METHODOLOGIES FOR ESTIMATING FUEL CONSUMPTION USING THE 2009 NATIONAL HOUSEHOLD TRAVEL SURVEY

Prepared For

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ESTIMATION METHODOLOGIES

INTRODUCTION

The National Household Travel Survey (NHTS) is the nation's inventory of local and long distance travel. Between April 2008 and April 2009, roughly 150 thousand households[1] were interviewed about their travel, based on the use of over 300 thousand vehicles, most of which are light-duty vehicles. Using confidential data collected during those interviews, coupled with EIA's retail fuel prices, external data sources of test fuel economy[2], and historical procedures for modifying test fuel economy to on-road, in-use fuel economy, EIA has gratefully extended this inventory to include the energy used for travel, thereby continuing a data series that was discontinued by EIA in 1994 due to resource constraints.[3] This documentation report presents the methods used for each eligible sampled vehicle to

1. Provide three fundamental inputs crucial to developing annual household vehicles energy consumption and expenditures information: composite fuel economy, retail fuel prices, and in-possession vehicle-miles traveled[4];

2. Adjust imputed composite fuel economy to calculate an on-road fuel economy;

3. Adjust on-road fuel economy to calculate an in-use fuel economy based on actual household driving characteristics; and,

4. Derive annual energy consumption and motor fuel expenditure information from exogenous inputs.

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[1] The NHTS collected travel data from the civilian, non-institutionalized population of the United States. People living in medical institutions, prisons and in barracks on military bases were excluded from the sample. However, telephone numbers in dormitory rooms, fraternity and sorority houses were included so long as no more than 10 people shared the same telephone number.

[2] Federal law requires automobile manufacturers to determine the fuel economy of new vehicles offered for sale in the U.S. This information is provided on a fuel economy label affixed to each vehicle's window to help consumers make informed decisions regarding fuel economy when purchasing a new vehicle. While these labels may vary somewhat in appearance, they must all provide the same information. Note that EPA reformulated its procedures beginning with 2008 model year vehicles.

[3] EIA, in 2005, and for the first time, conducted modeling of the 2001 NHTS to augment it with energy and energy-related statistics that were considered high-value to the transport, policy and statistical communities (see http://www.eia.doe.gov/emeu/rtecs/contents.html), all of which agrees with EIA's mission to report energy statistics supporting sound policy making.

[4] EIA, for the 2001 NHTS, modified the annual vehicle-miles traveled estimates; however, those modifications were not possible for the 2009 NHTS. See documentation from the Oak Ridge National Laboratory on developing the BESTMILE variable.

Such methods allow EIA to calculate estimates on the amount of and expenditures for energy consumed by the nation's vehicles operated for residential transportation. These estimates also include number and types of vehicles per household, and for each vehicle: annual miles traveled, gallons of fuel consumed, types of fuel used, price paid for fuel, and fuel economy (gasoline mileage). Hereafter, these procedures and data are generally referenced as the "EIA Supplement."

In-Scope Households and Vehicles

Unlike the 2001 NHTS, for which EIA's modeling efforts focused on light-duty vehicles, all 2009 NHTS sampled vehicles are considered in-scope for this report. During 2008 and 2009, the NHTS interviewed the members of 150,147 households that had 309,163 vehicles at some point during the survey period.

For the definition of a light-duty residential passenger vehicle used in prior household vehicle reports, see *vehicle* in the "Glossary" of this report.

DISCLAIMER AND JUSTIFICATION

EIA has justified its augmentation of the 2009 NHTS as part of its core responsibilities to report on energy and energy-related statistics and to support decision-making policies of the nation that rely on the timely availability and accuracy of energy statistics. Had these results come from information supplied by respondents to the NHTS directly, there would be no reason for EIA to model energy statistics or to provide an explicit warning to users about the uncertainty of these data. Because NHTS did not collect information on fuel economy, retail fuel price, or fuel type, EIA rightly cautions readers that, for every single one of the over 300 thousand sampled vehicles, all energy and energy-related statistics in this report and associated tables, public-use files, and future analyses are constructed from imputed information.

Unlike the 2001 NHTS, EIA attempted to impute energy and energy-related information for all sampled vehicles in the 2009 NHTS. In the 2001 NHTS, only light-duty passenger vehicles were imputed with energy-related information because EIA excluded motorcycles, mopeds, large trucks, and buses in an effort to continue its past residential transportation series, which was discontinued in 1994. To maintain consistency among the relevant transportation series, users are cautioned to use the proper vehicle type filters.[5]

The calculation of energy-related statistics – vehicle fuel consumption and expenditures – in this report occurred in several steps. Multiple steps were required because respondents, when completing their NHTS survey questionnaires, were not directly asked to report information necessary to derive their vehicle's on-road, in-use fuel economy, nor were they asked to provide the type or price of the fuel that was used to power their vehicle(s). Without all of these critical components, there is no way to determine exactly a vehicle's consumption of and expenditures for transportation fuel. With the use of confidential NHTS data and other external data sources, however, EIA's imputation procedures modeled these policy-needed measures for most sampled vehicles (see "In-Scope Households and Vehicles" text boxes for details).

[5] Due to the different nature of the NHTS and RTECS programs, users are cautioned about combining the RTECS and NHTS data sets into a single time series.

DATA SOURCES

To derive vehicle-miles traveled (VMT); assign and adjust vehicle fuel economy (given in terms of miles per gasoline equivalent gallon (MPG); compute vehicle fuel consumption, and assign fuel prices to calculate vehicle fuel expenditures, EIA relied on administrative data from several federal agencies. These statistical procedures relied on confidential data from the U.S. Federal Highway Administration's (FHWA) 2009 National Household Travel Survey (NHTS); the EIA's 1985, 1988, and 1991 Residential Transportation Energy Consumption Survey (RTECS)[6]; the U.S. Environmental Protection Agency's (EPA) fuel economy test results[7]; and the EIA's retail pump price series[8] for 2008 and 2009.

PROCEDURES AND DEFINITIONS

EIA's purpose in partnering with the U.S. Department of Transportation was to enhance the use and usefulness of the January 2010 release of the 2009 NHTS public-use file, augmenting it with energy-related data for use by policy and decision-makers. Figure B1 depicts the estimation of those energy-related statistics: VMT, vehicle fuel economy, vehicle fuel consumption, and vehicle fuel expenditures. These steps were initially applied to each vehicle reported by households in the national sample of the NHTS. However, item nonresponse (mostly of crucial vehicle characteristics), incomplete fuel economy and sales data (generally for those vehicles having a gross vehicle weight rating heavier than 8,500 lbs), and the goal to update national estimates that conceptually compare to those found in EIA's previous residential transportation studies – 1985, 1988, 1991, and 1994 RTECS – mostly guided the scope of EIA's augmented vehicle data. The effect of those inter-dependent challenges resulted in methodologies and greater focus on light-duty passenger vehicles in households that are nationally weighted as "100-percent-household" by the NHTS.

First, annual VMT (as contained in the BESTMILE variable) was derived by the U.S. Department of Energy's Oak Ridge National Laboratory (see the NHTS User's documentation of BESTMILE provided by Oak Ridge National Laboratory (ORNL)). Moreover, because vehicles are acquired and disposed of by sample households during the survey year, the annual VMT were subsequently adjusted to reflect the period of the survey year in which the household "owned or used" the vehicle.[9] Second, the annual on-road fuel economy, reported in terms of MPG, was estimated using questionnaire responses[10], EPA fuel economy test results, and the period between

[6] This series was discontinued after EIA conducted the 1994 Residential Transportation Energy Consumption survey.

[7] Fuel economy test values and vehicle production sales data were received from the U.S. Department of Transportation, National Highway and Traffic Safety Administration for model year's 1978 through 2008. Note that 2009 model year information was not available at the time of this release.

[8] Energy Information Administration. Forms EIA-782A, "Refiners'/Gas Plant Operators' Monthly Petroleum Product Sales report," and EIA-782B, "Resellers'/Retailers' Monthly Petroleum Product Sales Report." Form EIA-888, "On-Highway Diesel Fuel Price Survey." Form EIA-895, "Monthly Quantity and Value of Natural Gas Report." Form EIA-826, "Monthly Electric Utility Sales and Revenue Report with State Distributions."

[9] See BESTMILE variable documentation provided by U.S. Department of Energy's Oak Ridge National Laboratory (ORNL).

[10] FHWA collected make (MAKECODE), model (MODLCODE), model year (VEHYEAR), and 8 categories of vehicle type (VEHTYPE), as given in *Section B: Vehicle Data* of the 2009 NHTS questionnaire. The collection of Vehicle Identification Numbers (VIN) would have provided a more accurate and richer source of vehicle characteristics. It is not known whether VINs will be collected in future survey cycles of the NHTS.

April 1, 2008 and March 31, 2009 that the vehicle was in use.[11] The MPG values were adjusted to account for the difference between EPA test values and on-road, in-use values. Third, estimated vehicle fuel consumption was derived by dividing the prorated VMT (i.e., BESTMILE variable) by the estimated MPG. Then, multiplying the vehicle's fuel consumption by its fuel price, on a monthly basis, derives motor fuel expenditures. Unfortunately, the NHTS did not collect the vehicle's motor fuel prices via fuel purchase diaries. Instead, each NHTS vehicle was assigned a retail price based on its imputed fuel type. All price information was obtained from the EIA's fuel price series.

The following sections of this appendix describe the estimation procedures used for calculating a vehicle's monthly VMT, MPG, fuel consumption, fuel price, and fuel expenditure.

The following terms are used throughout this report:

Fuel Economy Term	Definition
EPA Composite MPG	The EPA dynamometer test procedure, performed on pre-production prototype vehicles, yields separate test values for EPA city and highway MPG. These city and highway MPG are often combined to form the "composite" MPG, as reported to EIA by the National Highway Traffic Safety Administration's (NHTSA) Corporate Fuel Economy Program (CAFE).
On-Road MPG	A Composite MPG that was adjusted to account for the shortfall between the test value and the fuel economy actually obtained on the road. The adjustment did not take into account the driving patterns of individual drivers and seasonal differences.
In-Use MPG	MPG that were adjusted for seasonal differences and annual miles driven. Vehicles that are driven relatively few miles during the year are assumed to be driven mostly on short trips that involve frequent stops. Vehicles that are driven relatively many miles are assumed to be driven mostly on long trips where few stops are needed.
MPG Shortfall	A measure of the difference between actual on-road MPG and the EPA laboratory test MPG, expressed as the ratio of test MPG to on-road MPG.

EPA test fuel economy value data are restricted to vehicles that are used to derive Corporate Average Fuel Economy under Title V of the Motor Vehicle Information and Cost Savings Act (15 U.S.C. 1901, et seq.) with subsequent amendments and Subtitle VI (49 U.S.C. 329). Corporate Average Fuel Economy (CAFE) is the sales-weighted average fuel economy, expressed in miles per gallon, of a manufacturer's fleet of passenger cars or light trucks with a gross vehicle weight rating (GVWR) of 8,500 lbs. or less, manufactured for sale in the United

[11] For 2009 model year vehicles, the NHTS calculates odometer-based VMT (BESTMILE) for the entire 12-month time period.

States, for any given model year.[12] Fuel economy is defined as the average mileage traveled by a vehicle per gallon of gasoline (or equivalent amount of other fuel) consumed as measured in accordance with the testing and evaluation protocol set forth by the U.S. Environmental Protection Agency (EPA).

Manufacturers also perform their own fuel economy tests of new vehicle models and submit the results to EPA. EPA is responsible for conducting its own tests or verifying the manufacturers' dynamometer tests. EPA also is responsible for compiling the production data from manufacturers' reports and furnishing CAFE results to NHTSA.

Fuel economy test data from the manufacturers and EPA serves as the starting point for both CAFE values and real-world fuel economy imputations. For CAFE program purposes, the test data are adjusted upward to account for any credits for dual-fuel alternative fuel vehicles (AFV) and dedicated AFV; and these values, for passenger cars only, are also adjusted upward for credits available to manufacturers to account for test procedure changes since the CAFE program was established. For NHTS and this report, such credits and their associated upward adjustments were removed, if so indicated by NHTSA.

Table B1. Sample Counts of Vehicles in EIA's Supplement for 2009 NHTS by Type and Model Year

Vehicle Type	NHTS Vehicle Type Code	Model Year of Vehicle				Total
		Pre-1978	1978 - 2008	2009 and 2010	Not Ascertained	
Automobile*	01	3,752	144,740	1,615	4,486	154,593
Van*	02	136	23,278	47	811	24,272
Sport Utility Vehicle*	03	312	52,719	344	1,385	54,760
Pickup Truck*	04	1,589	56,475	158	2,562	60,784
Other Truck	05	148	894	2	108	1,152
Recreation Vehicle*	06	105	1,989	5	94	2,193
Motorcycle	07	477	8,763	70	892	10,202
Other (e.g., golf cart)	08	2	245	0	45	292
Not Ascertained		21	528	3	363	915
Total		**6,542**	**289,631**	**2,244**	**10,746**	**309,163**

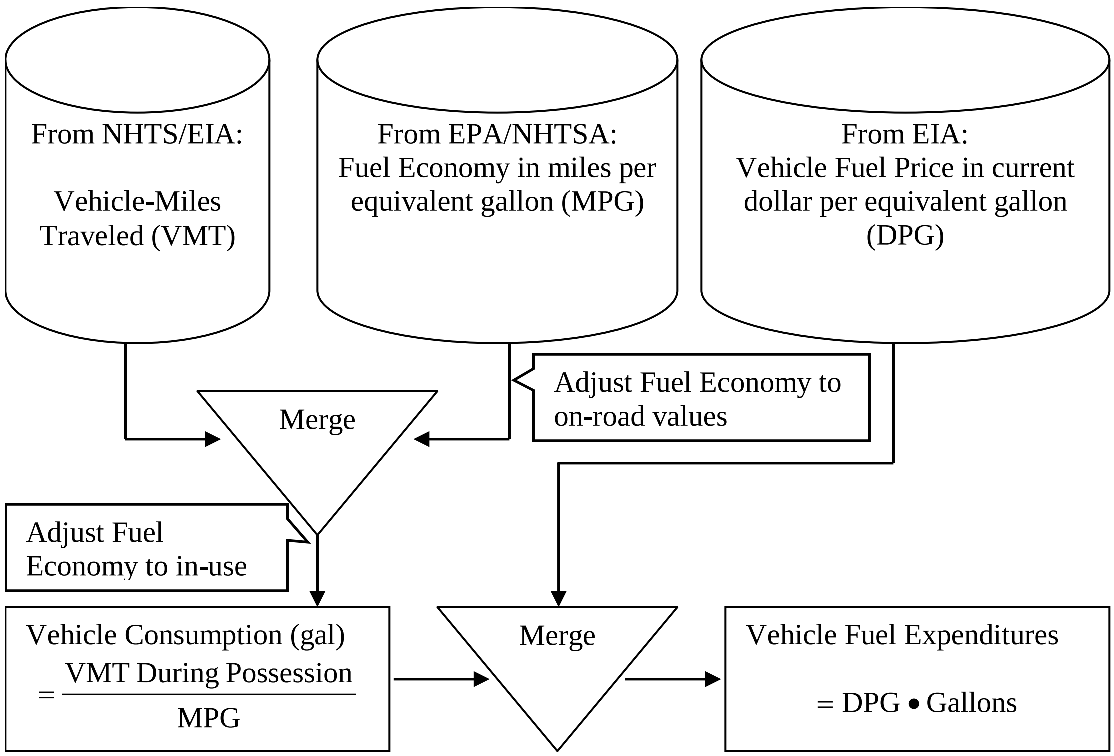
Source: U.S. Department of Transportation, Federal Highway Administration, *2009 National Household Travel Survey*, January 2010 release. (Washington, DC). *Note: All NHTS sampled vehicles are displayed; however, EIA's primary focus is *light-duty residential passenger vehicles*, which fits with EIA report's definition of a *vehicle* (see "Glossary" for details).

Since the NHTS is a national survey, it collected data from a nationally representative sample of households to derive statistically reliable travel estimates at the national, region (4) and division (9) levels. Sample data in the NHTS are generally not adequate to provide state or smaller area-specific estimates. Indeed, NHTS recommends limited analysis below census

[12] These vehicles are conceptually consistent with 2009 NHTS sample vehicles having a vehicle type of "01" (Automobile), "02" (Van), "03" (Sport Utility Vehicle), "04" (Pickup Truck). EPA does not provide test data for vehicles such as the Ford Excursion, Hummer H1 and Hummer H2 because they have a GVWR greater than 8,500 lbs. However, EIA experts made minor additions to account for these vehicles, either in unit or in total.

divisions. However, the 2009 NHTS sample includes several jurisdictions where additional sample households were purchased and subsequently interviewed. The jurisdictions that purchased these additional samples are referred to as the "add-on" areas (see http://nhts.ornl.gov/index.shtml for details).[13] The responses to these add-on samples are contained on the Public-Use version of the 2009 NHTS and considered property of the respective add-on sponsor. These additional sample cases were included in developing the energy consumption and expenditures data.

Figure B1. Estimation Schematic



Note: NHTS – National Household Travel Survey, EPA – U.S. Environmental Protection Agency, EIA – Energy Information Administration, and NHTSA – National Highway Transportation Safety Administration.

VEHICLE MILES TRAVELED

In the 2009 NHTS, the number of miles (VMT) driven by an NHTS household vehicle can be estimated in three different ways. First, one can use the single odometer reading to compute an estimate of annual mileage. Second, a designated household member was asked to report the total number of miles driven in each of the household vehicles (hereafter referred to as "self-reported VMT"). Finally, the amount of annual driving can be estimated based on the amount a vehicle is driven during the designated sample day (i.e., the travel day). Ideally, annualizing the odometer readings would probably generate the most reliable VMT estimate compared to estimates based on the other two approaches. Unfortunately, not all vehicles had an odometer reading recorded. Furthermore, of those that had their odometer reading recorded, the quality of some of the odometer readings is less than desirable. As such, ORNL was asked to estimate the number of

[13] See http://www.bts.gov/external_links/government/metropolitan_planning_organizations.html for a complete list.

miles driven by each of the NHTS vehicles based on the best available data. This estimate is hereafter referred to as the BESTMILE or annual VMT. BESTMILEs are computed only for automobiles, pickup trucks, vans, and sport utility vehicles. The value of the BESTMILE for motorcycles, other trucks, and recreational vehicles (RV) equals the value of the self-reported VMT for those vehicles with such information available. The BESTMILE estimates were developed using Version 2.0 of the 2009 NHTS data and conducted by U.S. Department of Energy's Oak Ridge National Laboratory (ORNL), Engineering Science Technology Division, Center for Transportation Analysis.

The percentage of vehicles with BESTMILE based on odometer data (63.9 percent) was higher than in the 2001 NHTS (47.5 percent). This reflects the fact the only one odometer reading was taken in the 2009 data, with two required for a vehicle to be considered usable in the 2001 data. Table 3 (in ORNL's documentation) summarizes the distribution of 2009 NHTS vehicles in terms of the key pieces of data. The structure of this table was the foundation for the differing ways in which BESTMILE was computed for the 2001 NHTS, and shaped computations in the same way for the 2009 NHTS vehicles.

There were 309,163 vehicles included in the 2009 NHTS survey. However, as indicated by ORNL's documentation, 14,754 of these vehicles were out-of-scope for the BESTMILE estimate. The out-of-scope vehicle types include "other trucks," "recreational vehicles," "light electric vehicle (golf cart)," and vehicles with missing vehicle type information. BESTMILE for these vehicles was set to the self-estimate for annual miles driven, where available.

IN-POSSESSION VEHICLE-MILES TRAVELED

Because the 2009 NHTS did not collect two odometer readings[14], EIA could not extend the logic of computing a vehicle's VMT by estimating the period of time that the vehicle was in the household's possession. This effort was possible with the 2001 NHTS.

With the 2001 NHTS modeled information this was done in multiple steps using public-use data provided by FHWA. Once annual VMT were obtained either through the work completed by ORNL or the two approaches (i.e., standard annualization or multiple regressions) undertaken by EIA, each vehicle's annual VMT value was adjusted to correspond to the time period that the vehicle was in the possession of the sample household during the survey year, which started on May 1, 2001 and ended on April 30, 2002. Using a vehicle's acquisition and disposition dates, as derived from NHTS interview contact and odometer reading dates or other relevant contact information on survey follow-up procedures[15], an in-possession VMT value was calculated based on standard monthly driving fractions, F_j.[16] By simply multiplying the annual VMT by the sum of the monthly driving fraction, prorated as needed, a *VMT during possession* was computed. These *VMT-during-possession* values formed the basis of analyses on energy consumption and

[14] Only one odometer reading was collected for each sample vehicle in the 2009 NHTS.

[15] Follow-up contacts with NHTS respondents were undertaken within a set procedure, according to correspondences with NHTS contractor, Mark Freedman of Westat.

[16] To ensure that the distribution of average monthly vehicle miles traveled given in Table B2 reflected 2001 driving patterns, EIA compared those fractions with the 2001 FHWA's highway-based values. No significant differences were found; however, the events occurring in September 2001 and soon thereafter may have unknown contributions to travel behavior patterns not shown here.

expenditures for residential passenger vehicle use in EIA's report *Household Vehicles Energy Use: Latest Data & Trends*.[17] Hence, caution must be used when making comparison between 2001 and 2009 household vehicles' energy and energy-related statistics from the NHTS programs.

VEHICLE FUEL ECONOMY

Fuel economy (MPG) must be estimated for each NHTS sample vehicle in order to estimate each vehicle's fuel consumption for the survey year. Then, fuel consumption is estimated by dividing BESTMILE[18] by the MPG.[19] The NHTS neither obtained actual fuel consumption data nor on-road MPG from fuel purchase diaries maintained by the respondents. Because NHTS did not require these data or diaries, MPG values were estimated using EPA laboratory test MPG that were adjusted to account for differences between actual on-road MPG and the EPA test MPG. This difference is known as MPG "shortfall." Lax, 1987[20]; Mintz, 1993[21]; and Reichert, 2000[22], investigated the feasibility of using shortfall-adjusted MPG in a household survey. The Lax study verified that the method yielded unbiased MPG, when using a database from a 1984 fuel purchase diary study performed by NPD Research, Inc. The adequacy of current shortfall adjustment methods is sufficient for late 1980 through early 1993's motor vehicle model years also (RTECS Technical Note 5).[23] For the 2009 NHTS, the adequacy of shortfall adjustments has been presumed for 1978 through 2008's motor vehicle model years.[24,25]

The NHTS sample vehicles were assigned EPA test MPG from the NHTSA Corporate Average Fuel Economy files. Each record of the NHTSA files contained an EPA Composite MPG (i.e., an unadjusted 45 percent highway and 55 percent city weighted estimate) for each unique combination of vehicle attributes within a given manufacture, model/carline, type and

[17] See http://www.eia.doe.gov/emeu/rtecs/nhts_survey/2001/index.html, accessed on December 7, 2010

[18] NHTS public-use data, which was released on January 2010, assumes a fixed 12-month period (starting on April 1, 2008 and ending March 31, 2009). No modifications were made to compute the fraction of the year in which the household had "actual" possession of the vehicle.

[19] The 2009 NHTS was conducted from April 2008 to March 2009. Unfortunately, that timing turned out to be problematic due to the rapid rise in the cost of transportation fuels.

[20] Lax, D. 1987. "Feasibility of Estimating In-Use Vehicle Fuel Efficiency from Household Survey Data." Research performed under contract for ORNL/DOE/EIA. Energy and Environmental Analysis Inc., Arlington, VA.

[21] Mintz, M., A. Vyas, and L. Conley, 1993. "Differences Between EPA-Test and In-Use Fuel Economy: Are the Correction Factors Correct?" Transportation Research Record 1416, pp. 124-130, Transportation Research Board, National Research Council, Washington, DC.

[22] Reichert, J. 2000. "Change in Method for Estimating Fuel Economy for the Residential Transportation Energy Consumption Survey," Energy Information Administration on www.eia.doe.gov/emeu/rtecs/contents.html.

[23] Harrison, I.M. "VMT 1991 Patterns," Residential Transportation Energy Consumption Survey Technical Note 5, unpublished document. (Washington, DC).

[24] Manufacturers may choose reformed or unreformed fuel economy testing standard beginning in Model Year 2008.

[25] Office of Transportation and Air Quality, "Fuel Economy Labeling of Motor Vehicle Revisions to Improve Calculation of Fuel Economy Estimates." EPA420-R-06-017, December 2006.

model year. These attributes included (1) number of cylinders, (2) cubic inches of engine displacement (CID), (3) type of transmission (manual or automatic), and (4) fuel metering (gasoline, diesel, electric, natural gas, duel-, or flexible-fuel vehicle).[26] Each record of the NHTSA files also contained the number of vehicles sold, in thousands of vehicles, for each unique combination of attributes. The vehicle attributes available to assign a Composite MPG for sample vehicles were the ones collected for each NHTS vehicle. Specifically, NHTS queried respondents on their vehicle's make, model, vehicle type, and model year attributes. Hence, merging, assigning and statistical linking to NHTSA's Corporate Average Fuel Economy files were restricted to those four vehicle attributes.[27] If, in the future, NHTS were to collect Vehicle Identification Numbers (VIN), then these linking procedures might be performed on a more robust set of vehicle attributes.[28]

NHTSA files served multiple purposes. In addition to assigning a Composite MPG, the NHTSA files were used to impute "missing" vehicle attributes: vehicle class, fuel metering and engine type for purposes of assigning an appropriate fuel price. Based on the limited set of vehicle attributes obtained from the NHTS questionnaire, several records from the NHTSA files were usually found to be potential "matches" to a given sample vehicle. A matching record was chosen from among the several applicable ones, with probability proportional to sales, using the sales figures on the NHTSA files. Once chosen, a record provided (1) EPA Composite MPG, (2) fuel metering, and (3) engine type. Although more attributes were available for selection, EIA limited its matched attributes to those required to assign an appropriate fuel price to a sample vehicle. Of the 309,163 eligible vehicles, EIA selected a matching record for 288,507 vehicle, or 93 percent. This matching routine commonly resulted in 1-to-many record linkages (see Figure C1 for more details). For the remaining 7 percent of in-scope sample vehicles, EIA employed expert knowledge, historical information from the U.S. Department of Transportation's *Highway Statistics* report series, average estimates from prior RTECS programs and assigning average on-road, in-use MPG values.

For post-1978 model year light-duty vehicles, the EPA Composite MPG is just the starting point for fuel economy computations. For the 2009 NHTS, EIA employs a sequential adjustment procedure in which the EPA Composite MPG are adjusted first to an on-road MPG, and then to an in-use MPG. For pre-1978 light-duty vehicles and non-light-duty vehicles, averages for on-road, in-use fuel economy are obtained from prior RTECS program histories and table VM-1 released by the U.S. Department of Transportation's *2008 Highway Statistics* report, respectively.

THE EPA COMPOSITE MPG

Beginning in the early 1970's, EPA measured fuel economy from tests that were conducted on a dynamometer to simulate actual driving conditions.[29] By 1975, EPA had incorporated

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[26] NHTSA file records do not include whether the vehicle's emissions control package met Federal or California standards.

[27] In the 2009 NHTS, information was collected on hybrid vehicles. When applicable, this variable served as a fifth vehicle attributed used in statistical linking.

[28] VINs may be decoded to yield the vehicle attributes, by use of the Highway Loss Data Institute's "Vindicator" software.

[29] And starting with 2008 model year light-duty vehicles, NHTSA accepts either the "reformed or unreformed" test fuel economy data (see http://www.nhtsa.gov/fuel-economy for details).

separate "city" and "highway" driving cycles into the test. The city and highway MPG were combined to form a "composite" MPG that was then weighted according to sales of the production vehicles in order to assess compliance with Corporate Average Fuel Economy (CAFE) standards. The EPA Composite MPG is based on the assumption of a "typical" vehicle-use pattern of 55 percent city driving and 45 percent highway driving, and has become a convenient single fuel economy measure for analytical and regulatory purposes.

The EPA Composite MPG[30] is defined as:

$$MPG_{(EPA\ 55/45)} = \frac{1}{0.55 \bullet \frac{1}{MPG_{(EPA\ city)}} + 0.45 \bullet \frac{1}{MPG_{(EPA\ hwy)}}} \qquad (1)$$

where:

$MPG_{(EPA\ 55/45)}$ denotes the composite MPG; $MPG_{(EPA\ city)}$ denotes the fuel economy when vehicle use pattern is city driving only; and, $MPG_{(EPA\ hwy)}$ denotes the fuel economy when vehicle use pattern is highway driving only.

Because separate city and highway fuel economy estimates were not available on the NHTSA files, a single "shortfall" adjustment factor was derived, approximating the adjustments given in the following sections.

FUEL ECONOMY SHORTFALL

Fuel economy shortfall occurs when the fuel economy that is actually obtained while using the vehicle is lower than the EPA test results. Reasons for this shortfall are (1) a result of the differences between EPA test vehicles and the vehicles actually in use and (2) the differences between EPA procedures for simulated driving conditions and actual driving conditions. For example, EPA test vehicles are prototypes that do not contain the wide variety of power-consuming accessories often found on vehicles sold to consumers. The test procedures also do not simulate the actual driving conditions that affect fuel economy such as speed and acceleration of individual drivers, road conditions, weather, and traffic. In the 2009 NHTS, adjustments for this fuel economy shortfall were made to the composite MPG ($MPG_{(EPA\ 55/45)}$) that were assigned to the sample vehicles.

Fuel economy shortfall was expressed in terms of the "Gallons per Mile Ratio" or GPMR:

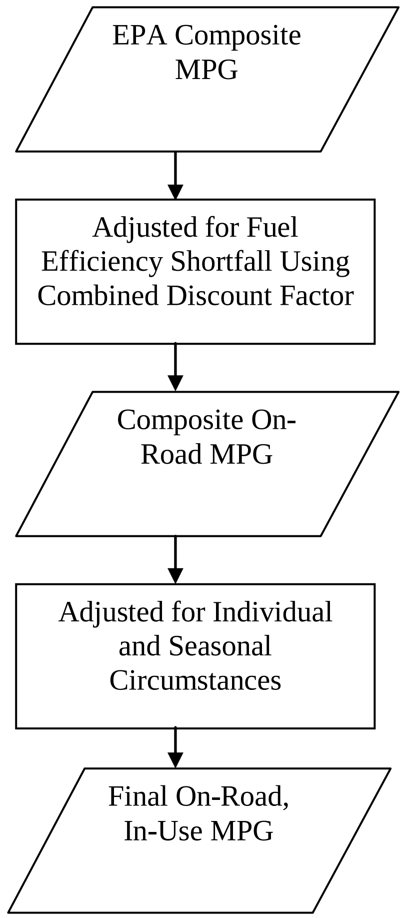
$$GPMR_i = \frac{MPG_{i\,(EPA55/45)}}{MPG_i} \qquad (2)$$

where:

[30] Specifically, the following formulas, as stated in Part 600, Subpart F, §600.207-86, §600.208-77, §600.209-85, §600.510-86 of the 7-1-1994 edition of the 40 CFR, are identified for these calculations.

$GPMR_i$ denotes Gallons per Mile Ratio for the i^{th} vehicle; MPG_i denotes the on-road MPG or in-use MPG for the i^{th} vehicle, depending on the analysis; and, $MPG_{i\ (EPA\ 55/45)}$ denotes the EPA Composite MPG applicable to the i^{th} vehicle.

Figure B2. Miles per Gasoline Equivalent Gallon Adjustments, post-1978 Light-Duty Vehicles



If $GPMR_i = 1$ then there is no perceived shortfall. If $GPMR_i > 1$ then there is a shortfall for vehicle *i*. That is, the on-road or in-use fuel economy is less than the fuel economy indicated by the EPA Composite MPG. Note that $GPMR_i$ can represent shortfall with respect to either the on-road or in-use MPG_i, depending on the analysis being performed. $GPMR_i$ is commonly chosen as a measure of shortfall as opposed to MPG_i for the following reasons:

- A shortfall adjustment is most often thought of as a correction factor, or multiplicative constant, rather than as an additive correction. $GPMR_i$ satisfies this convention.

- Shortfall is usually dependent on a vehicle's fuel economy level. That is, shortfall is usually higher at high levels of $MPG_{(EPA\ 55/45)}$ than at low levels of $MPG_{(EPA\ 55/45)}$. Therefore, it is more informative to express the amount of shortfall relative to $MPG_{(EPA\ 55/45)}$ rather than as an absolute quantity.

- $GPMR_i$ is a linear function of $MPG_{(EPA\ 55/45)}$ and can be modeled using ordinary least squares linear regression.

- $GPMR_i$ is a transformation that stabilizes error variances for the purposes of least squares linear regression.

THE ON-ROAD MPG

On-road MPG is a composite MPG that was adjusted to account for the shortfall between the EPA fuel economy and the actual fuel economy obtained on the road.

The EPA developed two general procedures for adjusting $MPG_{(EPA\ 55/45)}$ to an on-road value. One procedure bases the size of the adjustment on specific technology features of the vehicle. The other procedure uses just two MPG discount factors, one to adjust the EPA highway estimate, the other to adjust the city estimate. These two factors are used for all vehicles, regardless of technology class. For our purposes, we approximated the earlier procedure with a single adjustment factor.

Either of these procedures could have been approximated to adjust $MPG_{(EPA\ 55/45)}$ to an on-road MPG value for use in the 2009 NHTS. Since both procedures were unbiased for trucks, the choice as to which to employ in the 2009 NHTS should be based on their performance with cars. According to the 1994 RTECS, the adjustment based on discount factors seemed to be less biased than the Technology-Specific Adjustment. Further, the discount factors are also less expensive since they do not require collection or imputation of information on fuel delivery system and drive-train. Because of these reasons the Discount Factors Adjustment Method was selected for approximation.

SHORTFALL ADJUSTMENT BASED ON DISCOUNT FACTORS

EPA's discount factors have widespread appeal because of their simplicity (Hellman and Murrell, 1985[31]; Hellman and Murrell, 1984[32]). The factors are 10 percent for city MPG and 22 percent for highway MPG. That is, for any vehicle *i*,

$$\begin{aligned} MPG_{i(\text{on - road, EPA city})} &= 0.90 \bullet MPG_{i(\text{epa city})} \\ MPG_{i(\text{on - road, EPA hwy})} &= 0.78 \bullet MPG_{i(\text{EPA hwy})} \end{aligned} \tag{3}$$

These discount factors are the ones used to produce the "window sticker" MPG figures seen on vehicles on dealer lots, and are used to produce the DOE/EPA Gas Mileage Guide.[33] The analysis behind the development of these factors was performed on a conglomerate database with data from Ford Motor Company, General Motors, Chrysler Corporation, DOE, and EPA. The database contained approximately 38,000 vehicle records with model years from 1979 through 1981 with some 1982 models included. The database contained predominately American-made

[31] Hellman, K.H., and Murrell, J.D. 1985. "On the Stability of the EPA MPG Adjustment Factors." Society of Automotive Engineers Technical Paper Series, SAE Paper No. 851216, Warrendale, PA.

[32] Hellman, K.H., and Murrell, J.D. 1984. "Development of Adjustment Factors for the EPA City and Highway MPG Values." Society of Automotive Engineers Technical Paper Series, SAE Paper No. 840496, Warrendale, PA.

[33] Notably, starting with 2008 model year light-duty vehicles, EPA has modified the method for deriving fuel economy.

vehicles, but also included foreign vehicles as well. The technology mix was dominated by rear-wheel drive and carbureted vehicles, but contained some vehicles with front-wheel drive or fuel injection. Vehicle records contained make, model, year, vehicle characteristics, the MPG as measured on the road, $MPG_{(EPA\ city)}$, and $MPG_{(EPA\ highway)}$. The database also included the driver's perceptions of the proportion of their travel that was mostly urban (so called "city fraction"), and their average miles driven per day (AMPD).

Fuel economy shortfall is affected by the vehicle use pattern: frequent starts and short trip lengths characterize city-driving pattern, while highway-driving pattern is characterized by infrequent starts and long trips. AMPD is a good surrogate variable for representing these different driving patterns.

The city-driving pattern was characterized by AMPD from 5 to 22 miles per day, while the highway-driving pattern was characterized by AMPD's from 15 to 105 miles per day (Hellman and Murrell, 1984). City fraction and AMPD were used to split the data into two sets, one for development of the city discount factor, the other for development of the highway factor. The "city" and "highway" data sets were each stratified by vehicle technology classes. Linear regression was performed within each stratum. GPMR was regressed on city fraction, AMPD, $MPG_{(EPA\ 55/45)}$, odometer reading, and average temperature. The fitted models were then weighted and combined across vehicle technology strata, to produce a single "city" shortfall model and a single "highway" shortfall model. The weights were used to increase the influence of those models that represented technology mixes expected to become more prominent in the future (e.g., front-wheel drive and fuel-injected vehicles). The discount factors were derived from the two weighted models set at average or typical values of the independent variables.

For each NHTS vehicle, if and only if separate city and highway MPG were available, discounted city and highway on-road MPG may be computed and then combined to form an on-road 55/45 composite as follows:

$$MPG_{(on-road,55/45)} = \frac{1}{0.55 \bullet \dfrac{1}{MPG_{(on-road,\ EPA\ city)}} + 0.45 \bullet \dfrac{1}{MPG_{(on-road,\ EPA\ hwy)}}} \qquad (4)$$

Then, a shortfall ratio based on EPA discount factors would be computed for each NHTS vehicle as follows:

$$GPMR_{i(on-road)} = \frac{MPG_{i(EPA\ 55/45)}}{MPG_{i(on-road,55/45)}} \qquad (5)$$

Unfortunately, separate on-road city and highway test MPG were not available from the NHTSA Corporate Average Fuel Economy files. Although a literature review reveals that shortfalls vary for particular vehicles or groups of vehicles, we have used a combined shortfall estimate of 15 percent, equating to a $GMPR_{i(on-road)}$ of 1/0.85, which may also be written to reveal that $MPG_{i(on-road,\ 55/45)} = 0.85 \bullet MPG_{i(EPA55/45)}$.[34]

[34] Hellman, K.H. and Murrell J.D., June 1982. "Why Vehicles Don't Achieve EPA MPG On the Road and How That Shortfall Can Be Accounted For," Society of Automotive Engineers Technical Paper Series, SAE Paper 820791.

THE IN-USE MPG

In-use MPG are MPG that are adjusted for individual driving circumstances. The on-road adjustments to $MPG_{(EPA\ 55/45)}$ discussed in the previous sections were “general” in that they did not take into account any effects on fuel economy that are due to the driver's individual circumstances. They, instead, utilized general attributes such as the technology features of the vehicle and average driving conditions. Fuel economy shortfall estimates can be refined for an individual vehicle by taking into account the following “in-use” effects.

- Urban versus rural driving pattern. That is, frequent starts and short trips as opposed to infrequent starts and longer trips. As mentioned in the previous section, a useful single variable for representing this effect is AMPD. High AMPD's usually represent mileage accumulated on the highway.
- Traffic congestion, which increases with population density.
- Seasonal temperature variations, especially for gasoline-carbureted vehicles.
- Humidity, which together with temperature affects air-conditioner use.
- Differences among geographic areas of the country.
- Altitude.
- Wind.
- Road gradient and road surface conditions.

Additionally, the seasonal change in gasoline composition and the mechanical condition of the sample vehicles affect on-road fuel economy. Both of these effects are unknown. More importantly, EIA has made no attempt to account for these unknown effects.

However, this appendix does address some of the individual vehicle influences. In general, the first four items are considered the most significant in-use influences (Crawford, 1983).[35] In the cited study, shortfall variations as high as 25 percent or more occurred over the range of typical AMPD. Shortfall was 16 percent higher in urban areas than in completely uncongested areas, and was 12 percent higher in suburban areas. Shortfall varied seasonally (i.e., monthly) by 7 percent in the South and by 13 percent in the North.

Regression models were developed (Crawford, 1983) for use in adjusting $GPMR_{i(on\text{-}road)}$ to an in-use shortfall employing measurements of several in-use effects as the independent variables.

The regressions yielded a shortfall adjustment that was an additive one, which may be written as follows:

$$GPMR_{ij(in-use)} = GPMR_{i(on-road)} + \delta_{ij} \qquad (6)$$

[35] Crawford, R. 1983. "Seasonal and Regional MPG as Influenced by Environmental Conditions and Travel Patterns." Research performed under contract for U.S. DOE. Energy and Environmental Analysis, Inc., Arlington, VA.

where GPMRij(in-use) denotes the in-use shortfall ratio estimate for the i[th] vehicle during the j[th] month (j = 1, 2, … 12); GPMRi(on-road) denotes the combined shortfall ratio fixed for the i[th] vehicle; and, δ_{ij} denotes the adjustment calculated for the i[th] vehicle during month j, from the a regression model.

One regression model from the Crawford reference that is appropriate for use in NHTS is as follows:

$$\begin{aligned}\delta_{ij} = 3.296 \bullet &\left[\left(\frac{1}{\mathrm{AMPD}_{ij}}\right) - \left(\frac{1}{35.6}\right)\right] + \\ \mathrm{NORTH} \bullet &\left[0.050 \bullet \sin\left(\frac{j\pi}{6}\right) + 0.075 \bullet \cos\left(\frac{j\pi}{6}\right)\right] + \\ \mathrm{SOUTH} \bullet &\left[0.030 \bullet \sin\left(\frac{j\pi}{6}\right) + 0.031 \bullet \cos\left(\frac{j\pi}{6}\right)\right]\end{aligned} \tag{7}$$

where AMPD_{ij} = Average Miles per Day for vehicle *i* and month *j*, typically 35.6 (i.e., 13,000 miles per year); NORTH = 1 if the household is in the North, otherwise NORTH = 0 if the household is not in the North; and, SOUTH = 1 if the household is in the South, otherwise SOUTH = 0 if the household is not in the South.

This regression model was chosen because the independent variables that are important in explaining shortfall were readily available from the 2009 NHTS data, using BESTMILE and the distribution of average monthly vehicle miles travel fractions found in Table B2. The model had two components. One component involved AMPD_{ij} and represented the influence of individual driving patterns for a given vehicle and month. The other component represented the change in shortfall that occurred throughout the seasons, due to the annual temperature cycle. The original regression equation also contained a minor term that accounted for the influence of air-conditioner use during hot, humid weather. This term was dropped in the estimations because it involved the rather complex computation of "Discomfort Index" from NOAA weather records, and the slight additional precision was judged insufficient to warrant the additional processing expense. Additional terms representing geographic regional effects, and the natural logarithm of population density (people per square mile, to represent the influence of traffic congestion) were not considered because of the computational cost.

Once a $\mathrm{GPMR}_{ij(\text{in-use})}$ was estimated it was used to estimate the final in-use fuel economy for vehicle *i* and month *j* as follows:

$$\mathrm{MPG}_{ij(\text{in - use})} = \frac{\mathrm{MPG}_{i(\text{EPA } 55/45)}}{\mathrm{GPMR}_{ij(\text{in - use})}} \tag{8}$$

The regression equation had separate seasonal components for the "North" and "South" because the difference between the winter shortfall and the summer shortfall was greater in the North than in the South. This difference can be seen in the model parameters. To define the North and South geographic areas the continental United States were divided into 97 two-digit ZIP Code regions. In the original model, these regions were grouped to form two aggregate regions

("North" and "South") according to average winter and summer temperatures, and seasonal shortfall trends.

ANNUAL VEHICLE FUEL CONSUMPTION

In the 2009 NHTS, annual consumption was calculated by dividing the annual VMT (i.e., BESTMILE variable) by the annual MPG. The derivation of the "annualized" VMT is given in the NHTS User's Guide.

The $MPG_{ij(in\text{-}use)}$ shown in the above section about fuel economy estimation procedures were final estimates of monthly in-use fuel economies for vehicle *i*, and could have been used for estimating monthly fuel consumptions and expenditures, if monthly VMT were known. Unfortunately, NHTS only collected data from which ORNL annualized VMT. Nevertheless, the 2009 NHTS still made use of the $MPG_{ij(in\text{-}use)}$ by disaggregating the annualized VMT of sample vehicles into monthly VMT, using monthly VMT driving fractions from the standard distribution in Table B2.[36]

Table B2. Distribution of Average Monthly Vehicle-Miles Traveled Fractions

$Month_j$	Average VMT per Vehicle	F_j	Alternate F_j
January	688	0.0728	0.0765
February	697	0.0738	0.0740
March	771	0.0816	0.0842
April	783	0.0829	0.0851
May	832	0.0880	0.0882
June	847	0.0896	0.0864
July	868	0.0919	0.0884
August	872	0.0923	0.0882
September	800	0.0847	0.0806
October	802	0.0849	0.0865
November	756	0.0800	0.0800
December	734	0.0777	0.0819
Total	9,450	1.0000	1.0000

Source: 1984 Petroleum Marketing Index (PMI) Survey, NPD Research Inc. The survey is a demographically and geographically balanced-quota sample of 4,100 households. Respondents maintained fuel purchase diaries for an average of 10 months. As part of the survey, information was collected on the characteristics of trips taken in vehicles during a designated day. Trip lengths were recorded as respondent perception rather than from odometer readings. The distribution of monthly mileage fractions has been obtained from this survey.

The annual consumption for vehicle *i* can be thought of as the sum of the individual monthly consumptions:

[36] Following the quality controls used in past RTECS surveys, EIA investigated the possibility that monthly travel patterns had changed based on a comparison of estimates between those found in Table B2 and the highway usage estimates from the Federal Highway Administration's *Traffic Volume Trends* data. The differences were negligible; thus, EIA applied the F_j distribution given in Table B2 in order to compute annualized VMT. Some would argue that a update of Table B2 is needed; unfortunately, a reasonable travel diary study has not been conducted to EIA's knowledge that would provide such an update.

$$C_i = \sum_{j=1}^{12} c_{ij} \tag{9}$$

where C_i denotes annual consumption of vehicle fuel for the i^{th} vehicle, in gasoline equivalent gallons and c_{ij} denotes consumption of vehicle motor fuel for the i^{th} vehicle during the j^{th} month.

Because the VMT values – as computed by ORNL and discussed in the NHTS User's Guide – in the version 2.0 public-use file provided by NHTS assume each vehicle was available for the *entire* 12-month period of the survey year[37], consumption and expenditure values for vehicle use are over-estimated. To eliminate, where possible, such over-estimation, EIA would require the acquisition and disposition dates for each sampled vehicle. Because such information is not available in the 2009 NHTS, EIA is unable to make this adjustment. In the 2001 NHTS, EIA did provide another public-use file in which the annual consumption for vehicle *i* can be thought of as the sum of the monthly consumption values, where the period covered equals the possession time of vehicles. Thus, in the 2001 NHTS, the starting and ending months refer to the possession time of vehicle *i* by the household.

Consumption for each month may be expressed in terms of monthly VMT and monthly in-use fuel economy:

$$c_{ij} = \frac{m_{ij}}{mpg_{ij}}, \forall\ j = 1, 2, \ldots, 12 \tag{10}$$

where m_{ij} denotes VMT for the i^{th} vehicle during the j^{th} month and mpg_{ij} denotes fuel economy in miles per gasoline equivalent gallon for the i^{th} vehicle during the j^{th} month. Now, Equation 10 can be rewritten as:

$$C_i = \sum_{j \in \mathit{used}} \frac{m_{ij}}{mpg_{ij}} \tag{11}$$

ORNL provided the annualized VMT estimate for NHTS that was used to calculate monthly VMT values. Given that value, a monthly VMT was derived for each annualized vehicle VMT as:

$$m_{ij} = M_i \bullet f_{(i,j)} \tag{12}$$

where M_i denotes for the i^{th} vehicle, calculated using odometer readings and procedures discussed in Appendix J and f_{ij} denotes the average fraction of "annual" VMT that was driven during the j^{th} month, estimate for the i^{th} vehicle. For all sample vehicles, $f_{(i,j)}$ is a function of the average fractions, F_j, found in Table B2.

[37] For the 2009 estimates, the time frame of April 1, 2008 to March 31, 2009 used for the 2009 BESTMILE estimates was chosen because the majority of the survey (and thus the majority of odometer readings) was conducted during this time.

There is no single distribution of average monthly VMT fractions, $f_{(i,j)}$. Rather, there was a family of distributions, depending on which particular months a vehicle was owned or used by a household. Because the monthly VMT fractions for a given vehicle *i* always sums to one – no matter the timeframe in which the vehicle was owned or used by the household – the following identity is always true:

$$\sum_{j \in used} f(i,j) = 1, \forall = 1,2,3,\ldots,n \qquad (13)$$

The i^{th} vehicle's $f_{(i,j)}$ were derived from F_j values found in Table B2 as follows:

$$f(i,j) = \frac{F_j}{\sum_{j \in used} F_j} \qquad (14)$$

If we assume that each and every vehicle is owned or used by its sampled household, then substituting $mpg_{ij} = MPG_{ij(in\text{-}use)}$ and m_{ij} from Equation 12 into Equation 11 yields the following estimate of annual consumption for the i^{th} vehicle:

$$C_i = \sum_{j=1}^{12} \frac{M_i \bullet F_{ij}}{MPG_{ij(in\text{-}use)}} \qquad (15)$$

The public-use file disseminated by NHTS (version 2.0) makes the above assumption on the timeframe for vehicle use. While the NHTS public-use file provides estimates based on the assumption that each and every sample vehicle was present in the sample household for 12 months, EIA's had hope to create an alternate estimator for consumption, $C_i^{(EIA)}$, in which acquired and disposed vehicles during the survey period are accounted for. Unfortunately, that was not possible; therefore, *used* in this estimator includes 12 months of travel and is written as:

$$C_i^{(EIA)} = \sum_{j \in used} \frac{M_i \bullet f(i,j)}{MPG_{ij(in\text{-}use)}} \qquad (16)$$

To simply calculations, a single "annualized" fuel economy, analogous to the "annualized" MPG_i from previous EIA surveys of the residential transportation sector, was estimated as:

$$MPG_{i(annualized)} = \frac{MPG_{i(EPA\ 55/45)}}{\sum_{j \in used} f(i,j) \bullet GPMR_{ij(in\text{-}use)}} \qquad (17)$$

Thus, annual consumption equals:

$$C_i = \frac{M_i}{MPG_{i(annualized)}}. \qquad (18)$$

ANNUAL VEHICLE FUEL EXPENDITURES AND PRICE

VEHICLE FUEL EXPENDITURES

In the 2009 NHTS, fuel expenditures were calculated by multiplying the vehicle-fuel consumption by the price of the vehicle fuel. The 2009 NHTS did not collect vehicle fuel prices via fuel purchase diaries. Instead, each NHTS sample vehicle was assigned a price based on imputed engine type and fuel metering values obtained from the NHTSA Corporate Average Fuel Economy files for model years 1978-2008. For pre-1978 model year vehicles, otto engine and gasoline were imputed for engine type and fuel metering, respectively. Fuel prices, by month, were obtained from the following Energy Information Administration survey questionnaires:

- Form EIA-888[38] “On-Highway Diesel Fuel Price Survey.”
- Form EIA-878[39] "Motor Gasoline Price Survey."
- Form EIA-895[40] “Monthly Quantity and Value of Natural Gas Report.”
- Form EIA-826[41] “Monthly Electric Utility Sales and Revenue Report with State Distributions.”

It is important to define the transportation fuels included in each of these prices. See the following sections for further details on transportation fuel prices.

It is also important to point out that the NHTS did not collect information on the use of alternate fuels. Because of that omission, it was not possible to properly assign fuel consumption for dual-fuel (or flexible-fuel) vehicles. While these supplemental data do not explicitly account for alternative fuel use, the supplemental NHTS data should allow for a user to freely assign an alternative fuel use fraction. For example, one common assumption is to assign an operating scenario where 50 percent of the time the vehicle runs on alternative fuel (e.g., E85) and 50 percent of the time on conventional fuel (i.e., gasoline). Using the supplemental data and VMT estimate, in conjunction with EIA’s fuel economy adjustment methodology, a user may make their own assignment of alternative fuel use. Because allowances have been made for self-

[38] The Form EIA-888 survey collects data on the National and Petroleum Administration for Defense (PAD) District level cash price of self-serve, motor vehicle diesel fuel. The data are used to monitor changes in motor vehicle diesel fuel prices and to report to the Congress and others when requested. Respondents are a scientifically selected sample of companies owning retail outlets which sell motor vehicle diesel fuel.

[39] The sample for the Motor Gasoline Price Survey was drawn from a frame of approximately 115,000 retail gasoline outlets. The gasoline outlet frame was constructed by combining information purchased from a private commercial source with information contained on existing EIA petroleum product frames and surveys. Outlet names and relevant zip codes were obtained from the private commercial data source. Additional information was obtained directly from companies selling retail gasoline to supplement information on the frame. The individual frame outlets were mapped to counties using their zip codes. The outlets were then assigned to the published geographic areas as defined by the EPA program area, or for conventional gasoline areas, as defined by the Census Bureau’s Standard Metropolitan Statistical Areas (SMSA) by using their county assignment.

[40] Monthly and annual production data are collected from the appropriate agencies of the natural gas producing States.

[41] Form EIA-826 collects information from regulated and unregulated companies that sell or deliver electric power to end users, including electric utilities, energy service providers, and distribution companies..

estimating alternate fuel use and, more importantly, the NHTS collected no data to verify any method for assigning alternative fuel use, all consumption and expenditures supplemental data are based on a dedicated use of motor gasoline, diesel, natural gas, or electricity. That is, all flexible-fuel vehicles are assumed to operate on 100 percent gasoline. Thus, estimates for flexible-fuel vehicles are accurate to the extent that this assumption is valid.

Unfortunately, respondents were not asked the type of fuel purchased for their transportation demands. Further, respondents were not queried on the grade of their purchased fuels. Thus, fuel type was imputed to a sample vehicle based on its representative "match" with the selected vehicle from the NHTSA files. A matching record was chosen from among the several applicable ones, with probability proportional to sales, using the sales figures on the NHTSA files. Once chosen, a record provided (1) EPA Composite MPG, (2) fuel metering, and (3) engine type. The latter two items provided enough information to impute a fuel type to a "matched" sample vehicle.

The EIA price series are published by month, by State, 5 PAD districts (PADD), and by type and grade of fuel. For the 2009 NHTS, annual fuel expenditures, E_i, was estimated by multiplying monthly gasoline prices by monthly consumption to produce monthly expenditures, summing over the monthly expenditures derived annual expenditures.

GASOLINE PRICES

Gasoline prices were determined from EIA's Form 888 "Motor Gasoline Price Survey." The sample for the Motor Gasoline Price Survey was drawn from a frame of approximately 115,000 retail gasoline outlets. The gasoline outlet frame was constructed by combining information purchased from a private commercial source with information contained on existing EIA petroleum product frames and surveys. Outlet names and relevant zip codes were obtained from the private commercial data source. Additional information was obtained directly from companies selling retail gasoline to supplement information on the frame. The individual frame outlets were mapped to counties using their zip codes. The outlets were then assigned to the published geographic areas as defined by the EPA program area, or for conventional gasoline areas, as defined by the Census Bureau's Standard Metropolitan Statistical Areas (SMSA) by using their county assignment.

To estimate average prices, sample weights were constructed based on the sampled outlet's number of pumps, a proxy for sales volume. These weights are applied each week to the reported outlet gasoline prices to obtain averages for the specific formulations, grades and geographic areas. Weights used in aggregating grades, formulations and geographic areas were derived using volume data from the EIA "Monthly Report of Prime Suppliers Sales of Petroleum Products Sold for Local Consumption," and demographic data from the Bureau of the Census and Department of Transportation on population, number of gasoline stations and number of vehicles.

The below is an excerpt from the glossary of the *Petroleum Marketing Monthly*, as reported by EIA, which identifies the composition of the motor gasoline sales.

Motor Gasoline (Finished)*: A complex mixture of relatively volatile hydrocarbons with or without small quantities of additives, blended to form a fuel suitable for use in spark-ignition engines. Motor gasoline, as defined in ASTM Specification D-4814 or Federal Specification VV-G-1690B, is characterized as having a boiling range of 122 to 158 degrees Fahrenheit at the 10 percent recovery point to 365 to 374 degrees Fahrenheit at the 90 percent recovery point. "Motor Gasoline" includes conventional gasoline; all types of oxygenated gasoline, including gasohol; and reformulated gasoline, but excludes aviation gasoline.*

Conventional Gasoline*: Motor gasoline not included in the oxygenated or reformulated gasoline categories. Excludes reformulated gasoline blendstock for oxygenate blending (RBOB).*

Oxygenated Gasoline*: Finished motor gasoline, other than reformulated gasoline, having an oxygen content of 2.7 percent or higher by weight and required by the U.S. Environmental Protection Agency (EPA) to be sold in areas designated by EPA as carbon monoxide (CO) nonattainment areas. Note: Oxygenated gasoline excludes oxygenated fuels program reformulated gasoline (OPRG) and reformulated gasoline blendstock for oxygenate blending (RBOB). Data on gasohol that has at least 2.7 percent oxygen, by weight, and is intended for sale inside CO nonattainment areas are included in data on oxygenated gasoline. Other data on gasohol are included in data on conventional gasoline.*

Reformulated Gasoline*: Finished motor gasoline formulated for use in motor vehicles, the composition and properties of which meet the requirements of the reformulated gasoline regulations promulgated by the U.S. Environmental Protection Agency under Section 211(k) of the Clean Air Act. Note: This category includes oxygenated fuels program reformulated gasoline (OPRG) but excludes reformulated gasoline blendstock for oxygenate blending (RBOB).*

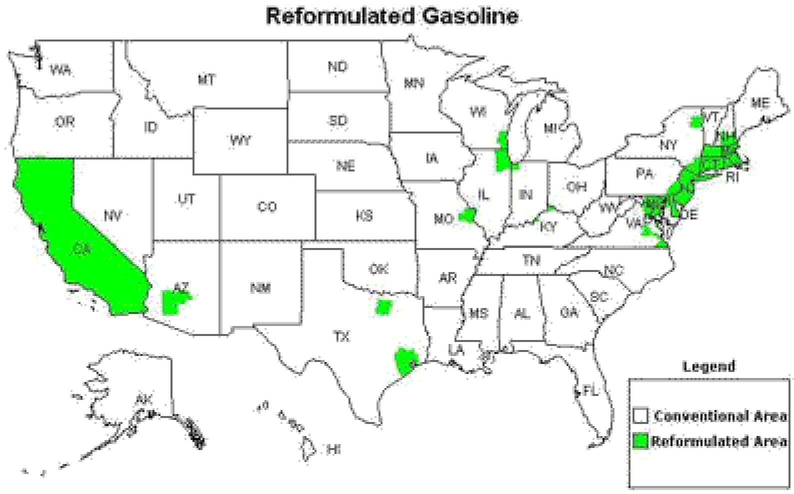
Further, EIA classifies gasoline by octane ratings, where each type of gasoline (conventional, oxygenated, and reformulated) is classified by three grades:

1) Regular Gasoline: Gasoline having an antiknock index (i.e., octane rating) greater than or equal to 85 and less than 88. Note: Octane requirements may vary by altitude.

2) Midgrade Gasoline: Gasoline having an antiknock index (i.e., octane rating) greater than or equal to 88 and less than or equal to 90. Note: Octane requirements may vary by altitude.

3) Premium Gasoline: Gasoline having an antiknock index (i.e., octane rating) greater than 90. Note: Octane requirements may vary by altitude.

Figure B3. Area Map for Reformulated Gasoline



Source: Energy Information Administration, website www.eia.doe.gov/oil_gas/petroleum/data_publications/wrgp/reformulated_map.html.

DIESEL FUEL PRICES

Prices published by the EIA supplier surveys are at the retail level for diesel fuel. The form EIA-888 survey collects data on the National and Petroleum Administration for Defense (PAD) District[42] level cash price of self-serve, motor vehicle diesel fuel. The data are used to monitor changes in motor vehicle diesel fuel prices and to report to the Congress and others when requested. Respondents are a scientifically selected sample of companies owning retail outlets that sell motor vehicle diesel fuel. Prices are published on http://tonto.eia.doe.gov/oog/info/wohdp/diesel.asp by EIA.

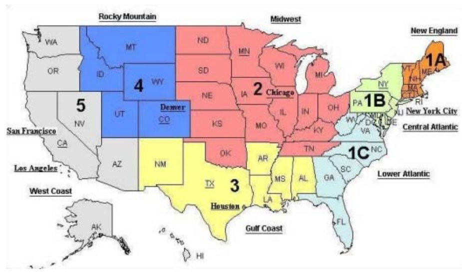
EIA conducts weekly Computer Assisted Telephone Interview surveys that collect prices at the outlet level. The EIA-888 collects prices of diesel fuel from truck stops and service stations across the country each Monday morning. Average prices of diesel fuel through outlets at the five Petroleum Administration for Defense District (PADD) levels, regions of the country, sub-PADD levels, and the state of California are released by the end of the day through Listserv, the Web, Fax, and telephone hotline.

Because the NHTS did not collect the type or grade of diesel consumed in each sample vehicle, diesel price was assigned to a diesel-powered vehicle based on a monthly fuel price represented by a PAD that includes the State in which the sample vehicle resides, according to

[42] PAD District 1 (East Coast) is composed of the following three subdistricts: Subdistrict 1A (New England): Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, Vermont. Subdistrict 1B (Central Atlantic): Delaware, District of Columbia, Maryland, New Jersey, New York, Pennsylvania. Subdistrict 1C (Lower Atlantic): Florida, Georgia, North Carolina, South Carolina, Virginia, West Virginia. PAD District 2 (Midwest): Illinois, Indiana, Iowa, Kansas, Kentucky, Michigan, Minnesota, Missouri, Nebraska, North Dakota, South Dakota, Ohio, Oklahoma, Tennessee, Wisconsin. PAD District 3 (Gulf Coast): Alabama, Arkansas, Louisiana, Mississippi, New Mexico, Texas. PAD District 4 (Rocky Mountain): Colorado Idaho, Montana, Utah, Wyoming. PAD District 5 (West Coast): Alaska, Arizona, California, Hawaii, Nevada, Oregon, and Washington.

NHTS, with the notable exception of the state of California where assignment was completed within state geographic boundaries.

Figure B4. Map of Petroleum Administration for Defense Districts



OTHER FUEL TYPE PRICES

Unfortunately, in the 2009 NHTS, all alternative-fuel vehicles were imputed as dedicated gasoline vehicles. That imputation rule was applied because (1) NHTS did not collect fuel type information on its survey questionnaire and (2) the majority of owners of vehicles capable of being powered by methanol, ethanol, and other alternative fuels are consuming blended motor gasoline since alternative fueling stations do not serve large areas of the nation.[43]

While the NHTS cannot delineate gasohol use, this appendix does address dedicated compressed natural gas (CNG) and electric vehicles.[44] For CNG, retail prices were obtained from form EIA-895, "Monthly Quantity and Value of Natural Gas Report". The EIA-895 collects monthly information from the applicable State agencies that collect data concerning natural gas production. Data are published in several of EIA's monthly and annual reports. For electricity, retail prices were obtained from form EIA-826, "Monthly Electric Utility Sales and Revenue Report with State Distributions." Form EIA-826 collects information from regulated and unregulated companies that sell or deliver electric power to end users. While three customer groups were available, residential customers were selected to represent electric prices because this group most accurately reflected the retail electric price for NHTS households. State and regional summaries of these data are published by EIA and used by public and private analysts.

[43] U.S. Department of Energy, Energy Efficiency and Renewable Energy, Alternative Fuels Data Center reports that over 7 thousand fueling stations dispense alternative fuels (see listing details on http://www.eere.energy.gov/afdc/infrastructure/station_counts.html, updated on November 11, 2010).

[44] Propane vehicles are not included in the NHTSA files. Thus, no propane-fuel vehicles are found in the additions made by EIA to NHTS data.

QUALITY OF THE DATA

INTRODUCTION

This section discusses several issues relating to the quality of the National Household Travel Survey (NHTS) data and to the interpretation of conclusions based on these data. In particular, the focus of our discussion is on the quality of specific data items, such as the fuel economy and fuel type, that were imputed to the NHTS via a cold-decking imputation procedure. This imputation procedure used vehicle-level information from the NHTSA Corporate Average Fuel Economy files for model year's 1978 through 2008.[45] It is nearly impossible to quantify directly the quality of this imputation procedure because NHTS does not collect the necessary fuel economy information for comparison. At best, we have indirect evidence on the quality of our imputations, which is addressed in the following sections. Indeed, such an imputation procedure could be vastly improved with the collection of Vehicle Identification Number (VIN), fuel type and retail fuel price for each sample vehicle. However, those collections may represent an unreasonable burden on NHTS respondents.

The quality of the data collection and the processing of the data affect the accuracy of estimates based on survey data. All the statistics published in this appendix, such as total vehicle-miles traveled (VMT), are estimates of population values. These estimates are based on observations from a randomly chosen subset of the entire population of occupied housing units. Consequently, the estimates always differ from the true population values. Because the NHTS is a sample survey, data from the survey are subject to various sources of nonsampling and sampling error.

Nonsampling error is a measure of variability due to the execution and processing of the survey. These errors can include: population undercoverage during sampling; questionnaire wording and format; response bias and variance; interviewer error; coding and/or keypunching error; and nonresponse bias. Nonsampling errors are treated in several sections of this appendix. The main section pertains to the imputation procedures used for "missing" fuel economy, fuel type, and fuel economy adjustments. In the previous sections, fuel economy adjustments were addressed. This section deals mainly with imputing fuel economy or $MPG_{i(EPA\ 55/45)}$ to each appropriate sample vehicle.

NONSAMPLING ERROR

Nonsampling errors are due to the conduct of the survey, and include both random errors and systematic errors or biases. The magnitudes of nonsampling biases cannot be estimated from the sample data. Thus, avoidance of systematic biases is a primary objective of all stages of survey design. Subsequent to conducting a survey, problems of unit nonresponse and item nonresponse need to be addressed.

In surveys with complex questionnaires and procedures, such as the NHTS, the final dataset reflects fundamental approaches taken in the data collection and editing processes. For the 2009 NHTS, two approaches may have had considerable impact on the resulting data.

[45] 2009 model year information was not available at the time of release of NHTS version 2.0 data.

The first is the reluctance to impute data. If the respondent did not answer an item, its value was generally not imputed, (i.e., determine what the logical response would be given the response to other items). Carefully performed imputation has its place in many statistical surveys, however Westat and U.S. DOT determined that imputation would be limited in the NHTS data. If data were imputed, an imputation/edit flag was set for the variable to indicate the values that were imputed. The treatment in the NHTS of these types of errors is discussed in the NHTS User's Guide.

Supplemental data, by definition, are 100 percent imputed. Thus, it is important that EIA thoroughly present the approach used to impute energy-related supplemental NHTS data (see EIA's Appendix B).

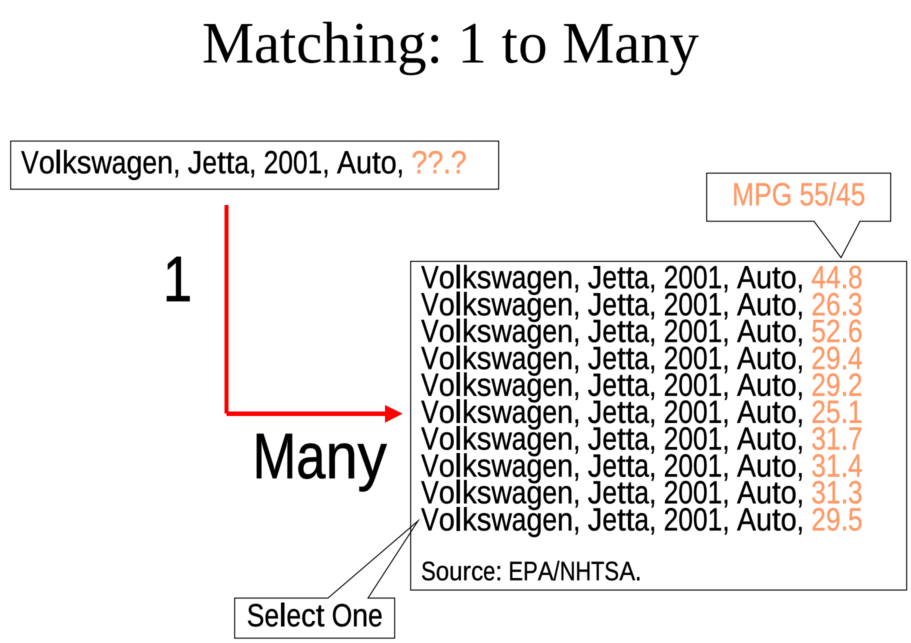
UNIT NONRESPONSE

Unit nonresponse is the type of nonresponse that occurs when no data are available for an entire sampled household. The respondent being unavailable or the respondent's refusal to cooperate causes most unit nonresponse cases. See the NHTS User's Guide for further details on unit nonresponse.

IMPUTATION PROCEDURES FOR SUPPLEMENTAL DATA

Imputation procedures fill in the gaps of "missing" data. Item nonresponse occurs when the respondents do not know the answer or refuse to answer a question, or when an interviewer does not ask a question or does not record an answer. Or, as in the case of this appendix, item nonresponse occurs when a question was not asked, such that imputation procedures are required to address the need to append supplemental data to a pre-existing file from other external, but related, files. As already mentioned, NHTS took a conservative approach to item nonresponse. For supplemental data, in an effort to facilitate "full-sample" data analyses, imputations were made to provide the most probable responses when responses were "missing." For linking supplemental data, a pseudo cold-decking imputation was employed. Figure C1 depicts the cold-deck approach, using NHTS make, model, model year, and vehicle type information to "match" with eligible donors from the NHTSA CAFE files.

Figure C1. Schematic for Linking or Matching a NHTS Sample Vehicle to Eligible EPA/NHTSA Vehicles



Note: EPA – Environmental Protection Agency, NHTSA – National Highway Transportation Safety Administration.

COLD-DECK PROCEDURE

Because the fuel economy for a sampled vehicle could not be unequivocally determined by its NHTS-collected descriptors, a cold-deck imputation procedure was employed to "match" a NHTSA file record to a sample vehicle. A matching record was chosen from among the several applicable ones, with probability proportional to sales, using the sales figures on the NHTSA files. Once chosen, a record provided (1) EPA Composite MPG, (2) fuel metering, and (3) engine type. Although more attributes were available for selection, EIA limited its "donated" vehicle attributes to those required to assign an appropriate fuel price to a sample vehicle. This matching routine commonly resulted in a 1-to-many record linkage (see Figure C1 for an example).

Cold-deck procedures make use of a fixed set of values, which covers all of the perspective data items. These values can be constructed with the use of historical data, subject-matter expertise, or a combination of both. Such a procedure is an attempt to create a "perfect'" questionnaire in order to fill in the missing data gaps or, in this case, append supplemental data. If these procedures are completed properly and with limited bias, imputation has the ability to derive a complete and accurate record that (1) contains an audit trail for evaluation purposes; and (2) ensures that the imputed records are internally consistent.

Multiple paths were used to "match" recipient NHTS sample vehicles to eligible donor NHTSA file record vehicles. Because matching used a combination of four common linking variables – vehicle manufacturer, vehicle model, vehicle model year, and vehicle type – several "matching" paths were followed. These paths are denoted (i.e., internally audited) with imputation flags, which are defined for each vehicle as follows:

- 01 denotes a NHTS sample vehicle that had multiple model names "matching" to eligible NHTSA file records using four linking variables: vehicle manufacturer, vehicle model, vehicle model year, and vehicle type.

- 02 denotes a NHTS sample vehicle that had multiple model names "matching" to eligible NHTSA file records using four linking variables: vehicle manufacturer, vehicle model, adjusted by adding one year to the reported vehicle model year, and vehicle type.

- 03 denotes a NHTS sample vehicle that had multiple model names "matching" to eligible NHTSA file records using four linking variables: vehicle manufacturer, vehicle model, adjusted by subtracting one year from the reported vehicle model year, and vehicle type

- 04 denotes a NHTS sample vehicle that had multiple model names "matching" to eligible NHTSA file records using four linking variables: vehicle manufacturer, vehicle model, adjusted by adding two years to the reported vehicle model year, and vehicle type.

- 05 denotes a NHTS sample vehicle that had multiple model names "matching" to eligible NHTSA file records using four linking variables: vehicle manufacturer, vehicle model, adjusted by subtracting two years from the reported vehicle model year, and vehicle type.

- 06 denotes a NHTS sample vehicle that had multiple model names "matching" to eligible NHTSA file records using three linking variables: vehicle manufacturer, vehicle model and vehicle type.

- 07 denotes a NHTS sample vehicle that had multiple model names "matching" to eligible NHTSA file records using three linking variables: vehicle manufacturer, vehicle model, and reported vehicle model year.

- 08 denotes a NHTS sample vehicle that had multiple model names "matching" to eligible NHTSA file records using three linking variables: vehicle manufacturer, vehicle model, and adding one year to the reported vehicle model year.

- 09 denotes a NHTS sample vehicle that had multiple model names "matching" to eligible NHTSA file records using three linking variables: vehicle manufacturer, vehicle model, and subtracting one year from the reported vehicle model year.

- 10 denotes a NHTS sample vehicle that had multiple model names "matching" to eligible NHTSA file records using three linking variables: vehicle manufacturer, vehicle model, and adding two years to the reported vehicle model year.

- 11 denotes a NHTS sample vehicle that had multiple model names "matching" to eligible NHTSA file records using three linking variables: vehicle manufacturer, vehicle model, and subtracting two years from the reported vehicle model year.

- 12 denotes a NHTS sample vehicle that had multiple model names "matching" to eligible NHTSA file records using two linking variables: vehicle manufacturer and vehicle model.

- 13 denotes a NHTS sample vehicle that had multiple model names "matching" to eligible NHTSA file records using two linking variables: vehicle style and vehicle model.

- 14 denotes a NHTS sample vehicle that had multiple model names "matching" to eligible NHTSA file records linked using vehicle style, and adjusted by adding one year from reported model year.

- 15 denotes a NHTS sample vehicle that had multiple model names "matching" to eligible NHTSA file records linked using vehicle type, and adjusted by subtracting one year from reported model year.

- 16 denotes a NHTS sample vehicle that had multiple model names "matching" to eligible NHTSA file records linked using vehicle type, and adjusted by adding two years from reported model year

- 18 denotes a NHTS sample vehicle that had multiple model names "matching" to eligible NHTSA file records linked using vehicle type.

- 99 denotes a NHTS sample vehicle that was internally hot-decked to match with its average on-road, in-use fuel economy value as defined by one or more vehicle characteristics, such as make, model, model year, and vehicle type. Some of these vehicles are based on EIA expert analysis using subject matter experience, in conjunction with past RTECS and Table VM-1 of U.S. Department of Transportation's *Highway Statistics* report series. These flagged values become more meaningful with pre-1978 model year vehicles since NHTSA's CAFE database excludes pre-1978 model years. EIA, therefore, recommends that users take extreme caution when making inferences concerning pre-1978 model year vehicles from this report.

Due to the errors in respondents reporting accurate model year or, to a lesser extent, due to deficiencies in the NHTSA files, it was necessary to incrementally increase or decrease (not simultaneously increase and decrease) the model year for "matching" to successively larger range of years. If, for example, an eligible match was not found for a NHTS sample vehicle having the following attributes: Volkswagen, Scirocco, 1990, Automobile. Toggling of model years, by a single year increase followed by a single year decrease of the reported model year, resulted in a match with a Volkswagen, Scirocco, 1988, Automobile. In this example, the Volkswagen, Scirocco, 1990, Automobile, while seemingly a respondent reporting error, would receive an imputation flag of "05" due to the "match" with the NHTSA file record corresponding to a Volkswagen, Scirocco, 1988, Automobile.

Please note, in Table C1, the total record count is 296,602, which is short of the total in the NHTS database at 309,163. In EIA's Residential Transportation Energy Consumption Survey (RTECS) program, which went away after the 1994 study, EIA only sampled "light-duty vehicles," which is defined as "light-duty vehicles and recreational vehicles." So, by aggregating under that definition, one should generate the Table C1 estimates.

Table C1. Distribution of NHTS Sample Light-Duty Vehicles by Fuel Economy Imputation Flag, 2009

Imputation Flag for $MPG_{(EPA\ 55/45)}$	Number of Vehicles in NHTS Sample
01	252,393
02	4,322
03	3,283
04	2,335
05	749
06	14,369
07	6,435
08	251
09	259
10	182
11	117
12	1,020
13	2,642
14	21
15	82
16	8
18	39
99	8,095
Total	**296,602**

Source: U.S. Department of Transportation, Federal Highway Administration, *National Household Travel Survey 2009*, augmented release by the Energy Information Administration, (Washington, DC).

While the distribution of imputation flags is helpful, further evidence is needed to quantify the quality of this procedure. To make the "match" distribution display more revealing, values from the above figure are tabulated to present range categories of donor vehicles in Table C2. Smaller ranges correlate with increased certainty of assigned fuel economy values.

Table C2. Distribution of All NHTS Sample Vehicles "Matched" by Range of Donor Vehicles

Range of Eligible Donor Vehicles	Number of Vehicles in NHTS Sample	Cumulative Percentage of Sampled Vehicles
1	30,985	10.7%
2	39,332	24.4%
3	20,457	31.5%
4	38,415	44.8%
5	18,825	51.3%
6	21,137	58.6%

Table C2. Distribution of All NHTS Sample Vehicles "Matched" by Range of Donor Vehicles

Range of Eligible Donor Vehicles	Number of Vehicles in NHTS Sample	Cumulative Percentage of Sampled Vehicles
7	10,875	62.4%
8	16,412	68.1%
9	8,935	71.2%
10 or more*	91,229	100.0%
Total	**296,602**	**100.0%**

Source: U.S. Department of Transportation, National Household Travel Survey 2009, National and Add-on releases, Federal Highway Administration, January 2011. (Washington, DC).*Note: To ensure consistency with Table C1, "10 or more" category includes those vehicles assigned a "99" fuel economy imputation flag.

QUALITY OF SPECIFIC SUPPLEMENTAL DATA ITEMS

COLD-DECK PROCEDURE: SENSITIVITY ANALYSIS

Although the accuracy and robustness of the cold-deck procedure and subsequent fuel economy adjustments are not quantifiable because we lack both fuel purchase and mileage diaries for calculating a vehicle's actual on-road, in-use fuel economy, we can assess the sensitivity of the cold-deck procedure in an effort to measure its robustness.

Because we use a single value imputation approach, multiple imputations is one approach available for investigating the uncertainty of our imputed values. Indeed, imputing a single value may result in estimating measures of precision (e.g., standard errors) that are too small because a single value ignores the uncertainty found in selecting from a listing of donated values. Rather than perform a series of multiple imputations, we have assumed that each sample vehicle's list of eligible donors represents a complete set of values for its "missing" unadjusted fuel economy variable. Therefore, the uncertainty associated with the imputation procedure may be assessed by imputing a pre-determined subset of values; that is, ones that represent the extremes and average of eligible donors. P5 and P95 – the 5th and 95th percentiles of sales-weighted fuel economy, respectively – represent our extreme distribution values, while the average value corresponded to the sales-weighted average of the eligible donor vehicles. Using Figure C1 as an example, we calculate: P5 = 25.1, P95 = 44.8 and a sales-weighted average of 30.8 miles per gallon.

By separately totaling the consumption of transportation fuel for each of these 3 outcomes and, then, comparing them to our single-value total, it is not surprising that we find that

- applying sales-weighted fuel economy values for each light-duty vehicle yields a energy consumption total 1 percent less than the single-value total;
- applying 5th percentile values for each light-duty vehicle yields an energy consumption total 8 percent more than the single-value total; and,
- applying 95th percentile values to each light-duty vehicle yields an energy consumption total 8 percent less than the single-value total.

Clearly, applying extreme distribution values – P5 and P95 – to each and every eligible sample vehicle results in biased energy-related estimates. While these extreme values are not acceptable to a researcher, such biased estimates illustrate the upper and lower uncertainty bounds associated with cold-deck estimates. Given these bounds, along with survey sampling and non-sampling errors, the use and usefulness of an enhanced 2009 National Household Travel Survey should be evaluated against a researcher's project requirements.

VEHICLE FUEL PRICE AND EXPENDITURES

In the 2009 NHTS, fuel price data were not collected via fuel purchase diaries, compared to previous EIA studies (e.g., RTECS). Instead, fuel prices were determined from EIA price series. Unfortunately, there is no way to validate the price methodology used to assign a monthly price paid for transportation fuel because EIA lacks the necessary fuel purchase diaries from NHTS repondents.

The Bureau of Labor Statistics (BLS) *Retail Pump Average Gasoline Prices* and the Lundberg Survey, Inc. offer alternate price series. However, there was a general consistency with using a price series from one statistical agency.

GASOLINE EQUIVALENT GALLON

The following table provides the gasoline equivalent gallon conversion used in this appendix. All conversion values, to the extent possible, have been made to mirror the conversion values used in deriving equivalent-gallon fuel economy estimates found in the NHTSA CAFE files.

Table C3. Gasoline Equivalent Gallon Conversion Values

Transportation Fuel	Gasoline Equivalent Gallon
Diesel	1 diesel gallon = 1 gasoline equivalent gallon
Electricity	33,705 Watt-hours = 1 gasoline equivalent gallon
Compressed Natural Gas	121.5 cubic feet = 1 gasoline equivalent gallon

Sources: 40 CFR Parts 80, 85, 86, 88, and 600 and 10 CFR Part 474.

GREET MODEL

Of course, there are other conversion factors available, depending on the various fuel-specific factors. For the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model, the U.S. Department of Energy, Argonne National Laboratory uses the following:

Table C4. Lower and Higher Heating Values for Select Transportation Fuels Based on the GREET Model

Transportation Fuel	LHV (net) Btu per gallon	HHV (gross) Btu per gallon	Density Grams per gallon	Carbon Content (% by wt)	Sulfur Content (ppm by wt)
Conv.Gasoline	115,500	125,000	2,791	85.5%	200
Ref. Gasoline	112,265	121,456	2,795	82.9%	30
Diesel	128,500	138,700	3,240	87.0%	250
Methanol	57,000	65,000	2,996	37.5%	0
Ethanol	76,000	84,500	2,996	52.2%	0

Table C4. Lower and Higher Heating Values for Select Transportation Fuels Based on the GREET Model

Transportation Fuel	LHV (net) Btu per gallon	HHV (gross) Btu per gallon	Density Grams per gallon	Carbon Content (% by wt)	Sulfur Content (ppm by wt)
LPG	84,000	91,300	2,000	82.0%	0
Natural gas	928	1,031	21	74.0%	7
Electricity	3,412	Btu/kWh			

Source: M. Wang, GREET 1.5 -- *Transportation Fuel-Cycle Model*, Volume 1: Methodologies, Development, Use, and Results, Center for Transportation Research, Argonne National Laboratory, ANL/ESD-39, Vol.1, Aug. 1999. M. Wang, GREET 1.5 -- Transportation Fuel-Cycle Model, Volume 2: Appendices of Data and Results, Center for Transportation Research, Argonne National Laboratory, ANL/ESD-39, Vol.2, Aug. 1999. Notes: 1) Gasoline results are for the mix of 70% conventional gasoline and 30% reformulated gasoline. 2) LPG results are for the mix of 40% LPG produced from crude and 60% from natural gas. 3) Electricity results are for the current average electricity generation mix.

EIA strongly encourages a consistent use of heating values.