**Energy Content of Fuels: which fuel is “best?”**

**There are many factors to consider when choosing a fuel. In this exercise, your group will work with a set of three different potential fuels and evaluate their performance in terms of price, energy density (per mole, per gram, and per volume) as well as in terms of CO2 emissions. You will then select which of your three fuels is the “best,” realizing that there are several possible considerations to select the “best” fuel. You will have to defend your choice, as well as your definition of “best!”**

**Learning Objectives**: Upon completion of this exercise, you should be able to:

1. use Hess's Law to determine enthalpy changes associated with chemical reactions.
2. use balanced chemical reactions, in combination with other relationships such as density, to derive other useful quantities related to a combustion reaction.
3. identify trends in a set of related chemical reactions and note important characteristics of reactants and/or products that are related to or cause these trends.
4. Account for for the many variables (chemical, societal, and political) associated with picking the "best" chemical fuels as well as for the ways in which their knowledge of thermochemistry and chemical reactions can be applied to understand these variables.
5. Draw a reaction coordinate diagram showing the function of a catalyst in a chemical reaction, specifically showing:
   1. how one could limiting the combustion of methane to form methanol instead of CO2
   2. how one could maximize the storing solar energy in a fuel

**Terms You Should Know:** heat of formation, combustion reaction, energy density, fuel, greenhouse gas

**Background Reading**: Atkins, Jones, & Laverman, Chapter 8.13-8.16, 8.21,; Chapter 19, Sections 9-10.

**After Completing this Exercise, Textbook Problems You Should be Able to Answer**:

8.51, 8.52, 8.86, 19.55, 19.58

**Background Information**

Energy derived from fuels is a complex topic. To properly discuss energy you must consider several interrelated concepts:

the chemistry of the chemical reaction (combustion)

the costs of the fuel

actual costs

environmental costs (CO2 emission, for example, but also pollution)

“political squabbles” over a desirable resource

properties of the fuel

energy density

energy per g/l/mol CO2

In this exercise, your group of 4-5 students will evaluate three potential fuels for use in our society. You will be tasked to choose the “best” fuel, and in order to do that, you will have to define “best” for your group. There is no absolutely correct answer to this question, but each class will vote on the overall “best” fuel based on the arguments you present in class.

**Deliverables:**

- By the end of class, fill out the table on the last page (one sheet per group). Make sure to write your name (*legibly*) on the sheet to receive credit for the assignment.

- fill out your data into the google sheet so the class can evaluate other fuels

- prepare about 3 talking points that allow you to define “best” in the context of fuels

- select your “best” fuel, according to your definition

- during the the last 10 minutes of class, each group will share their definition of “best” and share their chosen “best” fuel

Points to Consider in Formulating Your Recommendation:

1. Energy density in terms of mole, mass, volume.
2. Cost of energy in both dollars and societal cost.
3. What is your definition of the “best” fuel?.

**Table 1. standard heats of formation, densities, and prices for common fuels.**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Fuel #** | **Fuel** | **ΔfH°(kJ/mol)** | **density (g/L)** | **Price** |
| 1 | *Hydrogen (H2)* | **0 (gas)** | **0.0899** | **$6/kg** |
| 2 | *Coal (C)* | **0 (solid)** | **1100** | **$65/metric ton††** |
| 3 | *Natural Gas (methane, CH4)* | **–74.9 (gas)** | **656** | **$2.09/GGE†** |
| 4 | *Methanol (CH4O)* | **–238.4 (liquid)** | **791** | **$6/gallon¶** |
| 5 | *Formaldehyde (CH2O)* | **–177.6 (solid)** | **880** | **$16.5/kg** |
| 6 | *Formic acid (CH2O2)* | **–425.0 (liquid)** | **1220** | **$1250/tonne††** |
| 7 | *Propane (C3H8)* | **–103.8 (gas)**  **–104.7 (liquid)** | **1.88 (gas)**  **582 (liquid)** | **$0.67/pound** |
| 8 | *Octane (C8H18)* | **–208.4 (liquid)** | **703** | **$4/gallon¶** |
| 9 | *Biodiesel (C19H34O2)¬* | **-604.88 (liquid)** | **889** | **$2.92/gallon¶\*** |
| 10 | *Ethanol (C2H6O)* | **-277.0 (liquid)** | **789** | **$2.13/gallon¶\*** |
| 11 | *Glucose (C6H12O6)* | **-1271 (solid)** | **1540** | **$1.00/pound\*\*** |
| 12 | *Sucrose (C12H22O11)* | **-2221.2 (solid)** | **1587** | **$0.50/pound\*\*** |

\*Prices of these fuels include government subsidies; the actual cost is higher by almost $1.50/gallon

\*\*prices of these fuels include government support; the actual cost is lower by about 0.05/pound; a pound is 0.454 kg

† gasoline-gallon equivalent = GGE; one GGE for natural gas = 1 gal CNG \* 0.25

†† one metric ton (tonne) is 1000 kg

¬ Biodiesel is a mixture of straight chain fatty acid esters made by saponification(!); it is modeled here as linoleic acid methyl ester, a liquid.

¶ a gallon is 3.79 liters

**Table 2. standard heats of formation for other compounds involved in combustion.**

|  |  |
| --- | --- |
| *Oxygen (O2 (g))* | **ΔfH° = 0 kJ/mol** |
| *Carbon Dioxide (CO2 (g))* | **ΔfH° = –393.5 kJ/mol** |
| *Water (H2O (l))* | **ΔfH° = –285.8 kJ/mol** |

**Exercises**

1) Write a balanced combustion reaction for each of your three assigned fuels. Remember, combustion is the process where one mole of fuel reacts with oxygen (O2) to give carbon dioxide and/or water.

2) Use standard enthalpies of formation to determine the enthalpy change (ΔcombH°) associated with combustion of your three fuels.

3) Calculate the energy density of your three fuels. Energy density is defined in three ways:

1. kJ of heat per mole of fuel
2. kJ of heat per gram of fuel
3. MJ of heat per liter of fuel (a megajoule is 106 J)

For each of your three assigned fuels, determine the energy content in each of the 3 above ways. Fill in your answers on the last page of this handout and, once you have solved for all 9 data points, enter your answers into the spreadsheet at the front of the classroom. If your value(s) differ(s) from that of another group, record your value in the cell, separating it with a comma.

4) Due to concerns about global climate change, we are also very interested in CO2 emissions. For each of your three fuels, determine how many mmol of CO2 are produced per kJ of heat. Enter this value into the spreadsheet.

5) Determine the price of the fuel, reported in $ per kJ heat produced. Enter this value into the spreadsheet.

6) Looking at the class data, can you pick out any trends with respect to the different fuels? What elemental compositions have large ∆­r­H° values?

What fuels or fuel types have large energy densities?

What is the best fuel if we want to minimize CO2?

What are potential problems associated with this/these fuels?

7) considering these points, list approximately three factors that you will use to decide upon your “best” fuel. Select the fuel that you think is “best.”

Group #\_\_\_\_\_\_\_

Print or tear off this and the following sheet to turn in at the end of class

Group members: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_, \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_, \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_,

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_, \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_, \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**Balanced chemical reactions for each fuel**

1

2

3

**Standard enthalpy of combustion (∆combH°) for each fuel**

1

2

3

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Fuel #** | **Fuel** | **Energy Density (kJ/mol)** | **Energy Density (kJ/g)** | **Energy Density (MJ/L)** | **mmol CO2 per kJ heat produced** | **Price ($) per kJ heat produced** |
| 1 |  |  |  |  |  |  |
| 2 |  |  |  |  |  |  |
| 3 |  |  |  |  |  |  |

**Criteria for “best” fuel:**

**1.**

**2.**

**3.**

**4.**

**Your group’s best fuel:**