Appendix G
Estimation of a CO Credit

Effect of Fuel Properties on Light-Duty Vehicle Exhaust CO Emissions

The ARB staff evaluated the available data to investigate the effects of the various fuel properties on exhaust CO emissions. Data that were evaluated by ARB staff include results from the Auto Oil Air Quality Improvement Research program, the Coordinated Research Council Low Sulfur Study, the American Automotive Manufacturer Association's Sulfur Study, and the ARB's Ethanol Test Program. To determine the how each fuel parameter effects CO emission, we use a paired-data analysis in which we evaluated data for vehicles that was tested on fuels that only had different levels of one fuel property with the other fuel parameters as closely matched as possible. Based on the available data, the three properties that have the largest effect on CO emissions are; oxygen, sulfur, and T50.

Oxygen Effect On CO Emissions

Based on available emission test data, staff calculated the percent changes in CO emission per one weight percent change in oxygen content. Table 1 shows the reductions in CO emissions when oxygen content is increased, and Table 2 shows the increases in CO emissions when oxygen content is decreased. The data presented in Table and Table 2 are based on tests conducted using the Federal Test Procedure (FTP). The reductions for Federal Tier 1 and Advanced Vehicles were sufficiently small that they will be assumed to be zero. In U.S. EPA draft document, 'Fuel Oxygen Effects on Exhaust CO Emissions, Recommendations for MOBILE6,' March 16, 1998, the U.S.EPA also assumed that the effects of oxygen addition to be zero on CO emissions from these vehicle emission control technology groups.

To be consistent with the definitions for the vehicle classes used in the Predictive Model. Vehicles have been separated into the following groups: older vehicles (81 to 85 model years), Current vehicles (86 to 89 model years), Current vehicles (91 to 95 model years), Federal Tier 1 vehicles, and Advanced Technology vehicles. The older vehicles group (81 to 85 model years) are Tech 3 vehicles, Current vehicles (86 to 89 model years) and Current vehicles (91 to 95 model years) are Tech 4 vehicles, and Federal Tier 1 vehicles and Advanced Technology vehicles are Tech 5 vehicles.

Table 1. Summary of Percent CO Reduction Associated with a one percent Increased in Fuel Oxygen from Selected Studies

	Tech 3 Vehicles	Tech 4 Vehicles		Tech 5 Vehicles	
Study	81-86 MY	86 to 90 MY	91 to 95 MY	Federal Tier 1	Advance Tech.
Auto/Oil Bulletin #1	5.5%	4.7%	N/A	N/A	N/A
Auto/Oil Bulletin #4	6.1%	N/A	N/A	N/A	N/A
Auto/Oil Bulletin #6	N/A	5.0%	N/A	N/A	N/A
Auto/Oil Bulletin #17	N/A	5.4%	N/A	0.6%	-0.5%
ARB EtOH	N/A	N/A	1.39%	N/A	N/A
Average	5.8%	5.0%	1.39%	0.0%	0.0%

Table 2. Summary of Percent CO Increases Associated with a one percent Increased in Fuel Oxygen from Selected Studies

	Tech 3 Vehicles	Tech 4 Vehicles		Tech 5 Vehicles	
Study	81-86 MY	86 to 90 MY	91 to 95 MY	Federal Tier 1	Advance Tech.
Auto/Oil Bulletin #1	-4.5%	-5.2%	N/A	N/A	N/A
Auto/Oil Bulletin #4	-5.6%	N/A	N/A	N/A	N/A
Auto/Oil Bulletin #6	N/A	-4.3%	N/A	N/A	N/A
Auto/Oil Bulletin #17	N/A	-4.8%	N/A	-0.6%	0.5%
ARB EtOH	N/A	N/A	-1.35%	N/A	N/A
Average	-5.1%	-4.8%	-1.35%	0.0%	0.0%

CO Credit resulting From the Increase of Oxygen Content

For our calculations of emissions changes, EMFAC 7G was used to determine a baseline for CO emissions from the different groups of light-duty vehicles for the year 2005. The emissions for the different model year groups in the year 2005 are presented in Table 3.

Table 3. CO Emissions from Gasoline Vehicles

	81-85 MY	86 to 90 MY	91 to 95 MY	96 to 05 MY	Total
CO Emissions, TPD	712.00	1171.00	1041.00	2071.00	4995.00
Total Evaporative HC Emissions, TPD	22.48	43.67	69.67	59.23	195.05
Total Exhaust HC Emissions, TPD	58.80	86.50	116.20	104.40	365.90

It has been suggested that staff include effects of oxygen on off-cycle emissions of CO. Based on data from the ARB Ethanol study, it is estimated that the amount of reductions in CO emissions calculated as a weighted average using FTP and REPO5 test data is 2.8 times that of those calculated using FTP composite test data, alone. Given the lack of any other directly relevant information, this analysis will include percent changes in CO emissions determined from using FTP composite test data and those determined from using the weighted average of FTP and REPO5 emissions test data. The changes in CO emission when the fuel oxygen content is increased one weight percent are given in Table 4 and Table 5.

Table 4. Calculations of CO Reductions Based on FTP Composite Emissions

	81-85 MY	86 to 90 MY	91 to 95 MY	95 to 05 MY	Total
% CO Reduction per wt. % Oxygen	-5.07%	-4.76%	-1.35%	0.00%	
WT. % Oxygen Increased (1.0)	1.00	1.00	1.00	1.00	
Adjusted CO Reductions, TPD	-36.10	-55.72	-14.05	0.00	-105.87
Ozone Equivalent to CO Reductions, TPD	-2.53	-3.90	-0.98	0.00	-7.41
Eavp HC credit due to CO Reduction, TPD	1.10	1.70	0.43	0.00	3.22
Percent of Evap. HC Credit	4.89%	3.88%	0.61%	0.00%	1.65%
Exh. HC Credit due to CO Reduction, TPD	0.75	1.16	0.29	0.00	2.21
Percent of Exh. HC Credit	1.28%	1.35%	0.25%	0.00%	0.60%

Table5. Calculations of CO Reductions Base on FTP and REPO5 Emissions

	81-85 MY	86 to 90 MY	91 to 95 MY	95 to 05 MY	Total
% CO Reduction per wt. % Oxygen	-5.07%	-4.76%	-1.35%	0.00%	
WT. % Oxygen Increased (1.0)	1.00	1.00	1.00	1.00	
Weighted / FTP COMP	2.8	2.8	2.8	2.8	
Adjusted CO Reductions	-101.08	-156.01	-39.35	0.00	-296.44
Ozone Reduction from CO Reductions	-7.08	-10.92	-2.75	0.00	-20.75
Eavp HC credit from CO Reduction	3.08	4.75	1.20	0.00	9.02
Percent of Evap. HC Credit	13.68%	10.87%	1.72%	0.00%	4.63%
Exh. HC Credit from CO Reduction	2.11	3.26	0.82	0.00	6.19
Percent of Exh. HC Credit	3.59%	3.77%	0.71%	0.00%	1.69%

As shown in TABLE 4, the reduction in CO emissions for an increase of one weight percent in the oxygen content is estimated to be about 106 tons per day based on FTP composite emissions data. The MIR factor for CO is 0.07 grams of ozone per grams of CO; therefore the reduction in ozone that could be expected is about 7.42 tons per day. The average MIR factor for evaporative emissions has been calculated to be 2.21 gram of ozone per gram of VOC, therefore the evaporative emission equivalent to 7.42 tons of ozone is about 3.37 tons. The average MIR factor for exhaust emissions has been calculated to be 3.35, so the exhaust HC emissions equivalent is expected to be about 2.21 tons. This means that the CO reduction resulted from the increase of the oxygen content one weight percent could be used to offset about 1.7% of the total evaporative HC emissions. Similarly, the CO reductions could be used to offset about 0.56% of the total exhaust HC emissions.

From TABLE 5, the reductions in CO emissions are estimated to be about 296 tons per day based on the composite FTP and REPO5 data. Following the calculations described above, the reduction in ozone resulting from an increase of the oxygen content of gasoline by one is about 20.7 tons per day. Repeating the same calculations, it follows that the CO reduction resulting from the increase of the oxygen content could be used to offset about 4.8% of the total evaporative HC emissions. Similarly, the CO reductions could be used to offset about 1.6% of the total exhaust HC emissions. The HC emissions credit would be applied to the final predicted percent change in exhaust or evaporative emissions in the Predictive Model.

Table 6. VOC Adjustment Factors for Increase in Oxygen content by One Weight %

	FTP DATA	FTP And REPO5 Data
Evaporative HC Credit	-1.7%	-4.8%
Exhaust HC Credit	-0.56%	-1.6%

<u>CO Debit Resulting form the Reduction in Oxygen</u>

Reducing the oxygen content of a gasoline will result in an increase in CO and HC emissions. If a refiner removed the oxygen from a fuel meeting the flat limits, then exhaust hydrocarbon emissions would increase. Refiners will need to adjust other parameters of gasoline in order to offset the increase in HC emissions resulting from the reduction in oxygen content. Of the eight fuel properties that are regulated by the CaRFG2 regulations, the ones that are most likely to be adjusted to offset the increase in hydrocarbon emissions would be sulfur and T50. Both lowering the sulfur content and the T50 of gasoline will lower HC emissions. In addition, lowering the sulfur content and T50 will also reduce CO emissions; this would reduce the impact associated with reducing the oxygen content of gasoline.

Although limited, the data from the ARB Ethanol testing program supported the proposition that there exists a differential effect on CO emission associated with increasing oxygen on off-cycle emissions. The ARB Ethanol testing program did not test a zero oxygen fuel. Data are available from a 1996 ARB Mobile Source Division emissions factor test program, where several fuels were tested on both the FTP cycle and the Unified Cycle (LA92 Cycle). The Unified Cycle was developed to represent the average trip in the South Coast Air Quality Management District. Data from this study indicated that there are no significant difference in the CO emissions between the FTP cycle and the Unified Cycle (LA92 Cycle) when comparing a non-oxygenated gasoline with a gasoline containing 2 percent oxygen. While, the two fuels differed in other properties, for CO the most important factor is the oxygen content. For assessing the impact on CO emissions associated with going from a 2 percent oxygen fuel to a zero percent oxygen no off-cycle adjustment will be used in the analysis.

Table 6 shows the increase in CO emissions CO emission for one-percent reduction in the oxygen content of gasoline.

Table 7. CO Increases Due to the Reduction in Oxygen

	81-85 MY	86 to 90 MY	91 to 95 MY	95 to 05 MY	Total
% CO Increased per wt. % Oxygen Reduced	5.80%	4.99%	1.39%	0.00%	
WT. % Oxygen Increased (1%)	1.00	1.00	1.00	1.00	
Adjusted CO Increases, TPD	41.27	58.48	14.47	0.00	114.22
Ozone Increases Due to CO Increase, TPD	2.89	4.09	1.01	0.00	8.00
Eavp. HC Debit from CO Increase, TPD	1.26	1.78	0.44	0.00	3.48
Percent of Evap. HC Debit	5.59%	4.08%	0.63%	0.00%	1.78%
Exh. HC Credit from CO Increase, TPD	0.86	1.22	0.30	0.00	2.39
Percent of Exh. HC Debit	1.47%	1.41%	0.26%	0.00%	0.65%

From Table 7, the increase in CO emissions resulting from a reduction of oxygen content by one weight percent is 115 tons per day based on the composite FTP data. This increase in CO ozone equates to an increase in ozone of about 8.0 tons per day. The CO increase associated with reducing oxygen content could result in a HC debit about 1.8% of the total evaporative HC emissions or about 0.65% of the total exhaust HC emissions.

Table 8 presents an estimate of how reducing the sulfur content of gasoline could offset the CO emissions increase associated from reducing the oxygen content of gasoline. The amount of CO emissions reduced by reducing the sulfur content 10 parts per million (ppm) is about 47 tpd.

TABLE 8. Sulfur Effect on CO Emissions

	81-85 MY	86 to 90 MY	91 to 95 MY	95 to 05 MY	Total
% CO Reduced per10 PPM Sulfur Reduced	0.0%	-0.4%	-0.4%	-1.8%	-0.9%
Sulfur Reduction (10 ppm)	1	1	1	1	1
% CO Decreased from Sulfur Redcution	0.0%	-0.4%	-0.4%	-1.8%	-0.9%
CO Decreases from Sulfur Redcution,TPD	0.0	-4.4	-4.0	-38.2	-46.6
Ozone Change Due to CO Increase, TPD	0.00	-0.31	-0.28	-2.67	-3.26

Table 9 presents an estimate of how reducing the T50 of gasoline could offset the CO emissions increase resulting from reducing the oxygen content of gasoline. The amount of CO emissions reduced by reducing the T50 by 5 degrees is about 40 tpd.

TABLE 9: Effect of T50 Reduction on CO Emission

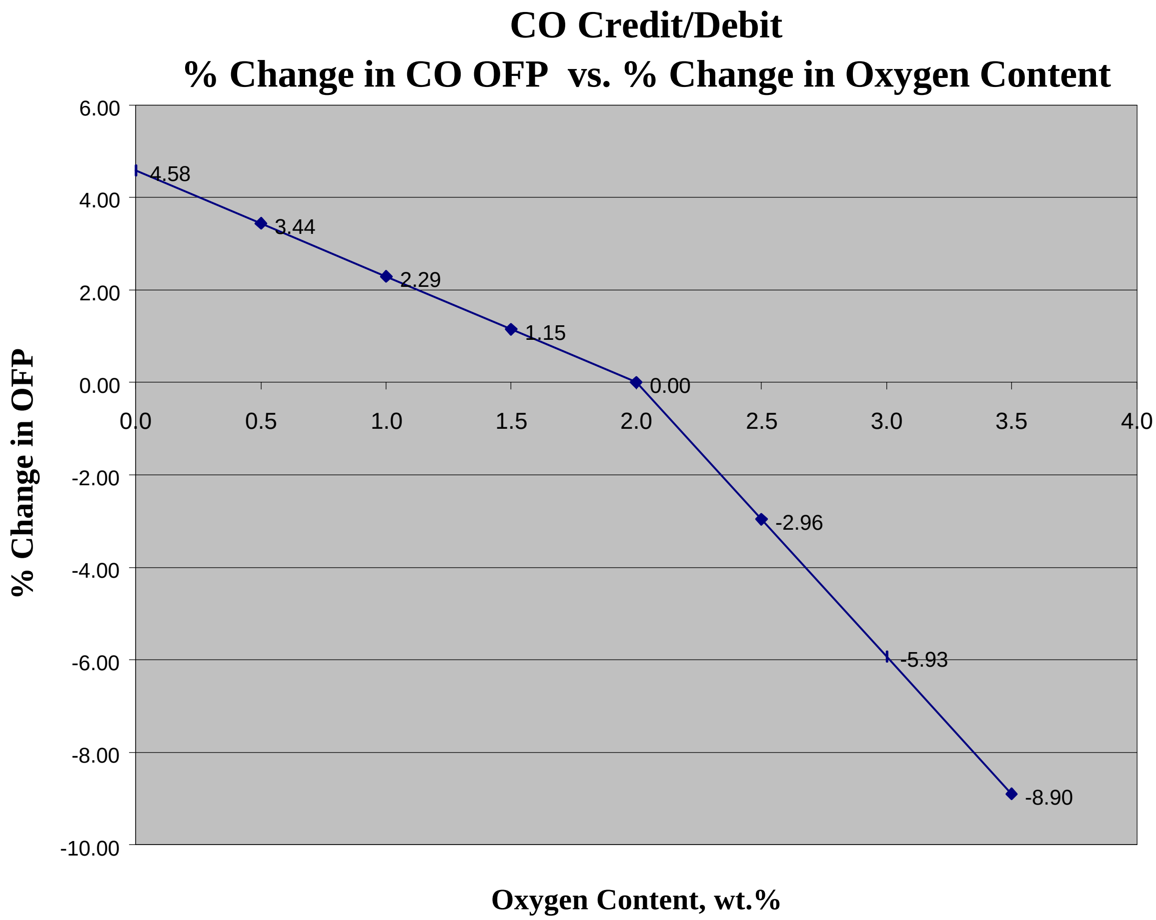
	81-85 MY	86 to 90 MY	91 to 95 MY	95 to 05 MY	Total
% CO Reduced per one degree T50 Reduced	-0.16%	-0.16%	-0.16%	-0.16%	-0.16%
T50 Reduction (5 dgrees)	5	5	5	5	5
% CO Decreased from T50 Redcution	-0.80%	-0.80%	-0.80%	-0.80%	-0.80%
CO Decreased from T50 Redcution, TPD	-5.7	-9.3	-8.3	-16.5	-39.8
Ozone Change Due to CO Increase, TPD	-0.4	-0.7	-0.6	-1.2	-2.8

Table 10 presents the expected change in CO emissions when oxygen content is decreased from 2.0% to 0%, sulfur content reduced by 10 ppm, and T50 reduced by 5 ^{o}F. A 9.9-tpd increase in ozone equates to about 4.5 tpd of evaporative emissions. This calculates to about 2.3 percent increase in evaporative HC emissions.

The flat limit for RVP in the proposed CaRFG3 specifications is 7.0 psi. Based on the proposed CaRFG3 Predictive Model the 6.9 baseline for using the evaporative hydrocarbon emissions model the 0.1 psi reduction in RVP would be expected to reduce emissions of evaporative hydrocarbons by about 3.4 percent. Therefore the effect on CO associated with a removing oxygen from a fuel complying with the proposed CaRFG3 specifications is significantly less than effect on emission from a 0.1 psi reduction in RVP.

Table 10. Expected Change in Emissions

	Change in CO, tpd	Expected Change in Ozone, tpd.	Change in Evaporative HC, tpd	Percent Change in Total Evaporative HC
Reducing Oxygen by 2 weight percent	228.4	16.0	7.2	3.7%
Reducing Sulfur by 10 ppmw	-46.6	-3.3	-1.5	-0.8%
Reducing T50 by 5 ^{o}F	-39.8	-2.8	-1.3	-0.7%
Total	142.0	9.9	4.5	2.3%


CO Credit/Debit
% Change in CO OFP vs. % Change in Oxygen Content
% Change in OFP
Oxygen Content, wt.%
6.00
4.00
2.00
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.58
3.44
2.29
1.15
0.00
-2.96
-5.93
-8.90

References to Example of CO Credit Calculations

1. Auto/Oil Air Quality Improvement Research Program, "Initial Mass Exhaust Emissions Results from Reformulated gasoline," Technical Bulletin No.1, December 1990.

2. Auto/Oil Air Quality Improvement Research Program, "Effects of Fuel Sulfur Levels on Mass Exhaust Emissions," Technical Bulletin No. 2, February 1991.

3. Auto/Oil Air Quality Improvement Research Program, " Emissions Results of Oxygenated Gasolines and Changes in RVP." Technical Bulletin No.6, September 1991.

4. Auto/Oil Air Quality Improvement Research Program, "Effects of Fuel Sulfur on Mass Exhaust Emissions, Air Toxics, and Reactivity." Technical Bulletin No. 8, February 1992.

5. Auto/Oil Air Quality Improvement Research Program, "Gasoline Reformulation and Vehicle Technology Effects on Exhaust Emission," Bulletin No. 17, August 1995.

6. Auto/Oil Air Quality Improvement Research Program, "Effects of Gasoline T50, T90, and Sulphur on Exhaust Emissions of Current and Future Vehicles," Technical Bulletin #18

7. Air Resources Board, Comparison Of The Effects Of A Fully-Complying Gasoline Blend And A High RVP Ethanol Gasoline Blend On Exhaust And Evaporative Emissions, November 1998

8. Results from the American Automobile Manufacturers Association's Sulfur Study

9. Results from the Coordinated Research Council's Sulfur Study