

# Single chamber solid oxide fuel cells, a critical review\*

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## Outline:

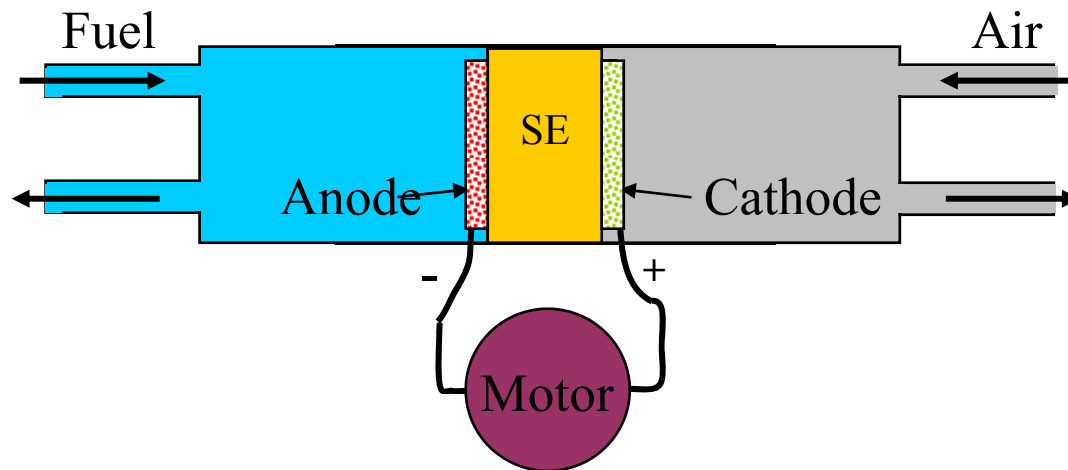
1. Fuel cells - conventional.
2. Mixed reactant fuel cells (MR-FCs) principle of operation.
3. Why is the SC-SOFC not necessarily a MR-SOFC.
4. Summary and future proposed research directions

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\* I. Riess, J. Power Sources, 175 (2008) 325.

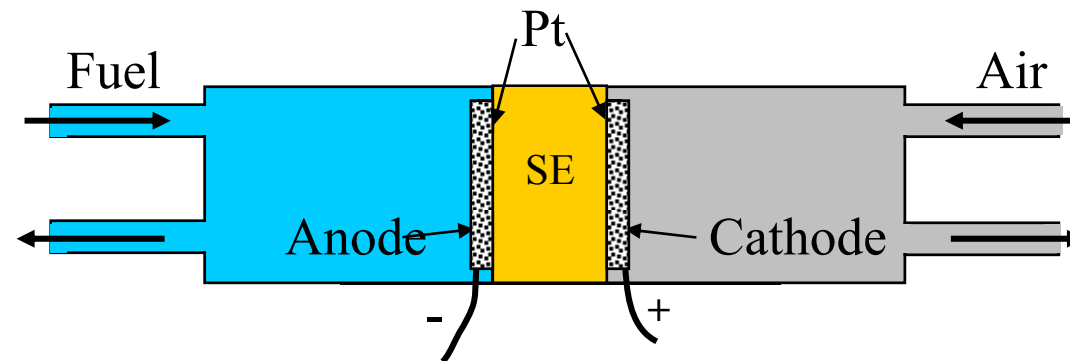
# 1. Principle of operation of a conventional SOFC:

Separated and well sealed cathode and anode compartments



## Remarks:

- Notice that the symmetry is broken by the difference in the gas composition.
- The same electrode material can be used, e.g. Pt.



- Typical performance in modern SOFC:

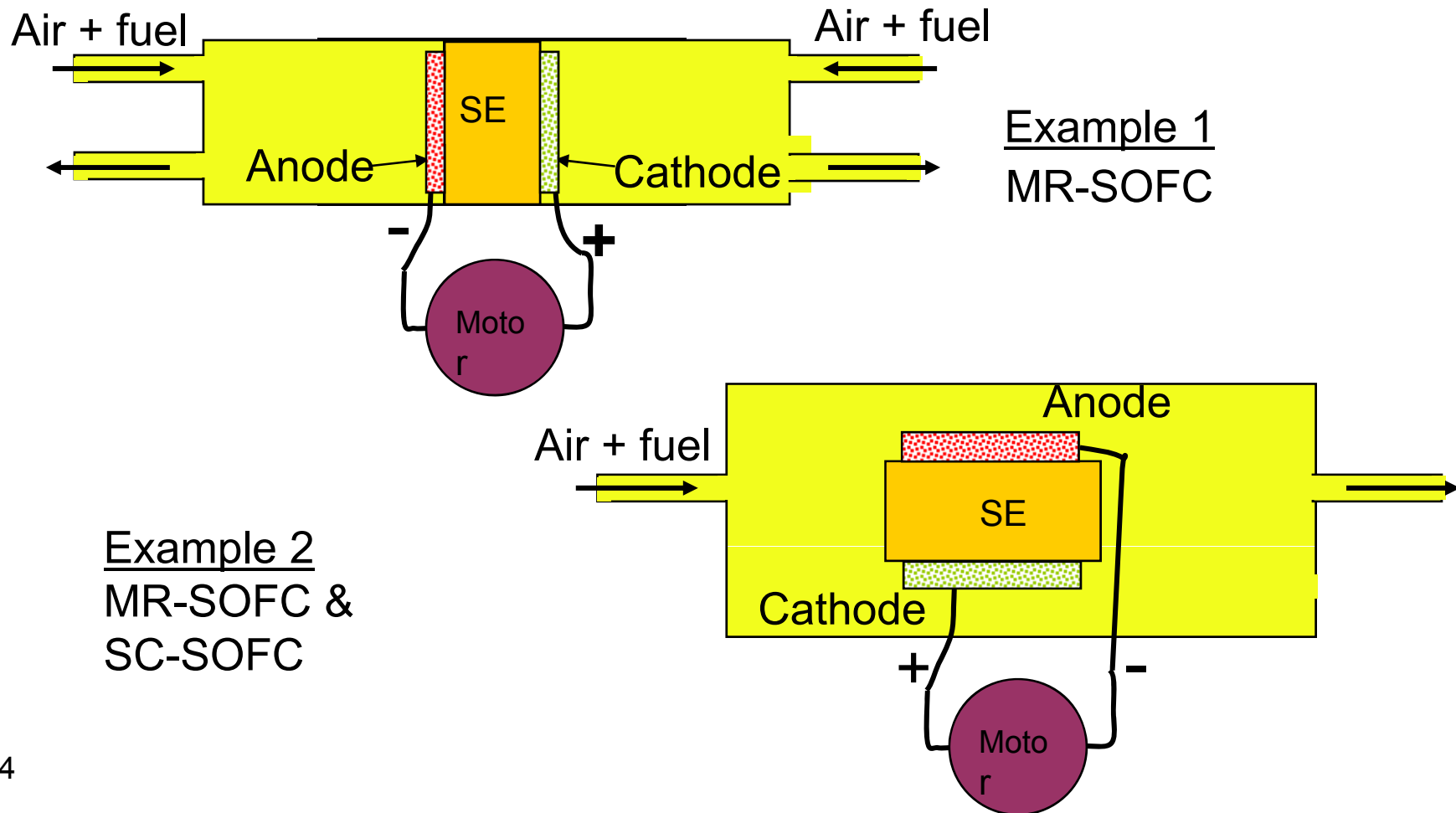
Current density  $1\text{A}/\text{cm}^2$  at maximum power output of  $0.5\text{W}/\text{cm}^2$

. These numbers are important in evaluating the flow rate and residence time in the cells.

## 2. FC without separation of the fuel from the air:

### a. Mixed Reactant SOFC (MR-SOFC), (single chamber SOFC (SC-SOFC)?)

Symmetry breaking: by different catalytic properties of electrodes.



b. Principle of operation of a true MR-SOFC:

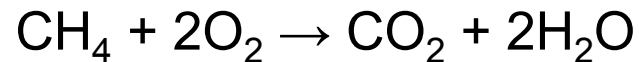
1) The direct chemical full oxidation reaction, fuel + oxygen, in the gas mixture should not be catalyzed by any of the components of the cell.

2) In the case of hydrocarbon partial oxidation can be tolerated, e.g.



3) This means that despite the presence of enough oxygen needed for full oxidation the chemical route is not completed.

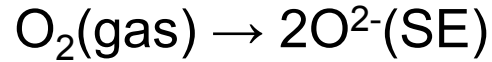
Reminder: for methane as fuel, full oxidation corresponds to,



4) In the case of H<sub>2</sub> as fuel there exist no partial chemical reaction that can be tolerated.

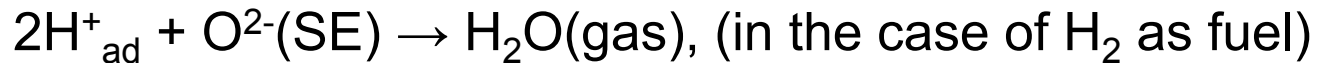
5) For oxygen ion solid electrolytes, SE(O<sup>2-</sup>):

The cathode should catalyze the electrochemical reaction:

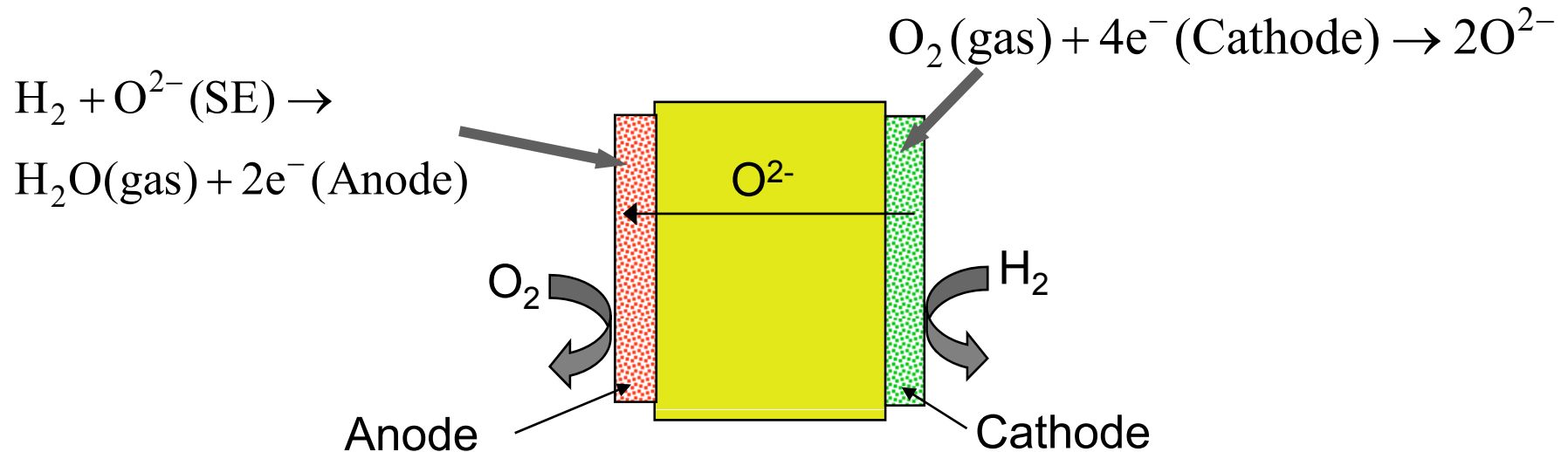


and should be inert with respect to adsorption of the fuel as molecules or ionic specie that can react with the oxygen directly.

6) The anode should catalyze the electrochemical reaction, e.g.:

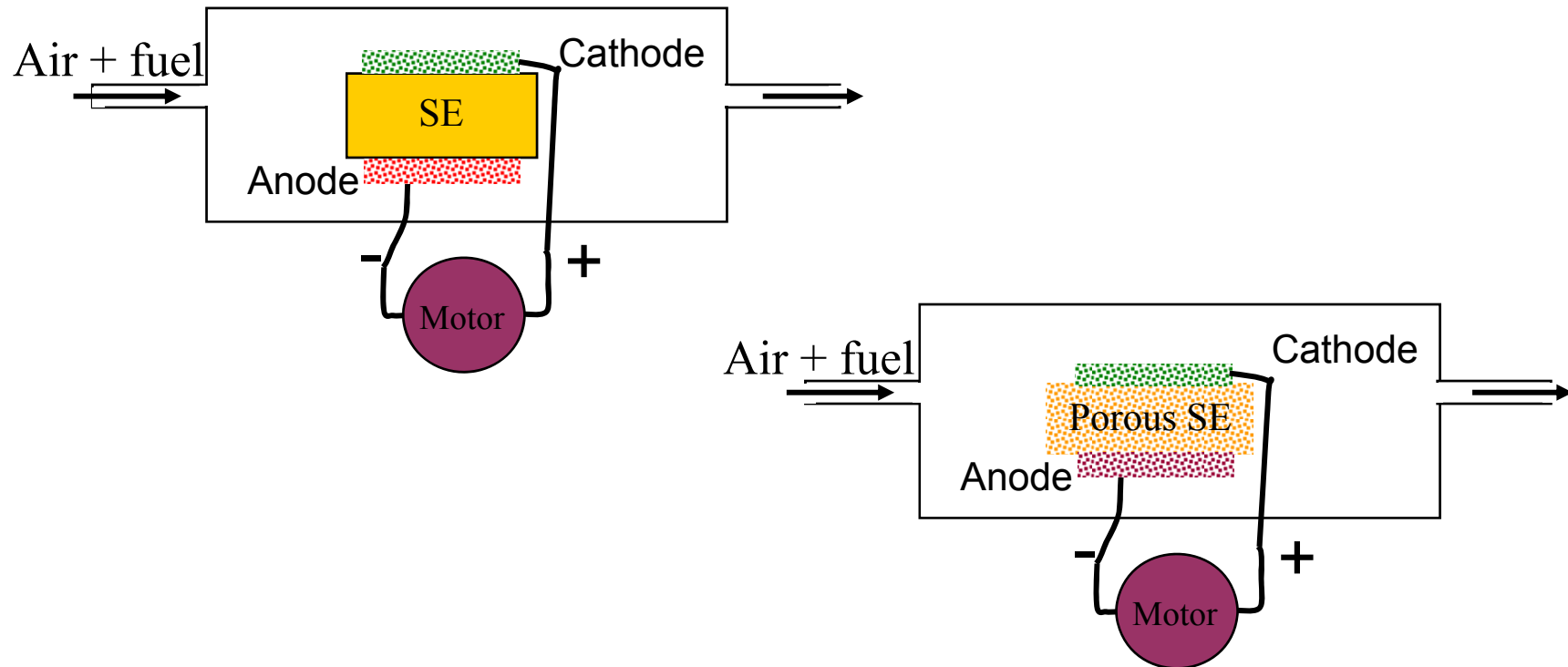


and should be inert with respect to oxygen.



### 3. Why bother with MR-SOFC? or the huge advantage of MR-SOFC:

a. The solid electrolyte can be porous:\*

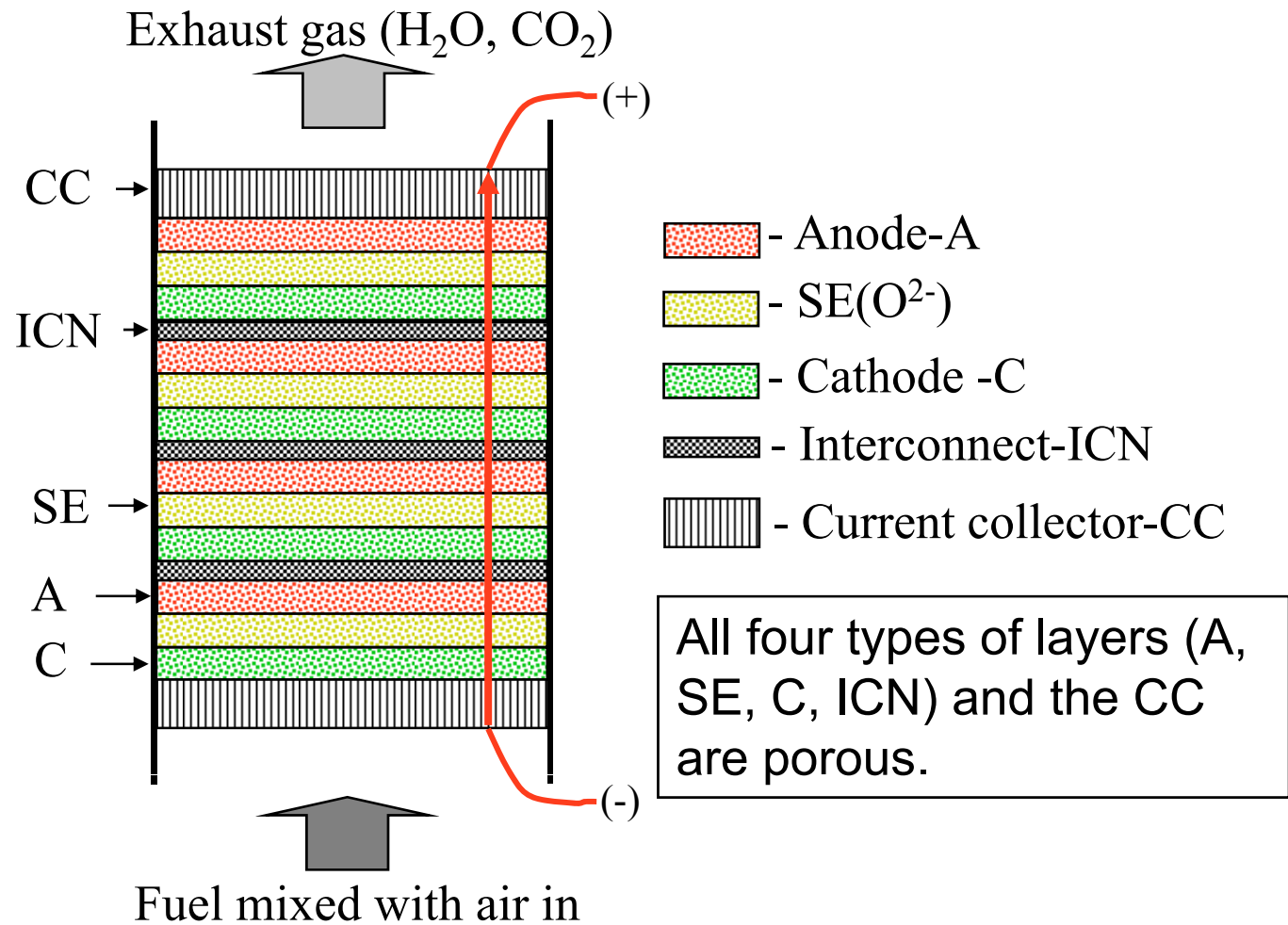


We next show a configuration that takes advantage of the allowed porosity of the SE.

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\*I. Riess, P.J. v-d Put and J. Schoonman, Solid State Ionics, 82 (1995) 1.

d. The most significant advantage of porosity appears in the following design:





e. Properties of this design:

1) High power density, E.g. in a

0.4 cm high stack, 10x10 cm<sup>2</sup> area,

(100 elements, assuming 10μm per layer),

at a power density of 0.5W/cm<sup>2</sup>: 5 kW !



2) Fuel utilization should be high.

3) Significant reduction in price.

4) Residence time of the gas mixture in the whole cell for this

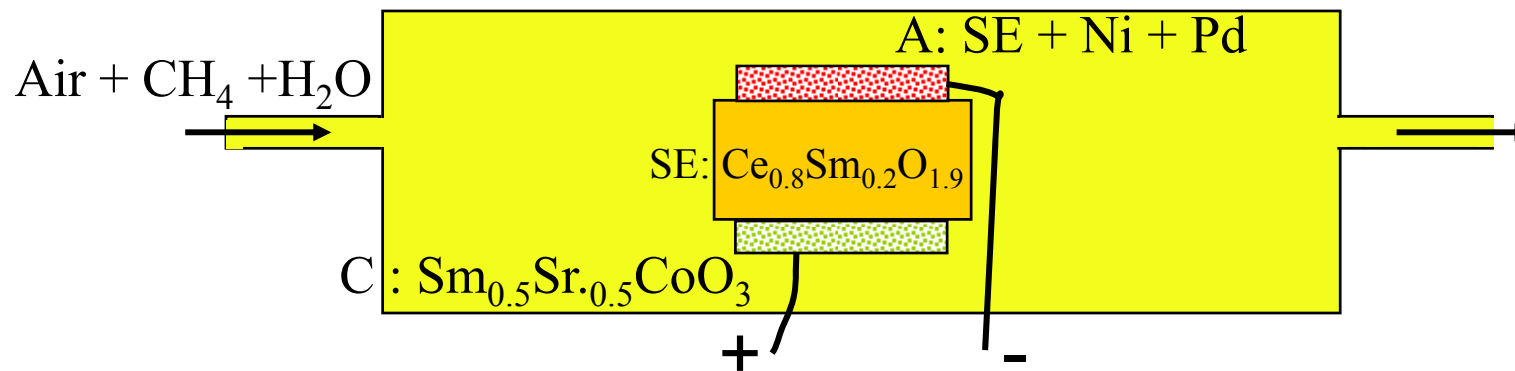
design at this power output: 10 mSec.

The short residence time is significant as it may allow to get rid of undesired and slow reactions.

#### 4. Supposedly MR-SOFC. In reality only SC-SOFC:

a. Example:  $0.64\text{mW}/\text{cm}^2$  from this fuel cell at  $550^\circ\text{C}$ .\*

This power density is similar to that obtained for the best conventional solid oxide fuel cells.

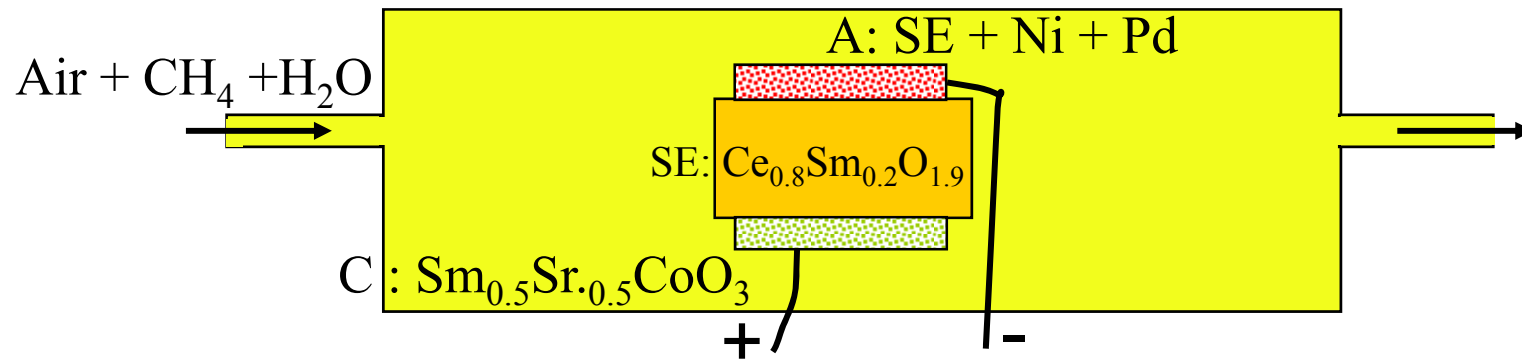


Notice that the electrode materials are those of common SOFC !

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\* T. Hibino, A. Hashimoto, M. Yano, M. Suzuki, S-I. Yoshida and M. Sano, J. Electrochem. Soc., **149** (2002) A133.

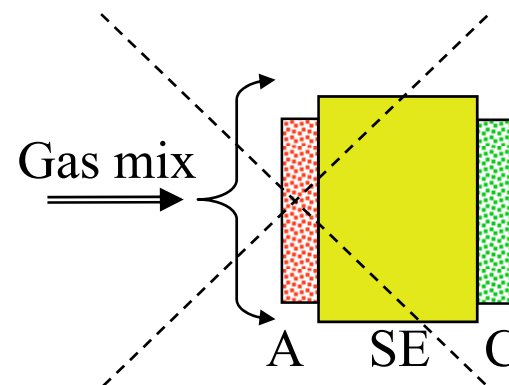
Review of SC-SOFCs: M. Yano et al., Solid State Ionics, 177 (2007) 3351.



This result is strange as the anode is known to be a catalyst for the full oxidation of methane and also the cathode exhibits some catalytic activity towards the same reaction!

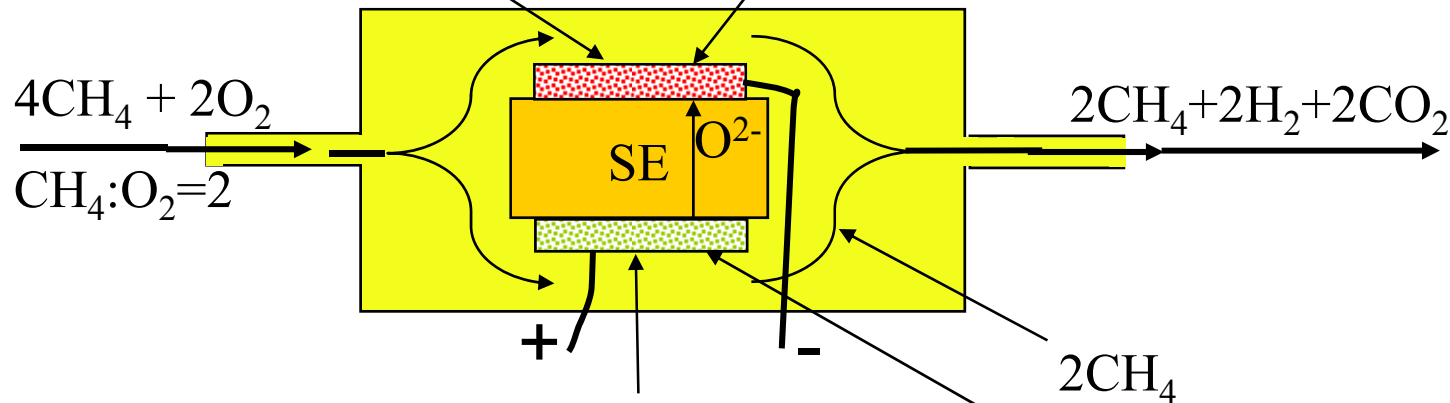
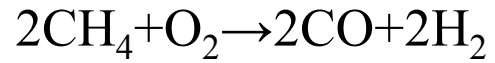
Furthermore this works only if:

- 1) There is excess of fuel.
- 2) The anode is not first in the gas path.
- 3) The gas flow is fast.



I.e. “good” results are obtained by manipulating the gas composition, flow pattern and flow rate..

The anode is not selective



The cathode is selective under high flow rate

1. Full fuel oxidation at the anode is avoided by limiting oxygen supply!  $\text{CH}_4:\text{O}_2 = 2$  instead of 0.5.
2. Fuel utilization is low. Can be improved by adding cells in series system (raising the cost of the device):

c. Obtaining performance as a SC-SOFC but not a MR-SOFC:

- 1) Assure that the gases in the cathode and anode compartments cannot mix.
- 2) The cell will function seemingly well if only the cathode is selective and the mixture is rich in fuel (excess fuel). Then the oxygen at the anode is consumed and the cell operates on the remaining fuel at the anode.
- 3) The cell will function seemingly well if only the anode is selective and the fuel is lean (excess oxygen). Then the fuel is consumed at the cathode and the cell operates on the remaining oxygen at the cathode.
- 4) In the experiments reported so far the mixture was rich. They did not work with stoichiometric or lean mixtures.
- 5) Conclusion: No selective anode for SOFC has been found so far.
- 6) This is supported by catalytic measurements that we did examining the chemical reaction over various anode materials tested with a GC.
- 7) In addition the results depended on the flow rate i.e. residence time (see below).
- 8) There is one FC reported that operates at low temperatures, on methanol mixed with air, that is a true MR-FC.\*

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\* S. Calabrese et al., J. Power Sources, 96 (2001) 329.

## 5. Conclusions:

- Existing designs of SOFC render them expensive.
- MR-SOFC in the flow through design have the advantage of price reduction, power density increase and high fuel utilization.
- To date the single chamber SOFC are no more than regular SOFC and at least the anode is non selective.
- An attempt by Burgler and Gauckler showed that the porous SOFC based on common materials is not a MR-SOFC.
- As a result the advantage of the true MR-SOFC cannot be realized, yet. Furthermore, fuel utilization in the SC-SOFC is very poor (a few %).
- **The answers have to be looked for through intensive research of the relevant heterogeneous catalytic processes, with selectivity between electrochemical (enhanced) reactions and chemical (slow) ones.**

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**END**