Workshop Series: Fuel Cell Systems

12th Workshop 2019

Progress in Fuel Cell Systems

Novotel Brugge Centrum

21/22nd May 2019, Brugge (Bruges), Belgium

UNIVERSITY OF BIRMINGHAM

EERA European Energy Research Alliance

HEATSTACK

Brief Overview of the workshop:

The current workshop will be the twelfth in the series that started off with the Large SOFC project.

As usual we are looking at fuel cell systems – somewhat with an emphasis on solid oxide, other high temperature technology, and stationary applications – but not exclusively so. As time goes by, interests broaden and in the past we have also had MCFC and PEFC technology on board, including SOFC applications for aircraft.

Nevertheless, the common theme is fuel cell systems and their components. One of the main reasons being that involvement of companies manufacturing and delivering system Balance of Plant is low in the fuel cell scene and we want to offer a platform for exchanging information and experiences between the system integrators, operators, and BoP suppliers.

Four presentations in this workshop will this time showcase results from the HEATSTACK project which focused on the development and industrialisation of cathode air pre-heaters for fuel cell systems.

Again, the workshop will be part of our activities in EERA, the European Energy Research Area, that is trying to establish a low TRL research programme to underpin the activities of the FCH JU on a European scale.

Presentations will take about 20 minutes with an added 10 minutes for questions and discussions.

The workshop will be followed by the BALANCE workshop on 22/23 May, looking into reversible SOC (SOFC/SOE) operation. Participants are welcome to also register for that event.

The evening programme will consist of a walk through town or a museum visit (t.b.c. and depending on the weather), followed by a traditional Flemish dinner in a nearby restaurant. Anyone arriving before 19:00 h on the Monday is welcome to join for a stroll through town and a visit to a 100-Belgian-beers pub.

The HEATSTACK project has received funding through the FCH 2 JU under contract number 700 564.

Tuesday , 21 May 2019	
8:30 – 8:55	*Registration and uploading of presentations*
FC System Technical Details	
9:00 – 9:30	SOC systems for PtX applications: a process engineering perspective – *S.Gupta, DLR*
9:30 – 10:00	Fuel cells for heavy-duty vehicles in Europe: an insight into both legislative and technical challenges – *Marcus Taylor, University of Birmingham*
10:00 – 10:30	Cooling with Heat - *Bhargav Pandya, University of Birmingham*
10:30 – 11:00	*Coffee Break*
11:00– 11:30	Thermo-sensing of SOFCs – *Jung-Sik Kim, University of Loughborough*
FC System Components / HEATSTACK results	
11:30 – 12:00	Status of the development and manufacturing of Sunfire-Home – *Tobias Seidel, Sunfire*
12:00 – 12:30	Gas/Gas heat exchanger for process intensification – *Carlo Tregambe, ICI Caldaie*
12:30 – 14:00	*Lunch*
14:00 – 14:30	Design and manufacture of Cathode Air Pre-Heaters – *Charlie Penny, Senior Flexonics*
14:30 – 15:00	Chromium release and corrosion on SOFC heat exchangers – *Kun Zhang, University of Birmingham*
15:00 – 15:30	*Coffee break*
15:30 – 16:00	HEATSTACK panel discussion - *Charlie Penny, Senior Flexonics*
16:30	*Brewery Museum Tour*
18:00	*Dinner at restaurant*

Wednesday , 22 May 2019	
8:30 – 8:55	*Registration and uploading of presentations*
Fuels for Fuel Cells: Biogas, syngas, and synthetic fuels	
9:00 – 9:30	Experience with a biogas fuelled SOFC: DEMOSOFC – *Massimo Santarelli, Politecnico di Torino*
9:30 – 10:00	Operation Experience With a Novel Highly Efficient Mirco-Scale SOFC CHP System Based on Biomass Gasification – *Nikolaus Soukup, AVL.*
10:00 – 10:30	Gas processing for Gasifier-SOFC systems - *Alessandro Cavalli, TU Delft*
10:30 – 11:00	*Coffee break*

11:00 - 11:30	A P2G concept for Indonesia – *Artur Majewski, University of Birmingham*
11:30 - 12:00	*end-of-meeting discussion* Project brokerage: FCH JU 2019 programme, EERA and other research, demonstration, and funding opportunities and interactions
12:00 – 13:30	*Lunch*
13:30	Coffee and End of Meeting

FUEL CELLS AND HYDROGEN
JOINT UNDERTAKING

HEATSTACK

Workshop Series: Fuel Cell Systems
12th Workshop 2019

Progress in
Fuel Cell Systems

Novotel Brugge Centrum

21st May 2019

Charles Penny

Coordinator

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PROJECT OVERIVEW

- Call year: 2015
- Call topic: H2020-JTI-FCH-2015-1 Production Ready Heat Exchangers and Fuel Cell Stacks for Fuel Cell mCHP
- Project dates: April 2016 to March 2019 extended to June 2019
- % stage of implementation 01/11/2017: 70%
- Total project budget: €2,899,760
- FCH JU max. contribution: €2,899,760
- Other financial contribution: None
- Partners: Senior UK Ltd, Senior Flexonics Czech s.r.o, Vaillant GmbH, The University of Birmingham, ICI Caldaie SPA, PNO Consultants Ltd, Sunfire GmbH

PROJECT SUMMARY

- HEATSTACK, Production Ready Heat Exchangers and Fuel Cell Stacks for mCHP
- Objectives
  - Significantly reduce the number of cells in the Cathode Air Pre-Heat from the current 28
  - Reduce the amount of glass material in the SOC stack by 50%
  - Reduce the time to manufacture a CAPH from 8.83 to 1.35 hours.
  - To generate a commercial document for 10,000 CAPHs / year that meets cost targets
  - To develop and prove tooling to meet objectives 2 and 3
  - To develop AluChrom as the material of choice for the CAPH
  - To have a production feasible repair method for CAPHs leaks
  - Develop a pilot production line for SOC glass seals
  - Run long-term performance on components (PACE)
  - Business plan to increase volumes to a critical mass

The Business Goals for Senior and Sunfire

Both Sunfire and Senior are commercial businesses and the ultimate goal is to make a profit for the shareholders.

At the end of Heatstack (and PACE) both businesses wish to have a FCmCHP that is correctly priced, in production and gives the customer value for money.

This will be the true measure of HEATSTACK's success

CAPH image

High Effectiveness > 85%
Low pressure drop for both fluids
Core manufactured from 0.3mm Aluchrom stainless

Risks and Challenges

There were four main risks or challenges when the project started.

Business development – Is there really a market for mCHP fuel cell systems? And if there is when will the European market hit 100,000 / year. This is still a major risk and needs a number of OEMs to develop the market. Vaillant the OEM within the consortium made a decision to stop the commercialisation of FCmCHP systems. Sunfire have taken over as both the stack and mCHP system developer.

CAPH material – A stainless steel with >3.5% aluminium was expected to recuperate its alumina surface and significantly reduce Chromium Evaporation. The pre-Heatstack development was done with Inconel plates. The challenges were was this true? Could it be formed? Could it be welded and give leak tightness within the specification? Was it durable in service?

Could CAPH cycle times be reduced to achieve target times?

Could the application of glass material to the SOC be automated? YES will be presented later today.

Business Development

Sunfire are participating in PACE and have forward volume predictions for sales.

Senior and Sunfire are looking for other applications that can utilize Senior's technology. Ideally the same plate but at least the same capital equipment.

Senior has supplied prototype CAPHs to a Japanese mCHP developer.

Senior are discussing prototype CAPHs with a British SOFC developer.

Senior is actively pursuing other opportunities.

ICICaldaie are not yet ready to move into production with the system that has been developed within Heatstack.
However, they have another application, for low volume production for the same technology

AluChrom 318 material

CAPH material – A stainless steel with >3.5% aluminium was expected to recuperate its alumina surface and significantly reduce Chromium Evaporation. The challenges were was this true?

Could it be formed?

Could it be welded and give leak tightness within the specification?

Was it durable in service?

AluChrom 318 material – Chromium oxide formation

Green Cr deposits shown on Inconel plate vs Aluchrom:

Different amount of chromium deposits in Inconel 625 (top) and Aluchrom (bottom) heat ex-

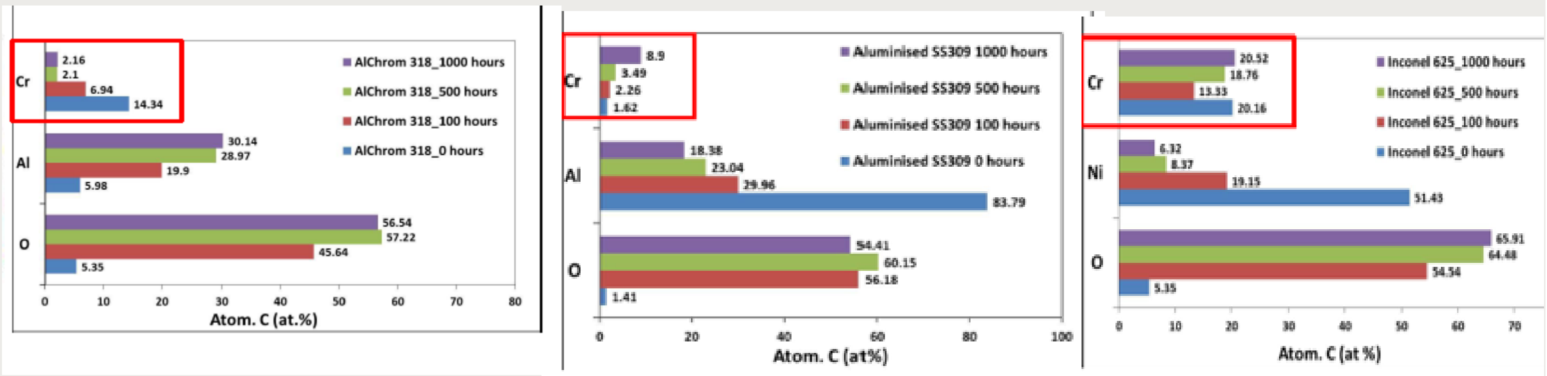
AluChrom 318 material – Chromium Evaporation

Achievement to-date Now

Info from material supplier

25% 50% 75%

100% confidence in performance



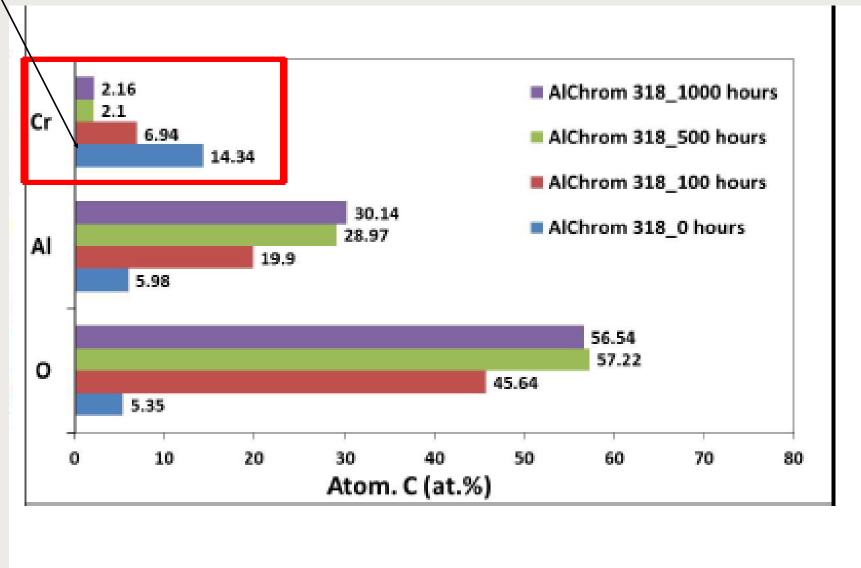
Test Conditions: 850 °C; 6.0 L/min Airflow; 3 vol% H_2O.

Equipment: Normal tubular glassware for high temperature corrosion test; Denuder Technique for evaporated Cr collection.

AluChrom 318 material – chromium evaporation

Although the operation of the CAPH causes the Alumina layer to form there are two problems. The alumina layer takes a finite time to form and it does not form on the cooler section of the CAPH thus Cr evaporation is not reduced as much as it could be.
The UoB are now working on how to pre-treat AluChrom to reduce the initial levels of Cr

A new objective has been added to Heatstack to develop a practical process for pre-heat treating the Aluchrom prior to delivery to the customer.
The temperature and time are now know but which processes to manufacture can be successfully used?



AluChrom 318 material - formability

Achievement to-date Now

Aluchrom Yhf trialled - splits

AluChrom 318 Forming and welding

25% 50% 75%

Over 3,000 plates formed with no splitting concerns.

AluChrom 318 material - weldability

Achievement to-date
Now

Aluchrom Yhf trialled - splits

25% 50% 75%

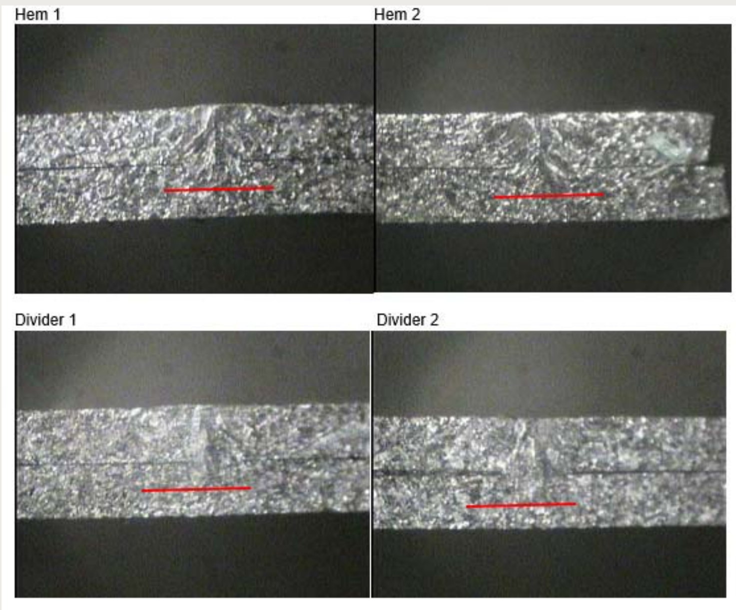
AluChrom 318 Forming and welding

85 stacks and 1360 cells welded.

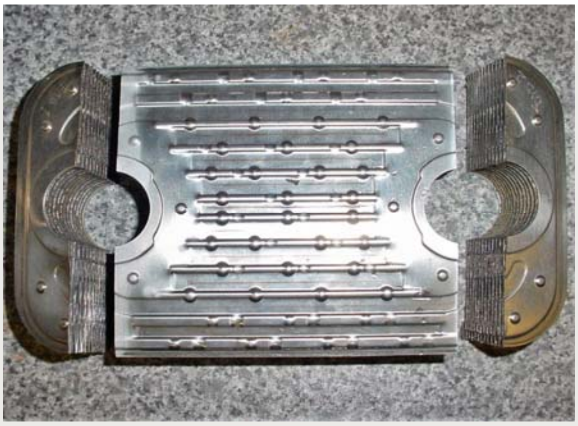
Cells and stacks are within the leak tightness specification

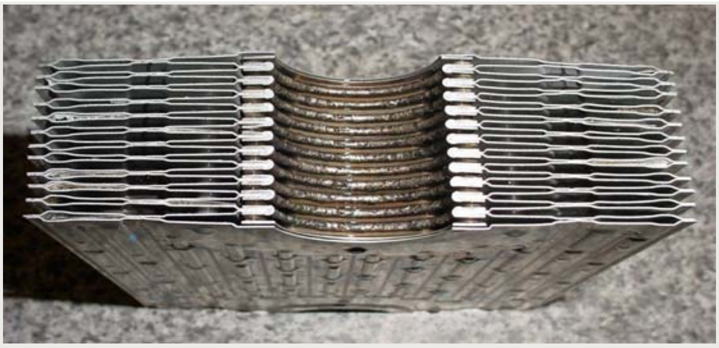
AluChrom 318 material – cell weldability

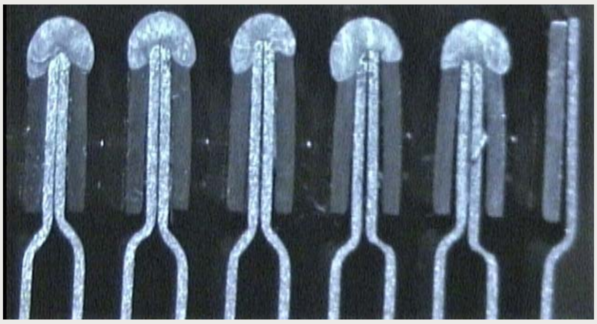
To achieve this quality of weld the tooling to clamp the plates together and the laser settings required significant development. As can been seen this has been successful.



AluChrom 318 material – cell to cell weldability







The cell to cell joint is a pair of rotary joints. One forming the air in and the other the air out. This joint must not only be leak tight but forms two columns that hold the whole core together.

AluChrom Material – Durability

Eight AluChrom CAPHs adapted to fit pre HEATSTACK mCHP have run.

Vaillant Fuel cell G5
Cathode Air Heat exchanger Al Cr

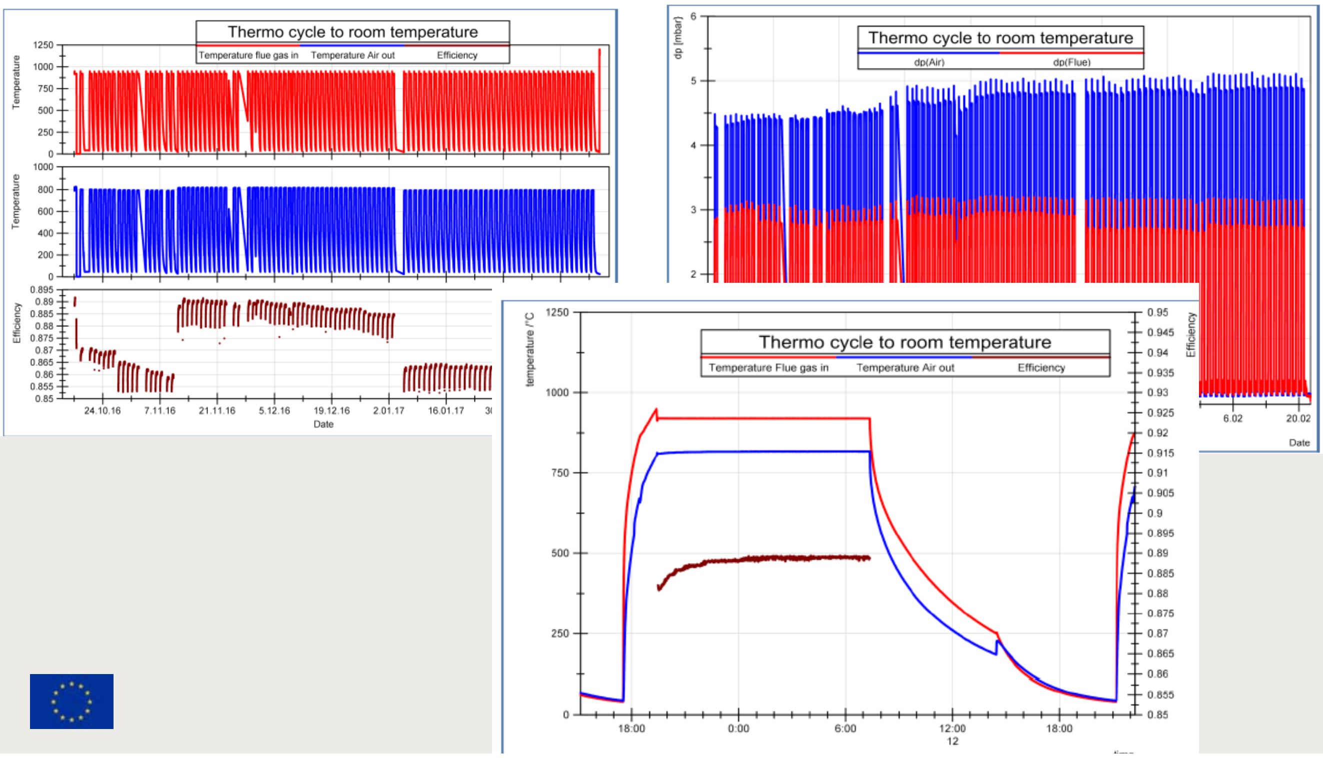
Number	Serialno.	Object	Installation Date CAPH	Exchange Date	Operating-hours	Stock
1	5200N4	5013	12.02.2015	09.05.2016	9915 h	
2	5199N9	5049	12.02.2015	17.05.2015	10496 h	
3	5110N0	5321	04.02.2015	11.05.2016	7001 h	
4	5114N4	5328	17.11.2015	14.02.2017	10534 h	Remscheid
5	5206N0	5376	25.11.2015	19.09.2017	11185 h	
6	5143N3	5378	19.11.2014	13.12.2017	25242 h	
7	5201N0	5389	16.09.2015	12.06.2017	11035 h	Remscheid
8	5202N6	5405	24.04.2017		6419 h	

Note: There have been no abnormalities in field.

Current status Fuel cell in field: 49 Systems are running.

4.204.631 running hours

AluChrom material Durability of CPAHs – Passed thermal cycle



Cycle times

Prior to Heatstack the TAKT time to build one prototype CAPH was 8.83 hours. The goal stated in Heatstack was to reduce the TAKT time to 1.35 hours.

The latest timing based on the capital and tooling developed within Heatstack is 2.83 hours, at 1,000 units/year. Using the same capital and tooling but with process improvements the time should reduce to 1.9 hours.

At 10,000 units/year and with further investment the 1.35 hours is achievable.

Cycle times

Summary of Senior's position

1. A CAPH manufactured from AluChrom is now production ready and a path forward agreed with Sunfire.
2. Senior Flexonics, Olomouc (Czech) will install the production line in October 2019.
3. Senior and UoB need to develop a production process for pre-heating the Aluchrom to generate an Alumina surface on the plate in the 'new' condition. The challenge is to have a practical and cost effective process.
4. Senior need to widen the customer base to further reduce costs.

Final thank yous

Firstly a thank you to Robert and his team at University of Birmingham for organising this event and more importantly their excellent work on Heatstack.

Secondly Sunfire who have stepped up to the challenge caused by Vaillant pulling out of SOFC mCHP.

All members of the HEATSTACK consortium who have been an absolute pleasure to work with.

And finally to Antonio Aguilo-Rullan and all at FCH-JU for their support and finance. It would not have happened without them.

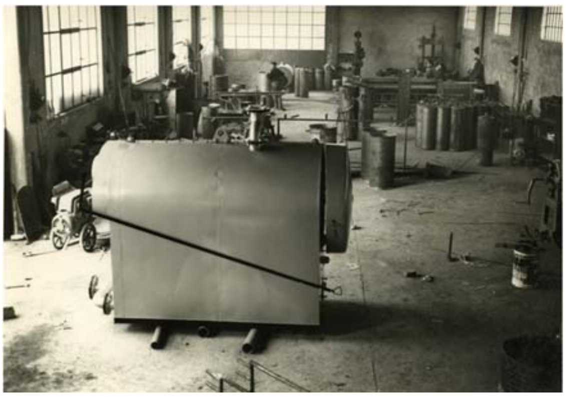
Progress in Fuel Cell systems: 12° Workshop 2019

Gas/Gas Heat Exchanger for process intensification

Bruge, 21/05/2019

ICI CALDAIE
THE EVOLUTION IN THE YEARS

ICI Caldaie **founded** as boiler manufacture in **1958**, became in the years one of the worlwide leader for the supply of heat generation systems.



ICI CALDAIE
APPLICATIONS SERVED

Supplying **complete systems** for applications in commercial and industrial sectors

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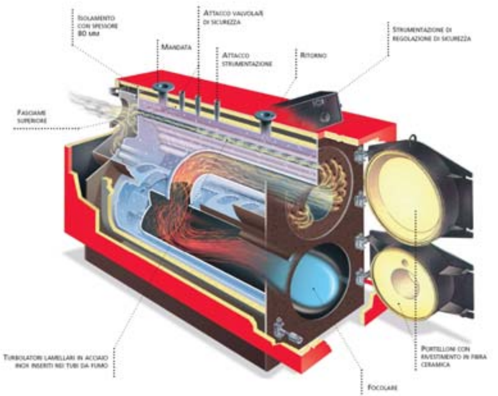
FROM BOILERS TO TOP BOILERS
THE BEGINNING. BURNING THE FUEL

Boilers have been invented to transform the chemical energy of the fuel into heat.
ICI brings the **efficiency** of this kind of system **to the top!**



FROM BOILERS TO TOP BOILERS
SECOND STEP. GREEN BOILERS

Next step is to decrease the **NOx emissions** using premix technology.
The emission of this kind of systems is nowadays **close to zero!**

LowNOx

FROM BOILERS TO TOP BOILERS
THIRD STEP. PREDICTIVE ADVANCED SYSTEMS

Jointly with top efficiency and low emissions, a predictive system is able to **change** its **behavior** in order to **follow the users' need** and minimizing the consumptions

ecovapor

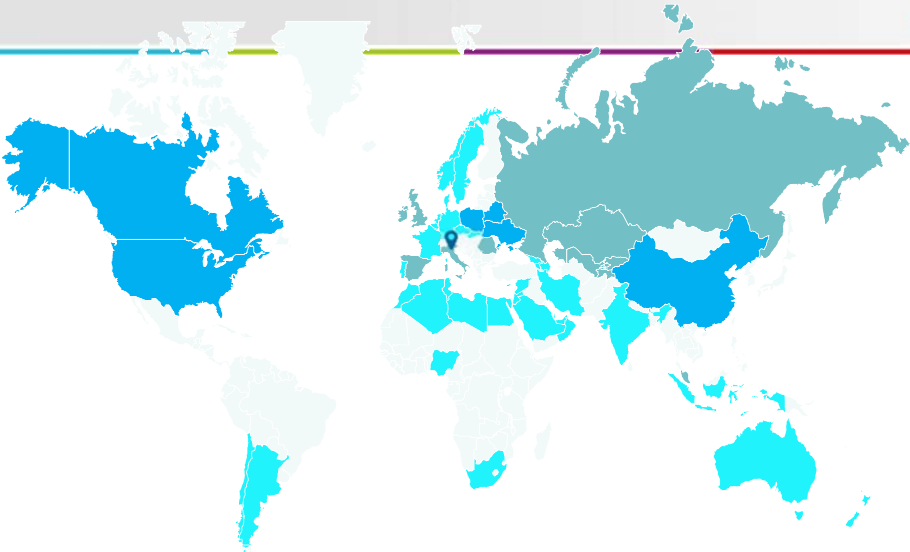
	Traditional boiler	ECOVAPOR
Daily Starting	153	1
Gas/steam cost	-14%	
Electric energy/steam cost	-20%	

ICI CALDAIE
CHOSEN BY INTERNATIONAL BRANDS

Evolution recognized by many international well-known brands

Progress in Fuel Cell Systems: 12th Workshop 2019

ICI CALDAIE
WORLWIDE PRESENCE



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THE UNCERTAIN FUTURE OF BOILERS

A TURNING IS APPROACHING

There is a public and political awareness that it is urgent to find a solution to the **too high production of CO2,** a gas considered to be one of the main causes of the greenhouse effect and its consequences.

There will be always a need for heat and energy, but they will be produced no longer by boilers based on Natural Gas, or at least not by the ones we use at the moment.

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BEYOND BOILERS

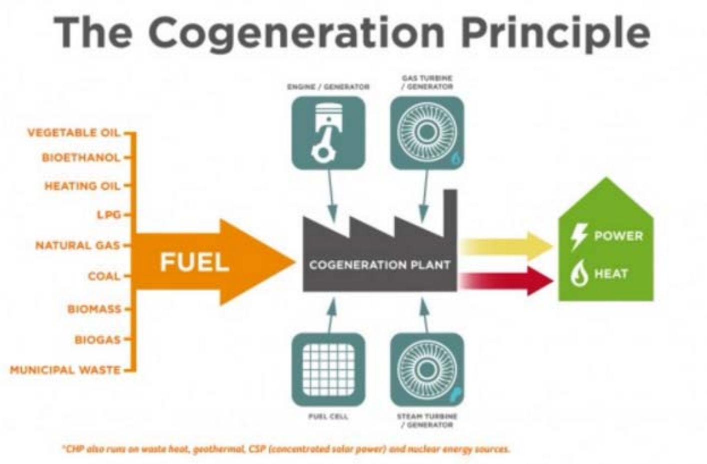
In 2007 ICI management launches an ambitious challenge to its technical staff: find **alternatives to boilers.**

The goal is to use ICI know-how and experience for the development of new products that are environmentally friendly with **reduced or null CO2 emissions.**

All new developed products need to be:
- produced and assembled **at ICI**
- **transportable** by standard means of transport (containers on trucks)
- **turnkey systems** easy to be installed
- can operate as stand-alone system or be part of a complete plant

FROM TOP BOILERS TO CHP
NEW CONCEPT TO PRODUCE ELECTRICITY

Improve the quality of energy transformation producing electricity from the combustion of the fuel and recovering the waste heat.



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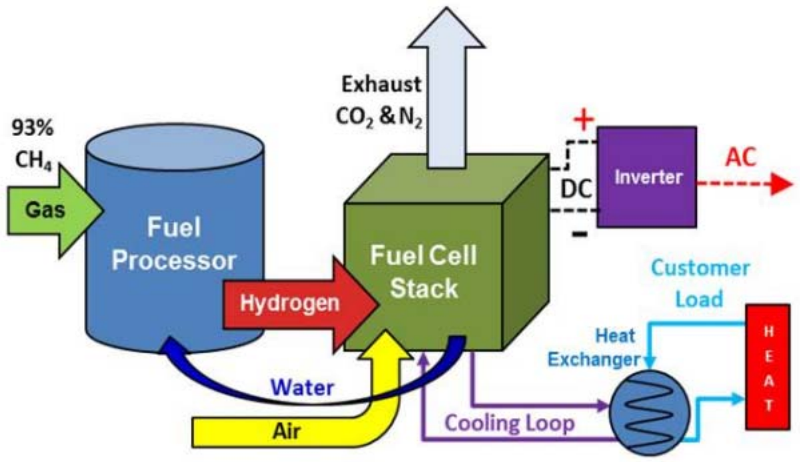
FROM TOP BOILERS TO CHP
NEXT STEP. NOT TO BURN THE FUEL

Improve the quality of energy transformation **from the combustion to a chemical reaction**.
Possibility for carbon capture and sequestration.



FROM TOP BOILERS TO CHP
TRANSITION TO HYDROGEN ECONOMY

- The natural outlet market for ICI is the small medium size cogeneration system
- Fuel Cell based CHP systems have been selected thanks to their potentially higher electrical efficiency
- Among the Fuel Cells, the LT-PEM are the most studied and well developed ones, in part due to the boost received by the automotive industry
- But LT-PEM can work only with pure H_2 or with syngas (coming for example from Natural Gas Reforming) only with a CO content lower then 10 ppm

ICI ACTIVITY
PROJECTS & PRODUCTS

Sidera 30 – CHP 30 kWe

Project start up 2007

Development of:

- fuel processor by Steam Reforming + WGS + PrOx
- PEM stacks integration
- Power conditioning
- BOP

ICI ACTIVITY
PROJECTS & PRODUCTS

CHP target characteristics		
Electric power out	kWe	30
Voltage	V	3 / 400
Current	A	44
Frequency	Hz	50
Electrical efficiency higher than	%	30
Heat power	kW	50
Heating water flow	l / h	4000
Outlet water temperature	° C	65
Thermal efficiency higher than	%	50
Total efficiency higher than	%	80
Voltage	V	230
Natural gas consumption from the grid	m³ / h	10,5
Approximate dimensions	mm	1300x3060x2600

ICI ACTIVITY
PROJECTS & PRODUCTS

Castelnuovo del Garda

ECOBARRIO Madrid

ICI ACTIVITY
PROJECTS & PRODUCTS

We are no

ICI ACTIVITY
PROJECTS & PRODUCTS

We are now in the second generation of FC based CHPs

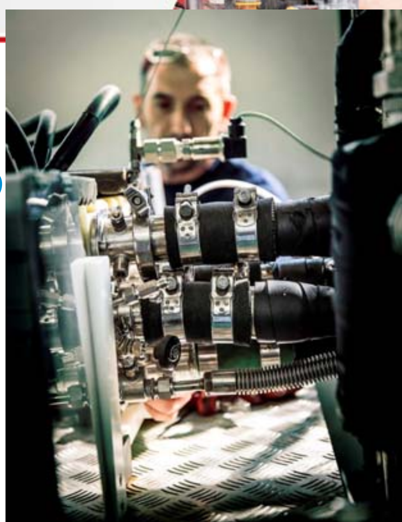
Results	unit	100%	80%	70%
Tcold	° C	17.21	17.27	17.54
Thot	° C	24.93	23.23	22.60
m H2O	kg/s	0.500	0.51	0.51
GN prod	Nm3/h	2.93	2.35	2.05
GN comb	Nm3/h	0.42	0.34	0.30
LHV GN	kJ/kmol	816971	818154	818128
Pel	kW	10.31	8.51	7.59
Paux	kW	1.08	1.40	1.17
Qin	kW	33.97	27.2	23.9
Pel netta	kW	9.2	7.1	6.4
Qth	kW	16.1	12.7	10.9
Eff. El. Lorda	%	30.35	31.29	31.75
Eff. El. Netta	%	27.17	26.09	26.89
Eff. Th.	%	47.52	46.55	45.48
Eff. Tot.	%	74.69	72.63	72.36

ICI CALDAIE FOCUSES ON INNOVATION COLLABORATIONS AND R&D

The success achieved in the **development** of the fuel processors for the production of syngas compatible with the LT-PEM and its **integration** in a CHP system based on FC, encourages ICI Caldaie to evaluate other possible ways for the exploitation of its knowledge and manufacturing capabilities

ICI CALDAIE GROWTH BY COLLABORATIONS

Along with research we believe in **knowledge sharing and dissemination;** for this reason we cooperate with research centers, technological laboratories and universities throughout all Europe.



Eindhoven University of Technology *(TU/e, The Netherlands)*
Fundación Tecnalia Research & innovation *(TECNALIA, Spain)*
Politecnico di Milano *(POLIMI, Italy)*
Commissariat à l'Énergie Atomique et aux Énergies Alternatives - LITEN *(CEA, France)*
Fraunhofer-Institut für Keramische Technologien und System IKTS *(IKTS, Germany)*
University of Birmingham *(UBHAM, UK)*
Università degli Studi di Salerno *(UNISA, Italy)*
Universidade do Porto *(U.Porto, Portugal)*
Deutsches Zentrum für Luft und Raumfahrt e.V. *(DLR, Germany)*
JRC – Joint Research Centre – European Commission *(JRC, Belgium)*
Stiftelsen Sintef *(Sintef, Norway)*
Technische Universität Graz *(TU Graz, Austria)*
Teknologian Tutkimuskeskus VTT *(VTT, Finland)*
Lappeenrannan Teknillinen Yliopisto *(LUT, Finland)*
Zachodniopomorski Uniwersytet Technologiczny w Szczecinie *(ZUT, Poland)*

ICI CALDAIE
GROWTH BY R&D

R&D - ICI Caldaie is involved in different **international projects** on efficiency heat production systems, **micro-cogeneration** system based on hydrogen fuel cells and **chemical reactors** development and manufacturing, **system integration**

Progress in Fuel Cell Systems: 12th Workshop 2019

Transition to hydrogen economy
CONVENTIONAL REACTORS

- ICI developed and is now in pre-commercial phase of reactors for syngas production
- Conventional Fuel Processor for Hydrogen production: different purity grade (CO down to < 5ppm) for different applications
- ICI holds several patents on new reactors design for: SMR – WGS – PrOx – Methanator

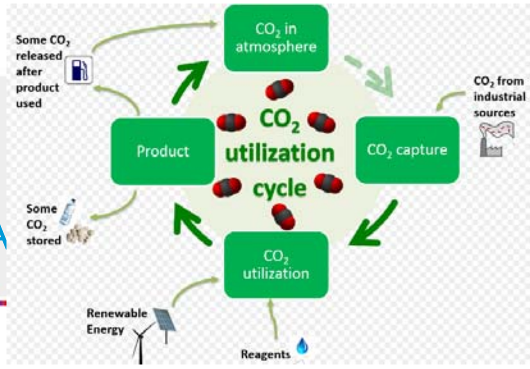
Transition to hydrogen economy
MEMBRANE REACTOR

The advantages of membrane reactors for on-site pure H_2 production starting from natural gas, compared with more conventional system (SMR + WGS + PSA) are:

- Simplicity (less reactors to be controlled)
- Costs (less reactors to be manufactured)
- Efficiency (less energy consumption)

Transition to hydrogen economy
MEMBRANE REACTOR

- On site H_2 production allows the reduction of the cost per Nm^3 of H_2 (there is no longer the transport problem) and allows a more efficient carbon capture and sequestration and a more effective CO_2 utilization.
- ICI experience shows that for the utilization of LT-PEM in the CHP systems, it is important to improve the Fuel Processor characteristics in terms of cost, H_2 quality and reliability

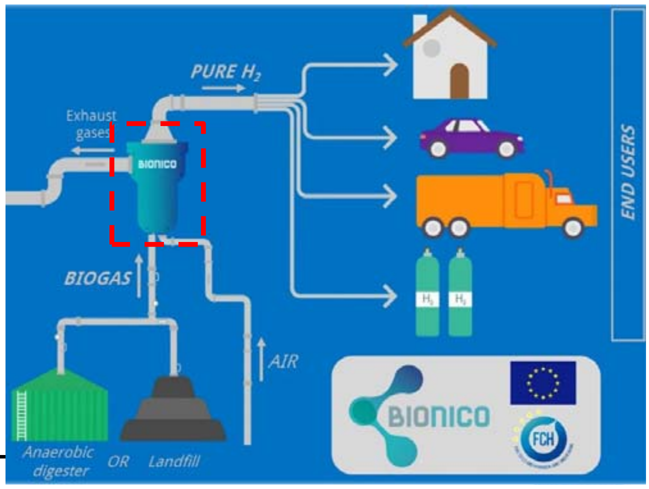


BIONICO Project:
A CASE STUDY OF CHEMICAL REACTOR DEVELOPMENT AND PROTOTYPING AT ICI CA

A novel reactor concept that integrate H_2 production and separation in a single vessel has been built by ICI Caldaie and will be demonstrated at TRL 6 at a real biogas plant, with a H_2 production capacity of 100 kg/ day.

- Fluidized bed catalyst for reforming reaction
- Pd based membrane for pure H_2 separation.

ICILab



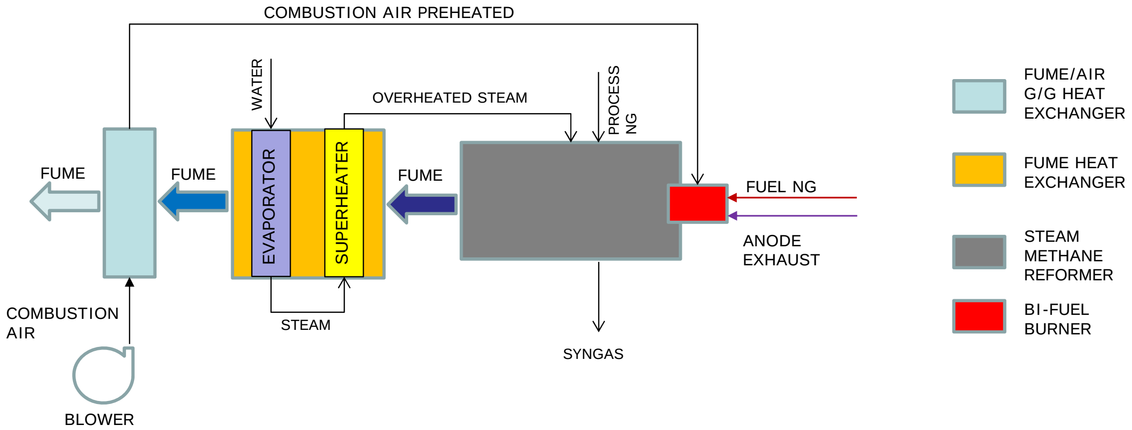
A SUMMARY OF CURRENT RESEARCH LINES AT ICI

- Conventional reactors for **on site syngas** production
- Membrane reactors for **on site pure hydrogen** production
- Reformer and prereformer development and **integration** in SOFC based CHP system
- **Integration** of membrane reformer for pure H2 production with LT-PEM in a CHP system
- **Integration** of SOEC with reactors for DME formation starting from CO2 and renewable energy in CCU application
- **Steam** generators with improved efficiency
- ......

ICI CALDAIE

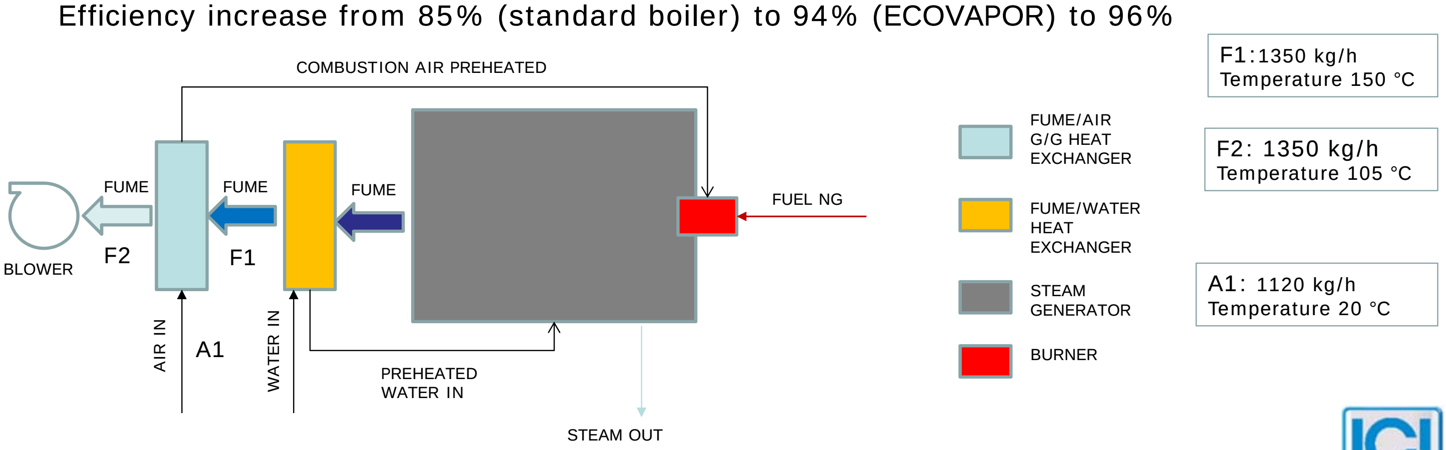
EXAMPLES OF GAS/GAS HEAT EXCHANGER UTILISATION IN ICI IMPROVED DEVICES REACTOR FOR ON SITE SYNGAS PRODUCTION

Efficiency increase from 80% to 83%



EXAMPLES OF GAS/GAS HEAT EXCHANGER UTILISATION IN ICI IMPROVED DEVICES SELF LEARNING STEAM GENERATION

Efficiency increase from 85% (standard boiler) to 94% (ECOVAPOR) to 96%



Progress in Fuel Cell systems: 12° Workshop 2019

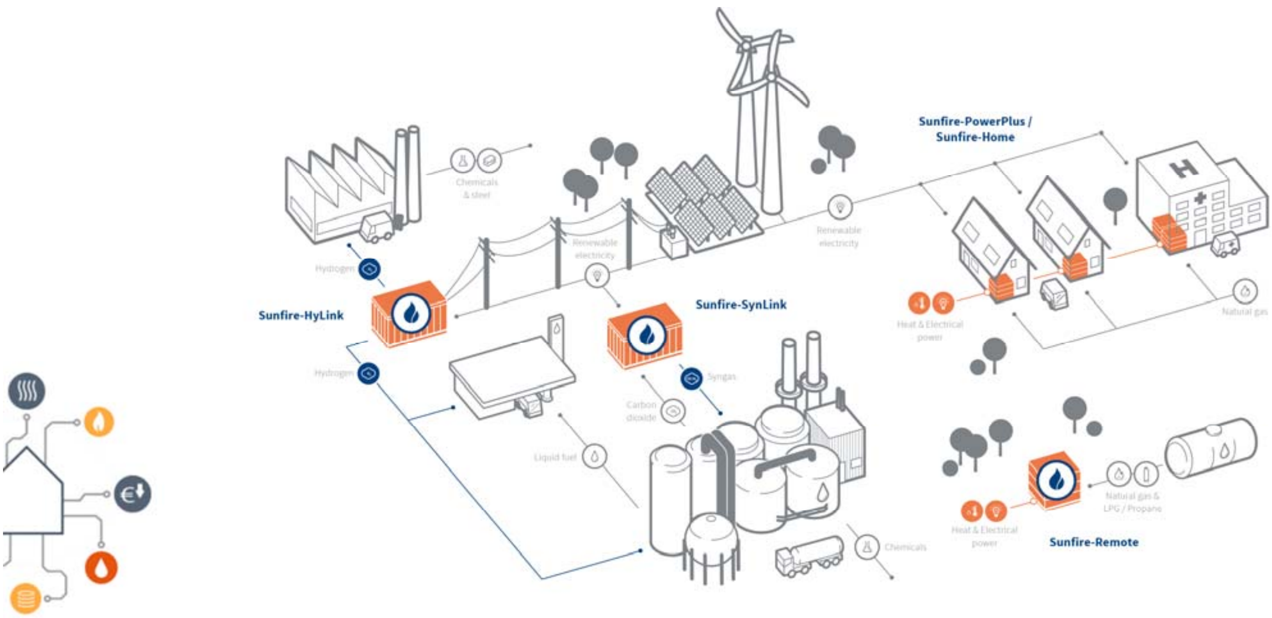
Thank you for your kind attention

Carlo Tregambe
carlo.tregambe@icicaldaie.com

SUNFIRE-HOME

Status of the development and manufacturing of Sunfire-Home

21st May 2019, Bruges
Tobias Seidel (Sunfire GmbH)

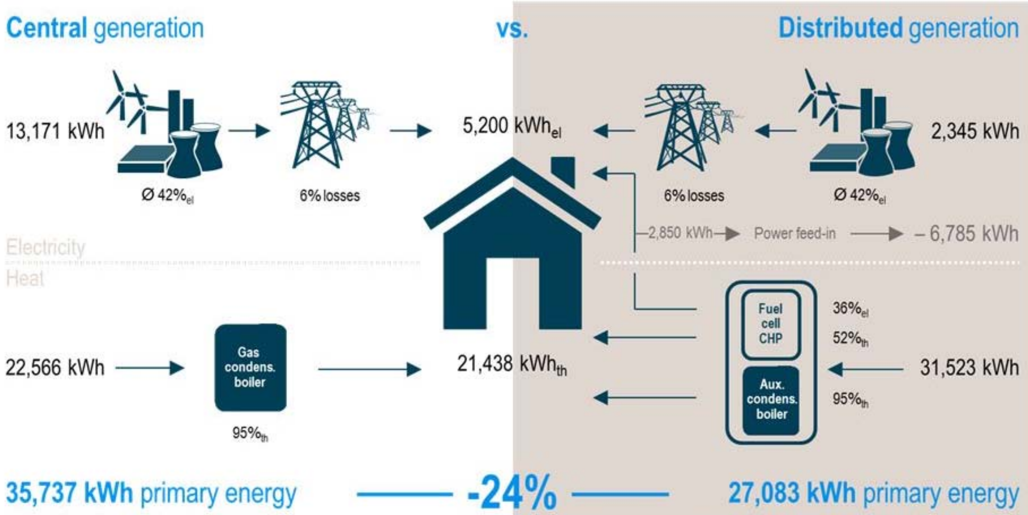


OUR VISION

Achieve a zero emission society in transport, industry and energy sectors via electricity based liquids and gases, making renewable energy available wherever and whenever it is needed.

BENCHMARKING HEAT-DRIVEN µCHP FOR DISTRIBUTED COGENERATION

Exemplary, of central status-quo primary energy consumption and distributed generation



Source: Roland Berger Strategy Consultants, Advancing Europe's energy systems: Stationary fuel cells in distributed generation, Publications Office of the European Union, 2015 – A study for FCH JU

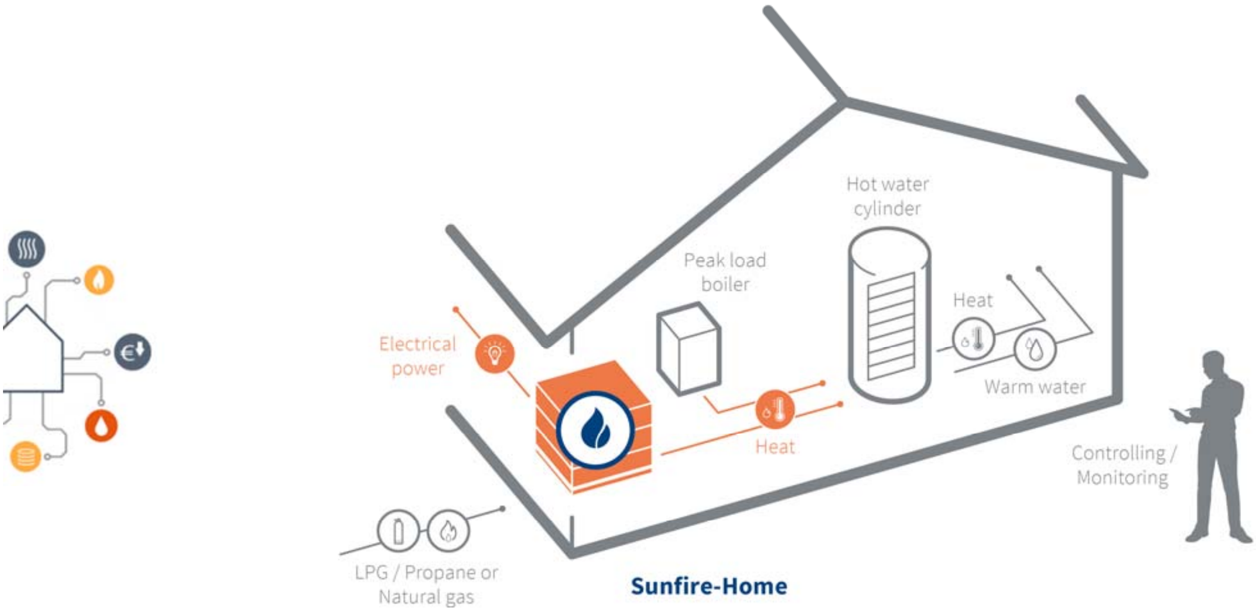
SUNFIRE-HOME:

Fuel Cell Heating System for European Market

- µCHP-System developed for households and two family houses
- SOFC stack technology developed by Sunfire
- Continuing system development by Vaillant
- Fuel: propane (LPG) or natural gas
- Dynamical operation and start-stop capability
- Market entry in 2019/20 within EU supported Projects PACE and HEATSTACK
- Available for other markets from 2021

✓ Efficient CHP-Solution for residential customers without gas grid access

INTEGRATION INTO HOMES



sunfire HEATSTACK FCH

TECHNICAL DATA TODAY: SUNFIRE-HOME 750 µCHP FUEL CELL SYSTEM

Main Properties	
Electrical output	750 W
Thermal Output	1,250 W
Electric efficiency	33 %
Overall efficiency CHP	88 %
Fuel	Propane or natural gas
Dimensions (H x B x T)	1,150 x 670 x 670 mm
Weight	~ 150 kg

Operation characteristics	
Start-up time	~ 4 h
Max. number of Start-ups	1 per 1,000 h (conservative approach)
Modulation range	P_{el} = 450 W - 750 W
Modulation time	~ 30 min
Max. number of modulations	130 / 1,000 h (conservative approach)
Typical operation time per year	5,000 – 6,000 h

sunfire HEATSTACK FCH

HEAT AND POWER IN PRIVATE ENVIRONMENTS

Sunfire-Home Highly Efficient Power Generation

- Powered by LPG or natural gas:
  - A clean alternative to heating oil
- Cutting down energy cost:
  - Easy installation
  - Low electricity production costs
  - Low maintenance
- Meeting regulatory standards:
  - Innovative CHP for actual and upcoming rules
  - Lower primary energy consumption
  - Less emissions

Application Site

COMPANY FACTS

Knowhow

- ~ 130 Employees in Dresden and Neubrandenburg
- Full value chain from Ceramics, Engineering, Stack + System Production, up to Synthesis Processes, Service etc.

Patents

- More than 60 patent families (e.g. »process patent sunfire« WO/2008/014854)

Revenues

- Multi-million Euro Revenues in Global Markets since 2011

Investors

Sunfire Headquarters

National and international awards
for innovative and pioneering technology

IMPRESSIONS

Sunfire Headquarter in Dresden

Sunfire-Home Production Facilities

Stack production

Sunfire Service

HEATSTACK

Work Packages of Sunfire

WORK PACKAGE 3: INDUSTRIAL SCALE UP – SOC STACK

Sunfire SOC stack characteristics

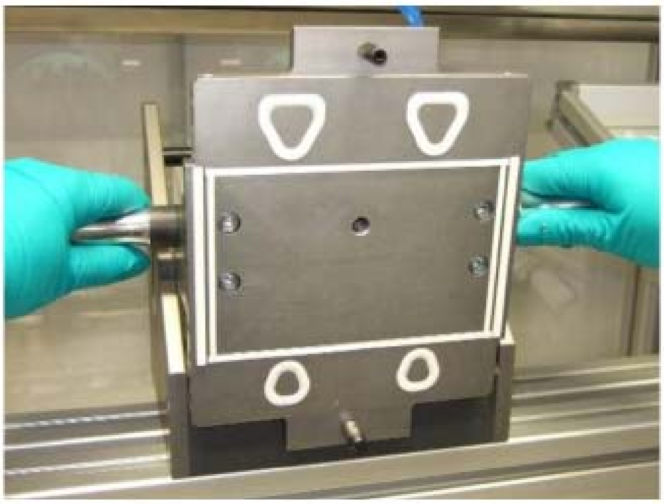
- ESC
- Sheet metal interconnect
- Open cathode design
- Glass seal between MEA and interconnect

WORK PACKAGE 3: INDUSTRIAL SCALE UP – SOC STACK

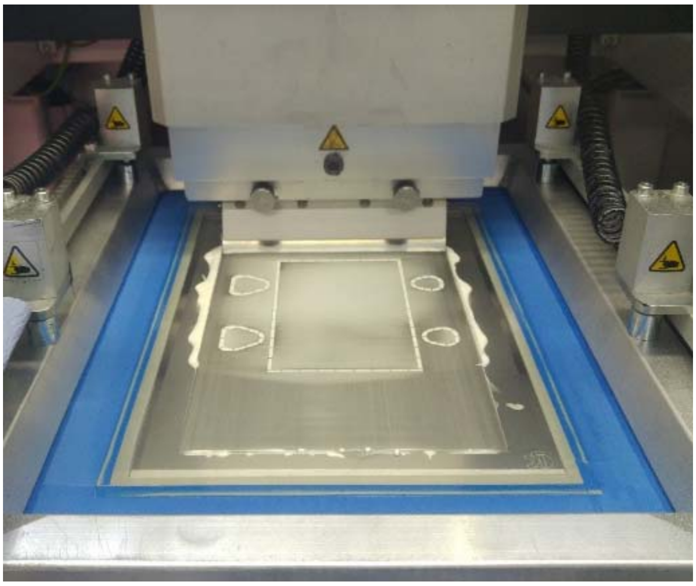
Manual glass seal process:

- Tape casting
- Calendering
- Punching
- Positioning + attaching

Automatable glass printing process



WORK PACKAGE 3: INDUSTRIAL SCALE UP – SOC STACK



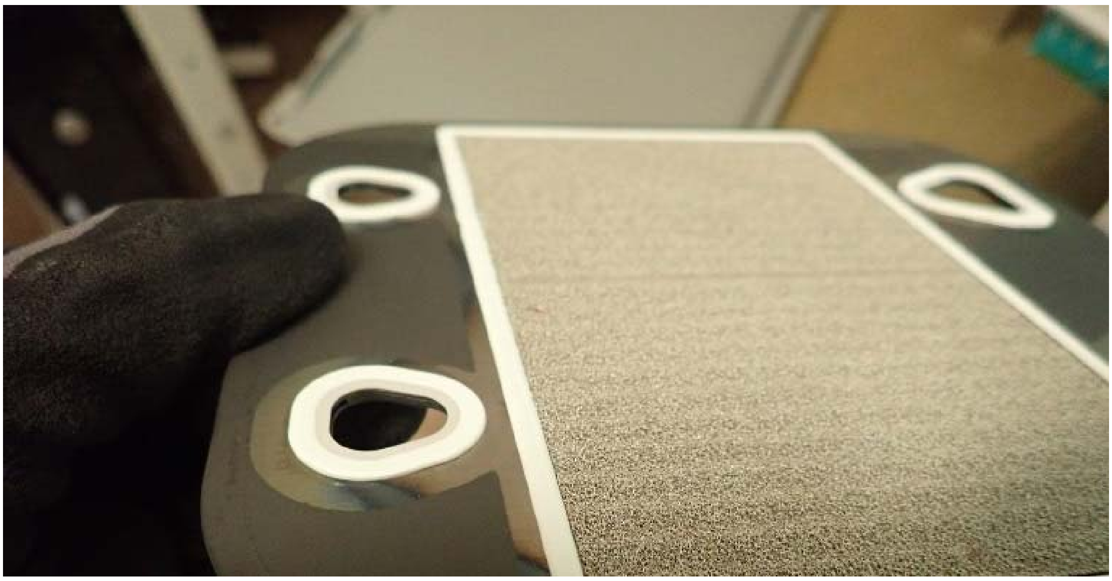
Process development for glass seal printing

- Process design study
- Development of a glass paste with tailored rheology
- Development of a stencil printing process
- Evaluation in Stack manufacturing trials

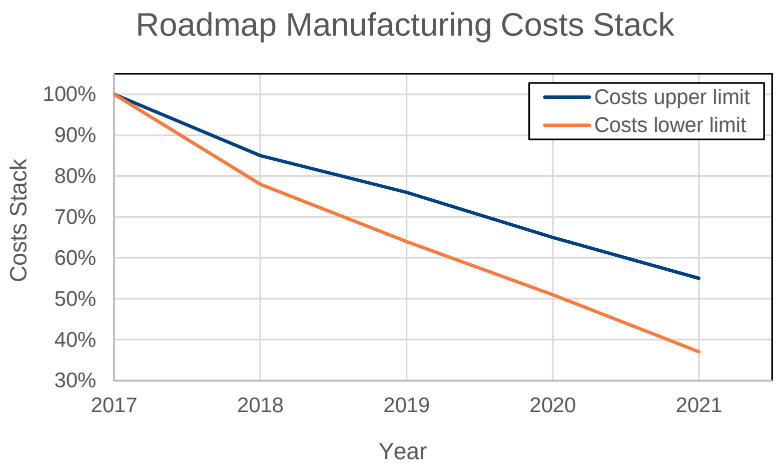
Process Automation

- Planning of a full / partially automated production line for printed glass seal
- Establishing of suitable quality control

WORK PACKAGE 3: INDUSTRIAL SCALE UP – SOC STACK



WORK PACKAGE 3: INDUSTRIAL SCALE UP – SOC STACK



Impact on Stack costs

- Glass seal responsible for approx. 10% of stack costs (material & personnel)
- Glass seal cost share reduced by 85% with printing process
- One major part of Sunfire's strategy for stack cost reduction

WORK PACKAGE 5: SOFC µCHP SYSTEM TESTING

Vaillant started the Activities of testing both developments in complete systems and Sunfire completes the tasks of testing:

- Glass-Printed Stacks
- Alucrome Cathode Air Preheater

… in order to use both developments in the systems produced in the PACE project

25.000 Hours operated Heat exchanger

THANK YOU!

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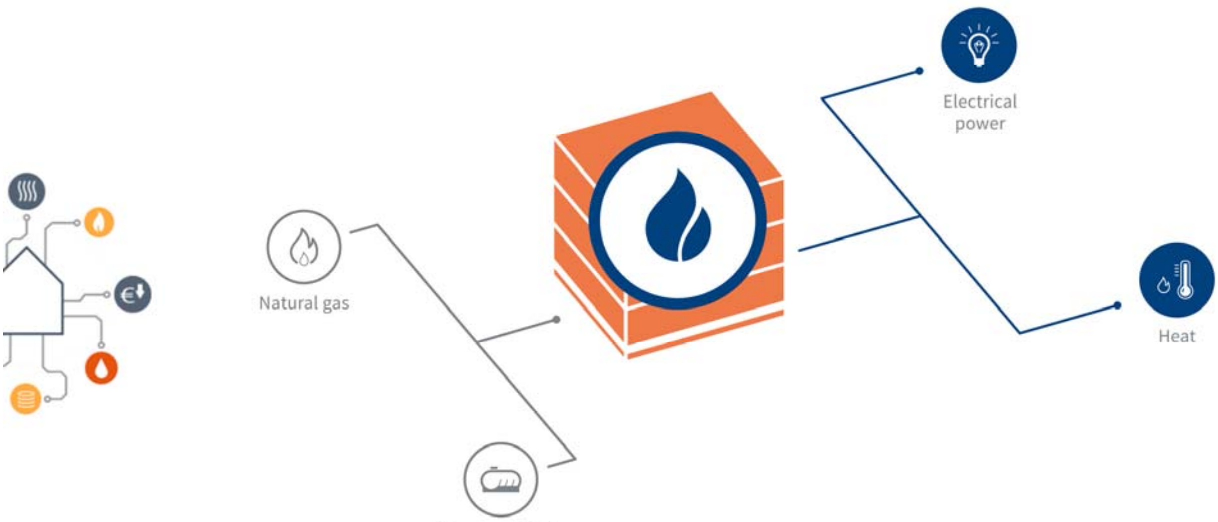
CHEMICAL ENERGY TO POWER AND HEAT

Sunfire-Home



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The Effect of Pre-heat Treatment of AluChrom 318 on the Corrosion Behavior and Cr Evaporation in SOFC Cathode Air Pre-heater

Kun Zhang, Ahmad El-kharouf, Robert Steinberger-Wilckens

Centre for Hydrogen & Fuel Cell Research

School of Chemical Engineering

University of Birmingham

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FCH

Previous Results
Material Selection Based on Cr Evaporation

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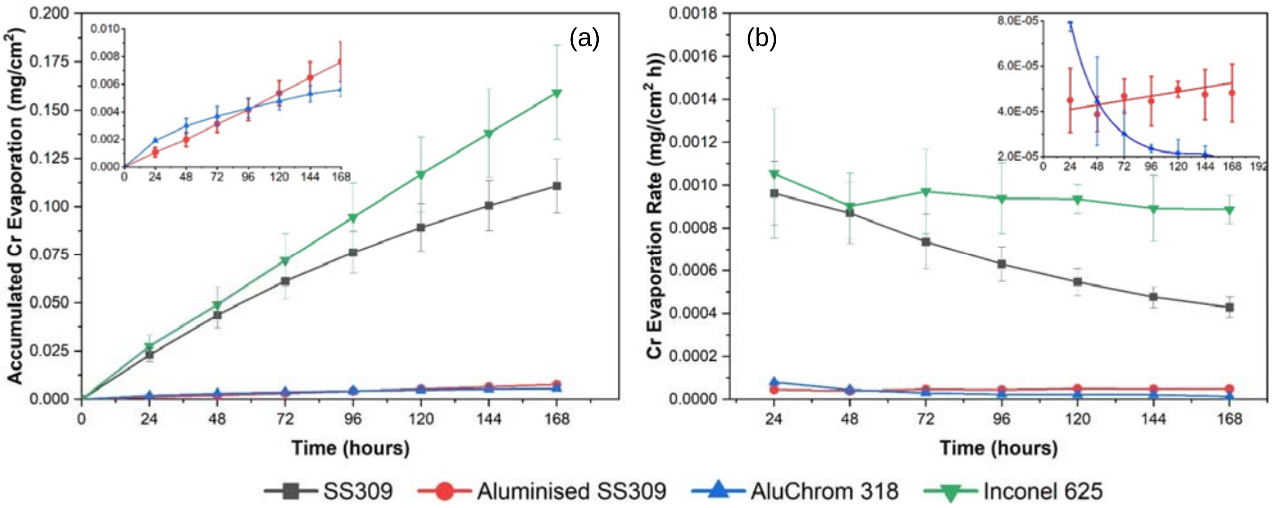

Figure. (a) Accumulated Cr evaporation and (b) Cr evaporation rates as a function of time for SS309, aluminised SS309 and AluChrom 318 exposed to 3 vol% H_2O humidified air at 850 ˚C for 168 hours.

AluChrom 318 shows the best Cr retention ability.

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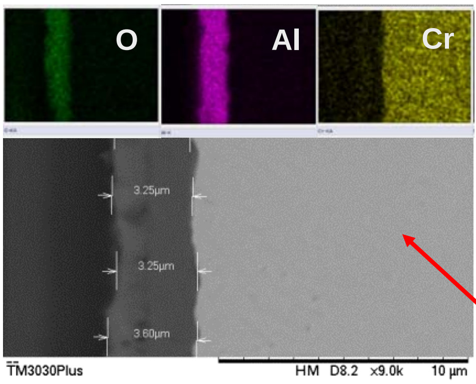
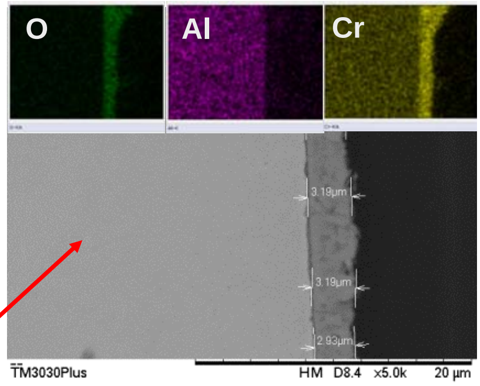
Cross-section SEM/EDX analysis for Heat Exchanger from Vaillant

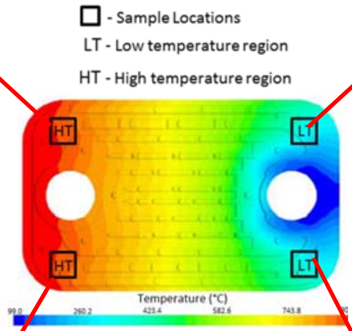
Steady state; AluChrom 318; 5800 hours; old design

Hot Zone Outside

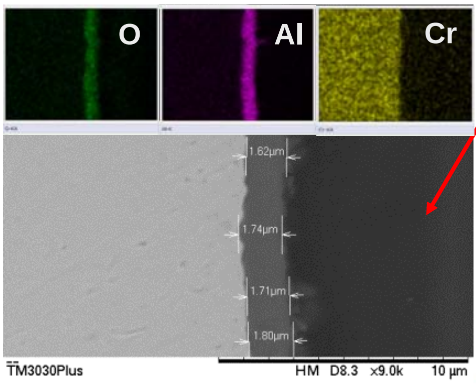


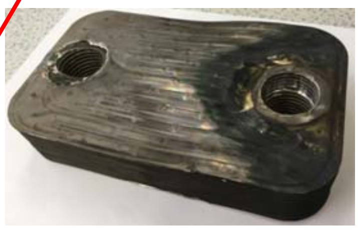
Cold Zone Outside



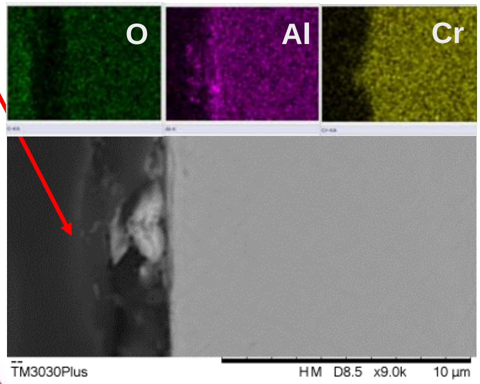


Hot Zone Inside





Cold Zone Inside



Pre-treatment for AluChrom 318

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(wt.%)	Fe	Cr	Mn	Al	Ni	Si	Nb	W	others
AluChrom 318	Bal.	18.8	0.21	3.58	0.24	0.32	0.73	2.02	Hf 0.06; Y 0.07; Zr 0.03; Cu 0.03; C 0.01; N 0.01

Variables: (1) Temperature; (2) Time.

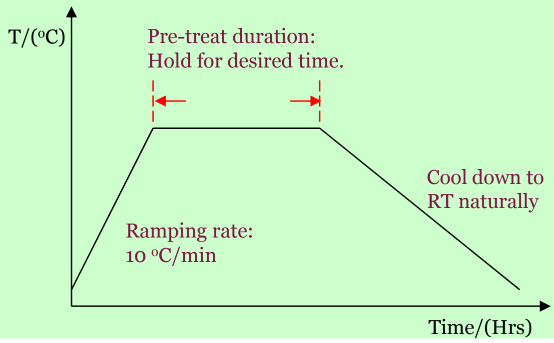
800 °C: 1 hour, 2 hours, 4 hours.

900 °C : 1 hour, 2 hours, 4 hours.

1000 °C : 1 hour, 2 hours, 4 hours.

1100 °C : 30 mins, 1 hour, 2 hours.

Atmosphere: Air (No flow)



The expected effect of pre-heat treatment:

1. To form the stable α-Al_2O_3 on the surface prior to exposure in SOFC environment;

2. To stop the Cr_2O_3 formation in cold zone;

3. To slow down the Al oxidation rate in hot zone.

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Effect of Time and Temperature on the Pre-treatment

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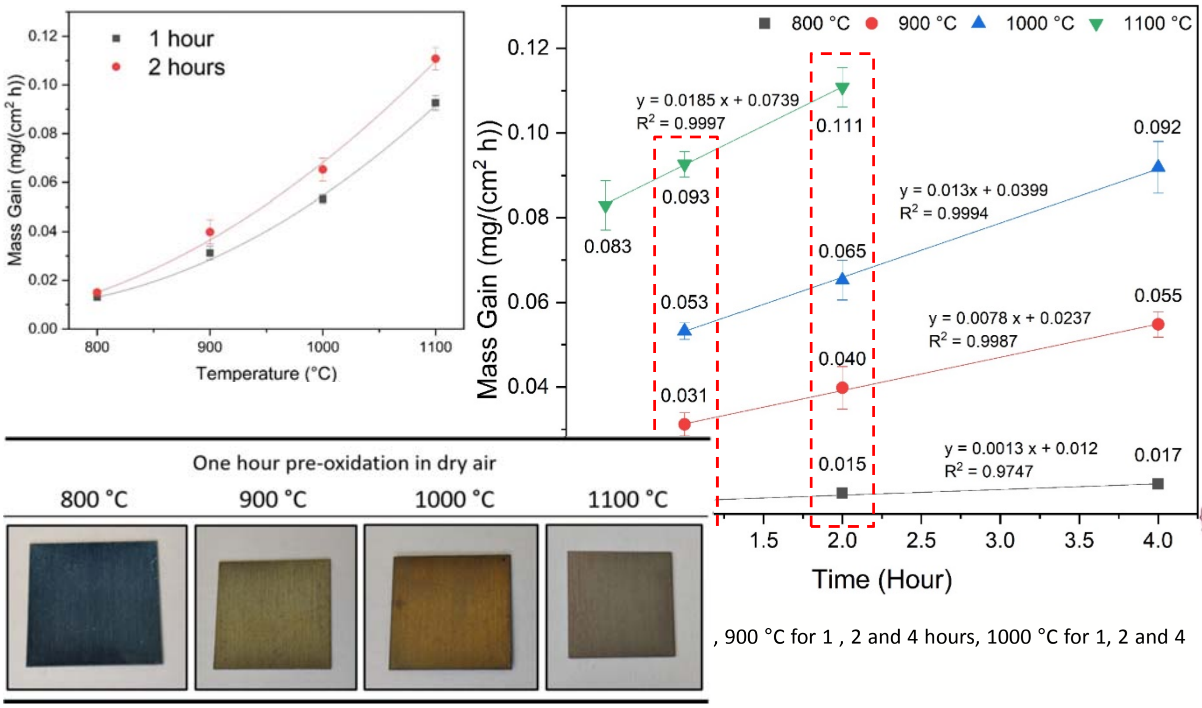

, 900 °C for 1 , 2 and 4 hours, 1000 °C for 1, 2 and 4

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EDX: Surface Element Concentration

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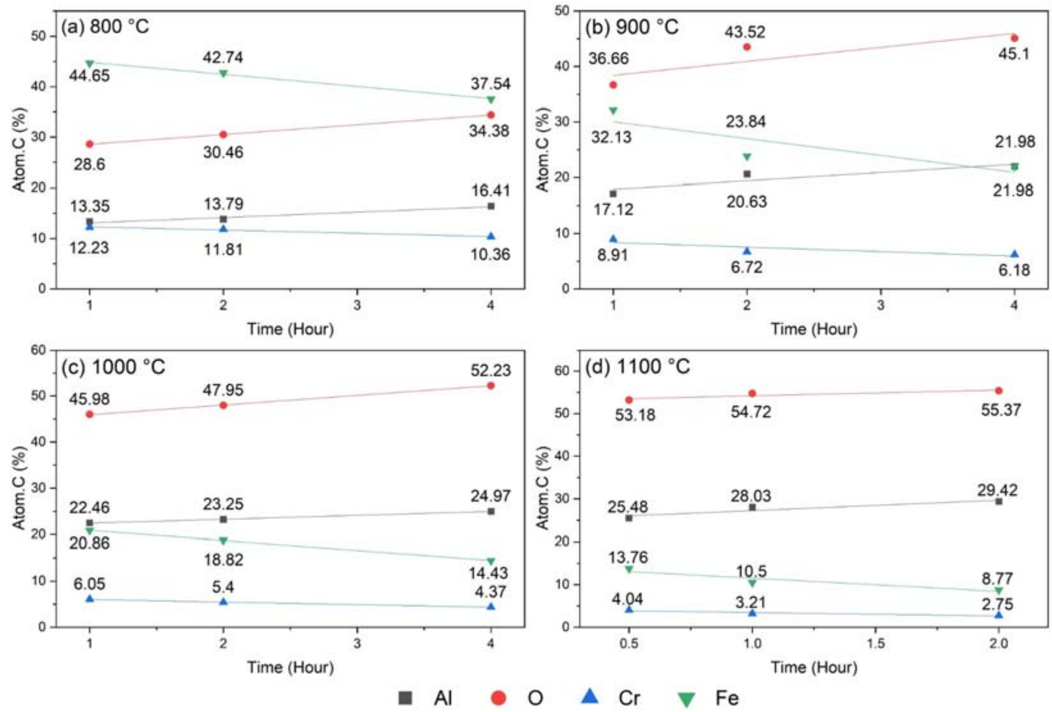

Figure. EDX elemental concentration of AluChrom 318 surface pre-heated at (a) 800 °C for 1, 2 and 4 hours, (b) 900 °C for 1 , 2 and 4 hours, (c) 1000 °C for 1, 2 and 4 hours and (d) 1100 °C for 0.5, 1 and 2 hours.

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XRD Analysis

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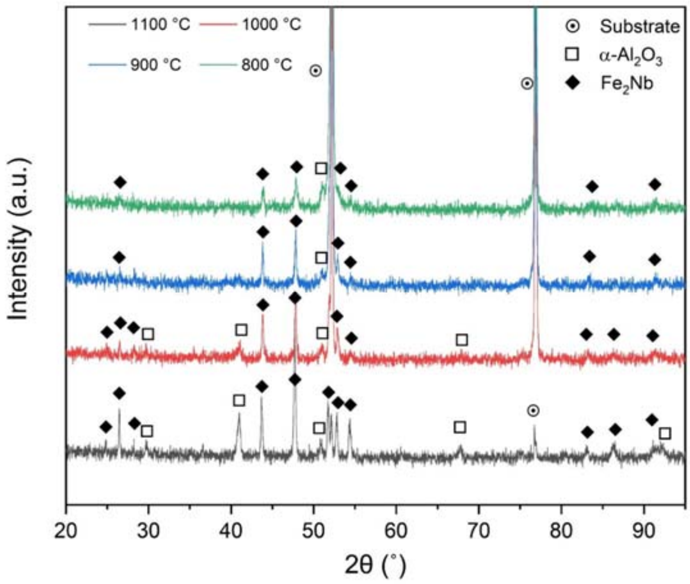

Figure. XRD patterns of the AluChrom 318 pre-treated at 800 °C, 900 °C, 1000 °C and 1100 °C for 1 hour.

- **Formation of Fe_2Nb Laves phase has been detected for all the pre-treated samples;**
- **Formation of corundum-type α-Al_2O_3 has been detected for samples pre-treated at 1000 °C and 1100 °C for 1 hour;**
- **The alumina scale formed on the samples pre-treated at 800 °C and 900 °C cannot be detected by XRD.**
- **The alumina form at 800 °C and 900 °C is mainly in metastable phases (γ- or θ-Al_2O_3) due to their easy nucleation at low temperature while the amount of the alumina formed is too low and below the detection limit of the XRD technique.**
- **The 1100 °C used for pre-treatment promotes faster phase transformation of metastable alumina formed during temperature ramping stage to the stable α-Al_2O_3 phase.**

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SEM/EDX Analysis

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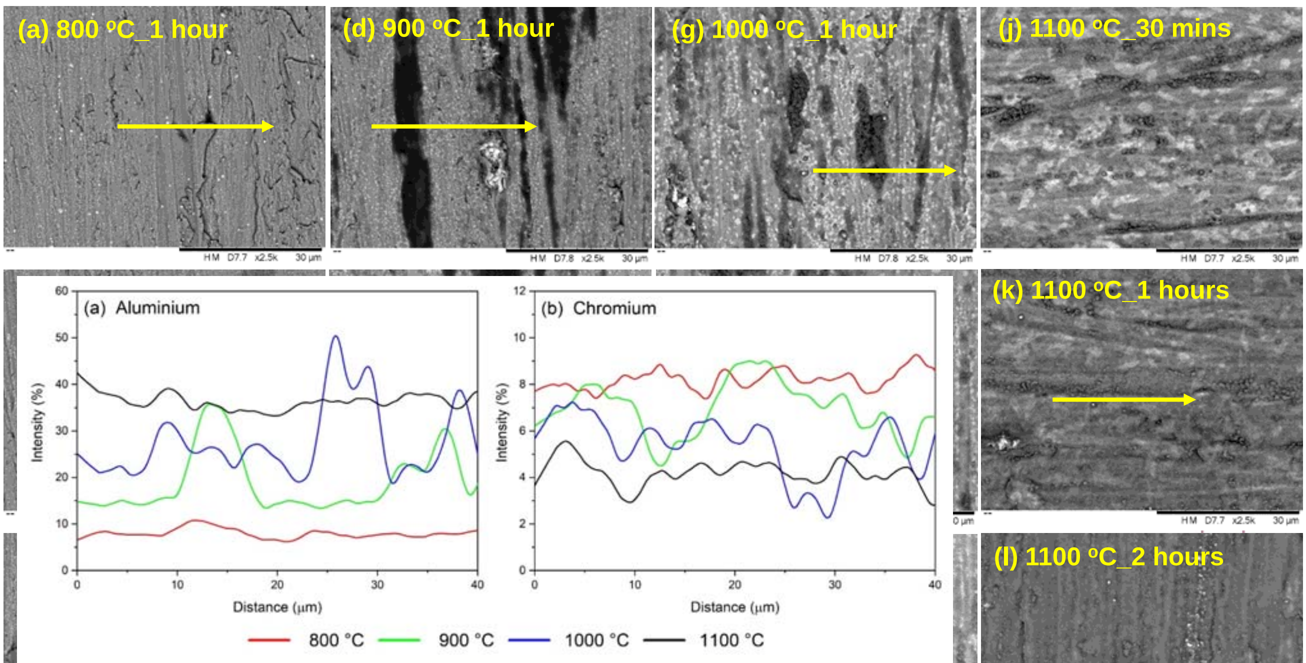

Figure. EDX line scan of Al (a) and Cr (b) for the AluChrom 318 pre-heated at 800 °C, 900 °C, 1000 °C and 1100 °C for 1 hour along the line indicated in the micrographs.

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Exposure Test

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- **Materials:**
  - Pre-treated AluChrom 318
- **Experiment:**
  - **High Temperature Oxidation Test: 500 hours**

    Normal Tubular Glassware
  - **Quantification of Cr Evaporation: 168 hours**

    Denuder Technique
- **Test Condition:**
  - 850 ˚C; 6.0 L/min air flow; 3% humidity
- **Post-analysis:**

  Mass measurement; Surface SEM/EDX; X-ray Diffraction.

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Corrosion Testing-Mass Gain

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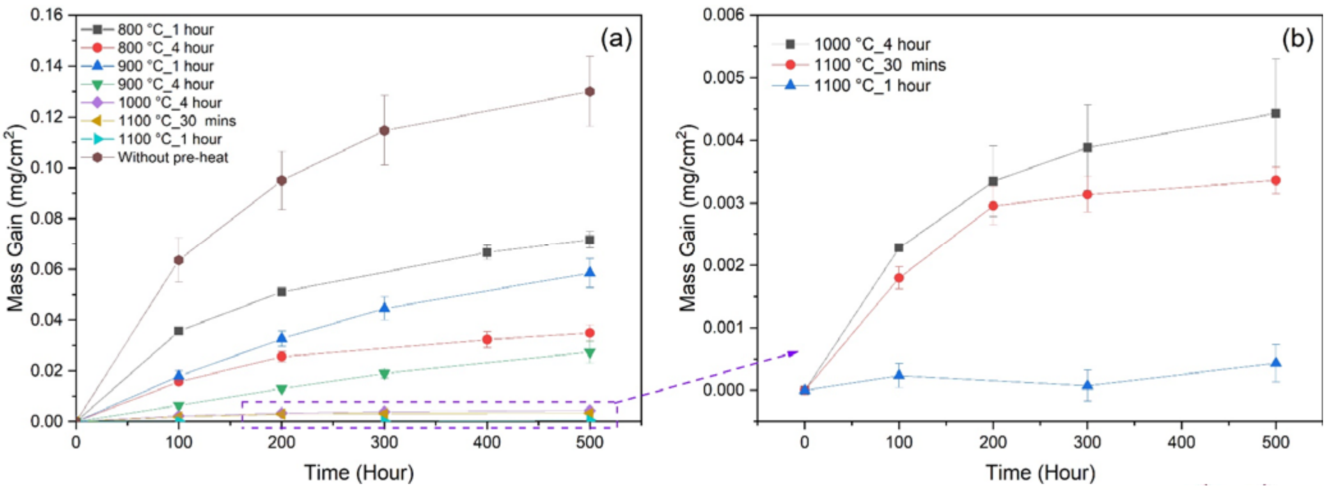

Figure. Discontinuous mass measurements of the non-treated and pre-treated AluChrom 318 exposed to 3% H_2O humidified air (6.0 L/min) at 850 °C for 500 hours.

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Cr Evaporation Test

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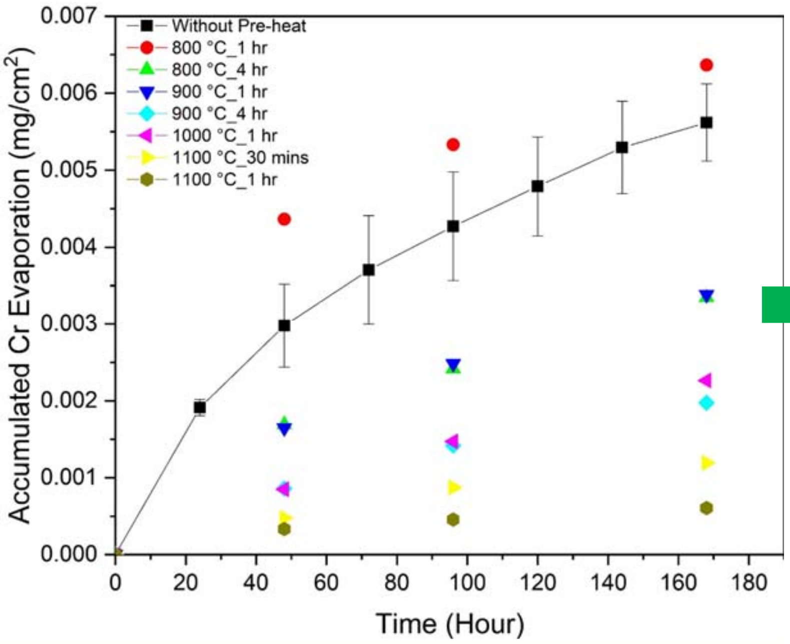

Figure. Accumulated Cr evaporation as function of time for the non-treated and pre-heated AluChrom 318 exposed at 850 °C in 3 vol% humidified air for 168 hours.

Samples	Cr Evaporation (mg/cm^2)
Non-treated sample	5.62E-03
800 °C_1 hour	6.37E-03
800 °C_4 hours	3.35E-03
900 °C_1 hour	3.38E-03
900 °C_4 hours	1.98E-03
1000 °C_1 hour	2.26E-03
1100 °C_0.5 hour	1.19E-03
1100 °C_1 hour	6.07E-04

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Surface Morphology After Exposure Tests

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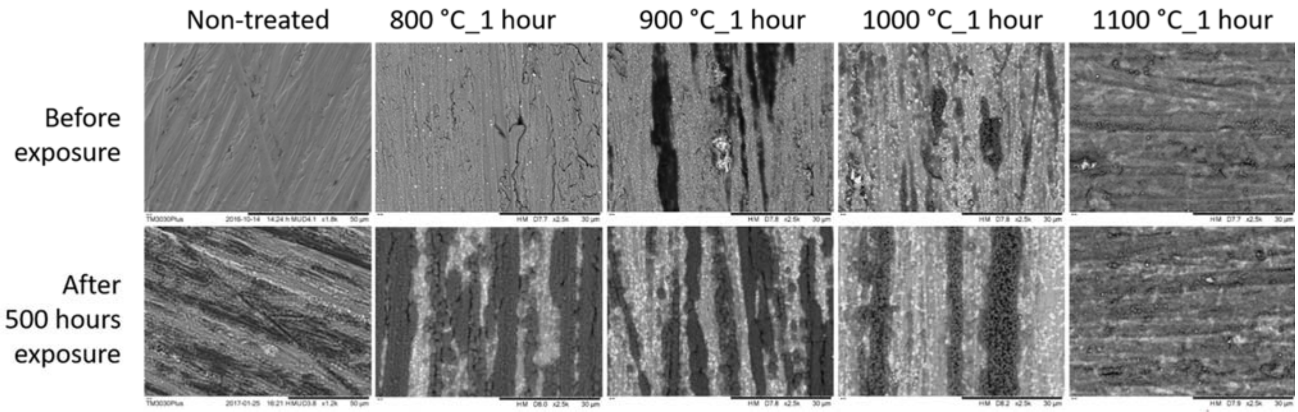

Figure. Surface SEM images of the non-treated AluChrom 318 (a) and the AluChrom 318 pre-treated for 1 hour at 800 °C, 900 °C, 1000 °C and 1100 °C before and after exposed for 500 hours at 850 °C in 3% humidified air (6.0 L/min).

Expansion of long ridged alumina after exposure tests:
800 °C_1 hour > 900 °C_1 hour > 1000 °C_1 hour > 1100 °C_1 hour

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Pre-treatment for single AluChrom 318 heat exchanger plate

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Non-treated plate

Senior Flexonics
1000 °C

UoB
1100 °C_1 hour

Cr evaporation of pre-treated AluChrom 318 single heat exchanger plate

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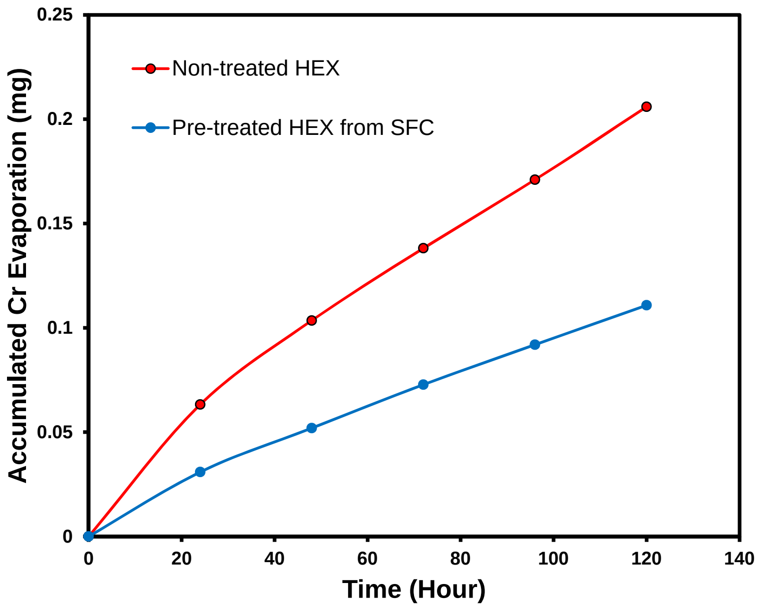

Non-treated plate
after exposure

Conclusions

- The kinetics of oxidation rate and Cr release for the pre-treated AluChrom 318 is governed by the phase formation of alumina on the alloy surface during pre-treatment. In this work, the 1100 °C used for pre-treatment promotes faster phase transformation of metastable alumina formed during temperature ramping stage to the stable α-Al_2O_3 phase compared to other lower temperatures used.
- Pre-treatment at 800 °C and 900 °C resulted in a less improvement in the oxidation resistance and Cr retention capability than at 1000 °C and 1100 °C due to the formed metastable alumina scale which allows relatively faster Al and Cr outward diffusion.
- The best corrosion resistance was observed for the samples pre-heated at 1100 °C for 1 hour with a 98% reduction of oxidation rate and 90% reduction of Cr evaporation compared to the non-treated AluChrom 318 compared to the non-treated AluChrom 318 due to the formation of a compact and homogenous α-Al_2O_3 scale which can effectively prevent the Al and Cr from outward diffusion in the simulated SOFC environment.
- For pre-treatment conditions, high temperature with short time is more effective than low temperature with long time.

Acknowledgements

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FUEL CELLS AND HYDROGEN
JOINT UNDERTAKING