About How We Keep Score on Fuel Economy and How it Impacts Greenhouse Gas Production

*By David McKeagan**

The methods used to quantify fuel economy need to be questioned. The way we have always done it leads to erroneous conclusions about the relative efficiency of gasoline and diesel engines. It also takes away focus from the importance of fuel chemistry on the relative amounts of greenhouse gases produced in any combustion process.

Fuel economy performance is reported on the basis of liquid volume of fuel consumed (miles/gallon or liters/100 kilometers). The actual power developed in either spark or pressure ignition engines depends on the heat of combustion of the fuel and the stoiciometry of the oxidation reactions. Greater heat of combustion and greater molar expansion give higher cylinder pressure and more power. It is possible to compare fuels using simple gas law calculations. In Table 1, the properties of a few representative fuels are shown. The 'adiabatic temperature' is that which is reached assuming no heat losses and theoretical oxygen requirements. The higher the (cylinder) 'relative pressure', the greater is the power output. The higher the carbon/hydrogen of the fuel, the higher is the relative amount of carbon dioxide (CO_2) produced.

Table 1
Performance Based on Equal Liquid Volume Burned

Fuel	Heating Value BTU/lb[1]	Adiabatic Temperature (^{0}F)	Relative Pressure	Relative CO_2
Octane	19,060	3359	1.00	1.00
Pentane	19,540	3386	0.93	0.89
Toluene	17,640	4002	1.11	1.36
Pentene	19,360	3348	0.95	0.95
Ethanol	11,520	3230	0.69	0.71
Methane	21,540	3270	0.49	0.38
Cetane	18,920	3453	1.13	1.15

This comparison is based on feeding the same liquid volume of fuel into either a gasoline or a diesel engine. Thus, compared to octane (C8H18),[2] pentane (C5H12, a typical light component of motor gasoline) produces about 7% less power. Pentane and octane are fully saturated paraffins and so contain the maximum amount of hydrogen for C5 and C8 carbon molecules respectively. Their relative power output and CO_2 production can be explained by the differences in carbon content and liquid density.

Commercial gasolines also contain olefins and aromatics that are deficient in hydrogen. These compounds come mostly from catalytic cracking. Toluene (C8H10) is an aromatic that produces about 11% more power than octane and is also desirable as an octane number enhancer. Toluene has 'higher energy content,' that is it has a higher density and a higher proportion of carbon than pentane or octane. Thus, it also produces more CO_2 when it burns. Olefins like pentene (C5H10) have intermediate performance between saturated paraffins and aromatics.

Two alternative fuels for gasoline engines are ethanol (C2H6O) and natural gas (methane, CH4). The figures in Table 1 support the view that on a liquid volume basis they produce less power than typical gasoline components, and that they also produce less CO_2.[3]

The traditional basis for comparing diesel fuels uses cetane (C16H34) as a reference. The figures in Table 1 explain why it is observed that diesel engines get 15-20% more miles to the gallon. This advantage is frequently explained by the 'higher energy content' of diesel fuels. However, this observation is purely an artifact of the practice of selling automotive fuels and measuring fuel economy on a unit volume basis (miles/gallon).

Consider how different fuels would stack up if instead the comparisons were done on a weight basis (e.g., miles/pound of fuel or kilograms/100 kilometers).

Table 2
Performance Based on Equal Weight Burned

Fuel	Heating Value BTU/lb[1]	Adiabatic Temperature (^{0}F)	Relative Pressure	Relative CO_2
Octane	19,060	3359	1.00	1.00
Pentane	19,540	3386	1.02	0.99
Toluene	17,640	4002	0.88	1.08
Pentene	19,360	3348	1.02	1.02
Ethanol	11,520	3359	0.60	0.62
Methane	21,540	3270	1.14	0.89
Cetane	18,920	3453	0.99	1.01

The cetane, pentane, pentene, and octane power output is nearly identical, as is the CO_2 produced. This shows that when comparing fuels on an equal weight basis, there is no difference in performance (miles/pound) between gasoline and diesel engines. It also shows that aromatics like toluene only seem to give better performance because of their higher density and higher energy content on a volume basis. Surprisingly, methane outperforms all the other hydrocarbons both on power output and CO_2 production. Ethanol gives the lowest power output; it may produce low CO_2 but per unit of power output, CO_2 generation is not distinguishable from the heavier hydrocarbons.

There is no reason why fuels could not be sold on a weight basis, given the capabilities of modern instrumentation. Fuels sold in bulk outside the United States are marketed this way, as are chemicals and plastics derived from petroleum.

The difference is important when one considers the greenhouse gas producing potential of different fuels. High energy content goes hand in hand with higher density, more carbon in the fuel molecule, and more carbon dioxide produced on burning.

If we measured fuel economy on a weight basis, we would encourage the production of higher hydrogen containing fuels and engines suited to lower molecular weight fuels. Measuring fuel efficiency based on volume encourages the production of 'high energy' fuels and more greenhouse gases. It artificially encourages the use of engines that produce greater pollution.

Footnotes

[1] Lower Heating Value

[2] The thermodynamics of combustion reactions are hardly affected by molecular structure. The kinetics are however dramatically affected by structure, hence the importance of octane and cetane number indexes in actual engine operation.

[3] These comparisons do not take into account the CO_2 given off in the production of these fuels.

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