JÜLICH FORSCHUNGSZENTRUM

Fuel Cells

Tutorial for: Energy Concepts of the Future

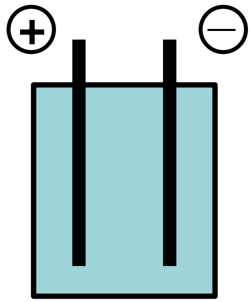
March 13, 2011 | Uwe Reimer

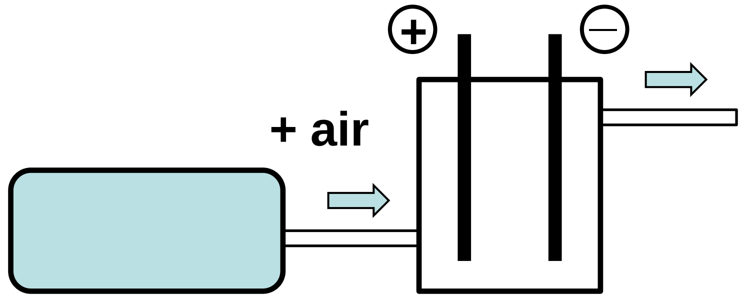
Institute for Energy and Climate Research – Fuel Cells (IEK-3)

Overview

- **Electrochemical converters**
- **Fuel cell types**
- **Principle of fuel cells**
- **Summary**

Electrochemical converters





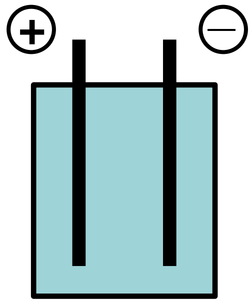
Battery

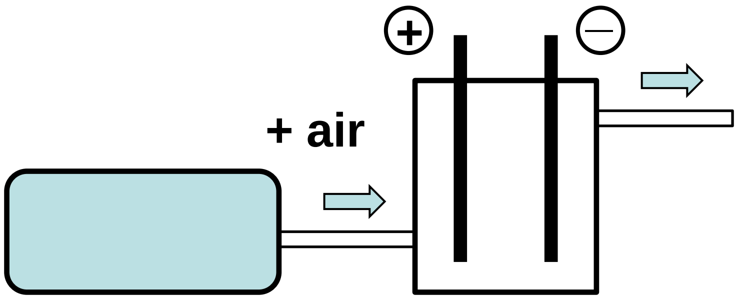
- fuel + electrodes = 'all in one'
- charging / discharging
- no emission
- upscaling: safety issue, mass

Fuel cell

- fuel + electrodes = separately
- refuelling
- emission of product gas (water,...)
- upscaling: easier

Electrochemical converters





Battery	**Fuel cell**
▪ fuel + electrodes = 'all in one'	▪ fuel + electrodes = separately
▪ charging / discharging	▪ refuelling
▪ no emission	▪ emission of product gas (water,...)
▪ upscaling: safety issue, mass	▪ upscaling: easier
▪ established market	▪ 'new technology'
▪ needs electr. power infrastructure	▪ needs fuel infrastructure
▪ efficiency 70 - 90 % (el. → el.)	▪ efficiency 40 - 60 % (fuel → el.)

Selected fuel cell types

PEFC (polymer electrolyte fuel cell)

- T_{OP} = 80 °C
- Fuel = pure H_2
- Membrane = polymer (Nafion)
- Catalyst = Pt

⋮

SOFC (solid oxide fuel cell)

- T_{OP} = 800 °C
- Fuel = pure H_2 and/ or CH_4 (with H_2O)
- Membrane = solid oxide (ceramics)
- Catalyst = Ni

Selected fuel cell types

PEFC (polymer electrolyte fuel cell)

- T_{OP} = 80 °C
- Fuel = pure H_2
- Membrane = polymer (Nafion)
- Catalyst = Pt

DMFC (direct methanol fuel cell)

- T_{OP} = 80 °C
- Fuel = CH_3OH (with H_2O)
- Membrane = polymer (Nafion)
- Catalyst = Pt / Ru

⋮

HT-PEFC (high temperature - polymer electrolyte fuel cell)

- T_{OP} = 160 °C
- Fuel = H_2 (reformate gas, 1 % CO)
- Membrane = polymer (PBI)/ H_3PO_4
- Catalyst = Pt

SOFC (solid oxide fuel cell)

- T_{OP} = 800 °C
- Fuel = pure H_2 and/ or CH_4 (with H_2O)
- Membrane = solid oxide (ceramics)
- Catalyst = Ni

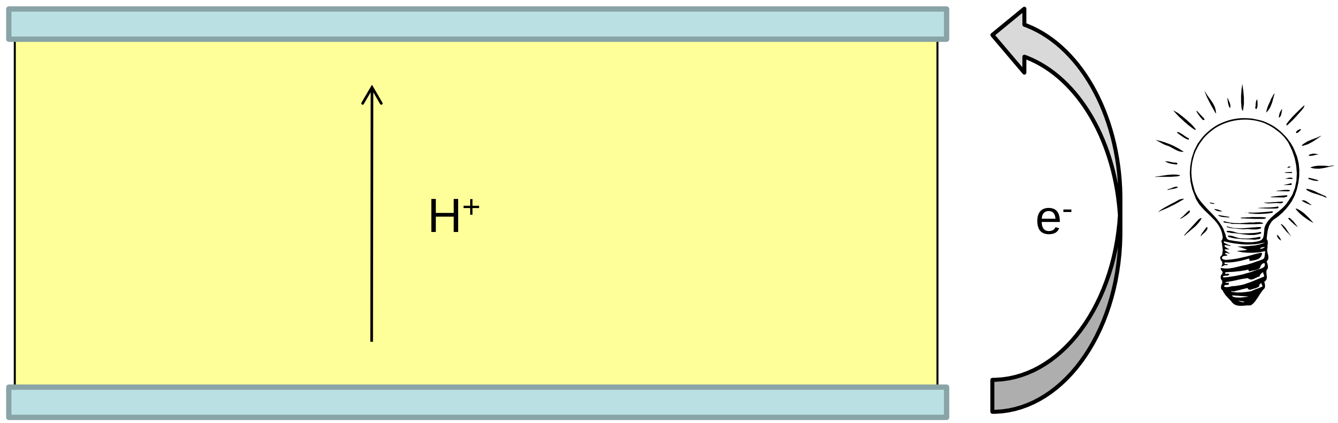
Fuel cell reaction: PEFC

over all $$2\,H_2 + O_2 \rightleftharpoons 2\,H_2O$$

air / O_2

cathode $$O_2 + 4\,e^- + 4\,H^+ \rightleftharpoons 2\,H_2O$$

membrane



anode $$2\;H_2 \rightleftharpoons 4\,H^+ + 4\,e^-$$

H_2

Basic equations

Electric energy:

$$W_{el} = E \cdot I \cdot t$$

Nernst equation (voltage):

$$E = E^{\circ} - \frac{R\,T}{2\,F}\, ln \frac{p_{H_2O}}{p_{H_2}\, p_{O_2}^{0.5}}$$

p reduced partial pressure (p/p_0)

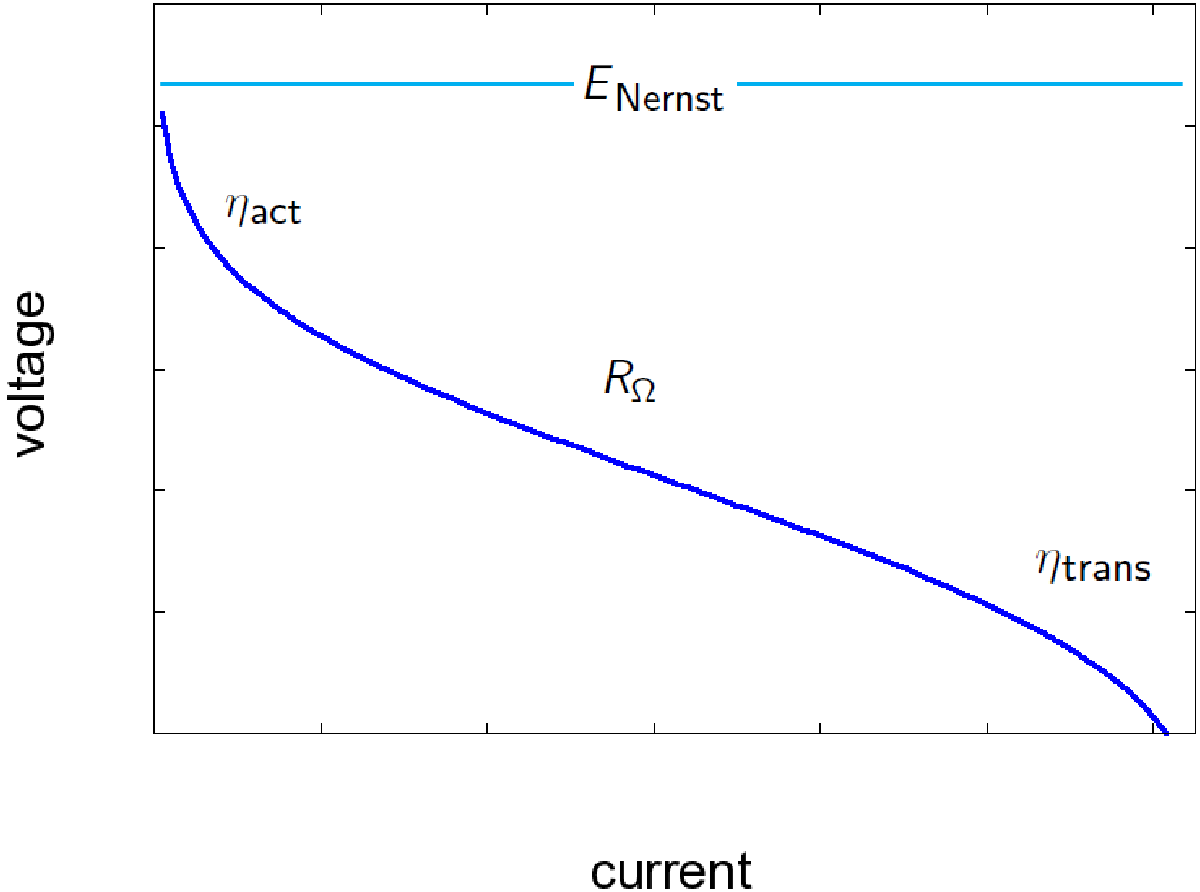
Faraday's law (current):

$$I \cdot t = n \cdot z \cdot F$$

1 A/cm^2 ~ 7 ml/min H_2

F = Faradays constant
z = 2 for H_2

Polarization curve

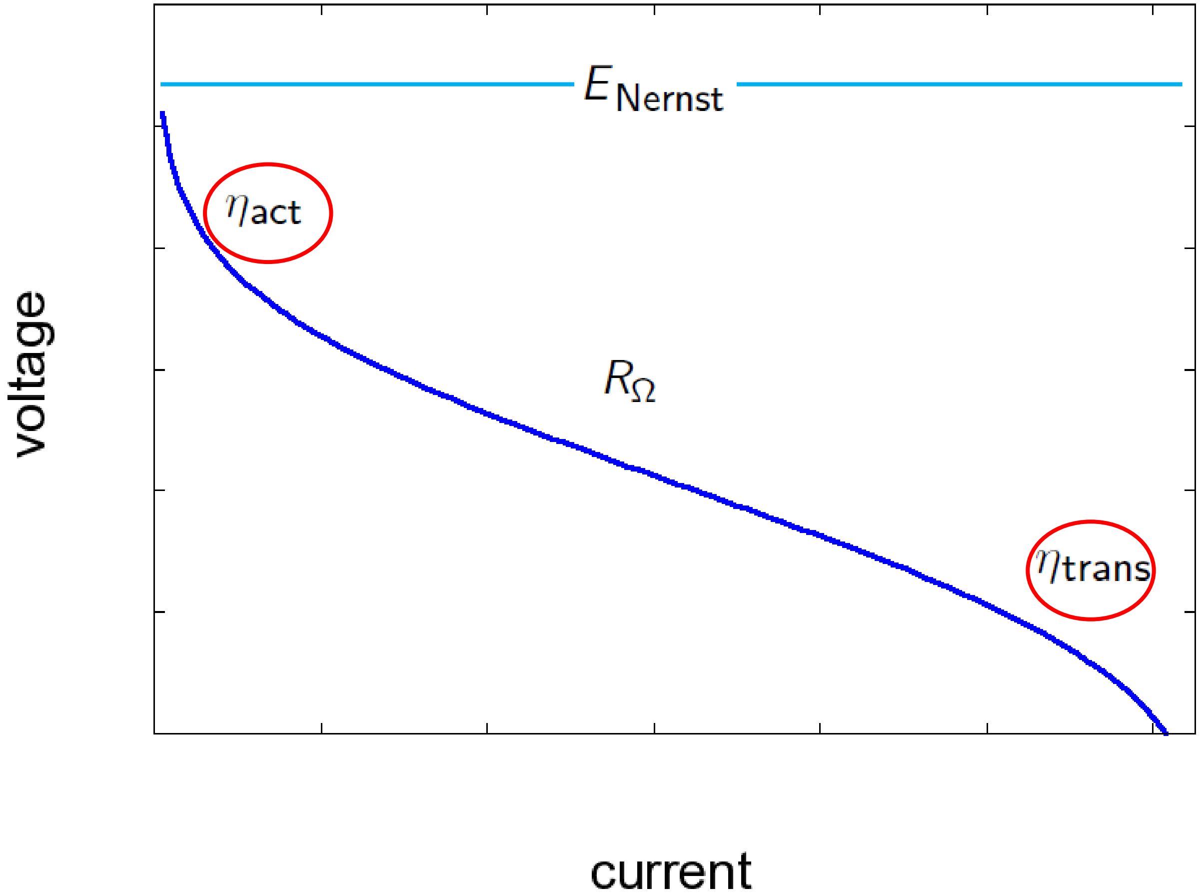


Basic idea: $E = E^0 - \eta(j)$

Nernst voltage minus losses

$$E_{cell} = E_{Nernst} - R_\Omega\, j - \eta_{act} - \eta_{trans}$$

Polarization curve

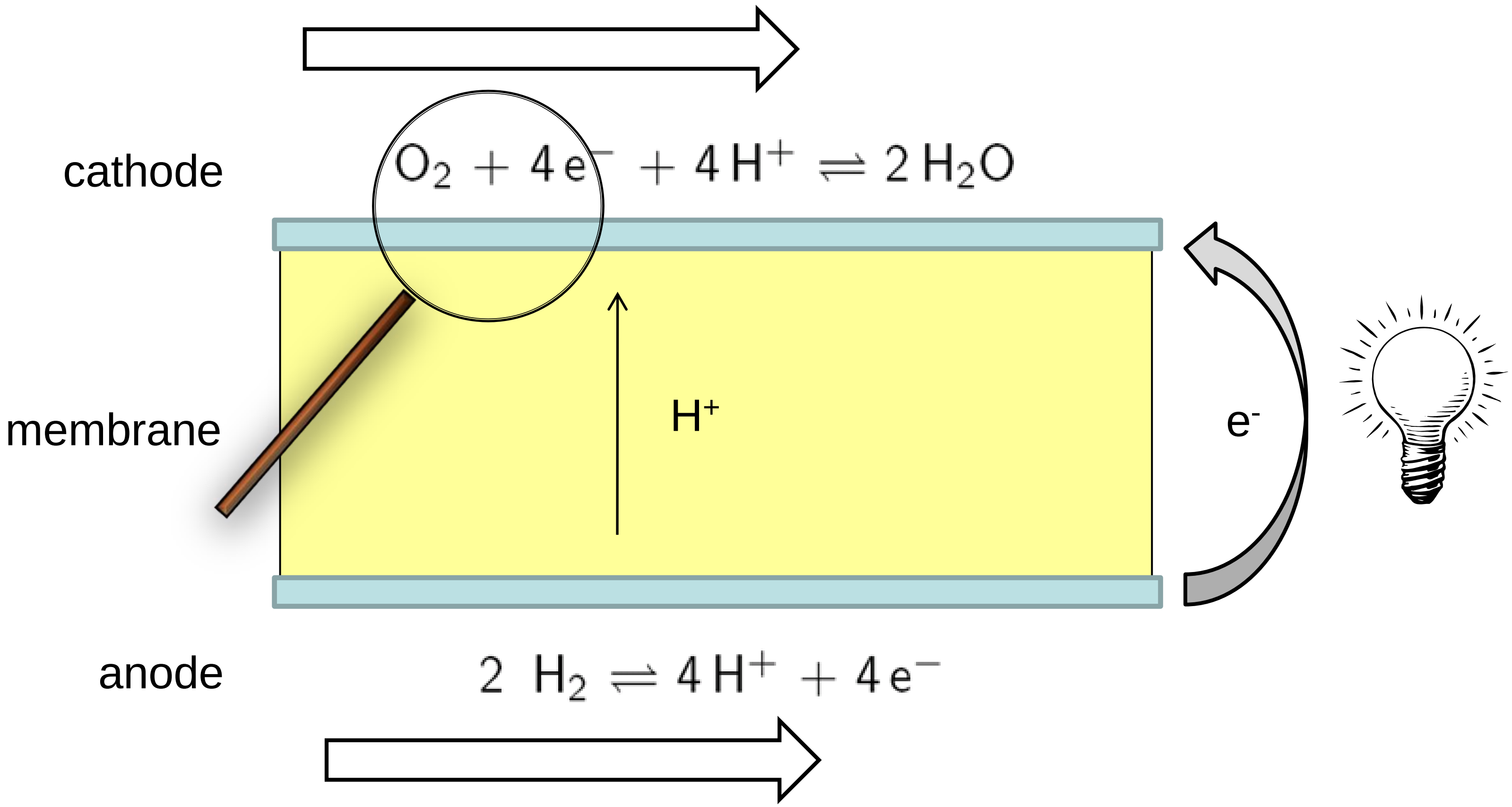


Basic idea: $E = E^0 - \eta(j)$

Nernst voltage minus losses

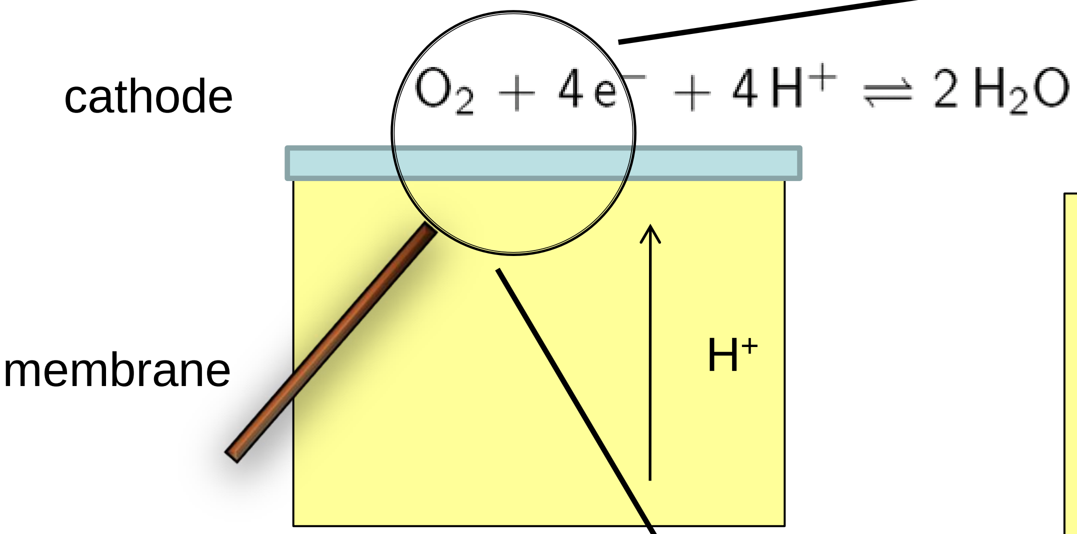
$$E_{\mathrm{cell}} = E_{\mathrm{Nernst}} - R_{\Omega}\, j - \eta_{\mathrm{act}} - \eta_{\mathrm{trans}}$$

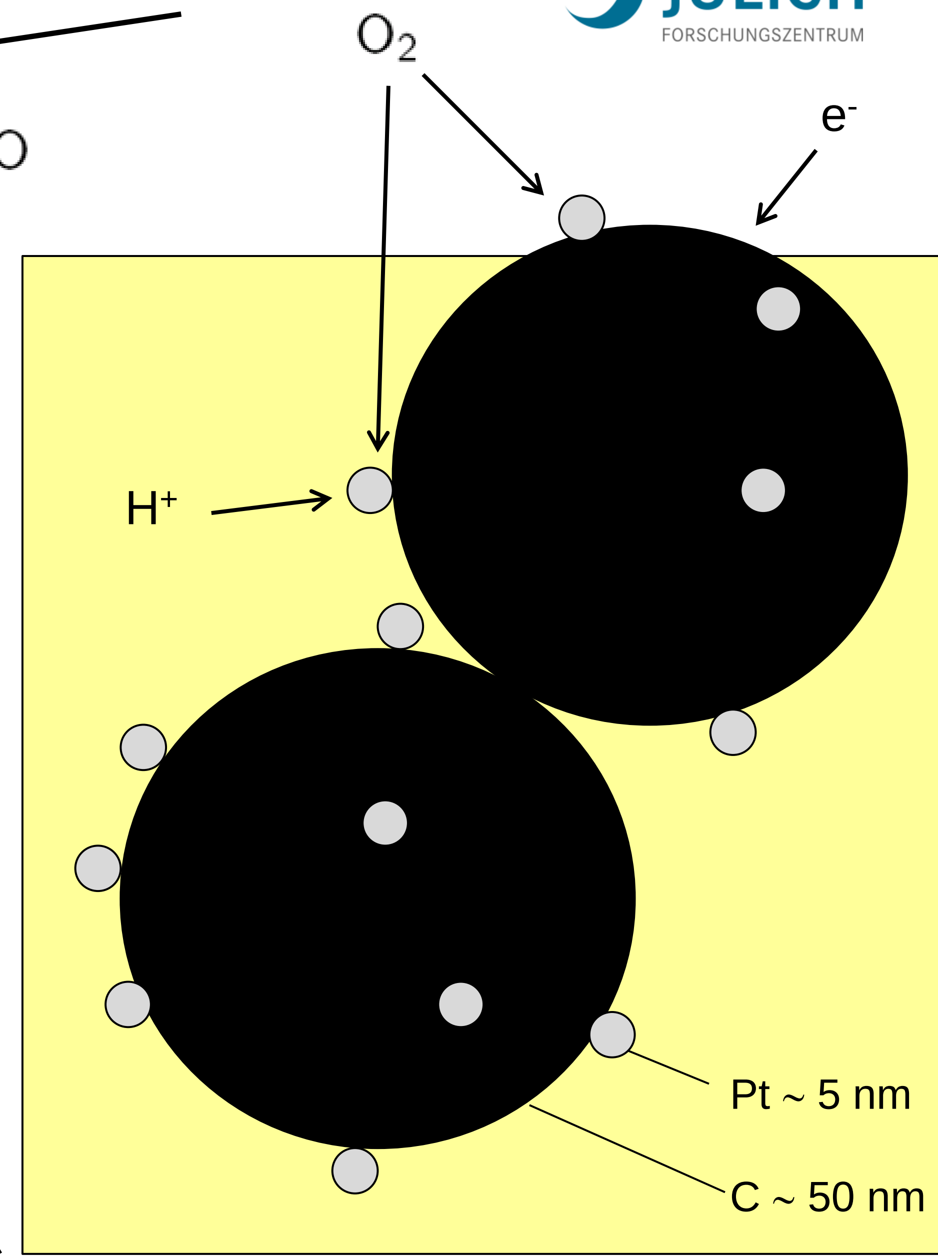
Activation loss



catalyst = carbon supported platinum

Activation loss





- Electric double layer at cat. surface
- Electrons are transfered from metal to adsorbed species

Activation loss

$$E_{\mathrm{cell}} = E_{\mathrm{Nernst}} - R_{\Omega}\, j - \eta_{\mathrm{act}} - \eta_{\mathrm{trans}}$$

$$\eta_{\mathrm{act}} = \frac{R\,T}{\alpha\, z\, F} \ln \frac{j}{j_0}$$

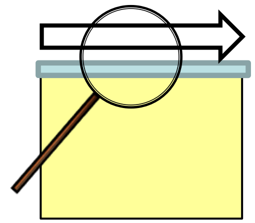
(Tafel equation)

j_0 exchange current density

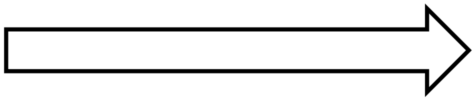
α symmetry factor

z number of electrons in slowest step

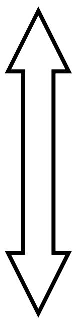
Transport loss / diffusion limitation



gas flow / channel

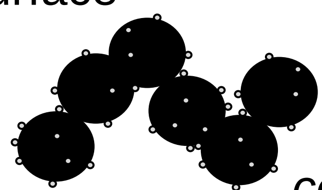


mass transport = convection



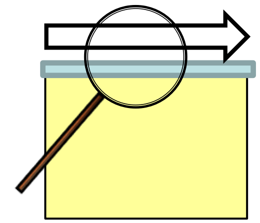
mass transport = diffusion

catalyst surface

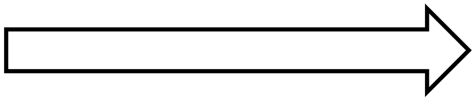


consumption at catalyst

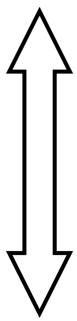
Transport loss / diffusion limitation



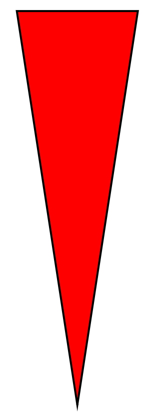
gas flow / channel



mass transport = convection

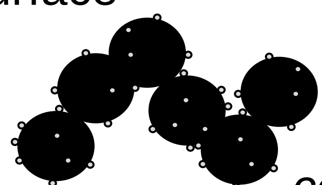


mass transport = diffusion



concentration gradient

catalyst surface



mass transport limitation, if consumption > diffusion

consumption at catalyst

Short summary: polarization curve

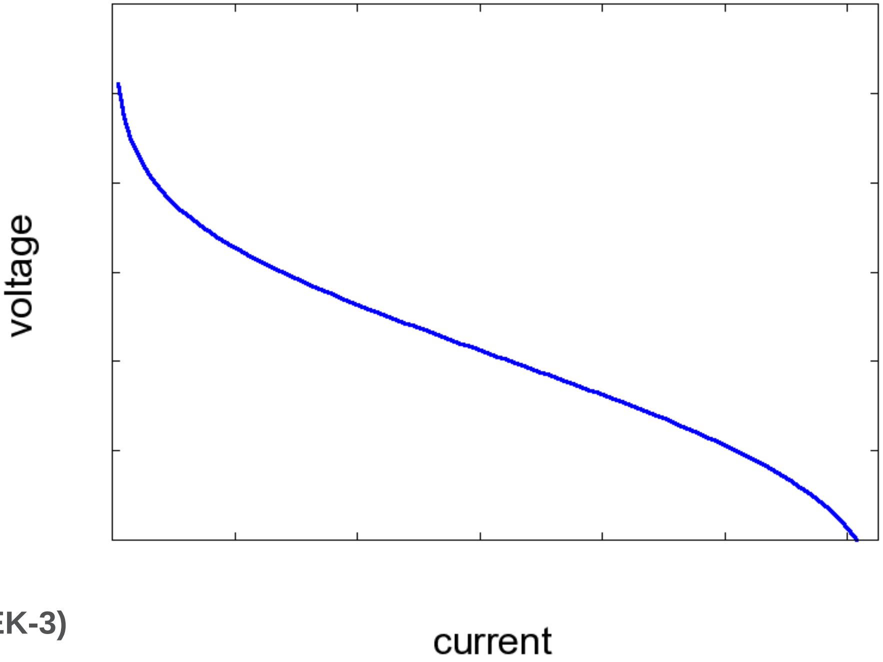
$$E_{\mathrm{cell}} = E_{\mathrm{Nernst}} - R_{\Omega}\, j - \eta_{\mathrm{act}} - \eta_{\mathrm{trans}}$$

$$E_{\mathrm{cell}}(T) = E^{\circ}(T) + \frac{R\,T}{2\,F} \ln \frac{p_{\mathrm{H2O}}}{p_{\mathrm{H2}}\, p_{\mathrm{O2}}{}^{0.5}} - R_{\Omega}(T)\, j - \frac{R\,T}{\alpha\,F} \ln \frac{j}{j_0(T)} - \frac{R\,T}{\alpha\,F} \ln \frac{j_{\mathrm{lim}}}{j_{\mathrm{lim}} - j}$$

j_0 exchange current density

j_{lim} limiting current density

α symmetry factor



Short summary: polarization curve

$$E_{\text{cell}} = E_{\text{Nernst}} - R_\Omega j - \eta_{\text{act}} - \eta_{\text{trans}}$$

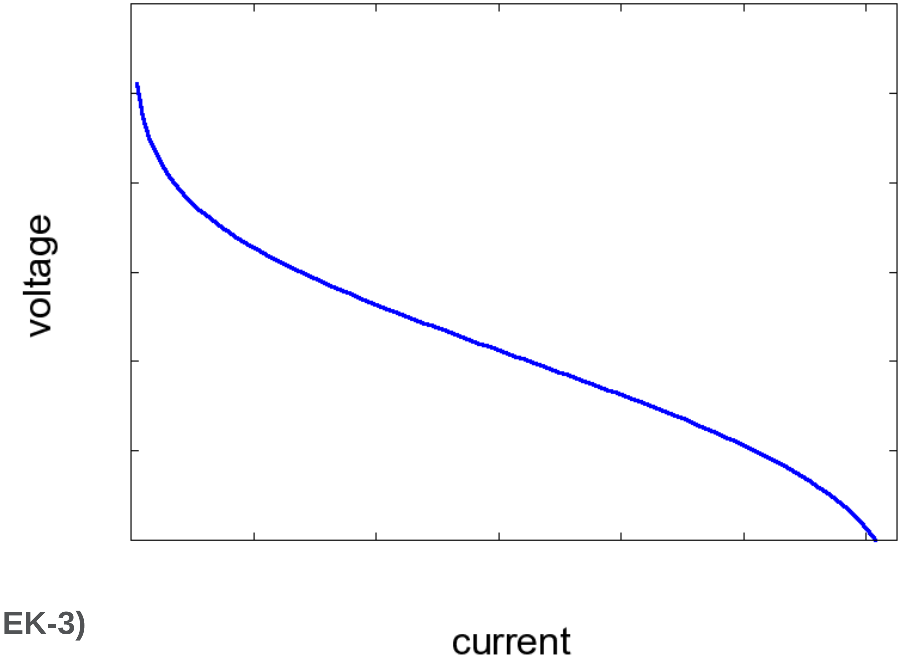
thermodynamics — kinetics

$$E_{\text{cell}}(T) = E^\circ(T) + \frac{R\,T}{2\,F}\ln\frac{p_{H2O}}{p_{H2}\,p_{O2}^{0.5}} - R_\Omega(T)\,j - \frac{R\,T}{\alpha\,F}\ln\frac{j}{j_0(T)} - \frac{R\,T}{\alpha\,F}\ln\frac{j_{\lim}}{j_{\lim}-j}$$

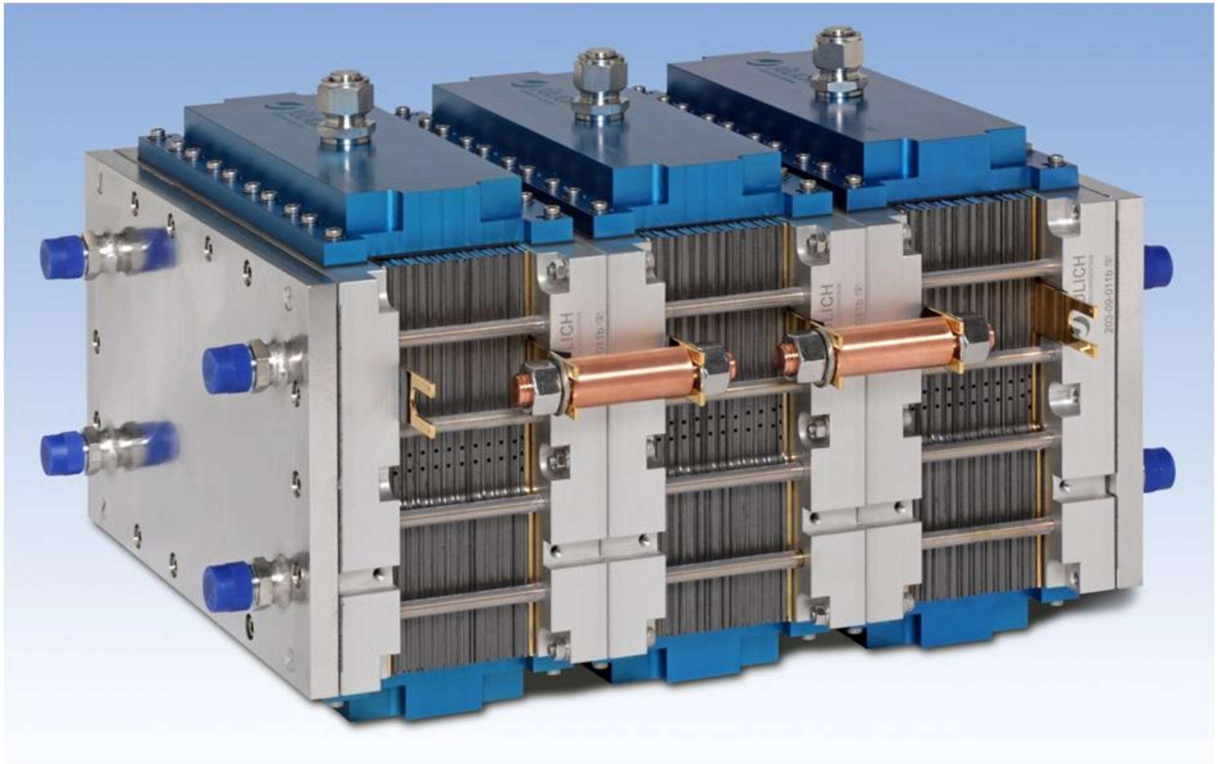
Present research:

- Improve materials
- Structure - function relationship

(mass transport and electrochem.)



Hardware example



- 3 kW HT-PEFC

  at FZ Jülich
- Membrane: PBI/ H_3PO_4
- T_{OP} = 160 °C
- Fuel: pure H_2 or reformate gas with up to 1 % CO
- Mass = 80 kg

Hardware example

- 3 kW HT-PEFC

  Serenergy/ Denmark
- Membrane: PBI/ H_3PO_4
- T_{OP} = 160 °C
- Fuel: pure H_2 or reformate gas with up to 1 % CO
- Mass = 22 kg

Summary

- Fuel cells and battery are not competitors.

- Advantages of fuel cells: long term storage of fuel,

  easier upscaling + safety

- There is a physical limit to efficiency,

  if large quantities of electric power have to be produced.

- The 'market entry' demands specific infrastructure of

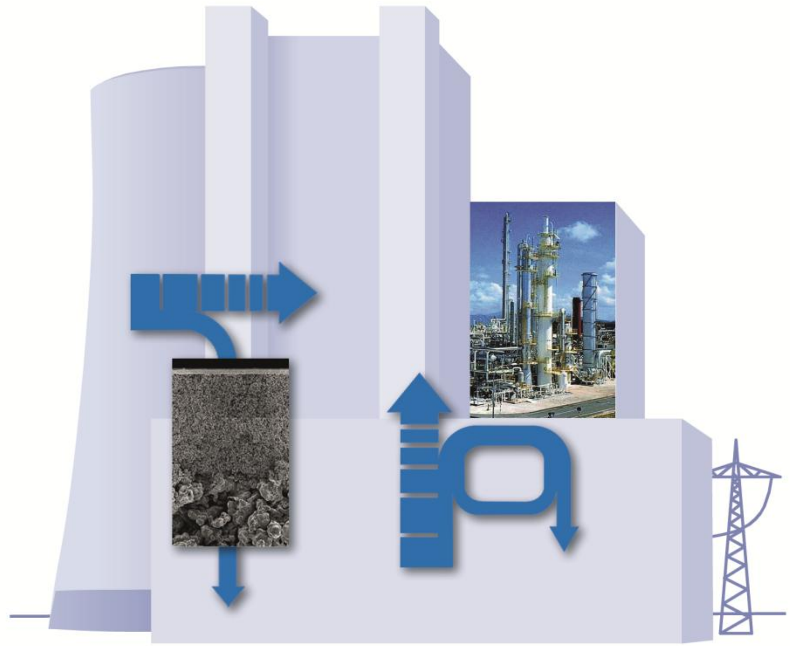
  power grid and fuel supply.

Thank You for Your Attention!

First Announcement

2nd International Conference on Energy Process Engineering:

Efficient Carbon Capture for Coal Power Plants



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www.icepe2011.de