Comparison of Gasoline Combustion and Hydrogen Fuel-Cell Energy Production Water Pollution

Introduction

Idealize gasoline to be octane: C_8H_{18}. When octane combusts O_2 is taken from the air and the following reactions hold:

$$2C_8H_{18} + 25O_2 \rightarrow 16CO_2 + 18H_2O$$

and

$$2C_8H_{18} + 17O_2 \rightarrow 16CO + 18H_2O.$$

(Neglect the latter CO production reaction, since it occurs rarely.)

When a hydrogen fuel cell produces energy O_2 is taken from the air and the following reaction holds:

$$2H_2 + O_2 \rightarrow 2H_2O.$$

Chemical Bonding Energies

Carbon-carbon bonds have the following energies (http://academic.pgcc.edu/~ssinex/struc_bond/carbon_carbon_bond.htm):

Type of bond	**Bond Energy** (kiloJoule/mole)
single	347
double	611
triple	837

Other bond energies are (http://www.science.uwaterloo.ca/~cchieh/cact/c120/bondel.html and http://www.cem.msu.edu/~reusch/VirtualText/react2.htm):

Type of bond	**Bond Energy** (kiloJoule/mole)
$C-H$	413
$H-H$	436
$O-O$	146
$O=O$	498
$C-O$	358
$C=O$ (CO_2)	803
$C=O$ (other)	741-749
$H-O$	464

Comparison of Energies Released by Gasoline Combustion and by Hydrogen Fuel Cells

Note that H_2O has two single $H-O$ bonds and CO_2 has two double $C=O$ bonds.

Using the bond energies given in the tables above one can calculate the difference in bond energies for the gasoline-combustion reaction. (There are 7 $C-C$ bonds and 18 $C-H$ bonds in octane.):

Gasoline Combustion	**Bond Energy** (kiloJoules/mole)
$2C_8H_{18}+25O_2$	$2\cdot 7\cdot 347+2\cdot 18\cdot 413+25\cdot 498=32176$
$16CO_2+18H_2O$	$16\cdot 2\cdot 803+18\cdot 2\cdot 464=42400$
Difference	$42400-32176=6696=10224$
Energy released per H atom	$\frac{10224}{2\cdot 18}=284$
Energy released per fuel mass	$\frac{10224}{2\left(8\cdot 12+18\right)}=44.8$

Using the bond energies given in the tables above one can calculate the difference in bond energies for the hydrogen-fuel-cell reaction:

Hydrogen Fuel Cell	**Bond Energy** (kiloJoules/mole)
$2H_2+O_2$	$2\cdot 436+498=1370$
$2H_2O$	$4\cdot 464=1856$
Difference	$1856-1370=486$
Energy released per H atom	$\frac{486}{4}=121$
Energy released per fuel mass	$\frac{486}{4}=121$

Thus, gasoline combustion releases $\boxed{\frac{284}{121}=2.35}$ times as much energy per hydrogen atom and $\boxed{\frac{44.8}{121}=0.370\frac{\text{G\_Energy}}{\text{H\_Energy}}}$ times as much energy per fuel mass as a hydrogen fuel cell does. Both reactions produce water; gasoline also produces carbon dioxide.

Comparison of Water Produced by Gasoline Combustion and by Hydrogen Fuel Cells

The ratio of water produced to fuel mass for the two cases is:

Process	Chemical ratio water to fuel	Mass ratio water to fuel
Gasoline combustion	$\frac{18H_2O}{2C_8H_{18}}$	$\frac{18(2+16)}{2(8\cdot 12+18)} = 1.42$
Hydrogen fuel cell	$\frac{2H_2O}{2H_2}$	$\frac{2(2+16)}{2\cdot 2} = 9$

That is, $\boxed{\frac{9}{1.42} = 6.34 = \frac{H\_Water}{G\_Water}}$ times as much water per fuel mass is released by hydrogen fuel cells as is released by gasoline combustion. The difference between the two reactions is because of the CO_2 produced in gasoline combustion, which carries off the difference in water masses.

The ratio of water released to energy-released per fuel mass is $\boxed{\frac{H\_Water}{G\_Water}\cdot\frac{G\_Energy}{H\_Energy} = \frac{H\_Water/H\_Energy}{G\_Water/G\_Energy} = 6.34\cdot 0.370 = 2.35}$ for hydrogen to gasoline. That is, **over two times as much water per unit of energy is released by a hydrogen fuel cell as is released in gasoline combustion for a given fuel mass.**

One could argue that fuel cells are more efficient at producing useable energy than is gasoline combustion. They would have to be several times more efficient to overcome this large water ratio.

The Significance of the Large Water Ratio for Hydrogen Fuel Cells Compared to Gasoline Combustion

The exhaust of gasoline combustion is at a temperature of a few hundred degrees Celsius. So the water comes out as vapor, along with the carbon dioxide, both of which are potent greenhouse gases.

The operating temperature of a hydrogen alkaline fuel cell (http://www.benwiens.com/energy4.html) is50-250 degrees Celsius. So the water comes out as a hot liquid or as low temperature steam, to be deposited on or above the roadway.

So over two times as much low-temperature water per energy released is emitted by a hydrogen fuel cell compared to the high-temperature water vapor emitted by gasoline combustion. This would cause dangerous driving conditions on roads, especially during cold weather.

However, it could have positive effects for railroad and water transportation.

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