FUEL CELLS AND HYDROGEN
JOINT UNDERTAKING

SElySOs

"Development of new electrode materials & understanding of degradation mechanisms on Solid Oxide Electrolysis Cells"

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Programme Review Days 2019

Brussels, 19-20 November 2019

PROJECT OVERVIEW

- **Call year:** 2014
- **Call topic:** H2020-JTI-FCH-02.1-2014: Research in electrolysis for cost effective hydrogen production
- **Project dates:** 02/11/2015 – 01/05/2020
- **% stage of implementation 01/11/2019:** 89 %
- **Total project budget:** 2,939,655.00 €
- **FCH JU max. contribution:** 2,939,655.00 €
- **Other financial contribution:** 0 €
- **Partners:**

FORTH	CERTH	JUELICH	VSCHT	CNRS	PROTOTECH	PYROGENESIS

PROJECT SUMMARY

SElySOs focuses on understanding the degradation & lifetime fundamentals on both of the SOEC electrodes, for minimization of their degradation & improvement of their performance and stability mainly under H_2O electrolysis and in a certain extent under H_2O/CO_2 co-electrolysis conditions. The main efforts comprise studies on:

- **Modified SoA Ni-based fuel electrodes**
- Alternative perovskite-type fuel electrodes
- **New O_2 electrodes**
- Advanced “Operando” electrode analysis under SOE conditions
- **Development of a theoretical model for description of the performance & degradation of the SOE H_2 electrode**
- SElySOs` results are compared to SoA, by means of “in-house” cell and short-stack measurements, including stability tests. There are promising improvements in regards to the European and Global R&D status for (●) performance, (●) efficiency and (●) degradation.
- **Further research and development on (i) cell, (ii) large-stack/s and (iii) SOE system level is definitely required, so as to appropriately implement the current know-how and to reach a total TRL-5 on the stack/system and operating conditions level.**

SElySOs PROGRESS/ACTIONS – Improved (SoA) Ni-based fuel electrodes

Decrease of ASR **Increase of Current density** **Decrease of catalyst loading**

Status at month 48 of a 54 months project at date 01/11/2019

Achievement to-date

SoA (Ni/GDC) values

3.7 Ohm*cm^2

-0.2 Acm^{-2} @ 1.8V

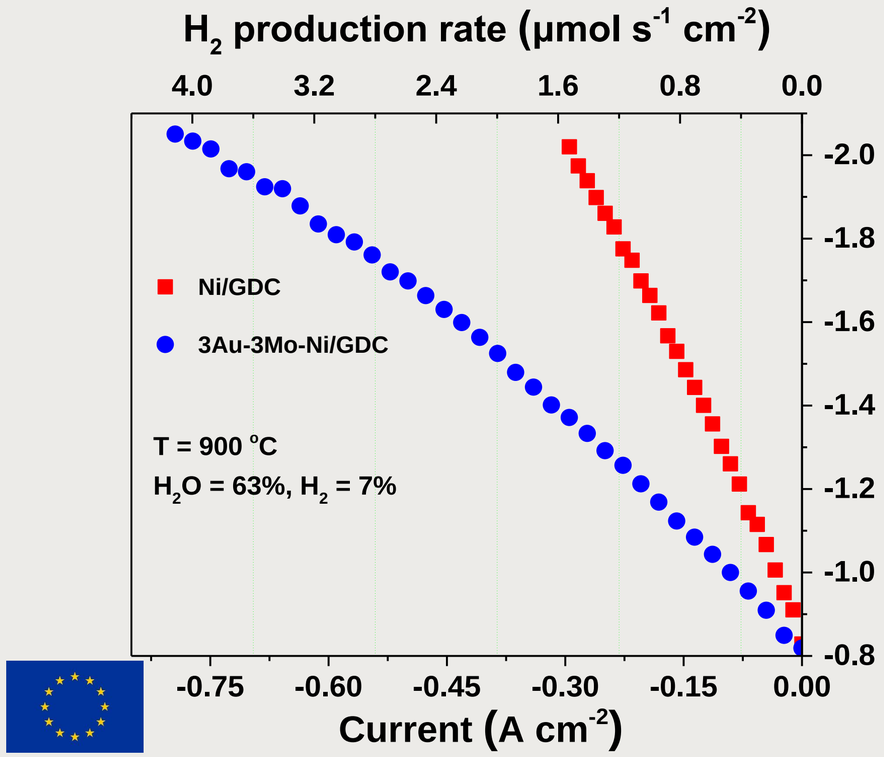
50 g_{cat}/(kgH_2/d)

85%

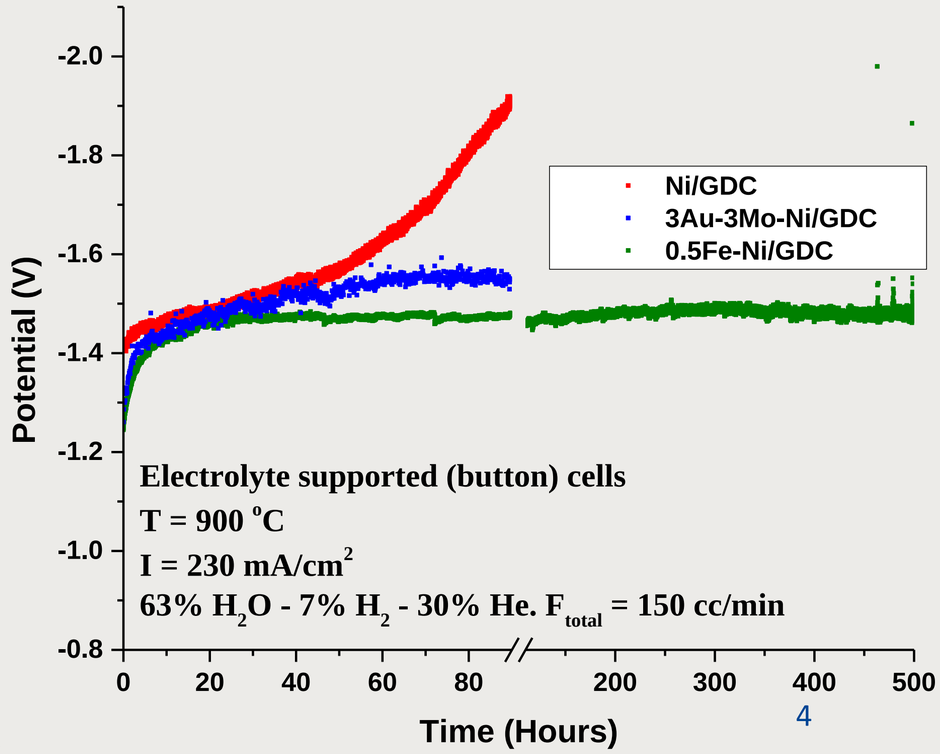
1.8 Ohm*cm^2

-0.6 Acm^{-2} @ 1.8V

18.5 g_{cat}/(kgH_2/d)



- Small (button) **Electrolyte-supported** cells (**8YSZ 150 µm**)
- Investigation of **Transition metal elements effect**
- **3Au-3Mo-Ni/GDC** an improved fuel electrode vs **Ni/GDC**
- **Fe modification: 0.5Fe-Ni/GDC** is recent & promising
- **Longer stability** measurements with **larger ESCs** are in progress.



SElySOs PROGRESS/ACTIONS – Alternative perovskite-type fuel electrodes

Decrease of ASR Increase of Current density

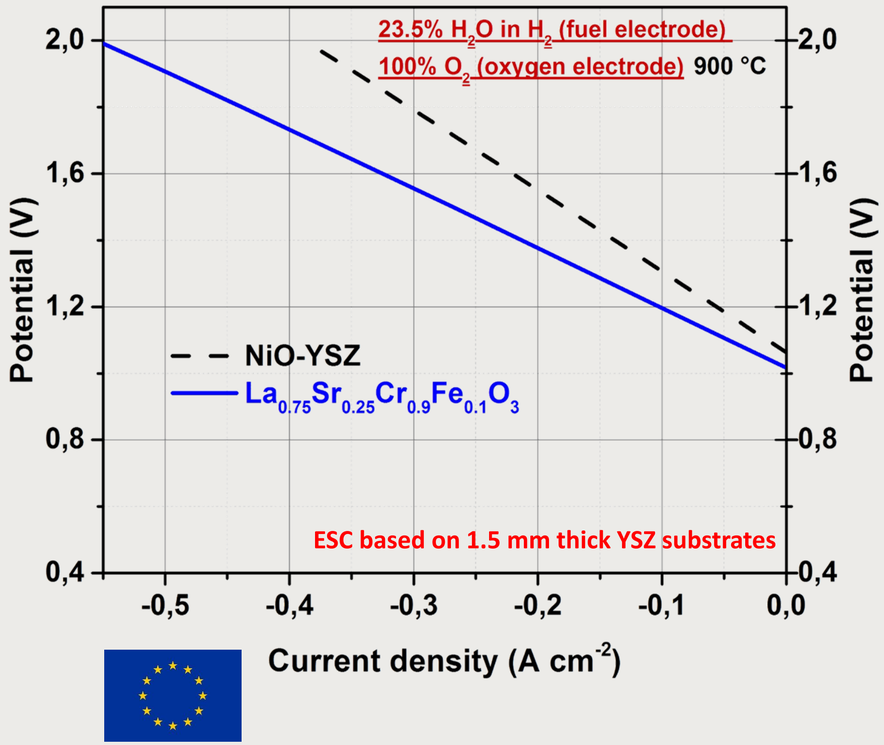
Status at month 48 of a 54 months project at date 01/11/2019

Achievement to-date

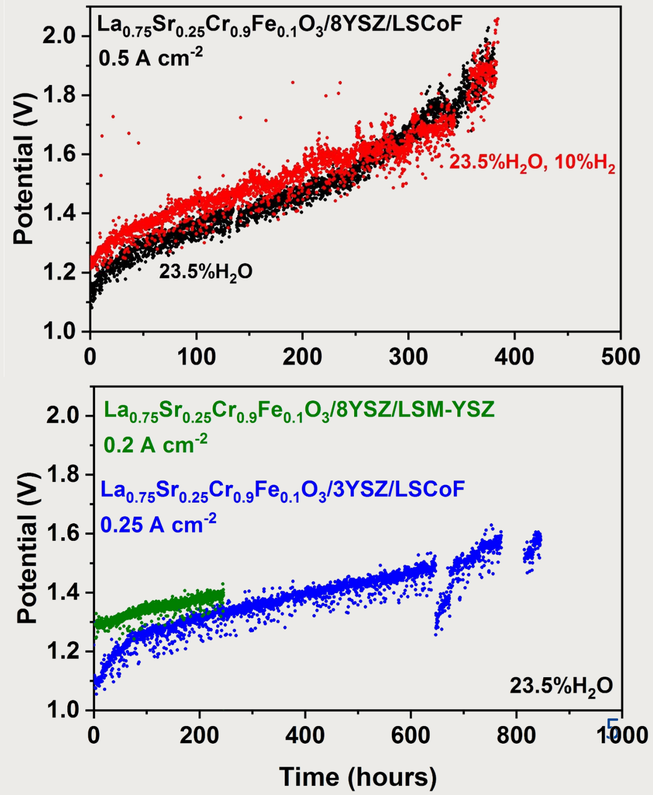
SoA (Ni/YSZ) values
2.5 Ohm cm^2
-0.3 Acm^{-2} @ 1.8V

1.8 Ohm cm^2
-0.44 Acm^{-2} @ 1.8V

70% 75%



- **Doped Lanthanum Chromites** as **tolerant & reversible**, **Ni-metal-free** fuel electrodes
- Best performing material: **$La_{0.75}Sr_{0.25}Cr_{0.9}Fe_{0.1}O$** (button, **Electrolyte-supported** Cells)
- **Operation without H_2 feed** (mild, reversible changes of oxidation state in response to the gas atmosphere = stability in reversible-dynamic operation)
- Adequate performance compared to Ni/YSZ & **higher tolerance in the absence of H_2**
- **Prolonged stability** measurements undergoing



SElySOs PROGRESS/ACTIONS – New O_2 electrodes

Increase of Current density

Decrease of catalyst loading

Status at month 48 of a 54 months project at date 01/11/2019

Achievement to-date

SoA (LSCoF) values

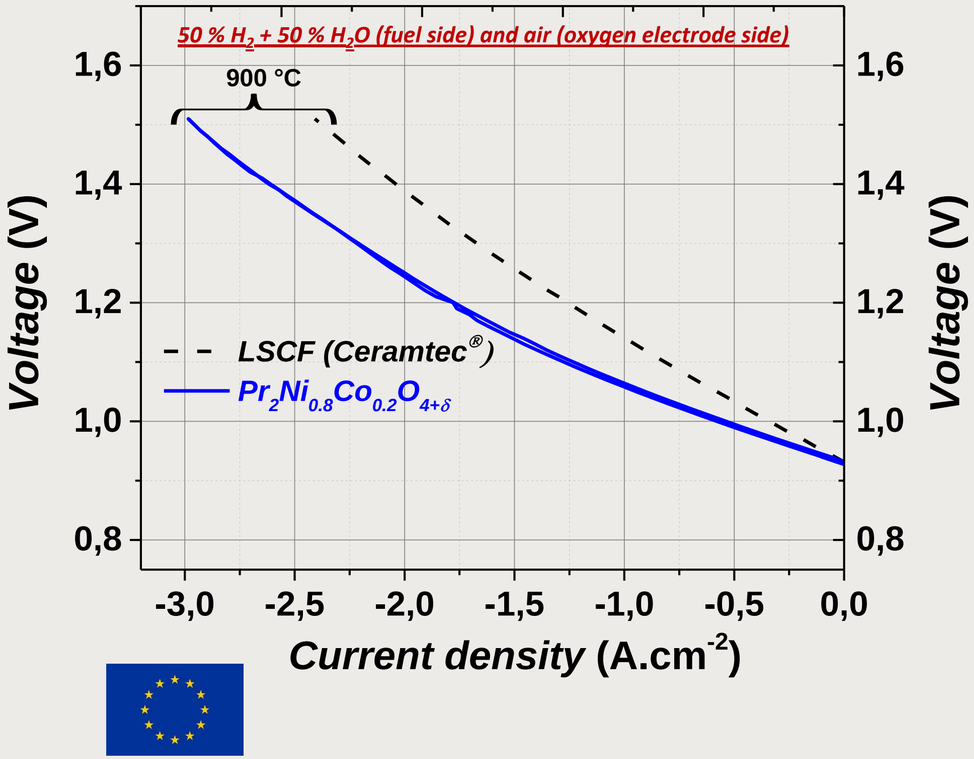
-2.4 Acm^{-2} @ 1.5V

7.9 g_{cat}/(kgH_2/d)

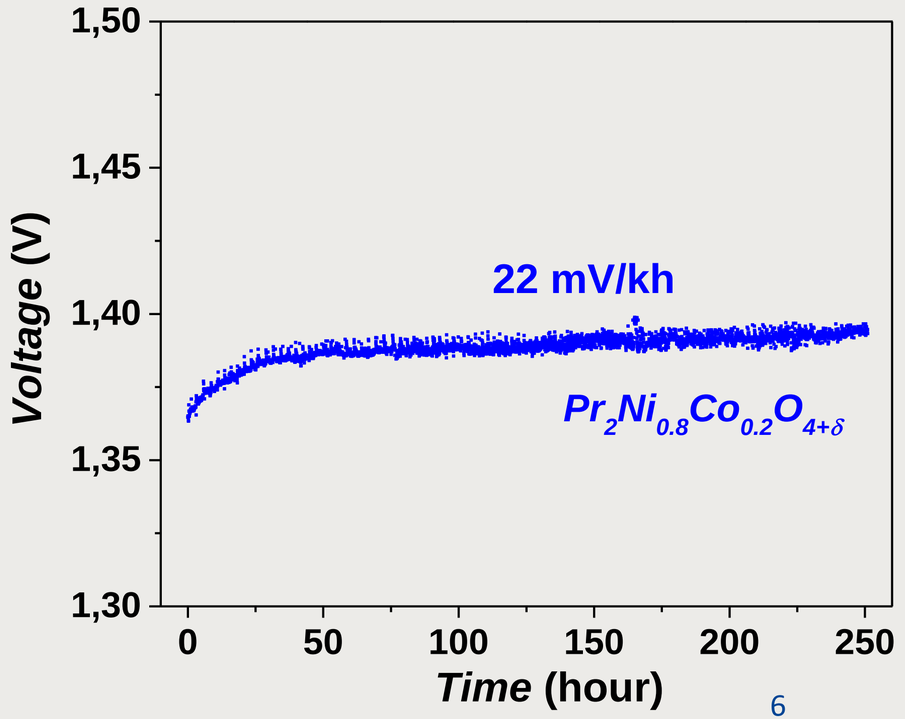
85%

-2.96 Acm^{-2} @ 1.5V

5.7 g_{cat}/(kgH_2/d)



- Small-button **Electrode-supported** cell measurements
- Investigation of **perovskite K_2NiF_4 type** (MIEC) **nickelates**
- **PNCo20** material showed the **best cell performance**, and the lowest degradation rate among all developed air electrodes
- **Stability measurements** are in progress



SElySOs PROGRESS/ACTIONS – Advanced “Operando” electrode analysis

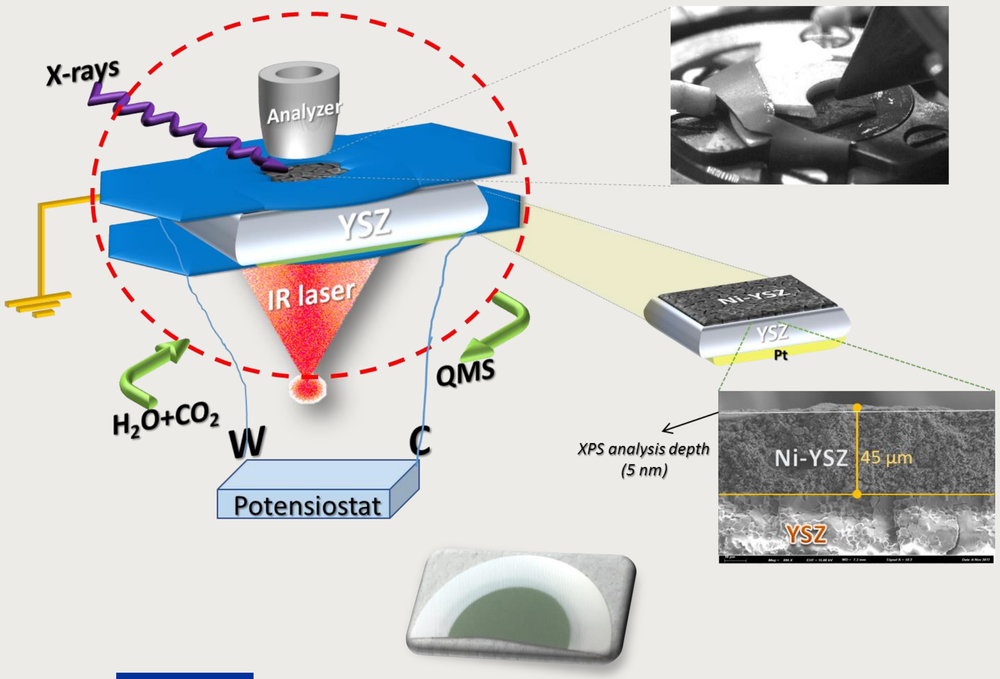
Understanding of SOE degradation & lifetime fundamentals e.g. via NAP XPS: Spectroscopy at the interface)

Status at month 48 of a 54 months project at date 01/11/2019

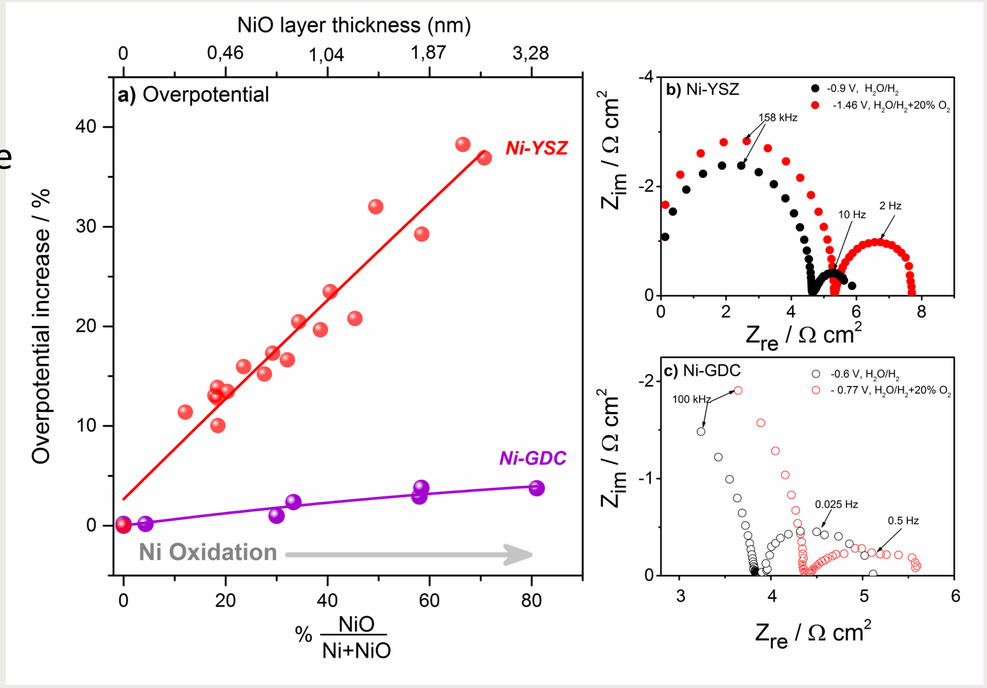
Achievement to-date

70%

All tasks in SElySOs have been achieved, but further investigation is required



- Reversible **modifications on the outer surface**, may have a major influence on the cell performance & degradation.
- **Surface NiO formation** increases significantly the degradation (overpotential) on **Ni/YSZ**, compared to **Ni/GDC**
- Further studies are required towards **tailored** operating **conditions** & electrodes` **properties**



SElySOs PROGRESS/ACTIONS – Mathematical modeling of SOcoE process

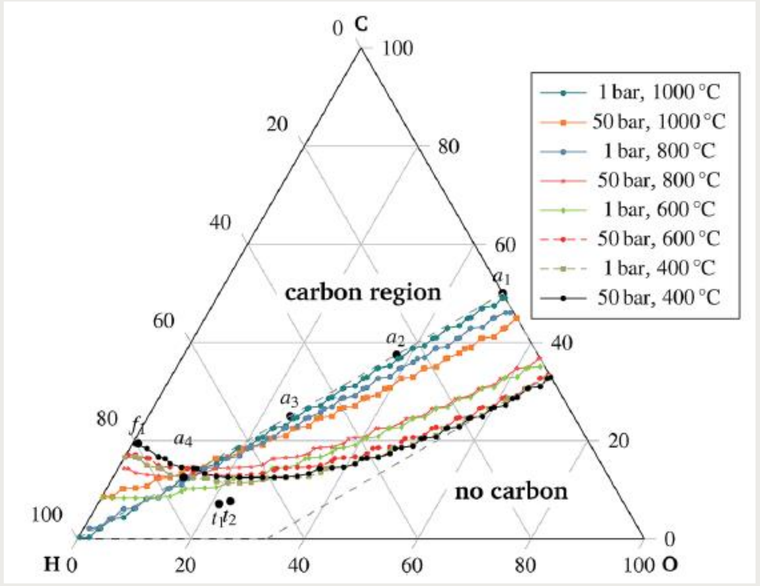
Availability of the model

Status at month 48 of a 54 months project at date 01/11/2019

Achievement to-date

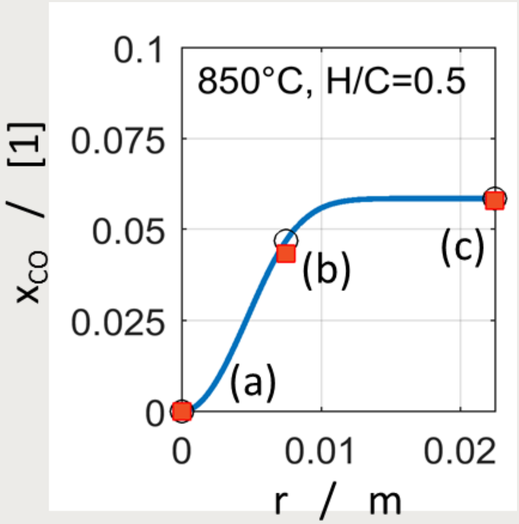
70%

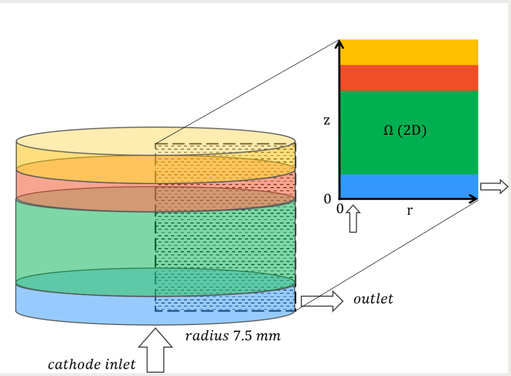
- **Equilibrium Thermodynamic Modeling** of C:H:O (including solid C) system has been developed.
- **Identification of adverse/favorable Conditions** (T, p, xi) for coking and CH_4 formation
- Calculated equilibrium composition – support for kinetic models validation



- The curves indicate (for given T,p) border of the C–formation / C–free region
- SOcoE region delimited by the dashed line

- **Modeling of lab-scale SOcoE** cell, by using experimental data
- **Micro-kinetic modeling** of the occurring catalytic reactions [C:H:O system], experimentally verified
- Investigation of the **CO_2 Electro-Catalytic Reduction Pathway**
- Next step – **model scale-up**





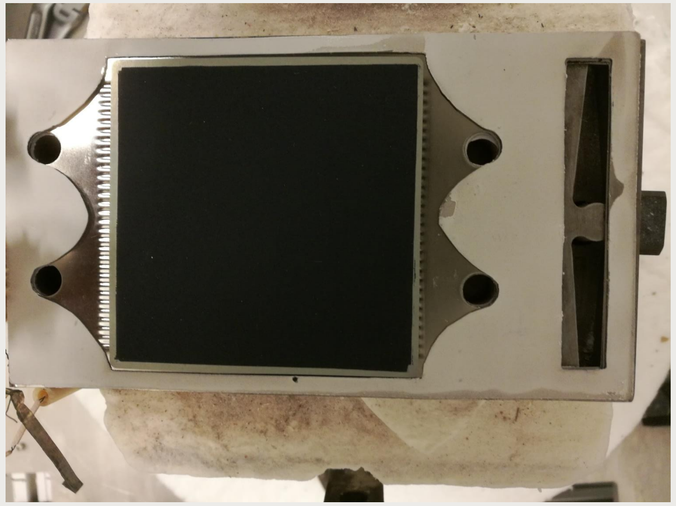
SElySOs PROGRESS/ACTIONS – “Combinatorial” cells – Stability measurements

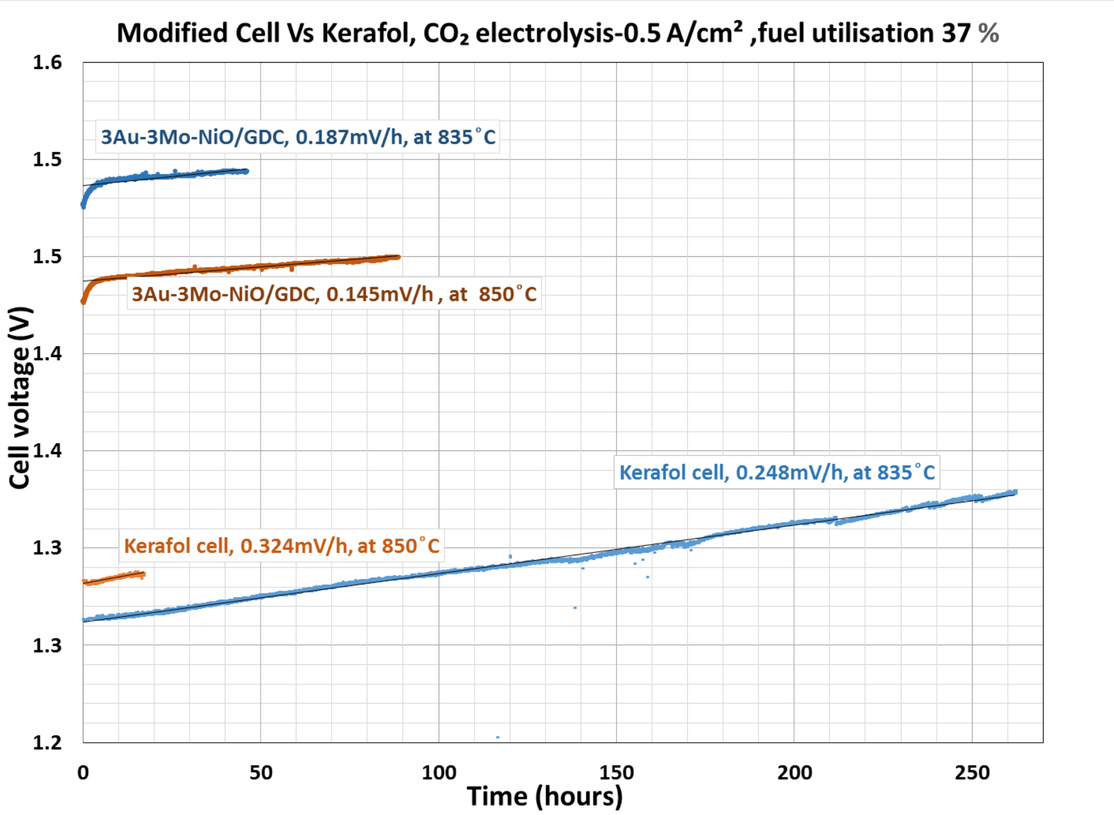
Modified Cells Availability **Decrease of degradation** **Long term testing progress**

Status at month 48 of a 54 months project at date 01/11/2019

Achievement to-date

65% 75% 85%





- Promising **decrease of degradation** rates (**approx. by a factor of 2**) in single-cell stack measurement under **CO_2 electrolysis** mode (***Preliminary tests***)
- **Cell** & **short stack stability measurements** with modified (49 cm^2) cells **in progress**

Risks and Challenges

- **So far, SElySOs has achieved many of its R&D objectives. Knowledge has been gained both in terms of the technological improvements, as well as on the suitable corrections towards the proper implementation of the findings.**
- The evaluation and classification of many different types of fuel and air electrodes
- **The joint preparation and evaluation of cells, comprising the best candidate type of developed electrodes.**
- Implementation of the developed electrodes in larger area SO cells and their incorporation/study in short-stack level
- **Advanced “Operando” electrode analysis under SOE conditions with suitable electrochemical reactors**
- Specific measurements for provision of proper experimental data for the development of the theoretical model/s
- **Further research and development on (i) cell, (ii) large cell / stack and (iii) SOE system level is required, so as to implement the current know-how and to reach a total TRL-5 on the stack/system & operating conditions level.**

SYNERGIES WITH OTHER PROJECTS AND PROGRAMMES

Interactions with projects funded under EU programmes

- **ROBANODE-245355/FP7 EU-FCH JU**: Understanding fuel electrode degradation in H_2 and natural gas fuelled SOFCs
- **T-CELL-298300/FP7 EU-FCH JU**: Innovative SOFC Architecture based on Triode operation and fuel electrode development
- **SOFC-Life-256694/FP7 EU-FCH JU**: SOFCs – Integrating Degradation Effects into Lifetime Prediction Models

Interactions with national and international-level projects and initiatives

- **Regenerative Fuel Cells for Mars Exploitation / European Space Agency**: High Temperature reversible SOCs based on perovskite-type electrodes
- **Project No.: TA01020930 / Funding agency: Technology Agency of the Czech Republic:** Research and development of advanced H_2 production technology by high temperature steam electrolysis”

Dissemination/Communication Activities

- **> 50 abstracts/participations in Conferences/Workshops (Europe, USA, Japan, Malaysia)**
- **12 Open Access publications in high impact peer reviewed journals (and some under preparation)**

- "Affecting the H_2O electrolysis process in SOECs through modification of NiO/GDC; Experimental case of Au-Mo-Ni synergy", Ch. Neofytidis, E. Ioannidou, L. Sygellou, M. Kollia and D. K. Niakolas, ***Journal of Catalysis, 373, pp: 260-275***, (**2019**). Doi: https://doi.org/10.1016/j.jcat.2019.04.002
- "Influence of Surface State on the Electrochemical Performance of Nickel-Based Cermet Electrodes during Steam Electrolysis", B. Mewafy, F. Paloukis, K.-M. Papazisi, S. P. Balomenou, W. Luo, D. Teschner, O. Joubert, A. Salle, D. K. Niakolas and S. Zafeiratos, ***ACS Applied Energy Materials*** **(*In Press*) 2019**. Doi: https://doi.org/10.1021/acsaem.9b00779
- "$La_2Ni_{1-x}Co_xO_{4+\delta}$ (x = 0.0, 0.1 and 0.2) based efficient oxygen electrode materials for solid oxide electrolysis cells", V. Vibhu, I.C. Vinke, R.-A. Eichel, J.-M. Bassat, L.G.J. de Haart, ***Journal of Power Sources, 444 (2019).*** Doi: https://doi.org/10.1016/j.jpowsour.2019.227292
- "Thermodynamic analysis of high temperature steam and carbon dioxide systems in solid oxide cells", P. Vágner, R. Kodým, K. Bouzek, ***Sustainable energy & Fuels, 3, pp: 2076-2086,*** **(2019).** Doi: 10.1039/C9SE00030E
- "Au-doped Ni/GDC as an Improved Cathode Electrocatalyst for H_2O Electrolysis in SOECs", E. Ioannidou, Ch. Neofytidis, L. Sygellou and D.K. Niakolas,. ***Applied Catalysis B Environmental, 236, pp. 253–264***, **(2018)** Doi: 10.1016/j.apcatb.2018.05.017

Dissemination/Communication Activities

- **7 Public deliverables out of 15,** for example:
  - Definition of the solid oxide steam electrolysis cathode mathematical model
  - SOEC manufacture and test report (short stack test)
- **Contribution to the EU - JRC & FCH2 JU efforts for the harmonization of testing protocols and procedures for high temperature electrolysis.**
- **Web site:** http://selysos.iceht.forth.gr/
- **Blog:** http://selyblog.iceht.forth.gr/
- **LinkedIn account:** SElySOs Project
- **The so far achievements have the potential to offer step change improvements on SOE performance for H_2O electrolysis and H_2O/CO_2 co-electrolysis. There is on-going further development and exploitation of the core findings, through the participation in other projects and communication with mature SMEs in the field.**

SElySOs – Consortium moments

Thank you!

FORTH	CERTH	JUELICH	VSCHT	CNRS	PROTOTECH	PYROGENESIS