

# **Using the California RFG Predictive Model to Estimate the Emissions and Ozone Changes from Using Ten Percent Ethanol Blends in Denver**

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22 October, 2007

The California RFG Predictive Model offers a convenient means to estimate emissions changes and ozone impacts from adding 10 percent ethanol to gasoline. This Predictive Model is actually an Excel spreadsheet and can be used with another compatible model known as the CARBOB Model. This latter model shows what the specifications of “before ethanol” fuel must be to meet the CaRFG3 standards after a prescribed amount of ethanol is added. That is, refineries use the CARBOB Model to determine pre-CaRFG3 fuel specifications before shipping gasoline via a pipeline for blending with ethanol before retail delivery by truck. These models are available at <http://www.arb.ca.gov/fuels/gasoline/premodel/pmdevelop.htm>.

While these models are not designed specifically for conventional gasolines, such as found in Denver, the core feature of the Predictive Model is estimating percent changes in light duty gasoline vehicle emissions as a function of fuel parameter changes. The Predictive Model’s Excel spreadsheets allow extraction of the emissions change information generated within the model.

The Air Resources Board periodically (nominally every 5 years) updates the Predictive Model to include any new emissions data and or statistical analysis software. Changes in fleet turnover are also updated, because a new “target date” is part of the periodic process. The Predictive Model is based on 9,000 exhaust emissions tests using a wide range of fuel variations and vehicle model-years. The updating process involves many day-long workshops where stake-holders are invited to see and discuss all of the current data and proposed changes to the model. The most recent update process also involved three special technical sub-committees (for statistics, emissions, and reactivity).

The current Predictive Model was finalized by the CARB as of 26 March, 2007. Besides incorporating 1000 new data points on exhaust nitrogen oxide (NO<sub>x</sub>) and volatile organic compound (VOC) emissions, the latest model includes permeation emissions due to ethanol and a new carbon monoxide statistical model similar to the exhaust VOC model. The new “target date” is 2015. That is, 2015 is the date where the mixture of vehicle model-years (*i.e.*, technologies) is used to determine the overall percentage changes in emissions predicted to occur as the various fuel parameters are varied.

The CARBOB model incorporates four changes to fuel specifications relevant to the Denver analysis of emission differences between conventional gasoline without ethanol (E0) and gasoline with a 10 percent ethanol blend (E10): first, properties like aromatics, olefins, sulfur, and benzene each are simply diluted proportionately by ethanol; second,

CARBOB adds 1 psi to the RVP when ethanol is added; third, T50 (the mid-boiling point of gasoline) is lowered for E10 compared to E0 by about 7 points for typical fuels; and fourth, T90 (the temperature where 90 percent of the gasoline boils) is lowered about 4 points going from E0 to E10. The parameters needed by the Predictive Model are the percentages in the fuel of aromatics, olefins, sulfur, benzene, and oxygen (which are directly related to the amount of ethanol). The only other properties required are the volatility (as Reid Vapor Pressure or RVP in psi), the T50, and the T90. Thus, the CARBOB model would probably not be of further use in Denver, since the T50 and T90 changes needed for comparing E0 and E10 are apparently the 7 and 4 points noted above. The rest of the needed information for Denver would be the typical values for E0 sold there.<sup>1</sup>

The core part of the CARB Predictive Model (PM) can be used to predict the percentage change in emissions in Denver due to splash-blending ethanol with E0 to produce E10. To provide the needed input fuel parameters some assumptions will be needed. For the Denver area, RVP can currently be assumed as 7.8 psi. Some data show that sulfur levels appear to average presently near 100 ppm, but by regulation should reach closer to 30 ppm by 2009. The E10 fuel can be assumed to result from splash-blending with the E0 fuel. Thus, the remaining fuel properties needed to use the PM are the percentages of aromatics, olefins, and benzene, plus the values of T50 and T90. For these parameters a bracket procedure will be used: at one side of the "bracket" the parameters from Auto/Oil Fuel A (generally considered to be "conventional gasoline") will be used and at the other side the fuel parameters found in CARB so called "flatline" CARBRFG3. CARB "flatline" is the base fuel used in for the Predictive Model and it has 5.7 percent ethanol, so the specifications of E0 fuel are created using the CARBOB Model. That is, the CARBOB model can show what fuel parameters are necessary to make "flatline" E5.7 gasoline and these fuel parameters are used to create "E0" for this analysis.

#### Fuel Characteristics with the 1 psi Ethanol Waiver

Table 1 shows the two bracket fuels each for E0 and E10 along with the E5.7 "flatline" fuel for reference. Note that reference to Auto/Oil Fuel A or to CARB RFG implies only the needed "bracket" parameters and not the ones assumed to be known in Denver such as fuel sulfur and RVP.

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<sup>1</sup> The CARBOB Model apparently does not consider how T50 could vary if the base RVP for Denver gasoline were lowered from the present 7.8 psi. For example, to change RVP to 7.0 psi, some highly volatile compounds would need to be removed and these would boil below the T50 point. The result is that lowering RVP can be expected to raise T50. Some data on this issue can be found in SAE Paper No. 920324, which presents information on the fuels used in the 50 million dollar Auto/Oil Air Quality Improvement Research Program. Auto/Oil Fuels A and V were blended to represent average conventional gasoline (circa 1990) differing only in RVP. Fuel A had an RVP of 8.7 psi and Fuel V had an RVP of 7.8 psi, while all other properties were intended to be the same. Appendix E of SAE Paper No. 920324 shows that reducing RVP by 0.9 psi resulted in a 2 point increase for T50.

Fuel/Parameter	Fuel A E0	Fuel A E10	CARBFRFG E0	"Flatline"	CARBFRFG E10
RVP	7.8	8.8	7.8	6.9	8.8
T50	220	213	215	213	208
T90	330	326	307	305	303
Aromatics	32	28.8	26.5	25	23.9
Olefins	9.2	8.3	6.4	6.0	5.7
Oxygen	0	3.5	0	2.0	3.5
Sulfur	100	90	100	20	90
Benzene	1.5	1.35	0.84	0.80	0.76

Based on application of the PM the fuel parameters shown in Table 1, Table 2 shows the mass emissions changes due to adding 10 percent ethanol for exhaust VOC, evaporative VOC, CO, NO<sub>x</sub>, potency-weighted toxics and ozone. For the ozone estimates two values are shown: one based on box-model MIR reactivity factors as incorporated in the PM and the other estimate changes only the CO reactivity to use a higher value estimated by CARB staff using a photochemical grid model (D. Luo, 2006).

	Fuel A	CaRFG
Exhaust VOC	-4.36	-7.46
Evaporative VOC	+12.46	+12.46
CO	-17.9	-18.25
NO <sub>x</sub>	+1.35	+2.1
Toxics	-8.38	-7.40
MIR Ozone	+0.51	-1.0
Grid Ozone	-0.72	-2.2

Note that the changes in evaporative emissions are the same (because RVP is the only parameter used in the PM) and, as noted above, they include permeation due to the ethanol. The four ozone estimates combine only the VOC and CO changes along with weighting factors based on mass contribution and relative reactivity of the three emissions categories (i.e. exhaust VOC, evaporative VOC, and CO). The average ozone change for the four estimates is -0.86 percent. That is, adding ethanol on average still reduces ozone somewhat, even with the 1 psi waiver. The mass contributions change somewhat as the E0 departs from the internal PM base, which is for "flatline." Also, the relative mass values of these three categories are probably somewhat different than the base inventory for Denver might be.

For “flatline” the relative mass contributions used in the PM are 0.0454, 0.0597, and 0.8949 for on-road gasoline-related exhaust VOC, evaporative VOC, and CO, respectively. The relative MIR-based ozone-forming values for these same three categories are 1.0 (by definition), 0.70, and 0.015, respectively. The CARB grid model relative reactivity for CO is 0.0229. The relative ozone-forming reactivity of the three categories may differ in the CAMx photochemical grid model from the MIR or CARB grid model estimates.

In spite of the caveats noted, the bracket technique used here along with the Predictive Model shows that adding 10 percent ethanol to gasoline appears to be ozone neutral even when permeation and the 1 psi waiver are considered. The average of the four estimates is a 0.86 percent reduction in ozone when ethanol is added.