

**Appendix N**  
**Effects of CaRFG on Greenhouse Gas Emissions**

a. Introduction

Greenhouse gases (GHG) are predominantly comprised of carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>) and nitrous oxide (N<sub>2</sub>O). The Intergovernmental Panel on Climate Change has developed the concept of Global Warming Potential, which compares the global warming impacts of various gases relative to CO<sub>2</sub>. These are illustrated in Table 1, as well as equivalent CO<sub>2</sub> California emissions of three GHGs in 1994.

**Table 1**  
**1994 California Greenhouse Gas Emissions**  
**(by gas type)**

Greenhouse Gas	Global Warming Potential	GHG Emissions in CO <sub>2</sub> Equivalent (thousand tons)
CO <sub>2</sub>	1	400,227 (87.7%)
CH <sub>4</sub>	21	49,327 (10.5%)
N <sub>2</sub> O	310	8,637 (1.8%)

Source: California Energy Commission

Based on data compiled by the CEC, CO<sub>2</sub> emissions from the consumption of motor gasoline constituted nearly 33 percent of the total California CO<sub>2</sub> emissions in 1994, or nearly 131 million tons. This is the single largest source of CO<sub>2</sub> emissions in California.

In evaluating the global warming impacts of the proposed amendments, staff relied on information comparing the GHG emissions of conventional and reformulated gasoline (produced with 11 volume percent MTBE), as well as the GHG emissions of these fuels compared to gasoline blended in 10 volume percent ethanol. Limited data exists on the global warming impacts of gasoline blended with ethanol concentrations less than 10 volume percent, and therefore was not considered in this analysis.

b. Methodology

In determining the impact of the proposed amendments on GHG emissions, staff has assumed two possible scenarios will develop in the future production of California gasoline. First, gasoline in California will no longer be produced with oxygenates. This scenario may develop for certain grades of gasoline throughout the State if the federal minimum 2.0 weight percent oxygen mandate is eliminated in California. Second, if this mandate is not removed, gasoline produced for California federal RFG areas, as well as certain gasoline grades in non-federal RFG areas, will continue to be produced with oxygenates, most likely ethanol.

To determine the overall impact of the proposed amendments on California GHG emissions, staff has broken the GHG emissions into two components. The first part includes the exhaust

GHG emissions for various gasoline types. The second part includes fuel-cycle GHG emissions (GHG emissions associated with the production of the fuel) for various types of gasoline. The sum of the emissions from these two components yields the total GHG emissions associated with each gasoline type. All estimates of CO<sub>2</sub> emissions are based on a near-future average fuel economy of 27.5 miles per gallon (MPG) in 2005.

Little data exists on the direct comparison of total GHG emissions of CaRFG2 produced with 11 volume percent MTBE and CaRFG2 produced with 10 volume percent ethanol. In order to evaluate the relative fuel-cycle GHG emissions between these two fuels, staff has estimated baseline GHG emissions of conventional (non-oxygenated) gasoline, and used available data comparing these fuels to the baseline.

c. Exhaust Emissions

Staff first evaluated CaRFG2 produced with 11 volume percent MTBE, and a gasoline with similar properties, but blended with 10 volume percent ethanol. Based on data compiled by the National Renewable Energy Laboratory (NREL), as shown in Table 2, it can be seen that the difference in GHG exhaust emissions between these two fuels is very small. Gasoline blended with 10 percent ethanol has approximately two percent less GHG exhaust emissions than CaRFG2 produced with 11 volume percent MTBE.

**Table 2**  
**Greenhouse Gas Exhaust Emissions\* of CaRFG2**  
**(By Oxygenate)**

Oxygenate	CO <sub>2</sub> emissions (g/mi)
MTBE (11 Vol. %)	318
Ethanol (10 Vol. %)	311

Source: National Renewable Energy Laboratory

\* Based on an average vehicle fuel economy of 27.5 MPG in 2005.

Staff also evaluated GHG exhaust emission data from a study prepared by Accurex Environmental Corporation (Accurex Study) for the ARB. This study shows relatively no difference between CaRFG2 produced with 11 volume percent MTBE and conventional gasoline, with both fuels producing 307 grams CO<sub>2</sub> per mile.

c. Fuel Cycle Emissions

Staff first evaluated the difference in fuel-cycle CO<sub>2</sub> emissions from conventional and CaRFG2 produced with 11 volume percent MTBE. As shown in Table 3, the Accurex Study estimated conventional (non-oxygenated) gasoline fuel-cycle emissions of 46 grams CO<sub>2</sub> per mile, as opposed to CaRFG2 emissions of 49 grams CO<sub>2</sub> per mile. The relative percent difference in fuel-cycle emissions of CaRFG2 compared to conventional gasoline is shown in parenthesis.

Staff then evaluated the fuel-cycle CO<sub>2</sub> emissions from ethanol (corn produced) blended gasoline. It is important to note that fuel-cycle emissions from corn-produced ethanol have been

the subject of intense controversy among researchers with respect to its net efficiency and CO<sub>2</sub> emissions. This is mostly due to the current practices associated with the U.S. corn-to-ethanol industry, and the use of fossil fuels, including petroleum and coal, in those practices. Analysis have ranged from concluding that ethanol use results in substantially higher, about the same, or somewhat lower CO<sub>2</sub> levels than other oxygenates. In a study prepared by the Argonne National Laboratory (Argonne Study), it was concluded that fuel-cycle GHG emissions from a gasoline produced with 10 volume percent ethanol were approximately 100 grams per mile. This compares to the fuel-cycle GHG emissions from the production of conventional (non-oxygenated) gasoline, which were 9 percent less at 91 grams per mile. These results are shown in Table 3. Again, the relative percent differences in fuel-cycle emissions compared to conventional gasoline are shown in parenthesis.

**Table 3**  
**Fuel-Cycle Emissions\* of Oxygenated and Reformulated Gasoline**  
**Compared to Conventional Gasoline**

Fuel Type	Accurex Study (g/mi)	Argonne Study (g/mi)
Conventional Gasoline ( <i>baseline fuel</i> )	46	91
CaRFG2 ( <i>11 vol. % MTBE</i> )	49 (+7%)	--
Oxygenated Gasoline ( <i>10 vol.% EtOH from corn</i> )	--	100 (+10%)
Oxygenated Gasoline ( <i>10 vol.% EtOH from w. biomass</i> )	--	73 (-20%)
Oxygenated Gasoline ( <i>10 vol.% EtOH from h. biomass</i> )	--	85 (-7%)

\* Based on an average vehicle fuel economy of 27.5 MPG in 2005.

In Table 3, it is interesting to note that the Accurex Study estimated fuel-cycle emissions to be 46 grams per mile for conventional gasoline, while the Argonne Study estimated the same emissions to be 91 grams per mile. While part of this difference may be due to the fact the Accurex Study only examined emissions of CO<sub>2</sub>, staff believes that this discrepancy is more likely the result of differences that can arise from the use of different methodologies in evaluating fuel-cycle emissions.

Staff also evaluated the fuel-cycle emissions from ethanol produced from biomass. In conducting an analysis of the fuel-cycle GHG emissions from biomass produced ethanol, staff relied on the Argonne Study. In that study, fuel-cycle GHG emissions from gasoline produced with 10 volume percent ethanol derived from woody biomass (i.e., forest waste, orchard prunings, etc.) were 20 percent lower than for conventional gasoline. For ethanol produced from herbaceous biomass ( i.e., rice straw), GHG fuel-cycle emissions were reduced by approximately 7 percent. These results are shown below in Table 3.

d. Total Fuel-Cycle Emissions of Greenhouse Gases

Table 4, shows the total GHG emissions (in CO<sub>2</sub> equivalency) of the various gasoline blends evaluated.

**Table 4**  
**Total GHG Emissions\* for Various Gasoline Blends**

Fuel Type	Exhaust Emissions (g/mi)	Fuel-Cycle Emissions (g/mi)		Total Emissions <sup>1</sup> (g/mi)	
		Accurex Study	Argonne Study	Accurex Study	Argonne Study
Conventional Gasoline ( <i>baseline fuel</i> )	307	46	91	<b>353</b>	<b>398</b>
CaRFG2 ( <i>11 vol. % MTBE</i> )	318	49	--	<b>367 (+4%)</b>	--
Oxygenated Gasoline ( <i>10 vol.% EtOH from corn</i> )	311	--	100	--	<b>412 (+4%)</b>
Oxygenated Gasoline ( <i>10 vol.% EtOH from w. biomass</i> )	311	--	73	--	<b>385 (-3%)</b>
Oxygenated Gasoline ( <i>10 vol.% EtOH from h. biomass</i> )	311	--	85	--	<b>397 (0%)</b>

\* Based on an average vehicle fuel economy of 27.5 MPG in 2005.

<sup>1</sup> The number in parenthesis is the relative emission difference between the fuel and it's baseline (conventional) fuel.

In determining the overall GHG emissions for the various gasoline fuels, staff relied on the NREL data to determine the exhaust contribution of GHG emissions for both CaRFG2 and oxygenated gasoline blended with 10 volume percent ethanol. This data was used since it is the most current available and is based on ARB data. To determine the exhaust contribution of GHG emissions from conventional gasoline, staff chose to use the Accurex data over the Argonne data since the exhaust GHG data in the Argonne Study was not consistent with the other studies. As can be seen from Table 4, there is very little difference in exhaust GHG emissions between the three gasoline types evaluated (conventional, reformulated and oxygenated gasoline). Both the oxygenated and reformulated gasolines show slight increases in exhaust GHG emissions compared to conventional gasoline. However, these increases are not significant (approximately 1 percent) when compared to the total GHG emissions.

More consideration was given in determining the appropriate method to evaluate fuel-cycle emissions from the various studies. As stated previously, different methodologies yield significantly different fuel-cycle GHG emissions. In order to evaluate the different studies on a "level playing field", the fuel-cycle GHG emission results from each study were normalized by evaluating the relative differences between the various gasoline types compared to the baseline conventional gasoline used in the applicable study. These results are shown in parenthesis in Table 4 as the percent change in fuel-cycle GHG emissions from their respective baseline gasoline.

As can be seen from both the Accurex and Argonne study, when the fuel-cycle emissions are combined with the exhaust emissions provided by NREL, there is no relative difference in overall GHG emissions from CaRFG2 produced with 11 volume percent MTBE and oxygenated gasoline blended with 10 volume percent ethanol derived from corn. Both fuels yield a similar 4% increase in GHG emissions compared to their baseline gasoline. However, as shown in the Argonne Study, when the ethanol is derived from biomass instead of corn, overall GHG emissions from oxygenated gasoline are reduced. This reduction in overall GHG emissions is 4 percent for ethanol derived from herbaceous biomass, and 7 percent for ethanol derived from woody biomass as compared to oxygenated gasoline blended 10 volume percent ethanol derived from corn.

The NREL took the analysis of the benefits of ethanol derived from biomass one step further, in that it considered the GHG impacts of the open-field burning of biomass that could otherwise be diverted towards the production of ethanol. In their analysis, the overall GHG emissions of CaRFG2 produced with 11 volume percent MTBE were combined with the overall GHG emissions of open-field burning of agricultural waste. These emissions were then compared to the overall GHG emissions of ethanol production from biomass and blended into an oxygenated gasoline with 10 volume percent ethanol. The results of this analysis show that fossil fuel CO<sub>2</sub> emissions are reduced between 32-50 percent when ethanol derived from biomass is used to produce oxygenated gasoline. The main source of these GHG emission reductions is the cogeneration of electricity during the ethanol production process, which displaces the combustion of fossil fuels for the production of a similar amount of electricity in a conventional fossil-fueled power plant.

#### e. Conclusions

Based on the staff evaluation of potential GHG emissions from various gasoline blends, the proposed CaRFG3 Regulations are not expected to increase emissions of greenhouse gases that may contribute to global warming. The proposed amendments may result in a significant net decrease in GHG emissions in California to the extent that ethanol produced from California biomass becomes available and is blended into the gasoline pool. In addition, staff estimate that gasoline produced with a lower oxygen content (less than 2 percent by weight) may result in small reductions in GHG emissions.