Lesson 6a Comparing Fuel cells with galvanic cells.

Fuel cells use electrodes that act as catalysts to speed up the rate of the half-cell reactions.

Most fuel cells use either hydrogen or methanol as their fuel, however, there are disadvantages with the use of these fuels. Expensive infrastructure needs to be developed to distribute and store liquid hydrogen. Adding to this draw back the manufacture of both hydrogen and methanol in commercial quantities requires natural gas (methane) in a process qual steam reformation. Steam reformation is a very expensive endothermic process that requires the burning of large quantities of natural gas to release the heat energy required for the steam reformation process. When using propane as a fuel, however, these disadvantages are not present. Propane gas can be easily liquefied and stored.

1) A propane fuel cell has the overall unbalanced equation shown below.

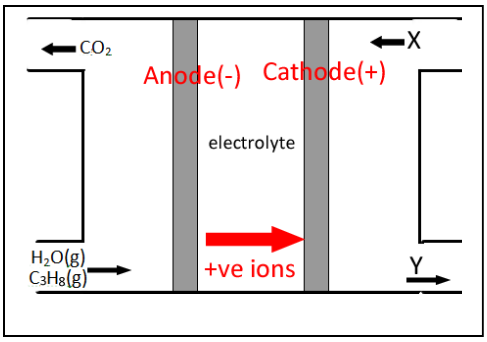
   $C_3H_8(g) + O_2(g) \rightarrow CO_2(g) + H_2O(g)$

   a) With reference to oxidation numbers suggest why this is or is not a redox reaction.

   C in C_2H_8 has an oxidation state of -4 and in CO_2 it has an oxidation state of +4. It is oxidised.

   Where as O in O_2 has an oxidation state of 0 and in H_2O it is -2. It is reduced.

   b) A diagram of the fuel cell is shown on the right.



   i. Label the anode and cathode.

   The fuel always reacts at the anode.

   ii. Give the balanced half-cell reaction, with states, that occurs at the :

   - anode $C_3H_8(g) + 6H_2O(g) \rightarrow 3CO_2(g) + 20H^+(aq) + 20e$
   - cathode $4H^+(aq) + 4e + O_2(g) \rightarrow 2H_2O(g)$

   iii. Identify "X"and "Y"

   $X = O_2(g)$, $Y = H_2O(g)$

   iv. Indicate the direction of positive ion flow through the electrolyte.

   v. Use the two half equations in (ii.) above to derive a balanced overall equation.

$C_3H_8(g) + 6H_2O(g) \rightarrow 3CO_2(g) + 20H^+(aq) + 20e$ --------1)

+

$(4H^+(aq) + 4e + O_2(g) \rightarrow 2H_2O(g)) \times 5$

=> $20H^+(aq) + 20e + 5O_2(g) \rightarrow 10H_2O(g)$ -----2)

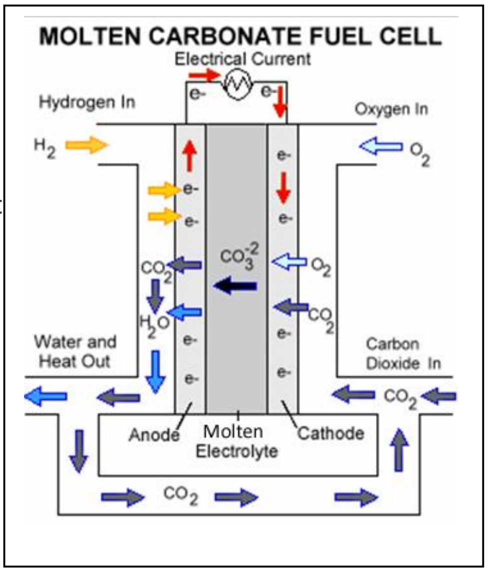
Now add the two equations 1) + 2) and cancel species that appear on both sides.

=> $C_3H_8(g) + 6H_2O(g) + \cancel{20H^+(aq)} + \cancel{20e} + 5O_2(g) \rightarrow 3CO_2(g) + \cancel{20H^+(aq)} + \cancel{20e} + 10H_2O(g)$

=> $C_3H_8(g) + \cancel{6H_2O(g)} + 5O_2(g) \rightarrow 3CO_2(g) + \cancel{10H_2O(g)}$

=> $C_3H_8(g) + 5O_2(g) \rightarrow 3CO_2(g) + 4H_2O(g)$

2) Molten carbonate fuel cells (MCFCs) use a molten carbonate salt suspended in a porous ceramic matrix as the electrolyte. Salts commonly used include lithium carbonate, potassium carbonate and sodium carbonate. They operate at high temperature, around 650ºC and the benefit of this is that the rate of reaction at both electrodes is significantly increased. This eliminates the use of expensive catalysts to improve the rate of reaction.



a) Consider the hydrogen MCFC shown on the right. The two half-cell equations are shown below.

1 ------ $H_2(g) + CO_3^{-2}(l) \rightarrow H_2O(g) + CO_2(g) + 2e$

2 ------ $O_2(g) + 2CO_2(g) + 4e \rightarrow 2CO_3^{-2}(l)$

i. Write the balanced overall equation. *$2H_2(g) + O_2(g) \rightarrow 2H_2O(l)$*

ii. What can you say about the net production of CO_2? *Zero net production of $CO_2(g)$*

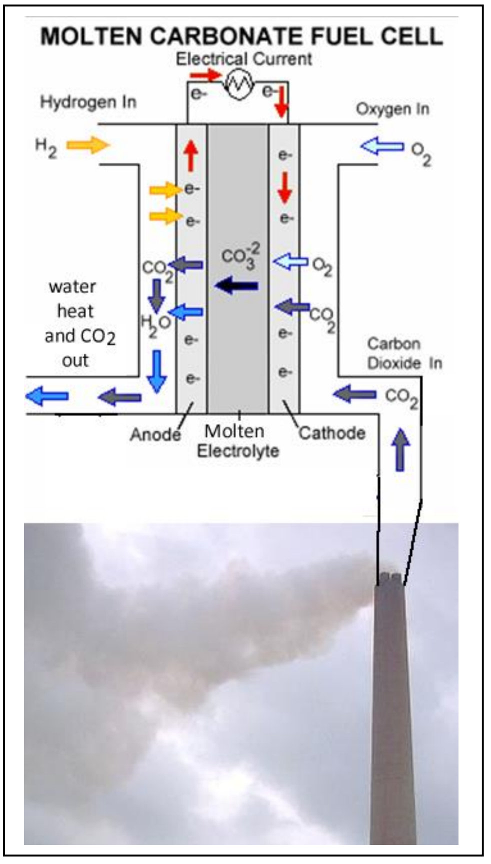
iii. How does the electrolyte change as the cell operates?

It does not change. Concentration of CO_3^{-2} ions remains constant in the electrolyte

iv. What is the benefit of operating fuel cells at high temperatures?

Rate of reaction is increased without the need for expensive catalysts

b) Consider the image shown on the right. It is suggested that MCFCs can be used to capture CO_2 emitted from the chimney stacks of power stations and in the process add to the electrical output of the station.



i. Discuss the chemistry behind the CO_2 capture.

The CO_2 gas passing from the chimney emissions into the fuel cell undergoes the following reaction.

$CO_2 + O^{-2} \rightarrow CO_3^{-2}$ at the cathode.

At the anode the reverse reaction takes place

$CO_3^{-2} \rightarrow CO_2 + O^{-2}$

releasing the CO_2 and allowing it to be separated from the H_2O and be collected.

ii. Discuss the benefits to electrical output and the environmental impact.

This allows for the generation of more electrical energy while allowing for the capture of CO_2 in conventional coal fired power stations.

3) Methanol is a liquid fuel that can be produced through fermentation. Direct methanol fuel cells use the electrochemical reactions below:

anode reaction $CH_3OH(g) + H_2O(g) \longrightarrow CO_2(g) + 6H^+ + 6e^-$

cathode reaction $3O_2(g) + 12H^+ + 12e^- \longrightarrow 6H_2O(g)$

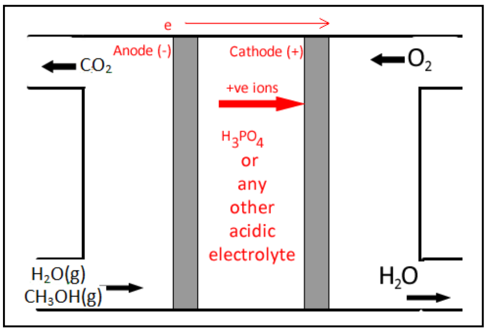
a) Give the overall cell reaction.

$2CH_3OH(g) + 2H_2O(g) + 3O_2(g) \longrightarrow 2CO_2(g) + 6H_2O(g)$

b) Draw a diagram of a methanol fuel cell in the space on the right.

Label the following:

- Anode and cathode and their polarity
- A suitable electrolyte
- Direction of positive ion flow through the internal circuit.
- Inlet for each reactant
- Outlet for products
- Direction of electron flow through the external circuit.



c) An **Alkali** hydrogen fuel cell operates on compressed hydrogen and oxygen. It uses a solution of **potassium hydroxide** in water as its electrolyte. Efficiency is about 70%, and operating temperature is anywhere between 150 and 200 °C.

i. Write the balanced equations to the reactions occurring at the

- anode *$CH_3OH(g) + 6OH^-(aq) \longrightarrow CO_2(g) + 5H_2O + 6e^-$*

- cathode *$3O_2(g) + 6H_2O(g) + 12e^- \longrightarrow 12OH^-(aq)$*

ii. What mass of oxygen gas needs to be pumped through the fuel cell to produce 233 mol of electrons?

According to the half-cell equation at the cathode for every 3 mol of O_2, 12 mol of electrons flow through the external circuit and are used in reduction of O_2 gas.

$3O_2(g) + 6H_2O(g) + 12e^- \longrightarrow 12OH^-(aq)$

=> for 233 mol of electrons 233/4 mol of O_2 molecules are needed.

=> 58.25 mol

Since the cell is 70% efficient in converting chemical energy into electrical energy an amount of 58.25/0.7 mol is needed.

=> 83.21 mol

Mas of O_2

=> 83.21 X 32.0 = 2.66Kg