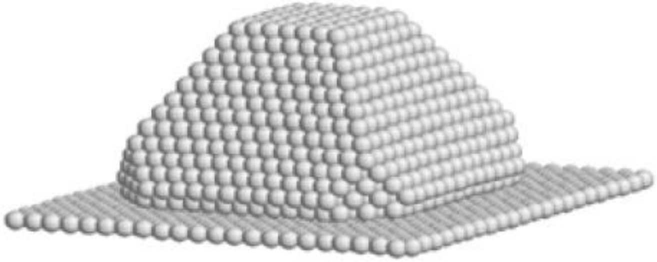
Norwegian University of Science and Technology

TMT4320 Nanomaterials
Septemeber 28th, 2016

- TNN4: Energy-related applications: Fuel Cells and Batteries



Last lectures

- Characterization of Nanomaterials: TEM, SEM, XPS, STM, AFM, XRD, SAXS, EDX, EELS, Nanoindentation

  - Electron Microscopy:
    - Transmission/Scanning Electron Microscopy (TEM/SEM)
    - Scanning tunneling Microsopy
    - Atomic Force Microscopy
    - Energy Dispersive X-Ray Spectroscopy (EDS/EDX)
    - Electron loss energy spectroscopy (EELS)
  - X-Ray Diffraction (XRD)
    - Small angle X-Ray scattering (SAXS)
  - Nanoindentation
  - Many others: FIM, SPM, IR, RAMAN, HR-TEM, ED, SIMS, LEIS, ND, etc…

Today lecture

Fuel Cells

-High Temperature Fuel Cells: O_2 and H^+-SOC

Fuel cell mode: Electricity

Electrolysis mode: H_2 production

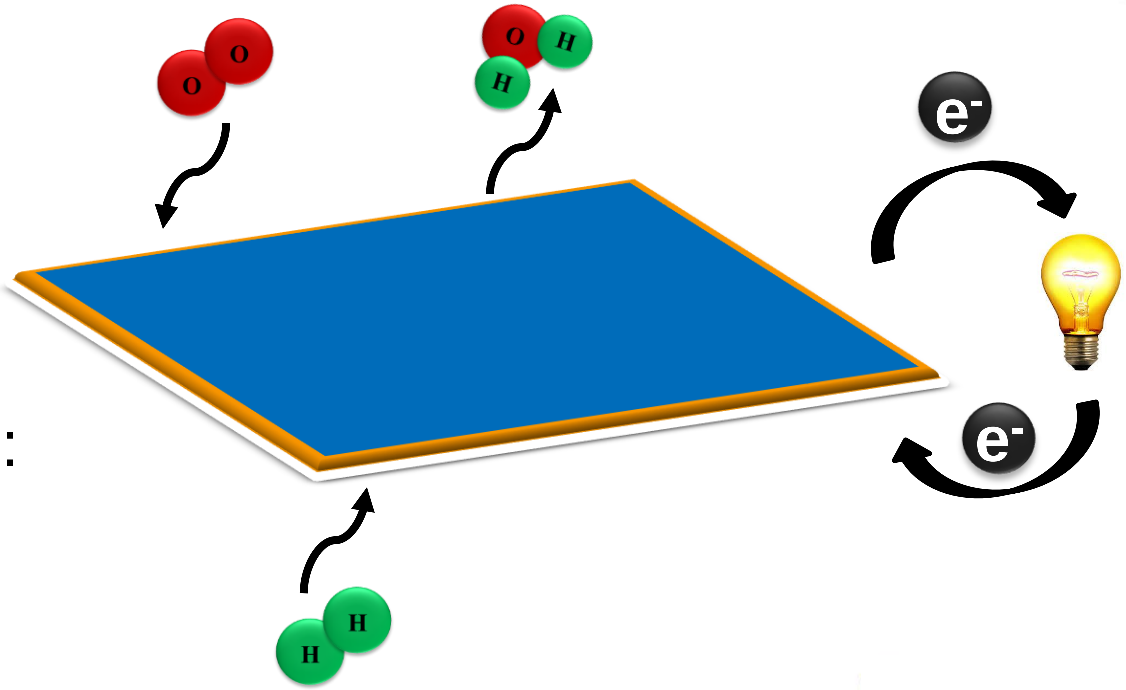
Batteries

-Lithium Batteries

-Other batteries: Metal-air batteries

What is a Solid Oxide Fuel Cell?

Type of fuel cell → Devices that converts a fuel into electricty through a chemical reaction

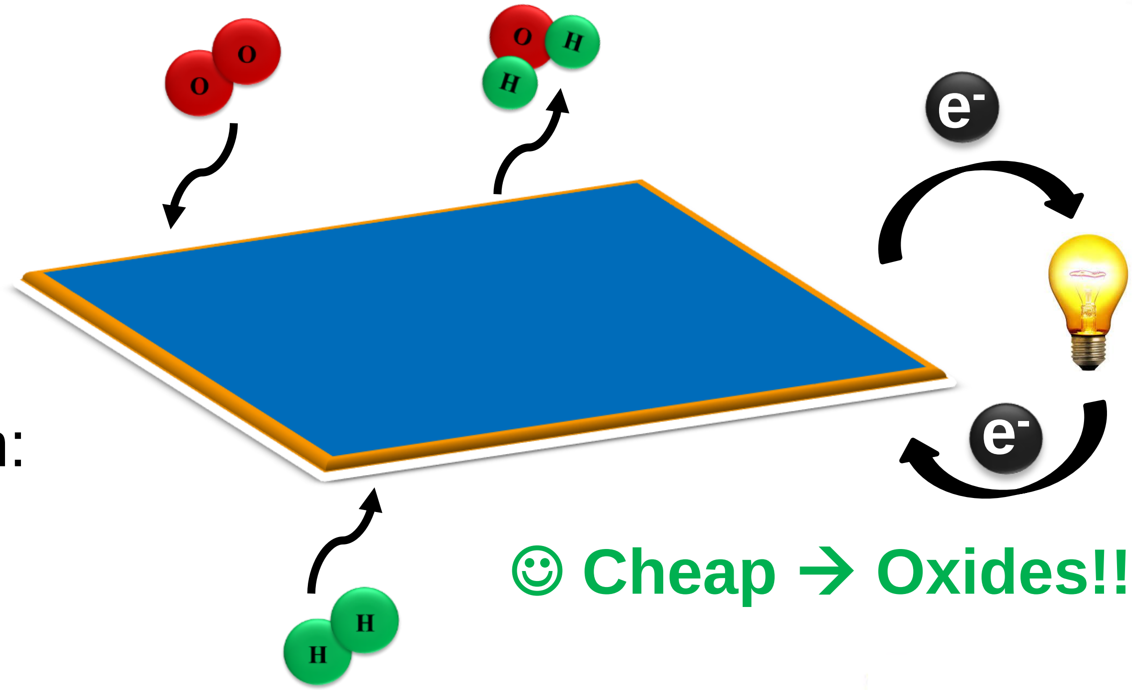


Chemical reaction:

$H_2 + ½ O_2 \rightarrow H_2O$

What is a Solid Oxide Fuel Cell?

Type of fuel cell → Devices that converts a fuel into electricty through a chemical reaction



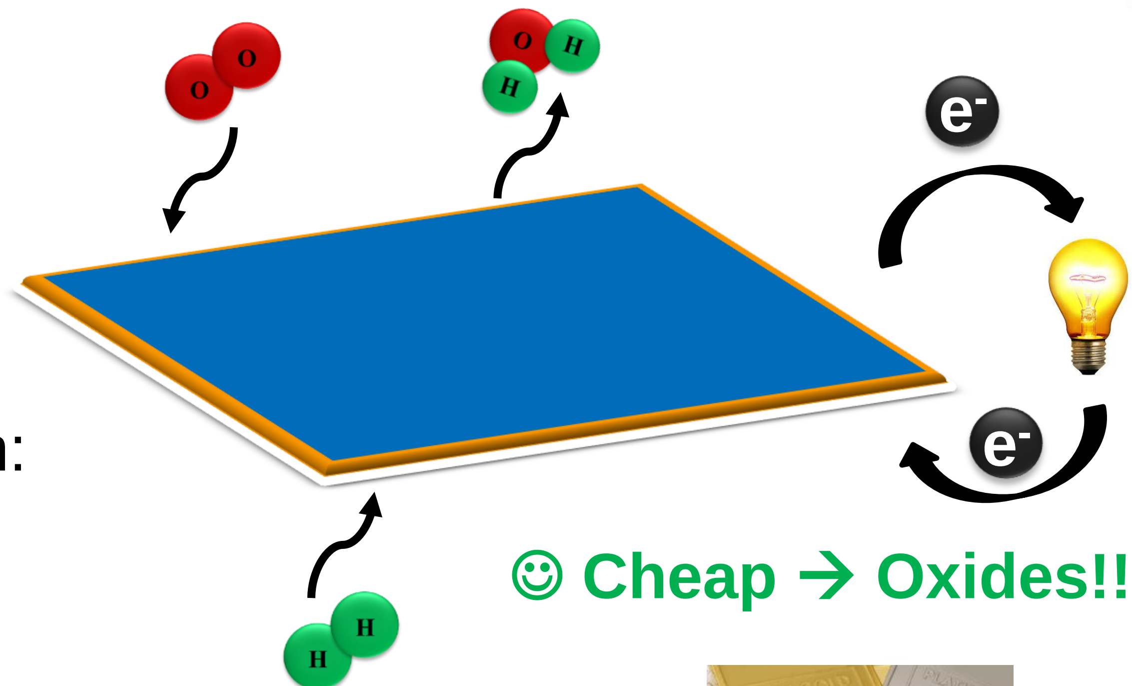
Chemical reaction:

$H_2 + ½\, O_2 \rightarrow H_2O$

☺ **Cheap → Oxides!!**

What is a Solid Oxide Fuel Cell?

Type of fuel cell → Devices that converts a fuel into electricty through a chemical reaction



Chemical reaction:

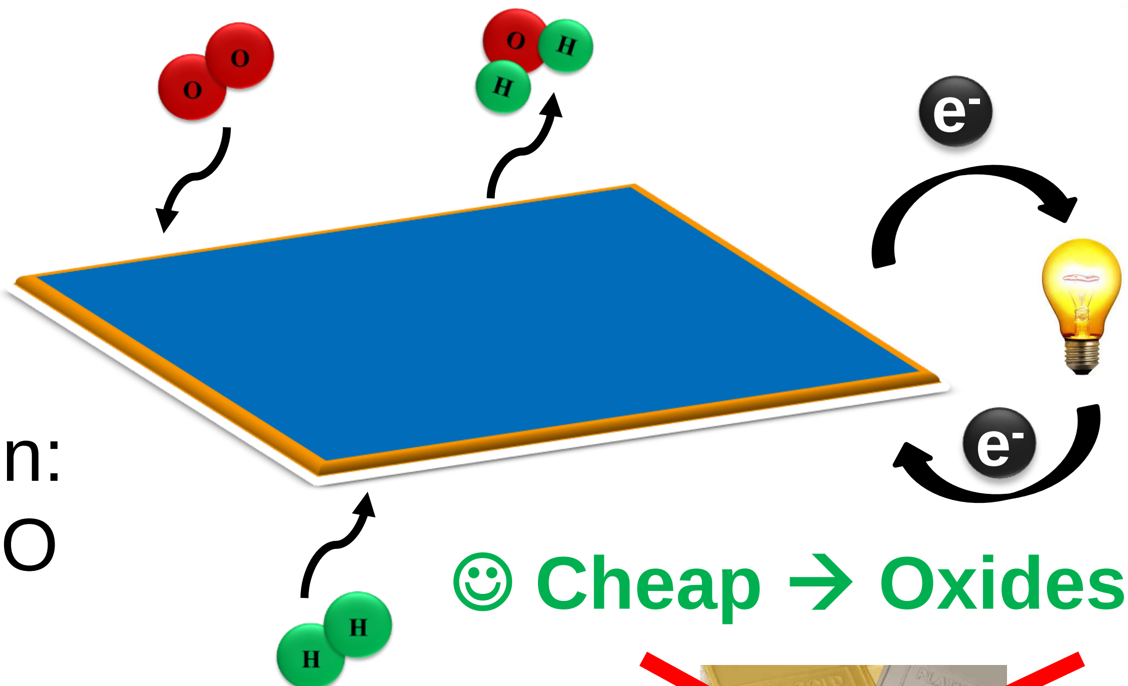
$H_2 + ½\ O_2 \rightarrow H_2O$

☺ **Cheap → Oxides!!**

Low temperature Fuel Cell uses nobel metals

What is a Solid Oxide Fuel Cell?

Type of fuel cell → Devices that converts a fuel into electricty through a chemical reaction



Chemical reaction:

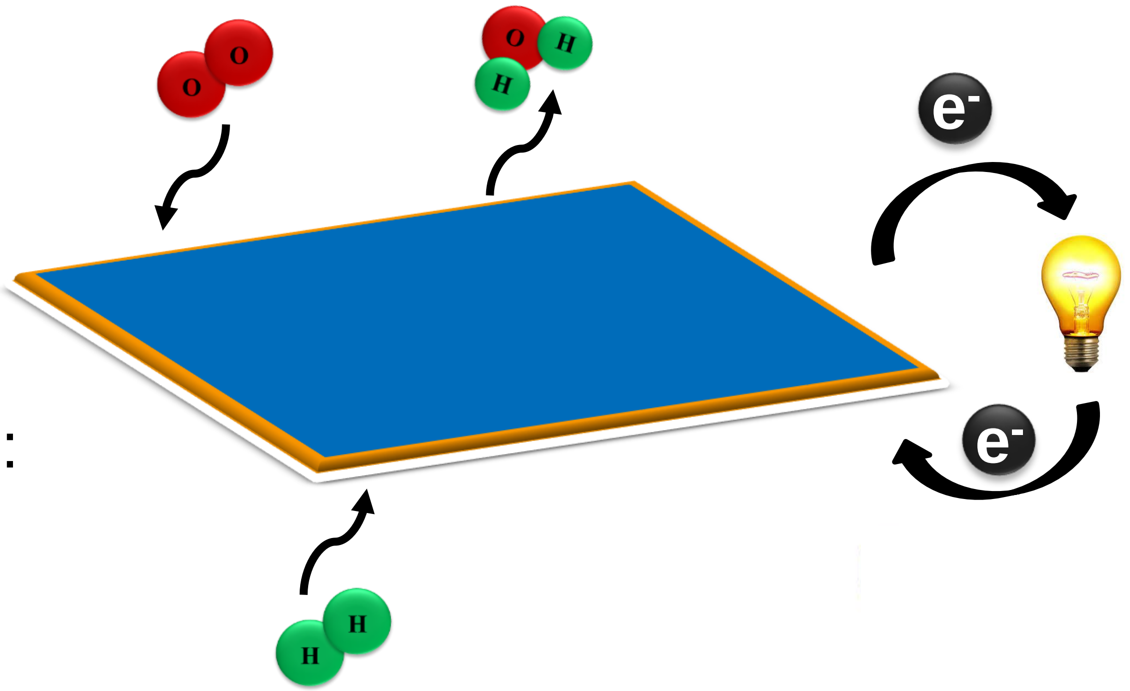
$H_2 + \frac{1}{2} O_2 \rightarrow H_2O$

☺ Cheap → Oxides!!

Low temperature Fuel Cell uses nobel metals

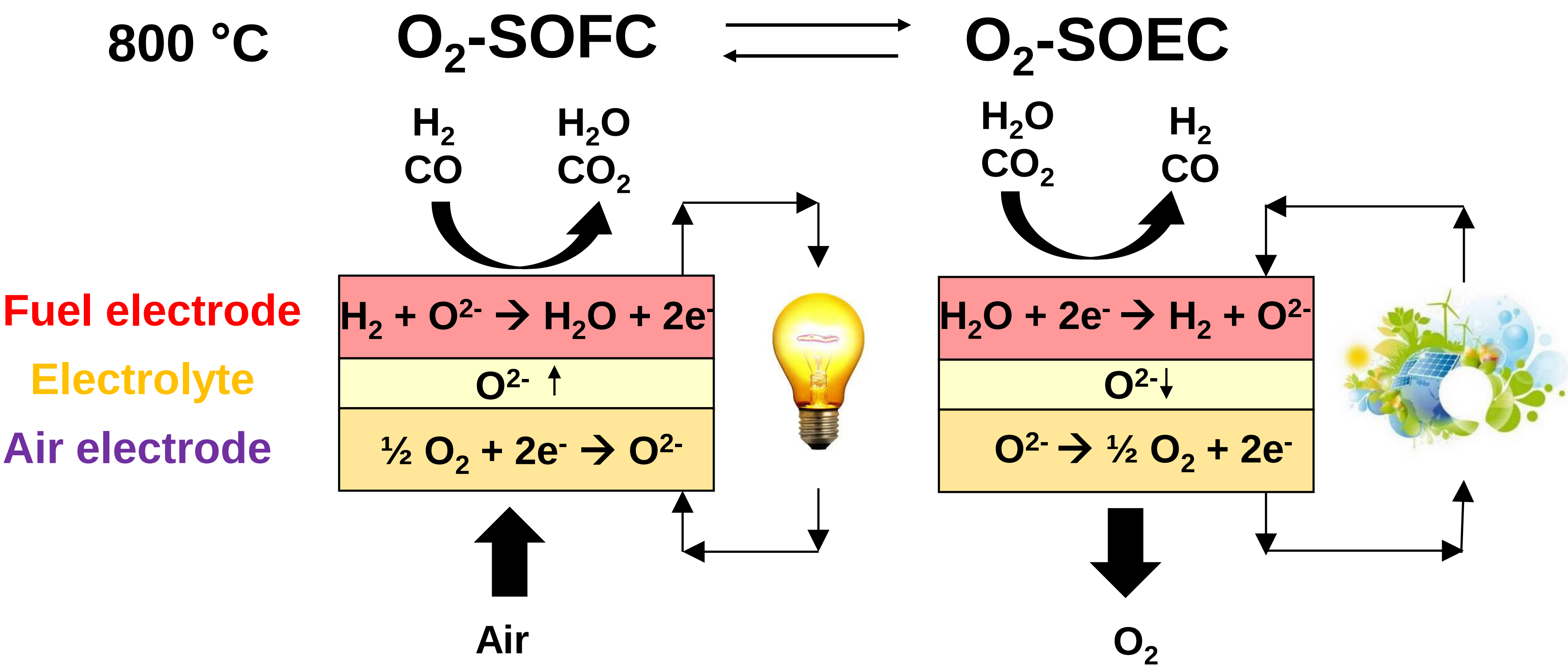
What is a Solid Oxide Fuel Cell?

Two main types depending of the electrolyte:
O^{2-}-SOFC: Electrolyte conducting O^{2-}
H^{+}-SOFC: Electrolyte conducting H^{+}

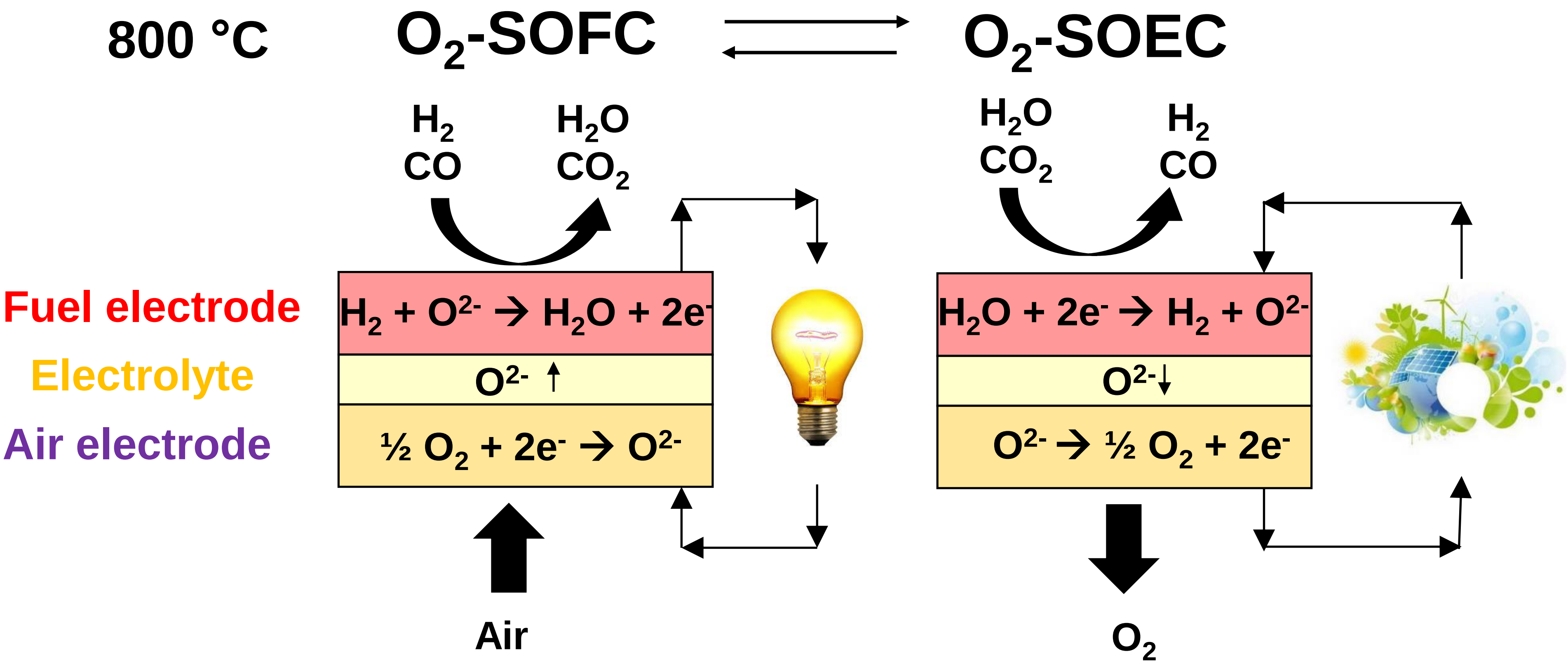


Chemical reaction:
$H_2 + \frac{1}{2} O_2 \rightarrow H_2O$

O_2-Solid Oxide Fuel/Electrolysis Cell



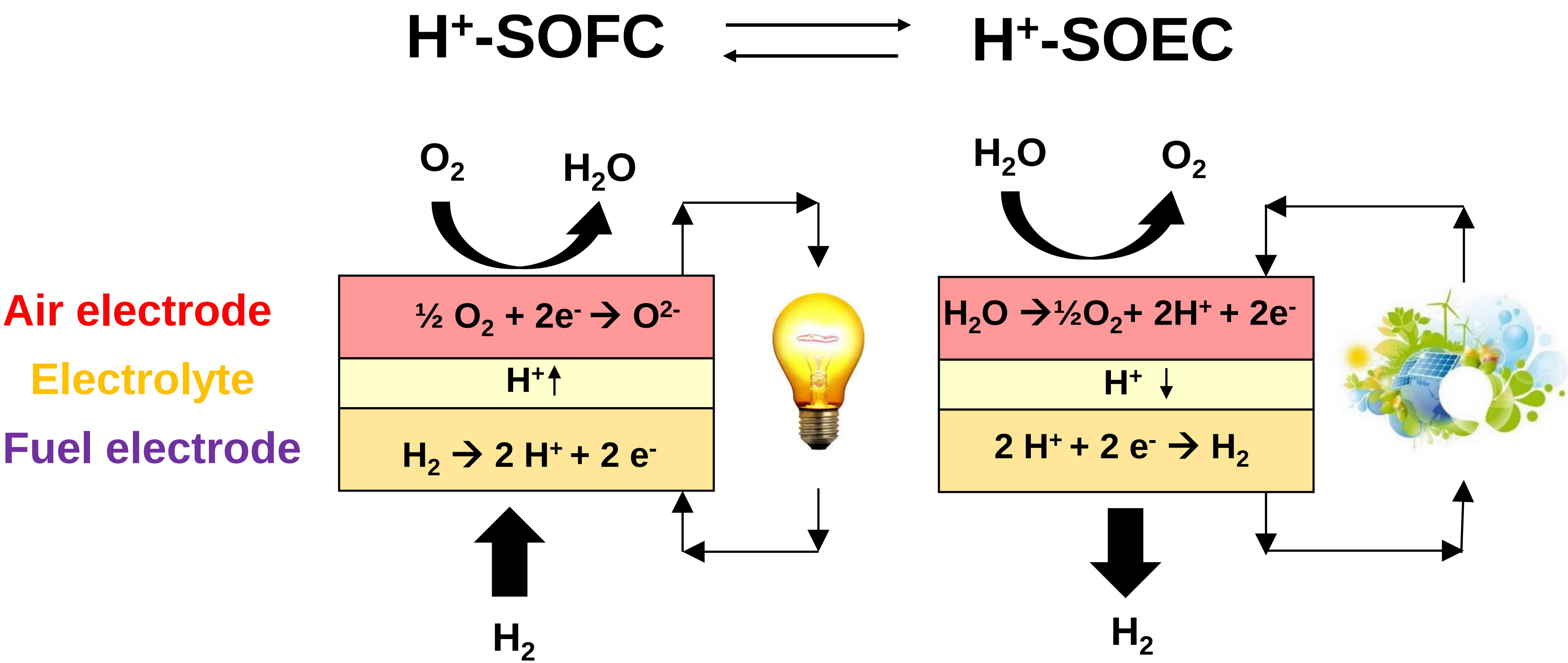
O_2-Solid Oxide Fuel/Electrolysis Cell



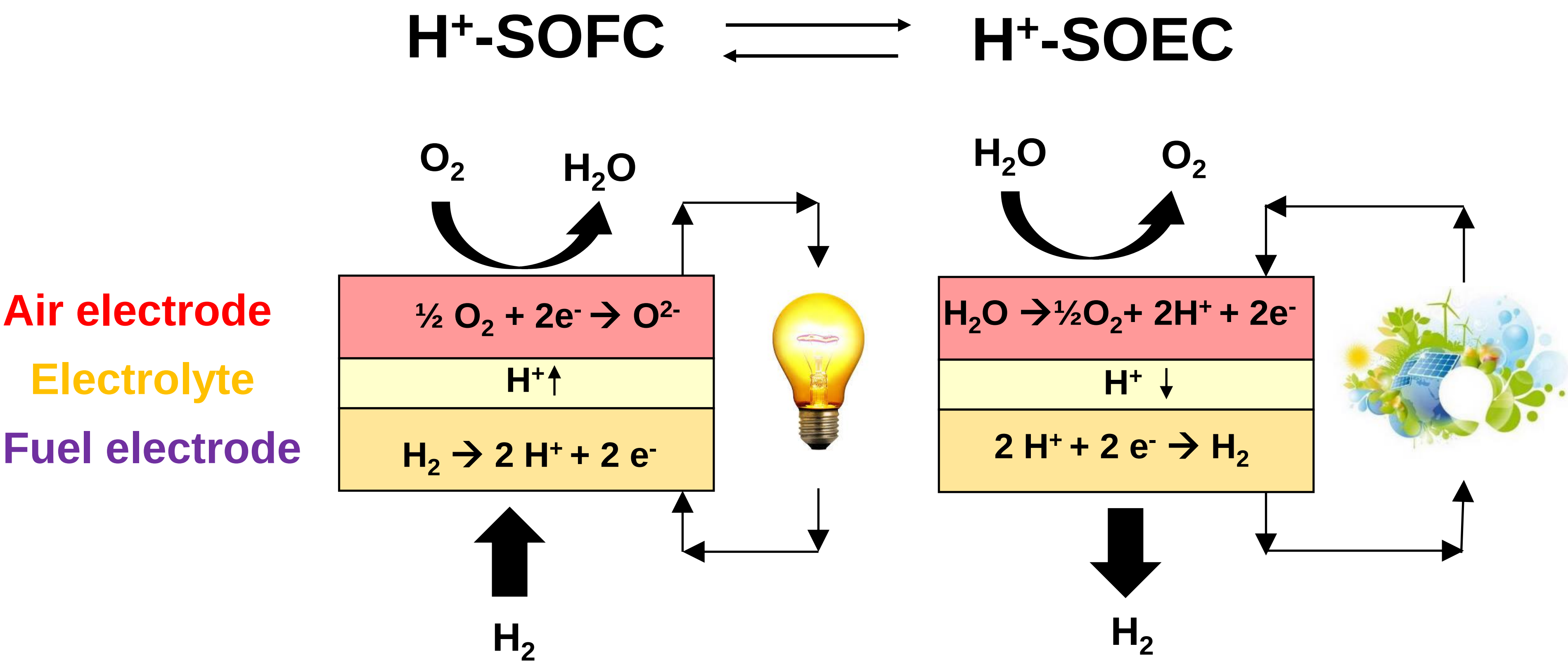
Main challenge:
- **Lower operation temperature** while keeping **high performance**

Alternative H^+-SOC technology

H^+-Solid Oxide Fuel/Electrolysis Cell



H⁺-Solid Oxide Fuel/Electrolysis Cell

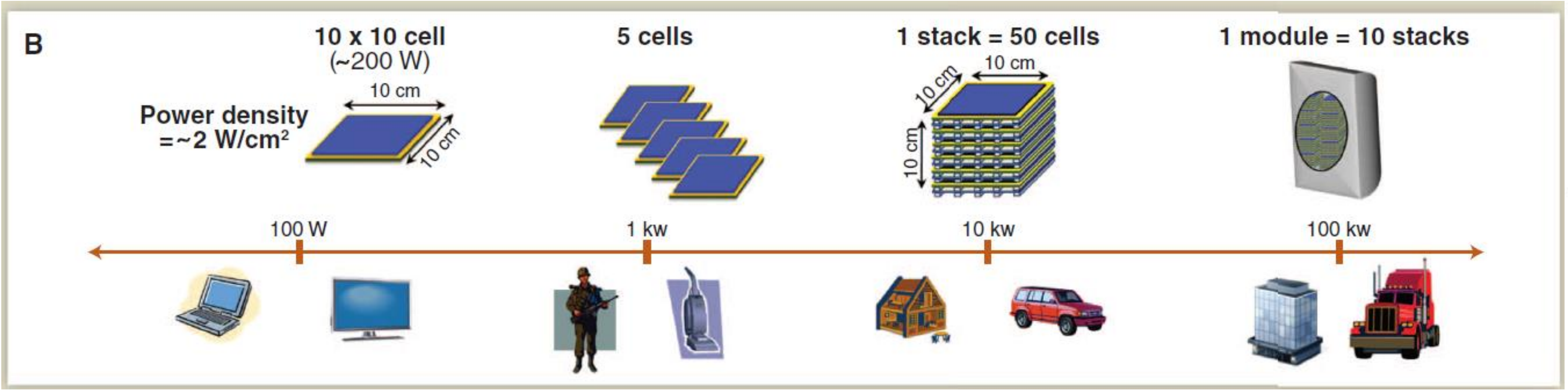


- Lower temperature operation (400-600 ^{o}C).
- Avoid fuel dilution.

→Poor cathode materials → Use mixed O^{2-}/e^{-} conductors without H^+ conduction

Applications

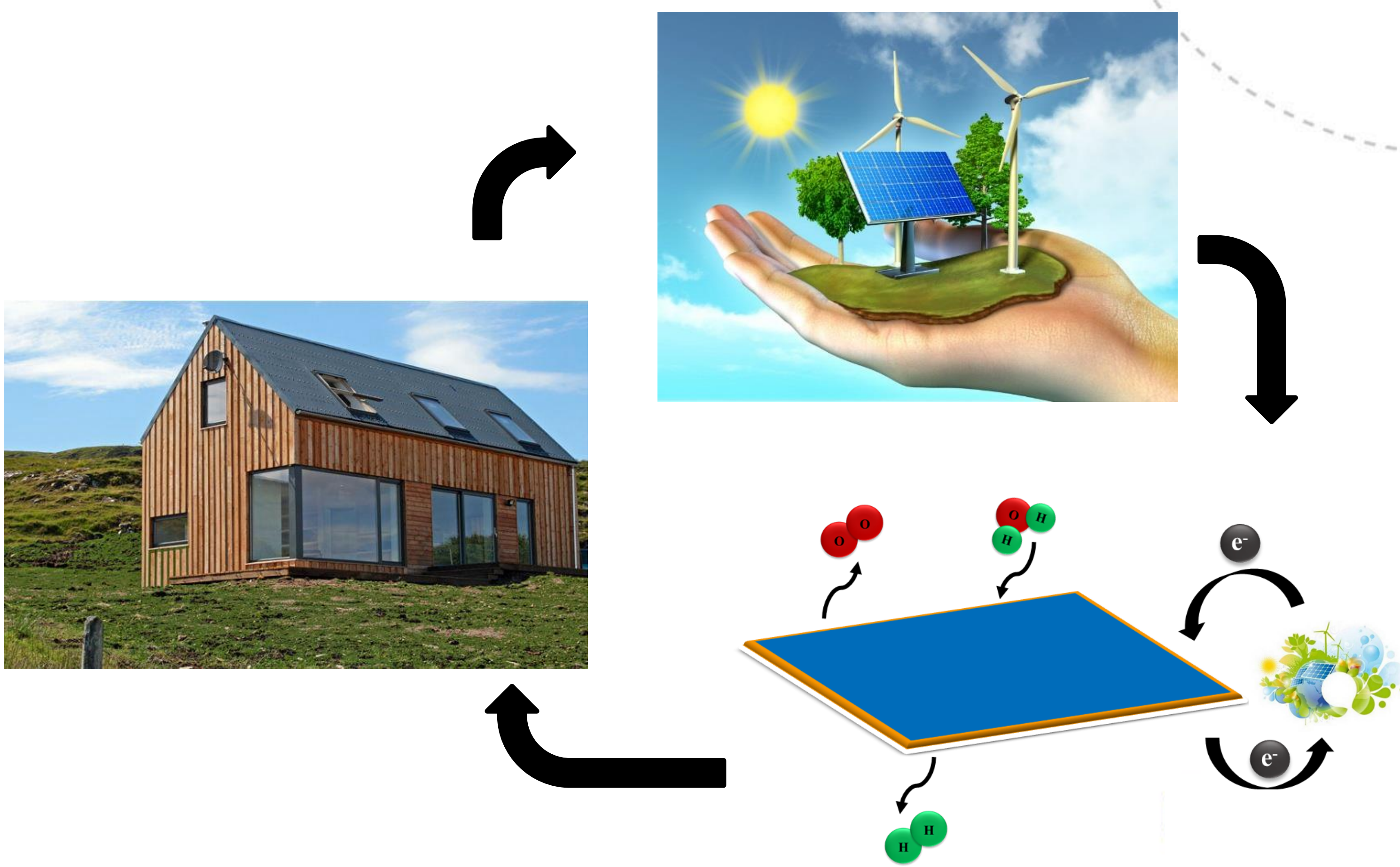
Stationary energy → Energy to power a house



http://science.sciencemag.org/content/334/6058/935

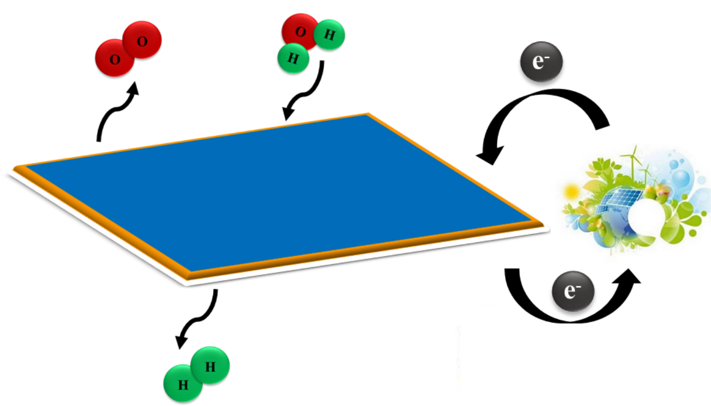
Applications

Stationary energy → Energy to power a house



Applications

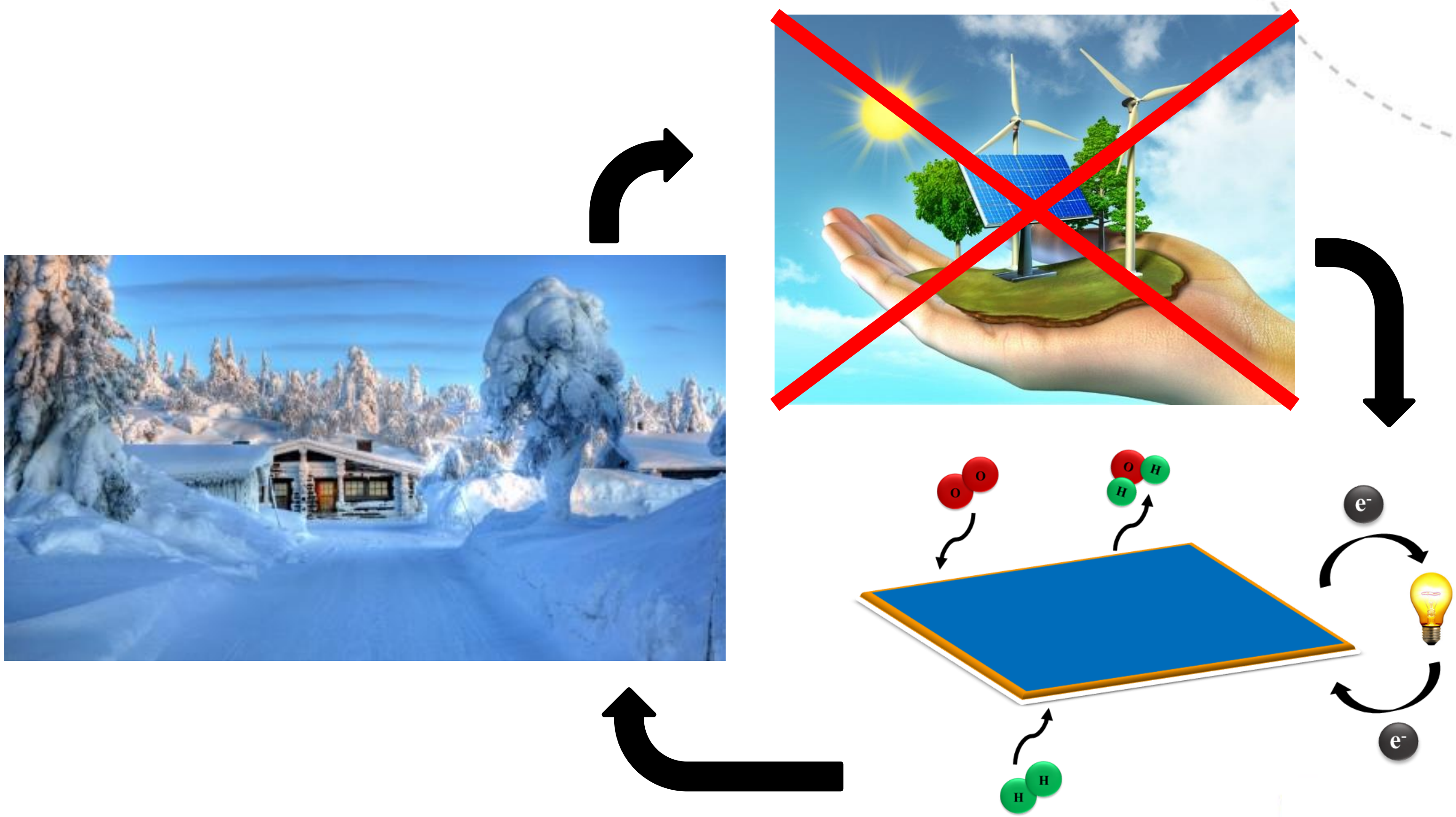
Stationary energy → Energy to power a house



Fuel production with excess energy

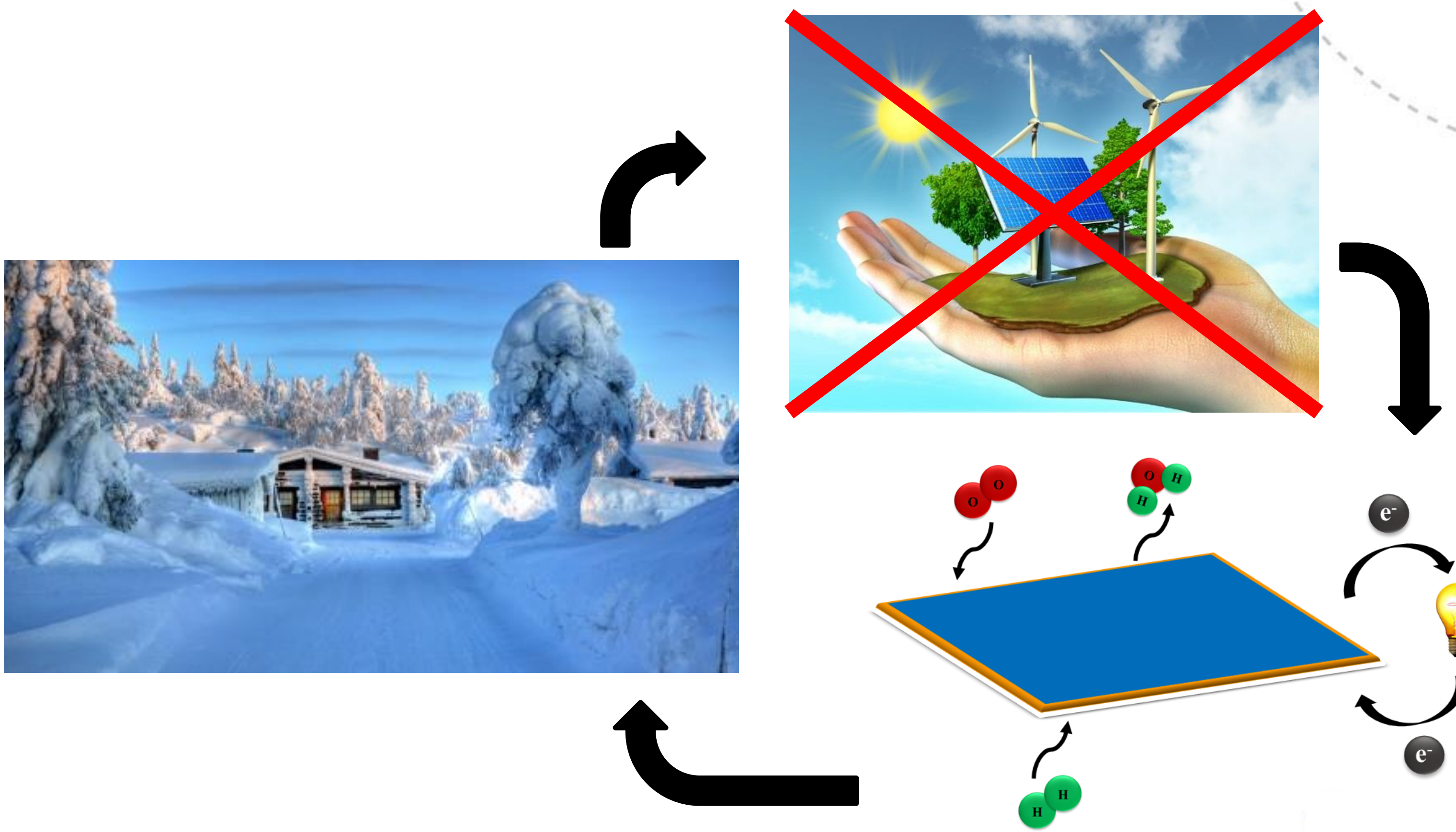
Applications

Stationary energy → Energy to power a house



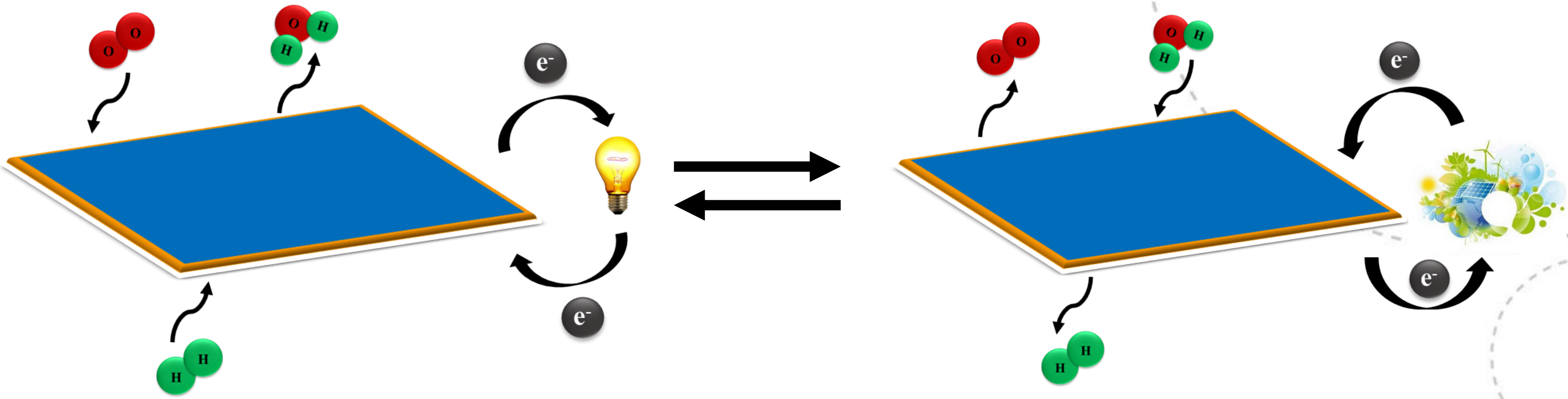
Applications

Stationary energy → Energy to power a house

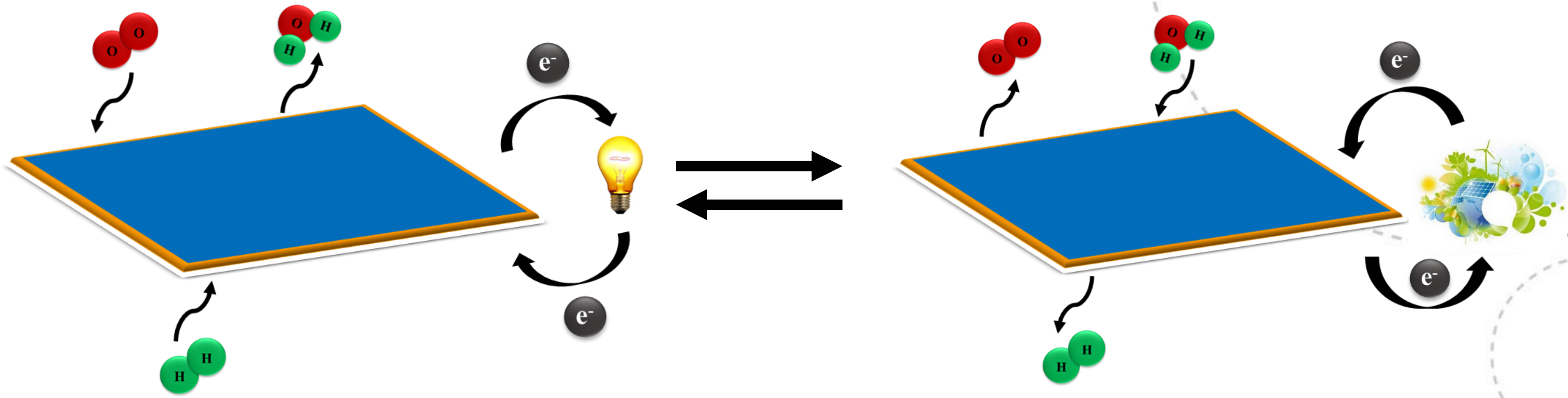


Use of fuel to generate electricity

Research challenges

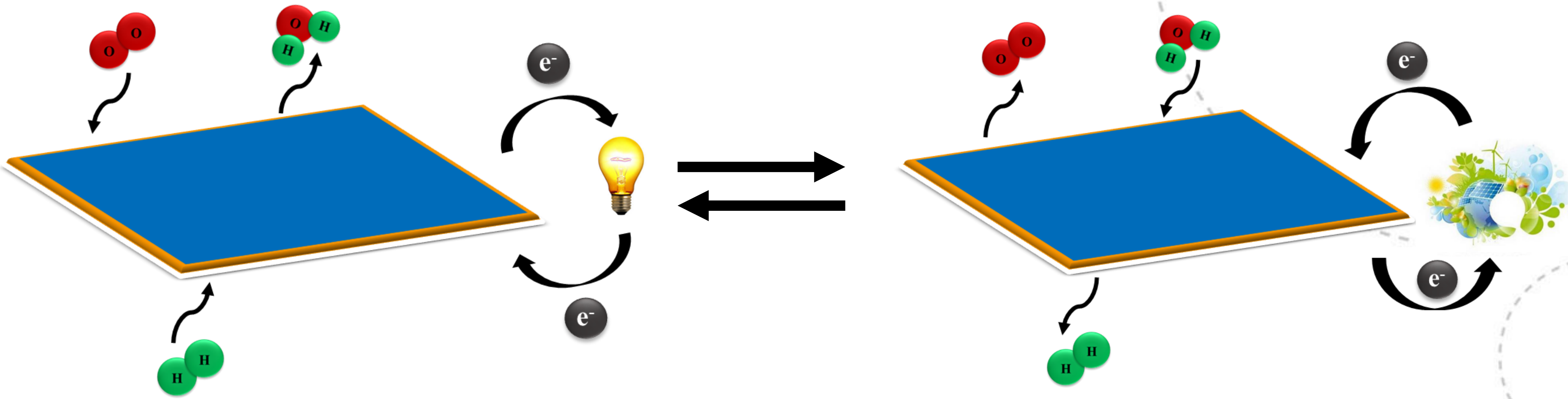


Research challenges



Materials operates at high temperature (> 600 ^{o}C)

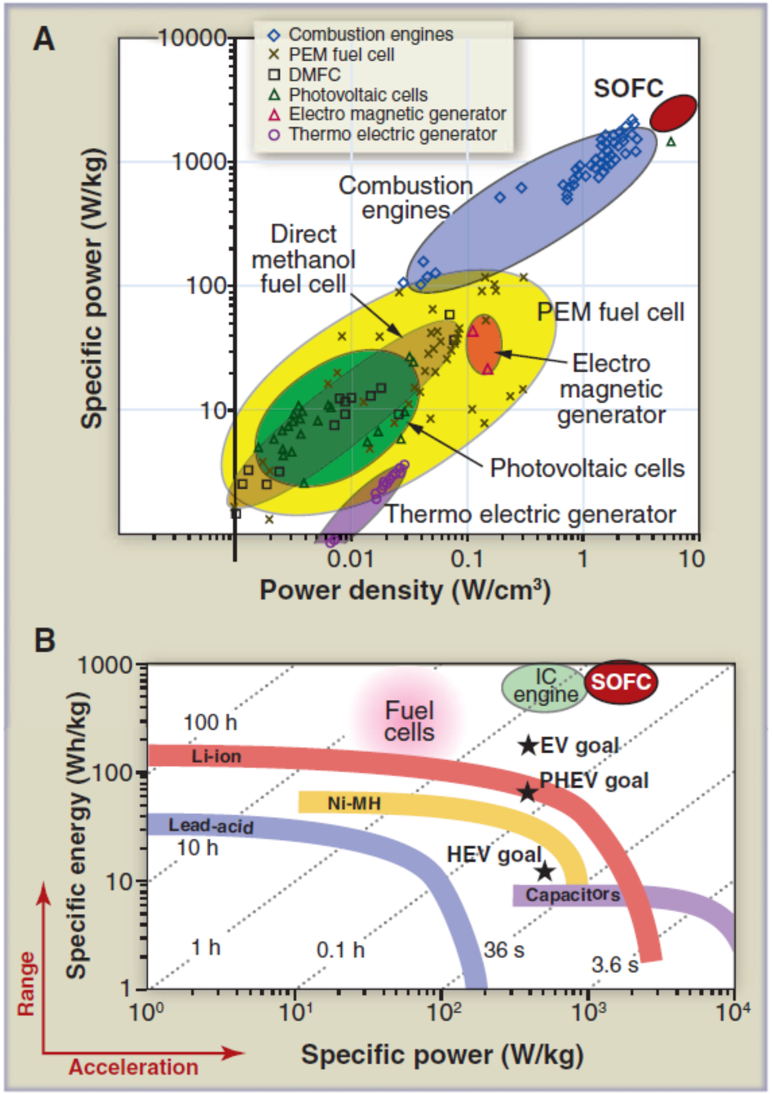
Research challenges



Materials operates at high temperature (> 600 ^oC)

Need to obtain novel materials with higher performance → Nanomaterials

Comparison



Very promising technology

Journal of Power Sources 196 (2011) 4396–4403

Contents lists available at ScienceDirect

Journal of Power Sources

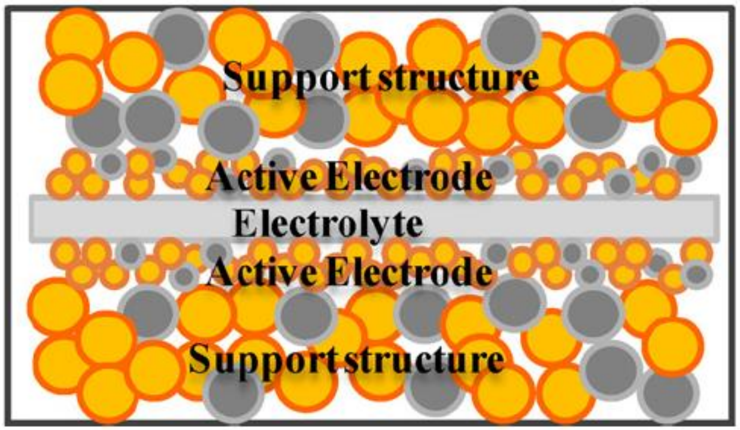
journal homepage: www.elsevier.com/locate/jpowsour

Electrochemical characterisation of solid oxide cell electrodes for hydrogen production

Carlos Bernuy-Lopez*, Ruth Knibbe, Zeming He, Xiaojian Mao, Anne Hauch, Karsten A. Nielsen

Fuel Cells and Solid State Chemistry Division, Risø National Laboratory for Sustainable Energy, Technical University of Denmark, 4000 Roskilde, Denmark

(a)

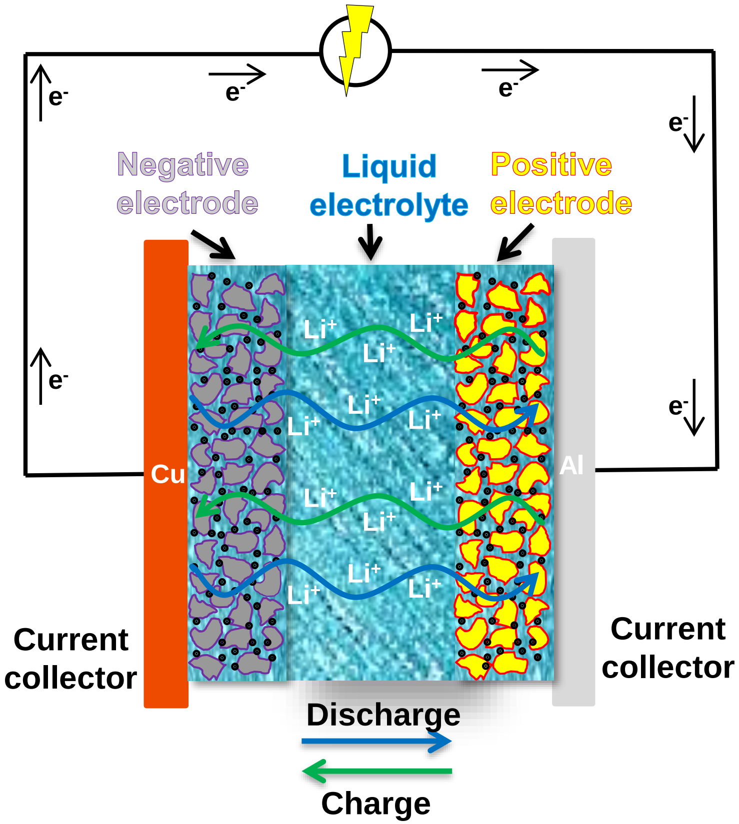


(b)

Fig. 1. Schematic of the symmetric cell configuration for the (a) oxygen electrode and (b) steam electrode cells.

Batteries

Current LIB



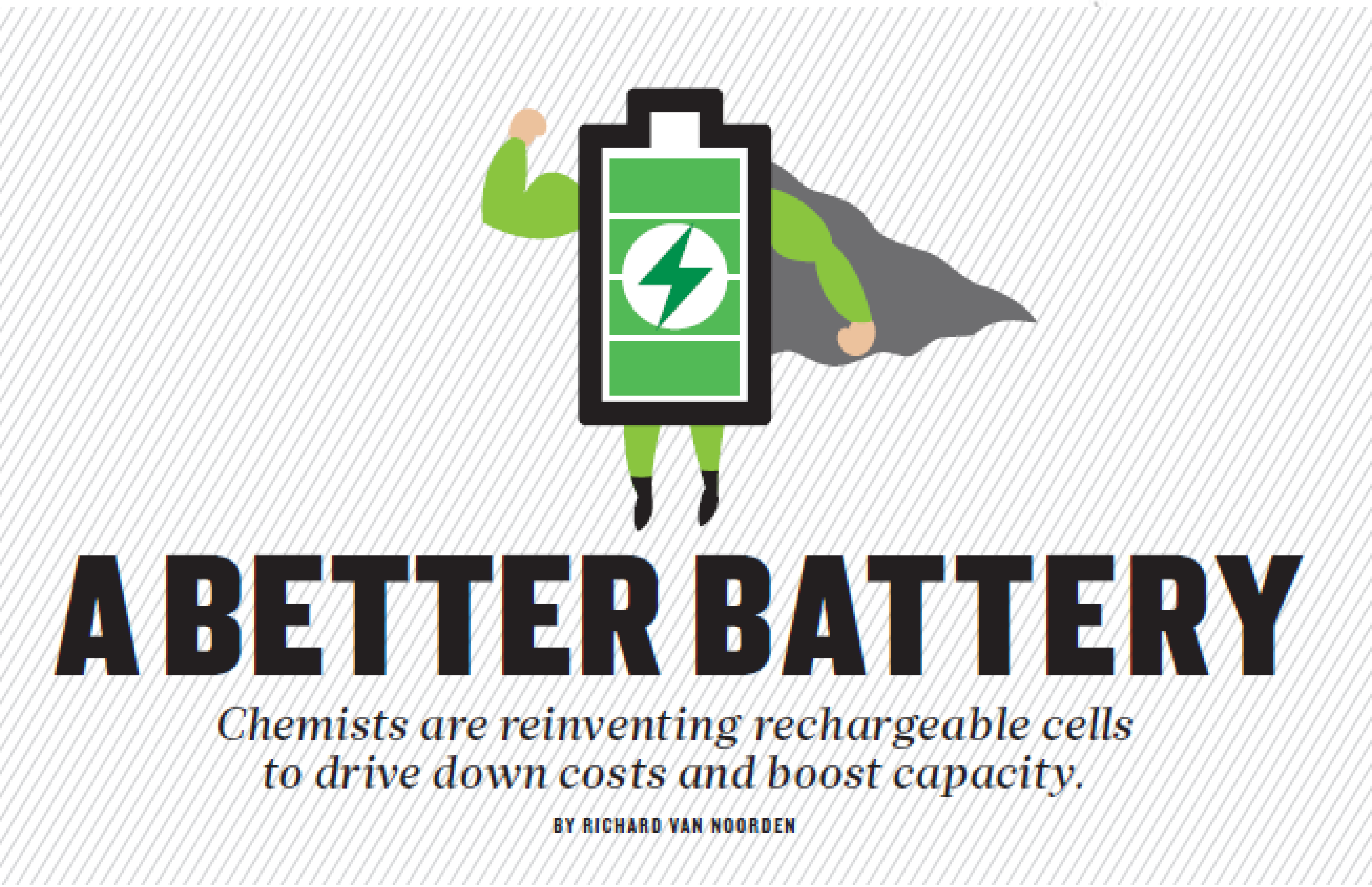
Liquid electrolyte limitations:

-**Safety**: flammable organic components

-**Performance**: limited stability window

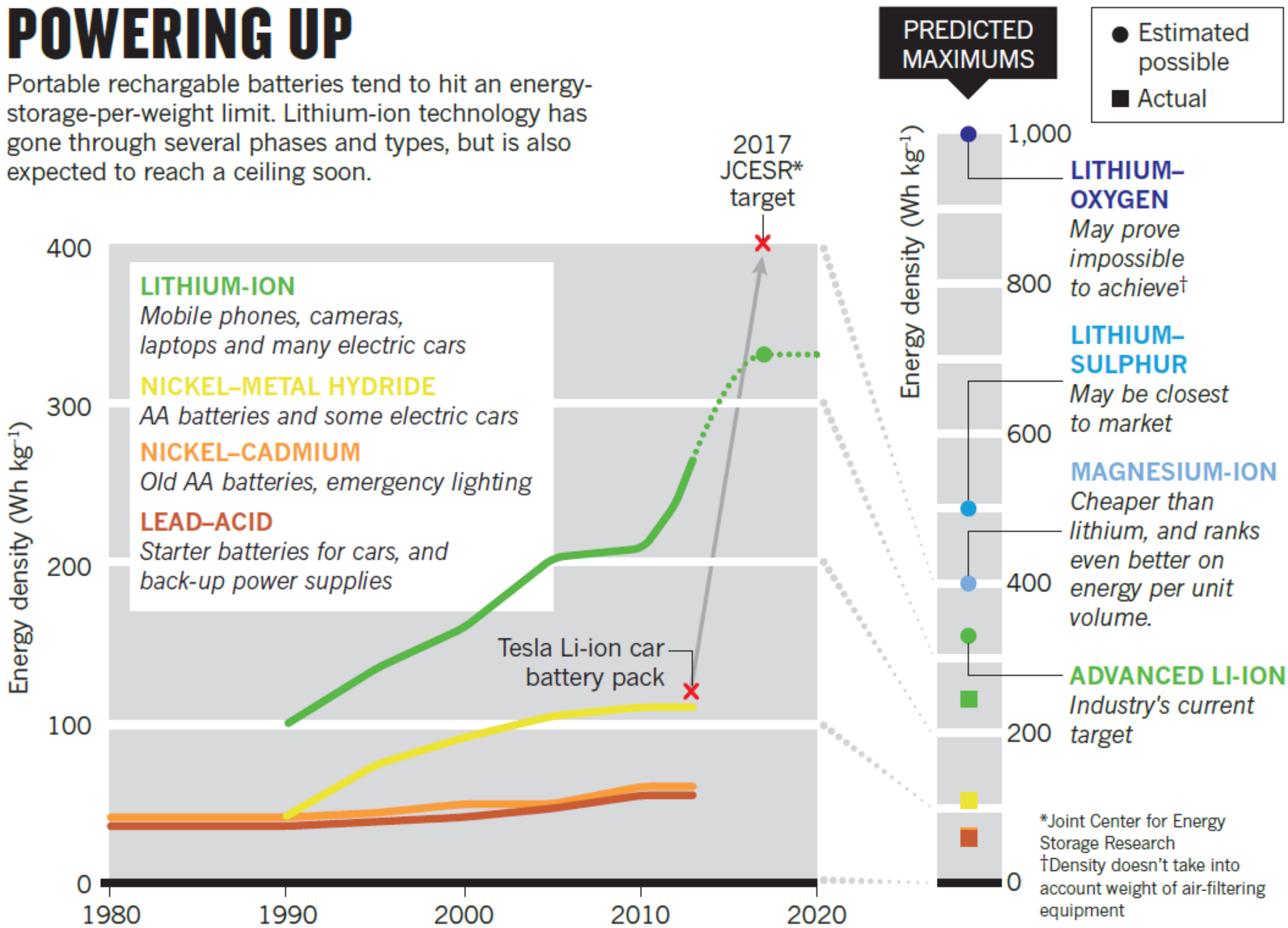
-**Cost**: Expensive and polluting materials

Batteries



http://www.nature.com/news/the-rechargeable-revolution-a-better-battery-1.14815

Batteries



http://www.nature.com/news/the-rechargeable-revolution-a-better-battery-1.14815

Batteries

Nanomaterials for Rechargeable Lithium Batteries**

Peter G. Bruce, Bruno Scrosati, and Jean-Marie Tarascon*

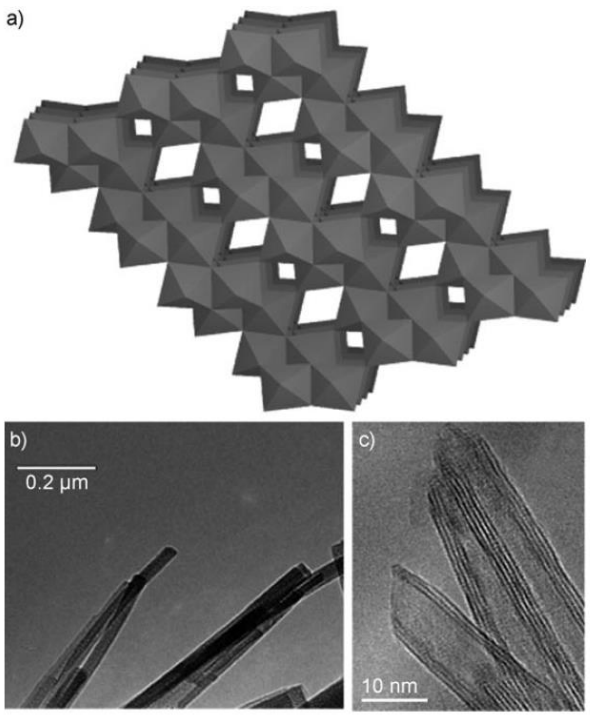


Figure 4. a) Crystal structure of TiO_2-B, TEM images of TiO_2-B b) nanowires and c) nanotubes.

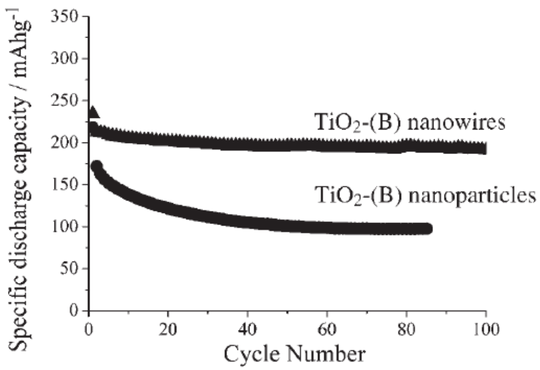


Figure 5. Charge (lithium) stored in the intercalation hosts, TiO_2-B nanowires and nanoparticles, on cycling (intercalation/deintercalation) at a rate of 50 mAg^{-1} (ca. *C*/4). The size of the nanoparticles is the same as the diameter of the nanowires.

http://onlinelibrary.wiley.com/doi/10.1002/anie.200702505/abstract

Batteries

Nanomaterials for Rechargeable Lithium Batteries**

Peter G. Bruce, Bruno Scrosati, and Jean-Marie Tarascon*

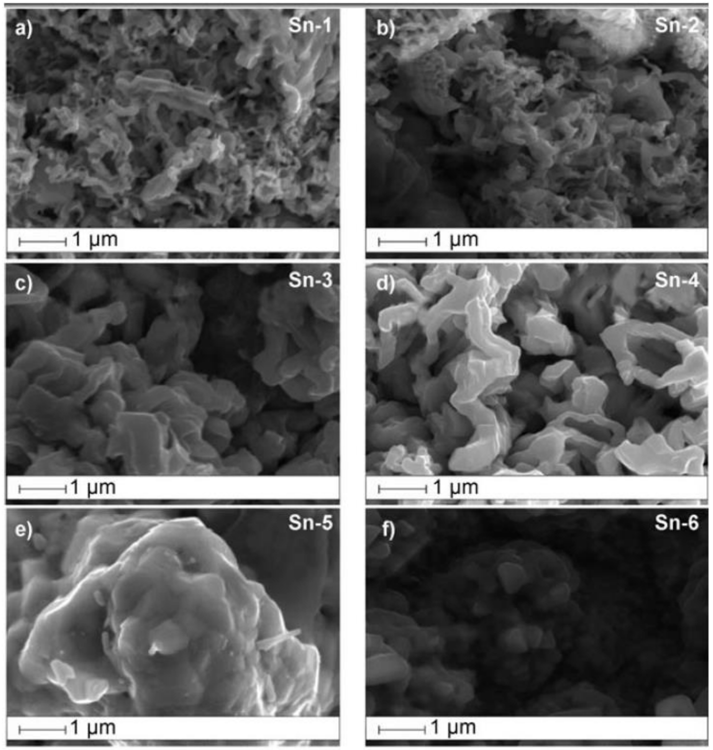


Figure 7. Scanning electron microscopy (SEM) images of various tin samples prepared under different electrodeposition conditions a) 0.5 $mA\,cm^{-2}$; 60 min; b) 1.0 $mA\,cm^{-2}$; 30 min; c) 2.0 $mA\,cm^{-2}$; 15 min; d) 3.0 $mA\,cm^{-2}$; 10 min ; e) 6.0 $mA\,cm^{-2}$; 5 min; f) 15 $mA\,cm^{-2}$; 2 min.

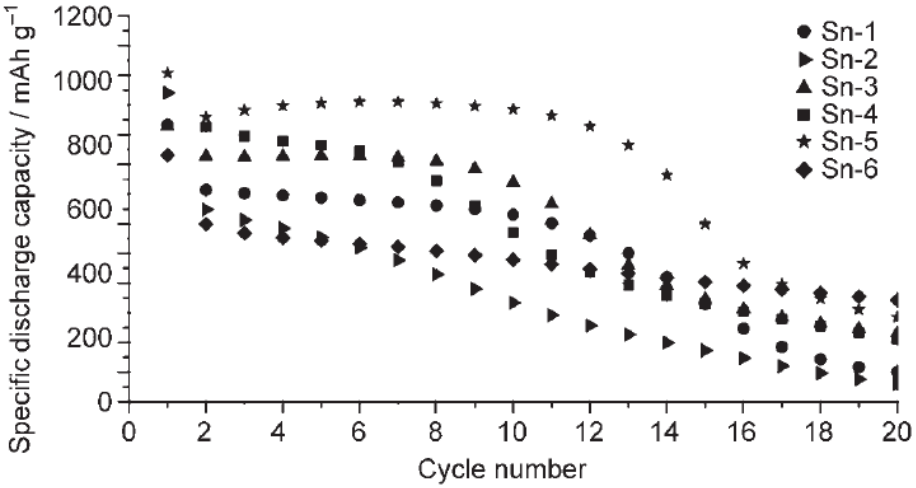


Figure 8. Specific discharge capacity versus cycle number for lithium cells using samples Sn-1, Sn-2, Sn-3, Sn-4, Sn-5, and Sn-6 (see Figure 7.), respectively, in EC:DMC 1:1 $LiPF_6$ electrolyte. Charge–discharge current density: 1 $A\,cm^{-2}\,g^{-1}$, rate: ca. 0.8 C. For the identification of the samples, see Figure 7.

Batteries

Nanomaterials for Rechargeable Lithium Batteries**

Peter G. Bruce, Bruno Scrosati, and Jean-Marie Tarascon*

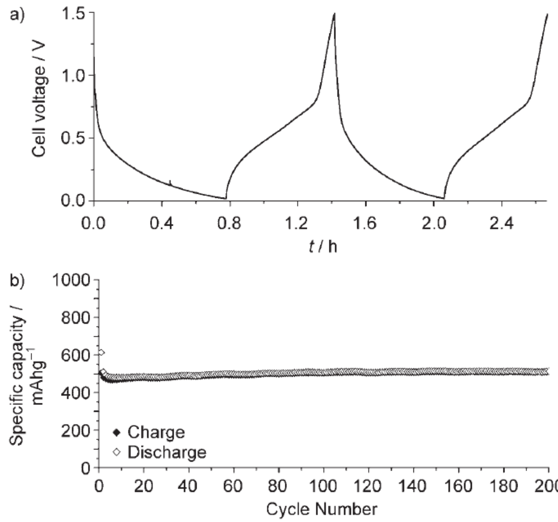


Figure 10. a) Voltage profiles of the first two cycles and b) capacity delivered upon cycling of nanostructured Ni_3Sn_4 used as the electrode in a lithium cell.

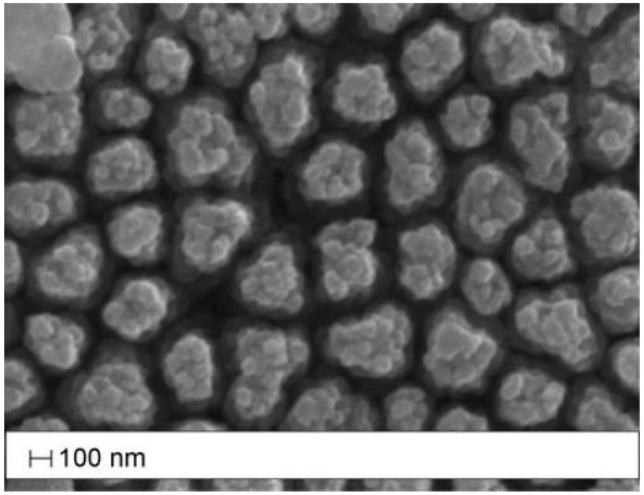


Figure 9. SEM image showing a top view of Ni_3Sn_4 electrodeposited on a copper–nanorod current collector.

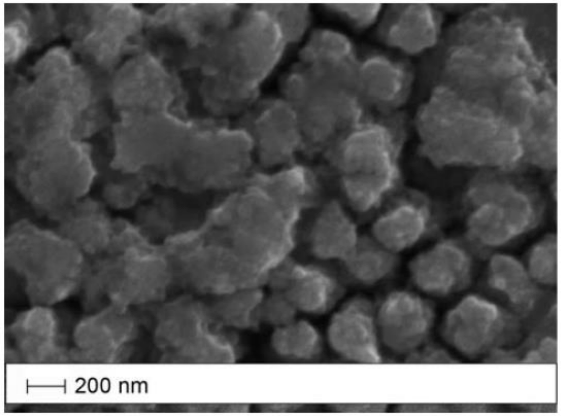
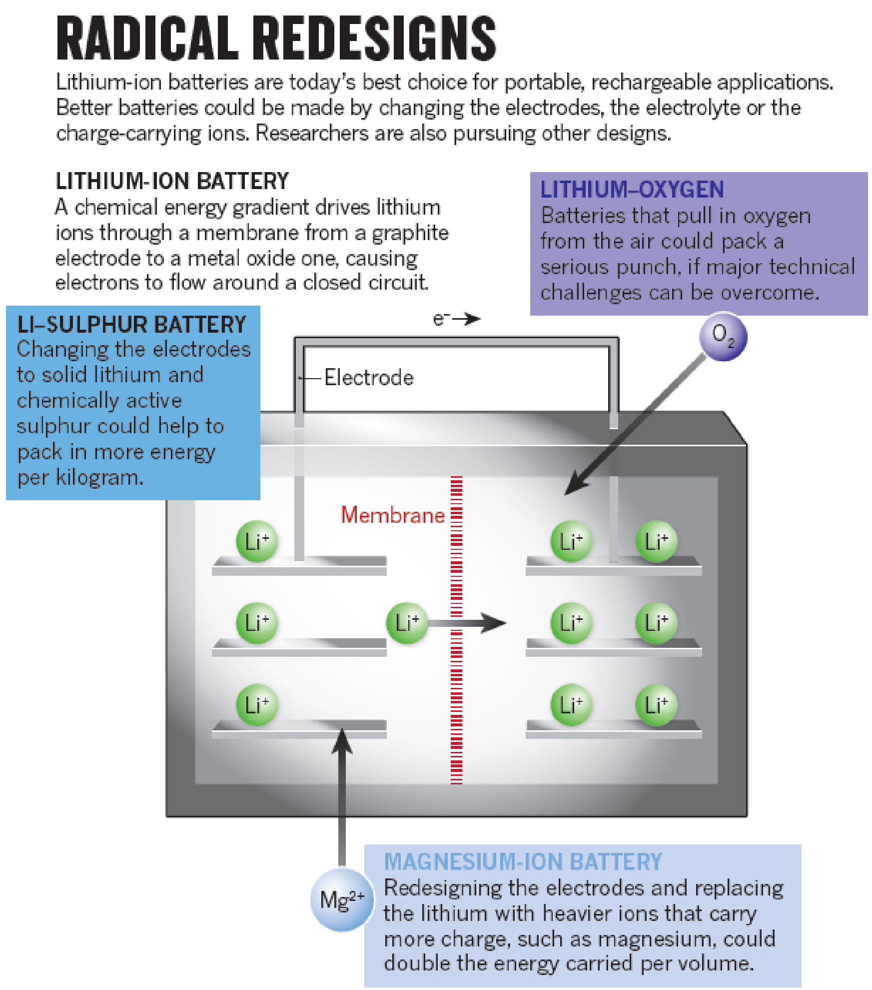


Figure 11. SEM image of the top view of the nanostructured Ni_3Sn_4 electrode after cycling as shown in Figure 10. No evidence of any appreciable change in the morphology is apparent (compare Figure 9). From reference [26].

Batteries



http://www.nature.com/news/the-rechargeable-revolution-a-better-battery-1.14815

Batteries

-Other batteries: High temperature Metal-air battery

Electrochimica Acta 214 (2016) 192–200

ELSEVIER

Contents lists available at ScienceDirect

Electrochimica Acta

journal homepage: www.elsevier.com/locate/electacta

Performance and long term stability of a liquid-tin anode metal-air solid electrolyte battery prototype

CrossMark

L. Otaegui[a,*], I. Laresgoiti[b,1], C. Bernuy-López[a,2], N. Gómez[a], M.A. Alvarez[b], L. Wang[a,3], T. Rojo[a,c], L.M. Rodriguez-Martinez[a]

[a] CIC Energigune, Parque Tecnológico de Álava, Albert Einstein 48, ED. CIC, 01510 Miñano (Álava), Spain
[b] IK4-Ikerlan, Energy Business Unit, Juan de la Cierva 1, 01510 Miñano (Álava), Spain
[c] Departamento de Química Inorgánica, Universidad del País Vasco UPV/EHU, P.O. Box. 644, Bilbao (Vizcaya), Spain

Batteries

Electrochimica Acta 214 (2016) 192–200
Contents lists available at ScienceDirect
Electrochimica Acta
journal homepage: www.elsevier.com/locate/electacta

Performance and long term stability of a liquid-tin anode metal-air solid electrolyte battery prototype

L. Otaegui[a,*], I. Laresgoiti[b,1], C. Bernuy-López[a,2], N. Gómez[a], M.A. Alvarez[b], L. Wang[a,3], T. Rojo[a,c], L.M. Rodriguez-Martinez[a]

[a] CIC Energigune, Parque Tecnológico de Álava, Albert Einstein 48, ED. CIC, 01510 Miñano (Álava), Spain
[b] IK4-Ikerlan, Energy Business Unit, Juan de la Cierva 1, 01510 Miñano (Álava), Spain
[c] Departamento de Química Inorgánica, Universidad del País Vasco UPV/EHU, P.O. Box. 644, Bilbao (Vizcaya), Spain

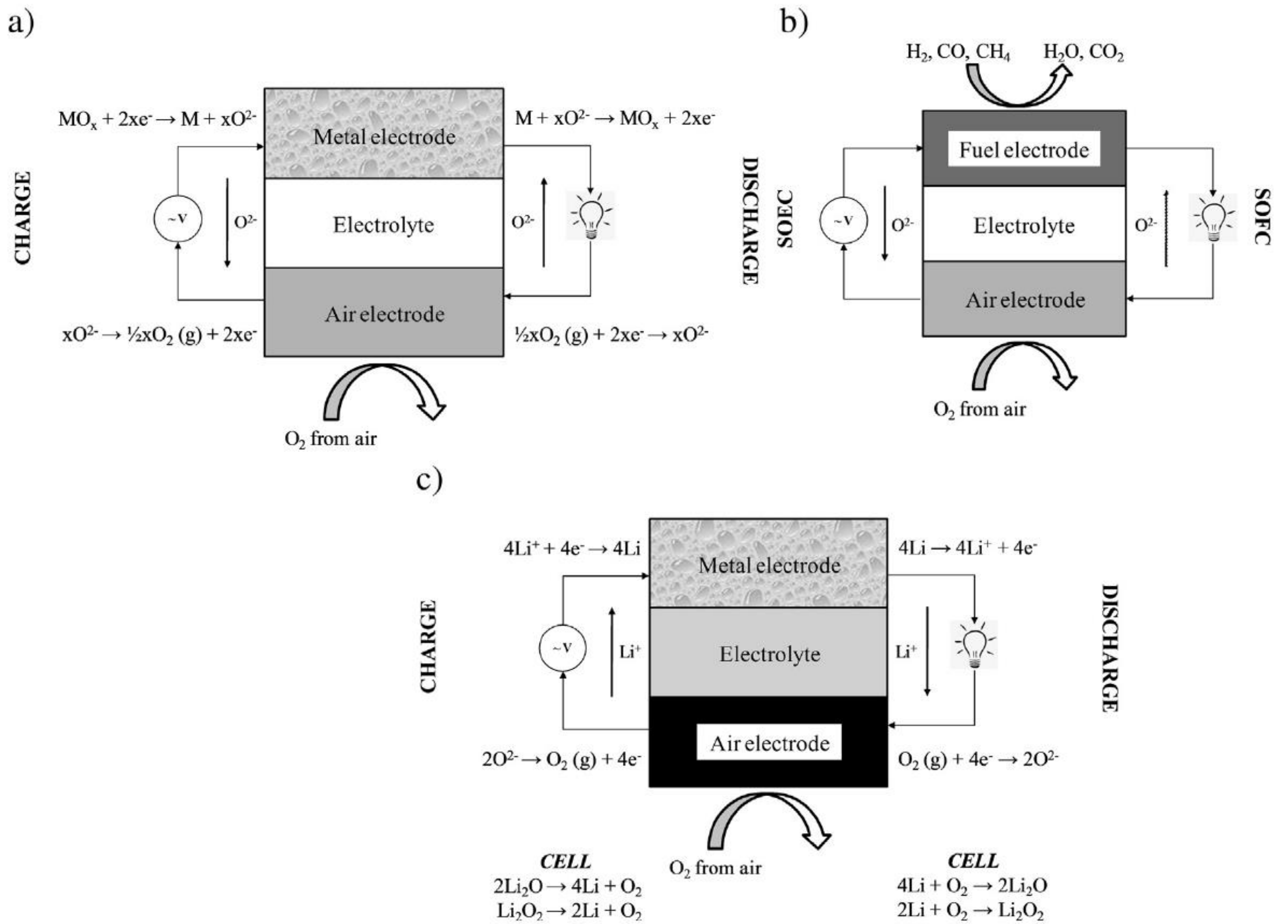


Fig. 1. (a) Electrochemical reactions in HTMABs, (b) SOFCs and (c) lithium–air batteries.

Batteries

Electrochimica Acta 214 (2016) 192–200

Contents lists available at ScienceDirect

Electrochimica Acta

journal homepage: www.elsevier.com/locate/electacta

Performance and long term stability of a liquid-tin anode metal-air solid electrolyte battery prototype

L. Otaegui[a,*], I. Laresgoiti[b,1], C. Bernuy-López[a,2], N. Gómez[a], M.A. Alvarez[b], L. Wang[a,3], T. Rojo[a,c], L.M. Rodriguez-Martinez[a]

[a] CIC Energigune, Parque Tecnológico de Álava, Albert Einstein 48, ED. CIC, 01510 Miñano (Álava), Spain
[b] IK4-Ikerlan, Energy Business Unit, Juan de la Cierva 1, 01510 Miñano (Álava), Spain
[c] Departamento de Química Inorgánica, Universidad del País Vasco UPV/EHU, P.O. Box. 644, Bilbao (Vizcaya), Spain

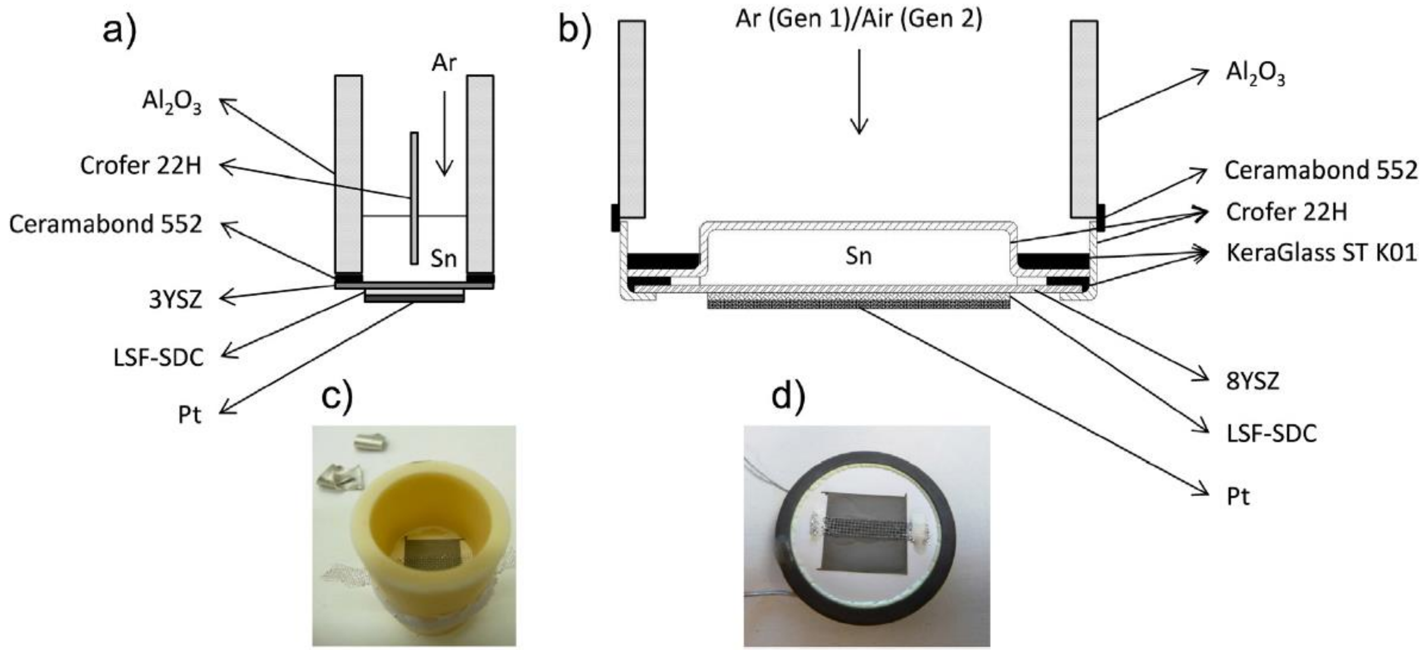


Fig. 1. (a and c) Lab-scale HTMAB device. (b and d) HTMAB prototype (Ceramabond 552 and Ar supply correspond to Gen 1 cells while in Gen 2 cells the whole device is exposed to ambient air).

Batteries

Electrochimica Acta 214 (2016) 192–200
Contents lists available at ScienceDirect
Electrochimica Acta
journal homepage: www.elsevier.com/locate/electacta

Performance and long term stability of a liquid-tin anode metal-air solid electrolyte battery prototype

L. Otaegui[a,*], I. Laresgoiti[b,1], C. Bernuy-López[a,2], N. Gómez[a], M.A. Alvarez[b], L. Wang[a,3], T. Rojo[a,c], L.M. Rodriguez-Martinez[a]

[a] CIC Energigune, Parque Tecnológico de Álava, Albert Einstein 48, ED. CIC, 01510 Miñano (Álava), Spain
[b] IK4-Ikerlan, Energy Business Unit, Juan de la Cierva 1, 01510 Miñano (Álava), Spain
[c] Departamento de Química Inorgánica, Universidad del País Vasco UPV/EHU, P.O. Box. 644, Bilbao (Vizcaya), Spain

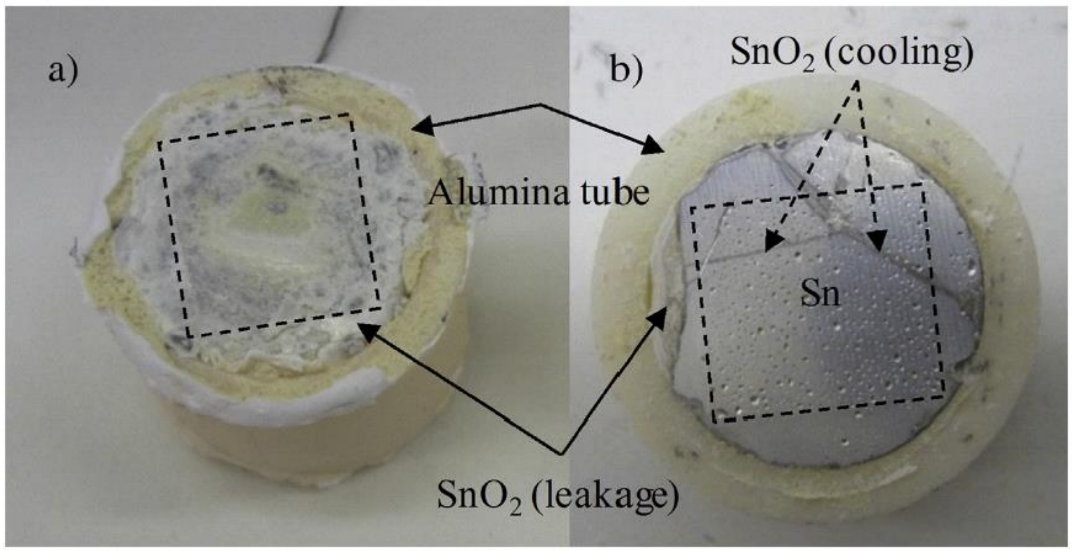


Fig. 3. Images of Sn surfaces which were in contact with the electrolyte. The metallic part is Sn and the white powder corresponds to SnO_2. The square in dashed lines indicates the active area. (a) Cell #1 with deficient sealing and (b) #4 with improved sealing system.

Batteries

Electrochimica Acta 214 (2016) 192–200

Contents lists available at ScienceDirect

Electrochimica Acta

journal homepage: www.elsevier.com/locate/electacta

Performance and long term stability of a liquid-tin anode metal-air solid electrolyte battery prototype

L. Otaegui[a,*], I. Laresgoiti[b,1], C. Bernuy-López[a,2], N. Gómez[a], M.A. Alvarez[b], L. Wang[a,3], T. Rojo[a,c], L.M. Rodriguez-Martinez[a]

[a] CIC Energigune, Parque Tecnológico de Álava, Albert Einstein 48, ED. CIC, 01510 Miñano (Álava), Spain
[b] IK4-Ikerlan, Energy Business Unit, Juan de la Cierva 1, 01510 Miñano (Álava), Spain
[c] Departamento de Química Inorgánica, Universidad del País Vasco UPV/EHU, P.O. Box. 644, Bilbao (Vizcaya), Spain