

Detergent additives (often packaged in combination with a cetane enhancer) help to prevent and remove coke deposits on fuel injector tips and other vulnerable locations. By maintaining new engine injection and mixing characteristics, these deposits can help to decrease in-use PM and HC emissions. A study for the California Air Resources Board estimated the increase in PM emissions from in-use trucks due to fuel injector problems as being more than 50% of new vehicle emissions levels. A significant fraction of this excess is unquestionably due to fuel injector deposits.

- The use of detergent additives to reduce deposits on injector components is highly recommended, especially on more modern engines.

## Alternative fuels

In addition to conventional gasoline and diesel fuels, many countries around the world have identified significant benefits associated with a shift to alternative fuels, especially CNG, LPG, and ethanol. Besides CNG (mainly composed of methane) and LPG (composed of propane or butane), alternative fuels include methanol, ethanol, hydrogen, electricity, vegetable oils (including biodiesel), synthetic liquid fuels derived from coal, and various fuel blends such as gasohol.

### Natural gas

Natural gas (85-99% methane) is clean burning, cheap and abundant in many parts of the world. Because natural gas is mostly methane, natural gas vehicles (NGVs) have much lower non-methane HC emissions than gasoline vehicles, but higher methane emissions. Since the NGV fuel system is sealed, there are no evaporative emissions and refuelling emissions are negligible. Cold-start emissions from NGVs are also low, since cold-start enrichment is not required. In addition, this reduces both VOC and CO emissions.  $\text{NO}_x$  emissions from uncontrolled NGVs may be higher or

lower than comparable gasoline vehicles, depending on the engine technology, but are typically slightly lower. Light duty NGVs equipped with modern electronic fuel control systems and three-way catalytic converters have achieved  $\text{NO}_x$  emissions more than 75% below the stringent California Ultra Low-Emission Vehicle standards.

As a substitute for diesel, NGVs should have somewhat lower  $\text{NO}_x$  and substantially lower PM emissions, unless the diesel vehicle is burning ULSD and is equipped with a PM filter.

Given equal energy efficiency, greenhouse gas (GHG) emissions from NGVs will be approximately 15–20% lower than from gasoline vehicles, since natural gas has lower carbon content per unit of energy than gasoline. NGVs have about the same GHGs as diesel fuel vehicles.




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**Natural gas vehicles such as the CNG taxi in Delhi (above) and the CNG bus in Thailand (right) are slowly growing in fleet number as the infrastructure and supply of natural gas develop**

Obstacles to the widespread use of NGVs include the absence of transportation and storage infrastructure, cost, loss of cargo space, increased refuelling time, and lower driving range.

## Liquefied petroleum gas

Engine technology for LPG vehicles is very similar to that for NGVs. As a fuel for spark-ignition engines, it has many of the same advantages as natural gas, with the additional advantage of being easier to carry aboard the vehicle. LPG's major disadvantage is the limited supply, which would rule out any large-scale conversion to LPG fuel.

LPG has many of the same emissions characteristics as natural gas. The fact that it is primarily propane (or a propane/butane




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mixture) rather than methane, affects the composition of exhaust VOC emissions, their photochemical reactivity, and its global warming potential, but otherwise the two fuels are similar.

The cost of conversion from gasoline to propane is considerably less than conversion to natural gas, due primarily to lower cost fuel tanks. As with natural gas, the cost of conversion for high-use vehicles can typically be recovered through lower fuel costs within a few years.

LPG is produced in the extraction of heavier liquids from natural gas, and as a by-product in petroleum refining. Presently, LPG supply exceeds demand in most petroleum-refining countries, so the price is low compared to other hydrocarbons. Depending on the locale, however, the additional costs of storing and transporting LPG may more than offset this advantage.

LPG is already widely used as a vehicle fuel in the United States, Canada, Netherlands, Japan and elsewhere. In Japan, 260,000 taxis—94% of the country's total taxi fleet—use LPG. Many diesel-fuelled taxis in Hong Kong, China have also shifted to LPG.

## Methanol

Methanol has many desirable combustion and emissions characteristics, including lean combustion capability, low flame temperature (leading to low NO<sub>x</sub> emissions) and low photochemical reactivity. It is also a liquid, which makes its storage and handling much simpler than gaseous fuels. At current and foreseeable prices, the most economical feedstock for methanol production is natural gas, especially natural gas found in remote regions where it has no ready market. The most common methanol fuel is M-85, a methanol-gasoline blend consisting of 85% methanol and 15% unleaded gasoline.

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**There are several obstacles to the widespread use of natural gas- and LPG-fuelled vehicles. These include the absence of transportation and storage infrastructure, additional cost (primarily of fuel storage tanks), loss of cargo space, increased refuelling time, and lower driving range**

Light duty methanol vehicles have  $\text{NO}_x$  and CO emissions similar to gasoline vehicles. VOC emissions are roughly half those of gasoline vehicles, and lower ozone reactivity of VOC results in lower ozone impacts. Emissions of formaldehyde (a primary combustion product of methanol) are higher than those from gasoline or other alternative-fuelled vehicles but can be controlled with a catalyst.

The GHG reduction potential of methanol is dependent on the feedstock. Burning M-85 derived from methane results in total life cycle GHG emissions very slightly lower than a gasoline vehicle, but life cycle GHG emissions from wood or cellulose-derived methanol are approximately 60% lower than from gasoline.

The major barrier to the widespread use of methanol is its high cost and price volatility. There is little prospect for it to become price-competitive with conventional fuels unless world oil prices increase greatly.

## Ethanol

Ethanol is produced primarily by starch fermentation from grains (mostly corn) or sugar from sugar cane. It is most commonly used as an oxygenate in reformulated gasoline and in a gasoline blend called "gasohol." These fuels can be burned in gasoline engines, but specialized engines are necessary to burn pure ethanol. In engines burning reformulated gasoline using ethanol, VOCs and CO are reduced but  $\text{NO}_x$  tends to increase slightly.

Vehicles burning gasohol will emit slightly more GHG emissions than conventional gasoline-fuelled vehicles. Reductions associated with burning pure ethanol depend on the feedstock. Ethanol produced from corn has life cycle GHG emissions about 15% less than gasoline vehicles, while ethanol produced from woody biomass (E-100 or 100% ethanol) has GHG emissions 60–75% below conventional gasoline.

A gasohol-fuelled automobile costs no more than a comparable gasoline vehicle. Since ethanol is derived from grains and sugars,

the production of ethanol for fuel is in direct competition with food production in most countries. This keeps ethanol prices relatively high, which has effectively ruled out its use as a motor fuel except where it is heavily subsidized, such as in Brazil and the United States.

The Brazilian “Proalcool” program to promote the use of fuel ethanol in motor vehicles has attracted worldwide attention as a successful alternative fuel program. Despite the availability of a large and inexpensive biomass resource however, this program still depends on massive government subsidies for its viability. The high cost of producing ethanol (compared to hydrocarbon fuels) remains the primary barrier to its widespread use.

## Biodiesel

Biodiesel is produced by reacting vegetable or animal fats with methanol or ethanol to produce a lower-viscosity fuel similar in physical characteristics to diesel, and which can be used neat or blended with petroleum diesel in a diesel engine.

Over the years, many factors have stimulated interest in biofuels including biodiesel. For example, the primary initial motivation for the Brazilian Alcohol program was energy-related concerns. However, it seems that the greatest motivation today for increased interest in biomass-based fuels in many countries is environmental concern, especially with urban air pollution and global warming. Further, there is growing interest in providing a profitable market for excess farm production.

Biodiesel is a zero-sulfur diesel fuel, therefore many of the points noted above apply equally to biodiesel, especially with regard to the potential impact on advanced diesel control technologies.

In general, biodiesel will soften and degrade certain types of elastomers and natural rubber compounds over time. Using high percent blends can impact fuel system components (primarily fuel hoses and fuel pump seals) that contain elastomer compounds incompatible with biodiesel. Manufacturers recommend that natural or butyl rubbers do not come in contact with pure

biodiesel, as this will degrade the materials over time, although the effect is lessened with biodiesel blends.

The general consensus is that blended or neat biodiesel has the potential to reduce diesel CO emissions (although these are already low), smoke opacity, and measured HC emissions. However, many studies show an increase in NO<sub>x</sub> emissions for biodiesel fuel when compared to diesel fuel at normal engine conditions. While research shows a reduction in HC emissions when biodiesel is used, the effect of organic acids and/or oxygenated compounds in biodiesel may affect the response of the instrument that measures HC (the flame ionization detector) and thus, understate the actual HC emissions. Particulate data are mixed; most studies show a reduction but some show increases under certain conditions. For example, one study found that "biodiesel gave generally higher particulate emissions and the highest levels of particulate associated soluble organic fraction for all driving cycles."<sup>14</sup>

The high cost of biodiesel is one of the principal barriers to it being an attractive diesel fuel substitute.

## Conclusions regarding alternative fuels

Today, the internal combustion engine fuelled by fossil fuel powers the vast majority of the world's vehicles. However, alternative fuels offer opportunities for significant emission reductions and efficiency increases for certain niche vehicle categories. The different alternative fuels and technologies are in various stages of development and each has unique performance and emission characteristics. Considering their current stages of development and emission reduction potentials, the following policy conclusions seem most appropriate:

- Where CNG is readily available in a given locality, and where ULSD is not readily and reliably available, strong consideration should be given to replacing diesel buses with CNG buses. Other centrally-fuelled fleets such as refuse trucks or local delivery trucks are also attractive candidates for replacement.

- Where CNG or LPG is readily available in a given locality, strong consideration should be given to replacing other high polluting vehicle types such as 2-stroke engine autorickshaws with CNG or LPG. Conversions to both LPG and CNG have been well established as a viable technology. In terms of PM and HC emission reductions, the most successful strategy for three wheelers is to replace existing gasoline-fuelled, 2-stroke engines with CNG- or LPG-fuelled 4-stroke engines.
- There are several obstacles to the widespread use of natural gas- and LPG-fuelled vehicles. These include the absence of transportation and storage infrastructure, additional cost (primarily of fuel storage tanks), loss of cargo space, increased refuelling time, and lower driving range. Therefore, economic incentives in the form of lower taxes on fuels or others should be considered as measures to stimulate the introduction and acceptance of these fuels.
- Where LPG is readily available, and where ULSD is not readily and reliably available, strong consideration should be given to replacing diesel- or gasoline-run taxicabs with LPG.
- Conversion of existing diesel vehicles to natural gas is difficult and problematic, and very often results in higher  $\text{NO}_x$  emissions. Therefore, replacement of diesel vehicles should be considered rather than conversion.
- Conversion of existing gasoline-fuelled vehicles to CNG or LPG is not very difficult and if done well can result in emission reductions.
- An inherent advantage of gaseous fuels is the assurance that adulteration will not be a problem.
- Depending on the feedstock and the process used to make these fuels, their GHG emissions can be very high or very low. For example, methanol made from coal would approximately double GHG emissions compared to conventional gasoline, whereas methanol made from natural gas would be slightly lower than gasoline and that made from cellulose would be about 60% lower.