Hydrogen Energy

by Means of Proton Conductors

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and Storage
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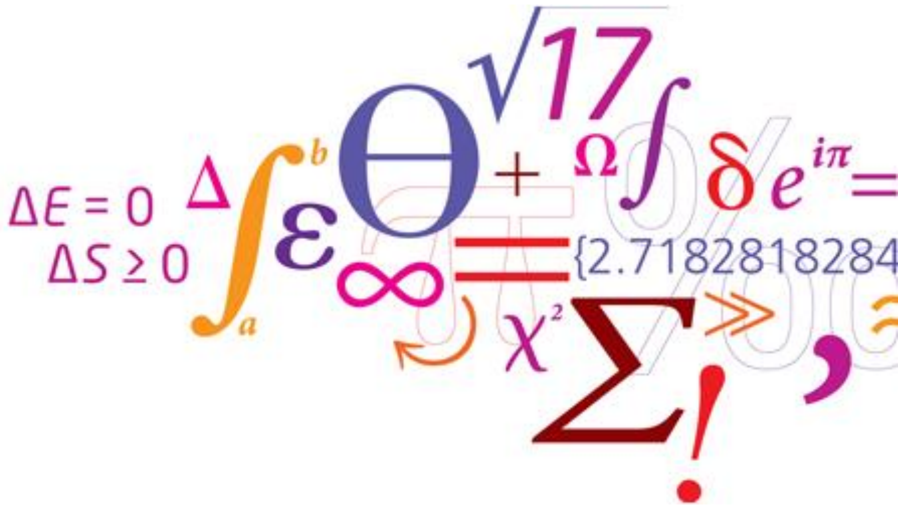
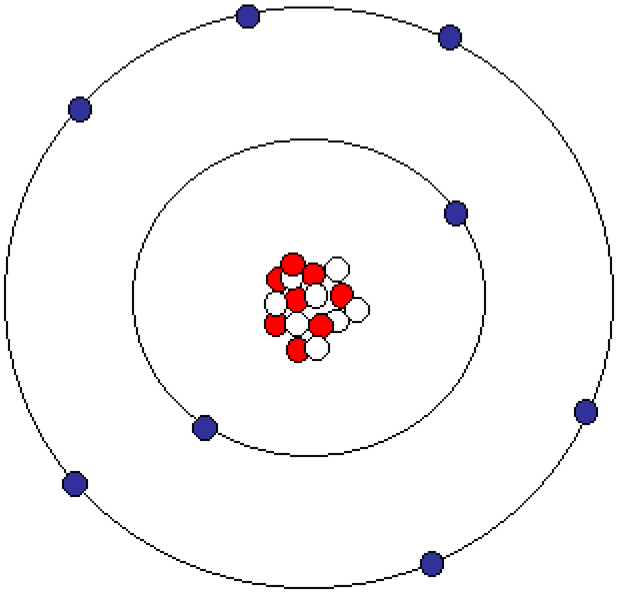
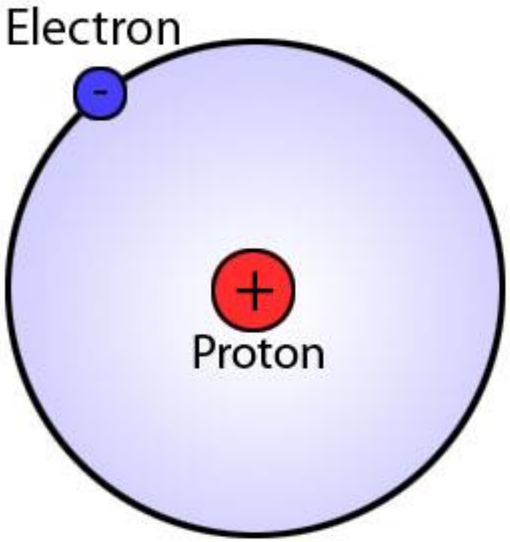
Denmark
jojen@dtu.dk



A proton, H^+



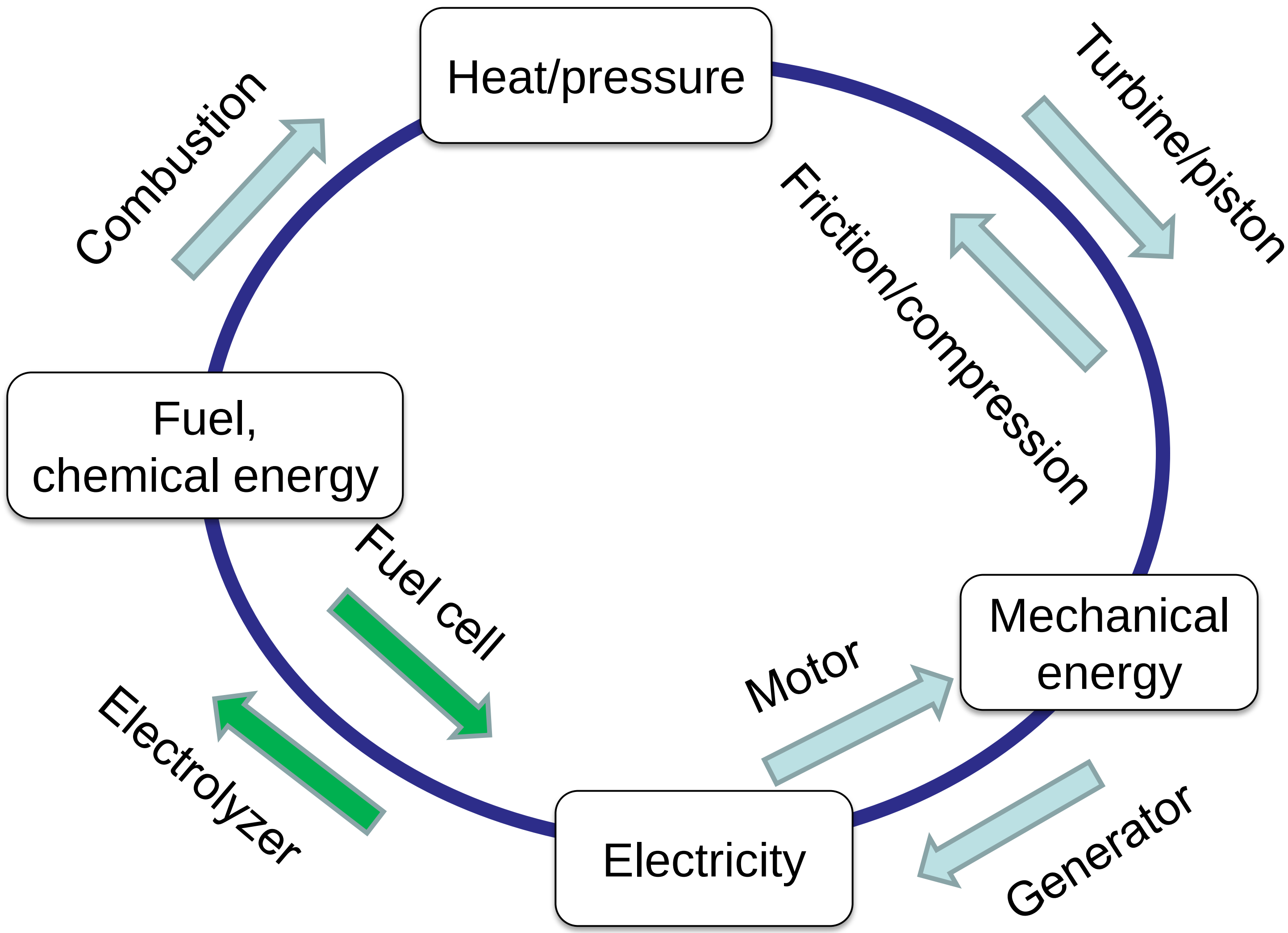
No. 8: Oxygen, O



No. 1: Hydrogen, H

$H_2 \rightarrow 2H^+ + e^-$

Energy conversion



Hydrogen as an energy carrier

IRD
POWERING PEOPLE ANYWHERE

$H_2 + ½O_2$

Fuel cell

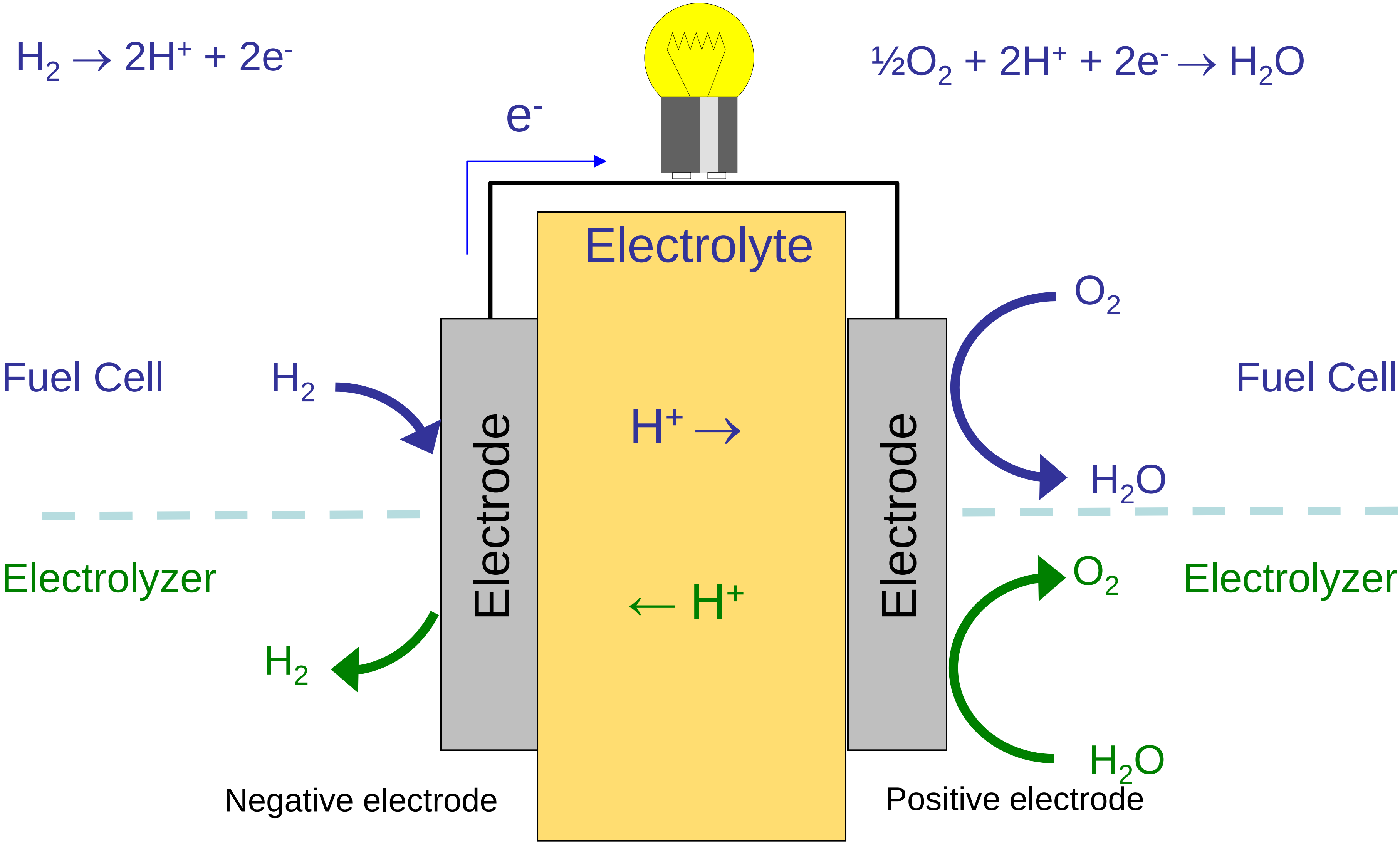
Electrolyzer

H_2O + Energy

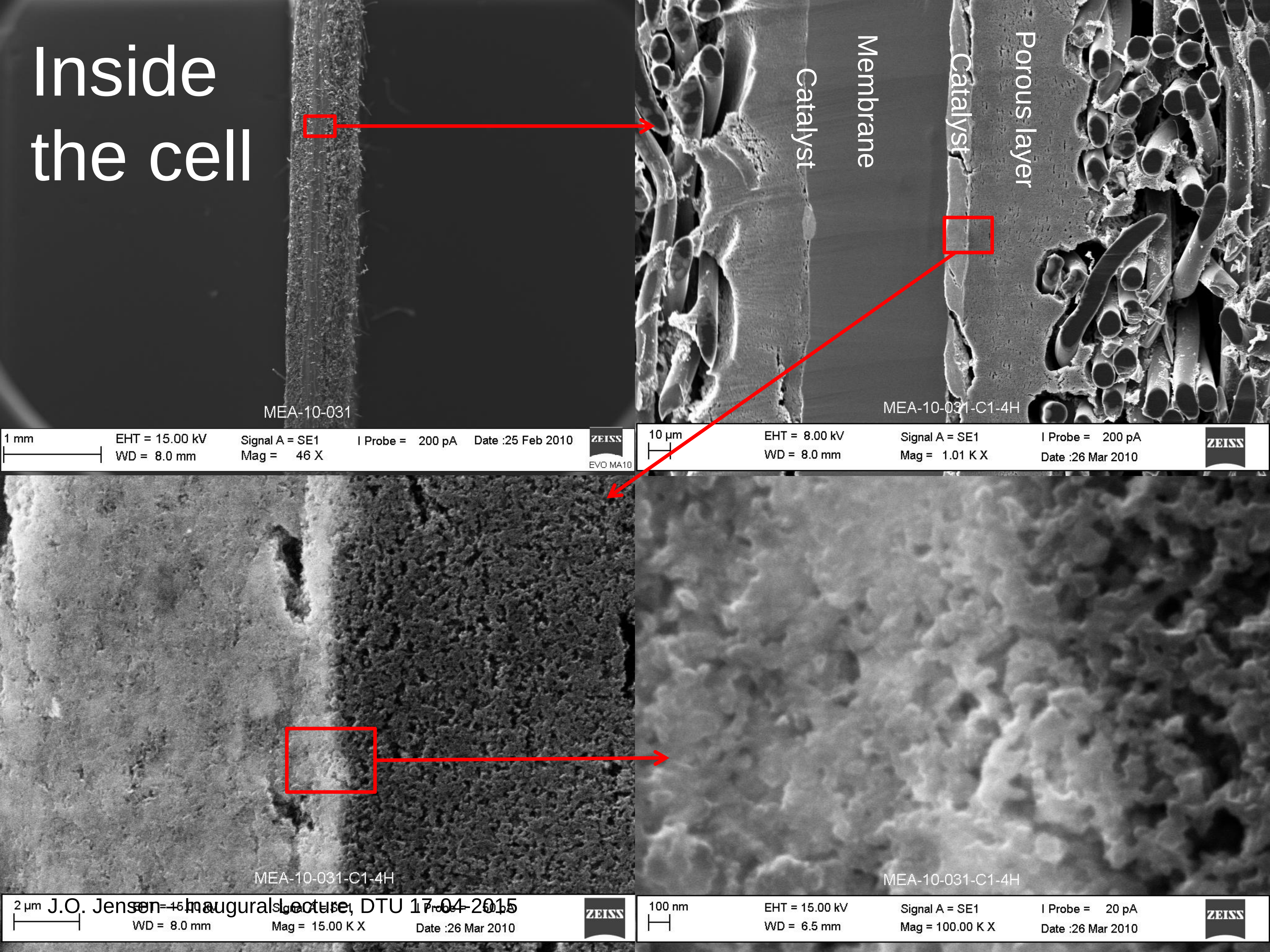
Purification Equipment Research Institute of CSIC

$$H_2 + ½O_2 \rightleftarrows H_2O + \textit{Energy}$$

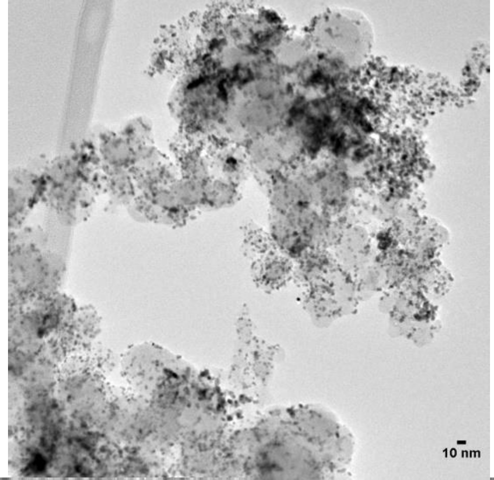
Fuel cell or electrolyzer

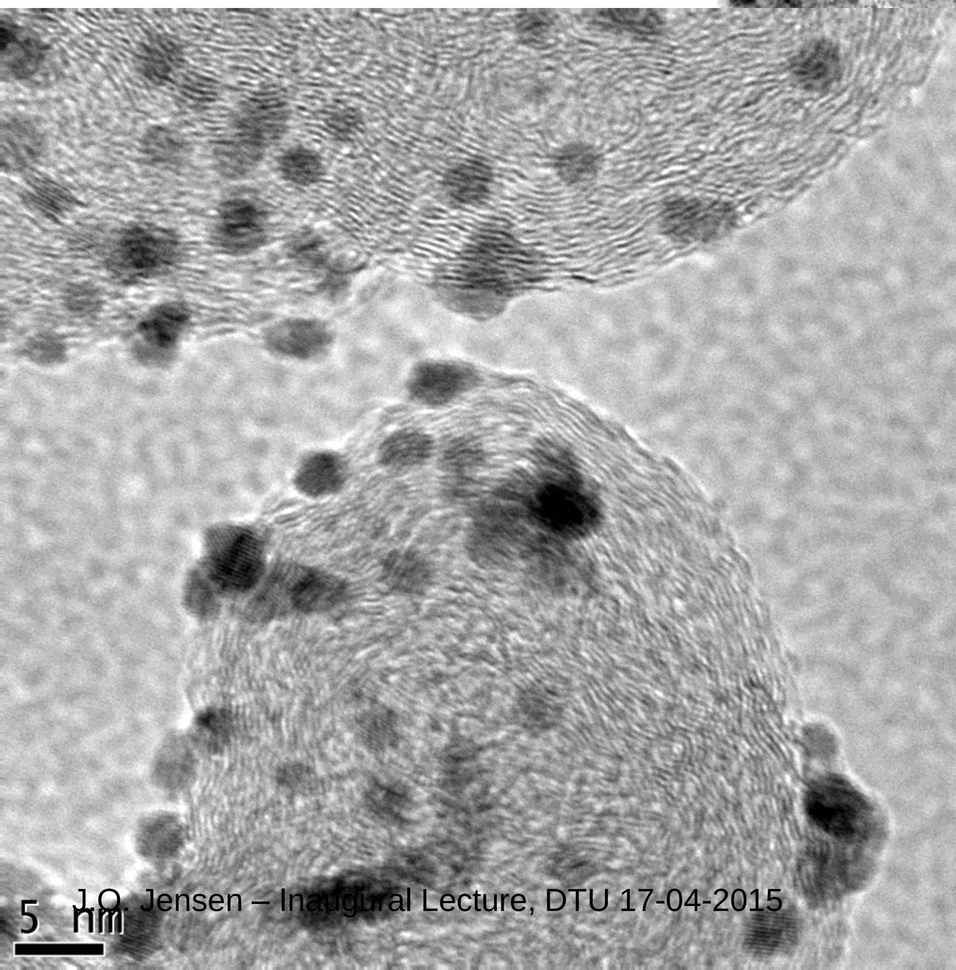


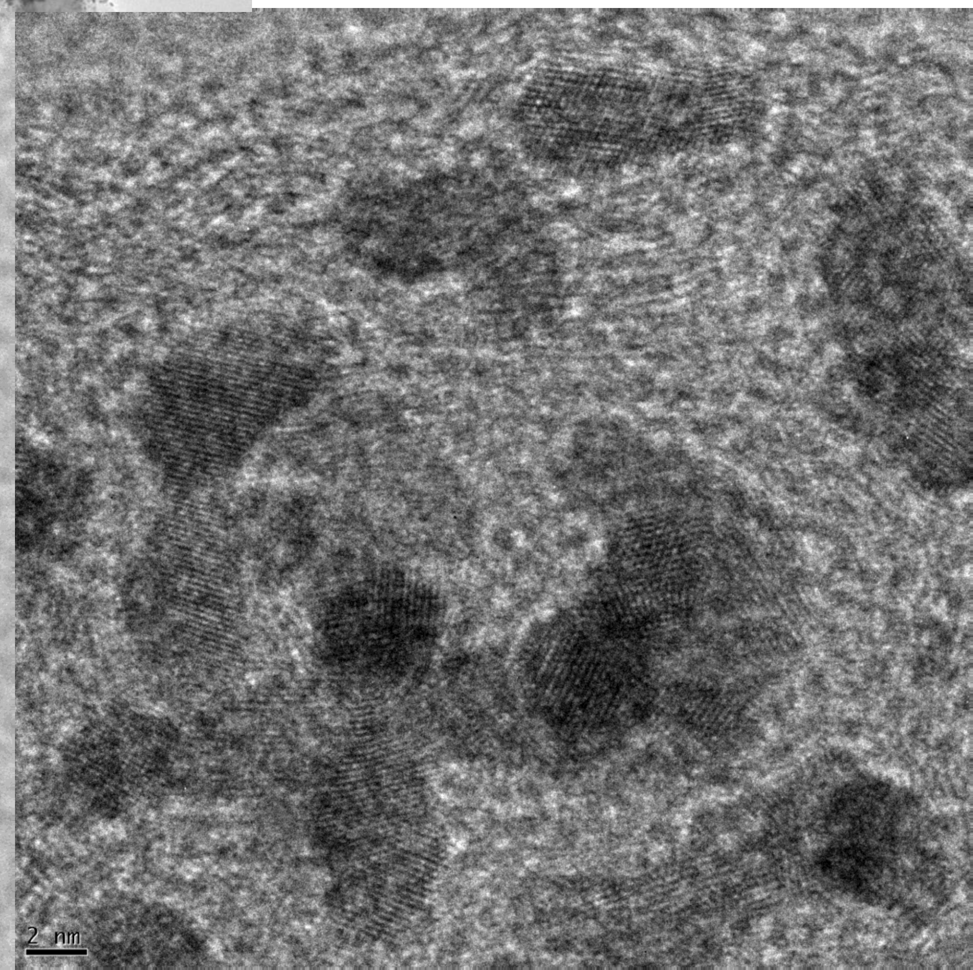
Inside the cell



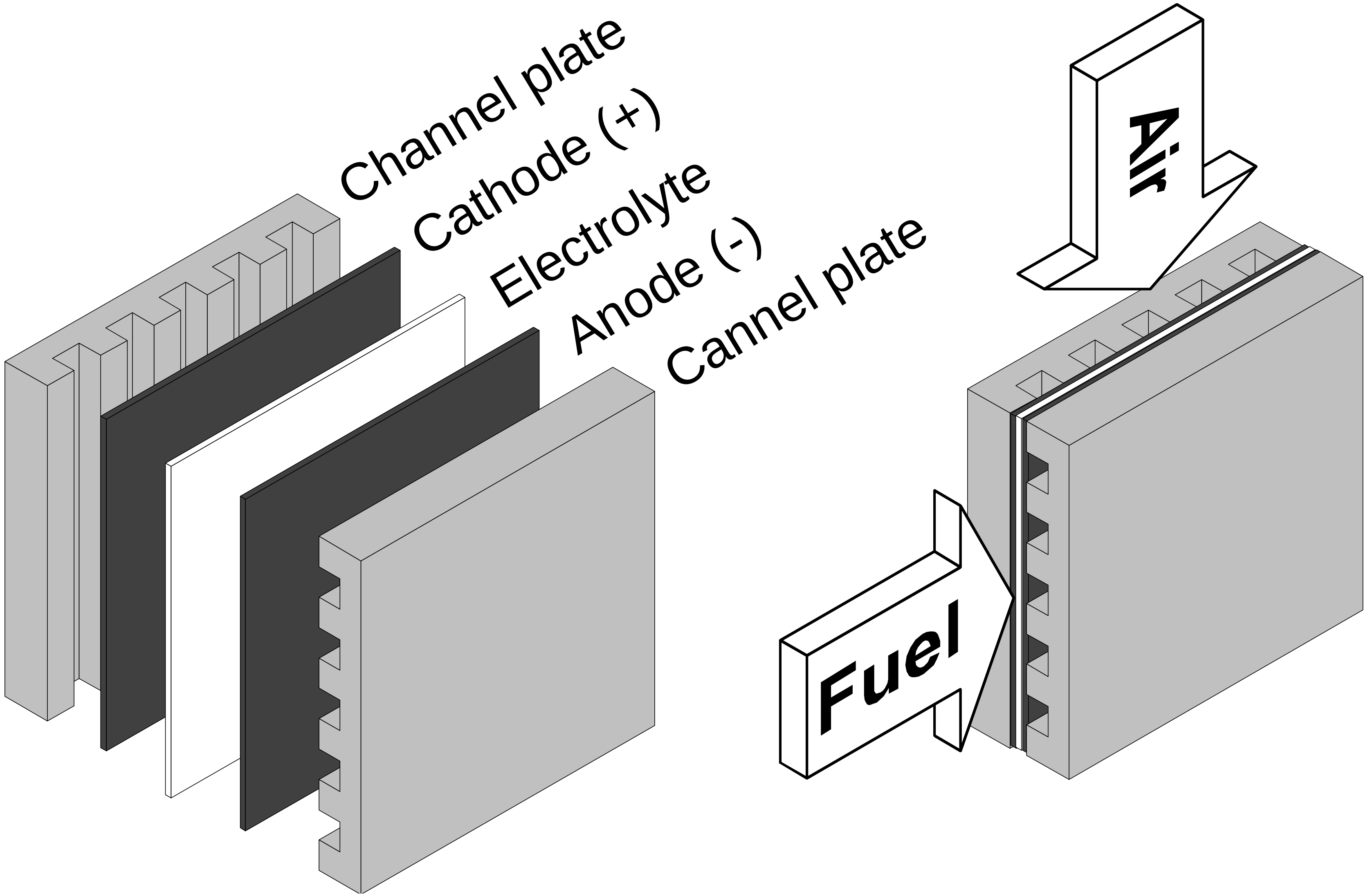
Catalyst



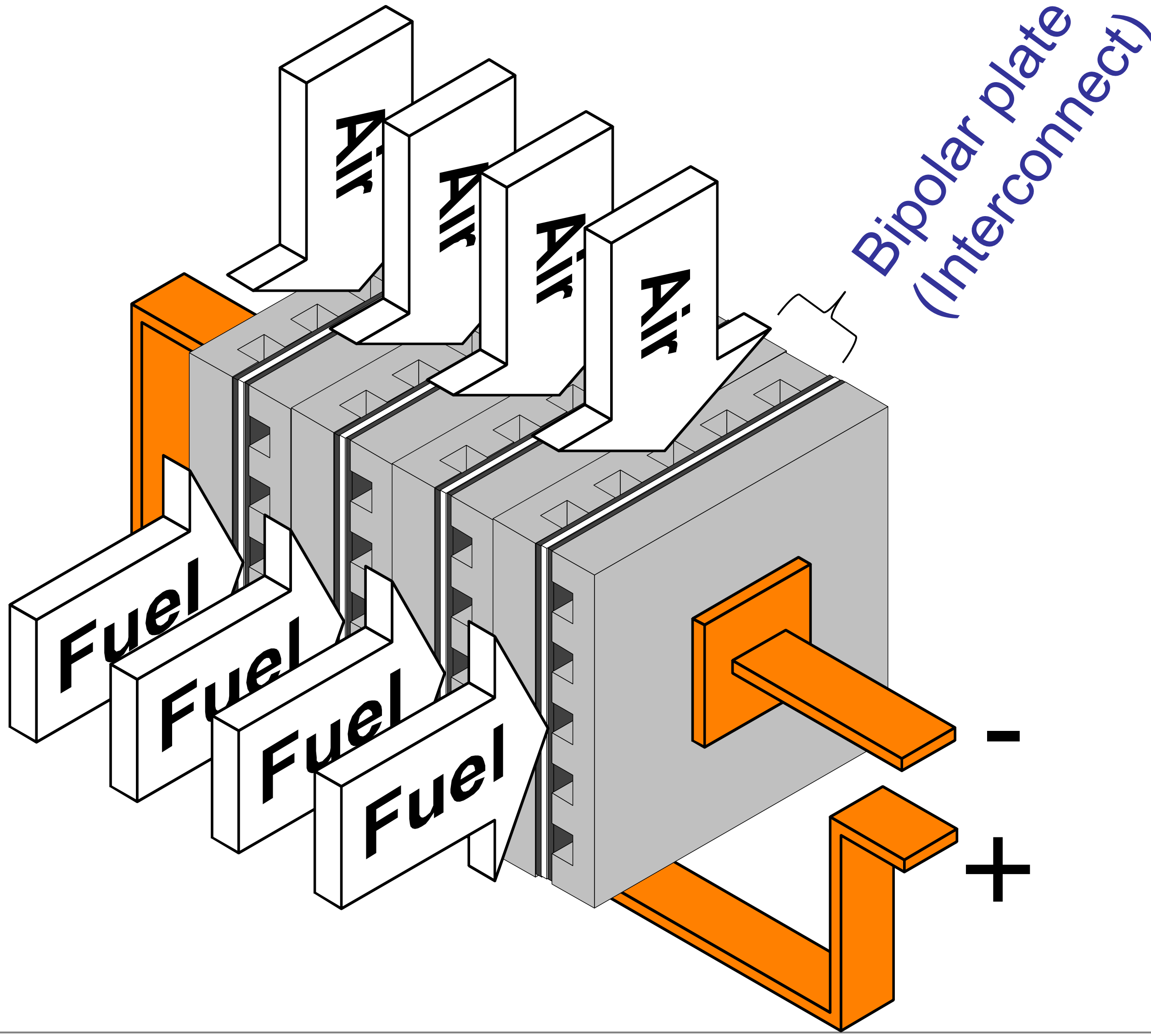




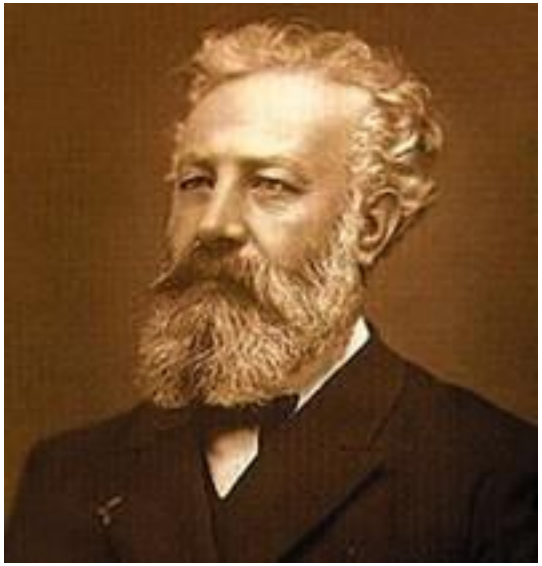
Single cell


Channel plate
Cathode (+)
Electrolyte
Anode (-)
Cannel plate
Air
Fuel

Stacking


Air
Air
Air
Air
Bipolar plate
(Interconnect)
Fuel
Fuel
Fuel
Fuel
-
+

Hydrogen energy



1874 Jules Verne predicted in “The Mysterious Island” (chapter 33):

Cyrus Harding:

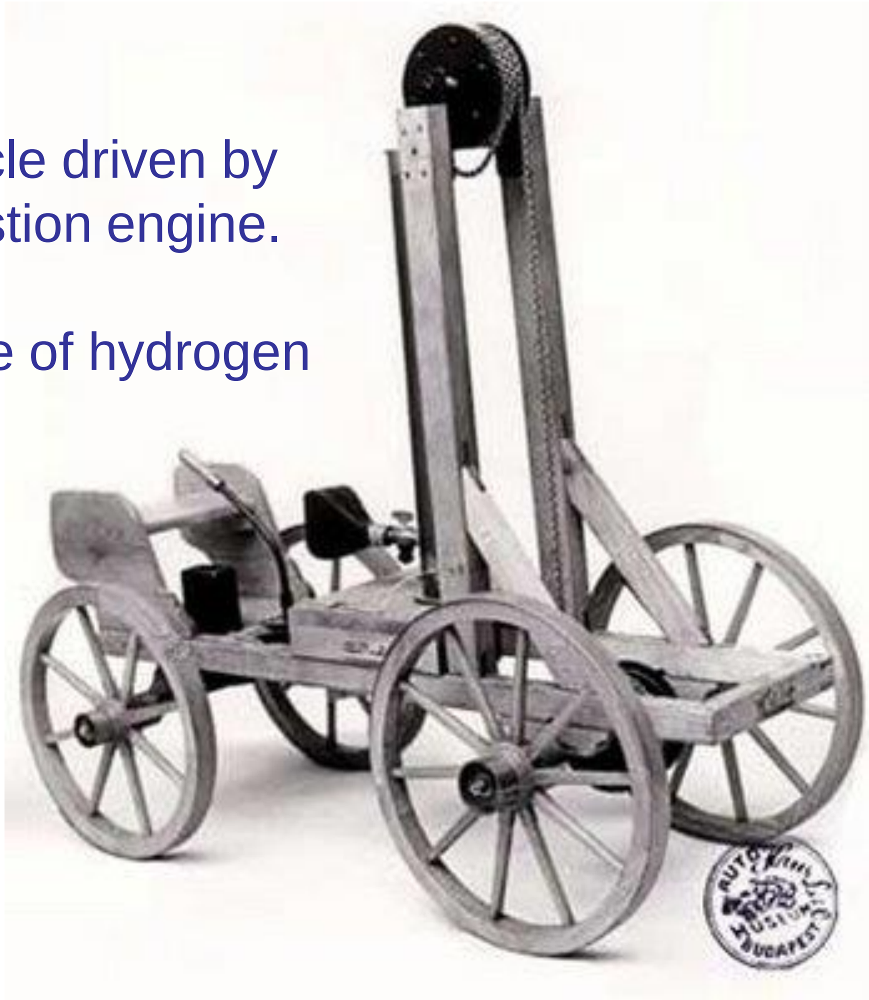
“*Yes, my friends, I believe that water will one day be employed as fuel, that hydrogen and oxygen which constitute it, used singly or together, will furnish an inexhaustible source of heat and light, of an intensity of which coal is not capable*.”

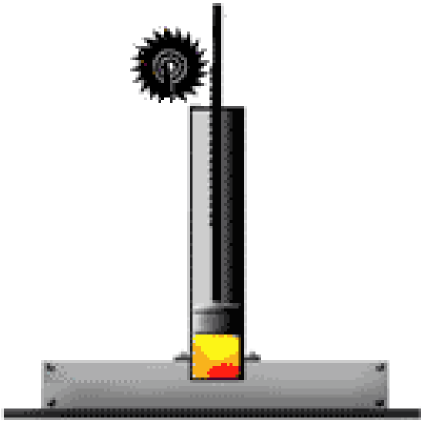
The first ICE powered vehicle

Francois Isaac de Rivaz (Switzerland),

In 1807: First vehicle driven by an internal combustion engine.

Driven by a mixture of hydrogen and oxygen.





The fist hydrogen society ?

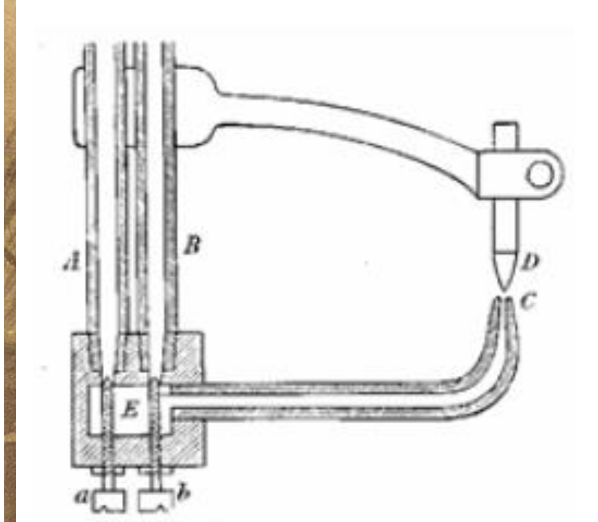


Fig 149. Knaldluftslampe fra Askov

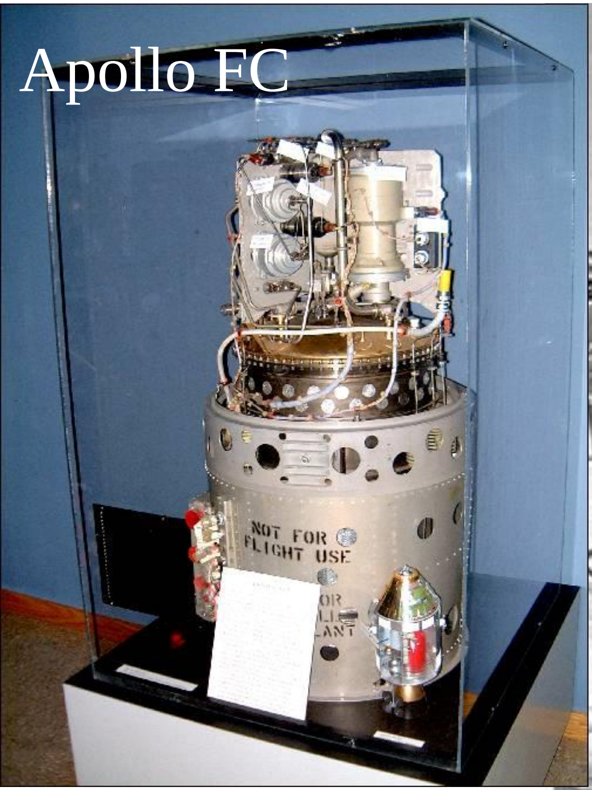
Askov Højskole, 1897 (a folk high school)

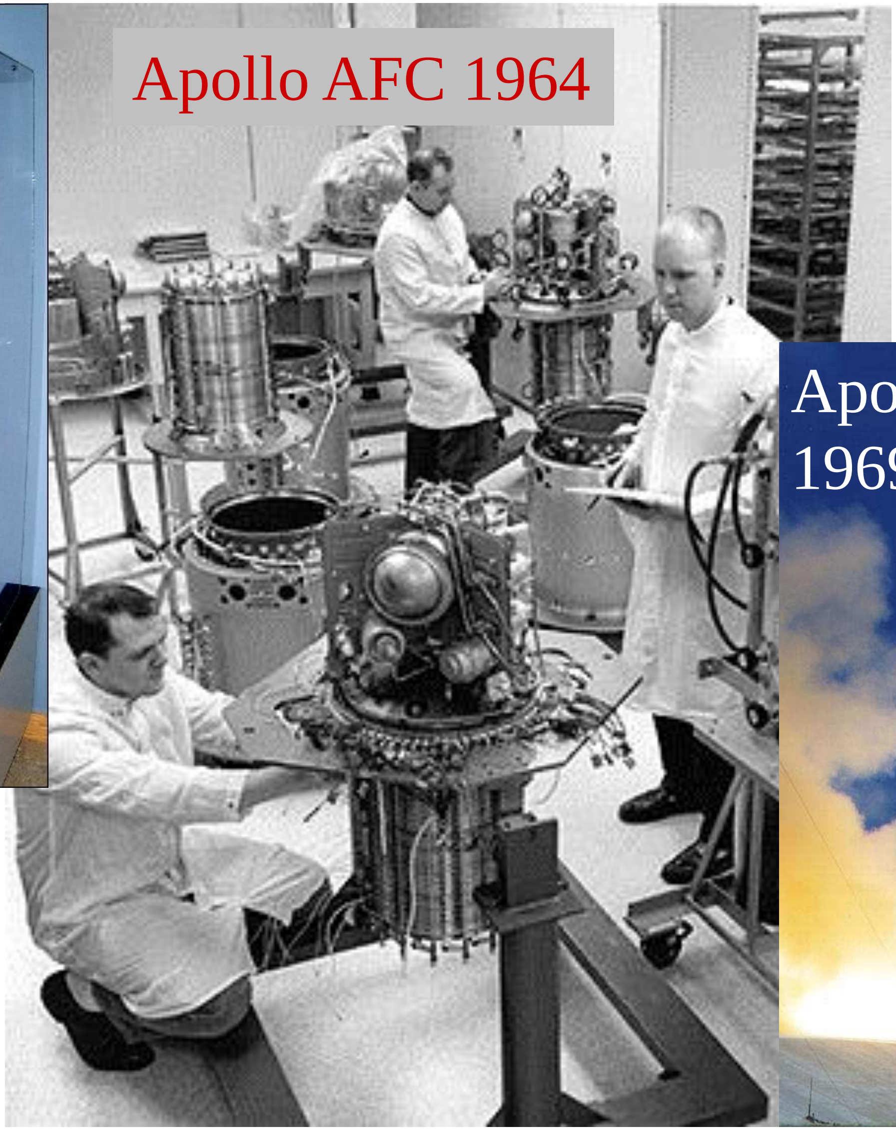
Mills + electrolysis for gas light

Poul la Cour

(1846-1908)

The space missions





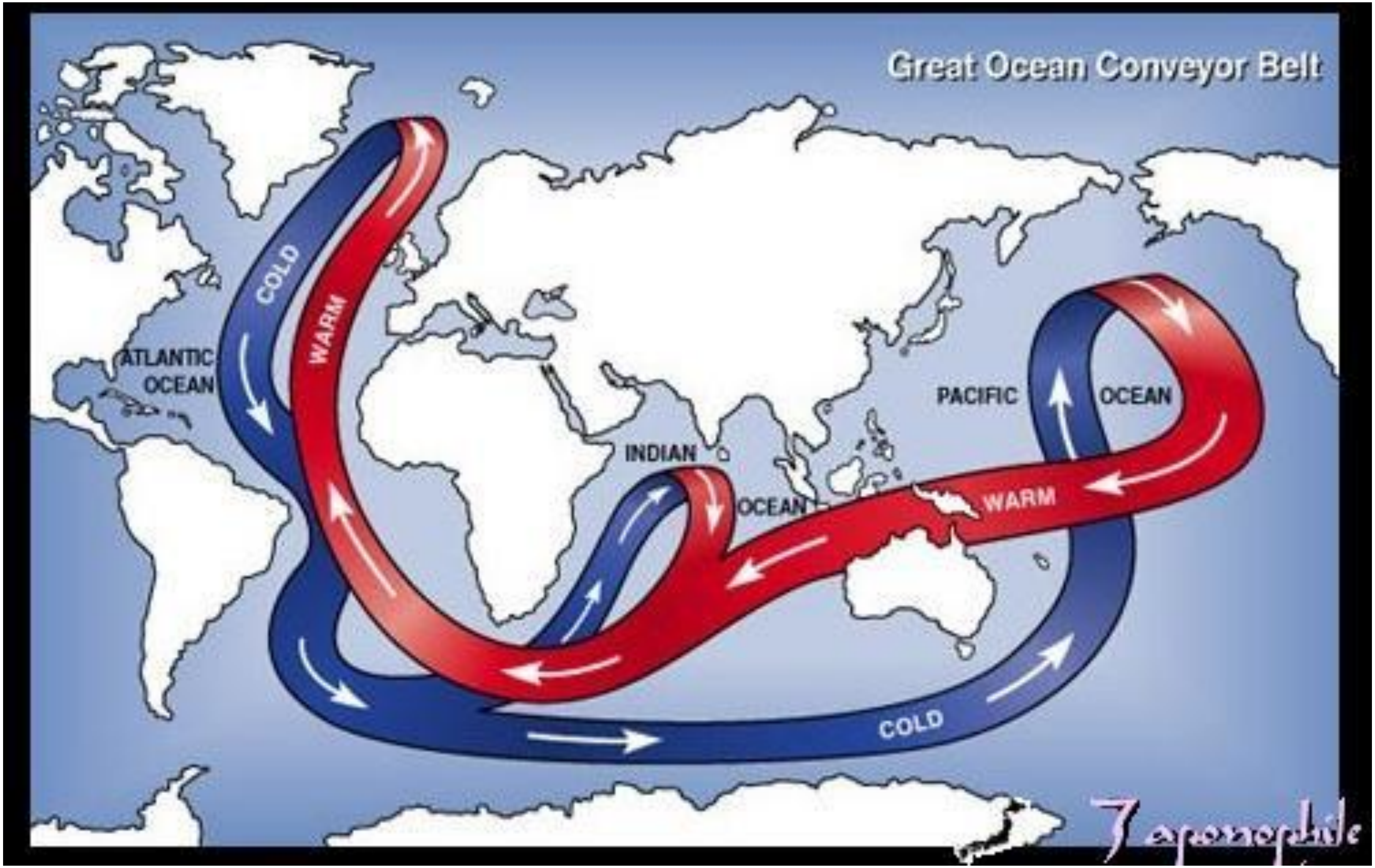
Early applications

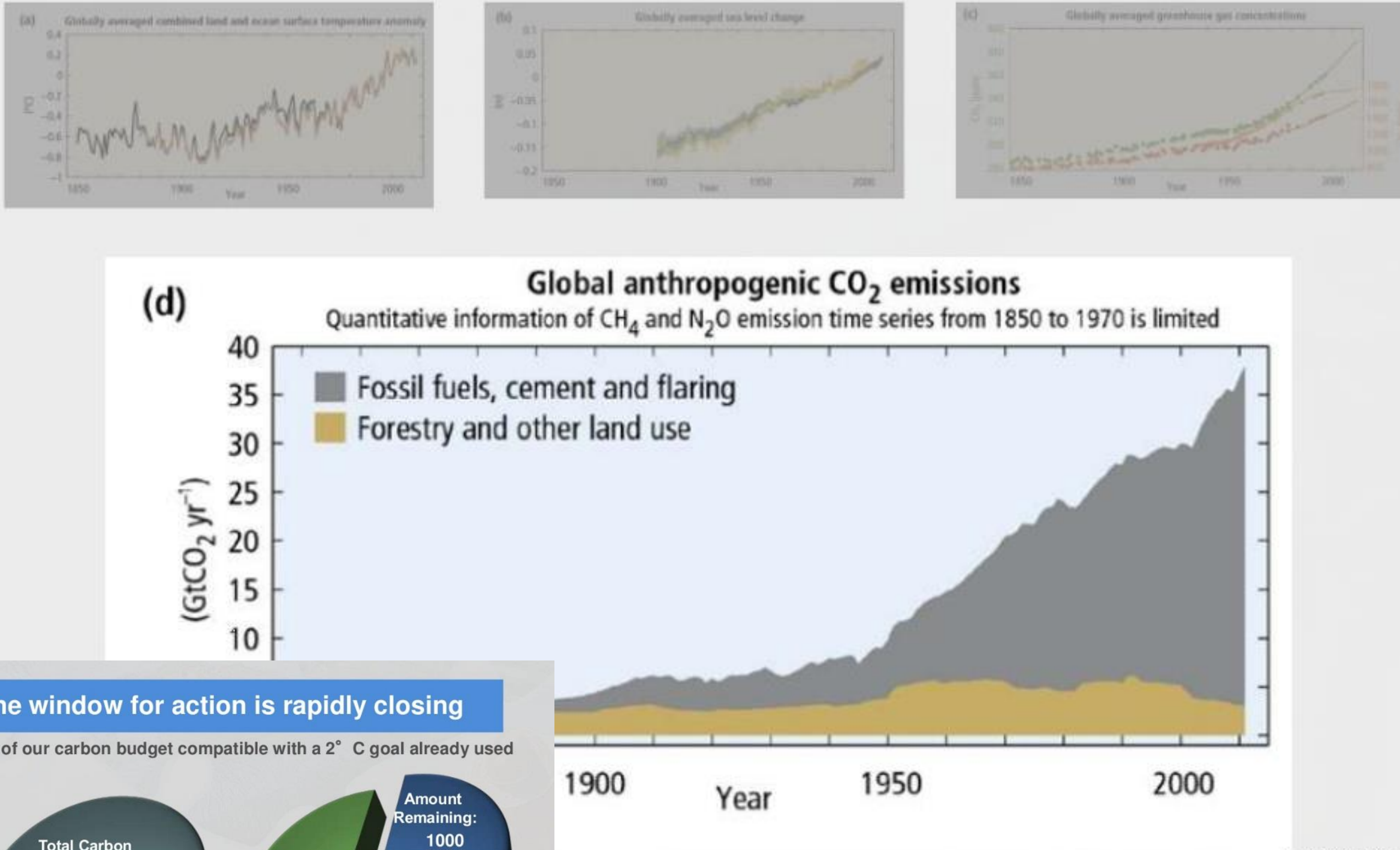
Karl Kordesch 1967

Climate change

Need to worry?

Gulf Stream

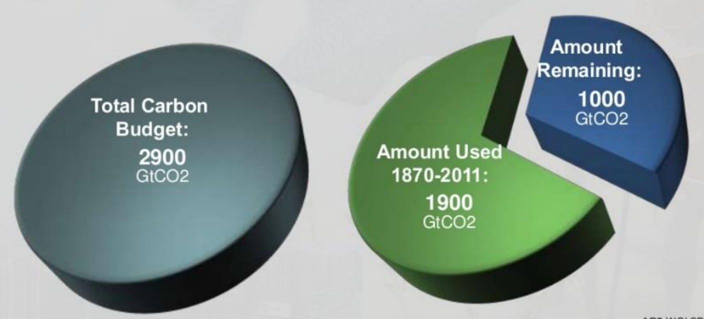

Great Ocean Conveyor Belt
ATLANTIC
OCEAN
COLD
WARM
INDIAN
OCEAN
PACIFIC
OCEAN
WARM
COLD



AR5 SYR SPM

The window for action is rapidly closing

65% of our carbon budget compatible with a 2° C goal already used



AR5 WGI SPM

IPCC AR5 Synthesis Report

INTERGOVERNMENTAL PANEL ON climate change

ipcc

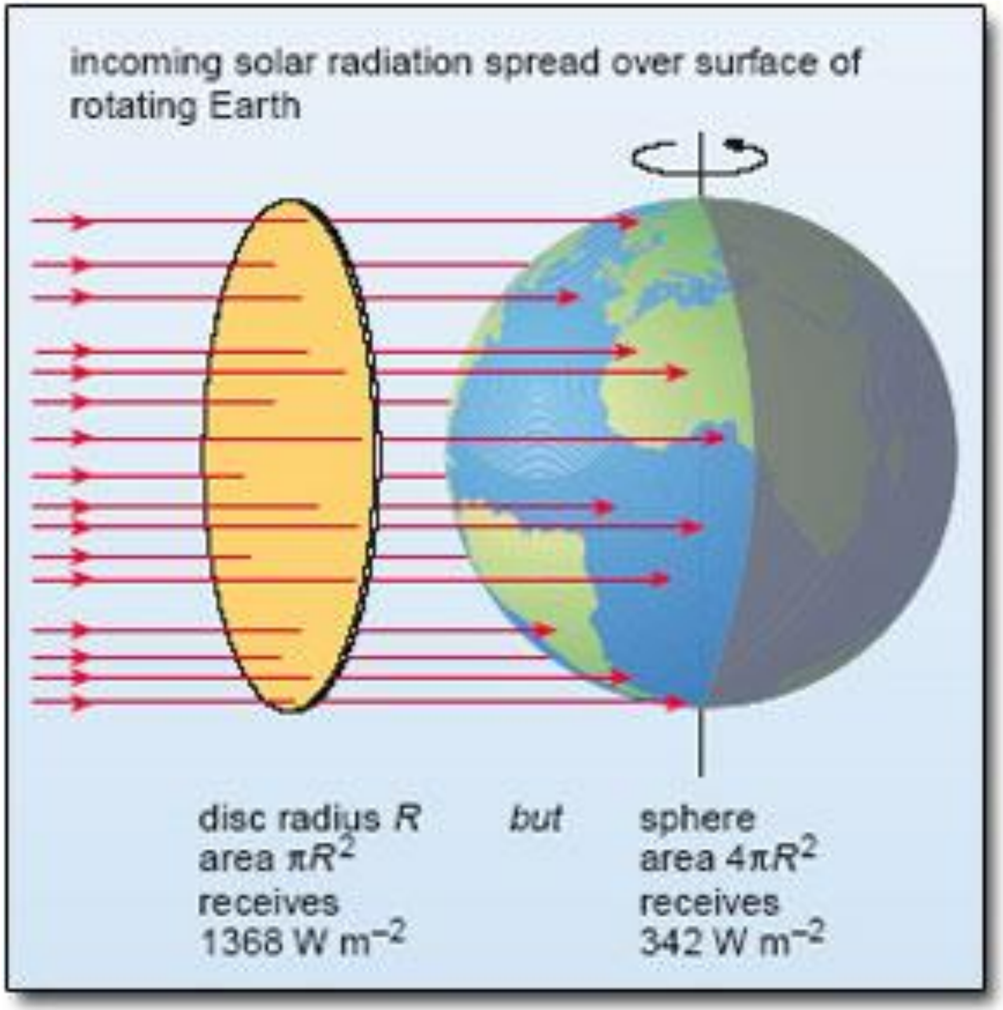
WMO UNEP

ipcc

INTERGOVERNMENTAL PANEL ON climate change

WMO UNEP

Solar influx



Total solar influx:

~ 10 000 times our energy demand.

Energy for one year
In less than one hour

Energy figures for Denmark

Energy consumption 2013

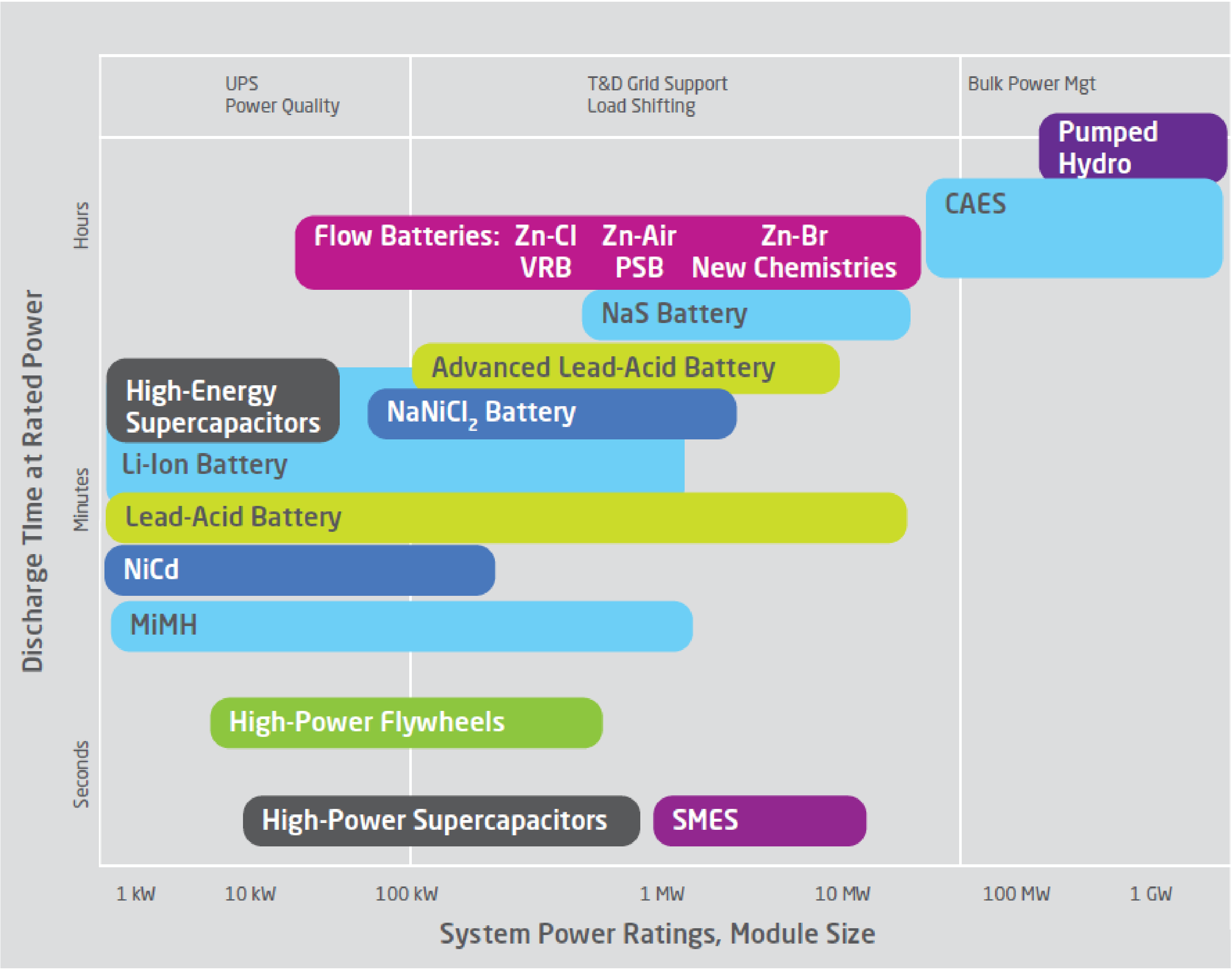
Total consumption	759 PJ
Extraction, convers., distrib.	150 PJ
Final consumption	609 PJ
- Hereof transport	*202 PJ*

DANISH ENERGY AGENCY

Potential for renewable energy		(utilized)
Electricity	1460 PJ	(26)
Heat	147 PJ	(7)
Bio mass + waste	310 PJ	(89)
Total:	1917 PJ	(122)

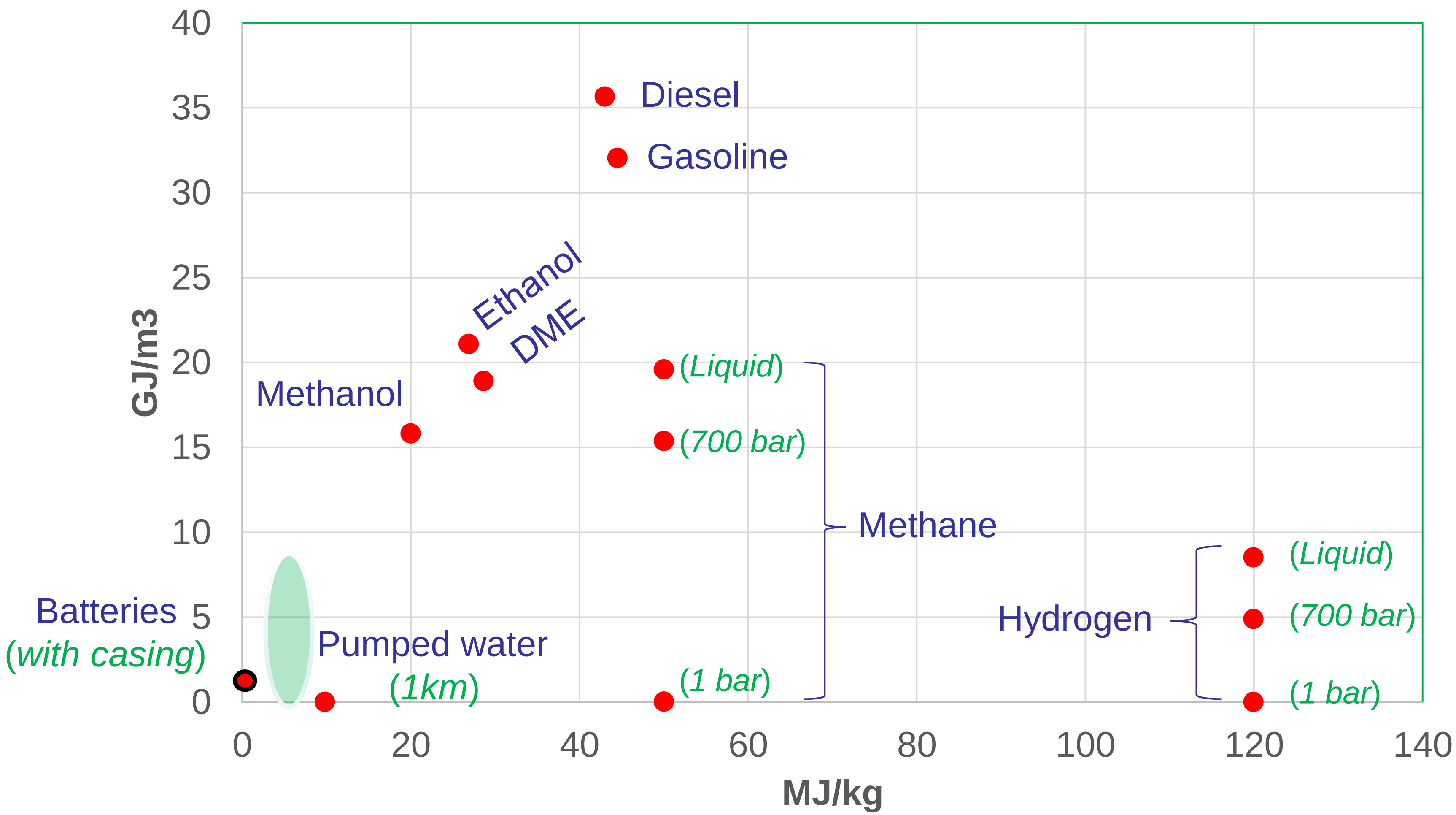
KLIMAKOMMISSIONEN
DANISH COMMISSION ON CLIMATE CHANGE POLICY

Energy storage technologies

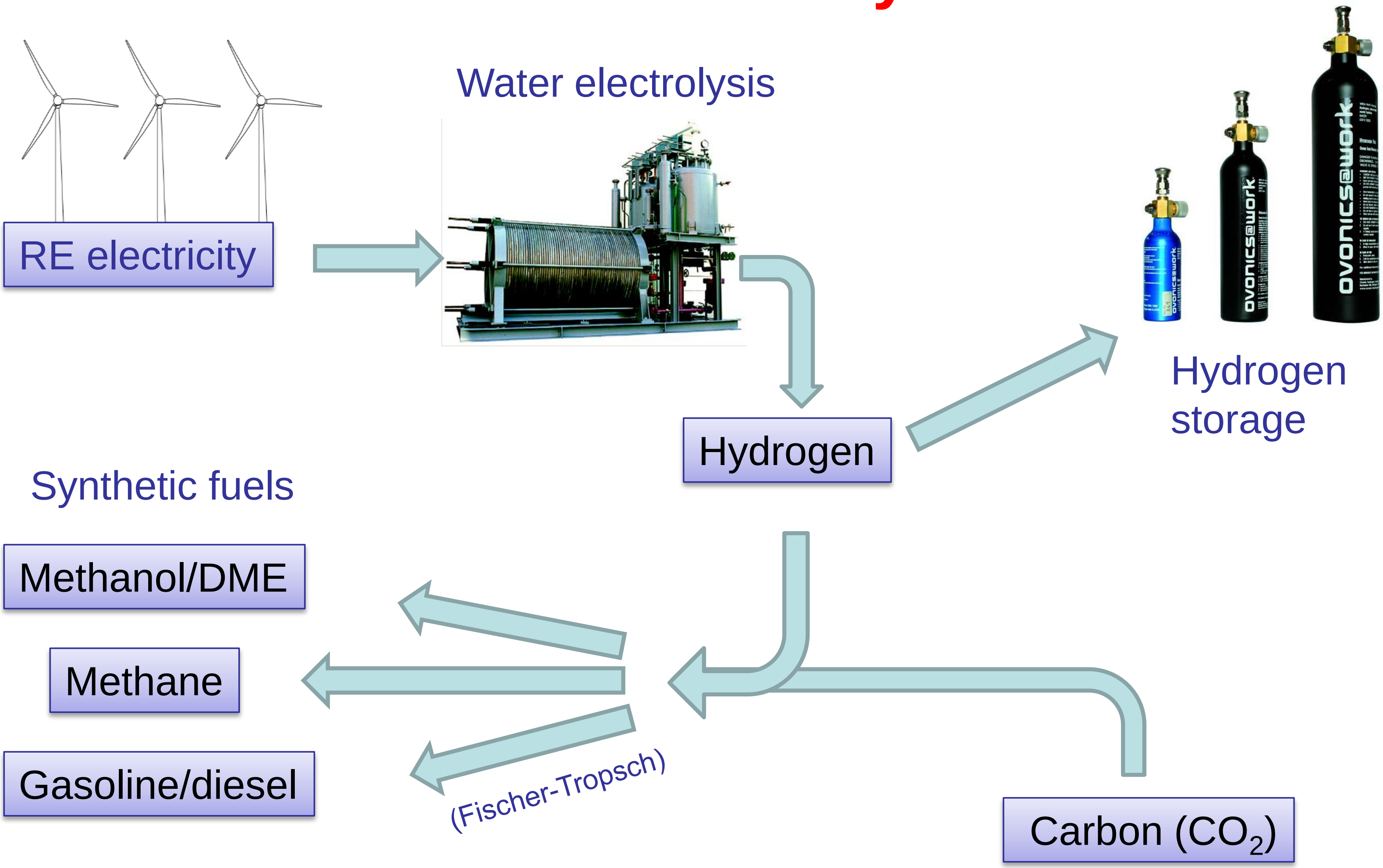


DTU International Energy Report 2013

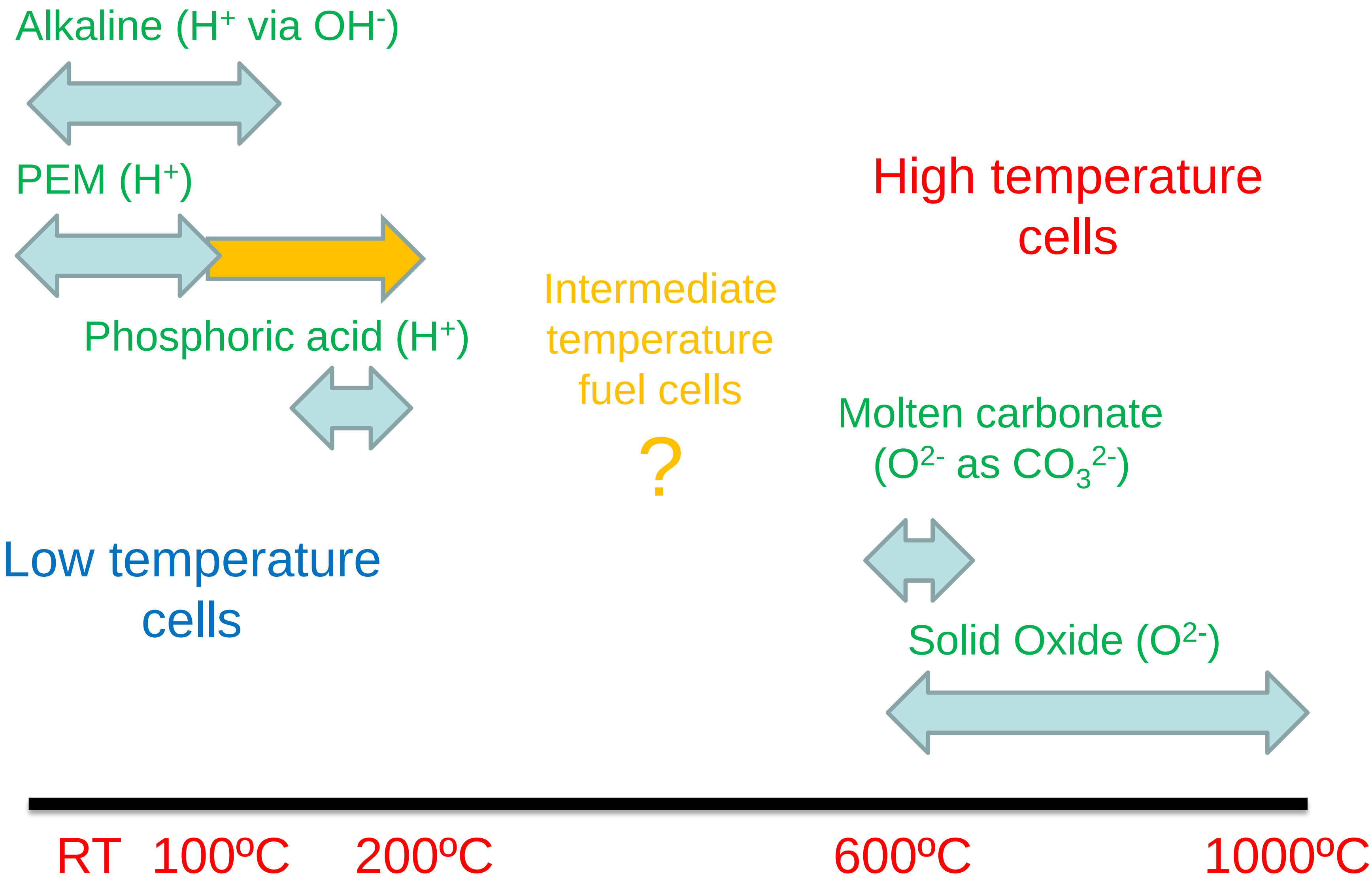
Energy storage density



Renewable electricity ⇒ Fuel



Fuel cell/electrolyzer temperatures



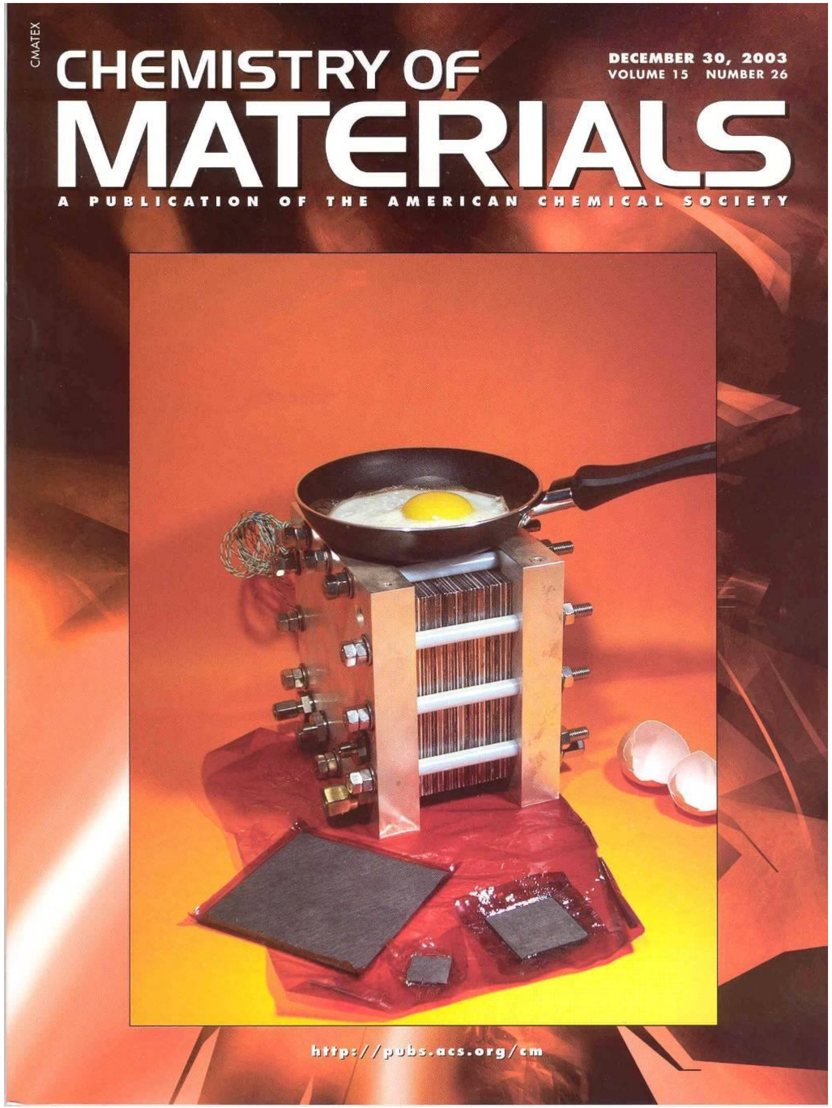
Why high temperature PEM fuel cells

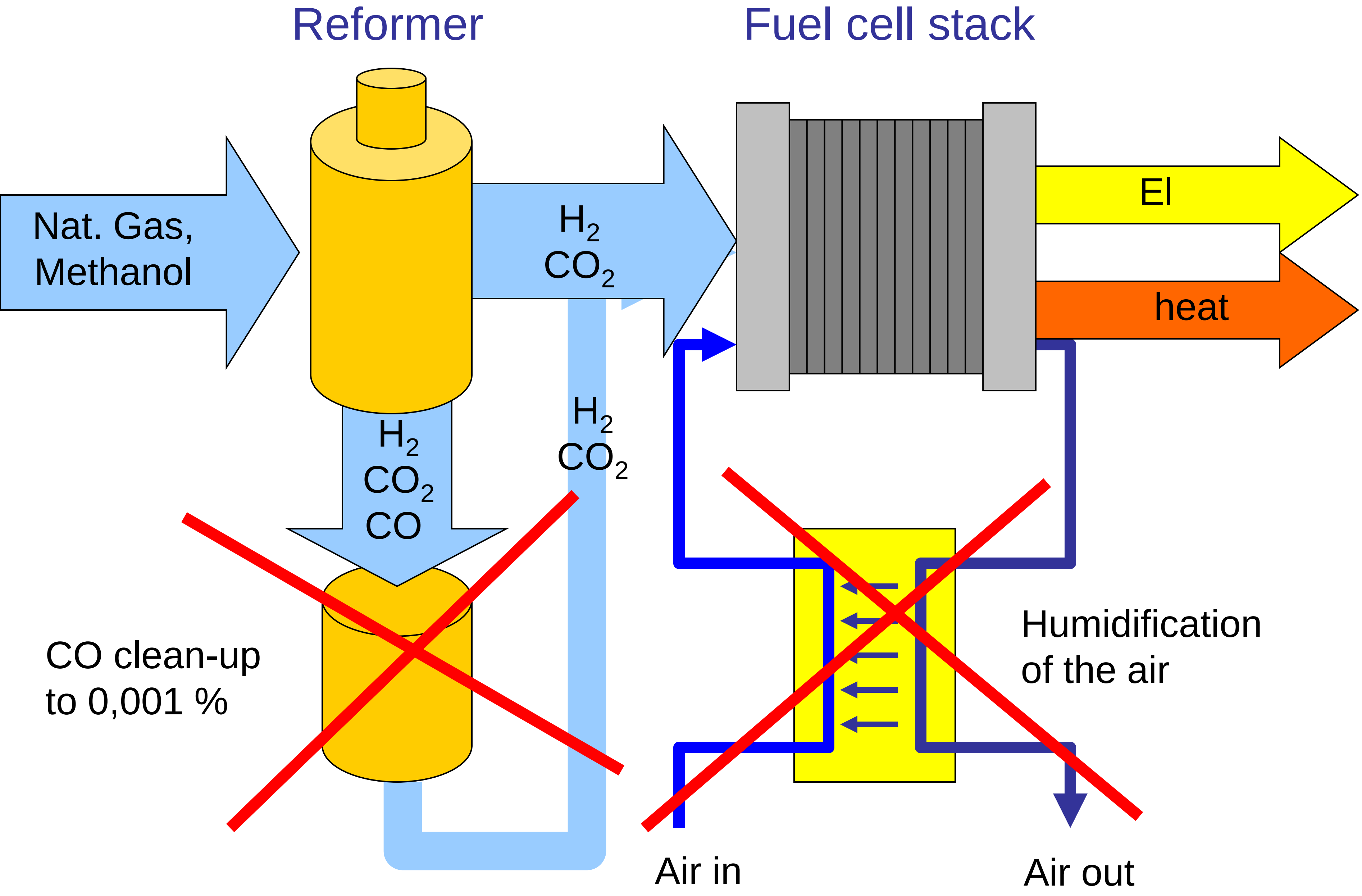
Low temperature
– a key advantage of PEMFC

- Many materials available
- Limited degradation (?)
- Easy start-up
- Limited heat losses for micro-cells

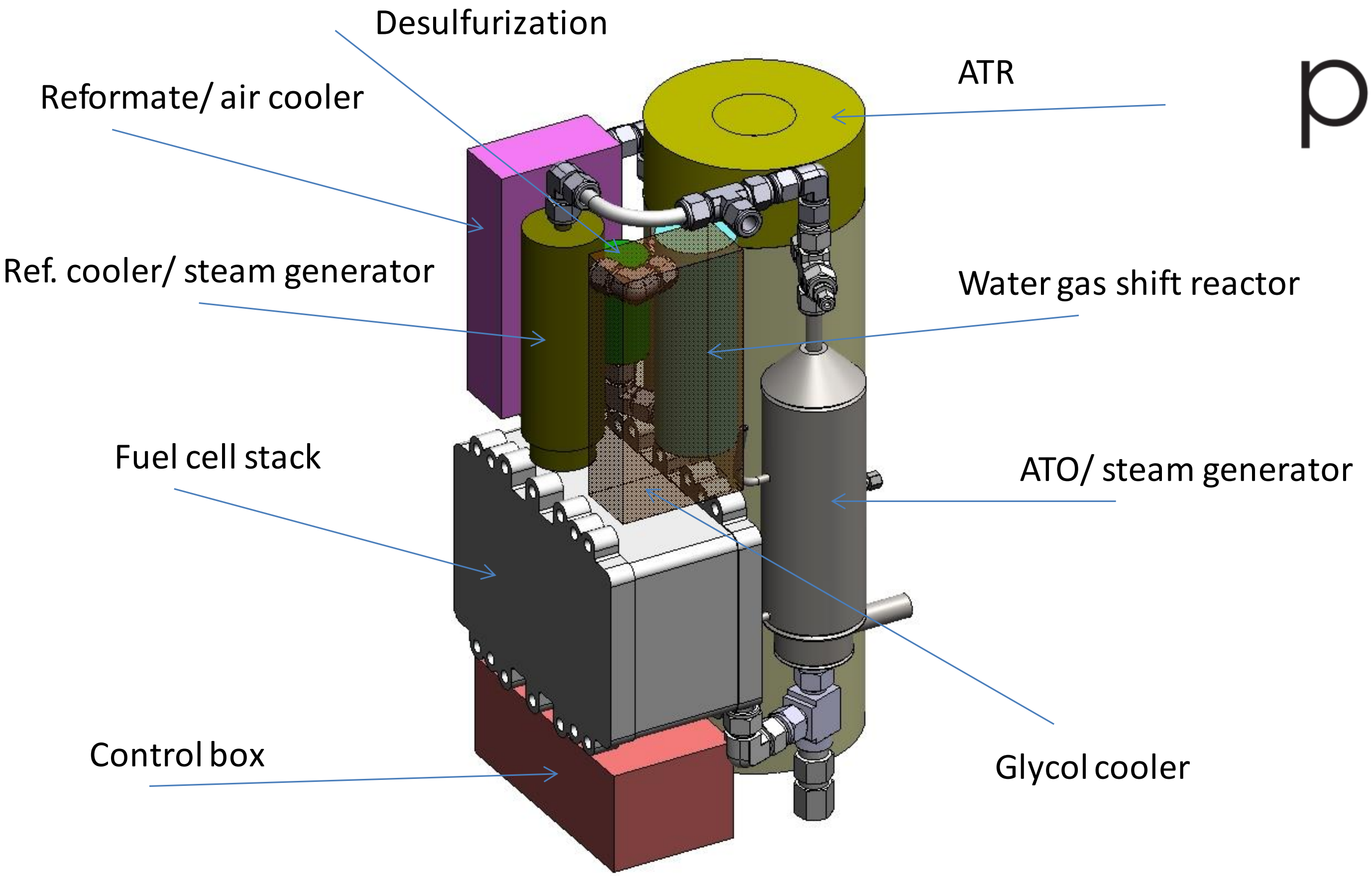
Advantages of higher temperature

- Better kinetics (cheaper catalysts?)
- Higher CO tolerance
- No water management - No liquid water
- Higher value of excess heat
- Easier cooling
- Alternative fuels?




Reformer
Fuel cell stack
Nat. Gas,
Methanol
H_2
CO_2
El
heat
H_2
CO_2
H_2
CO_2
CO
CO clean-up
to 0,001 %
Humidification
of the air
Air in
Air out

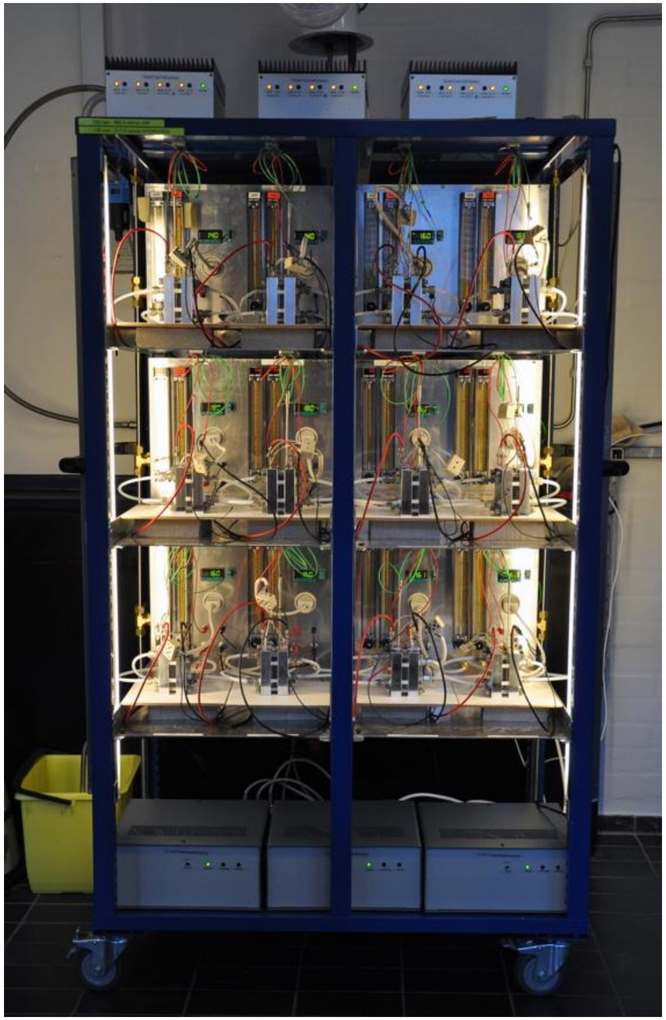
PURE Project (EU FP7)

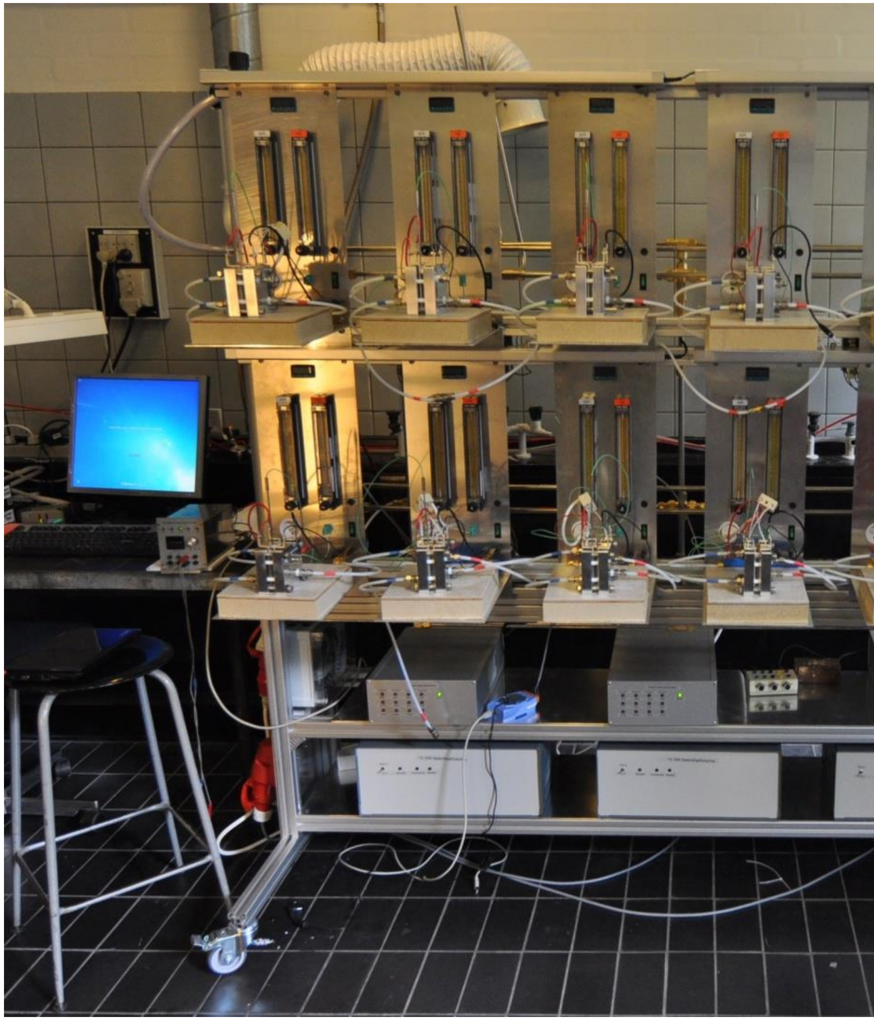


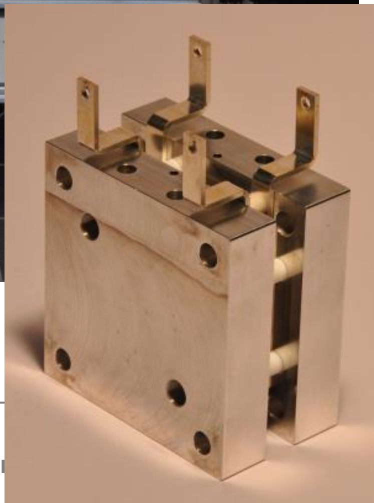
Auxiliary power unit for boats (on propane)

Activities at DTU

Single cell durability

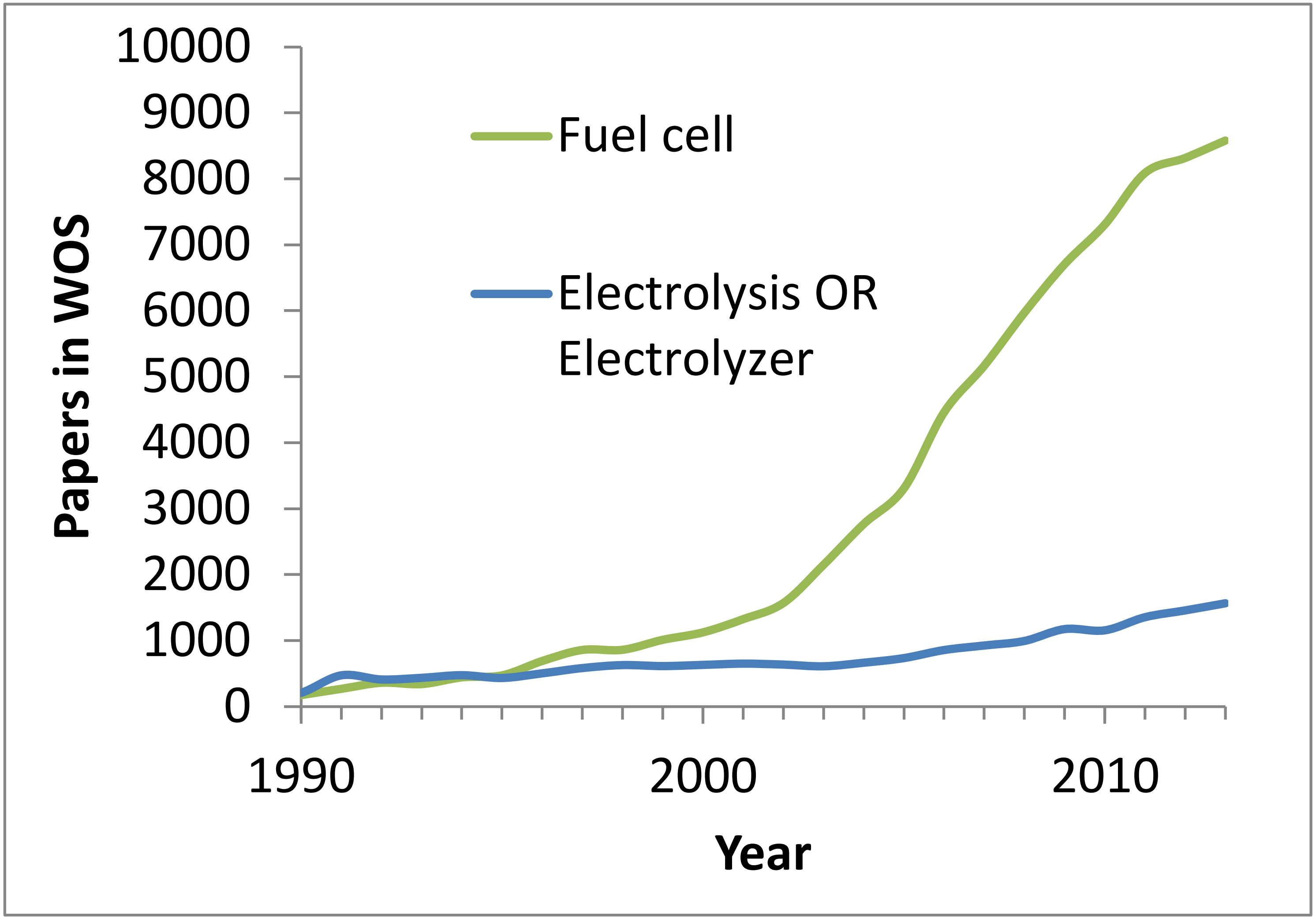






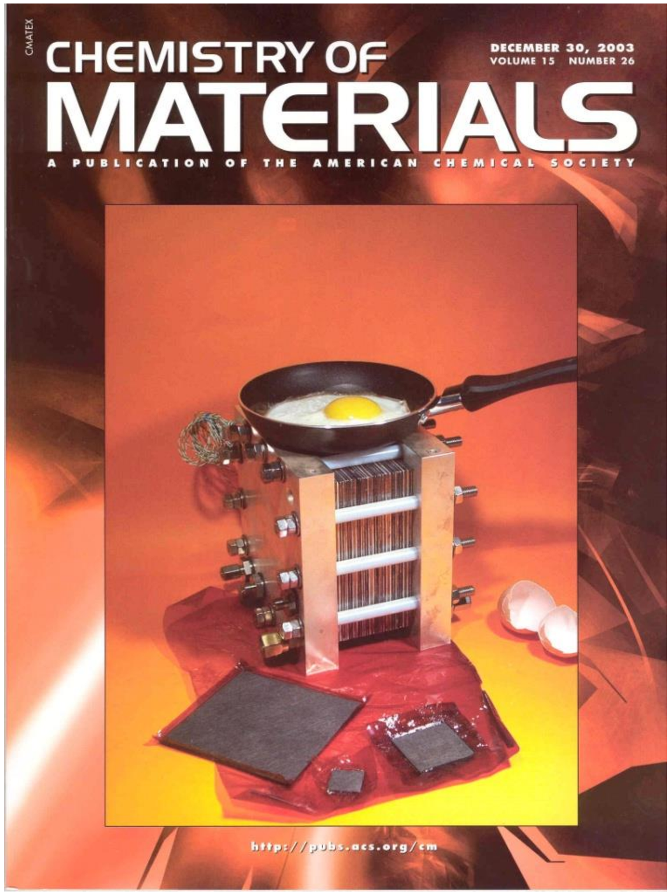
2 X 12 channel test bench (cells 10 cm^2)

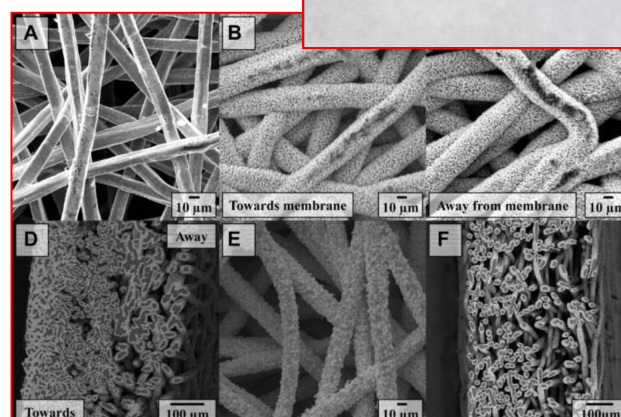
Research in fuel cells and electrolyzers



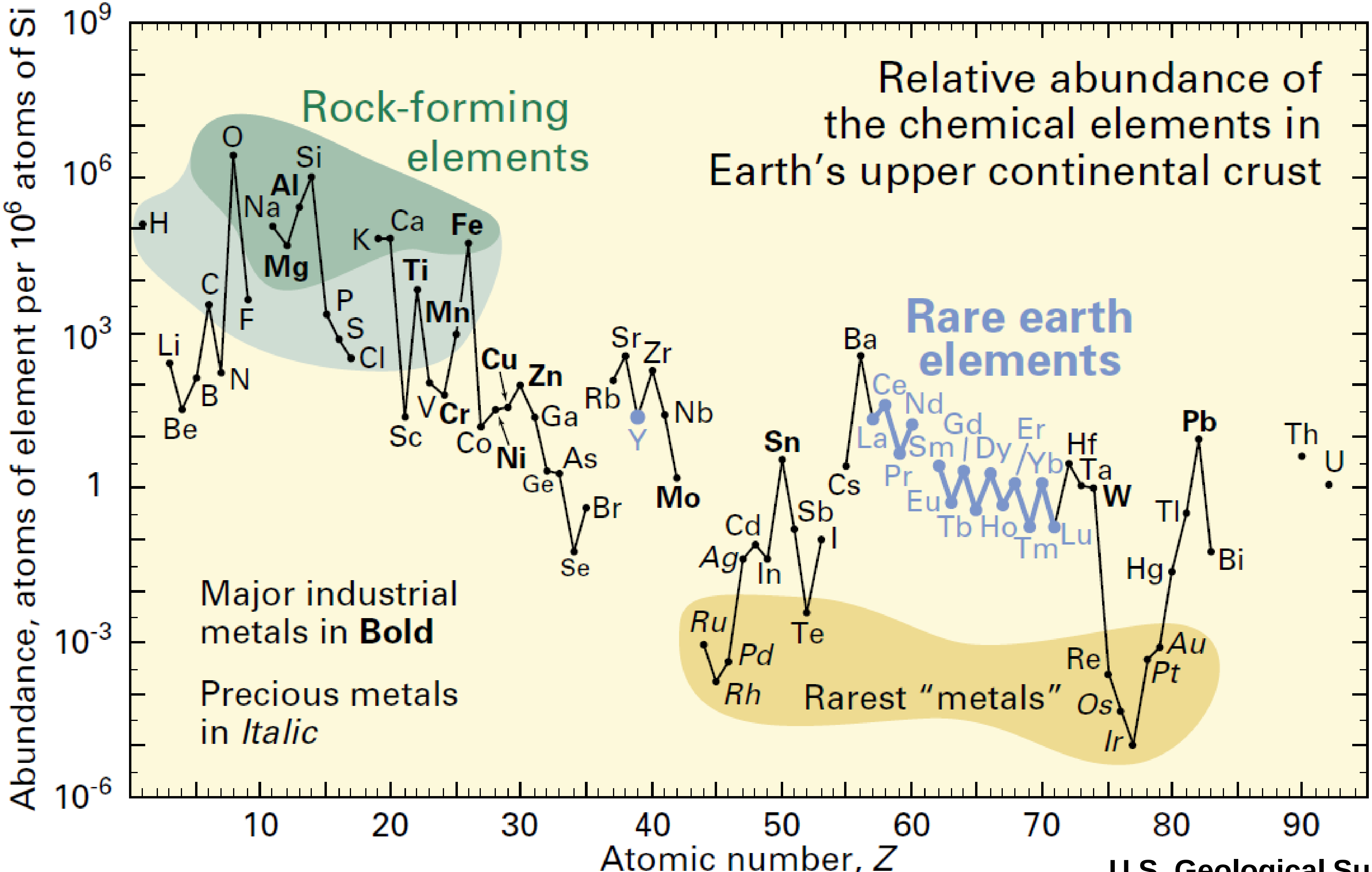
Why not make electrolyzers ?

High temperature PEM fuel cells ⟹ High temperature PEM electrolyzers



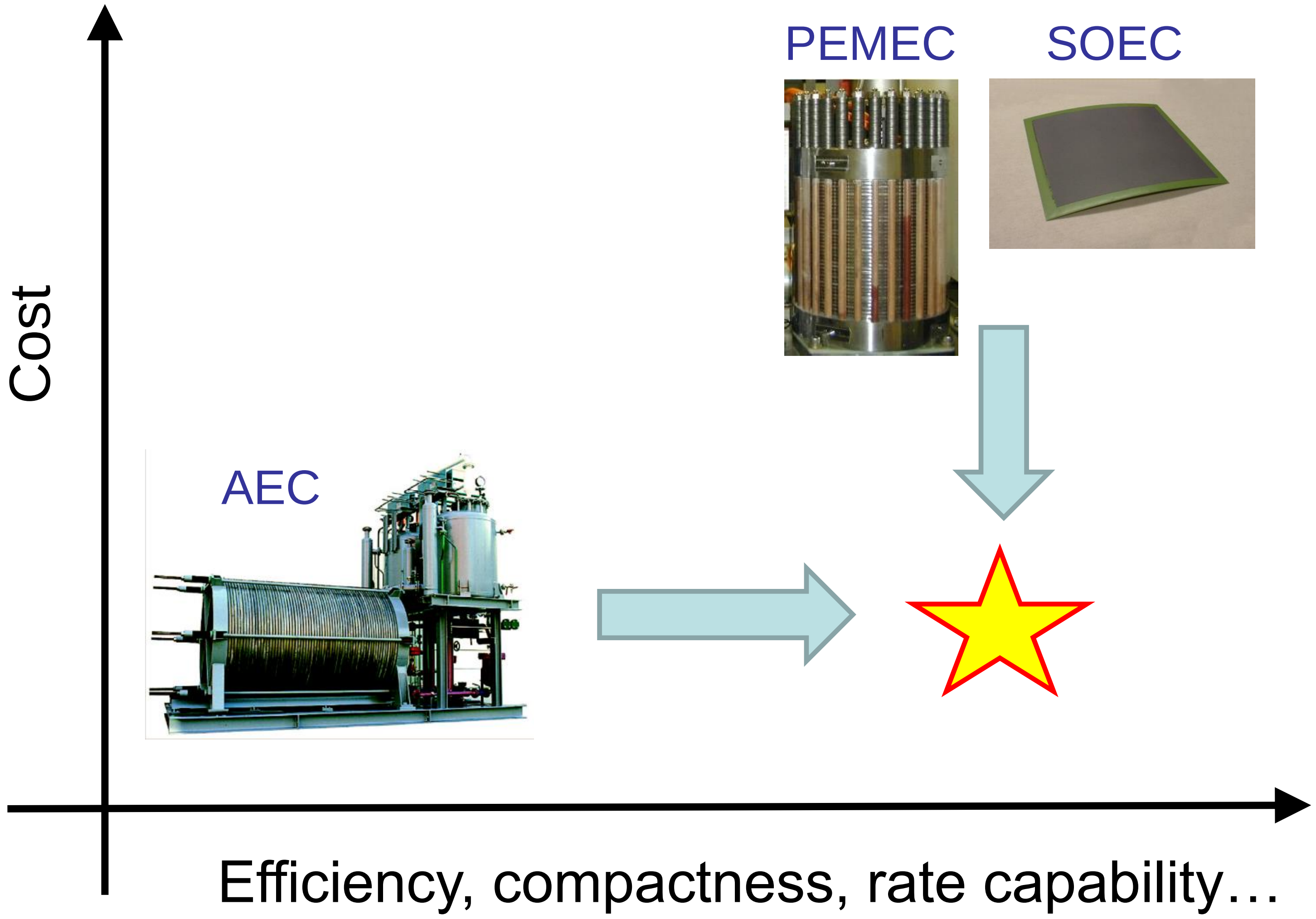


Elemental abundance

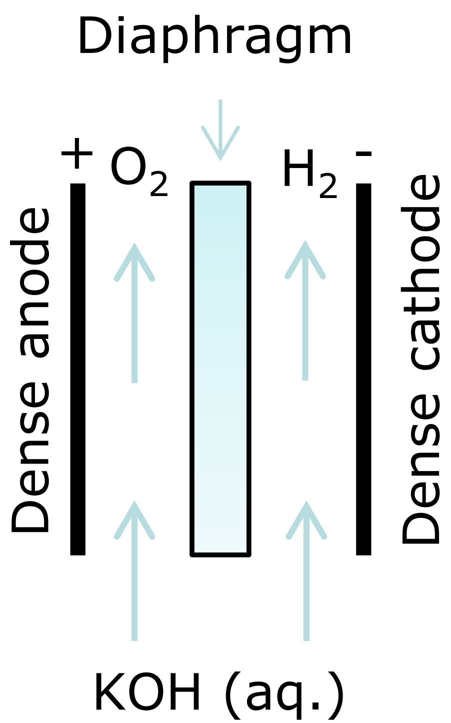


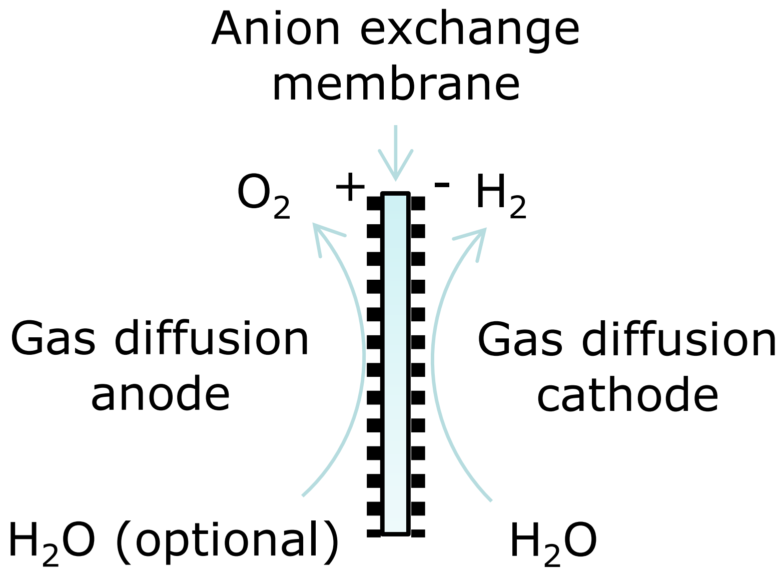
U.S. Geological Survey
Fact Sheet 087-02

Efficient low cost electrolyzers



Improvement of alkaline water electrolysis





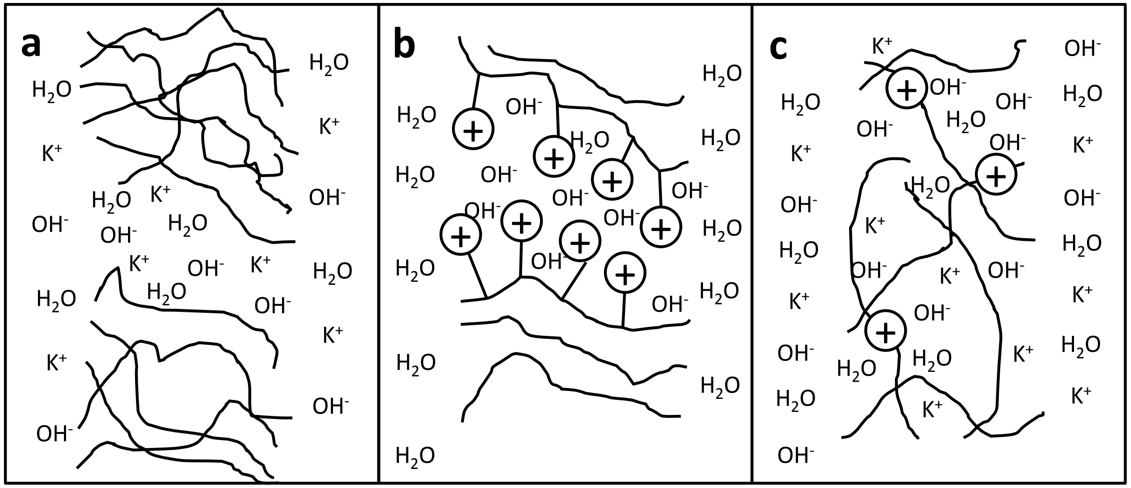
Traditional gap design

- Mature
- Inexpensive
- Low current

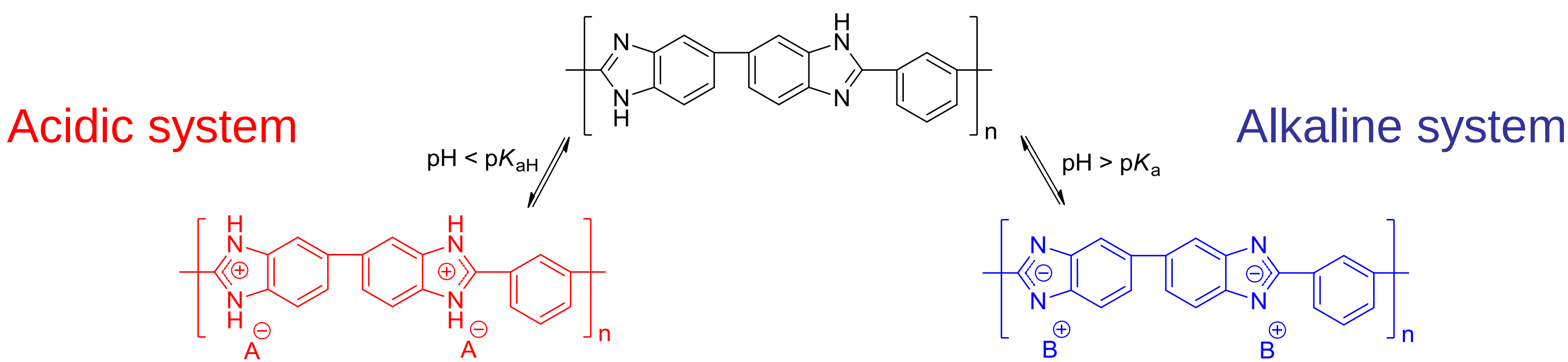
Zero gap design

- Immature
- Gas diffusion electrodes
- High current

Ways to anion conducting polymer membr.



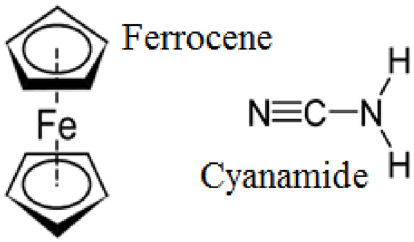
Porous membrane (diaphragm)	Ion exchange membrane	Imbibed (doped) membrane



$A^{\ominus}$ = *e.g.* $H_2PO_4^-$, HSO_4^-, $CF_3SO_3^-$

$B^{\oplus}$ = *e.g.* Na^+, K^+

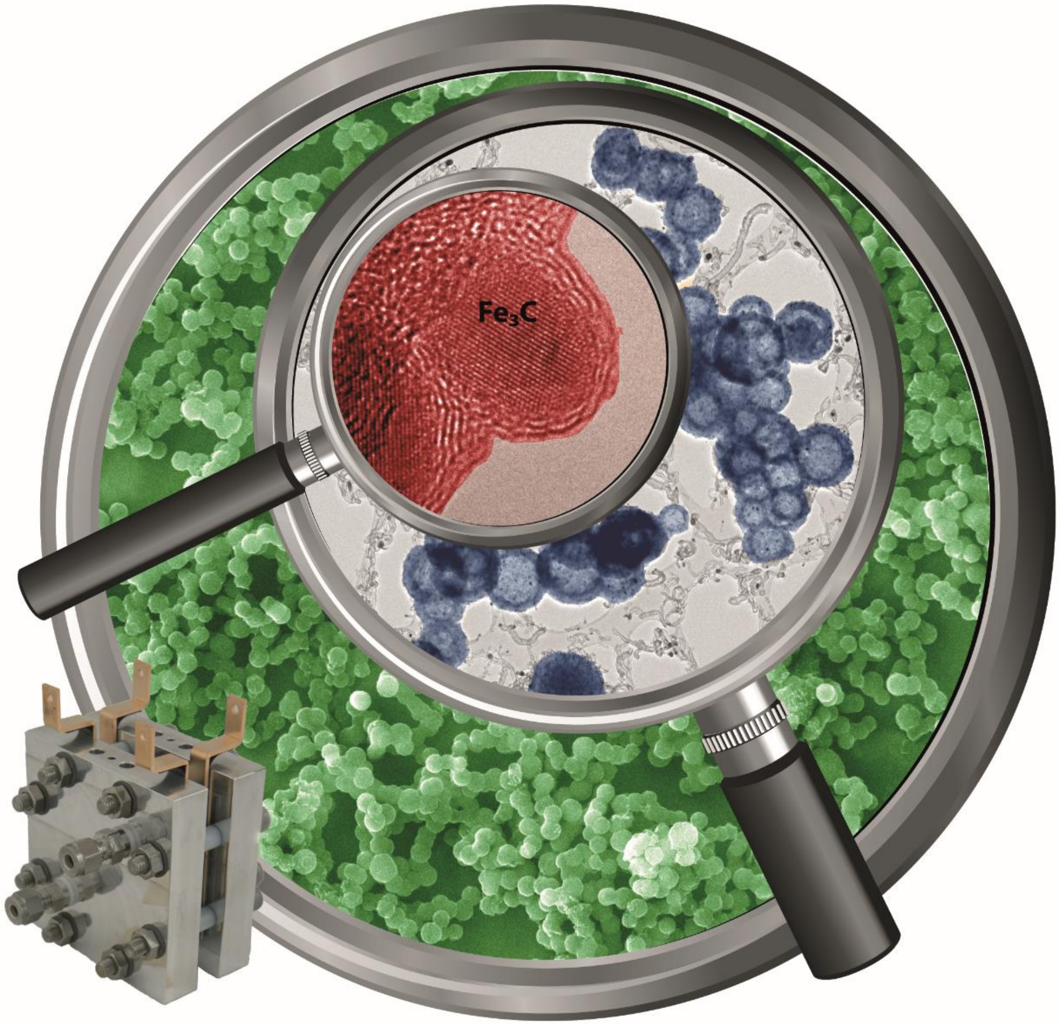
Platinum free catalysts



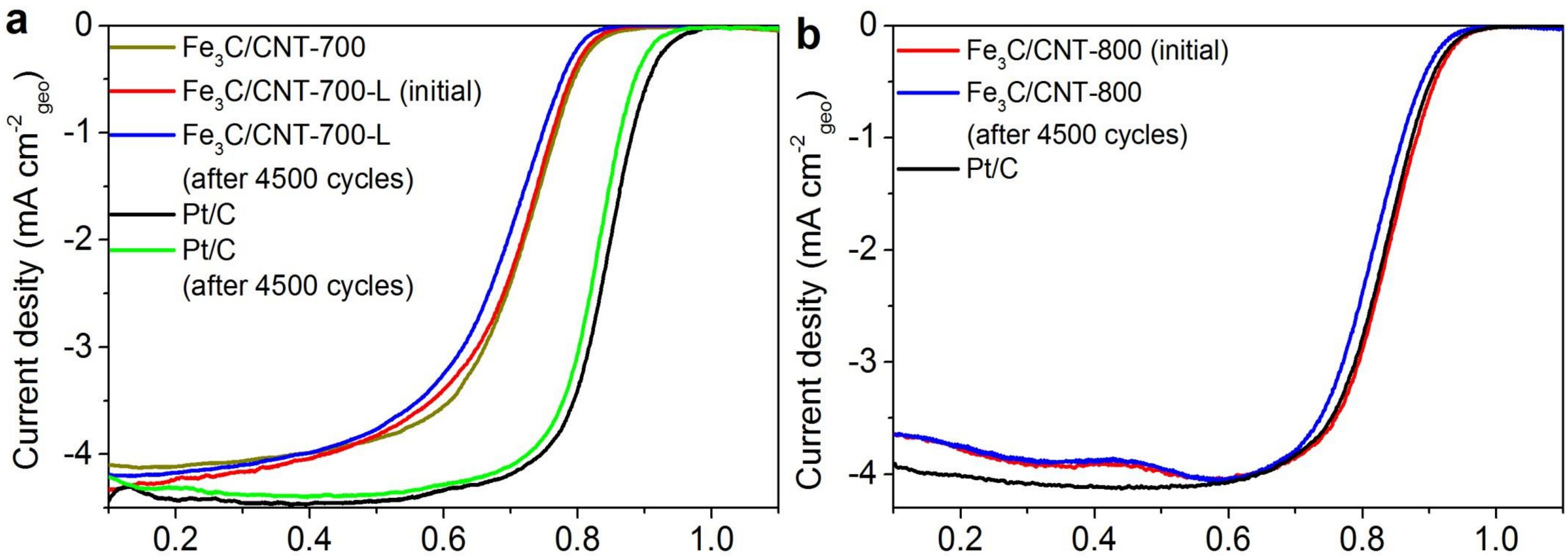
Starting material

Autoclave

500-800°C



Activity experiments



E vs. RHE

E vs. RHE

Acidic (0.1 M $HClO_4$)

Alkaline (0.1 M KOH)

Y. Hu, J. O. Jensen, W. Zhang, L. N. Cleemann, W. Xing, N. J. Bjerrum, Q. Li, *Angew. Chem. Int. Ed*. **53** (2014) 3675.

Fuel cell driving in Denmark

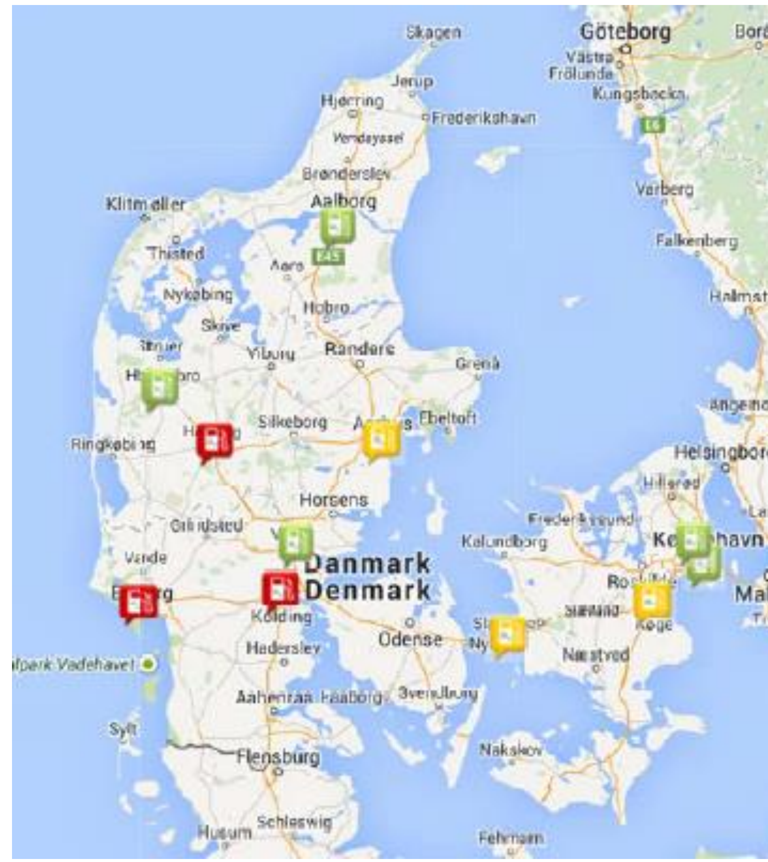
Active

Decided/construction

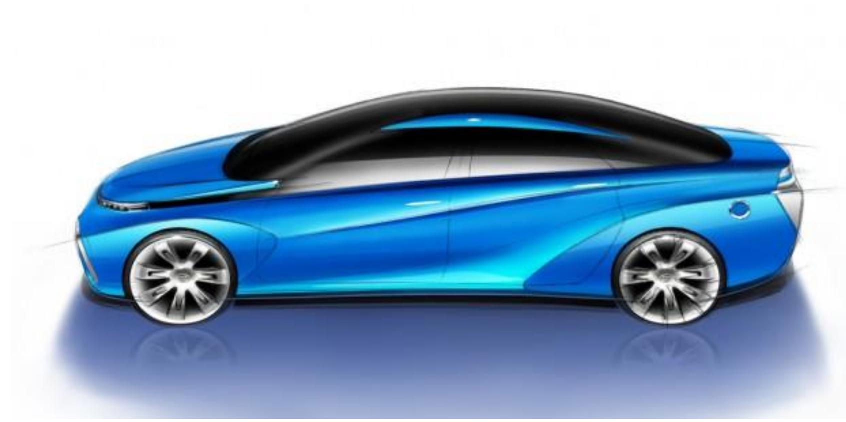
Planned

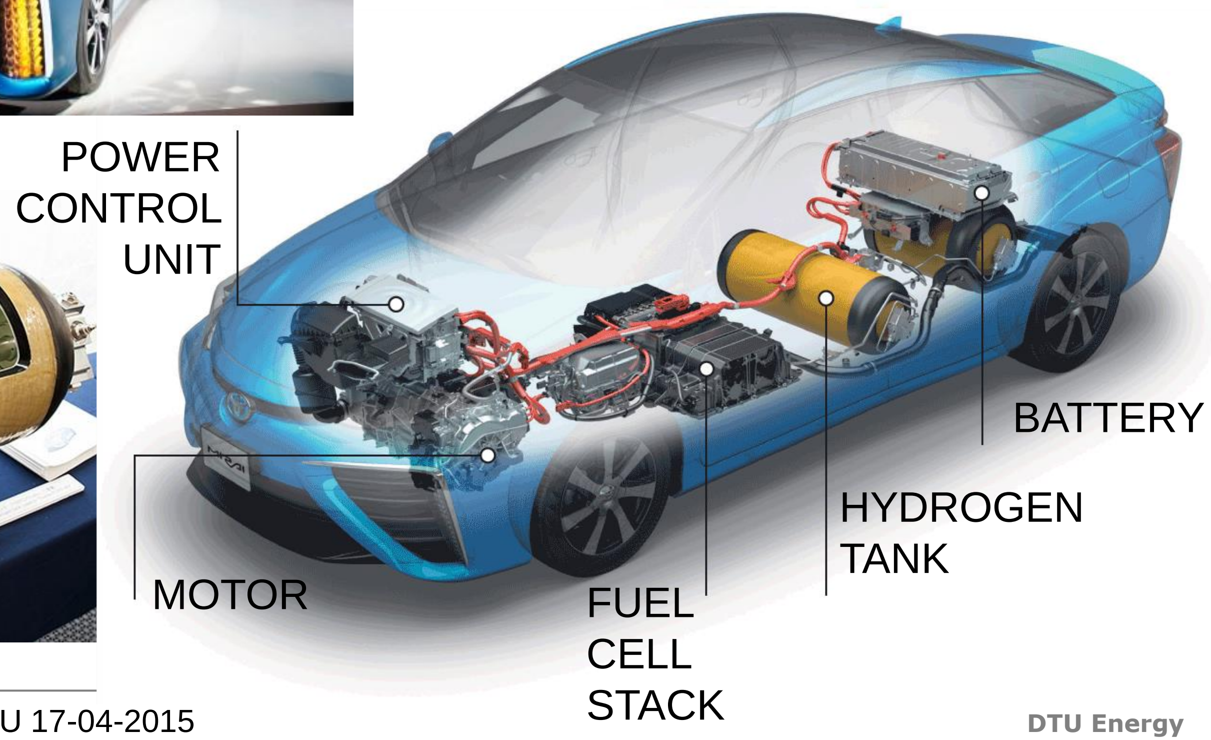
Copenhagen (Sydhavnen)

15 Hyundai 2013

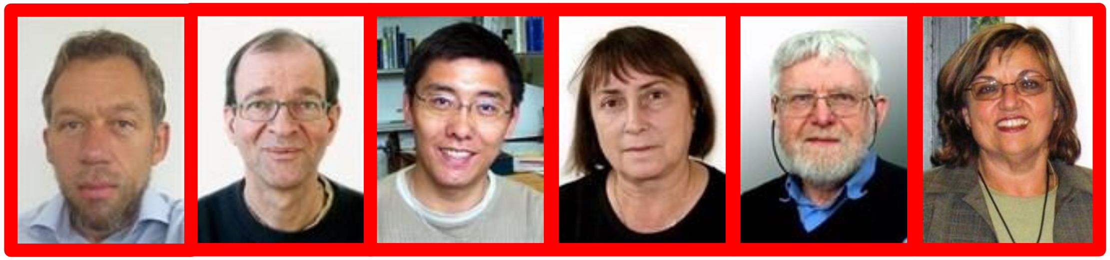


Toyota FCV from 2015



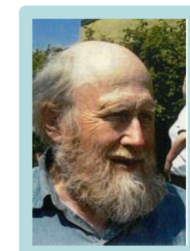


Meet the Proton Conductors



Seniors

Technicians



Scientists/Post docs

PhD students

Secretary

Guest

Danmarks Tekniske Universitet DTU

Inaugural Lectures

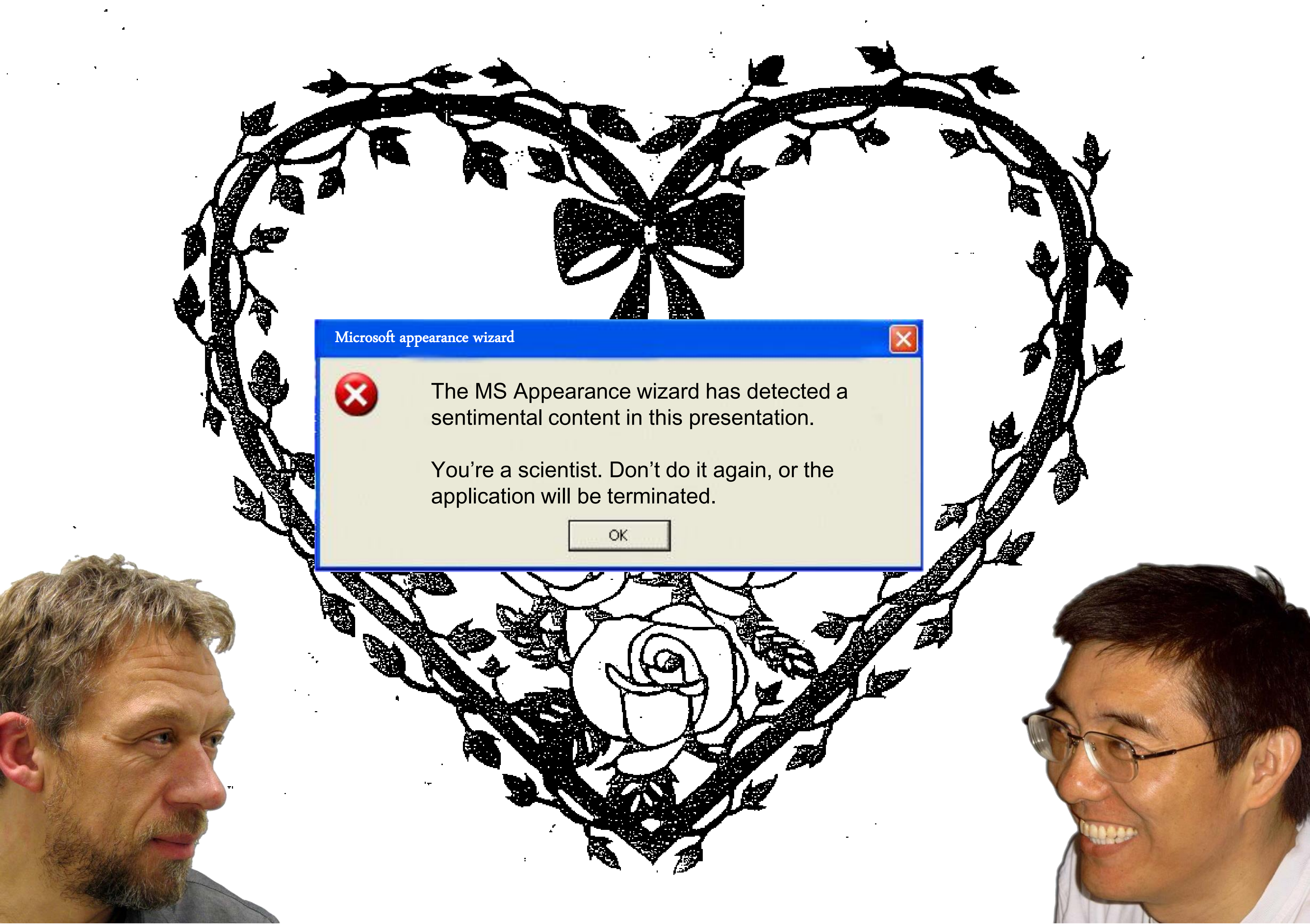
On 1 December 2014 Jens Oluf Jensen and Qingfeng Li were appointed professors at DTU Energy.

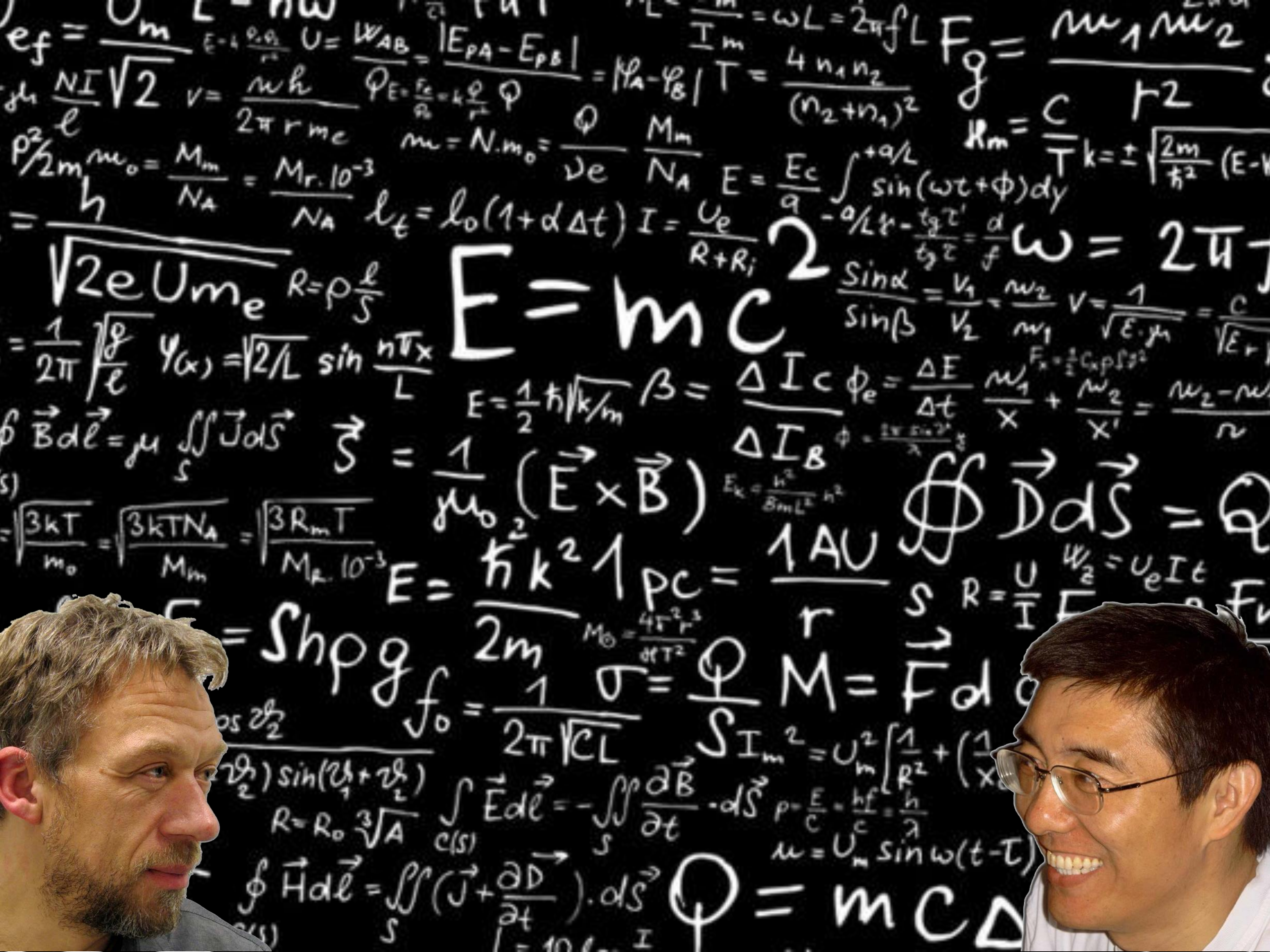
We cordially invite you to their inaugural lectures on Friday, 17 April at 2.30-4.15 PM at Technical University of Denmark in Lyngby, building 101A, meeting room 1, Anker Engelundsvej 1, 2800 Lyngby. First, Jens Oluf Jensen will talk on "Hydrogen Energy by Means of Proton Conductors", followed by Qingfeng Li's lecture "Proton Conducting Fuel Cells where Electrochemistry Meets Material Science".

After the lectures there will be a reception.

Yours sincerely

Søren Linderoth
Head of department


Microsoft appearance wizard
The MS Appearance wizard has detected a sentimental content in this presentation.
You’re a scientist. Don’t do it again, or the application will be terminated.
OK



E=mc²
S = 1/μ₀ (E×B)
Q=mcΔ
M=Fd
ω = 2π