTTRAT	Input Data (G)	Fraction of total truck sales attributed to fleets	Percent	TEXOG	80
FLTTSHR	Input Data (G)	Fraction of fleet trucks purchased by a given fleet type	Percent	TEXOG	80
FLTVMT	Variable	Total VMT driven by fleet vehicles	Vehicle Miles Traveled	TFLTVMTS	108
FLTVMTECH	Variable	Fleet VMT by technology, vehicle type, and fleet type	Vehicle Miles Traveled	TFLTVMTS	109
FLTVMTYR	Variable	Annual miles of travel per vehicle, by vehicle and fleet type	Miles	TFLTVMTS	108
FMSHC	Variable	The market share of fleet cars, from the AFV model	Percent	TFLTMPG	110
FMSHLT	Variable	The market share of fleet light trucks, from the AFV model	Percent	TFLTMPG	110
IR	Index	Corresponding regions: *ST* = CA, MA, NY; *IR* = 9,1,2	—	TLEGIS	—
IS	Index	Index of size classes: 1 = small, 2 = medium, 3 = large	—	TFLTSTKS	—
ITECH	Index	Index of engine technologies: 1-5 = alternative fuels (neat), 6 = gasoline	—	TFLTSTKS	—
ITF	Index	Index of fleet vehicle technologies, corresponding to *IT* = 3,5,7,8,9	—	TLEGIS	—
ITY	Index	Index of fleet type: 1 = business, 2 = government, 3 = utility	—	TFLTVMTS	—
MAXVINT	Index	Maximum *IVINT* index associated with a given vehicle and fleet type	—	TFLTMPG	—
MPGFLTSTK	Variable	Fleet MPG by vehicle and fleet type, and technology, across vintages	Miles per Gallon	TFLTMPG	114
MPGFSTK	Variable	Fleet MPG by vehicle and fleet type, technology, and vintage	Miles per Gallon	TFLTMPG	113
NAMPG	Variable	New AFV fuel efficiency, from the AFV model	Miles per Gallon	TALT3	110
NCSTECH	Variable	Regional new car sales by technology, within six size classes: *OSC* = 1-6; *IS* = 2,1,1,3,3,2	Units	TLEGIS	107
NLTECH	Variable	Regional light truck sales by technology, with six size classes: *OSC* = 1-6; *IS* = 1,2,1,3,2,3	Units	TLEGIS	107
OLDFSTK	Variable	Old fleet stocks of given types and vintages, transferred to the private sector	Units	TFLTSTKS	87
QBTU	Input Data (I)	Energy content of the fuel associated with each technology	Btu/Gal	TFLTCONS	117

LIGHT DUTY VEHICLE FLEET MODULE					
ITEM	**CLASS.**	**DESCRIPTION**	**UNITS**	**SUBROUTINE**	**EQ #**
RSHR	Variable	Regional VMT shares, from the Regional Sales Module	Percent	TREG	118
ST	Index	Index of participating state: CA, MA, NY	—	TLEGIS	—
STATESHR	Variable	Share of national vehicle sales attributed to a given state	Percent	TLEGIS	94
SURVFLTT	Input Data (G)	Survival rate of a given vintage	Percent	TFLTSTKS	86
TFLTECHSTK	Variable	Total stock within each technology and fleet type	Units	TFLTSTKS	88
TMC_SQDTRUCKSL	Variable	Total light truck sales in a given year	Units	TMAC	80
TMC_SQTRCARS	Variable	Total automobile sales in a given year	Units	TMAC	80
TOTFLTSTK	Variable	Total of all surviving fleet vehicles	Units	TFLTSTKS	89
ULEV	Data Input (J)	State-mandated minimum sales share of ULEV's	Percent	TLEGIS	94
ULEVST	Variable	State-mandated minimum sales of ULEV's	Units	TLEGIS	94
VFSTKPF	Variable	Share of fleet stock by vehicle type and technology	Percent	TFLTSTKS	90
VSALES	Variable	Total disaggregate vehicle sales	Units	TLEGIS	91
VSALESC16	Variable	Total new car sales by technology: *IS* = 1, *OSC* = 2,3; *IS* = 2, *OSC* = 1,6; *IS* = 3, *OSC* = 4,5	Units	TLEGIS	103
VSALEST	Variable	Total regional vehicle sales, by size class	Units	TLEGIS	93
VSALEST16	Variable	Total new light truck sales by technology: *IS* = 1, *OSC* = 1,3; *IS* = 2, *OSC* = 2,5; *IS* = 3, *OSC* = 4,6	Units	TLEGIS	103
VT	Index	Index of vehicle type: 1 = cars, 2 = light trucks	—	TFLTSTKS	—
ZEV	Data Input (J)	State-mandated minimum sales share of ZEV's	Percent	TLEGIS	94
ZEVST	Variable	State-mandated minimum sales of ZEV's	Units	TLEGIS	94
ZEVSTSC	Variable	Mandated ZEV sales by size class and state	Units	TLEGIS	95

AIR TRAVEL MODULE: Air Travel Demand Model					
ITEM	**CLASS.**	**DESCRIPTION**	**UNITS**	**SUBROUTINE**	**EQ #**
DFRT	Parameter (O)	Fraction of freight ton-miles transported on dedicated carriers.	Percent	TAIRT	199
DI	Parameter (O)	Demographic air travel index, reflecting public's propensity to fly	—	TAIRT	201
EQSM	Input Data (O)	Equivalent seat-miles conversion factor; used to transform freight RTMs to seat-miles	—	TAIRT	204
LFDOM	Parameter (O)	Load factor, the average fraction of seats which are occupied in domestic travel.	Percent	TAIRT	204
LFINTER	Parameter (O)	Load factor for international travel.	Percent	TAIRT	204
OPCST	Input Data (O)	Airline operating costs.	Dollars per Aircraft-Mile	TAIRT	195
PCTINT	Parameter (O)	Proportionality factor relating international to domestic travel levels	—	TAIRT	198
RPMB	Variable	Revenue passenger miles of domestic travel for business purposes.	Passenger Miles	TAIRT	200
RPMBPC	Variable	Per capita domestic RPM for business travellers.	Miles per Capita	TAIRT	196
RPMD	Variable	Total domestic revenue passenger miles.	Passenger Miles	TAIRT	203
RPMI	Variable	Revenue passenger miles of international travel.	Passenger Miles	TAIRT	202
RPMIPC	Variable	Per capita international RPM	Miles per Capita	TAIRT	198
RPMP	Variable	Revenue passenger miles of domestic travel for personal purposes.	Passenger Miles	TAIRT	201
RPMPPC	Variable	Per capita domestic RPM for personal travel.	Miles per Capita	TAIRT	197
RTM	Variable	Revenue ton miles of cargo.	Ton Miles	TAIRT	199
ASMDEMD	Variable	Total seat-miles demanded for domestic and international travel	Seat Miles	TAIRT	204
TMC_GDP	Variable	Real gross domestic product	Dollars per Capita	TMAC	196
TMC_POPAFO	Variable	U.S. population	People	TMAC	196
TMC_YD	Variable	Real gross disposable personal income	Dollars per Capita	TMAC	197
TPJFTR	Variable	Price of Jet Fuel.	Dollars per Gallon	TMAC	195
YIELD	Variable	Airline revenue per passenger mile	Dollars per Passenger-Mile	TAIRT	195

AIR TRAVEL MODULE: Aircraft Fleet Efficiency Model					
ITEM	**CLASS.**	**DESCRIPTION**	**UNITS**	**SUBROUTINE**	**EQ #**
AGD	Variable	Demand for aviation gasoline, in gallons	Gallons	TAIREFF	226
AGDBTU	Variable	Aviation gasoline demand, in Btu	Btu	TAIREFF	224
AIRHRS	Input Data (P)	Average number of airborne hours per aircraft, by type.	Hours per Year	TAIREFF	205
ASMDEMD	Variable	Demand for available seat-miles, by aircraft type	Seat Miles	TAIREFF	207
ASMP	Variable	The available seat-miles per plane, by type	Seat Miles	TAIREFF	205
AVSPD	Input Data (P)	Average flight speed, by type.	Miles per Hour	TAIREFF	205
BASEAGD	Parameter	Baseline demand for aviation gasoline	Gallons	TAIREFF	223
BASECONST	Parameter	Baseline constant, used to anchor the technology penetration curve	—	TAIREFF	216
COSTFX	Parameter	Factor reflecting the magnitude of the difference between the price of jet fuel and the trigger price of the considered technology	—	TAIREFF	215
DELTA	Parameter	User-specified rate of passenger shifts between aircraft types	—	TAIREFF	206
EFFIMP	Input Data (P)	Fractional improvement associated with a given technology	Percent	TAIREFF	218
FRACIMP	Variable	Fractional improvement over base year (1990) fuel efficiency, by type	Percent	TAIREFF	218
GAMMA	Parameter (P)	Baseline adjustment factor	—	TAIREFF	223
IFX	Index	Index of technology improvements (1-6)	—	TAIREFF	—
IT	Index	Index of aircraft type: 1 = narrow body, 2 = wide body	—	TAIREFF	—
IVINT	Index	Index of aircraft vintage	—	TAIREFF	—
IYEAR	Index	Current year	—	TAIREFF	—
JFBTU	Variable	Jet fuel demand, in Btu	Btu	TAIREFF	224
JFGAL	Variable	Consumption of jet fuel, in gallons	Gallons	TAIREFF	222
KAPPA	Parameter (P)	Exogenously-specified decay constant	—	TAIREFF	223
NEWSMPG	Variable	Average seat-miles per gallon of new aircraft purchases	SMPG	TAIREFF	219
NPCHSE	Variable	Number of aircraft purchased, by body type.	Aircraft	TAIREFF	209
NSURV	Variable	Number of surviving aircraft, by body type.	Aircraft	TAIREFF	212
QAGR	Variable	Regional demand for aviation gasoline	Btu	TAIREFF	225
QJETR	Variable	Regional demand for jet fuel	Btu	TAIREFF	225
RHO	Parameter (P)	Average historic rate of growth of fuel efficiency	—	TAIREFF	220
SEAT	Input Data (P)	Average number of seats per aircraft, by type.	Seats per Aircraft	TAIREFF	205

AIR TRAVEL MODULE: Aircraft Fleet Efficiency Model					
ITEM	**CLASS.**	**DESCRIPTION**	**UNITS**	**SUBROUTINE**	**EQ #**
SMFRACN	Variable	Fraction of seat-mile demand on narrow-body planes	Percent	TAIREFF	206
SMFRACN	Variable	Fraction of seat miles handled by surviving stock and new purchases, by type.	——	TAIREFF	221
SMPG	Variable	Average seat miles per gallon for new purchases and surviving fleet, by type.	Seat Miles per Gallon	TAIREFF	219
SMPGT	Variable	Overall fleet average seat-miles per gallon	SMPG	TAIREFF	221
SMSURV	Variable	Surviving travel capacity by body type.	Seat Miles	TAIREFF	209
SSURVPCT	Parameter (P)	Marginal survival rate of planes of a given vintage	Percent	TAIREFF	208
STKOLD	Variable	Fraction of planes older than one year, by aircraft type	Percent	TAIREFF	213
SURVK	Parameter (P)	User-specified proportionality constant	—	TAIREFF	208
SURVPCT	Input Data (P)	Survival rate of planes of a given vintage *IVINT*	Percent	TAIREFF	208
T50	Parameter (P)	User-specified vintage at which stock survival is 50%	Years	TAIREFF	208
TIMECONST	Parameter (P)	User-specified scaling constant, reflecting the importance of the passage of time	—	TAIREFF	214
TIMEFX	Parameter (P)	Factor reflecting the length of time an aircraft technology improvement has been commercially viable	—	TAIREFF	214
TOTALFX	Parameter (P)	Overall effect of fuel price and time on implementation of technology *IFX*	—	TAIREFF	216
TPJFGAL	Variable	Price of jet fuel	$ per Gallon	TAIREFF	215
TPN	Variable	Binary variable (0,1) which tests whether current fuel price exceeds the considered techology's trigger price	—	TAIREFF	214
TPZ	Variable	Binary variable which tests whether implementation of the considered technology is dependent on fuel price	—	TAIREFF	215
TRIGPRICE	Parameter (P)	Price of jet fuel above which the considered technology is assumed to be commercially viable	$ per Gallon	TAIREFF	215
TYRN	Variable	Binary variable which tests whether current year exceeds the considered technology's year of introduction	—	TAIREFF	215
XAIR	Variable	Fractional change in air travel from base year	Percent	TAIREFF	226
XAIREFF	Variable	Fractional change in aircraft fuel efficiency from base year	Percent	TAIREFF	226

FREIGHT TRANSPORT MODULE					
ITEM	**CLASS.**	**DESCRIPTION**	**UNITS**	**SUBROUTINE**	**EQ #**
FAC	Input Data (Q)	Freight Adjustment Coefficient—relates growth in value added in industry I to growth in freight transportation	—	TFREI	162
FBENCH	Parameter (I)	Benchmarking factor to ensure congruence with 1990 data	—	TFREI	168
FERAIL	Input Data (B)	Rail fuel efficiency	Miles per gallon	TRAIL	182
FESHIP	Input Data (B)	Domestic freighter fuel efficiency		TSHIP	188
FFD	Variable	Truck Fuel Demand, by type of fuel and class of vehicle.	MMBtu	TFREI	176
FFDT	Variable	Total fuel demand, by technology, in MMBtu	Gallons	TFREI	178
FFMPG	Variable	Average truck fuel economy for second size class for use in TMISC	MPG	TFREI	177
FFVMT	Variable	Total freight truck vehicle-miles traveled in industry group *IX*	Vehicle-miles	TFREI	165
FLVMTSHR	Variable	Share of fuel technology in total truck VMT	Percent	TFREI	169
FMPG	Variable	Truck Fuel Efficiency, by class of truck.	Miles per Gallon	TFREI	174
FRLOAD	Parameter (Q)	Load factor associated with a given industry's output	—	TFREI	163
FSHR	Variable	Adjusted technology share of VMT demand	Percent	TFREI	169
FTMT	Variable	Total highway freight traffic, by industry	Ton Miles	TFREI	162
FTOTVMT	Variable	Total VMT demand for trucks	Vehicle miles	TFREI	166
FVMT	Variable	Freight transport demand by class of truck.	Vehicle Miles	TFREI	163
FVMTECHSC	Variable	Total highway freight VMT, by size class and fuel technology	Vehicle Miles	TFREI	172
FVMTSC	Variable	Total highway freight VMT, by size class	Vehicle Miles	TFREI	168
GROSST	Variable	Value of gross trade (imports + exports)	$	TSHIP	191
GROWTH	Parameter	Factor which specifies changes in truck VMT by each fuel technology over time	—	TFREI	169
IF	Index	Index of fuel type	—	TRAIL	—
IS	Index	Index of truck size class (1-3)	—	TFREI	—
ISFD	Variable	International freighter energy demand, by fuel	MMBtu	TSHIP	192
ISFDT	Variable	Total international shipping energy demand	MMBtu	TSHIP	191
ISFSHARE	Parameter (B)	International shipping fuel allocation factor	—	TSHIP	192
IX	Index	Place holder for industry group	—	TFREI	—
OUTPUT	Variable	Value of output of each industry in base year dollars.	Dollars	TFREI	162

FREIGHT TRANSPORT MODULE					
ITEM	**CLASS.**	**DESCRIPTION**	**UNITS**	**SUBROUTINE**	**EQ #**
QBTU	Input Data (I)	Heat content of fuel used by each technology	MMBtu per gallon	TFREI	176
RTMT	Variable	Total rail freight traffic, by industry	Ton Miles	TRAIL	180
RTMTT	Variable	Total rail ton-miles traveled	Ton Miles	TRAIL	181
SEDSHR	Parameter (K)	Regional shares of shipping fuel demand	Percent	TFREI	179
SFD	Variable	Domestic freighter energy demand, by fuel	MMBtu	TSHIP	189
SFDBENCH	Parameter (I)	Benchmark factor to ensure congruence with 1990 data	—	TSHIP	188
SFDT	Variable	Domestic freighter energy demand	MMBtu	TSHIP	188
SFSHARE	Parameter (B)	Domestic shipping fuel allocation factor	—	TSHIP	189
STMT	Variable	Total waterborne freight traffic, by industry	Ton Miles	TSHIP	186
STMTT	Variable	Total ship ton-miles traveled	Ton Miles	TSHIP	187
SUMFVMT	Variable	Total freight VMT for the second size class for use in TMISC	Vehicle Miles	TFREI	173
TBETA1	Parameter	Base rate of fuel economy growth, by size class	Percent	TFREI	174
TBETA2	Parameter	Fuel-price sensitive rate of fuel economy growth, by size class	Percent	TFREI	174
TECH	Index	Index of engine technology (1-5)	—	TFREI	—
TMC_YD	Variable	Disposable personal income, from the MACRO module	$	TFREI	165
TPMGTR	Variable	Price of motor gasoline used for highway transport	$ per Gallon	TFREI	174
TQFREIR	Variable	Total regional truck fuel consumption for each technology	MMBtu	TFREI	179
TQFREIRSC	Variable	Total regional freight energy demand by technology and size class	MMBtu	TFREI	179
TQISHIPR	Variable	Total regional energy demand by international freighters	MMBtu	TSHIP	193
TQRAIL	Variable	Total demand for each fuel by rail freight sector in year *T*	MMBtu	TRAIL	183
TQRAILR	Variable	Total regional rail fuel consumption for each technology	MMBtu	TRAIL	184
TQRAILT	Variable	Total energy consumption by freight trains in year *T*	MMBtu	TRAIL	182
TQSHIPR	Variable	Total regional energy demand by domestic freighters, by fuel type	MMBtu	TSHIP	190
TRSCSHR	Input Data (B)	Travel share distribution factors, held constant	—	TFREI	168
TSIC	Variable	Value of output of industry *I*, in base year (1990) dollars	$	TFREI	162

FREIGHT TRANSPORT MODULE					
ITEM	**CLASS.**	**DESCRIPTION**	**UNITS**	**SUBROUTINE**	**EQ #**
TSIC90	Input Data (I)	Base year value of industrial output	$	TFREI	165
TYD8290	Input Data (I)	Base year disposable personal income	$	TFREI	165
XFREFF	Variable	Fuel economy improvement over base year	Percent	TFREI	175
XRAIL	Variable	Growth in rail travel from base year	Percent	TRAIL	185
XRAILEFF	Variable	Growth in rail efficiency from base year	Percent	TRAIL	185
XSHIP	Variable	Growth in ship travel from base year	Percent	TSHIP	194
XSHIPEFF	Variable	Growth in ship efficiency from base year	Percent	TSHIP	194
XTOTVMT	Variable	Fractional growth in freight VMT over base year	Percent	TFREI	167

MISCELLANEOUS ENERGY DEMAND MODULE					
ITEM	CLASS.	DESCRIPTION	UNITS	SUBROUTINE	EQ #
BETALUB	Parameter (K)	Coefficient of proportionality, relating highway travel to lubricant demand	—	TMISC	238
BETAMS	Parameter (B)	Coefficient of proportionality, relating mass transit to LDV travel	—	TMISC	230
BETAREC	Parameter (B)	Coefficient of proportionality relating income to fuel demand for boats	—	TMISC	234
FLTVMT	Variable	Total fleet vehicle VMT, from the Fleet Module	Vehicle Miles	TFLTVMTS	237
FMPG	Variable	Fuel efficiency for mass transit vehicles, by vehicle type, from the Freight Module	Miles per gallon	TFREI	231
FMPG89	Data Input (B)	Base-year fuel efficiency for mass transit vehicles, by vehicle type, from the Freight Module	Miles per gallon	TEXOG	231
FTVMT	Variable	Total freight truck VMT, from the Freight Module	Vehicle Miles	TMISC	236
FVMTSC	Variable	Freight truck VMT, by size class		TMISC	236
HYWAY	Variable	Total highway VMT	Vehicle Miles	TMISC	237
IF	Index	Index of fuel type: 1=Distillate, 2=Naphtha, 3=Residual, 4=Kerosene	—	TMISC	—
IM	Index	Index of transportation mode: 1 = LDV's, 2-4 = Buses, 5-7 = Rail	—	TMISC	—
IM	Index	Index of transportation mode: 1 = LDV's, 2-4 = Buses, 5-7 = Rail		TMISC	—
LUBFD	Variable	Total demand for lubricants in year T	MMBtu	TMISC	238
MFD	Variable	Total military consumption of each fuel in year T	MMBtu	TMISC	228
MILTARGR	Variable	The growth in the military budget from the previous year	Percent	TMISC	227
MILTRSHR	Input Data (L)	Regional consumption shares, from 1991 data, held constant	Percent	TMISC	229
QLUBR	Variable	Regional demand for lubricants in year T	MMBtu	TMISC	239
QMILTR	Variable	Regional military fuel consumption, by fuel type	MMBtu	TMISC	229
QMODR	Variable	Regional consumption of fuel, by mode	MMBtu	TMISC	233
QRECR	Variable	Regional fuel consumption by recreational boats in year T	MMBtu	TMISC	235
RECFD	Variable	National recreational boat gasoline consumption in year T	MMBtu	TMISC	234
TMC_GFML87	Variable	Total defense budget in year T, from the macro economic segment of NEMS	$	TMAC	227
TMC_POPAFO	Variable	Regional population forecasts, from the Macro Module	People	TMAC	233
TMC_YD	Variable	Total disposable personal income, from the Macro Module	$	TMAC	234
TMEFF89	Input Data (B)	Base-year Btu per vehicle-mile, by mass transit mode	Btu per vehicle mile	TMISC	231

MISCELLANEOUS ENERGY DEMAND MODULE					
ITEM	**CLASS.**	**DESCRIPTION**	**UNITS**	**SUBROUTINE**	**EQ #**
TMEFFL	Variable	Btu per passenger-mile, by mass transit mode	Btu per passenger mile	TMISC	231
TMFD	Variable	Total mass-transit fuel consumption by mode	Gallons	TMISC	232
TMOD	Variable	Passenger-miles traveled, by mode	Passenger miles	TMISC	230
TMLOAD89	Data Input (B)	Average passengers per vehicle, by mode, held constant at 1989 values (1=LDV's)	Units	TMISC	230
TYPE	Index	Vehicle type, from the Freight Module: 1 = Mid-size trucks, 2 = Rail	—	TFREI	231
VMTEE	Variable	LDV vehicle-miles traveled, from the VMT module	Vehicle miles	TVMT	230

TRANSPORTATION EMISSIONS MODULE					
ITEM	**CLASS.**	**DESCRIPTION**	**UNITS**	**SUBROUTINE**	**EQ #**
EFACT	Parameter (M)	Emissions factor relating measures of travel to pollutant emissions	—	TEMISS	240
EMISS	Variable	Regional emissions of a given pollutant, by mode of travel	Tons per year	TEMISS	240
IE	Index	Index of pollutants: 1 = SO_x, 2 = NO_x, 3 = C, 4 = CO_2, 5 = CO, 6 = VOC	—	TEMISS	240
IM	Index	Index of travel mode: references individual vehicle types used in the preceding modules	—	TEMISS	240
IR	Index	Index identifying census region	—	TEMISS	240
U	Variable	Measure of travel demand, by mode: units in VMT for highway travel, gallons of fuel consumption for other modes	—	TEMISS	240

SOURCES OF DATA INPUTS AND PARAMETERS USED IN THE NEMS TRANSPORTATION MODEL

CODE	SOURCE
A	*Conventional Light-Duty Vehicle Fuel Economy*, Decision Analysis Corporation of Virginia and Energy and Environmental Analysis, Inc., Prepared For: Energy Information Administration, U.S. Department of Energy, Washington D.C., November, 1992.
B	*Transportation Energy Data Book: Edition 12*, Oak Ridge National Laboratory, Prepared For: Office of Transportation Technologies, U.S. Department of Energy, Washington, D.C., March 1992.
C	*Revised VMT Forecasting Model*, Unpublished Memorandum, U.S. Department of Energy, February 22, 1993.
D	*1990 National Personal Transportation Survey*, Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., March 1992.
E	*Alternative-Fuel Vehicle Module*, Decision Analysis Corporation of Virginia, Prepared For: Energy Information Administration, U.S. Department of Energy, Washington, D.C., September 1992.
F	*Demand for Clean-Fuel Personal Vehicles in California: A Discrete-Choice Stated Preference Survey*, D. S. Bunch, *et. al.*, University of California, Davis, UCD-ITS-RR-91-14, December 1991.
G	*Fleet Vehicles in the United States*, Oak Ridge National Laboratories, Prepared For: Office of Transportation Technologies and Office of Policy, Planning and Analysis, U.S. Department of Energy, Washington, D.C., March 1992.
H	*Assessment of Costs and Benefits of Flexible and Alternative Fuel Use in the U.S. Transportation Sector; Technical Report Ten: Analysis of Alternative-Fuel Fleet Requirements*, Office of Domestic and International Energy Policy, U.S. Department of Energy, May 1992.
I	*Annual Energy Outlook 1993*, Energy Information Administration, Office of Integrated Analysis and Forecasting, U.S. Department of Energy, Washington, D.C., January 1993.
J	*Proposed Regulations for Low-Emission Vehicles and Clean Fuels*, State of California Air Resources Board, August 13, 1990.
K	*State Energy Data Survey 1991*, Energy Information Administration, Office of Energy Markets and End Use, U.S. Department of Energy, Washington, D.C., May 1993.
L	*Fuel Oil and Kerosene Sales 1991*, Energy Information Administration, Office of Oil and Gas, U.S. Department of Energy, Washington D.C., November 1992.
M	*Emissions Regulations, Inventories, and Emission Factor for the NEMS Transportation Energy and Research Forecasting Model*, Decision Analysis Corporation of Virginia, Prepared For: Energy Information Administration, U.S. Department of Energy, Washington, D.C., September 1992.
N	*Fuel Efficiency Degradation Factor*, Decision Analysis Corporation of Virginia, Prepared For: Energy Information Administration, U.S. Department of Energy, Washington, D.C., August 1992.
O	*Proposed Methodology for Projecting Air Transportation Demand*, Decision Analysis Corporation of Virginia, Prepared For: Energy Information Administration, U.S. Department of Energy, Washington, D.C., July 1992.
P	*Preliminary Estimation of the NEMS Aircraft Fleet Efficiency Module*, Decision Analysis Corporation of Virginia, Prepared For: Energy Information Administration, U.S. Department of Energy, Washington, D.C., September 1992.
Q	*Freight Transportation Requirements Analysis for the NEMS Transportation Sector Model*, Decision Analysis Corporation of Virginia, Prepared For: Energy Information Administration, U.S. Department of Energy, Washington, D.C., August 1992.

Table A-2. Light Duty Vehicle Market Classes

CLASS	DEFINITION	EXAMPLE MODEL
AUTOMOBILES (Domestic and Import)		
Minicompact	Interior passenger volume < 79 ft^3	Geo Metro, Toyota Paseo (no domestic cars)
Subcompact	Passenger volume between 79 ft^3 and 89 ft^3	Nissan Sentra, Honda Civic, GM Saturn, Ford Escort
Sports	Two door high performance cars costing less than $25,000	VW Corrado, Honda Prelude, Chevy Camaro, Ford Mustang
Compact	Passenger volume between 89 and 95 ft^3	Honda Accord, Toyota Camry, Ford Tempo, Pontiac Grand Am
Intermediate	Passenger volume between 96 and 105 ft^3	Nissan Maxima, Ford Taurus, Chevy Lumina
Large	Passenger volume >105 ft^3	Ford Crown Victoria, Pontiac Bonneville (no imports)
Luxury	Cars over $25,000	Lincoln Continental, Cadillac, all Mercedes, Lexus LS400
LIGHT TRUCKS (Domestic and Import)		
Compact Pickup	Trucks with inertia weight between 2750 and 4000 lbs.	All import trucks, Ford Ranger, GM S-10/15
Compact Van	Vans with inertia weight between 3000 and 4250 lbs.	All import vans, Plymouth, Voyager, Ford Aerostar
Compact Utility	Utility vehicles with inertia weight between 3000 and 4250 lbs.	Nissan Pathfinder, Toyota SR-5, Ford Bronco II, Jeep Cherokee
Standard Pickup	Trucks with inertia weight over 4000 lbs.	GM C-10, Ford F-150 (no imports)
Standard Van	Vans with inertia weight over 4250 lbs.	GM C15 van, Ford E-150 (no imports)
Standard Utility	Utility vehicles with inertia weight over 4250 lbs.	Toyota Land Cruiser, GM Suburban, Ford Blazer
Mini-truck	Utility/trucks below 2750 lbs. inertia weight	Suzuki Samurai (no domestics)

Table A-3. Maximum Light Duty Vehicle Market Penetration Parameters

Old Market Share	New PMAX (Automobiles)	New PMAX (Light Trucks)
≤ 1%	1%	1%
1.1-2%	2%	2%
2.1-3%	5%	5%
3.1-6%	12%	10%
6.1-10%	28%	22%
10.1-12%	32%	26%
12.1-14%	36%	30%
14.1-17%	41%	35%
17.1-20%	47%	40%
20.1-24%	53%	47%
24.1-27%	56%	50%
27.1-31%	60%	54%
31.1-35%	64%	58%
35.1-40%	68%	62%
40.1-45%	73%	67%
45.1-53%	78%	73%
53.1-62%	83%	79%
62.1-73%	88%	85%
73.1-85%	94%	92%
85.1-100%	100%	100%

Table A-4. Aircraft Fleet Efficiency Model Adjustment Factors

Year	DI	PCTINT	DFRT
1979	0.974	0.27	0.509
1980	0.976	0.32	0.523
1981	0.978	0.30	0.514
1982	0.980	0.28	0.509
1983	0.982	0.27	0.508
1984	0.985	0.28	0.522
1985	0.988	0.28	0.518
1986	0.991	0.25	0.520
1987	0.994	0.28	0.540
1988	0.996	0.30	0.545
1989	0.998	0.33	0.551
1990	1.000	0.35	0.555
1991	1.003	0.38	0.564
1992	1.004	0.40	0.569
1993	1.005	0.41	0.573
1994	1.007	0.42	0.577
1995	1.008	0.43	0.579
1996	1.007	0.44	0.584
1997	1.007	0.45	0.585
1998	1.006	0.46	0.591
1999	1.006	0.46	0.593
2000	1.005	0.47	0.598
2001	1.003	0.47	0.601
2002	1.001	0.48	0.604
2003	0.998	0.48	0.604
2004	0.996	0.48	0.604
2005	0.994	0.48	0.604
2006	0.992	0.49	0.604
2007	0.989	0.49	0.604
2008	0.987	0.49	0.604
2009	0.985	0.49	0.604
2010	0.983	0.49	0.604
2011	0.980	0.49	0.604
2012	0.978	0.49	0.604
2013	0.975	0.50	0.604
2014	0.972	0.50	0.604
2015	0.970	0.50	0.604
2016	0.967	0.50	0.604
2017	0.965	0.50	0.604
2018	0.962	0.50	0.604
2019	0.960	0.50	0.604
2020	0.957	0.50	0.604
2021	0.956	0.50	0.604
2022	0.954	0.50	0.604
2023	0.952	0.50	0.604
2024	0.951	0.50	0.604
2025	0.949	0.50	0.604
2026	0.948	0.50	0.604
2027	0.946	0.50	0.604
2028	0.944	0.50	0.604
2029	0.943	0.50	0.604
2030	0.941	0.50	0.604

Table A-5. List of Expected Aircraft Technology Improvements

Proposed Technology	Intro. Year	Jet Fuel Price[1] ('87 $/Gal)	SMPG Gain Over 1990's	
			Narrow Body	Wide Body
ENGINES:				
Ultra-high Bypass	1995	$0.69	10%	10%
Propfan	2000	$1.36	23%	0%
AERODYNAMICS:				
Hybrid Laminar Flow	2020	$1.53	15%	15%
Advanced Aerodynamics	2000	$1.70	18%	18%
OTHER:				
Weight Reducing Materials	2000	—	15%	15%
Thermodynamics	2010	$1.22	20%	20%

[1] These figures represent the minimum jet fuel prices (1987 $) at which the corresponding technologies are assumed to become cost-effective.

Appendix B. Mathematical Representation

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Introduction

This appendix provides a detailed mathematical description of the transportation model. Equations are presented in the order in which they are encountered in the code, identified by subroutine and model component. The equations follow the logic of the FORTRAN source code very closely to facilitate an understanding of the code and its structure. In several instances, a variable name will appear on both sides of an equation. This is a FORTRAN programming device that allows a previous calculation to be updated (for example, multiplied by a factor) and re-stored under the same variable name.

In the interest of clarity, initialization statements, variable name reassignments, and error-trapping tests are omitted, except where such descriptions are essential to an understanding of the process. Representative equations are also employed in those instances where the model specifies numerous, but essentially identical, calculations (most notably in the emissions component).

FUEL ECONOMY MODEL Subroutine FEMCALC

1) Calculate the fuel cost slope, used to linearly extrapolate expected fuel cost over the desired payback period:

$$PSLOPE = \frac{MAX\ (0, FUELCOST_{YEAR-3} - FUELCOST_{YEAR-5})}{2} \tag{B-1}$$

where:

PSLOPE = The fuel cost slope
FUELCOST = The cost of fuel in the specified prior years

2) Calculate the expected fuel price in year i (where i goes from 1 to PAYBACK):

$$PRICE\$EX_i = PSLOPE*(i+2) + FUELCOST_{YEAR-3} \tag{B-2}$$

where:

$PRICE\$EX_i$ = The expected price of fuel

3) Calculate the expected present value of fuel savings over the payback period:

$$FUELSAVE_{itc} = \sum_{i=1}^{PAYBACK} VMT_i * \left(\frac{1}{FE_{itc,YEAR-1}} - \frac{1}{(1 + DEL\$FE_{itc} * FE_{itc,YEAR-1})} \right) * PRICE\$EX_i * (1 + DISCOUNT)^{-i} \tag{B-3}$$

where:

itc = The index representing the technology under consideration
FE = The fuel economy of technology *itc*
DEL$FE = The fractional change in fuel economy associated with technology *itc*
PAYBACK = The user-specified payback period
DISCOUNT = The user-specified discount rate

4) Calculate the cost of technology *itc*:

$$TECHCOST_{itc} = DEL\$COSTABS_{itc} - \big(DEL\$COSTWGT_{itc} * DEL\$WGTWGT_{itc} * WEIGHT_{BASEYR}\big) \quad \textbf{(B-4)}$$

where:

DEL$COSTABS = The fixed dollar cost of technology *itc*
DEL$COSTWGT = The weight-based change in cost ($/lb)
DEL$WGTWGT = The fractional change in weight associated with technology *itc*
WEIGHT = The original vehicle weight

5) Calculate the perceived value of performance associated with technology *itc*:

$$VAL\$PERF_{itc} = VALUEPERF_{itc} * \frac{INCOME_{YEAR}}{INCOME_{YEAR-1}} * \frac{FE_{YEAR-1} * (1 + DEL\$FE_{itc})}{FE_{YEAR-1}} * \frac{FUELCOST_{YEAR-1}}{PRICE\$EX_{1}} * DEL\$HP_{itc} \quad \textbf{(B-5)}$$

where:

VAL$PERF = The dollar value of performance of technology *itc*
VALUEPERF = The value associated with an incremental change in performance
DEL$HP = The fractional change in horsepower of technology *itc*
PRICE$EX = The expected price of fuel
FUELCOST = The actual price of fuel (in the previous year)

6) Calculate the cost effectiveness of technology *itc*:

$$COSTEFFECT_{itc} = \frac{FUELSAVE_{itc} - TECHCOST_{itc} + VAL\$PERF_{itc} + \big(REGCOST * FE_{YEAR-1} * DEL\$FE_{itc}\big)}{ABS\big(TECHCOST_{itc}\big)} \quad \textbf{(B-6)}$$

where:

COSTEFFECT = A unitless measure of cost effectiveness
REGCOST = A factor representing regulatory pressure to increase fuel economy
TECHCOST = The cost of the considered technology
VAL$PERF = The performance value associated with technology *itc*

7) Calculate the preliminary economic market share of technology *itc*:

$$ACTUAL\$MKT_{itc} = MMAX_{itc} * PMAX_{itc} * \left(1 + e^{-2 \, * \, COSTEFFECT_{itc}}\right)^{-1} \qquad \textbf{(B-7)}$$

where:

ACTUAL\$MKT = The economic share, prior to consideration of engineering or regulatory constraints. The subsequent adjusted value is stored in the variable MKT\$PEN.

MMAX = The maximum market share for technology *itc*, obtained from MKT\$MAX

PMAX = The institutional maximum market share, which models tooling constraints on the part of the manufacturers, and is set in the subroutine FUNCMAX.

8) Ensure that existing technologies maintain market share in the absence of competing technologies:

$$ACTUAL\$MKT_{itc} = MAX\,(\,MKT\$PEN_{YEAR-1}\,,\ ACTUAL\$MKT_{itc}\,) \qquad \textbf{(B-8)}$$

where:

$MKT\$PEN_{Year-1}$ = The previous year's market share of technology *itc*

9) Apply mandatory constraints:

$$ACTUAL\$MKT_{itc} = MAX\left(ACTUAL\$MKT_{itc}\,,\ MANDMKSH_{itc}\right) \qquad \textbf{(B-9)}$$

where:

MANDMKSH = The minimum market share of technology *itc* required by legislative mandate.

10) Apply required engineering constraints (following a call to the subsequent subroutine NOTE\$SUPER):

a) Sum the market shares of the required technologies (*req*):

$$REQ\$MKT = MIN\left(\sum_{req} ACTUAL\$MKT_{req}\,,\ 1.0\right) \qquad \textbf{(B-10)}$$

where:

REQ\$MKT = The total market share of those technologies which are required for the implementation of technology *itc*, indicating that technology's maximum share

b) Compare REQ$MKT to the market share of technology referred to by the engineering note, $ACTUAL\$MKT_{itc}$, selecting the smaller share:

$$ACTUAL\$MKT_{itc} = MIN\left(ACTUAL\$MKT_{itc}\ ,\ REQ\$MKT\right) \qquad \textbf{(B-11)}$$

11) Assign the preliminary market share value to the permanent variable:

$$MKT\$PEN_{icl,igp,itc,year} = ACTUAL\$MKT_{itc} \qquad \textbf{(B-12)}$$

where:

MKT$PEN = The market penetration of technology *itc* by vehicle group *igp* and vechilce class *icl*

12) Apply synergistic engineering constraints to those technologies whose combination provide non-additive benifits to fuel economy:

$$\begin{aligned} FE_{YEAR} = FE_{YEAR} &+ \left(MKT\$PEN_{itc1,YEAR} - MKT\$PEN_{itc1,YEAR-1}\right) \\ &* \left(MKT\$PEN_{itc2,YEAR} - MKT\$PEN_{itc2,YEAR-1}\right) * SYNR\$DEL_{itc1,itc2} \end{aligned} \qquad \textbf{(B-13)}$$

where:

itc1 = First synergistic technology

itc2 = Second synergistic technology

SYNR$DEL = The synergistic effect of the two technologies on fuel economy

13) Calculate the change in market share for a given technology:

$$DELTA\$MKT_{itc} = MKT\$PEN_{itc,YEAR} - MKT\$PEN_{itc,YEAR-1} \qquad \textbf{(B-14)}$$

where:

$DELTA\$MKT_{itc}$ = The change in market share for technology *itc*

14) Calculate current fuel economy for the considered vehicle class:

$$FE_{YEAR} = FE_{YEAR-1} + \sum_{itc=1}^{NUMTECH} FE_{YEAR-1} * DELTA\$MKT_{itc} * DEL\$FE_{itc} \quad \textbf{(B-15)}$$

where:

DEL\$FE*itc* = The fractional change in fuel economy attributed to technology *itc*

15) Calculate average vehicle weight for the considered class:

$$WEIGHT_{YEAR} = WEIGHT_{YEAR-1} + \sum_{itc=1}^{NUMTECH} DELTA\$MKT_{itc} * \Big[DEL\$WGTABS_{itc} + \big(WEIGHT_{BASEYR} * DEL\$WGTWGT_{itc} \big) \Big] \quad \textbf{(B-16)}$$

where:

DEL\$WGTABS = The change in weight (lbs) associated with technology *itc*

DEL\$WGTWGT = The fractional change in vehicle weight due to technology *itc*

$WEIGHT_{BASEYEAR}$ = The base year vehicle weight, absent the considered technology

16) Calculate the average vehicle price for the considered class:

$$PRICE_{YEAR} = PRICE_{YEAR-1} + \sum_{itc=1}^{NUMTECH} DELTA\$MKT_{itc} * \Big[DEL\$COSTABS_{itc} + (WEIGHT_{YEAR} - WEIGHT_{BASEYR}) * DEL\$COSTWGT_{itc} \Big] \quad \textbf{(B-17)}$$

where:

DEL\$COSTABS = The cost of technology *itc*

DEL\$COSTWGT = The weight-based change in cost of technology *itc* (\$/lb)

17) Calculate horsepower, assuming a constant weight to horsepower ratio:

$$HP_{YEAR} = HP_{BASEYR} * \frac{WEIGHT_{YEAR}}{WEIGHT_{BASEYR}} \quad \textbf{(B-18)}$$

where:

$HP_{BASEYEAR}$ = The base year average horseposer for the considered vehicle class

18) Calculate the horsepower adjustment factor:

$$ADJHP = PERFFACT * \left[\left(\frac{INCOME_{YEAR}}{INCOME_{YEAR-1}} \right)^{0.9} * \left(\frac{PRICE_{YEAR-1}}{PRICE_{YEAR}} \right)^{0.9} * \left(\frac{FE_{YEAR}}{FE_{YEAR-1}} \right)^{0.2} * \left(\frac{FUELCOST_{YEAR-1}}{FUELCOST_{YEAR}} \right)^{0.2} - 1 \right] \quad \textbf{(B-19)}$$

where:

ADJHP = The fractional change in horspower from the previous year within a given vehicle class
INCOME = Household income
PRICE = Vehicle price
FE = Vehicle fuel economy
FUELCOST = Fuel price

19) Calculate current year horsepower, summing incremental changes from the initial year:

$$HP_{YEAR} = HP_{YEAR} * \left(1 + \sum_{1990}^{YEAR} ADJHP \right) \quad \textbf{(B-20)}$$

20) Calculate fractional change in fuel economy due to horsepower change:

$$\begin{aligned} ADJFE &= -0.22 * ADJHP - 0.560 * ADJHP^2 \quad ; \quad ADJHP \geq 0 \\ ADJFE &= -0.22 * ADJHP + 0.560 * ADJHP^2 \quad ; \quad ADJHP < 0 \end{aligned} \quad \textbf{(B-21)}$$

where:

ADJFE = The fuel economy adjustment factor

21) Calculate the adjusted fuel economy:

$$FE = FE * (1 + ADJFE) \quad \textbf{(B-22)}$$

22) Calculate the vehicle price, adjusted for the change in performance:

$$PRICE = PRICE + ADJHP * VALUEPERF \quad \textbf{(B-23)}$$

This subroutine is called from subroutine FEMCALC in order to check whether new technologies have superseded older ones. Affected technologies are grouped in a hierarchy, and market shares are adjusted so that the sum does not exceed the maximum market penetration of the group.

1) Calculate aggregate market share of superseding technologies:

$$TOT\$MKT = \sum_{ino=1}^{num\$sup} ACTUAL\$MKT_{ino} \qquad \textbf{(B-24)}$$

where:

TOT$MKT = The total market share of the considered group of technologies

ino = The index identifying the technologies in the superseding group

num$sup = The number of technologies in the superseding group

2) Establish the maximum market share for the group:

$$MAX\$SHARE = MAX\ (MKT\$MAX_{ino}) \qquad \textbf{(B-25)}$$

--where:

MKT$MAX = The maximum market share for the considered technology, exogenously set

MAX$SHARE = The maximum market share of the group, *ino*

3) If the aggregate market share (TOT$MKT) is greater than the maximum share (MAX$SHARE), reduce the market shares of those technologies which are lower in the hierarchy:

a) Calculate the reduction in market share of a superseded technology, ensuring that the decrement does not exceed that technology's total share:

$$DEL\$MKT = MIN\Big((TOT\$MKT - MAX\$SHARE)\ ,\ ACTUAL\$MKT_{isno} \Big) \qquad \textbf{(B-26)}$$

where:

DEL$MKT = The amount of the superseded technology's market share to be removed

isno = An index indicating the superseded technology

b) Adjust total market share to reflect this decrement

$$TOT\$MKT = TOT\$MKT - DEL\$MKT \quad \textbf{(B-27)}$$

c) Adjust the market share of the superseded technology to reflect the decrement

$$ACTUAL\$MKT_{isno} = ACTUAL\$MKT_{isno} - DEL\$MKT \quad \textbf{(B-28)}$$

These values are returned to the preceding subroutine.

FUEL ECONOMY MODEL Subroutine CMKSCALC

1) Calculate incremental change in class market share ratio:

a) For all vehicles except luxury cars:

$$DIFF\$LN = A * \ln\left(\frac{YEAR}{1990}\right) + B * \ln\left(\frac{FUELCOST_{YEAR}}{FUELCOST_{1990}}\right) + C * \ln\left(\frac{INCOME_{YEAR} - \$13{,}000}{INCOME_{1990} - \$13{,}000}\right) \quad \textbf{(B-29)}$$

where:

DIFF$LN = The increment from the base year (1990) of the log of the market share ratio

b) For luxury cars:

$$DIFF\$LN = A * \ln\left(\frac{YEAR}{1990}\right) + B * \ln\left(\frac{FUELCOST_{YEAR}}{FUELCOST_{1990}}\right) + C * \ln\left(\frac{INCOME_{YEAR}}{INCOME_{1990}}\right) \quad \textbf{(B-30)}$$

2) Solve for the log-share ratio:

$$RATIO\$LN = DIFF\$LN + \ln\left(\frac{CLASS\$SHARE_{1990}}{1 - CLASS\$SHARE_{1990}}\right) \quad \textbf{(B-31)}$$

where:

RATIO$LN = Log of the market share ratio of the considered vehicle class

3) Solve for the class market share:

$$CMKS = \frac{EXP\ (RATIO\$LN)}{1 + EXP\ (RATIO\$LN)} \tag{B-32}$$

where:

CMKS = Class market share, subsequently reassigned to the appropriate vehicle class and group, $CLASS\$SHARE_{icl,igp}$

4) Normalize so that shares total 100% within each CAFE group:

$$CLASS\$SHARE_{icl,igp,YEAR} = \frac{CLASS\$SHARE_{icl,igp,YEAR}}{\sum_{icl=1}^{7} CLASS\$SHARE_{icl,igp,YEAR}} \tag{B-33}$$

FUEL ECONOMY MODEL Subroutine CAFECALC

1) Calculate the Corporate Average Fuel Economy for each of the four CAFE groups:

$$CAFE_{icl,igp,YEAR} = \frac{\sum_{icl=1}^{7} CLASS\$SHARE_{icl,igp,YEAR}}{\sum_{icl=1}^{7} \frac{CLASS\$SHARE_{icl,igp,YEAR}}{FE_{icl,igp,YEAR}}} \tag{B-34}$$

where:

icl = FEM vehicle size class index (7)

igp = CAFE group index: 1 = domestic car, 2 = import car, 3 = domestic light truck, 4 = import light truck

This subroutine maps vehicle sales and fuel economy generated for the seven size classes considered in the Fuel Economy Model (FEM) into the six vehicle size classes used in subsequent sectors.

1) Determine the number of Light Truck sales which are classified as LDT's:

$$T\_LDT\_MAC_N = MC\_SQDTRUCKS_N * LT10K * \left[(LT2A4 * LT2A4LDV) + (LTOSU * LTOSULDV) \right] \quad (35)$$

where:

T_LDT_MAC = Total LDT's (under 8,500 pounds), as estimated by the Macro Module
MC_SQDTRUCKS = Total Light Truck sales (under 14,000 pounds), from Macro
LT10K = Fraction of these trucks under 10,000 pounds
LT2A4 = Fraction of light trucks with a 2-axle, 4-tire configuration
LT2A4LDV = Fraction of these trucks less than 8,500 pounds
LTOSU = Fraction of light trucks with other axle configurations
LTOSULDV = Fraction of these trucks less than 8,500 pounds

2) Calculate total LDV sales:

$$T\_LDV\_MAC_N = MC\_SQTRCARS_N + T\_LDT\_MAC_N \quad (36)$$

where:

T_LDV_MAC = Total car and adjusted light truck sales
MC-SQTRCARS = Total car sales, from the Macro Module

3) Allocate LDV sales between cars and light trucks:

$$TMC\_SQTRCARS_N = T\_LDV\_MAC_N * (1 - CARLTSHR)$$
$$and$$
$$TMC\_SQDTRUCKS_N = T\_LDV\_MAC_N * CARLTSHR \quad (37)$$

where:

TMC_SQTRCARS = Total sales of new cars
TMC_SQDTRUCKS = Total sales of new light trucks

CARLTSHR = Allocation factor representing LDT fraction of LDV sales (Appendix F, Attachment 8)

4) Map vehicle sales from seven size classes to six:

$$MAPSALE_{igp,icl,osc,N} = NVS7SC_{igp,icl,N} * MAP_{igp,icl,osc} \quad \text{(B-38)}$$

where:

MAPSALE = Disaggregate vehicle sales
NVS7SC = New vehicle sales within the seven FEM size classes, calculated in subroutine TSIZE
MAP = Array of mapping constants, which converts FEM to ORNL size classes
osc = ORNL size class index (6)
N = Time period index (1990 = 1)

5) Sum across sales within each size class:

$$TOTNVS7 = \sum_{icl=1}^{7} MAPSALE_{igp,icl,osc,N} \quad \text{(B-39)}$$

where:

TOTNVS7 = Total new vehicle sales within the six ORNL size classes

6) Create a mapping share:

$$MAPSHR_{igp,icl,osc,N} = \frac{MAPSALE_{igp,icl,osc,N}}{TOTNVS7_{igp,osc,N}} \quad \text{(B-40)}$$

where:

MAPSHR = Sales shares within the disaggregate array

7) Multiply MPG by mapped sales share:

$$FEMPG_{igp,osc,N} = \sum_{icl=1}^{7} FE_{icl,igp,YEAR} * MAPSHR_{igp,icl,osc,N} \quad \text{(B-41)}$$

where:

FEMPG = Average fuel economy by six ORNL size classes

FE = Average fuel economy by seven FEM size classes
$YEAR$ = Year index ($YEAR = N+1$)

8) Create benchmark factors for each CAFE group *igp*, held constant after 1992:

$$BENCHMPG_{igp,osc} = \frac{ORNLMPG_{igp,osc}}{FEMPG_{igp,osc,N=3}} \quad \textbf{(B-42)}$$

where:

BENCHMPG = MPG benchmark factors to ensure congruence with most recent data from ORNL
ORNLMPG = Most recent (1992) fuel economy data from ORNL

9) Apply the benchmark factor to each size class, combining domestic and imported vehicles:

$$FESIXC_{osc,N} = \sum_{igp=1}^{2} FEMPG_{igp,osc,N} * BENCHMPG_{igp,osc} * ORNLSHR_{igp,osc}$$
$$FESIXT_{osc,N} = \sum_{igm=3}^{4} FEMPG_{igp,osc,N} * BENCHMPG_{igp,osc,} * ORNLSHR_{igp,osc} \quad \textbf{(B-43)}$$

where:

FESIXC = Fuel economy for cars within six size classes
FESIXT = Fuel economy for light trucks within six size classes

REGIONAL SALES MODEL — Subroutine TSIZE

1) Estimate non-fleet, non-commercial sales of cars and light-trucks within each of the seven size classes considered by FEM (subsequently passed to subroutine FEMSIZE):

a) For cars, *igp* = 1,2:

$$NVS7SC_{igp,icl,N} = CLASS\$SHARE_{icl,igp,YEAR} * TMC\_SQTRCARS_N * \left(1 - FLTCRAT_{1990}\right) * SALESHR_{igp,N} \quad \textbf{(B-44)}$$

where:

NVS7SC = New vehicle sales in the original seven FEM size classes, by CAFE group *igp*
TMC_SQTRCARS = Total new car sales (supplied by the MACRO module)
CLASS$SHARE = The market share for each automobile class, from FEM
FLTCRAT = Fraction of new cars purchased by fleets
SALESHR = Fraction of vehicle sales which are domestic/imported

b) For light trucks, *igp* = 3,4:

$$NVS7SC_{igp,icl,N} = CLASS\$SHARE_{icl,igp,YEAR} * TMC\_SQDTRUCKS_{N} * \left(1 - (FLTTRAT_{1990} + COMTSHR)\right) * SALESHR_{igp,N} \quad \textbf{(B-45)}$$

where:

TMC_SQDTRUCKS = Total new light truck sales (from the MACRO module)
FLTTRAT = Fraction of new light trucks purchased by fleets
COMTSHR = Fraction of new light trucks dedicated to commercial freight

2) Redistribute car and truck sales among six size classes, combining import and domestic:

a) For cars:

$$NCSTSCC_{osc,N} = \sum_{igp=1}^{2} \sum_{icl=1}^{7} \left(NVS7SC_{igp,icl,N}\right) * MAP_{igp,icl,osc} \quad \textbf{(B-46)}$$

where:

NCSTSCC = Total new car sales by size class *osc*
MAP = Array of constants which map sales from seven to six size classes

b) For light trucks:

$$NLTSTSCC_{osc,N} = \sum_{igp=3}^{4} \sum_{icl=1}^{7} \left(NVS7SC_{igp,icl,N}\right) * MAP_{igp,icl,osc} \quad \textbf{(B-47)}$$

where:

NLTSTSCC = Total new light truck sales by size class *osc*

3) Calculate the market shares of cars and light trucks by size class:

$$PASSHRR_{osc,N} = \frac{NCSTSCC_{osc,N}}{\sum_{osc=1}^{6} NCSTSCC_{osc,N}} \quad \textbf{(B-48)}$$

and:

$$LTSHRR_{osc,N} = \frac{NLTSTSCC_{osc,N}}{\sum_{osc=1}^{6} NLTSTSCC_{osc,N}} \quad \textbf{(B-49)}$$

where:

PASSHRR = Non-fleet market shares of automobiles, by size class *osc*
NLTSHRR = Non-fleet market shares of light trucks, by size class *osc*

4) Reassign horsepower estimates to six size classes:

$$HPCAR_{osc,N} = \sum_{igp=1}^{2} \sum_{icl=1}^{7} \left(HP_{icl,igp,YEAR}\right) * SALESHR_{igp} * MAP_{igp,icl,osc} \quad \textbf{(B-50)}$$

and:

$$HPTRUCK_{osc,N} = \sum_{igp=3}^{4} \sum_{icl=1}^{7} \left(HP_{icl,igp,YEAR}\right) * SALESHR_{igp} * MAP_{igp,icl,osc} \quad \textbf{(B-51)}$$

where:

HPCAR = Average horsepower of automobiles, by size class *osc*
HPTRUCK = Average horsepower of light trucks, by size class *osc*
HP = Vehicle horsepower by FEM size class *icl* and CAFE group *igp*
SALESHR = Domestic vs. import market share for automobiles and light trucks, from ORNL

5) Calculate average horsepower of cars and light trucks, by size class *osc*:

$$AHPCAR_{N} = \sum_{osc=1}^{6} HPCAR_{osc,N} * PASSHRR_{osc,N} \quad \textbf{(B-52)}$$

and:

$$AHPTRUCK_N = \sum_{osc=1}^{6} HPTRUCK_{osc,N} * LTSHRR_{osc,N} \quad \textbf{(B-53)}$$

where:

AHPCAR = Average automobile horsepower
AHPTRUCK = Average light truck horsepower

REGIONAL SALES MODEL — Subroutine TREG

1) Calculate regional shares of fuel demand, and normalize:

$$SEDSHR_{FUEL,REG,T} = \frac{SEDSHR_{FUEL,REG,T-1} * \left(\frac{TMC\_YD_{REG,T}}{TMC\_YD_{REG,T-1}} \right)}{\sum_{REG=1}^{9} SEDSHR_{FUEL,REG,T-1} * \left(\frac{TMC\_YD_{REG,T}}{TMC\_YD_{REG,T-1}} \right)} \quad \textbf{(B-54)}$$

where:

SEDSHR = Regional share of the consumption of a given fuel in period *T*
TMC_YD = Estimated disposable personal income by region, *REG* (9)
FUEL = Index of fuel type (11)

2) Calculate regional cost of driving per mile:

$$COSTMIR_{REG,T} = 0.1251 * \left(\frac{TPMGTR_{REG,T}}{MPGFLT_{T-1}} \right) \quad \textbf{(B-55)}$$

where:

COSTMIR = The cost per mile of driving in region *REG*, in $/mile
TPMGTR = The regional price of motor gasoline, in $/MMBTU
MPGFLT = The previous year's stock MPG for non-fleet vehicles
.1251 = A conversion factor for gasoline, in MMBTU/gal

3) Calculate regional income:

$$INCOMER_{REG,T} = \left(\frac{TMC\_YD_{REG,T}}{TMC\_POPAFO_{REG,T}} \right) \quad \textbf{(B-56)}$$

where:

INCOMER = Regional per capita disposable income

TMC_POPAFO = Total population in region *REG*

4) Estimate regional driving demand:

$$\begin{aligned} VMT16R_{REG,T} = \rho\, VMT16R_{REG,T-1} + \beta_0 (1 - \rho) + \beta_1 \left(COSTMIR_{REG,T} - \rho\, COSTMIR_{REG,T-1} \right) \\ + \beta_2 \left(INCOMER_{REG,T} - \rho\, INCOMER_{REG,T-1} \right) + \beta_3 \left(PRFEM_T - \rho\, PRFEM_{T-1} \right) \end{aligned} \quad \textbf{(B-57)}$$

and:

$$VMTEER_{REG,T} = VMT16R_{REG,T} * TMC\_POP16_{REG,T} * DAF_T \quad \textbf{(B-58)}$$

where:

VMT16R = Vehicle-miles traveled per population over 16 years of age

PRFEM = Ratio of female to male driving rates

ρ = Lag factor for the difference equation

VMTEER = Total VMT in region *REG*

TMC_POP16 = Total regional population over the age of 16

DAF = A demographic adjustment factor, to reflect different age groups' driving patterns

5) Calculate regional VMT shares (RSHR):

$$RSHR_{REG,T} = \frac{VMTEER_{REG,T}}{\sum_{REG=1}^{9} VMTEER_{REG,T}} \quad \textbf{(B-59)}$$

6) Divide non-fleet car and light truck sales according to regional VMT shares:

$$NCS_{REG,SC,T} = NCSTSCC_{SC,T} * RSHR_{REG,T} \quad \textbf{(B-60)}$$

and:

$$NLTS_{REG,SC,T} = NLTSTSCC_{SC,T} * RSHR_{REG,T} \quad \textbf{(B-61)}$$

where:

NCS = New car sales, by size class *SC* and region *REG*
NLTS = New light truck sales, by size class and region

ALTERNATIVE FUEL VEHICLE MODEL Subroutine TALT3

1) Calculate commercial availability by technology:

$$COMAV_{IT,N} = \left[1 + EXP\left(\frac{TT50_{IT} - YEAR}{2} \right) \right]^{-1} \quad \textbf{(B-62)}$$

where:

COMAV = The fraction of market demand of a given technology which is commercially available
IT = Index of the sixteen engine technologies considered by the model
TT50 = The exogenously specified year in which 50% of the demand for technology *IT* can be met

2) Calculate the weighted average fuel price for each technology, by region:

$$AFCOST_{IT,IR,N} = \frac{\sum_{FUEL} (RFP_{FUEL,IR,N} \cdot FAVAIL_{FUEL,IR,N})}{\sum_{FUEL} FAVAIL_{FUEL,IR,N}} \quad \textbf{(B-63)}$$

where:

AFCOST = Weighted average fuel price, in 1990 cents/MMBTU, for each technology *IT*
RFP = Price of each fuel used by the corresponding technology
FAVAIL = Relative availability of the corresponding fuel

3) Map fuel economy for cars and light trucks from six to three size classes for use in the AFV model:

a) For cars:

$$FEC3SC_{ISC,N} = \left[\frac{\sum_{OSC} \left(\frac{NCSTSCC_{OSC,N}}{FESIXC_{OSC,N}} \right)}{\sum_{OSC} NCSTSCC_{OSC,N}} \right]^{-1} \quad \text{(B-64)}$$

where:

FEC3SC = Automobile fuel economy within the three reduced size classes
NCSTSCC = New car sales within the six size classes *OSC*
FESIXC = New car fuel economy within the six size classes *OSC*
ISC = Index of reduced size classes, mapped as follows for cars: *ISC* = 1, *OSC* = 2, 3; *ISC* = 2, *OSC* = 1, 6; *ISC* = 3, *OSC* = 4, 5

b) For light trucks:

$$FET3SC_{ISC,N} = \left[\frac{\sum_{OSC} \left(\frac{NLTSTSCC_{OSC,N}}{FESIXT_{OSC,N}} \right)}{\sum_{OSC} NLTSTSCC_{OSC,N}} \right]^{-1} \quad \text{(B-65)}$$

where:

FET3SC = Light truck fuel economy within the three reduced size classes
NLTSTSCC = New light truck sales within the six size classes *OSC*
FESIXT = New light truck fuel economy within the six size classes *OSC*
ISC = Index of reduced size classes, mapped as follows for trucks: *ISC* = 1, *OSC* = 1, 3; *ISC* = 2, *OSC* = 2, 5; *ISC* = 3, *OSC* = 4, 6

4) Convert fuel economy from miles per gallon to miles per MMBTU:

$$VEFFACT_{ISC,N} = \frac{FEC3SC_{ISC,N}}{0.125} \quad \text{(B-66)}$$

where:

VEFFACT = Gasoline vehicle fuel economy, used as a baseline

5) Calculate alternative vehicle fuel economy, using gasoline baseline:

$$VEFFBTU_{ISC,IT,N} = VEFF_{ISC,IT,N} * VEFFACT_{ISC,N} \qquad \textbf{(B-67)}$$

where:

VEFFBTU = Fuel economy by technology *IT*, in miles per MMBTU
VEFF = Fuel economy of technology *IT*, relative to gasoline baseline

6) Calculate AFV operating cost, by region:

$$COPCOST_{IT,ISC,IR,N} = \frac{AFCOST_{IT,IT,N} * 100}{VEFFBTU_{ISC,IT,N}} \qquad \textbf{(B-68)}$$

where:

COPCOST = Regional vehicle operating cost, in 1990$/mile

7) Calculate utility of electric and electric hybrid vehicles (*IT* = 7-10):

$$\begin{aligned} VC3_{IT,IR} = \; & BETACONST_{IT} + BETAVP \cdot VPRICE3_{IS,IT,N} + BETAFC \cdot COPCOST3_{IT,IS,IR,N} \\ & + BETAVR \cdot VRANGE3_{IS,IT,N} + BETAVR2 \cdot VRANGE3^{2}_{IS,IT,N} + BETAEM \cdot EMISS3_{IS,IT,N} \\ & + BETAEM2 \cdot EMISS3^{2}_{IS,IT,N} + BETAFA \cdot FAVAIL3_{IT,IR,N} + BETAFA2 \cdot FAVAIL3^{2}_{IT,IR,N} \end{aligned} \qquad \textbf{(B-69)}$$

where:

VC3 = Utility vector for electric vehicles
BETACONST = Constant associated with each considered technology *IT*
COPCOST3 = Fuel operating costs for electric vehicles
VPRICE3 = Price of each considered EV technology in 1990$
VRANGE3 = Vehicle range of the considered EV technology
EMISS3 = EV emissions levels relative to gasoline ICE's
FAVAIL33 = Fuel availability for EV technologies
BETAVP = Coefficient associated with vehicle price
VETAFC = Coefficient associated with fuel cost
BETAVR = Coefficient associated with vehicle range
BETAEM = Coefficient associated with vehicle emissions
BETAFA = Coefficient associated with fuel availability
BETAVR2 = Coefficient associated with the square of vehicle range
BETAEM2 = Coefficient associated with the square of vehicle emissions
BETAFA2 = Coefficient associated with the square of fuel availability

8) Exponentiate utility vector, and adjust by commercial availability factor:

$$EVC3_{IT,IS,IR,N} = EXP\left[VC3_{IT,IS,IR,N}\right] * COMAV_{IT,N} \quad \textbf{(B-70)}$$

where:

EVC3 = Exponentiated value of electric vehicle utility vector

9) Calculate electric vehicle market shares, by region:

$$APSHR33_{IS,IR,IT,N} = \frac{EVC3_{IT,IS,IR,N}}{\sum_{IT=7}^{10} EVC3_{IT,IS,IR,N}} \quad \textbf{(B-71)}$$

where:

APSHR33 = Relative market shares within the electric vehicle group

ALTERNATIVE FUEL VEHICLE MODEL Subroutine TALT2

1) Calculate weighted average characteristics of electric vehicles, and reconfigure technology indices to reflect the compression of four EV technologies into one prototype:

$$\Psi_{IS,IT,IR,N} = \sum_{IT=7}^{10} \Psi_{IS,IT,IR,N} \cdot APSHR33_{IS,IR,IT,N} \quad \textbf{(B-72)}$$

where:

Ψ = VPRICE3, VEMISS3, VRANGE3, COMAV, COPCOST, FAVAIL33, and BETACONST

2) Calculate utility for alternative fuel vehicles (*IT* = 3-13):

$$\begin{aligned} VC2_{IT,IR} = {} & BETACONST2_{IT} + BETAVP \cdot VPRICE2_{IS,IT,N} + BETAFC \cdot COPCOST2_{IT,IS,IR,N} \\ & + BETAVR \cdot VRANGE2_{IS,IT,N} + BETAVR2 \cdot VRANGE2^2_{IS,IT,N} + BETAEM \cdot EMISS2_{IS,IT,N} \\ & + BETAEM2 \cdot EMISS2^2_{IS,IT,N} + BETAFA \cdot FAVAIL22_{IT,IR,N} + BETAFA2 \cdot FAVAIL22^2_{IT,IR,N} \end{aligned} \quad \textbf{(B-73)}$$

where:

VC2 = Utility vector for alternative vehicles

BETACONST2 = Constant associated with each considered AFV technology
COPCOST2 = Fuel operating costs for alternative vehicles
VPRICE2 = Price of each considered AFV technology in 1990$
VRANGE2 = Vehicle range of the considered AFV technology
EMISS2 = AFV emissions levels relative to gasoline ICE's
FAVAIL22 = Alternative fuel availability

3) Exponentiate utility vector, and adjust by commercial availability factor:

$$EVC2_{IT,IS,IR,N} = EXP\left[VC2_{IT,IS,IR,N}\right] * COMAV_{IT,N} \tag{B-74}$$

where:

EVC2 = Exponentiated value of alternative vehicle utility vector

4) Calculate alternative vehicle market shares, by region:

$$APSHR22_{IS,IR,IT,N} = \frac{EVC2_{IT,IS,IR,N}}{\sum_{IT=3}^{13} EVC2_{IT,IS,IR,N}} \tag{B-75}$$

where:

APSHR22 = Relative market shares within the alternative vehicle group

ALTERNATIVE FUEL VEHICLE MODEL Subroutine TALT1

1) Calculate weighted average characteristics of alternative vehicles, and reconfigure technology indices to reflect the compression of eleven alternative technologies into one prototype:

$$\Psi_{IS,IT,IR,N} = \sum_{IT=3}^{13} \Psi_{IS,IT,IR,N} \cdot APSHR22_{IS,IR,IT,N} \tag{B-76}$$

where:

Ψ = VPRICE2, VEMISS2, VRANGE2, COMAV, COPCOST2, FAVAIL22, and BETACONST2

2) Calculate utility for all vehicles (IT = 1-3):

$$
\begin{aligned}
VC1_{IT,IR} = \; & BETACONST1_{IT} + BETAVP \cdot VPRICE1_{IS,IT,N} + BETAFC \cdot COPCOST1_{IT,IS,IR,N} \\
& + BETAVR \cdot VRANGE1_{IS,IT,N} + BETAVR2 \cdot VRANGE1^{2}_{IS,IT,N} + BETAEM \cdot EMISS1_{IS,IT,N} \\
& + BETAEM2 \cdot EMISS1^{2}_{IS,IT,N} + BETAFA \cdot FAVAIL11_{IT,IR,N} + BETAFA2 \cdot FAVAIL11^{2}_{IT,IR,N}
\end{aligned}
\tag{B-77}
$$

where:

VC1 = Utility vector for conventional and alternative vehicles

BETACONST1 = Constant associated with each considered technology

COPCOST1 = Fuel operating costs for conventional and alternative vehicles

VPRICE1 = Price of each considered technology in 1990$

VRANGE1 = Vehicle range of the considered technology

EMISS1 = Emissions levels relative to gasoline ICE's

FAVAIL11 = Fuel availability

3) Exponentiate utility vector, and adjust by commercial availability factor:

$$EVC1_{IT,IS,IR,N} = EXP\left[VC1_{IT,IS,IR,N}\right] * COMAV_{IT,N} \tag{B-78}$$

where:

EVC1 = Exponentiated value of vehicle utility vector

4) Calculate vehicle market shares, by region:

$$APSHR11_{IS,IR,IT,N} = \frac{EVC1_{IT,IS,IR,N}}{\sum_{IT=1}^{3} EVC1_{IT,IS,IR,N}} \tag{B-79}$$

where:

APSHR11 = Relative market shares of conventional and alternative vehicles

5) Expand market share estimates to generate absolute market shares for each of the sixteen conventional and alternative technologies:

a) For conventional vehicles (IT = 16,15; $IT1$ = 1,2):

$$APSHR44_{IS,IR,IT,N} = APSHR11_{IS,IR,IT1,N} * APSHR22_{IS,IR,IT2,N} \quad \textbf{(B-80)}$$

where:

APSHR44 = Absolute market share of technology IT

b) For non-electric alternative vehicles (IT = 1-6,11-14; $IT1$ = 3; $IT2$ = 5,6,3,4,8-13):

$$APSHR44_{IS,IR,IT,N} = APSHR11_{IS,IR,IT1,N} \quad \textbf{(B-81)}$$

c) For electric and electric hybrid vehicles (IT = 7-10; $IT1$ = 3; $IT2$ = 7; $IT3$ = 1-4):

$$APSHR44_{IS,IR,IT,N} = APSHR11_{IS,IR,IT1,N} * APSHR22_{IS,IR,IT2,N} * APSHR33_{IS,IR,IT3,N} \quad \textbf{(B-82)}$$

LIGHT DUTY VEHICLE FLEET MODULE Subroutine TFLTSTKS

1) Calculate fleet acquisitions of cars and light trucks:

$$FLTSAL_{VT=1,ITY,T} = FLTCRAT * SQTRCARS_T * FLTCSHR_{ITY}$$

and: **(B-83)**

$$FLTSAL_{VT=2,ITY,T} = FLTTRAT * SQDTRUCKSL_T * FLTTSHR_{ITY}$$

where:

FLTSAL = Sales to fleets by vehicle and fleet type
FLTCRAT = Fraction of total car sales attributed to fleets
FLTTRAT = Fraction of total truck sales attributed to fleets
SQTRCARS = Total automobile sales in a given year
SQTRUCKSL = Total light truck sales in a given year
FLTCSHR = Fraction of fleet cars purchased by a given fleet type
FLTTSHR = 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

2) Determine total alternative fuel fleet vehicle sales, using either the market-driven or legislatively mandated values :

$$FLTALT_{VT,ITY,T} = MAX\left[\left(FLTSAL_{VT,ITY,T} * FLTAPSHR1_{ITY}\right),\ EPACT_{VT,ITY,T}\right] \quad \textbf{(B-84)}$$

where:

FLTALT = Number of AFV's purchased by each fleet type in a given year
FLTAPSHR1 = Fraction of each fleets' purchases which are AFV's, from historical data
EPACT = Legislative mandates for AFV purchases, by fleet type

3) Calculate the difference between total sales and AFV sales (representing conventional sales):

$$FLTCONV_{VT,ITY,T} = FLTSAL_{VT,ITY,T} - FLTALT_{VT,ITY,T} \quad \textbf{(B-85)}$$

where:

FLTCONV = Fleet purchases of conventional vehicles

4) Distribute fleet purchases among three size classes:

$$FLTSLSCA_{VT,ITY,IS,T} = FLTALT_{VT,ITY,T} * FLTSSHR_{VT,ITY,IS}$$

and: **(B-86)**

$$FLTSLSCC_{VT,ITY,IS,T} = FLTCONV_{VT,ITY,T} * FLTSSHR_{VT,ITY,IS}$$

where:

FLTSLSCA = Fleet purchases of AFV's, by size class

FLTSLSCC = Fleet purchases of conventional vehicles, by size class

FLTSSHR = Percentage of fleet vehicles in each size class, from historical data

IS = Index of size classes: 1 = small, 2 = medium, 3 = large

5) Disaggregate AFV sales by engine technology:

$$FLTECHSAL_{VT,ITY=1,IS,ITECH,T} = FLTSLSCA_{VT,ITY=1,IS,T} * APSHRFLTB_{VT,ITECH,ITY=1,T}$$

$$FLTECHSAL_{VT,ITY\neq 1,IS,ITECH,T} = FLTSLSCA_{VT,ITY\neq 1,IS,T} * FLTECHSHR_{ITECH,ITY,T}$$ **(B-87)**

and:

$$FLTECHSAL_{VT,ITY,IS,ITECH=6,T} = FLTSLSCC_{VT,ITY,IS,T}$$

where:

FLTECHSAL = Fleet sales by size, technology, and fleet type

APSHRFLTB = Alternative technology shares for the business fleet

FLTECHSHR = Alternative technology shares for the government and utility fleets

ITECH = Index of engine technologies: 1-5 = alternative fuels (neat), 6 = gasoline

6) Sum sales across size classes:

$$FLTECH_{VT,ITY,ITECH,T} = \sum_{IS=1}^{3} FLTECHSAL_{VT,ITY,IS,ITECH,T}$$ **(B-88)**

where:

FLTECH = Vehicle purchases by fleet type and technology

7) Calculate survival of older vehicles, and modify vintage array:

$$FLTSTKVN_{VT,ITY,ITECH,IVIN,T} = FLTSTKVN_{VT,ITY,ITECH,IVIN-1,T-1} * SURVFLTT_{VT,IVIN-1}$$

and: **(B-89)**

$$FLTSTKVN_{VT,ITY,ITECH,IVIN=1,T} = FLTECH_{VT,ITY,ITECH,T}$$

where:

FLTSTKVN = Fleet stock by fleet type, technology, and vintage

SURVFLTT = Survival rate of a given vintage

8) Assign fleet vehicles of retirement vintage to another variable, prior to removal from the fleet:

$$OLDFSTK_{VT,ITY,ITECH,RVINT,T} = FLTSTKVN_{VT,ITY,ITECH,RVINT,T} \qquad \textbf{(B-90)}$$

where:

OLDFSTK = Old fleet stocks of given types and vintages, transferred to the private sector

RVINT = Retirement vintage of fleet vehicles: If *VT* = 1, *ITY* = 1,2,3, *RVINT* = 5,6,7; If *VT* = 2, *ITY* = 1,2,3, *RVINT* = 6,7,6

9) Calculate total surviving vehicles, by vehicle, fleet type, and engine technology:

$$TFLTECHSTK_{VT,ITY,ITECH,T} = \sum_{IVIN=1}^{6} FLTSTKVN_{VT,ITY,ITECH,IVIN,T} \qquad \textbf{(B-91)}$$

where:

TFLTECHSTK = Total stock within each technology and fleet type

10) Calculate grand total of surviving vehicles:

$$TOTFLTSTK_{T} = \sum_{VT=1}^{2} \sum_{ITY=1}^{3} \sum_{ITECH=1}^{6} TFLTECHSTK_{VT,ITY,ITECH,T} \qquad \textbf{(B-92)}$$

where:

TOTFLTSTK = Total of all surviving fleet vehicles

11) Calculate percentage of fleet stock represented by each of the vehicle, fleet types, and engine technologies:

$$VFSTKPF_{VT,ITY,ITECH,T} = \frac{TFLTECHSTK_{VT,ITY,ITECH,T}}{TOTFLTSTK_{T}} \quad \textbf{(B-93)}$$

where:

VFSTKPF = Share of fleet stock by vehicle type and technology

LIGHT DUTY VEHICLE FLEET MODULE Subroutine TLEGIS

This subroutine adjusts vehicle sales and market shares to reflect California's legislative mandates on sales of zero-emission vehicles (ZEV's) and ultra-low emission vehicles (ULEV's), which have also been tentatively adopted by New York and Massachusetts.

1) Calculate regional vehicle sales, by technology, within three size classes:

$$VSALES_{IS,IR,IT,N} = \sum_{OSC} APSHR44_{IS,IR,IT,N} * \left(NCS_{IR,OSC,N} + NLTS_{IR,OSC,N}\right) \quad \textbf{(B-94)}$$

where:

VSALES = Total disaggregate vehicle sales

APSHR44 = Absolute market share of new vehicles, by region, size, and technology

IS = Index of reduced size class (1-3)

OSC = Index of original size class (1-6)

NCS = Regional new car sales within corresponding size classes *OSC*:

$IS = 1, OSC = 2,3$; $IS = 2, OSC = 1,6$; $IS = 3, OSC = 4,5$

NLTS = Regional new light truck sales within corresponding size classes *OSC*

$IS = 1, OSC = 1,2$; $IS = 2, OSC = 3,4$; $IS = 3, OSC = 5,6$

2) Calculate total regional sales of electric and electric hybrid vehicles:

$$ELECVSAL_{IR,N} = \sum_{IS=1}^{3} \sum_{IT=7}^{10} VSALES_{IS,IR,IT,N} \quad \textbf{(B-95)}$$

where:

ELECVSAL = Regional electric vehicle sales

3) Calculate total vehicle sales across all technologies:

$$VSALEST_{IS,IR,N} = \sum_{IT=1}^{16} VSALES_{IS,IR,IT,N} \quad \textbf{(B-96)}$$

where:

VSALEST = Total regional vehicle sales, by size class

4) Calculate mandated sales of ZEV's and ULEV's by participating state:

$$ZEVST_{ST,N} = \left(TMC\_SQTRCARS_N * STATESHR_{ST,VT=1,N} + TMC\_SQDTRUCKSL_N * STATESHR_{ST,VT=2,N}\right) * ZEV_N$$

and **(B-97)**

$$ULEVST_{ST,N} = \left(TMC\_SQTRCARS_N * STATESHR_{ST,VT=1,N} + TMC\_SQDTRUCKSL_N * STATESHR_{ST,VT=2,N}\right) * ULEV_N$$

where:

ZEVST = State-mandated minimum sales of ZEV's
ULEVST = State-mandated minimum sales of ULEV's
TMC_SQTRCARS = Total car sales, from the MACRO module
TMC_SQDTRUCKSL = Total light truck sales, from the MACRO module
STATESHR = Share of national vehicle sales attributed to a given state
ZEV = State-mandated minimum sales share of ZEV's
ULEV = State-mandated minimum sales share of ULEV's
ST = Index of participating state: CA, MA, NY
VT = Index of vehicle type: 1 = cars, 2 = light trucks

5) If mandated sales exceed actual sales, then adjust actual sales as follows:

a) Evenly distribute mandated sales among three size classes:

$$ZEVSTSC_{ST,IS,N} = \frac{ZEVST_{ST,N}}{3} \quad \textbf{(B-98)}$$

where:

ZEVSTSC = Mandated ZEV sales by size class and state

b) Evenly distribute actual electric vehicle sales among three size classes:

$$ELECVSALSC_{IR,IS,N} = \frac{ELECVSAL_{IR,N}}{3} \quad \textbf{(B-99)}$$

where:

ELECVSALSC = Regional ZEV sales within corresponding regions

IR = Corresponding regions: *ST* = CA, MA, NY; *IR* = 9,1,2

c) Calculate mandated ZEV sales by EV technology (*IT* = 7-10):

$$AVSALES_{IS,IR,IT,N} = ZEVSTSC_{ST,IS,N} * APSHR33_{IS,IR,IT,N} \quad \textbf{(B-100)}$$

where:

AVSALES = Regional adjusted vehicle sales by size class

APSHR33 = Relative market shares of electric vehicle technologies

d) Reduce sales of gasoline vehicles (*IT* = 16) to compensate for increased ZEV sales in the affected regions (*IR* = 1,2,9):

$$AVSALES_{IS,IR,IT=16,N} = VSALES_{IS,IR,IT=16,N} - \left(ZEVSTSC_{ST,IS,N} - ELECVSALSC_{IR,IS,N}\right) \quad \textbf{(B-101)}$$

6) Reassign vehicle sales in unaffected regions ($IR \neq 1,2,9$):

$$AVSALES_{IS,IR,IT,N} = VSALES_{IS,IR,IT,N} \quad \textbf{(B-102)}$$

7) Sum adjusted vehicle sales across technologies:

$$AVSALEST_{IS,IR,N} = \sum_{IT=1}^{16} AVSALES_{IS,IR,IT,N} \quad \textbf{(B-103)}$$

where:

AVSALEST = Total regional adjusted vehicle sales by size class

8) Calculate new absolute market shares for each vehicle technology:

$$APSHR55_{IS,IR,IT,N} = \frac{AVSALES_{IS,IR,IT,N}}{AVSALEST_{IS,IR,N}} \quad \textbf{(B-104)}$$

where:

APSHR55 = Absolute regional market shares of adjusted vehicle sales

9) Reset conventional vehicle market shares so that diesel represents 2.5% of conventional vehicle sales:

$$APSHR55_{IS,IR,IT=15,N} = \sum_{IT=15}^{16} APSHR55_{IS,IR,IT,N} * 0.025$$

and **(B-105)**

$$APSHR55_{IS,IR,IT=16,N} = \sum_{IT=15}^{16} APSHR55_{IS,IR,IT,N} * 0.975$$

10) Calculate new fleet market shares for use with business fleets:

a) Calculate total vehicle sales by technology:

$$VSALESC16_{IT,N} = \sum_{IR=1}^{9} \sum_{IS=1}^{3} APSHR55_{IS,IR,IT,N} * \left(\sum_{OSC} NCS_{IR,OSC,N} \right)$$

and **(B-106)**

$$VSALEST16_{IT,N} = \sum_{IR=1}^{9} \sum_{IS=1}^{3} APSHR55_{IS,IR,IT,N} * \left(\sum_{OSC} NLTS_{IR,OSC,N} \right)$$

where:

VSALESC16 = Total new car sales by technology:

$IS = 1, OSC = 2,3;\ IS = 2, OSC = 1,6;\ IS = 3, OSC = 4,5$

VSALEST16 = Total new light truck sales by technology

$IS = 1, OSC = 1,3;\ IS = 2, OSC = 2,5;\ IS = 3, OSC = 4,6$

b) Calculate market shares by technology:

$$APSHRNC_{IT,N} = \frac{VSALESC16_{IT,N}}{\sum_{IT=1}^{16} VSALESC16_{IT,N}}$$

and **(B-107)**

$$APSHRNT_{IT,N} = \frac{VSALEST16_{IT,N}}{\sum_{IT=1}^{16} VSALEST16_{IT,N}}$$

where:

APSHRNC = Market shares of new cars by technology

APSHRNT = Market shares of new light trucks by technology

c) Sum market shares for affected fleet technologies:

$$APSHRFLTOT_{VT=1,N} = \sum_{ITF} APSHRNC_{ITF,N}$$

and **(B-108)**

$$APSHRFLTOT_{VT=2,N} = \sum_{ITF} APSHRNT_{ITF,N}$$

where:

APSHRFLTOT = Aggregate market shares of fleet vehicle technologies

VT = Index of vehicle type: 1 = cars; 2 = light trucks

ITF = Index of fleet vehicle technologies, corresponding to IT = 3,5,7,8,9

d) Normalize business fleet market shares:

$$APSHRFLTB_{VT=1,ITF,N} = \frac{APSHRNC_{IT,N}}{APSHRFLTOT_{VT=1,N}}$$

and **(B-109)**

$$APSHRFLTB_{VT=2,ITF,N} = \frac{APSHRNT_{IT,N}}{APSHRFLTOT_{VT=2,N}}$$

where:

APSHRFLTB = Market shares of business fleet by vehicle type and technology

11) Reset new car and light truck sales using market shares, mapped from three to six size classes:

$$NCSTECH_{IR,OSC,IT,N} = NCS_{IR,OSC,N} * APSHR55_{IS,IR,IT,N}$$

and **(B-110)**

$$NLTECH_{IR,OSC,IT,N} = NLTS_{IR,OSC,N} * APSHR55_{IS,IR,IT,N}$$

where:

NCSTECH = Regional new car sales by technology, within six size classes:
OSC = 1-6; IS = 2,1,1,3,3,2

NLTECH = Regional light truck sales by technology, with six size classes:
OSC = 1-6; IS = 1,2,1,3,2,3

LIGHT DUTY VEHICLE FLEET MODULE Subroutine TFLTVMTS

This subroutine calculates VMT for fleets.

1) Use historical data on fleet vehicle travel to estimate total fleet VMT:

$$FLTVMT_T = \sum_{VT=1}^{2} \sum_{ITY=1}^{3} \sum_{ITECH=1}^{6} \left(TFLTECHSTK_{VT,ITY,ITECH,T} * FLTVMTYR_{VT,ITY,T}\right) \quad \textbf{(B-111)}$$

where:

FLTVMT = Total VMT driven by fleet vehicles

FLTVMTYR = Annual miles of travel per vehicle, by vehicle and fleet type

VT = Index of vehicle type: 1 = cars, 2 = light trucks

ITY = Index of fleet type: Business, Government, Utility

ITECH = Index of fleet engine technology, corresponding to *IT* = 3,5,9,7,8

2) Disaggregate total VMT by vehicle type and technology:

$$FLVMTECH_{VT,ITY,ITECH,T} = FLVMT_{T} * VFSTKPF_{VT,ITY,ITECH,T} \quad \textbf{(B-112)}$$

where:

FLTVMTECH = Fleet VMT by technology, vehicle type, and fleet type

VFSTKPF = Share of fleet stock by vehicle type and technology

This subroutine calculates fuel efficiency for the fleet stock

1) Calculate the average efficiencies of the five non-gasoline technologies (*ITECH* = 1-5):

$$FLTMPG_{VT=1,ITY,ITECH} = \left[\sum_{IS=1}^{3} \frac{FMSHC_{ITY,ITECH,IS}}{NAMPG_{IT,IS}} \right]^{-1}$$

and: **(B-113)**

$$FLTMPG_{VT=2,ITY,ITECH} = \left[\sum_{IS=1}^{3} \frac{FMSHLT_{ITY,ITECH,IS}}{NAMPG_{IT,IS} * RATIO_{IS}} \right]^{-1}$$

where:

FLTMPG = New fleet vehicle fuel efficiency, by fleet type and engine technology
FMSHC = The market share of fleet cars, from the AFV model
FMSHLT = The market share of fleet light trucks, from the AFV model
NAMPG = New AFV fuel efficiency, from the AFV model
IT = Index which matches technologies in the AFV model to corresponding *ITECH*:
ITECH = 1-5, *IT* = 4,2,7,5,6
IS = Index of reduced size class (1-3)
VT = Index of vehicle type: 1 = cars, 2 = light trucks

2) Calculate the average efficiencies of conventional vehicles:

$$FLTMPG_{VT=1,ITY,ITECH} = \left[\sum_{IS=1}^{3} \frac{FMSHC_{ITY,ITECH,IS}}{FEC3SC_{IS}} \right]^{-1}$$

and: **(B-114)**

$$FLTMPG_{VT=2,ITY,ITECH} = \left[\sum_{IS=1}^{3} \frac{FMSHLT_{ITY,ITECH,IS}}{FET3SC_{IS}} \right]^{-1}$$

where:

FEC3SC = New car MPG, by three size classes, from the FEM model
FET3SC = New light truck MPG, by three size classes, from the FEM model

3) Calculate the average fleet MPG for cars and light trucks:

$$FLTMPGTOT_{VT,T} = \left[\frac{\sum_{IS=1}^{3} \sum_{ITECH=1}^{6} \frac{FLTECH_{VT,IS,ITECH,N}}{FLTMPG_{VT,IS,ITECH,N}}}{\sum_{IS=1}^{3} \sum_{ITECH=1}^{6} FLTECH_{VT,IS,ITECH,N}} \right]^{-1} \quad \textbf{(B-115)}$$

where:

FLTMPGTOT = Overall fuel efficiency of new fleet cars and light trucks

4) Adjust vintage array of fleet stock efficiencies to account for new additions:

$$MPGFSTK_{VT,ITY,ITECH,IVIN,T} = MPGFSTK_{VT,ITY,ITECH,IVIN-1,T-1}$$

and: **(B-116)**

$$MPGFSTK_{VY,ITY,ITECH,IVIN=1,T} = FLTMPG_{VT,ITY,ITECH,T}$$

where:

MPGFSTK = Fleet MPG by vehicle and fleet type, technology, and vintage

IVIN = Index of fleet vintages

5) Calculate average fuel efficiency by vehicle and fleet type:

$$MPGFLTSTK_{VT,ITY,ITECH,T} = \left[\sum_{IVIN=1}^{MAXVINT} \frac{\left(\frac{FLTSTKVN_{VT,ITY,ITECH,IVIN,T}}{MPGFSTK_{VT,ITY,ITECH,IVIN,T} * VDF_{VT}} \right)}{\left(TFLTECHSTK_{VT,ITY,ITECH,T} \right)} \right]^{-1} \quad \textbf{(B-117)}$$

where:

MPGFLTSTK = Fleet MPG by vehicle and fleet type, and technology, across vintages

MAXVINT = Maximum *IVIN* index associated with a given vehicle and fleet type

VDF = Vehicle degradation factor

TFLTECHSTK = Total fleet stocks by vehicle, fleet type, and technology

6) Calculate overall fleet average MPG for cars and light trucks:

$$FLTTOTMPG_{VT,T} = \left[\sum_{ITY=1}^{3} \sum_{ITECH=1}^{6} \frac{VFSTKPF_{VT,ITY,ITECH,T}}{MPGFLTSTK_{VT,ITY,ITECH,T}} \right]^{-1} \quad \textbf{(B-118)}$$

where:

FLTTOTMPG = Fleet vehicle average fuel efficiency for cars and light trucks

This subroutine calculates fuel consumption of fleet vehicles.

1) Calculate fuel consumption:

$$FLTLDVC_{VT,ITY,ITECH,T} = \frac{FLTVMTECH_{VT,ITY,ITECH,T}}{MPGFLTSTK_{VT,ITY,ITECH,T}} \quad \textbf{(B-119)}$$

where:

FLTLDVC = Fuel consumption by technology, vehicle and fleet type

2) Sum consumption across fleet types, and convert to Btu values:

$$FLTFCLDVBTU_{VT,ITECH,T} = \sum_{ITY=1}^{3} FLTLDVC_{VT,ITY,ITECH,T} * QBTU_{ITECH} \quad \textbf{(B-120)}$$

where:

FLTFCLDVBTU = Fuel consumption, in Btu, by vehicle type and technology

QBTU = Energy content, in Btu/Gal, of the fuel associated with each technology

Consumption by trucks and cars are added, and total consumption is subsequently divided among regions:

$$FLTFCLDVBTUR_{IR,ITECH,T} = \sum_{VT=1}^{2} FLTFCLDVBTU_{VT,ITECH,T} * RSHR_{IR,T} \quad \textbf{(B-121)}$$

where:

FLTFCLDVBTUR = Regional fuel consumption by fleet vehicles, by technology

RSHR = Regional VMT shares, from the Regional Sales Module

1) Calculate LCT sales:

$$LT\_CLTT_N = MC\_SQDTRUCKSL_N * LT10K * 1e^6 \quad \textbf{(B-122)}$$

where:

LT_CLTT_N = Sales of light trucks less than 10,000 pounds
$MC\_SQTRUCKSL_N$ = Total sales of light trucks, from the Macro Model
LT10K = Fraction of Light Duty Trucks with a gross vehicle weight of less than 10,000 pounds

2) Divide LCT sales between 2-axle, 4-tire and other single-unit (OSU) trucks:

$$CLTSAL2A4T_N = LT\_CLTT_N * LT2A4$$
$$and \quad \textbf{(B-123)}$$
$$CLTSALOSU_N = LT\_CLTT_N * LTOSU$$

where:

LT2A4 = Fraction of new light trucks of the 2-axle, 4 tire configuration
LTOSU = Fraction of new light trucks of other configuration

3) Divide sales of both truck types into pickup and non-pickup styles for trucks between 8,500 and 10,000 pounds:

$$CLTSAL2A4TS_{istyl,N} = CLTSAL2A4T_N * LT2A4CLT_{istyl}$$
$$and \quad \textbf{(B-124)}$$
$$CLTSALOSUS_{istyl,N} = CLTSALOSU_N * LTOSUCLT_{istyl}$$

where:

$LT2A4CLT_{istyl}$ = Fraction of 2-axle, 4-tire trucks between 8.5 and 10 thousand pounds, by style
$LTOSUCLT_{istyl}$ = Fraction of other single unit trucks between 8.5 and 10 thousand pounds, by style
istyl = Index of truck style: 1 = pickup, 2 = other

4) Allocate sales among the aggegate major-use groups:

$$CLTSAL_{is,istyl,isic,N} = CLTSAL2A4TS_{istyl,N} * CLTSICSHR_{is,istyl,isic} \quad for\ is = 1$$

$$and \quad \textbf{(B-125)}$$

$$CLTSAL_{is,istyl,isic,N} = CLTSALOSUS_{istyl,N} * CLTSICSHR_{is,istyl,isic} \quad for\ is = 2$$

where:

CLTSICSHR = Share of LCT sales allocated to each major-use group, by truck type and style

is = Index of truck type: 1 = 2-axle, 4-tire; 2 = other single-unit truck

isic = Index of major use group: 1 = Agriculture; 2 = Mining; 3 = Construction; 4 = Trade; 5 = Utilities; 6 = Personal

5) Update LCT stocks to reflect survival curve and sales:

$$CLTSTK_{is,istyl,isic,N} = CLTSTK_{is,istyl,isic,N-1} * SURVCLT_{is} + CLTSAL_{is,istyl,isic,N} \quad \textbf{(B-126)}$$

where:

CLTSTK = Light commercial truck stock

SURVCLT = Percentage of previous year's stock which gets carried over, by truck type

6) Estimate the VMT demand for LCT's, by sector:

$$CLTVMT_{is,istyl,isic,N} = CLTVMT_{is,istyl,isic,N-1} * \left[\frac{CLTSIC_{isic,N}}{CLTSIC_{isic,N-1}} \right] \quad \textbf{(B-127)}$$

where:

$CLTSIC_{isic}$ = Aggregate measures of industrial output for sectors 1-5; level of personal travel demand for sector 6.

7) Estimate new LCT fuel economy, assuming that growth from baseline (1992) values parallels that of other light-duty trucks:

$$NCLTMPG_{is,istyl,isic,N} = NCLTMPG_{is,istyl,isic,N-1} * \left[\frac{MPGT_N}{MPGT_{N-1}} \right] \quad \textbf{(B-128)}$$

where:

MPGT = Light-duty truck miles per gallon (gasoline technology), from the LDV Stock Module

8) Incorporate new LCT estimates into existing stock:

$$CLTMPG_{is,istyl,isic,N} = \left[\frac{\left\{ \left(\frac{CLTSTK_{is,istyl,isic,N-1} * SURVCLT_{is}}{CLTMPG_{is,istyl,isic,N-1}} \right) + \left(\frac{CLTSAL_{is,istyl,isic,N-1}}{NCLTMPG_{is,istyl,isic,N-1}} \right) * LTDFRFG_N \right\}}{CLTSTK_{is,istyl,isic,N}} \right]^{-1} \quad \textbf{(B-129)}$$

where:

CLTMPG = Stock MPG of light commercial trucks, by truck type and style

LTDFRFG = Scaling factor, associated with the increased use of reformulated gasoline

LIGHT COMMERCIAL TRUCK MODEL Subroutine TCLTMPG

9) Calculate aggregate sales-weighted new LCT MPG:

$$NCLTMPGT_N = \left[\sum_{is} \sum_{istyl} \sum_{isic} \left\{ \frac{\left(\frac{CLTSAL_{is,istyl,isic,N}}{\sum_{is} \sum_{istyl} \sum_{isic} CLTSAL_{is,istyl,isic,N}} \right)}{NCLTMPG_{is,istyl,isic,N}} \right\} \right]^{-1} \quad \textbf{(B-130)}$$

10) Calculate VMT-weighted stock average MPG for light commercial trucks:

$$CLTMPGT_N = \left[\sum_{is} \sum_{istyl} \sum_{isic} \left\{ \frac{\left(\frac{CLTVMT_{is,istyl,isic,N}}{\sum_{is} \sum_{istyl} \sum_{isic} CLTVMT_{is,istyl,isic,N} * 1e^9} \right)}{CLTMPG_{is,istyl,isic,N}} \right\} \right]^{-1} \quad \textbf{(B-131)}$$

11) Calculate fuel consumption in gallons and Btu's for each truck type, style, and major-use category:

$$CLTGAL_{is,istyl,isic,N} = \frac{CLTVMT_{is,istyl,isic,N}}{CLTMPG_{is,istyl,isic,N}}$$

and **(B-132)**

$$CLTBTU_{is,istyl,isic,N} = CLTGAL_{is,istyl,isic,N} * \frac{5.253}{42}$$

12) Calculate total Btu consumption by light commercial trucks, by summing over the indices:

$$CLTBTUT_N = \sum_{is} \sum_{istyl} \sum_{isic} CLTBTU_{is,istyl,isic,N}$$ **(B-133)**

LIGHT DUTY VEHICLE STOCK ACCOUNTING MODEL Subroutine TSMOD

1) Sum across size classes and regions to obtain vehicle sales by technology:

$$TECHNCS_{IT,T} = \sum_{OSC=1}^{6} \sum_{IR=1}^{9} NCSTECH_{IR,OSC,IT,T}$$

and: **(B-134)**

$$TECHNLT_{IT,T} = \sum_{OSC=1}^{6} \sum_{IR=1}^{9} NLTECH_{IR,OSC,IT,T}$$

where:

TECHNCS = Total new car sales, by technology
TECHNLT = Total new light truck sales, by technology
NCSTECH = New car sales, by region, size class, and technology, from the AFV Module
NLTECH = New light truck sales, by region, size class, and technology
OSC = Index of size class (1-6)
IR = Index of region (1-9)
IT = Index of vehicle technology (1-16)

2) These variables are assigned to the first vintages of the automobile and light truck stock arrays, and the population of subsequent vintages are calculated:

a) For *VINT* = 2-9:

$$PASSTK_{IT,VINT,T} = PASSTK_{IT,VINT-1,T-1} * SSURVP_{VINT-1}$$

and: **(B-135)**

$$LTSTK_{IT,VINT,T} = LTSTK_{IT,VINT-1,T-1} * SSURVLT_{VINT-1}$$

b) For *VINT* = 10:

$$PASSTK_{IT,VINT=10,T} = \left(PASSTK_{IT,VINT=9,T-1} * SSURVP_{VINT=9}\right) + \left(PASSTK_{IT,VINT=10,T-1} * SSURVP_{VINT=10}\right)$$

and **(B-136)**

$$LTSTK_{IT,VINT=10,T} = \left(LTSTK_{IT,VINT=9,T-1} * SSURVLT_{VINT=10}\right) + \left(LTSTK_{IT,VINT=10,T-1} * SSURVLT_{VINT=10}\right)$$

where:

PASSTK = Surviving automobile stock, by technology and vintage
LTSTK = Surviving light truck stock, by technology and vintage
SSURVP = Fraction of a given vintage's automobiles which survive
SSURVLT = Fraction of a given vintage's light trucks which survive
VINT = Index of vehicle vintage (1-10)

3) Add retired fleet vehicles to the appropriate vintage of the non-fleet population:

$$PASSTK_{IT,TVINT} = PASSTK_{IT,TVINT} + OLDFSTK_{VT=1,TYPE,ITECH,TVINT}$$

and: **(B-137)**

$$LTSTK_{IT,TVINT} = LTSTK_{IT,TVINT} + OLDFSTK_{VT=2,TYPE,ITECH,TVINT}$$

where:

OLTFSTK = Number of fleet vehicles rolled over into corresponding private categories
TVINT = Transition vintage: vintage at which vehicles of a given type are transferred
TYPE = Type of fleet vehicle: Business, Government, or Utility
ITECH = Index for the six fleet vehicle technologies: mapped to corresponding *IT* index

4) Sum over vintages and technologies to obtain total stocks of cars and light trucks:

$$STKCAR_T = \sum_{VINT=1}^{10} \sum_{IT=1}^{16} PASSTK_{IT,VINT,T}$$

and: **(B-138)**

$$STKTR_T = \sum_{VINT=1}^{10} \sum_{IT=1}^{16} LTSTK_{IT,VINT,T}$$

where:

STKCAR = Total stock of non-fleet automobiles in year *T*

STKTR = Total stock of non-fleet light trucks in year *T*

5) Calculate LDV shares of each technology:

$$VSPLDV_{IT,T} = \frac{\sum_{VINT=1}^{10} \left(PASSTK_{IT,VINT,T} + LTSTK_{IT,VINT,T} \right)}{STKCAR_T + STKTR_T} \quad \textbf{(B-139)}$$

where:

VSPLDV = The light duty vehicle shares of each of the sixteen vehicle technologies

LIGHT DUTY VEHICLE STOCK ACCOUNTING MODEL Subroutine TMPGSTK

1) Map non-gasoline vehicle sales from six to three size classes (*IT* = 1-15):

$$NCS3A_{IS,IT,T} = \sum_{OSC} \sum_{IR=1}^{9} NCSTECH_{IR,OSC,IT,T}$$

and **(B-140)**

$$NLT3A_{IS,IT,T} = \sum_{OSC} \sum_{IR=1}^{9} NLTECH_{IR,OSC,IT,T}$$

where:

NCS3A = New car sales by reduced size class and engine technology:

IS = 1, *OSC* = 1,6; *IS* = 2, *OSC* = 2,3; *IS* = 3, *OSC* = 4,5

NLT3A = New light truck sales by reduced size class and technolgy:

IS = 1, *OSC* = 1,3; *IS* = 2, *OSC* = 2,5; *IS* = 3, *OSC* = 4,6

NCSTECH = New car sales by region, technology, and six size classes

NLTECH = New light truck sales by region, technology, and six size classes

2) Calculate total regional sales of vehicles by reduced size class:

$$NCSR_{IR,IS,T} = \sum_{OSC} NCS_{IR,OSC,T}$$

and **(B-141)**

$$NLTSR_{IR,IS,T} = \sum_{OSC} NLTS_{IR,OSC,T}$$

where:

NCSR = Regional new car sales by reduced size class
NLTSR = Regional new light truck sales by reduced size class

3) Sum across regions:

$$NCS3SC_{IS,T} = \sum_{IR=1}^{9} NCSR_{IR,IS,T}$$

and **(B-142)**

$$NLTS3SC_{IS,T} = \sum_{IR=1}^{9} NLTSR_{IR,IS,T}$$

where:

NCS3SC = Total new car sales by reduced size class
NLTS3SC = Total new light truck sales by reduced size class

4) Sum conventional vehicle sales across regions:

$$NNCSCA_{OSC,T} = \sum_{IR=1}^{9} NCSTECH_{IR,OSC,IT=16,T}$$

and **(B-143)**

$$NNLTCA_{OSC,T} = \sum_{IR=1}^{9} NLTECH_{IR,OSC,IT=16,T}$$

where:

NNCSCA = New conventional car sales by six size classes
NNLTCA = New conventional light truck sales by six size classes

5) Calculate average MPG within reduced size classes:

$$AMPGC_{IS,T} = \sum_{OSC} \frac{NCMPG_{VT=1,OSC,T}}{2}$$

and **(B-144)**

$$AMPGT_{IS,T} = \sum_{OSC} \frac{NCMPG_{VT=2,OSC,T}}{2}$$

where:

AMPGC = Average new car MPG mapped from six to three size classes:

IS = 1, *OSC* = 2,3; *IS* = 2, *OSC* = 1,6; *IS* = 3, *OSC* = 4,5

AMPGT = Average new truck MPG mapped from six to three size classes:

IS = 1, *OSC* = 1,3; *IS* = 2, *OSC* = 2,5; *IS* = 3, *OSC* = 4,6

VT = Index of vehicle type: 1 = cars, 2 = light trucks

6) Calculate ratio of truck to car MPG by size class:

$$RATIO_{IS,T} = \frac{AMPGT_{IS,T}}{AMPGC_{IS,T}} \quad \textbf{(B-145)}$$

where:

RATIO = Light truck MPG adjustment factor

7) Calculate the average efficiencies of the fifteen non-gasoline technologies:

$$MPGC_{IT,T} = \left[\frac{\sum_{IS=1}^{3} \frac{NCS3A_{IS,IT,T}}{NAMPG_{IT,IS,T}}}{\sum_{IS=1}^{3} NCS3A_{IS,IT,T}} \right]^{-1}$$

and: **(B-146)**

$$MPGT_{IT,T} = \left[\frac{\sum_{IS=1}^{3} \frac{NLT3A_{IS,IT,T}}{NAMPG_{IT,IS,T} \; * \; RATIO_{IS,T}}}{\sum_{IS=1}^{3} NLT3A_{IS,IT,T}} \right]^{-1}$$

where:

MPGC = New car fuel efficiency, by engine technology
MPGT = New light truck fuel efficiency, by engine technology
NAMPG = New AFV fuel efficiency, from the AFV model

8) Calculate new vehicle MPG for gasoline ICE's (IT = 16):

$$MPGC_{IT=16,T} = \left[\frac{\sum_{OSC=1}^{6} \frac{NNCSCA_{OSC,T}}{NCMPG_{OSC,T}}}{\sum_{OSC=1}^{6} NNCSCA_{OSC,T}} \right]^{-1}$$

and: **(B-147)**

$$MPGT_{IT=16,T} = \left[\frac{\sum_{OSC=1}^{6} \frac{NNLTCA_{OSC,T}}{NLTMPG_{OSC,T}}}{\sum_{OSC=1}^{6} NNLTCA_{OSC,T}} \right]^{-1}$$

where:

NCMPG = New car MPG, from the FEM model
NLTMPG = New light truck MPG, from the FEM model

9) Calculate average fuel efficiency across all technologies for cars and light trucks:

$$ANCMPG_{T} = \left[\sum_{IT=1}^{16} \frac{APSHRNC_{IT,T}}{MPGC_{IT,T}} \right]^{-1}$$

and: **(B-148)**

$$ANTMPG_{T} = \left[\sum_{IT=1}^{16} \frac{APSHRNT_{IT,T}}{MPGT_{IT,T}} \right]^{-1}$$

where:

ANCMPG = Average new car MPG
ANTMPG = Average new light truck MPG
APSHRNC = Absolute market share of new cars, by technology, from the AFV model
APSHRNT = Absolute market share of new light trucks, by technology, from the AFV model

10) Calculate total miles driven by each type of vehicle:

$$TOTMICT_T = \sum_{IT=1}^{16} \sum_{IV=1}^{10} PASSTK_{IT,IV,T} * PVMT_{IV}$$

and: **(B-149)**

$$TOTMITT_T = \sum_{IT=1}^{16} \sum_{IV=1}^{10} LTSTK_{IT,IV,T} * LVMT_{IV}$$

where:

TOTMICT = Total miles driven by cars
TOTMITT = Total miles driven by light trucks
PVMT = Average automobile VMT, by vintage, from RTECS
LVMT = Average light truck VMT, by vintage, from RTECS

11) Calculate total energy consumption:

$$CMPGT_T = \sum_{IT=1}^{16} \sum_{IV=1}^{10} \frac{PASSTK_{IT,IV,T} * PVMT_{IV}}{CMPGSTK_{IT,IV,T} * VDF_{VT=1}}$$

and: **(B-150)**

$$TMPGT_T = \sum_{IT=1}^{16} \sum_{IV=1}^{10} \frac{LTSTK_{IT,IV,T} * LVMT_{IV}}{TTMPGSTK_{IT,IV,T} * VDF_{VT=2}}$$

where:

CMPGT = Automobile stock MPG
TMPGT = Light truck stock MPG
CMPGSTK = Automobile stock MPG, by vintage and technology
TTMPGSTK = Light truck stock MPG, by vintage and technology
VDF = Vehicle fuel efficiency degradation factor: $VT = 1$ for cars, $VT = 2$ for trucks

12) Calculate stock fuel efficiency:

$$SCMPG_T = \frac{TOTMICT_T}{CMPGT_T}$$

and: **(B-151)**

$$STMPG_T = \frac{TOTMITT_T}{TMPGT_T}$$

where:

SCMPG = Stock MPG for automobiles
STMPG = Stock MPG for light trucks

13) Calculate average fuel efficiency of light duty vehicles:

$$MPGFLT_T = \frac{TOTMICT_T + TOTMITT_T}{CMPGT_T + TMPGT_T} \quad \textbf{(B-152)}$$

where:

MPGFLT = Stock MPG for all light duty vehicles

14) Calculate average fuel efficiency by technology:

$$MPGTECH_{IT,N} = \frac{\sum_{IV=1}^{10} \frac{PASSTK_{IT,IV,T} * PVMT_{IV}}{CMPGSTK_{IT,IV,T} * VDF_{VT=1}} + \sum_{IV=1}^{10} \frac{LTSTK_{IT,IV,T} * LVMT_{IV}}{TTMPGSTK_{IT,IV,T} * VDF_{VT=2}}}{TOTMICT_T + TOTMITT_T} \quad \textbf{(B-153)}$$

where:

MPGTECH = Average stock MPG by technology

1) Calculate the cost of driving per mile:

$$COSTMI_T = \frac{TPMGTR_T * 0.125}{MPGFLT_T} \quad \textbf{(B-154)}$$

where:

COSTMI = Cost of driving per mile
TPMGTR = Price of motor gasoline
MPGFLT = Fuel economy of the automobile fleet
0.125 = Conversion factor for gasoline, in MMBtu/gallon

2) Calculate per capita income:

$$INCOME_T = \frac{TMC\_YD_T}{TMC\_POPAFO_T} \quad \textbf{(B-155)}$$

where:

INCOME = Per capita disposable personal income
TMC_YD = Total disposable personal income, from MACRO module
TMC_POPAFO = Total population, from MACRO module

3) Calculate unadjusted VMT per capita:

$$\begin{aligned} VMT16_T = {} & RHO \cdot VMTPC_{T-1} + ALPHA\,(1 - RHO) \\ & - BETAPE\,(COSTMI_T - RHO \cdot COSTMI_{T-1}) \\ & + BETAIE\,(INCOME_T - RHO \cdot INCOME_{T-1}) \\ & + BETADEM\,(PrFem_T - RHO \cdot PrFem_{T-1}) \end{aligned} \quad \textbf{(B-156)}$$

where:

VMT16 = Per capita VMT for persons 16 and older
ALPHA = Constant parameter for the VMT difference equation
BETAPE = Parameter associated with the cost of driving
BETAIE = Parameter associated with disposable persoal income
BETADEM = Parameter associated with demographic influences

PrFem = Ratio of per capita female driving to per capita male driving.
RHO = Lag factor, estimated using the Cochrane-Orcutt iterative procedure to be 0.72.

4) Calculate adjusted VMT per capita:

$$ADJVMTPC_T = VMT16_T \cdot DAF_T \quad \textbf{(B-157)}$$

where:

ADJVMTPC = Demographically-adjusted per capita VMT
DAF = Demographic adjustment factor

5) Calculate total VMT:

$$VMTLDV_T = ADJVMTPC_T * TMC\_POP16_T \quad \textbf{(B-158)}$$

where:

VMTLDV = Total VMT for light duty vehicles

6) Calculate net VMT, subtracting off fleet and light truck freight VMT:

$$VMTEE_T = VMTLDV_T - \left(FLTVMT_T + FVMTSC_{IS=1,T}\right) \quad \textbf{(B-159)}$$

where:

VMTEE = VMT for personal travel
FLTVMT = Fleet VMT
FVMTSC = Freight VMT by size class

7) Calculate VMT by technology:

$$VMTECH_{IT,T} = VMTEE_T * VSPLDV_{IT,T} \quad \textbf{(B-160)}$$

where:

VMTECH = Personal travel VMT by technology
VSPLDV = Sales shares of vehicles by technology

8) Calculate fractional change of VMT:

$$XLDVMT_T = \frac{VMTEE_T}{VMTEE_{T=1}} \quad \textbf{(B-161)}$$

where:

XLDVMT = Fractional change of VMT over base year (1990)

VEHICLE MILES TRAVELED MODEL Subroutine TFREISMOD

1) Calculate light truck sales dedicated to freight:

$$TRSAL_T = 0.408427 * TMC\_SQDTRUCKSL_T \quad \textbf{(B-162)}$$

where:

TRSAL = Light truck sales for freight
TMC_SQDTRUCKSL = Total light truck sales, from MACRO module

2) Calculate sales by technology:

$$TRSALTECH_{IT,T} = TRSAL_T * FLVMTSHR_{IS=1,IT,T} \quad \textbf{(B-163)}$$

where:

TRSALTECH = Light truck sales by technology
FLVMTSHR = VMT-weighted shares by size class and technology

3) Add to vintage array and adjust stock survival:

$$TRSTKTECH_{IT,IV=1,T} = TRSALTECH_{IT,T}$$

$$TRSTKTECH_{IT,IV,T} = TRSTKTECH_{IT,IV-1,T-1} * SSURVLT_{IV-1} \quad ; \quad IV = 2 - 9$$

and **(B-164)**

$$TRSTKTECH_{IT,IV=10,T} = \left(TRSTKTECH_{IT,IV=9,T-1} * SSURVLT_{IV=9}\right) + \left(TRSTKTECH_{IT,IV=10,T-1} * SSURVLT_{IV=10}\right)$$

where:

TRSTKTECH = Light truck stock by technology

SSURVLT = Array of survival rates for light trucks

4) Sum over vintages:

$$TRSTKTOT_{IT,T} = \sum_{IV=1}^{10} TRSTKTECH_{IT,IV,T} \quad \textbf{(B-165)}$$

where:

TRSTKTOT = Total light truck stock by technology

5) Sum over technologies:

$$TRSTK_{T} = \sum_{IT=1}^{5} TRSTKTOT_{IT,T} \quad \textbf{(B-166)}$$

where:

TRSTK = Total light truck stock

6) Calculate average MPG for light trucks:

$$TRFLTMPG_{T} = \left[\frac{\sum_{IT=1}^{5} \left(\frac{TRSTKTOT_{IT,T}}{FMPG_{IS=1,IT,T}} \right)}{\sum_{IT=1}^{5} TRSTKTOT_{IT,T}} \right]^{-1} \quad \textbf{(B-167)}$$

where:

TRFLTMPG = Average light truck MPG

This subroutine calculates aggregate fuel efficiencies for cars and light trucks.

1) Sum fleet vehicle sales over size class:

$$FLTECHSALT_{VT,ITY,ITECH,T} = \sum_{IS=1}^{3} FLTECHSAL_{VT,ITY,IS,ITECH,T} \qquad \textbf{(B-168)}$$

where:

FLTECHSALT = Vehicle purchases by fleet type and technolgy
FLTECHSAL = Fleet sales by size, technology, and fleet type
VT = Index of vehicle type: 1 = cars, 2 = light trucks
ITECH = Index of engine technology (1-6)
ITY = Index of fleet type: Business, Government, Utility
IS = Index of size class (1-3)

2) Calculate new vehicle MPG:

$$FLTMPGNEW_{VT,ITECH,T} = \left[\frac{\sum_{ITY=1}^{3} \frac{FLTECHSALT_{VT,ITY,ITECH,T}}{FLTMPG_{VT,ITY,ITECH,T}}}{\sum_{ITY=1}^{3} FLTECHSALT_{VT,ITY,ITECH,T}} \right]^{-1} \qquad \textbf{(B-169)}$$

where:

FLTMPGNEW = New fleet vehicle MPG by vehicle type and technology
FLTMPG = Fleet vehicle MPG by vehicle type, size class, and technology

3) Sum fleet stock across fleet types:

$$FLTSTOCK_{VT,ITECH,T} = \sum_{ITY=1}^{3} FLTECHSTK_{VT,ITY,ITECH,T} \qquad \textbf{(B-170)}$$

where:

FLTSTOCK = Total fleet vehicle stock, by technology
FLTECHSTK = Total fleet vehicle stock, by technology and fleet type

4) Calculate average MPG of fleet and non-fleet vehicles, by technology:

a) For cars:

$$CCMPGLDV_{IT,T} = \left[\frac{\left(\frac{TECHNCS_{IT,T}}{MPGC_{IT,T}} \right) + \left(\frac{FLTSTOCK_{VT=1,ITECH,T}}{FLTMPGNEW_{VT=1,ITECH,T}} \right)}{TECHNCS_{IT,T} + FLTSTOCK_{VT=1,ITECH,T}} \right]^{-1} \quad \textbf{(B-171)}$$

where:

CCMPGLDV = New car MPG, by technology *IT*
IT = Index of vehicle technology (1-16)
ITECH = Index of fleet vehicle technologies which correspond to the *IT* index
TECHNCS = Non-fleet new car sales, by technology *IT*
MPGC = New car MPG, by technology *IT*
FLTSTOCK = New fleet stock, by vehicle type and technology *ITECH*
FLTMPGNEW = New fleet vehicle MPG, by vehicle type and technology *ITECH*

b) For light trucks:

$$TTMPGLDV_{IT,T} = \left[\frac{\left(\frac{TECHNLT_{IT,T}}{MPGT_{IT,T}} \right) + \left(\frac{FLTSTOCK_{VT=2,ITECH,T}}{FLTMPGNEW_{VT=2,ITECH,T}} \right)}{TECHNLT_{IT,T} + FLTSTOCK_{VT=2,ITECH,T}} \right]^{-1} \quad \textbf{(B-172)}$$

where:

TTMPGLDV = New light truck MPG, by technology *IT*
TECHNLT = Non-fleet new light truck sales, by technology *IT*
MPGT = New light truck MPG, by technology *IT*

5) Calculate total stock by vehicle type and technology:

$$STOCKLDV_{VT,IT2,T} = STKCT_{VT,IT,T} + FLTSTOCK_{VT,ITECH,T} \quad \textbf{(B-173)}$$

where:

STOCKLDV = Total stock of fleet and non-fleet vehicles, by technology
STKCT = Stock of non-fleet vehicles, by technology
IT = Index of vehicle technology (1-16)

$IT2$ = Reassigned indices of vehicle technology $IT2$ = 1-16; IT = 16,15,1-14

$ITECH$ = Index of fleet technologies which map to corresponding IT and $IT2$ as follows:

$IT2$ = 1,3,5,7,8,9; IT = 16,1,3,5,6,7; $ITECH$ = 6,1,2,3,4,5

6) Calculate total stock across technologies:

$$TSTOCKLDV_{VT,T} = \sum_{IT2=1}^{16} STOCKLDV_{VT,IT2,T} \qquad \text{(B-174)}$$

where:

TSTOCKLDV = Total stock by vehicle type VT

7) Calculate average MPG of cars and light trucks:

$$TMPGLDVSTK_{VT=1,T} = \left[\frac{\sum_{IT2=1}^{16} \left(\dfrac{STOCKLDV_{VT=1,IT2,T}}{CCMPGLDV_{IT2,T}} \right)}{\sum_{IT2=1}^{16} STOCKLDV_{VT=1,IT2,T}} \right]^{-1}$$

and **(B-175)**

$$TMPGLDVSTK_{VT=2,T} = \left[\frac{\sum_{IT2=1}^{16} \left(\dfrac{STOCKLDV_{VT=2,IT2,T}}{TTMPGLDV_{IT2,T}} \right)}{\sum_{IT2=1}^{16} STOCKLDV_{VT=2,IT2,T}} \right]^{-1}$$

where:

TMPGLDVSTK = Average MPG by vehicle type VT

8) Calculate overall average MPG of light-duty vehicle fleet:

$$TLDVMPG_{T} = \left[\frac{\sum_{VT=1}^{2} \left(\dfrac{TSTOCKLDV_{VT,T}}{TMPGLDVSTK_{VT,T}} \right)}{\sum_{VT=1}^{2} TSTOCKLDV_{VT,T}} \right]^{-1} \qquad \text{(B-176)}$$

where:

TLDVMPG = Average fuel economy of light-duty vehicles

HIGHWAY FREIGHT MODEL Subroutine TFREI

Estimate New Truck Fuel Economies

1) Calculate the average fuel price over the previous three years:

$$AVGPRC_{T,FUEL} = \frac{(PRICE_{T,FUEL} + PRICE_{T-1,FUEL} + PRICE_{T-2,FUEL})}{3} \qquad \textbf{(B-177)}$$

where:

T = Index referring to model run year; where T = 0,...,23

$FUEL$ = Index referring to fuel type, where $FUEL$ = 1 refers to diesel, $FUEL$ = 2 refers to gasoline, $FUEL$ = 3 refers to LPG and $FUEL$ = 4 refers to CNG

AVGPRC = Average price of fuel $FUEL$ over three year period, in $ per MBtu

PRICE = Price of each fuel, in $ per MBtu

2) If the technology has not yet entered market and the average price is greater than the technology's trigger price, the technology enters the market during the current year:

$$For\ TECH = 6,...,16$$

$$If \quad AVGPRC_{T,FUEL} \geq TRIGPRC_{SC,FUEL,TECH} \qquad \textbf{(B-178)}$$

$$!$$

$$INITYR_{SC,FUEL,TRECH} = T$$

where:

$TECH$ = Index referring to fuel-saving technologies, where $TECH$ = 1,...,5 refers to currently available technologies and $TECH$ = 6,...,16 refers to future technologies

SC = Index referring to truck size class, where SC = 2 refers to medium trucks and SC = 3 refers to heavy trucks

INITYR = Year in which technology $TECH$ enters market

TRIGPRC = Exogenously determined fuel price at which technology $TECH$ becomes economically viable

3) If a future technology enters market in the current year, coefficients for the logistic market penetration curve are determined:

$$COEFT_{SC,FUEL,TECH} = \frac{\ln(0.01)}{\left[\frac{CYCLE_{SC,FUEL,TECH}}{2}\right]}$$

and **(B-179)**

$$MIDYR_{SC,FUEL,TECH} = INITYR_{SC,FUEL,TECH} + \left[\frac{CYCLE_{SC,FUEL,TECH}}{2}\right]$$

where:

COEFT = Endogenously determined logistic market penetration curve parameter

CYCLE = Exogenously determined logistic market penetration curve parameter representing number of years until 99 percent of maximum market penetration

MIDYR = Endogenously determined logistic market penetration curve parameter

4) For each technology which has entered the market, and for existing technologies, the effect of fuel prices on market penetration is determined for the current year:

$$PREFF_{T,SC,FUEL,TECH} = 1 + PRCVAR_{SC,FUEL,TECH} \cdot \left[\frac{AVGPRC_{T,FUEL}}{TRIGPRC_{SC,FUEL,TECH}} - 1\right] \quad \textbf{(B-180)}$$

where:

PREFF = Effect of fuel price on market penetration rates for six fuel-saving technologies

PRCVAR = Exogenously determined fuel price sensitivity parameter for each technology, representing percent increase in technology market share if fuel price exceeds trigger price by 100%

5) For each available technology, including existing technologies, the model determines its share of the available market in the current year:

$$For\ TECH = 1,...,5$$

$$TECH_{T,SC,FUEL,TECH} = \min \left\{ PREFF_{T,SC,FUEL,TECH} \cdot [\ BSHRT_{SC,TECH} + \left(ESHRT_{SC,FUEL,TECH} - BSHRT_{SC,TECH}\right) \cdot \left(1 - e^{CONST_{SC,TECH} + COEFT_{SC,TECH} \cdot T}\right)]\ ,\ 1 \right. \tag{B-181}$$

$$For\ TECH = 6,.....,16$$

$$TECHSHR_{T,SC,FUEL,TECH} = \min \left\{ PREFF_{T,SC,FUEL,TECH} \cdot \frac{ESHRT_{SC,FUEL,TECH}}{1 + e^{COEFT_{SC,FUEL,TECH} \cdot \left(T - MDYR_{SC,FUEL,TECH}\right)}}\ ,\ 1 \right\}$$

where:

TECHSHR = Market share of fuel-saving technology *TECH* for size class *SC* and fuel type *FUEL*
CONST = Exogenously determined market penetration curve parameter for existing technologies
COEFT = Market penetration curve parameter; exogenous for existing technologies, endogenous for future technologies
BSHRT = Exogenously determined market penetration curve parameter representing market share of existing technology *TECH* in 1992
ESHRT = Exogenously determined market penetration curve parameter representing final market share of technology *TECH* if fuel price were always equal to trigger price

6) If a technology A is superseded by another mutually exclusive technology B at any time during the model run, technology A's market share must be adjusted to reflect the smaller pool of vehicles in its base market:

$$TECHSHR_{T,SC,FUEL,TECH} = \left(1 - SPRSDEFF_{T,SC,FUEL,TECH}\right) \cdot TECHSHR_{T,SC,FUEL,TECH} \tag{B-182}$$

where:

SPRSDEFF = Superseding effect, equal to the market share of the superseding technology

7) Determine MPG effects:

$$MPGEFF_{T,SC,FUEL} = \prod_{TECH=1}^{16} \left(1 + MPGINCR_{SC,FUEL,TECH} \cdot TECHSHR_{T,SC,FUEL,TECH}\right) \tag{B-183}$$

where:

MPGEFF = Total effect of all fuel-saving technologies on new truck fuel economy in year *T*
MPGINCR= Exogenous factor representing percent improvement in fuel economy due to each technology

8) Fuel economy of new medium and heavy trucks can finally be determined:

$$MPG_{T,SC,AGE=0,FUEL} = BASEMPG_{SC,FUEL} \cdot MPGEFF_{T,SC,FUEL} \qquad \text{(B-184)}$$

where:

BASEMPG = Fuel economy of new medium and heavy trucks with no fuel-saving technologies

Determine the Share of Each Fuel Type in Current Year's Class of New Trucks

9) Calculate the fuel cost per mile for trucks of each size class and fuel type:

$$FCOST_{T,SC,FUEL} = \frac{AVGPRC_{T,FUEL}}{MPG_{T,SC,FUEL}} \cdot HTRATE \qquad \text{(B-185)}$$

where:

FCOST = Fuel cost of driving a truck of fuel type *FUEL*, in dollars per mile

HTRATE = Heat rate of gasoline, in million Btu per gallon

10) Calculate the fuel cost of driving diesel trucks relative to AFVs:

$$RCOST_{T,SC,FUEL} = 1 - \left[\frac{FCOST_{T,SC,FUEL}}{FCOST_{T,SC,FUEL=1}} - 1 \right] \cdot PRCDIFFVAR_{SC,FUEL} \qquad \text{(B-186)}$$

where:

RCOST = Fuel cost per mile of diesel relative to LPG and CNG

PRCDIFFVAR = Exogenously determined parameter representing inherent variation in AFV market share due to difference in fuel prices

11) Determine the market penetration curve parameters during a user-specified trigger year:

$$COEFAFV_{SC,FUEL,FLT} = \frac{\ln(0.01)}{\left[\frac{CYCAFV_{SC,FUEL,FLT}}{2} \right]}$$

$$and \qquad \text{(B-187)}$$

$$MYRAFV_{SC,FUEL,FLT} = TRYRAFV_{SC,FUEL,FLT} + \frac{CYCAFV_{SC,FUEL,FLT}}{2}$$

where:

FLT	=	Index referring to fleet type, where *FLT* = 1 refers to trucks in fleets of nine or less and *FLT* = 2 refers to trucks in fleets of ten or more
COEFAFV	=	Endogenously determined logistic market penetration curve parameter
CYCAFV	=	Exogenously determined logistic market penetration curve parameter representing number of years until maximum market penetration
MYRAFV	=	Logistic market penetration curve parameter representing “halfway point” to maximum market penetration
TRYRAFV	=	Exogenously determined year in which each alternative fuel begins to increase in market share, due to EPACT or other factors

12) The AFV market trend is determined through a logistic function:

$$MPATH_{T,SC,FUEL,FLT} = RCOST_{T,SC,FUEL} \cdot \left[BSHRF_{SC,FUEL,FLT} + \frac{ESHRF_{SC,FUEL,FLT} - BSHRF_{SC,FUEL,FLT}}{1 + e^{COEFAFV_{SC,FUEL,FLT} \cdot (T - MYRAFV_{SC,FUEL,FLT})}} \right] \quad \textbf{(B-188)}$$

where:

BSHRF	=	Base year (1992) market share of each fuel type
ESHRF	=	Exogenously determined final market share of each fuel type

13) Forecast the share of diesel in conventional truck sales:

$$MPATH_{T,SC,FUEL=1,FLT} = BSHRF_{SC,FUEL,FLT} + \left[ESHRF_{SC,FUEL,FLT} - BSHRF_{SC,FUEL,FLT} \right] \cdot \left(1 - e^{CONSD_{SC,FLT} + COEFT_{SC,FLT} \cdot T} \right) \quad \textbf{(B-189)}$$

where:

CONSD	=	Exogenously determined market penetration curve parameter for diesel trucks
COEFD	=	Exogenously determined market penetration curve parameter for diesel trucks

14) The actual AFV market share is thus calculated as the maximum of historical and forecast shares:

$$FSHR_{T,SEC,SC,FUEL=3,4,FLT} = \max \left[BSEC_{SEC,SC,FUEL,FLT} \, , \, MPATH_{T,SC,FUEL,FLT} \right] \quad \textbf{(B-190)}$$

where:

BSEC	=	Exogenously determined base year (1992) share of alternative fuels in truck purchases

15) Diesel market share is calculated as the forecast share of diesel in conventional truck sales multiplied by the share occupied by conventional trucks:

$$FSHR_{T,SEC,SC,FUEL=1,FLT} = \left(1 - \sum_{FUEL=3}^{4} FSHR_{T,SEC,SC,FUEL,FLT}\right) \cdot \left(\min\left[MPATH_{T,SC,FUEL,FLT} \cdot BSECD_{SEC,SC,FLT}\ ,\ 1\right]\right) \quad \textbf{(B-191)}$$

where:

BSECD = Exogenously determined parameter representing tendency of each sector to purchase diesel trucks

16) The remainder of truck purchases are assumed to be gasoline:

$$FSHR_{T,SEC,SC,FUEL=2,FLT} = 1 - \sum_{FUEL=1,3,4} FSHR_{T,SEC,SC,FUEL,FLT} \quad \textbf{(B-192)}$$

Determine Composition of Existing Truck Stock

17) Scrappage rates are applied to the current truck population:

$$TRKSTK_{T,SEC,SC,AGE,FUEL,FLT} = TRKSTK_{T-1,SEC,SC,AGE-1,FUEL,FLT} \cdot \left(1 - SCRAP_{SC,AGE-1}\right) \quad \textbf{(B-193)}$$

where:

TRKSTK = Stock of trucks in year T

SCRAP = Exogenously determined factor which consists of the percentage of trucks of each age which are scrapped each year

18) A number of trucks are transferred in each year from fleets of ten or more to fleets of nine or less. Transfers of conventional trucks are based on exogenously determined transfer rates:

$$TRF1_{T,SEC,SC,AGE,FUEL} = TRFRATE_{SC,AGE} \cdot TRKSTK_{T,SEC,SC,AGE,FUEL,FLT=2} \quad \textbf{(B-194)}$$

where:

TRF1 = Number of trucks transferred from fleet to non-fleet populations, if no restrictions are placed on the transfer of alternative-fuel trucks

TRFRATE = Exogenously determined parameter representing the percentage of trucks of each vintage to be transferred from fleets to non-fleets in each year

19) Restricted AFV transfers are calculated as follows:

$$TRF2_{T,SEC,SC,AGE,FUEL=3,4} = FSHR_{T,SEC,SC,FUEL,FLT=1} \cdot TRFRATE_{SC,AGE} \cdot \sum_{FUEL=1}^{4} TRKSTK_{T,SEC,SC,AGE,FUEL,FLT=1} \quad \textbf{(B-195)}$$

where:

TRF2 = Number of trucks transferred from fleet to non-fleet populations, if the fuel mix of fleet transfers is exactly the same as the fuel mix of new non-fleet purchases

20) Actual fleet transfers are then defined as the unrestricted fleet transfers as calculated in *TRF1* for conventional trucks, and the minimum of unrestricted and restricted transfers for AFVs:

$$TRF_{T,SEC,SC,AGE,FUEL=1,2} = TRF1_{T,SEC,SC,AGE,FUEL,FLT}$$

$$and \quad \textbf{(B-196)}$$

$$TRF_{T,SEC,SC,AGE,FUEL=3,4} = \min\left[TRF1_{T,SEC,SC,AGE,FUEL}\ ,\ TRF2_{T,SEC,SC,AGE,FUEL}\right]$$

where:

TRF = Total number of trucks transferred from fleet to non-fleet populations

21) Allocate fleet transfers based on each sector's share of the total non-fleet truck population of each vintage of trucks:

$$TRFSHR_{T,SC,SEC} = \frac{\sum_{FUEL=1}^{4} \sum_{AGE=1}^{11} sUSUMTRKSTK_{T,SEC,SC,AGE,FUEL,FLT=1}}{\sum_{FUEL=1}^{4} \sum_{AGE=1}^{11} \sum_{SEC=1}^{12} TRKSTK_{T,SEC,SC,AGE,FUEL,FLT=1}} \quad \textbf{(B-197)}$$

where:

TRFSHR = Share of fleet transfers which goes to each sector

22) The new existing population of trucks is simply the existing population (after scrappage) modified by fleet transfers:

$$TRKSTK_{T,SEC,SC,AGE,FUEL,FLT=2} = TRKSTK_{T,SEC,SC,AGE,FUEL,FLT=2} - TRF_{T,SEC,SC,AGE,FUEL}$$

$$and \quad \textbf{(B-198)}$$

$$TRKSTK_{T,SEC,SC,AGE,FUEL,FLT=1} = TRKSTK_{T,SEC,SC,AGE,FUEL,FLT=1} + TRFSHR_{T,SEC,SC} \cdot \sum_{SEC=1}^{12} TRF_{T,SEC,SC,AGE,FUEL}$$

Calculate Purchases of New Trucks

23) Calculate index of average annual VMT per truck:

$$VMTTREND_{T,SC} = \frac{BSHRV_{SC} + \left(ESHRV_{SC} - BSHRV_{SC}\right) \cdot \left(1 - e^{CONSV_{SC} + COEFV_{SC} \cdot T}\right)}{BSHRV_{SC} + \left(ESHRV_{SC} - BSHRV_{SC}\right) \cdot \left(1 - e^{CONSV_{SC} + COEFV_{SC} \cdot 1992}\right)} \quad \textbf{(B-199)}$$

where:

VMTTREND = Index of average annual VMT per truck, where 1992 = 1

BSHRV = Exogenously determined VMT per vehicle increase factor representing minimum annual vehicle mileage

ESHRV = Exogenously determined VMT per vehicle increase factor representing maximum annual vehicle mileage

CONSV = Exogenously determined exponential VMT per vehicle increase factor

COEFV = Exogenously determined exponential VMT per vehicle increase factor

24) Calculate VMT per truck in each year:

$$ANNVMT_{T,SEC,SC,AGE,FUEL} = ANNVMTBASE_{T,SEC,SC,AGE,FUEL} \cdot VMTTREND_{T,SC} \quad \textbf{(B-200)}$$

where:

ANNVMT = Average annual VMT per vehicle by sector, size class, truck age and fuel type

ANNVMTBASE = Base year average annual VMT per vehicle by sector, size class, truck age and fuel type

25) Determine the VMT which can be provided by the current population of trucks in each sector:

$$VMTOLD_{T,SEC} = \sum_{FLT=1}^{2} \sum_{FUEL=1}^{16} \sum_{AGE=1}^{11} \sum_{SC=1}^{3} TRKSTK_{T,SEC,SC,AGE,FUEL,FLT} \cdot ANNVMT_{SEC,SC,AGE,FUEL} \quad \textbf{(B-201)}$$

where:

VMTOLD = VMT which can be provided by existing stock of trucks in each sector, after scrappage

26) Calculate the current year FAC as follows:

$$COEFFAC = \ln\left[\frac{9}{T90 - T50)}\right]$$

!

and **(B-202)**

$$FACTR_{T,SEC} = AFFACBASE_{SEC} + \frac{1 - FACBASE_{SEC}}{1 + e^{COEFFAC \cdot (T50 - T)}}$$

where:

COEFFAC = FAC decay parameter

T90 = User-specified year by which 90% of FAC decay is experienced

T50 = User-specified year by which 50% of FAC decay is experienced

FACTR = "Freight Adjustment Coefficient": factor relating growth in value added of sector *SEC* to growth in demand for freight truck VMT

FACBASE = Base year Freight Adjustment Coefficient

27) Calculate the actual VMT demand in each sector:

$$For\ T = 0$$

$$VMTDMD_{T,SEC} = VMTDMDBASE_{SEC} \cdot FACTR_{SEC} \cdot \frac{OUTPUT_{T,SEC}}{OUTPUT_{T-1,SEC}}$$

$$For\ T = 1-22$$

$$VMTDMD_{T,SEC} = VMTDMD_{T-1,SEC} \cdot FACTR_{SEC} \cdot \frac{OUTPUT_{T,SEC}}{OUTPUT_{T-1,SEC}}$$

(B-203)

where:

VMTDMD = Demand for freight travel by sector *SEC*, in year *T*

VMTDMDBASE = Demand for freight travel by sector *SEC*, in year 0

FACTR = "Freight Adjustment Coefficient": exogenously determined factor relating growth in value added of sector *SEC* to growth in demand for freight truck VMT

28) Calculate perceived VMT growth:

$$PVMTGROWTH_{T,SEC} = 0.5 \cdot \left[\frac{OUTPUT_{T,SEC}}{OUTPUT_{T-1,SEC}} - 1\right] + 0.5 \cdot \left[\frac{OUTPUT_{T-1,SEC}}{OUTPUT_{T-2,SEC}} - 1\right]$$ **(B-204)**

where:

PVMTGROWTH = Growth rate with which perceived demand for freight travel in year *T* is forecast by freight companies

29) Calculate perceived baselineVMT demand:

$$For\ T = 0$$

$$PVMTBASE_{T,SC} = 0.5 \cdot VMTDMDBASE_{SEC}$$

(B-205)

$$For\ T = 1-22$$

$$PVMTBASE_{T,SC} = 0.5 \cdot VMTDMD_{T,SEC} + 0.25 \cdot VMTDMD_{T-1,SEC}$$

where:

PVMTBASE = Baseline from which perceived demand for freight travel in year T is calculated.

30) Calculate perceived VMT demand:

$$PVMTBASE_{T,SEC} = 0.5 \cdot VMTDMT_{T-1,SEC} + 0.25 \cdot VMTDMD_{T-2,SEC}$$

$$and$$

(B-206)

$$VMTDMD_{T,SEC} = 0.25 \cdot VMTDMD_{T,SEC} + PVMTBASE_{T,SEC} \cdot \left(1 + PVMTGROWTH_{T,SEC}\right) \cdot FACTR_{SI}$$

where:

PVMTBASE = Baseline from which perceived demand for freight travel in year *T* is forecast by freight companies

PVMTDMD = Perceived demand for freight travel in year *T*

31) Calculate perceived unmet VMT demand, which is provided by purchasing new trucks:

$$PVMTUNMET_{T,SEC} = PVMTDMT_{T,SEC} - VMTOLD_{T,SEC}$$

(B-207)

where:

PVMTUNMET = Difference between perceived VMT demand and demand which can be met by existing stock of trucks

32) Allocate unmet VMT demand among size classes and fleet types by means of constant size class

and fleet type allocation factors.

$$PVMT_{T,SEC,SC,FLT=1} = MAX\left[PVMTUNMET_{T,SEC} \cdot VMTSCFAC_{SEC,SC} \cdot \left(1 - FLTSHR_{SEC,SC}\right),\ 0\right]$$

$$and \qquad \textbf{(B-208)}$$

$$PVMT_{T,SEC,SC,FLT=2} = MAX\left[PVMTUNMET_{T,SEC} \cdot VMTSCFAC_{SEC,SC} \cdot FLTSHR_{SEC,SC},\ 0\right]$$

where:

PVMT = Perceived demand for freight travel by new trucks of size class *SC* and fleet type *FLT* in sector *SEC*

VMTSCFAC = Exogenously determined parameter representing percentage of new truck sales which go to each size class *SC* in sector *SEC*

FLTSHR = Exogenous parameter representing percentage of new truck sales of each size class *SC* which go to fleets of ten or more in sector *SEC*

33) Calculate a fuel technology-weighted average annual VMT per vehicle of the current year's class of new fleet and non-fleet trucks:

$$PVN_{T,SEC,SC,FLT} = \sum_{FUEL=1}^{4} FSHR_{T,SEC,SC,FUEL,FLT} \cdot ANNVMT_{T,SEC,SC,AGE=0,FUEL} \qquad \textbf{(B-209)}$$

where:

AGE = 0 refers to new trucks

PVN = Annual VMT per vehicle for new trucks in year *T*

34) Truck purchases are finally calculated as the perceived unmet VMT demand divided by VMT per truck, weighted by fuel type:

$$TRKSTK_{T,SEC,SC,AGE=0,FUEL,FLT} = \left[\frac{PVMT_{T,SEC,SC,FLT}}{PVN_{T,SEC,SC,FLT}}\right] \cdot FSHR_{T,SEC,SC,FUEL,FLT} \qquad \textbf{(B-210)}$$

Calculate Fuel Consumption

35) Allocate actual VMT demand among truck types:

$$VMT_{T,SEC,SC,AGE,FUEL,FLT} = TRKSTK_{T,SEC,SC,AGE,FUEL,FLT} \cdot ANNVMT_{T,SEC,SC,AGE,FUEL} \cdot \left[\frac{\sum_{SEC=1}^{12} VMTDMD_{T,SEC}}{\sum_{SEC=1}^{12} PVMTDMD_{T,SEC}} \right] \quad \textbf{(B-211)}$$

where:

VMT = Actual VMT by trucks of each type in year *T*

36) Reduce the light-duty vehicle degradation calculated in FEM to reflect the higher percentage of highway miles driven by freight trucks:

$$MPGDEGFAC_{T,SC} = \frac{1 - \left[\left(1 - MPGDEGFAC_{T,LDV}\right) \cdot \frac{URBANSHR_{SC}}{URBSHRLDV} \right]}{1 - \left[\left(1 - MPGDEGFAC_{T=0,LDV}\right) \cdot \frac{URBANSHR_{SC}}{URBSHRLDV} \right]} \quad \textbf{(B-212)}$$

where:

$MPGDEGFAC_{LDV}$ = Fuel economy degradation factor, from LDV Module
MPGDEGFAC = Fuel economy degradation factor for freight trucks
URBANSHR = % of miles driven in urban areas by trucks of each size class in base year (1992)
URBSHRLDV = % of miles driven in urban areas by LDVs in base year (1992)

37) Calculate fuel consumption, in gallons of gasoline equivalent:

$$FUEL_{T,SEC,SC,AGE,FUEL,FLT} = \frac{VMT_{T,SEC,SC,AGE,FUEL,FLT}}{MPG_{T,SEC,SC,AGE,FUEL} \cdot MPGDEGFAC_{T,SC}} \quad \textbf{(B-213)}$$

where:

FUEL = Total freight truck fuel consumption by sector, size class and fuel type in year *T*, in gallons of gasoline equivalent
$MPGDEGFAC_{T,SC}$ = Fuel economy degredation factor, overwritten in the code by 0.99.

38) Converting from gasoline equivalent to trillion Btu:

$$TRIL_{T,SEC,SC,FUEL,FLT} = \sum_{AGE=0}^{11} FUEL_{T,SEC,SC,AGE,FUEL,FLT} \cdot HTRATE \cdot 10^{-6} \quad \textbf{(B-214)}$$

where:

TRIL = Total fleet truck fuel consumption by sector, size class and fuel type in year *T*, in trillion Btu

Roll Truck Population and Fuel Economy

39) Calculate new fuel economies of trucks which are ten years old or older:

$$MPG_{T+1,SC,SGE=10,FUEL} = \frac{\sum_{FLT=1}^{2} \sum_{AGE=10}^{11} \sum_{SEC=1}^{12} VMT_{T,SEC,SC,AGE,FUEL,FLT}}{\sum_{FLT=1}^{2} \sum_{AGE=10}^{11} \sum_{SEC=1}^{12} FUEL_{T,SEC,SC,AGE,FUEL,FLT}} \quad \textbf{(B-215)}$$

where:

AGE = 10 refers to trucks in the tenth vintage, i.e., trucks which are ten years old during model run year *t*

AGE = 11 refers to trucks in the eleventh vintage, i.e., trucks which are eleven years old or older during model run year *t*

T+1 = refers to the next model run year

40) Collapse the last two vintages of trucks into one:

$$TRKSTK_{T,SEC,SC,AGE=10,FUEL,FLT} = TRKSTK_{T,SEC,SC,AGE=10,FUEL,FLT} + TRKSTK_{T,SEC,SC,AGE=11,FUEL,FLT} \quad \textbf{(B-216)}$$

RAIL FREIGHT MODEL Subroutine TRAIL

1) Calcutate ton-miles traveled for rail, by industry:

$$RTMT_{I,T} = RTMT_{I,T_0} \cdot FAC_{I,MODE} \cdot \left[\frac{TSIC_{I,T}}{TSIC_{I,T_0}}\right] \quad \textbf{(B-217)}$$

where:

RTMT = Rail ton-miles traveled, by industry *I*
MODE = Index of freight mode: truck, rail, marine
TSIC = Value of industrial output, by industry
I = Index of NEMS industrial category
FAC = Freight adjustment coefficient, by industry and mode

2) Sum across industries:

$$RTMTT_T = \sum_{I=1}^{10} RTMT_{I,T} \quad \text{(B-218)}$$

where:

RTMTT = Total rail ton-miles traveled

3) Estimate energy consumption by rail:

$$TQRAILT_T = FERAIL_T \cdot RTMTT_T \quad \text{(B-219)}$$

where:

TQRAILT = Total energy demand by rail
FERAIL = Rail efficiency coefficient, in Btu/ton-mile

4) Increment rail demand for specific fuels:

$$TQRAIL_{IF,T} = TQRAIL_{IF,T-1} \cdot \left(\frac{TQRAILT_T}{TQRAILT_{T-1}} \right) \quad \text{(B-220)}$$

where:

TQRAIL = Rail demand, by fuel *IF*
IF = Index of fuel type

5) Divide into regions:

$$TQRAILR_{IF,IR,T} = TQRAIL_{IF,T} * SEDSHR_{IF,IR,T} \quad \text{(B-221)}$$

where:

TQRAILR = Regional demand by fuel type

SEDSHR = Regional shares of fuel demand, from SEDS

IR = Index of census region (1-9)

6) Calculate fractional change in rail travel and fuel efficiency:

$$XRAIL_T = \frac{RTMTT_T}{RTMTT_{T-1}}$$

and **(B-222)**

$$XRAILEFF_T = \frac{FERAIL_{T-1}}{FERAIL_T}$$

where:

XRAIL = Growth in rail travel from base year

XRAILEFF = Growth in rail efficiency from base year

WATERBORNE FREIGHT MODEL Subroutine TSHIP

1) Calcutate ton-miles traveled for domestic shipping, by industry:

$$STMT_{I,T} = STMT_{I,T_0} \cdot FAC_{I,MODE} \cdot \left[\frac{TSIC_{I,T}}{TSIC_{I,T_0}}\right] \quad \textbf{(B-223)}$$

where:

STMT = Ship ton-miles traveled, by industry *I*

2) Sum across industries:

$$STMTT_T = \sum_{I=1}^{10} STMT_{I,T} \quad \textbf{(B-224)}$$

where:

STMTT = Total ship ton-miles traveled

3) Estimate energy consumption by ship:

$$SFDT_T = FESHIP_T \cdot STMTT_T \cdot SFDBENCH \quad \textbf{(B-225)}$$

where:

SFDT = Total energy demand by ship
FESHIP = Ship efficiency coefficient, in Btu/ton-mile
SFDBENCH = Benchmark factor to ensure congruence with 1990 data

4) Allocate energy demand among specific fuels:

$$SFD_{IF,T} = SFDT_T \cdot SFSHARE_{IF} \quad \textbf{(B-226)}$$

where:

SFD = Domestic ship energy demand, by fuel *IF*
SFSHARE = Constant allocation share for domestic shipping, by fuel

5) Divide into regions:

$$TQSHIPR_{IF,IR,T} = SFD_{IF,T} * SEDSHR_{IF,IR,T} \quad \textbf{(B-227)}$$

where:

TQSHIPR = Regional ship demand by fuel type
SEDSHR = Regional shares of fuel demand, from SEDS

6) Calculate international shipping fuel demand:

$$ISFDT_T = ISFDT_{T-1} + \left[\frac{GROSST_T}{GROSST_{T-1}} - 1 \right] * 0.5 * ISFDT_{T-1} \quad \textbf{(B-228)}$$

where:

ISFDT = Total international shipping fuel demand
GROSST = Value of gross trade (imports + exports)

7) Allocate among the considered fuels:

$$ISFD_{IF,T} = ISFDT_T \cdot ISFSHARE_{IF} \tag{B-229}$$

where:

ISFD = International ship energy demand, by fuel *IF*

ISFSAHRE = Constant allocation share for international shipping, by fuel

8) Divide into regions:

$$TQISHIPR_{IF,IR,T} = ISFD_{IF,T} * SEDSHR_{IF,IR,T} \tag{B-230}$$

where:

TQISHIPR = Regional international shipping demand by fuel type

9) Calculate fractional change in domestic ship travel and fuel efficiency:

$$XSHIP_T = \frac{STMTT_T}{STMTT_{T=1}}$$

and (B-231)

$$XSHIPEFF_T = \frac{FESHIP_T}{FESHIP_{T=1}}$$

where:

XSHIP = Growth in ship travel from base year

XSHIPEFF = Growth in ship efficiency from base year

AIR TRAVEL MODULE

AIR TRAVEL DEMAND MODEL — Subroutine TAIRT

1) Calculate the cost of flying:

$$YIELD_T = 9.73 + .794\, TPJFTR_T \quad \textbf{(B-232)}$$

where:

YIELD = Cost of air travel, expressed in cents per RPM
TPJFTR = Price of jet fuel, in dollars per million Btu

2) Calculate the revenue passenger-miles per capita for each type of travel:

a) For business travel:

$$RPMBPC_T = 89.70 + .029\left(\frac{TMC\_GDP_T}{TMC\_POPAFO_T}\right) - 16.04\, YIELD_T \quad \textbf{(B-233)}$$

b) For personal travel:

$$RPMPPC_T = -481.84 + .083\left(\frac{TMC\_YD_T}{TMC\_POPAFO_T}\right) - 18.68\, YIELD_T \quad \textbf{(B-234)}$$

c) For international travel:

$$RPMIPC_T = PCTINT_T \cdot (RPMBPC_T + RPMPPC_T) \quad \textbf{(B-235)}$$

where:

RPMBPC = Per capita revenue passenger miles for business travel
RPMPPC = Per capita revenue passenger miles for personal travel
RPMIPC = Per capita revenue passenger miles for international travel
TMC_GDP = Gross domestic product, from MACRO module
TMC_YD = Disposable personal income, from MACRO module
TMC_POPAFO = Total domestic population, from MACRO module
PCTINT = Proportionality factor relating international to domestic travel levels

3) Calculate the revenue ton-miles (RTM) of air freight:

$$RTM_T = \left(-14{,}556 + 19.81\, TMC\_EXDN92_T + 3.49\, TMC\_GDP_T\right) \cdot DFRT_T \tag{B-236}$$

where:

TMC_EXDN92 = Value of merchandise exports, from MACRO module
DFRT = Fraction of freight ton-miles transported by dedicated carriers

4) Calculate total revenue passenger-miles flown for each category of travel:

a) For business travel:

$$RPMB_T = RPMBPC_T \cdot TMC\_POPAFO_T \tag{B-237}$$

b) For personal travel:

$$RPMP_T = RPMPPC_T \cdot TMC\_POPAFO_T \cdot DI_T \tag{B-238}$$

c) For international travel:

$$RPMI_T = RPMIPC_T \cdot TMC\_POPAFO_T \tag{B-239}$$

where:

RPMB = Revenue passenger miles for business travel
RPMP = Revenue passenger miles for personal travel
RPMI = Revenue passenger miles for international travel
DI = Demographic adjustment index, reflecting the public's propensity to fly

5) Calculate total domestic air travel:

$$RPMD_T = RPMB_T + RPMP_T \tag{B-240}$$

where:

RPMD = Total domestic air travel

6) Calculate the total demand for available seat-miles:

$$ASMDEMD_T = \left(\frac{RPMD_T}{LFDOM_T}\right) + \left(\frac{RPMI_T}{2 * LFINTER_T}\right) + (RTM_T \cdot EQSM) \tag{B-241}$$

where:

ASMDEMD = Total demand for available seat-miles

LFDOM = Load factor for domestic travel
LFINTER = Load factor for international travel
EQSM = Equivalent seat-miles conversion factor; used to transform freight RTM's

AIRCRAFT FLEET EFFICIENCY MODEL Subroutine TAIREFF

1) Calculate available seat-miles per plane, by aircraft type:

$$ASMP_{IT,T} = AIRHRS_{IT,T} * AVSPD_{IT,T} * SEAT_{IT,T} \quad \textbf{(B-242)}$$

where:

ASMP = The available seat-miles per plane, by type.
AIRHRS = The average number of airborne hours per aircraft.
AVSPD = The average flight speed.
SEAT = The average number of seats per aircraft.
IT = Index of aircraft type: 1 = narrow body, 2 = wide body

2) Calculate fraction of seat-mile demand accomodated by narrow-body aircraft:

$$SMFRACN_T = \left[\left(\frac{ASMDEMD_{IT=1,T-1}}{SMDEMD_{T-1}}\right) + DELTA \cdot \left(\frac{ASMDEMD_{IT=2,T-1}}{SMDEMD_{T-1}}\right)\right] \; ; \; DELTA \geq 0$$
$$= \left[\left(\frac{ASMDEMD_{IT=1,T-1}}{SMDEMD_{T-1}}\right) \cdot (1 + DELTA)\right] \; ; \; DELTA < 0 \quad \textbf{(B-243)}$$

where:

SMFRACN = Fraction of seat-mile demand on narrow-body planes
ASMDEMD = Demand for available seat-miles, by aircraft type
DELTA = User-specified rate of passenger shifts between aircraft types

3) Calculate current seat-miles demanded by aircraft type:

$$ASMDEMD_{IT=1,T} = SMDEMD_T * SMFRACN_T$$

and **(B-244)**

$$ASDEMD_{IT=2,T} = SMDEMD_T * \left(1.0 - SMFRACN_T\right)$$

4) Calculate survival rates of aircraft:

$$SURVPCT_{IVINT} = \left[1 + EXP\,(\,SURVK * (\,T50 - IVINT\,)\,) \right]^{-1}$$

and **(B-245)**

$$SSURVPCT_{IVINT} = \frac{SURVPCT_{IVINT}}{SURVPCT_{IVINT-1}}$$

where:

SURVPCT = Survival rate of planes of a given vintage *IVINT*
SSURVPCT = Marginal survival rate of planes of a given vintage
IVINT = Index of aircraft vintage
SURVK = User-specified proportionality constant
T50 = User-specified vintage at which stock survival is 50%

5) Calculate surviving seat-miles from previous year:

$$SMSURV_{IT,T} = \sum_{IVINT=2}^{60} NPCHSE_{IT,IVINT-1,T-1} * SSURVPCT_{IVINT} * ASMP_{IT,T} \quad \textbf{(B-246)}$$

where:

SMSURV = Surviving available seat-miles, by aircraft type
NPCHSE = Surviving aircraft stock, by vintage and aircraft type

6) Calculate new aircraft purchases:

$$NPCHSE_{IT,IVINT=1,T} = \left[\frac{ASMDEMD_{IT,T} - SMSURV_{IT,T}}{ASMP_{IT,T}} \right] \quad \textbf{(B-247)}$$

7) Adjust array of aircraft stocks by vintage:

$$NPCHSE_{IT,IVINT,T} = NPCHSE_{IT,IVINT-1,T-1} * SSURVPCT_{IVINT} \quad ; \quad IVINT = 2 - 60 \quad \textbf{(B-248)}$$

8) Calculate aircraft stock across vintages:

$$NSURV_{IT,T} = \sum_{IVINT=1}^{60} NPCHSE_{IT,IVINT,T} \quad \textbf{(B-249)}$$

where:

NSURV = Number of surviving aircraft, by type

9) Calculate fraction of current year stock which is old (*IVINT* > 1):

$$STKOLD_{IT,T} = \frac{\left(NSURV_{IT,T} - NPCHSE_{IT,IVINT=1,T}\right)}{NSURV_{IT,T}} \quad \textbf{(B-250)}$$

where:

STKOLD = Fraction of planes older than one year, by aircraft type

10) Calculate effect of technology improvements:

a) Calculate time effect:

$$TIMEFX_{IFX,T} = TIMEFX_{IFX,T-1} + \left(TIMECONST * TPN_{IFX} * TYRN_{IFX}\right) \quad \textbf{(B-251)}$$

where:

TIMEFX = Factor reflecting the length of time an aircraft technology improvement has been commercially viable

IFX = Index of technology improvements (1-6)

TIMECONST = User-specified scaling constant, reflecting the importance of the passage of time

TPN = Binary variable (0,1) which tests whether current fuel price exceeds the considered techology's trigger price

TYRN = Binary variable which tests whether current year exceeds the considered technology's year of introduction

b) Calculate the cost effect:

$$COSTFX_{IFX,T} = 10 * \left(\frac{TPJFGAL_T - TRAGPRICE_{IFX}}{TPJFGAL_T}\right) * TPN_{IFX} * TYRN_{IFX} * TPZ_{IFX} \quad \textbf{(B-252)}$$

where:

COSTFX = Factor reflecting the magnitude of the difference between the price of jet fuel and the trigger price of the considered technology

TPJFGAL = Price of jet fuel
TRIGPRICE = Price of jet fuel above which the considered technology is assumed to be commercially viable
TPZ = Binary variable which tests whether implementation of the considered technology is dependent on fuel price

c) Calculate the total effect:

$$TOTALFX_{IFX,T} = TIMEFX_{IFX,T} + COSTFX_{IFX,T} - BASECONST \quad \text{(B-253)}$$

where:

TOTALFX = Overall effect of fuel price and time on implementation of technology *IFX*
BASECONST = Baseline constant, used to anchor the technology penetration curve

d) Calculate the penetration of new technologies:

$$TECHFRAC_{IFX,T} = \left[1 + EXP\left(-TOTALFX_{IFX,T}\right) \right]^{-1} \quad \text{(B-254)}$$

where:

TECHFRAC = Fration of new aircraft purchases which incorporate a given technology

11) Calculate fractional fuel efficiency improvement for new aircraft, by type:

$$FRACIMP_{IT=1,T} = 1.0 + EFFIMP_{IFX=1} * \left(TECHFRAC_{IFX=1,T} - TECHFRAC_{IFX=2,T}\right) + \sum_{IFX=2}^{6} EFFIMP_{IFX} * TECHFRAC_{IFX,T}$$

and

$$FRACIMP_{IT=2,T} = 1.0 + \sum_{IFX=1}^{6} EFFIMP_{IFX} * TECHFRAC_{IFX,T} \quad ; \quad IFX \neq 2 \quad \text{(B-255)}$$

where:

FRACIMP = Fractional improvement over base year (1990) fuel efficiency, by type
EFFIMP = Fractional improvement associated with a given technology

12) Ensure that technical improvements provide at least as much efficiency gain as average growth in remainder of air fleet:

$$NEWSMPG_{IT,T} = MAX\left[\left(FRACIMP_{IT,T} * SMPG_{IT,T=1}\right), \left(\left(1.0 + P_{IT,T}\right) * SMPGIT,T-1 * 1.05\right)\right] \quad \text{(B-256)}$$

where:

NEWSMPG = Average seat-miles per gallon of new aircraft purchases
SMPG = Surviving fleet average seat-miles per gallon, by aircraft type
RHO = Average historic rate of growth of fuel efficiency

13) Calculate average fuel economy of aircraft fleet, by type:

$$SMPG_{IT,T} = \left[\left(\frac{STKOLD_{IT,T}}{\left(1 + RHO_{IT}\right) \cdot \left(SMPG_{IT,T-1}\right)} \right) + \left(\frac{1 - STKOLD_{IT,T}}{NEWSMPG_{IT,T}} \right) \right]^{-1} \quad \textbf{(B-257)}$$

14) Calculate average fuel economy of aircraft fleet:

$$SMPGT_{T} = \left[\left(\frac{SMFRACN_{T}}{SMPG_{IT=1,T}} \right) + \left(\frac{\left(1 - SMFRACN_{T}\right)}{SMPG_{IT=2,T}} \right) \right]^{-1} \quad \textbf{(B-258)}$$

where:

SMPGT = Overall fleet average seat-miles per gallon

15) Calculate demand for jet fuel, incrementing by 5% to reflect consumption by private aircraft:

$$JFGAL_{T} = \left(\frac{SMDEMD_{T}}{SMPGT_{T}} \right) * 1.05 \quad \textbf{(B-259)}$$

where:

JFGAL = Consumption of jet fuel, in gallons

16) Calculate demand for aviation gasoline:

$$AGD_{T} = BASEAGD + GAMMA * EXP\left[-KAPPA * (IYEAR - 1979) \right] \quad \textbf{(B-260)}$$

where:

AGD = Demand for aviation gasoline, in gallons
BASEAGD = Baseline demand for aviation gasoline
GAMMA = Baseline adjustment factor
KAPPA = Exogenously-specified decay constant
IYEAR = Current year

17) Convert from gallons to Btu:

$$JFBTU_T = JFGAL_T * \left(\frac{5.670 \ MMBtu/bbl}{42 \ gal/bbl} \right)$$

and **(B-261)**

$$AGDBTU_T = AGD_T * \left(\frac{5.048 \ MMBtu/bbl}{42 \ gal/bbl} \right)$$

where:

JFBTU = Jet fuel demand, in Btu
AGDBTU = Aviation gasoline demand, in Btu

18) Regionalize demand:

$$QJETR_{IR,T} = JFBTU_T * SEDSHR_{IF,IR,T}$$

and **(B-262)**

$$QAGR_{IR,T} = QAGDBTU_T * SEDSHR_{IF,IR,T}$$

where:

QJETR = Regional demand for jet fuel
QAGR = Regional demand for aviation gasoline
SEDSHR = Regional shares of fuel demand, from SEDS

19) Calculate fractional changes in air travel and aircraft efficiency:

$$XAIR_T = \frac{SMDEMD_T}{SMDEMD_{T=1}}$$

and **(B-263)**

$$XAIREFF_T = \frac{SMPGT_T}{SMPGT_{T=1}}$$

where:

XAIR = Fractional change in air travel from base year
XAIREFF = Fractional change in aircraft fuel efficiency from base year

MILITARY DEMAND MODEL Subroutine TMISC

Calculate military energy use:

1) Calculate growth in military budget:

$$MILTARGR_{T} = \frac{TMC\_GRML87_{T}}{TMC\_GFML87_{T-1}} \tag{B-264}$$

where:

MILTARGR = Fractional growth of military budget
TMC_GRML87 = Military budget, from MACRO module

2) Calculate fuel demand:

$$MFD_{IF,T} = MFD_{IF,T-1} * MILTARGR_{T} \tag{B-265}$$

where:

MFD = Demand for fuel by military
IF = Index of fuel type

3) Regionalize demand:

$$QMILTR_{IF,IR,T} = MFD_{IF,T} * MILTRSHR_{IF,IR,T} \tag{B-266}$$

where:

QMILTR = Regional military demand for fuel
MILTRSHR = Regional shares of military demand for fuel

Calculate mass-transit consumption:

1) Calculate passenger-miles by mode:

$$TMOD_{IM=1,T} = VMTEE_T * TMLOAD89_{IM=1}$$

and:

$$TMOD_{IM,T} = TMOD_{IM,T-1} * \left[\frac{TMOD_{1,T}}{TMOD_{1,T-1}}\right]^{BETAMS} \qquad \textbf{(B-267)}$$

where:

TMOD = Passenger-miles traveled, by mode
VMTEE = LDV vehicle-miles traveled, from the VMT module
TMLOAD89 = Average passengers per vehicle, by mode (1=LDV's)
BETAMS = Coefficient of proportionality, relating mass transit to LDV travel
IM = Index of transportation mode: 1 = LDV's, 2-4 = Buses, 5-7 = Rail

2) Calculate mass transit efficiencies, in Btu per passenger-mile:

$$TMEFFL_{IM,T} = \frac{\left[TMEFF89_{IM} * \left(\frac{FMPG_{TYPE,T}}{FMPG89_{TYPE}}\right)\right]}{TMLOAD89_{IM}} \qquad \textbf{(B-268)}$$

where:

TMEFFL = Btu per passenger-mile, by mass transit mode
TMEFF89 = Base-year Btu per vehicle-mile, by mode
FMPG = Fuel efficiency, by vehicle type, from the Freight Module
FMPG89 = Base-year fuel efficiency, by vehicle type, from the Freight Module
TYPE = Vehicle type, from the Freight Module: 1 = Mid-size trucks, 2 = Rail

3) Calculate fuel consumption by mode:

$$TMFD_{IM,T} = TMOD_{IM,T} * TMEFFL_{IM,T} \qquad \textbf{(B-269)}$$

where:

TMFD = Total mass-transit fuel consumption by mode

4) Regionalize consumption:

$$QMODR_{IM,IR,T} = TMFD_{IM,T} * \left[\frac{TMC\_POPAFO_{IR,T}}{\sum_{IR=1}^{9} TMC\_POPAFO_{IR,T}} \right] \quad \textbf{(B-270)}$$

where:

QMODR = Regional consumption of fuel, by mode
TMC_POPAFO = Regional population forecasts, from the Macro Module

RECREATIONAL BOATING DEMAND MODEL Subroutine TMISC

Calculate recreational boat fuel use:

1) Calculate fuel demand:

$$RECFD_{T} = RECFD_{T-1} * \left[\frac{TMC\_YD_{T}}{TMC\_YD_{T-1}} \right]^{BETAREC} \quad \textbf{(B-271)}$$

where:

RECFD = National recreational boat gasoline consumption in year T
TMC_YD = Total disposable personal income, from the Macro Module
BETAREC = Coefficient of proportionality relating income to fuel demand for boats

2) Regionalize consumption according to population:

$$QRECR_{IR,T} = RECFD_{T} * \left[\frac{TMC\_POPAFO_{IR,T}}{\sum_{IR=1}^{9} TMC\_POPAFO_{IR,T}} \right] \quad \textbf{(B-272)}$$

where:

QRECR = Regional fuel consumption by recreational boats in year T

Calculate lubricant demand:

1) Sum freight truck VMT across size classes:

$$FTVMT_T = \sum_{SC=1}^{3} FVMTSC_{SC,T} \quad \text{(B-273)}$$

where:

FTVMT = Total freight truck VMT
FVMTSC = Freight truck VMT, by size class

2) Calculate total highway travel:

$$HYWAY_T = VMTEE_T + FTVMT_T + FLTVMT_T \quad \text{(B-274)}$$

where:

HYWAY = Total highway VMT
FLTVMT = Total fleet vehicle VMT, from the Fleet Module

3) Calculate lubricant demand:

$$LUBFD_T = LUBFD_{T-1} * \left[\frac{HYWAY_T}{HYWAY_{T-1}}\right]^{BETALUB} \quad \text{(B-275)}$$

where:

LUBFD = Total demand for lubricants in year T
BETALUB = Constant of proportionality, relating highway travel to lubricant demand

4) Regionalize lubricant demand:

$$QLUBR_{IR,T} = LUBFD_T * \left[\frac{\left(\left(VMTEE_T + FLTVMT_T\right) * SEDSHR_{IF,IR,T}\right) + \left(FTVMT_T * SEDSHR_{IF,IR,T}\right)}{HYWAY_T}\right] \quad \text{(B-276)}$$

where:

QLUBR = Regional demand for lubricants in year T, in Btu
SEDSHR = Regional share of fuel consumption, from SEDS
IF = Index of fuel type: gasoline for light-duty vehicles, diesel for freight trucks

VEHICLE EMISSIONS MODULE Subroutine TEMISS

This subroutine calculates the emissions of six airborne pollutants, at every conceivable level of aggregation. A single, representative equation is provided.

1) Calculate disaggregate emissions of airborne pollutants:

$$EMISS_{IE,IM,IR,T} = EFACT_{IE,IM,IR,T} * U_{IM,IR,T} \tag{B-277}$$

where:

EMISS = Regional emissions of a given pollutant, by mode of travel
EFACT = Emissions factor relating measures of travel to pollutant emissions
U = Measure of travel demand, by mode: units in VMT for highway travel, gallons of fuel consumption for other modes
IM = Index of travel mode: references individual vehicle types used in the preceding modules, and may be further subdivided by size class, vehicle technology, and vehicle type
IE = Index of pollutants: 1 = SO_x, 2 = NO_x, 3 = C, 4 = CO_2, 5 = CO, 6 = VOC
IR = Index identifying census region

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Appendix D. Model Abstract

Model Name:

Transportation Sector Model

Model Acronym:

TRAN

Description:

The Transportation Sector Model incorporates an integrated modular design which is based upon economic, engineering, and demographic relationships that model transportation sector energy consumption at the nine Census Division level of detail. The Transportation Sector Model comprises the following components: Light Duty Vehicles, Light Duty Fleet Vehicles, Freight Transport (truck, rail, and marine), Aircraft, Miscellaneous Transport (military, mass transit, and recreational boats), and Transportation Emissions. The model provides sales estimates of 2 conventional and 14 alternative-fuel light duty vehicles, and consumption estimates of 12 main fuels.

Purpose of the Model:

As a component of the National Energy Modeling System integrated forecasting tool, the transportation model generates mid-term forecasts of transportation sector energy consumption. The transportation model facilitates policy analysis of energy markets, technological development, environmental issues, and regulatory development as they impact transportation sector energy consumption.

Most Recent Model Update:

October, 1997.

Part of Another Model?

National Energy Modeling system (NEMS).

Model Interfaces:

Receives inputs from the Electricity Market Module, Oil and Gas Market Module, Renewable Fuels Module, and the Macroeconomic Activity Module.

Official Model Representative:

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Documentation:

Model Documentation Report: Transportation Sector Model of the National Energy Modeling System, October, 1997.

Archive Media and Installation Manual(s):

The model will be archived on IBM tape compatible with the IBM RS6000 mainframe system upon completion of the NEMS production runs to generate the Annual Energy Outlook 1998.

Energy System Described:

Domestic transportation sector energy consumption.

Coverage:

- Geographic: Nine Census Divisions: New England, Mid Atlantic, East North Central, West North Central, South Atlantic, East South Central, West South Central, Mountain, Pacific.
- Time Unit/Frequency: Annual, 1990 through 2010.
- Products: Motor gasoline, aviation gasoline, diesel/distillate, residual oil, electricity, jet fuel, LPG, CNG, methanol, ethanol, hydrogen, lubricants.
- Economic Sectors: Forecasts are produced for personal travel, freight trucks, railroads, domestic and international marine, aviation, mass transit, and military use.

Model Interfaces:

Model outputs are provided to the Integrating Module, which then sends them back to the supply modules.

Model Structure:

Light-duty vehicles are classified according to the six EPA size classes for cars and light trucks. Freight trucks are divided into light-duty, medium-duty and heavy-duty size classes. The air transport module contains both wide- and narrow-body aircraft. Rail transportation is composed of freight rail and three modes of personal rail travel: commuter, intercity and transit. Shipping is divided into domestic and international categories.

Special Feautres:

The Transportation Sector Model has been created to allow the user to change various exogenous and endogenous input levels. The range of policy issues that the transportation model can evaluate are: fuel taxes and subsidies; fuel economy levels by size class; CAFE levels; vehicle pricing policies by size class; demand for vehicle performance within size classes; fleet vehicle sales by technology type; alternative-fuel vehicle sales shares; the Energy Policy Act; Low Emission Vehicle Program; VMT reduction; and greenhouse gas emissions levels.

Modeling Techniques:

The modeling techniques employed in the Transportation Sector Model vary by module: econometrics for passenger travel, aviation, and new vehicle market shares; exogenous engineering and judgement for MPG, aircraft efficiency, and various freight characteristics; and structural for light-duty vehicle and aircraft capital stock estimations.

Computing Environment:

■	Hardware Used:	IBM RS6000
■	Operating System:	AIX Version 4.2.1
■	Language/Software Used:	XL FORTRAN90, Ver 4.0
■	Memory Requirement:	9,500 K
■	Storage Requirement:	35,000 K
■	Estimated Run Time:	15 Seconds
■	Special Features:	None.

Independent Expert Reviews Conducted:

Independent Expert Review of Transportation Sector Component Design Report, June, 1992, conducted by David L. Greene, Oak Ridge National Laboratory.

Status of Evaluation Efforts by Sponsor:

None.

DOE Input Sources:

- State Energy Data System (SEDS), 1991, May 1993.
- Residential Transportation Energy Consumption Survey (RTECS), 1991, December 1993
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Non-DOE Input Sources:

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Appendix E. Data Quality and Estimation

LIST OF TABLES

Appendix E. Data Quality and Estimation

This appendix presents results of the statistical tests conducted for those componenents of the transportation model which rely on econometric estimations. These components include: The Fuel Economy Model, the Alternative Fuel Vehicle Model, the Vehicle-Miles Traveled Model, and the Air Travel Demand Model. To date, no data quality studies have been conducted in order to valididitate the transportation model's input data.

Fuel Economy Model

The methodology employed to assess the influence of macroeconomic and time-dependent variables on the mix of size classes and performance was log-linear regression analysis using historical data on car and light truck sales over the 1979-1990 period. Greater detail is provided in Attachment 1 of Appendix F.

The following equations were used to estimate the class market shares of new vehicle purchases:

All Vehicle Classes Except Luxury Cars:[1]

$$\ln\left(\frac{CLASS\$SHARE_i}{1 - CLASS\$SHARE_i}\right)_{YEAR} - \ln\left(\frac{CLASS\$SHARE_i}{1 - CLASS\$SHARE_i}\right)_{1990} = A * \ln\left(\frac{YEAR}{1990}\right) + B * \ln\left(\frac{FUELCOST_{YEAR}}{FUELCOST_{1990}}\right) + C * \ln\left(\frac{INCOME_{YEAR} - \$13{,}000}{INCOME_{1990} - \$13{,}000}\right) \quad \text{(E-1)}$$

where:

$CLASS\$SHARE_i$ = The market share of the i^{th} vehicle class
FUELCOST = The price of gasoline
INCOME = Per capita disposable income

[1]Note: Market shares for Mini and Sub-Compact cars are solved jointly. The resulting combined market share is allocated between the two classes based on the original 1990 allocation. Special treatment of these two classes was made necessary by the small sample size in the analysis data sets.

Luxury Cars:

$$\ln\left(\frac{CLASS\$SHARE_i}{1 - CLASS\$SHARE_i}\right)_{YEAR} - \ln\left(\frac{CLASS\$SHARE_i}{1 - CLASS\$SHARE_i}\right)_{1990} = A * \ln\left(\frac{YEAR}{1990}\right) + B * \ln\left(\frac{FUELCOST_{YEAR}}{FUELCOST_{1990}}\right) + C * \ln\left(\frac{INCOME_{YEAR}}{INCOME_{1990}}\right) \quad \text{(E-2)}$$

The values of the coefficients with their associated T-statistics are provided below in Table E-1.

Table E-1. Regression Results From The Market Share Model

Group	F Val	R^2	Intercept	YEAR	FUELCOST	INCOME
Mini and Subcompact	14.359	0.891	-5.428	0.056 (1.761)	1.33 (1.828)	-0.169 (-1.524)
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)
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)
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)
Compact Van	804.167	0.998	-9.3	0.01 (.352)	0.832 (1.727)	0.307 (3.045)
Compact Utility	274.104	0.994	-7.36	-0.042 (-1.447)	-0.2 (-.396)	0.366 (2.933)
Standard Size Trucks	1.582	0.475	-2.779	-0.056 (-1.523)	0.252 (.307)	0.144 (.846)

Alternative Fuel Vehicle Model

The AFV model uses a multinomial nested logit approach to estimate market shares of sixteen vehicle technologies. Model coefficients are taken from a study sponsored by the California Energy Commission, using a stated preference survey of California residents. The applicability of this study to a nationwide model has not been tested. Market shares are based on the exponentiated value of the consumer utility function, represented as follows:

$$\begin{aligned} VC1_{IT,IR} = \; & CONST_{IT} + \beta_1 \, VPRI_{IS,IT,N} + \beta_2 \, COPCOST_{IT,IS,IR,N} \\ & + \beta_3 \, VRANGE_{IS,IT,N} + \beta_4 \, VRANGE^2_{IS,IT,N} + \beta_5 \, EMISS_{IS,IT,N} \\ & + \beta_6 \, EMISS^2_{IS,IT,N} + \beta_7 \, FAVAIL_{IT,IR,N} + \beta_8 \, FAVAIL^2_{IT,IR,N} \end{aligned} \qquad \textbf{(E-3)}$$

where:

VC1 = Utility vector for conventional and alternative vehicles
CONST = Constant associated with each considered technology *IT*
VPRI = Price of each considered technology in 1990$
VRANGE = Vehicle range of the considered technology
EMISS = Emissions levels relative to gasoline ICE's
FAVAIL = Relative availability of the considered fuel

Model coefficients and relevant T-statistics are provided in Table E-2, on the following page. An extensive description of the data base development process is provided as an attachment in Appendix F.

Table E-2. Alternative Fuel Vehicle Model Coefficients

VARIABLE	COEFFICIENT	T-STATISTIC
VPRI	-.134	10.1
COPCOST	-.190	16.4
VRANGE	2.52	11.4
VRANGE^2	-.408	7.4
EMISS	-2.45	7.0
EMISS^2	0.855	2.7
FAVAIL	2.96	5.7
FAVAIL^2	-1.63	3.5
CONST (Technology-Specific, as Follows)		
Gasoline	0.0	—
Diesel	0.0	—
Ethanol Flex	0.693	6.7
Ethanol Neat	0.0979	0.9
Methanol Flex	0.693	6.7
Methanol Neat	0.0979	0.9
Electric	-.0240	0.1
Electric Hybrid/Large ICE	-.257	1.5
Electric Hybrid/Small ICE	-.257	1.5
Electric Hybrid/Turbine	-.257	1.5
CNG	0.0979	0.9
LPG	0.0979	0.9
Turbine/Gasoline	0.0	—
Turbine/CNG	0.0979	0.9
Fuel Cell/Methanol	0.0979	0.9
Fuel Cell/Hydrogen	0.0979	0.9

Vehicle-Miles Traveled Model

Vehicle-miles traveled is estimated on a per capita basis using a generalized difference equation, estimated using the Cochrane-Orcutt iterative procedure:

$$VMTPC_T = \rho\, VMTPC_{T-1} + 4.52\,(1-\rho) - 7.50\,(CPM_T - \rho\, CPM_{T-1}) + 3.6x10^{-4}\,(YPC_T - \rho\, YPC_{T-1}) + 8.36\,(PrFem_T - \rho\, PrFem_{T-1}) \quad \text{(E-4)}$$

where:

CPM = The cost of driving a mile
YPC = Disposable personal income per capita
PrFem = The ratio of per capita female driving to per capita male driving.

The parameters and relevant T-statistics are provided in Table E-3, below.

Table E-3. Model of VMT per Capita

	ρ̂	α	CPM92	YPC92	PrFem	Adj. R-Sq
Parameter	0.736	0.28	-.101	2.64 e-04	1.805	0.855
T-Statistic			-4.0	4.0	1.8	

Air Travel Demand Model

This report presents the results of a re-estimation of the four equations comprising the Air Travel Demand Model. This model was originally estimated in 1992, using data from the years following the deregulation of airlines. With the acquisition of five years of additional data (1991-1995), and the revision of major macroeconomic variables, the parameters have been recalculated and are presented, along with the supporting data, on the following pages.

Although various alternative specifications were tested with the updated data sets, three of the four original equations provided results with the highest explanatory power.[2] The single equation which has been altered is that representing average travel costs in the "yield" equation: the non-fuel operating cost has been eliminated as an input due to its relatively static nature over the course of time, and its subsequent lack of explanatory significance.

In all of the regressions, the Durbin-Watson statistic indicates that autocorrelation may be present, but efforts to correct for this using a lagged-dependent variable approach have not provided acceptable results. In conclusion, the suggested model specification represents a simple forecasting tool which is sensitive to aircraft fuel prices and measures of economic activity. With a periodic updating of data and the re-estimation of these equations, the level of confidence in this approach should increase.

[2] For a description of the development of this model, see Appendix B, which reproduces the original report.

Appendix F. Attachments to the Transportation Model

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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 not 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 entire car and light truck 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

$$\begin{aligned} \Delta FE &= -0.22\,\Delta HP - 0.56\,\Delta HP^2 \;; \qquad \Delta HP > 0 \\ &= -0.22\,\Delta HP + 0.56\,\Delta HP^2 \;; \qquad \Delta HP < 0 \end{aligned}$$

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	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	0.60	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	***0.090***	***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	***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	1998	0.1
VVT II	0.100	***130***	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	***0.053***	***20***	0.00	0	0.00	2018	0
ACC I	***0.010***	***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***

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	***0.090***	***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	***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	***1998***	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 predicted are in line with pricing assumptions.

5 Includes ethanol/methanol.

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 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

6 Assumes manufacturer makes normal return on investment.

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.

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

[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.

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 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

[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.

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 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

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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.

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 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

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[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.

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 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

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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.

[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.

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 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

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[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.

[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.

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 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).
- 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

[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.

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 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.

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

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.

Table F-19. LDV and AFV Cost Decay Rates

FUEL TYPE	LOW	BASE	HIGH	EXPLANATION
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.

[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			EXPLANATION
	BASE	HIGH	LOW	
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 auto-makers 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.

EXPONENTIAL RATE OF CLOSURE

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

[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.

degradation factor or gap is formulated as:

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

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.

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

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

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[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

[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.

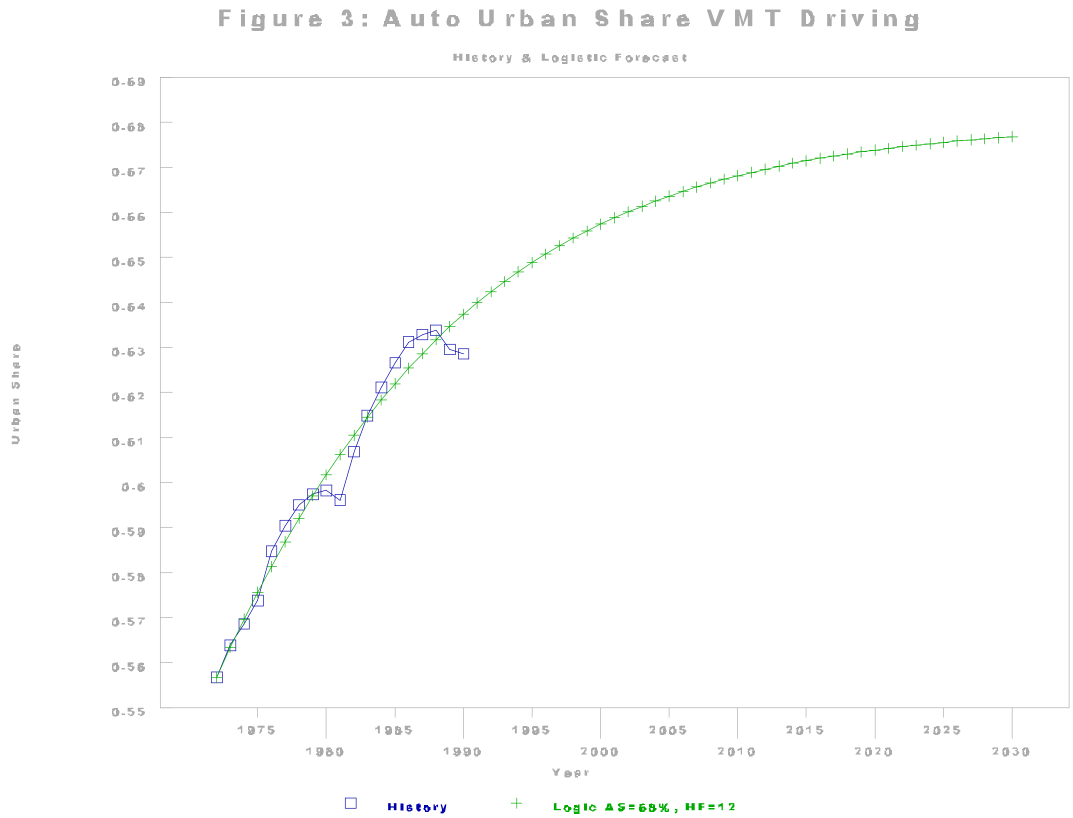
The decomposition is based on road types. Thus, VMT driving on roads identified as "interstate" and "other freeways and expressways" in urban areas are considered part of the highway driving share. Other road types located in urban areas are considered part of the city driving share. In addition, VMT 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 %

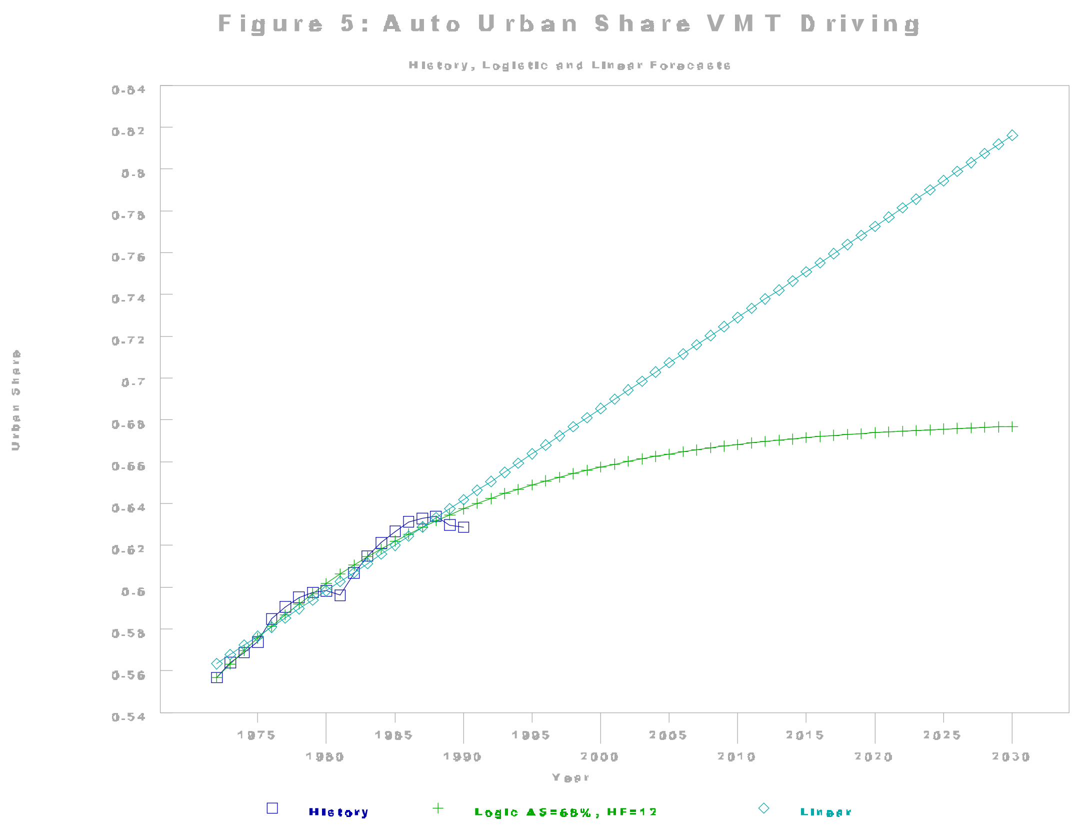
These adjusted city and highway shares are the bases for the calculations of the fuel efficiency gap projections in this chapter. The impact on fuel efficiency, from each of the three factors considered in this study, is affected by these adjusted shares. The impact from the increasing urban share trend 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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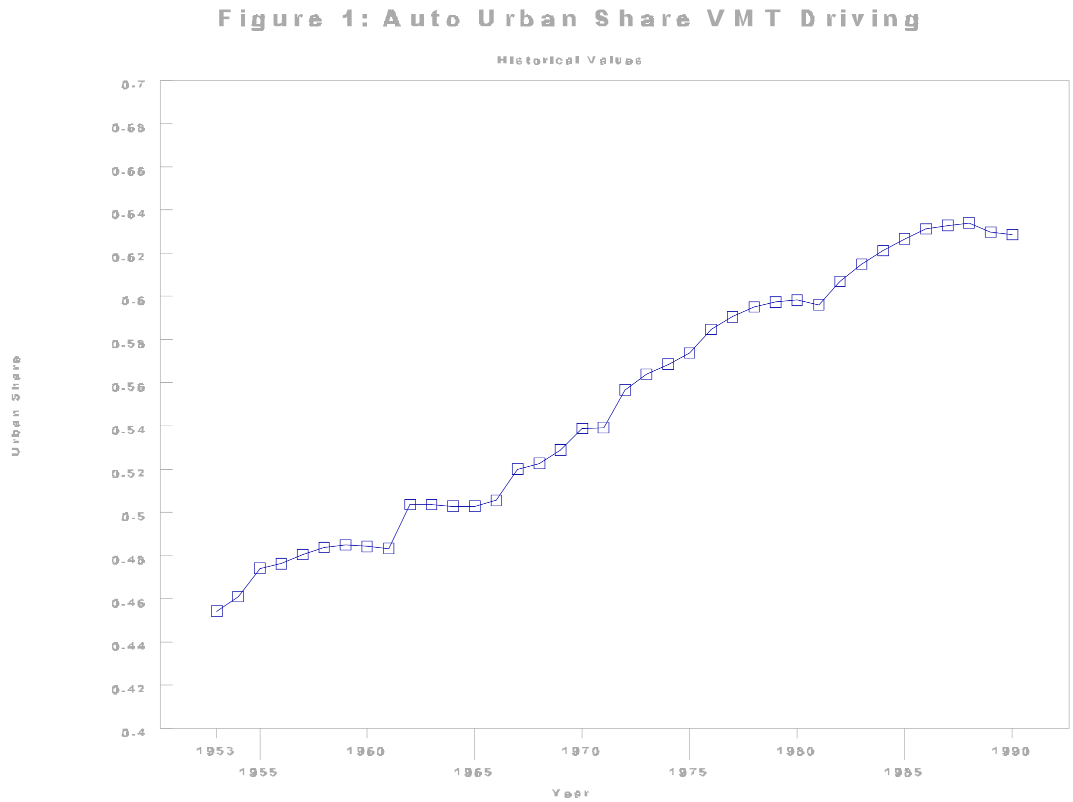
[42] Data on VMT is published annually by the U.S. Department of Transportation, Federal Highway Administration, in Highway Statistics.

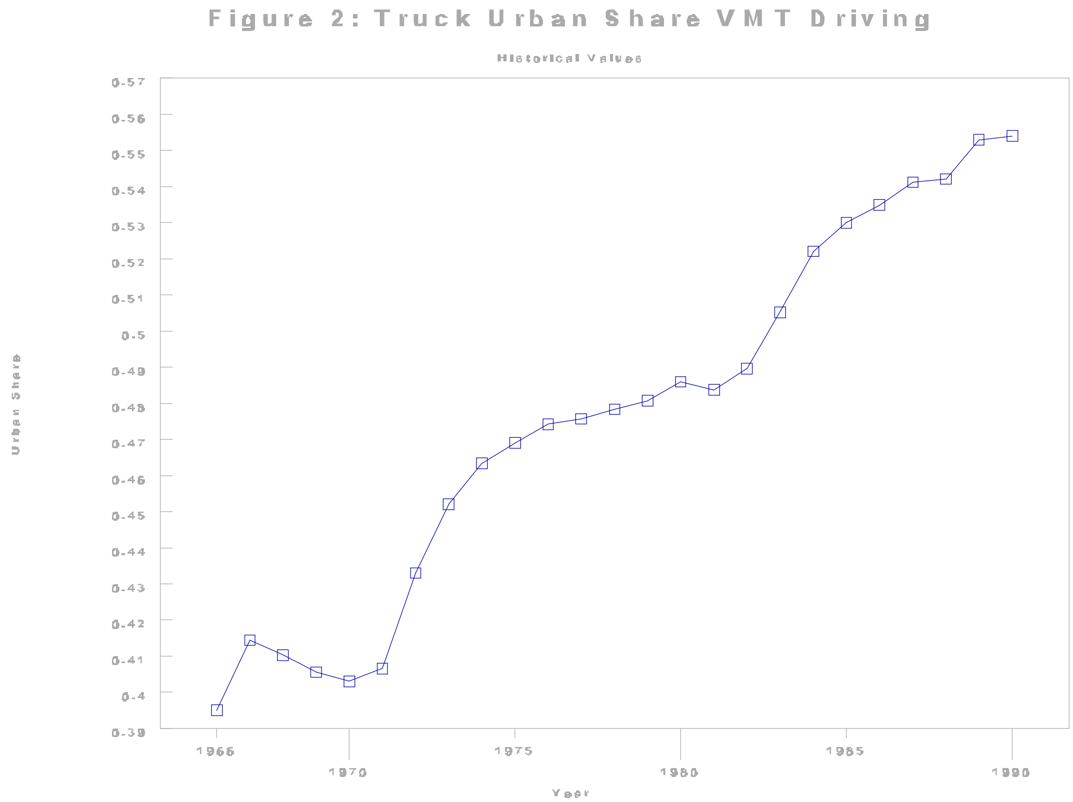
[43] Westbrook, F. and Patterson, P., "Changing Driving Patterns and Their Effect on Fuel Economy," presented May 2, 1989 at the 1989 SAE Government/Industry Meeting, Washington, D.C.

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.

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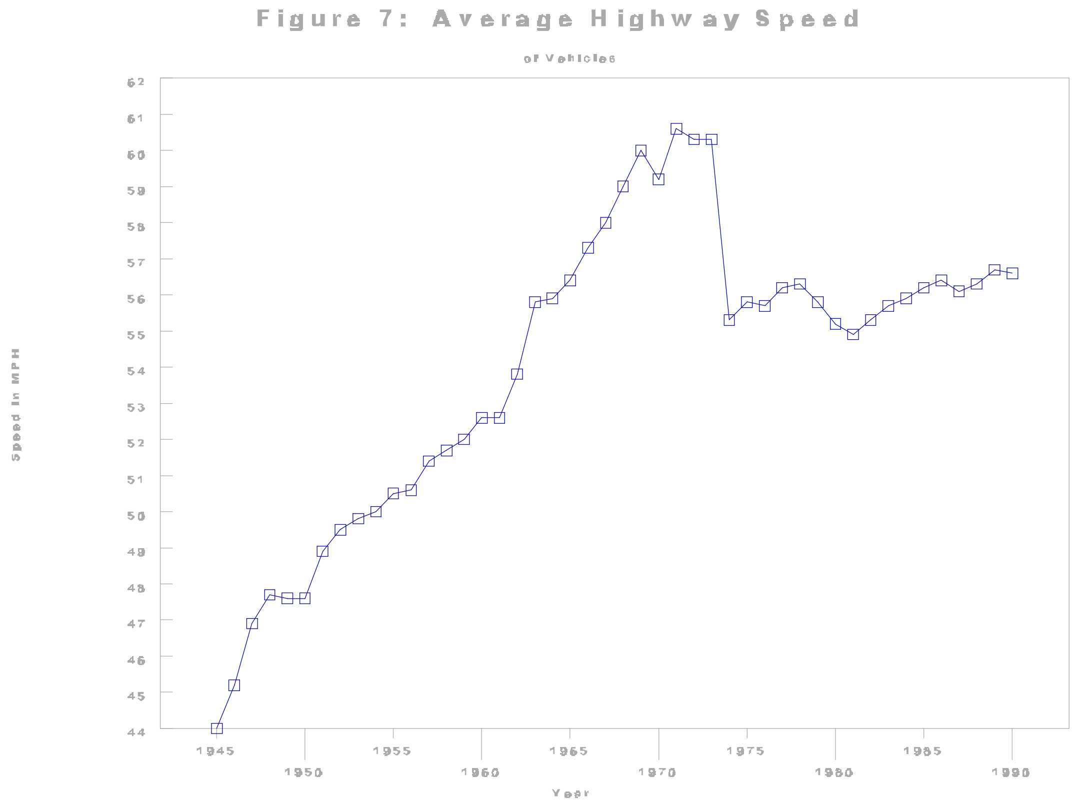
The estimation of the overall impact of speed trends in fuel economy is dependent on the specific data type selected to measure this trend and on the methodology used to forecast this trend. One could choose a disaggregated approach in which speed trend forecasts are developed by urban and rural driving, 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:

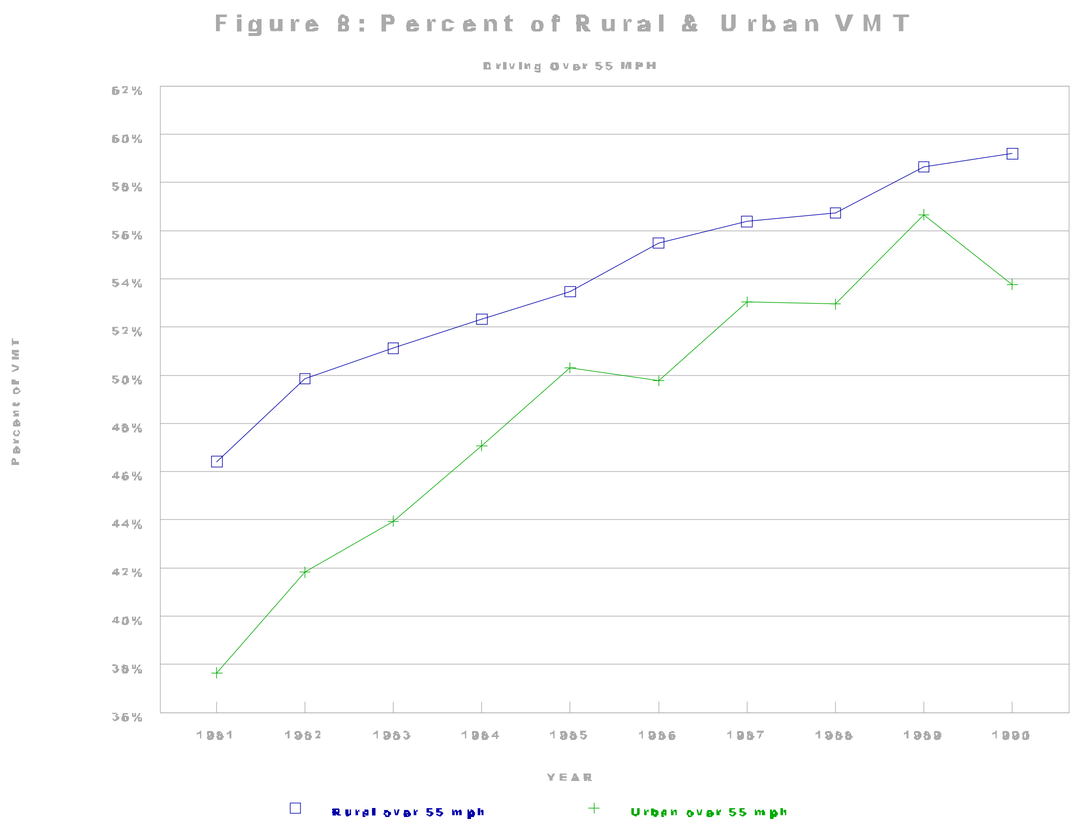
Table F-34 summarizes the impact of the adjusted highway share speeds on the composite fuel efficiency gap for automobiles using the logistic approach. Unlike the adjusted results for the urban driving share, the fuel efficiency gap forecasts indicate that in 2010 the gap has increased to 17.02 percent, 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.

Differing methodologies have been developed recently to measure the extent and duration of freeway

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

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]

[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)

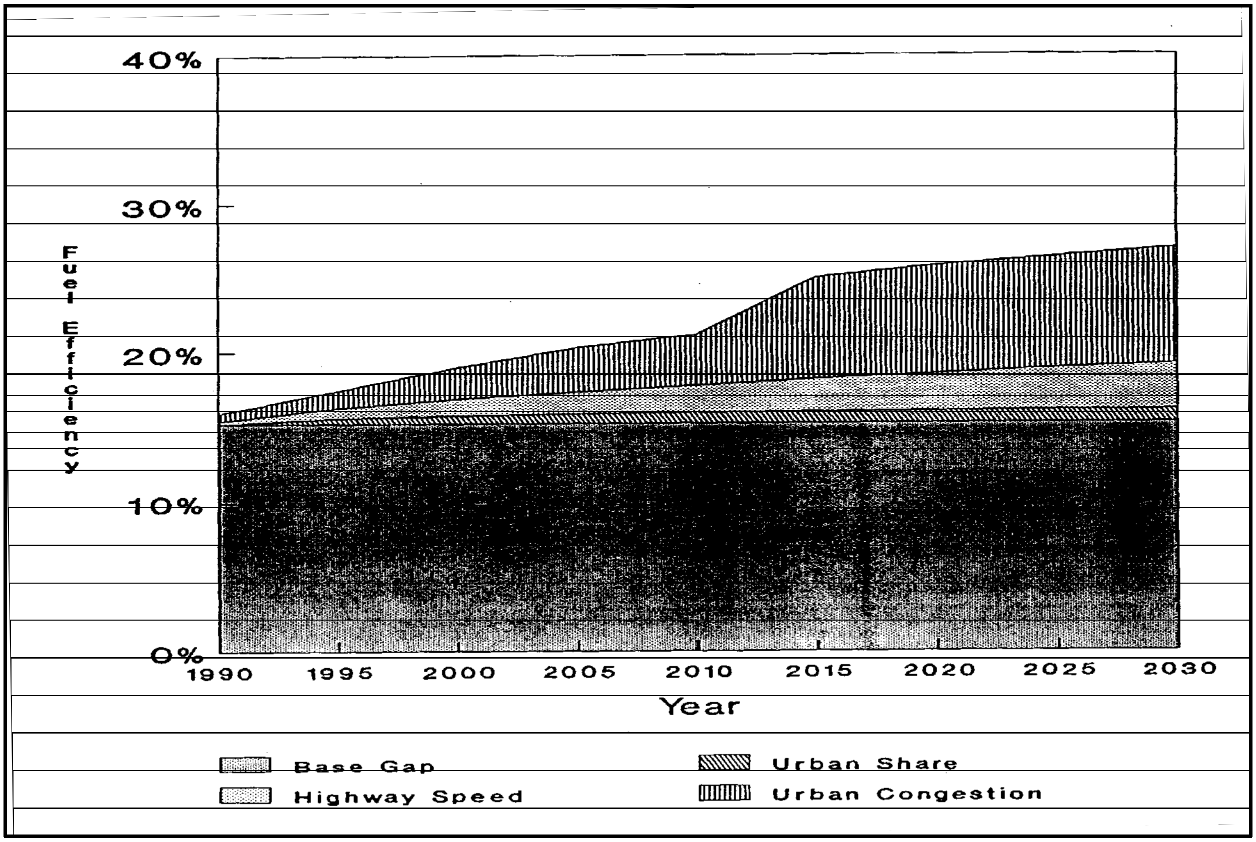


Figure F-8. Fuel Efficiency Gap for Light Duty Trucks (Logistic Forecast)

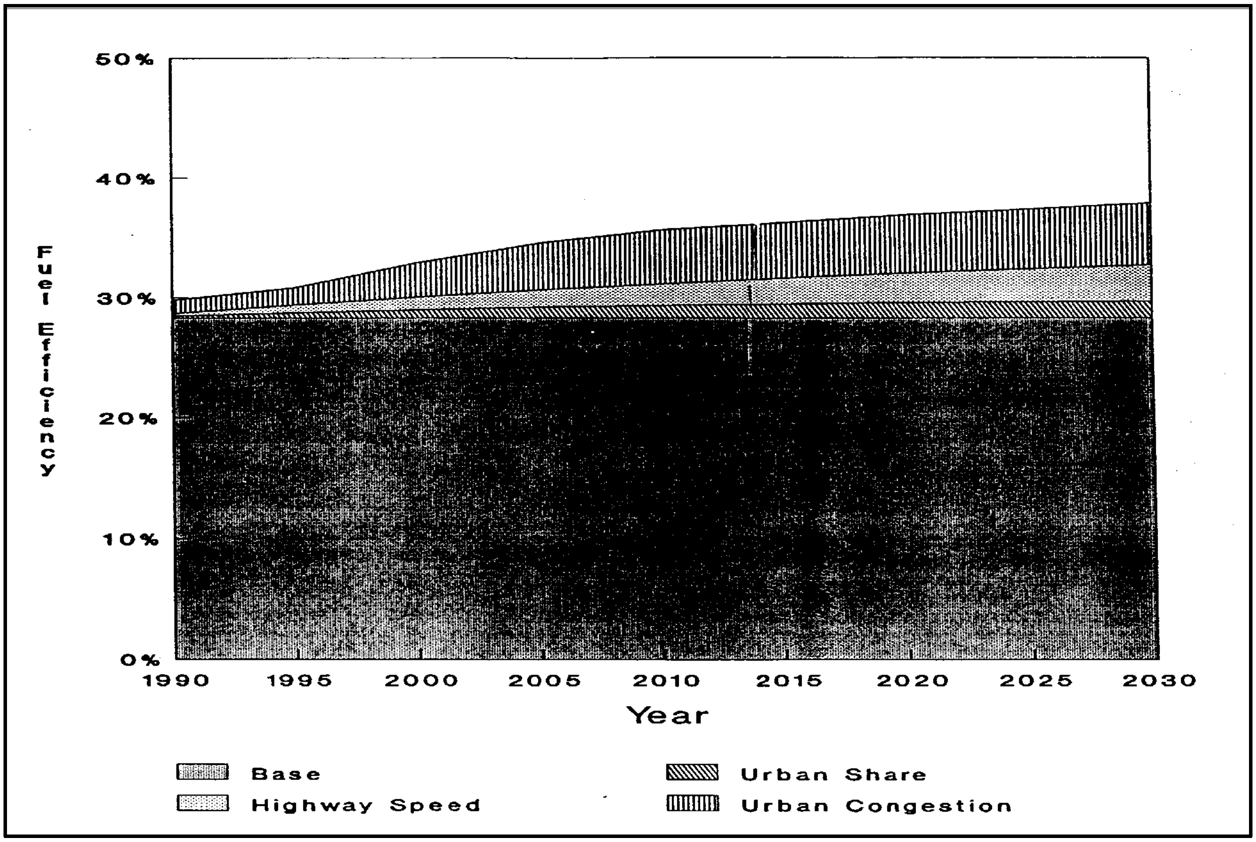


Table F-40. Light Truck Fuel Efficiency Gap Projections: Logistic Increasing Congestion Trend (with Adjusted City/Highway Driving Share)

	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

Attachment 4: Light Duty Vehicle Fleet Model

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. Business fleets are directly mapped to the "Municipal and Private" column above, government fleets

[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.

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%

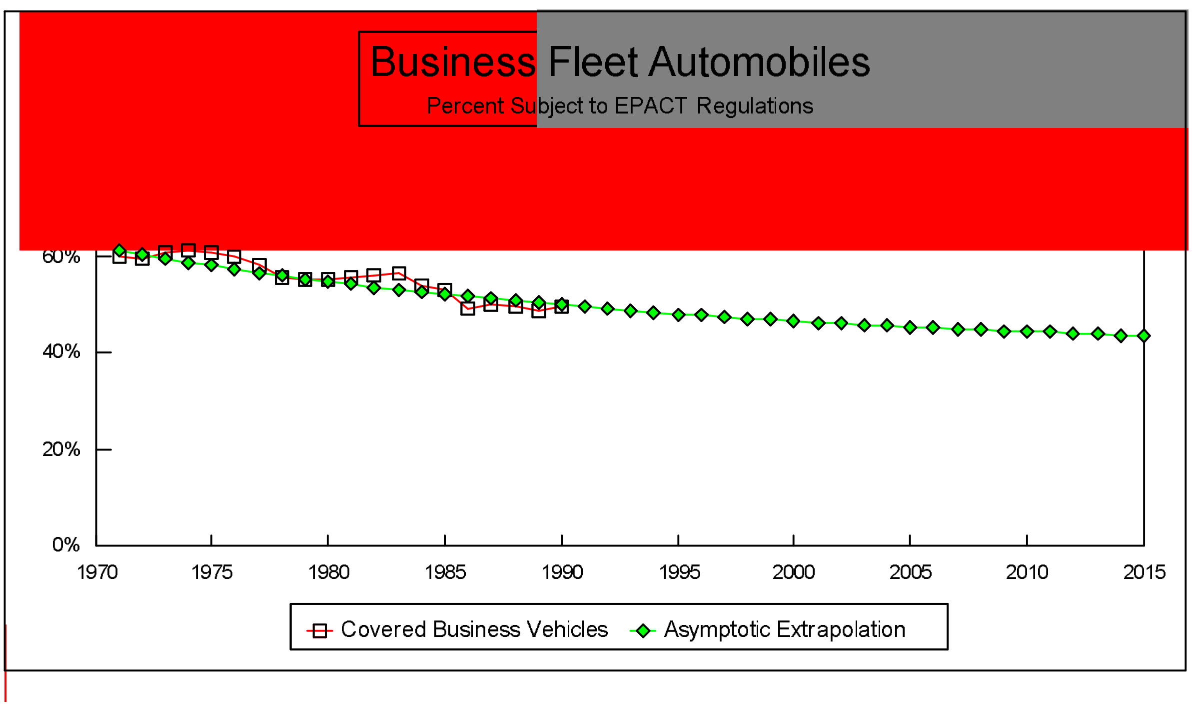
A new variable, BFLTFRAC, has been established to further stratify the stock of business fleet cars, with only the "covered" vehicles being used to estimate AFV purchases under EPACT. This variable is estimated using an asymptotic extrapolation of the historical trend, using an assumed lower limit of 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 relationships among elements of one data set are also valid in the other. Vehicle characteristics from

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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.

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:

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

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:

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

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

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

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

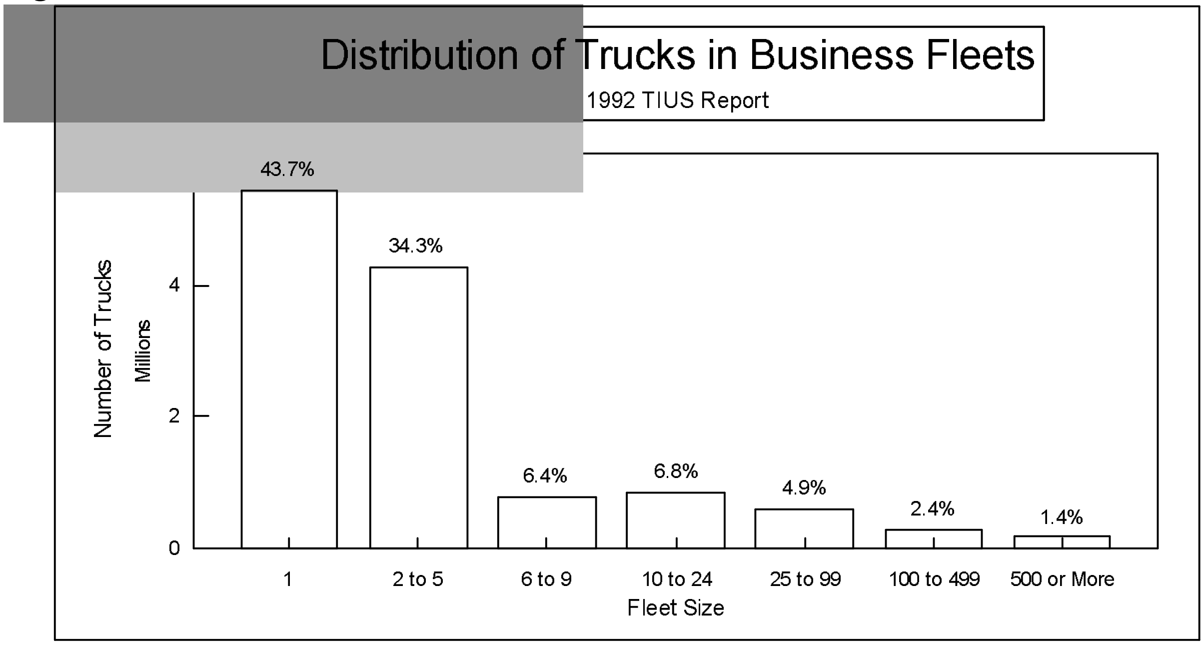
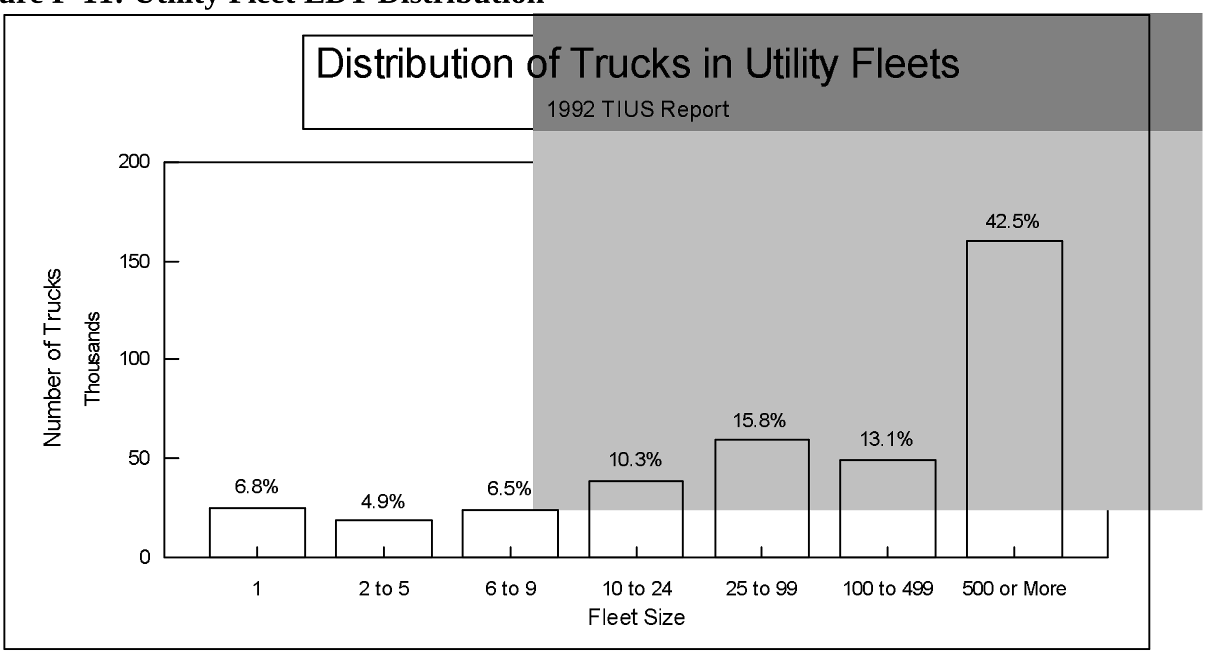


Figure F-11: Utility Fleet LDT Distribution



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

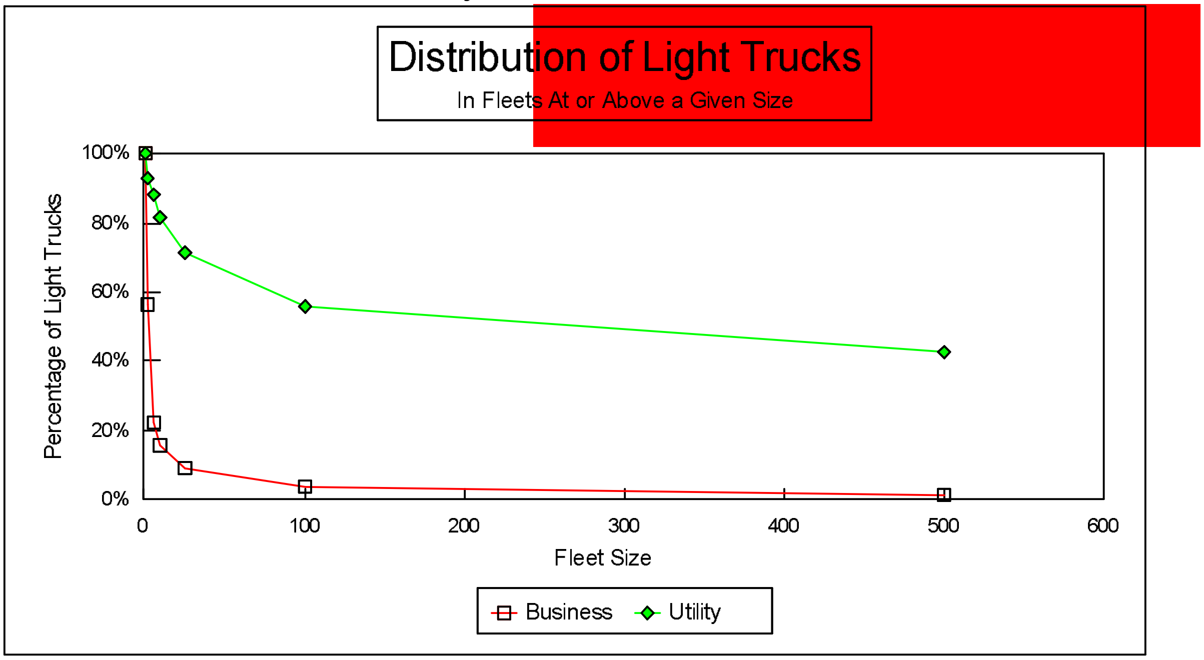
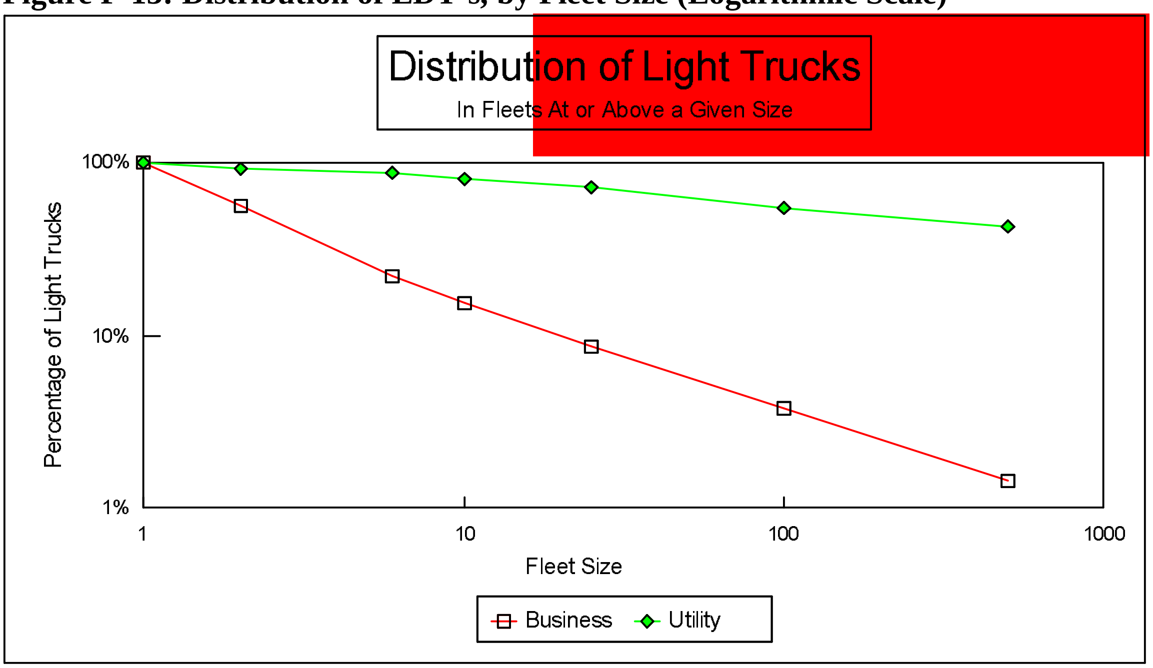


Figure F-13: Distribution of LDT's, by Fleet Size (Logarithmic Scale)



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:

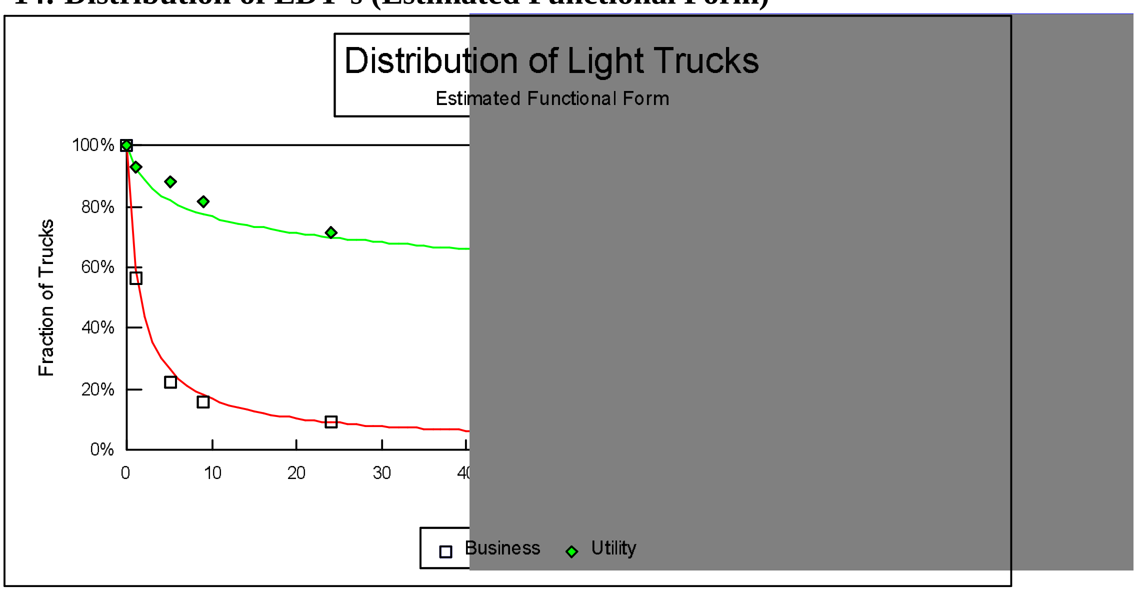
Q(n) = The reverse cumulative distribution: the percentage of trucks in fleets of size greater than or equal to *n*.

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

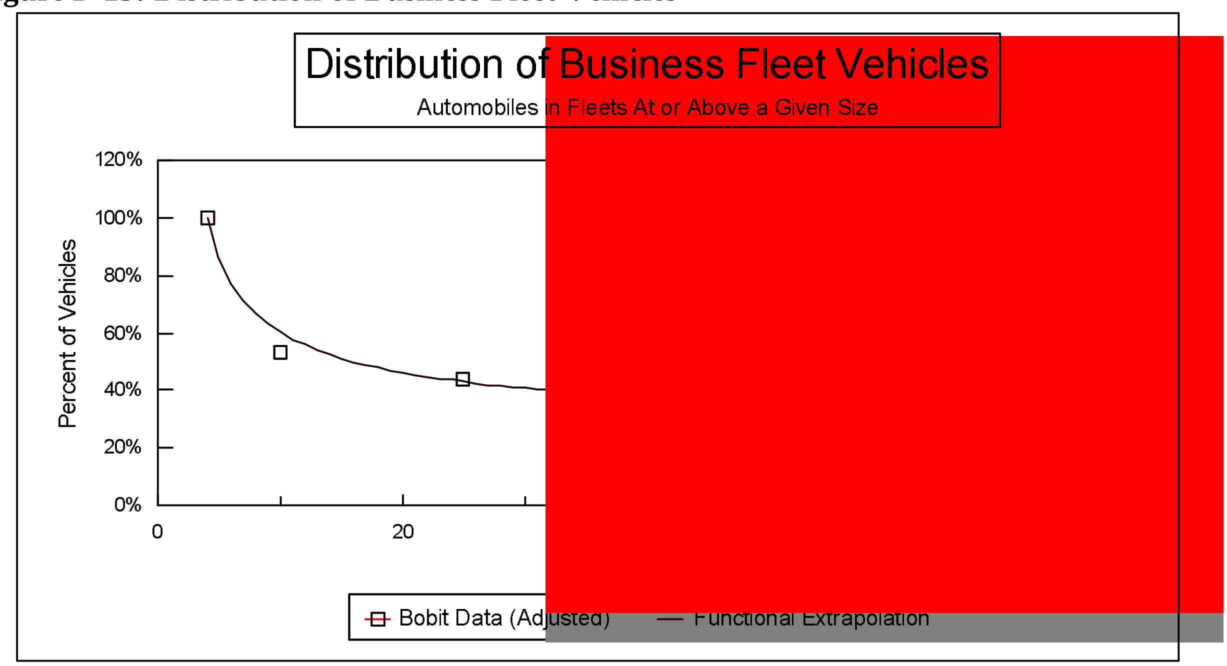


Table F-52: Percentage of Business Fleet Automobiles (FLTSIZE)			
Fleet Size	**Index (IFS)**	**Calculation**	**Percent**
Non-Fleet (<20 Cars)	1	Q(1) - Q(20)	53.7%
Small Fleet (20-50 Cars)	2	Q(20) - Q(50)	10.8%
Large Fleet (>50 Cars)	3	Q(50)	35.4%
Total			**100%**

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

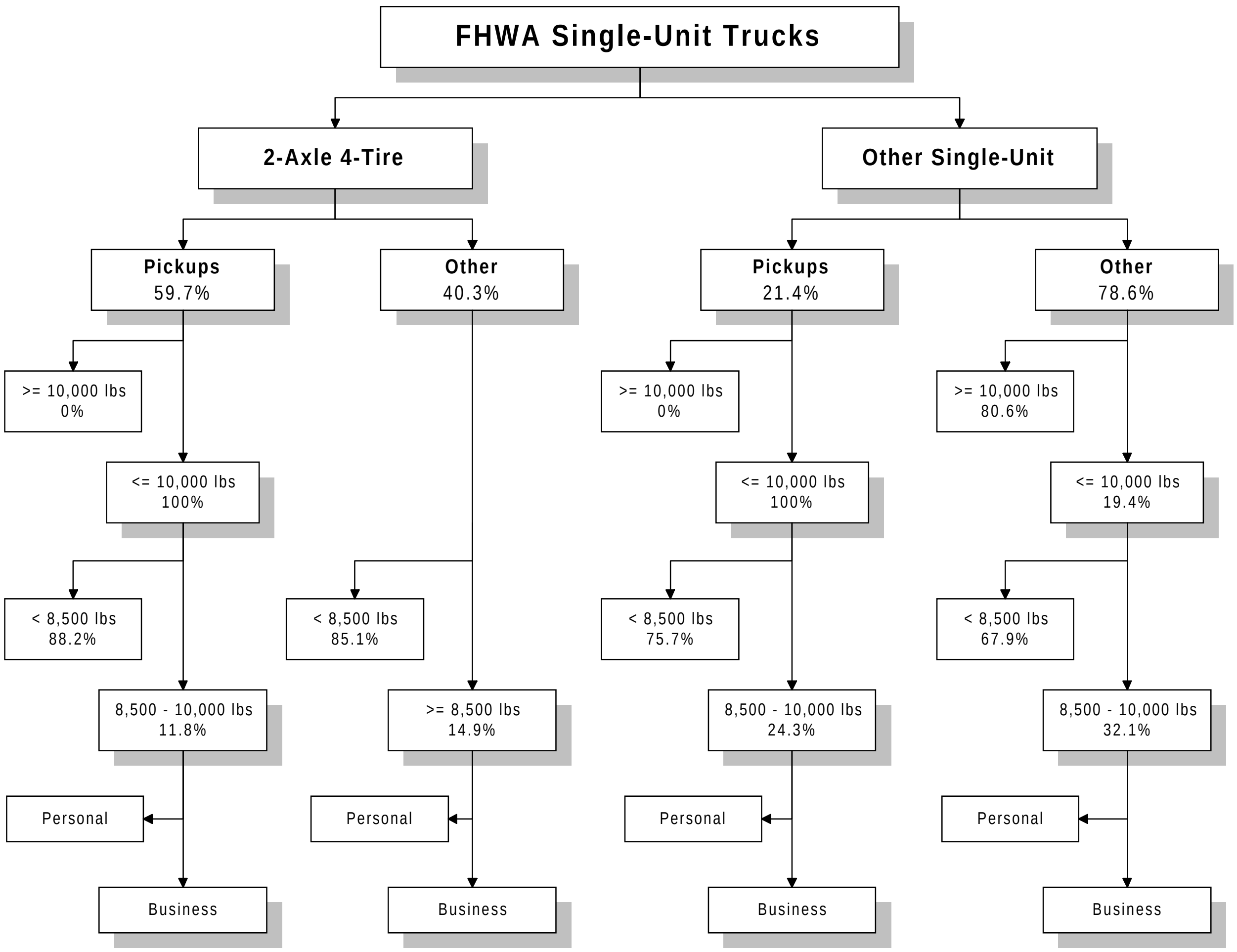
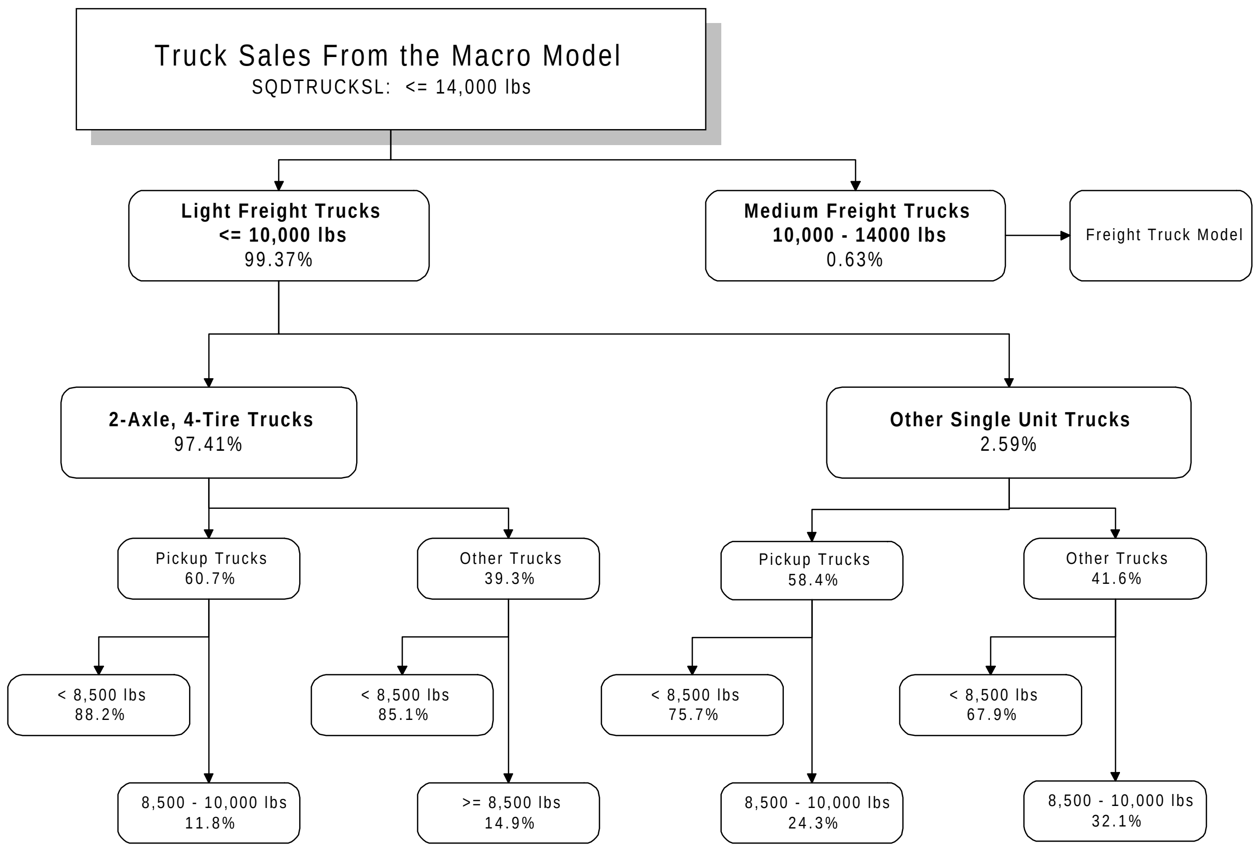


Figure F-17: Distribution of Light Truck Sales



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:

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

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

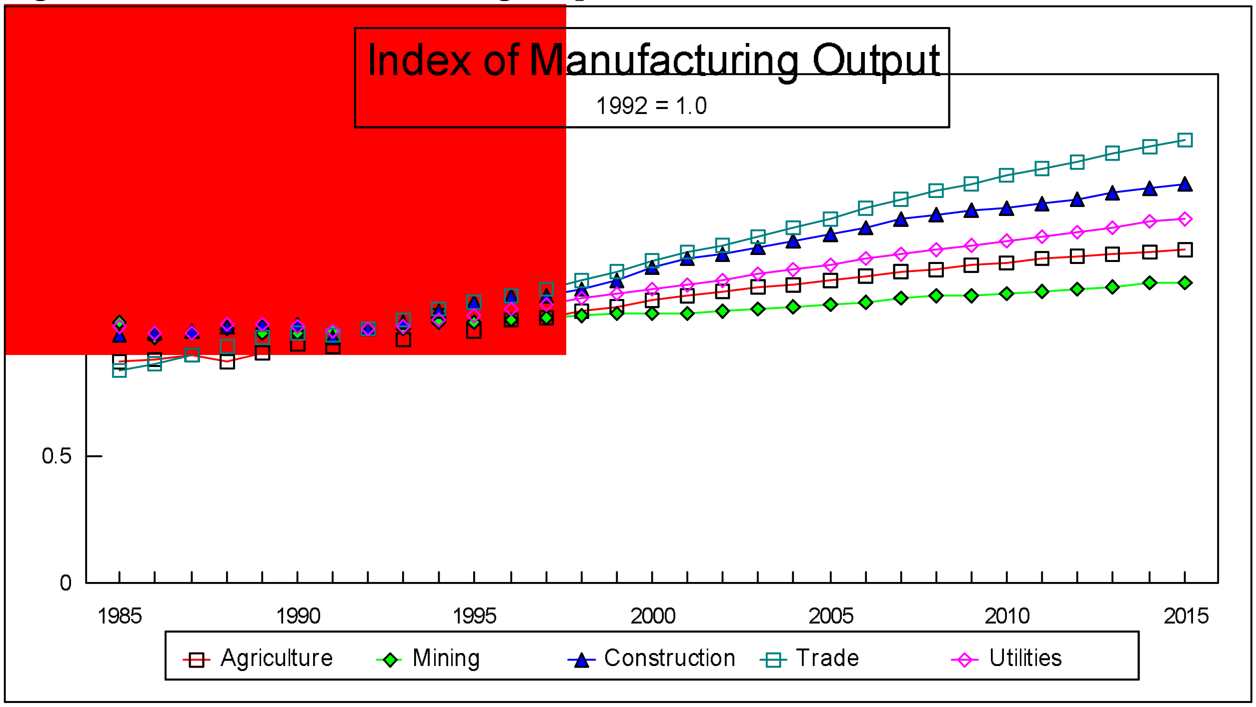
The number of trucks in each year is assumed to represent the net effect of a fixed scrappage rate applied to the previous year's stock, and the allocation of new purchases from the Macro Model. Because light truck purchases are exogenously supplied, the scrappage rate must be inferred. The table below 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.

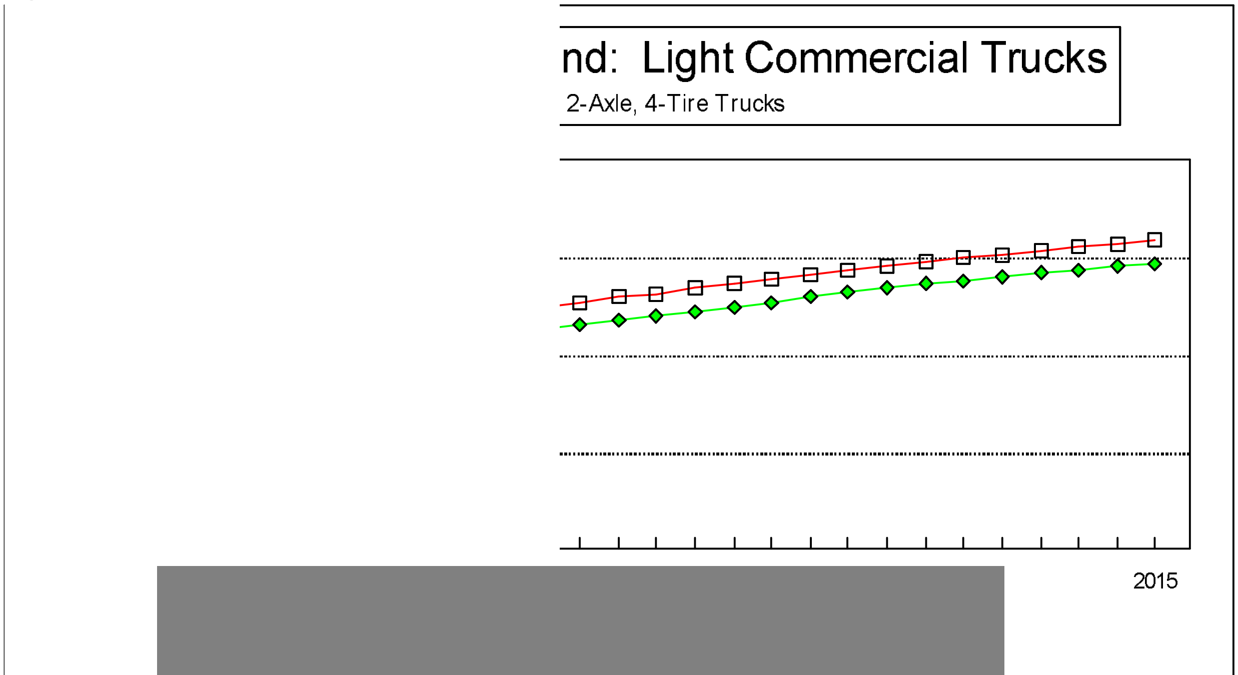
Figure F-18: Index of Manufacturing Output



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



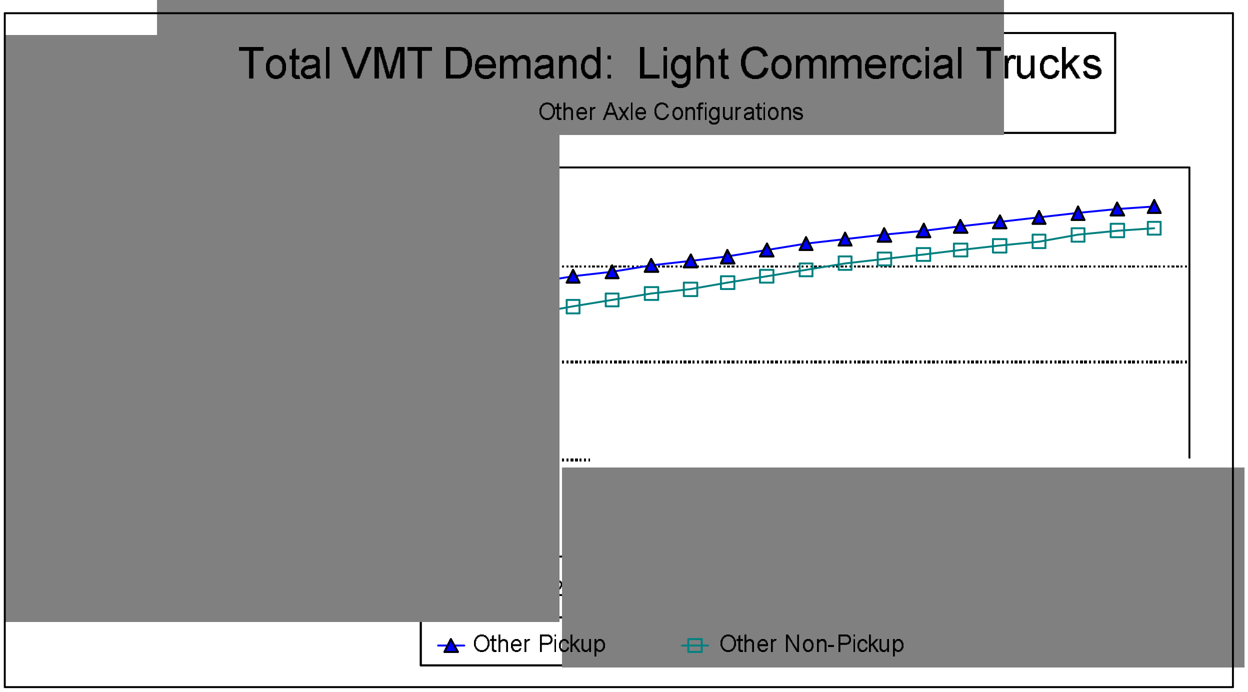
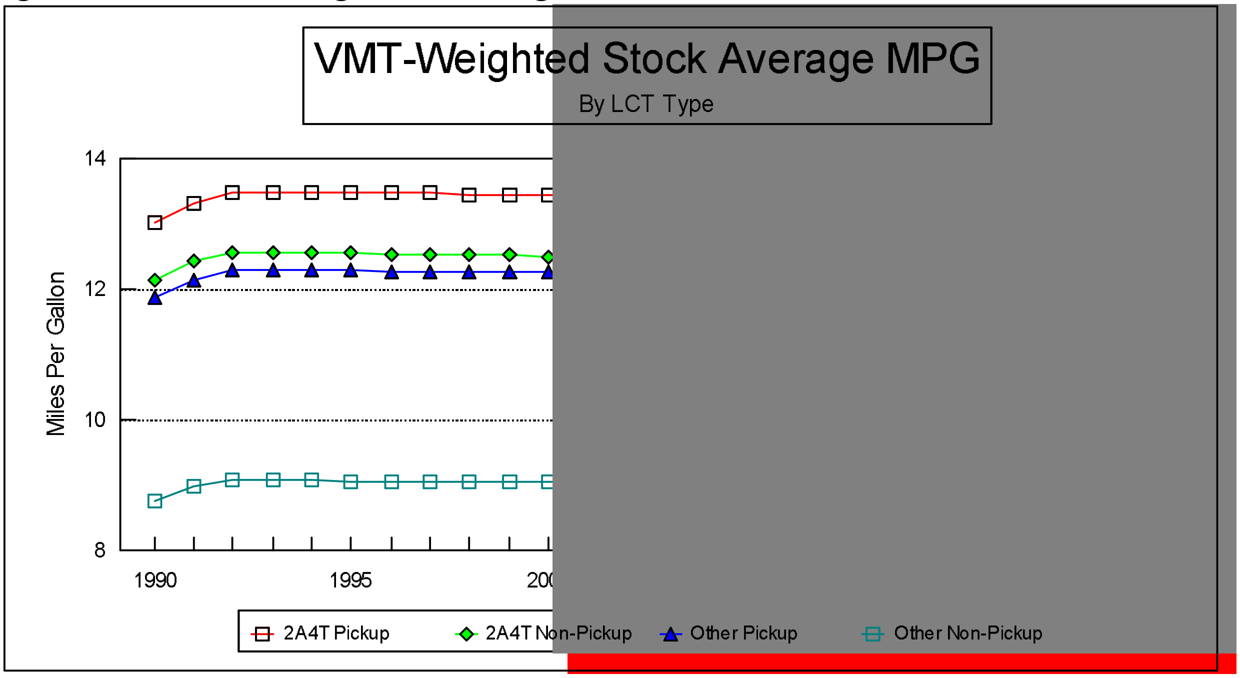


Figure F-20: Stock Average MPG for Light Commercial Trucks

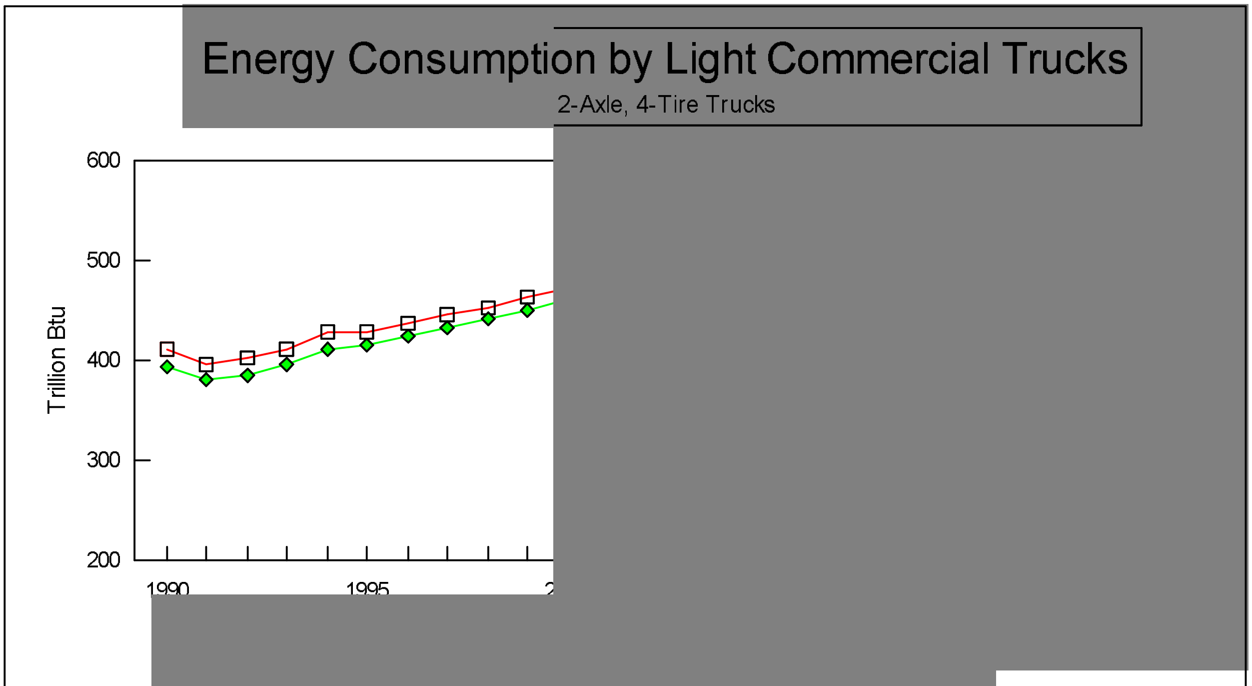


Energy Demand

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



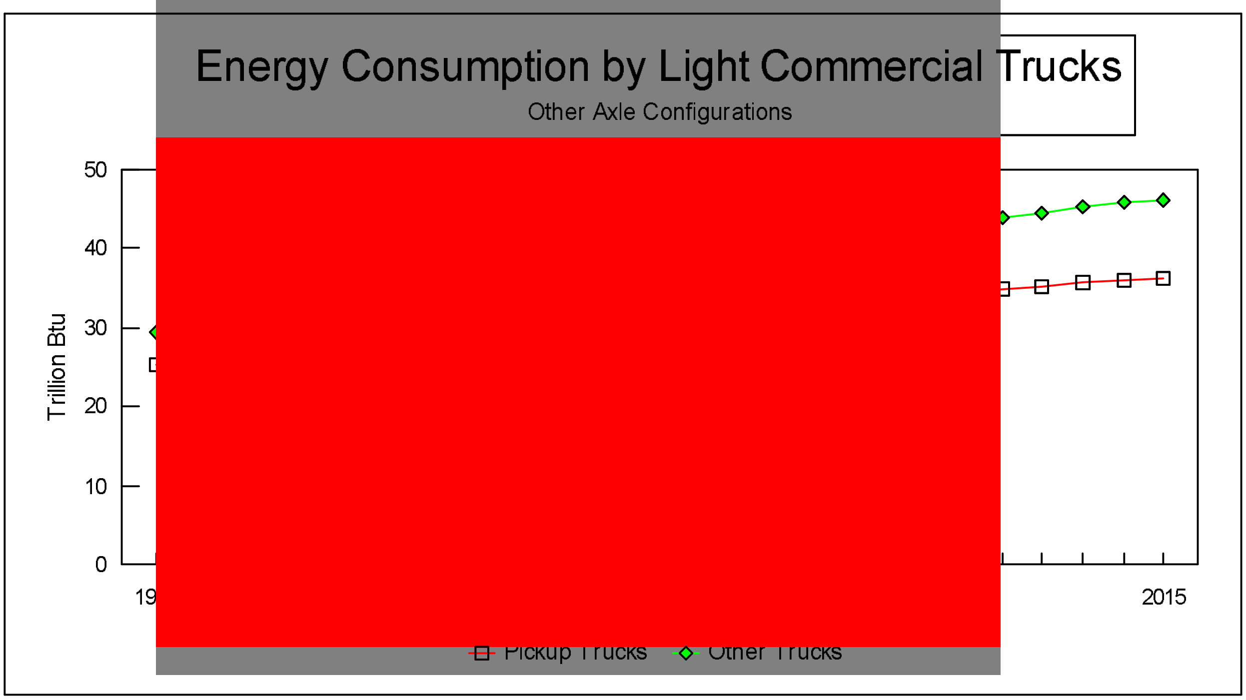
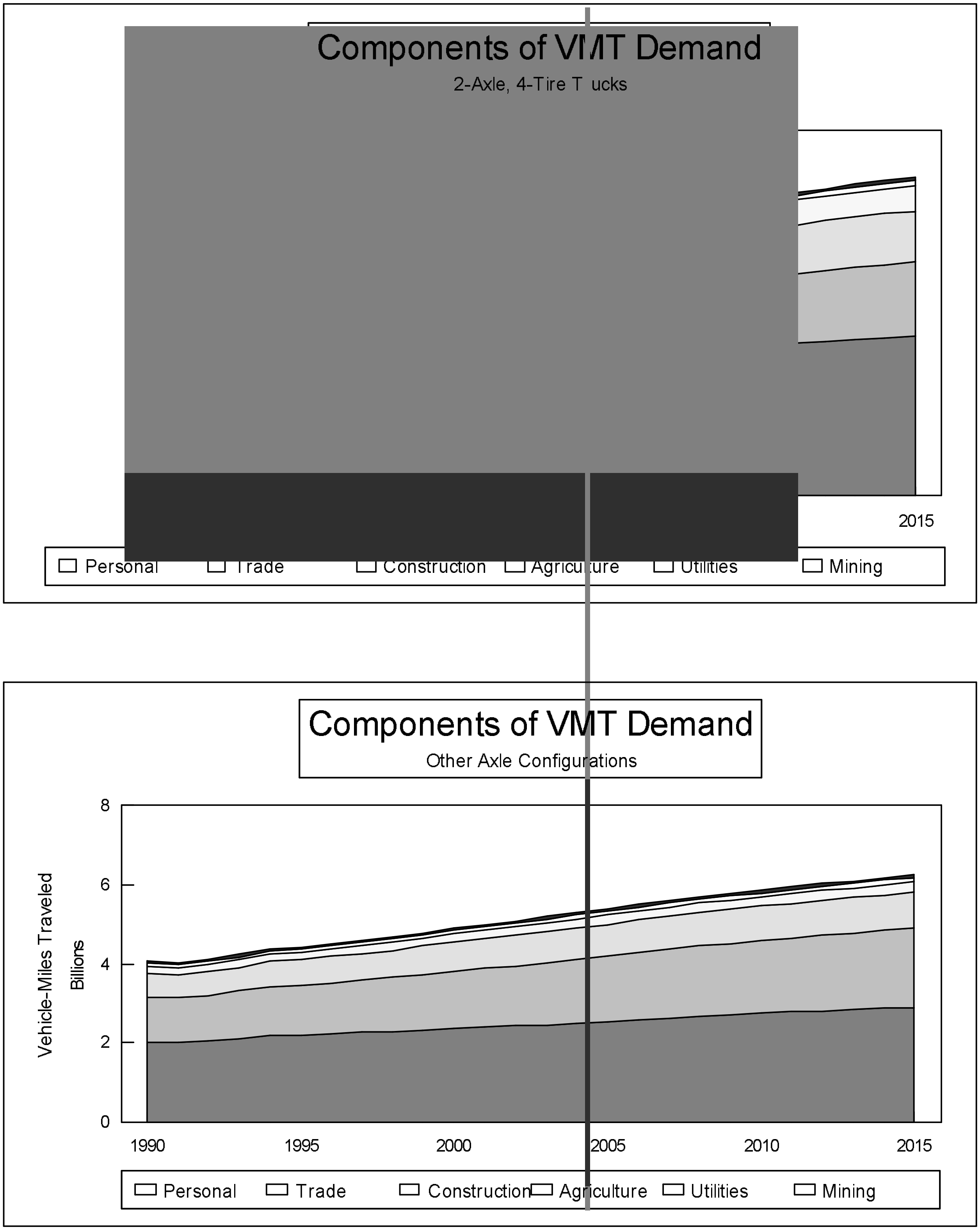


Figure F-22: Components of VMT Demand for LCT's



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