Fuels summary Solutions

1. The term 'clean coal' is increasingly being used to describe black coal. On the other hand, brown coal is described as a dirty alternative to black coal. Terms such as “clean or dirty” tend to muddy the argument in the use of coal as a fuel.
   a. Can coal, in all its forms, ever be a clean fuel alternative? Explain.
   No. Coal is a fossil fuel which produces CO_2 when burnt.

   b. Explain why is black coal given the term “clean coal” over the alternative brown coal?
   Black coal is older than brown coal and is a more pure form of dry carbon than brown coal. Brown coal is 60% water and so must be dried before it can be burnt. This drying process produces extra carbon emissions into the atmosphere. For this reason, brown coal is termed as “dirty coal” compare to black coal which is termed “clean coal”. There is no such thing as “clean coal”.

   a. A 68.0 litre gas tank is used to store fuel at 25°C and 2300 kpa pressure in a passenger vehicle.
   Two fuels are considered for powering this vehicle, hydrogen or methane. The tank is filled with either methane or hydrogen and both fuels stored in the under identical conditions.

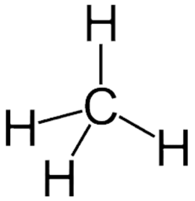
   b. On a full tank of fuel, calculate the mol of each gas that is present. Give the answer to the right number of significant figures.
   - ⇨ *PV = nRT*
   - ⇨ *n = PV/RT = 2300 X 68.0 / (8.31 X 298)*
   - ⇨ *63.2 mol*

   c. Calculate the total amount of heat energy, kJ, that can be delivered on a full tank for each fuel.
   Hydrogen
   Mass of H_2 = 63.2 X 2.0 = 126.4 g
   Using the data booklet we obtain the value of energy per gram for hydrogen as 141kJ/g
   Energy contained = 126.4 X 141 kJ/g = 17,833kJ = 1.8 X 10^4 kJ (2 sig figs)
   This could also be calculated using the mol of hydrogen gas.
   Again using the data booklet we get the energy per mol for hydrogen as 282 kJ/mol
   => Energy contained = 63.2 X 282 = 1.8 X 10^4kJ (2 sig figs)

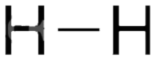
Methane

Mass of CH_4 = 63.2 X 16.0 = 1011g
Using the data booklet we obtain the value of energy per gram for methane as 16 kJ/g
Energy contained = 1011 X 56 kJ/g = 5.6×10^4 kJ (2 sig figs)
This could also be calculated using the mol of methane gas.
Again using the data booklet we get the energy per mol for methane as 890 kJ/mol
=> Energy contained = 63.2 X 890 = 5.6×10^4 kJ (2 sig figs)

2. Hydrogen and methane are common fuels. Even though hydrogen has a higher energy density than methane
   a. Draw the molecule of:



methane



hydrogen

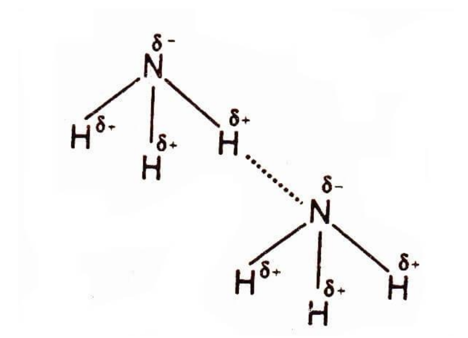
   b. Describe the intermolecular bonds found amongst the molecules of methane and hydrogen. *Both hydrogen and methane are symmetrical molecules therefore the intermolecular forces are composed entirely of weak dispersion forces.*

   c. Explain why methane is currently more widely used as a fuel than hydrogen. In your answer show an understanding of the role intermolecular forces play in each gas.

Hydrogen gas molecules are small and symmetrical hence have intermolecular forces that are solely due to weak dispersion forces. Methane is also a symmetrical molecule that relies solely on dispersion forces, however, being a much larger molecule than hydrogen, the forces of attraction between the molecules of methane are far stronger than the forces of attraction between hydrogen molecules. Molecules such as hydrogen, with very weak intermolecular forces of attraction, need very low temperatures and very high pressures to liquefy them. Low temperatures and high pressures are very difficult and expensive to maintain.

3. Liquefied ammonia and hydrogen can be transported via huge sea-going vessels. The cost of shipping hydrogen, however, is much greater than shipping ammonia. Given the boiling temperatures of hydrogen and ammonia are -253°C and -33°C respectively and that hydrogen is an odourless gas compared to the distinct and noticeable odour of ammonia, answer the following questions.

   a. Explain why, with reference to molecular structure of each molecule, transporting ammonia is a lot cheaper than the same mass of hydrogen gas.



Intermolecular forces of attraction between ammonia molecules consist of dispersion forces and relatively strong hydrogen bonding. Intermolecular forces of attraction between hydrogen molecules, on the other hand, consist only of very weak dispersion forces. The relatively strong intermolecular forces of attraction between ammonia molecules means that ammonia can be liquefied without the use of low temperatures and high pressures which adds significant costs to the fit-out of large vessels with equipment needed maintain small molecules, such as hydrogen, in the liquid form.

   b. Why is it safer to transport ammonia than it is to transport pure hydrogen gas?

The absence of high pressure piping in vessels transporting liquid ammonia is a safer alternative than the high pressure pipes present on vessels transporting liquid hydrogen. Since ammonia has a distinct odour any leakage can easily be detected and dealt with. Hydrogen, however, is odourless and any leaks can build up and cause an explosive situation.

   c. "A greater mass of hydrogen can be transported in a given storage tank, under identical conditions, in the form of ammonia gas than as pure hydrogen gas" Justify this comment.

Since hydrogen and ammonia are two gases stored under exactly the same conditions the mol of each substance is the same.
Let's assume we have one mol of each gas.
=> One mol of H_2 has a mass of 2 grams of hydrogen.
=> One mol of NH_3 has a mass of 3 grams of hydrogen.

d. Calculate the mass of hydrogen present in a 300.0 litre storage tank at 30°C and 400 kPa pressure containing:

i. pure hydrogen gas.

PV =nRT
=> n = PV/RT = 400 kPa X 300.0 L / (8.31 X 303) = 47.7 mol
=> mass of hydrogen gas = 47.7 X 2.0 = 95 grams

ii. pure ammonia gas.

=> Since the conditions are the same ammonia has the same number of mol as hydrogen gas.
=> mass ammonia = 47.7 X 17.0 = 811 grams

Step 1	fermentation	$C_6H_{12}O_6(aq) \rightarrow 2CH_3CH_2OH(aq) + 2CO_2(g)$
Step 2	oxidation	$CH_3CH_2OH(aq) + O_2(aq) \rightarrow CH_3COOH(aq) + H_2O(l)$
Step 3	neutralisation	$2CH_3COOH(aq) + CaCO_3(s) \rightarrow Ca(CH_3COO)_2(aq) + CO_2(g) + H_2O(l)$
Step 4	bacterial conversion	$Ca(CH_3COO)_2(aq) + H_2O(l) \rightarrow 2CH_4(g) + CO_2(g) + CaCO_3(s)$

4. Biogas can be produced from waste water and organic material where sugars are present. A 4 step process is used and pictured above.

a. Assuming ten molecules of glucose reacted, under identical conditions, in step 1 what is the value of the expression shown on the right? *2/1 = 2*

$$\frac{\text{Final volume of } CH_4 \text{ formed in step 4}}{\text{Final volume of } CO_2 \text{ formed in step 4}}$$

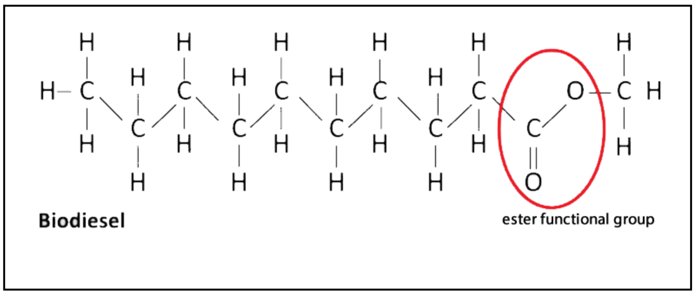
b. Is biogas, formed in this way, renewable and environmentally friendly?
Biogas is a renewable and to a large extent environmentally friendly.
It is renewable because supplies can be replenished in a relative short time frame so that stores of gas do not runout. It is environmentally friendly from the point of view that it does not contribute to a net increase to atmospheric CO_2.

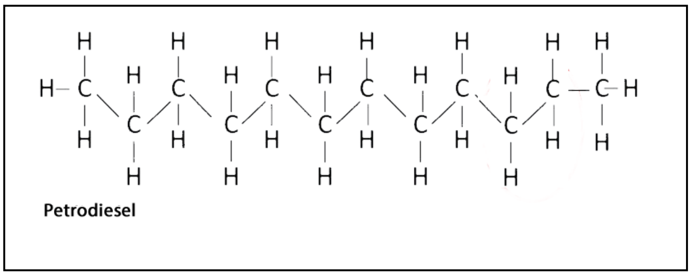
The carbon present in glucose ($C_6H_{12}O_6$), in step 1, was removed from the atmosphere during the process of photosynthesis.

$6CO_2$ (g) + $6H_2O$ (l)→ $C_6H_{12}O_6$(aq) + $6O_2$(g) (*note remember this equation)

The CO_2 captured from the atmosphere is steadily returned back to the atmosphere in the two process (3 and 4) neutralisation and bacterial conversion.

5. On the right are two molecules that are typical of biodiesel and petrodiesel.





a. Which one of these two molecules would you expect to form flammable vapours at the lowest temperature? Explain.

The weaker the intermolecular forces of attraction the lower the temperature at which the molecule will change from a liquid to a gas. In other words, the lower the temperature at which it can form vapours that can ignite.

So we have to look at which molecule has the weakest intermolecular forces of attraction. Biodiesel has an ester functional group that can create dipole-dipole bonding between molecules. Dispersion forces are also present, hence the intermolecular forces acting between the biodiesel molecules is dipole-dipole as well as dispersion forces.

Petrodiesel, on the other hand, has weaker intermolecular forces consisting only of dispersion forces. These weaker intermolecular forces cause vapours to form at lower temperatures in such quantities as to ignite in the presence of a flame.

b. Write the balanced chemical equations for the complete combustion reaction for each molecule. States not included.

$2C_{12}H_{26} + 37O_2 \rightarrow 24CO_2 + 26H_2O$

$2C_{11}H_{22}O_2 + 31O_2 \rightarrow 22CO_2 + 22H_2O$

c. Which one of these two molecules is likely to burn completely in a low oxygen environment and produce less energy than the other? Explain.

The biodiesel. Looking at the combustion equations for each molecule it is obvious that the biodiesel requires less atmospheric oxygen to undergo complete combustion. This is because each biodiesel molecule has 2 oxygen atoms attached.

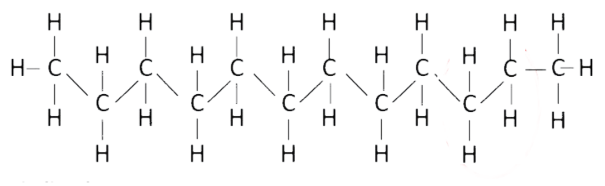
Biodiesel being already partially oxidised will produce less energy than the petrodiesel.

6. Calculate the mass, in grams, of methane gas needed to be burnt completely in order to raise the temperature of 200 mL of water from 25.0 °C to 55.0°C. Assume 100% of the heat energy is absorbed by the water sample.

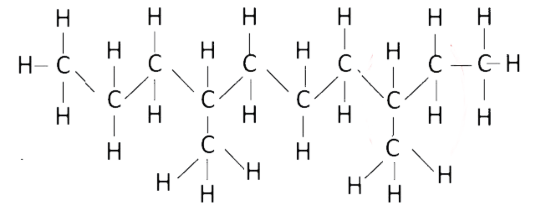
Step 1 find the amount of energy required to increase 200 grams of water by 30.0 °C.
Since the temperature of the water is 25°C use the density of the water provided in the data booklet to calculate the mass of the water.
=> mass = density X volume = 0.997 g/mL X 200 = 199.4 g
=> Energy (joules) = 4.18 J/g/°C X 199.4 X 30.0 = 25005 = 25.0 kJ

Step 2 find the mass of methane needed
=> mass of methane = 25005 J / 5.6 X 10^3J = 0.45 grams (2 sig figs since the energy density is given as 56 in the table above. Usually the energy density would be sourced from the data booklet.

7. Consider the two hydrocarbons shown on the right. These molecules are considered as a fuel in a town high in the mountains where the temperature can drop to below zero for several months of the year. Which molecule is best suited as a fuel under such conditions? Explain.



Molecule A



Molecule B

The two molecules are saturated hydrocarbons of equal molecular mass. They both have intermolecular forces formed by dispersion forces. Their physical structure, however, is very different. Molecule B is branched while molecule A is linear. This difference has an influence on the strength of electrostatic forces of attraction generated by instantaneous dipoles (dispersion forces). Since a more branched molecule has a lower surface area over which weak dispersion forces act, the strength of the force of attraction generated is weaker than the intermolecular force of attraction generated by a linear molecule of the same molecular mass.

Cold temperatures will tend to cause the fuel to solidify, thus blocking the fuel lines. So a fuel with a lower melting temperature is desirable. Since melting temperature is directly related to the strength of intermolecular forces, molecule B, with its lower strength intermolecular forces, is more suitable in a cold climate than molecule A.

Cold weather can affect the performance of diesel fuels, such as petrodiesel and biodiesel.
As the temperature is lowered, a point is reached at which the larger molecules in the fuel begin to solidify out of the liquid. When this point is reached, the fuel starts to become cloudy.
The temperature at which this point is reached is known as the ***cloud point***.

Flash point is the lowest temperature at which a liquid fuel will form a vapour above its surface that will ignite, on exposure to an open flame.

Consider the following four fuels, propane, propan-1-ol, methyl hexanoate and heptane
a. Identify the intermolecular bonding that exists in each.

i. *propane* *dispersion forces*
ii. *propan-1-ol* *h-bonding + dispersion forces*
iii. *methyl hexanoate* *dipole-dipole + dispersion forces*
iv. *Heptane* *dispersion forces*

b. Place the following four molecules in the appropriate box under each category.

Low → Strength of intermolecular forces of attraction → High

Propane	***heptane***	***propan-1-ol***	***methyl hexanoate***

Low → Boiling point → High

Propane	***heptane***	***propan-1-ol***	***methyl hexanoate***

Low → Flash point → High

Propane	***heptane***	***propan-1-ol***	***methyl hexanoate***

Low → Cloud point → High

Propane	***heptane***	***propan-1-ol***	***methyl hexanoate***

The fuel with the highest cloud point is most likely to solidify as the temperature drops. Methyl hexanoate has strong intermolecular bonds and is likely to solidify first as the temperature drops.

The fuel with the lowest flash point is most likely to form explosive vapours in a sealed container. Propane has the weakest intermolecular forces and hence will start to form vapours at very low temperatures. These vapours may ignite in the presence of a flame.

10. Climate change has been identified as a threat to the environment. Fossil fuels are recognised as a significant contributor to the rise in carbon dioxide levels in the atmosphere. The replacement of fossil fuels as an energy source represents a challenge and has been the focus of research for a number of years. However, there are different opinions/views about the suitability of using a biofuel, such as biodiesel, as a replacement for fossil fuels.
Using the chemistry that you studied, discuss the **carbon neutrality** and the **sustainability** of using biodiesel as a fuel for transport.

Valid discussion points included:
Carbon neutrality
- *For:*

- *CO_2 is absorbed/used by the crops/plants (used to produce the biodiesel)*
- *more carbon neutral as biodiesel produces less new CO_2 than other fuels*

- *Against:*

- *use of petroleum diesel (or other fuels) to produce biodiesel – a large amount of energy is required to produce biodiesel fuel from soy crops, as energy is needed for sowing, fertilising, harvesting, transporting and processing crops*
- *clearing land for crops by burning trees releases CO_2 and destroys habitats*
- *there is less photosynthesis when land is cleared*
- *burning biomass directly emits a bit more carbon dioxide than fossil fuels for the same amount of generated energy*

Sustainability of using biodiesel as a fuel
- *For:*

- *plants can be produced/grown in a short period of time*
- *can be made from waste vegetable oils, animal fats, or restaurant grease*
- *releases fewer toxic chemicals if spilled or released to the environment/many by-products are biodegradable*
- *biodiesel produces less soot (particulate matter), carbon monoxide, unburned hydrocarbons, sulfur dioxide*
- *crops (that produce oil) can be grown in many places*
- *can use second-generation technologies to convert material such as crop residues into bioenergy and avoid competition for land*

- *Against:*

- *some regions are not suitable for oil producing crops*
- *uses crops/land that could be used for food/food production*
- *the excess use of fertilisers can result in soil erosion and land pollution*
- *nitrous oxide released from fertilisers could have a greater (300 times more) global warming effect than carbon dioxide*

• the use of water to produce more crops can put pressure on local water resources

Using biodiesel as a fuel for transport

• For:

• produces less toxic pollutants and greenhouse gases than petroleum diesel
• reduces dependence on foreign oil reserves as it is domestically produced
• can be used in any diesel engine with little or no modification to the engine or the fuel system
• higher flashpoint, which makes it less combustible and therefore safer to handle, store and transport
• the lubricating property of the biodiesel may lengthen the lifetime of engines
• Against:

• higher viscosity/not suitable for use in low temperatures
• biodiesel fuel is more expensive than petroleum diesel fuel.