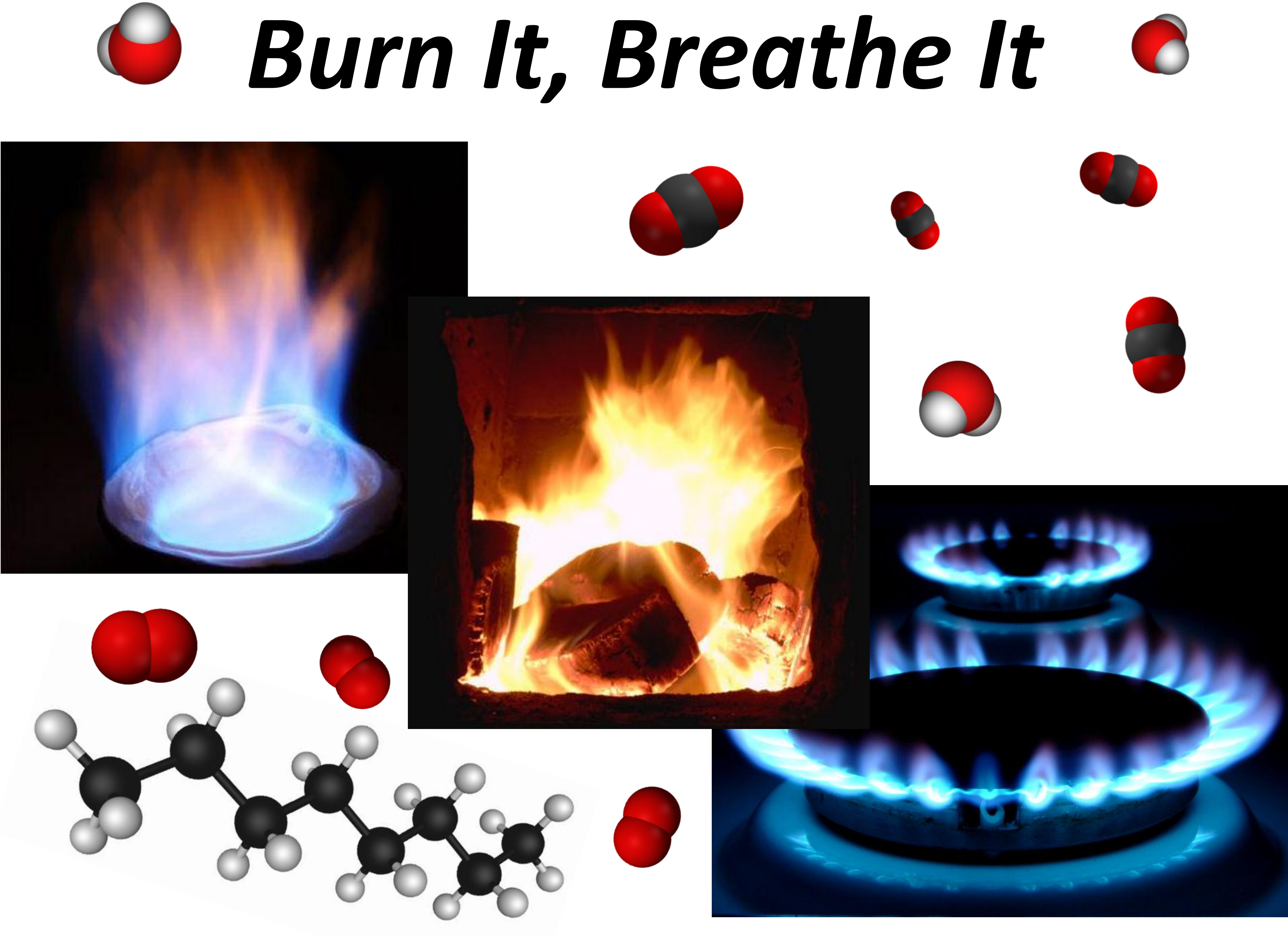
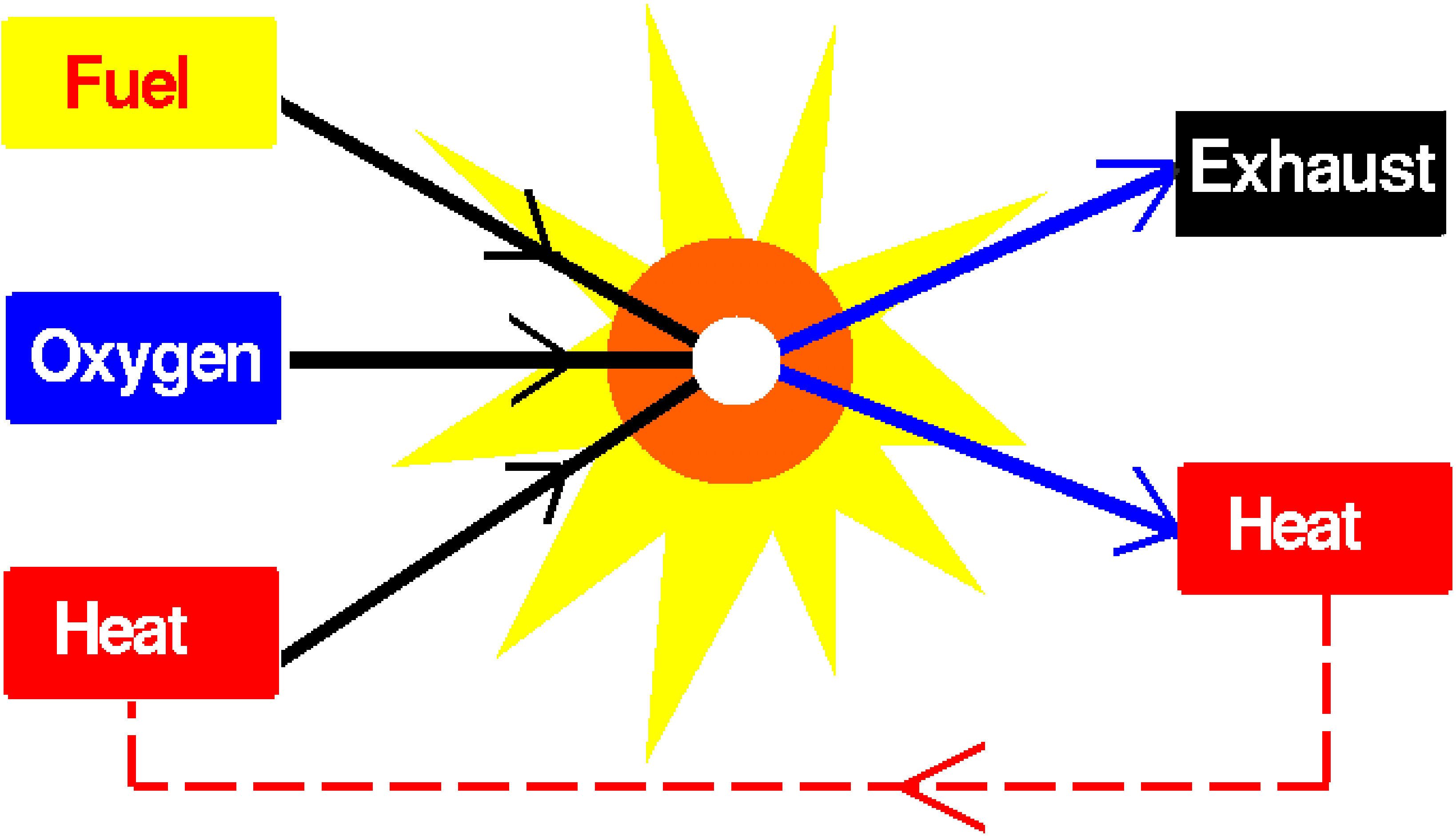
Burn It, Breathe It



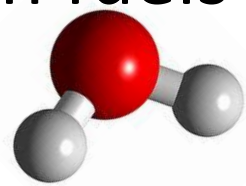
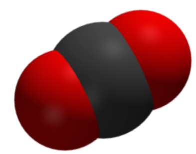
Combustion

Glenn
Research
Center

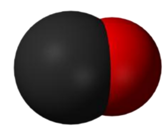
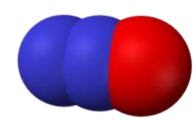
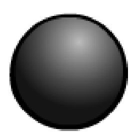


What’s in the Exhaust?

For most hydrocarbon fuels burned efficiently:

- Water vapor (H_2O) 
- Carbon dioxide (CO_2) 

Inefficient combustion can also produce:

- Carbon monoxide (CO) 
- Nitrogen-oxygen compounds (NO_X) 
- Soot (C) 

Brain Teaser: What's Your Guess?

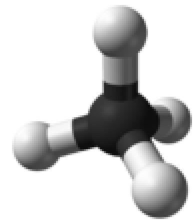
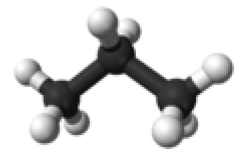
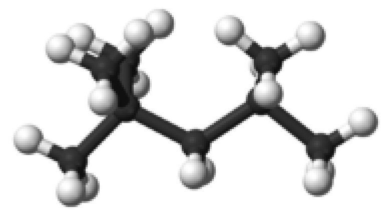
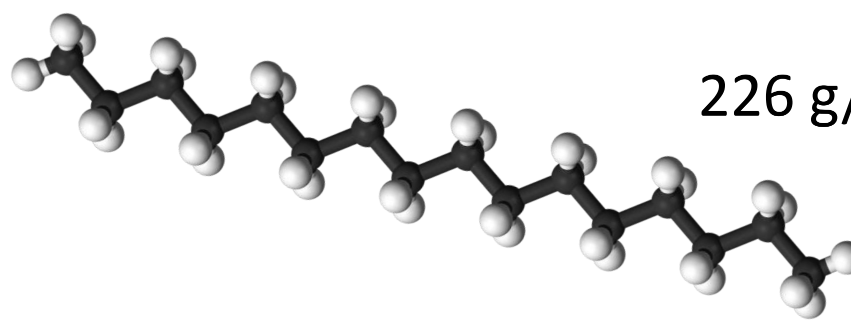
Rank the following by how much CO_2 you guess is released during combustion, 1 = most, 5 = least. Assume you're burning amounts of each that release equivalent energy.

Fuel	**CO_2 Ranking**
Gasoline	1 2 3 4 5
Methane	1 2 3 4 5
Biodiesel	1 2 3 4 5
Coal	1 2 3 4 5
Uranium	1 2 3 4 5

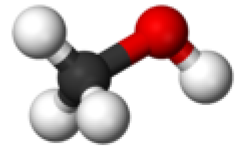
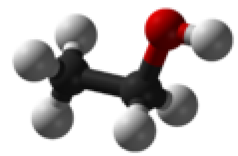
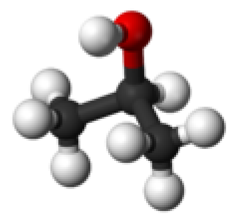
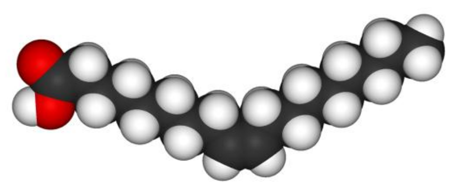
Want to know?

Do the math!

Carbon Puts the Carbon in Hydrocarbon

- Methane (CH_4)  16 g/mole
- Propane (C_3H_8)  44 g/mole
- Octane (C_8H_{18})  114 g/mole
- Cetane ($C_{16}H_{34}$)  226 g/mole

Carbon in Alcohols and Biodiesel

- Methanol (CH_3OH)  32 g/mole
- Ethanol (C_2H_5OH)  46 g/mole
- Isopropanol (C_3H_7OH)  60 g/mole
- Biodiesel ($C_{19}H_{36}O_2$)  296 g/mole

Balanced Combustion Reactions

Hydrogen: $2H_2 + O_2$ --> $2H_2O$

Methane: $CH_4 + 2O_2$ --> $CO_2 + 2H_2O$

Gasoline: $2C_8H_{18} + 25O_2$ --> $16CO_2 + 18H_2O$

Biodiesel: $C_{19}H_{36}O_2 + 27O_2$ --> $19CO_2 +18H_2O$

Methanol: $2CH_3OH + 3O_2$ --> $2CO_2 + 4H_2O$

Ethanol: $C_2H_5OH + 3O_2$ --> $2CO_2 + 3H_2O$

Isopropanol: $2C_3H_7OH + 9O_2$ --> $6CO_2 + 8H_2O$

Coal: $C + O_2$ --> CO_2

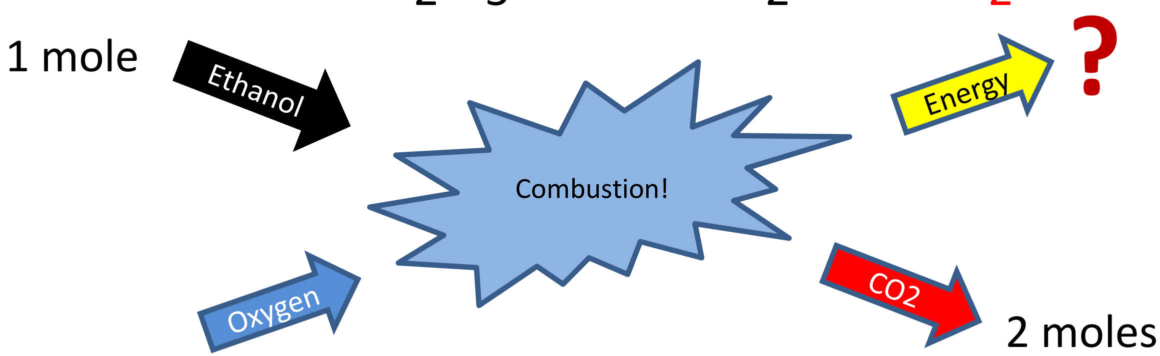
How Much Carbon?

Comparing the combustion of gasoline and ethanol:

- Gasoline: $2C_8H_{18} + 25O_2 > 16CO_2 + 18H_2O$

Each molecule (or mole) of gasoline produces 8 CO_2 molecules, and each molecule of ethanol produces 2 CO_2 molecules.

- Ethanol: $C_2H_5OH + 3O_2 > 2CO_2 + 3H_2O$



Is burning ethanol, then, "greener" than burning gasoline?

Is this a fair comparison?

How Much Carbon?

How much **energy** is released by burning a certain amount of fuel? *(weight, volume, number of molecules)*

To release equivalent amounts of energy, what quantity of different types of fuel do you burn?

How much **CO_2** is released by burning those amounts of fuel?

Energy-Equivalent Volumes of Fuels

Fuel	Kilojoules per cc*
Hydrogen gas (compressed at 700 bars)	7.61
Gasoline	31.95
Biodiesel oil	32.80
Methanol	15.91
Ethanol	21.26
Isopropanol	23.93
Coal (Anthracite)	34.23
Uranium 238	382,000,000

Comparing two liquid fuels, gasoline packs 31.95 kJ of energy per cc of volume, while ethanol stores 21.26 kJ/cc.

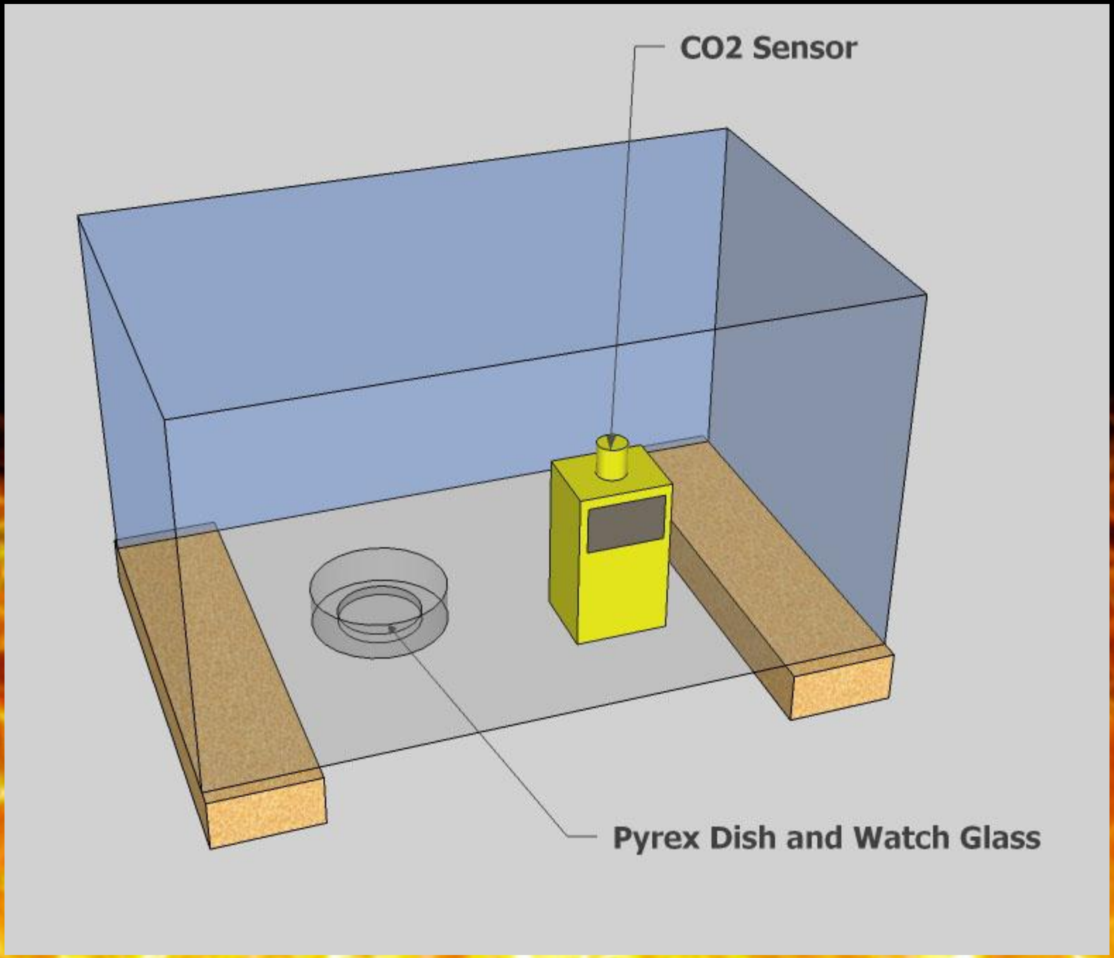
So gasoline contains 31.95 / 21.26 = 1.5 times the energy of ethanol per unit volume…

…so in comparing gasoline and ethanol, you need to burn 1.5 times the volume of ethanol to release the same energy as gasoline.

Comparing energy density of fuels by volume is useful because it tells you the relative volumes of liquid storage tanks that would store equivalent amounts of fuel energy.

*Unless otherwise noted, the value for energy density is the “lower heating value (LHV)” that only accounts for energy released as direct heat, and not energy stored as latent heat in water vapor.
Note: 1 kiloJoule = 0.00028 kWh

How Much Carbon is Released in a Fair Fuel Contest?



Let's burn some fuel and find out!

How Much Carbon *Should* Have Been Released?

Fuel	Kilojoules per cc*	Kilojoules per gram*	Molar Mass (grams/mole)	Kilojoules per mole*
Hydrogen gas (compressed at 700 bars)	7.61	121	2	242
Gasoline	31.95	44.4	114	5062
Biodiesel oil	32.80	37.27	296	11032
Methanol	15.91	19.93	32	638
Ethanol	21.26	26.95	46	1240
Isopropanol	23.93	30.45	60	1827
Coal (Anthracite)	34.23	22.73	12	273
Uranium 238	382,000,000	20,000,000 (fission)	238	4,760,000,000

*Unless otherwise noted, the value for energy density is the "lower heating value (LHV)" that only accounts for energy released as direct heat, and not energy stored as latent heat in water vapor.

Note: 1 kiloJoule = 0.00028 kWh

Doing The Math

Fuel	Kilojoules per mole	Energy Equivalent Amount	CO_2 Output Ratio	CO_2 Released (moles)
Gasoline	5062	1	8	8
Ethanol	1240	4.08	2	7.6

To get an equivalent amount of energy from ethanol and gasoline, you need to burn

- 5062 / 1240 = 4.08 times as many ethanol molecules

So burning 1 mole of gasoline and 4.08 moles of ethanol produces:

- From gasoline: (1 x 8) --> 8 moles of CO_2
- From ethanol: (4.08 x 2) --> 8.16 moles of CO_2

Doing The Math

Fuel	Kilojoules per mole	Energy Equivalent Amount	CO_2 Output Ratio	CO_2 Released (moles)
Gasoline	5062	1	8	8
Ethanol	1240	4.08	2	8.16
Methanol	638	7.93	1	7.93
Isopropanol	1827	2.77	3	8.31
Biodiesel	11032	0.46	19	8.74
Coal	273	18.54	1	18.54
Methane	778	6.51	1	6.51

What's Your Guess?

Rank the following by how much CO_2 you guess is released during combustion, from most to least. Assume you're burning amounts of each that release equivalent energy.

By my calculations…

Fuel	CO_2 Ranking
Gasoline	1 2 (3) 4 5
Methane	1 2 3 (4) 5
Biodiesel	1 (2) 3 4 5
Coal	(1) 2 3 4 5
Uranium	1 2 3 4 (5)

(Even if you could combust uranium, as it contains no carbon, it wouldn't produce any CO_2)