Original thinking on fuel cell technology

Professor Dimitrios Tsiplakides and Dr Stella Balomenou aim to improve the design of solid oxide fuel cells by exploring a novel electrochemical approach. In principle, the new architecture offers enhanced power output and overall thermodynamic efficiency, as well as control over the rate of carbon deposition and poisoning by fuel impurities.

Can you begin by introducing the Innovative SOFC Architecture based on Triode Operation (T-CELL) project?

DT: The primary objective of the T-CELL project is to develop a radically new triode approach to solid oxide fuel cell (SOFC) technology together with a novel, advanced architecture for cell and stack design. The novelty of the proposed work lies in the pioneering effort to apply new nickel (Ni)-based multmetallic materials, of proven advanced tolerance, as anodic electrodes in SOFCs and also in the exploitation of our novel triode SOFC concept, which introduces a new controllable variable into fuel cell operation. These advanced anodic composites together with control of the anode overpotential via triode operation will enable us to arrive at an integrated cell structure and design for SOFC technology with multi-fuel capability and increased efficiency.

SB: According to the 2011 Annual Implementation Plan of the EU’s Fuel Cells and Hydrogen Joint Undertaking (FCH JU), breakthrough research on novel architectures for cell and/or stack design is required to provide step change improvements over existing technology in terms of performance, endurance, robustness, tolerance to contaminants and cost targets for relevant applications. In this respect, the demonstration of triode architectures in SOFCs through the T-CELL project is expected to enhance SOFC power output and overall thermodynamic efficiency and, even more importantly, to offer a unique tool for controlling the rate of carbon deposition and poisoning by fuel impurities.

How important is the development of novel and advanced architectures for both cell and stack design?

DT: Both state-of-the-art Ni-based cermets anode materials and advanced Ni-modified SOFC anodes employing additives consisting of a second (eg. gold – Au) or a third metal (eg. molybdenum – Mo) are evaluated. All synthesised materials are characterised before and after use by a very wide range of in situ and ex situ physicochemical techniques. In order to assess their efficiency and stability under realistic conditions, experimental work includes the operation of the cells in normal and triode mode, fuelled with hydrogen or methane in the absence or presence of co-fed steam, and also in the absence and presence of sulphur compounds.

SB: A key design issue for the triode cells of the stack concerns the optimum configuration in terms of relative electrode geometry and specific arrangement (size, position, alignment). In this respect, a detailed model accounting for all design and operational features of triode cells has been developed and is being validated. We have already concluded that the resistance between cathode and auxiliary electrode plays a very significant role in the triode’s operation. In order to minimise this resistance, cathode and auxiliary electrodes should be as close as possible while the three-phase boundary length should be as long as possible. Based on these conclusions, the final geometry of the triode cells will be defined and applied accordingly in a prototype short stack of five cells.

In what ways are you investigating and evaluating both unmodified and modified Ni-based ceramic-metallic composite (cermet) anodes, especially with respect to examining operating conditions and stability?

DT: The T-CELL partnership has been carefully assembled in order to possess advanced knowledge, techniques and expertise in high-temperature fuel cells, ceramic materials preparation and catalyst synthesis for SOFCs, electrocatalytic layer deposition and structure, as well as stack development and testing. Therefore, the T-CELL consortium contains the complementary competence necessary to accomplish the ambitious project objectives. The collaboration among partners and their commitment to the project is remarkable, resulting in efficient work progress while safely managing any contingencies.

SB: Among the project’s many accomplishments, the greatest findings are the proof of synergy between Au-Ni anodes regarding electrocatalytic stability under methane steam reforming, and the demonstration that triode operation results in a 40-50 per cent lower carbon deposition rate compared to commercial anodes under realistic operating conditions. The latter finding is a direct demonstration of the effective in situ control of anode degradation through the triode design and operation mode.

Have you identified the key design parameters, and how are these used to guide the development of new SOFC materials and systems?

DT: As an EU-level consortium, how significant is collaboration between the different partners, and have each offered their own unique expertise to the project?

SB: What do you consider the project’s greatest achievements to date and what impact do you expect to have on future fuel cells and their design?
A project funded by the EU’s **Fuel Cells and Hydrogen Joint Undertaking** is exploring radical new designs for solid oxide fuel cell electrodes, including an advanced ceramic-metal composite anode and the introduction of a third auxiliary electrode.
It will be possible to operate solid oxide fuel cells at temperatures less than 800°C – a significant advance considering many conventional cells suffer a dramatic performance reduction below this temperature.

The best properties of ceramics and metals; that is, the high-temperature resistance and hardness of ceramics, and the plastic deformation capabilities of metals. The researchers are using both Ni-based cermet anode materials and Ni-modified SOFC anodes employing additives consisting of a second metal, such as gold (Au), or a third metal, such as molybdenum (Mo).

These new anode materials are evaluated prior to and following experiments via a range of in situ and ex situ physicochemical techniques. Such tests allow the T-CELL team to determine which combination most reduces the rate of carbon deposition and the effects of sulphur poisoning. If the anodes can perform with increased poison tolerance and decreased carbon deposition, the range of usable fuels will be significantly expanded. This means that fuel preprocessing costs will be reduced and overall efficiency will increase.

**MODELLING THE TRIODE**

A key part of making the triode SOFC as efficient as possible is to optimally place the electrodes. The T-CELL team has used mathematical modelling to expose the fundamental role of the resistance value between fuel cell and auxiliary circuits in explaining triode operation; that is, because resistance between the cathode and third electrode plays a significant role in triode operation, it needs to be minimised. Electrode performance is believed to be associated with the length of the so-called three-phase boundary, where the electronic conductor, ionic conductor and gases are in contact with one another. The T-CELL models aim to find a balance between making the cathode and auxiliary electrode as close as possible while simultaneously increasing the three-phase boundary length.

Modelling has already shown that the aspect ratio between the two electrodes’ distance and the electrolyte thickness is the key parameter for communicating between the two circuits. Further results from modelling for the geometry and specific size, position and alignment will soon be available and will be implemented in the model SOFC. The team is also working on molecular-level modelling which will help describe the benefits of triode operation in the presence of carbon deposition and/or sulphur poisoning.

**PROOF OF CONCEPT**

The primary deliverable of the T-CELL project in August will be a proof-of-concept prototype triode SOFC stack consisting of at least four repeating units. This prototype will be put through similar tests to the Ni-based anodes, including methane and steam co-feeding as well as tests mimicking fuel poisoning.

The ultimate aims of the project are a greater than 55 per cent electrical efficiency using natural gas and biogas fuels in the presence of approximately 30 ppm sulphur, a 40,000 hour stack lifetime, new architectures, adaptations of cell and/or stack designs to specific applications and system designs, and new materials development to improve tolerance to contaminants. T-CELL has already provided exciting innovations and encouraging results, including novel prototype triode cells and Au- and Mo-modified Ni-based cermet anodes. If the remaining objectives are met, the results of the initiative will not only offer new ways of thinking about cell and stack design, they will provide a firm foundation for meeting the full potential of SOFCs.