CONVERSION, FLEXIBLE FUEL AND DEDICATED ENGINES: EMISSIONS, PROPERTIES, COSTS, AND DRIVING RANGE

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WHY USE ALTERNATIVE FUELS?

There are two main reasons to use alternative fuels: to reduce dependence on petroleum fuels and to reduce air pollution caused by vehicles using petroleum fuels. While these are desirable objectives, alternative fuels and alternative fuel vehicles are not widely available. Those who endeavor to use alternative fuels today face uncertainties that include evolving vehicle technologies and the availability of infrastructure to make alternative fuels available to the public. This paper briefly discusses alternative fuel vehicle technology at this stage of development and provides some insight into the effect various alternative fuel vehicles might have on fleet operations and cost.

TECHNOLOGY AND EMISSION CHARACTERISTICS

Natural Gas

There are two primary methods of storing natural gas on transportation vehicles: compressed (CNG) and liquefied (LNG). CNG technology is more developed than that of LNG, but neither represent "show-stoppers" relative to widespread use of natural gas as a transportation vehicle fuel. The natural gas engine fuel and emission systems are the same whether the natural gas is stored as CNG or LNG (LNG has some potential advantages due to its low temperature that may be exploited, but these advantages are far off into the future). Natural gas vehicle (NGV) emission characteristics include very low carbon monoxide (CO) emissions, low non-methane emissions, zero evaporative emissions, about 10% lower carbon dioxide (CO_2) emissions relative to petroleum fuels, and typically higher oxides of nitrogen (NO_x) emissions. Optimization of emission catalyst technology and development of lean-burn systems could result in significantly lower NO_x and methane emissions from NGVs.

Light duty NGVs will have a small power loss compared to use of conventional fuels, typically in the range of 5 to 10%. This is because the natural gas enters the cylinder as a gas whereas gasoline enters as a combination of liquid and vapor. This situation is reversed for converted diesel engines where power output can be increased because the air in the cylinder is used more completely compared to diesel combustion.

CNG is stored onboard the vehicle using high-pressure (2400 or 3000 psi) cylindrical tanks. CNG has about one-fifth the energy storage density of gasoline, meaning that five times the volume of CNG must be stored to provide the same driving range as gasoline. The most common cylinder material is steel, though reinforced aluminum is very popular and reinforced plastic cylinders are becoming popular for vehicle use because they weigh much less (though they cost more). Packaging of sufficient CNG cylinders on the vehicle to give the same operating range when using gasoline or diesel fuel can be very difficult, especially for passenger cars. For this reason, most CNG passenger cars are bi-fuel, i.e., they retain the conventional fuel system and add the CNG fuel system, but can only operate using one at a time. Bi-fuel vehicles tend to result in compromises in terms of performance and emissions, being optimum for neither natural gas nor the conventional fuel. CNG vehicles will be heavier than conventional fuel vehicles by a small amount to several hundred pounds.

LNG is stored in highly insulated containers to keep it below methane's boiling point of -259° F. The insulation while being very good, is not perfect, and vaporized natural gas will have to be vented periodically unless the fuel is used by the vehicle. Venting times vary by fuel tank design, and are as short as a few days or as long as 10 to 14 days. LNG has about two-thirds the energy content of gasoline, so approximately 50% more must be stored to provide equal driving range. LNG tanks are lighter than CNG tanks but more costly.

LP Gases

The vehicle fuel system technology and emission characteristics of LP Gas vehicles are very similar to natural gas vehicles. The major difference in emissions is that unburned hydrocarbons are primarily propane instead of methane. LP Gas fuel tanks are similar in size and weight as LNG tanks, but are much less costly than LNG or CNG tanks. Like natural gas, engine power is reduced slightly, and vehicles can be dedicated or bi-fuel.

Methanol

There are two primary approaches to using methanol as a fuel, one for spark ignition engines and one for compression ignition engines. For spark ignition engines, 15% gasoline is added to the methanol (M85) to give it sufficient vapor pressure to allow cold starts to the same low temperatures as gasoline alone. Other than changes to address material compatibility and increase the fuel flow rate to compensate for the decreased energy content of methanol, no other engine changes are needed. Because of methanol's high octane rating, an increase in compression ratio is possible with its resultant advantages, but this modification would be for dedicated engines only. Most current methanol engines are light duty and are "flexible fuel," i.e., they are capable of using methanol, gasoline, or any blend in between in the same fuel tank (no separation is required - just add the fuel that is available). Flexible fuel vehicles (FFVs) have a sensor in the fuel line to the engine that can measure the percentage of methanol vs. gasoline being delivered to the engine, and provide compensation of spark timing and fuel injection quantity/timing correspondingly. The only drawback to FFV technology is that engine design is constrained by the need to operate on gasoline. Advanced methanol engines have demonstrated very low emissions and very high efficiency, without the need for gasoline addition. These advanced engines are many years away from production but illustrate the emissions potential for methanol as a fuel. Methanol vehicles have similar mass emissions as gasoline, but the advantage is that methanol is less reactive than gasoline hydrocarbons. The range and number of toxic emissions are reduced when using methanol, but methanol produces formaldehyde emissions instead. Advanced methanol engine emissions have the potential for reduced CO, CO_2, and NO_x emissions.

The compression ignition engines modified to use methanol are to date all converted from heavy duty diesel engines. The only commercially available engine is the Detroit Diesel Corporation (DDC) 6V-92TA engine that uses neat (100% pure) methanol as fuel (with the addition of a small amount of additive). The DDC 6V-92TA uses a combination of glow plugs and combustion system design to achieve ignition under all engine operating conditions. This engine is the cleanest heavy duty diesel engine ever certified by the Environmental Protection Agency. Diesel engines also can be readily retrofitted to use methanol as a fuel by adding an ignition improver additive and modifying the fuel injection system to be methanol compatible and to provide the necessary fuel flow rate. Methanol compression ignition engines have very low particulate emissions and can have very low NO_x emissions depending on design and calibration.

Ethanol

There are three primary methods that ethanol could be used as a transportation fuel: 1) as a blend with gasoline, typically 10% and commonly known as "Gasohol"; 2) as a component of reformulated gasoline both directly but probably more likely transformed into a compound such as Ethyl Teritary Butyl Ether (ETBE); or 3) used directly as a fuel, probably with 15% gasoline known as "E85." Ethanol by itself has a very low vapor pressure, but when blended in small amounts with gasoline, it causes the resulting blend to have a disproportionate increase in vapor pressure. For this reason, there is great interest in using fuels such as ETBE as reformulated gasoline components. The primary emission advantage of using ethanol blends is that CO emissions are reduced through the "blend-leaning" effect that is caused by the oxygen content of ethanol. The oxygen in the fuel contributes to combustion much the same as adding additional air would. Because this additional oxygen is being added through the fuel, the engine fuel and emission systems are "fooled" into operating leaner than designed, with the result being lower CO emissions and typically slightly higher NO_x emissions. The blend-leaning effect is most pronounced in older vehicles that do not have feedback control systems, however, even the newest technology vehicles typically show some reduction in CO emissions. The vehicle technology to use E85 is virtually the same as that to use M85; thus, there will be very little difficulty developing E85 vehicles. The emission characteristics of E85 vehicles are not well known, but it is expected that they will be comparable to the latest vehicles using reformulated gasoline and M85 vehicles with the exception that E85 produces acetaldehyde instead of formaldehyde when combusted.

COSTS AND RANGE

Because alternative fuel vehicle technology is evolving rapidly, it is difficult to generalize about costs. However, the following table summarizes the current situation with respect to incremental vehicle costs that can be expected. Note that these are just vehicle costs - maintenance and fuel costs are in addition. Many states are offering incentives to defray some of these incremental costs.

Type of Alternative Fuel Vehicle	Typical Incremental Cost, $
Light Duty CNG	$ 1,000 +
Medium and Heavy Duty CNG	$ 3,000[1] +
Light Duty LNG	$ 2,000 +
Medium and Heavy Duty LNG	$ 4,000 +
Light Duty LP Gas	$ 750 +
Medium and Heavy Duty LP Gas	$ 1,500 +
Methanol FFV	0 to $ 2,000[2]
Ethanol FFV	0 to $ 2,000[3]
Heavy Duty Methanol	$10,000[4] +
Heavy Duty Ethanol	$10,000[5] +

Notes:

1. Assumes conversion of existing engine. Costs for dedicated heavy duty natural gas engines not established. Some CNG transit buses cost $30,000 to $50,000 more.
2. Ford and General Motors have been charging $2,000 extra for their FFVs, but Chrysler claims that in volume production, they would not charge anything extra for FFV.
3. Assumes that ethanol FFVs would use the same technology as methanol FFVs.
4. Costs for methanol heavy duty engines not well-established and likely to come down as volume grows.
5. Same engines as for methanol heavy duty vehicles - other changes similar.

OPERATING CONCERNS

Emissions

At present, there are emission regulations only for light duty methanol vehicles and heavy duty methanol engines. EPA has draft regulations for natural gas and LP Gas vehicles and engines that should be finalized in 1993. No regulations exist for ethanol vehicles and engines. Many states have not addressed how alternative fuel vehicles should be treated in terms of Inspection/Maintenance emission tests. This is of particular concern for converted and bi-fuel vehicles.

Range

These alternative fuels have less energy per gallon than gasoline or diesel fuel. If the vehicle is bi-fuel, it usually has the same range when operated on the conventional fuel, plus the range it travel on the alternative fuel. Dedicated alternative fuel vehicles generally have lower operating range than their conventional fuel counterparts. In general, light duty CNG vehicles will have half to two-thirds the range of their gasoline counterparts. Medium and heavy duty CNG vehicles can easily have near-equivalent range because they typically have sufficient room to place the required number of CNG cylinders. LNG and LP Gas vehicles do not have as much difficulty finding room for the number and size of fuel tanks that will give them near-equivalent range as when operating on conventional fuels. Light duty methanol FFVs have about 60% the range of the same vehicle using gasoline, unless an auxiliary fuel tank is added. Light duty ethanol FFVs should have about 75% the range of the same vehicle using gasoline, unless an auxiliary fuel tank is added. Both methanol and ethanol heavy duty vehicles can usually add sufficient fuel tank capacity to have essentially equal range as when operating using diesel fuel.

Complexity

Bi-fuel vehicles are inherently more complex because there are two fuel systems onboard. However, the fuel systems to use alternative fuels are also inherently more complex than those for gasoline or diesel fuel because of the differences in materials, operating principles, pressures, safety precautions, and fuel temperatures. Implementation of alternative fuel vehicles will require significant retraining of existing maintenance staff.

OTHER CONSIDERATIONS

This paper has concentrated on alternative fuel vehicles themselves - however, there are many other considerations when deciding whether to implement alternative fuel vehicles. These concerns include: Are alternative fuels readily available commercially, or must dedicated refueling facilities be established? What will be the delivered cost of the alternative fuel? Will there be a resale market for alternative fuel vehicles? How will alternative fuel vehicle affect my operations? It will be many years until these questions can be answered with some certainty. Until then, implementing alternative fuel vehicles will require careful planning to avoid costly mistakes.