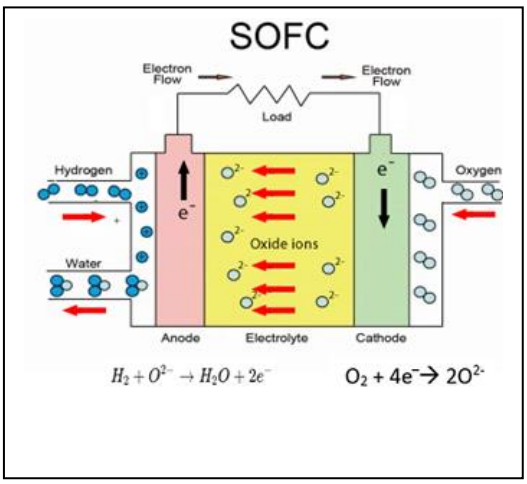
Innovation

Reversible Solid Oxide Fuel Cells (RSOCs):

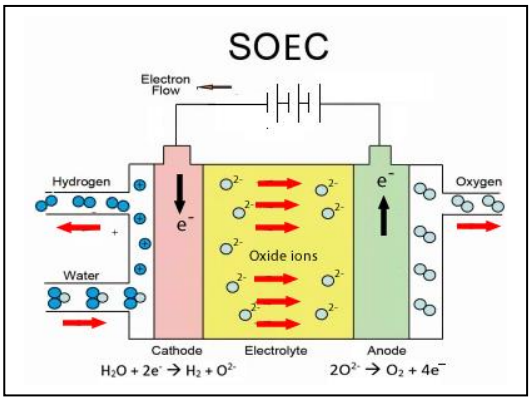


RSOCs can operate both as fuel cells, generating electricity from fuels like hydrogen and as electrolysis cells, producing hydrogen from electricity or syngas from CO_2 and H_2O. This dual functionality offers a versatile solution for energy storage and conversion. Here are a few points of why RSOC are important:

- Efficient Energy Storage - They can store excess renewable energy by producing hydrogen when electricity demand is low.
- Dual Functionality - A single system can generate electricity from fuels or create fuels from electricity.
- High Efficiency - RSOCs operate at 600–900°C, leading to better efficiency compared to low-temperature electrolysis.
- Carbon Capture Potential: Can convert CO_2 and H_2O into syngas ($CO_2 + H_2O \rightarrow H_2 + CO + O_2$), enabling synthetic fuel production.

RSOCs work by operating in two modes:

1. Fuel Cell Mode (SOFC - Solid Oxide Fuel Cell):
    - Converts chemical energy in the form of hydrogen, syngas, or other fuels, into electricity.
    - Oxygen from the air is reduced at the cathode, forming oxide ions. According to the reduction half equation $O_2 + 4e \rightarrow 2O^{2-}$
    - These oxide ions migrate through the solid oxide electrolyte to the anode, where they react with hydrogen or another fuel, releasing electrons and producing water, carbon dioxide, if using hydrocarbons and heat.
    - Electrons flow through an external circuit, generating electric power.
2. Electrolysis Mode (SOEC - Solid Oxide Electrolysis Cell):
    - Uses electricity, from renewable sources like wind or solar, to split water or CO_2 into hydrogen and oxygen
    - Oxygen ions migrate to the anode, through the electrolyte, in reverse direction when compared to the fuel cell mode.
    - At the cathode, water is reduced to form hydrogen and oxide ions. Whilst oxide ions are oxidised to oxygen gas at the anode.



1. The use of RSOCs align well with a number of United Nations Sustainable Development Goals. Identify three and justify each of your selections.
Any three from the list below as long as the justification is valid.

UNSDG 7 – Affordable and Clean Energy

*RSOCs improve energy efficiency and enable large-scale hydrogen production, supporting the transition to **renewable energy** by:*

- *Acting as a fuel cells to generate electricity efficiently from hydrogen.*
- *Function as electrolysers to store excess renewable energy as hydrogen, reducing reliance on fossil fuels.*

UNSDG 9 – Industry, Innovation, and Infrastructure

RSOCs enable hydrogen-based industries to thrive with cleaner energy infrastructure by

- *Providing an avenue of storing excess renewable energy as hydrogen.*
- *Enables industrial decarbonisation, by facilitating the use of hydrogen over fossil fuels in industries such as steelmaking, ammonia production, and transport.*

UNSDG 12 – Responsible Consumption and Production

RSOCs contribute to sustainable energy production with minimal waste.

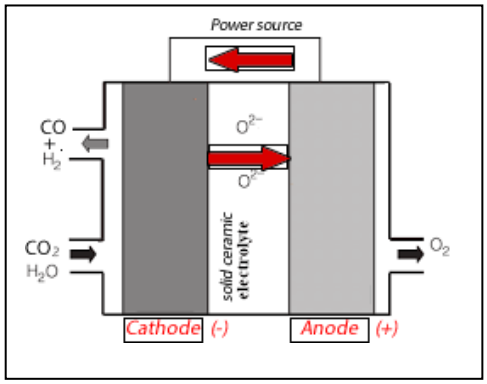
- *Uses recycling of CO_2 by using CO_2 in the synthesis and storage of fuels such as syngas.*
- *Reduces reliance on rare and expensive metals by operating at high temperatures (800^o C)*

5. UNSDG 13 – Climate Action

RSOCs reduce carbon emissions by replacing fossil fuels with green hydrogen.

- *Converts CO_2 and H_2O into syngas, enabling carbon capture and utilisation.*
- *Enables hydrogen-based energy storage (syngas), reducing fossil fuel dependency.*

2. A RSOC is operated as an electrolytic cell using an external, renewable power source. Carbon dioxide and water are feedstocks to the formation of syngas (CO and H_2).



a. Consider diagram 3. Label the:
   i. Anode and cathode
   ii. Give the polarity of each electrode.
   Anode _____
   Cathode _____
   iii. Direction of electron flow
   iv. Direction of ion flow.

b. Complete the following half equation taking place at one of the electrodes.

$$\_\_4e^-\_\_ + CO_2 + H_2O \rightarrow H_2 + CO + \_\_\_2O^{2-}\_\_$$

Follow the steps for balancing SOFC

Add oxygens in the form of O^{2-} to side deficient in oxygens and then balance for charge by adding electrons to the most positive side.

c. Is the reaction given by the half equation in question b. above taking place at the anode or the cathode? Circle the correct response and justify your answer.

Anode (Cathode)

It is the site of reduction in this electrolytic cell hence it is taking place at the negative electrode (cathode).

or

Electrons are being consumed indicating reduction is taking place, hence it is the cathode.

Students can also use oxidation numbers (C = +4 → C = +2) to justify that this reaction is taking place at the anode.

d. Give the balanced half equation taking place at the other electrode.

$$\_\_\_\_\_2O^{2-} \rightarrow O_2 + 4e^-\_\_\_\_\_$$

e. The external power source delivers a current of 13.0 amps for 13.00 hours as the sun is shining. This energy is surplus to requirements. It is decided that syngas will be formed from the energy source and stored for later use.
Assuming the electrolytic cell is 70.0% efficient, calculate the mass, in kg, of hydrogen gas that is formed. Give your answer to the right number of significant figures.

Consequential marks apply with the half equation from question b.

Step 1 find the total charge delivered by the current over 13.00 hours.

=> Q = It => 13.0 X 13.00 X 60 X 60 = 608400 C

Step 2 find n_e

=> 608400/96500 = 6.30

Step 3 find the mol of H_2 that is formed using the half equation given in question b. above.

=> $4e^- + CO_2 + H_2O \rightarrow H_2 + CO + 2O^{2-}$

according to the stoichiometry the ratio is 4 : 1

=> Hence mol of H_2 formed is ¼ X 6.30 = 1.58

Step 4 Find the mass of H_2

=> 1.58 X 2.0 = 3.16 g

Since the cell is 70.0% efficient converting energy into hydrogen gas, only 70.0% of the total possible mass of hydrogen will be produced

=> 3.16 X 0.700 = 2.21g = 2.2 X 10^{-3} kg (units not required as they are stated in the stem of the question)

f. RSOC cells provide an innovative solution to the mitigation of climate change. When operating as a SOFC the cell burns all forms of fuel including fossil fuels thus contributing to the net increase of atmospheric carbon dioxide.

i. Give the overall equation for the combustion of ethane in an RSOC acting as a fuel cell.

_____ *$2C_2H_6 + 7O_2 \rightarrow 4CO_2 + 6H_2O$* _____

ii. RSOC cells, when operating as electrolytic cells, are said to help reduce the human impact on climate change. Explain how RSOCs achieve this. In your answer, describe what happens to ethane (C_2H_6) when the RSOC is operating as a fuel cell and suggest what could be done with any byproducts to make the system more sustainable.

When ethane (C_2H_6) is used as a fuel in an RSOC operating in fuel cell mode, it reacts with oxygen to produce carbon dioxide (CO_2) and water (H_2O). Since CO_2 is a major greenhouse gas, its release contributes to climate change. However, this CO_2 can be captured and stored rather than being released into the atmosphere. ----- *1 mark*

When the RSOC operates in electrolytic mode, using excess renewable energy, the captured CO_2 and H_2O can be converted into syngas ($CO+H_2$), which is an important fuel and chemical feedstock.

The products (syngas) from the reaction at the cathode is shown below.

$CO_2 + H_2O \rightarrow CO + H_2$ ---- *1mark*

the mark was also awarded if the student wrote the overall cell reaction when operating as an electrolytic cell.

$CO_2 + H_2O \rightarrow CO + H_2 + O_2$

By recycling CO_2 into useful products instead of releasing it into the atmosphere , RSOC systems help reduce the human impact on climate change and promote a more sustainable energy cycle.

---- *1 mark*