Electrochemical cells- revision

An experimental electrochemical cell, known as a carbon-air cell, uses stored, pressurised CO_2 gas as a fuel to store and generate electrical energy. A simplified diagram of the setup during recharge and discharge is shown below. This unit combines a solid oxide fuel cell (SOFC) and an electrolytic cell.

Recharging

SOFC

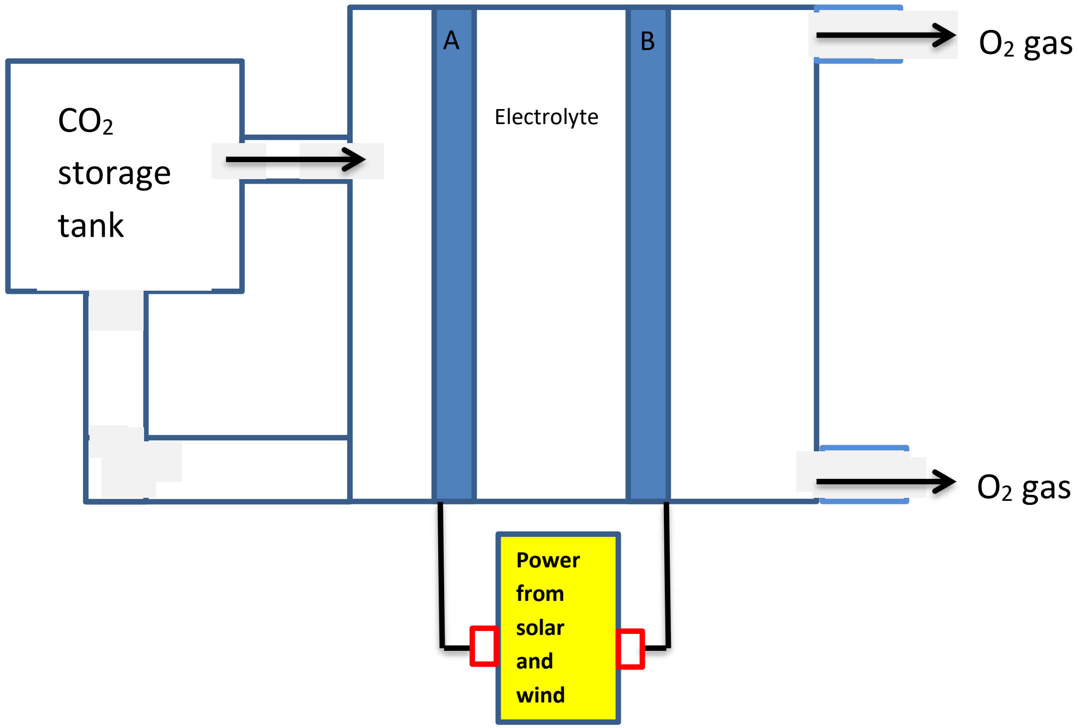

Diagram 1

1) Write a balanced half equation, states not required, for the reaction taking place at electrode :
   “A” ___*$CO_2 + 4e \rightarrow C + 2O^{2-}$*______________________________
   “B” ___ *$2O^{2-} \rightarrow O_2 + 4e$* ______________________________
2) Identify the polarity of electrode “A” and give a reason as to why it is the anode or the cathode. *Electrode “A” is the cathode as it is the site of reduction (electron acceptance)*
3) In which direction are electrons flowing through the cell shown above? *From B → A*
4) What ions flow though the electrolyte and in what direction? *O^{2-} from A → B*
5) Circle the type of electrochemical cell represented by the diagram above. Justify your selection.
   a. Primary cell
   b. Secondary cell
   c. Fuel cell
   d. [✓ Electrolytic cell.]

This cell uses external electrical energy to drive non-spontaneous redox reactions to store chemical energy. It converts electrical energy into chemical energy.

Discharging

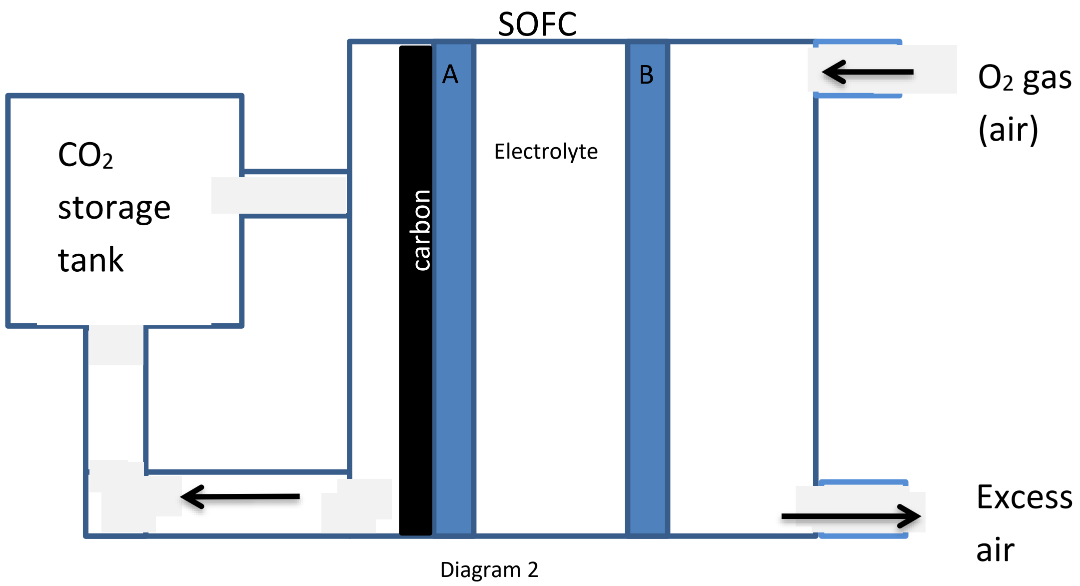

Diagram 2

6) Does this energy system deliver renewable energy? Explain.
   Yes. Energy needed to recharge energy storage comes from renewable sources such as solar and wind.
7) Write a balanced half equation, states not required, for the reaction taking place at electrode :
   "A" ___ $C + 2O^{2-} \rightarrow CO_2 + 4e$ ______________________________
   "B" ___ $O_2 + 4e \rightarrow 2O^{2-}$ ______________________________
8) Identify the polarity of electrode "A" and give a reason as to why it is the anode or the cathode. *Electrode "A" is the anode (negative) as it is the site of oxidation (electron donation)*
9) In which direction are electrons flowing through the cell shown above? *From B → A*
10) What ions flow though the electrolyte and in what direction? *O^{2-} from B → A*
11) Circle the type of electrochemical cell represented by the diagram above. Justify your selection.

   a.Primary cell
   [✓ b. Secondary cell]
   c. Fuel cell
   d. Electrolytic

   This cell converts a finite, stored chemical energy into electrical energy . Since the amount of reactant supplied is finite it cannot be a fuel cell. This cell can be recharged so it is a secondary cell.

12) What changes occur to electrodes A and B during:

- discharge *– the carbon deposited on electrode "A" will decrease while no change to electrode "B" takes place.*
- recharge *– carbon is deposited on electrode "A"while no change to electrode "B" takes place.*

13) In a typical carbon-air cell 3.00 grams of carbon is deposited during the recharge cycle and is used during the discharge phase.
a. Calculate the time, in hours, that the cell can operate for to produce a current of 0.50 A. Assume the cell is 100% efficient. Express your answer to the right number of significant figures.

Step 1 Find the mol of C
=> 3.00/12.0 = 0.250
Step 2 Find the mol of electrons produced
$C + 2O^{2-} \rightarrow CO_2 + 4e$
=> 1.00 mol of electrons with a charge of one Faraday (96500 Coulomb).
Step 3 Find the time in seconds
$Q = It$
$=> Q/I = t$
=> 96500 / 0.50 = 193000 s = 54 hours (2 sig figs)

b. What mass of carbon should be deposited if the cell is 83.0% efficient to produce a current of 0.500 A for 24.6 hours?
Step 1 Calculate the charge, in Coulombs, produced.
=> Q = It = 0.500 X 24.6 X 60 X 60 = 44280 C
Step 2 Calculate the mol of electrons represented by 44280 C
=> 44280/96500 = 0.459 mol.
Step 3 Calculate the mass of carbon needed to produce 0.459 mol of electrons.
=> $C + 2O^{2-} \rightarrow CO_2 + 4e$
=> 0.459 / 4 = 0.1147 mol
Step 4 Calculate the mass of carbon assuming 83.0% efficient.
=> (0.1147 X 12.0) / 0.83 = 1.66 grams

14) The storage tank of another carbon-air cell has a capacity of 46.0 litres and stores gas at 120°C and 300 kPa pressure.
a. Calculate the maximum mol of CO_2 gas that can be stored in the tank under these conditions.
=> PV = nRT
=> n = PV/(RT) = 300kPa X 46.0 L / (8.31 X 393 K) = 4.34 mol

b. Calculate the electrical energy, in kilojoules, generated by the cell during a 24.0 hour period running at 2.75 volts, assuming 100% efficiency. Energy (J) = Voltage(V) X Charge(C)
Step 1 Find the mol of carbon
=> $C + 2O^{2-} \rightarrow CO_2 + 4e$
=> the mol of carbon is equal to the mol of CO_2 *= 4.34 mol.*
Step 2 Find the mol of electrons
=> 4.34 X 4 = 17.36 mol
Step 3 Find the charge in Coulombs
=> $17.36 \times 96500 = 1.675 \times 10^6 C$
Step 4 Find the energy in joules.
=> Energy = VQ = $2.75 \times 1.675 \times 10^6 = 4.61 \times 10^3 kJ$.

c. For this particular type of cell the mass of the gas that can be stored is not important, rather it is the volume that is the critical factor. It is suggested that the cell be slightly modified to use hydrogen to replace CO_2. Argue for or against this proposal. Use calculations of energy density (kilojoules/litre) and environmental considerations to justify your decision.

The tank can hold equal amount of mol of hydrogen and carbon dioxide at the given conditions of 46.0 litres, 120°C and 300 kPa pressure. That is, 4.34 mol of either CO_2 or H_2 gas.
The energy density for CO_2 is
=> $4.61 X 10^3$kJ / 46.0 = $1.00 X 10^2$kJ/L
The energy density of hydrogen is half that of CO_2 (50 kj/L), as each molecule of H_2 produces half as many electrons as one molecule of CO_2.

$C + 2O^{2-} \rightarrow CO_2 + 4e$
$H_2 + O^{-2} \rightarrow H_2O + 2e$

The cell produces zero net atmospheric CO_2 as the gas is trapped and recycled. Hence there is no advantage from an environmental perspective using hydrogen gas or carbon dioxide gas as a fuel. It can also be argued that CO_2 produced by the burning of fossil fuel can be used to drive such carbon-air cells and so these type of cells may have a part to play in storing CO_2 via carbon capture and preventing its escape into the atmosphere.