Examination of Temperature and RVP Effects on CO Emissions in EPA's Certification Database

Final Report
CRC Project No. E-74a

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April 11, 2005

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Index of Acronyms and Abbreviations Used in This Report

AIR	Air Improvement Resource, Inc.
ARB	(California) Air Resources Board
ASTM	American Society of Testing and Materials
CARB	California Air Resources Board
CNG	Compressed Natural Gas
CO	carbon monoxide
CRC	Coordinating Research Council, Inc.
CVS	Constant Volume Sampler
CY	Calendar Year
EEE	EPA's Unleaded or Indolene gasoline
EPA	(United States) Environmental Protection Agency
ETW	(Design) Equivalent Test Weight
FTP	Federal Test Procedure
g/mi	grams per mile
GM	General Motors
HC	hydrocarbons
LA92	Los Angeles 92, California inventory test cycle
LDGV	Light-Duty Gasoline Vehicle
LDT	Light-Duty Truck
LEV	Low-Emission Vehicle
MOBILE	EPA's Highway Vehicle Emissions Model
MOVES	MOtor Vehicle Emission Simulator Model (EPA's)
MTBE	methyl tertiary butyl ether
NAAQS	National Ambient Air Quality Standards
NLEV	National Low-Emission Vehicle
NOx	oxides of nitrogen
PC	Passenger Car
ppm	parts per million
psi	pounds per square inch
PZEV	Partial-Zero Emission Vehicle
RFG	ReFormulated Gasoline
RFP	Request For Proposal
RVP	Reid Vapor Pressure or volatility
SULEV	Super-Ultra-Low Emission Vehicle
TLEV	Transitional-Low Emission Vehicles
ULEV	Ultra-Low Emission Vehicle
WSPA	Western States Petroleum Association

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1.0 Executive Summary

Although the number of areas still out of attainment with the ambient air quality standard for carbon monoxide (CO) has been steadily declining, there remain a number of cities that require wintertime gasoline formulations designed to reduce mobile source CO emissions. In most cases, these wintertime gasoline programs consist of a prescribed minimum oxygen content required during specified months. Two of these cities, Phoenix and Las Vegas, enforce a vapor pressure cap of 9.0 psi in addition to a minimum 3.5 wt % oxygen content as a part of their winter gasoline programs.

Ambient air quality monitoring data show that neither Phoenix nor Las Vegas has had an exceedance of the CO standard for at least five years. This fact has prompted the local air quality agencies to apply to the EPA for redesignation to attainment status for CO. EPA requires that areas submit a maintenance plan along with such requests for redesignation. The maintenance plan must demonstrate that CO emissions will not increase in future years such that the area will once again experience exceedances of the subject air quality standard.

EPA requires states to use the most current version of EPA's MOBILE emissions factors model to predict impacts on the local mobile source inventory of any proposed modifications to its fuels program. In the case of Phoenix and Las Vegas, MOBILE6 was used, and it predicted that relaxing the current winter 9.0 psi vapor pressure cap would result in substantial increases in CO emissions. Specifically, for a relaxation from 9 psi to 13.5 psi, which is the maximum RVP contained in the ASTM D4814 specification for the subject winter months, MOBILE6 suggests CO emissions would increase by about 45%.

Given this large predicted increase in CO emissions, the responsible agencies in Arizona and Nevada do not feel they can relax their winter vapor pressure requirements, and have, therefore, submitted maintenance plans that include continuation of the existing wintertime gasoline requirements for vapor pressure and oxygen content. However, examination of the MOBILE6 model has shown that the CO emissions versus RVP relationship is based on tests on early 1980s vehicles. It is not known whether these effects can really be applied to Tier 1 and more advanced technology vehicles on the road today.

While a testing program could be run to evaluate these issues, CRC decided to first conduct an analysis of vehicle emission certification data to see what could be gleaned from these data. During certification, vehicles are tested at different temperatures and at different RVPs, and these data are submitted to the various regulatory agencies and are available for analysis. The objective of this effort is to determine if the EPA certification data can be used to evaluate the temperature and RVP effects on CO, and if not, to assist in deciding how to conduct a testing program on more recent vehicles.

AIR first analyzed the MOBILE6 model at different temperatures and RVPs to evaluate the combined effects. This analysis showed that there are really two different CO effects in MOBILE6. Lower temperatures increase CO emissions due to the cold start effect. But at moderate and higher temperatures, higher fuel volatilities also increase CO emissions, according to MOBILE6. The mechanism for these higher CO emissions is what we call the “purge” effect, which is a shift in fuel/air ratio due to purging fuel vapor from the vehicle’s gas tank, when fuel volatilities are higher than 9 RVP. At moderate temperatures, vehicle operation can heat fuel in the tank, causing fuel vapor to flow from the tank through the canister and into the engine. It is primarily this purge effect that causes higher CO emissions in Phoenix and Las Vegas during wintertime temperatures.

AIR obtained the certification data from the EPA, and information on certification fuels from both EPA and some of the vehicle manufacturers. AIR assembled a certification database to examine both RVP and temperature effects on CO emissions. Results of our analysis of this database revealed the following:

- The certification database can be used to examine cold temperature effects.

- Analysis of the temperature effects showed an increase in CO emissions at colder temperatures for all vehicles. However, the increase in emissions for advanced technology vehicles was much less than for older technology vehicles.

- A comparison of the CO emission increases in the database and the MOBILE6 model indicates that EPA’s cold CO estimates are appropriate for Tier 1 vehicles, but over predict CO emissions at colder temperatures for LEV and Tier 2 vehicles. AIR believes these certification results could be used to update the MOBILE6 model, and that such an update would result in lower CO emissions at colder temperatures than the current model.

- Most of the CO increases at lower temperatures occur at temperatures below 50° F. There appears to be very little increase in CO emissions between 75° F and 50° F, regardless of vehicle class or technology.

- The certification database could not be used to examine the purge effects, but could be used to examine the effects of RVP on CO at 75º F.

- Fuel volatility increases between 7 RVP and 9 RVP have little effect on CO emissions at 75° F. This is consistent with the MOBILE6 model, because the MOBILE model predicts CO increases only at volatilities above 9 RVP.

- AIR recommends conducting a testing program primarily to evaluate the purge effect. Vehicles of Tier 1 and later technologies would be tested at temperatures of 40° F and higher, and fuel volatilities of 9 RVP and higher. Some of these fuels should include oxygenates.

2.0 Introduction

Although the number of areas still out of attainment with the ambient air quality standard for carbon monoxide (CO) has been steadily declining, there remain a number of cities that require wintertime gasoline formulations designed to reduce mobile source CO emissions. In most cases, these wintertime gasoline programs consist of a prescribed minimum oxygen content required during specified months. Two of these cities, Phoenix and Las Vegas, enforce a vapor pressure cap of 9.0 psi in addition to a minimum 3.5 wt % oxygen content as a part of their winter gasoline programs.

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While a testing program could be run to evaluate these issues, CRC decided to first conduct an analysis of vehicle emission certification data to see what could be gleaned from these data. During certification, vehicles are tested at different temperatures and at different RVPs, and these data are submitted to the various regulatory agencies and are available for analysis. The objective of this effort is to determine if the EPA certification data can be used to evaluate the temperature and RVP effects on CO, and if not, to assist in deciding how to conduct a testing program on more recent vehicles.

This report is divided into the following sections. The Background section discusses causes of higher CO emissions, and what EPA's MOBILE6 predicts as the temperature and RVP effects on CO emissions. The Methods section discusses the formation of the certification database for analyzing CO emissions at different temperatures and RVPs. The Results section discusses the results of the analysis of the certification database. Finally, the Discussion section summarizes the major results, and discusses the implications of these results for a potential vehicle testing program.

3.0 Background

The Western States Petroleum Association (WSPA) hired Sierra Research to evaluate selected areas in the western states which still have wintertime gasoline programs aimed at reducing CO emissions, with an eye to identifying areas where reclassification to attainment status for the CO NAAQS appeared feasible and where wintertime gasoline programs might reasonably be suspended. [1] As a part of that evaluation, Sierra Research was also asked to evaluate the MOBILE6 model as regards to its treatment of CO emissions. [2]

Sierra's analysis of MOBILE6 identified two significant problems with the way in which the model predicts CO emissions. First, Sierra found that the model predicts that CO emissions from newer NLEV and Tier 2 vehicles will be the same as older Tier 1 vehicles, despite the fact that both certification and in-use emissions data from such vehicles clearly demonstrate that they emit at substantially lower levels than Tier 1 vehicles. This problem was pointed out to the EPA, and they acknowledged that corrections to the model were in order. The recently released MOBILE6.2 model appears to incorporate changes partially addressing this problem, by lowering the CO emissions of "normal emitting" LEV and Tier 2 vehicles. [3]

AIR also recently reviewed the CO corrections in the final MOBILE6.2 model for the Alliance of Automobile Manufacturers (The Alliance). AIR found that while the corrections implemented by the EPA were appropriate, there are other corrections to CO emissions that could have been made as well so that the whole CO modeling approach is consistent**.** AIR found that while EPA modified the normal emitter emission rates, it did not modify the "high emitter" CO emission rates. EPA did modify the high emitter emissions rates for HC and NOx for the lower NLEV and Tier 2 standards, so modifying the high emitter emission rates for CO would have been consistent with their overall modeling approach. A second item overlooked is that NLEV and Tier 2 vehicles getting I/M repairs are repaired only to the Tier 1 level, instead of the NLEV or Tier 2 level, as they are for HC and NOx. Finally, EPA did not change the "cold CO offsets"[1] for NLEVs and Tier 2 vehicles. The certification data, however, indicate that, much like the 75°F data, the cold CO offsets for NLEVs and Tier 2 vehicles are lower than for Tier 1 vehicles. Thus, the changes implemented by EPA for CO emissions in the final version of MOBILE6.2 only address a part of the CO over prediction problem.

The second significant problem with MOBILE6 treatment of CO emissions identified by Sierra concerns the correlation in the model between vapor pressure, temperature, and vehicle CO emissions. What Sierra found is that the vapor pressure/T/CO correlation in MOBILE6 is the same as that used in MOBILE5 and MOBILE4. The present correlation is based upon data acquired on early 1980s vehicle technology. This does not make the correlation wrong by itself, but with the number of emissions improvements since the 1980s, it is very likely that this particular correlation has changed significantly.

[1] Most of the temperature correction factors in MOBILE are multiplicative. The exception is CO, where CO emissions in g/mi are added to the 75F emissions to predict emissions at lower temperatures. These are referred to as "cold CO offsets," and they vary with temperature.

3.1 Causes of High CO Emissions

Aside from vehicles malfunctioning[2] and becoming high CO emitters, there are several factors that can increase CO emissions from on-road gasoline vehicles. First, there is temperature. At lower temperatures, combustion is less complete until the engine is warmed-up; consequently, fuel/air ratios are higher to improve engine starting. Also, the catalytic converter is not yet warmed up. This leads to the "cold-start" effect, which increases CO emissions. There are cold CO emissions standards for 1994 and later cars and light trucks that, along with tighter HC standards at warm temperatures, have resulted in significantly lower cold start emissions for 1994 and later vehicles.

Another factor that can lead to increased CO emissions at warmer temperatures is high RVP fuels, at least in older vehicles. Prior to the enhanced evaporative standards that were implemented in the 1990s, the evaporative systems on 1980s and early 1990s vehicles were relatively simple, consisting of a charcoal canister connected to the fuel tank, with a purge line for the charcoal canister attached to the engine. At warm ambient temperatures, gasoline in the tank could get significantly heated by the exhaust system, and by recirculating fuel from the fuel delivery system. As this fuel was heated, more vapor would be created in the tank. This gasoline vapor would flow through the canister and into the engine where it would be burned. Higher volatility fuels produce more gasoline vapor at the same temperatures. If the pressure in the fuel tank became too high, pressure relief valves would allow the vapor to escape, leading to "running losses." In 1980 vehicles, the oxygen sensors used were not necessarily capable of quickly adjusting the air fuel ratio to the engine in response to the extra gasoline vapor flowing in from the fuel tank. This would cause higher fuel/air ratios during combustion, thereby increasing CO emissions. We refer to this effect in this paper as the "purge" effect.

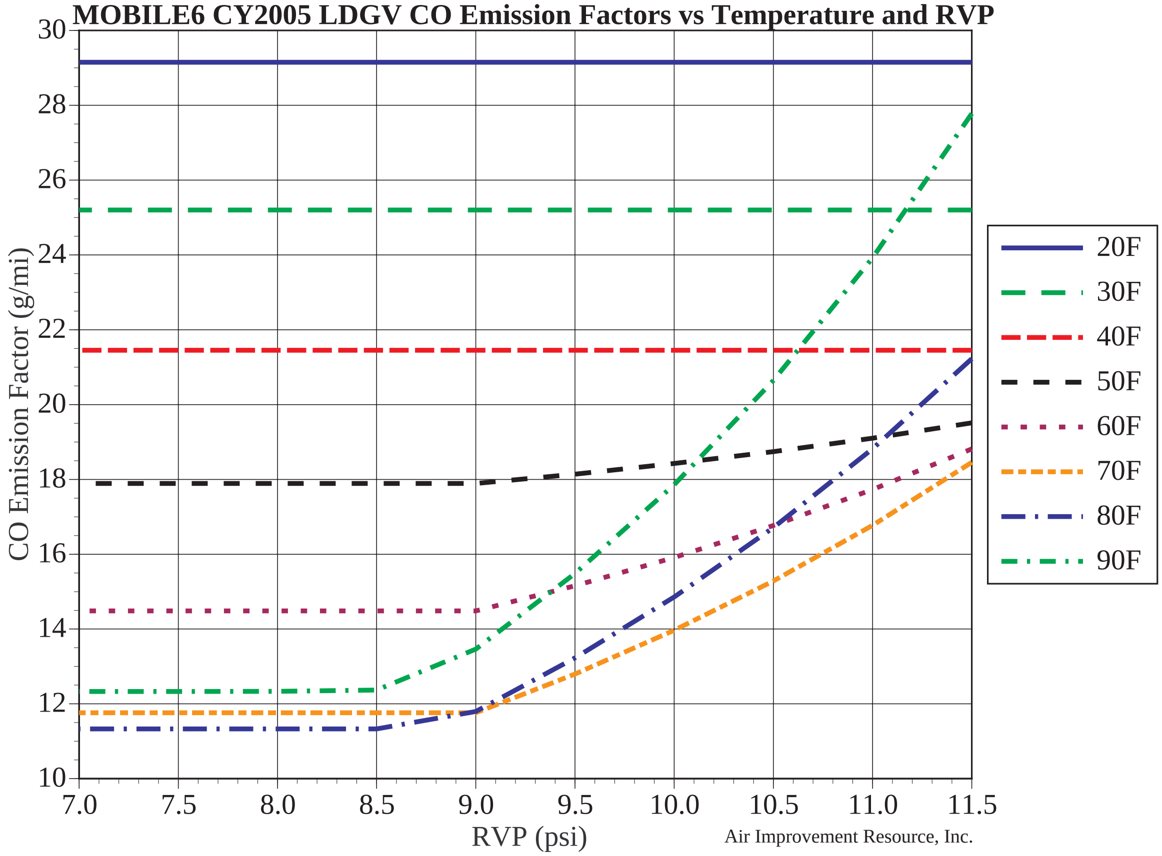
There are other factors that can increase CO emissions, for example, high sulfur fuels used in Tier 1, Low Emission Vehicles (LEVs), and Tier 2 vehicles can increase CO emissions by reducing catalytic converter activity. However, the Tier 2/low sulfur fuel regulations are significantly reducing gasoline sulfur levels, so this should no longer be a factor.

The cold start effect and the purge effect are shown in Figure 1. In this analysis, AIR varied both temperature and fuel volatility in the final MOBILE6.2 model for the 2005 calendar year light-duty gasoline vehicle (LDGV) fleet. Speeds were MOBILE6 default, and operating modes included both cold start and warmed-up driving. Temperatures were varied from 20º F to 90º F, and gasoline RVPs were varied between 7 and 11.5 psi.

[2] Malfunctions that increase CO emissions would be the loss of air/fuel ratio control for any reason, and catalytic converter malfunction.

Figure 1.

MOBILE6 CY2005 LDGV CO Emission Factors vs Temperature and RVP



The results show both effects. Examination of the RVP levels between 7 and 9 show that as temperature is reduced, CO emissions increase significantly, revealing the cold start effect. For example, at 70º F, MOBILE6 predicts that CO emissions from the LDGV fleet are about 12 g/mi. This increases to 29 g/mi at 20º F. Since this is the 2005 fleet, it would include vehicles from 1980-2005 model years. The older vehicles would have higher CO emissions than the newer ones, especially since the newer ones are subject to the cold CO standards.

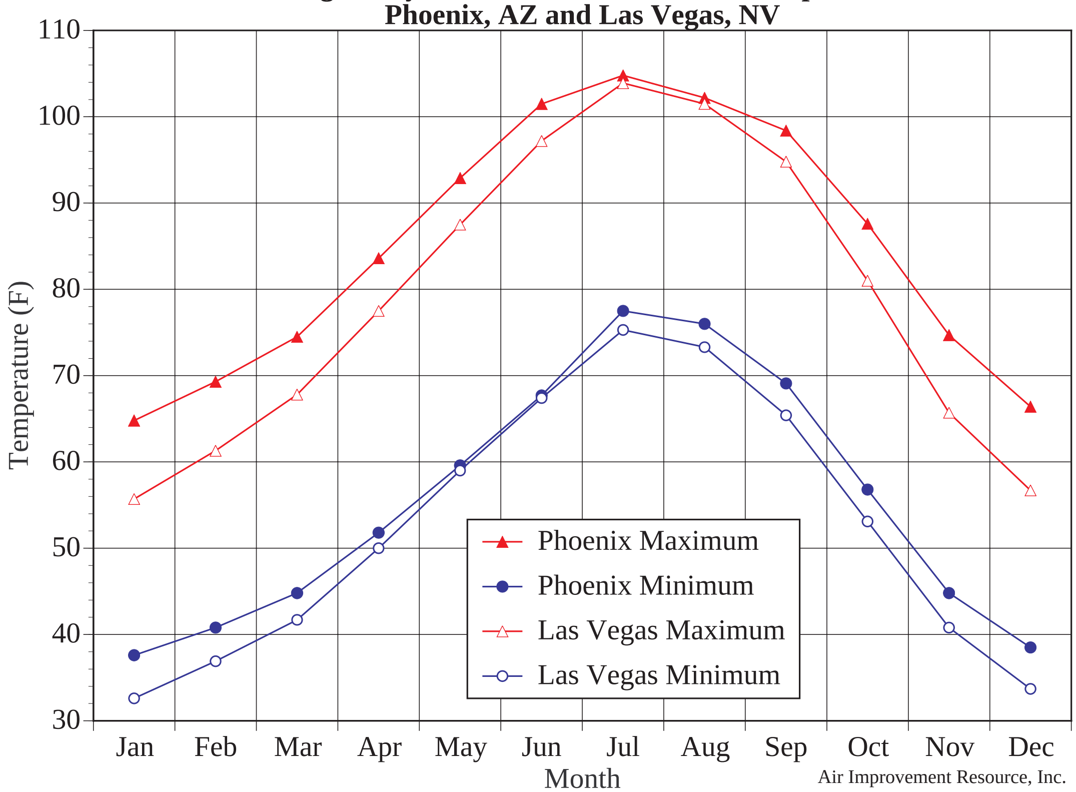
At colder temperatures under about 50º F, there is no change in emissions versus fuel volatility, but at temperatures above 50º F, there is a significant increase in CO emissions with fuel volatilities above 9 psi. This is caused by the "purge effect," and is most likely the effect that both Phoenix and Las Vegas have referred to, since their wintertime CO modeling would probably not be done at temperatures significantly under 50º F. If this "purge effect" were not present in the MOBILE6 model, we would expect to see the lines of temperature run parallel to each other, similar to the temperatures below 50º F. The purge effect as modeled by MOBILE6 results in very high CO emissions. For example, the predicted CO emissions at 90º F for the fleet running on 11.5 fuel are higher than they would be at 30º F running on the same fuel. At 70º F, the increase in CO emissions from 9.0 to 11.5 RVP is about 50%.

Based on the above chart, the CO emissions of on-road vehicles at intermediate temperatures typical of those used in Phoenix and Las Vegas modeling is based on two factors: (1) the cold start CO effect, and (2) the purge effect. At lower temperatures, the model indicates the cold start effect is more important. At higher temperatures approaching 70º F (and higher), the RVP effect is much greater. The key question is how real these two effects are, and whether or not they properly take into account the latest data.

Figure 2 shows monthly normal maximum and minimum daily temperatures in both Phoenix and Las Vegas. In January, it is typical for the morning temperature to be in the 30s and for the daytime high to be in the 50s to 60s. Thus, vehicles in the morning commute could experience the cold start effect, and vehicles in the afternoon commute or afternoon could be experiencing the purge effect.

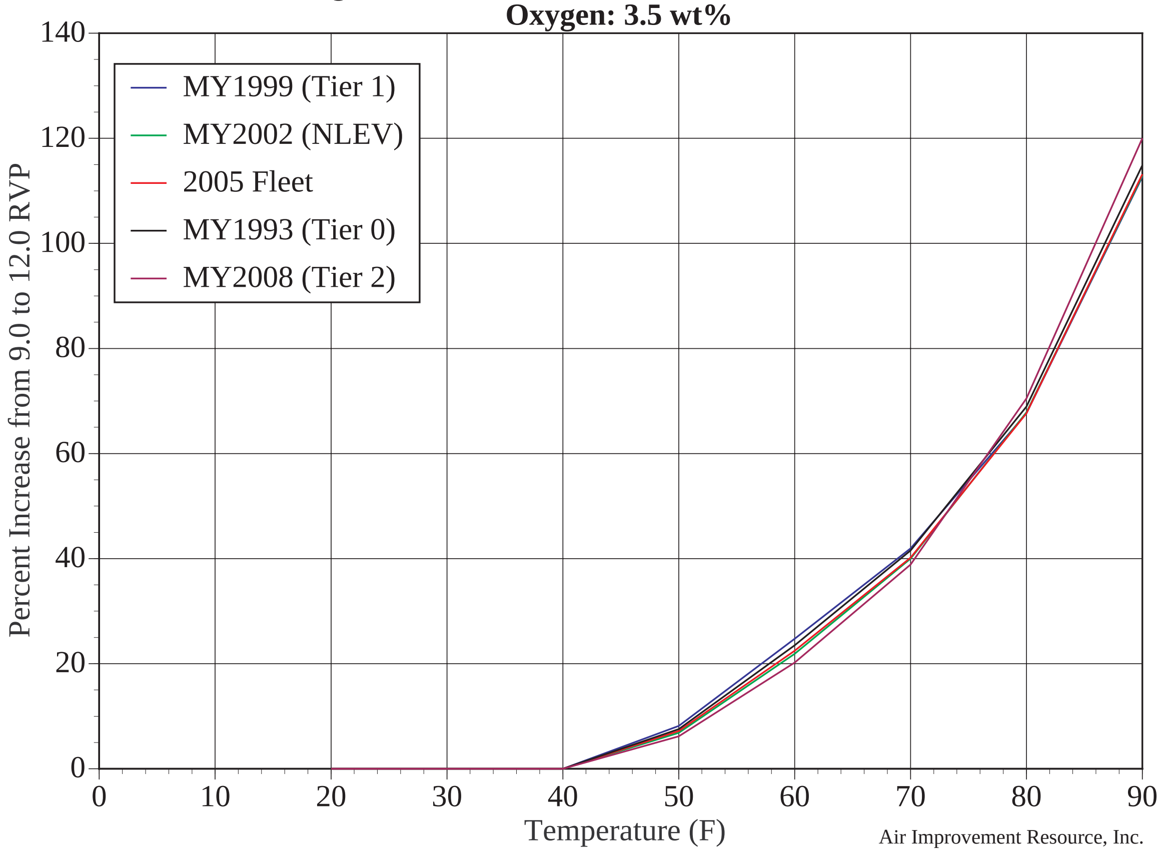
Figure 2

Average Daily Maximum and Minimum Temperatures
Phoenix, AZ and Las Vegas, NV



EPA's cold start method takes into account the effects of the cold CO standards on emissions, and also, as indicated earlier, EPA updated the CO emissions for NLEVs and Tier 2 vehicles for MOBILE6.2. For the purge effect, we examined the percent change in emissions from 9 to 12 RVP for passenger cars at five years of age, of different vintages. We chose Tier 0 vehicles, Tier 1 vehicles, NLEVs, Tier 2 vehicles, and the 2005 fleet, and plotted the increase in CO from each of these groups of vehicles, versus temperature. We assumed a fuel oxygen content of 3.5 wt%. Results are shown in Figure 3.

Figure 3
Passenger Cars Percent Increase in CO from 9 to 12 RVP
Oxygen: 3.5 wt%



The results show that regardless which vehicle technology is selected, the percent increase in emissions at different temperatures due to the purge effect is about the same. The effect starts at 40º F. At 60º F, there is a 20% increase in emissions. At 70º F, the increase is 40%.

It is highly unlikely that the purge effect due to an RVP increase is this uniform for different technologies. Running loss evaporative control has led to much more attention to thermal management of the fuel tank. Tighter HC and NOx standards have lead to much tighter air/fuel ratio control and systems that respond much quicker to changes (i.e., purging the canister and fuel tank vapors). AIR believes there could still be a purge effect for late model year vehicles, but it would probably be much less than estimated by data on early 1980s model year vehicles.

The objective of this effort is to determine if the EPA certification data can be used to evaluate both of these effects, and if not, to assist in deciding how to conduct a testing program on more recent vehicles.

3.2 Usefulness of the Certification Data to Examine these Issues

Certification data are available at three temperatures, 20º F, 50º F, and 75º F, and at several RVPs: 7.0 (California Phase 2 fuel), 9.0 (Federal certification fuel), and 11.5 (cold CO fuel). The 11.5 RVP fuel is only used at 20º F. Both 7.0 RVP and 9.0 are used at both 50º F and 75º F. This matrix of fuels and temperatures is shown in Table 1, along with the region identified as the “purge effect” region. The “Xs” mark the available certification data temperatures and RVPs.

<table>
<tr><th colspan="8">Table 1. Available Certification Data by RVP and Temperature</th></tr>
<tr><td>RVP</td><td>20º F</td><td>30º F</td><td>40º F</td><td>50º F</td><td>60º F</td><td>70º F</td><td>80º F</td></tr>
<tr><td>7</td><td></td><td></td><td></td><td>X</td><td></td><td>X</td><td></td></tr>
<tr><td>7.5</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>8</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>8.5</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>9</td><td></td><td></td><td></td><td>X</td><td></td><td>X</td><td></td></tr>
<tr><td>9.5</td><td></td><td></td><td></td><td colspan="4" rowspan="6">“Purge Effect” Region, According to MOBILE6.2 Model</td></tr>
<tr><td>10</td><td></td><td></td><td></td></tr>
<tr><td>10.5</td><td></td><td></td><td></td></tr>
<tr><td>11</td><td></td><td></td><td></td></tr>
<tr><td>11.5</td><td>X</td><td></td><td></td></tr>
<tr><td>12</td><td></td><td></td><td></td></tr>
</table>

More details will be explained later with regard to these fuels and temperatures; but as will be shown later, there are no certification data using RVPs above 9 at temperatures between 50º F and 75º F, so that it will be very difficult to use the certification data to evaluate the purge effect on later model year vehicles. The certification data, however, can be used to evaluate the cold start effect between 75º F and either 20º F or 50º F. Also, the certification data can be used to determine the RVP effect between 7 and 9 RVP. However, the MOBILE model shows no RVP sensitivity in this range of RVPs, and clearly, the RVP region of interest for the southwestern United States in the winter is at RVPs of 9 and above.

4.0 Methods

This section describes methods used to create a database from EPA's certification database. This database contained a number of different fuels that are used for emissions testing at different temperatures. AIR contacted the vehicle manufacturers and EPA to obtain more information on fuel specifications that could be useful in analyzing the CO data. This section also describes the results of this inquiry. Finally, this section discusses techniques used to analyze the certification data.

EPA's certification database consists of vehicles that are tested by the manufacturers to determine compliance with the various emission standards. The vehicles are maintained according to the manufacturers' recommended maintenance intervals.

There are a number of factors in the database that would have an effect on the CO emissions of these vehicles, as follows:

<u>Vehicle Class</u> – There are a wide range of vehicle classes in the certification database. The different classes have different CO emission standards. This study focused on cars and LDTs less than 8,500 lbs.

<u>CO emission standards</u> – There are a number of different emission standards for the different vehicle classes, and also for different durability levels. Also, there are cold CO standards for 1994 and later cars and LDTs that have an effect on CO emissions.

<u>Durability level</u> – There are a number of different durability levels. Tier 1 vehicles were certified to 50,000 miles and 100,000 miles; Tier 2 vehicles are certified to 50,000 miles and 120,000 miles. Emissions can increase with vehicle mileage.

<u>Test Temperature</u> – Depending on the sales area, tests are performed at 20°F, 50°F, and 75°F.

<u>Fuel RVP</u> – Fuel RVPs range from 7.0 for California fuel to 11.5 for Cold CO fuel.

<u>Fuel sulfur level</u> – Fuel sulfur levels can also vary. The sulfur level of California Phase 2 certification fuel is usually around 30 ppm. For Federal fuels, cars tested prior to the advent of the Tier 2 standards were usually tested on Indolene, which usually has a sulfur level well below 50 ppm. The Cold CO certification fuels, however, require a higher sulfur fuel. After Tier 2, the fuel sulfur level of both Cold CO and fuel used at 75º F is around 30 ppm.

<u>Fuel oxygen level</u> – California Phase 2 certification fuel contains MTBE, and the Federal certification fuels do not. MTBE can have an effect of reducing CO emissions, but the extent of this effect on late model vehicles with adaptive learning is debatable. However, there is probably some effect of MTBE on cold start CO emissions at 50º F before the catalyst is fully operating.

All of the above variables were considered in setting up the data to use in the database for this study.

4.1 Certification Database

AIR first obtained all certification data on cars and light-duty trucks from the 1994 model year to the 2004 model year. AIR retained key information that would be needed to analyze CO emissions. This key information is as follows:

Manufacturer code
Manufacturer name
Engine family
Engine family system number
Division
Carline
Displacement
Transmission
Design Equivalent Test Weight (ETW)
Axle ratio
Rated horsepower
Test procedure
Fuel type
Sales area
Useful life
Standard
CO emissions

Some of the above information like displacement, transmission, engine family, axle ratio, sales area, and engine family number was used to match vehicles that had tests at two or three different temperatures. Equivalent test weight, standard, and useful life were used to group vehicles with similar classes and standards together for analysis. The test procedure field was used to determine whether a particular test was at 20º F, 50º F, or 75º F. More details on some of these categories are discussed below.

4.1.1 Test procedure

There are a number of different exhaust and evaporative tests in the certification database. All evaporative tests were eliminated, and only the following exhaust tests were retained:

CVS 75:	The Federal test procedure performed at 75°F (several fuels)
Cold CO:	The Federal test procedure performed at 20°F (several fuels)
CA fuel 50º F Exhaust:	The Federal test procedure performed at 50°F on California Phase 2 fuel
Fed Fuel 50º F Exhaust:	The Federal test procedure performed at 50°F on Federal certification fuel

As shown above, only the Federal Test Procedure test results were retained. Other results like tests on US06 and SCO3 were omitted, since these are not performed at different temperatures and on different fuels.

4.1.2 Fuel Type

The EPA database contains test results on many different fuel types from diesel to gasoline to E85 and CNG. The database only retained tests on the following gasoline fuel types:

CARB Phase 2 gasoline
Cold CO Regular (pre-Tier 2)
Cold CO Premium (pre-Tier 2)
Cold CO Regular (Tier 2)
Cold CO Premium (Tier 2)
EPA Unleaded (sometimes referred to as EEE or Indolene)
Tier 2 Unleaded

Note that Cold CO regular, Cold CO premium, and Unleaded have two phases – a pre-Tier 2 and a Tier 2 phase. The Tier 2 regulations reduced fuel sulfur levels to around 30 ppm. So, starting in 2003, the Tier 2 Cold CO and regular unleaded gasolines came into use as certification fuels.

4.1.3 Sales Area

Cars are designated for a number of sales areas. AIR retained all of these in the database, but did not perform specific analysis of CO emissions by sales area. Sales area was sometimes used to determine matching vehicles across different temperatures. The sales areas are:

California
California + NLEV
Federal all altitude
Federal + California Tier 2
NLEV – all states

4.1.4 Useful Life

Emission test results are reported at a number of different useful lives. Certain test procedures require testing only at certain useful lives. The possible useful lives are as follows:

4K (4,000 miles)
50K (50,000 miles)
100K (100,000 miles)
120K (120,000 miles)
150K (150,000 miles)

Tier 1 vehicles generally have test results at 50,000 miles and 100,000 miles. Tier 2 vehicles and California LEV vehicles have tests at 50,000 miles and 120,000 miles. California PZEVs are tested at 150,000 miles.

The Cold CO testing, however, is only performed at 50,000 miles. All of the analyses in this study will use the 50,000 mile results, as these comprise the bulk of the certification test data.

4.1.5 Equivalent Test Weight

Vehicles in different weight classes are subject to different 75º F and 20º F CO emissions standards. Equivalent test weight was used to classify vehicles according to their weight class. In nearly all cases, we were able to separate the light-duty trucks (LDTs) from the passenger cars. The LDTs were separated into the different LDT classes.

LDT1: 0<ETW<3750
LDT2 and LDT3: 3751<ETW<5750
LDT4: 5751<ETW<8500

4.1.6 Emission Standards

The certification database also lists many possible emission standards. All of these were retained in the analysis database: however, AIR examined the 50,000 mile and 120,000 mile durability standards for Tier 0 vehicles, Tier 1 vehicles, Tier 2 vehicles, LEV-1 vehicles, and LEV-2 vehicles, and grouped these according to similar 50K and either 100K or 120K CO emission standards for analysis. This created five "Standard" groups, which are shown in Table 2.

Table 2. Method of Grouping Vehicles by Similar Standard
(each of these groups are present for each grouped vehicle class)

"Standard" Group	Vehicle Standards in Group
Tier 0	All vehicles identified as "Tier 0" vehicles
Tier 1	All vehicles identified as "Tier 1" vehicles
4.2 g/mi at 120K	All vehicles identified as Tier 2 Bins 5-10, LEV-I, LEV-II, and TLEV vehicles
2.1 g/mi at 120K	All vehicles identified as Tier 2 Bins 2-4, ULEV-I, and ULEV-II vehicles
1.0 g/mi CO at 120K	All vehicles identified as SULEV-I or SULEV-II vehicles

There are five standard groups for each of the 3 vehicle weight classes shown in Section 4.1.5. For vehicles meeting the Tier 2 standards, the emission standards are the same regardless of the vehicle weight class. But for Tier 0 and Tier 1 vehicles, the CO emission standards can be different by weight class. Because the CO emission standards can be different for Tier 0 and Tier 1 vehicles by weight class, the analysis of emission data will retain the 5 standard groups for each weight class of vehicles (15 weight class/standard groups).

4.2 Manufacturer Fuels Data

The Federal Register prescribes the fuels that must be used to certify vehicles to the different emission standards. Each fuel has certain fuel specifications that must be met for fuel volatility (RVP) and sulfur level. The primary properties affecting CO emissions are RVP, sulfur, and oxygen content. Specifications for these properties for certification gasolines in the certification database are shown in Table 3.

Table 3. Specifications for Certification Gasolines

Certification Gasoline	RVP (psi)	Sulfur (ppm)	MTBE Content (vol%)
California Phase 2	6.7-7.0	30-40	10.8-11.2
EPA Unleaded*	8.7-9.2	1000 max*	None
EPA Tier 2	8.7-9.2	30-40	None
Cold CO Regular	11.3-11.7	250±150	None
Cold CO Regular - Tier 2	11.3-11.7	30-40	None

* Typically manufacturers have used Indolene, which has sulfur levels less than 50 ppm.

The RFP indicated that this study should focus on the 1994-2004 certification data, because the cold CO standards started phasing-in in 1994 and were 100% phased-in by 1996. In examining EPA's certification data, however, no fuel information was available for 1994-1997 vehicles. AIR contacted the EPA, and EPA indicated that the fuels data were lost for 1994-1997 vehicles when the certification data were recently transferred from one operating system to a new one. Fuels data are available for all 1998 and later vehicles, so this study examines certification results on 1998 and later light-duty vehicles and trucks in the certification database. As a result, no Tier 0 vehicles were included in the fuels database, since Tier 0 vehicles were phased-out completely in 1996.

The table shows that some of the specifications, for example, sulfur, can vary significantly. For this reason, AIR contacted the following organizations to obtain more information on the sulfur and RVP levels of the different fuels.

- EPA
- Ford
- General Motors
- DaimlerChrysler
- Toyota
- Volkswagen
- Honda

One goal of contacting these organizations was to determine if particular certification tests in the database could be associated with a unique fuel, as determined from the manufacturers. However, none of the manufacturers retains this level of detail. In most cases, manufacturers order large batches of fuel and use it for a period of several months, or even a year, and have information on the fuel characteristics for these batches.

Since they do not keep records on which vehicles were tested in each batch of fuel, it was not possible to assign particular fuels to particular vehicles.

Responses were obtained from EPA, GM, and Toyota. This information is summarized below.

EPA – EPA provided data on two fuels – the EPA unleaded and California Phase 2 fuels. Since EPA does not perform Cold CO testing, EPA does not have test results on any Cold CO fuels. EPA tests the fuels when they are loaded into storage. The test results for unleaded gasoline and California Phase 2 gasoline are summarized in Tables 4 and 5.

Table 4. EPA's Test Results on EPA Unleaded Gasoline

Date	RVP (psi)	Sulfur (ppm)
July/1998	9.0	48
December/1998	9.2	45
August/1999	9.0	63
May/2000	9.0	48
September/2001	9.1	42
December/2001	9.1	30
December/2002	9.1	30
May/2003	8.8	31
April/2004	8.9	35
June/2004	9.0	27

Prior to December 2001, sulfur levels of EPA unleaded appear to be higher than 30 ppm. However, after December 2001, sulfur levels are in the 27-35 ppm range, which would be representative of the Tier 2 fuel.

Table 5. EPA's Test Results on California Phase 2 Gasoline

Date	RVP	Sulfur (ppm)
Aug/1999	6.9	23
May/2000	6.9	23
January 2001	6.9	38
October/2002	6.9	33
March/2004	6.8	36

The California test fuel used by EPA has an average RVP of about 6.9 and sulfur ranges from 23-38 ppm.

General Motors - General Motors analyzed some of their own data for Cold CO fuels, EPA Unleaded, and ARB Phase 2 fuel. The RVP and sulfur levels of Cold CO regular fuels are shown in Table 6.

Table 6. RVP and Sulfur Levels of GM Certification Fuels		
Date Received	RVP (psi)	Sulfur (ppm)
10/16/2000	11.97	n/a
10/25/2000	11.59	277
1/15/2002	11.28	290
9/13/2002	11.81	31
2/17/2003	11.59	27
2/10/2004	11.30	25

The average fuel volatility of this Cold CO regular fuel is about 11.6 psi. Note that sulfur is 277-290 ppm up until the middle of 2002, when the sulfur level was reduced to 31 ppm to start certifying Tier 2 vehicles.

Sulfur test results for other GM fuels are shown in Table 7.

Table 7. Sulfur Test Results for Other GM Fuels		
Fuel	Date	Sulfur (ppm)
Cold CO Premium	1/95-1/02	290
Cold CO Premium	1/02 +	30
EEE Test (EPA Unleaded, or Indolene)	All	10
Ca RFG2	All	30

From January 1995 to January 2002, the cold CO premium fuel had an average sulfur level of 290 ppm. In 2002, this dropped to 30 ppm for Tier 2 vehicles. The EPA unleaded gasoline used by GM had a fuel sulfur level of 10 ppm. California Phase 2 RFG used by GM has a sulfur level of 30 ppm.

<u>Toyota</u> - RVPs and sulfur levels for fuels used at Toyota's lab in Ann Arbor are shown in Table 8.

Table 8. Fuel RVP and Sulfur Levels of Fuels Used at Toyota's Ann Arbor Laboratory			
Fuel	Sulfur	RVP	Date
Cold CO Premium*	25	11.3	11/2001
California Phase 2	30	7.0	9/2004
	30	7.0	8/2004
	35	6.9	2/2004
	35	6.9	11/2003
	35	6.9	10/2003
	34	6.9	8/2003
	30	6.9	3/2003
EPA Tier 2	29	9.0	10/2004
	30	8.7	8/2004
	26	9.2	6/2004
	27	9.0	5/2004
	30	9.0	12/2003
	25-35	9.2	6/2003

* Not typically tested in Ann Arbor

Fuel Properties Assumed in This Study – Based on the required specifications and input from the various manufacturers, the fuel parameters shown in Table 9 will be assumed for various fuels in the certification database. It appears that the EPA unleaded fuel prior to Tier 2 actually had a lower sulfur level than Tier 2 fuel; therefore, for Tier 2, the certification sulfur level goes up a small amount.

Table 9. Fuel Characteristics Assumed in this Study			
Fuel	RVP	Sulfur	Oxygen?
California Phase 2	7.0	30	Yes
Cold CO (Regular or Premium)	11.6	280	No
Tier 2 Cold CO (Regular or Premium)	11.6	30	No
EPA Unleaded	9.0	10	No
EPA Tier 2	9.0	30	No

4.3 Final Analysis Database

The number of vehicles in the final database for different vehicle classes, vehicle certification CO standards, temperatures and RVP levels, are shown in Table 10.

Table 10. Certification Database Vehicle Sample Sizes (1998 and later vehicles)										
Vehicle Class Group	Tier Code	20° F			50° F			75° F		
		7 RVP	9 RVP	11.6 RVP	7 RVP	9 RVP	11.6 RVP	7 RVP	9 RVP	11.6 RVP
PC, LDT1	T0	0	0	0	0	0	0	0	0	0
	T1	0	61	295	0	0	0	38	493	0
	4.2	5	21	994	186	66	0	875	488	0
	2.1	0	1	156	27	6	0	156	65	0
	1	0	0	28	2	1	0	12	1	0
LDT2,3	T0	0	0	0	0	0	0	0	0	0
	T1	0	3	153	0	0	0	36	218	0
	4.2	9	1	386	30	12	0	333	188	0
	2.1	0	0	62	26	2	0	56	39	0
	1	0	0	0	0	0	0	0	0	0
LDT4	T0	0	0	0	0	0	0	0	0	0
	T1	0	1	92	0	0	0	80	129	0
	4.2	0	0	192	13	20	2	118	129	0
	2.1	0	0	31	11	2	0	25	25	0
	1	0	0	0	0	0	0	0	0	0

At 20º F, most of the tests are at 11.6 RVP, but there appear to be some tests at 9 RVP and even 7 RVP. There are no Tier 0 vehicles in this database of 1998 and later vehicles. At 50º F, there are tests at both 7 and 9 RVP, and there appear to be 2 tests on LDT4 4.2 vehicles at 11.6. At 75º F, there are tests at both 7 RVP and 9 RVP, and none at 11.6 RVP.

4.4 Analytical Techniques

The focus of the analysis is to evaluate the temperature effects, RVP effects, and perhaps combined temperature and RVP effects. Another focus of the analysis is to determine if these temperature and RVP effects are affected by changes in CO emission standards. For example, are vehicles which meet a standard of 2.1 g/mi at 120K miles (ULEVs, Tier 2 Bin 2-4) less sensitive to temperature or RVP than vehicles which meet a standard of 4.2 g/mi at 120K miles (LEVs, Tier 2 Bin 5+)?

In performing most of these analyses, it is necessary to match vehicles with tests at different RVPs and temperatures. There is no unique vehicle identifier like the "VIN" in the certification database, therefore, the following information was used to match vehicles with tests at different temperatures and RVPs:

- Model Year
- Engine family
- Evaporative Family
- Test Weight

In some cases, vehicles were coded as both Tier 1 and 4.2 or 2.1 vehicles (LEVs or ULEVs). These cases represent vehicles sold in California as LEVs and ULEVs, but Federally they were labeled as Tier 1 vehicles. In these cases, they were all assigned the lower emission standard.

Techniques used to evaluate the temperature and RVP effects are discussed below.

4.4.1 General Analysis

In the first analysis, we examine mean emissions and 90% confidence intervals of the means at each one of the conditions as shown in Table 10. In many of the cases, sample sizes are large enough to make conclusions about the influence of vehicle technology, temperature, and RVP on emissions. We are assuming that if the 90% confidence intervals of the means do not overlap, the values are statistically different.

4.4.2 Temperature Effects – Matched Vehicle Analysis

In this analysis, we evaluate temperature effects on vehicles that have been tested at all three temperatures – 20º F, 50º F, and 75º F. Table 10 shows that there are no vehicles with tests on all three temperatures and the same RVP. However, there are a number of vehicles with different emission standards that are tested at 11.6/9/9 and 11.6/7/7 for temperatures 20/50/75. Mean emissions and 90% confidence intervals of the means are plotted at all three temperatures and at the different RVP levels for different weight classes and emission standard groups.

The comparisons between emissions on 7 RVP and 9 RVP fuels may reflect more than just RVP. The 7 RVP fuel contains 2 wt % oxygen as MTBE, whereas the 9 RVP fuel contains no oxygenate. Also, in some cases (particularly for Tier 1 vehicles), the sulfur levels may be higher with the 9 RVP than with the 7 RVP fuel. However, for the 4.2, 2.1, and 1.0 CO standard vehicles, sulfur levels should all be low, and the only differences which should affect CO will be RVP and oxygen.

4.4.3 RVP Effects

For RVP effects, there were no matching vehicles tested at different RVPs at either 20º F or 50º F, but there were a number of vehicles that were tested at both 9 RVP and 7 RVP at 75º F. For this analysis, we examined mean CO emissions and 90% confidence intervals of the means at both 9 RVP and 7 RVP for the different weight classes and standard groups. This comparison, however, also includes differences in oxygenate, as described above.

4.4.4 Multivariable regression analysis

In this analysis, AIR utilized all the data and performed a multivariable regression analysis of the log of CO emission versus all possible variables. The analysis creates a regression equation with variables that have a statistically significant effect on CO emissions.

5.0 Results

5.1 General Temperature and RVP Effects

Table 11 shows mean 50K CO emissions from the certification database for the different vehicle classes, standard groups, temperatures, and fuel volatilities. Ninety percent confidence intervals were also examined and are shown in the table.

Table 11. 50K CO Means and 90% Confidence Intervals for Certification Data

			20F			50F			75F		
Vehicle	Tier	Data	7	9	11.6	7	9	11.6	7	9	11.6
PCLDT1	T1	Mean		5.46	5.26				1.16	1.21	
		90% CI		0.28	0.14				0.08	0.02	
	4.2	Mean	2.51	4.04	3.60	1.07	0.80		0.75	0.67	
		90% CI	0.01	0.48	0.08	0.07	0.10		0.02	0.02	
	2.1	Mean		3.68	2.20	0.51	0.17		0.40	0.44	
		90% CI			0.13	0.06	0.04		0.02	0.03	
	1.0	Mean			1.06	0.09	0.26		0.09	0.00	
		90% CI			0.14	0.02			0.03		
LDT23	T1	Mean		6.32	5.66				2.04	1.69	
		90% CI		1.88	0.27				0.15	0.07	
	4.2	Mean	4.93	5.00	4.97	1.33	1.13		1.16	1.13	
		90% CI	0.46		0.16	0.21	0.38		0.04	0.05	
	2.1	Mean			2.89	0.92	0.99		0.88	0.92	
		90% CI			0.27	0.24	0.00		0.12	0.09	
LDT4	T1	Mean		8.80	5.09				2.52	2.12	
		90% CI			0.25				0.18	0.11	
	4.2	Mean			4.91	2.60	1.50	1.80	1.76	1.44	
		90% CI			0.17	0.52	0.17	0.00	0.11	0.08	
	2.1	Mean			4.56	2.88	1.15		1.94	1.34	
		90% CI			0.22	0.28	0.00		0.29	0.08	

There are a number of interesting observations from Table 11. Some of these are listed below.

1. At 20º F and 11.6 RVP fuel, there is a trend toward lower CO emissions for the lower emission standards, for PC/LDT1s and LDT2/LDT3s. While CO emissions for LDT4s are lower for the lower CO standards, the differences are not statistically significant. For example, for PCs and LDT1s, the Tier 1 emissions at 20º F are 5.26 g/mi. This drops to 1.06 g/mi for vehicles certified to a 1.0 g/mi CO standard (at 75 º F). The differences are statistically significant between each level of the emission standards (except for LDT4s). Similar trends with lower CO standards are shown at the other temperatures (50º F and 75º F). These data seem to indicate that EPA's MOBILE6 approach of grouping all Tier 2 vehicles together and all LEV-type vehicles together in estimating CO emissions at any

temperature is inappropriate – the Tier 2 and LEV vehicles should be grouped by similar CO standards.

2. CO emissions increase with lower temperatures, with higher increases coming between 50° F and 20° F than between 75° F and 50° F. Not all of the CO emissions increases between 75° F and 50° F for the different vehicle classes and standards are statistically significant, but all of the increases between 75° F and 20° F and 50° F and 20° F are statistically significant.

3. At 75º F, in some cases there is no statistically significant difference between the 7 and 9 RVP results, and in other cases, there is a significant difference. MOBILE6 indicates no difference in CO emissions between 7 RVP and 9 RVP (the "purge" effect in MOBILE6 is only evident at RVPs higher than 9).

4. At 75º F, for Tier 1, 4.2 and 2.1 vehicles, the increase in vehicle weight results in higher CO emissions. For example, the average CO emissions of PCs and LDT1s certified to the 4.2 standard on 9 RVP fuel are 0.67 g/mi. LDT2s and LDT3s are 1.14 g/mi, and LDT4s are 1.44 g/mi.

The data in Table 11 can be used to develop a rough estimate of whether the cold CO offsets in the MOBILE6 model are appropriate. The CO offset is basically the difference in FTP CO emissions between 75º F and 20º F. The CO offset assumed for Tier 1, Tier 2, and LEV vehicles in the MOBILE6 model is 3.82 g/mi. This was based on an analysis of Tier 1 1997 certification data.

Table 12 shows an estimate of the CO offset from the data in Table 11. The 11.6 RVP, 20° F results were obtained directly from Table 11. For 75° F, the results for 9 RVP and 7 RVP were averaged.

Table 12. Estimate of CO Offset from Certification Data

Vehicle Class Group	Standard	11.6 RVP, 20º F (g/mi)	Average of 7 RVP and 9 RVP, 75º F (g/mi)	Difference, g/mi (CO Offset)
PC, LDT1	T1	5.263	1.186	4.078
	4.2	3.602	0.713	2.890
	2.1	2.197	0.423	1.774
	1.0	1.058	0.047	1.010
LDT2,3	T1	5.664	3.797	1.867
	4.2	4.967	3.818	1.149
	2.1	2.893	1.991	0.902
LDT4	T1	5.086	2.770	2.316
	4.2	4.912	3.314	1.598
	2.1	4.563	2.923	1.640

The results in Table 12 (last column) show that the MOBILE6 value of 3.82 g/mi is probably slightly low for Tier 1 PCs and LDT1s meeting the cold CO standards, but that it is too high for vehicles meeting 4.2, 2.1, or 1.0 CO standard (in other words, all LEVs and Bin 5 and higher Tier 2 vehicles). For example, the CO offset for PCs and LDT1s meeting a 4.2 standard is about 2.9 g/mi, or 24% lower than EPA's value. The CO offset for vehicles meeting the 2.1 standard (ULEVs and Tier 2 Bins 2-3) is 1.77 g/mi, or 53% lower than the MOBILE6 value. If these results were incorporated into MOBILE6, it would compress the lines in Figure 1, especially for future years where LEVs and Tier 2 vehicles dominate.

Our conclusion with regard to the MOBILE6 temperature correction factors between 75º F and 20º F is that they are probably appropriate for calendar years 2000 and earlier, but they overestimate CO emissions – at least the cold start effect – for calendar years 2001 and later, where there are significant numbers of LEVs and Tier 2 vehicles. A broader conclusion here is that EPA should not simply lump together Tier 1 and later vehicles for CO because they have the same CO standards at 50,000 miles (3.4 g/mi).

Since the above test data only focuses on emissions at 75º F and 20º F, the comments above only relate to the cold start effects. They do not relate to the "purge effect" discussed earlier, because we do not have test data on fuel RVPs higher than 9 RVP at temperatures between 40º F and 90º F where the purge effect is assumed to take place.

5.2 Temperature Effects – Matched Sample Effects

The previous analysis evaluated CO results for different vehicles at different temperatures and RVPs. This analysis will try to evaluate matched samples of vehicles for temperature effects – that is, the same vehicles tested at three different temperatures.

This analysis examined matched sets of vehicles tested at 20º F/50º F/75º F with either 11.6/7/7 RVP fuels or 11.6/9/9 fuels. Table 13 shows vehicle sample sizes for these combinations of RVPs and temperatures for vehicles in different weight classes and standards. There were no 1998 and later Tier 1 or 1.0 standard vehicles that had tests at all three temperatures.

Table 13. Available Vehicle Class/Standard/RVP Combinations of Certification Data At 20ºF, 50ºF, and 75ºF			
Vehicle Class	Standard	RVP combinations	Sample Size (Vehicles)
PC/LDT1	2.1	11.6/7/7	12
		11.6/9/9	6
	4.2	11.6/7/7	120
		11.6/9/9	60
LDT2,3	2.1	11.6/7/7	22
	4.2	11.6/7/7	29
		11.6/9/9	12
LDT4	4.2	11.6/7/7	7
		11.6/9/9	7

Figures 4 and 5 show CO emissions at 20° F, 50° F and 75° F for passenger cars and LDT1s combined. Ninety percent confidence intervals about the mean values are also shown. Figure 4 shows the CO emissions for vehicles which meet the 2.1 g/mi CO standard, and Figure 5 shows CO emissions for vehicles meeting the 4.2 standard. In each figure, there are two sets of lines – one based on 11.6/7/7 at 20/50/75, and one at 11.6/9/9 at 20/50/75.

Figure 4 for 2.1 standard vehicles shows the following:

1. There is no increase in CO emissions for the 9 RVP fuel between 75° F and 50° F. For the 7 RVP fuel there is a small increase in CO emissions between 75° F and 50° F. At both 75° F and 50° F, the vehicles tested on 7 RVP have higher CO emissions than the vehicles tested on 9 RVP, but we do not know if this is an RVP effect, because they were different vehicles tested on the different fuels.

2. There are significant increases in CO emissions between 50° F and 20° F for both fuels.

3. The certification level CO emissions of these vehicles at 75° F are in the range of 0.2-0.4 g/mi, even though the standard at 75° F is 2.1 g/mi (120,000 miles).

4. The CO emissions of both sets of vehicles at 20° F are not statistically different, and are about 1.8 g/mi. The cold CO standard is 10 g/mi, so the CO emissions of these vehicles are about 20% of the cold CO standard.

Figure 4

PC/LDT1 CO Certification Emission Factors vs Temperature and RVP

2.1 g/mi Standard

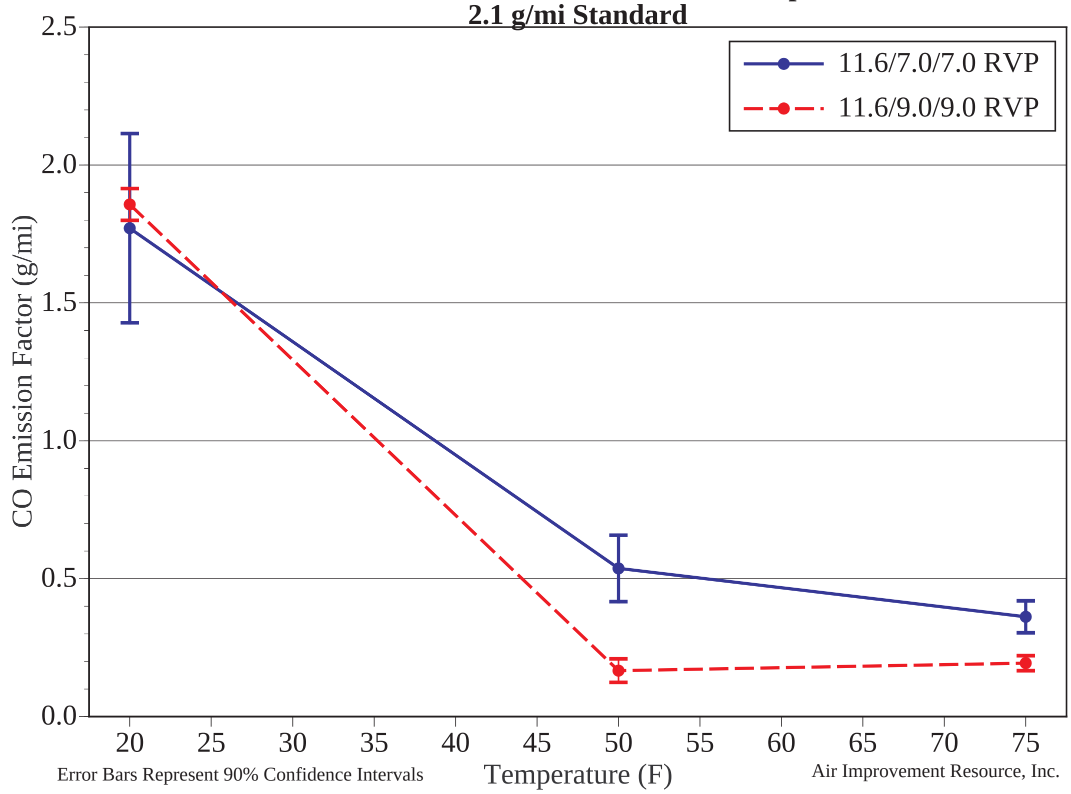


Figure 5

PC/LDT1 CO Certification Emission Factors vs Temperature and RVP

4.2 g/mi Standard

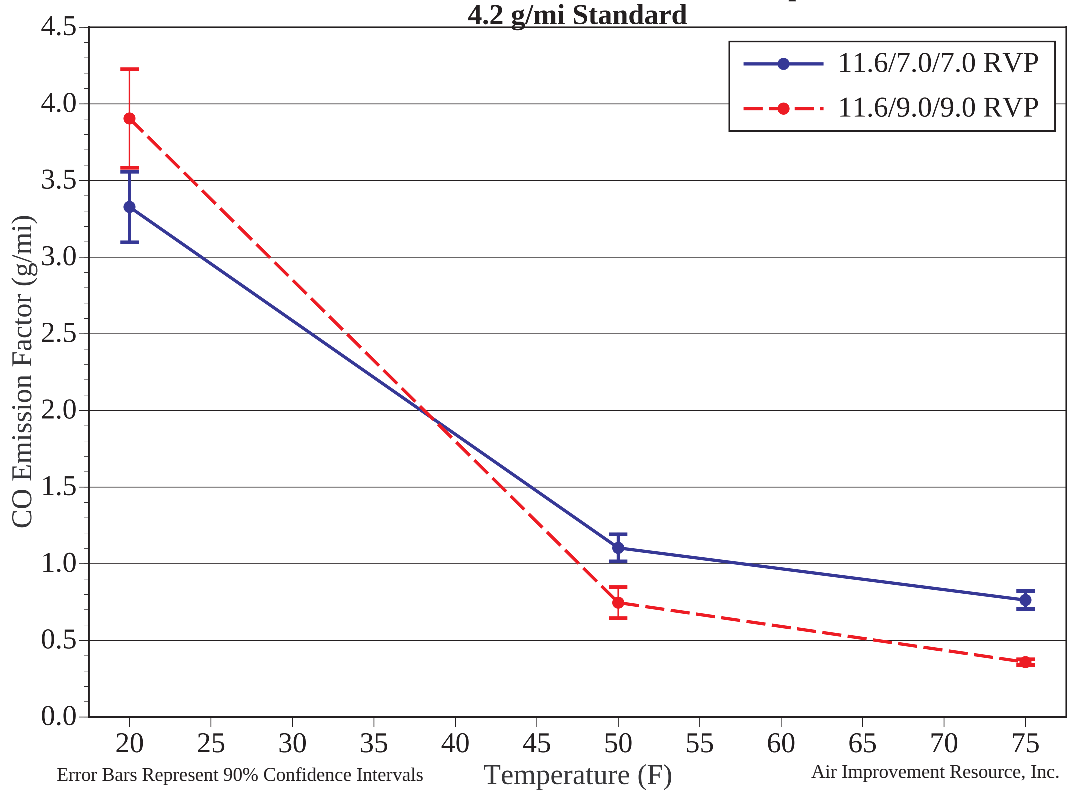


Figure 5 for 4.2 standard vehicles shows the following:

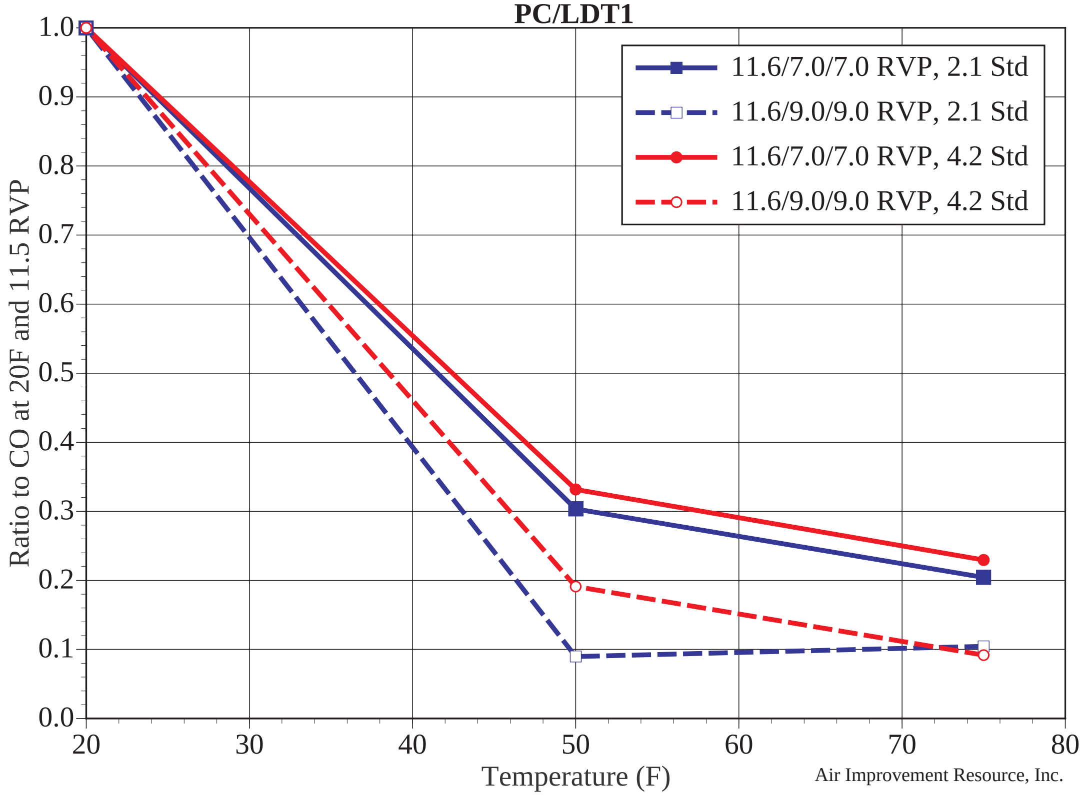
1. There is a small increase in CO emissions between 75° F to 50° F for both fuels, and the differences between the temperatures are statistically significant. At these two temperatures, the emissions of vehicles tested on 7 RVP fuel are higher than the emissions of vehicles tested on 9 RVP fuel.

2. CO emissions increase for both fuels between 50° F and 20° F.

Figure 6 shows the ratio of emissions at 20° F to emissions at 50° F and 75° F for both the 2.1 and 4.2 standard passenger cars and LDT1s. The chart shows that CO emissions at 50° F are 10-30% of the levels at 20° F, and that emissions at 75° F are 10-22% of the levels at 20° F.

Figure 6

Ratio of CO Certification Emission Factors Relative to 20F and 11.6 RVP PC/LDT1



Figures 7 and 8 show CO emissions versus temperature for LDT2/3s. Figure 7 shows emissions for 2.1 standard vehicles, and Figure 8 shows emissions for 4.2 standard vehicles. Figure 9 shows the ratio of emissions at 20° F to emissions at 50° F and 75° F. These figures are similar to Figures 3-5 for PC/LDT1s. These figures show the same trends as shown for PCs/LDT1s, in that CO emissions between 50° F and 75° F are relatively flat, but increase between 50° F and 20° F.

Figure 7
LDT2/3 CO Certification Emission Factors vs Temperature and RVP
2.1 g/mi Standard

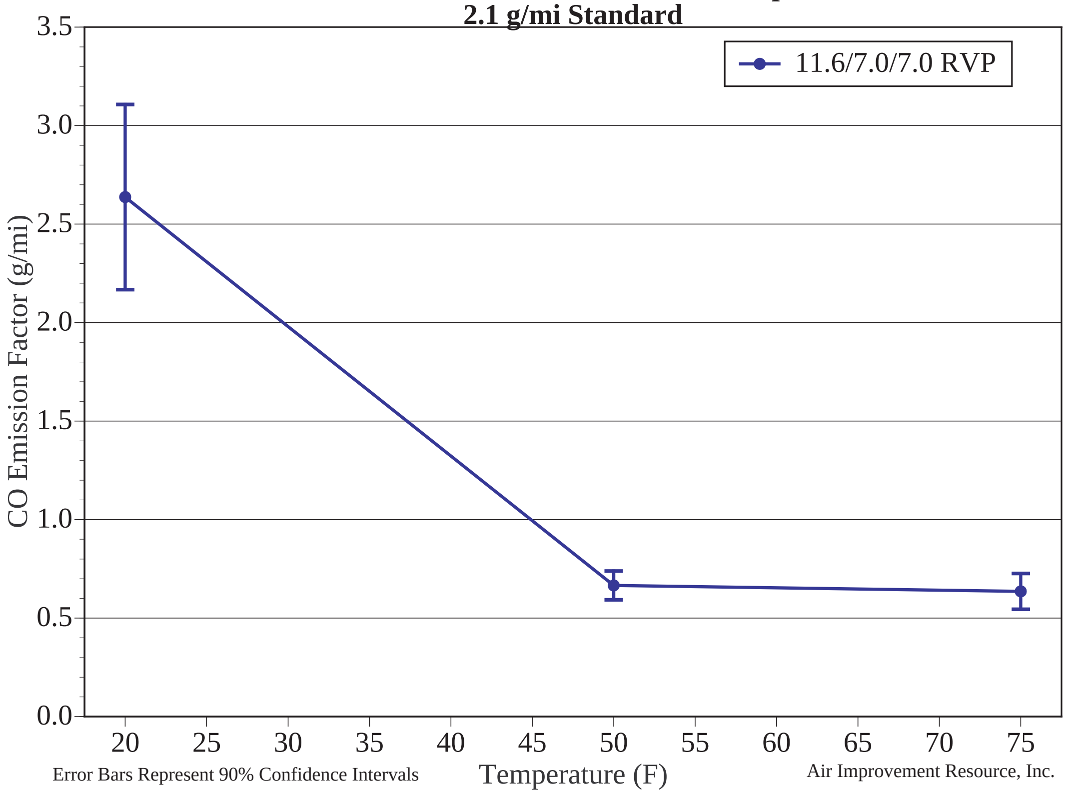


Figure 8
LDT2/3 CO Certification Emission Factors vs Temperature and RVP
4.2 g/mi Standard

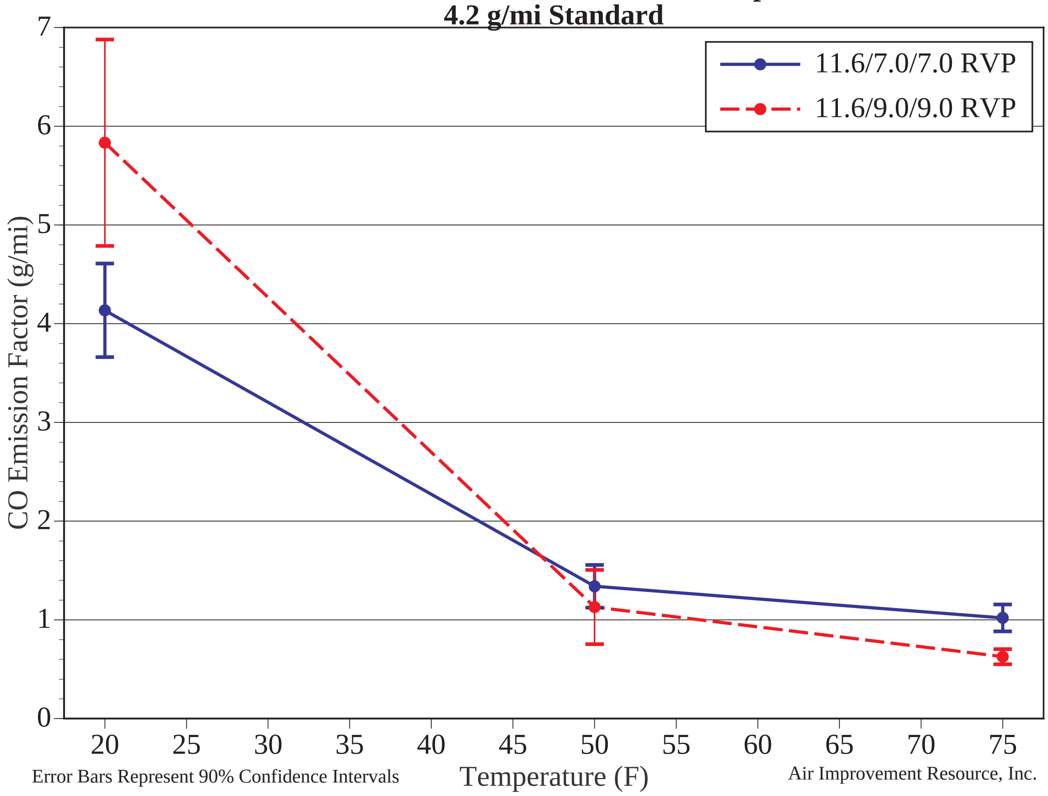
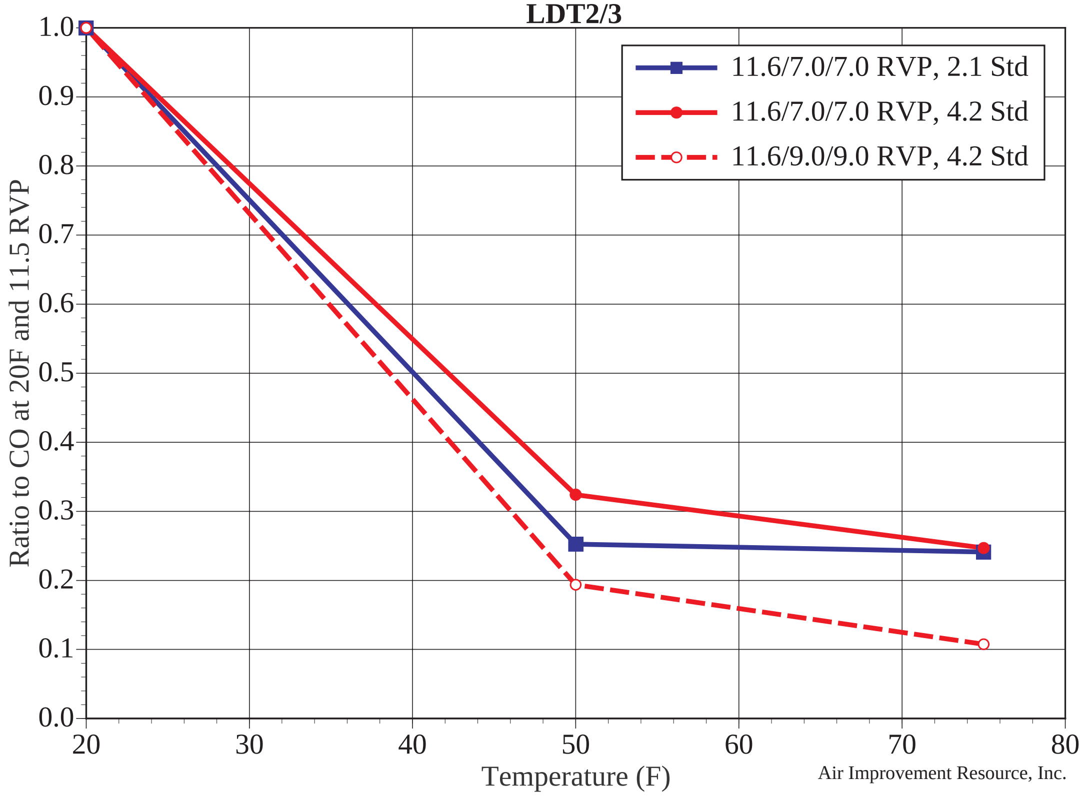


Figure 9
Ratio of CO Certification Emission Factors Relative to 20F and 11.6 RVP
LDT2/3



Figures 10 and 11 show CO emissions and ratios of emissions for LDT4 vehicles subject to the 4.2 CO standard. Figure 10 shows that vehicles that were tested on 7 RVP fuel at 50° F and 75° F have higher CO emissions at all temperatures than vehicles that were tested on 9 RVP fuel, and these differences are statistically significant. Figure 11 shows very little difference in sensitivity of CO emissions to temperature between the vehicles tested on 9 RVP versus 7 RVP fuel.

Figure 10

LDT4 CO Certification Emission Factors vs Temperature and RVP

4.2 g/mi Standard

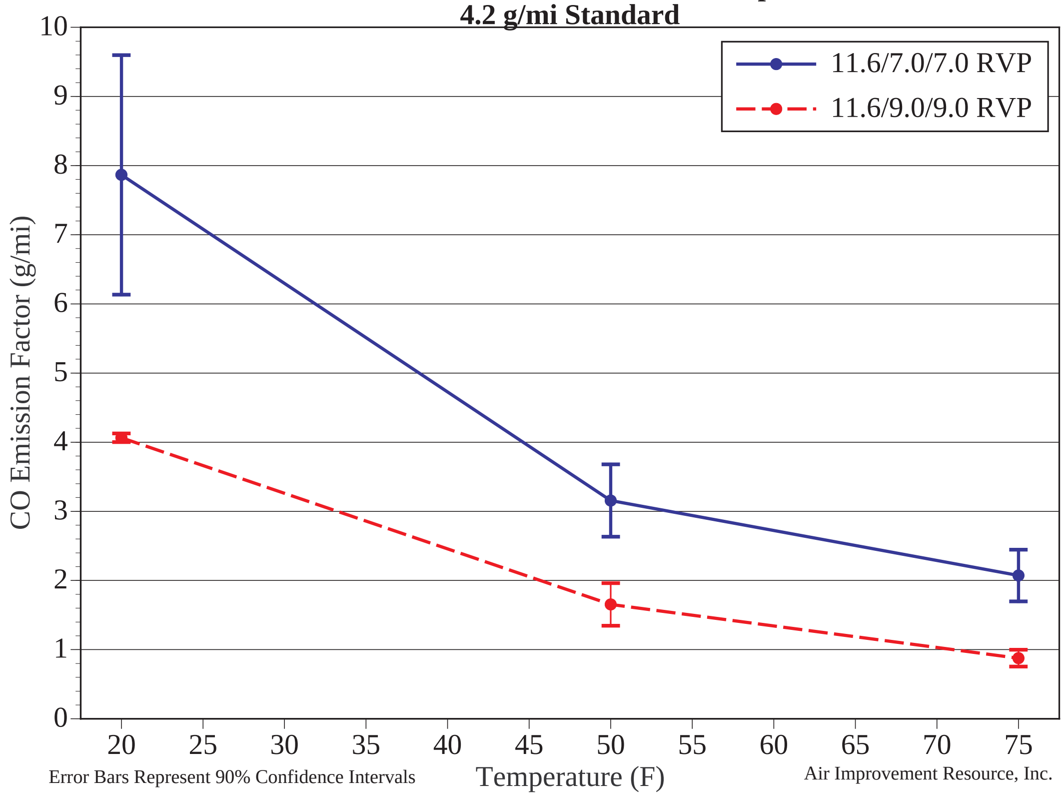
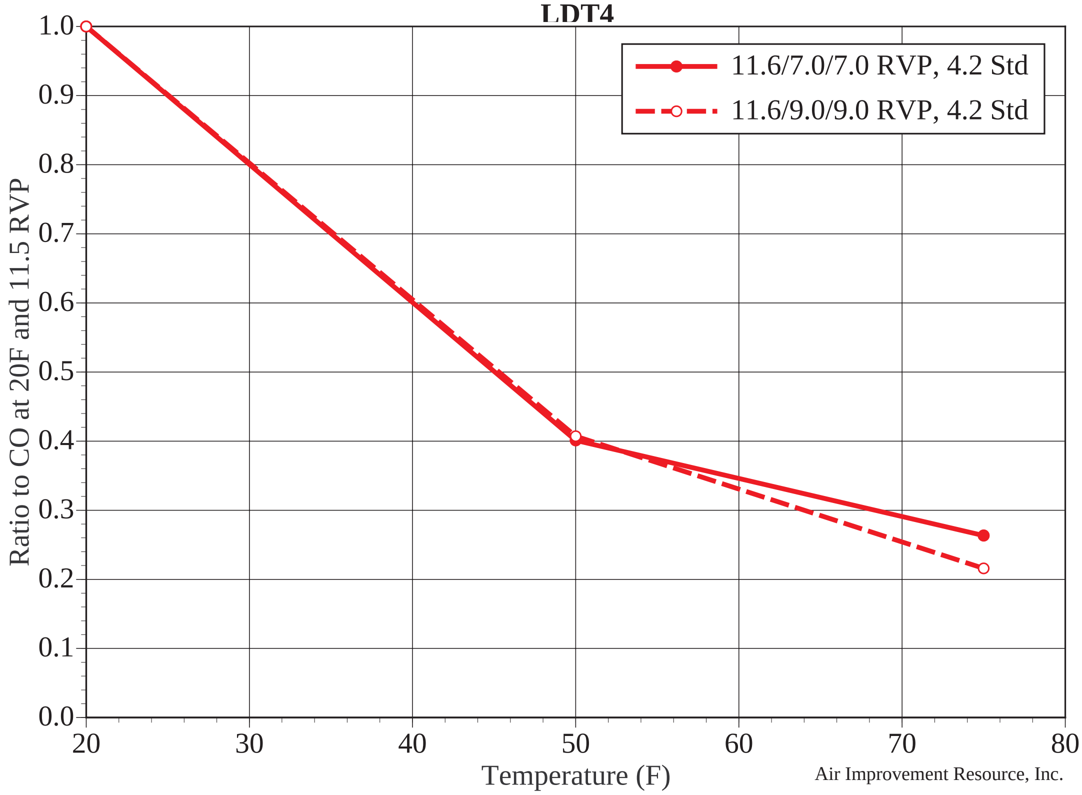


Figure 11

Ratio of CO Certification Emission Factors Relative to 20F and 11.6 RVP

LDT4



5.3 RVP Effects

The previous sections examined temperature and RVP effects for matched samples of vehicles tested at the different temperatures. The vehicles were not “matched” between RVPs. In the previous section, some differences in emissions between 7 RVP and 9 RVP were noted, but we do not know whether the differences are due to different samples, or to RVP (or oxygenate). This section addresses this issue in more detail.

In this RVP analysis, we found matched samples of vehicles at 75° F that were tested on both 7 RVP and 9 RVP, so that we could examine the RVP effects only. RVP effects were examined for matched vehicles at 75° F only, as no matched vehicles could be found at two RVPs at 50° F. Sample sizes for this comparison are shown in Table 14.

Figure 12 shows CO emissions at both 7 RVP and 9 RVP for the various vehicle classes and CO emission standards. Ninety percent confidence intervals for the means in Figure 12 are shown in Appendix 1.

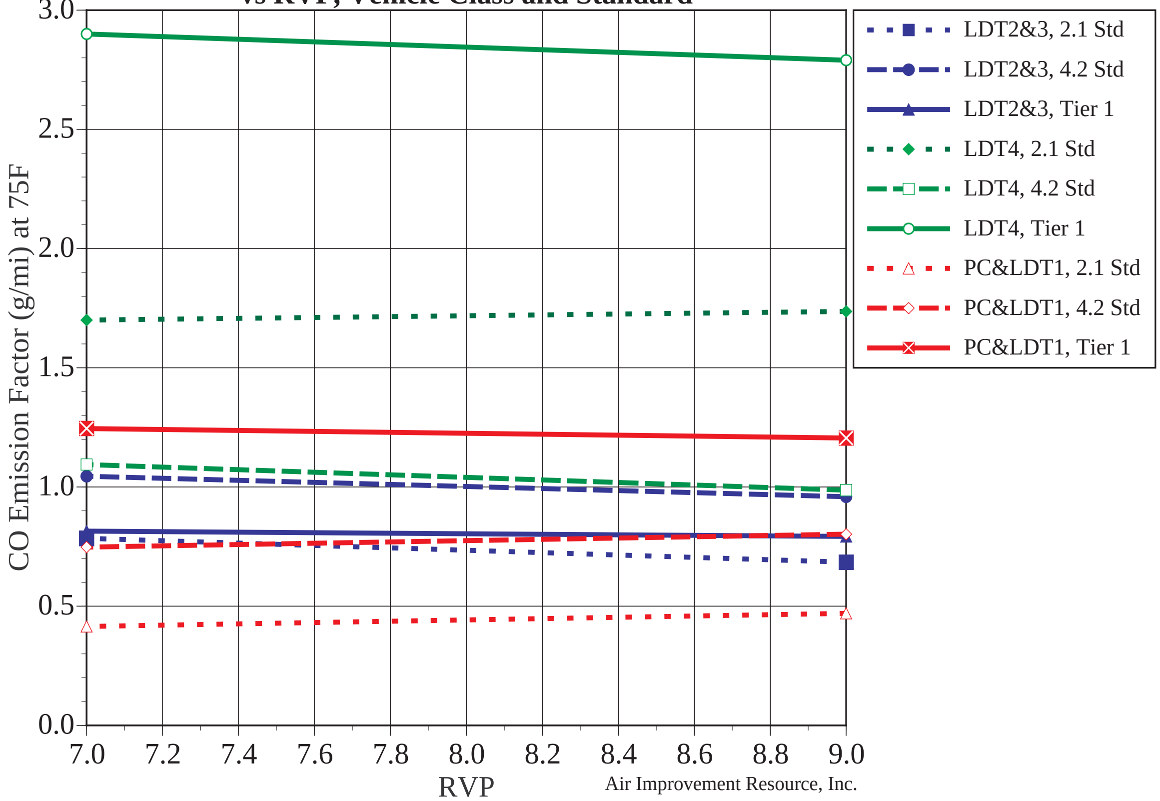
Table 14. Sample Sizes for RVP Comparison

Vehicle Class	CO Standard	Vehicle Sample Size
PC/LDT1	Tier 1	20
	4.2	128
	2.1	30
LDT2,3	Tier 1	2
	4.2	45
	2.1	15
LDT4	Tier 1	4
	4.2	19
	2.1	10

The results show very little CO emissions response to RVP at 75° F between 7 and 9 RVP. Most of the lines are flat, and lines that have slope are only slightly inclined. Appendix 1 also shows that the mean emissions at 7 and 9 RVP at 75° F are not statistically different.

This result in this analysis is somewhat different than the previous section, because the previous section indicated that there could be CO differences due to RVP differences at 75° F. However this analysis on matched vehicles indicates that there are no impacts of RVP (or oxygen) at 75° F; therefore, we are inclined to believe that the differences shown in the previous section are due to vehicle emission differences, or oxygen differences, but not RVP differences.

Figure 12
CO Certification Emission Factors at 75F
vs RVP, Vehicle Class and Standard



5.4 Multivariable Regression Analysis

AIR also performed a multivariable regression analysis of CO emissions versus a number of variables. We first tried a regression of CO emissions versus a number of variables, but the regression gave us negative emissions at certain points. To remedy this, we developed a regression of the natural log of CO (LnCO). The results are shown in Table 15. The coefficients are with respect to PC/LDT1s with a standard of 4.2 at 120,000 miles. All coefficients shown are statistically significant. The R-squared value of the regression is 0.66.

Table 15. Regression Coefficients of the Natural Log of CO (LnCO)

Variable	Coefficient	Standard Error of Coefficient
Constant	2.88	0.1193
Temperature (F)	-0.910	0.0040
Temperature^2 (F)	0.00066	0.0000
RVP (psi)	-0.024	0.0064
Standard 1.0	-1.41	0.0682
Standard 2.1	-0.40	0.0178
Standard Tier 1	0.496	0.0130
LDT23	0.392	0.0132
LDT4	0.633	0.0162

In this analysis, temperature and RVP are independent variables, but there is some covariance because very few tests were performed at 20° F and 7 and 9 RVP; the great majority of tests performed at 20° F were at 11.6 RVP, and no tests were performed at 50º F and 75º F on 11.6 RVP. This does affect the validity of this regression; it is not as if there were equal numbers of tests with different RVPs at the three different temperatures.

Table 15 shows that RVP emerged as a significant variable, along with the others which were expected, like temperature, emission standard, and vehicle class. The coefficient of -0.024, however, is small in comparison with temperature, indicating that while the RVP is statistically significant, its impact is small compared to the other variables.

The regression in Table 15 was used to develop several plots of CO emissions versus temperature and RVP for PC/LDT1s certified to the 4.2 standard. These are shown in Figures 13 and 14. It should be noted that this regression may not be valid in the "purge effect" region at temperatures greater than 40º F and RVPs higher than 9 RVP, if the purge effect is still a factor in this region on more recent technology vehicles.

Figure 13 shows a strong temperature effect, and very little RVP effect. Figure 14 shows very little RVP effect, and also shows very little temperature effect between 75º and 50º F at any RVP. This is consistent with the earlier matched vehicle analysis and the analysis of overall vehicle averages presented in Section 5.1.

Figure 13
CO Emission Factors vs Temperature and RVP
PC/LDT1, 4.2 Std

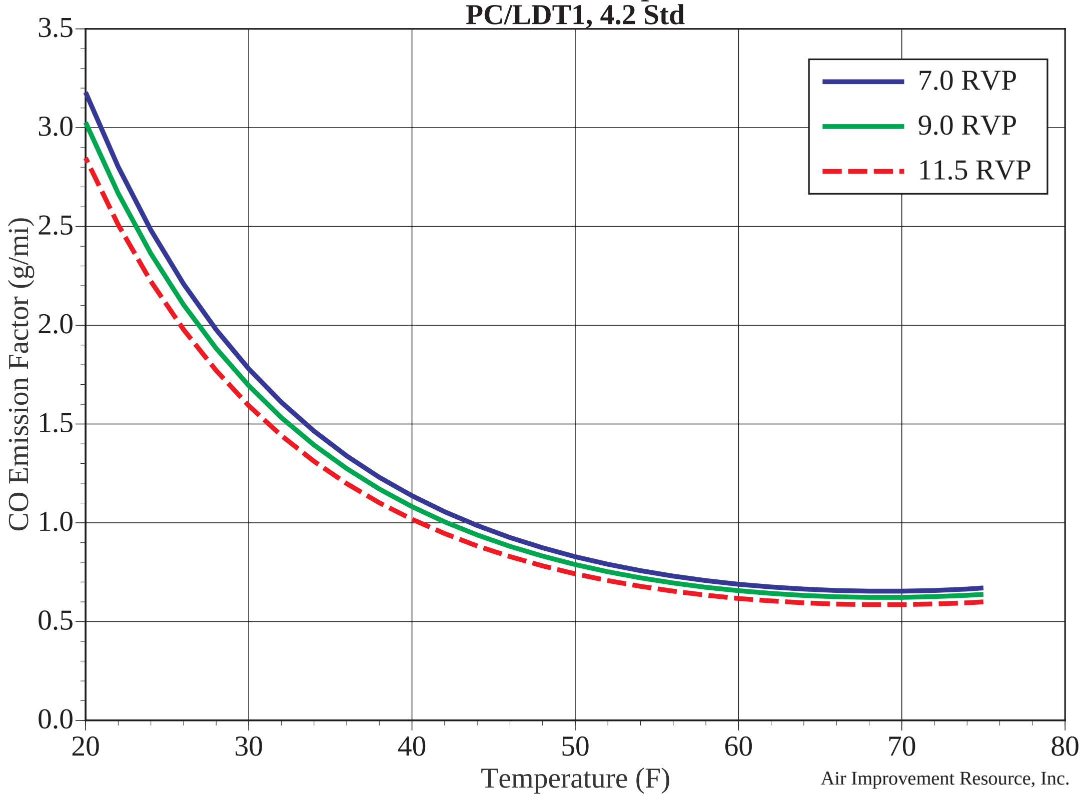
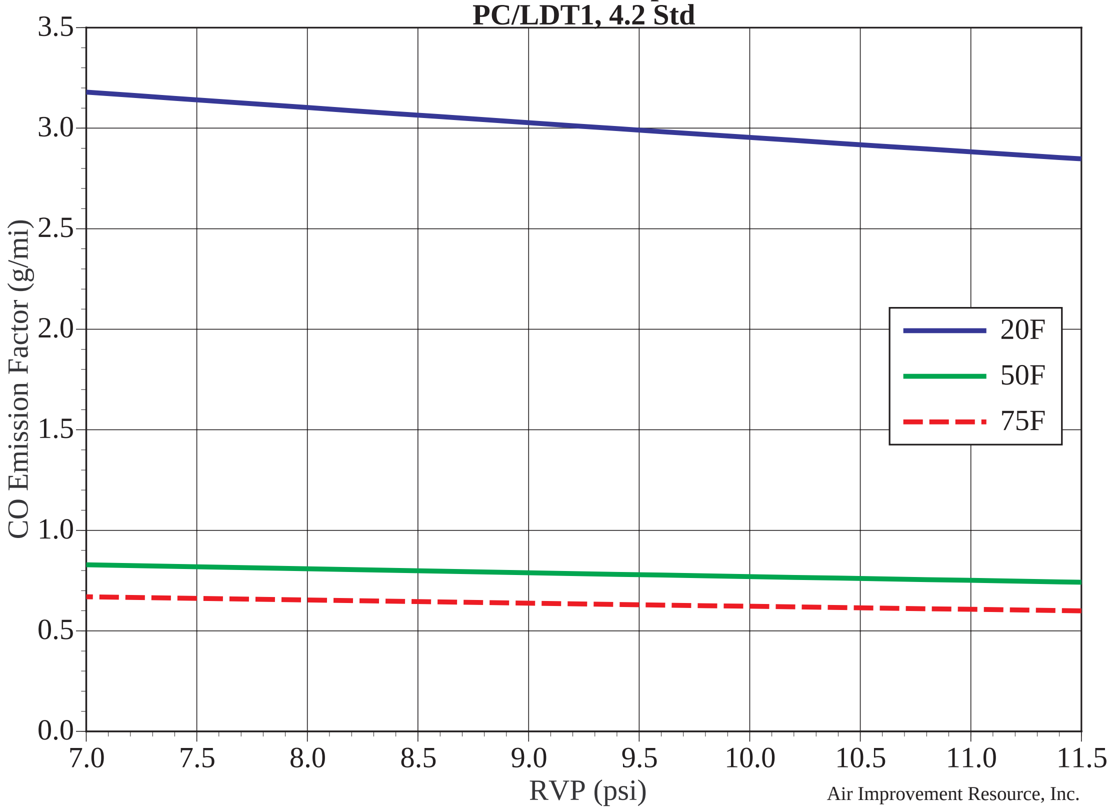


Figure 14
CO Emission Factors vs Temperature and RVP
PC/LDT1, 4.2 Std



6.0 Discussion

This section summarizes the major conclusions from this analysis and discusses the implications for a possible vehicle testing program to evaluate both temperature and RVP effects.

6.1 Brief Summary of Results

The results have shown that temperature has an effect on CO emissions, but that the influence of fuel volatility (and perhaps oxygenate) is small or nonexistent at RVPs between 7 and 9 psi. The effects of temperature on CO emissions are less significant for more advanced technology vehicles than for earlier vehicles such as Tier 1 vehicles. The certification data indicate that the MOBILE model overstates CO emissions at colder temperatures for advanced technology vehicles such as LEVs and Tier 2 vehicles.

An examination of the MOBILE6 model shows that two factors influence CO emissions – colder temperatures, and the "purge" effect at moderate and higher temperatures, coupled with fuels with RVPs above 9 psi. The purge effect in the model is very significant, but is based on early 1980 vehicles, few of which are in the vehicle fleet. It is very likely that the purge effect is much less on advanced technology vehicles than on 1980s vehicles. However, the analysis of certification data was not able to evaluate the purge effect, since RVPs above 9 psi are not utilized in tests above 50° F.

This analysis could be used to update the cold CO effects in MOBILE6; if this were to take place, predicted CO emissions at colder temperatures would be lower than the current version of MOBILE6 for calendar years 2000 and higher, since these calendar years include significant numbers of NLEVs and Tier 2 vehicles that are less sensitive to temperature than previous vehicles such as Tier 1 and Tier 0 vehicles.

6.2 Implications for a Vehicle Testing Program

It is clear that in order to adequately evaluate the purge effect, tests on Tier 1 and later vehicles are needed at temperatures above 40° F, and at fuel volatilities above 9 RVP. For example, tests could be conducted at 50° F, 60° F, and 70° F at fuel volatilities of 10, 11, and 12 RVP. There is little point in testing at temperatures higher than 60° F or 70° F, as wintertime temperatures in areas such as Phoenix and Las Vegas may not exceed these levels very often. Some of the higher volatility fuels should contain an oxygenate like ethanol, and some should not.

If there are adequate resources, it would also be good to test the vehicles at lower temperatures such as 20° F and 30° F. These data could be used to augment this analysis of the effects of cold temperatures on CO emissions.

One of the key testing issues in conducting the purge effect testing is to ensure the vehicle fuel tank temperatures during testing are representative of in-use temperatures on real roads. It is not clear that the testing done by EPA on 1980 vehicles properly controlled fuel tank temperature, and if tank temperatures significantly exceeded in-use temperatures, this could be a major factor influencing the "purge" effect. If adequate air flow is not supplied during testing, fuel tank temperatures can be higher during testing than during typical vehicle operation. Both the manufacturers and the regulatory agencies learned a great deal about the influence of fuel temperatures on running loss emissions during establishment of the running loss test procedure, which was a part of the enhanced evaporative regulations.

In terms of the vehicles of each technology required for such a testing program, we would recommend a minimum of 4-5 vehicles of each technology (Tier 1, LEV, ULEV, and a couple of SULEVs). It is probably not necessary to test Tier 0 vehicles, since these were phased-out in 1996. Most of the vehicles should be passenger cars, LDT1s, and LDT2s.

Another issue is the usefulness of the data for EPA's new MOVES model, in addition to the MOBILE model. The MOVES model utilizes second-by-second emissions data to evaluate emissions by various vehicle specific power bins. If resources are available, it may be advisable to collect modal (second-by-second) emissions data.

Another decision will be which testing procedure to use. The FTP could be the best choice, but another very good choice would be California's LA92 schedule, which is a self-weighting inventory cycle that appears to have the appropriate frequency of high speed and higher accelerations.

If the above testing were conducted, it would significantly augment our understanding of the influence of fuel volatility on CO emissions. We believe the data would not only be useful for the MOBILE6 model, but would also be valuable for the MOVES model.

7.0 References

1. "Review of CO Compliance Status in Selected Western Areas," Sierra Research, Inc., Report No. SR02-09-04, September 2002.

2. "Review of Current and Future CO Emissions from On-Road Vehicles in Selected Western Areas," Sierra Research, Inc., Report No. SR03-01-01, January 28, 2003.

3. "Questions and Answers on MOBILE6.2," EPA420-F-03-043, November 2003.

4. "Exhaust Emission Temperature Correction Factors for MOBILE6: Engine Start and Running LA4 Emissions for Gasoline Vehicles," M6.STE.004.

Appendix 1

Means and 90% Confidence Intervals Figure 12

Class/Tier	RVP	Mean CO	90% CI	Lower	Upper
PCLDT1, T1	7	1.245	0.106	1.140	1.351
	9	1.205	0.094	1.111	1.299
PCLDT1, 4.2	7	0.748	0.038	0.709	0.786
	9	0.802	0.034	0.767	0.836
PCLDT1, 2.1	7	0.415	0.038	0.377	0.453
	9	0.470	0.032	0.438	0.502
LDT23, T1	7	0.815	0.095	0.720	0.910
	9	0.793	0.018	0.775	0.810
LDT23, 4.2	7	1.045	0.090	0.954	1.135
	9	0.959	0.096	0.862	1.055
LDT23, 2.1	7	0.784	0.142	0.643	0.926
	9	0.684	0.115	0.570	0.799
LDT4, T1	7	2.900	1.486	1.414	4.386
	9	2.790	0.930	1.860	3.720
LDT4, 4.2	7	1.094	0.132	0.962	1.226
	9	0.986	0.112	0.874	1.099
LDT4, 21	7	1.700	0.155	1.545	1.855
	9	1.736	0.205	1.531	1.941