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Effects of using renewable fuels on vehicle emissions

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A R T I C L E I N F O

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A B S T R A C T

In an effort to reduce greenhouse gas emissions, renewable fuels (biofuels) are being developed and used in motor vehicles. The most common of these are bioethanol and biodiesel that are blended with petroleum based gasoline and diesel fuels at varying percentages. This provides some reduction in the fossil carbon emissions from these fuels. Biomethane (produced from biogas) can and is used as a vehicle fuel to a much more limited extent. Significant modifications are required for the motor vehicle to use biomethane.

The use of bioethanol blended fuels leads to increases in emissions of formaldehyde and acetaldehyde, with an accompanying decrease in benzene emissions. Nitrogen oxides (NO_x) emissions are often increased with the use of bioethanol. The use of biodiesel blended fuels generally leads to increased NO_x emissions, and decreases in particulate matter (PM) emissions. The use of biomethane is expected to have little adverse impact on the emissions from the combustion process, but it will lead to increased emissions of methane due to leakage and unburned fuel emissions. Methane is a stronger greenhouse gas than CO_2, which is the greenhouse gas emitted in largest quantities from all combustion processes. With the appropriate time and effort, operating and emission control technologies can be developed to minimize the adverse effects that biofuel use will have on vehicle emissions. But this will require that vehicles be properly designed for the use of specific biofuels or biofuel blends. Renewable fuels may lead to decreases in greenhouse gas emissions, even with increasing use of transport fuels. No improvement, and more likely deteriorating air quality, is expected in the future with increasing renewable fuel use.

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1. Introduction

Currently there are about one billion light-duty motor vehicles in operation throughout the world, with approximately 75% in the developed, OECD nations. The number of light-duty, personal vehicles is expected to grow from 0.8 billion in 2010 to 1.7 billion by 2040; approximately 80% of this growth is expected to occur in the developing, non-OECD nations. This growth in the vehicle population is expected to be largely offset by the improved vehicle fuel economy, so that future light-duty vehicle fuel demand is only expected to increase slightly (about 5%) [1]. The demand for commercial transport is also expected to substantially increase by 2040, and the fuel demand for heavy-duty vehicles (trucks and buses) is expected to increase by about 70%. Currently, heavy-duty vehicle fuel demand is about 80% of that for light-duty vehicles, however by 2040 it is expected to be about 130% [1].

Transportation sources currently constitute about 15% of the global greenhouse gas emissions, although it is a more important contributor in many areas of the world. In an effort to reduce greenhouse gas emissions, renewable fuels (biofuels) are being developed and used in motor vehicles; the most common are bioethanol and biodiesel, which are blended with petroleum based gasoline and diesel fuels, at varying percentages. Use of biofuels provides some reduction in the fossil carbon emissions from vehicles. At this time, biofuel use accounts for only about 3.4% of the on-road transportation fuel used globally. About 80% of the transportation biofuel is bioethanol, and about 20% is biodiesel; total biofuel production actually declined slightly during 2012 [2]. Small percentage biofuel blends have been used in motor vehicles, with little modification to the vehicle. The assumption has been that the use of these fuels would have little adverse effects on air quality.

Natural gas used as a vehicle fuel may have slightly lower greenhouse gas emissions than gasoline or diesel fuel [3], and may be useful for initiating development of infrastructure, which could ultimately serve for biomethane distribution as a vehicle fuel. Fossil natural gas is clearly not a sustainable vehicle fuel. As biomethane (from biogas) production increases, it can be blended in increasing quantities with fossil natural gas to supply gas needs. Natural gas is used extensively as a vehicle fuel in a few countries, and is used to a small extent in many more. For example, Sweden had over 38,000 natural gas vehicles (NGVs) in 2012, and biomethane accounted for over 60% of the fuel used in these vehicles [4].

This review discusses vehicle emissions and air quality impacts for bioethanol, biodiesel and biomethane vehicle fuels. The discussion of bioethanol and biodiesel will be based on previous publications [5,6], and will be supplemented by more recent information. The effects of biomethane use will be assessed by reviewing the effects of compressed natural gas (CNG) and liquid natural gas (LNG) on vehicle emissions.

2. Bioethanol

Ethanol blended fuels have been used extensively in Brazil as a vehicle fuel since the 1980s [5]. By 1983, most new light-duty (non-diesel) vehicles produced in Brazil were built to run on hydrous ethanol, rather than gasoline or gasohol (a gasoline–ethanol blend). By 1990, sugar prices had increased and fuel ethanol production had dropped to the point Brazil was forced to import ethanol for fuel use. The high cost and availability issues for this ethanol fuel ended the production of ethanol-only vehicles by the mid-1990s. In 1993, Brazil enacted a law that required all gasoline be blended with at least 20–25% ethanol. Around 2003, Brazil started significant production of flex-fuel vehicles that could operate on the E20 blend (gasohol), ethanol, or any mix of these fuels. This permits these newer vehicles to use the least expensive fuel available at the time. The vehicle emissions data from Brazil generally showed that nitrogen oxides (NO_x) emissions were higher from gasohol than ethanol fueled vehicles, and the aldehyde emissions were higher from ethanol than gasohol fueled vehicles [5]. The emissions of acetaldehyde are higher than formaldehyde with all ethanol blended fuels.

The resulting concentrations of both formaldehyde and acetaldehyde observed in Brazil are generally higher than observed in other countries [5]; acetaldehyde, formaldehyde and nitrogen oxides are all important initiators of photochemical air pollution problems such as ozone. Severe ozone air quality problems have been observed in a number of cities in Brazil. The concentrations of ozone precursors and ozone have decreased in recent years from more stringent vehicle emissions standards, but ozone issues persist in Brazil.

Anderson and Wilkes [7] analyzed the effects of using 10% ethanol blended (E10) fuel use on vehicle emissions in a very large data set. Beginning in 1995, the state of Colorado started an advanced inspection and maintenance (I/M) program. This program required that 1982 and newer light-duty vehicles undergo a centralized IM240 dynamometer emissions test. From November through February, Colorado required that all gasoline sold in the area be blended with an oxygenated compound (either ethanol or methyl tertiary butyl ether [MTBE]), this was intended to reduce carbon monoxide (CO) concentrations during winter periods. Over 80% of the fuel sold during the winter periods of 1995 and 1996 was an E10 blend, supplies of fuel ethanol were sufficiently limited that only a small fraction of the fuel sold in other months of the year were blended with ethanol. The vehicle emissions data collected during the winter months of a calendar year (January, February, November and December) were compared with the emissions data collected during the months of April through September. Data collected in March and October were not used, since fuel with variable ethanol content was sold. Table 1 shows a summary of the effects of this program on vehicle emissions, and because of the large number of vehicles tested, each of the percent differences are statistically significant. Hydrocarbon (HC) emissions were found to decrease by 1.3% and 0.2% during the E10 fuel use periods of 1995 and 1996. Similarly, CO emissions were found to be 7.0% and 4.9% lower, and NO_x emissions were found to be 13.5% and 13.1% higher during the E10 periods of 1995 and 1996. The emissions reductions for CO were lower than expected, while the increases in NO_x emissions were higher.

Jacobsen [8] used a nested global-urban air pollution/weather forecast model, combined with high-resolution future emission inventories, population data, and health effects data, to examine the effect of converting from gasoline to E85, on cancer, mortality, and hospitalization in the United States. The results suggested that E85 (85% ethanol, 15% gasoline) may increase ozone-related mortality, hospitalization, and asthma by about 9% in the Los Angeles area and 4% on average in the United States. The model predicted ozone increases in Los Angeles and the northeast US, and decreases in the southeast; it also predicted increases in peroxyacetyl nitrate (PAN) concentrations in the US.

López-Aparicio and Hak [9] evaluated the effects of use of bioethanol (E95–95% ethanol) fueled buses in Oslo, Norway. Aldehydes were

Table 1
Results of the analysis of I/M240 emissions data for 1995 and 1996 [7].

	1995	1996
Number of vehicles tested	721,942	651,223
HC emissions	−1.3%[a]	−0.2%
CO emissions	−7.0%	−4.9%
NO_x emissions	+13.5%	+13.1%

[a] The table shows the % difference between the winter (E10) months and the summer (non-oxygenated fuel) months.