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**THE ALLOCATION OF THE SOCIAL COSTS OF MOTOR-VEHICLE
USE TO SIX CLASSES OF MOTOR VEHICLES**

Report #10 in the series: *The Annualized Social Cost of Motor-Vehicle Use in
the United States, based on 1990-1991 Data*

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REPORTS IN THE SOCIAL-COST SERIES

There are 20 reports in this series. Each report has the publication number UCD-ITS-RR-96-3 (#), where the # in parentheses is the report number:

- Report 1:** The Annualized Social Cost of Motor-Vehicle Use in the U.S., 1990-1991: Summary of Theory, Methods, Data, and Results (M. Delucchi)
- Report 2:** Some Conceptual and Methodological Issues in the Analysis of the Social Cost of Motor-Vehicle Use (M. Delucchi)
- Report 3:** Review of Some of the Literature on the Social Cost of Motor-Vehicle Use (J. Murphy and M. Delucchi)
- Report 4:** Personal Nonmonetary Costs of Motor-Vehicle Use (M. Delucchi)
- Report 5:** Motor-Vehicle Goods and Services Priced in the Private Sector (M. Delucchi)
- Report 6:** Motor-Vehicle Goods and Services Bundled in the Private Sector (M. Delucchi, with J. Murphy)
- Report 7:** Motor-Vehicle Infrastructure and Services Provided by the Public Sector (M. Delucchi And J. Murphy)
- Report 8:** Monetary Externalities of Motor-Vehicle Use (M. Delucchi)
- Report 9:** Summary of the Nonmonetary Externalities of Motor-Vehicle Use (M. Delucchi)
- Report 10:** The Allocation of the Social Costs of Motor-Vehicle Use to Six Classes of Motor Vehicles (M. Delucchi)
- Report 11:** The Cost of the Health Effects of Air Pollution from Motor Vehicles (D. McCubbin and M. Delucchi)
- Report 12:** The Cost of Crop Losses Caused by Ozone Air Pollution from Motor Vehicles (M. Delucchi, J. Murphy, J. Kim, and D. McCubbin)
- Report 13:** The Cost of Reduced Visibility Due to Particulate Air Pollution from Motor Vehicles (M. Delucchi, J. Murphy, D. McCubbin, and J. Kim)
- Report 14:** The External Damage Cost of Direct Noise from Motor Vehicles (M. Delucchi and S. Hsu) (with separate 174-page data Appendix)
- Report 15:** U.S. Military Expenditures to Protect the Use of Persian-Gulf Oil for Motor Vehicles (M. Delucchi and J. Murphy)
- Report 16:** The Contribution of Motor Vehicles and Other Sources to Ambient Air Pollution (M. Delucchi and D. McCubbin)
- Report 17:** Tax and Fee Payments by Motor-Vehicle Users for the Use of Highways, Fuels, and Vehicles (M. Delucchi)
- Report 18:** Tax Expenditures Related to the Production and Consumption of Transportation Fuels (M. Delucchi and J. Murphy)
- Report 19:** Some Comments on the Benefits of Motor-Vehicle Use (M. Delucchi)
- Report 20:** References and Bibliography

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LIST OF ACRONYMS AND ABBREVIATIONS AND OTHER NAMES

The following are used throughout all 20 reports of the series, although not necessarily in this particular report

AER = *Annual Energy Review* (Energy Information Administration)
AHS = *American Housing Survey* (Bureau of the Census and others)
ARB = Air Resources Board
BLS = Bureau of Labor Statistics (U. S. Department of Labor)
BEA = Bureau of Economic Analysis (U. S. Department of Commerce)
BTS = Bureau of Transportation Statistics (U. S. Department of Transportation)
CARB = California Air Resources Board
CMB = chemical mass-balance [model]
CO = carbon monoxide
dB = decibel
DOE = Department of Energy
DOT = Department of Transportation
EIA = Energy Information Administration (U. S. Department of Energy)
EPA = United States Environmental Protection Agency
EMFAC = California's emission-factor model
FHWA = Federal Highway Administration (U. S. Department of Transportation)
FTA = Federal Transit Administration (U. S. Department of Transportation)
GNP = Gross National Product
GSA = General Services Administration
HC = hydrocarbon
HDDT = heavy-duty diesel truck
HDDV = heavy-duty diesel vehicle
HDGT = heavy-duty gasoline truck
HDGV = heavy-duty gasoline vehicle
HDT = heavy-duty truck
HDV = heavy-duty vehicle
HU = housing unit
IEA = International Energy Agency
IMPC = Institutional and Municipal Parking Congress
LDDT = light-duty diesel truck
LDDV = light-duty diesel vehicle
LDGT = light-duty gasoline truck
LDGV = light-duty gasoline vehicle
LDT = light-duty truck
LDV = light-duty vehicle
MC = marginal cost
MOBILE5 = EPA's mobile-source emission-factor model.
MSC = marginal social cost

MV = motor vehicle
NIPA = National Income Product Accounts
NO_x = nitrogen oxides
NPTS = Nationwide Personal Transportation Survey
OECD = Organization for Economic Cooperation and Development
O₃ = ozone
OTA = Office of Technology Assessment (U. S. Congress; now defunct)
PART5 = EPA's mobile-source particulate emission-factor model
PCE = Personal Consumption Expenditures (in the National Income Product Accounts)
PM = particulate matter
PM₁₀ = particulate matter of 10 micrometers or less aerodynamic diameter
PM_{2.5} = particulate matter of 2.5 micrometers or less aerodynamic diameter
PMT = person-miles of travel
RECS = Residential Energy Consumption Survey
SIC = standard industrial classification
SO_x = sulfur oxides
TIA = *Transportation in America*
TSP = total suspended particulate matter
TIUS = *Truck Inventory and Use Survey* (U. S. Bureau of the Census)
USDOE = U. S. Department of Energy
USDOL = U. S. Department of Labor
USDOT = U. S. Department of Transportation
VMT = vehicle-miles of travel
VOC = volatile organic compound
WTP = willingness-to-pay

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10. THE ALLOCATION OF THE SOCIAL COSTS OF MOTOR-VEHICLE USE TO SIX CLASSES OF MOTOR VEHICLES

10.1 BACKGROUND

In our analysis of the social cost of motor-vehicle use, many of our data sources, methods, and estimates of cost apply in the first instance to all classes of motor vehicles. For example, we are given, or can estimate from primary data, the following:

- total government expenditures on the highways
- the air-pollution damage cost of emissions from gasoline service stations
- the air-pollution damage cost of emissions of PM₁₀ from re-entrained road dust
- highway-patrol expenditures
- the cost of garages and parking spaces
- the cost of oil spills, per barrel of oil

All of these costs pertain to all motor vehicles: all autos, trucks, and buses. Although it can be interesting to estimate the cost of all motor-vehicle use, it typically will be more useful to estimate the cost of different classes of vehicles or of different fuel types, because analysts, policy makers, and regulators typically are interested in specific classes of vehicles, and specific fuels, rather than all motor-vehicles as a group. (For example, pollution regulations are set for individual classes of vehicles, not for all motor vehicles as a class.) Thus, it is useful to carry the analysis of total social cost a step further, and take a cost that initially applies to all motor-vehicles and apportion it to specific vehicle and fuel classes. This report develops such “allocation factors,” which can be used to apportion or disaggregate a total cost to specific vehicle and fuel classes.

10.1.1 Outline

The first step in the allocation of total cost is to decide on the number and types of vehicle and fuel classes to which the total will be apportioned. As explained below, I have opted for a relatively simple yet broadly useful classification of six vehicle and fuel classes.

The next step is to decide on what basis total cost should be apportioned to the six classes. In this report, I develop some broadly useful overall allocation factors,

including factors that can be used for simple allocations of government expenditures related to motor-vehicle use.

Then, I develop a detailed set of allocation factors for point and area-source emissions attributable to motor vehicles. These last allocation factors are used to apportion the total cost of point and area-source emissions attributable to motor-vehicle use.

Finally, I estimate the fraction of imported petroleum, and imported petroleum from the Middle East specifically, that is or becomes motor fuel. These fractions are used to allocate defense expenditures related to the Middle East, the cost of the Strategic Petroleum Reserve, and environmental excise taxes on imported petroleum.

10.2 APPORTIONING TO SIX CLASSES OF MOTOR VEHICLES

I follow the vehicle classification used in the U.S. Environmental Protection Agency's (EPA's) emissions inventories, and distinguish between gasoline and diesel fuel, and between three weight classes (EPA, *National Air Pollutant Emission Trends, 1900-1992, 1993*; EPA, data file containing containing county-level emissions estimates, 1995). I thus have six classes of vehicles¹:

- **Light-duty gasoline automobiles:** passenger vehicles, including station wagons and motorcycles, that use gasoline as a fuel. In some cases I ignore motorcycles, which account for but a tiny fraction of highway travel (Federal Highway Administration [FHWA], *Highway Statistics 1992, 1993*) and emissions (EPA, *National Air Pollutant Emission Trends, 1900-1992, 1993*). (The EPA's *National Air Pollutant Emission Trends, 1900-1992* includes motorcycles, but the computer data file does not.)
- **Light-duty gasoline trucks:** trucks, vans, minivans, jeeps, and utility vehicles, that run on gasoline and have a gross vehicle weight rating of 8,500 lbs or less and a curb weight of 6,000 lbs or less. (The FHWA' annual *Highway Statistics* annual report uses a slightly different category, "two-axle, single-unit" trucks.)

¹As discussed in Report #7 of this social-cost series (see the list at the beginning of this document), *Government Expenditures Related to the Use of Motor Vehicles*, bicycles and pedestrians should bear a very small portion of the cost of basic roads, and hence should be included in the allocation of the analysis of highway expenditures. However, the share is so small as to have no noticeable affect on the amount allocated to motor vehicles. It matters only in the estimation of the social cost of bicycle use, which is not covered in this social-cost analysis.

- **Heavy-duty gasoline vehicles:** all other trucks, and buses, that run on gasoline. In some cases I ignore buses, which in the U.S. account for a tiny fraction of highway travel (FHWA, *Highway Statistics* 1992, 1993).
- **Light-duty diesel automobiles:** same as light-duty gasoline automobiles, except that they use diesel fuel.
- **Light-duty diesel trucks:** same as light-duty gasoline trucks, except that they use diesel fuel.
- **Heavy-duty diesel vehicles:** same as heavy-duty gasoline vehicles, except that they use diesel fuel.

I chose these because they are the classes in the EPA's inventory of direct motor-vehicle emissions, and because analysts, policy makers, and regulators usually distinguish between gasoline and diesel fuel, between trucks and automobiles, and between heavy-duty and light-duty vehicles.

10.3 ESTIMATION OF GENERAL ALLOCATION FACTORS

103.1 General

On what basis should one apportion a total cost to the six individual classes of motor vehicles? In principle, costs should be allocated on the basis of a model that relates total cost to a variety of cost-determining factors. Thus, one would apportion highway maintenance costs on the basis of axle weights, vehicle speeds, road types, and other factors; air-pollution damages from road dust on the basis of a sophisticated model of vehicle turbulence and tire contact; and so on.

However, in this report, I have not developed or used sophisticated cost-allocation models. Instead, I have estimated several relatively simple cost allocation factors, which give a rough idea of how different kinds of total costs (e.g., highway expenditures, police expenditures, road-dust emissions) might be allocated to the six different vehicle classes established above. Thus, rather than apportion road-dust damages on the basis of a sophisticated model of vehicle turbulence, I apportion with a simple nonlinear weight function.

I have estimated eight general bases for allocating costs to each of the six vehicle classes:

- vehicle miles of travel (VMT)
- total vehicle ton-miles of travel (one vehicle weighing one ton and traveling one mile produces one vehicle ton-mile)
- total vehicle ton-miles of travel, where tonnage is raised to the 0.7 power

- total vehicle ton-miles of travel per axle
- total fuel use (gallons of gasoline or diesel fuel)
- total vehicle sales
- total vehicle-tons manufactured in the U.S
- total expenditures on maintenance and repair

These allocation factors tell us, for example, what fraction of total vehicle ton-miles heavy-duty diesel vehicles are responsible for. This fraction, multiplied by any total cost that is a function of vehicle ton-miles (say, for simplicity, highway damages), tells us the amount of that cost that is assignable to heavy-duty diesel vehicles.

10.3.1 Summary of major data sources and allocation factors

To estimate the eight cost-allocation factors for each of the six vehicle classes, I make use of several sources of original or primary data on vehicle travel, fuel use, fuel economy, vehicle weight, vehicle sales, expenditures on motor vehicles, ton-miles, and other statistics. Because I refer to these data sources repeatedly throughout the analysis, I have summarized them in Tables 10-1 and 10-2.

Table 10-3 presents the estimation of vehicle-miles of travel (VMT), ton-miles, weighted ton-miles, ton-miles per axle, fuel use, vehicle sales, vehicle-tons made, and maintenance and repair expenditures pertaining to gasoline and diesel fuel light-duty autos, light-duty trucks, and heavy-duty vehicles. Note that each vehicle class's allocation share varies considerably from one type of factor to the next. For example, heavy-duty diesel vehicles account for less than 2% of total vehicle sales, but 10% of total vehicle tons manufactured, and more than 50% of total vehicle ton-miles of travel. The notes to Table 10-3 explain how the apportioning factors were derived.

Because the "truck" categories in FHWA's annual *Highway Statistics* report, which is the primary source of national VMT and fuel-use data, are not the same as my light-duty and heavy-duty vehicle categories, I have used the Bureau of the Census' *1987 Truck Inventory and Use Survey* (1990) to map statistics from my truck categories into the FHWA's truck categories. Table 10-4 summarizes the national VMT and fuel-use data from the FHWA. Table 10-5 shows statistics for light and heavy-duty trucks, as I define them, organized into the FHWA's truck categories, and Table 10-6 summarizes the data from the *1987 Truck Inventory and Use Survey* (Bureau of the Census, 1990) that I use in the analysis of Table 10-5.

Table 10-7 develops the estimates of maintenance and repair expenditures, which, as shown in Table 10-8, are used to allocate emissions from SIC 75 to the six different vehicle classes.

10.4 ALLOCATION OF POINT AND AREA-SOURCE EMISSIONS TO SIX CLASSES OF MOTOR VEHICLES

In this section, I develop factors that are used to apportion indirect motor-vehicle-related emissions (from petroleum refineries, vehicle manufacture, and so on) to the six classes of vehicles defined above. In most cases, this proceeds in two steps. First, I estimate the motor-vehicle-related fraction of total point or area-source emissions of a certain type -- say, emissions from petroleum refineries. Then, I apportion the motor-vehicle-related total to the six classes of motor vehicles.

10.4.1 Background

In Reports 11, 12, and 13 of this social-cost series (see the list at the beginning of this report), we develop dose-response functions that estimate changes in human health, crop production, and visibility as a function of changes in ambient air pollution:

$$\Delta E = f(\Delta P, O) = f(PI, PP, O)$$

where:

ΔE = the change in the effect of interest (human health, crop production, or visibility)

ΔP = the change in ambient air pollution

O = other variables (such as population in the county, or the incidence rate of a health problem or cause of death; see Reports 11, 12, and 13 of the social-cost series listed at the beginning of this report)

PI = the initial pollution level (estimated from data on actual ambient air quality in counties in the U.S.; see Reports 11, 12, and 13)

PP = the pollution level after the change in pollution -- in our analysis, the level had there been no motor-vehicle-related emissions (Report #16)

The total damage cost is equal to the change in the effect of interest (ΔE ; e.g., number of deaths due to motor-vehicle air pollution) multiplied by the dollar value per effect (e.g., the value of life). This economic valuation is discussed in Reports 11, 12, and 13.

Note that we estimate the effects of a specific, "marginal" change in pollution: the difference between actual pollution (PI) and, what pollution would have been had there been no emissions *related* to motor-vehicle use (PP). Note the emphasis on "related". When I say "related," I mean that we consider not only emissions directly from motor vehicles themselves, but emissions indirectly related to motor-vehicle use: emissions from the production of motor fuel at refineries, emissions from the assembly of motor vehicles, emissions from the servicing of motor vehicles, emissions from the manufacture of materials used in motor vehicles, emissions from road construction, and so on. Because so many sources are related to motor-vehicle use in one way or another, we incorporate formally into our model a motor-vehicle share factor, which is the share

of emissions, from *each* source in the emissions inventory, that is related to motor-vehicle use. From some of the sources in the inventory (such as highway construction, and of course motor-vehicles themselves), *all* of the emissions are attributable to motor-vehicle use; from other sources (such as agricultural operations), *none* of the emissions are attributable to motor vehicle use; and from still other sources (such as petroleum refineries), *some* portion of the emissions are attributable to motor-vehicle use. Thus, in Report #16 we develop the following model to estimate PP, the pollution level had there been no motor-vehicle-related emissions:

$$PP_{P,r}^* = C_{P' \rightarrow P} \left(\sum_i E_{P1' \wedge, r, i} \times D_i, \sum_i E_{P2' \wedge, r, i} \times D_i \dots \right)$$

$$E_{P1' \wedge, r, i} = E_{P1', r, i} - E_{P1', r, i} \times MS_{P1', i} = E_{P1', r, i} \times (1 - MS_{P1', i})$$

where:

subscript P = the ambient pollutants, measured at the ambient air-quality monitors and included in health, crop, or visibility damage functions: carbon monoxide (CO), ozone (O₃), nitrogen oxides (NO_x), total suspended particulate matter (TSP), particulate matter less than 10 microns in aerodynamic diameter (PM₁₀), and particulate matter less than 2.5 microns (PM_{2.5})

subscript P' = the emitted pollutants: CO' (-> CO), PM₁₀' (-> PM₁₀), PM_{2.5}' (-> PM_{2.5}), NO_x' (-> NO_x, O₃, PM₁₀, PM_{2.5}); volatile organic compounds (VOCs'; -> O₃, PM_{2.5}), SO₂' (-> PM₁₀, PM_{2.5}), ammonia (NH₃' -> PM₁₀, PM_{2.5})

subscript i = sources of emissions of P' (includes all sources in the emissions inventory: motor vehicles, power plants, industries, farms, and so on)

PP_{P,r}* = the modeled level of total ambient pollution P "received" or formed at air-quality monitors in region r, in a year, excluding the contribution of motor-vehicle related emissions

C_{P'→P} = the chemical transformation of emissions of precursor pollutants P' (P1', P2',...) to ambient pollutant P (this is assumed to be the same in each region, and to be independent of the source of the emissions)

E_{P1',r,i} = yearly emissions of precursor pollutant P1' from source i in region r

E_{P2',r,i} = yearly emissions of precursor pollutant P2' from source i in region r

D_i = the fraction of emissions of precursor pollutants P' from source i that reach the ambient air quality monitor (assumed to be the same for all pollutants P' from a given source i)

E_{P1'∧,r,i} = yearly emissions of precursor pollutant P1' from source i in region r, excluding emissions related to motor-vehicle use

$E_{P2',r,i}$ = yearly emissions of precursor pollutant $P2'$ from source i in region r , excluding emissions related to motor-vehicle use

$MS_{P,i}$ = the motor-vehicle-related fraction of emissions of precursor pollutant P' ($P1'$, $P2'$...) from emissions source i : that is, of the emissions of pollutant P' , from source i , $MS_{P,i}$ is the fraction that is related to motor-vehicle use (e.g., all tailpipe emissions from motor-vehicles are related to motor-vehicle use; some fraction of refinery emissions is related to motor-vehicle use, and no fraction of emissions from agricultural tillage is related to motor-vehicle use)

All of the variables except $MS_{P,i}$ are discussed in Report #16. *In this section of this report, we estimate $MS_{P,i}$, the motor-vehicle-related fraction of emissions of precursor pollutant P' ($P1'$, $P2'$...) from emissions source i .*

Direct motor-vehicle emissions. For the purpose of estimating $MS_{P,i}$, and further allocating the motor-vehicle share to individual vehicle classes, it is useful to distinguish between direct and indirect motor-vehicle emissions. Direct emissions are tailpipe and evaporative emissions from motor vehicles. These emissions are estimated, for each of the six vehicle classes, by the EPA (*National Air Pollutant Emission Trends, 1900-1992, 1993*). For direct emissions, the variable $MS_{P,i}$ in the equation above obviously equals 1.0. Furthermore, because the EPA has estimated direct emissions from each of the six vehicle classes, they in effect already have done the job of apportioning $MS_{P,i}$ to individual vehicle classes. Hence, no further analysis of direct emissions here is required.

Indirect motor-vehicle emissions. Indirect motor-vehicle emissions are point and area-source emissions from the production, transport, and servicing of motor fuels, motor vehicles, and the motor-vehicle infrastructure. They include emissions from vehicle manufacture and road dust, and a portion of emissions from petroleum refineries, crude oil production, and so on.

There is no ready-made inventory of indirect point and area-source emissions associated with motor-vehicle use per se. The EPA's official national inventory (EPA, data file containing containing county-level emissions estimates, 1995) estimates emissions from industries, such as petroleum refining (classified according to the Standard Industrial Classification [SIC]), and from area sources, but of course does not identify what fraction of emissions is attributable indirectly to motor-vehicle use. Thus, my task here is to examine all of the emissions sources in the inventory, and for each one estimate the fraction of emissions attributable to motor-vehicle use ($MS_{P,i}$). Then, this fraction must be allocated to the six individual classes of motor vehicles.

10.4.2 Sources of indirect emissions associated with motor-vehicle use

I assume that in the EPA's emissions inventory, the following emissions sources are entirely ($MS_{p,i} = 1.0$; marked with a double asterisk, **) or partly ($0 < MS_{p,i} < 1.0$) related to motor vehicle use:

- Oil and gas extraction
- Synthetic rubber production
- Asphalt mixtures and blocks
- Lubricating oils and grease
- Tires and inner tubes
- Primary metals
- Automotive stampings **
- Motor vehicles and motor-vehicle equipment **
- Motorcycles and bicycles
- Travel trailers & campers **
- Truck terminals **
- Water transport of freight
- Marine cargo handling
- Crude petroleum pipeline
- Petroleum product pipeline
- Electric services
- Motor vehicle supplies and new parts **
- Auto-body shredding **
- Petroleum terminals
- Petroleum products, n.e.c
- New and used car dealers **
- Gasoline service stations **
- Automotive repair, services, and parking **
- Any transport of crude oil
- Any transport of gasoline
- Transport of oil products
- Liquid asphalt
- Road construction **
- Traffic markings **
- Surface coating of vehicles **
- Re-entrained road dust **

All of the emissions from the sources marked with a double asterisk (**) are attributable entirely to motor vehicles. With these sources, the task is to allocate the

emissions to each of the six classes of motor vehicles. With the other (unmarked) sources, only a portion of the emissions are attributable to motor-vehicle use. For example, only a portion of the emissions from petroleum refineries are associated with making motor fuels, because refineries produce more than just motor fuels. With emission sources such as these, one first must estimate the portion of total emissions that is attributable to motor-vehicle use². This attribution can be done on the basis of the energy or emissions associated with making gasoline or diesel fuel, or by assuming that the portion of emissions that is related to motor-vehicle use is equal to the portion of output or throughput (rubber, tires, electricity, crude oil, etc.) that is related to motor-vehicle use. Thus, with the latter method, if 50% of the crude oil that is shipped by pipeline is used to make motor fuel, then 50% of the emissions from crude-oil pipelines are attributable to motor vehicles. (Of course, this simple assumption ignores the economic forces that affect output. I discuss this complication more later.) The motor-vehicle portion of total emissions then is further apportioned to the six classes of motor vehicles.

The remainder of this report details the allocation of these indirect emissions to the six classes of motor vehicles.

10.4.3 The general method

I allocate point- and area-source emissions on the basis of factors that are the same as, or consistent with, the actual emission factors that the EPA used to calculate the point or area-source emissions in the first place, in its emissions inventories (EPA, *National Air Pollutant Emission Trends, 1900-1992, 1993*; EPA, data file containing containing county-level emissions estimates, 1995). For example, the EPA estimates emissions of road dust from unpaved roads as a function ton-miles of travel, where tonnage is raised to the 0.7 power. Therefore, I allocate unpaved-road-dust emissions to the six vehicle classes on the basis of ton-miles of travel, where tonnage is raised to the 0.7 power. As another example, the EPA estimates emissions from marine petroleum-cargo handling as a function of fuel volatility, fuel throughput, and emissions controls, and so I allocate these emissions to the six vehicle classes on the basis of the same factors. The details of the calculations are presented below, and in the notes to the tables.

The final estimated allocation factors are shown in Table 10-8. The subsequent tables document intermediate calculations in the development of the factors of Table 10-8. Table 10-9 estimates the fraction of emissions, of each pollutant, that is attributable to the production and transport of crude oil, gasoline, and diesel fuel. Table 10-10 gives details of the calculation of the motor-vehicle-class shares of emissions from waterborne commerce. Tables 10-11 and 10-12 detail the calculation of the fraction of electricity-

²Note that just because, say, emissions from petroleum refineries are related to motor-vehicle use, it does not follow the optimal way to address petroleum-refinery emissions is to control or tax the use of motor-vehicles or motor fuels. Obviously, emissions from petroleum refineries -- indeed, emissions from any source -- should be addressed *at the source*.

generation emissions that are attributable to the six vehicle classes. The results of Tables 10-9 to 10-12 are used in Table 10-8.

10.4.4 Data and methods used to apportion upstream point-source and area-source emissions to six vehicle classes (Table 10-8)

SIC 13, oil and gas extraction. This includes SICs 1311, 1321, 1381, 1382, and 1389, and “area source” emissions associated with petroleum extraction.

Emissions from oil and gas extraction are a function of many factors, including: the amount and kind of energy used to explore for, lift, process, and transport crude oil and gas; the kind of processing technologies and methods used; the volume of crude oil stored in the field, and the characteristics of the storage vessels; the characteristics of the crude oil extracted; the number of producing wells; and emission controls used (EPA, *Compilation of Air Pollutant Emission Factors, Volume 1, Stationary Sources*, 1995; Burklin et al., 1992; DeLuchi et al., 1992; EPA, *AIRS Facility Subsystem Source Classification Codes and Emission Factor Listing for Criteria Air Pollutants*, 1990). Generally, emissions of all pollutants other than VOCs and toxics arise mainly from the use of process energy, whereas emissions of VOCs arise primarily from area-source evaporation. Nevertheless, in this analysis, for simplicity, I allocate emissions from oil and gas extraction solely on the basis of the use of process energy.

The allocation calculation here proceeds in three steps. First, the total process energy used for joint production of oil and gas is separated into energy used to extract crude oil and energy used to extract natural gas. Second, the process energy used to extract crude oil is allocated to the highway gasoline and highway diesel fuel eventually produced from the crude oil. These two steps are documented in Table 10-9.

The final step is to allocate gasoline’s share of emissions to the three gasoline vehicle classes, and diesel’s share to the three diesel vehicle classes. This step is done in Table 10-8. For gasoline vehicles, each of the vehicle-class emission shares shown in Table 10-8 is equal to: crude oil’s share of all emissions in SIC 13 (Table 10-9; note that this share is different for different pollutants), multiplied by the fraction of crude-oil production emissions assignable to highway gasoline (Table 10-9), multiplied by the fraction of total highway gasoline assignable to each gasoline-vehicle class (Table 10-3). The calculation is analogous for diesel vehicles.

I caution the reader that this allocation ignores important economic forces. See section 10.4.5 for details.

SIC 2822, synthetic rubber. Emissions in SIC 2822 are a function of tons of rubber produced (EPA, *Compilation of Air Pollutant Emission Factors, Volume 1, Stationary Sources*, 1995; EPA, *AIRS Facility Subsystem Source Classification Codes and Emission Factor Listing for Criteria Air Pollutants*, 1990): Therefore, emissions from this SIC should be allocated to each class of motor vehicles in proportion to the amount of material consumed in making vehicles in each class. Formally:

$$F_v = Ru_a \times T_v$$

where:

F_v = the fraction of total emissions in SIC 2822 allocated to vehicle type v (light-duty gasoline auto, light-duty gasoline truck, etc.) in 1991

Ru_a = the ratio of synthetic rubber consumed for all motor-vehicle related purposes to total consumption of synthetic rubber in 1990 (0.55: the ratio of rubber used in motor vehicles and replacement parts to total rubber use was 0.50 [calculated from data in the Motor Vehicle Manufacturers Association, 1992], to which I have added an additional 10% that I assume accounts for other motor-vehicle related uses of rubber)

T_v = tons of vehicle type v made divided by total tons of motor vehicles made, in 1991 (Table 10-3)

SIC 2911, petroleum refining. There are three major sources of emissions in petroleum refineries: fuel combustion in boilers to raise process heat (emissions of all pollutants); fuel processing, such as catalytic cracking (emissions of all pollutants); and fugitive emissions of VOCs from valves, flanges, separation tanks, and other areas (EPA, *Compilation of Air Pollutant Emission Factors, Volume 1, Stationary Sources*, 1995; EPA, *AIRS Facility Subsystem Source Classification Codes and Emission Factor Listing for Criteria Air Pollutants*, 1990; DeLuchi et al., 1992). In Table 10-9, I allocate emissions from all of these sources to individual product classes (gasoline, distillates, and residual fuel) (DeLuchi et al., 1992). In Table 10-8, I allocate gasoline's share of the emissions to three gasoline-vehicle classes, and diesel's share to three diesel-vehicle classes. For gasoline-vehicle classes, each fraction shown is equal to the fraction of refinery emissions assignable to production of highway gasoline (Table 10-9) multiplied by the fraction of total highway gasoline assignable to each gasoline-vehicle class (Table 10-3). For diesel-vehicle classes, each fraction shown is equal to the fraction of refinery emissions assignable to production of highway diesel (Table 10-9) multiplied by the fraction of total highway diesel assignable to each diesel-vehicle class (Table 10-3).

SIC 2951, asphalt paving mixtures and blocks. Emissions in this SIC are a function of the tons of material processed, and of the amount and kind of fuel used for process energy (EPA, *Compilation of Air Pollutant Emission Factors, Volume 1, Stationary Sources*, 1995; EPA, *AIRS Facility Subsystem Source Classification Codes and Emission Factor Listing for Criteria Air Pollutants*, 1990). The first step in allocating emissions from this SIC is to determine the fraction of total emissions attributable to all highway transportation. I assume that emissions from the production of paving materials used specifically for roads should be assigned to highway transportation. Now, Tyler et al. (1990) cite an estimate that in 1987, 85% of asphalt production in the U.S. was for roads. If this is true of all asphalt production, then presumably a much larger percentage of the output of SIC 2951 -- asphalt paving mixtures and blocks -- is used for roads. I assume that 95% of the output of, and hence 95% of the emissions from, SIC 2951 are attributable to roads.

Next, I must allocate the highway-share of emissions (95%) to individual vehicle classes. I do this on the basis of ton/miles per axle (Table 10-3), because road damage and necessary road strength are related to the axle weight of vehicles (FHWA, *Final Report on the Federal Highway Cost Allocation Study*, 1982). (Of course, one could argue that one should allocate on the basis of road space, rather than road strength, in which case one would use VMT shares to allocate emissions.)

SIC 2992, lubricating oils and greases. First, I assume that emissions in this SIC are a function of output, and allocate emissions to transportation according to the fraction of output of all lubricating oils and greases that is consumed by all highway vehicles. I assume that the fraction of total production of lubricating oils and greases that is used by highway vehicles is equal to the fraction of total crude oil production that is converted to motor-vehicle fuels -- 51% in 1991 (Table 10-9). Then, I allocate this motor-vehicle share to individual vehicle classes in proportion to fuel consumption (Table 10-3), on the assumption that consumption of oil and lubricating greases is proportional to fuel consumption.

SIC 3011, tires and inner tubes. This SIC includes establishments that manufacture tires and tubes for all kinds of vehicles, including airplanes and farm equipment, and toys (Office of Management and Budget, *Standard Industrial Classification Manual*, 1987). Emissions in this SIC are a function of the number of tires produced or the amount of solvent used (*AIRS Facility Subsystem Source Classification Codes and Emission Factor Listing for Criteria Air Pollutants*, 1990), which presumably is a function of the number of tires produced. As explained below, I assume that 85% of the output of this industry goes to motor vehicles, and distribute this 85% to individual vehicle classes on the basis of ton-miles of travel by each class (Table 10-3), because tire wear (and hence tire replacement) is related to ton-miles of travel.

In 1987, SIC 3011 shipped \$10.4 billion worth of products (Bureau of the Census, *Statistical Abstract of the United States 1992*, 1992). In 1987, SIC 371, motor vehicles and equipment, bought \$2.7 billion worth of tires and inner tubes. The \$2.7 includes only tires bought by manufacturers for use on new vehicles; it does not include replacement tires. If there are two to three replacement tires for every new tire, then the total cost of motor-vehicle tires bought wholesale would be \$8 to \$11 billion, or at least 80% of the value of products shipped by SIC 3011. This rough comparison ignores differences between the measure "value of shipments" by SIC 3011 and the measure "cost of materials" in SIC 371, and imports and exports. Nevertheless, it seems roughly right, and suggests that something like 85% of the output of SIC 3011 goes to motor vehicles.

SIC 33, primary metals. Emissions in SIC 33 are a function of tons of material processed (EPA, *Compilation of Air Pollutant Emission Factors, Volume 1, Stationary Sources*, 1995; EPA, *AIRS Facility Subsystem Source Classification Codes and Emission Factor Listing for Criteria Air Pollutants*, 1990): Therefore, emissions from this SIC should be

allocated to each class of motor vehicles in proportion to the amount of material consumed in making vehicles in each class. Formally:

$$F_v = P_a \times T_v$$

where:

F_v = the fraction of total emissions in SIC 33 allocated to vehicle type v (light-duty gasoline auto, light-duty gasoline truck, etc.) in 1991

P_a = the ratio of primary metals consumed for all motor-vehicle related purposes to total consumption of primary metals in 1990 (0.17: the ratio of metal used in motor vehicles and replacement parts to total metal use was 0.16 [calculated from data in Motor Vehicle Manufacturers Association, 1992], to which I have added an additional 10% that I assume accounts for other motor-vehicle related uses of metal)

T_v = tons of vehicle type v made divided by total tons of motor vehicles made, in 1991 (Table 10-3)

SIC 3465, automotive stampings. Emissions in SIC 34 are a function are a function of tons processed or amount of materials consumed (EPA, *AIRS Facility Subsystem Source Classification Codes and Emission Factor Listing for Criteria Air Pollutants*, 1990): Therefore, emissions from this SIC should be allocated to each class of motor vehicles in proportion to the amount of material consumed in making vehicles in each class. I use the fractions of Table 10-3 to allocate the emissions to the six classes of motor vehicles.

SIC 371, motor vehicles and motor vehicle equipment. SIC 371 includes SICs 3711, 3713, 3714, 3715, and 3716. Emissions in SIC 371 are a function of the number of vehicles made and of the amount of fuel consumed (which in turn is a function of the amount of material manufactured and assembled) (EPA, *Compilation of Air Pollutant Emission Factors, Volume 1, Stationary Sources*, 1995; EPA, *AIRS Facility Subsystem Source Classification Codes and Emission Factor Listing for Criteria Air Pollutants*, 1990): Therefore, emissions from this SIC should be allocated to each class of motor vehicles in proportion to the amount of material consumed in making vehicles in each class. (Although emissions from solder joint grinding in automobile assembly [SIC 371] are expressed per vehicle processed, it is clear that these emissions are more nearly related to vehicle tonnage processed, and that total emissions, however calculated, should be allocated to individual vehicle classes on the basis of vehicle tonnage.) I use the fractions of Table 10-3 to allocate the emissions to the six classes of motor vehicles.

SIC 3751, motor cycles, bicycles, and parts. I assume that half of the emissions in this SIC are attributable to the manufacture of motorcycles, and then classify motorcycles with light-duty gasoline autos.

SIC 3792, travel trailers and campers. This SIC includes establishments “primarily engaged in manufacturing travel trailers and campers for attachment to passenger cars or other vehicles, pickup coaches (campers) and caps (covers) for mounting on pickup trucks” (Office of Management and Budget, *Standard Industrial Classification Manual*, 1987, p. 241). It does not include emissions from manufacturing mobile homes. I assume that emissions from this SIC are related to the amount of output, and assume that the output is used primarily by LDTs. Specifically, I assume that the ratio of VMT by LDTs with camper or trailer to VMT by all LDTs is seven times the corresponding ratio for LDAs, and 70 times the corresponding ratio for HDVs. I apply these relative usage ratios to total VMT shares (Table 10-3) to generate the emission apportioning factors shown here.

SIC 4231, terminals and facilities for motor-freight transportation. This SIC includes “establishments primarily engaged in the operation of terminal facilities used by highway-type property carrying vehicles” (Office of Management and Budget, *Standard Industrial Classification Manual*, 1987, p. 272). I assume, therefore, that emissions from this SIC are related to the amount of freight tonnage handled, which I assume in turn is related to the amount of freight tonnage carried. Unfortunately, data on tonnage carried by vehicle class are not available, so instead, I allocate emissions to truck classes on the basis of ton-miles of freight by trucks used for non-personal transportation (Table 10-3).

SICs 442, 443, 444, water transportation of freight. Emissions from water transportation arise mainly from fuel combustion to propel the vessel (EPA, *AIRS Facility Subsystem Source Classification Codes and Emission Factor Listing for Criteria Air Pollutants*, 1990; EPA, *National Air Pollutant Emissions Trends, 1990-1992, 1993*; DeLuchi et al., 1992; EPA, *Compilation of Air Pollutant Emission Factors, Volume II, Mobile Sources*, 1985). Fuel consumption is a function of vessel design, engine type, vehicle speed, vessel weight, and other factors. In this analysis, I allocate emissions to different types of cargo on the basis of weight, and assume that each cargo-type’s share of emissions is equal to its share of total cargo weight. The weight shares of motor vehicles and motor-vehicle products, by vehicle class, are calculated in Table 10-10.

SIC4491, marine cargo handling. Emissions from handling crude oil and petroleum products at marine terminals arise from loading operations, ballasting operations, and in-transit losses (EPA, *Compilation of Air Pollutant Emission Factors, Volume 1, Stationary Sources*, 1995; DeLuchi et al., 1992). DeLuchi et al. (1992) estimated loading, ballasting, and in-transit emissions from tankers and barges that carry crude oil or petroleum products, in the years 1988 and 2000. (Emissions in Alaska were included.) Using the 1988 data from the model documented in DeLuchi et al. (1992), I assign emissions from handling gasoline to gasoline (obviously), and emissions from handling crude to individual products on the basis of the mass yield of products from a barrel of crude oil. The result of this calculation is that 79% of the emissions from marine vessel

loading of crude oil and petroleum products are assigned to highway gasoline, and 2.9% to highway diesel. (I assume that conditions in 1991 were similar to conditions in 1988.) I then further distribute gasoline's 79% and diesel's 2.9% to individual vehicle classes using the gallon-share factors of Table 10-3.

Note that the allocation factors shown do not apply to all emissions in SIC 4491, but only to those arising from handling of petroleum.

SIC 4612, crude petroleum pipelines. Emissions from the operation of crude-oil pipelines are a function of the amount of crude oil shipped. Hence, I allocate emissions in this SIC to gasoline and diesel fuel according to the amount of crude that ends up being converted to gasoline, and the amount that ends up being converted to diesel fuel. In 1991, 41% of all crude oil was made into highway gasoline, and 9.5% was made into highway diesel fuel (on a mass basis; see Table 10-9). I assume that the crude oil that was shipped by pipeline yielded this national-average slate of products. I then further distribute gasoline's 41% and diesel's 9.5% to individual vehicle classes using the gallon-share factors of Table 10-3.

SIC 4613, refined petroleum pipelines. Emissions from petroleum-product pipelines are a function of the amount of product shipped. In 1991, pipelines moved 1249.335 million barrels of petroleum products, of which 55% (684.949 million barrels) were finished motor gasoline and motor-gasoline blending components, and 21% (256.639 million barrels) were distillates (EIA, *Petroleum Supply Annual 1991, 1992*). (These percentages apparently are stable over time: In 1990, pipelines moved 1279.934 million barrels of petroleum products, of which 54% [695.575 million barrels] were finished motor gasoline and motor-gasoline blending components, and 21% [271.383 million barrels] were distillates [EIA, *Petroleum Supply Annual 1990, 1991*]. In 1993, pipelines moved 1374.599 million barrels of petroleum products, of which 54% [741.238 million barrels] were finished motor gasoline and motor-gasoline blending components, and 21% [283.423 million barrels] were distillates [EIA, *Petroleum Supply Annual 1993, 1994*].) I assume that 96% of the gasoline was highway gasoline, and that 46% of the distillate was highway diesel fuel (Table 10-9). Then, I distribute highway gasoline's 53% ($0.96 \cdot 0.55$) share and highway diesel's 10% ($0.46 \cdot 0.21$) share to individual vehicle classes using the gallon-share factors of Table 10-3.

SIC 4911, electric services. Emissions from electricity generation are, of course, a function of the amount of electricity generated. Hence, the task is to the amount of electricity used by various motor-vehicle related processes, expressed as a fraction of total electricity use in the U.S. Each fraction here is calculated by the following formula:

$$F_v = \sum_a \frac{E_{a,v} \times Q_{a,v}}{G \times T}$$

where:

F_v = the fraction of total electricity consumption attributable to vehicle type v (light-duty gasoline auto, light-duty gasoline truck, etc.) in 1991
 $E_{a,v}$ = electricity consumption due to activity a by vehicle type v in 1991, expressed in terms of kWh consumed per unit of activity: kWh per gallon of fuel produced and refined; kWh per gallon of fuel marketed and dispensed; kWh per lb of vehicle assembled; kWh per lb of material produced for motor-vehicles, parts, supplies, and equipment; kWh per dollar spent on automobile services; and kWh per vehicle or part or supply sold (estimated in Table 10-11 below)
 $Q_{a,v}$ = the amount of activity a attributable vehicle type v in 1991 (Table 10-3)
 G = total electricity generation by electric utilities in 1991 (2825 billion kWh; EIA, *Annual Energy Review* 1992, 1993; I use generation by electric utilities, rather than total generation [which includes generation by non-utilities], because the emissions inventory that I am allocating has a category for electric utilities only)
 T = transmission and distribution efficiency (0.92; EIA, *Annual Energy Review* 1992, 1993)

This method, which applies a national average to county-level emissions, assumes that in every county with electricity generation, roughly 5% of the generation is attributable indirectly to motor-vehicle use. This obviously is not correct, because, for example, some counties with power plants do not have refineries or motor-vehicle production plants. However, for two reasons, the method might not be as far wrong as might seem at first thought. First, even though some *counties* that have power plants do not have refineries or motor-vehicle factories, electricity production and fuel production and even motor-vehicle production often are concentrated in the a particular *region* (e.g., Texas-Louisiana, New York-New Jersey, California, Pennsylvania-Ohio..), if not a particular county, and electricity generally is dispatched and traded at the regional level, across many counties. Second, about 25% of the total electricity use attributable to motor vehicles is in fact very decentralized use that occurs in virtually every county: electricity use at service stations, automobile repair shops, car dealers, and the like.

SIC 5013, motor vehicle supplies and new parts. I assume that emissions in this SIC should be allocated to motor-vehicle classes in proportion to the amount of supplies and parts used by each class. I assume that expenditures on maintenance and repair (Table 10-3) represent the amount of supplies and parts used.

SIC 5093, auto body shredding. In SIC 5093, emissions are a function of the tonnage scrapped (*AIRS Facility Subsystem Source Classification Codes and Emission Factor Listing for Criteria Air Pollutants*, 1990). I assume that vehicle tonnage scrapped by vehicle class is proportional to vehicle tonnage manufactured (Table 10-3).

SIC 517, petroleum and petroleum products, and SIC 5541, gasoline service stations. SIC 517 includes SIC 5171, petroleum bulk stations and terminals, and SIC 5172, petroleum and petroleum product wholesalers, except bulk stations and terminals. Emissions in these SICs are a function of the amount of product stored and transferred, the characteristics of the product, ambient conditions, characteristics of the storage systems, emission controls, and other factors (EPA, *Compilation of Air Pollutant Emission Factors, Volume 1, Stationary Sources*, 1995; DeLuchi et al., 1992; EPA, *AIRS Facility Subsystem Source Classification Codes and Emission Factor Listing for Criteria Air Pollutants*, 1990). Hence, the fractions shown here are estimated on the basis of the volatility of each kind of fuel and the amount of each kind of fuel handled. For gasoline vehicles, each fraction shown is equal to the fraction of SIC emissions assignable to highway gasoline (Table 10-9) multiplied by the fraction of total highway gasoline assignable to each gasoline-vehicle class (Table 10-3). The calculation is analogous for diesel-fuel vehicles.

I have assigned all of the emissions in SIC 5541 (gasoline service stations) to motor-vehicle use, even though gasoline stations do some business (such as food sales) that is not related to motor-vehicle use, because the emissions in question are VOC emissions from the spillage and evaporation of motor gasoline.

SIC 551 and 552, motor vehicle dealers. I assume that emissions from motor-vehicle dealers are a function of the amount of vehicles sold, and so distribute the emissions to vehicle classes according to the fraction of vehicles sold in each class (Table 10-3).

I have assigned all of the emissions here to motor-vehicle use, even though some motor-vehicle dealers do some business that is not related to motor-vehicle use, because the emissions in question are VOC emissions that presumably are related to the use of fuels and volatile compounds for motor vehicles.

SIC 75, automotive services. This SIC includes SICs 7531, 7532, 7533, 7534, 7535, 7538, 7539, and 7542. Emissions from flares and incinerators (in SIC 75) are a function of the amount and kind of fuel used. Emissions from degreasing operations (in SIC 75) generally are a function of the amount of solvent used, and fugitive emissions are a function of the amount of product. Emissions from tire retreading (in SIC 7534) are a function of the amount of tires processed. Emissions from brake-shoe debonding (in SIC 7539) are a function of the tons put into the incinerator. (All emission factors cited from EPA, *AIRS Facility Subsystem Source Classification Codes and Emission Factor Listing for Criteria Air Pollutants*, 1990.) I believe that emissions from all of these activities are proportional to expenditures in the SIC of interest, and so allocate total emissions to individual vehicle classes in proportion to SIC-75 expenditures by each vehicle class. The expenditures fractions shown here are from Table 10-3 and are derived in Table 10-7.

Any transport of crude oil. See data and methods for SIC 4612, crude petroleum pipeline.

Any transport of gasoline. I estimate that motor vehicles use 96.2% of all gasoline (FHWA, *Highway Statistics 1991, 1992*) and distribute this 96.2% to the three classes of gasoline vehicles in proportion to gasoline consumption by these three classes (Table 10-3).

Transport of oil products. I assume that emissions from the transport of petroleum products should be allocated the same way that emissions from storage (SIC 5171) are allocated.

Liquid asphalt. There are two major types of liquid asphalt: cutback asphalt, and emulsified asphalt. Cutback asphalt is liquid asphalt that has been diluted, or “cutback,” with volatile petroleum distillates. Emulsified asphalt is produced by combining asphalt with water and an emulsifying agent EPA, *Compilation of Air Pollutant Emission Factors, Volume 1, Stationary Sources*, 1995).

Liquid asphalt is used to tack and seal, to prime roadbeds, and to pave relatively thin roads (up to a several inches thick) (EPA, *Compilation of Air Pollutant Emission Factors, Volume 1, Stationary Sources*, 1995). Up to 95% of the volatile diluent evaporates, and thereby becomes VOC emissions. Total VOC emissions are a function of the type and amount of diluent, and the total amount of asphalt (EPA, *Compilation of Air Pollutant Emission Factors, Volume 1, Stationary Sources*, 1995). Cutback asphalt is the major source of emissions.

As explained in the notes to SIC 2951, I assume that 95% of liquid asphalt is used for roads. I then allocate this 95% to individual vehicle classes on the basis of ton-miles/axle of vehicle travel (Table 10-3), on the assumption that damage to pavement is related to axle weight per vehicle mile.

Road construction. The construction of roads appears to produce substantial amounts of PM-dust air pollution, and thus to engender significant health-damage costs. Unfortunately, the emission factor for road construction is poor. The factor is simply tons per acre of construction activity per month, and was estimated on the basis of a tests at a few construction sites (EPA, *Compilation of Air Pollutant Emission Factors, Volume 1, Stationary Sources*, 1995).

It is clear that essentially all of the cost of PM pollution from road construction should be allocated to motor-vehicle use generally. However, there is no formal way to allocate the road-construction emissions to *specific* classes of motor vehicles, because there is no formal physical or economic relationship between the use of any particular class of motor vehicle or motor fuel, and dust emissions from road construction. The allocation of road-construction emissions to particular vehicle classes is, for most part, arbitrary.

I allocate emissions from road construction to vehicle classes on the basis of vehicle miles of travel by each class (Table 10-3), because vehicle-miles of travel might be related to the area of the roadway, which as noted above is the basis of the emission factor. However, because the allocation of the total to particular classes by and large is arbitrary, the reader should view the allocated results with caution.

Traffic markings. Emissions from traffic markings are a function of (among other things) the amount and kind of marking (EPA, *Compilation of Air Pollutant Emission Factors, Volume 1, Stationary Sources*, 1995; EPA, *AIRS Facility Subsystem Source Classification Codes and Emission Factor Listing for Criteria Air Pollutants*, 1990), which are a function of road lane mileage. I assign road-lane mileage, or road usage, to vehicle classes on the basis of vehicle miles of travel by vehicle class (Table 10-3).

Surface coating of vehicles. Emissions from surface coating of automobiles are a function of the area coated per vehicle, the thickness of the coating, the volatility of the coating, and other factors (EPA, *Compilation of Air Pollutant Emission Factors, Volume 1, Stationary Sources*, 1995). For my purposes, the key variable is the surface area per vehicle. (The EPA does not give emission factors for large trucks, but I assume that those emissions too are a function of the surface area of the vehicles.) I do not know the surface area of vehicles and parts, but I do know the mass of vehicles by vehicle class (Table 10-3). Hence, I assume that for each vehicle class c , the ratio of surface coatings applied in class c to total surface coatings applied to all vehicles equals the ratio of tons of c -vehicles manufactured to total tons of all vehicles manufactured (Table 10-3).

Re-entrained road dust. Re-entrained road dust is small debris kicked up off of roads by the wakes and tires of vehicles. Emissions of road dust are a function of the amount and size of dust deposited on the road, weather conditions (mainly moisture and wind), the number of wheels and their area of contact with the road, and the turbulence created by traffic (Mollinger et al., 1993; Nicholson et al., 1989). Traffic turbulence, which is a major source of dust, is related to traffic speed, vehicle size, the clearance between vehicles and the road, and the aerodynamic properties of vehicles. Emissions of road dust increase with increasing traffic speed, increasing number of vehicles, increasing number of wheels, decreasing clearance between vehicles and the road, and increasing aerodynamic drag of vehicles (Mollinger et al., 1993; Nicholson et al., 1989).

Of course, for simplicity, the available emission-factor equations use only a subset -- in some cases a small subset -- of the relevant explanatory variables. In the EPA's emission-factor handbook, emissions of dust from paved roads, which contribute much more to human exposure to particulate pollution than do emissions from unpaved roads, are estimated as a function of silt loading and vehicle weight raised to the 1.5 power ($\text{weight}/3^{1.5}$) (EPA, *Compilation of Air Pollutant Emission Factors, Volume 1, Stationary Sources*, 1995). This simple function was estimated statistically, and has an R^2 of about 0.75 (Midwest Research Institute, 1993). There are no other explanatory

variables in the emission factor equation. Moreover, the EPA contractor who estimated the equation noted that other specifications were equally as good (Midwest Research Institute, 1993).

In the previous version of the emission-factor handbook, emissions from industrial paved roads were a function of weight to the 0.7 power, and emissions from paved urban roads were not a function of weight or any other vehicle characteristics at all.

In the current version of the emission-factor handbook, emissions of dust from unpaved roads are estimated as a function of the silt content of the dust, vehicle speed, the mean number of wheels, days of precipitation, and vehicle weight (raised to the 0.7 power $(\text{weight}/3)^{0.7}$) (EPA, *Compilation of Air Pollutant Emission Factors, Volume 1, Stationary Sources*, 1995). Although the equation does not contain vehicle footprint or clearance as an explanatory variable, weight raised to the 0.7 power perhaps is a proxy for the combined effect of vehicle weight and size.

On what basis, then, should one allocate to different vehicle classes total motor-vehicle emissions of road dust? For two reasons, I have chosen to allocate on the basis of adjusted ton-miles of travel, where the adjustment is to use $(\text{weight}/3)^{0.7}$ -- that is, to allocate according to $\text{ton}^{0.7}$ -miles, instead of $\text{ton}^{1.5}$ -miles, or just ton miles (Table 10-3). First, $\text{weight}^{0.7}$ is an explanatory variable in the current AP-42 equation for emissions from unpaved roads, and in the equation for paved industrial roads in the previous edition of AP-42. (Also, a model with $\text{weight}^{0.7}$ can reproduce EPA's estimated national emissions of road dust from paved urban roads in 1992.)

Second, and more important, $\text{weight}^{0.7}$ seems a better proxy than is $\text{weight}^{1.5}$ for the combined effect of the vehicle characteristics that determine emissions: weight, footprint, number of wheels, clearance, size, and tire contact area. A heavy-duty vehicle has about 3 times the clearance, 4 times the number of wheels, 5 times the footprint, and 10-30 times the weight and hence tire contact area of a light-duty vehicle. Recall that emissions increase with increasing vehicle footprint, tire contact area, and aerodynamic drag, but apparently decrease with increasing clearance. Overall, then, the relationships between heavy and light-duty vehicles suggest that heavy-duty vehicles cause not more than 10 times more emissions of road dust per mile than do light-duty vehicles. Hence, I need a basis for allocating emissions that will give to HDVs about 10 times more emissions per mile than to LDVs. An allocation based strictly on ton-miles will assign to heavy-duty vehicles 10-30 times more road-dust emissions per mile than to light-duty vehicles -- more than seems reasonable. An allocation based on $\text{ton}^{1.5}$ -miles will be even worse, resulting in 30-160 times more emissions per mile for heavy than for light vehicles. On the other hand, an allocation based on $\text{ton}^{0.7}$ -miles will result in 5 to 11 times more emissions per mile for heavy than for light vehicles, which seems reasonable.

The resulting apportioning of emissions to vehicle classes is shown in Table 10-33.

10.4.5 The true relationship between motor-vehicle use and emissions from the production of motor-vehicles and motor-vehicle fuels

In the foregoing apportionments of indirect point and area-source emissions, total domestic emissions from each domestic industry or emissions source, as estimated by the EPA, are allocated in accordance with some measure of total domestic usage of the output of the industry or source. This method assumes that in each industry, domestic production and hence emissions from production are simply proportional to domestic consumption. Put another way, it assumes that if U.S. production of, say, motor vehicles is equal to Y% of U.S. demand for motor vehicles, and if U.S. demand for vehicles changes by X%, then U.S. production and hence emissions will change by X*Y %.

For two reasons, this assumption never is strictly correct, and in some instances might be seriously in error. First, a change in consumption in the transportation sector for item W, which I assume will proportionately change emissions from the production of W, actually will affect the price of W and its raw materials, and thereby affect demand for and production of *other* finished products made from the same raw materials. Thus, the net change in production and hence emissions will not be proportional to the net change in consumption of W in the transportation sector.

Second, a change in consumption of item W in the transportation sector might not affect domestic production of W proportionately if a substantial amount of W is imported or exported.

1). *The effects of price changes.* The basic mechanism here is simple: a change in consumption of item W will change the price of W and its raw materials, which in turn will affect demand for other products made from the same raw materials.

Let us consider as an example changes in consumption of petroleum transportation fuels. Suppose that we are evaluating the environmental effects of a proposal to increase the fleet-average fuel economy of light-duty gasoline vehicles. The equilibrium⁴ reduction in consumption of gasoline will reduce consumption of crude

³Keep in mind that the emissions inventory for road dust is very uncertain. In particular, the EPA emission factors might greatly overestimate road-dust emissions, especially of PM_{2.5} (Balogh et al., 1993).

⁴By definition, the relevant change is the equilibrium change in consumption, which is not necessarily the same as the "initial" change in demand. To see this, let us return to the fuel economy example. Suppose that fuel economy will increase from 20 to 25 mpg, and that we want to estimate the reduction in emissions from petroleum refineries as a result of the decline in gasoline usage. Suppose further that refinery output of gasoline is equal to final consumption of gasoline, and that refinery emissions are proportional to refinery production of gasoline, so that all we need to do is estimate the net change in gasoline consumption. Now, if fuel economy increased instantly from 20 to 25 mpg, then the instantaneous change in gasoline consumption would be simply $(M/20 - M/25)$, where M is the number of miles of travel by light-duty gasoline vehicles. However, for two reasons, the net or equilibrium change in gasoline demand and hence refinery output would not be $(M/20 - M/25)$. First, the initial reduction in

oil, and hence reduce the price of crude oil. This, in turn, will reduce the price of other finished petroleum products, such as diesel fuel, or heating oil. The drop in the price of these other products will spur consumption. The increase in consumption of these other products will cause an increase in emissions from the petroleum fuelcycle, which will partially offset the reduction in emissions due to the net decrease in gasoline consumption. The extent of this offset depends on the magnitude of the relevant elasticities (i.e., the relationships between changes in price and changes in consumption).

In sum, the equilibrium change in petroleum production and hence emissions from the petroleum fuelcycle will not be simply proportional to the initial change in demand for gasoline. In fact, the assumption of proportionality overestimates emissions, because it ignores the second-order increase in output due to the lower prices.

One can postulate the same sort of effect in the market for steel. A change in demand for motor vehicles will change the price of steel, which in turn will change the demand for and production of steel for nontransportation sectors.

My analysis ignores these sorts of complexities.

2). *The effect of importing and exporting.* Imports and exports matter in the allocation of emissions from production because some of the production -- and hence some of the emissions from production -- might occur overseas and hence be of no concern in an analysis of the cost of air pollution in the U.S, and also because some domestic production might be destined for export and hence not directly influenced by domestic demand.

This can be illustrated by an example. Suppose that we are trying to allocate emissions associated with the production of motor-vehicle widget W. Let us assume the following:

Production and consumption of W, 1991

- i). The EPA estimates that the W industry emitted 100,000 tons of pollution.
- ii). Motorists bought 10 million W total.
- iii). In scenario A, domestic producers made 1 million W; in scenario B, they made 5 million; in scenario C, they made 10 million; and in scenario D, they made 20 million.

demand for highway gasoline would reduce its price, which in turn would spur a second-order increase in demand for highway gasoline, which would "take back" some of the "initial" reduction of $M/20 - M/25$ units. In the case of gasoline and vehicle fuel economy, this "take-back" or "rebound" effect is on the order of 10% (Greene, 1992). Second, the reduction in price would increase demand for gasoline by heavy-duty vehicles and off-highway vehicles and engines; this increase would further erode the reduction in consumption due to the higher fuel economy. (In this example, the erosion would be minor, because heavy-duty vehicles and off-highway vehicles and engines consume less than 5% of the amount of gasoline consumed by light-duty vehicles [Table 10-3; FHWA, *Highway Statistics* 1992, 1993].)

How much would emissions have been reduced, if motorists had bought 5 million fewer W net (i.e., in equilibrium, after adjustments in response to the price changes discussed above)? For simplicity, let us assume that emissions from production are proportional to output. (As shown above, this in fact typically is implicitly or explicitly assumed in most of the emission factors used to estimate the official emissions inventory.) In this report, I have assumed that the percentage reduction in emissions would have equaled the percentage reduction in demand: 50%, or 50,000 tons. However, the true reduction depends on whether the foregone W was foreign or domestic made, and whether the domestic industry produced 1 million (scenario 1), 5 million (scenario B), 10 million (scenario C), or 20 million (scenario D) of W. The range of outcomes, depending on the balance of foreign versus domestic-made foregone W, and production scenario A, B, C, or D, is as follows (in tons of emissions reduced):

<i>Domestic production of W</i>	<i>Millions of domestically made W foregone</i>					
	0	1	2	3	4	5
Scenario A: 1 million	0	100,000	n.a.	n.a.	n.a.	n.a.
Scenario B: 5 million	0	20,000	40,000	60,000	80,000	100,000
Scenario C: 10 million	0	10,000	20,000	30,000	40,000	50,000
Scenario D: 20 million	0	5,000	10,000	15,000	20,000	25,000

n.a. = not applicable.

These results confirm what is intuitively clear: the greater the exports of production or imports for consumption, the less of an effect a general reduction in domestic demand will have on domestic production and emissions -- and, the more my assumption will tend to overestimate the emissions associated with a change in consumption. Of course, in some situations, my assumption -- that changes in domestic output and emissions are proportional to changes in domestic demand -- will underestimate the emissions associated with a change in consumption. For example, if all domestic production of W is consumed domestically, but is small relative to total demand for W, then a change in consumption of W will tend to have a disproportionately large effect on domestic production of W. This is Scenario A in the table above.

So how much in error might I be with the simplifying assumption that indirect point and area-source emissions are simply proportional to final demand for fuel and vehicles? In some cases, probably not much; in others, perhaps a lot. As just illustrated, the answer depends on the amount of imports and exports relative to domestic demand, and how changes in demand are distributed across foreign and domestic producers.

Consider fuel use by motor vehicles. U.S. refineries produce virtually all of the highway fuel used in the U.S., and highway vehicles use virtually all of the gasoline produced. In 1993, gasoline imports were only 3% of total gasoline supply, gasoline exports were only 1% of total gasoline supply, diesel-fuel imports were only 6% of total

diesel supply, and diesel fuel exports were 9% of total diesel supply (EIA, *Petroleum Supply Annual* 1993, 1994). The upshot of all of this is that -- ignoring price effects, stock adjustments, and so on -- if consumption of highway fuel changes by X units, U.S. refinery production probably will change by approximately X units.

Imports and exports play a larger although still not dominant role in the market for motor vehicles. Domestic automobile manufacturers export only 10% of their production, mostly to Canada (Motor Vehicle Manufacturers Association, 1992), which means that to a first approximation, U.S. motor vehicle manufacturers produce exclusively for the domestic motor-vehicle market. However, the U.S. does import a nontrivial number of motor vehicles, although fewer than might be expected: in 1991, imported motor vehicles accounted for 21% of retail sales of motor vehicles in the U.S. (Motor Vehicle Manufacturers Association, 1992). Thus, unless a change in U.S. demand for motor vehicles has a drastically disproportionate affect on imports, my assumption - that if demand for motor vehicles changes by X units, then U.S. production of motor vehicles will change by 0.79X units -- probably will not be too far off.

However, imports and exports are even more prominent in the market for automotive parts. In 1994, the U.S. automotive-parts industry produced \$113 billion worth of parts, of which a substantial fraction, \$37.1-billion worth, was exported (mainly to Canada, Mexico, and Europe) (International Trade Administration, 1995). Imports, primarily from Japan, amounted to \$44.9 billion (International Trade Administration, 1995). Thus, exports were 31%, and imports 37%, of the final supply (domestic production + imports - exports) of automotive parts. These shares are large enough to call into question my assumption that a change of X% in consumption of auto parts will change U.S. production by X%.

If in the market for automotive parts the assumption that emissions are proportional to domestic consumption can be called into question, then in the market for crude oil, the assumption probably can be thrown out altogether, because the U.S. imports roughly 50% of the crude oil that it consumes. Moreover, as discussed earlier, price effects (whereby a change in transportation oil demand changes oil prices and hence demand for and consumption of non-transportation petroleum products) also are important in the market for crude oil, because only 50% of crude oil is used in highway transportation.

Therefore, regarding crude oil, these two salient facts -- that in the U.S., half of the crude oil is imported, and half is used to make products other than transportation fuels -- mean that there really is no simple rule for determining how U.S. oil producers, and hence emissions from U.S. oil production, will be affected by a change in demand for transportation fuels. My assumption -- that a change of X units in U.S. demand for motor fuel causes crude oil output (of all producers, foreign and domestic) to change by the amount needed to produce X units of fuel -- probably overstates the emissions cost of using petroleum in transportation. A better analysis would attempt to estimate what

actually will happen in the world petroleum market, at the margin, as a result of a specific policy⁵.

10.5 FRACTION OF IMPORTED PETROLEUM THAT IS OR BECOMES HIGHWAY GASOLINE OR DIESEL FUEL

10.5.1 Background

In Report #15, we estimate military expenditures to protect the use of Persian-Gulf oil for motor vehicles, and apportion those expenditures to motor-fuels according to the fraction of oil from the Middle East that is or becomes motor fuel used by highway vehicles. In Report #7, we estimate the cost of the Strategic Petroleum Reserve (SPR), and argue that if the main purpose of the SPR is to buffer against disruptions in the supply of oil, and if the oil supply from the Middle East is particularly likely to be disrupted, then one reasonably might allocate the cost of the SPR to different uses of oil in proportion to the amount of oil that comes from the Middle East. And finally, in Report #17, we estimate environmental excise taxes paid on barrels of domestic and imported petroleum, and apportion those tax payments to motor fuels according to the fraction of domestic petroleum and the fraction of imported petroleum that is or becomes motor fuel used by highway vehicles.

10.5.2 General methods and data

To estimate these apportioning factors, I start with detailed EIA data on the production, imports, and refinery inputs of crude oil and petroleum products, in volume units (thousand bbl) (Table 10-13a). In order to properly trace and allocate the various flows of crude oil and petroleum products, the volume data must be converted to mass data, because mass, not volume, is conserved. This is done by multiplying the basic EIA volume data of Table 10-13a by the appropriate densities. The resulting mass of crude oil and petroleum products produced, imported, and input to refineries is shown in Table 10-13b. The data of Table 10-13b, and other data and assumptions, are used to calculate the data of Table 10-14, which in turn are used to estimate costs for six classes of motor vehicles, as follows:

⁵Note that it is only here, in the estimation of the cost of emissions associated with the production of domestic oil used to make motor fuels, that I assume that the production of domestic and foreign crude oil used to make motor fuels is proportional to total demand for motor fuels. In the estimation of all other costs associated with the production of crude oil for motor fuels -- military expenditures related to the use of Persian Gulf oil for motor vehicles (Report #15), the cost of the Strategic Petroleum Reserve (Report #7), and macroeconomic costs of importing oil (Report #8) -- and in the estimation of taxes paid on crude oil (Reports #17 and #18), we have two scenarios: one in which motor fuels come disproportionately from domestic crude, and one in which they come disproportionately from foreign crude. We did not use two scenarios here because upstream emissions associated with crude oil production are relatively minor, and because in general we do not have low/high scenarios for allocation factors for indirect emissions.

- Lines 6L and 6H of Table 10-14: used to allocate environmental excise taxes on domestic crude oil, severance taxes on oil, and miscellaneous oil taxes and license fees (Report #17); also used in calculation of the allocation of severance taxes on oil and gas combined (Report #17)
- Lines 8L and 8H: used to allocate the cost of the Strategic Petroleum Reserve (Report #7) and military expenditures to protect the use of petroleum from the Middle East (Report #15)
- Lines 9L and 9H: used in the calculation of the pecuniary externality of consuming oil for highway vehicles, and the calculation of the macroeconomic cost of importing oil for highway vehicles (Report #8)
- Lines 11L and 11H: used to allocate payments of environmental excise taxes on imported petroleum (Report #17)

10.5.3 Key assumptions: the extent to which highway fuels are made from domestic crude oil, or crude oil imported from the Middle East

These allocation factors of Table 10-14 depend heavily on assumptions about the extent to which highway fuels are made from domestic crude oil, or from crude oil imported from the Middle East. If all crude oil -- domestic, imported, and imported from the Middle East specifically -- simply were mixed randomly in a big pot before being input to refineries, then on average, 54.1% of the crude oil in highway fuel would have been domestic crude oil, and 14.0% would have been crude oil or unfinished oil imported from the Middle East (calculated from the data of Table 10-14).

Of course, in reality, domestic and crude oil are not mixed randomly. At the margin, or even on average, the mix of domestic and imported crude oil used to make motor fuels depends on short-run and long-run production costs, contractual obligations, national laws and policies, the quality of the oil, transportation arrangements, corporate strategies, and other factors. In the long run, it is possible that a reduction in the use of motor fuel mainly will reduce exploration for and production of domestic oil, because the marginal crude oil in the U.S. is so costly to produce. In the short run, the picture is less clear. The Alternative-Fuels Trade Model of the U. S. Department of Energy predicts that a decrease in domestic use of oil in transportation will reduce oil imports, not domestic production, because OPEC is modeled as a “swing” producer (Fulton, 1995).

Rather than attempt to quantify the extent to which domestic oil, or oil imported specifically from the Middle East, is used to make motor fuel, I simply assume that anywhere from 40% (high-cost case) to 68% (low-cost case) of the crude oil embodied in highway fuels is domestic, and that 7% (low-cost case) to 21% (high-cost case) of the crude oil embodied is crude or unfinished oil imported from the Middle East. (This percentages do not include crude oil in finished fuels imported from the Middle East.) With these assumptions and the data of Table 10-13b, I calculate the allocation factors of Table 10-14. (I check to ensure that the assumptions do not result in greater crude oil from any source than actually was available, or in negative residual masses.)

10.5.4 Non-petroleum components in gasoline

In order to allocate the use of petroleum or crude oil per se, one must account for and exclude any constituents of gasoline or diesel fuel that are not ultimately derived from crude oil. Motor gasoline is made from crude oil and crude oil derivatives (such as unfinished oils and motor-gasoline blending components), natural-gas liquids (such as pentanes and butanes), alcohols, and other hydrocarbons (such as coal-tar derivatives). The mass of natural-gas liquids, alcohols, and other hydrocarbons in motor gasoline should be excluded from any allocation of crude petroleum per se. (I will refer to these components as non-crude gasoline constituents, NCGCs.) If one assumes, as the EIA does (*Petroleum Supply Annual 1991, 1992*), that all refinery input of natural gas liquids and other hydrocarbons and alcohol is used to make motor gasoline, then one can calculate from the data of Table 10-13b that NCGCs are 6.7% of the mass of motor gasoline produced, and hence that crude oil and crude-oil derivatives are 93.3% of the mass of gasoline produced. The use of the 93.3% and 6.7% figures are indicated in the explanations of the lines of Table 10-13b.

Diesel fuel and other petroleum products, including motor-gasoline blending components, which are naphthas, are derived entirely from crude oil.

10.5.5 The low-cost and the high-cost cases

Note that the “low” and the “high” case assumptions are not the numerically low or high values, but rather the values that result in the lowest overall motor-vehicle costs and highest overall motor-vehicle costs. Thus, the lower the amount of domestic oil assumed to be embodied in motor fuels, the higher the amount of foreign oil embodied, and consequently the higher the cost, because of the relatively high pecuniary and macroeconomic costs of importing oil. For internal consistency, the low and the high values are fixed for all of the calculations (i.e, the low and the high are not switched from one application to the next).

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TABLE 10-1. MOTOR VEHICLE DATA AND CLASSIFICATION IN VARIOUS DATA SOURCES.

Reference source -->	<i>Light-Duty Automotive Technology and Fuel Economy Trends Through 1993</i> (Heavenrich et al., 1993) (annual)	Residential Transportation Energy Consumption Survey (EIA; Davis, 1992) (triennial)	<i>1987 Census of Transportation, Truck Inventory and Use Survey</i> [TIUS] (Bureau of the Census, 1990) (quinquennial)	Consumer expenditures on transportation (Division of Consumer Expenditure Surveys, February 1993) (annual)	Personal Consumption Expenditures (Bureau of Economic Analysis, 1990; <i>Survey of Current Business</i> , annual)	<i>Transportation in America</i> 1993
Passenger cars	sales, mpg and other data pertaining to "cars," from two-seaters and minicompacts up through large station wagons, excluding motorcycles	survey of energy use and other data pertaining to household passenger cars, from two-seaters and minicompacts up through large station wagons, excluding motorcycles	excluded	survey of household expenditures on passenger vehicles, including motorcycles and mopeds	personal expenditures on "autos", based partly on data from Motor Vehicle Manufacturers Association	personal expenditures on "private transportation" including automobiles and home data from (Statistical Census Bureau)
Trucks	sales, mpg, and other data pertaining to light-duty trucks: small and large vans, pickups, and utility vehicles (gross vehicle weight up to 8,500 lbs)	survey of household light trucks, including small and large vans, pickups, and utility vehicles	survey of minivans, vans, pickups, panel trucks, utility vehicles, jeeps, station wagons on truck classes, single-unit light trucks, single-unit heavy trucks, truck tractors	survey of household expenditures on trucks and vans, including trailers and recreational vehicles	personal expenditures on "other motor vehicles": trucks, vans, RVs, and apparently motorcycles; based partly on data from MVMA (see MVMA classification)	review of interstate and commercial trucking in <i>Highway Statistics</i> and other sources

Includes business and government vehicles?	presumably, because based on total sales in U. S.	no; survey of households only; excludes government and business-use vehicles	includes personal and business trucks; excludes government vehicles, ambulances, buses, off-road vehicles	no; survey of households only; excludes government and business-use vehicles and costs	no; excludes expenditures for or by business and government	pa trans app ex gov con truck may gov
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TABLE 10-2. ORIGINAL (OR PARTLY ORIGINAL) TRUCK, VMT, TON-MILE, AND FUEL-USE DATA

Source	Data relevant here	Coverage
Bureau of the Census, <i>1987 Census of Transportation, Truck Inventory and Use Survey</i> (1990) (quinquennial)	VMT, fuel economy, number of trucks, size, fuel use, average weight	all privately owned trucks in
Bureau of the Census, <i>Motor Freight Transportation and Warehousing Survey 1993</i> (1995) (annual)	operating costs, fuel costs, maintenance and repair costs	employer firms in Standard Industrial Classification 421, Trucking and Services, except air
Federal Highway Administration, <i>Highway Statistics</i> (annual)	VMT, fuel use, number of vehicles	passenger cars, motorcycles, buses, trucks, annually
Smith, <i>Transportation in America</i> (1993) (annual)	ton-miles, tons, average length of haul	intercity and local freight trucks
Heavenrich et al., <i>Light-Duty Automotive Technology and Fuel Economy Trends Through 1993</i> (1993) (annual)	fuel economy, vehicle sales, vehicle weight, fuel type	passenger cars and light-duty trucks
Bureau of Economic Analysis, National Income Product Accounts, <i>Survey of Current Business</i> (annual)	sales of automobiles and trucks to persons, businesses, and households	all motor vehicles, new and used
Davis and Strang, <i>Transportation Energy Data Book</i> (1993) (annual)	transportation energy use by mode and fuel type	automobiles, motorcycles, transit buses, intercity buses, school buses, light trucks, other trucks, military operations, nonhighway
Federal Highway Administration, <i>Nationwide Personal Transportation Study</i> (Hu and Young, 1993, 1994)	number of vehicles, VMT	personal vehicles
Environmental Protection Agency, <i>Motor-Vehicle-Related Air Toxics Study</i> (1992)	current VMT and projections of VMT	diesel and gasoline passenger vehicles, trucks
Energy Information Administration, <i>Annual Energy Review</i> (annual)	U. S. Government agency consumption of motor gasoline	all federal agencies
Energy Information Administration, <i>Fuel Oil and Kerosene Sales</i> (annual)	on-highway use of distillate fuel oil (calculated from FHWA data)	all highway use
Energy Information Administration, <i>Petroleum Marketing Annual</i> (annual)	refiner sales volumes of motor gasoline	motor gasoline
Energy Information Administration, <i>Household Vehicles Energy Consumption</i> (annual)	vehicles in use, VMT, fuel use	household light-duty vehicles
American Public Transit Association, <i>Transit Fact Book</i> (annual)	VMT, vehicles, fuel consumed	public transit vehicles

<i>Automotive Fleet Fact Book</i> (annual)	vehicle registrations	business and government fleets, class 1-5 trucks
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TABLE 10-3. ALLOCATION FACTORS FOR GASOLINE AND DIESEL MOTOR VEHICLES IN THE U.S., 1991

Allocation factor	Gasoline vehicles			Diesel vehicles		
	<i>LDAs</i>	<i>LDTs</i>	<i>HDVs</i>	<i>LDAs</i>	<i>LDTs</i>	<i>HDVs</i>
Vehicle travel (10^9 VMT) ^a	1,525	439	24	18	13	154
Fraction of total travel	0.702	0.202	0.011	0.008	0.006	0.071
Weight-travel (10^9 ton-miles) ^b	2,382	853	217	29	28	4,198
Fraction of total ton-miles	0.309	0.111	0.028	0.004	0.004	0.545
Fraction of ton ^{0.7} -miles ^c	0.466	0.156	0.025	0.006	0.005	0.342
Freight ton-miles (10^9) ^d	0	305	208	0	12	4,191
Fraction of freight ton-miles	0.000	0.065	0.044	0.000	0.003	0.889
10^9 ton-miles per axle ^e	1,191	424	88	15	14	1,047
Fraction of ton-miles/axle	0.429	0.152	0.032	0.005	0.005	0.377
Highway fuel (10^6 gal) ^f	70,227	28,771	3,367	649	714	24,833
Fraction of total highway fuel	0.546	0.224	0.026	0.005	0.006	0.193
Fraction of hwy. gas or diesel	0.686	0.281	0.033	0.025	0.027	0.948
New vehicles sold (10^3) ^g	8,164	4,017	40	11	18	290
Fraction of total number sold	0.651	0.320	0.003	0.001	0.001	0.023
Vehicle-tons made (10^3) ^h	7,703	5,658	327	10	26	2,365
Fraction of total amount made	0.479	0.352	0.020	0.001	0.002	0.147
Spent on m & r (10^6 \$) ⁱ	68,124	27,594	2,264	629	685	16,703
Fraction of total expenditures	0.587	0.238	0.020	0.005	0.006	0.144

Source: My calculations based on the data of Tables 10-4, 10-5, 10-6, and other sources, as documented further in the notes below.

All calculations ignore the use LPG and other alternative transportation fuels, which account for but a tiny fraction of motor-vehicle energy use.

Note that in all of the calculations of Table 10-5, the results of which are input to this table, I assume that in each weight class (0 to 6,000; 6,001 to 7,500, etc.), all truck characteristics -- average vehicle weight, fraction of fuel that is diesel fuel, fraction of travel that is non-personal, number of axles per truck, and fuel economy -- are constant across the axle-type categories (two-axle, other single unit, and combinations).

LDA = light-duty automobiles (includes station wagons and motorcycles but not minivans, which are classified as light-duty trucks); LDT = light-duty trucks (those with a gross vehicle weight [GVW] rating of 8,500 lbs or less, and a curb[empty] weight of 6,000 lbs

or less; includes passenger vans and jeeps and utility vehicles); HDV = (heavy-duty vehicles; all other trucks, including buses); VMT = vehicle miles of travel; hwy. = highway; m & r = maintenance and repair.

^aVMT = vehicle miles traveled. As summarized in Table 10-4, the FHWA's *Highway Statistics* 1992 (1993), which is the standard (and perhaps only) source of estimates of national VMT by all vehicles, reports revised final estimates of total national VMT by passenger cars, motorcycles, 2-axle four-tire trucks, other trucks, and buses in 1991 (Table 10-4). In the following paragraphs I explain how I allocate the FHWA's estimates by vehicle type to my vehicle size categories, which (as defined above) are different than the FHWA's, and to gasoline and diesel-fuel vehicles.

Light-duty automobiles (passenger cars and motorcycles in FHWA's classification). VMT by LDAs as defined here is equal to VMT by passenger cars as defined by the FHWA plus VMT by motorcycles. (Although the EPA's mobile-source inventory data file does not include motorcycles, for purpose of allocating point and area-source emissions to motor-vehicles, I include travel by motorcycles, as light-duty automobiles.) It appears that the definition of "passenger car" in the FHWA statistics is the same as the definition of "LDA" (except motorcycles) used here.

I use data from the Residential Transportation Energy Consumption Survey (RTECS) of the EIA (*Household Vehicles Energy Consumption*, 1991, 1993) to separate travel by gasoline cars from travel by diesel cars. According to the RTECS, diesel-fueled household passenger cars (including station wagons but excluding motorcycles) accounted for 1.2% of total VMT by household passenger cars in 1991. I assume that this distribution (1.2% to diesel, 98.8% to gasoline [including "gasohol," which is oxygenated gasoline]) applies to all passenger cars (i.e., to government and commercial vehicles as well as household vehicles), because the FHWA's VMT total for passenger cars includes all passenger cars, not just household passenger cars.

Light-duty and heavy-duty trucks]. I use data from the 1987 *Truck Inventory and Use Survey* (TIUS) (Bureau of the Census, 1990), summarized in Table 10-5, to allocate the FHWA's VMT data to my categories of LDT and HDV, and to distinguish between gasoline and diesel fuel. The equation used to calculate VMT for each truck type (light-duty gasoline, heavy-duty gasoline, light-duty diesel, and heavy-duty diesel) is:

$$M_t = \sum_c M_c \times S_{t,c}$$

where:

M_t = vehicle miles of travel by truck type t in 1991

M_c = vehicle miles of travel by all trucks in FHWA class c (two-axle four-tire, other single unit, or combination; Table 10-4) in 1991

$S_{t,c}$ = miles traveled by truck type t of FHWA truck class c , divided by miles traveled by all trucks in class c , in 1991 (I do not know this ratio for 1991, but do know it for 1987 [Table 10-5], and assume that the ratio in 1991 equaled the ratio in 1987; also, I assume that the TIUS class "two-axle" truck is the same as the FHWA's class "two-axle four-tire" truck)

t = my truck types (light-duty gasoline, heavy-duty gasoline, light-duty diesel, or heavy-duty diesel)

c = the FHWA classes (two-axle four-tire, other single unit, and combination)

Buses. I count buses as HDVs, and use the FHWA's estimate of VMT by all buses. Davis and Strang (1993) estimate that diesel-fueled buses consume 83% of all gallons consumed by all buses in 1990. I assume that the VMT share of diesel buses is slightly larger than the gallon share: 85%.

^bGenerally, ton-miles of travel by a vehicle type is equal to vehicle miles of travel (VMT) multiplied by the average weight of the vehicle, including its average payload.

Light-duty autos. VMT by light-duty automobiles is explained in footnote a. To estimate the average loaded weight of passenger cars on the road in 1991, I start with the average curb (empty) weight of each model-year passenger car from 1975 to 1992 (Murrell et al. 1993). I add 150 lbs per person multiplied by 1.6 person/vehicle (average occupancy of personal transportation vehicles in 1990, according to the Nationwide Personal Transportation Survey [Hu and Young, 1993]), plus an assumed 40 lbs of cargo, less 30 l lbs of fuel consumed on average (the curb weight apparently includes a full tank of gas). Then, I multiply each model-year average vehicle weight by the ratio of VMT by that model year in 1991 to total VMT by all model years in 1991 (calculated from data in CARB, 1988), and sum the resultant products. This results in an average VMT-weighted weight of 3125 lbs in 1991. I assume that diesel passenger cars weigh 125 lbs more than this average, because diesel vehicles are about 125 lbs heavier than gasoline vehicles (Energy and Environmental Analysis, 1991). I ignore motorcycles in this calculation.

Trucks. The equation used to calculate ton-miles for each truck type (light-duty gasoline, heavy-duty gasoline, light-duty diesel, and heavy-duty diesel) is:

$$T_t = \sum_c M_c \times S_{t,c} \times \frac{W_{t,c}}{2000}$$

where:

T_t = ton-miles of travel by truck type t in 1991

M_c , $S_{t,c}$, t , and s are as defined in footnote a

$W_{t,c}$ = the average weight (in lbs) of truck type t of FHWA truck class c in 1991 (I do not know the weight in 1991, but do know it in 1987 [Table 10-5], and assume that the weight in 1991 equaled the weight in 1987; also, I assume that the TIUS class "two-axle" truck is the same as the FHWA's class "two-axle four-tire" truck)

I ignore buses in this calculation.

I could not find a published estimate of total ton-miles, including vehicle weight, for comparison with my estimate of total ton-miles for HDTs. However, I can adapt an estimate by Smith (1993), for comparison. Smith (1993) estimates that intercity freight trucks (both ICC trucks and non-ICC trucks) carried $758 \cdot 10^9$ ton-miles of freight in 1991, but his estimate excludes the weight of the vehicle, and excludes intracity transport. If the empty vehicle weighs 35-40% of the loaded vehicle, then Smith's estimate implies about $2,000 \cdot 10^9$ ton-miles in 1991, including the weight of the vehicle, but still excluding intracity shipments. Next, I can scale Smith's estimate to account for intracity-shipment. Unpublished data from the 1983 Commodity Transportation Survey of the Bureau of the Census indicate that in 1983, trucks moved about 500 to 1,000 billion ton-miles of freight, excluding the weight of the trucks

themselves, but including intracity shipments. Now, Smith (1993) estimates $575 \cdot 10^9$ ton-miles in 1983 (again, excluding intracity shipments), which, in its relation to the 1983 Commodity Transportation Survey, suggests that intracity shipments are on the order of 50% of intercity shipments. This, in turn, scales Smith's (1993) estimate for 1991 to about $3,000 \cdot 10^9$ ton-miles. This is considerably lower than my estimate of ton-miles by heavy-duty diesel-vehicles alone, but I am unable to resolve the discrepancy. (In support of Smith's estimate, I note that Transearch, a private consulting firm, estimates virtually the same total tonnage shipped by truck in 1990 as does Smith [Transearch data reported by Decision Analysis Corporation of Virginia, 1992].)

^cI include this measure because, as I explain in the text, I allocate emissions of particulate matter (dust) from roads on the basis of $\text{ton}^{0.7}$ -miles of travel. This is the same as ton-miles of travel except that the vehicle weight is raised to the 0.7 power. Ton miles with tonnage to the 0.7 power is calculated using the same equation used to calculate ordinary ton-miles (footnote b), except that the $W_{t,c}$ are raised to the 0.7 power. I show only the resulting distribution here because the absolute $\text{ton}^{0.7}$ -miles are not meaningful.

^dI assume that only trucks are used for freight transport for business (non-personal) purposes. The equation used to calculate non-personal [freight] ton-miles for each truck type (light-duty gasoline, heavy-duty gasoline, light-duty diesel, and heavy-duty diesel) is:

$$F_t = \sum_c M_c \times S_{t,c} \times \left(\frac{W_{t,c}}{2000} \right) \times F_{t,c}$$

where:

F_t = non-personal [freight] ton-miles of travel by truck type t in 1991

M_c , $S_{t,c}$, $W_{t,c}$, t , and s are as defined in footnote a

$F_{t,c}$ = non-personal [freight] ton-miles of travel by truck type t of FHWA truck class c in 1991 divided by total ton miles of travel by truck type t of FHWA truck class c in 1991 (I do not know this ratio in 1991, but do know it in 1987 [Table 10-5], and assume that the ratio in 1991 equaled the ratio in 1987; also, I assume that the TIUS class "two-axle" truck is the same as the FHWA's class "two-axle four-tire" truck)

^eEqual to the ton-miles divided by the average number of axles. I assume that all light-duty automobiles have two axles. The equation used to calculate ton-miles/axle for each truck type (light-duty gasoline, heavy-duty gasoline, light-duty diesel, and heavy-duty diesel) is:

$$A_t = \sum_c M_c \times S_{t,c} \times \left(\frac{W_{t,c}}{2000 \times a_{t,c}} \right)$$

where:

A_t = ton-miles/axle, for truck type t in 1991

M_c , $S_{t,c}$, $W_{t,c}$, t , and s are as defined in footnote a

$a_{t,c}$ = average number of axles of truck type t of FHWA truck class c in 1991 (I do not know this number in 1991, but do know it in 1987 [Table 10-5], and

assume that the number in 1991 equaled the number in 1987; also, I assume that the TIUS class “two-axle” truck is the same as the FHWA’s class “two-axle four-tire” truck)

^fThe FHWA’s *Highway Statistics 1992* (1993) reports revised final estimates of total fuel consumption (in gallons) by passenger cars, motorcycles, 2-axle four-tire trucks, other trucks, and buses in 1991 (Table 10-4). I use these data to estimate fuel use by gasoline and diesel light-duty autos, light-duty trucks, and heavy-duty vehicles as follows:

Light-duty automobiles. According to the Residential Transportation Energy Consumption Survey of the EIA (*Household Vehicles Energy Consumption, 1991, 1993*), diesel-fueled household passenger cars (including station wagons but excluding motorcycles) accounted for 0.9% of total fuel consumed by household passenger cars in 1991. I assume that this distribution (0.9% to diesel, 99.1% to gasoline) applies to all passenger cars (i.e., to government and commercial vehicles as well as household vehicles). I assume that motorcycles use gasoline only.

Trucks. The equation used to calculate fuel use by each truck type (light-duty gasoline, heavy-duty gasoline, light-duty diesel, and heavy-duty diesel) is:

$$G_t = \sum_c G_c \times E_{t,c}$$

where:

G_t = fuel use (in gallons) by truck type t in 1991

G_c = fuel use by all trucks in FHWA class c (two-axle four-tire, other single unit, or combination; Table 10-4) in 1991

$E_{t,c}$ = fuel use by truck type t of FHWA truck class c , divided by fuel use by all trucks in class c , in 1991 (I do not know this ratio for 1991, but do know it for 1987 [Table 10-5], and assume that the ratio in 1991 equaled the ratio in 1987; also, I assume that the TIUS class “two-axle” truck is the same as the FHWA’s class “two-axle four-tire” truck)

t = my truck types (light-duty gasoline, heavy-duty gasoline, light-duty diesel, or heavy-duty diesel)

c = the FHWA classes (two-axle four-tire, other single unit, and combination)

Buses [under “heavy-duty vehicles” in this table]. Davis and Strang (1993) estimate that diesel-fueled buses consumed 83% of all fuel consumed by all buses in 1990.

^g*Light-duty automobiles sold:* According to the Motor Vehicle Manufacturers Association of the United States (MVMA, 1992), 8.175 million new passenger cars were sold in 1991. Davis and Strang (1993) report that 0.13% of the new cars sold were diesel fueled. I ignore sales of motorcycles.

Light-duty and heavy-duty trucks sold: The MVMA (1992) reports that 4.365 million new trucks were sold in 1991. Of these, 3.246 million had a GVW rating of 6,000 lbs or less, 0.876 million had a GVW rating of 6,001 to 10,000 lbs, and the rest had a GVW rating of 10,001 lbs or more. Unfortunately, the MVMA GVW class of 6,001 to 10,000 lbs straddles my division between light-duty (GVW of 8,500 lbs or less) and heavy-duty trucks (all others). Furthermore, the MVMA does not report retail sales of gasoline trucks separately from retail sales of diesel, although it does report factory sales of diesel separately. I handle this second

issue by assuming that the distribution of retail sales of gasoline and diesel trucks follows the distribution of factory sales (i.e., that if 85% of all heavy trucks sold from the factory in 1991 were diesel fueled, then 85% of heavy trucks sold retail in 1991 were diesel fueled). This leaves the problem of dividing the 6,001 to 10,000 GVW class into two classes: 6,001 to 8,500, and 8,501 to 10,000. To do this, I compare the MVMA data with the data on model-year sales of gasoline and diesel trucks up to 8,500 GVW reported by Murrell et al. (1993) (I do not use the Murrell et al. data directly because they do not report sales of HDVs.) For this comparison, I first must convert the Murrell et al. (1993) model-year data to a calendar-year basis, which I do by assuming that 25% of model year n is sold in year n-1, and 75% in year n. I then estimate sales of gasoline and diesel vehicles in the 6,001 to 8,500 GVW class, and compare the estimates to MVMA's reported sales of 6,001 to 10,000 GVW trucks. On the basis of this comparison, I estimate that sales of 6,001 to 8,500 GVW trucks constitute 90% of sales of 6,001 to 10,00 GVW trucks, as reported by MVMA (1992), and that sales of 6,001 to 8,500 GVW diesel trucks constitute 10% of sales of 6,001 to 10,000 GVW diesel trucks. (This means that diesels are sold mainly in the heavier weight class, which is reasonable.) These data and assumptions are sufficient to allocate MVMA-reported factory and retail sales to my truck classes.

^hCalculated by multiplying the number of vehicles produced by the average vehicle curb weight (in tons) in each category.

Number of vehicles produced. I use MVMA (1992) data on factory sales, rather than MVMA data on actual production (1992), because the factory-sales data distinguish diesel trucks from gasoline trucks, whereas the production data do not, and total factory sales very nearly equal total production. As above, I assume that 0.13% of light-duty automobiles sold by factories were diesel-fueled. Also as above, I estimate factory sales of light-duty and heavy-duty gasoline and diesel trucks using the MVMA (1992) factory sales data and assuming that sales of 6,001 to 8,500 GVW trucks constitute 90% of sales of 6,001 to 10,000 GVW trucks, as reported by MVMA (1992), and that sales of 6,001 to 8,500 GVW diesel trucks constitute 10% of sales of 6,001 to 10,000 GVW diesel trucks.

Average vehicle curb weight. Murrell et al. (1993) report that 1991 model-year passenger cars sold had an average inertial weight of 3153 lbs, and that 1991 model-year light-duty trucks (those with a GVW below 8,501 lbs) sold had an average inertial weight of 3949 lbs. I subtract 300 lbs from the average inertial weight to get the average curb weight (because inertial weight = curb weight + 300 lbs) of gasoline passenger cars and light-duty trucks. In the case of the diesel passenger cars and light trucks I add back 125 lbs of curb weight because diesel vehicles are about 125 lbs heavier than gasoline vehicles (Energy and Environmental Analysis, 1991). I assume that all heavy-duty trucks (those with an inertial weight of more than 8,500 lbs) have a curb weight of 20,625 lbs (DeLuchi, 1993).

ⁱI include this measure because I assume that emissions attributable to the use of motor-vehicle services, such as maintenance and repair (m & r), are proportional to the amount of money spent on m & r services.

The estimates of expenditures on maintenance and repair are equal to total gallons of fuel consumed, in this table, multiplied by dollars of maintenance and repair expenditures per gallon of fuel consumed, from Table 10-7.

TABLE 10-4. SUMMARY MILEAGE AND FUEL-USE STATISTICS FOR 1991

<i>Vehicle category</i>	<i>Vehicle-miles (10^{12})</i>	<i>Fuel use (10^3 gallons)</i>
passenger cars	1,533.552	70,692,039
motorcycles	9.178	183,560
two-axle, four-tire trucks	472.848	32,530,830
other single-unit trucks	53.787	7,133,698
combination trucks	96.942	17,156,506
buses	5.743	863,999
Total	2,172.050	128,560,632

Source: Federal Highway Administration, *Highway Statistics 1992* (1993).

TABLE 10-5. CALCULATED STATISTICS FROM THE 1987 TRUCK INVENTORY AND USE SURVEY

	Mileage fractions ^a	Truck weight (lbs) ^b	Axles per truck ^c	Non-personal ton-mile fractions ^d	Fuel-use fractions ^e
<i>Two-axle trucks</i>					
LDGTs	0.917	3,876	2.00	0.356	0.873
HDGTs	0.031	15,980	2.00	0.934	0.063
LDDTs	0.027	4,334	2.00	0.436	0.021
HDDTs	0.025	20,487	2.00	0.956	0.043
<i>Other single-unit trucks</i>					
LDGTs	0.011	4,828	3.12	0.506	0.005
HDGTs	0.073	26,609	3.04	0.994	0.075
LDDTs	0.001	5,911	3.15	0.619	0.000
HDDTs	0.915	50,762	3.18	0.999	0.920
<i>Combination trucks</i>					
LDGTs	0.050	4,500	3.43	0.462	0.020
HDGTs	0.042	22,180	3.97	0.979	0.038
LDDTs	0.002	5,574	3.40	0.588	0.001
HDDTs	0.906	64,456	4.75	0.999	0.941
<i>All trucks</i>					
LDGTs	0.794	3,881	2.01	0.357	0.623
HDGTs	0.033	17,294	2.27	0.946	0.056
LDDTs	0.023	4,350	2.01	0.439	0.015
HDDTs	0.149	57,040	4.29	0.997	0.305

Source: My calculations, based on data in the Bureau of the Census, *1987 Census of Transportation, Truck Inventory and Use Survey* (TIUS) (1990) and other sources, presented in Table 10-6. LDGT = light-duty gasoline truck (GVW of 8,500 lbs or less); HDGT = heavy-duty gasoline truck (all other gasoline trucks); LDDT = light-duty diesel truck (GVW rating of 8,500 lbs or less); HDDT = heavy-duty diesel truck (all other trucks). These are my definitions; they are the ones that the EPA uses in its emissions inventory (EPA, *National Air Pollutant Emission Trends, 1900-1992, 1993*; EPA, 1995), but they are not the same as the Census' definitions.

Note that in all of the calculations that follow, I assume that in each weight class (0 to 6,000; 6,001 to 7,500, etc.), all truck characteristics -- average vehicle weight, fraction of fuel that is diesel fuel, fraction of travel that is non-personal, number of axles per truck, and fuel economy -- are constant across the axle-type categories (two-axle, other single unit, and combinations).

^aFor each type of truck (e.g., two-axle LDGT), the mileage fraction is equal to the total miles traveled by that type of truck in 1987 divided by total miles traveled by all types of trucks in the general axle class (two-axle, other single-unit, or combination). Miles for each type of truck in 1987 are calculated from the data of Table 10-6, using the following equations:

Two-axle trucks:

$$\text{LDGTs: } \sum_{1425}^{7500} h \times (1 - d)$$

$$\text{HDGTs: } \sum_{7501}^{160000} h \times (1 - d)$$

$$\text{LDDTs: } \sum_{1425}^{7500} h \times d$$

$$\text{HDDTs: } \sum_{7501}^{160000} h \times d$$

where:

h = values from column h of Table 10-6

d = values from column d of Table 10-6

1425-7500 = values from the first two weight classes -- from 1,425 lbs to 7,500 lbs (light-duty trucks) -- of Table 10-6

7501-160000 = values from the next the 13 weight classes -- from 7,501 to 160,000 lbs (heavy-duty trucks) -- of Table 10-6

Other single-unit trucks:

Calculated using the same equations used for two-axle trucks (above), except that values from column i are used in place of values from column h, from Table 10-6.

Combinations trucks:

Calculated using the same equations used for two-axle trucks (above), except that values from column j are used in place of values from column h, from Table 10-6.

All trucks:

The sum of values for two-axle trucks, other single-unit trucks, and combination trucks.

^bFor each type of truck (e.g., two-axle LDGT), the weight in lbs is equal to the total ton-miles traveled by that type of truck in 1987 divided by the total miles traveled by that type of truck

in 1987 (multiplied by 2000 lbs/ton). Total ton-miles for each type of truck is calculated using the same set of equations used to calculate vehicle miles (footnote a), except that “assumed weight” values from column c of Table 10-6 are added as multipliers (so that, for example, the calculation for two-axle LDGTs looks like: $\sum h \cdot (1-d) \cdot c/2000$, where the letters refer to columns of Table 10-6).

^cFor each type of truck (e.g., two-axle LDGT), the number of axles is equal to total ton-miles traveled by that type of truck divided by total ton-miles per axle for that type of truck, in 1987. The calculation of total ton-miles is explained in footnote b. To calculate ton-miles/axle, I further disaggregate the truck universe into nine axle categories (for each of my weight classes), and for each category calculate ton-miles and then divide by the number of axles. The nine axle categories are: 2-axle single unit, 3-axle single unit, 4-axle single unit, 3-axle combination, 4-axle combination, 5-axle combination, 6-axle combination, 7-axle combination, 8-axle combination. These 9 categories actually are a consolidation of 16 categories in the TIUS. In the TIUS tabulation of truck miles by axle class, many data points are withheld for statistical reasons. I estimate the withheld data either by subtracting subtotals from higher level totals, or if that is not determinative, then by guessing. I ignore the minuscule amount of data “not reported”. Also, I treat any TIUS category of the form “n axles or more” as if it is just “n axles”.

^dFor each type of truck (e.g., two-axle LDGT), the non-personal [business-use] ton-mileage fraction is equal to ton-miles of non-personal-use [business-use] travel divided by total ton-miles of travel for that type of truck, in 1987. The calculation of ton-miles of travel is explained in footnote b. Non-personal-use [business-use] ton-miles of travel is calculated using the same equations used to calculate ton-miles of travel, except that “business-use” fractions from column e of Table 10-6 are included as multipliers (so that, for example, the calculation for two-axle LDGTs looks like: $\sum h \cdot (1-d) \cdot c/2000 \cdot e$, where the letters refer to columns of Table 10-6).

^eFor each type of truck (e.g., two-axle LDGT), the fuel-use fraction is equal to the total fuel used by that type of truck in 1987 divided by total fuel used by all types of trucks in the general axle class (two-axle, other single-unit, or combination). Total fuel use is calculated using the same set of equations used to calculate vehicle miles (footnote a), except that the inverse of the “fuel economy” values from columns f and g of Table 10-6 are added as multipliers (so that, for example, the calculation for two-axle LDGTs looks like: $\sum h \cdot (1-d) \cdot 1/g$, where the letters refer to columns of Table 10-6).

TABLE 10-6. TRUCK-MILES OF TRAVEL AND OTHER DATA BY WEIGHT CLASS AND TRUCK TYPE

Average wt. class (lbs)		Assumed weight in class (lbs)	Share of truck miles		Fuel economy (mpg)		Total truck miles, 1987		
from	to		diesel trucks	business- use trucks	diesel trucks	gasoline trucks	2-axle trucks	other singles	
<i>a</i>	<i>b</i>	<i>c</i>	<i>d</i>	<i>e</i>	<i>f</i>	<i>g</i>	<i>h</i>	<i>i</i>	
1,425	6,000	3,713	0.024	0.322	18.69	14.95	404,337	53	
6,001	7,500	6,751	0.100	0.681	13.94	11.15	24,942	34	
7,501	10,000	8,751	0.500	0.681	10.81	8.65	6,236	8	
10,001	14,000	12,001	0.100	0.892	9.96	7.97	4,721	23	
14,001	16,000	15,001	0.300	0.986	8.91	7.13	2,287	38	
16,001	19,500	17,751	0.600	0.983	7.99	6.39	2,224	73	
19,501	26,000	22,751	0.482	0.996	7.36	5.89	5,987	343	
26,001	33,000	29,501	0.550	0.999	6.65	5.32	2,969	480	
33,001	40,000	36,501	0.980	0.999	6.30	5.04	578	851	
40,001	50,000	45,001	0.990	0.999	5.94	4.75	312	2,336	
50,001	60,000	55,001	0.990	1.000	5.64	4.51	127	1,408	
60,001	80,000	70,001	1.000	1.000	5.13	4.10	72	1,505	
80,001	100,000	90,001	1.000	0.999	4.75	3.80	27	51	
100,001	130,000	115,001	1.000	0.998	4.30	3.44	4	10	
130,001	160,000	145,001	1.000	0.996	3.90	3.12	0	1	

Notes: see next page.

Column letters also are footnotes to the table.

Source: Bureau of the Census, *1987 Census of Transportation, Truck Inventory and Use Survey* (TIUS) (1990), except as noted.

^aSave for three adjustments, these are the weight classes used in the TIUS. I split the TIUS second category, "6,001 to 10,000" into two categories. I changed the TIUS' first category, "less than 6,001", into "1,425 to 6,001". Finally, I changed the TIUS' last category, "130,001 or more", into "130,001 to 160,000". These adjustments are explained next.

i) I split the TIUS' second category into "6,001 to 7,500" and "7,501 to 10,000" so that I would have a class boundary that corresponds to my own distinction between light-duty and heavy-duty trucks. Recall that my ultimate goal is to develop statistics for light-duty and heavy-duty trucks, to be used to allocate total motor-vehicle costs to different vehicle classes. I chose only two truck classes, for simplicity, and adopted the EPA's definition of a light-duty truck, which is a truck with a gross vehicle weight (GVW) of 8,500 lbs or less and a curb weight of 6,000 lbs or less. As mentioned above, the main source of data on vehicle travel and fuel use, the FHWA's *Highway Statistics*, uses yet another classification of trucks (two-axle, other single unit, and combination). Therefore, to be able to use the FHWA data, I must map my truck classes into the FHWA's truck classes. I use the TIUS to do this. But to use the TIUS to do this, it must have a truck weight class that corresponds to my boundary between light-duty and heavy-duty trucks. A truck with a GVW (i.e., maximum anticipated weight) of 8,500 lbs and a curb (i.e. empty) weight of 6,000 lbs obviously has an *average* weight -- which is the basis of the TIUS -- of between 6,000 and 8,500 lbs. (The Census' categories based on average weight, which is equal to the empty weight plus the average weight of the load carried, whereas mine is based on gross vehicle weight, which is the empty weight plus the maximum anticipated load.) I assume that the average weight of a truck with a GVW of 8,500 is 7,500 lbs, and so split the TIUS' second category at 7,500 lbs. (I have to make an assumption because there is no formal relationship between curb weight, average weight, and GVW.) I further assume that 80% of the truck mileage in the original 6,001 to 10,000-lb class falls into the new 6,001 to 7,500-lb class. (This assumption is based partly on a comparison of MVMA [1992] sales data for light-duty trucks with sales data reported by Murrell et al. [1993], as described in footnote g of Table 10-3).

ii). For the purpose of calculating the average weight in the first class (column c of this table), I assume that the lower bound of the first weight class (less than 6,001 lbs) is 1,425 lbs. I choose this as the lower bound because it results in an average truck weight of around 3,900 lbs for light-duty gasoline trucks (my definition; see Table 10-5, column 3, Two-axle trucks, LDGTs), which make up the first two weight classes of this table. I aimed for 3,900 lbs because other data, discussed next, indicate that indeed is the average weight of light-duty trucks. To estimate the average weight of light-duty trucks (those with a GVW of 8,500 lbs or less, which as I explain above I assume corresponds to an average weight of 7,500 lbs or less) on the road in 1991, I start with the inertial weight of each model-year light-duty truck from 1975 to 1992 (Murrell et al. 1993; they define LDTs the same way that I do [GVW of 8,500 lbs or less]). (The inertial weight is the curb (empty) weight plus a 300-lb payload, which probably is close to the average payload for light trucks.) Then, I multiply each model-year average vehicle weight by the ratio of VMT by that model year in 1991 to total VMT by all model years in 1991 (calculated from data in CARB, 1988), and sum the resultant products. This results in an average VMT-weighted weight of around 3,900 lbs in 1991.

iii). For the purpose of calculating the average weight in the class (column c), which I use to estimate the average weight of light-duty and heavy-duty trucks, I must bound the last class. I assume 160,000 lbs.

^bSee footnote a.

^cI assume that the average weight of trucks in each of the 15 average-weight classes is equal to the midpoint of the class. (The average weight in each of these 15 weight class is used to estimate the average weight of light-duty and heavy-duty gasoline and diesel trucks, in Table 10-5.)

^dIn order to estimate statistics for diesel and gasoline trucks separately, I must know miles of travel by diesel fuel trucks in each of my 15 weight categories. (The share fractions in this column show diesel truck miles divided by total truck miles, in each weight class.) The TIUS reports miles of travel by diesel trucks in four aggregated weight classes (0 to 10,000 lbs; 10,001 to 19,500 lbs; 19,500 lbs to 26,000 lbs; 26,001 lbs and up), and by truck type (two-axle, other single-unit, and combination), but not by detailed weight class. I estimated the shares shown here, for the 15 weight classes. I chose the share fractions so that the diesel VMT that I back-calculated from them, for the four aggregated weight classes and three truck types, equaled (or very nearly equaled) the VMT actually reported by the TIUS.

The share of travel by gasoline trucks is assumed to be one minus the diesel share. I ignore travel by LPG trucks, which according to the TIUS accounted for about 0.1% of total truck miles of travel in 1987.

^eIn some cases, I need to know the amount that trucks are used for commercial (mainly freight) transportation, as opposed to personal transportation. The TIUS reports miles of truck travel for personal use, by detailed weight class (i.e., for the 14 original weight categories in the TIUS). I assume that all non-personal usage of trucks is for commercial (mainly freight) transportation.

^fOur estimates are derived from Davis (1994). Davis (1994) uses the public-use tape from the 1987 TIUS to estimate the fuel economy of all trucks (gasoline and diesel-fuel combined) in each of 8 weight classes. Her first 7 weight classes are the same as the first 7 disaggregated weight classes in the TIUS; her last class, 33,001 lbs and heavier, collapses the last 7 TIUS classes into one. I chose fuel economy values for the 15 weight classes (the 14 original TIUS weight classes plus one, as explained above), and for gasoline and diesel fuel separately, so that the back-calculated fuel-economy for diesel and gasoline combined in each of the more aggregated 8 classes equaled Davis' results for the 8 classes. In all weight classes, I assume that the miles-per-gallon fuel economy of diesel trucks is 25% higher than that of gasoline trucks: 10% due to the higher energy content of diesel fuel per gallon (137,800 BTU/gallon HHV versus 125,000 BTU/gallon HHV), and 15% due to the higher compression ratio of diesel engines. (Energy and Environmental Analysis, 1991, reports that four 1987-model-year diesel vehicles had 20% to 36% higher fuel economy than the gasoline version of the vehicle.)

^gSee footnote f.

^hFrom the TIUS.

ⁱFrom the TIUS.

^jFrom the TIUS.

^kSum of results from columns h-j.

TABLE 10-7. CALCULATION OF MAINTENANCE AND REPAIR EXPENDITURES PER GALLON OF FUEL CONSUMED, FOR DIFFERENT VEHICLE CLASSES, 1991

	<i>LDAs: use Personal Consumption Expenditures^a</i>	<i>LDTs: use SIC 4212, Local trucking with no storage^b</i>	<i>HDVs: use SIC 4213, Trucking except local^b</i>
Expenditures on m & r for vehicles (10 ⁶ \$) ^c	81,700	1,651	3,392
Expenditures on fuel for vehicles (10 ⁶ \$) ^d	100,225	1,985	5,757
Average fuel price (\$/gallon) ^e	1.19	1.15	1.14
Fuel used by vehicles (10 ⁶ gal) ^f	84,223	1,721	5,043
Maintenance & repair (\$/gallon)^g	0.97	0.96	0.67

LDAs = light duty automobiles, including station wagons and motorcycles; LDT = light-duty trucks (GVW less than 8,500 lbs), including minivans and jeeps and utility vehicles; HDV = heavy-duty vehicles (other trucks, and buses); SIC = standard industrial classification; m & r = maintenance and repair.

^aI could not find estimates of total national expenditures on fuel and m & r for passenger cars (excluding trucks) per se. Instead, I use the Bureau of Economic Analysis' (BEA's) estimates of "Personal Consumption Expenditures" (PCEs), for user-operated transportation, in the National Income and Product Accounts (NIPA) of the United States (*Survey of Current Business*, "National Income and Product Accounts," 1992). PCEs include goods and services purchased by individuals, the operating expenses of nonprofit institutions, and the value of food, fuel, clothing, rent, and financial services received in kind by individuals (BEA, *Personal Consumption Expenditures*, 1990). PCEs exclude transportation expenditures by businesses and by the government, including reimbursable business expenses by persons and expenses related to the business use of motor vehicles purchased for both business use and personal use. Hence, the BEA's PCEs do include expenditures on personal-use trucks as well as on personal-use passenger cars. Nevertheless, for the following reasons, I believe that the PCE data will provide a serviceable approximation of m & r expenditures on passenger cars per gallon of fuel consumed: i) virtually all personal-use trucks are light-duty trucks (Bureau of the Census, *Truck Inventory and Use Survey*, 1990); ii) m & r expenditures per gallon for light trucks probably are close to m & r expenditures per gallon for passenger cars; and iii) PCEs on passenger cars undoubtedly greatly exceed PCEs on light trucks.

^bI could not find estimates of total national expenditures on fuel and m & r for different weight classes of trucks. Instead, I use the Bureau of Census' (*Motor Freight Transportation and Warehousing Survey: 1993, 1995*) estimates of expenditures by local (SIC 4212) and non-local (SIC 4213) trucking firms that provide commercial trucking services. The Census' survey excludes private motor carriers that operate as auxiliaries to nontransportation companies,

and independent owner-operators with no paid employees. According to the Bureau of the Census' *Truck Inventory and Use Survey* (TIUS) (1990), light-duty trucks (my definition; GVW of 8,500 lbs or less) account for about 90% of total mileage by "local" trucks. Hence, it is reasonable to assume that expenditures in SIC 4212 (local trucking) can be extrapolated to represent expenditures on all light-duty trucks. I also assume that expenditures in SIC 4213 (non-local trucks) can be extrapolated to represent expenditures on heavy trucks, even though the TIUS indicates that heavy-duty trucks (all trucks other than light-duty trucks as I define them) account for only about 40% of mileage by non-local trucks.

^cThe BEA's NIPA/PCE/transportation (*Survey of Current Business*, 1992) report has an expenditure category called "tires, tubes, accessories, and other parts," and a category called "repair, greasing, washing, parking, storage, rental, and leasing". The Bureau of the Census' (*Motor Freight Transportation and Warehousing Survey: 1993, 1995*) has an expenditure category called "maintenance and repair costs", which includes parts, purchased repair services for motor vehicles, and purchased repair services for non-vehicular equipment and buildings. To make the two data sources consistent, I made the following adjustments. i) I added the "tires...parts" category of the PCEs to the "repair...leasing" category, and then subtracted an estimate of leasing, renting, storage, and parking costs. I estimated leasing, renting, storage, and parking costs to be \$25 billion, on the basis of data from the Consumer Expenditure Surveys of the Bureau of Labor Statistics (Division of Consumer Expenditures Survey, 1993). ii) From the Census-reported m & r expenditures, I deducted purchased repairs to buildings and nonvehicular equipment. Detailed expenditure data for all of SIC 421 indicate that purchased repairs to buildings and non-vehicular equipment are 11.3% of total expenditures on m & r (Bureau of the Census, *Motor Freight Transportation and Warehousing Survey: 1993, 1995*; the Census gives detailed expenditures for all of SIC 421, but not for the sub-SICs 4212 and 4213).

Note that the m & r expenditures reported by the Census for SIC 421 include only the amounts paid to *other firms* -- they do not include the time cost of employees doing repair "in-house". To the extent that these in-house costs are significant, I have underestimated total m & r in SIC 421. Now, the \$/gallon m & r cost, excluding in-house costs, for SIC 4212, which is mainly LDTs, is about equal to PCEs for m & r of LDAs (\$0.96 vs. \$0.97/gallon). Assuming that LDTs in SIC 4212 should have the same \$/gallon m & r cost as do personal LDAs, the estimated equality might suggest that in-house expenditures in SIC 4212 are not significant. This, however, would be an incorrect assumption, because as estimated in Report #4, people spend a lot of their personal time repairing and maintaining their cars. Thus, it is possible that there are significant in-house expenditures on m & r in SIC 4212.

Both the BEA and Bureau of the Census estimates include sales taxes.

^dThe BEA's NIPA/PCE/transportation (*Survey of Current Business*, 1992) report has an expenditure category called "gasoline and oil". The Bureau of the Census' (*Motor Freight Transportation and Warehousing Survey: 1993, 1995*) has an expenditure category called "purchased fuels," which includes fuel consumed for heat and power. To make the two data sources consistent, I made the following adjustments. i) I assumed that expenditures on oil are 5% of expenditures on "gasoline and oil" in the PCE data. ii) From the Census-reported expenditures on purchased fuels, I deducted fuels purchased for heat or power. Detailed expenditure data for all of SIC 421 indicate that purchased fuels for heat and power are 3.3% of total fuel purchases (Bureau of the Census, *Motor Freight Transportation and Warehousing*

Survey: 1993, 1995; the Census gives detailed expenditures for all of SIC 421, but not for the sub-SICs 4212 and 4213).

Both the BEA and Bureau of the Census estimates include sales taxes and excise taxes. The PCEs of the NIPA (*Survey of Current Business*, 1992) show expenditures on fuels and lubricants for personal transportation.

^eTwo partially independent calculations indicate that the average price of fuel consumed by light-duty passenger cars in 1991 was \$1.19/gallon. First, according to the EIA's survey of residential transportation energy consumption in 1991 (*Household Vehicle Energy Consumption 1991*, 1993), total household expenditures on fuel divided by total household fuel consumption equaled \$1.186/gallon. Second, using the equation and fuel prices given in the next paragraph, and given that F_g for household vehicles equals 98.8% (EIA, *Household Vehicle Energy Consumption 1991*, 1993), I calculate an average price of \$1.195/gallon.

For local and nonlocal trucks, the average price is calculated with these equations:

$$P_a = P_g \times F_g + P_d \times F_d$$

$$P_d = (R_d \times A + S_{ed} + F_{ed}) \times S_a$$

where:

P_a = the consumption-weighted average price of fuel in 1991

P_g = the sales-weighted average price of gasoline, including taxes, in 1991 (\$1.196/gallon; EIA, *Annual Energy Review 1992*, 1993)

F_g = gasoline consumption divided by total fuel consumption, for each vehicle category (98.8% for passenger cars, according to the EIA, *Household Vehicle Energy Consumption 1991*, 1993; 57.5% for local, non-personal use trucks, according to my calculations using data from the TIUS; 45.5% for non-local, non-personal use trucks, according to my calculations using data from the TIUS)

P_d = the sales-weighted average price of diesel fuel, including taxes, in 1991

F_d = diesel consumption divided by total fuel consumption, for each vehicle category (1 minus the percentages for gasoline [F_g])

R_d = the pre-tax price of number two diesel fuel that service stations owned by refining companies charged to end users in 1991, including bulk customers. Number two diesel fuel includes the "Type T-T" diesel fuel used by trucks (\$0.648/gallon; EIA, *Annual Energy Review 1993*, 1994)

A = a factor to account for the apparent fact that R_d , which is the pre-tax diesel-fuel retail price at certain kinds of stations, most likely is lower than the average pre-tax diesel-fuel retail price at all service stations. For gasoline sales, this factor -- the ratio of the pre-tax retail price at all service stations divided by pre-tax retail price at company-owned outlets -- is 1.08 (calculated by comparing the pre-tax price of gasoline sold by service stations owned by refining companies with the sales-weighted average retail of all motor gasoline [EIA, *Annual Energy Review 1994*, 1995]); I assume that the factor is the same for diesel fuel

S_{ed} = the average state excise tax on diesel fuel in 1991 (\$0.177/gallon; FHWA, *Highway Statistics 1991*, 1992)

F_{ed} = the Federal excise tax on diesel fuel in 1991 (\$0.201/gallon; FHWA, *Highway Statistics 1991*, 1992)

Sa = sales tax multiplier (1.0165; Table 17-14)

The EIA reports that the actual weighted average sales price of all grades of motor gasoline was \$0.957/gallon in 1987, and \$1.196 in 1991, including taxes (*Annual Energy Review* 1994, 1995). Neither the EIA nor anybody else reports the average sales price of highway diesel fuel in 1987 and 1991. (The International Energy Agency [*Energy Prices and Taxes*, 1994] uses the same data on pre-tax price and Federal and state excise taxes that I use here, but different data on sales taxes, to calculate the price of diesel fuel in the U.S.)

Note that my method here assumes that the ratio of gasoline to diesel use by trucks in the Census' *Motor Freight Transportation and Warehousing Survey* is the same as the ratio for all nonpersonal truck -- probably a reasonable assumption.

fEqual to expenditures on fuel for vehicles divided by the average fuel price.

gEqual to expenditures on m & r divided by fuel used by vehicles.

TABLE 10-8. STATIONARY AND AREA-SOURCE EMISSIONS ATTRIBUTABLE TO SIX MOTOR-VEHICLE CLASSES (FRACTION OF TOTAL EMISSIONS ATTRIBUTABLE TO EACH CLASS)

SIC	Name of sic	Pol- lutant	Basis of allocation	Gasoline vehicles			Diesel vehicles		
				LDAs	LDTs	HDVs	LDAs	LDTs	HDVs
13	Oil & gas extraction	VOCs	process energy	0.212	0.087	0.010	0.002	0.002	0.067
13	"	CO	"	0.213	0.087	0.010	0.002	0.002	0.068
13	"	NO _x	"	0.193	0.079	0.009	0.002	0.002	0.061
13	"	SO _x	"	0.249	0.102	0.012	0.002	0.002	0.079
13	"	PM _x	"	0.225	0.092	0.011	0.002	0.002	0.090
2822	Synthetic rubber	all	vehicle-tons	0.263	0.193	0.011	0.000	0.001	0.081
2911	Petroleum refining	VOCs	making fuels ^e	0.395	0.162	0.019	0.002	0.002	0.076
2911	"	CO	"	0.420	0.172	0.020	0.002	0.003	0.094
2911	"	NO _x	"	0.433	0.178	0.021	0.002	0.002	0.062
2911	"	SO _x	"	0.360	0.147	0.017	0.002	0.002	0.087
2911	"	PM _x	"	0.426	0.174	0.020	0.002	0.002	0.086
2951	Asphalt mixtures & blocks	all	ton-mi/axle	0.407	0.145	0.030	0.005	0.005	0.358
2992	Lubricating oils and grease	all	gallons of fuel	0.277	0.113	0.013	0.003	0.003	0.098
3011	Tires and inner tubes	all	ton-miles	0.263	0.094	0.024	0.003	0.003	0.463
33	Primary metals	all	vehicle-tons	0.082	0.060	0.003	0.000	0.000	0.025
3465	Automotive stampings	all	vehicle-tons	0.479	0.352	0.020	0.001	0.002	0.147
371	Motor vehicles	all	vehicle-tons	0.479	0.352	0.020	0.001	0.002	0.147
3751	Motorcycles and bicycles	all	MCs are LDAs	0.500	0.000	0.000	0.000	0.000	0.000
3792	Travel trailers & campers	all	VMT, usage	0.323	0.651	0.001	0.004	0.019	0.003
4231	Truck terminals	all	ton-miles	0.000	0.065	0.044	0.000	0.003	0.889
442-4	Water transport of freight	all	cargo tons	0.106	0.043	0.005	0.001	0.001	0.039
4491	Marine cargo handling	VOCs	fuel properties	0.544	0.223	0.026	0.001	0.001	0.028
4612	Crude petroleum pipeline	all	product yield	0.283	0.116	0.014	0.002	0.003	0.090
4613	Petroleum product pipeline	all	products sent	0.364	0.149	0.017	0.002	0.003	0.091
4911	Electric services (fuel)	all	various	0.025	0.013	0.001	0.000	0.000	0.008
5013	Auto supplies and parts	all	expenditures	0.587	0.238	0.020	0.005	0.006	0.144
5093	Auto-body shredding	all	vehicle tons	0.479	0.352	0.020	0.001	0.002	0.147
5171	Petroleum terminals	all	fuel properties	0.627	0.257	0.030	0.000	0.000	0.009
5172	Petroleum products, n.e.c	all	fuel properties	0.069	0.028	0.003	0.000	0.000	0.000
551-2	New & used car dealers	VOCs	New car sales	0.651	0.320	0.003	0.001	0.001	0.023
5541	Gasoline service stations	VOCs	fuel properties	0.665	0.273	0.032	0.001	0.001	0.028
75	Automotive services	all	expenditures	0.587	0.238	0.020	0.005	0.006	0.144

Table continued on next page.

	<i>Name of area source</i>	<i>Pol- lutant</i>	<i>Basis of allocation</i>	Gasoline vehicles			Diesel vehicles		
				<i>LDA</i> s	<i>LDT</i> s	<i>HDV</i> s	<i>LDA</i> s	<i>LDT</i> s	<i>HDV</i> s
n.a.	Any transport of crude oil	VOCs	product yield	0.283	0.116	0.014	0.002	0.003	0.090
n.a.	Any transport of gasoline	VOCs	gasoline use	0.660	0.270	0.032	0.000	0.000	0.000
n.a.	Transport of oil products	VOCs	fuel properties	0.627	0.257	0.030	0.000	0.000	0.009
n.a.	Liquid asphalt	VOCs	ton-mi/ axle	0.407	0.145	0.030	0.005	0.005	0.358
n.a.	Road construction	PM ₁₀	vehicle miles	0.702	0.202	0.011	0.008	0.006	0.071
n.a.	Traffic markings	VOCs	vehicle miles	0.702	0.202	0.011	0.008	0.006	0.071
n.a.	Surface coating of vehicles	VOCs	vehicle tons	0.479	0.352	0.020	0.001	0.002	0.147
n.a.	Re-entrained road dust	PM	ton- miles	0.466	0.156	0.025	0.006	0.005	0.342

See text for explanation of data and methods. SIC is the “standard industrial classification” used by the Bureau of the Census. LDA = light-duty automobile (includes motorcycles and station wagons); LDT = light-duty truck (GVW of 8,500 lbs or less, and curb weight of 6,000 lbs or less, including minivans); HDV = heavy-duty vehicle (all other trucks, and buses); n.e.c = not elsewhere classified. VOCs = volatile organic compounds; CO = carbon monoxide; NO_x = nitrogen oxides; SO_x = sulfur oxides; PM = particulate matter; PM₁₀ = particulate matter of diameter 10 microns or less; n.a. = not applicable.

TABLE 10-9. ALLOCATION OF FUELCYCLE EMISSIONS OF CRITERIA POLLUTANTS TO GASOLINE AND DIESEL FUEL, 1991

	VOCs	CO	NO _x	SO _x	PM
<i>13 Oil and gas extraction^a</i>					
Share to crude oil	0.751	0.753	0.683	0.880	0.798
Share to natural gas	0.224	0.222	0.285	0.108	0.182
Share to NG liquids	0.025	0.025	0.032	0.012	0.021
<i>13: of the share to crude oil^b</i>					
Highway gasoline	0.412	0.412	0.412	0.412	0.412
Highway diesel	0.095	0.095	0.095	0.095	0.095
Residual fuel	0.074	0.074	0.074	0.074	0.074
<i>2911 Petroleum refining^c</i>					
Gasoline	0.599	0.637	0.657	0.545	0.646
Highway gasoline ^d	0.576	0.612	0.632	0.524	0.621
Distillates, jet fuel, kerosene	0.267	0.329	0.216	0.304	0.302
Highway diesel ^d	0.080	0.099	0.065	0.091	0.091
Residual fuel	0.042	0.070	0.043	0.013	0.062
<i>5171 Petroleum bulk stations & terminals^e</i>					
Highway gasoline	0.914	n.a.	n.a.	n.a.	n.a.
Highway diesel	0.009	n.a.	n.a.	n.a.	n.a.
Residual fuel	0.010	n.a.	n.a.	n.a.	n.a.
<i>5172 Petroleum products n.e.c^e</i>					
Highway gasoline	0.10	n.a.	n.a.	n.a.	n.a.
Highway diesel	0.00	n.a.	n.a.	n.a.	n.a.
Residual fuel	0.00	n.a.	n.a.	n.a.	n.a.
<i>5541 Gasoline service stations^e</i>					
Highway gasoline	0.970	n.a.	n.a.	n.a.	n.a.
Highway diesel	0.030	n.a.	n.a.	n.a.	n.a.
Residual fuel	0.000	n.a.	n.a.	n.a.	n.a.

Notes: see next page.

VOCs = volatile organic compounds; CO = carbon monoxide; NO_x = nitrogen oxides; SO_x = sulfur oxides; PM = particulate matter.

^aEstimated using from the following equation:

$$S_{e,p} = \frac{\left(\sum_f A_{f,e} \times E_{f,p} \right) \times R_e \times F_e}{\sum_e \left(\sum_f A_{f,e} \times E_{f,p} \right) \times R_e \times F_e}$$

where:

$S_{p,e}$ = the share of emissions of pollutant p attributable to primary energy source e (crude oil, natural gas, or natural-gas liquids) in 1991

$A_{f,e}$ = the share of fuel type f (crude oil, residual fuel, diesel fuel, natural gas, gasoline or coal; electricity is excluded here) of the total amount of fuel used to recover primary energy source e in 1991 ($BTU_f / \sum_f BTU_f$) (from DeLuchi [1991] for the year 1987; I assume that the values were the same through 1991)

$E_{f,p}$ = emissions of pollutant p (VOCs, CO, NO_x, SO_x, PM) from the use of recovery-fuel type f (lbs/10⁶ Btu) (from DeLuchi, 1993, who used EPA's AP-42 emission factors and assumed that crude oil, residual fuel, natural gas, and coal [coke] were used in industrial boilers, and that diesel was used in well equipment and gasoline in gasoline engines)

R_e = the energy effectiveness of fuel used to recover primary energy source e in 1991 (BTUs of total recovery fuel per BTU of e recovered) (0.03 for crude oil; 0.028 for natural gas; 0.025 for natural gas liquids; from the model documented in DeLuchi [1991, 1993] for the year 1987; I assume that the values were the same through 1991)

F_e = production of primary energy source e, expressed as a fraction of total production of all three sources in 1991 ($BTU_e \text{ produced} / (BTU_{oil} + BTU_{NG} + BTU_{NGLs})$) (0.433 for oil, 0.504 for natural gas, and 0.064 for NGLs; from the EIA's *Annual Energy Review 1992, 1993*] for 1991)

^bEmissions attributable to the production and transport of crude oil must be allocated to the fuels eventually produced from that crude oil. I do this on the basis of the average mass output of refineries in the U.S. -- not on the basis of the volume output -- because mass but not volume is conserved, and energy use in the production and transport of crude oil is related to the mass of the oil. In other words, if gasoline accounts for 42.8% of the total mass of refinery output, but 46% of the total volume output, then I assume that 42.8% (not 42.8%) of the emissions from producing the crude input to refineries ultimately is attributable to gasoline use. I use data on 1991 volume output and density by product (EIA, *Petroleum Supply Annual 1991, 1992*) to calculate the mass output of gasoline and distillates from refineries, and then calculate the fraction of total gasoline that is used on the highways (96.2%), and the fraction of total distillate production that is used on the highways (see note d below). Thus, 42.8% x 96.2% = 41.2% of emissions attributable to the production and transport of crude oil

are assignable to highway gasoline, and 20.7% (distillate mass share of refinery output) multiplied by 45.8% (highway diesel share of total distillates) = 9.5% are assignable to highway diesel fuel.

^cThe attribution of pollutant emissions to production of gasoline (including aviation gasoline), distillate-plus-jet-fuel-plus kerosene, and residual fuel is based on the data and analyses in DeLuchi et al. (1992). They estimated emissions from refinery boilers and refinery process areas, and then attributed energy use by boilers and activity at process areas to those three classes of products. They lumped distillates, jet fuel, and kerosene together because the three kinds of products are processed similarly, and could not be analyzed individually in terms of energy use or processing requirements. DeLuchi et al. (1992) do not present the fractions shown here; I calculated the fractions using their spreadsheet model, with 1991 values for the major parameters.

Emissions from the generation of bought electricity are not included in the figures shown here, but are included elsewhere in this analysis.

^dHighway gasoline is a subset of gasoline, and highway diesel is a subset of distillates, jet fuel (naphtha and kerosene type), and kerosene. Distillate includes diesel fuel used on the highways and diesel fuel used in other applications. I assume that the ratio of refinery production of highway-use gasoline to refinery production of all gasoline (including aviation gasoline) is equal to the ratio of highway use of gasoline to total use of gasoline (including aviation gasoline) -- 0.962. The latter ratio is calculated from FHWA statistics for 1991 (FHWA, *Highway Statistics 1991*, 1992).

I assume that the ratio of refinery production of highway-use diesel fuel to refinery production of distillates et al. (including jet fuel and kerosene) is equal to the ratio of highway use of diesel fuel to total supply of distillates et al (0.301). I assume that highway use of diesel fuel is equal to 99% of highway use of "special fuels" in 1991 as reported by the FHWA (*Highway Statistics 1991*, 1993; the EIA, in *Fuel Oil and Kerosene Sales 1991*, 1992, calculates that diesel fuel is "more than 98%" of the FHWA's "special fuels" [the rest is mainly LPG]). The total supply of distillates et al. in 1991 is reported in the EIA's *Petroleum Supply Annual 1991* (1992).

^eOn the basis of fuel throughput and relative volatility, DeLuchi et al. (1992) assume that 95% of the VOC emissions from petroleum marketing are attributable to gasoline. Because most emissions from petroleum marketing are from bulk stations and terminals, I assume that 95% of VOC emissions in SIC 5171 (petroleum bulk stations and terminals) are from gasoline. Of this 95% attributable to all gasoline, 96.2% is attributable to highway gasoline specifically. To distribute this $0.962 \times 0.95 = 91.4\%$ to the three classes of gasoline vehicles, I use the factors of Table 10-3.

I assume that 3% of the emissions in this SIC are attributable to distillates, jet fuel and kerosene, and the remainder to residual fuel oil and other products. Of the 3%, 30% is attributable to highway diesel fuel specifically.

SIC 5172 covers establishments engaged in the wholesale distribution of petroleum products, except those establishments with bulk liquid storage facilities (Office of Management and Budget, 1987). Presumably, most of these establishments handle little if any gasoline and diesel fuel, which generally are stored at and distributed by large facilities. I

assume that only 10% of the VOC emissions from this SIC are attributable to highway gasoline, and that 0% are attributable to diesel fuel.

Finally, I assume that service stations (SIC 5541) handle only highway gasoline and highway diesel, and that 97% of the emissions are attributable to highway gasoline, which is many times more volatile than is highway diesel fuel.

TABLE 10-10. ALLOCATION OF DOMESTIC WATERBORNE SHIPMENTS TO MOTOR VEHICLES

Commodity	Code	Domestic shipment 10 ³ tons ^a	Fraction to all vehicles ^b	Allocation of commodity tons (10 ³)			
				Gasoline vehicles			Diesel vehicles
				LDA's	LDT's	HDV's	LDA's
Crude petroleum	1311	181,833,864	0.51	51,393,953	21,055,581	2,463,726	426,829
Gasoline	2911	86,230,019	0.96	56,885,816	23,305,541	2,726,995	0
Distillate fuel oil	2914	58,052,393	0.46	0	0	0	657,043
Lubricating oils and greases	2916	5,941,917	0.51	2,113,784	608,676	32,961	25,080
Asphalt, tar and pitches	2918	10,148,126	0.85	6,054,834	1,743,525	94,414	71,842
Rubber & miscellaneous plastics	3011	167,116	0.10	7,920	5,817	336	11
Iron and steel	331	4,860,244	0.17	398,159	292,422	16,897	541
Nonferrous metals	3321	26,792	0.25	3,153	2,316	134	4
Machinery, except electrical	3511	1,022,524	0.06	29,610	21,747	1,257	40
Vehicles, parts, and equipment	3711	1,003,866	1.00	480,654	353,010	20,398	653
Totals		349,286,861		117,363,818	47,385,648	5,356,945	1,182,038
Fractions of total commodities ^d		0.317		0.106	0.043	0.005	0.001

Notes: see next page.

LDAs = light duty automobiles, including station wagons and motorcycles; LDT = light-duty trucks (GVW of 8,500 lbs or less, and curb weight of 6,000 lbs or less), including minivans and jeeps and utility vehicles; HDV = heavy-duty vehicles (other trucks, and buses); al. = aluminum

^aFrom the Army Corps of Engineers (1991), for the calendar year 1989. The amounts shown are tons of domestic shipments of each commodity in coastal, lake, and river waterways of the U.S. Recall that the intent here is to allocate to motor-vehicle classes the estimated emissions from marine transport. I assume that the marine-transport emissions estimates include emissions from all domestic waterborne commerce but no emissions from foreign commerce. In fact, the emissions estimates might be more detailed than this, and include foreign traffic when it is near the U.S. coast, and exclude domestic traffic between the U.S. mainland and Alaska and Hawaii. This would be appropriate, because one should exclude emissions on the open ocean but count emissions near urban ports. However, I ignore these complications.

^bThe fraction of tonnage of each commodity that should be assigned to motor-vehicles as a whole. The fractions were estimated as follows:

Crude petroleum: the fraction of the mass of a barrel that is used to make highway gasoline or highway diesel (my analysis of data in the EIA's *Petroleum Supply Annual 1991, 1992*);

Gasoline: the ratio of highway use of gasoline to total use of gasoline (FHWA, *Highway Statistics 1991, 1992*).

Distillate fuel oil: ratio of highway use of diesel fuel (FHWA, *Highway Statistics 1991, 1992*; assume diesel = 99% of "special fuels") to total supply of distillates (EIA, *Petroleum Supply Annual 1991, 1992*).

Lubricating oils and greases: assume same ratio as for crude oil.

Asphalt, tar and pitches: Tyler et al. (1990) state that in 1987 85% of asphalt production in the U.S. was for roads.

Rubber & miscellaneous plastics: ratio of automotive consumption of plastic, natural rubber, and synthetic rubber to total consumption of plastic, natural rubber, and synthetic rubber (MVMA, 1992). (The relevant SIC categories are: "synthetic rubber" [2822], "plastic materials and resins" [2821], and "rubber and miscellaneous plastic products" [30]. On the basis of the MVMA's description of their "rubber" categories, I assume that their "natural rubber", "synthetic rubber", and "plastics" categories correspond to SIC 30 ["rubber and miscellaneous plastic products"], even though "synthetic rubber" actually is the name of a different SIC [2822].) The MVMA states that "for most materials listed automotive consumption includes materials used for cars, trucks, buses, and replacement parts" (p. 47). To account for materials used in buildings, machinery, supplies, and other items relevant to motor-vehicle use and manufacturing but not included in the MVMA estimates, I multiply the MVMA estimates by 1.10.

Iron and steel, and nonferrous metals: the ratio of automotive consumption of these metals to total U.S. consumption of these metals, as estimated from MVMA (1992) data. This estimate is crude, because the categories used by the MVMA -- "aluminum," "copper," "ductile iron," "gray iron," "malleable iron," "lead," "platinum," "alloy steel," "stainless steel," "total steel," and "zinc" -- do not correspond to the categories in *Waterborne Commerce* categories -- "iron and steel primary forms"; "iron and steel shapes, excluding sheet"; "iron and steel plates, sheets"; "iron and steel products not elsewhere classified"; "nonferrous

metals not elsewhere classified". Hence, I simply have collapsed both the MVMA the *Waterborne Commerce* categories into two catch-all metals categories: iron and steel, and nonferrous metals. The MVMA states that "for most materials listed automotive consumption includes materials used for cars, trucks, buses, and replacement parts" (p. 47). To account for materials used in buildings, machinery, supplies, and other items relevant to motor-vehicle use and manufacturing but not included in the MVMA estimates, I multiply the MVMA estimates by 1.10.

Machinery, except electrical: As explained in Table 17-17, I estimate that about 5% of the machinery from this SIC is used in motor-vehicle related industries.

Motor vehicles, parts, and equipment: presumably, by definition equal to 1.0.

^cEqual to:

$$T_{c-i} = T_{c-t} \times \left(\frac{T_{c-mv}}{T_{c-t}} \right) \times \left(\frac{T_{c-i}}{T_{c-mv}} \right)$$

where:

T_{c-i} = tonnage of commodity c attributable to motor-vehicle class i

(T_{c-t}) = total tonnage of commodity c (column 3 of this table; Army Corps of Engineers, 1991)

$(T_{c-mv})/(T_{c-t})$ = fraction of total tonnage (t) of each commodity c that should be assigned to motor-vehicles (mv) as a whole (column 4 of this table; see note b above)

$(T_{c-i})/(T_{c-mv})$ = of the tonnage of commodity c attributable to motor vehicles as a class, the fraction attributable to individual vehicle class i (calculated as follows: *crude oil* -- on the basis of the mass yield of gasoline and diesel fuel from crude oil and consumption of gasoline and diesel fuel by vehicle type; *gasoline and diesel fuel* -- on the basis of highway fuels consumed by vehicle type; *lubricating oils and greases, and asphalt, tar and pitches* -- on the basis of vehicle-miles of travel by vehicle type; *rubber and miscellaneous plastics, iron and steel, and motor-vehicles, parts and equipment* -- on the basis of vehicle-tons made by vehicle type; see data in Tables 10-3 and 10-8)

^dEach fraction is equal to the total shown immediately above divided by the grand total domestic waterborne commerce of 1,102,532,159 tons in 1989 (Army Corps of Engineers, 1991).

TABLE 10-11. ELECTRICITY USE PER UNIT OF MOTOR-VEHICLE-RELATED ACTIVITY

	Gasoline	Diesel
kWh/ gallon fuel (fuel & feedstock production & transport) ^a	0.409	0.355
kWh/ gallon fuel (fuel storage & dispensing) (SIC 554, 517) ^b	0.113	0.113
kWh/lb (vehicle assembly) (SIC 371) ^c	0.656	0.656
kWh/lb (manufacture of materials for vehicles, parts, etc.) ^d	0.815	0.815
kWh/ dollar spent on automobile repair & services (SIC 75) ^b	0.0729	0.0729
kWh/ vehicle or part or supply sold (SIC 55 except 554) ^b	754	754

^aCalculated as follows:

$$EF_f = \left(\sum_s P_{f,s} \times F_s \right) \times \frac{H_f}{3412}$$

where:

EF_f = Electricity consumed by the production and transport of fuel f , per gallon of fuel f (gasoline or diesel fuel)

$P_{f,s}$ = the amount of process energy consumed at stage s of the fuelcycle of fuel f , per unit of fuel f produced by the entire fuelcycle (BTUs-process energy/BTU-fuel f ; the stages are feedstock recovery, feedstock transport, fuel production, and fuel distribution; values of P from DeLuchi [1991], for conventional gasoline and diesel fuel)

F_s = the fraction of process energy consumed at stage s that is electricity (BTU-s electricity [at 3412 BTU/kWh] per BTU-process energy; values from DeLuchi, 1991, except value for petroleum refining, which is from the EIA's *Manufacturing Energy Consumption Survey 1991, 1994* [equal to BTU-s net electricity divided by total BTUs for heat, power, and electricity generation])

H_f = the higher heating value of fuel f (125,000 BTU/gallon for gasoline; 137,800 BTU/gallon for diesel fuel)

3412 = BTU/kWh

^bCalculated as follows:

$$E_a = \frac{D_a \times A_a}{P_a \times O_a}$$

where:

E_a = Electricity use per unit of activity a (kWh/gallon stored or dispensed; kWh/vehicle-sold; kWh/\$-spent-on-maintenance-and-repair)

D_a = Total dollars spent on electricity in 1987 in the SIC that most closely corresponds to the activity (Table 10-12)

O_a = Amount of activity a in 1987 in the corresponding SIC (gallons in SICs 554 and 517; vehicle sales in SIC 55 except 554; expenditures on m & rs for SIC 75) (Table 10-12)

P_a = price of a kWh sold in each SIC corresponding to activity a (\$/kWh) (Table 10-12)

A_a = adjustment factor for activity a, to account for activity in SICs other than the corresponding SIC (Table 10-12)

I assume that E_a has not changed since 1987.

^cIn 1991, SIC 371, "Motor vehicles and equipment," purchased 21.5617 billion kWh (Bureau of the Census, *1991 Annual Survey of Manufactures*, 1992). However, manufacturers in this SIC also sold electricity, and those sales should be netted out. According to the EIA's *Manufacturing Energy Consumption Survey 1991* (1994), sales and transfers of electricity out of SIC 37 were 2.15% of total electricity purchases (the EIA report does not give energy consumption data specifically for SIC 371). Thus, I assume that SIC 371 consumed 21.1 billion kWh of net electricity. I divide this by the total number of pounds of vehicles made (Table 10-3).

^dCalculated as follows:

$$EM = 1.20 \times \sum_m P_m \times F_m \times W_m$$

where:

EM = electricity consumption to make automotive materials, per lb of vehicle

P_m = total process energy required to make material m (BTU-energy/lb-material m; values from DeLuchi, 1993, for the year 2000; I assume the same for 1991)

F_m = fraction of total process energy that is electricity, for material m (BTU-electricity/BTU-process energy; electricity counted at 3412 BTU/kWh; values from DeLuchi, 1993, for the year 2000; I assume the same for 1991)

W_m = pounds of material m per pound of vehicle weight (MVMA, 1992, for calendar year 1992,)

1.20 = factor to account for manufacture of materials for replacement parts, automotive supplies, and machinery and buildings relevant to motor-vehicle use (my estimate)

TABLE 10-12. CALCULATION OF ELECTRICITY USE PER UNIT ACTIVITY AT SERVICE STATIONS, BULK STORAGE FACILITIES, MOTOR-VEHICLE DEALERSHIPS, MOTOR-VEHICLE PARTS STORES, AND AUTO REPAIR AND SERVICE FACILITIES

	Electricity in 1987				Activity in 1987 ^e
	expenditures (\$) ^a	SIC ^b	Adjustment ^c	price (\$/kWh) ^d	
Petroleum marketing	150,727,651	517	0.900	0.0600	222.68 10 ⁹ gal ^c
Service stations	666,328,600	554	1.000	0.0677	87.26 10 ⁹ gal ^d
Motor vehicles and parts	749,745,677	55 ex. 554	1.034	0.0677	15.19 10 ⁶ vehicles ^e
Motor-vehicle services	466,524,973	75	1.000	0.0677	94,492 10 ⁶ \$-m & r ^f

^aThese data are from the Bureau of the Census' quinquennial surveys: data for SIC 517 are from the 1987 *Census of Wholesale Trade, Subject Series, Measures of Value Produced, Capital Expenditures, Depreciable Assets and Operating Expenses* (1991); data for SICs 554 and 55 except 554 are from the 1987 *Census of Retail Trade, Measures of Value Produced, Capital expenditures, Depreciable assets, and Operating Expenses* (1991); and data for SIC 75 are from the 1987 *Census of Service Industries, Capital expenditures, Depreciable assets, and Operating Expenses* (1991).

The expenditure estimates published from these surveys are actual, direct payments for electricity in the indicated SIC; they do not include the cost of any electricity that was included in normal lease or rental payments or franchise fees. Therefore, the published expenditure estimates need to be scaled up to account for the use of electricity that was paid for in lease, rental, or franchise fees and hence did not show up in the published expenditures. Because the Census does not have any data on the cost of energy included in lease, rental, or franchise fees, this scaling must be done indirectly. The Census does have unpublished data that allow one to calculate the ratio of: total operating expenses for all firms in the SIC of interest (that is, operating expenses of firms that paid for electricity, *plus* the operating expenses of firms whose electricity use was covered by lease, rental, or franchise fees) to the operating expenses of firms that reported only direct payments for electricity (Bureau of the Census, Business Division, personal communication, 1993). I assume that this ratio is equal to the ratio that I would really like to know, namely: payments for all electricity (including the cost of electricity covered in lease, rental, or franchise fees) to reported actual payments for electricity. Therefore, I multiply reported direct payments for electricity in each SIC by the ratio of total operating expenses of all firms to operating expenses of firms that reported direct payments for electricity, in each SIC.

^bThe SIC group for which the electricity expenditures are estimated.

^cIn Table 10-11, electricity use per unit activity is estimated by dividing total electricity consumption in kWh by the relevant total activity. The total electricity consumption, in turn, is estimated by dividing total \$ expenditures on electricity by the \$/kWh price of electricity. The total \$ expenditures are estimated by multiplying expenditures in the relevant SIC (see footnotes a and b) by an adjustment factor. The adjustment factor accounts for the fact that, on the one hand, some of the electricity expenditures in an SIC (say, SIC 554, gasoline service

stations) apply towards activities unrelated to motor-vehicle use (say, running a food refrigerator), and, on the other, that there are relevant motor-vehicle activities outside of the main SIC (for example, some department stores sell automotive supplies).

Petroleum marketing: SIC 517. I assume: 1) that SIC 517 handles only petroleum products, and 2) that there is little or no bulk storage of petroleum fuels outside of SIC 517. With the first assumption, all electricity use SIC 517 can be assigned to the use of petroleum. With the second assumption, the kWh/gallon figure calculated for SIC 517 represents kWh/gallon for all bulk storage of petroleum. Hence, in this case, there is no need to adjust the electricity-expenditure data (i.e., the adjustment factor is 1.0).

Service stations: based on SIC 554. Establishments in SIC 554 sell more than just highway fuels, repair services, and automotive supplies: in 1987, food, drinks, drugs, household merchandise, and other non-automotive goods were slightly more than 10% of the sales in SIC 554 (Bureau of the Census, *1987 Census of Retail Trade, Subject Series, Merchandise Line Sales*, 1990). On this basis, I assume that 10% of the expenditures on electricity in SIC 554 should be assigned to non-automotive products (which people would buy elsewhere if they did not drive), and that 90% should be assigned to automotive products (i.e., the adjustment factor = 0.90). I assume that electricity expenditures per gallon fuel at establishments not in SIC 554 (e.g., convenience stores that sell a small amount of motor fuel) is the same as expenditures per gallon in SIC 554, and therefore apply the \$/gallon figure derived from SIC 554 to all highway fuels sold, not just the amount sold in SIC 554.

Motor vehicles & parts: based on SIC 55. As noted above, the Census reports total electricity expenditures in SIC 55 (excluding 554). However, some establishments in SIC 55 sell products unrelated to motor-vehicle use, and some establishments outside of SIC 55 sell motor vehicles and related products. To adjust the electricity expenditures in SIC 55 (except 554) to approximate electricity expenditures associated with the sale of all motor-vehicles and parts and supplies, I multiply electricity expenditures in SIC 55 (except 554) by the ratio of dollar sales of all automotive merchandise lines in all SICs (except 554) to dollar sales of all merchandise in SIC 55 (except 554) (Table 17-14). This adjustment factor is 1.034.

Motor-vehicle services: based on SIC 75. As noted above, the Census reports total electricity expenditures in SIC 75. I assume that establishments in SIC 75 perform only services related to motor-vehicle use, and that there is no maintenance and repair or automotive service work done outside of SICs 75 or 55. Given that electricity expenditures related to automotive services in SIC 55 are counted above, we may use the Census electricity expenditure estimates for SIC 75 without adjustment.

^CIn 1987, the average electricity price in the U.S. in the commercial sector as a whole was \$0.0708/kWh, and in 1986 the average electricity price to mercantile and service commercial buildings specifically was \$0.0686/kWh (EIA, *Annual Energy Review* 1992, 1993; the figure for 1986 is from the Commercial Buildings Energy Consumption Survey, which was done in 1986 and 1989 but not 1987). The price to mercantile and service buildings in 1987 can be approximated as the price in 1986 multiplied by the ratio of the price to the commercial sector as a whole in 1987 to the price to the commercial sector as a whole in 1986. This results in \$0.0677/kWh, which I use as the average electricity price in SICs 554, 55 except 554, and 75.

I assume that the price to SIC 517 is between the commercial-sector average price of \$0.0708/kWh and the industrial-sector average price of \$0.0477/kWh (EIA, *Annual Energy Review* 1992, 1993).

^dThe activity basis is selected and estimated as follows:

Petroleum marketing. I assume that electricity use at bulk-storage facilities is proportional to the amount of fuel handled. I also assume that all highway fuels pass through a bulk-storage facility, and that no gallon of any fuel is sold twice within SIC 517. With these assumptions, the appropriate activity to use in the calculation of kWh/gallon in Table 10-11 is the total amount of gallons sold in SIC 517. My estimate of total gallons sold, shown in this table, is equal to the number of gallons sold by those establishments in SIC 517 that reported product sales by type, multiplied by the ratio of dollar sales by all establishments in SIC 517 to dollar sales by those establishments in SIC 517 that reported product sales by type (Bureau of the Census, *1987 Census of Wholesale Trade, Miscellaneous Subjects*, 1991).

Note that the definition of “petroleum bulk stations and terminals” that is used in the electricity-expenditure part of the survey (Bureau of the Census *1987 Census of Wholesale Trade, Measures of Value Produced, Capital expenditures, Depreciable assets, and Operating Expenses*, 1991) is slightly different than the definition used in the gallon-sales part of the survey (Bureau of the Census, *1987 Census of Wholesale Trade, Miscellaneous Subjects*, 1991). Nevertheless, I use electricity-expenditure data from the *Measures of Value Produced...* report, and gallon data from the *Miscellaneous Subjects* report.

Service stations. I assume that electricity use at service stations for automotive purposes is proportional to the amount of fuel dispensed. In 1987, service stations in SIC 554 sold 87.26 billion gallons of fuel (Bureau of the Census, *1987 Census of Retail Trade, Measures of Value Produced, Capital expenditures, Depreciable assets, and Operating Expenses*, 1991). Note that the gallon-sales data and the electricity-expenditure data are from the same survey (Bureau of the Census, *The 1987 Census of Retail Trade*, 1991) and pertain to the same population of service stations.

Motor vehicles & parts. I assume that electricity use at motor-vehicle dealerships and automotive parts stores for automotive purposes is related to the amount of motor-vehicles sold. Total vehicle sales in 1987 (the figure shown in this table) are reported by the MVMA (1992).

Motor-vehicle services. I assume that electricity consumption for motor-vehicle services is proportional to expenditures on maintenance and repair (m & r). M & r expenditures for motor vehicles in 1987 (the figure in this table) are calculated by multiplying 1991 expenditures (estimated in Tables 10-3 and 10-7) by the ratio of total revenues in SIC 75 in 1987 to total revenues in 1991 (Bureau of the Census, *Service Annual Survey: 1994, 1996*). (Note that m & r as I define it here and in Tables 10-3 and 10-7 is not the same as automotive services in SIC 75.) Alternatively, one can multiply 1991 m & r expenditures on LDAs (Table 10-3) by the ratio of 1987-to-1991 PCEs on tires, tubes, accessories, and other parts, plus repair, greasing, washing, parking, storage, and rental (*Survey of Current Business*, 1990, 1992), and 1991 m & r expenditures on LDTs and HDVs (Table 10-3) by the ratio of 1987-to-1991 m & r expenditures for freight trucks (Bureau of the Census, *Motor Freight Transportation and Warehousing Survey: 1993, 1995*), and obtain \$94.6 billion in 1987.

TABLE 10-13A. PETROLEUM SUPPLY, 1991 (10³ BBL)

Material	Field production	Refinery production	Imports	Imports from the Middle East^a	Refinery inputs
Crude oil	2,707,039	0	2,110,532	668,516	4,855,016
Pentanes plus	118,147	0	8,266	3,889 ^b	61,432
Ethane/ethylene	193,319	9,344	2,994	390 ^c	0
Propane/propylene	177,863	155,958	33,274	4,338 ^c	3
Normal butane/butylene	54,818	28,671	12,836	1,674 ^c	54,276
Isobutane	61,511	1,604	4,569	596 ^c	56,595
Other hydrocarbons/alcohol	33,531	0	1,219	574 ^b	31,574
Unfinished oils	0	0	150,736	33,707	151,618 ^d
Motor gasoline blending components	0	0	13,065	51	19,684
Aviation gasoline blending components	0	0	0	0 ^b	97
Finished motor gasoline	0	2,546,974	108,462	12,289	0
Finished aviation gasoline	0	8,031	68	32 ^b	0
Jet fuel, naptha type	0	59,837	4,355	242 ^e	
Jet fuel, kerosene type	0	465,136	20,169	1,118 ^e	0
Kerosene	0	13,952	4,351	0	0
Distillate fuel oil	0	1,081,018	74,778	85	0
Residual fuel oil	0	341,080	165,424	14,936	0
Naptha for petrochemical feedstock	0	47,852	9,172	283	0
Other oils for petrochemical feedstock	0	100,006	41,662	41,662	0
Special naphthas	0	18,797	2,676	0	0
Lubricants	0	57,001	2,915	0	0
Waxes	0	6,681	491	231 ^b	0
Petroleum coke	0	207,463	805	379 ^b	0
Asphalt and road oil	0	155,840	10,154	0	0
Still gas	0	237,759	0	0	0
Miscellaneous products	0	25,544	790	372 ^b	0
Total	3,346,228	5,568,548	2,783,763	785,363	5,230,295

From the EIA *Petroleum Supply Annual 1991* (1992), except as noted.

^aI define the Middle East to include the members of Arab OPEC, plus Bahrain, Egypt, Oman, Syria, and Yemen.

^bIn its data on imports by country, the EIA classifies these as “other products”. The EIA reports total imports of each of the other products, and imports of total other products from each country, but not imports of each of the other products from each country. I have disaggregated the “other products” category by assuming that $O_{mi}/O_{mt} = O_i/O_t$, where O_{mi} = imports of other product i from the Middle East, O_{mt} = imports of all other products from the Middle East (5.476 million barrels), O_i = total imports of other product i (shown in this table) and O_t = total imports of other products (the sum of the O_i).

^cThe EIA classifies these four products -- ethane, propane, butane, and isobutane -- as natural gas liquids (NGLs). The EIA reports total imports of each of the individual NGLs, and imports of total NGLs from each country, but not imports of each NGL from each country. I have disaggregated total NGL imports from the Middle East by assuming that $NGL_{mi}/NGL_{mt} = NGL_i/NGL_t$, where NGL_{mi} = imports of NGL i from the Middle East, NGL_{mt} = imports of all NGLs from the Middle East (6.998 million barrels), NGL_i = total imports of NGL i (shown in this table), and NGL_t = total imports of NGLs (the sum of the NGL_i).

^dAccording to the EIA, this is the “net” input of unfinished oil, equal to total reported input less total reported refinery production. The EIA actually reports 228,910 thousand bbl net input for 1991, but also reports -77,292 thousand bbl unfinished oil product supplied. In its explanatory notes, the EIA writes that a negative value for product supplied means that “products such as..unfinished oils have entered the primary supply channels with their production not having been reported, e.g., streams returned to refineries from petrochemical plants”. This means that production of unfinished oils is underestimated by the amount of (negative) product supplied, and hence that net input (gross input less gross production) is overestimated by the amount of product supplied. Consequently, I have deducted the 77,292 bbl that apparently should have been but were not reported as production from the 228,910 net refinery input.

^eThe EIA reports only total jet fuel imports by country. I have split this total into kerosene and naptha types according to the proportion of each in total jet fuel imports (as per the method for disaggregating NGLs and other products in notes b and c).

TABLE 10-13B. PETROLEUM SUPPLY, 1991 (10³ METRIC TONS)

Material	Field production	Refinery production	Imports	Imports from the Middle East^a	Refinery inputs
Crude oil	373,043	0	290,841	92,125	669,496
Pentanes plus	11,762	0	823	387	6,116
Ethane/ethylene	17,581	850	272	35	0
Propane/propylene	16,429	14,406	3,074	401	0
Normal butane/butylene	5,098	2,667	1,194	156	5,048
Isobutane	5,369	140	399	52	4,940
Other hydrocarbons/alcohol	4,105	0	149	70	3,865
Unfinished oils	0	0	20,772	4,645	20,894
Motor gasoline blending components	0	0	1,589	6	2,395
Aviation gasoline blending components	0	0	0	0	12
Finished motor gasoline	0	298,590	12,715	1,441	0
Finished aviation gasoline	0	902	8	4	0
Jet fuel, naptha type	0	7,235	527	29	0
Jet fuel, kerosene type	0	58,655	2,543	141	0
Kerosene	0	1,805	563	0	0
Distillate fuel oil	0	144,909	10,024	11	0
Residual fuel oil	0	51,213	24,838	2,243	0
Naptha for petrochemical feedstock	0	5,821	1,116	34	0
Other oils for petrochemical feedstock	0	13,406	5,585	5,585	0
Special naphthas	0	2,287	326	0	0
Lubricants	0	8,143	416	0	0
Waxes	0	849	62	29	0
Petroleum coke	0	37,652	146	69	0
Asphalt and road oil	0	25,716	1,676	0	0
Still gas	0	29,109	0	0	0
Miscellaneous products	0	3,177	98	46	0
Total	433,388	707,532	379,757	107,509	712,779

Notes: see next page.

The masses in this table are calculated by multiplying the volume of each product, from Table10-13a, by its density, in metric tons/bbl. The densities are as follows:

<i>material</i>	<i>density</i>	<i>reference</i>
Crude oil	0.1379	Calculated from the formula: $\text{kg/l} = 1/((\text{API}+131.5)/141.5)$, where API is the weighted-average API gravity of crude oil input to refineries in 1991 (31.64; EIA, <i>Petroleum Supply Annual 1991</i> , 1992)
Pentanes plus	0.0996	density of pentane (<i>CRC Handbook of Chemistry and Physics</i> , 1984)
Ethane/ethylene	0.0909	density of ethane (<i>CRC Handbook of Chemistry and Physics</i> , 1984)
Propane/propylene	0.0924	assume density is closer to that of propane than that of propylene (<i>CRC Handbook of Chemistry and Physics</i> , 1984)
Normal butane/butylene	0.0930	assume density in between that of butane and that of butene (<i>CRC Handbook of Chemistry and Physics</i> , 1984)
Isobutane	0.0873	density of isobutane (<i>CRC Handbook of Chemistry and Physics</i> , 1984)
Other hydrocarbons/alcohol	0.1224	typical density of olefins and alcohols
Unfinished oils	0.1378	assume the density of crude oil
Motor gasoline blending components	0.1217	these are mainly naphthas, so assume the density of naphtha
Aviation gasoline blending components	0.1217	these are mainly naphthas, so assume the density of naphtha
Finished motor gasoline	0.1172	EIA, <i>International Energy Annual 1993</i> (1995)
Finished aviation gasoline	0.1124	EIA, <i>International Energy Annual 1993</i> (1995)
Jet fuel, naphtha type	0.1209	EIA, <i>International Energy Annual 1993</i> (1995)
Jet fuel, kerosene type	0.1261	EIA, <i>International Energy Annual 1993</i> (1995)
Kerosene	0.1294	EIA, <i>International Energy Annual 1993</i> (1995)
Distillate fuel oil	0.1340	EIA, <i>International Energy Annual 1993</i> (1995)
Residual fuel oil	0.1502	EIA, <i>International Energy Annual 1993</i> (1995)
Naphtha for petrochemical feedstock	0.1217	EIA, <i>International Energy Annual 1993</i> (1995)
Other oils for petrochemical feedstock	0.1340	these have a boiling range similar to that of distillates, so assume the density of distillate fuel oil
Special naphthas	0.1217	EIA, <i>International Energy Annual 1993</i> (1995)
Lubricants	0.1429	EIA, <i>International Energy Annual 1993</i> (1995)
Waxes	0.1271	EIA, <i>International Energy Annual 1993</i> (1995)
Petroleum coke	0.1815	EIA, <i>International Energy Annual 1993</i> (1995)
Asphalt and road oil	0.1650	EIA, <i>International Energy Annual 1993</i> (1995)
Still gas	0.1378	density calculated from data in DeLuchi (1993)

Miscellaneous products 0.1244 EIA, *International Energy Annual 1993* (1995)

^aI define the Middle East to include the members of Arab OPEC, plus Bahrain, Egypt, Oman, Syria, and Yemen.

TABLE 10-14. ALLOCATION OF DOMESTIC CRUDE OIL, IMPORTED CRUDE OIL AND PRODUCTS, AND IMPORTED CRUDE OIL AND PRODUCTS FROM THE MIDDLE EAST, TO SIX CLASSES OF MOTOR VEHICLES, 1991 (10³ METRIC TONS, EXCEPT AS NOTED)

<i>Line</i>	Gasoline vehicles			Diesel vehicles			Total
	<i>LDAs</i>	<i>LDTs</i>	<i>HDVs</i>	<i>LDAs</i>	<i>LDTs</i>	<i>HDVs</i>	
1	70.23	28.77	3.37	0.65	0.71	24.83	128.56
2	0.686	0.281	0.033	0.025	0.027	0.948	n.a.
3	196,023	80,308	9,397	2,070	2,278	79,259	369,335
4	182,913	74,937	8,768	2,070	2,278	79,259	350,226
5L	124,381	50,957	5,963	1,408	1,549	53,896	238,153
5H	73,165	29,975	3,507	828	911	31,703	140,090
6L	0.333	0.137	0.016	0.004	0.004	0.144	0.638
6H	0.196	0.080	0.009	0.002	0.002	0.085	0.375
7L	14,180	5,810	680	145	160	5,552	26,526
7H	39,846	16,325	1,910	435	479	16,650	75,645
8L	0.132	0.054	0.006	0.001	0.001	0.052	0.247
8H	0.370	0.152	0.018	0.004	0.004	0.155	0.703
9L	58,532	23,980	2,806	662	729	25,363	112,072
9H	109,748	44,962	5,261	1,242	1,367	47,555	210,135
10L	60,758	24,892	2,913	662	729	25,363	115,317
10H	112,067	45,913	5,372	1,242	1,367	47,555	213,516
11L	0.160	0.066	0.008	0.002	0.002	0.067	0.303
11H	0.295	0.121	0.014	0.003	0.004	0.125	0.562
12L	10,884	4,459	522	0	0	0	15,865
12H	10,790	4,421	517	0	0	0	15,728

Notes (explanations of lines): In the following, I will refer to pentanes plus, normal butane/butylene, isobutane, and other hydrocarbons/alcohol as “non-crude gasoline constituents”, or NCGCs.

1. Volume of highway fuel consumed (10⁹ gallons) (Table 10-3).
2. Fraction of total gasoline or diesel highway fuel consumed (Table 10-3).
3. Mass of highway fuel consumed (Line 1 · density [metric-ton/bbl]; density from Table 10-13b).

4. Mass of crude oil embodied in highway fuel (gasoline: $\text{Line 3} \cdot 0.933$; diesel: Line 3). See the discussion in the text.
- 5L. Mass of domestic crude oil embodied in highway fuel (low). Line 4 multiplied by the “low” fraction of embodied crude oil that is domestic. See the discussion in the text.
- 5H. Mass of domestic crude oil embodied in highway fuel (high). (Line 4 multiplied by the “high” fraction of embodied crude oil that is domestic. See the discussion in the text.
- 6L. Line 5L as a fraction of total domestic crude oil produced (total from Table 10-13b).
- 6H. Line 5H as a fraction of total domestic crude oil produced (total from Table 10-13b).
- 7L. Mass of crude oil and unfinished oil imported from the Middle East and used to make highway fuel, plus mass of finished motor gasoline and distillate fuel imported from Middle East and used as highway fuel, plus mass of NCGCs and motor-gasoline blending components imported from the Middle East and used to make highway fuel (low). I assume that 95% to 99% of finished motor gasoline, NCGCs, and motor-gasoline blending components is or becomes gasoline used by highway vehicles, and that 36% to 56% of distillate fuel is or becomes diesel fuel used by highway vehicles. (The ratio of highway-gasoline use to total motor-gasoline use is 0.97 [FHWA, *Highway Statistics 1991, 1992*], and the ratio of highway consumption of diesel fuel [FHWA, *Highway Statistics 1991, 1992*] to total supply of distillate fuel [EIA, *Petroleum Supply Annual 1991, 1992*] is 0.46.)
- 7H. Mass of crude oil and unfinished oil imported from the Middle East and used to make highway fuel, plus mass of finished motor gasoline and distillate fuel imported from Middle East and used as highway fuel, plus mass of NCGCs and motor-gasoline blending components imported from the Middle East and used to make highway fuel (high). See details for line 7L.
- 8L. Line 7L as a fraction of total imports of crude oil, unfinished oil, and petroleum products from the Middle East (total from Table 10-13b).
- 8H. Line 7H as a fraction of total imports of crude oil, unfinished oil, and petroleum products from the Middle East (total from Table 10-13b).
- 9L. Mass of foreign crude oil (including unfinished oil) embodied in highway fuel (low) (Line 4 - line 5L).
- 9H. Mass of foreign crude oil (including unfinished oil) embodied in highway fuel (high) (Line 4 - Line 5H).
- 10L. Line 9L, plus mass of NCGCs in imported finished highway gasoline or imported and used to make highway gasoline (low). As discussed in the text, I estimate that NCGCs constitute 6.7% of the mass of motor gasoline. I assume that 100% of the imported NCGCs are used to make motor gasoline, and that 95% to 99% of the motor gasoline is used by highway vehicles. Data on NCGCs are from Table 10-13b.
- 10H. Line 9H, plus mass of NCGCs in imported finished highway gasoline or imported and used to make highway gasoline (high). See explanation of Line 10L for details.
- 11L. Line 10L as a fraction of total imports of crude oil, unfinished oil, and petroleum products (total from Table 10-13b).
- 11H. Line 10H as a fraction of total imports of crude oil, unfinished oil, and petroleum products (total from Table 10-13b).

- 12L. Mass of domestic NCGCs in highway fuel (low) (Line 3- Line 5L- Line 10L). This is the calculated residual mass, which is presented here in order to show that the assumptions regarding the mass of domestic crude oil embodied in highway fuels do not result in a negative residual.
- 12H. Mass of domestic NCGCs in highway fuel (high) (Line 3- Line 5H- Line 10H). This is the calculated residual mass, which is presented here in order to show that the assumptions regarding the mass of domestic crude oil embodied in highway fuels do not result in a negative residual.