Uses of solid electrochemical cells in energy related fields

I. Riess

Physics Department, Technion, Haifa 32000

riess@tx.technion.ac.il

Outline:

1. Two types of electrochemical cells
2. Solid oxide fuel cells
3. High temperature electrolyzers for water
4. High temperature electrolyzers for CO_2
5. Oxygen generators for coal gasification
6. Oxygen sensors for fuel consumption control

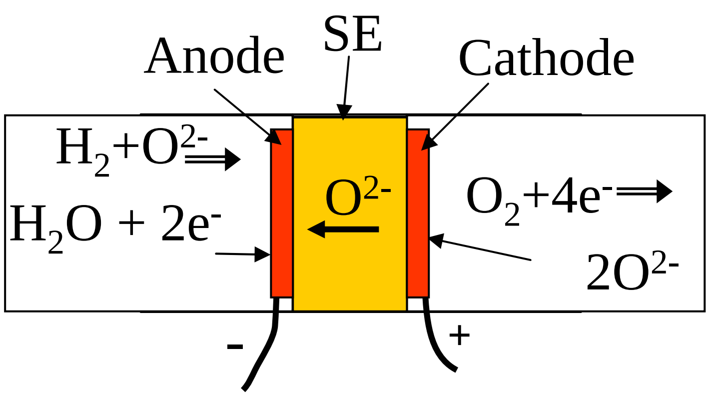
1. Two types of electrochemical cells:

1a. In an electronic device only electrons are transferred in the electrode process:

Metal	semiconductor	Metal

2a. "Regular electrochemical cells": an electrolyte between two electrodes, as in batteries and fuel cells.

- e.g.,



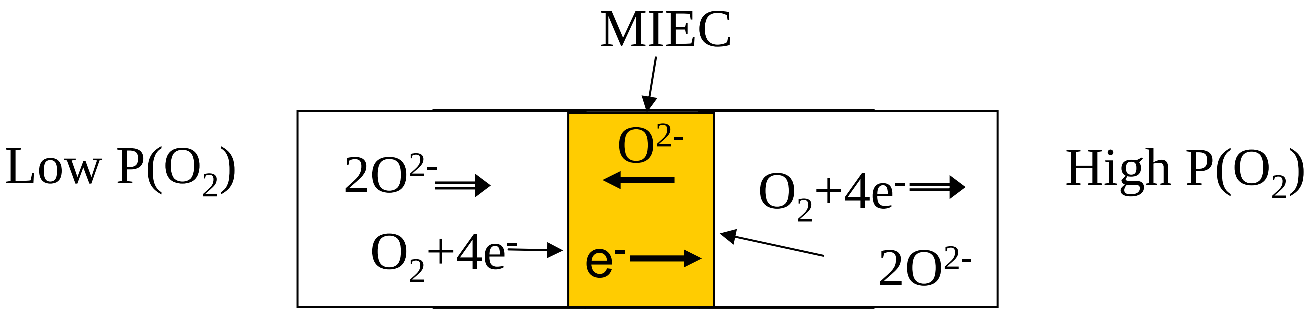
SE = solid electrolyte

- The reaction at the cathode $O_2 + 4e^- \rightarrow 2O^{2-}$ represents a transfer of both charge and matter and is therefore an electro+chemical one.

- So is also the one at the anode: $H_2 + O^{2-} \rightarrow H_2O + 2e^-$.

1b. Second type of electrochemical cells:

- It is possible only in solid cells because it requires the presence of electrons beside ions in the ionic conductor.
- MIEC- Thus the solid is a mixed-ionic-electronic-conductor
- e.g.



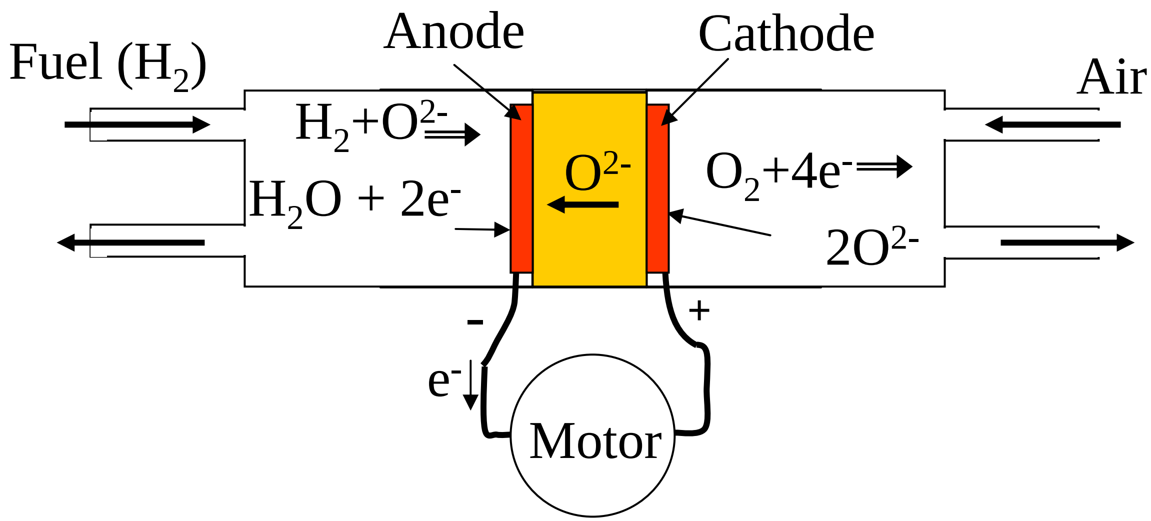
- No solid electrolyte is involved
- No additional electrodes.
- Obviously, the reactions on both sides of the MIEC are electrochemical ones, i.e. involve both mater and charge transfer.

- We shall discuss devices based on both types of cells

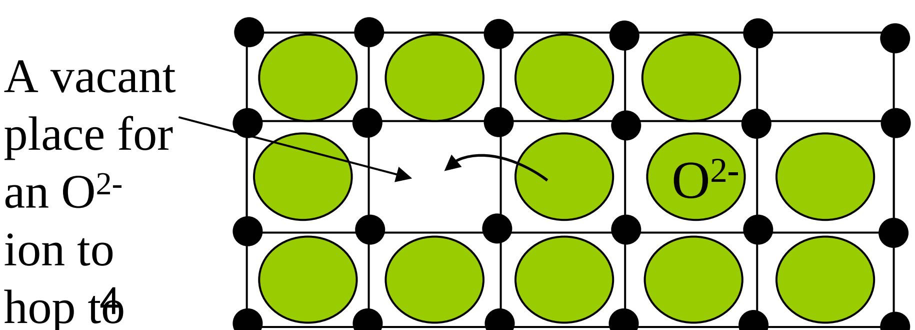
2. Solid oxide fuel cells (SOFCs):

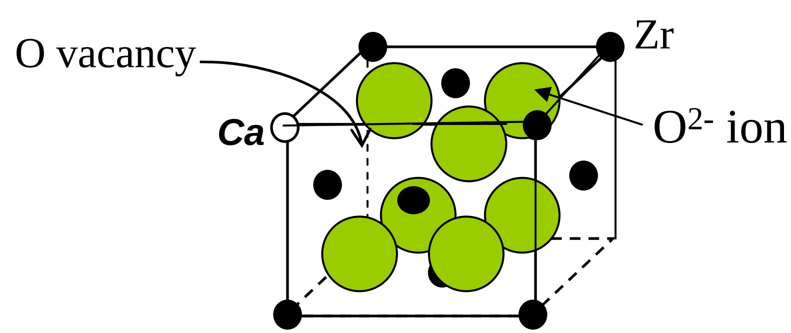
2a. Those based on oxygen ion conductors.

- Schematics:



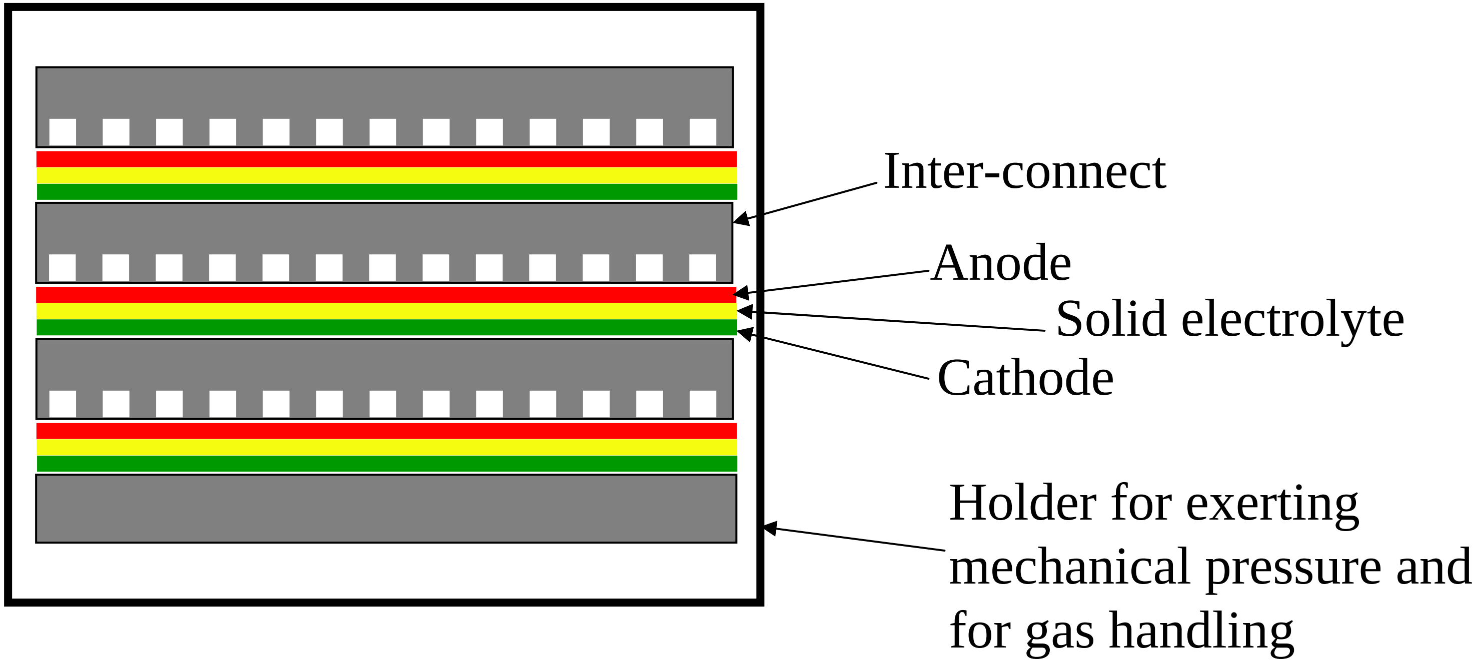
- How does a solid conduct ions?

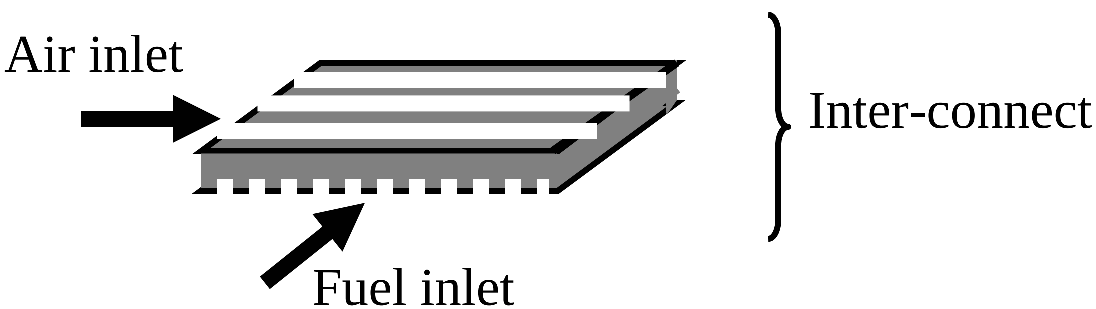


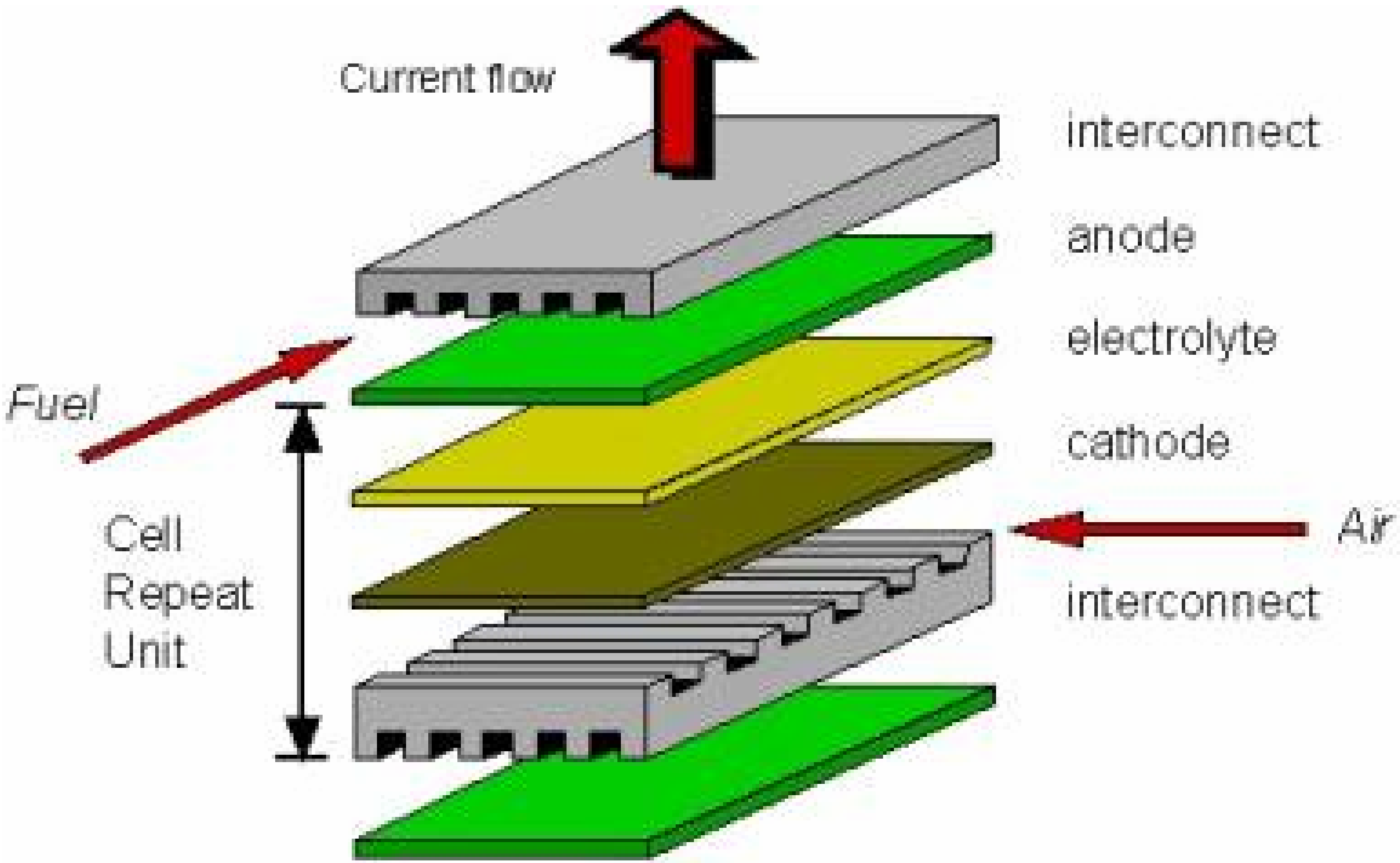


2b. Realization of SOFCs based on oxygen conductors:

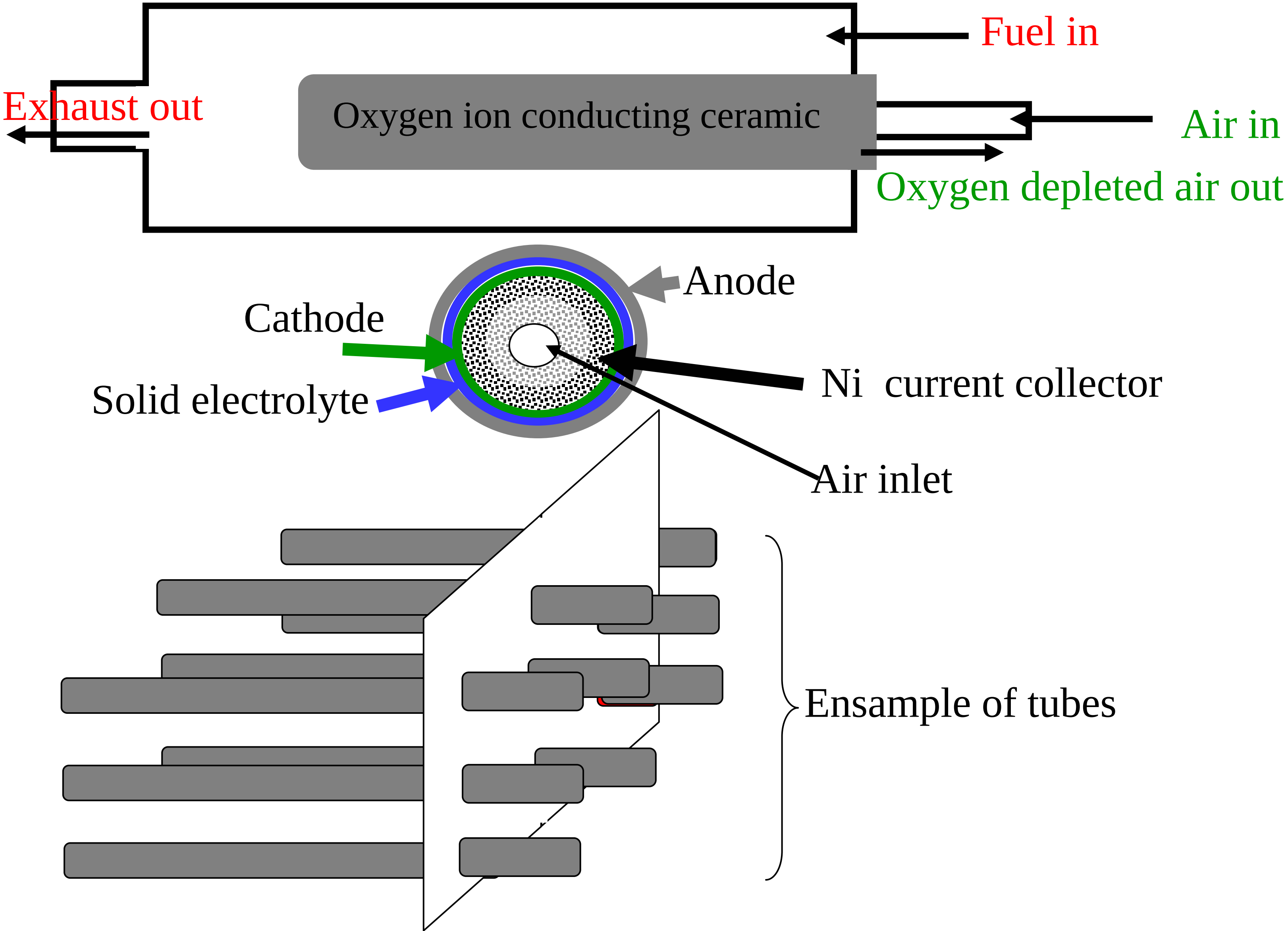
• Planar cells (most popular):



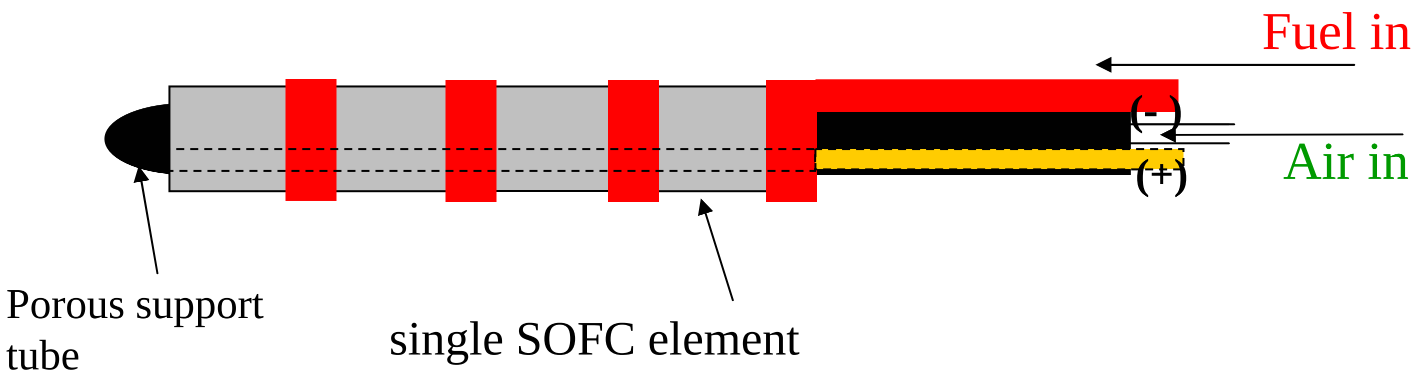


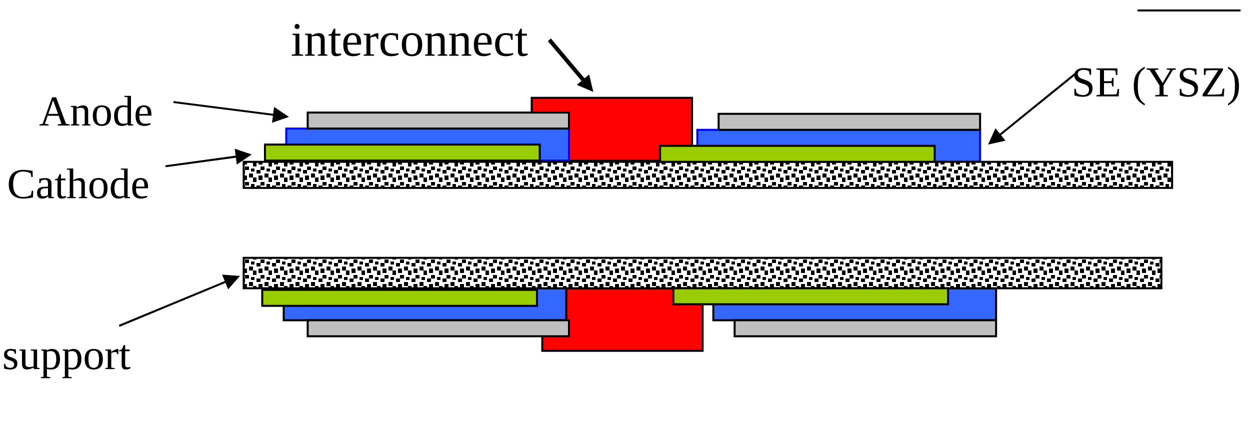

Current flow
interconnect
anode
electrolyte
cathode
Fuel
Air
Cell
Repeat
Unit
interconnect

- Tubular design of different types:
- Simple tubular (Westinghouse/Siemens):



- Other tubular designs:





A proof-of-concept HPD Delta 9 stack
(picture courtesy of Siemens)

Flattened tubular (Simens):

MHI:

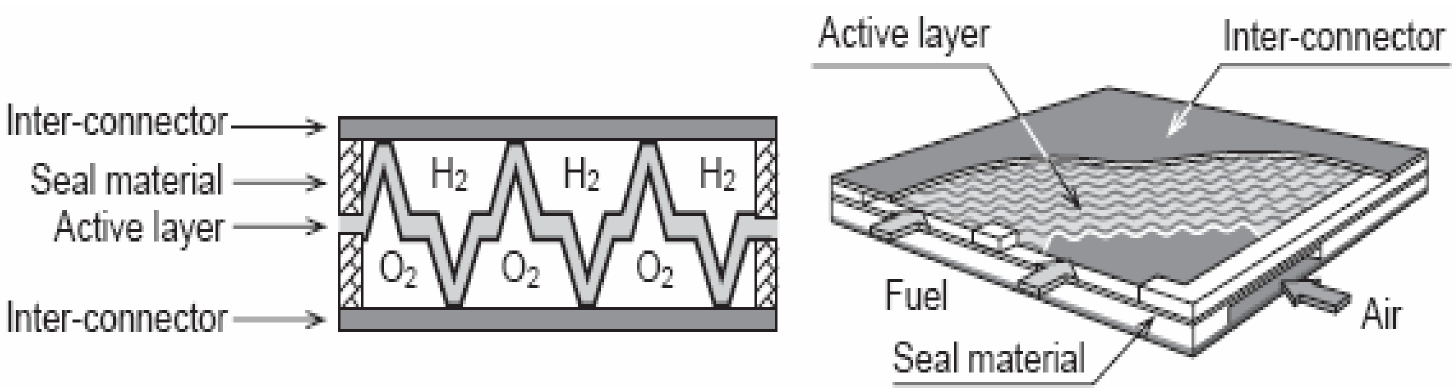


Fig. 9 Structure of MOLB Type SOFC

2c. SOFCs based on proton conductors:

• Proton conductor SOFCs have certain advantages (mainly: H_2 is not diluted by the exhaust gas).

•The SE is: $BaCe_{0.9}Y_{0.1}O_3$ (or Sr based).

• Unfortunately, these materials are unstable in the presence of CO_2 and decompose while forming the carbonate $BaCO_3$ or $SrCO_3$.

• More R&D is required in this direction.

3. High temperature electrolyzers for water (for generating H_2 as fuel e.g. in nuclear facilities):

• Regular electrolysis decompose the water at room temperature:

$$H_2O + \Delta G \rightarrow H_2 + \frac{1}{2}O_2$$

where ΔG is the free energy of formation of water and fixes the minimum energy required to decompose the water.

• ΔG(T) depends on temperature and is considerably reduced at elevated T.

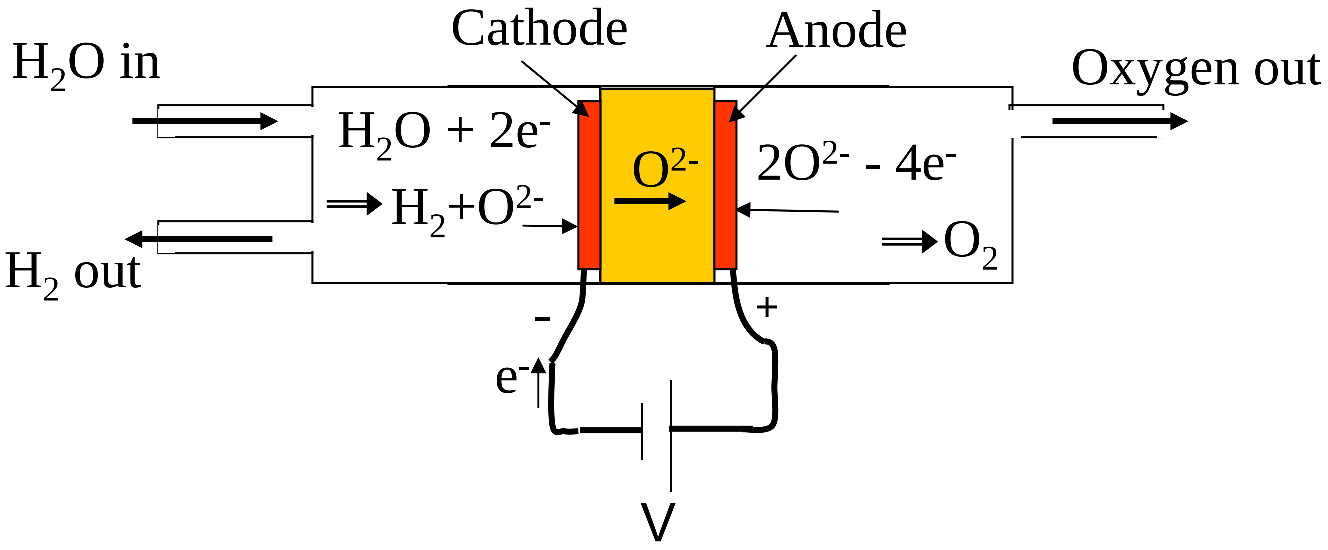
• At a T > 2000 ^{o}C ΔG vanishes and water decomposes spontaneously.

• This high temperature is above practical. What can one do to take advantage of the decrease in ΔG(T) with T?

• Answer: electrolyze the water at elevated T. This requires a lower energy investment (assuming that the energy of heating the gases is mostly recovered through a heat exchanger).

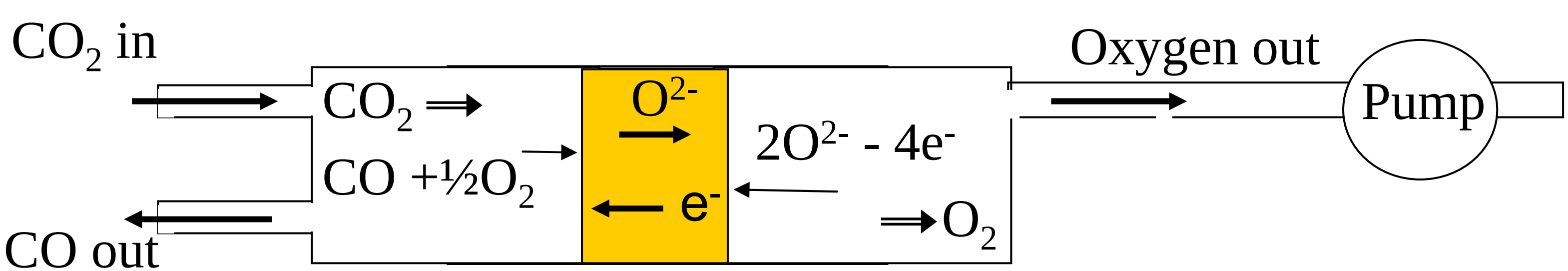
• Electrolysis at elevated T (~1000 °C) can only be done using ceramic solid oxide cells.

• They have the structure of a SOFC but operate under an applied voltage and in the reverse direction:



4. High temperature electrolyzers for CO_2 (for removing and turning it into a useful product CO):

- CO_2 also tends to decompose at elevated T.
- One can electrolyze in a manner discussed before for electrolyzing water at elevated T.
- Alternatively one can go to higher T where spontaneous decomposition occurs with a small ΔG.
- However, at T > 1000 °C there are no known SEs and all known oxides are MIECs.
- Yet CO_2 can be electrolyzed by using a MIEC replacing the driving force of the electrical field with a pressure gradient:



5. Oxygen generators for coal gasification

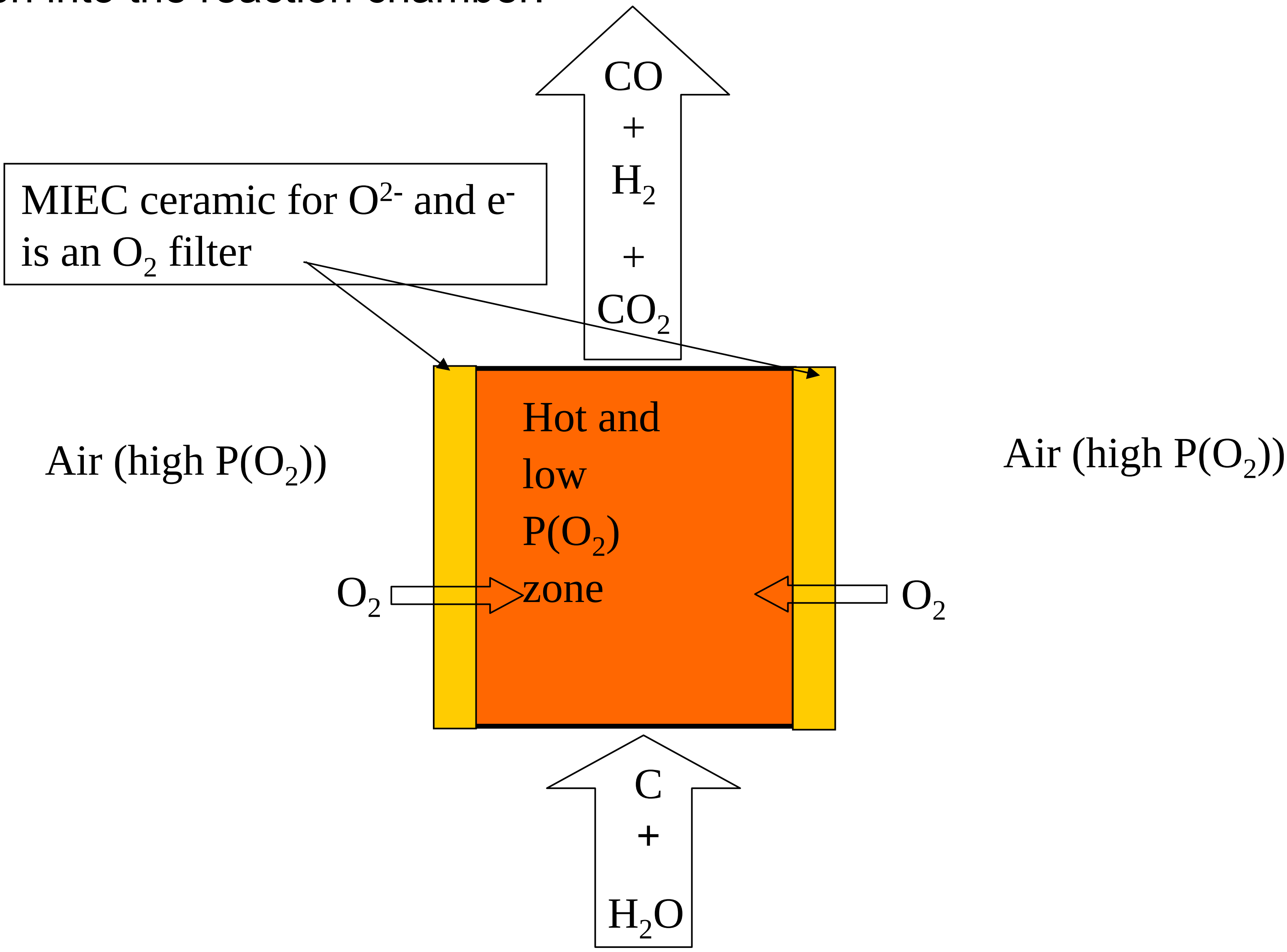
- Coal as a solid is not so convenient for use.
- There are processes that use coal to produce valuable gases.
- E.g.

$$C + H_2O = CO + H_2$$

which is syngas.

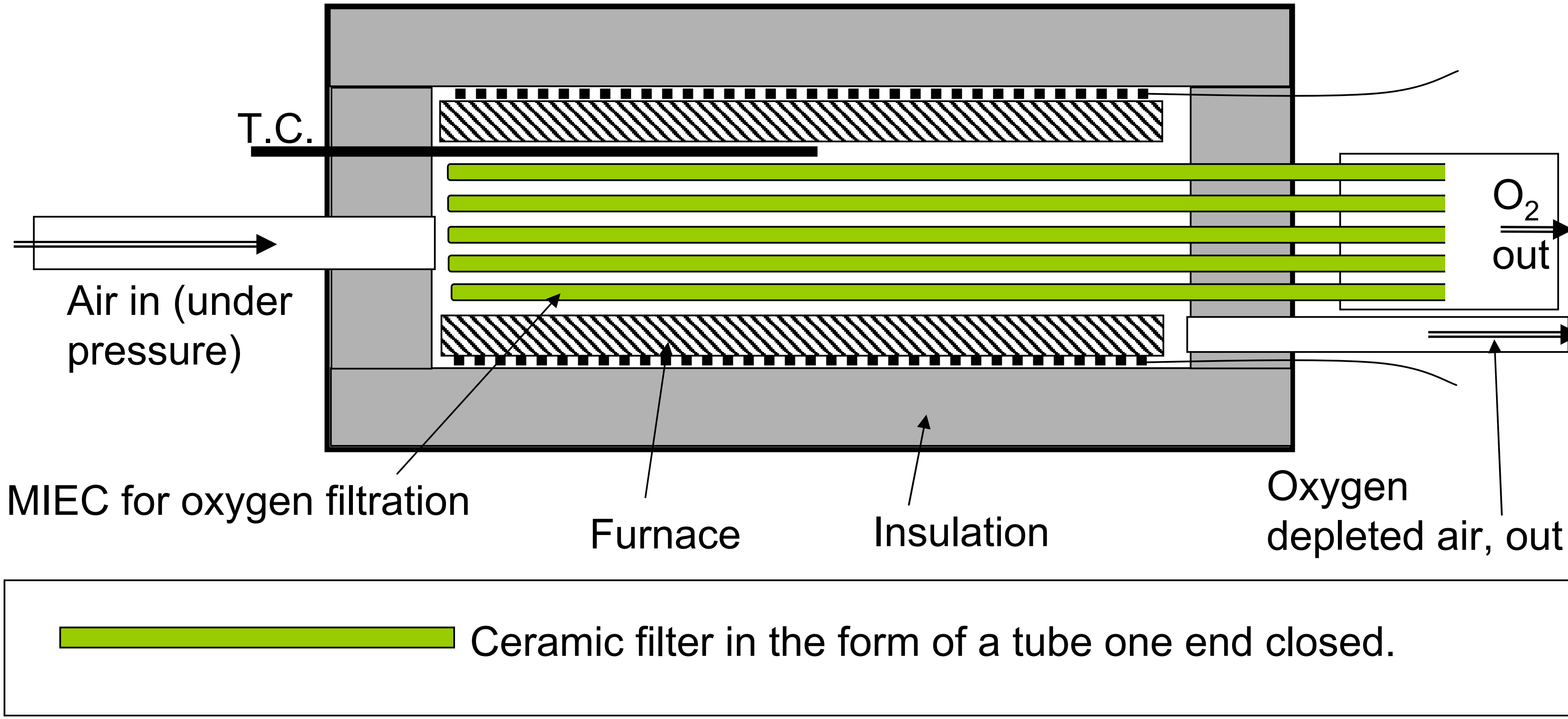
- Both CO and H_2 can serve as fuel and CO is valuable for the chemical industry.
- Unfortunately this process is endothermic and heat has to be supplied.
- For heating some oxygen is introduced to allow oxidation (burning) of coal.
- The practice prefers adding oxygen to the reaction. Thus one cannot use air as the nitrogen will dilute the gas products.

• Integrated solution: the use of MIEC for directly introducing pure oxygen into the reaction chamber:



- Alternatively, oxygen can be filtered separately and then fed into the reactor.

- Device for oxygen separation:

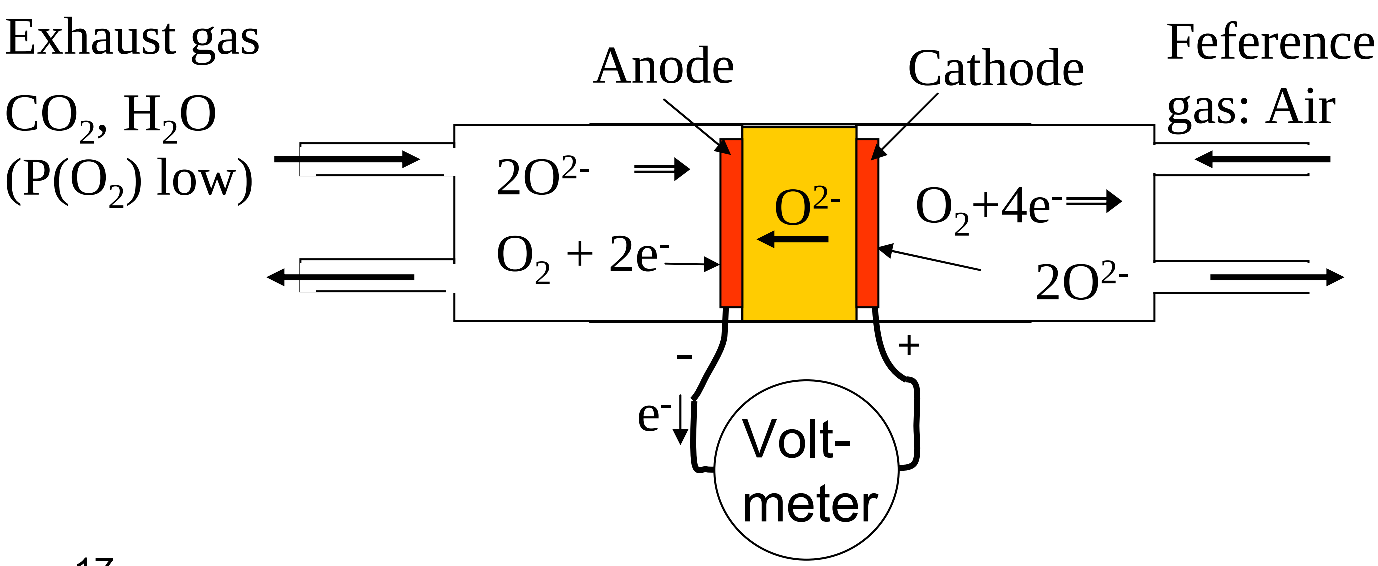


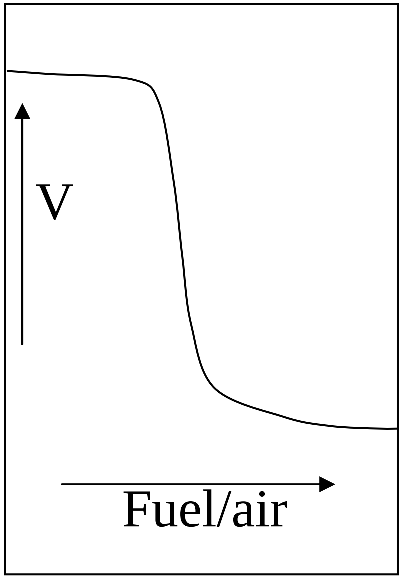
6. Oxygen sensors for fuel consumption control

• Control of proper combustion is achieved using a solid electrochemical cell in the SOFC configuration.

• The difference is only that no fuel is supplied and no power is withdrawn, only open circuit voltage is measured.

• Thus the detection of proper combustion by measuring $P(O_2)$ in a car exhaust gas (Lambda sensor) is schematically:





Thank you