CHALMERS

THE FUEL CELL GROUP
CHALMERS

Improving Lifetime Performance of SOFC for Truck APUs

(Förbättringar av livslängden av fastoxidbränsleceller-APU för tunga fordons applikationer)

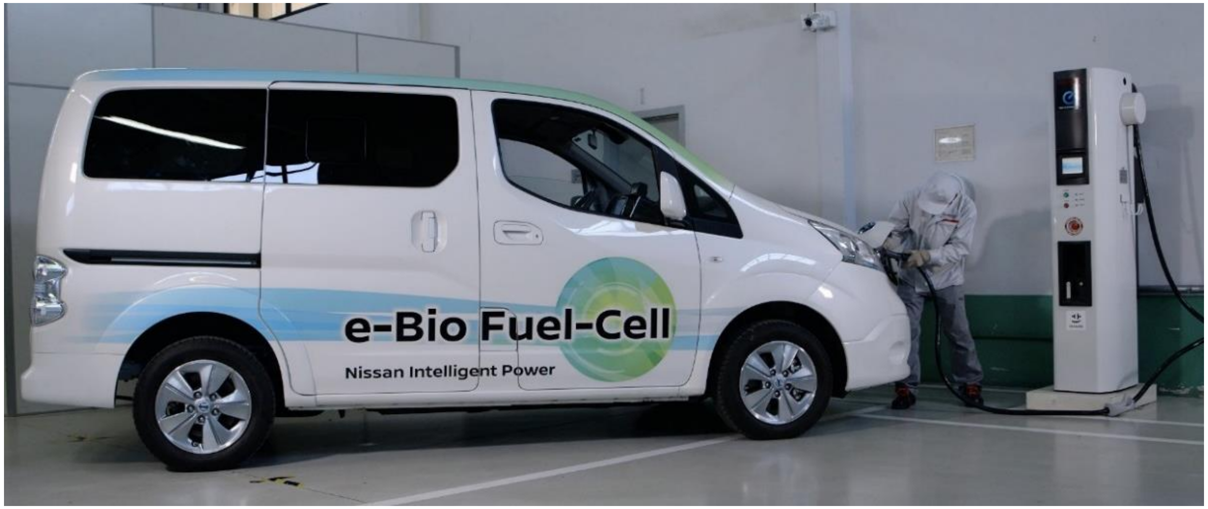
Hannes Falk Windisch, Jan Froitzheim and Jan-Erik Svensson

Energy and Materials
Chemistry and Chemical Engineering
Chalmers University of Technology

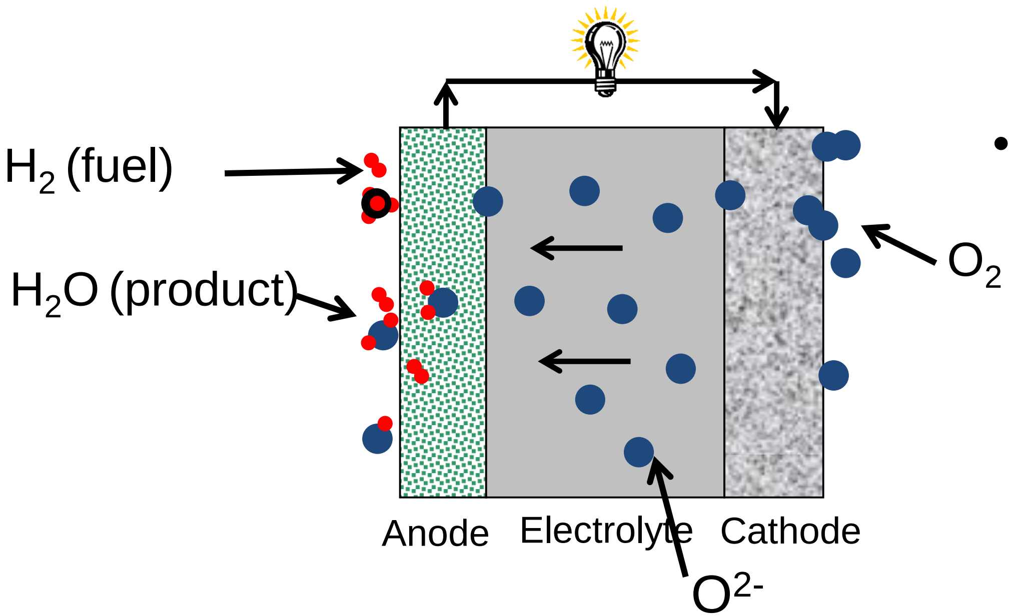
Outline

Part I: Overview SOFC Technology

Part II: Recent results from the FFI project



Solid Oxide Fuel Cell (SOFC)



Advantages

- High electrical efficiency

- O^{2-} conductive electrolyte
  - Fuel flexibility (H_2, natural gas, biogas.. diesel)
- High operating temperature
  - No need for expensive catalysts such as Pt

The electrolyte is a oxygen ion conducting material (600-900 ºC)

SOFC as APU for mobile applications

350k+ Heavy Duty Trucks in the US

Produce 11 Mt CO_2, 18 kt NOX, 5 kt particulate matter

Electrical efficiency: 4%

<u>SOFC APU:</u>
Fuel: Diesel
Function: cabin climatisiation, electrification, engine pre-heating

Electrical efficiency[1]: 30%

[1] *http://www.desta-project.eu/desta-project/*

Nissan Unveils World's First Solid-Oxide Fuel Cell e-NV200

- A electric car with a 5 kW SOFC system and a 30 liter thank for bio-ethanol.
- Range: 600 km (compared to 170 km without the SOFC range extender)

*http://insideevs.com/nissan-unveils-worlds-first-solid-oxide-fuel-cell-vehicle-e-nv200-sofc/

Nissan has finalised an agreement with Horsham-based Ceres Power (SOFC) to develop fuel cell technology that will be an alternative to hydrogen

Range is a limiting factor for electric vehicles at the moment

http://www.proactiveinvestors.co.uk/companies/news/127565/ceres-powers-up-alongside-nissan-127565.html#?platform=hootsuite

The FFI project

Energimyndigheten

Projectpartners

CHALMERS

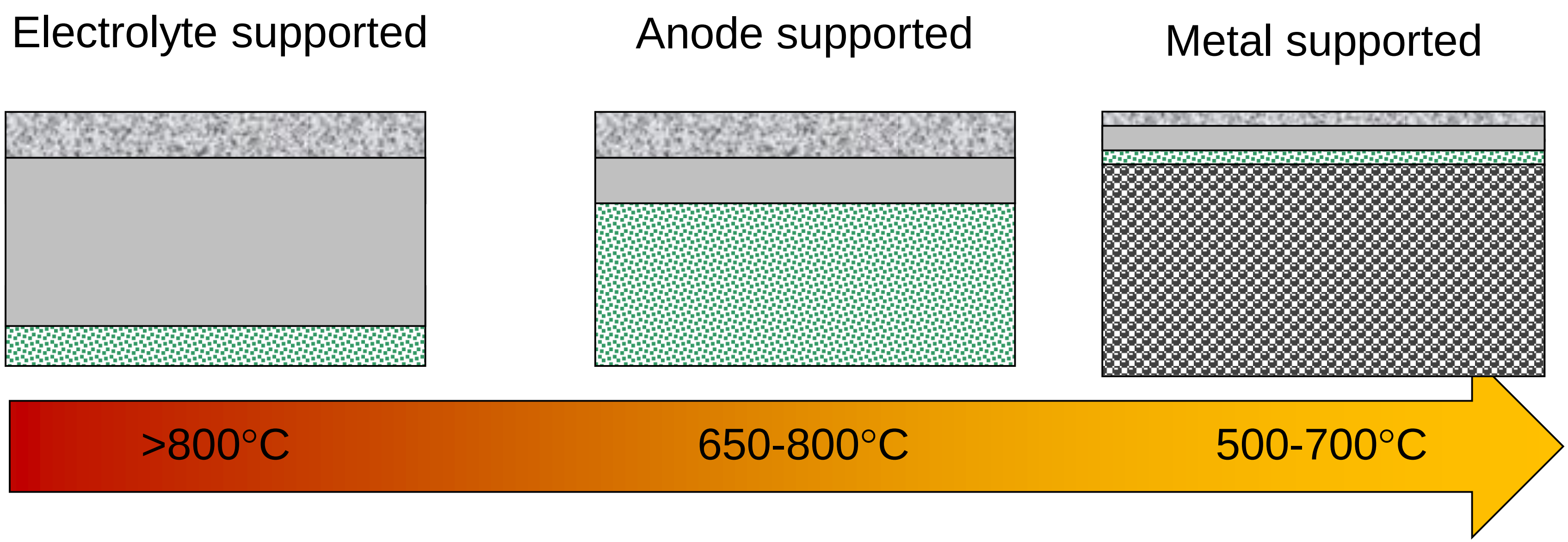
SANDVIK → Fuel cell technology elcogen → VOLVO

Objectives

Improving Lifetime and Performance of SOFC for Truck APUs
- In a cost efficient way

- Improve oxidation resistance at the cathode and the anode side
- Reduce chromium evaporation
- Reduce costs! Cheaper steel, cheaper coating methods

Solid Oxide Fuel Cell (SOFC)

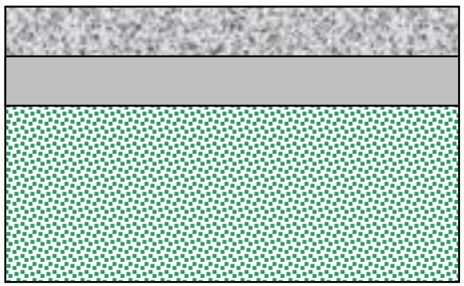


There is a general trend towards lower operating temperatures.

$\Rightarrow$ Possibility to use less expensive materials
$\Rightarrow$ Higher efficiency possible
$\Rightarrow$ Longer lifetimes
$\Rightarrow$ Faster heating/cooling

Solid Oxide Fuel Cell (SOFC)

Anode supported



650-800 °C

Fuel cell technology elcogen

Versa Power Systems

FuelCell Energy Ultra-Clean, Efficient, Reliable Power

NEW ENERGY GENERATION SOLID POWER

Solid Power
(SOFCpower and Ceramic Fuel Cells)

ENGEN™ 2500

Scale: refrigerator

Scale: dishwasher

BlueGEN

NEW ENERGY GENERATION
SOLID POWER ®

Product specs	EnGen-2500	BlueGEN
▪ Electricity power output (net, AC)	2.5 kW	1.5 kW
▪ Electric efficiency (net AC, LHV)	50%	**60%**
▪ Cogeneration efficiency (LHV)	**90%**	85%
▪ Modulation range	1:3	1:3
▪ Installation	Floor standing	Floor standing
▪ Grid connection	On-grid	On-grid

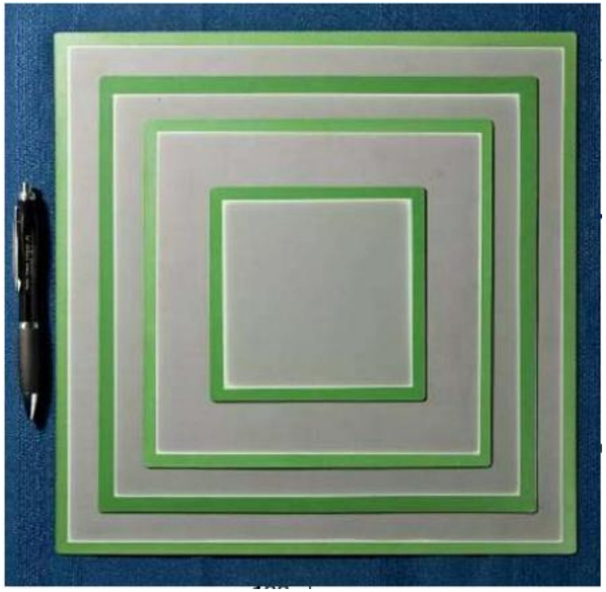
60% net AC
(74% DC single pass)

Versa Power Systems

FuelCell Energy
Ultra-Clean, Efficient, Reliable Power

Versa Power/ Fuel Cell Energy

Incorporated the larger-scale SOFC components into fuel cell stacks as large as 60 kilowatts (kW).



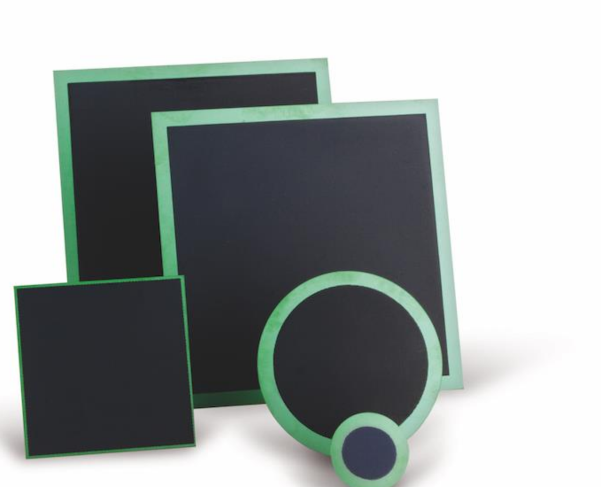
33 x 33cm cells

Fuel cell technology
elcogen

Our project partner is Elcogen

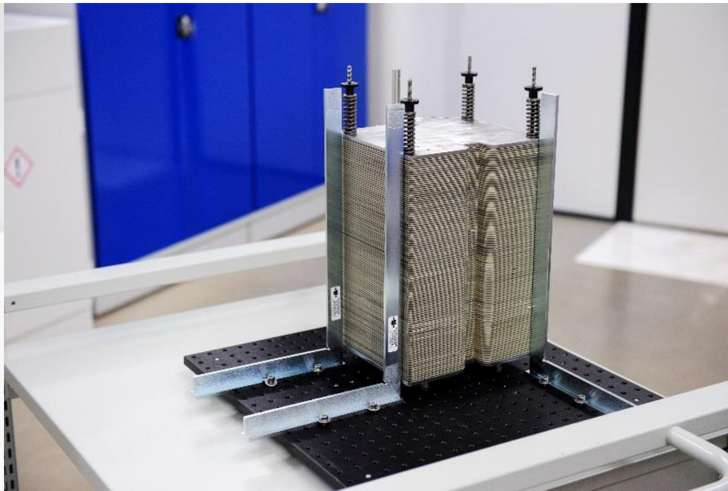
Elcogen is a Finnish/Estonian SOFC developer selling cells and stacks

Single cells



1 kW stack

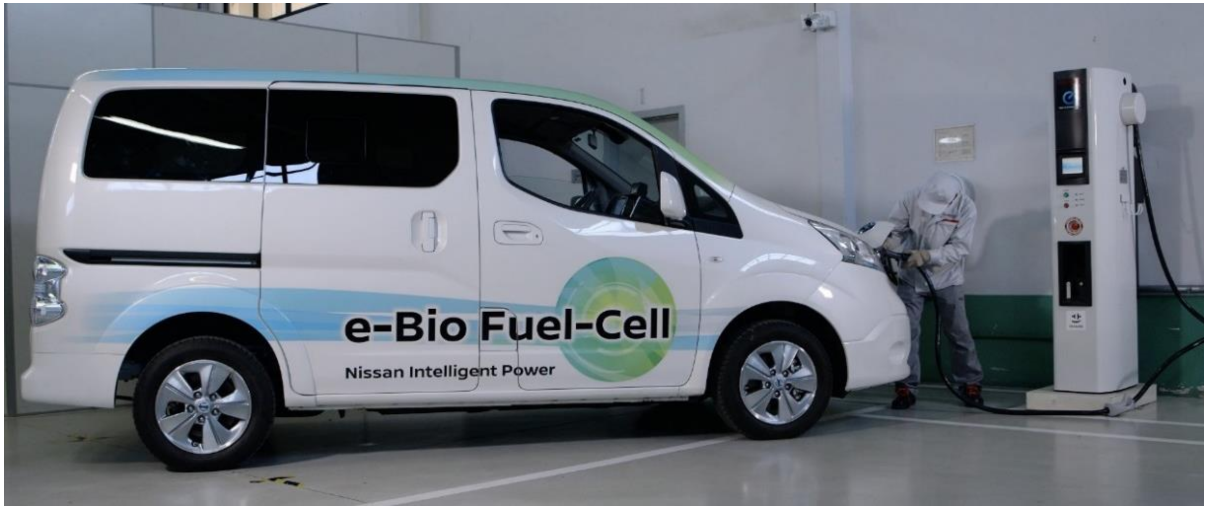
3 kW stack



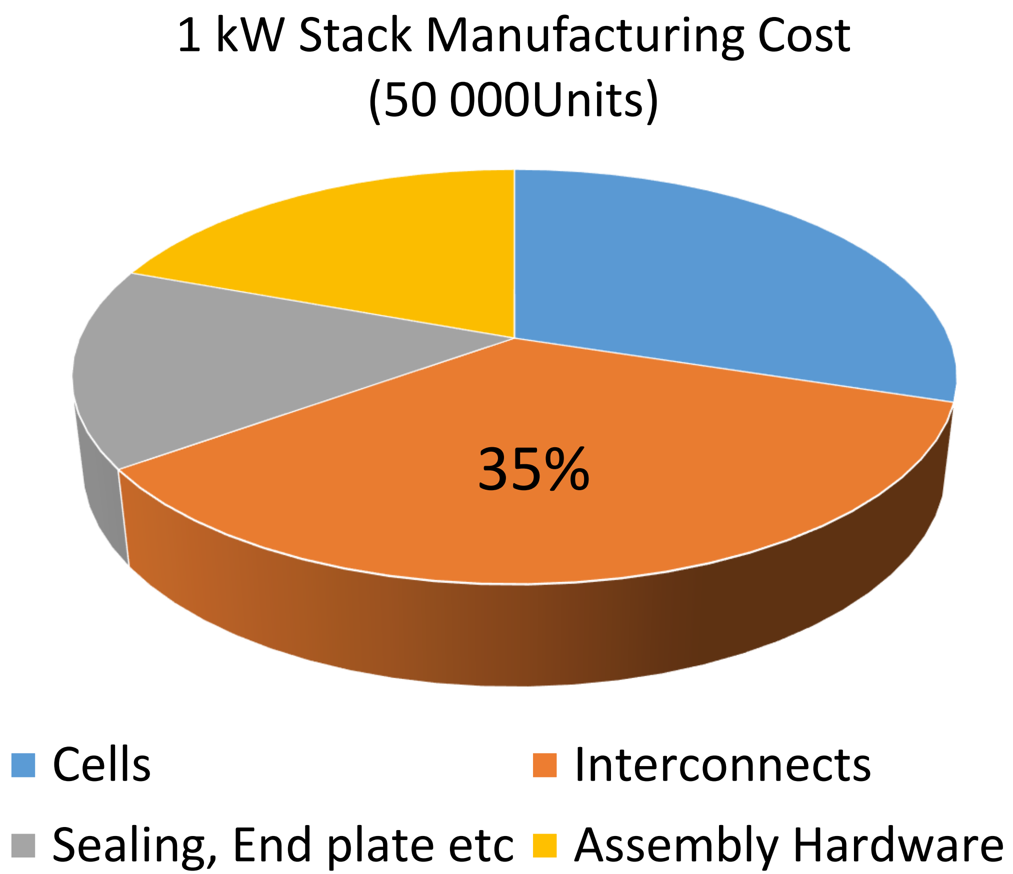
Outline

Part I: Overview SOFC Technology

Part II: Recent results from the FFI project



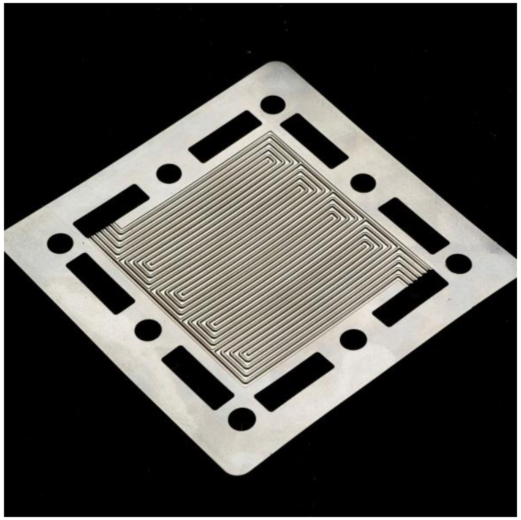
Cost analysis 1 kW Stack



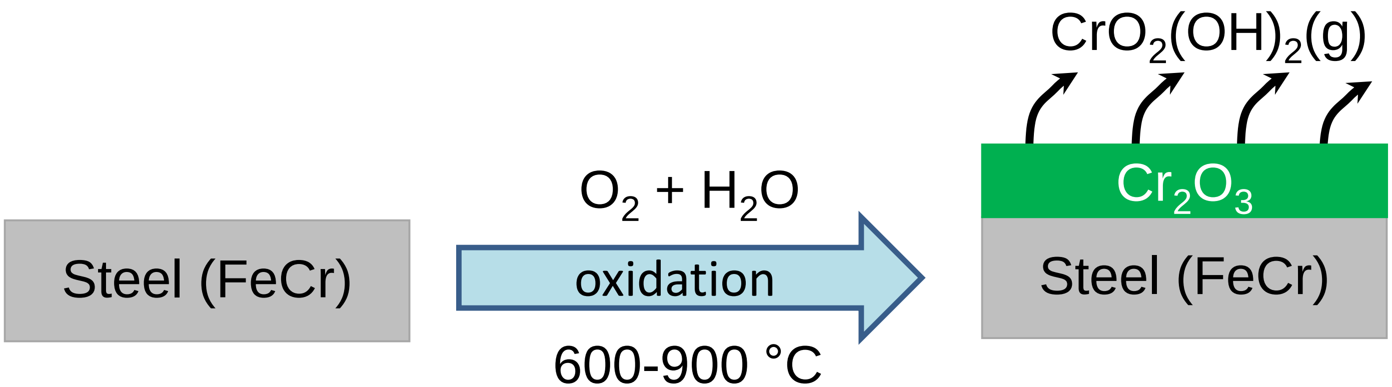
*Source: Battelle study prepared for US DOE (2014)

Ferritic Cr_2O_3-forming steels as interconnect material in SOFC

- Similar thermal expansion as the ceramics used in SOFC
- Good electrical and thermal conductivity
- Form conductive oxide scales (Cr_2O_3)
- Formability
- Cheap to produce



However

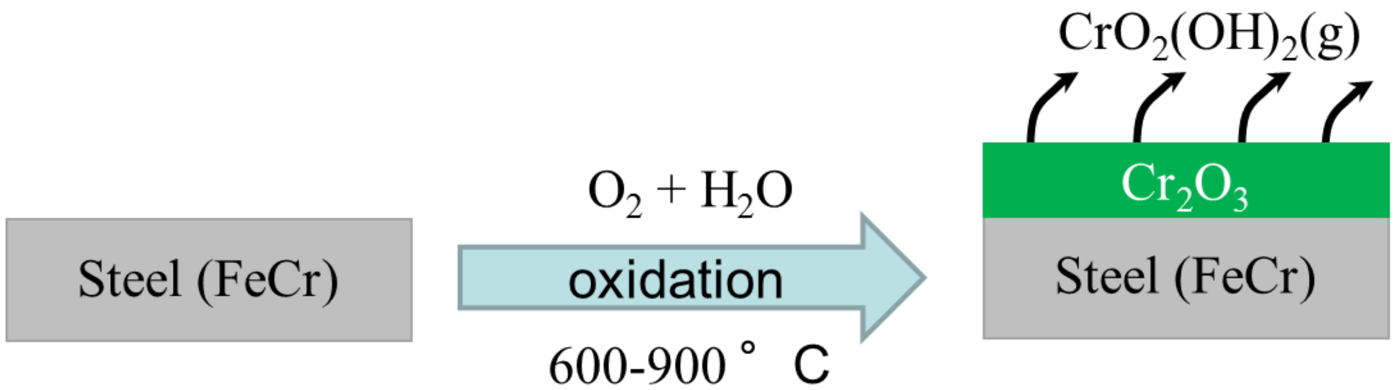


Oxide scale growth → increased electrical resistance

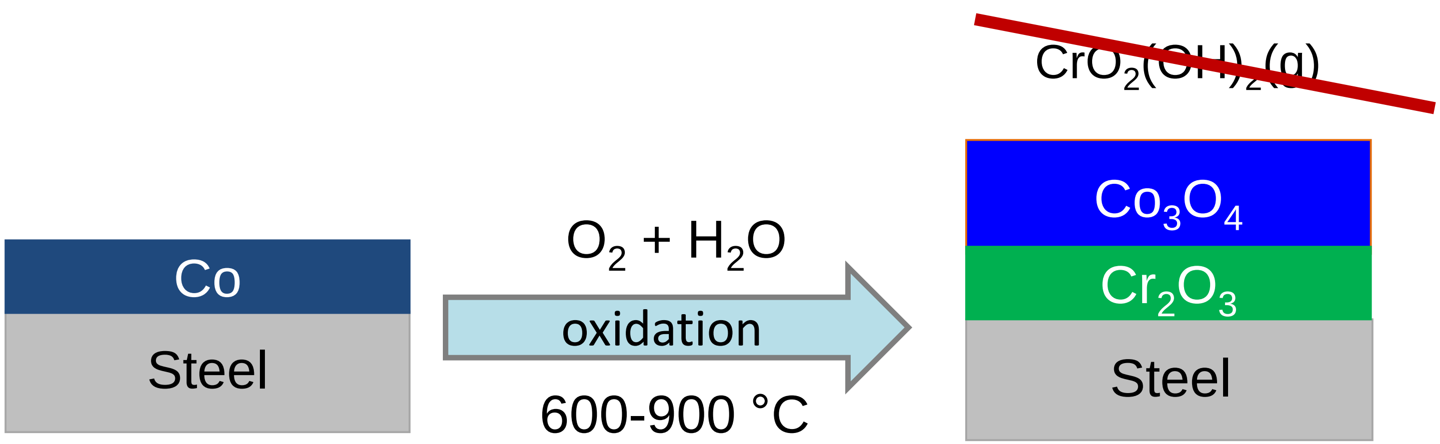
Cr vaporization: $Cr_2O_3(s) + O_2(g) + H_2O(g) \rightarrow CrO_2(OH)_2(g)$

→ Cathode poisoning

How to reduce Cr vaporization?

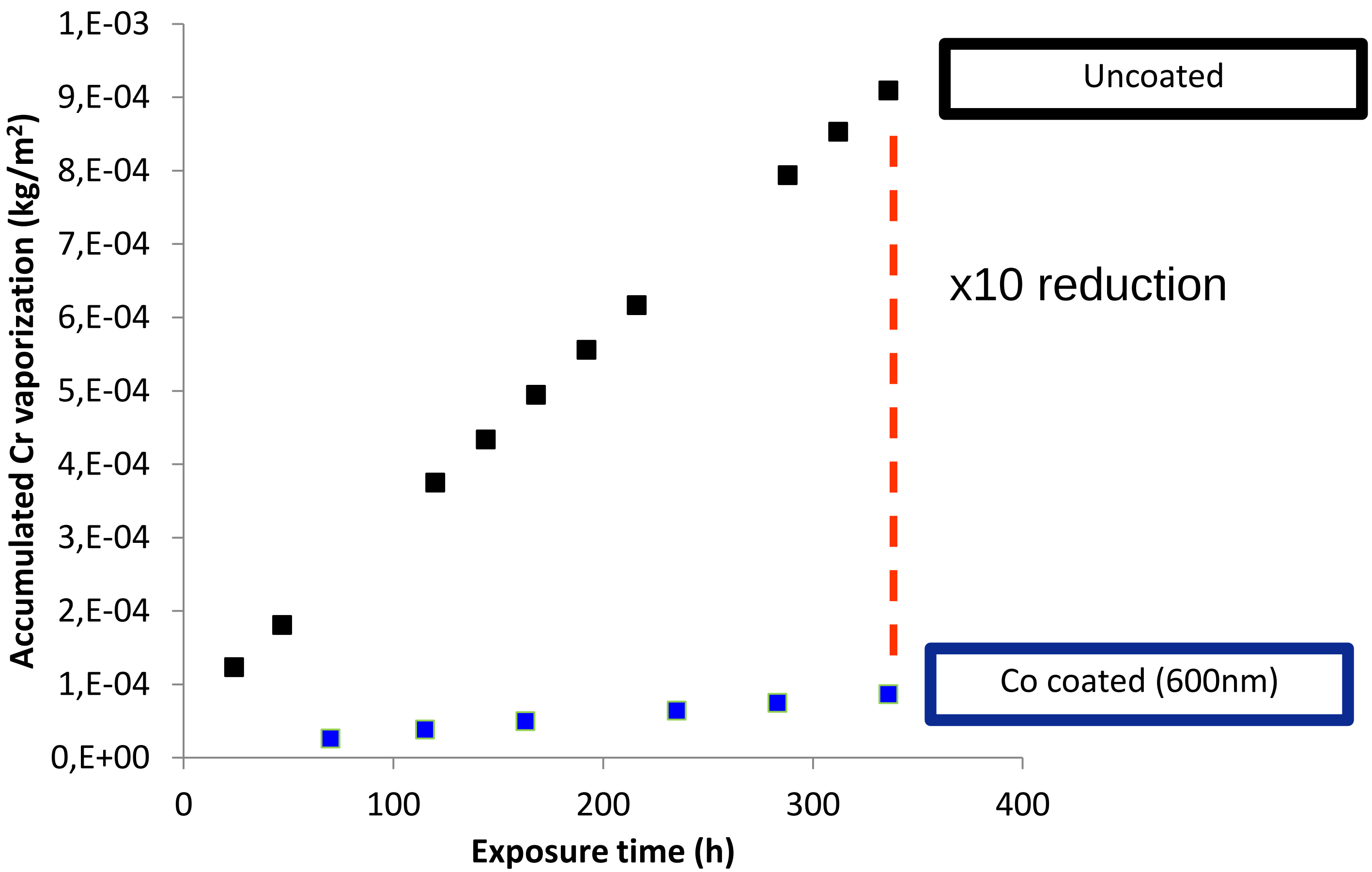


Our approach apply metallic nano coatings:



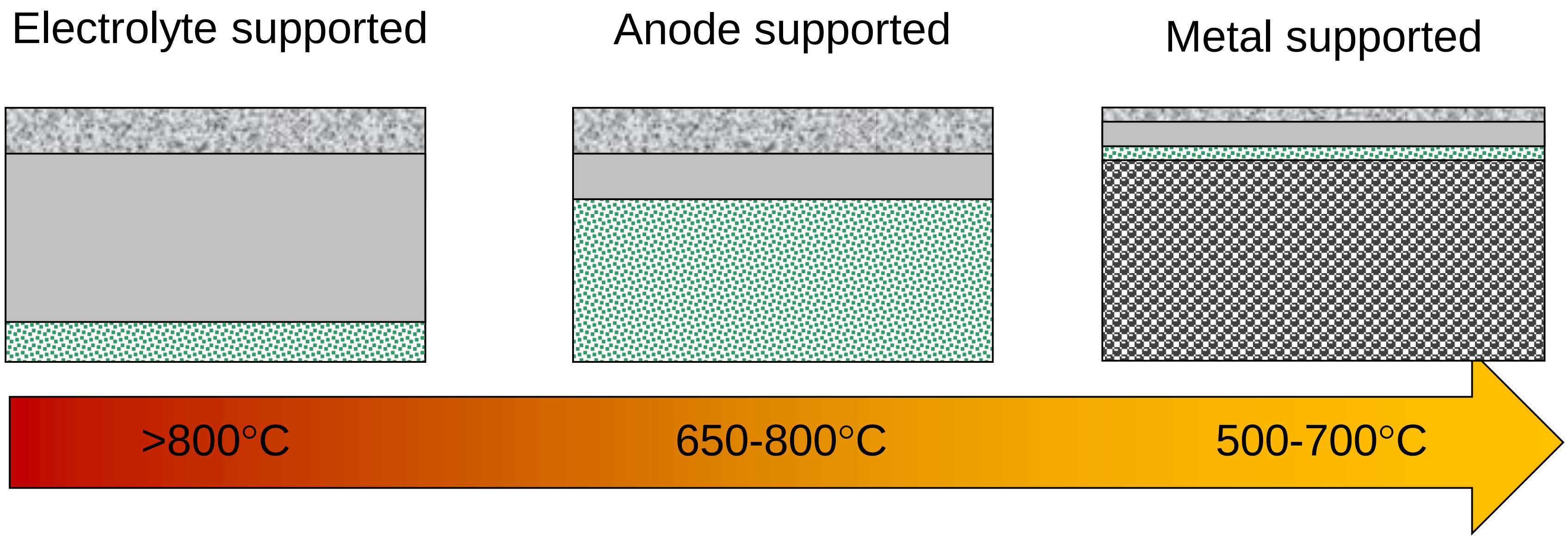
Cr vaporization

Air, 850 ºC



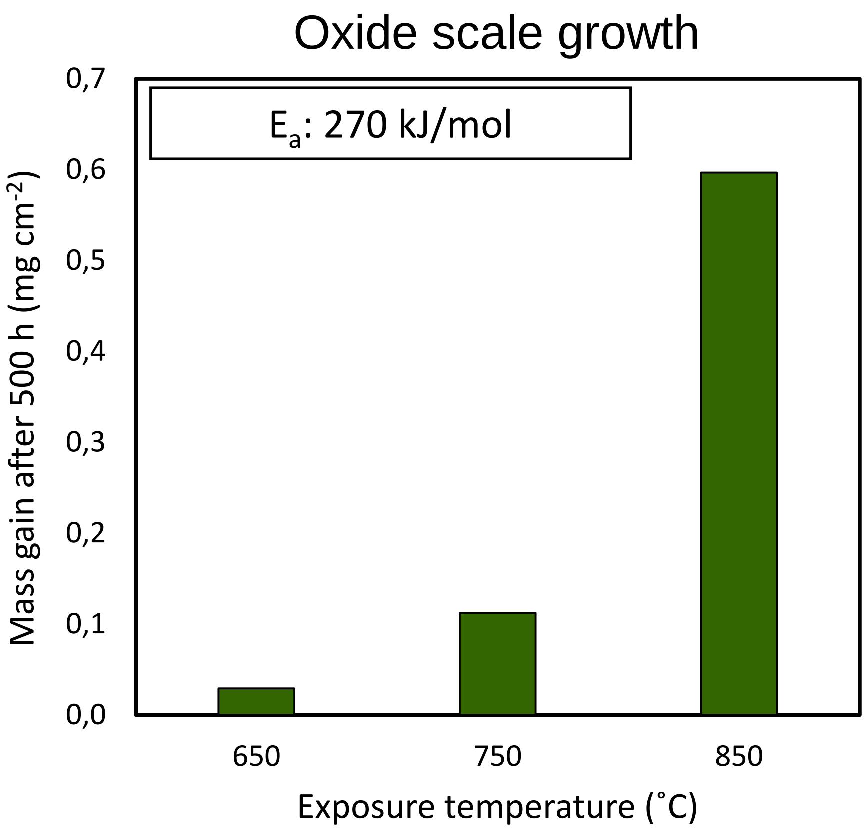
*H. Falk-Windisch et al. / Journal of Power Sources 297 (2015) 217-223

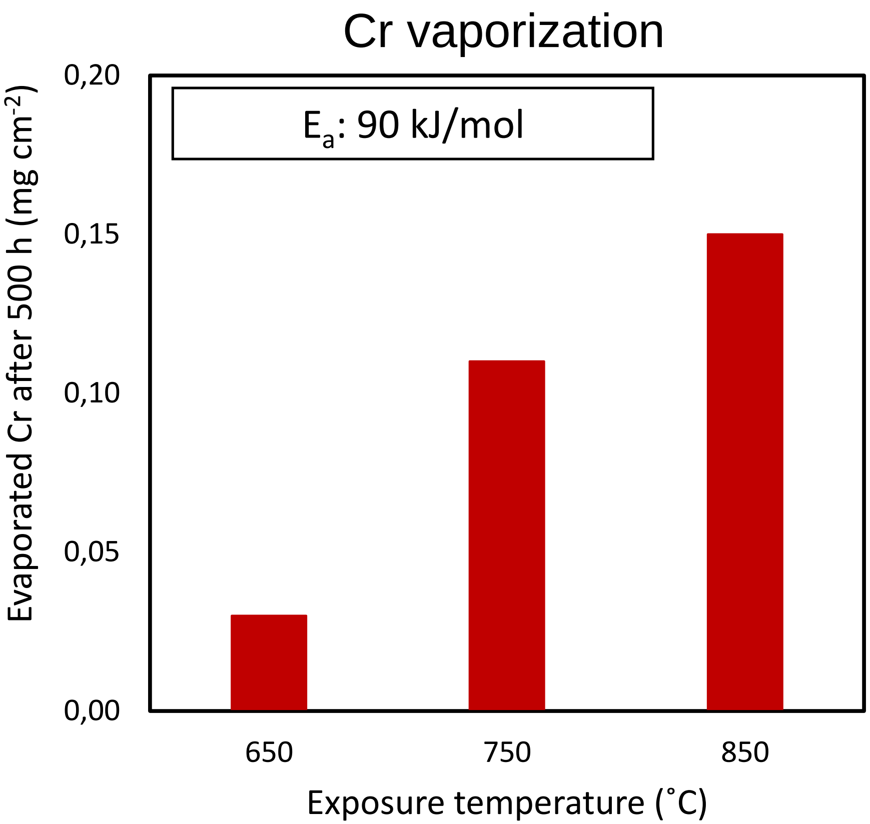
Solid Oxide Fuel Cell (SOFC)



There is a general trend towards lower operating temperatures.

⇒ Possibility to use less expensive materials
⇒ Higher efficiency possible
⇒ Longer lifetimes
⇒ Faster heating/cooling





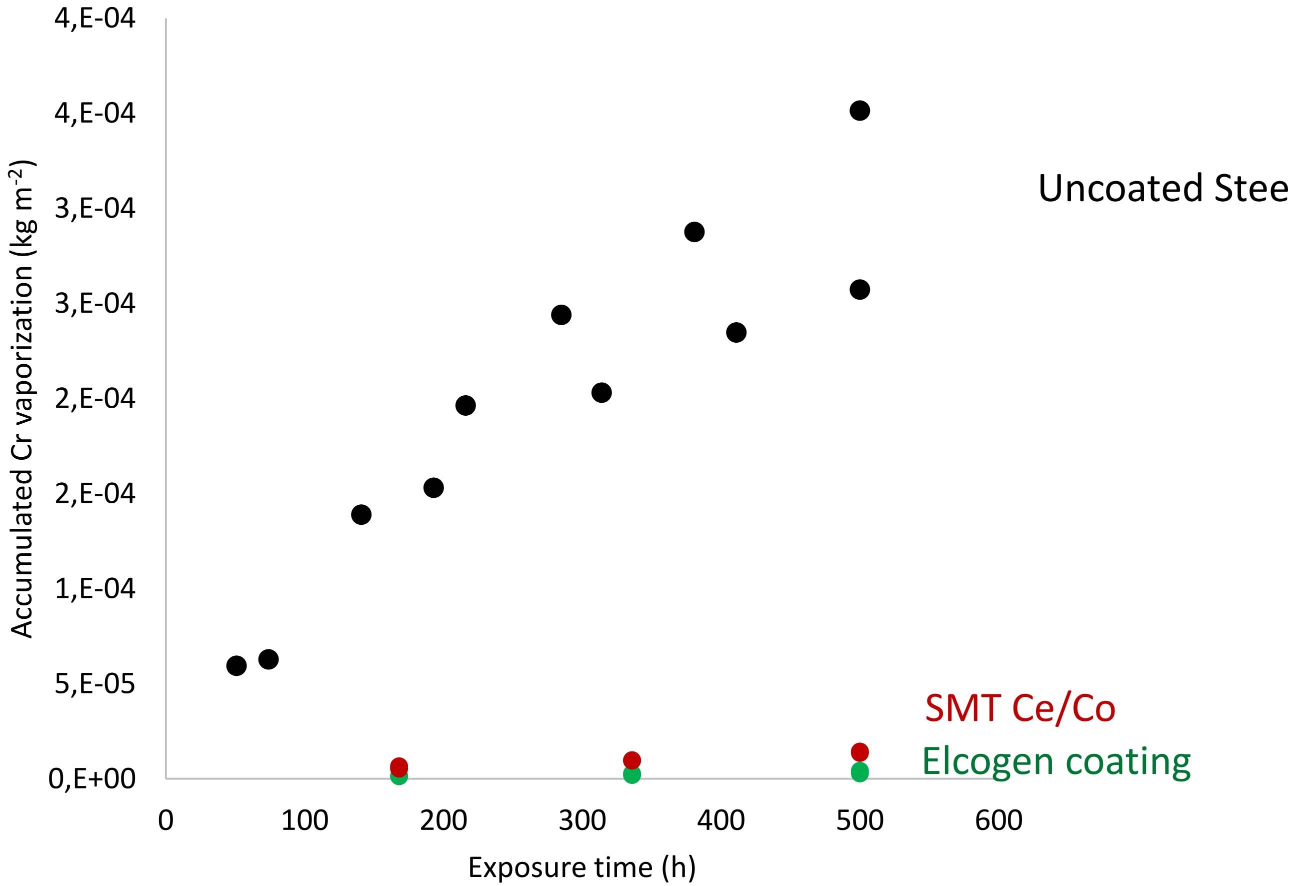
Significantly slower oxide scale growth rate at lower temperature

Much smaller decrease in Cr vaporization rate

=> Coatings are necessary also at lower temperatures (650 ºC)

*H. Falk-Windisch et al. / Journal of Power Sources 297 (2015) 217-223

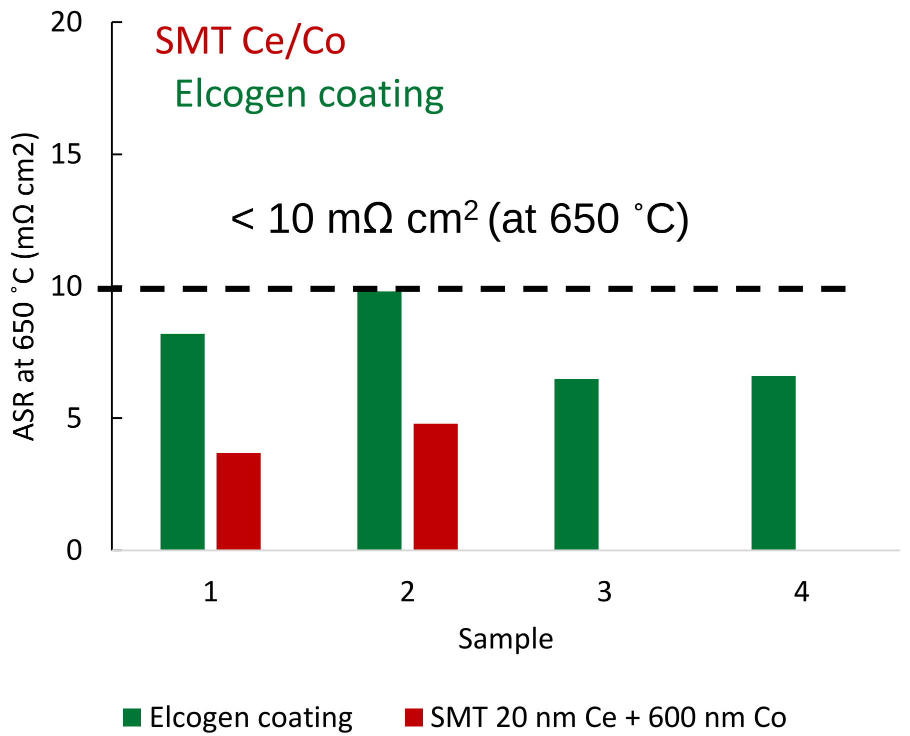
Comparsion Sandvik thin-film Ce/Co coating and Elcogen standard coating



Both materials significantly mitigates Cr vaporization at 650 ˚C

CHALMERS

Comparsion Sandvik thin-film Ce/Co coating and Elcogen standard coating



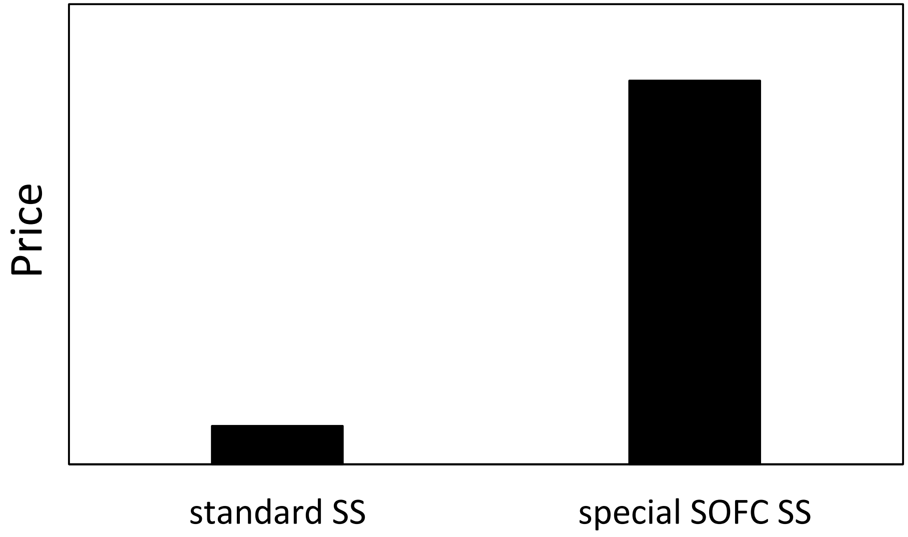
Very low ASR for both materials
(lowest for Sandvik thin-film Ce/Co coating)

Summary Part 1

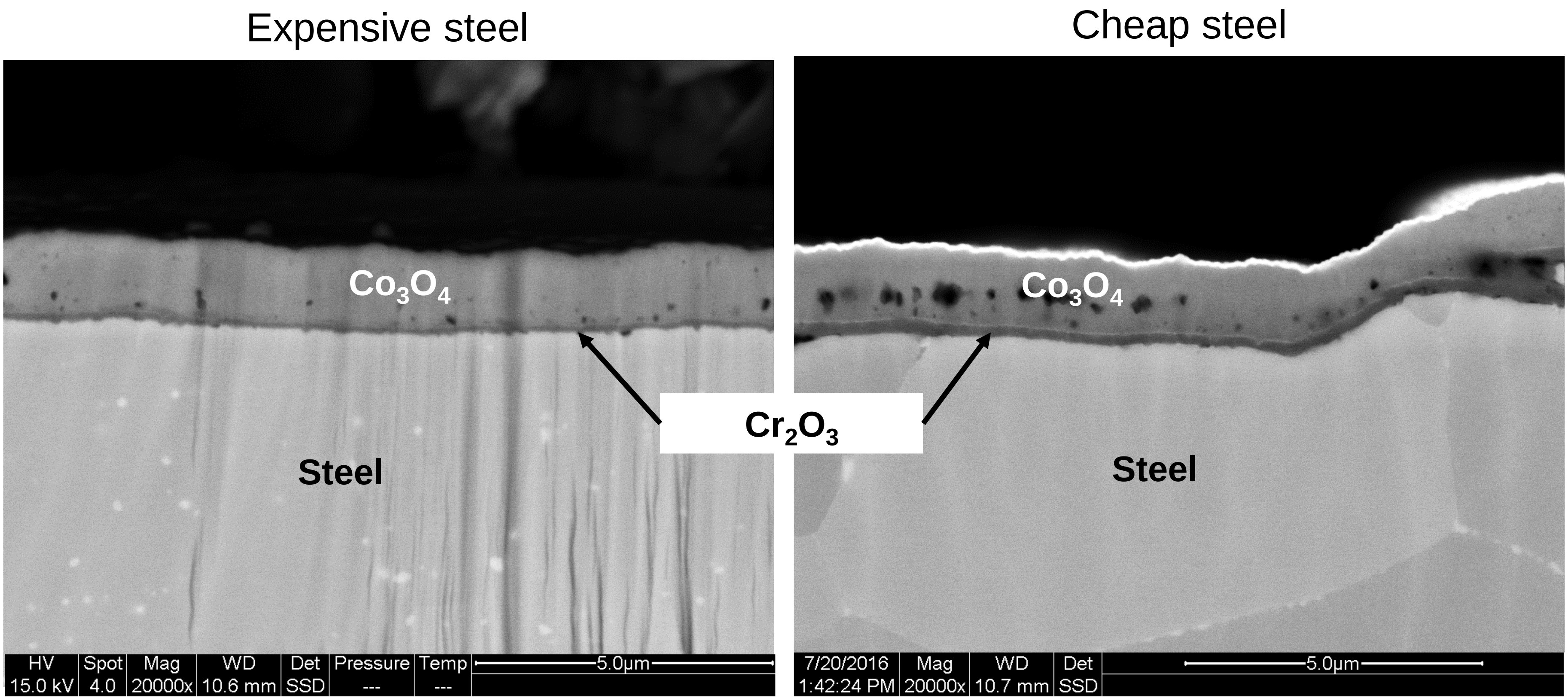
On a component level Sandvik Ce/Co thin-film coatings performed as good, or even better then the standard Elcogen coating

Part 2 is to decrease steel costs

By using standard stainless steels, the price of the interconnect can be reduced significantly! (factor 10)

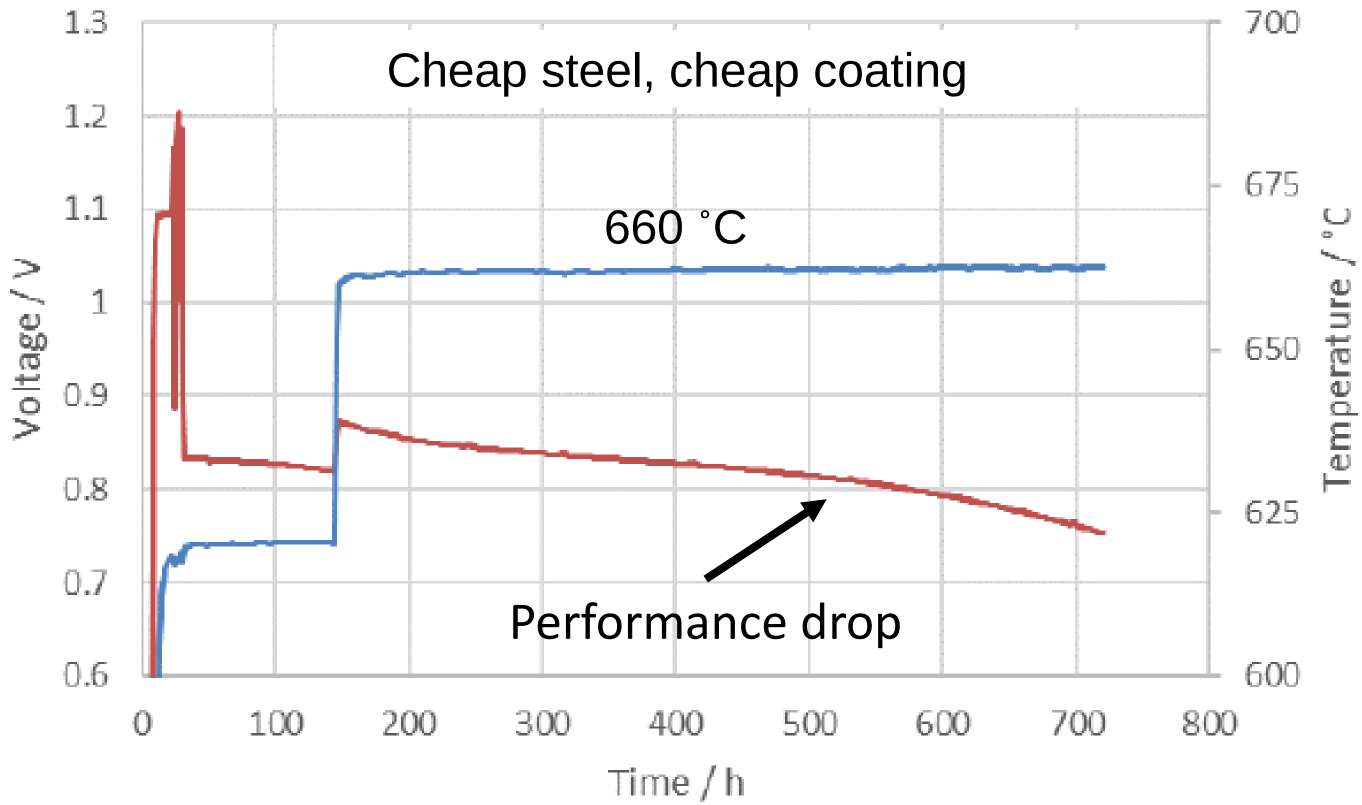


Part 2: Substituting the expensive steel to a cheap standard stainless steel



No difference in oxide scale thickness (and ASR) was observed as the expensive steel was substituted to a cheap steel after 500 h at 650 ˚C.

Lab results very promising, however,…..



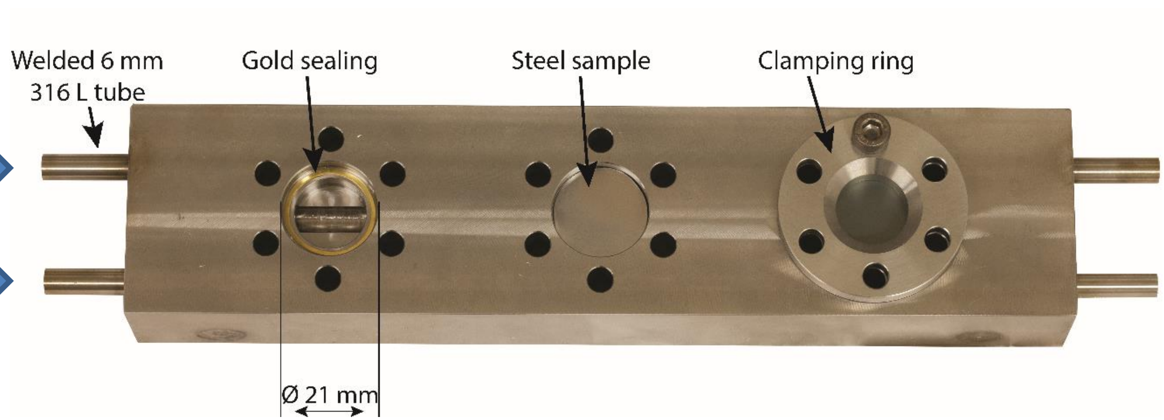
Fist stack test, not as successful as hoped for

Why?

Development of new test method

Ar-5%H_2-3%H_2O

Air



Simulated stack environment

*P. Alnegren et al. / Journal of Power Sources 301 (2016) 170-178

Dual atomsphere effect

H_2 on the anode side suppresses the ability for the steel to form a protective chromia scale on the cathode side at low temperature.

*P. Alnegren et al. / Journal of Power Sources 301 (2016) 170-178

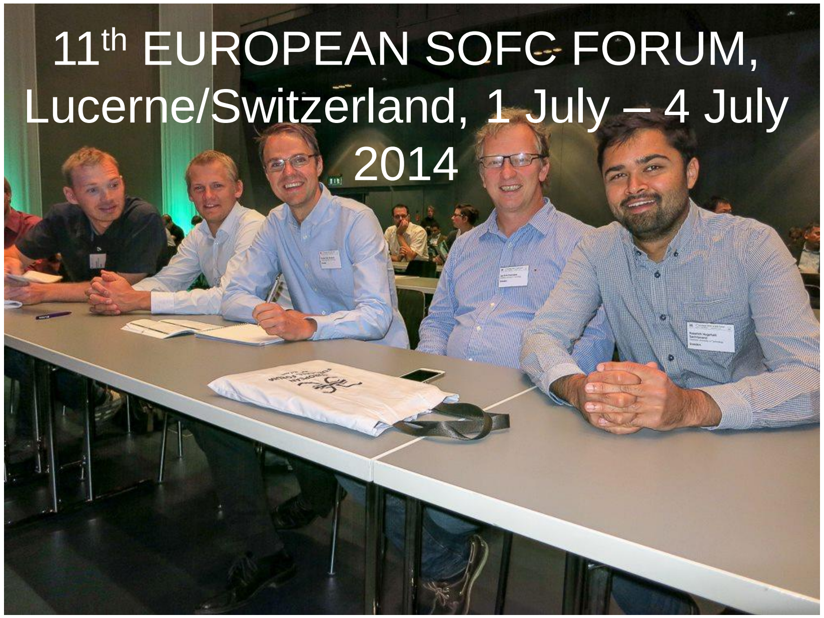
Summary and future work

- Decreasing the SOFC operating temperature has many advantages
- Component studies showed promising results for the low-cost steel AISI 441 coated with Sandvik thin-film Ce/Co coating
- First stack test (cheap steel, cheap coating), not as successful as hoped for
- New stack test (ongoing) with cheap coating but expensive steel (Elcogen standard steel)
- A fundamental understanding of the dual atmosphere effect is necessary in order to be able to allow for low-cost materials.

➡ More research needed!!!

CHALMERS

Bevakningsuppdraget



11th EUROPEAN SOFC FORUM, Lucerne/Switzerland, 1 July – 4 July 2014

Fuel Cell Seminar 2015, Los Angeles, USA

12th EUROPEAN SOFC FORUM, Lucerne/Switzerland, 5 July – 8 July 2016

Thank you,

Going to these fuel cell conferences during my PhD have helped me to do better and more relevant research.