SOFC technology development, in connection to FFI project Improved life time for SOFC-APU

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Chalmers University of Technology

Improving Lifetime Performance of SOFC for Truck APUs

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

Jan-Erik Svensson, Jan Froitzheim and Hannes Falk Windisch

Energy and Materials
Chemistry and Chemical Engineering
Chalmers University of Technology

Rolling homes that need electricity

Why trucks are idling?

- Electricity is needed during breaks for
  - Cooling
  - Heating
  - Fridge
  - Lighting
  - Radio, PC, TV
  - Etc.

Advantages with SOFC-APU

SOFC-APU can operate on diesel

- No extra tank required
- No new infrastruktur required
- An SOFC-APU is quiet…
- More effecitve than diesel engine (Efficiency 35%)

There are several types of fuel cells, the most common are:

•PEM (Polymer Electrolyte Membrane Fuel cells)
Operate at 80 °C, high efficiency, fast start up, high sensitivity for fuel impurities

•SOFC (Solid oxide fuel cells)
Operate at 600-900 °C, high efficiency, fuel flexibility, high-temperature corrosion

Projectpartners

CHALMERS

SANDVIK → Fuel cell technology elcogen → VOLVO

Objectives

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

➡ Metallic Interconnect is the key! (Up to 40% of the cost of a stack!

This project tries to mitigate three main causes of stack degradation in relation to the interconnects,

- cathode side oxidation
- chromium evaporation and
- anode side oxidation, that diminishes power output and can lead to stack failure

The idea behind the proposal is to resolve these issues in a cost-effective way, using standard ferritic FeCr strip steel protected by multi-layered nano coatings

Outline

Part I: Overview SOFC Technology

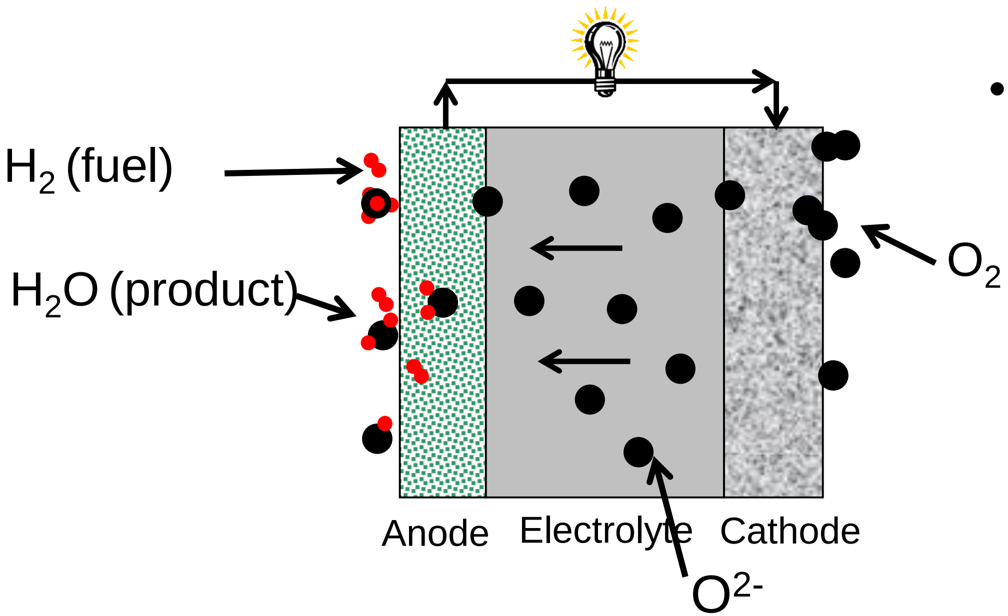
Part II: Recent results from the FFI project

Solid Oxide Fuel Cell (SOFC)

Advantages

- High electrical efficiency

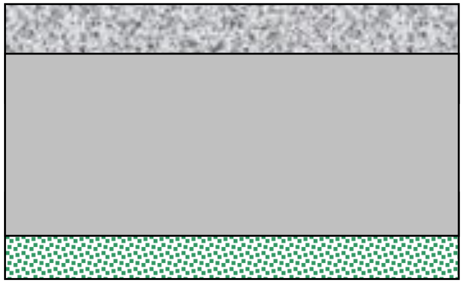
- O^{2-} conductive electrolyte
  - Fuel flexibility (H_2, natural gas, biogas.. diesel)
- High operating temperature
  - No need for expensive catalysts such as Pt



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

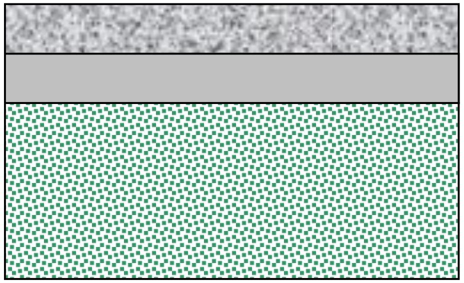
Solid Oxide Fuel Cell (SOFC)

Electrolyte supported



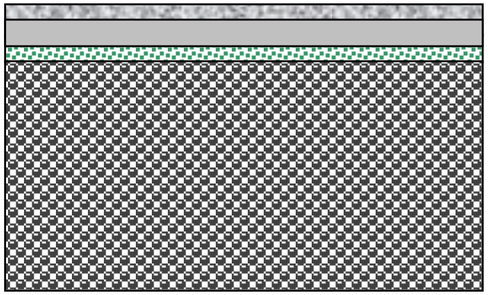
>800°C

Anode supported



650-800°C

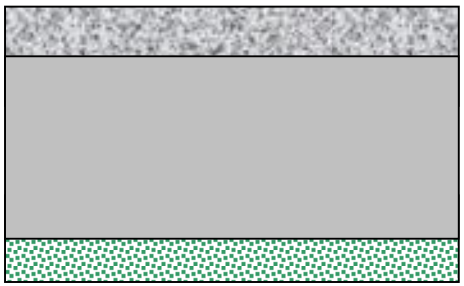
Metal supported



<700°C

Solid Oxide Fuel Cell (SOFC)

Electrolyte supported



>800°C

NEXCERIS
where energy meets environment

HEXIS

Bloomenergy

sunfire

KYOCERA

NEXCERIS
where energy meets environment

Mainly military applications (APU)

unmanned under water vehicle

military ground vehicle APU

unmanned aerial systems

power systems for lunar and Martian landers.

Hexis (Viessmann)

HEXIS

Elektrolyte supported design

$1\ kW_{el}$

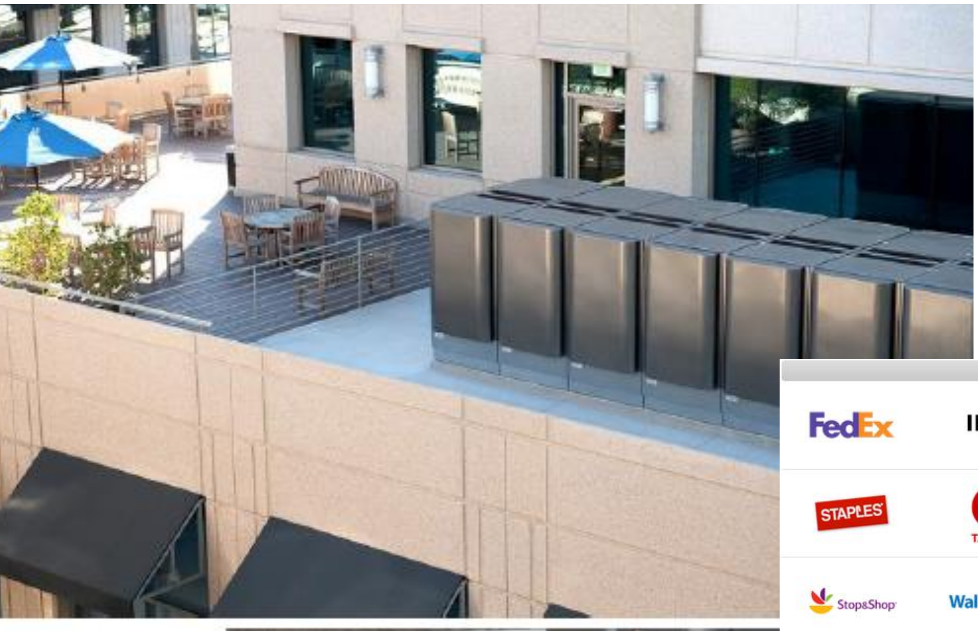
$1.8\ kW_{heat}$

For a Better Tomorrow
AISIN GROUP

KYOCERA

46.5% is achieved — with an overall energy efficiency of 90.0%

Bloom Energy



- Bloom: ~100 MW installed

Banking, Real Estate and Financial Services
Bank of America, JMB Realty Corporation, Hines, JPMorganChase, Macerich, Morgan Stanley, The Ratkovich Company, SoftBank

Manufacturing
Altera, Honda, maxim integrated, Owens Corning, TaylorMade, Xilinx

Food and Beverage
The Coca-Cola Company, Kellogg's, Pacific Cheese, Roll global, Sutter Home, Taylor Farms

Data Centers
Apple, CenturyLink, ebay inc, Equinix

Biotechnology and Healthcare
ASP, BD, Kaiser Permanente, Life technologies, Medtronic, Prime Healthcare Services, Sutter Health Plus

Government and Military

Utilities
delmarva power, PG&E, Washington Gas

Nonprofits and Universities
Caltech, Keio University

Entertainment
DreamWorks, Ducks, Staples Center

Retail and Logistics
FedEx, IKEA, macy's, Safeway, Staples, Target, URBN, Americold, Stop&Shop, Walmart, Williams-Sonoma, Inc.

Technology
Adobe, Apple, AT&T, Baker Hughes, Comcast, Cox Enterprises, Cypress, ebay inc, Google, Juniper Networks, NTT Communications, Nokia, Panasonic, Verizon, Yahoo!

sunfire

powered by staxera:

- Sunfire bought Staxera
- Located in Dresden/Germany
- Focus on both SOFC and SOEC
- rSOC Reversible SOC

sunfire

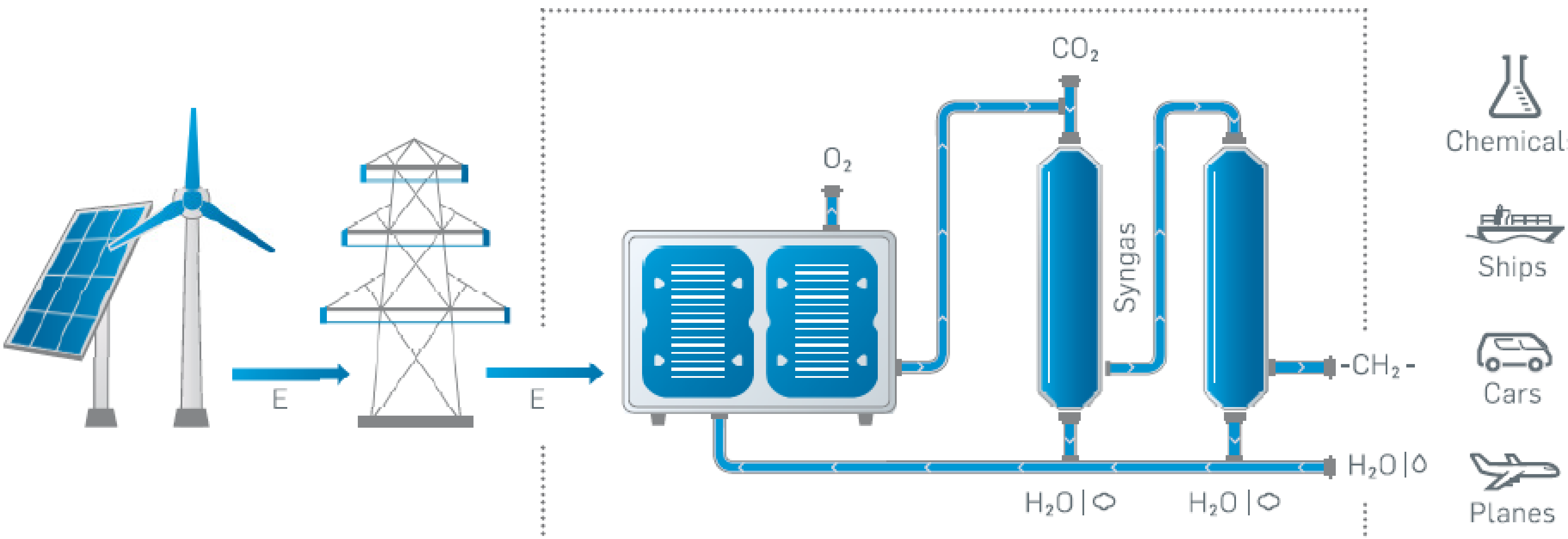
powered by staxera:

SOEC Power to liquid process:

Process efficiency 70%

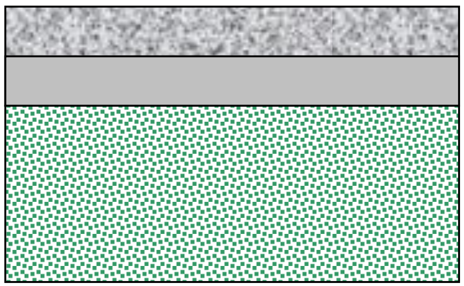
SOEC efficiency >90%

Cost (500t/day) ~1€/liter



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

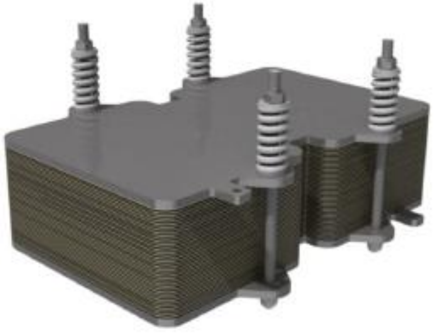
Product specs	EnGen-2500	BlueGEN
▪ Electricity power output (net, AC)	2.5 kW	1.5 kW
▪ Electric efficiency (net AC, LHV)	50%	**60%**
▪ Cogeneration efficiency (LHV)	**90%**	85%
▪ Modulation range	1:3	1:3
▪ Installation	Floor standing	Floor standing
▪ Grid connection	On-grid	On-grid

60% electric =Record!
(74% DC single pass)

Elcogen in brief

Fuel cell technology
elcogen

- Concentrating on solid oxide fuel cell (SOFC) technology
- *Elcogen* AS was founded in 2001 to Estonia as *unit cell manufacturing company*
- Elcogen AS has its own production facilities for unit cell production
- *Elcogen* Oy was founded in 2009 to Finland as *stack manufacturing company*
- More than 30 active customers worldwide
- Elcogen AS and Elcogen Oy are privately owned limited companies



VNT MANAGEMENT

Courtesy of Elcogen

Fuel cell technology
elcogen

Elcogen production facilities

- New production facilities for Elcogen unit cells was opened in July 2014 in Tallinn, Estonia
- First stage ramp-up capability 10 MW annual unit cell production

- Elcogen stack production line under validation in Vantaa (Helsinki area), Finland
- Pilot production line enables 1 MW annual stack production

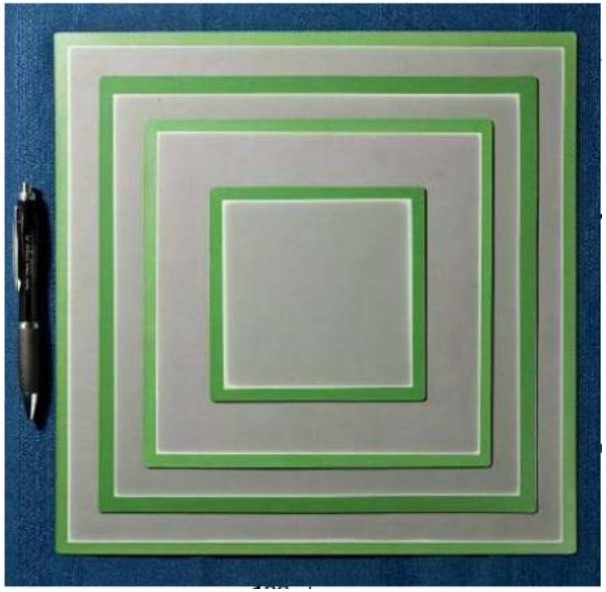
Courtesy of Elcogen

Versa Power Systems

FuelCell Energy
Ultra-Clean, Efficient, Reliable Power

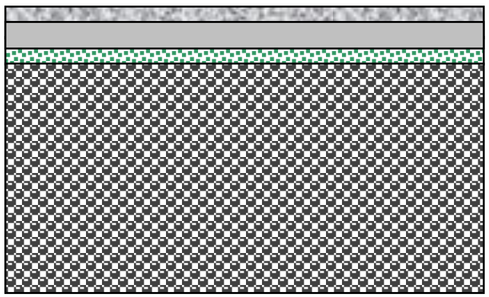
Versa Power/ Fuel Cell Energy

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



33 x 33cm cells

Metal supported

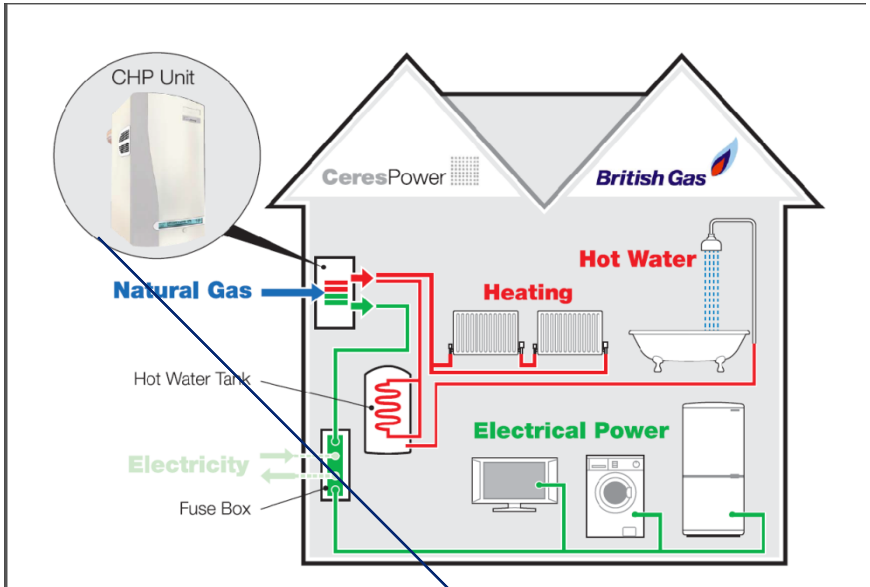


<700°C

CeresPower®

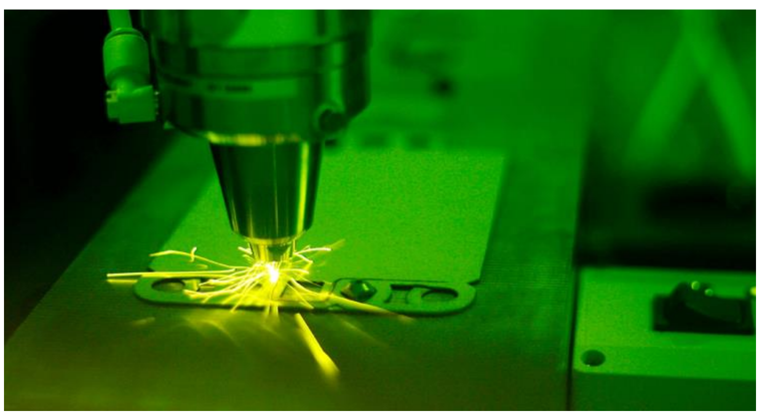
PLANSEE

Ceres Power



Ceres Power:

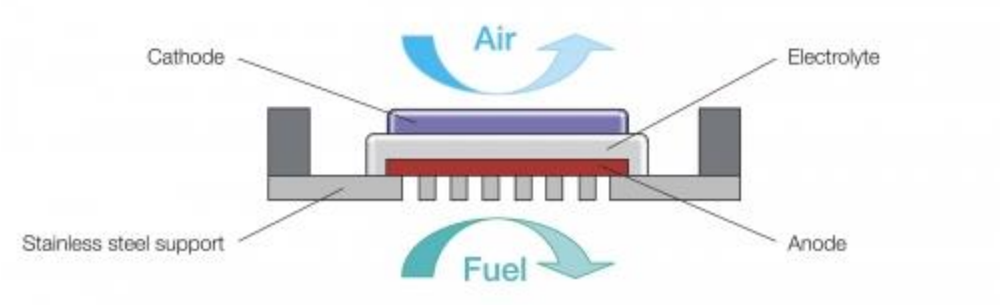
- Low temperature (<600°C), low cost approach
- 97% of the stack is steel – 3% ceramics

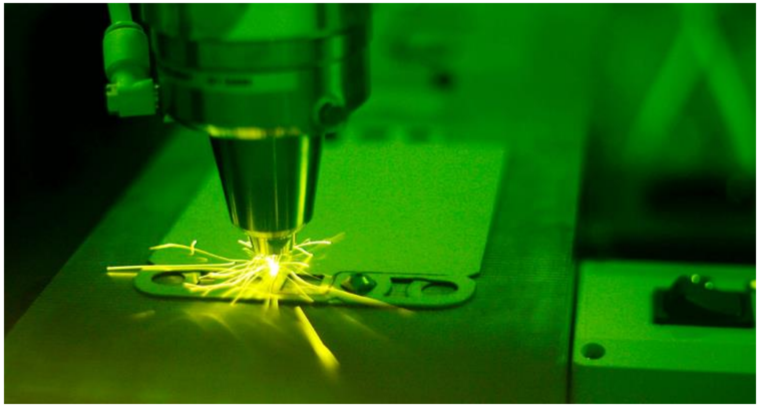


Source:http://www.cerespower.com/ProductOverview/ResidentialCHP/)

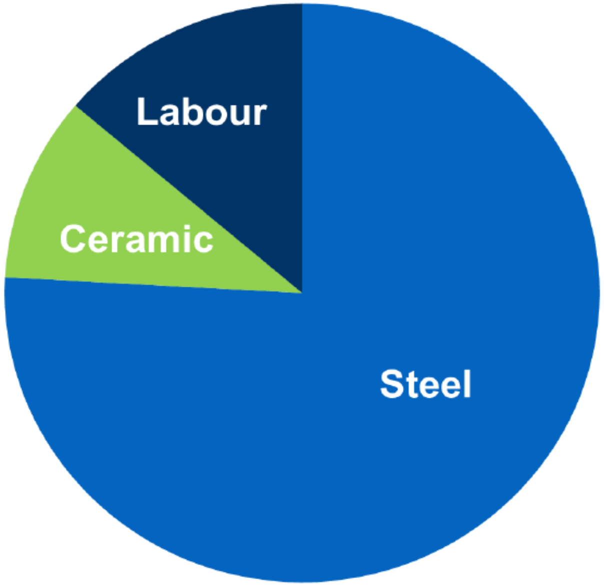
Metal supported FC

The steel cell





- 50% electrical efficiency (goal is 55%)
- Natural Gas, steam reforming
- < 600 ˚C => low cost materials
- Start up time < 30 min



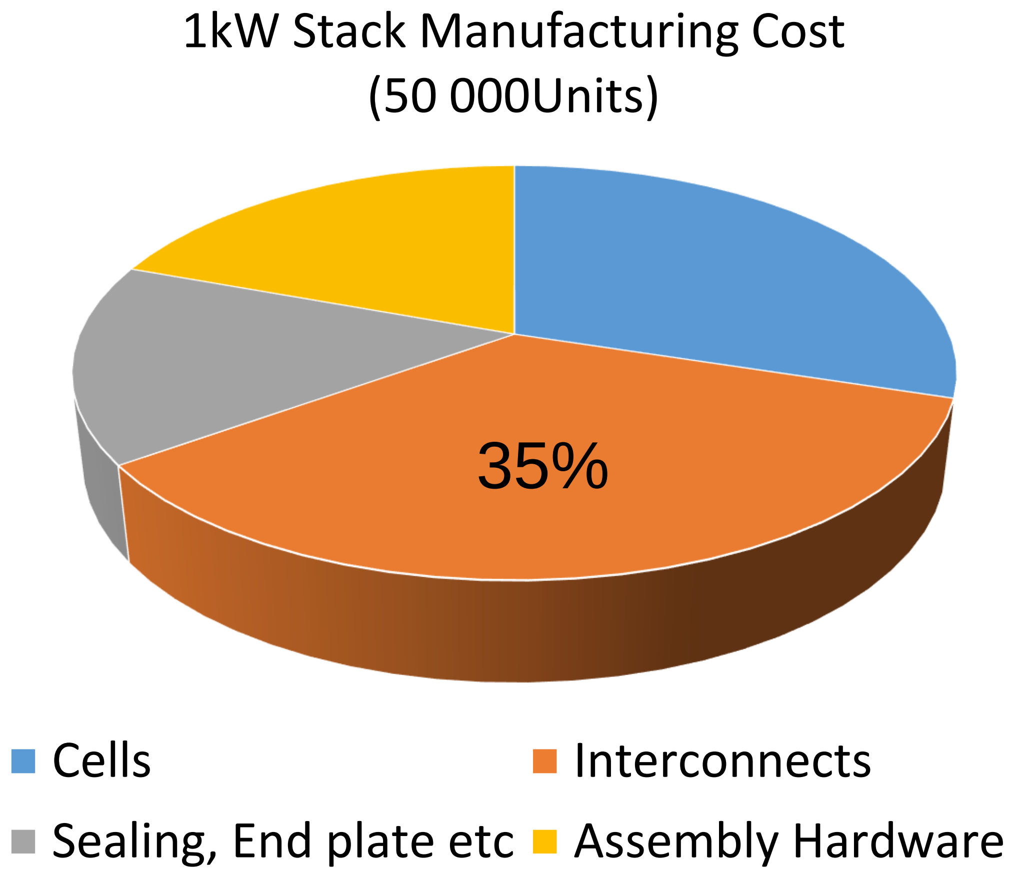
CeresPower®

Outline

Part I: Overview SOFC Technology

Part II: Recent results from the FFI project

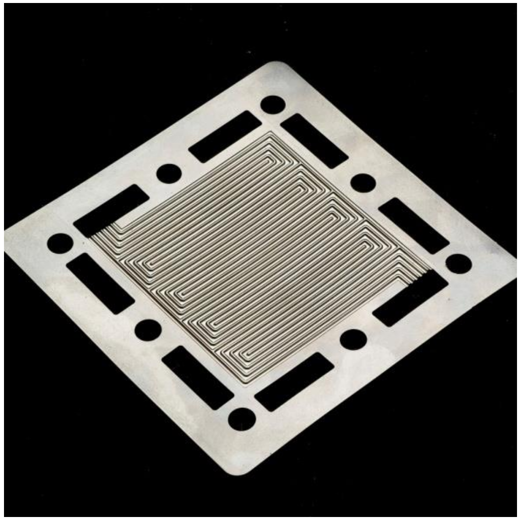
Cost analysis 1kW Stack



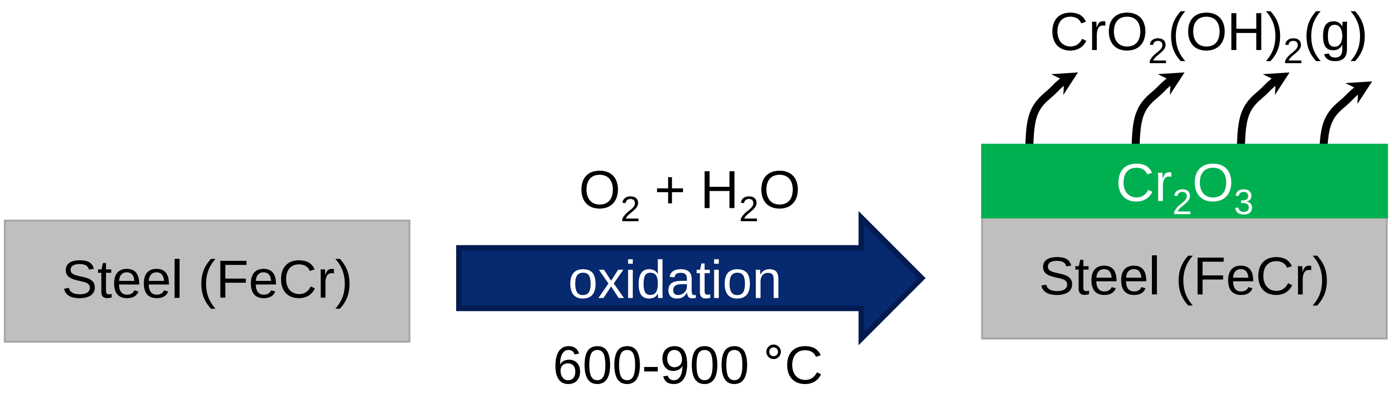
Source: Battelle study prepared for US DOE (2014)

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

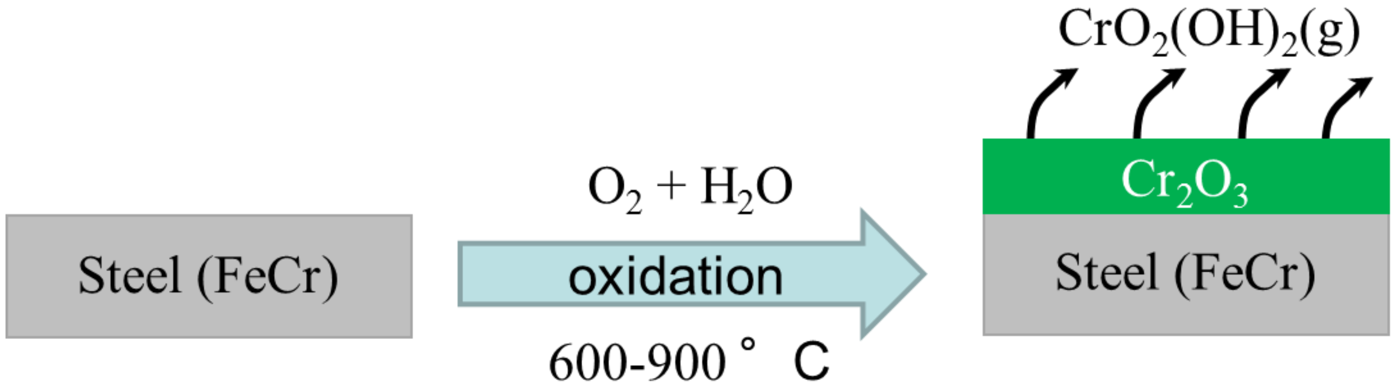


Oxide scale growth → increased electrical resistance

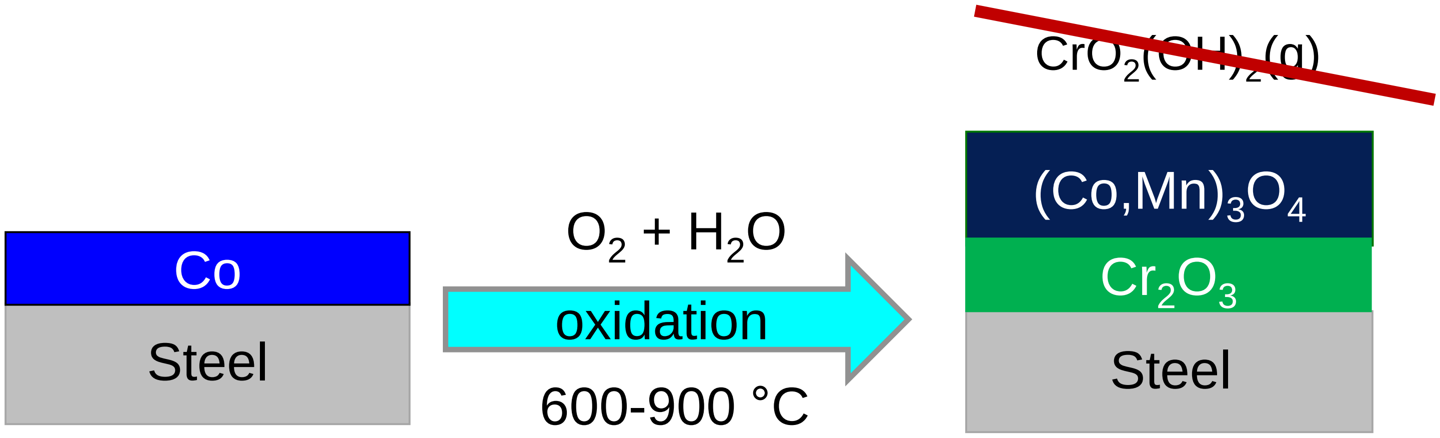
Cr vaporization: $Cr_2O_3(s) + O_2(g) + H_2O(g) \rightarrow CrO_2(OH)_2(g)$

→ Cathode poisoning

How to reduce Cr vaporization?

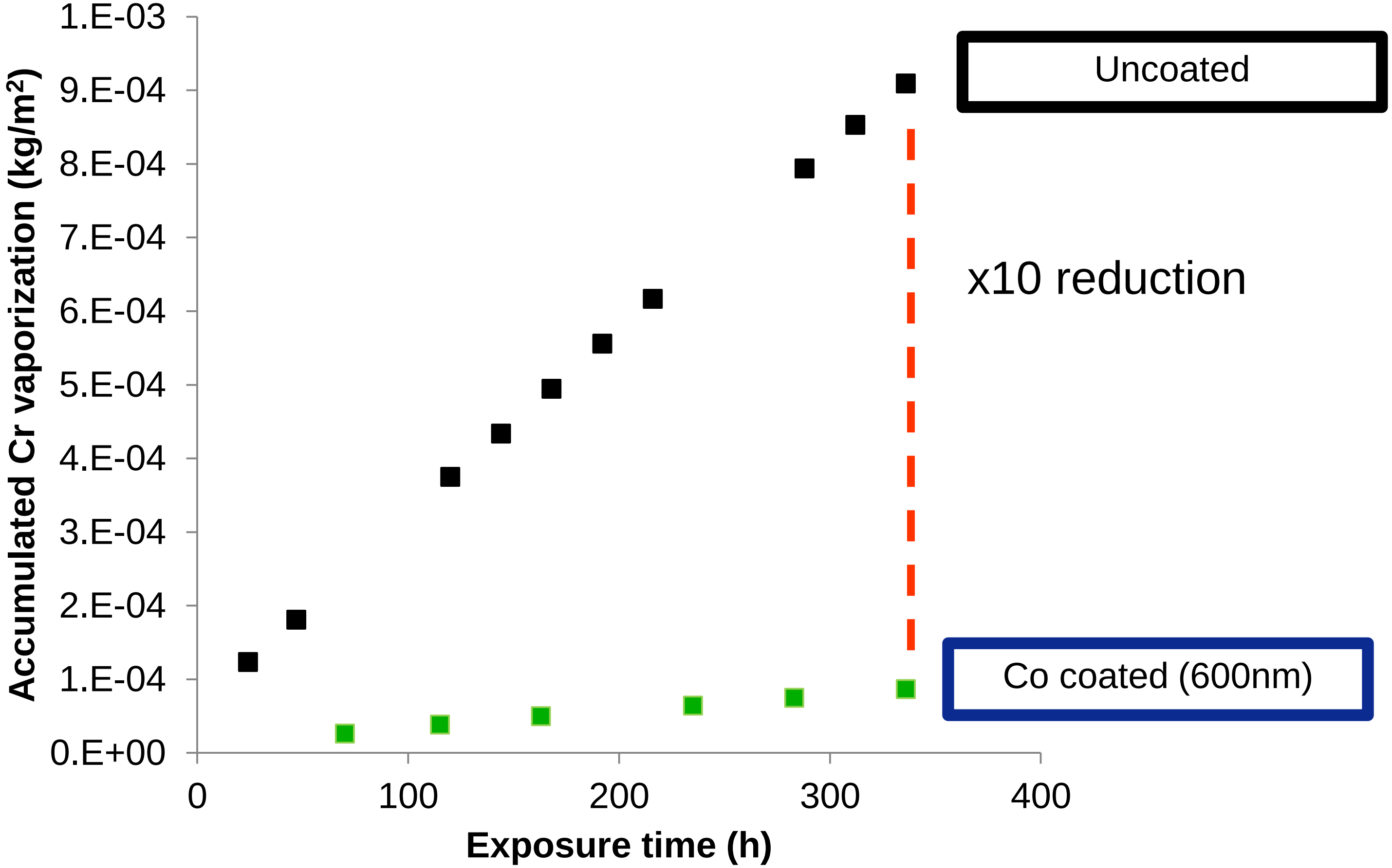


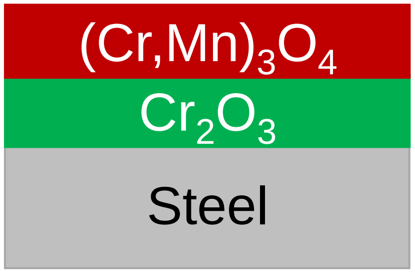
Our approach apply metallic nano coatings:

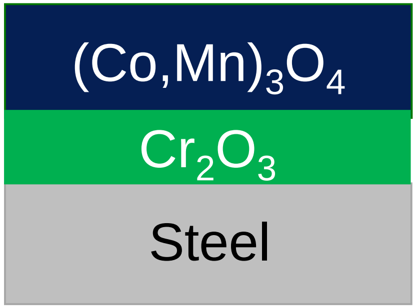


Cr vaporization

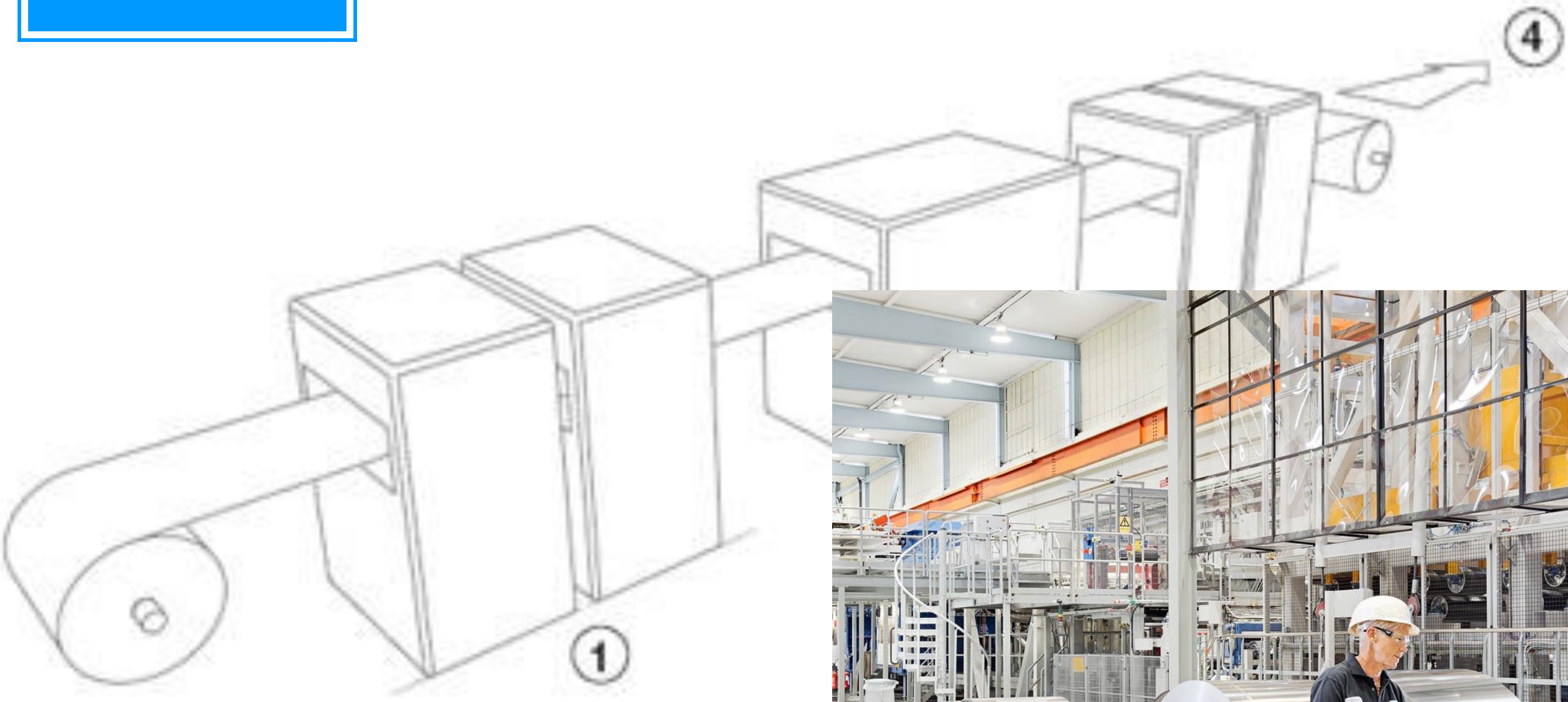
Air, 850 ºC



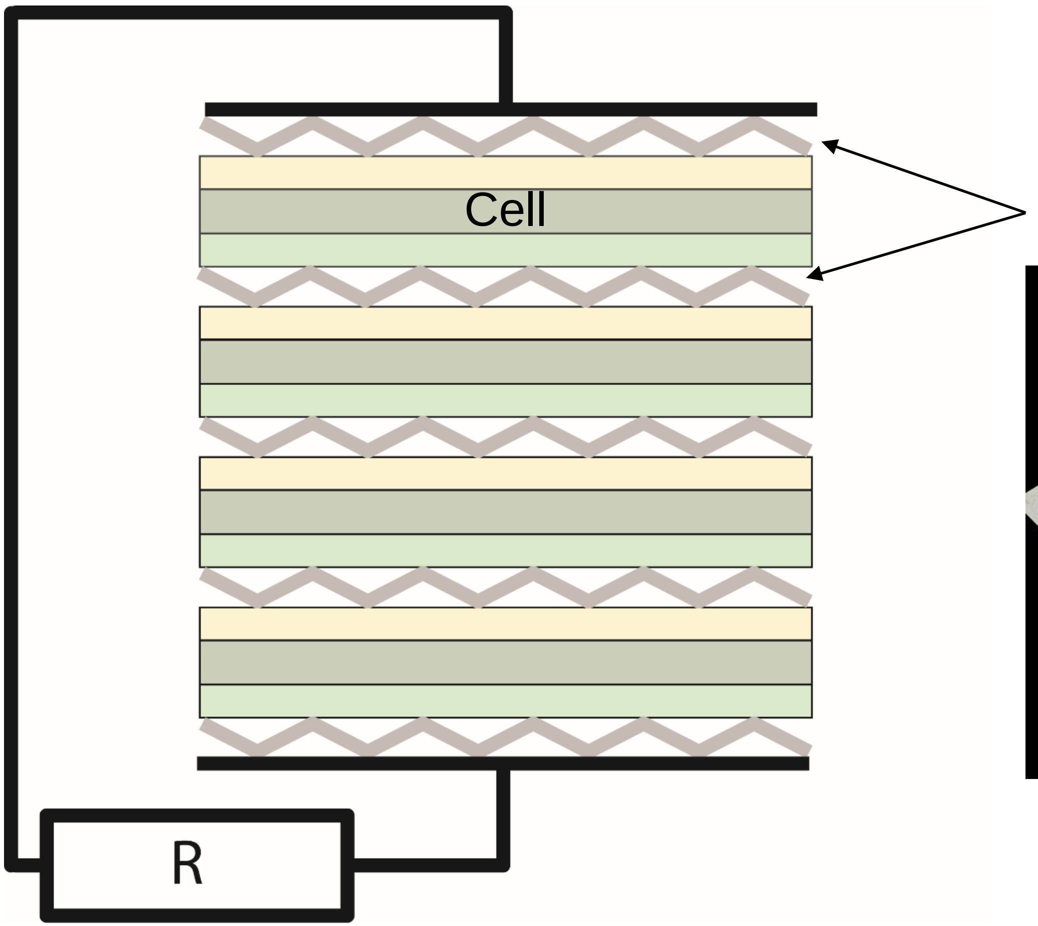


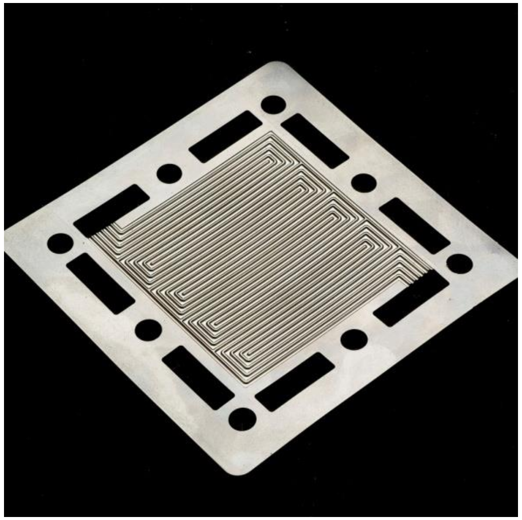


The pre-coated concept

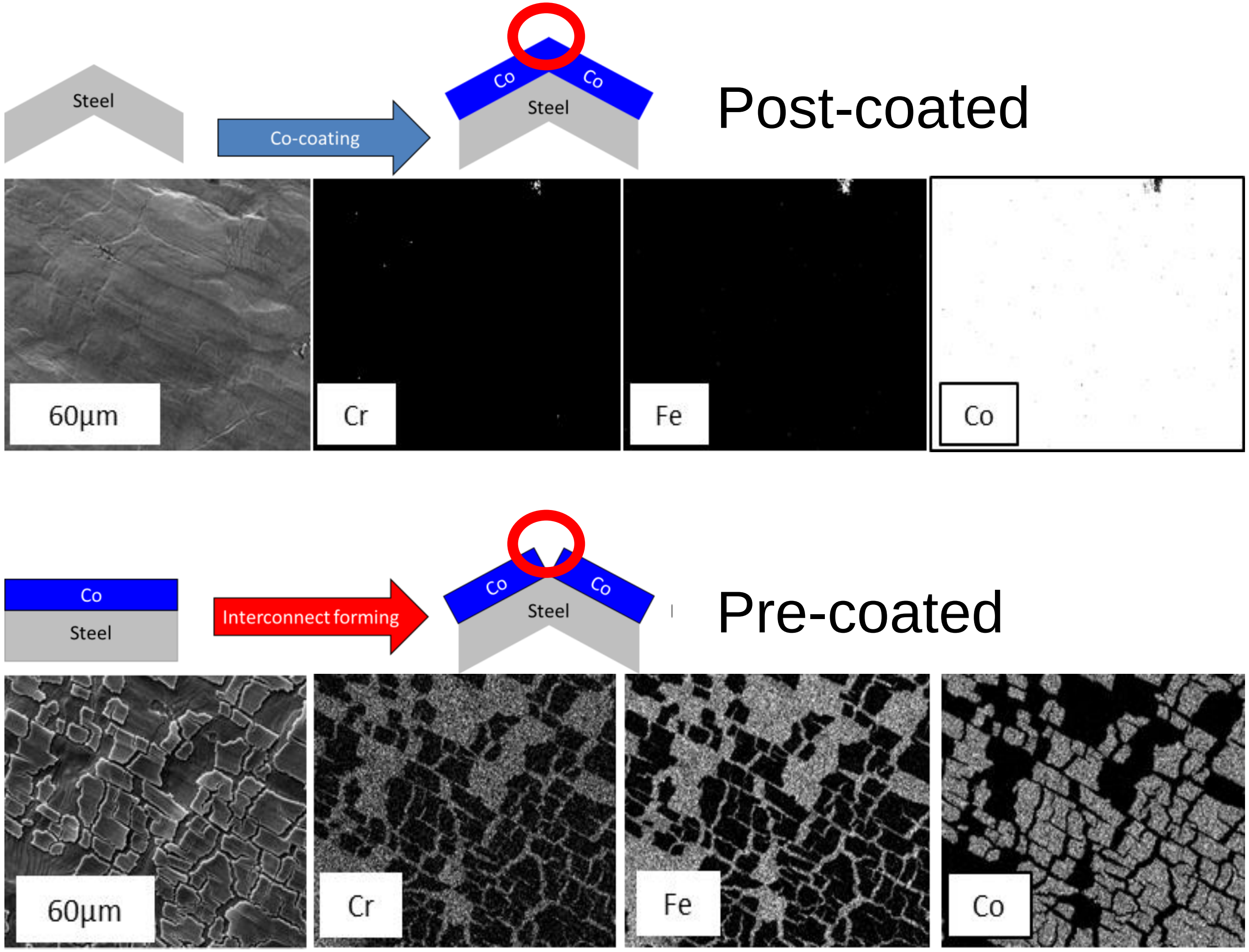


The interconnect material has to be shaped in a way to allow for gas distribution



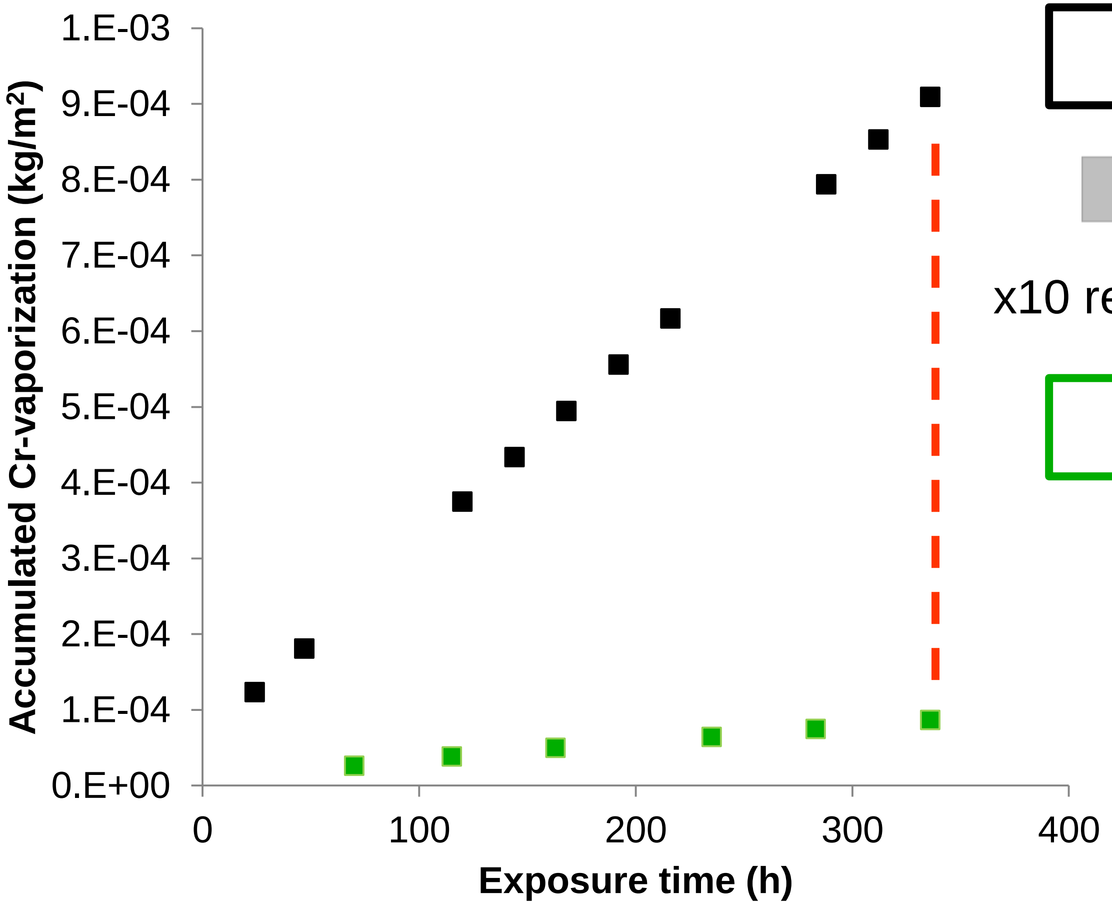


Before exposure

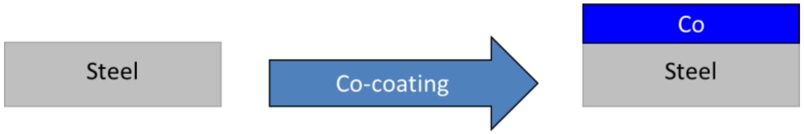


Cr vaporization

Air, 850 ºC



Uncoated and undeformed

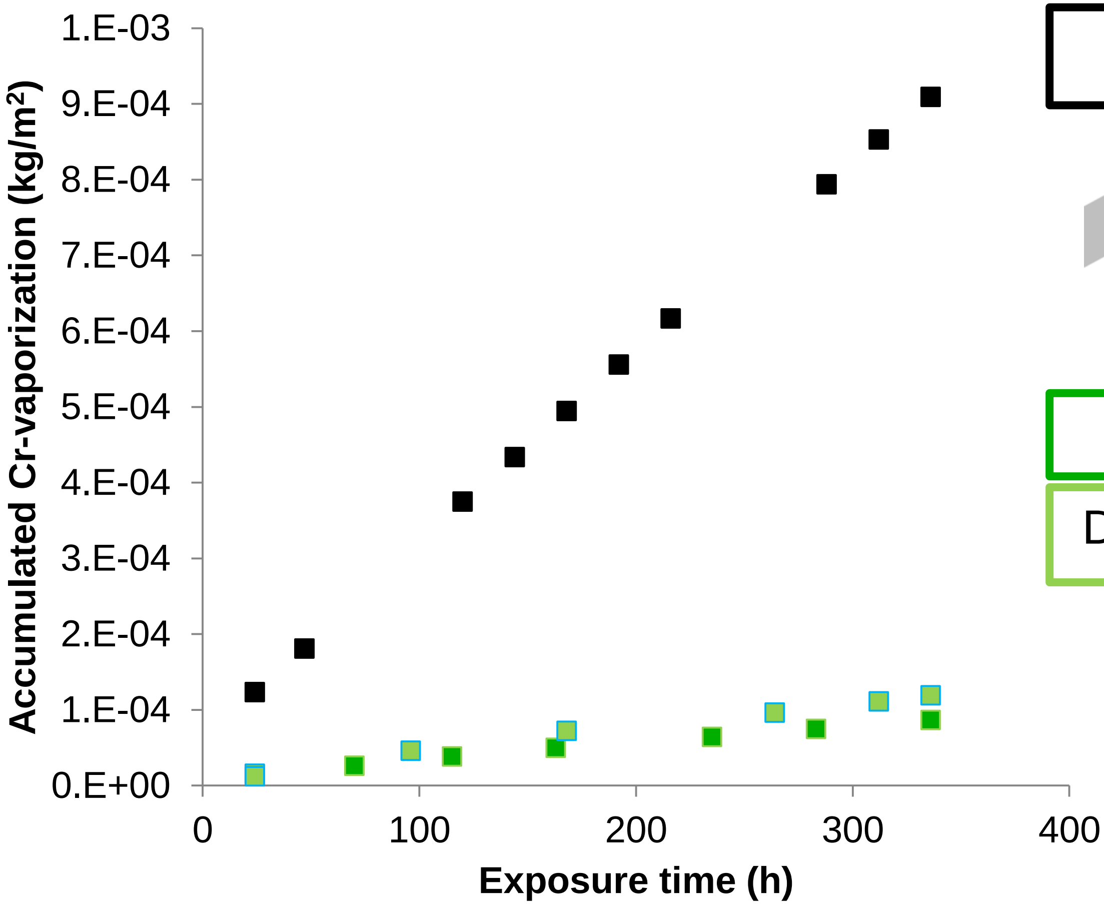


x10 reduction

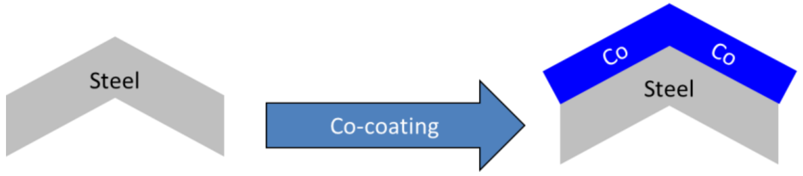
Undeformed (600nm Co)

Cr vaporization

Air, 850 ºC



Uncoated and undeformed

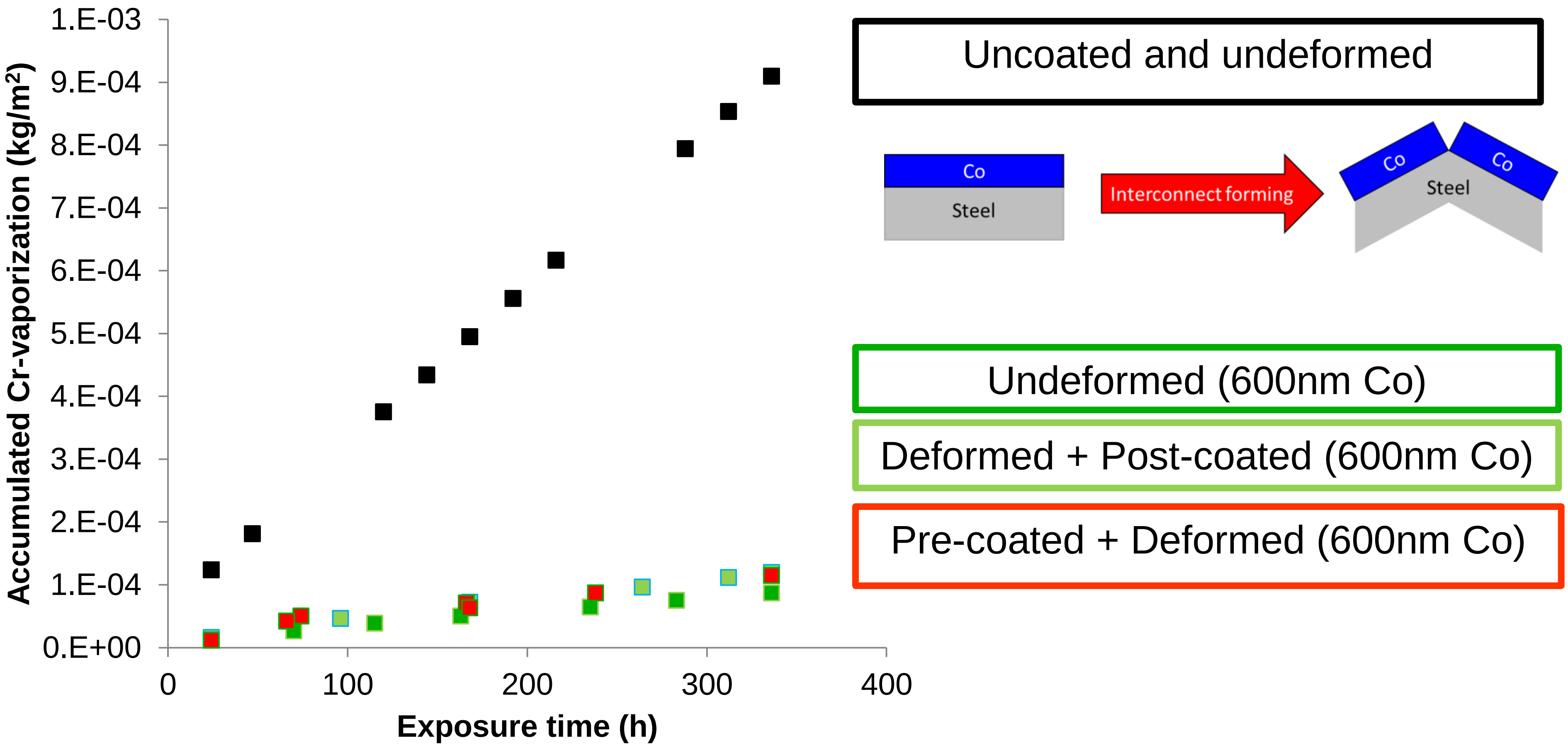


Undeformed (600nm Co)

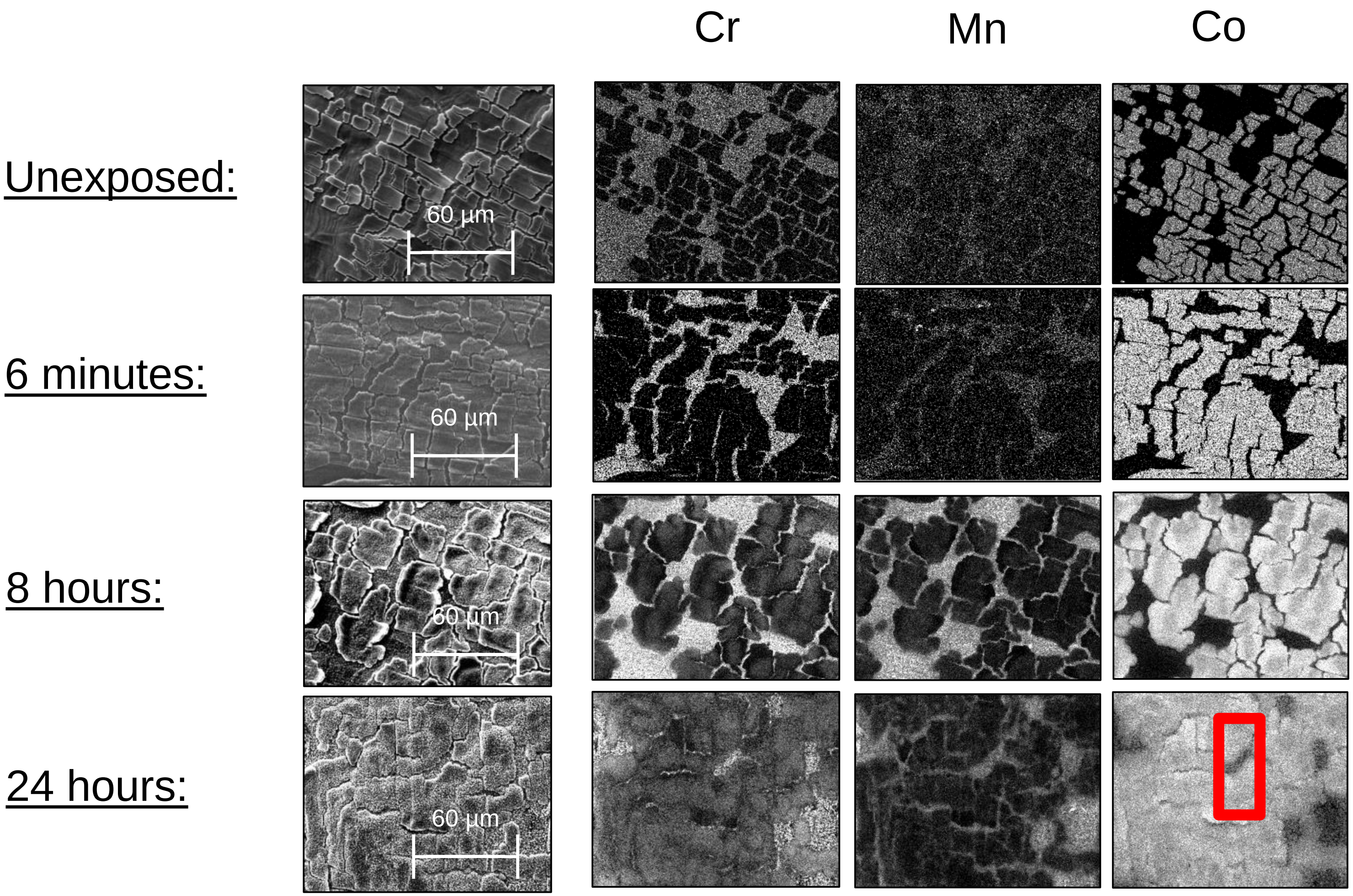
Deformed + post-coated (600nm Co)

Cr vaporization

Air, 850 ºC



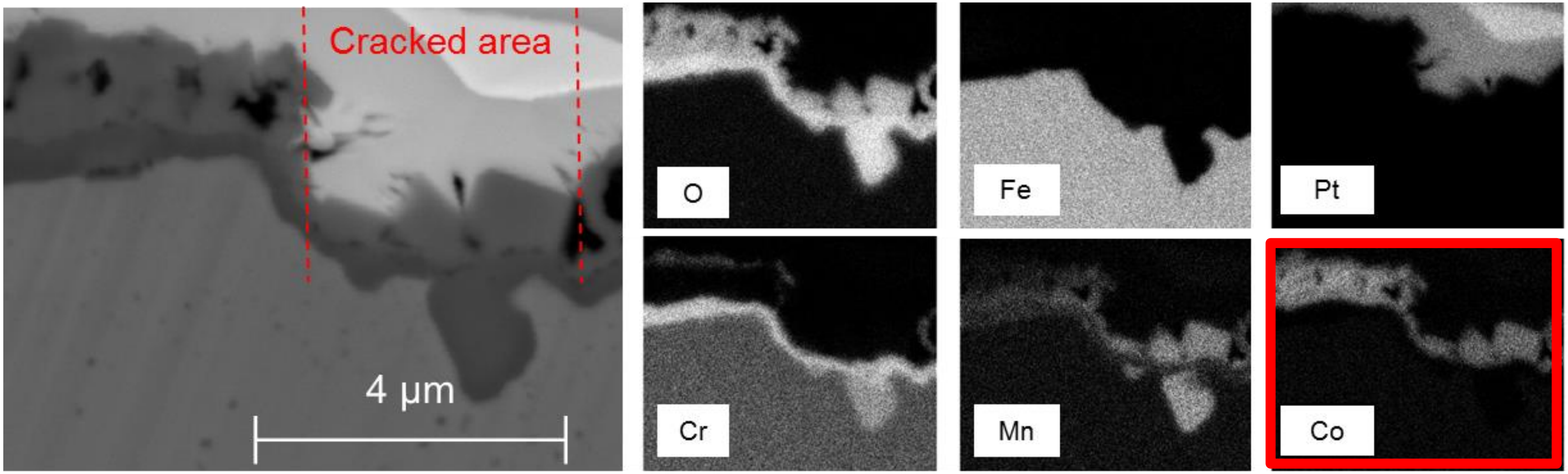
No signs of increased Cr-vaporization after mechanical deformation/stamping



Mn enrichment within the cracked area

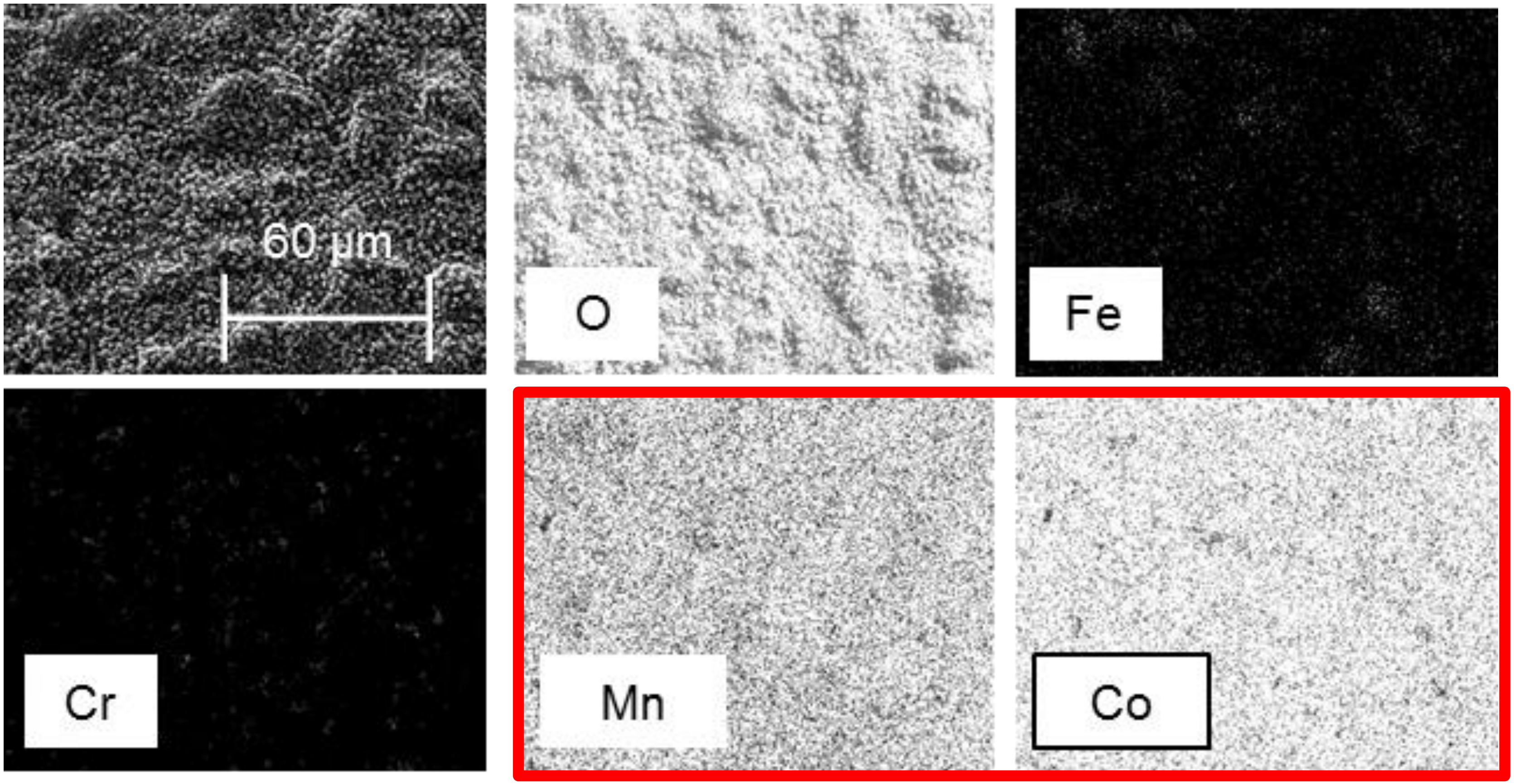
More homogenues Cr, Mn and Co signal after 24 h

24 h (Air, 850 ºC):



Thin Co-rich layer within the cracked area
Growth of $(Co,Mn)_3O_4$ crystals within cracked area

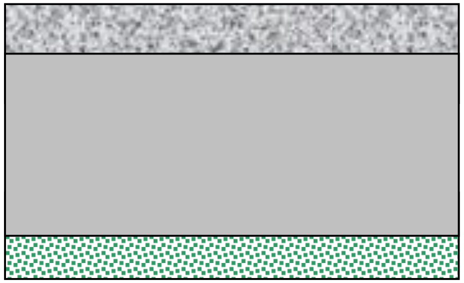
336 h (Air, 850 ºC):



Surface homogenously covered by an oxide rich in Co and Mn

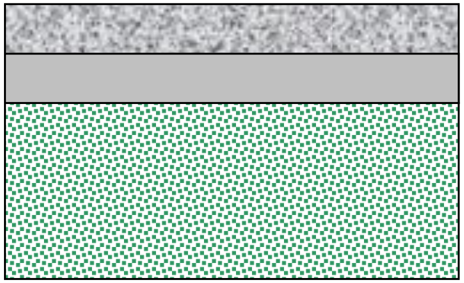
Solid Oxide Fuel Cell (SOFC)

Electrolyte supported



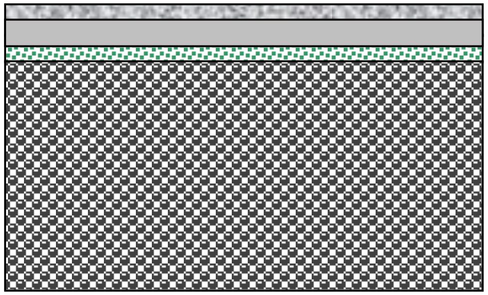
>800°C

Anode supported



650-800°C

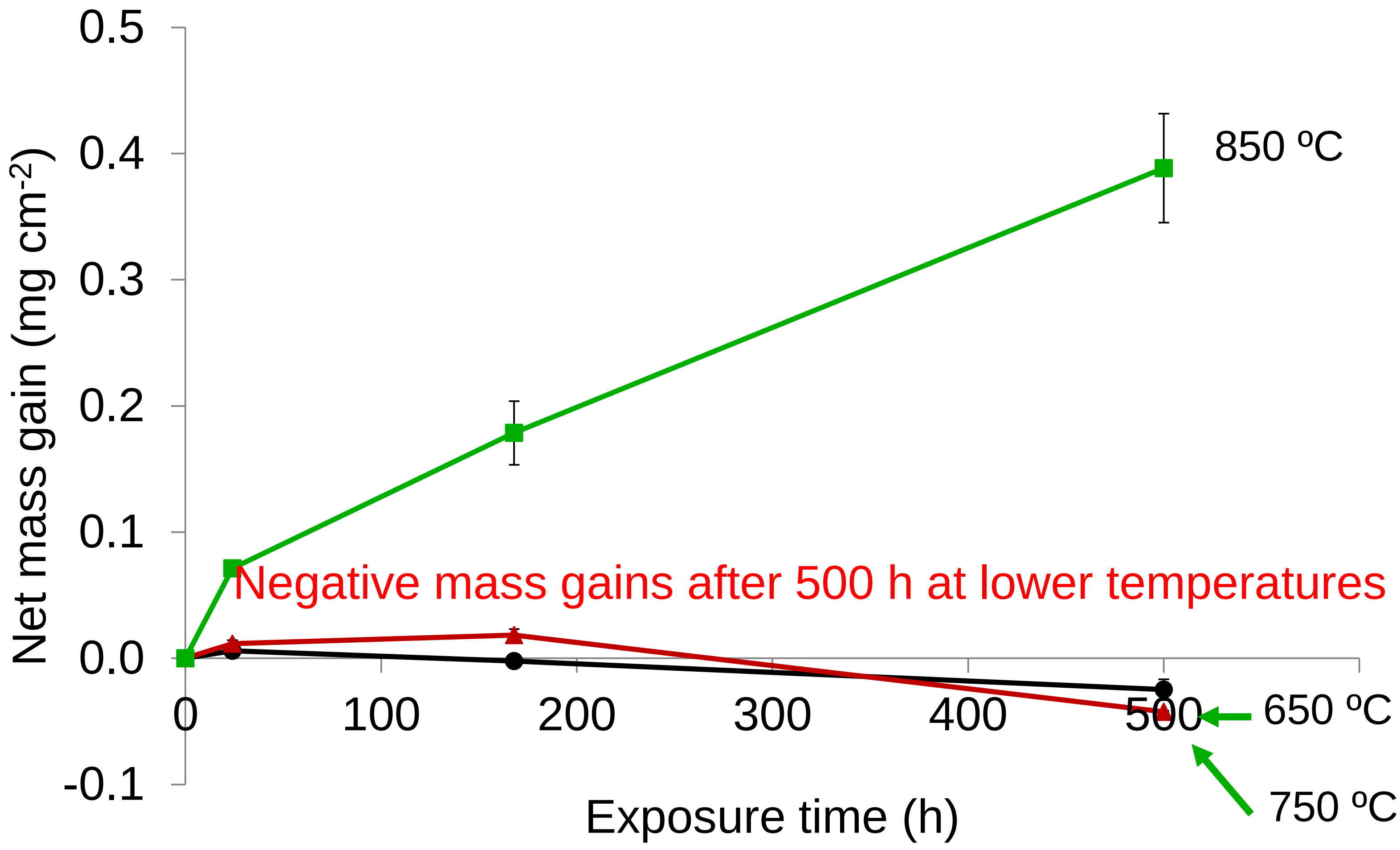
Metal supported



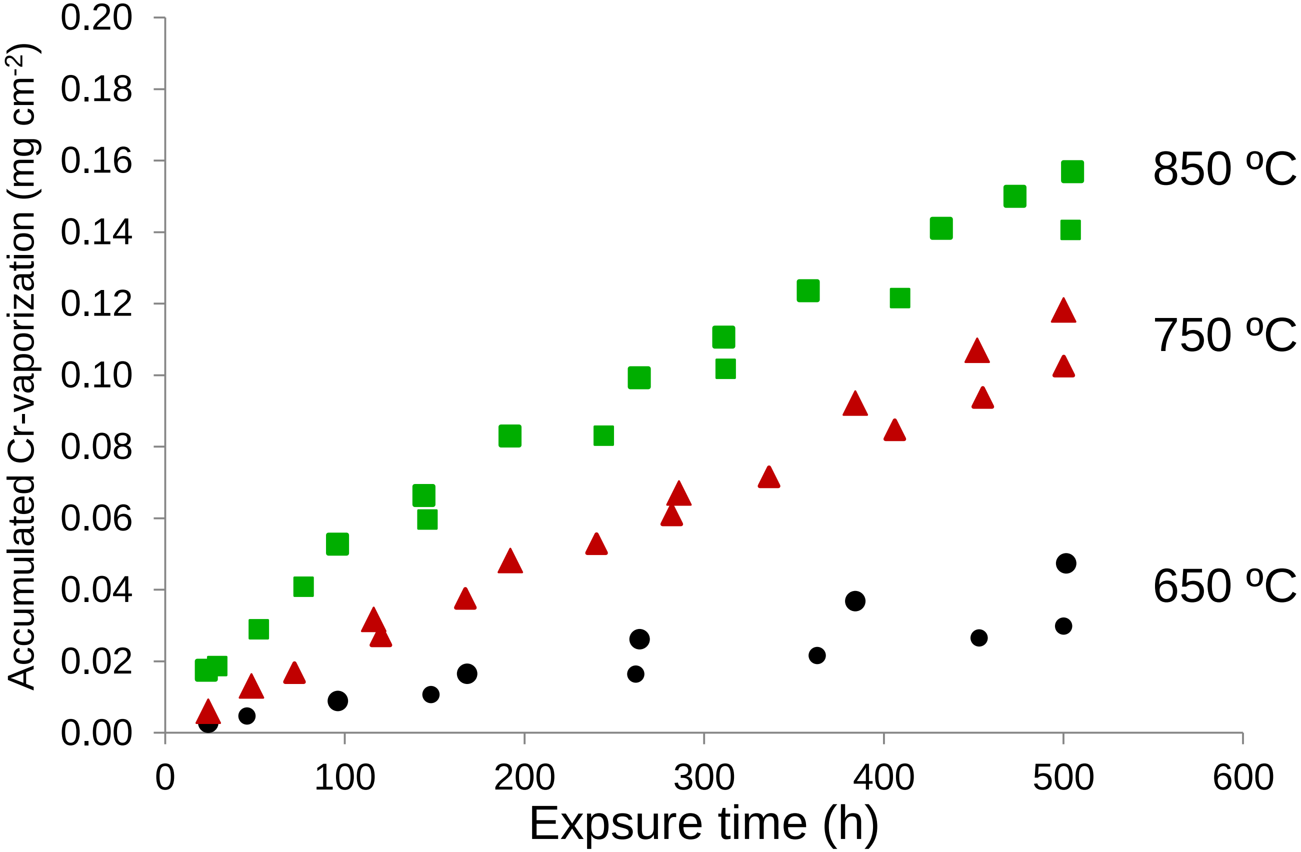
<700°C

Operating temperature for SOFC systems lies in between 600-900°C

The effect of temperature on mass gain



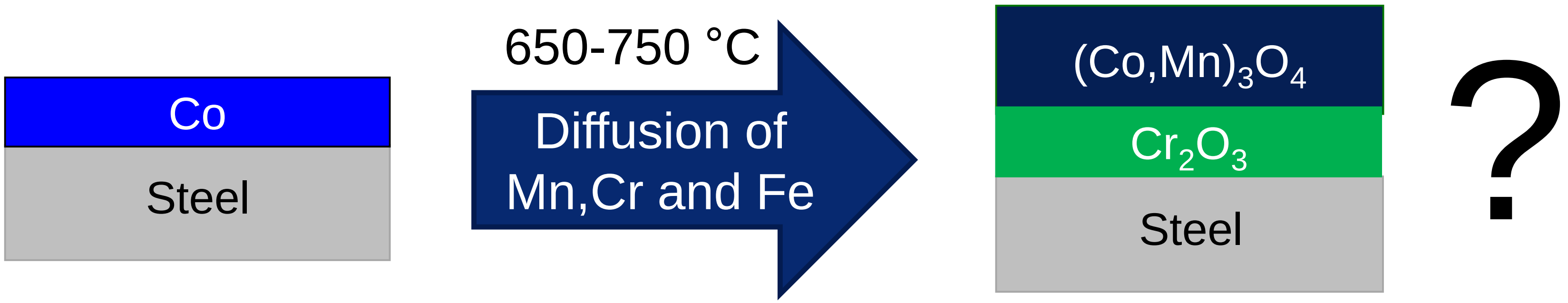
The effect of temperature on Cr vaporization



Small effect of temperatur for Cr vaporization

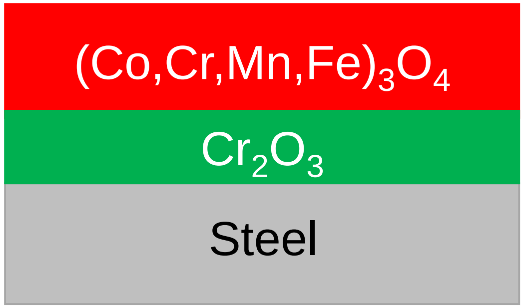
=> Coatings are necessary also at lower temperatures (650 ºC)

How is the metallic Co coating influenced by a lower temperatue?



If not, what is formed instead?
And what is the effect on Cr vaporization and oxide scale growth?

Do we need to design low-temperature coatings?



Summary and future work

- Novel nano coatings for superior properties (Cr vaporization and oxidation rate)

- Pre-coated concept to reduce costs
    - Crack formation due to mechanical deformation (stamping)
    - Self-healing of the $(Co,Mn)_3O_4$ toplayer

- Coatings necessary even at low temperatures
    - ➢ Cr vaporization is less influenced by temperature than oxide scale growth

- A need for special designed low-temperature coatings?
    - ➢ Microstructure and chemical composition of the coating not the same at lower temperatures

➢ Stack tests (Elcogen) with novel nano coatings are scheduled to be carried out beginning of 2016