CALIFORNIA ENVIRONMENTAL PROTECTION AGENCY
AIR RESOURCES BOARD

TECHNICAL SUPPORT DOCUMENT FOR
STAFF PROPOSAL REGARDING REDUCTION OF GREENHOUSE GAS EMISSIONS FROM MOTOR VEHICLES

CLIMATE CHANGE EMISSIONS INVENTORY

August 6, 2004

AB 1493 Staff Report Technical Support Document

Climate Change Emissions Inventory

Introduction

AB 1493 requires the Air Resources Board to adopt regulations to reduce emissions from passenger vehicles, light-duty trucks, and other vehicles used for noncommercial personal transportation in California. An emissions inventory has been established to support the development of climate change emissions standards, estimation of early reduction credits, and estimation of emission reduction benefits. The inventory will include emissions from passenger cars and light-duty trucks up to 8500 lbs. gross vehicle weight rating (GVWR).

This section will discuss the pollutants included in the inventory, their relative global warming potentials, and the basis for estimating emissions of those pollutants from light-duty vehicles.

Background

Pollutant Species

Under the bill, Section 42801.1(g) of the California Health and Safety Code identifies specific climate change pollutants. These include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons and sulfur hexafluoride. In addition, the criteria pollutants[1] and black carbon have been evaluated for possible inclusion in the inventory.

After an extensive literature search and industry inquiries, we have found no evidence to suggest that perfluorocarbons and sulfur hexafluoride are associated with motor vehicles in California. Therefore, we have not included these species in the motor vehicle climate change inventory.

While the criteria pollutants are known to have global climate change impacts, there is no scientifically accepted quantification of their impact. The criteria pollutants are short-lived gases and particles, and not distributed uniformly in the atmosphere. Because of these characteristics, they have not been assigned global warming potential values. Because of the uncertainties surrounding the role of the criteria pollutants in global climate change, we have chosen not to include them in the inventory at this time.

[1] The criteria pollutants include reactive organic gases and oxides of nitrogen as precursors to ozone, and carbon monoxide, fine particulate matter, and oxides of sulfur.

Black carbon from combustion sources can absorb solar radiation, thereby warming the atmosphere. Most atmospheric measurements show that when black carbon is mixed with other aerosol material its radiative warming effect is considerably enhanced over that of black carbon existing as separate particles. Although the atmospheric warming effect of black carbon has been well established, what is not clear is what impact this has on climate forcing. Research continues into the climate forcing potential of black carbon. ARB does not propose its inclusion in the climate change emissions inventory at this time. ARB staff will continue to review the results from existing and ongoing studies and when sufficient progress is made, the black carbon emissions inventory will be revisited.

Relative Global Warming Potential

Each of the species included in the motor vehicle climate change inventory has a different effect on the Earth's radiative energy balance. The Intergovernmental Panel on Climate Change (IPCC) has developed the concept of Global Warming Potential (GWP) to compare the radiative forcing effect of different climate change pollutants. The GWP is the ratio of the global warming capability, or radiative forcing, of a gas relative to carbon dioxide. GWP is thus a measure of the potency of a gas in trapping atmospheric heat and warming the Earth. The GWP most frequently used is the 100-year GWP, which is calculated by integrating all the greenhouse effects of a gas over a 100-year period. The IPCC is constantly evaluating GWP values based on the latest published research. Table 1 presents the GWPs from the IPCC Third Assessment Report: Climate Change 2001.

Table 1
Global Warming Potentials from the Intergovernmental Panel on Climate Change Third Assessment Report (2001)

Gas	Global Warming Potential	
	20 years	100 years
Carbon Dioxide	1	1
Methane	62	23
Nitrous Oxide	275	296
HFC-134a	3300	1300

Estimating Climate Change Emissions

ARB has developed and used emissions inventories for many years in its efforts to attain and maintain health based air quality standards. We have used our existing, proven inventory tools to the fullest extent possible in the motor vehicle climate change inventory supporting AB 1493 implementation. This includes the EMFAC model currently used to estimate emissions for on-road vehicles in California. In addition to estimating emissions for criteria pollutants, EMFAC estimates emissions of carbon dioxide and methane.

EMFAC is a sophisticated mathematical model that divides on-road vehicles into thirteen classes including passenger cars, light- and heavy-duty trucks, buses, motor homes, and motorcycles. EMFAC can create an inventory for any calendar year from 1970 to 2040; each calendar year includes up to 45 vehicle model years. EMFAC includes vehicles that use gasoline, diesel fuel, and electricity as fuel sources. The model includes three exhaust processes (vehicle starts, running exhaust, and idling exhaust) and four evaporative processes (diurnal, hot soak, running losses, and resting losses).

EMFAC estimates emissions by multiplying a process rate, usually either grams per hour or grams per mile, by the number of vehicles or other unit of activity (such as vehicle mile of travel, or VMT). EMFAC then expresses the product as tons per day of emissions. Emission factors are usually derived from in-use vehicle testing by ARB and U.S. EPA. Vehicle populations are derived from the California Department of Motor Vehicles (DMV) registration data. Activity data are typically obtained from local transportation planning agencies, such as councils of government or metropolitan planning organizations. Other sources of input data are the California Department of Transportation, the Bureau of Automotive Repair, and instrumented vehicle surveys conducted by ARB and U.S. EPA.

The emission factors used in EMFAC are subject to a number of correction factors that adjust the base inventory to more accurately reflect emissions from real-world driving conditions. These adjustments accommodate a wide range of vehicle speeds, varying ambient air temperatures, varying fuel composition, use of air conditioning, varying soak time between starts, relative humidity, and altitude. The EMFAC model also includes the impact of deterioration on vehicle emissions control systems with accumulated miles traveled. The model includes the impact of the Smog Check vehicle inspection and maintenance program on emissions. Also reflected are changes in vehicle population and vehicle miles traveled (VMT) that occur over time, and changes in emissions due to changes in emissions standards. Documentation for the EMFAC model is available online at http://www.arb.ca.gov/msei/msei.htm.

As stated above, the EMFAC model currently estimates emissions for carbon dioxide and methane. These estimates are being used for the climate change inventory. EMFAC does not currently estimate emissions for nitrous oxide or hydrofluorocarbons. Until recently, little data have been available to estimate emission rates for these pollutants from motor vehicles. ARB has engaged in a series of research programs to gather additional data. The nitrous oxide research efforts and inventory development are discussed below. The HFC emissions inventory is discussed below and inventory development and research activities are detailed in the subsequent section, "HFC-134a Emissions from Light Duty Vehicles."

Initial Climate Change Inventory Workshop

A public workshop on the motor vehicle climate change inventory was held on December 3, 2002 to receive comments on staff findings and recommendations. At this workshop, staff presented a draft climate change inventory, highlighted data gaps in the existing inventory, and described the research programs proposed to fill in those data gaps. Workshop presentations are available online at http://arb.ca.gov/cc/cc.htm.

The Climate Change Emissions Inventory

Staff has estimated the baseline emissions from light duty vehicles for calendar years 2010, 2020, and 2030. These inventories are shown in Table 2. Table 3 shows these inventories in terms of total CO_2 equivalent emissions based on the global warming potentials previously discussed. These inventories represent what emissions from the light duty fleet would be without the proposed regulation and serve as a baseline from which to estimate the benefits of the proposed regulation. The following subsections describe how these inventories were developed and validated.

Inventory Development for Carbon Dioxide and Methane

We are using the EMFAC2002 mobile source emissions model, version 2.2 (Apr03), to estimate the inventory for carbon dioxide and methane. The EMFAC model estimates the emissions of carbon dioxide and methane based on data collected from in-use vehicle testing at ARB's Haagen-Smit laboratory as part of the light-duty vehicle surveillance program.

The amount of carbon dioxide and total hydrocarbons emitted from vehicle tailpipes and the total hydrocarbons emitted from evaporative processes are directly measured as vehicles are operated in the laboratory over various driving cycles that simulate real world conditions. Methane emission rates are derived from total hydrocarbon rates by the use of conversion factors based on speciation profiles. The development of these conversion factors is discussed in Appendix A.

EMFAC combines these emission rates with estimates of vehicle activity to calculate carbon dioxide and methane emissions in tons per day for a given calendar year.

Table 2
Baseline Inventory for Light Duty Motor Vehicles

Calendar Year 2010 Emissions in Tons per Day[2]				
	CH_4	**CO_2**	**N_2O**	**HFCs**
PC/T1 *(Passenger Cars and Trucks 0-3750 lb. LVW[3])*	26	296,320	12	4
T2 *(Trucks 3751 lb. LVW[3] - 8500 lb. GVWR[4])*	11	120,760	8	1
Total Light Duty	**37**	**417,080**	**20**	**5**
Calendar Year 2020 Emissions in Tons per Day[2]				
	CH_4	**CO_2**	**N_2O**	**HFCs**
PC/T1 *(Passenger Cars and Trucks 0-3750 lb. LVW[3])*	12	341,640	7	5
T2 *(Trucks 3751 lb. LVW[3] - 8500 lb. GVWR[4])*	7	143,510	4	2
Total Light Duty	**19**	**485,150**	**11**	**7**
Calendar Year 2030 Emissions in Tons per Day[2]				
	CH_4	**CO_2**	**N_2O**	**HFCs**
PC/T1 *(Passenger Cars and Trucks 0-3750 lb. LVW[3])*	8	390,600	5	6
T2 *(Trucks 3751 lb. LVW[3] - 8500 lb. GVWR[4])*	5	171,670	4	2
Total Light Duty	**13**	**562,270**	**9**	**8**

[2] Annual average
[3] Loaded vehicle weight equals curb weight plus 300 lb.
[4] There are a few vehicle models over 8,500 lbs. gross vehicle weight rating (GVWR) that are used for noncommercial transportation and are thus subject to the climate change regulations. Likewise, there are some vehicles weighing less that 8,500 lbs. that are used in commercial service. It does not appear possible to accurately identify these two sets of vehicles from license registration records. Because both sets of vehicles make up a very small portion of the light duty fleet, we believe that no significant error is introduced by defining the inventory as all vehicles up to 8,500 lbs.

Table 3
CO_2 Equivalent Inventory for Light Duty Motor Vehicles[5]

	2010 (tons per day)	2020 (tons per day)	2030 (tons per day)
PC/T1 *(Passenger Cars and Trucks 0-3750 lb. LVW[6])*	305,400	350,500	400,000
T2 *(Trucks 3751 lb. LVW[6] - 8500 lb. GVWR[7])*	124,800	146,900	175,500
Total Light Duty	**430,200**	**497,400**	**575,500**

For CO_2 and total hydrocarbons emissions tests included both the Federal Test Procedure (FTP) and the Unified Cycle (UC), which was developed to better match typical driving. Test data were split into three vehicle class groups, including light duty cars, light duty trucks, and medium duty vehicles. Vehicles were then split into their corresponding technology group, including non-catalyst, carbureted, throttle body, and multipoint fuel injected. The carbureted technology group includes carbureted vehicles with a catalyst, while the non-catalyst carbureted equipped vehicles were assigned to the noncatalyst technology group. Each technology group was further split into model year groups. The mean exhaust emission rates for CO_2 by vehicle class, technology group, and model year group, are shown in Table 1 in Appendix B.

With the vehicle fleet split into these unique technology groups, the emission rates in EMFAC assume that each group represents vehicles with distinct emission control technologies, similar in-use deterioration rates, and similar responses to repair. Further, vehicles in each technology group can be sub-divided into emission regimes. An emission regime is defined such that emissions from vehicles within the regime do not increase with mileage accumulation. The emissions characteristic of a vehicle technology group can be represented across these emission regimes, and vehicle deterioration can be simulated by the movement of vehicles among these regimes. In EMFAC, vehicles in each technology group are categorized into the following five regimes:

- Normals
- Moderates
- Highs
- Very Highs
- Supers

[5] Emissions have been rounded to four significant figures
[6] Loaded vehicle weight equals curb weight plus 300 lb.
[7] Gross vehicle weight rating

In general, normal vehicles are those that maintain their emission levels at or below the vehicle's FTP certification standards. Moderate vehicles have emission levels that are between one and two times the FTP standards. Highs, very highs, and super emission regimes have emissions levels that may be four, six, and seven or more times the FTP standards, respectively. As vehicles age (or accumulate mileage), their emissions increase as a result of deterioration, causing them to migrate from normal emitting regimes to higher emitting regimes. Additional information on the development of the emission rates used in EMFAC can be found in the EMFAC Technical Support Document available on-line at http://www.arb.ca.gov/msei/on-road/doctable_test.htm.

Carbon Dioxide Inventory Verification

The California Energy Commission (CEC), as required by Senate Bill 1771 (2000), develops a statewide inventory of greenhouse gases for both stationary and mobile sources. The CEC carbon dioxide inventory uses a top-down approach based on fossil fuel combustion and aggregates mobile sources into a broad transportation sector. Since the CEC is estimating emissions for the entire transportation sector, it is not possible to compare those emissions directly with our inventory for the light duty fleet. CEC does, however, estimate fuel consumption for the on-road fleet using the CALCARS estimation model. It is possible to use fuel consumption as a surrogate for carbon dioxide emissions and compare the fuel consumption estimates from CALCARS and EMFAC.

A comparison was made of the statewide fuel consumption estimated by each model for calendar years 2000, 2002, and 2010. For each year the entire light and medium duty fleet (cars and trucks up to 10,000 lbs. GVWR) for all model years was compared. In addition, for calendar year 2002 a comparison was made of just the model year 2000 light and medium duty fleet. Table 4 summarizes the percentage differences in gasoline consumption estimates for CALCARS relative to EMFAC.

Table 4
Comparison of CALCARS Model to EMFAC Model
Percent Difference in Gasoline Consumption
for CALCARS relative to EMFAC

	CY 2000	CY 2002	CY 2010
All Model Years	-6%	-4%	1%
Model Year 2000	--	17%	--

Based on this comparison:

- CALCARS and EMFAC give reasonable agreement when comparing gasoline consumption for the entire light/medium duty fleet.

- There was a greater difference between CALCARS and EMFAC when comparing gasoline consumption for a specific model year.

- Both models use fuel economy estimates to determines gasoline usage:
  - CALCARS calculates gasoline usage by combining VMT with fuel economy estimates developed from survey data.
  - EMFAC calculates gasoline usage by combining VMT with fuel economy estimates obtained by carbon balance on CO_2, CO, and HC emissions.

- VMT estimates used in CALCARS and EMFAC are derived using different methodologies and sources of data:
  - CALCARS VMT is estimated from vehicle population and mileage accrual rates, derived from socioeconomic indicators of how different types of households drive their vehicles.
  - EMFAC VMT estimates are developed by local and regional transportation planning agencies, using travel demand models validated with survey data and traffic counts. EMFAC also relies on Bureau of Automotive Repair (BAR) smog check odometer data.

Inventory Development for Nitrous Oxide

Nitrous Oxide (N_2O) emissions are produced by gasoline vehicles, and have been found to be higher from catalyst-equipped vehicles than vehicles without catalytic converters. Previous studies indicate that catalyst temperature is probably the most significant factor associated with the formation of N_2O over the catalyst surface. The ARB has collected N_2O emissions data from vehicles that have been tested as part of the ARB's 16th and 17th Vehicle Surveillance Projects (VSPs) at the Haagen-Smit Laboratory in El Monte, California.

The purpose of the emissions testing effort is to gain a better understanding of the factors that lead to the formation of N_2O, and to develop applicable emission factors that can be used to develop an emissions inventory.

The VSPs are conducted to measure in-use emissions from a fleet of light-duty gasoline vehicles including passenger cars and light-duty trucks up through 8,500 lb. GVWR. HC, CO, NO_x, and CO_2 emissions are measured as part of each VSP. Beginning with the 17th VSP, N_2O emissions measurements for all VSP vehicles have been added. N_2O emissions data collection and analysis methods are similar to methods employed for traditional exhaust emissions such as carbon dioxide and oxides of nitrogen. N_2O emissions are measured using Fourier transformation infrared (FTIR) spectroscopy.

The VSP test cycles include the light-duty Federal Test Procedure (FTP) and the Unified Cycle (UC). Integrated, by-phase emissions are being collected for each vehicle tested. This means that a single, separate emissions measurement is being made for each of the three phases (i.e., cold start, hot stabilized, and hot start) of the FTP and UC.

A pilot program was conducted during the 16th VSP and N_2O emissions were collected from 37 light duty cars and trucks. The nitrous oxide (N_2O) inventory presented at the December 2002 workshop was derived from this limited set of vehicle test data. N_2O emissions from the 300 vehicles being tested as part of the 17th VSP are being collected to expand the N_2O database. As of the time the N_2O emissions inventory for this report was prepared, over 100 light duty cars and trucks have been tested, ranging over model years 1981 to 2002, including vehicles from both the 16th and 17th VSPs. Additional N_2O data will be incorporated into ARB's inventory when it becomes available in the future.

Both the NOx and N_2O emission rates measured as part of the VSPs have been used to develop the N_2O inventory. Staff utilized statistical analysis software to discern whether a correlation existed between the grams per mile emission rate of NOx and the grams per mile emissions of N_2O. A polynomial fit of the data was judged the best, yielding an R^2 statistic of 0.40. The resulting correlation equation was then applied to the model year specific grams per mile NOx emission rates estimated by EMFAC 2002, version 2.2 (Apr03), in order to develop model year specific grams per mile N_2O emission factors. Each model year's N_2O emission factor was then multiplied by an estimate of miles per day driven by those model year vehicles during the calendar year to yield a tons per day inventory for N_2O.

Inventory Development for Hydrofluorocarbons

HFC-134a is directly emitted from mobile air conditioning (AC) systems. ARB staff has used calendar year 2003 data to estimate the average per-vehicle emissions of HFC-134a to be 80 grams per year. This emission rate is based on modeling of vehicle lifetime emissions and an analysis of the amounts of HFC-134a used by fleets. A detailed description of the development of this emission rate can be found in the section, "HFC-134a Emissions from Light Duty Vehicles."

We have used the 80 grams per vehicle per year emission rate with vehicle population estimates from EMFAC to develop the HFC-134a emissions inventory shown in Table 2. Some vehicles began using HFC-134a in the 1992 model year, but it was not until model year 1994 that all vehicles sold in the U.S used HFC-134a. We are basing emissions on the population of 1994 and newer cars and light trucks that are equipped with AC. Table 5 shows the values used by EMFAC for the fraction of vehicles equipped with air conditioning.

Table 5
Fraction of Vehicles Equipped with AC

Model Year	% Cars equipped with A/C	% Light Trucks equipped with A/C
94	93	86
95	94	89
96	95	91
97	97	93
98	98	95
99	98	95
00+	98	95

Emissions Benefits of Proposed Regulation

The emissions benefits are based on the projected reductions in CO_2 equivalent emission rates resulting from implementation of this proposed regulation. Using the results of modeling done by the Northeast States Center for a Clean Air Future (NESCCAF), and the proposed phase-in schedule for the regulation, ARB staff has estimated the percent reduction in CO_2 emissions rates by model year for those vehicles subject to the proposed regulation.[8] Table 6 shows the percentage reductions in CO_2 by model year and vehicle class.

[8] ARB staff has estimated the percent reduction in CO_2 emission rates using model year 2002 vehicles as a baseline.

Table 6
Impact of Proposed Regulation on Baseline CO_2 Emission Rates

	Model Year	Vehicle Class[9]	% Reduction
Near-term phase-in	2009	PC/T1	1.3%
		T2	2.1%
	2010	PC/T1	4.4%
		T2	5.5%
	2011	PC/T1	14.0%
		T2	11.8%
	2012	PC/T1	24.9%
		T2	18.3%
Mid-term phase-in	2013	PC/T1	26.7%
		T2	19.6%
	2014	PC/T1	28.5%
		T2	20.9%
	2015	PC/T1	31.2%
		T2	22.9%
	2016 and later	PC/T1	33.9%
		T2	24.8%

Staff has applied the percent reductions shown in Table 6 to the baseline CO_2 emissions by model year from the EMFAC2002 mobile source emissions model, version 2.2 (Apr03) for calendar years 2020 and 2030. Applying the percent reductions to emissions rather than emission rates assumes the emission rates in the model do not vary significantly by model year.[10] The calculated CO2 reductions are then subtracted from the baseline CO2 equivalent inventory presented in Table 3 to obtain the adjusted inventory that reflects the impact of the proposed regulation. Table 7 presents the baseline inventory, the adjusted inventory with the proposed regulation in place, and the estimated benefits of the regulation.

[9] PC/T1 = Passenger Cars (All) and Trucks 0-3750 lb. Loaded Vehicle Weight,
T2 = Trucks 3751 lb. Loaded Vehicle Weight - 8500 lb. GVWR

[10] CO2 emission rates for light duty vehicles vary less than 4% for model years 2002, 2010, 2020, and 2030 in EMFAC.

Table 7
Light Duty Fleet CO2 Equivalent Emissions and Reductions

Baseline Inventory without Proposed Regulation		
	2020 (tons per day)	**2030 (tons per day)**
PC/T1 *(Passenger Cars and Trucks 0-3750 lb. LVW[11])*	350,500	400,000
T2 *(Trucks 3751 lb. LVW[11] - 8500 lb. GVWR[12])*	146,900	175,500
Total Light Duty	**497,400**	**575,500**
Adjusted Inventory with Proposed Regulation		
	2020 (tons per day)	**2030 (tons per day)**
PC/T1 *(Passenger Cars and Trucks 0-3750 lb. LVW[11])*	282,600	281,500
T2 *(Trucks 3751 lb. LVW[11] - 8500 lb. GVWR[12])*	127,400	139,500
Total Light Duty	**410,000**	**421,000**
Emissions Reductions for Proposed Regulation		
	2020 (tons per day)	**2030 (tons per day)**
PC/T1 *(Passenger Cars and Trucks 0-3750 lb. LVW[11])*	67,900	118,500
T2 *(Trucks 3751 lb. LVW[11] - 8500 lb. GVWR[12])*	19,500	36,000
Total Light Duty	**87,400**	**154,500**

[11] Loaded vehicle weight equals curb weight plus 300 lb.
[12] Gross vehicle weight rating

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HFC-134a Emissions from Light Duty Vehicles

Introduction

This section focuses on the emissions of refrigerant HFC-134a from the air conditioners of light-duty vehicles. We also discuss other uses and emission sources of HFC-134a.

In this section, vehicular air conditioners are termed “MACS” (for “mobile air conditioning systems”).

After the 1994 model year, all vehicles sold in the U.S. have used HFC-134a as the refrigerant. The earliest model year to use HFC-134a was 1992. The refrigerant is emitted via gradual leakage, releases during accidents and other events in which the containment is breached, and releases when vehicles are scrapped without recovery of the refrigerant.

HFC-134a emissions from MACS need to be assessed for two purposes: estimating current annual emissions and estimating the benefits of control measures that may be employed in model year 2009 and subsequent vehicles. “Annual emissions” refers to the emission *rate* (e.g., mass/year) averaged over the actual on-road vehicle population at some specific time (in this case, the calendar year 2003). In contrast, the effect of a regulation should be assessed on the basis of cumulative *lifetime* emissions from a typical or “average” vehicle. Total lifetime emissions should be considered because (1) emissions can be a strong function of age, and (2) reducing the emission rate during the life of a vehicle will provide no benefit if the retained refrigerant is released to the atmosphere when the vehicle is scrapped.

Emissions of Refrigerant from Light-Duty MACS

The leakage of refrigerant from MACS may vary substantially by design of the system, vehicle age, maintenance practice, model year, and operating environment. Little is known about the effects of these variables.

Some direct measurements of leakage rates (i.e., grams per day) from vehicles are available. (See “Previous Work by Others”, Section A to Appendix C.3.) However, these data, like any other laboratory test data that could be generated today, are just “snapshots” of emissions specific to isolated values of the presumed variables. They would have to be very numerous to span the scope of the variables. The leak rate data now on hand are too few and restricted in scope to enable quantification of leakage from the on-road population with good confidence. One important limitation of the existing data from vehicles is that none have been taken with the AC compressor in operation.

The lack of sufficient emission-rate test data has prompted the staff to consider, instead, various data related to the long-term loss of charge from aggregations of vehicles. The data are of these types:

1. Measurements of the loss of charge in many MACS over time (Two such studies done in Europe are described in Section A of Appendix C.3.)
2. Data on refrigerant consumption by fleets
3. Data from fleets and commercial repair shops on refrigerant capacities and amounts per recharge
4. Responses by vehicle owners to surveys on repair incidence

These data reflect refrigerant losses accumulated over substantial in-use periods for large aggregations of vehicles. The data span the entire range of useful lives of vehicles.[13] Thus, although they do not report actual emission rates, they reflect leakage integrated over a wide spectrum of real-world effects for in-use vehicles and over all stages of vehicular life. We believe that our analyses of these data provide the most robust emission estimates that are now possible. The analyses are described in Section B of Appendix C.3, "Quantification of Vehicular HFC Emissions".

With data of types 2 through 4, we have developed a model for the average lifetime emissions of refrigerant from HFC-134a vehicles of ~2000 MY and estimates of on-road emissions in 2003. Limited data of type 1 appear to be consistent with our results. (See the end of Section B.)

The form of the lifetime emission model is:

$$LVE = C * (1 - g + N * f)$$

where: LVE is the lifetime vehicular emissions (mass)

C is the system capacity (mass) for HFC-134a

"1" represents the initial charge

g is the fraction (of a full charge) recovered by the dismantler at scrapping

N is the number of times a vehicle is recharged during its life

f is the fraction of a full charge missing (leaked) before the recharge

[13] However, they do not span the eventual lifetimes of vehicles with *original* HFC-134a systems because the oldest such vehicle was only ten years old at the time of our analysis. (To represent older HFC-134a vehicles, our analysis uses data from older vehicles that have been converted to HFC-134a.)

The lifetime to which the model applies is 16 years, which is the average vehicle lifetime derived from the "survival fractions" in EMFAC.

The model is a mass balance that is valid and exact for any vehicle. It equates lifetime emissions to the sum of all charges of refrigerant to the vehicle less any recovery at dismantling. To apply the model to reflect the "average" vehicle, each parameter in the model has been estimated separately by averaging data from various sources specific to that parameter. The averages we have derived are:

C = 951 $\pm$ 254 (std. dev.) grams

g = 0.085 fraction recovered at scrapping

N = 1.0 lifetime (16 years) recharge per vehicle [14]

f = 0.52 $\pm$ .35 (std. dev.) fraction empty before recharging

These values applied in the mass balance result in the approximation:

LVE = 1.36 kg per 16-year lifetime

Also, we have estimated the average per-vehicle emissions in 2003 by an analysis related to the derivation of the lifetime emission model and by analyzing the amounts of HFC-134a used by fleets. The common result of the two analyses is:

Annual emissions in 2003 $\simeq$ 80 grams per HFC-134a vehicle.

Part of the emissions occur during accidental breaches of MACS (sometimes termed "irregular emissions"), as distinct from gradual leakage ("regular emissions") and from releases at dismantling. The data that support our emission estimates do not allow us to isolate the accidental emissions from leakage. However, some other information on this subject is presented of Appendix C.3 C, "Analyses of the Effects of Control Measures".

Our estimates reflect only emissions from HFC-134a vehicles and fugitive emissions incidental to professional servicing. They do not include emissions due to wastage during "do-it-yourself" repairs of vehicles with HFC-134a systems or due to leakage from vehicles with Freon systems that are recharged with HFC-134a. These matters are discussed qualitatively in the next section.

However, our estimates do include fugitive losses associated with professional servicing. That is so because our data record the amounts of HCF-134a expended during service, which includes the fugitive losses as well as

[14] Note that while for any single vehicle, N is limited to integral values (0, 1, 2, etc,), the average over a large population is not so limited; the coincidence of this average with an integer is happenstance.

replenishment of what had already leaked from the serviced vehicles. If they occur, fugitive losses should inflate somewhat the apparent values of C and f.

Other Uses and Emissions of HFC-134a

<u>Uses</u>

According to the United Nations Environmental Programme [15], HFC-134a has several uses in addition to automotive air conditioning:

- commercial (retail sales) refrigerators
- refrigerated trucks
- domestic refrigerators
- industrial refrigerators
- manufacture of closed-cell foam insulation
- miscellaneous uses (~20% of total use[16]); includes propellant in consumer products

Some of the use occurs in mixtures of refrigerants.

In 2000, the production of HFC-134a in the northern hemisphere was reported to be about 127,000 metric tons.[16] If use is distributed geographically according to national economic output [17], the use of HFC-134a in the U.S. was about 36,000 metric tons.

Although we have few data on the use rates of HFC-134a, it appears that automotive air conditioning accounts for the major part of the total use. The Mobile Air Conditioning Society estimated use of HFC-134a by commercial AC repair shops in the U.S. at about 7,000 metric tons in 2000.[18] Some unknown additional amount was used in fleet maintenance and do-it-yourself “top-offs”. (See the last section, below.) If the approximately 20 million new vehicles (including heavy-duty vehicles) sold annually in the U.S. have an average HFC-134a capacity of 1,000 grams, the annual consumption by vehicle manufacturers is about 20,000 metric tons. Thus, the total HFC-134a use related to automotive air conditioning may have been 27,000+ metric tons in 2000. (Compare to 36,000 tons, total estimated use.)

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[15] Montreal Protocol on Substances That Deplete the Ozone Layer, “2002 Report of the Refrigeration, Air Conditioning and Heat Pumps Technical Options Committee”

[16] Information from the Alternate Fluorocarbon Environmental Feasibility Study (AFEAS)

[17] According to Energy Information Administration, “International Energy Annual 2001”, Table B2, the US accounted for 28% of total GDP in the northern hemisphere in 2000.

[18] MACS, “Mobile Air Conditioning and the Environment” May 2002.

There are four major producers of HFC-134a, all international companies with U.S. operations.

Retail Sales of HFC-134a; "Excess" Emissions

HFC-134a is sold at retail in small (usually 12-ounce) cans. It is legally used by vehicle owners in "do-it-yourself" (DIY) vehicle repairs of HFC-134a vehicles. Also, it is likely used to refill MACS that are intended to receive "Freon" (R-12) refrigerant.[19] The unavailability of Freon at retail and the low price of HFC-134a are powerful incentives for owners of old vehicles to use the HFC-134a if they must replenish leaked Freon and do not want to incur the cost of leak repair.

Per serviced vehicle, emissions from the DIY activity may exceed substantially the average emissions deduced by the ARB staff from data taken from professionally serviced vehicles. Some of the excess emissions are releases that do not occur during professional service. They include the escape of the charge in the MAC when it is breached (illegally) for repair and the residuals in the 12-ounce cans that are used to refill the system. According to estimates published by the Mobile Air Conditioning Society,[20] from 2 to 10 percent of each can is unrecoverable, and the final can may still contain half its content when the system is full. Presumably, the residuals eventually escape from the discarded cans.

In addition to the fugitive releases, there may be excess leakage of HFC-134a from DIY vehicles that are recharged without repair of the leaking components, including the components of Freon systems that are operated with HFC-134a.

There are no substantiated estimates of the overall importance of the excess DIY emissions. We have only incomplete data on the amount of HFC-134a that is sold in California at retail. However, an upper limit on those emissions may be estimated as follows.

The U.S. EPA[21] has published estimates of emissions of HFC-134a from mobile sources (leaks and servicing emissions) for 1995 to 2001 that the ARB staff has extrapolated to about 21,000 metric tons in 2003 in the U.S. We estimate in this report that the average emission rate from HFC-134a vehicles in use in California is 80 grams per year. Assuming that there are about 150 million HFC-134a vehicles in the U.S. (ten times the California population) and applying the staff's estimate of 80 grams/yr yields 12,000 metric tons in the U.S. per year. This suggests that 9,000 metric tons (about 40% of the EPA's total emission figure) might be unaccounted by the staff's 80-gram estimate.

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[19] This practice is illegal by federal regulation unless the Freon has been removed first.

[20] "Mobile Air Conditioning Systems and the Environment", May 2002.

[21] Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 2001, Final Version, EPA 430-R-03-004, April 2003. Note: Estimates for HFC-134a published in this document are less than what EPA published in earlier inventories.

Neither the inputs nor the data sources for the EPA model are public information. Thus, the apparent excess over the staff's estimate is highly uncertain and should be viewed as only a rough estimate. The ARB staff continues to seek information to refine the numbers, and we will welcome the receipt of such information.

If the 9,000 metric tons is a valid figure and ten percent (900 tons) is attributable to emissions in California, there are about 2 million "excess" pounds of HFC-134a released in California per year, about 70 grams per light-duty HFC-134a vehicle. This material can be attributed to five sources:

1. replenishment of leakage from light-duty HFC-134a vehicles*,* in excess of 80 grams/year/vehicle accounted by the staff's estimate
2. replenishment of leakage in vehicles with Freon systems that operate on HFC-134a (either with or without conversion to HFC-134a systems)
3. replenishment of leakage from medium- and heavy-duty vehicles
4. residuals in 12-ounce cans
5. replenishment of MACS charges that are released without recovery during DIY repairs or improperly done professional repairs
6. other fugitive releases during servicing

Information on potential sources 3 through 6 is as follows.

3. Med. & heavy-duty vehicles -- In California, these vehicles number about 0.15 times the light-duty population. Thus the leakage from them may be about 15% of the total emissions, equivalent to an extra 0.15 * 80 = 12 grams for each light-duty vehicle.

4. Can residuals -- The Mobile Air Conditioning Society has estimated that the residuals in cans from a system fill is between 2 and 18 percent of the cans' contents. At the mid-point value (10 percent), 0.2 million of the 2 million excess pounds are non-vehicular emissions *if* the excess material comes in the cans. This is equivalent to about 7 grams/year/light-duty HFC-134a vehicle on the road.

5. Repairs without recovery -- If the average system content that is released without recovery is the same as the mean value of "f" in our analysis, about 500 grams are released, which equals about 38% of the average lifetime vehicular leakage and (per repair) about 31 grams per year of a 16-year average vehicle life. We do not know how many repairs are conducted without recovery. <u>Assume</u> they are equivalent to 10 percent of all repairs to vehicles containing

HFC-134a.[22] Then, these excess emissions would be equivalent to about 3 grams/year/light-duty HFC-134a vehicle on the road.

6. Other fugitives -- From our observations of professional repairs, the fugitive emissions are very small when the repair is done correctly.

Thus, if the U.S. EPA's estimate of vehicular HFC-134a emissions is correct (which cannot be assessed), the major part of the excess emissions, perhaps around 70 - 12 - 7 - 3 =~ 50 grams/year/ light-duty HFC-134a vehicle, would be attributed to the sum of potential sources 1 and 2, above.
Allocating this possible 50 grams between sources 1 and 2 is difficult. ARB staff has heard anecdotally that Freon vehicles (potential source 2) are replenished with HFC-134a and that Freon vehicles are leakier than HFC-134a vehicles. However, there are no data on the subject; so, there is no basis to estimate the magnitude of potential source 2. Thus, it can only be said that 50 grams/year/vehicle is an upper bound on the possible excess emissions from DIY activity over the estimated 80 grams per year emitted per light-duty HFC-134a vehicle. As noted above, the existence of any excess is based in part on the U.S. EPA's emission estimates, whose validity cannot be examined.

Other Emission Sources

HFC-134a is emitted during the manufacture and packaging of the refrigerant, initial filling of MACS, and during the maintenance of vehicular MACS. A 2003 report for the European Commission[23] (EC) summarizes relevant information in addition to the empirical work on leakage summarized elsewhere in this report and the ARB staff's leakage analysis. The following table summarizes the findings in the EC report. The numbers are uncertain because of a paucity of data and some reliance on proprietary data. The ranges are large because of uncertainty about how various cases analyzed in the source documents relate to typical practices.

The analyses reviewed in the EC report were mostly done in Europe. The latter fact is particularly salient for the estimates of AC servicing emissions, which apparently reflect operations that do not comply with the requirements placed by the U.S. EPA on the practices and equipment at commercial AC repair shops and fleet maintenance shops. If, as seems likely, the tabulated AC servicing emissions are too high to apply in the US, the total effect of the three sources is very small compared to the 1.4 system capacities (1.36 kg / 951 grams capacity) that we have estimated for the average lifetime loss from vehicles.

[22] That is: releases from HFC-134a vehicles + releases from Freon vehicles that contain HFC-134a = 0.1 * recharges of HFC-134a vehicles = 0.1 * 951 * .52 * 1 per lifetime/16

[23] Barrault, S. et al; "Analysis of the Economic and Environmental Consequences of a Phase-Out or Considerable Reduction Leakage of Mobile Air Conditioners", European Commission, February 2003.

Conclusions by Barrault et al. on Fugitive Emissions (in Europe)

	Loss as Fraction of Avg. MAC Capacity	ARB Staff's Comment
Manufacturing & packaging	1 to 5%	Based on 1 U.S. plant with good operational practice. The values 1% and 5% represent (respectively) the cases that distributors do not or do release the heels in containers returned to them. Such release is illegal in the U.S.
AC servicing	10 to 20%	Very inconsistent with U.S. regulations and ARB staff's observations of shop practices
Initial vehicle fill	(not discussed)	The EC estimate for recharging loss is 0.2%.

Existing Regulation of MACS Refrigerants

Until the 1992 model year, all vehicular air conditioners used the compound CFC-12 (aka: dichlorofluoromethane and Freon®) as the refrigerant. CFC-12 participates in the depletion of the stratospheric ozone layer. Therefore, an international agreement, the Montreal Protocol, required the phase-out of production of CFCs (chlorofluorocarbons) by 1996 and requires a phase-out of other compounds by 2030.[24] Worldwide, automakers chose HFC-134a as the replacement for MACS.

In 1991, Assembly Bill 859 required the Air Resources Board to adopt a regulation to phase-out CFC-12 in new California vehicles by January 1, 1995. The Board adopted the regulation into Section 2300, Chapter 8, Title 13 of the California Code of Regulations. It required that the phase-out begin with the 1993 model year. (Some manufacturers produced some 1992 models with HFC-134a.)

The U.S. Environmental Protection Agency (U.S. EPA), under Section 612 of the Clear Air Act, administers the Significant New Alternatives Policy (SNAP) program. SNAP identifies alternatives to ozone-depleting substances and publishes lists of compounds that are legally acceptable or unacceptable in specific uses. The criteria of acceptability include environmental and human health factors. HFC-134a has been approved by U.S. EPA as an automotive refrigerant, but HFC-152a has not been addressed. (No manufacturer has applied for its approval in automotive use.) Several other compounds or mixtures are approved as automotive refrigerants and may be bought at retail. However, it is illegal to mix refrigerants in a system.

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[24] The deadlines in 1996 and 2000 apply to the "developed" nations. Other nations have a slower phase-out and still produce some CFC-12.

Regulations by the USEPA require that no automotive refrigerant shall be vented to the atmosphere during service of the air conditioner. Evacuation of the system must be into a USEPA-approved recovery device, and recovered refrigerant must be either recharged to a vehicle, sent to a certified reclaimer, or destroyed. Commercial service of air conditioners must be done by a certified technician. No refrigerant may be put into any vehicle unless that vehicle already is charged with the same refrigerant or the original refrigerant has been evacuated.

Despite these strictures, SNAP does not forbid the retail sale of HFC-134a and SNAP-approved alternatives to personal vehicle owners, who have no means to comply with the recovery requirements.

The European Parliament has adopted a prohibition of HFC-134a in new vehicles in model years 2011 and 2012. After 2012, only refrigerants with GWPs less than 50 would be allowed. This will admit CO_2 but not HFC-152a (GWP = 150). This decision does not yet have the force of law.

Austria has already banned all HFCs (including 152a) as refrigerants in new vehicles after 2008.

Effects of Possible Control Measures

Re-designing HFC134a Systems

One potential measure for reducing the climate-change effect of refrigerant emissions is to design and assemble AC systems so that less HFC-134a will be emitted. Two approaches to better design could be followed. They would affect different modes of emission.

1. Reducing the thermal demand on the AC system so that its size and (thus) its charge of refrigerant can be reduced. The reduction in the charge would reduce the amount of refrigerant suddenly released if the vehicle has an accident or the system is accidentally breached in some other way.
2. Improving "leak-tightness" so that leakage by mechanisms such as permeation and passage through seals, gaskets, and couplings would be reduced.

Apparently, most attention is being paid to improved leak-tightness. There is not a clear prospect for reducing sudden releases of refrigerant.

The value of improved leak-tightness would depend on the diligence with which auto dismantlers recover the refrigerant from vehicles when they reach their ends of life. As discussed in Section B of Appendix C.3, the staff doubts that most recoverable HFC-134a is actually recovered by dismantlers.

If there were no recovery at all, the refrigerant that would be retained by a more leak-tight system would all be released at scrapping. With no recovery, a reduction in the leak rate would be beneficial only if the reduction would be enough to eliminate a recharging event. In that case, the residual amount in the system at the end of life could be less than if a recharge had occurred. To the extent that recovery actually occurs, improved leak-tightness would reduce lifetime emissions but less than in proportion to the improvement in leak-tightness.

Thus, there are two factors that limit the benefit of improved leak-tightness in terms of the total lifetime emissions from MACS: the existence of sudden leakage (sometimes termed “irregular emissions”) due to accidental breaches of MACS and the incomplete recovery of refrigerant that would be retained in the systems.

The net effect of some degree of reduction of slow leakage (sometimes termed “regular emissions”) is very complex to model because the population is composed of vehicles with widely different characteristics related to lifetime emissions. We have analyzed the effect for two special example vehicles:

- a vehicle that behaves as does the “average” current vehicle represented by the lifetime emission model (described in “HFC-134a Emissions from Light- and Medium-Duty Vehicles”), receiving one lifetime recharge
- a vehicle that receives no recharges

Also, we have made an estimate based on the “N’ analysis” that is presented in above in this document. The analyses are in Section C of Appendix C.3, “Analyses of Effects of Control Measures”.

In these analyses , the overall reduction of emissions from a 50-percent reduction of slow leakage (“regular emissions”) ranges from 13% to 18%. None of the three example estimates is both rigorous and encyclopedic in its treatment of the vehicle population. However, the three results suggest that the effect of improving the leak-tightness of MACS would be much less than the nominal degree of leakage control.

<u>Changing Refrigerant</u>

If a refrigerant with a GWP less than that of HFC-134a were used, the harmful effect of all emissions associated with MACs would be reduced in proportion to the GWP. The refrigerants that could be used in place of HFC-134a in the next decade are HFC-152a (GWP = 120) and CO_2 (GWP = 1). If the mass rates of emissions would not change relative to HFC-134a, the effects of changing refrigerant would be equivalent to a 91% emission reduction in the case of HFC-152a and virtually 100% in the case of CO_2.

Emissions of CO_2 could be higher than emissions of HFC-134a. However, such an increase could not seriously reduce the benefit from the 1300-fold reduction of GWP. Mass emissions of HFC-152a would likely be less than those of HFC-134a. Because of very similar systems, the volumetric emission rate should not be greater for HFC-152a than for HFC-134a. However, the lower molecular weight of the HFC-152a would provide lower mass emissions.

Appendix A

FACTORS FOR CONVERTING TOTAL HYDROCARBON EMISSION RATES TO TOG/ROG/CH4

This section describes the factors used in determining the fraction of total hydrocarbons (THC) that are comprised of total organic gases (TOG), reactive organic gases (ROG), and methane (CH4).

Introduction

During exhaust or evaporative emissions testing conducted during the Federal Test Procedure (FTP), the hydrocarbon emissions are measured using a flame ionization detector (FID). The FID measures total hydrocarbons or compounds with hydrogen and carbon atoms only; carbonyls are not included in THC. This is reflected in the exhaust and evaporative emission rates, which are measurements of THC. TOG includes all organic gases emitted to the atmosphere. ROG is the fraction of TOG that is reactive and does not include compounds that are exempt from regulations, i.e., methane, ethane, and acetone. The fraction of TOG that is either THC or ROG is determined by examination of the speciation profiles.

Methodology

In the EMFAC model, there are 13 vehicle classes (Table 1) with each vehicle class having up to six emission processes: starting, running exhaust, hot soak, diurnal, resting loss, and running loss emissions. Ideally, given sufficient speciation data, one could derive conversion factors that are vehicle class, emissions process and fuel (pre and post cleaner burning gas or clean diesel) dependent. However, because of insufficient data, the conversion factors (Table 2) cover several vehicle classes and technology groups. For example, the THC to TOG equation for running exhaust emissions is assumed to be the same for both catalyst and non-catalyst equipped vehicles, and across all vehicle classes. This assumption results from the fact that speciation tests have not been performed on non-catalyst equipped vehicles, other than passenger cars or light-duty trucks.

The conversion factors shown in Table 2 are valid to 0.1 g/mi. THC. Below this value, the conversion factors can be unreliable. The model is coded to generate the same conversion factors assuming 0.1 g/mi. for THC for emission rates below this level.

Table 1 Vehicle Classes in EMFAC2000

Vehicle Class	Fuel	Code	Description	Weight Class
1	ALL	PC	PASSENGER CARS	ALL
2	ALL	T1	LIGHT-DUTY TRUCKS	0- 3750
3	ALL	T2	LIGHT-DUTY TRUCKS	3751- 5750
4	ALL	T3	MEDIUM-DUTY TRUCKS	5751- 8500
5	ALL	T4	LIGHT-HEAVY DUTY TRUCKS	8501-10000
6	ALL	T5	LIGHT-HEAVY DUTY TRUCKS	10001-14000
7	ALL	T6	MEDIUM-HEAVY DUTY TRUCKS	14001-33000
8	ALL	T7	HEAVY-HEAVY DUTY TRUCKS	33001-60000
9	ALL	T8	LINE-HAUL VEHICLES	60001+
10	DSL	UB	URBAN BUSES	ALL
11	ALL	MC	MOTORCYCLES	ALL
12	ALL	SB	SCHOOL BUSES	ALL
13	ALL	MH	MOTOR HOMES	ALL

Table 2 TOG/ROG/CH4 Conversion Factors					
Vehicle Class	Fuel Code	Fuel Type	Technology Group	Emissions Process	Equation
1,2,3,4,5,6,7, 8,9,11,12,13	Gasoline	Pre-Cleaner Burning Gas	Catalyst	Running Exhaust	TOG = 0.00721572 + 1.04581*THC + 0.000596997/(THC) – 0.000107319/(THC^2) ROG = TOG{0.915753 – 0.0570135/(THC) – 0.00469847/(THC^2) + 0.0008465052/(THC^3)} CH4 = TOG{0.0627696 + 0.0584035/(THC) + 0.00476385/(THC^2) – 0.000860145/(THC^3)}
" "	" "	" "	" "	Starting	TOG = 1.0324 * THC ROG = 0.9230 * TOG = 0.95291 * THC CH4 = 0.0624 * TOG = 0.06442 * THC
" "	" "	" "	" "	Hot Soak	TOG = 1.0026 * THC ROG = 1.0000 * TOG = 1.0026 * THC CH4 = 0.0000 * TOG = 0.0000 * THC
" "	" "	" "	" "	Running Loss	TOG = 1.0026 * THC ROG = 1.0000 * TOG = 1.0026 * THC CH4 = 0.0000 * TOG = 0.0000 * THC
" "	" "	" "	" "	Diurnal	TOG = 1.0380 * THC ROG = 1.0000 * TOG = 1.0380 * THC CH4 = 0.0000 * TOG = 0.0000 * THC
" "	" "	" "	" "	Resting Loss	TOG = 1.0380 * THC ROG = 1.0000 * TOG = 1.0380 * THC CH4 = 0.0000 * TOG = 0.0000 * THC

1,2,3,4,5,6,7, 8,9,11,12,13	Gasoline	Pre-Cleaner Burning Gas	Non - Catalyst	Running Exhaust	TOG = 0.00721572 + 1.04581*THC + 0.000596997/(THC) – 0.000107319/(THC^2) ROG = TOG{0.915753 – 0.0570135/(THC) – 0.00469847/(THC^2) + 0.0008465052/(THC^3)} CH4 = TOG{0.0627696 + 0.0584035/(THC) + 0.00476385/(THC^2) – 0.000860145/(THC^3)}
" "	" "	" "	" "	Starting	TOG = 1.0361 * THC ROG = 0.8957 * TOG = 0.92803 * THC CH4 = 0.0935 * TOG = 0.09687 * THC
" "	" "	" "	" "	Hot Soak	TOG = 1.0026 * THC ROG = 1.0000 * TOG = 1.0026 * THC CH4 = 0.0000 * TOG = 0.0000 * THC
" "	" "	" "	" "	Running Loss	TOG = 1.0026 * THC ROG = 1.0000 * TOG = 1.0026 * THC CH4 = 0.0000 * TOG = 0.0000 * THC
" "	" "	" "	" "	Diurnal	TOG = 1.0380 * THC ROG = 1.0000 * TOG = 1.0380 * THC CH4 = 0.0000 * TOG = 0.0000 * THC
" "	" "	" "	" "	Resting Loss	TOG = 1.0380 * THC ROG = 1.0000 * TOG = 1.0380 * THC CH4 = 0.0000 * TOG = 0.0000 * THC
1,2,3,4,5,6,7, 8,9,11,12,13	Gasoline	Cleaner Burning Gas	Catalyst	Running Exhaust	TOG = 0.0115168 + 1.05894*THC - 0.00129204/(THC) + 5.66768E-05/(THC^2) ROG = TOG{0.95015 – 0.105111/(THC) + 0.012543/(THC^2) - 0.000616031/(THC^3)} CH4 = TOG{0.0356821 + 0.106396/(THC) - 0.0125986/(THC^2) – 0.000613197/(THC^3)}
" "	" "	" "	" "	Starting	TOG = 1.0641 * THC ROG = 0.9366 * TOG = 0.99664 * THC CH4 = 0.0528 * TOG = 0.05618 * THC
" "	" "	" "	" "	Hot Soak	TOG = 1.0644 * THC ROG = 1.0000 * TOG = 1.0644 * THC

					$CH4 = 0.0000 * TOG = 0.0000 * THC$
" "	" "	" "	" "	Running Loss	$TOG = 1.0644 * THC$ $ROG = 1.0000 * TOG = 1.0644 * THC$ $CH4 = 0.0000 * TOG = 0.0000 * THC$
" "	" "	" "	" "	Diurnal	$TOG = 1.1248 * THC$ $ROG = 1.0000 * TOG = 1.1248 * THC$ $CH4 = 0.0000 * TOG = 0.0000 * THC$
" "	" "	" "	" "	Resting Loss	$TOG = 1.1248 * THC$ $ROG = 1.0000 * TOG = 1.1248 * THC$ $CH4 = 0.0000 * TOG = 0.0000 * THC$
1,2,3,4,5,6,7, 8,9,11,12,13	Gasoline	Cleaner Burning Gas	Non - Catalyst	Running Exhaust	$TOG = 0.0115168 + 1.05894*THC - 0.00129204/(THC) + 5.66768E\text{-}05/(THC^2)$ $ROG = TOG\{0.95015 – 0.105111/(THC) + 0.012543/(THC^2) - 0.000616031/(THC^3)\}$ $CH4 = TOG\{0.0356821 + 0.106396/(THC) - 0.0125986/(THC^2) – 0.000613197/(THC^3)\}$

Appendix B

CO_2 BASE EMISSION RATES

Introduction

This section explains the derivation of the passenger car (PC), light duty truck (LDT) and medium duty truck (MDT) gasoline and diesel carbon dioxide (CO_2) base emission rates (BERs) incorporated in the EMFAC model. These base emission rates are for the Unified Cycle (UC) and the Federal Test Procedure (FTP).

Gasoline PC, LDT and MDT CO_2

The analysis was conducted on data from surveillance and UC research test projects that included an FTP and a corresponding UC for each vehicle. The surveillance tests included projects 2S93C1, 2S95C1, and 2S97C1. Surveillance Project 2S97C1 was in progress during the analysis, so only data collected through March 11, 1999 were included. The research test projects included 2R9312, 2R9513, and 2R9811. Tests were also prescreened to determine if there was a corresponding UC for every FTP. Only baseline exhaust emission results were used for the analysis.

The data were split into three vehicle class groups, including light duty cars, light duty trucks, and medium duty vehicles. Standard vehicle class definitions were used.

Vehicles were then split into their corresponding technology and model year groups. Four technology groups were used, including non-catalyst, carbureted, throttle body, and multi-point fuel injected. The carbureted technology group includes carbureted vehicles with a catalyst, while the non-catalyst carbureted equipped vehicles were assigned to the non-catalyst technology group.

Each technology group was further split into model year groups. The non-catalyst group contained only one model year group for vehicles less than or equal to the 1979 model year. The carbureted technology group includes model year group splits of 1975 to 1980, 1981 to 1985, and greater than or equal to the 1986 model year. The throttle body technology group was split into three model year groups that included less than or equal to 1980, 1981 to 1984, and greater than or equal to the 1985 model year. The fuel injection technology group was split into four model year groups that included less than or equal to 1980, 1981 to 1985, 1986 to 1992, and greater than or equal to the 1993 model year.

The mean exhaust emission rates for CO_2 by vehicle class, technology group, and model year group are shown in Table 1. The CO_2 exhaust emission rates have been determined for bags one, two and three of the FTP and for bags one and two of the UC. For each vehicle class, technology group, and model year group combination, the ratio of its CO_2 bag emission rates to the corresponding PC vehicle class bag emission rates were also determined. These ratios were used to adjust the PC base emission rates (similar to “ratio of the standards” adjustments) to be consistent with how EMFAC2002 handles hydrocarbons (HC), carbon monoxide (CO) and oxides of nitrogen (NOx). Careful examination of Table 1 shows that for several of the LDT and MDV technology/model year groupings, insufficient data were available to determine meaningful mean FTP and UC emissions. For these groups, staff used their judgment as to the most appropriate ratio. Note that each Technology Group in Table 1 has a number associated with it (in parentheses). These numbers are used in conjunction with Table 2 to map to EMFAC technology groups. The ratios are applied to each regime.

Table 1 Gasoline CO_2 Base Exhaust Emission Rates.

Vehicle Class	Tech Group	Model Year Group	FTP Bag 1 CO_2 (g/mi)	FTP Bag 2 CO_2 (g/mi)	FTP Bag 3 CO_2 (g/mi)	UC Bag 1 CO_2 (g/mi)	UC Bag 2 CO_2 (g/mi)	Ratio FTP Bag 1 CO_2 (g/mi)	Ratio FTP Bag 2 CO_2 (g/mi)	Ratio FTP Bag 3 CO_2 (g/mi)	Ratio UC Bag 1 CO_2 (g/mi)	Ratio UC Bag 2 CO_2 (g/mi)
PC	CB (7)	75_TO_80	565.003	548.018	492.284	848.013	524.852	1.000	1.000	1.000	1.000	1.000
PC	CB (8)	81_TO_85	386.298	392.103	336.312	597.765	363.154	1.000	1.000	1.000	1.000	1.000
PC	CB (9)	GE____86	339.043	342.227	294.719	526.110	320.738	1.000	1.000	1.000	1.000	1.000
PC	FI (1)	81_TO_85	438.143	437.199	372.958	669.262	403.968	1.000	1.000	1.000	1.000	1.000
PC	FI (2)	86_TO_92	403.625	412.167	350.430	630.219	380.286	1.000	1.000	1.000	1.000	1.000
PC	FI (3)	GE____93	382.104	390.171	330.001	613.298	359.311	1.000	1.000	1.000	1.000	1.000
PC	FI (4)	LE____80	456.434	458.658	399.755	700.804	444.563	1.000	1.000	1.000	1.000	1.000
PC	NC (10)	LE____79	531.379	533.908	470.196	775.012	500.514	1.000	1.000	1.000	1.000	1.000
PC	TB (5)	81_TO_84	490.818	506.503	426.637	778.659	454.627	1.000	1.000	1.000	1.000	1.000
PC	TB (6)	GE____85	395.071	394.943	340.523	620.788	368.565	1.000	1.000	1.000	1.000	1.000
LDT	CB (7)	75_TO_80	551.944	557.559	481.999	799.516	516.415	0.977	1.017	0.979	0.943	0.984
LDT	CB (8)	81_TO_85	475.414	482.079	417.758	715.870	450.645	1.231	1.229	1.242	1.198	1.241
LDT	CB (9)	GE____86	431.495	449.432	383.052	664.956	413.640	1.273	1.313	1.300	1.264	1.290
LDT	FI (1)	81_TO_85	395.021	386.901	353.039	598.550	392.158	0.902	0.885	0.947	0.894	0.971
LDT	FI (2)	86_TO_92	501.600	473.622	440.456	730.175	468.251	1.243	1.149	1.257	1.159	1.231
LDT	FI (3)	GE____93	491.438	484.795	424.401	751.564	463.967	1.286	1.243	1.286	1.225	1.291
LDT	FI (4)	LE____80						0.902	0.885	0.947	0.894	0.971
LDT	NC (10)	LE____79	517.370	508.583	475.965	765.559	491.444	0.974	0.953	1.012	0.988	0.982
LDT	TB (5)	81_TO_84						1.207	1.245	1.233	1.186	1.214
LDT	TB (6)	GE____85	476.997	491.805	419.732	736.015	447.597	1.207	1.245	1.233	1.186	1.214
MDV	CB (7)	75_TO_80	758.334	757.851	680.104	1027.239	663.853	1.342	1.383	1.382	1.211	1.265
MDV	CB (8)	81_TO_85	667.630	622.117	563.320	982.126	610.185	1.728	1.587	1.675	1.643	1.680
MDV	CB (9)	GE____86						1.728	1.587	1.675	1.643	1.680
MDV	FI (1)	81_TO_85						1.572	1.350	1.592	1.431	1.649
MDV	FI (2)	86_TO_92	634.404	556.395	557.818	902.014	627.115	1.572	1.350	1.592	1.431	1.649
MDV	FI (3)	GE____93	692.183	634.684	606.174	979.587	662.343	1.812	1.627	1.837	1.597	1.843
MDV	FI (4)	LE____80						1.572	1.350	1.592	1.431	1.649
MDV	NC (10)	LE____79	747.185	732.107	683.418	1082.332	704.537	1.406	1.371	1.453	1.397	1.408
MDV	TB (5)	81_TO_84						1.762	1.696	2.192	1.669	1.778

MDV	TB (6)	GE____85	695.968	669.791	746.257	1036.150	655.345	1.762	1.696	2.192	1.669	1.778

Table 2 EMFAC Technology Groups

MAP_Grp	Tech Grp	Model Yr		Description
10	1	<75	LDV	no AIR
10	2	<75	LDV	with AIR
10	3	75+	LDV	noncatalyst
7	4	75-76	LDV	OxCat with AIR
7	5	75-79	LDV	OxCat no AIR
8	6	80+	LDV	OxCat no AIR
7	7	77+	LDV	OxCat with AIR
7	8	77-79	LDV	TWC TBI/CARB
5	9	81-84	LDV	TWC TBI/CARB 0.7 Nox
6	10	85+	LDV	TWC TBI/CARB 0.7 Nox
4	11	77-80	LDV	TWC MPFI
1	12	81-85	LDV	TWC MPFI 0.7 NOx
2	13	86+	LDV	TWC MPFI 0.7 NOx
5	14	81+	LDV	TWC TBI/CARB 0.4 Nox
1	15	81+	LDV	TWC MPFI 0.4 NOx
7	16	1980	LDV	TWC TBI/CARB
6	17	93+	LDV	TWC TBI/CARB .25 HC
3	18	93+	LDV	TWC MPFI .25 HC
6	19	96+	LDV	TWC TBI/CRB .25 OBD2
3	20	96+	LDV	TWC MPFI .25HC OBD2
3	21	94-95	LDV	TLEV MPFI .25HC
3	22	96+	LDV	TLEV OBD2 GCL
3	23	96+	LDV	LEV OBD2 GCL CBC AFC
3	24	96+	LDV	ULEV OBD2 GCL CBC AFC
	25	ALL	ZEV	
3	26	96+	LDT	TWC MPFI OBD2 .7NOx
6	27	96+	LDT	TWC TBI/CARB OBD2

Diesel PC, LDT and MDT CO_2

To derive CO_2 BERs from diesel vehicles, 138 light-to-medium duty vehicles from CARB's surveillance database were analyzed. The fleet was comprised of 29 pre-1981 vehicles, 89 1981-1983 vehicles, and 20 1984-1985 vehicles. There were an insufficient number of trucks to analyze separately, so the vehicles were collapsed into one class for analysis. Although these data were collected in the early 1980s, staff believe that these results are valid for vehicles operating currently, since staff analyzed the CO_2 data and found no deterioration with age or odometer. Additionally, since these data pre-date the LA92/UC cycle, it is assumed that the FTP and UC rates are equivalent
(Table 3).

Table 3 Diesel PC, LDT and MDT FTP/UC CO_2 BERS (grams/mile)

		BAG 1		BAG 2		BAG 3	
CLASS	MY	ZM	DR	ZM	DR	ZM	DR
PC DSL CO2	1965-74	392.430	0.000	455.100	0.000	375.130	0.000
	1975-79	392.430	0.000	455.100	0.000	375.130	0.000
	1980	392.430	0.000	455.100	0.000	375.130	0.000
	1981-83	381.160	0.000	437.550	0.000	364.870	0.000
	1984-85	345.720	0.000	397.840	0.000	329.880	0.000
	1986	345.720	0.000	397.840	0.000	329.880	0.000
	1987-95	345.720	0.000	397.840	0.000	329.880	0.000
	1996+	345.720	0.000	397.840	0.000	329.880	0.000
LDT DSL CO2	1965-74	392.430	0.000	455.100	0.000	375.130	0.000
	1975-79	392.430	0.000	455.100	0.000	375.130	0.000
	1980	392.430	0.000	455.100	0.000	375.130	0.000
	1981-83	381.160	0.000	437.550	0.000	364.870	0.000
	1984-85	345.720	0.000	397.840	0.000	329.880	0.000
	1986	345.720	0.000	397.840	0.000	329.880	0.000
	1987-95	345.720	0.000	397.840	0.000	329.880	0.000
	1996+	345.720	0.000	397.840	0.000	329.880	0.000
MDT DSL CO2	1965-74	392.430	0.000	455.100	0.000	375.130	0.000
	1975-79	392.430	0.000	455.100	0.000	375.130	0.000
	1980	392.430	0.000	455.100	0.000	375.130	0.000
	1981-83	381.160	0.000	437.550	0.000	364.870	0.000
	1984-85	345.720	0.000	397.840	0.000	329.880	0.000
	1986	345.720	0.000	397.840	0.000	329.880	0.000
	1987-95	345.720	0.000	397.840	0.000	329.880	0.000
	1996+	345.720	0.000	397.840	0.000	329.880	0.000