Innovative SOFC Architecture based on Triode Operation T-CELL

(Contract number: 298300)

Dimitrios Tsiplakides
CPERI/CERTH

www.tcellproject.eu

PROJECT OVERVIEW

- **Call topic:** SP1-JTI-FCH.2011.3.1 & SP1-JTI-FCH.2011.3.4
- **Application Area:** Stationary Power Production and CHP
- **Start date:** September 1, 2012 - **End date:** February 28, 2016
- **Total budget:** € 3,424,167.80 - **FCH JU contribution:** € 1,796,267
- **Consortium overview**

- **Short summary/abstract of project**
  Main objective of **T-CELL** is the investigation of the **synergetic effect** of **advanced Ni-based cermet anodes** (doped with a second and/or a third metal such as **Au** & **Mo**) in conjunction with **triode design/operation**, in order to **control the rate of carbon deposition and sulphur poisoning**. Proof of the triode concept will be provided through the development and testing of prototype triode stacks, consisting of at least 5 repeating units.
- **Stage of implementation:** 85%

PROJECT TARGETS AND ACHIEVEMENTS

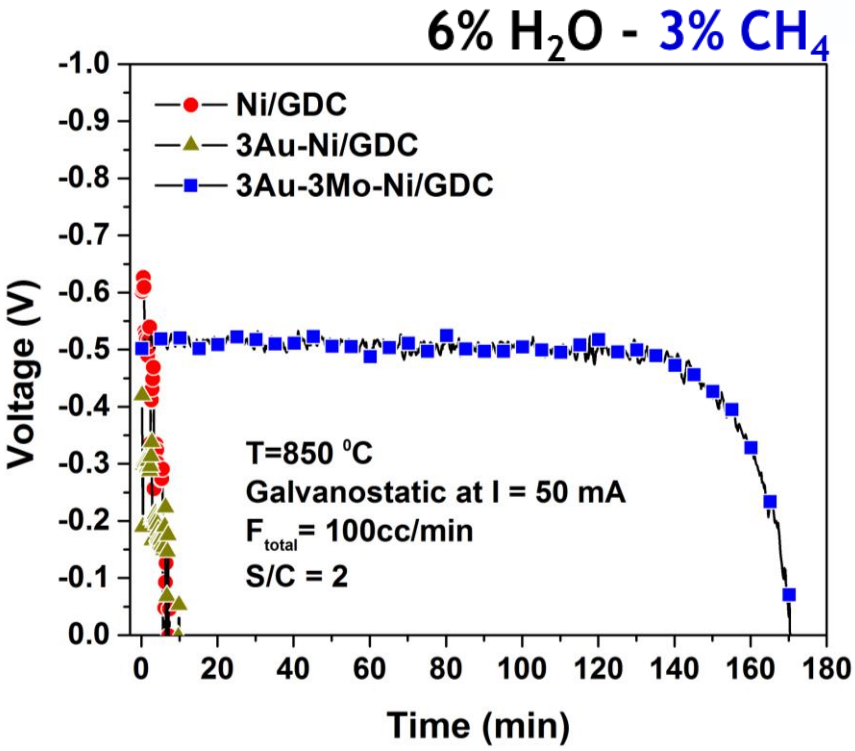
Programme objective/target	Project objective/target	Project achievements to-date	Expected final achievement
MAIP 2008-2014			
2015 target: 55% electrical efficiency (natural gas and biogas fuels)	>55% (natural gas fueled in presence of ~30ppm sulphur)	Test in progress	Test is not finalized in stack level
2015 target: 20,000 hrs stack lifetime	40,000 hrs	Triode operation results in 40-50% lower carbon deposition rate	Stack testing has not initiated yet

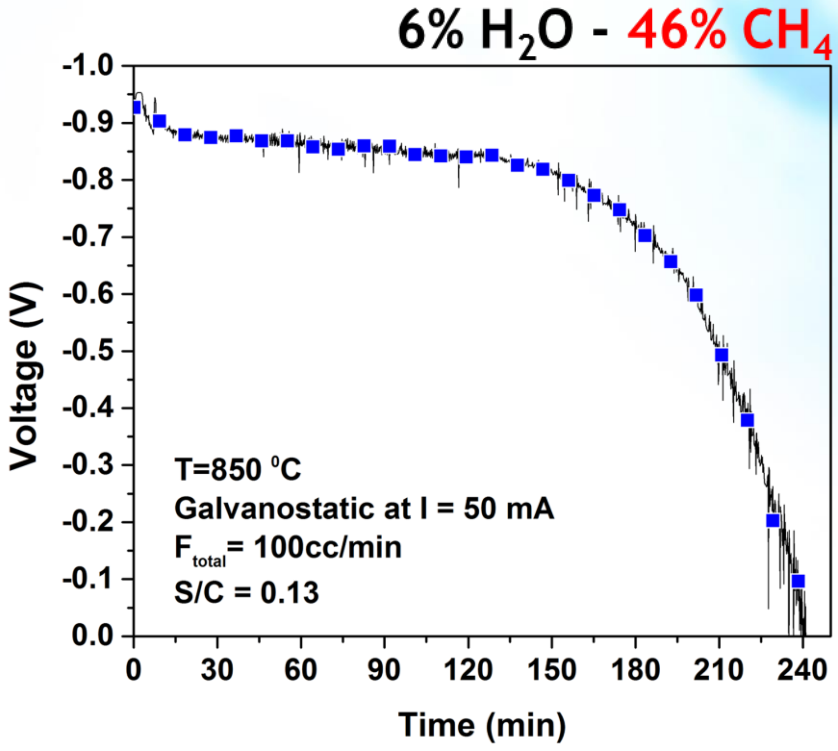
PROJECT TARGETS AND ACHIEVEMENTS

Programme objective/target	Project objective/target	Project achievements to-date	Expected final achievement
AIP 2011			
New architectures, adaptation of cell and/or stack designs to specific applications and system designs	N/A	Preparation of triode cells	N/A
New materials and/or strategies to improve tolerance to contaminants	N/A	Development of Au and Mo modified Ni-based cermet anodes	N/A
Improved tolerance to contaminants with respect to state of art FCs	N/A	Triode operation results in 40-50% lower carbon deposition rate	Stack testing has not initiated yet
Improved (>50%) electrical efficiency over the state-of-the-art	>55%	N/A (test not finalized)	Test is not finalized in stack level
25,000 hours stack lifetime	40,000 hrs	Triode operation results in 40-50% lower C deposition rate	Stack testing has not initiated yet

PROJECT TARGETS AND ACHIEVEMENTS

- **Major project findings and achievements**
  - Incorporating Au and Mo nanoparticles into the Ni/GDC anodes results in higher stability in **10 ppm H_2S** under CH_4 ISR conditions

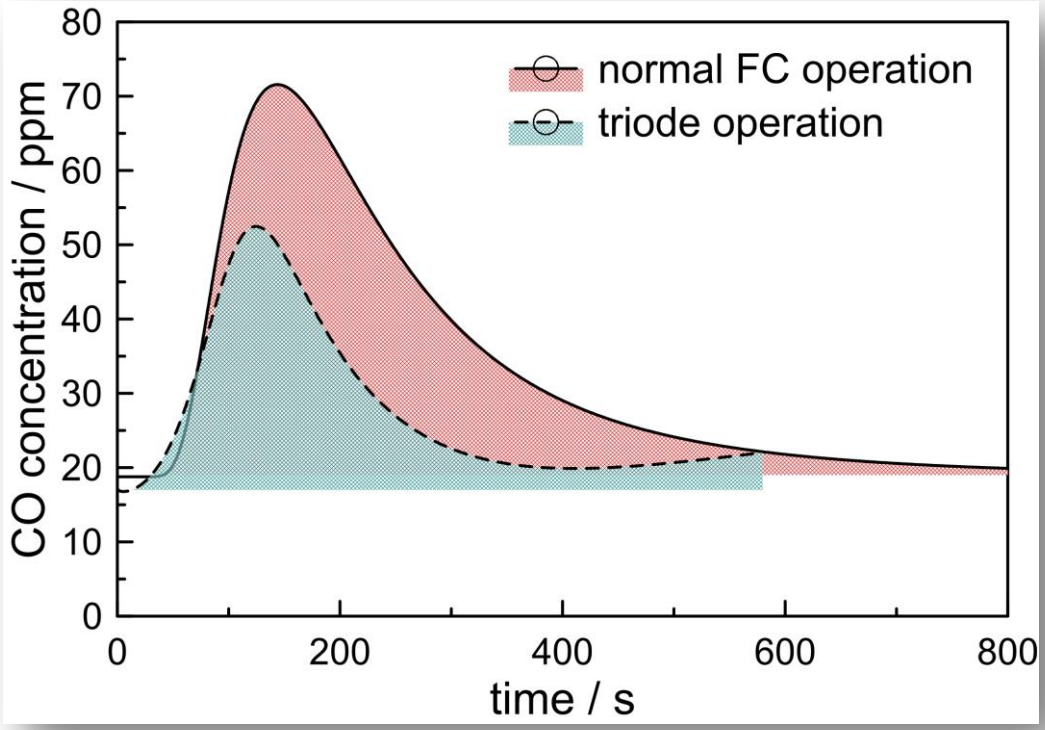


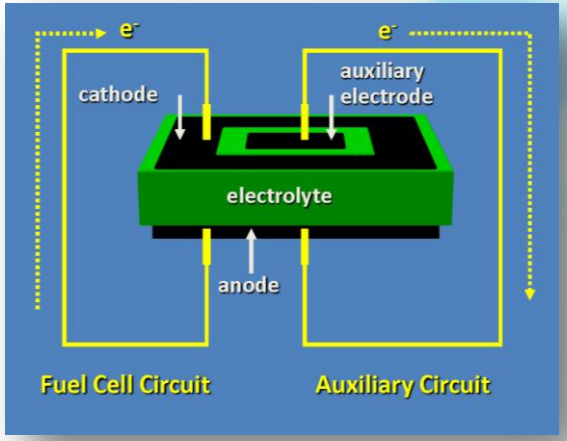


- *Ni/GDC and 3Au-Ni/GDC degraded instantly at S/C=2 and did not recover*
- *Higher stability in 10 ppm H_2S under IMSR was proven for Au-Mo-Ni/GDC anodes*
- *Au-Mo-Ni/GDC operated in both IMSR conditions, though it finally degraded*

PROJECT TARGETS AND ACHIEVEMENTS

- **Major project findings and achievements**
  - Triode design & operation results in 40-50% lower carbon deposition rate on standard Ni/GDC anodes





Carbon deposition rate	
Normal FC	5.7×10^{-7} mol C h^{-1}
Triode	2.8×10^{-7} mol C h^{-1}

Carbon gasification following stability experiment under reforming conditions (800°C, 100% CH_4, S/C=0.3) at a fixed cell potential (0.7 V), for conventional and triode operation mode

PROJECT TARGETS AND ACHIEVEMENTS

- **Major project findings and achievements**
  - The synergy between Au-Mo-Ni regarding electrocatalytic activity and stability under CH_4 steam reforming conditions has been proven
    - The addition of Au and Au-Mo modifies the reducibility of both Ni/YSZ and Ni/GDC catalysts
    - The presence of Au and Mo, in an optimum nominal loading of 3wt% affects the Ni crystal phase and has a significant positive effect in inhibiting carbon deposition
    - Au-Mo-Ni/GDC exhibits the best tolerance in 10 ppm H_2S under both high and low S/C in ISR conditions
  - Triode design and operation has been proven to inhibit carbon deposition rate by 40-50% on Ni/GDC anodes
  - The ability of the triode operation to *in situ* control & enhance C-tolerance is related to
    - FC potential fixation at a controllable value which alters the chemical potential of chemisorbed species in the vicinity of the TPB (including the chemical potential of carbonaceous residues formed) and thus affects C-deposition rate
    - Hydrogen release locally at the anode through water (steam) electrolysis which can act as carbon gasification agent, through the methanation reaction

PROJECT TARGETS AND ACHIEVEMENTS

- **Advancements with respect to international technological state-of-the-art**

Assessment criteria/Parameter	SoA	Project targets	Current status of project achievements
FC electrical efficiency calculated on HHV of fuel	52 %	55 %	60 %

- **Next steps**
  - Incorporation of Au and Mo nanoparticles into the anodes in order to get a well-controlled dispersion of these two elements in the other zones of the electrodes
  - Further investigation of sintering and stability of Au and Mo modifiers
  - Investigation of cell geometry on fuel cell power enhancement under triode operation
  - Further developments and verification of the model in order to reflect the experimental data
  - Design and construction of a 5-cell triode stack

SYNERGIES WITH OTHER PROJECTS AND INITIATIVES

FCH JU projects	Description of complementarity, nature of interaction and/or joint activities
ROBANODE	The alignment of the two projects lies on the affinity of the two approaches, the new triode architecture for SOFCs (T-CELL), and the advanced tolerant anode materials together with the model describing degradation phenomena (ROBANODE), towards the common aim of developing efficient SOFC systems of increased useful lifetime to an acceptable level
SOFCOM	Experience transfer to T-CELL from partners participating in this project
MMLCR=SOFC	Experience transfer to T-CELL from partners participating in this project

HORIZONTAL ACTIVITIES

Horizontal activities	Description of activities/achievements
Training and education	4 PhD-students and 6 postdocs performing research on FCs (materials, processing, modeling) are working on the project.
Safety, regulations, codes and standards	A global, harmonized Triode SOFC Testing Protocol was developed and applied through the project, based on in-house testing protocols in harmonization with the series of testing procedures and Testing Modules developed and validated under the FP6 FCTESQA Project.
Public awareness	1) A press release has been sent to the media following project kick-off meeting (published 12 Oct. 2012) 2) Publication in Greek General Secretariat for Research and Technology newsletter (published Nov. 2012) 3) Presentation during the "Fuel Cells and Hydrogen Joint Undertaking Stakeholders General Assembly held in Brussels (11-12 Nov. 2013) 4) “T-CELL: Innovative SOFC architecture based on triode operation”, Int. INNOVATION, Iss. 173 (published Feb. 2015)

DISSEMINATION ACTIVITIES

Dissemination	Description of activities/achievements
Conference presentations	**15 presentations** at International Conferences, including: • Fifth European Fuel Cell Technology & Applications Conference - Piero Lunghi Conference, Italy (2013) • 65th Annual meeting of the International Society of Electrochemistry, Switzerland (2014) • 11th European SOFC & SOE Forum, Switzerland (2014) • European Hydrogen Energy Conference (EHEC), Spain (2014) • ECS Conference on Electrochemical Energy Conversion & Storage with SOFC-XIV, Scotland (2015)
Publications	**5 publications** in peer-reviewed journals (Int. J. Hydrogen Energy, Applied Catalysis A, Solid State Ionics, Topics in Catalysis, ECS Transactions)
Workshops	3rd International Workshop on Degradation Issues of Fuel Cells and Electrolysers, Greece (2015)

EXPLOITATION PLAN/EXPECTED IMPACT

- **Exploitation plan**

SOLIDpower is in position to adapt and exploit various levels of T-CELL research and development outputs, starting from **new tolerant materials**, **electrode & cell design** and **interconnects** to complete **novel stack architectures**. **SOLIDpower**'s fuel cells can be applied for remote (off grid) power generation or combined electricity and heat production for household use (hot water, space heating and electricity).

PROTOTECH will use the experience and technology gain from the project (controlled tolerant operation of HC fuelled SOFCs) to bridge it with their expertise in **system integration** for the benefit of their commercialization program **for SOFC energy applications** at a cost level suitable for regular power production and buffering of renewable energy.

MANTIS has expanded their **range of products and coating services to energy related applications**, and benefit from being able to specialize in the important niche energy market represented by SOFCs.