PROJECT FINAL REPORT

Grant Agreement number:325323

Project acronym: SAFARI

Project title: SOFC APU FOR AUXILIARY ROAD-TRUCK INSTALLATIONS

Funding Scheme: FCH JU SP1-JTI-FCH.2011.4.4

Period covered: from 1/01/2014 to 20/05/2016

Name of the scientific representative of the project's co-ordinator[1], Title and Organisation:

Dr Kevin Kendall, Adelan Ltd

Tel: +44 121 427 8033

E-mail: kevin.kendall@adelan.co.uk

Project website[2] address: http://safari-project.eu/

4.1 Final publishable summary report

Executive Summary

This final report summarises the three periodic reports [1-3] written during the project. SAFARI aimed to design, optimise and build 5 100We SOFC stacks, and to integrate them into 2 truck (Fig 1) cab power systems comprising both rapid heating planar SOFC from ALM and microtubular SOFC from ADE, together with a battery and appliances found in a modern truck. Additional components of the system were a gas processor to clean up the molecules from LNG plus other equipment for Balance of Plant (BoP) and heater/chiller. All these components were constituents of a fuel cell unit which was to be first tested in the lab and then in a truck platform. SAFARI was primarily focussed on trucks at HARDSTAFF who ran a fleet of LNG trucks. HAR became insolvent and was replaced by VAYON (Vayon Group). The project also considered other options including buses and delivery vehicles using LNG. Trials were to be undertaken in the UK, especially to comply with approvals for codes and standards, as well as assessing the economic fleet potential. Unfortunately, FCH-JU cancelled the 3year project after only 2 years of work.

Figure 1 Volvo LNG truck for installation of SOFC APU

The problem was that the truck company partner HARDSTAFF went bankrupt in February 2015, just over 13 months into the 3 year project. This eventually led to the shutdown of the project by FCH-JU, despite the fact that the remaining partners wished to continue. Normally a bankruptcy does not cause a project to be closed, so there was disappointment in the SAFARI collaborative partnership. In particular, several partners including UOB, VAY and ADE had put much of their own funds into finding more partners to keep the project going, but with overriding resistance from

SAFARI

FCH-JU This final report attempts to summarise the plan, the work, the results and the dissemination obtained by the Consortium from January 2014 to May 2016 when the project was terminated.

SAFARI was organised around a supply chain consortium model. The product champion in the market was HARDSTAFF (HAR), an LNG Truck adaptor and user, providing about 50 LNG trucks each year mainly for supermarkets, with a defined need for practical and economic SOFC auxiliary power systems to augment the battery and to use any boil-off natural gas from the cryotank. The fuel cell system supplier was Adelan (ADE), a spin-out company from University of Birmingham (UOB) with long experience of microtubular SOFCs. ALMUS (ALM) was a second SME fuel cell supplier using planar stacks to compare with the tubular system from Adelan. Academic institutions IREC (IRE) in Barcelona and University of Birmingham in UK studied the scientific aspects of the materials and the catalysts, while ZUT in Poland devised computational models to fit the experimental results.

The project comprised six partners collaborating on seven technical work packages (WPs), starting at WP2 with definition of the market requirements, continuing with research on cells and stacks in WP3, going on to developing BOP in WP4 and modelling in WP5, following with fuel and packaging issues in WPs 6 and 7. WP8 was the field testing package. The other two WPs were WP1 on Management and WP9 on dissemination. Management of the project was mainly by Adelan in WP1 which was pursued all through the project. A major change in the project arose in April 2015 when the Project Monitoring Officer stopped the project after the bankruptcy of the truck company HARDSTAFF. He used the reason ‘poor performance’ but the partners are still not clear how ‘bankruptcy’ can be confused with ‘poor performance’ The project was then restructured by ADELAN at great cost to bring in a new partner VAYON to restart on 1st November 2015. Unfortunately, the Project Monitoring Officer stopped the project again in May 2016 and it has not been possible to restart it because of the negative messages from Brussels.

The conclusions drawn from the project are:

- The microtubular SOFC power supply for the LNG truck has been successfully investigated and looks feasible
- The planar rapid-start SOFC also looks feasible but was not fully tested before termination
- A suitable innovative design for the truck fuel cell product has been attained and partially proved
- One patent has been filed while numerous exhibition, conference and journal disseminations have been achieved

Summary description of project context and objectives

"SAFARI" was a novel proposal with a new consortium assembled to apply Solid Oxide Fuel Cells (SOFCs both tubular and planar) in trucks using Liquid Natural Gas (LNG), the fuel most widely expected to replace diesel in the next 50 years. It is a significant step forward technically because no-one has yet been able to apply SOFC successfully in this early truck market. Technical improvements like low emissions, low noise, long life, rapid warm-up and good heat usage were proposed and have been partially proved in the project results.

The project assembled perfect partners for addressing the SOFC materials, the stack and system development, the fuel issues, the modelling, independent testing, and the early market development. Dissemination was excellent because the industry partners and RTD institutions organized conferences and numerous other events to publicise the results and create impact through journal publications.

In order to achieve these objectives, the consortium was organised on a supply chain model, with the truck manufacturer defining the end product spec and the two SOFC manufacturers feeding their technology in, while RDT institutions provided testing and computer modelling at the consumer end. Adelan coordinated the project, managing the activities over 2 years before cancellation by FCH-JU, then writing the periodic reports.

The consortium is shown in Table1 with contact names

Table 1

Participant no.	Participant organisation	Logo	Type and Key Roles	Country	CONTACT
1	Adelan Ltd		SME – Coordinator and researcher on fuel cells	UK	Kevin Kendall
2	Vayon		Truck company LNG	UK	Neil Whittaker
3	ALMUS		SME– Planar SOFC designer and supplier	Germany	Ulf Bossel
4	University of Birmingham		Experts in SOFC and catalyst testing	UK	Artur Majewski
5	IREC		Institute for development of materials	Spain	Marc Torrell
6	West Pomeranian University of Technology		University – Developer (modelling experts)	Poland	Paulina Pianko

The project objectives were

- Manage the project financially and technically (WP1)
- Define the physical, performance and interface requirements to guide the technical team in defining the generator (WP2)
- Collaborate to improve the SOFC materials in terms of lifetime, performance and costs (WP3)
- Deliver and improve tubular and planar cells capable of powering this application (WP3)
- Design and manufacture stacks, both tubular and planar (WP3)
- Develop fuel cell systems, both planar and microtubular, for testing and optimization. (WP4,6,7)
- Design a CPOX system to pre-process the LNG fuel (WP4,6)
- Model the single cells, stacks and balance of plant to inform the system design processes and cross-validate with experimental testing (WP5)
- Plan integration of SOFC stack and BoP, and packaging in the truck (WPs 3, 4, 6, 7)
- Carry out demonstration and proving trials with fuel cell installed in truck (WP8 cancelled by FCH-JU)
- Disseminate by submitting papers to peer reviewed conferences; maintain the SAFARI webpage (WP9)

Microtubular SOFCs

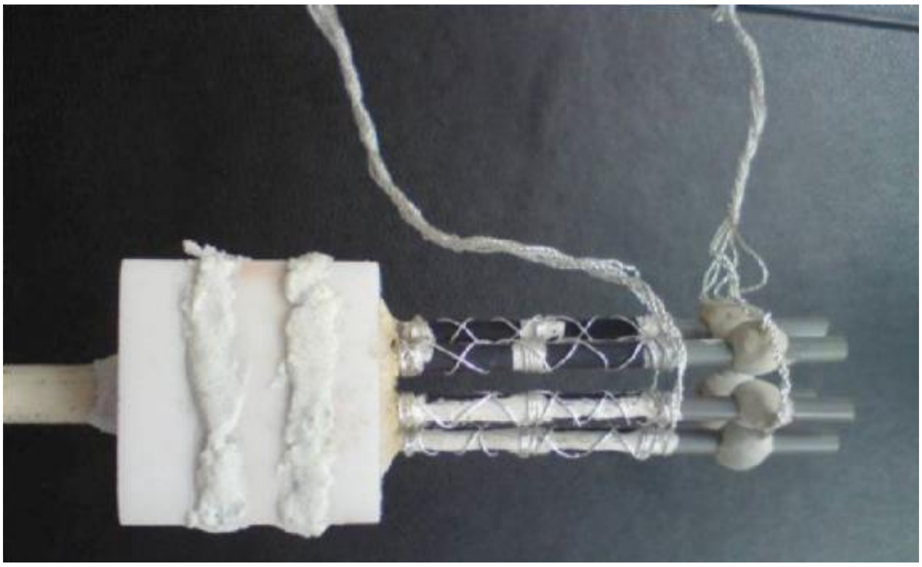


Figure 2 Initial scheme of the mSOFC stack in lab tests

These objectives were predictable because of the massive innovations in SOFC technology produced since the 1990s by Adelan (ADE), the project instigator and coordinator for tubular cells and Almus (ALM) the partner developing rapid start planar stacks. The project was based on background IP owned by ADE, a spin-out commercial SME from the University of Birmingham. That IP has defined products based on rapid start-up microtubular SOFCs (Fig 2) extruded by particular polymer compounding, then put together in a series of new designs of reactor containing many tubes, from tens to thousands, in order to provide compact, portable SOFC systems. Such a reactor requires the following innovations:-

a) The invention of a YSZ (yttria-stabilised zirconia) formulation which can withstand the large numbers of hours and cycles of operation expected in the applications of the product, typically 3000 hours life and 100 to 1000 cycles, without excessive drop-off in performance, addressed in WP3.
b) Stacking cells in an optimum system design for ease of assembly, transfer of heat and optimisation of performance from BOP (balance of plant).
c) Greater understanding of the fundamentals of microtubular system design and performance through modelling and test data, especially in application for the early market in LNG trucks (WP4-8).

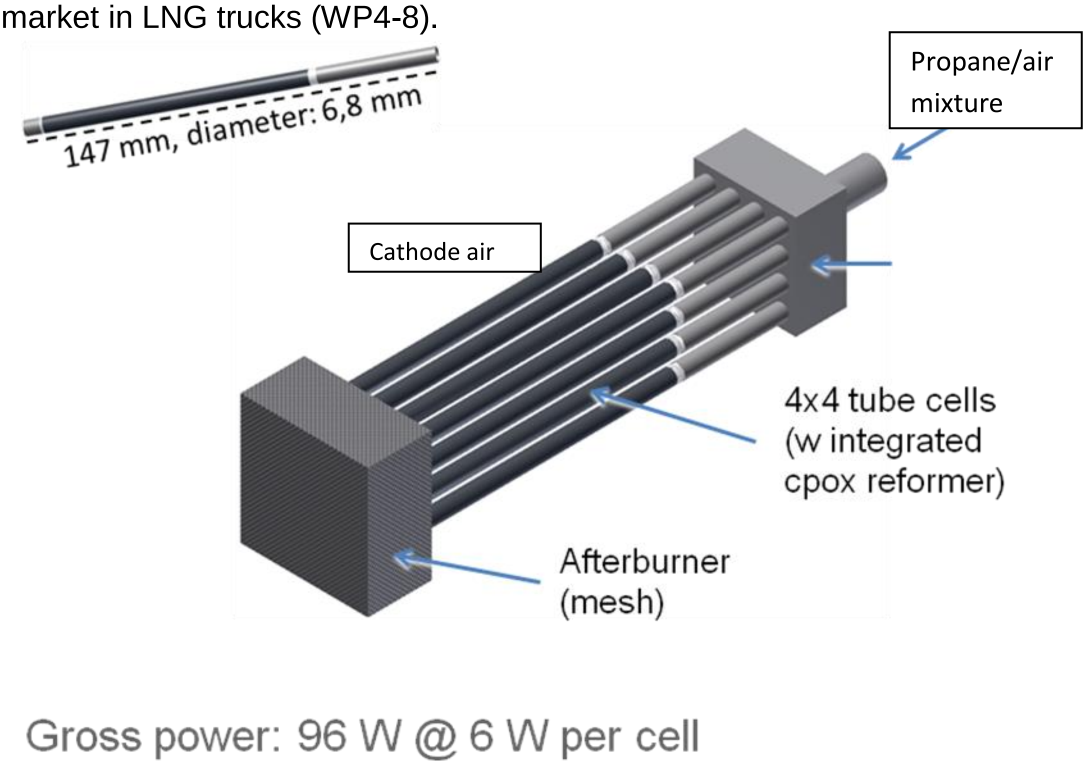


Figure 3 Microtubular cells and stack concept developed in earlier SAPIENS project

Figure 3 shows the tubular cells in the 16cell unit that ADE developed during the earlier SAPIENS project. This proved to be a useful concept providing a low resistance anode contact was produced, as demonstrated in a patent obtained during the SAPIENS project, allowing a number of practical working stacks to be produced (Fig 4).

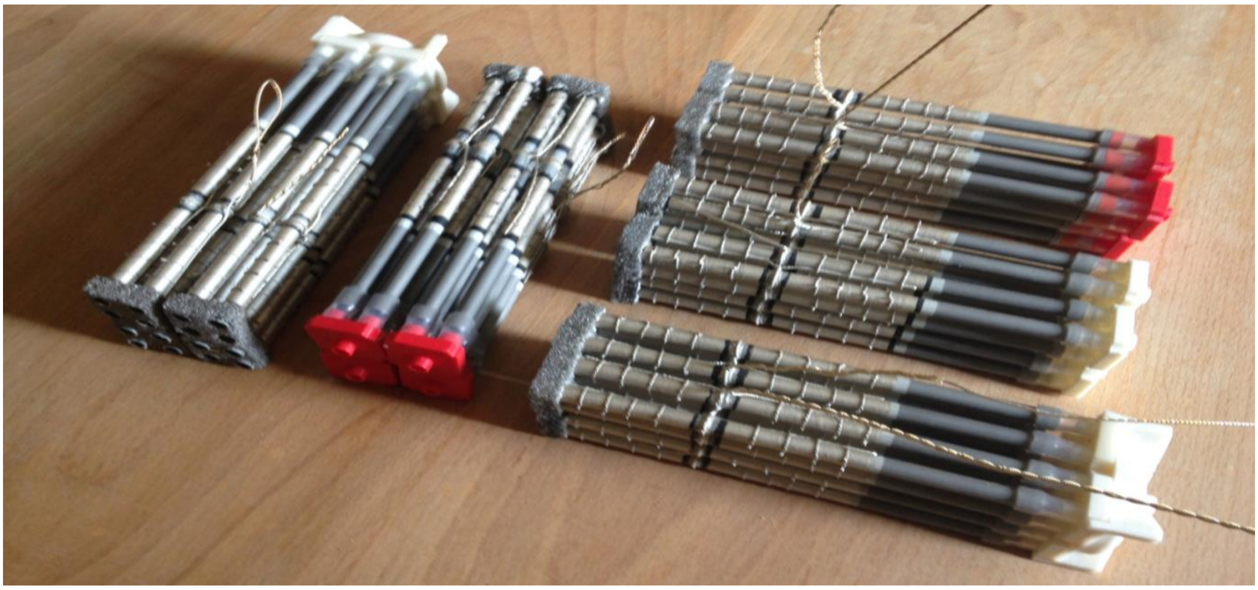


Figure 4 Five 100W stacks produced during the SAPIENS project

Figure 3 shows the SAPIENS stacking geometry with its innovative inlet manifold and integrated catalytic oxidiser of the anode off-gas, as it stood at the beginning of the SAFARI project. Although this is a simplified schematic, the scaleable nature of the geometry and the natural integration into CPOX reforming and cathode air preheat are evident. In Fig 3, the fuel inlet on the right is shown entering the tube manifold. This fuel is evaporated LNG (liquid natural gas) premixed with a metered amount of air to give the desired partial oxidation reaction. This mixture reacts inside each tube on a catalytic mesh which converts the fuel into mainly hydrogen and carbon monoxide. This innovative concept, having each fuel cell tube with its own catalytic partial oxidation (CPOX) catalyst was originally devised by Adelan in 1994-1996 and has been again proved in experiments during this SAFARI project (WP4.2).

Cathode air flows over the outer tube surfaces, with oxygen molecules being reduced to O^{2-} ions, then being transported through the electrolyte of the tube walls, to react with the fuel at the inner nickel anode. At the end of each tube, mixing of anode and cathode streams occurs on the surface of the catalytic afterburner, with products then led to the hot exhaust where heat can be utilised. Fig 4 shows several 16 tube stack assemblies from the SAPIENS project.

Planar SOFCs

Another fundamental aim of the SAFARI project was to compare the microtubular design with a rapid heating planar SOFC system made by ALM. This unit had been marketed by ALM for several years as an academic SOFC demonstrator using hydrogen as fuel. The novel aspect of the SAFARI project was to adapt the stack (Fig 5) to using LNG as fuel, then to install on the LNG truck (Fig 6) and compare with the microtubular design above.

Figure 5 Planar SOFC from ALM showing stack mass of 905g

The planar stack was clearly much heavier (905g) than the microtubular which weighed 150g, and it also required special heater plates to give rapid start-up

After this research on the cells, stacks and systems, both tubular and planar product assemblies were to be packaged in the LNG truck and tested in the field to show the potential for the early market. Unfortunately, FCH-JU stopped the project before these demonstrations could be achieved.

Finally, dissemination was to be carried out by reporting the scientific observations through many varying channels of communication. A key aspect was to drive the fuel-cell-truck around the EU to demonstrate its virtues. The FCH-JU cancellation meant this was impossible. But three special conferences [4-6] were organised to report on the project, and many lectures and posters were delivered around the EU during the truncated 2 years of the SAFARI project.

Description of the main S&T results/foregrounds

Design of the system

The project started with discussion between the partners about how the fuel cell might be fitted into the LNG truck owned by VAY. Fig 6 shows the arrangement that looked most practical.

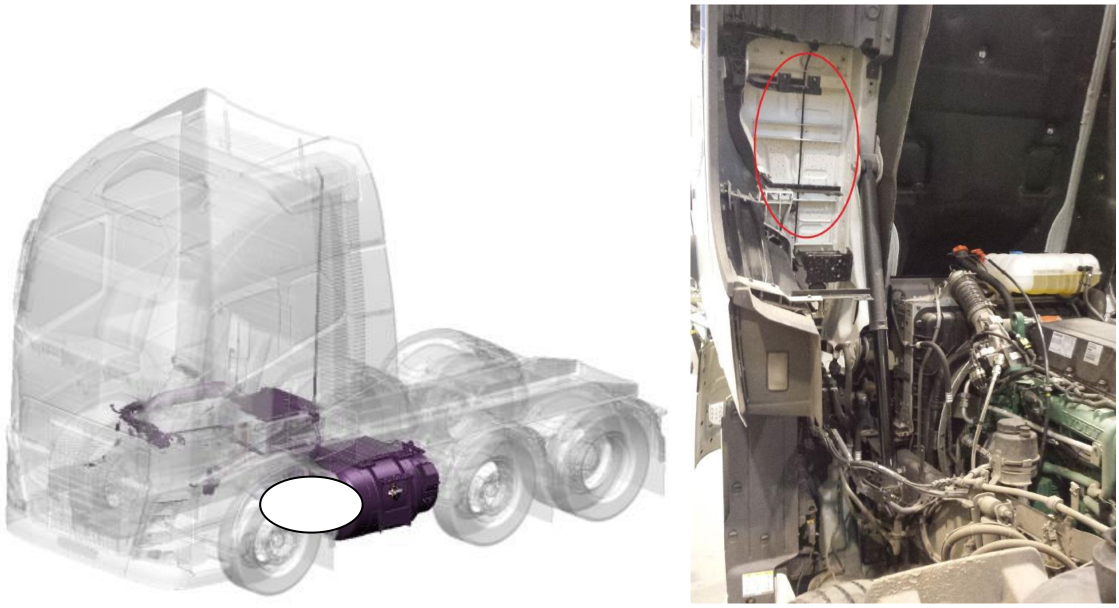


Figure 6 Left: the tractor of the VAY truck with the space available under the cab; right; the cab has been lifted forward to show the space circled in red

The fuel cell compartment was positioned under the cab near the LNG tank and the cab heat exchanger for temperature control. Volume was limited but the shape of space available was suitable for fitting both tubular and planar designs as shown in Fig 7.

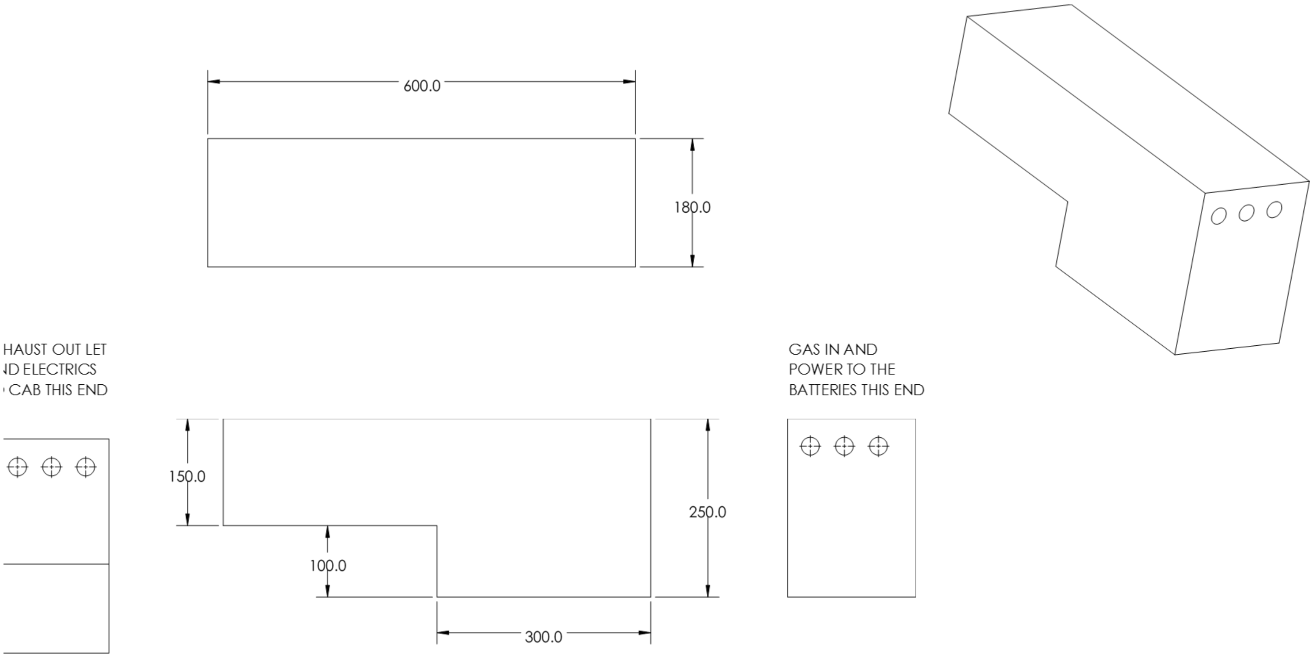


Figure 7 Space available under the truck cab, suitable for fuel cell box to be inserted

In SAFARI the aim was to design fuel cells to meet the specifications of the 2012 call to give 100W power with weight less than 3.5kg and volume less than 5 litre.

Requirements

Deliverable 2.5 described the key performance requirements of the stack and energy storage components. The document should be read in conjunction with the Performance Specifications Deliverable 2.6, which describes the specification of the fuel cell device planned for installation in Period 3. These specifications had been agreed with the platform supplier VAY and the fuel cell suppliers ADE and ALM. Vayon updated D2.6 in this period.

Further adjustments of these specifications were needed in Feb 2016 during the project review meeting when a misunderstanding occurred in defining the acceptable volume of the fuel cell (excluding fuel tank and supply pipes). The discussion was based on the definition of fuel cell weight and volume as defined in the original call from 2012.The coordinator ADE explained that there were two volumes to be discussed:-

1) The volume of the fuel cell system itself; this was the number we worked towards
2) The volume of the space available in the truck to accommodate the fuel cell; this depended on many factors related to the specific truck cab design

It was clear to the partners that these volumes could be very different. The PO disagreed.

Definition of dimensional targets

Both microtubular and planar systems are being designed according to the 2012 call to give 100W power with weight less than 3.5kg and volume less than 5litre. The final ADE design was 300mm x 90mm x90mm and 1kg weight which easily satisfies the call conditions. The previous iteration is shown in Fig 8

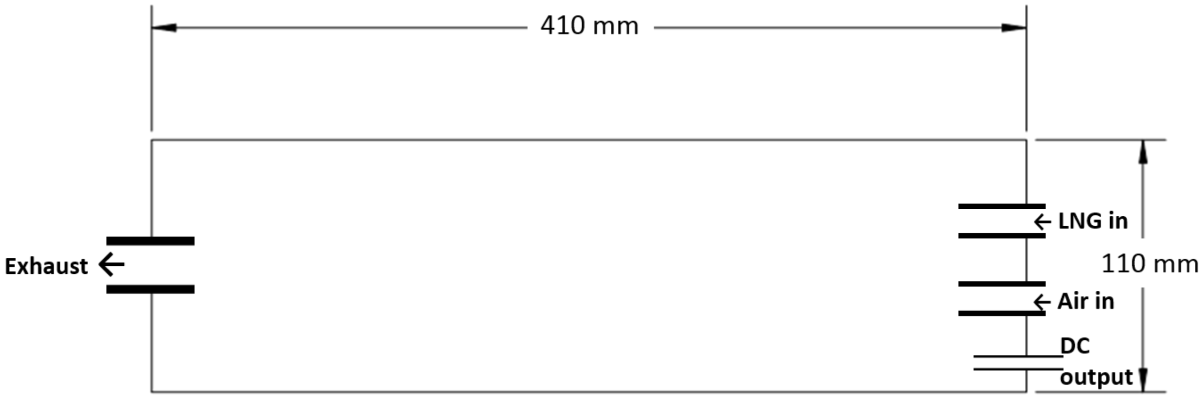


Figure 8 Dimensions of ADE design in early period 3

The detailed early Period 2 design of ADE microtubular fuel cell, excluding fuel tank, is shown below in Fig 9. This was revealing because it showed that most of the volume (and weight) was taken up with thermal insulation material shown in pale green colour. A priority later in period 3 was to produce a new design which cut the insulation significantly, as described later.

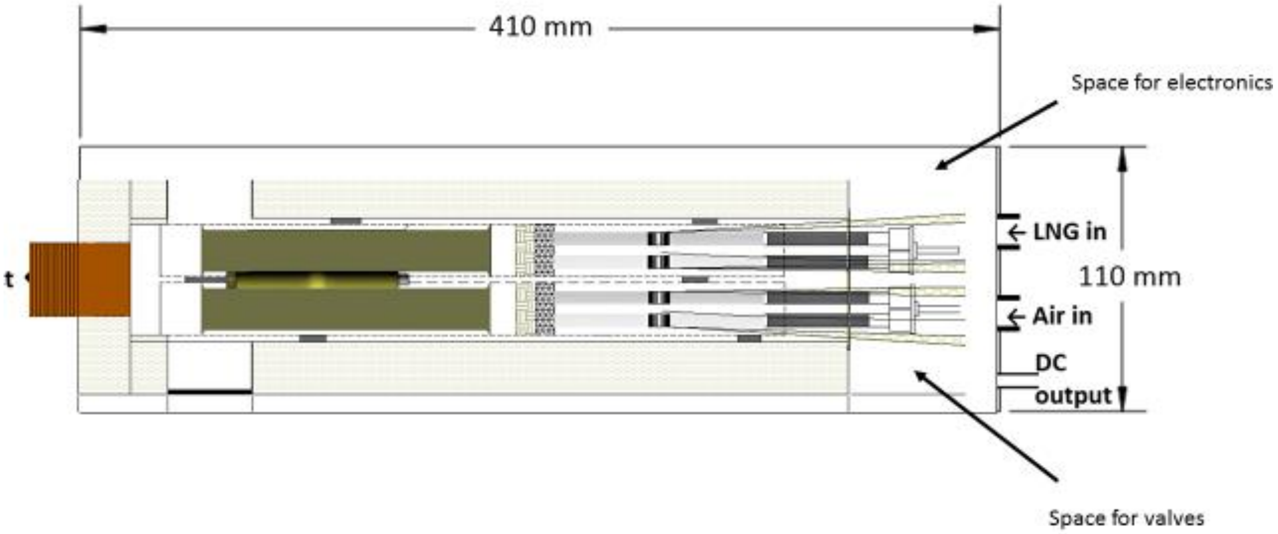


Figure 9 Internal design of ADE fuel cell system fitting in cab space built in Period 2

The second largest contribution to the Fuel cell system volume was the recuperator, that is the air preheater comprising four stainless steel tubes, one of which is shown in the photo of Fig 10 as the 4-tube substack was inserted during the assembly stage. The length of the recuperator parts was reduced later from 300mm to 260mm to shrink the overall volume further as described later.

Figure 10 Stainless steel recuperator tube (30 cm long) shown as the 4-tube sub-stack assembly was inserted on the right.

The final assembly of the tubular system is shown in Fig 11, with the electronic control board sitting on top. This Printed Circuit Board (PCB) was to be miniaturised later in the final product.and did not substantially increase the system volume.

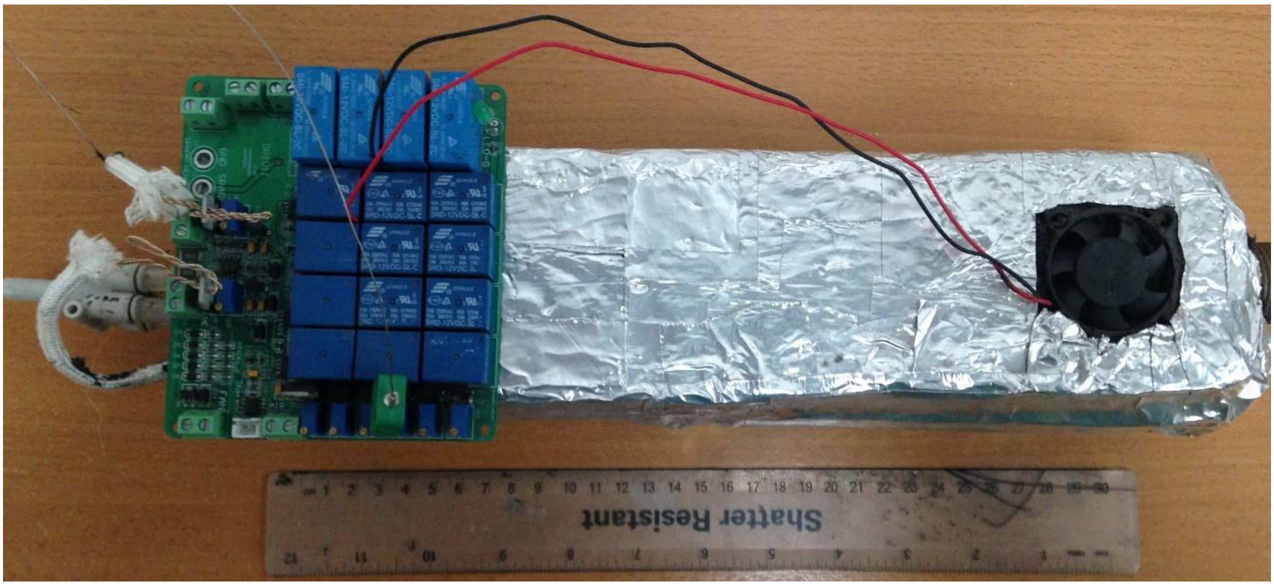


Figure 11 Photograph of prototype tubular system

The tubular fuel cell system of Fig 11 consisted of the following components readily fitting into the 5L space designed by truck company VAY. The conclusion was that the microtubular system easily satisfied the call criteria, though the truck space available was considerably larger than the fuel cell volume.

Table 3

component	Weight
1 16-cells stack:	171 g
CPOX reformer:	Included in stack
Combustion catalyst	10 g
Air pump:	100 g
Recuperator (4 tubes)	400g
thermo isolation	100g
Ceramic plate (to support thermo isolation)	20g
Ignition system	50g
Air and fuel supply:	On truck
Air and fuel exhaust:	On truck
Valves etc.	200 g
Total weight:	1051g

The planar fuel cell system shown in Fig 12 consisted of the following components, giving a weight twice that of the microtubular design but still within the call specifications of 3.5kg and volume of 5 Litres.

Figure 12 16-cell planar ALM stack with feed tubes

The planar components weights and volume are below

Weight:

1 16-cells stack:	800 g
CPOX reformer:	300 g
Air preheater:	400 g
Air pump:	150 g
Air and fuel supply:	200 g
Air and fuel exhaust:	200 g
Valves etc.	200 g
Total weight:	2,050 g

Volume:

Stack:	190 cm^3
CPOX reformer and afterburner:	200 cm^3
Air preheater:	300 cm^3
Air pump:	150 cm^3

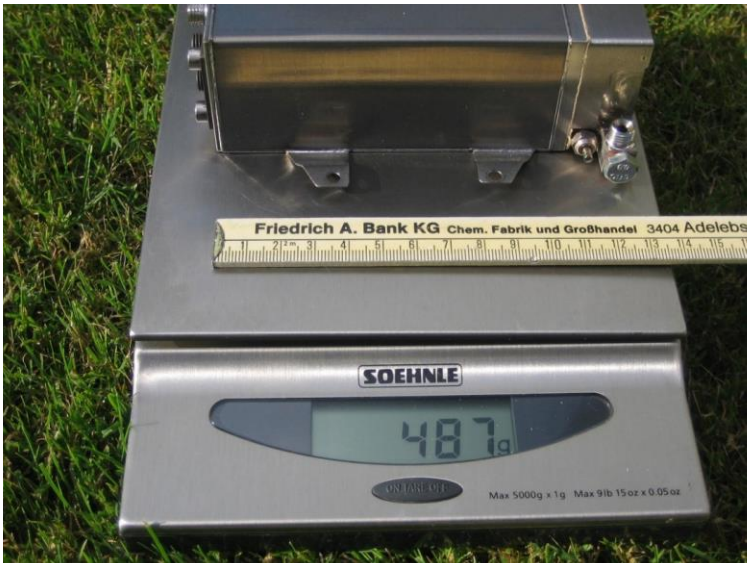


Figure 13 Afterburner/reformer, the final unit will be shorter with the same weight

These components were closely packed, connected by pipes and valves and surrounded by electric leads, thermocouples etc. to fit in a box with dimensions 410x110x110 mm. Fig 12 shows the stack with connecting pipes on the balance giving a mass of 905g. Fig 13 shows the afterburner reformer with mass of 487g. The conclusion was that both the microtubular and the planar fuel cell systems fitted the call specifications.

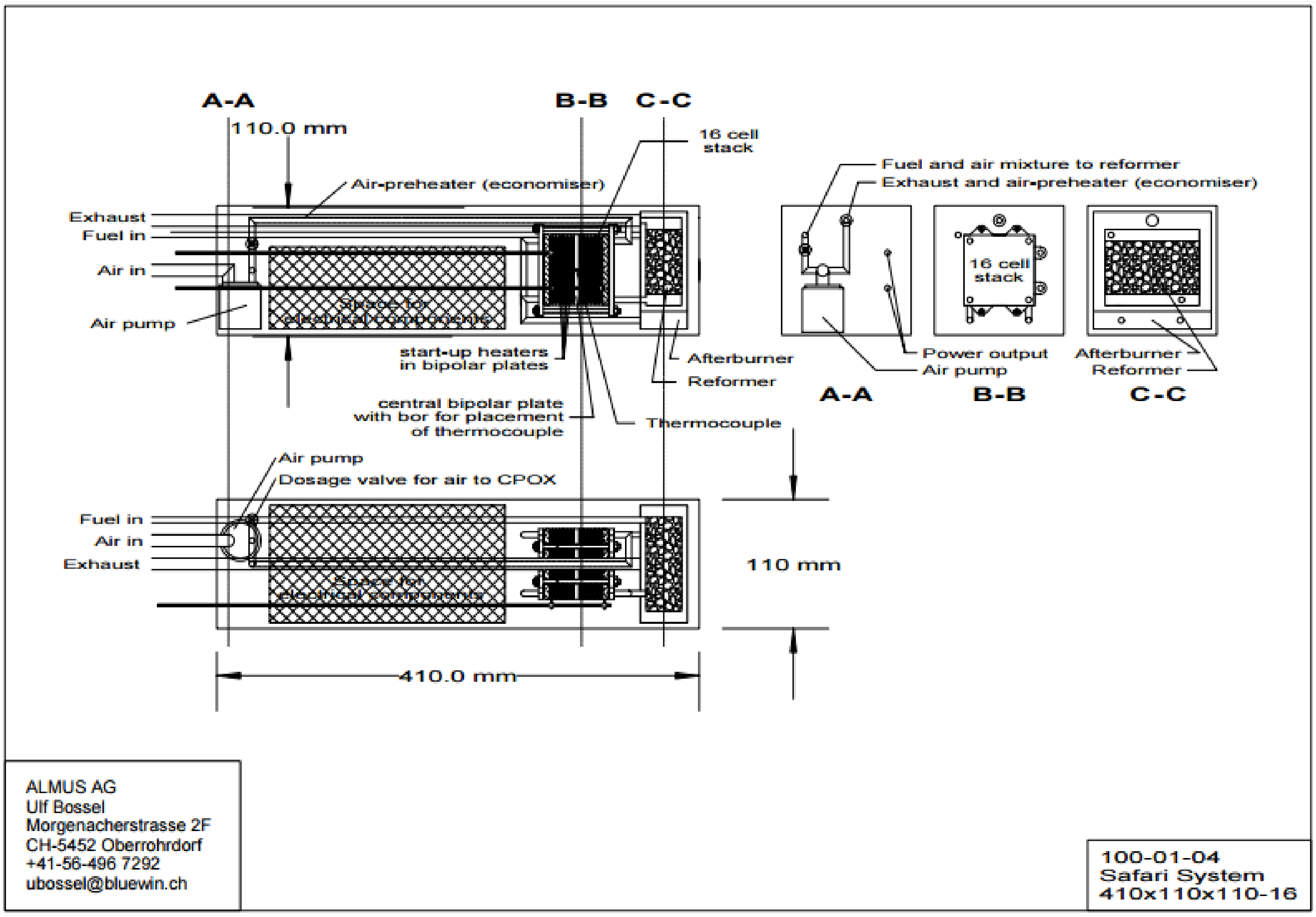


Figure 14 CAD drawing showing fit of the planar system in 5L box

Cell and stack performance

One of the main tasks in the project was to improve the output and lifetime of the cells, both tubular and planar. IRE made a breakthrough in showing that fuel utilisation strongly influenced the lifetime. Initial experiments performed on the SAFARI tube cells showed a degradation problem due to the anode related to the operation under high Fuel utilization (Fu) conditions, causing a decrease of the lifetime of the cells. At high Fuel utilizations and under high currents a large amount of water is produced which creates oxidizing atmospheres in the anode, leading to nickel oxidation and agglomeration. Combination of these two phenomena promotes, in the most severe cases, decohesion of the anode-electrolyte interlayer. Improving the anode microstructure would enhance the evacuation of steam produced from the catalytic active sites and avoid or minimize nickel reoxidation.

This hypothesis has been confirmed by long-term studies at different Fuel utilizations and different gas flows followed by final SEM characterization of the cells. The aim of IREC, following from the previous degradation tests and the identified weak points of the cells, was to optimise and improve the performance of the cells in terms of lifetime by suggesting modifications of the different components of the cells and/or the operation modes. Evaluation of the performance under cycling operation mode (thermal and current cycles) was attained at an early stage of the project in order to simulate the operation of the system under real conditions. In previous investigations, this test was performed in <25cycles. Within SAFARI project, the cyclic operation test was performed at a longer term, i.e. 400h of operation and 100 cycles. Figure 15a shows the scheme of one of the cycles during this test. The degradation observed in this test was ca. 4% of the power output observed in the plot of Figure 15b.

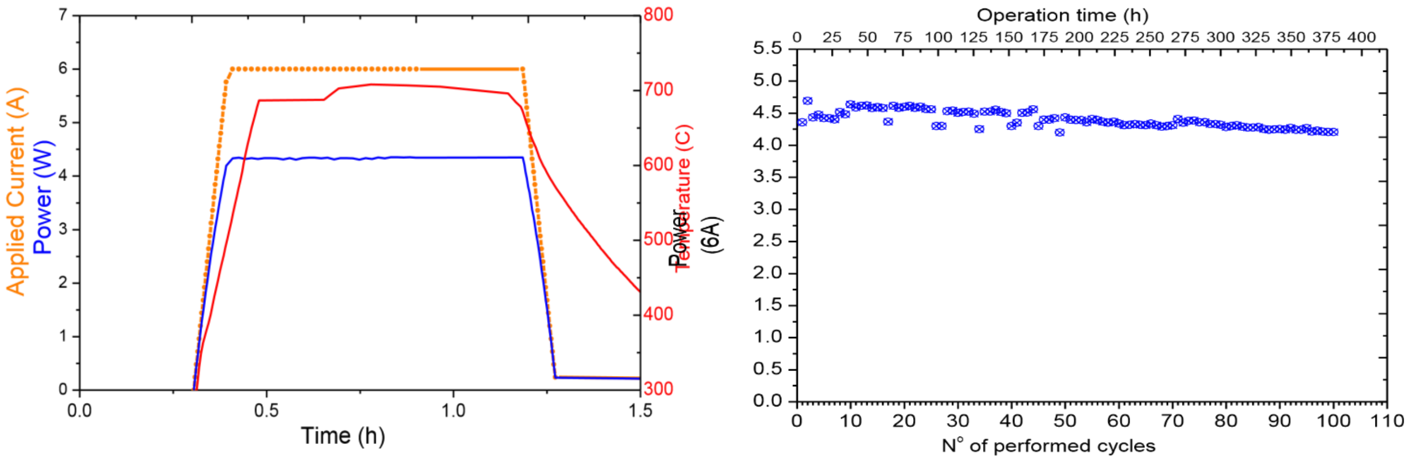


Figure 15 a: Scheme of one of the 100 thermal and current cycles applied to the m-tubular cell; b: maximum power extracted at each cycle from the SAFARI m-tubular cell during 100 cycles.

The initial and final I-V curves shown in Fig 16 were performed at the beginning and at the end of the single cell cycling test. The I-V and power curves show slight decrease in cell performance due to the cell degradation. In the electrochemical impedance spectroscopy (Fig 17) it can be observed that the main contribution to the cell resistance is the ohmic resistance, which is probably linked to the degradation of the current collectors.

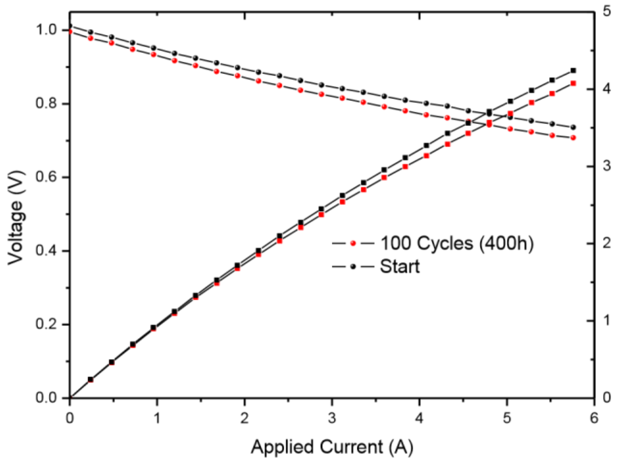


Figure 16 Initial and final I-V and power curves for the m-tubular cells submitted to the cycling operation long term test.

The spectra show an ohmic resistance of 0.03Ω from the beginning, which increases to 0.036 Ω, while the polarization resistance is kept around 0.0025 Ω. In order to elucidate the thermal contribution of the degradation versus the degradation produced by the cell operation, thermal cycling degradation tests were performed to the m-tubular cells. A 100 cycle test (figure 18) was performed with the same conditions as in the experiment above giving the results of Fig 19.

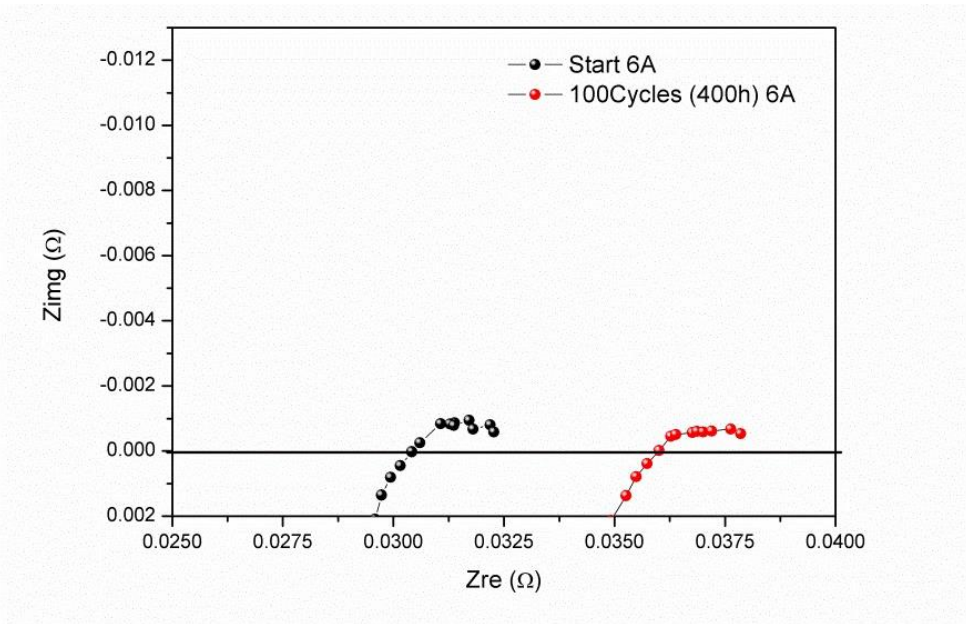


Figure 17 EIS analysis of the m-tubular cell before and after the cycling operation test.

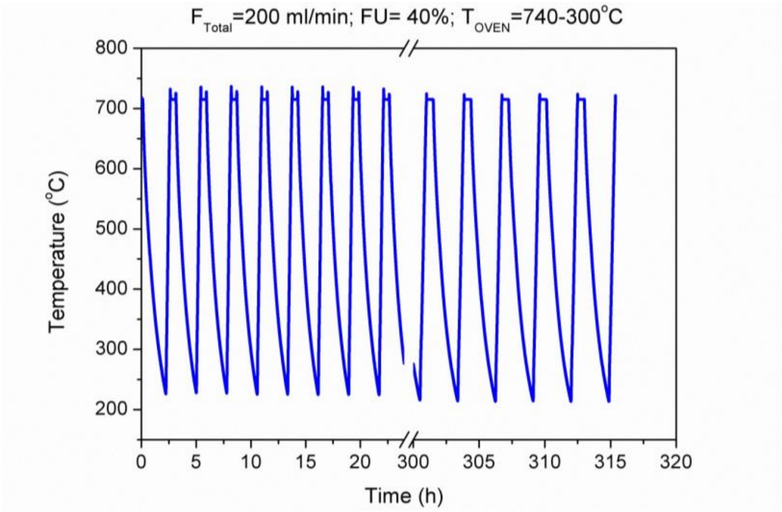


Figure 18 Scheme of the thermal cycles of the thermal cycling test.

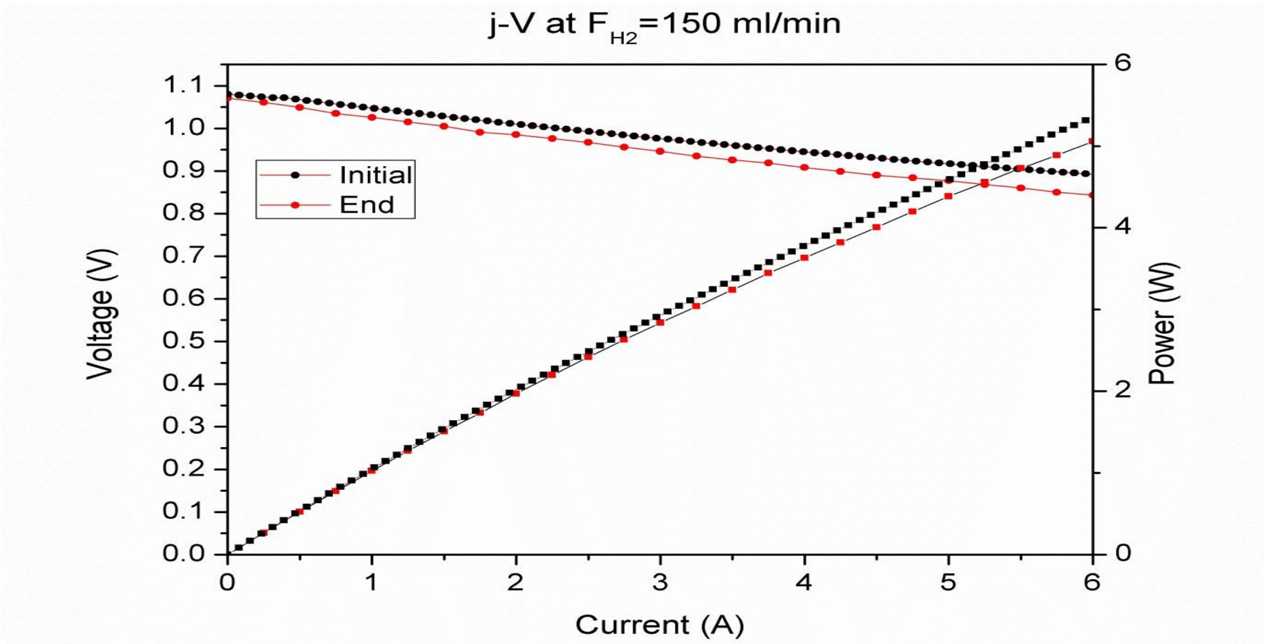


Figure 19 I-V polarization and power curves before and after the thermal cycling test.

Analysing the polarization curves, before and after this thermal cycling test, degradation close to the 4% of the extracted power per cell was observed. Thus, thermal cycling is one of the main causes of the cell degradation. The analysis of the EIS obtained before and after the thermal cycling test also showed a very similar behaviour to that observed in the thermal and current cycling test. In these cases the EIS spectra (Fig. 20) were also reported.

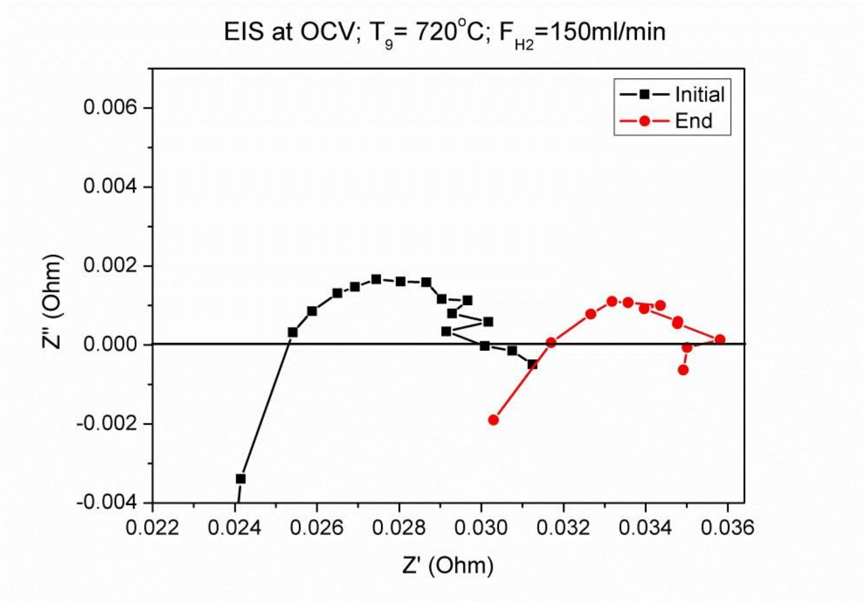


Figure 20 EIS spectra before and after the thermal cycling test.

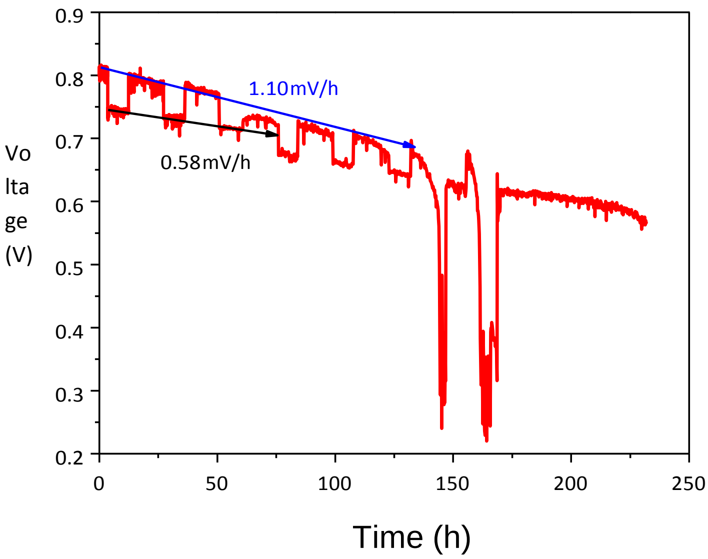


Figure 21 Cyclic dual operation at FU of 60% and 25%, under 6A and 200ml/min of total flow.

IREC worked on the optimisation of the fuel/air ratio to get a more efficient system in terms of fuel consumption. This study aims to reach higher fuel utilizations (e.g. 80%) while keeping the degradation rate at acceptable levels. To identify the most favourable operating conditions, fuel utilization cycling analysis was employed (named *dual fuel utilization mode*). In this mode, results of Figure 21 showed a higher degradation rate when low FU conditions were used while an improvement of the cell durability was observed for higher fuel utilization. These results evidenced mass transport issues at low FU even at the beginning of the operation, which may be related to the evacuation of produced water. This situation was reversed when higher flow of carrier gas was employed (high FU).

Fig 22 shows a 1000h experiment of dual fuel utilization mode using higher fuel dilution. Lower degradation rates and extended lifetime were obtained, confirming the improvement of the cell performance and identifying the carrier gas flow as a key factor for enhancing cell efficiency.

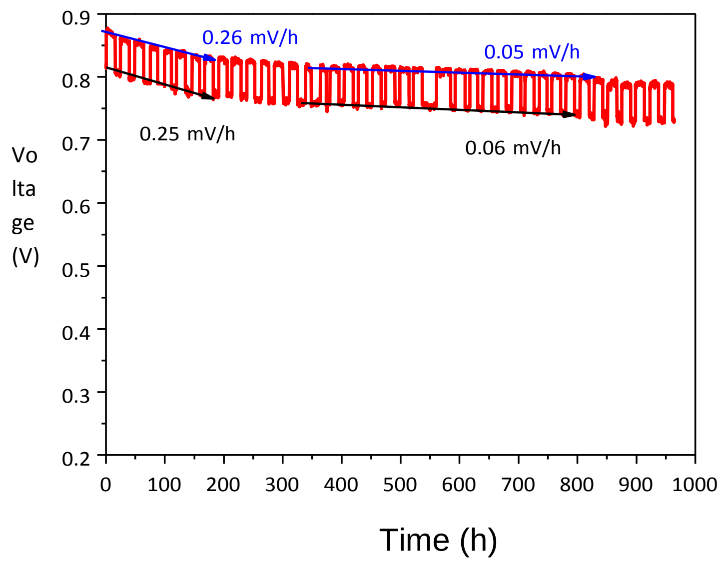
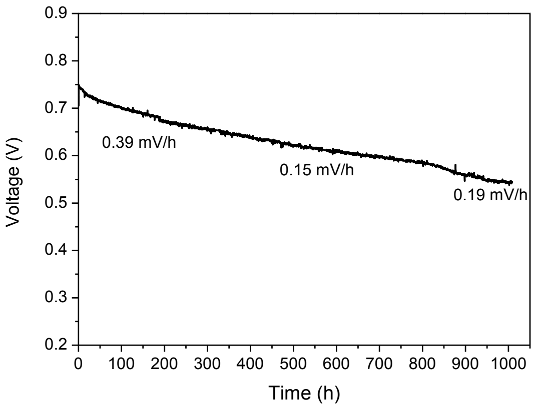


Figure 22 Cyclic dual operation at FU of 60% and 25%, under 6A and 300ml/min of total flow.

Following this theory, experiments of 1000h duration under highly severe 80% fuel utilisation conditions were carried out at different total gas flows (Figure 23). Figure 23b shows that the increase in total gas flow, at 80% fuel utilization, led to a remarkable improvement of the degradation rate.



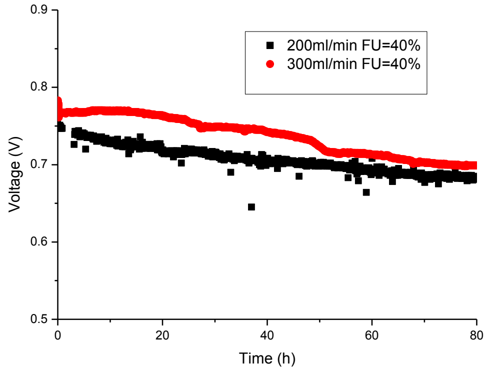


Figure. 23a Galvanostatic measurements at 6A under a FU of 80% and 300ml/min of total flow.

Fig. 23b Galvanostatic measurements at 6A under 40% of FU and different total flow from 300ml/min to 200ml/min.

The SEM microstructural characterisation of the cell measured at the worst conditions (80% Fu and 200ml/min H_2) showed a clear evolution of the anode microstructure. There was Ni agglomeration on the closest anode layers to the electrolyte and also some lack of continuity of the SDC barrier layer. All this evidence detected during the microstructural characterisation confirmed that the architecture of the cell was good, achieving a high cell performance. However, for longer life, the Ni-YSZ functional layer porosity needed to be optimised or the operation point has to be determined precisely to avoid the evolution of the anode microstructures (Figs 24 a-c)

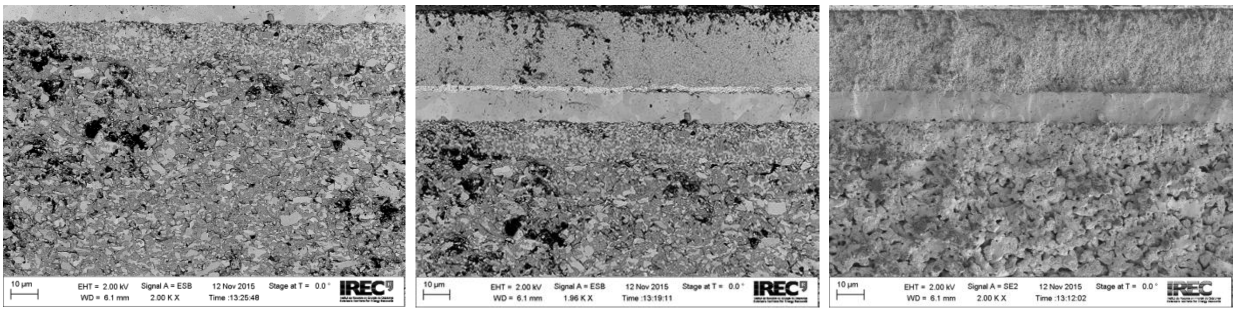


Figure 24a) SEM detailed microstructured of the anode cross section by ESB

b) SEM general view of the cell cross section by ESB

c) SEM general view of the cell cross section by SE.

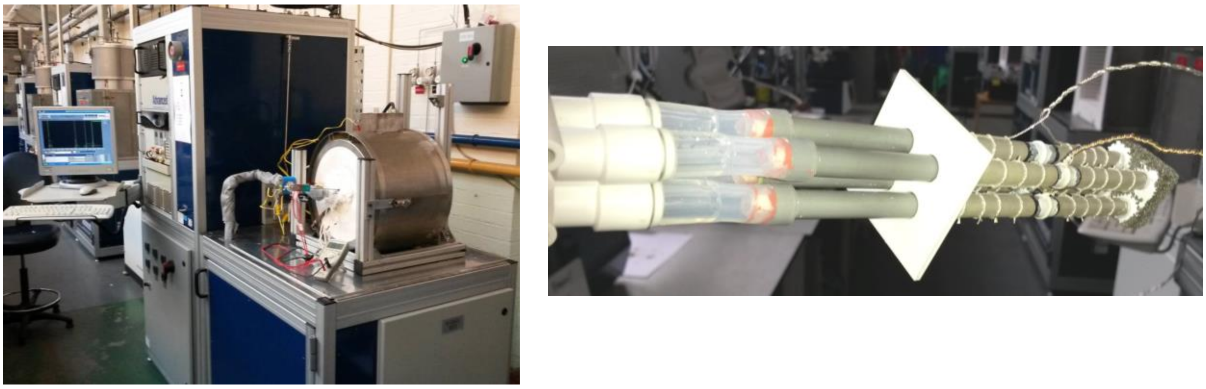
Stack testing, tubular and planar

Stack testing- m-tubular cells

Several stacks were produced by ADELAN and some of these were delivered to UOB to work on the stack testing.

Stack tests at UOB

The test station was modified (Fig 25a) to incorporate a new tubular furnace suitable for stack testing. 4-cell sub-stacks built by ADE and UOB were addressed (Fig 25b). Hydrogen was the primary fuel in the early stages of the experiments, in order to maintain and obtain a baseline for cell performance. Reformed methane was tested in the second stage of this work as simulated fuel from the CPOX reaction.



(a) *(b)*

Figure 25. (a) Test setup. (b) A typical 4 cell stack before the experiment.

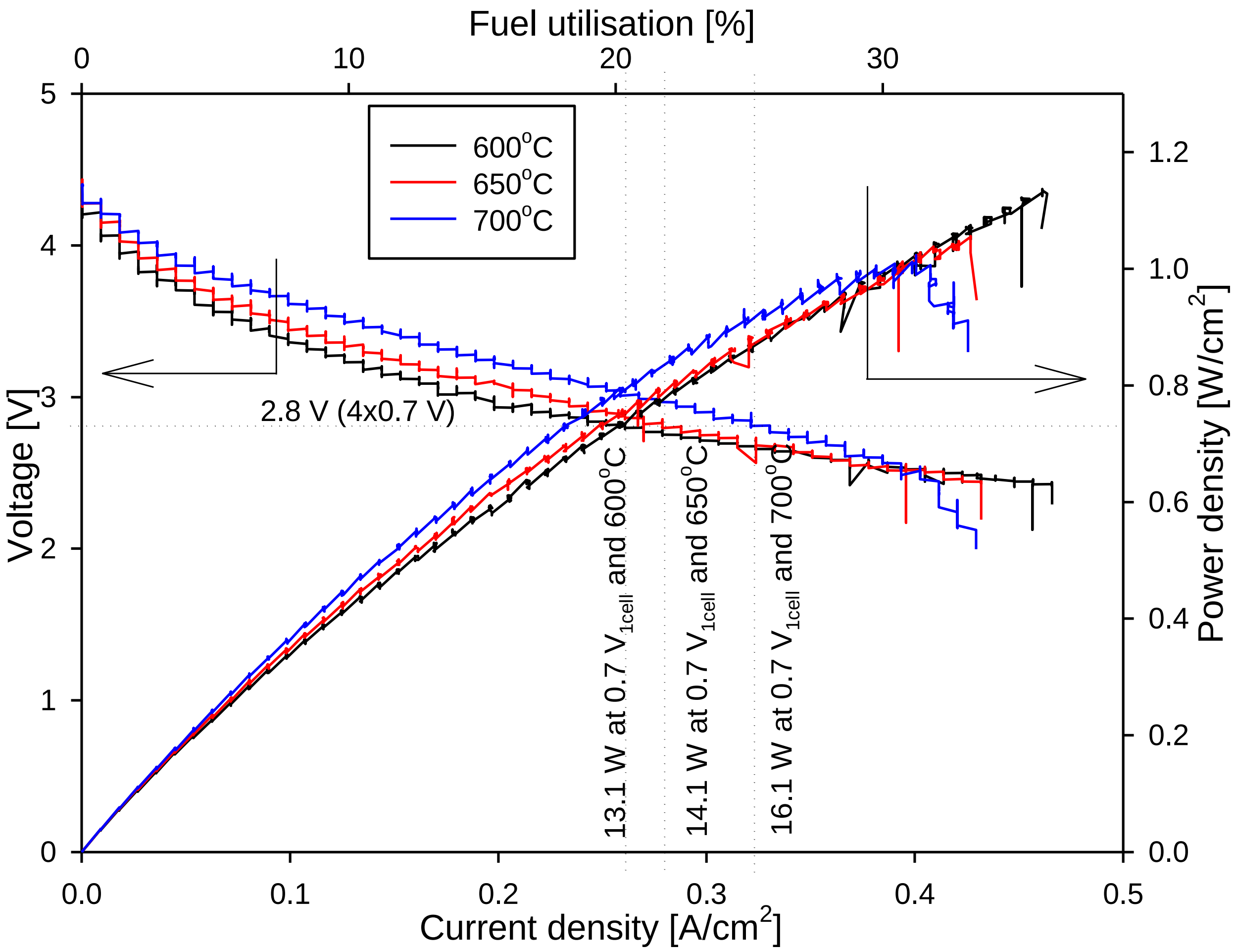


Figure 26 I-V measurements at 3 different temperatures 600, 650 and 700°C; H_2 0,6 l/min air 1,4 l/min, stack no 4.

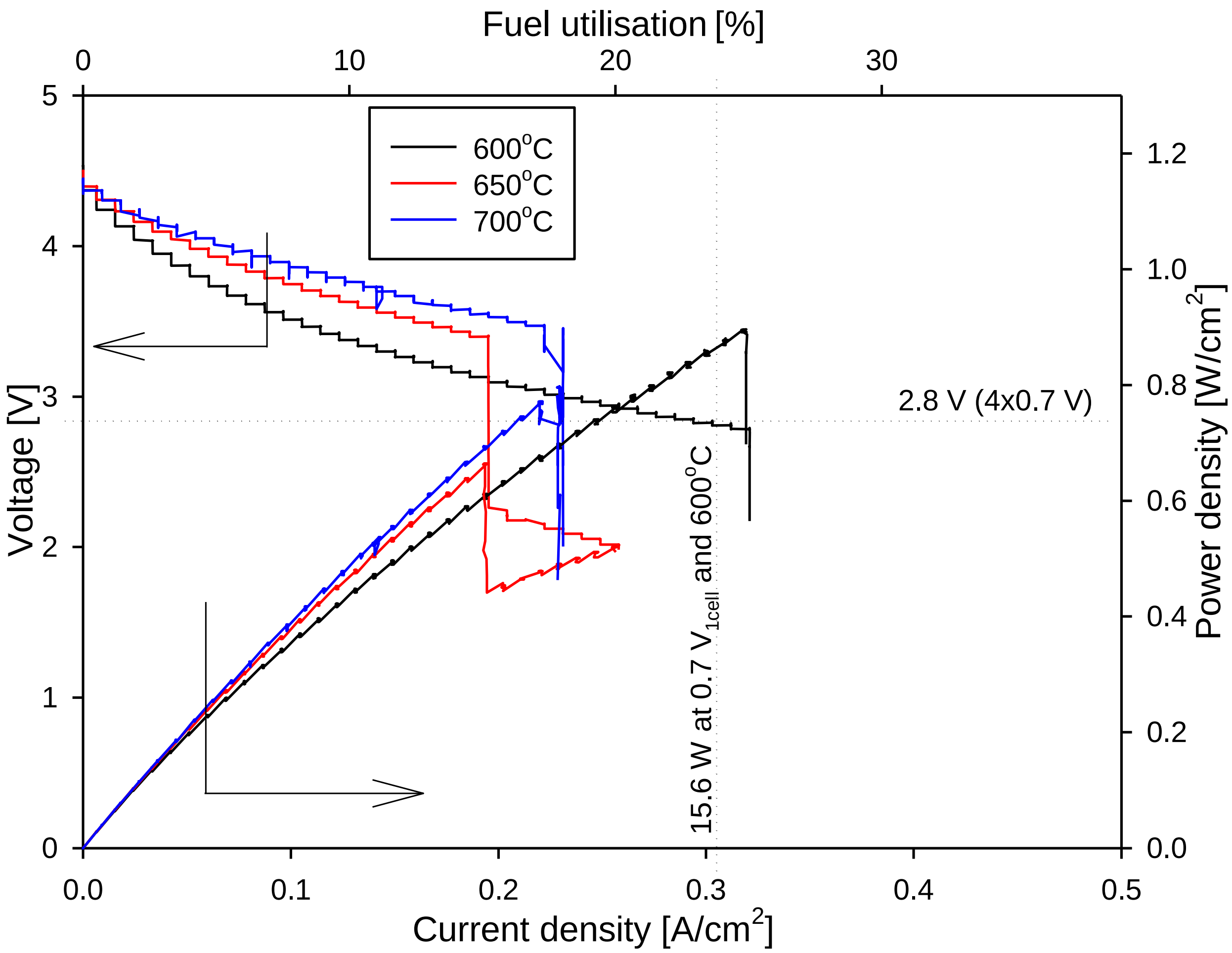
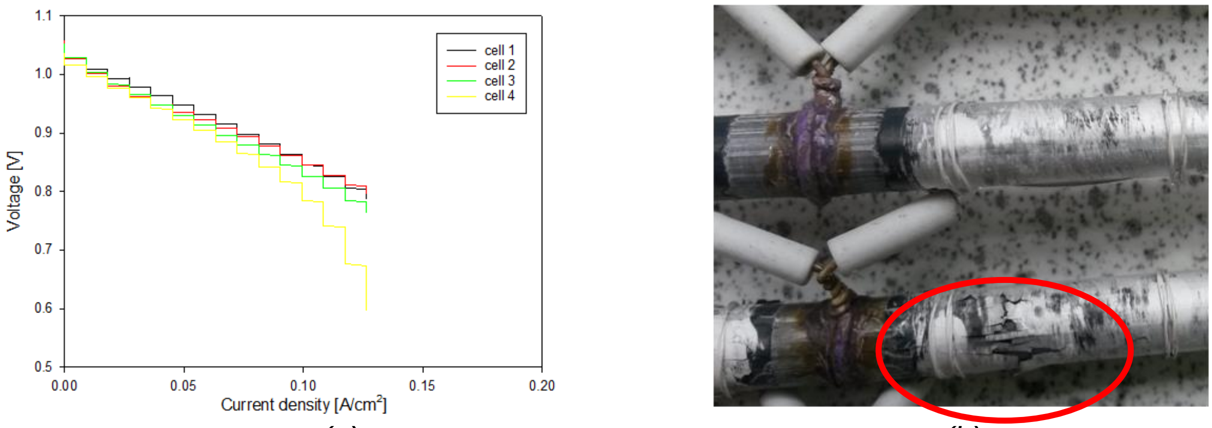


Figure 27 I-V measurements at reaction temperature 600, 650 and 700ºC, stack no 3.

The polarisation curves at three temperatures were plotted in Figs 26,27. A high open circuit voltage was observed (OCV) of 4.2 V which suggested good sealing. The stack power at the desired operating condition of 600ºC and 2.8 V (4x0,7 V) was 13W and this increased to16 W at 700ºC.

Results for stack no 3 are presented in Fig 27. The stack performance was promising at the beginning with 15.6 W from the stack at 600ºC and 2.8 V (4x0,7 V). However, at the higher current density above 0.2 A/cm^2 at 650 and 700ºC and above 0.31 A/cm^2 at 600ºC, the performance of the stack was unstable and voltage quickly decreased below the voltage limit of 2 V. OCV slightly decreased with increase in reaction temperature. We were unable to perform the durability test or thermo-cycling. Post-mortem inspection confirmed silver migration and short circuit formation.

The performance of one cell was found to be critical in affecting the stack operation. Fig 28 shows results from stack testing with one defective cell (cell no 4). Observations showed that this tube was cracked, allowing fuel to escape and causing a hotspot (Fig 28b). Consequently, the stack power was very low, giving 6.5 W at 2.8 V (4x0.7 V), only a quarter of the design power. This damage affected all remaining cells and the overall stack performance was degraded.



(a) *(b)*

Figure 28 Polarisation measurements at reaction temperature 700°C H_2 as fuel , stack no 5. a) – single cell I-V curves, b) damaged cell no 4 showing visible crack.

ADE stack test in Patented recuperator

One stackable unit, containing one four-cell sub-stack, was tested on hydrogen to investigate the stack power and temperature distribution. Fig 29 shows thermocouple positions; 1 at 10 mm along cathode, 2 at 25 mm, 3 at 50 mm and 4 at 80 mm along the 100 mm long cathode.

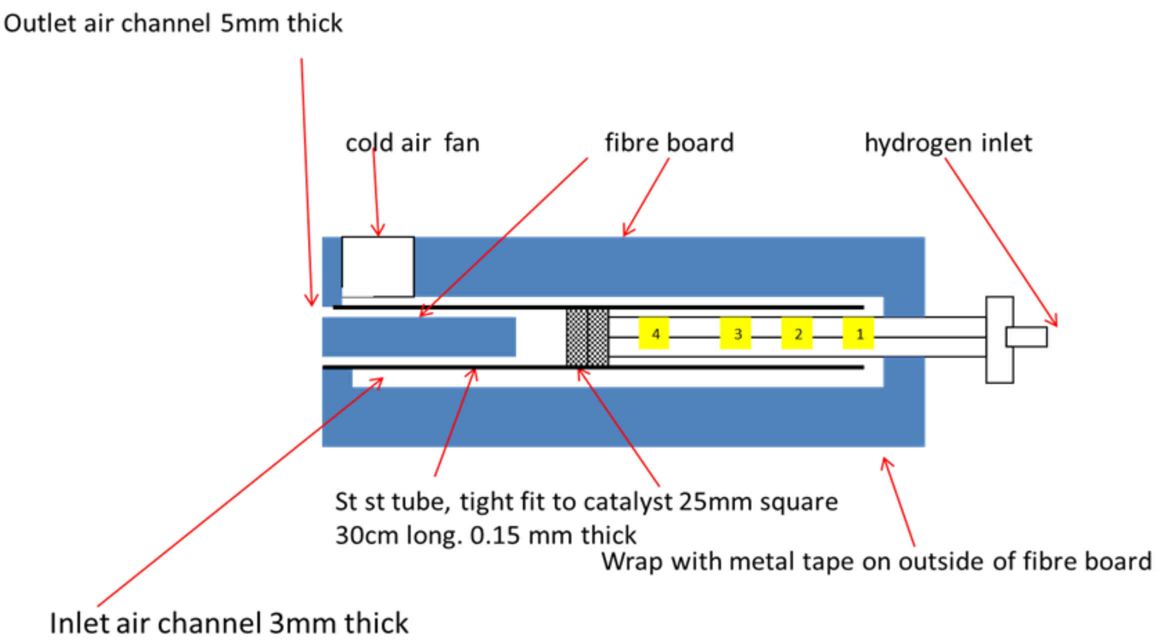


Figure 29 The test rig for 4-tube sub-stack running on hydrogen.

Initially, the air fan was started at 8 V and the temperature of the tubes was raised by heating the incoming air with a burner until the hydrogen flowing at 400 ml/min kicked off at 32^{o}C on the platinum based combustion catalyst. Then the ramp rate was observed on the thermocouples, mainly the central control thermocouple with results shown in Fig 30.

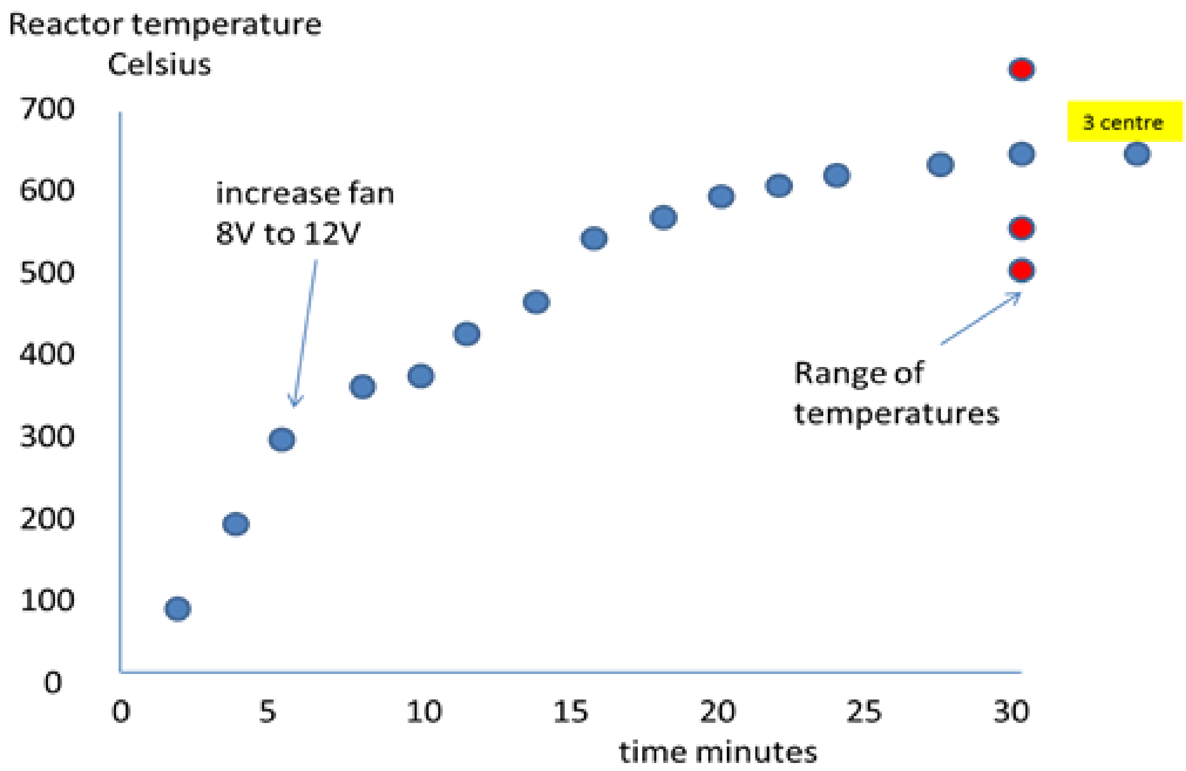


Figure 30 Warm-up of the rig on hydrogen showing blue points for thermocouple no 3 in the middle of the cathode area. The red points show the readings from thermocouples 1,2 and 4 illustrating the 200Celsius gradient along the tubes

The arrow in Fig 30 at 6 minutes into the test-run indicated where the fan-speed was increased to inject more air onto the cathodes. The results showed that increasing the fan speed lowered the heating rate from 60º/min to 20º/min. It would have been better to keep the fan at 8 V, then stabilise later. The power output was good even at low temperatures indicated on the central thermocouple. Fig 31 showed how the power went up and stabilised at 600 then 650ºC. Even at 500ºC going up, the power was 17 W, probably because the downstream end of the tube was hotter. 22 W was the peak power at 650ºC, whereas at 600ºC the power was 20 W.

When the hydrogen flow was reduced to 300 ml/min to cool down, the power output dropped significantly, although the temperature gradient changed only from 270 to 200ºC.

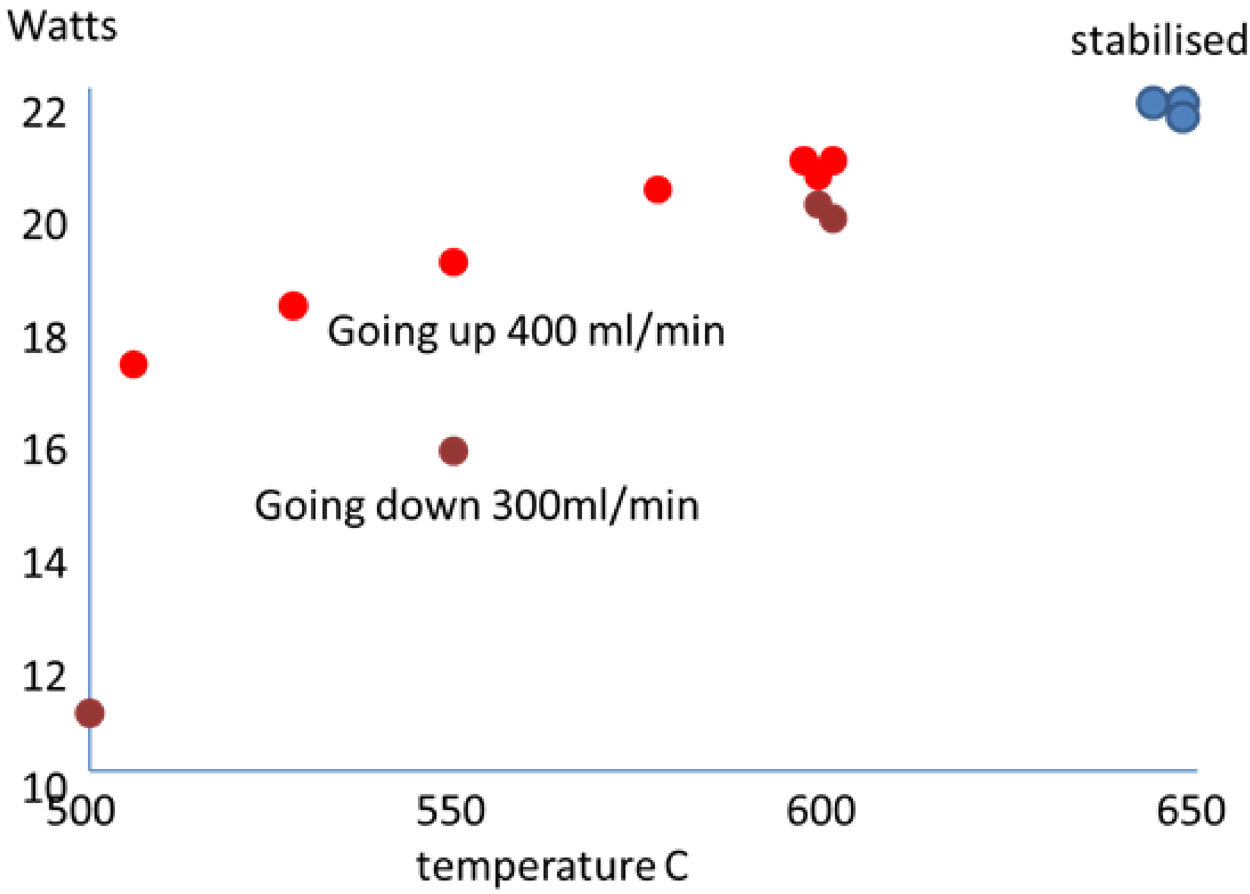


Figure 31. Power output as the temperature of the central thermocouple was increased, then stabilised, then dropped.

These results show that a 4cell stack (Fig 31) produced 23 W when running on hydrogen in the SAFARI patented recuperator. This will be a modular system, four of these stacks should produce 92 W. As seen in Fig 30 the temperature along the stack gave a gradient from 500ºC at the cathode air inlet to 700ºC approaching the combustion catalyst. This test did not include the CPOX. When the CPOX reformer tubes were inserted at the inlet end of each SOFC tube, the CPOX exotherm warmed this cool end of the tube, as described later, reducing the gradient along the cathode. With a more uniform temperature distribution along the cells, more power could be produced.

Further tests were planned by ADE in period 3 but these had to be dropped because of project termination. A specially designed tubular stack tester was obtained from Toyo as shown in Fig 32. This picture shows the gas manifold set-up on the left, the furnace holding the 16tube stack in the centre and the control system/measurement module on the right.

Figure 32 Test rig obtained by ADE for testing the 16 tube stack

This equipment underwent preliminary testing and was shown to give uniform conditions capable of obtaining the optimum power from an assembled stack.

<u>Stack testing- planar cells</u>

Fig 33 shows results on the ALM 16cell planar stack using hydrogen and air over several different temperatures. The 16cell stack had an active area of 432cm^2 and at 760 Celsius produced a peak power between 100 and 120W. The temperature could be reduced to 680 ºC while still obtaining the desired 100W output from the 32cell full stack designed for the truck.

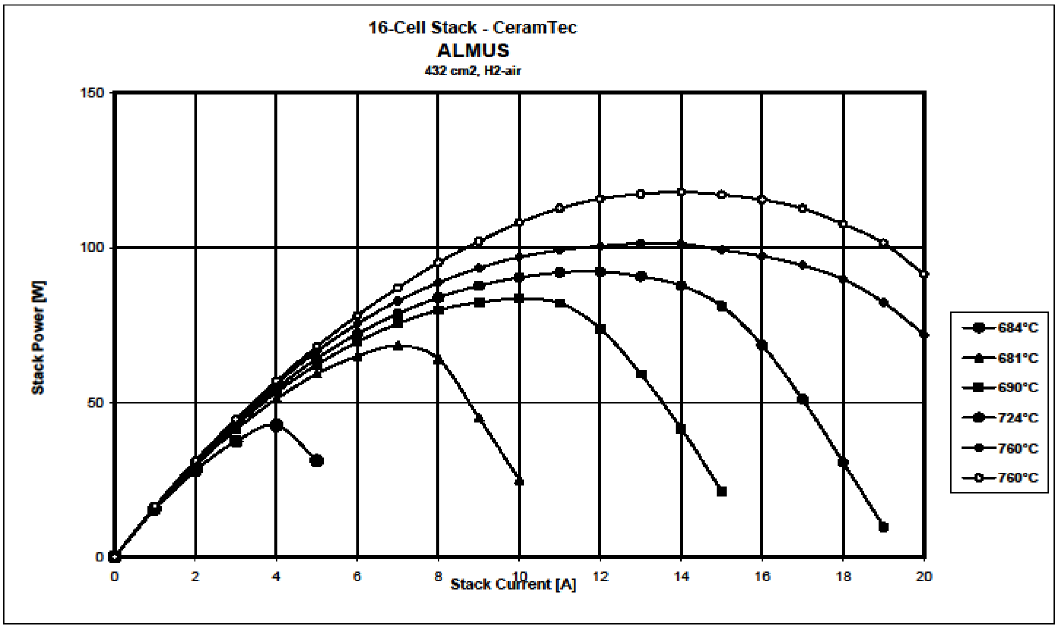


Figure 33 Planar FC results (presented Feb 23, 2016)

Fig 34 showed results on single cells indicating that rise in temperature above 700 ^oC had little effect on power output. Typically, a current of 10A per cell at 700 ^oC gave 7W of power each, showing that 32 cells were easily sufficient to provide the 100W specified in the truck project.

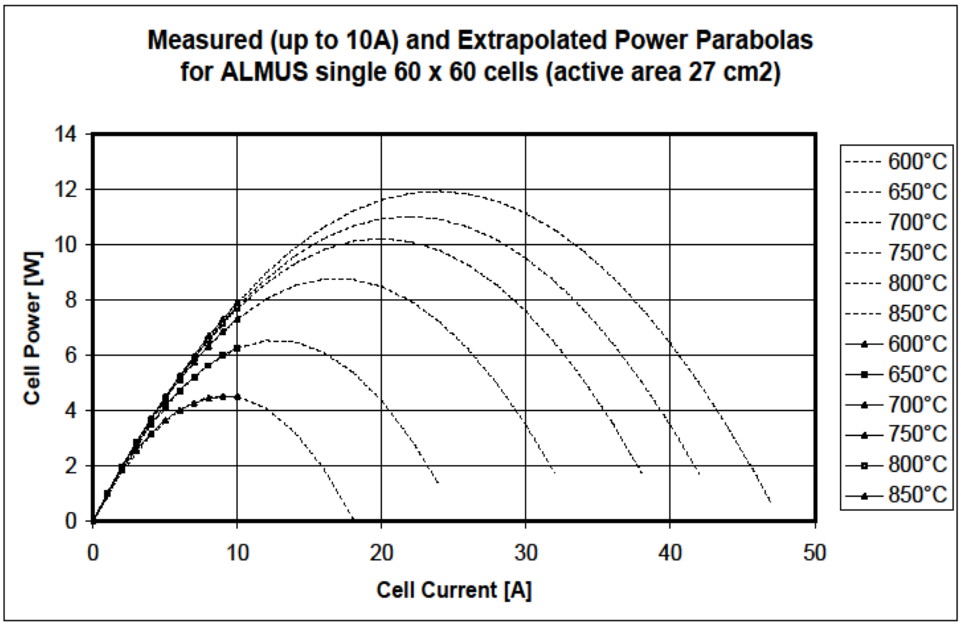


Figure 34 Further planar single cell results over wider temperature range.

Planar experiments with fully assembled 16cell stacks revealed that some cells must have cracked during the initial start-up and anode reduction phase. Several experiments were performed to identify the source of failure and to develop corrective procedures. Ten cells were used in the test. Length and width of all cells square were measured before the tests with 1/100 mm accuracy. The length varied between 59.88 and 59.96 mm. 59.90 to 59.95 mm were measured for the width of the ten cells. The first test series was the start-up of an assembled short 5-cell stack without anode reduction. The stacks were compressed by four M4-rods and nuts fastened by hand with gentle force. The stacks were then heated in the furnace to 600°C in two hours. The temperature at the centre of the short stack was sensed by the thermocouple placed in the centre of the stack. After reaching 600°C the temperature was held for 3 hours. Then the heating was shut off and the stack was left to cool down in about 5 hours. These experiments did not result in any breakage of cells.

A similar test series was conducted, again with 5 new cells, but hydrogen was admitted to the anodes 30 minutes after 600°C had been obtained. The hydrogen flow rate was set at 1 g/h, sufficiently high for the anode reduction process. The hydrogen flow lasted for 2.5 hours and was shut off together with the heating power three hours after 600°C has been reached. The disassembly of the stack showed that all cells were perfectly reduced. Between two points 5 cm apart on the anode surface the electric resistance was 0.2 to 0.3Ohms. However, three cells had developed cracks, two were broken into three and five sections. The dimensions of the unbroken cells were measured and compared to the original values. Without reduction the first set of cells did not show any significant change of length and width. Apparently, the thermal expansion of cells (Zirconia) and bipolar plates (Crofer 22 H) was well matched. Also, the cells had withstood the heating process and not developed internal stresses leading to destruction.

In contrast, the five cells of the second set had shrunk by about 0.04 mm (0.067%) as a result of the reduction of nickel oxide to metallic nickel in the anode layer. As the cells were fixed at all four sides by compression of the stack, they were not able to move freely. Consequently, the shrinkage of the supporting anode layer (0.25 mm thick) may have caused the thin sheets (0.01 mm) of the ceramic electrolytes to crack. This observation suggests that the anodes should be reduced in a loosely assembled stack and compressed for tight edge sealing after the reduction process.

Stack testing Conclusions

Microtubular and planar cells and stacks have been tested and the results have been used to improve and optimise performance for both planar and microtubular SOFC.

a) The cell connection geometry has been optimised.

b) The anode connection leakage problem with tubular cells has been addressed
c) The short circuits in tubular cells have been removed.
d) Stack results for both planar and microtubular fuel cells show that both are on target to produce close to 100 W with 16 cells.

Catalytic clean-up

It was intended from the start of the project that reforming of methane would take place CPOX (Catalytic Partial Oxidation). There is no steam readily available on a truck, thus steam reforming would be difficult to perform.

When oxygen and methane are mixed a range of possible reactions can occur, which depend on the methane/air ratio, temperature and other conditions. A balance is required to produce the highest possible conversion to H_2 without C formation (coking)

Table 3

ΔH^o_{298} -36 kJ/mol	$CH_4 + 0.5O_2 \rightarrow CO + 2H_2$	[1] CH_4 partial oxidation
ΔH^o_{298} -802 kJ/mol	$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$	[2] CH_4 combustion
ΔH^o_{298} -41 kJ/mol	$CO + H_2O \leftrightarrow CO_2 + H_2$	[3] water gas shift
ΔH^o_{298} +206 kJ/mol	$CH_4 + H_2O \leftrightarrow CO + 3H_2$	[4] CH_4 steam reforming
ΔH^o_{298} +247 kJ/mol	$CH_4 + CO_2 \leftrightarrow 2CO + 2H_2$	[5] CH_4 dry reforming
ΔH^o_{298} -131 kJ/mol	$CO + H_2 \leftrightarrow C + H_2O$	[6] CO hydrogenation
ΔH^o_{298} +75 kJ/mol	$CH_4 \leftrightarrow C + 2H_2$	[7] CH_4 cracking
ΔH^o_{298} -173 kJ/mol	$2CO \leftrightarrow CO_2 + C$	[8] Boudouard
ΔH^o_{298} -282 kJ/mol	$CO + 0.5O_2 \rightarrow CO_2$	[9] CO oxidation
ΔH^o_{298} -241 kJ/mol	$H_2 + 0.5O_2 \rightarrow H_2O$	[10] H_2 oxidation

Several commercially supplied CPOX catalysts were tested under different conditions.

m-tubular

Adelan patented technology was used to reform methane in the tubular SOFC. A tube as shown in Fig 35 (weight 1.6 g) was inserted in each mSOFC tube. CPOX occurred in the honeycomb catalyst. Any unconverted methane that passed into the mSOFC tube reformed by a number of reactions, including steam reforming (using water generated by the fuel cell reactions). This novel method of reforming is inexpensive and provides for low weight of the overall system. The total weight of the reforming tubes was 25.6 g compared to140 g for the external reformer being developed for the ALM planar system, utilising the same catalyst. Our proposed reforming method enabled the tubular system to meet the call targets on weight, volume and cost. This also enabled an excellent comparison of the two geometries for SOFC.

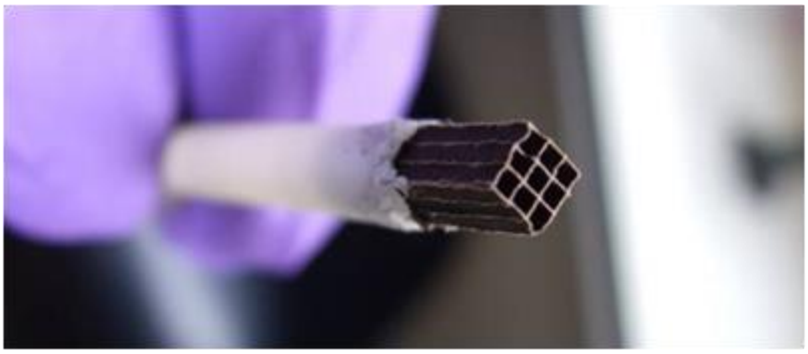


Figure 35 Honeycomb CPOX catalyst inserted in tube used in SAFARI project

Reforming experiments were carried out to explore several of CH_4:air compositions to evaluate the CPOX operating window. A good window was found to be 1:2.4, CH_4:air. The partners have had papers on SAFARI results for this work accepted and published, the results of which were presented at the Feb 2016 meeting. A key result was after 850 h of stable cell operation (shown in Fig 36) there was no visible carbon deposition on the anode. There was some coke deposition on the 'external' surface of the CPOX catalyst. This is not surprising since during operation the cell generates a significant amount of steam. The fuel not converted on the CPOX catalyst is converted along the anode by steam reforming. It is not necessary to convert all the fuel to syngas. There is extensive literature showing that even 10 % of fuel conversion significantly reduces coke deposition on the anode. The goal of the CPOX catalyst is not to convert 100% fuel but to convert it to the level that will prevent coke deposition on the anode.

Initial poor results were caused by problems with the anode lead connection and silver migration, not coke deposition. A SAFARI paper that explains the cell degradation related to silver migration was presented at the 12th European SOFC & SOE forum conference, Lucerne, 5 to 8th July 2016. Thus, the early problems have been solved for the new generation of cells.

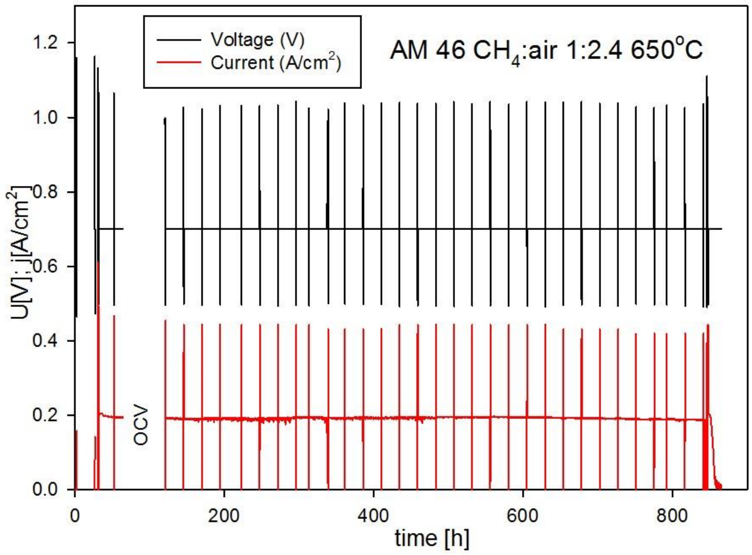


Figure 36 Results of 850hr test on tubular cell with CPOX, 650ºC, CH4 : air 1 : 2.4, 0.7 V (durability + load cycling).

One of the key measurements made at UOB during this work was the effect of the CPOX exotherm on the temperature distribution along the SOFC tubes. Fig 37 top shows the furnace arrangement using one SOFC tube down the middle, with an exhaust ceramic tube allowing the gas to exit on the right. The blue cold anode gas can be seen entering on the left, and warming rapidly as it moves right towards the exit. The top picture relates to hydrogen fuel at open circuit (OCV) and is a cool 390ºC at the electrode start, rising to the furnace temperature 649ºC at the exit. At 0.7V with hydrogen the cell warms up slightly because the electrochemical reaction produces heat.

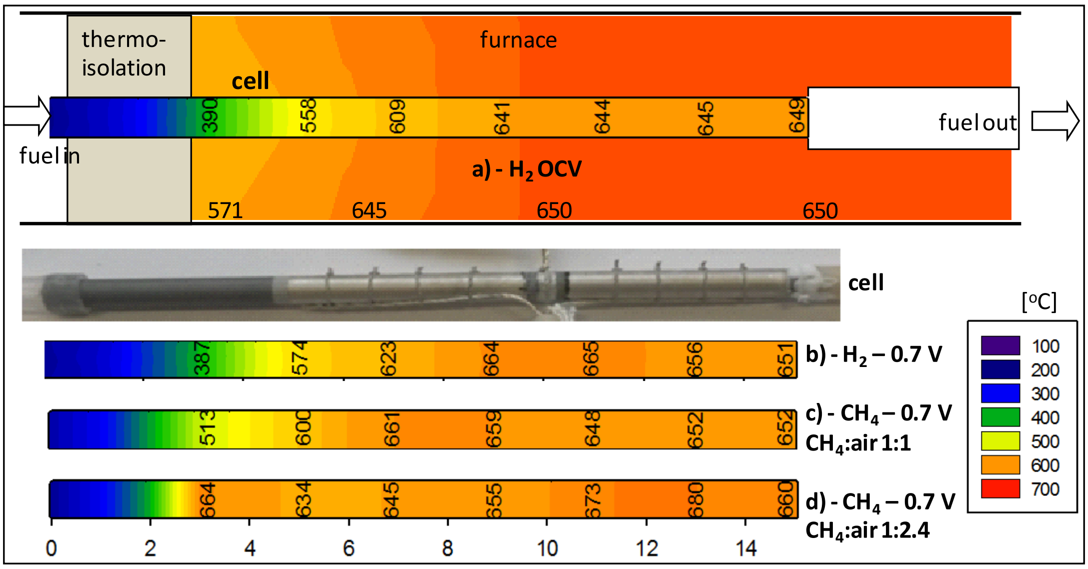


Figure 37 Temperature results along single SOFC tubes with cold inlet gas mix

But the bottom result shows the strong effect of CPOX with methane/air of 1/2.4 giving a strong exotherm to warm the tube inside to 664 ºC, thus levelling out the temperature gradient along the electrodes.

By measuring the temperature inside the honeycomb catalyst over its 15mm length, the hotspot can be seen 200 degrees higher than the pure hydrogen case at 5mm in.

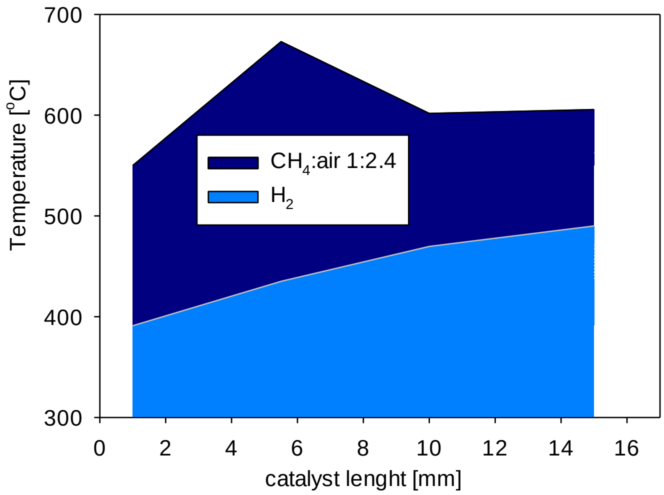
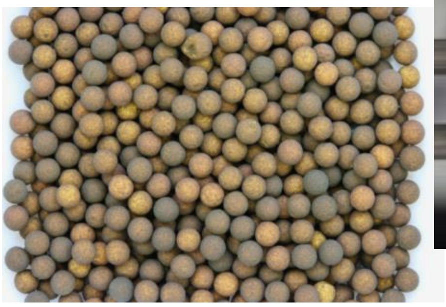
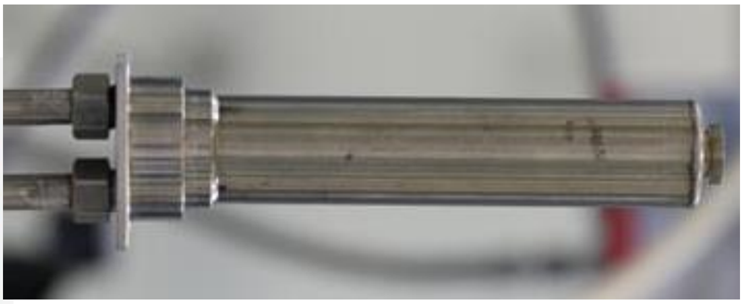


Figure 38 Temperature inside the CPOX catalyst honeycomb comparing hydrogen with methane/air of 1 /2.4

Planar

The CPOX reformer integrated into the planar unit has been tested by UOB with excellent results. For planar systems, the same catalyst as for tubular cells was tested, HiFUEL AB10 from Johnson Matthey. The catalyst for the planar system was deposited on alumina pellets 2 mm diameter (Fig 39a). The catalyst (5 g) was located into the fix-bed reactor - stainless steel container (Fig 39b), both fitting into the catalyst system (Fig 40).

1.  

(a) (b)

Figure 39 a) - catalyst HiFUEL AB10 - pellets. b) - External reformer for planar cells (designed and manufactured by ALMUS).

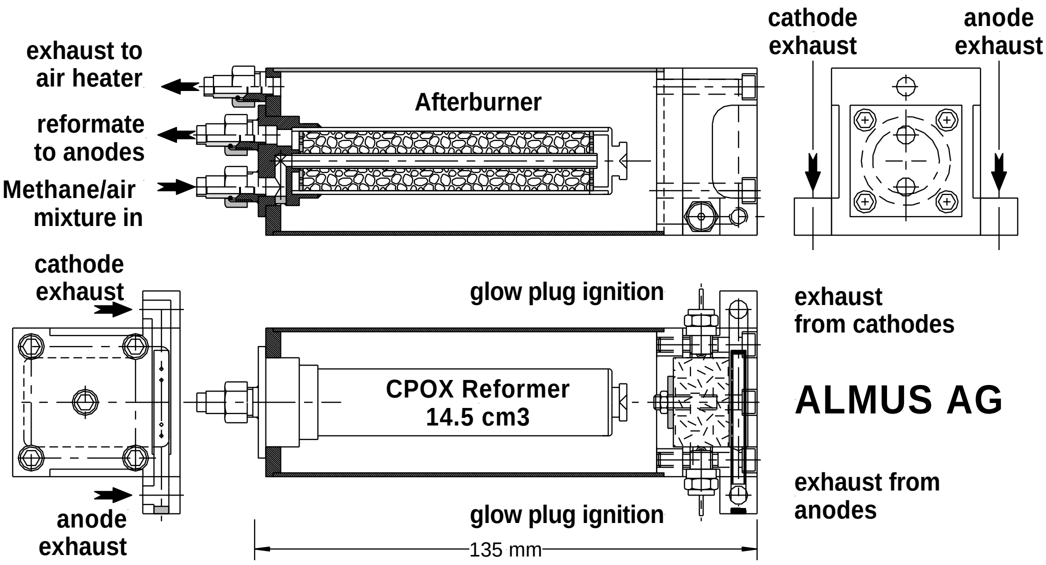


Figure 40 Planar fuel cell catalyst (CPOX plus afterburner) design from ALM.

For planar cells, we are not limited in the reactor size. The GHSV is much lower $3.0x10^4$ ml/h g_{cat}. Therefore, the expected methane conversion was higher than for tubular cells. According to literature, methane conversion is expected to be around 85-95%, at temperature 700-750ºC, 1 bar, proportion CH_4:air in gas 1:2.4 and GHSV $3x10^4$. Also partial oxidation thermodynamics predicts high methane conversion for this reaction condition, as shown by results in Fig 41.

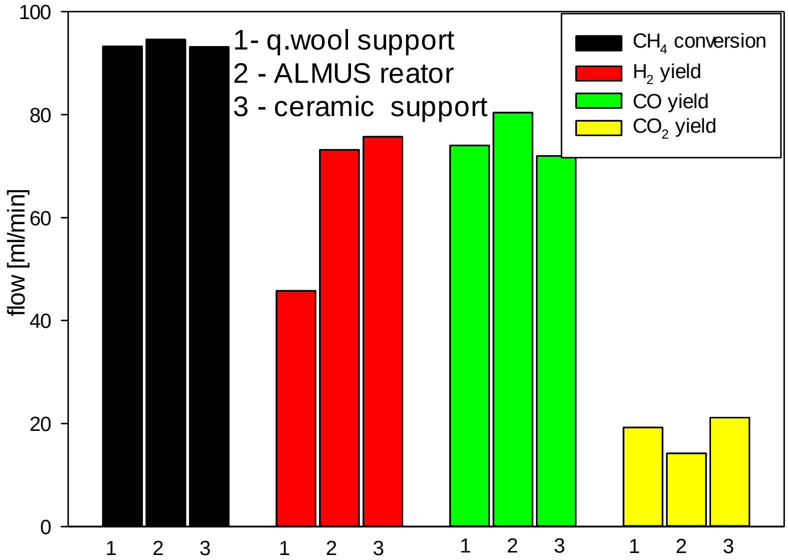


Figure 41 Gas composition at the reactor exhaust from different reactors (average from 24 h reaction): 1 - reactor with quartz support, 2 - ALMUS reactor, 3 - reactor with ceramic support. Reaction at 700^oC, CH_4:air 1:2.4, AB10 catalyst 5 g, CH_4 724 ml/min.

Three reactor configurations were tested for partial oxidation reaction at the identical condition, all with the 5 g of catalyst (Fig 41): stainless steel fix bed reactor with quartz wool, reactor designed by Almus, and ceramic support reactor. Using quartz wool as a support for catalyst resulted in an increase in reactor pressure probably because of wool compression. The lowest back pressure was in the reactor with highly porous ceramic support. The CH_4 conversion was respectively 93.3, 94.6 and 93.1% (average from 24 h reaction).

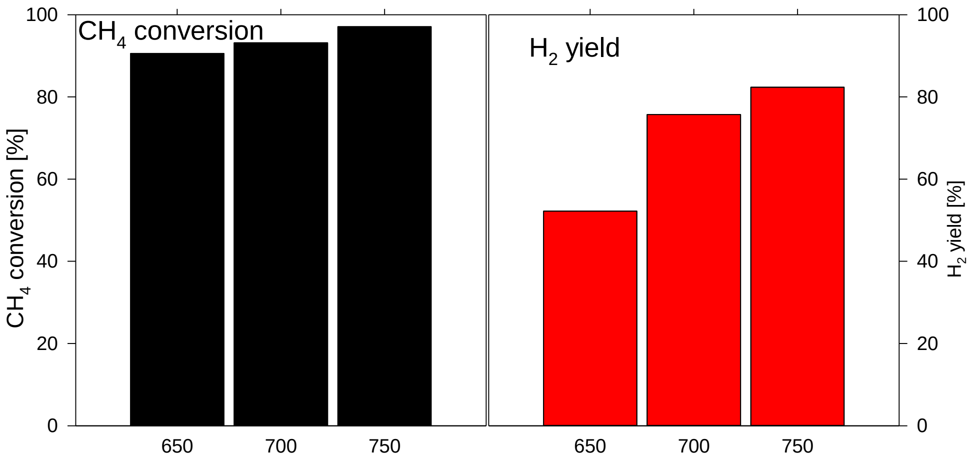


Figure 42 Reactor performance at the different reaction temperature. (average from 24 h). CH_4:air 1:2.4, 5 g AB10 catalyst, CH_4 gas-in flow 724 ml/min.

Increasing reaction temperature improved syngas production and methane conversion. As expected CH_4 conversion increased (Fig 42). That was affected by increasing the efficiency of steam (4) and dry (5) reforming reactions at the high reaction temperature. H_2 yield increased from 52 to 92 % by increasing reaction temperature from 650 to 750°C. The fact that CO_2 flow increased at 700°C and decreased when the temperature reached 750°C was a result of water gas shift reaction (3) and improved dry reforming (5).

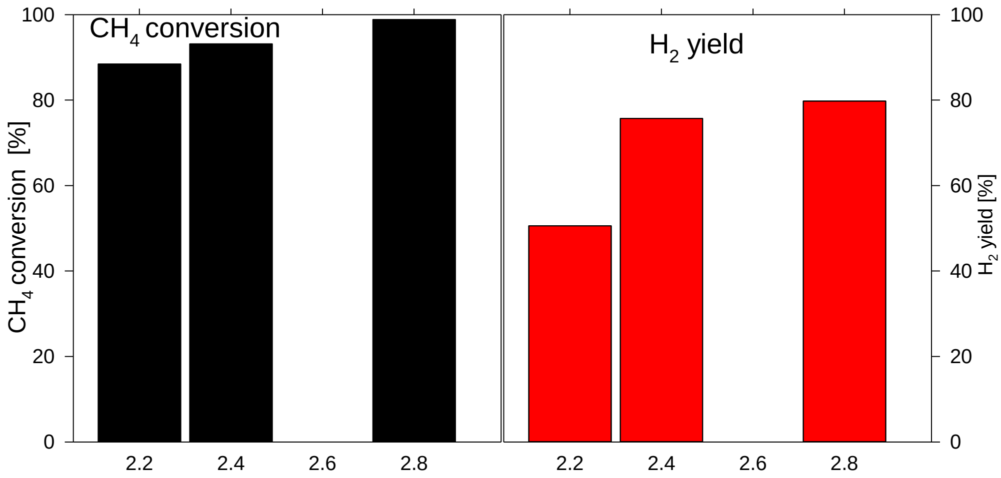


Figure 43 Reactor performance for different air/CH_4 ratio (average from 24 h). Reaction temperature 700°C, 5 g AB10 catalyst CH_4 if flow 724 ml/min.

Increasing the air partial pressure improved CH_4 conversion and H_2 yield (Fig 43).

Planar SOFC results were different from tubular, mostly caused by the much higher GHSV, $1.2x10^5$ for tubular cells and $3.0x10^4$ mL/h g_{cat} for planar. For the planar cells in the external reactor, fuel had much longer contact time with the catalyst. Therefore, the slower reactions of steam and dry reforming that followed the methane oxidation had enough time to complete, giving CH_4 conversion, reduced CO_2 production and improved CO and H_2 yield.

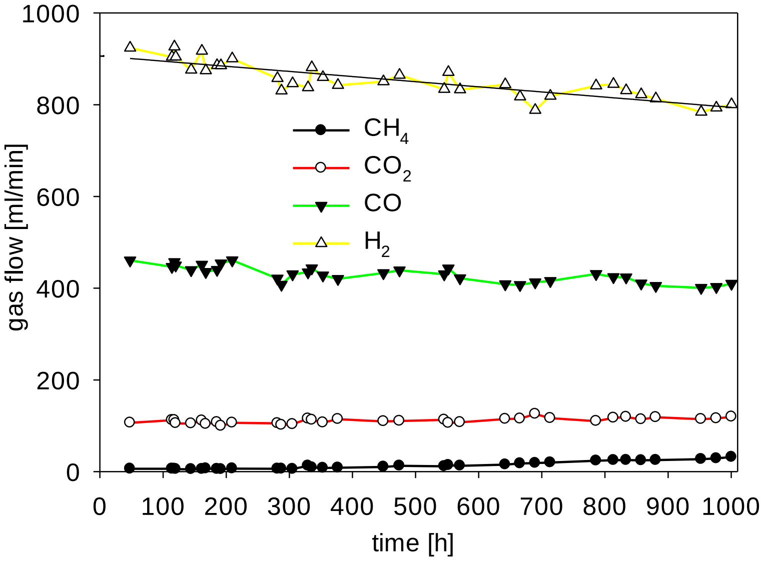


Figure 44 Change of gas composition at the reactor outlet with time. Partial oxidation CH_4:air 1:2.6, at 750°C, AB10 catalyst 5 g with GHSV 1.5x10^5 ml/h g_{cat}.

Degradation in hydrogen yield was around 10% after 1000 h partial oxidation (Fig 44). The gas was significantly diluted by N_2 and Ar, with around 1.6 l/min of N_2 at the reactor exhaust. For tubular cells dilution by N_2 even improved cell performance by improving temperature distribution along the cell. The yield of CO and CO_2 was relatively stable during 1000 h testing. The CH_4 concentration slowly increased. However, even after 1000 h, the CH_4 concentration was below 1%.

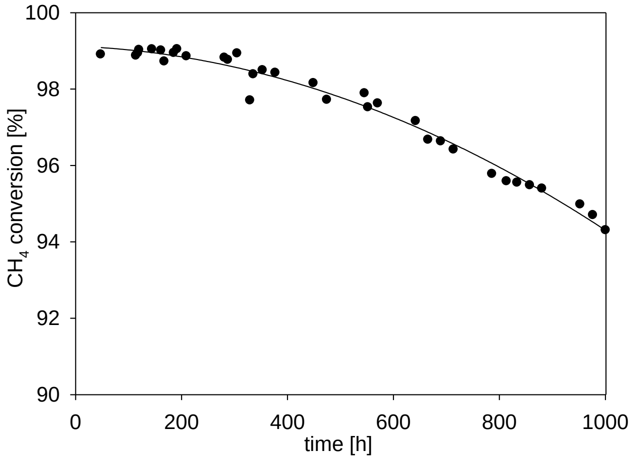


Figure 45 Change in methane conversion with time. Partial oxidation CH_4:air 1:2.6, at 750°C, AB10 catalyst 5 g with GHSV 1.5x10^5 ml/h g_{cat}.

CH_4 conversion decreased by around 5% from almost 99 to 94% after 1000 hours operation (Fig 45). With this rate of degradation in catalyst activity, the reactor should operate with relatively high efficiency for minimum 5,000 h.

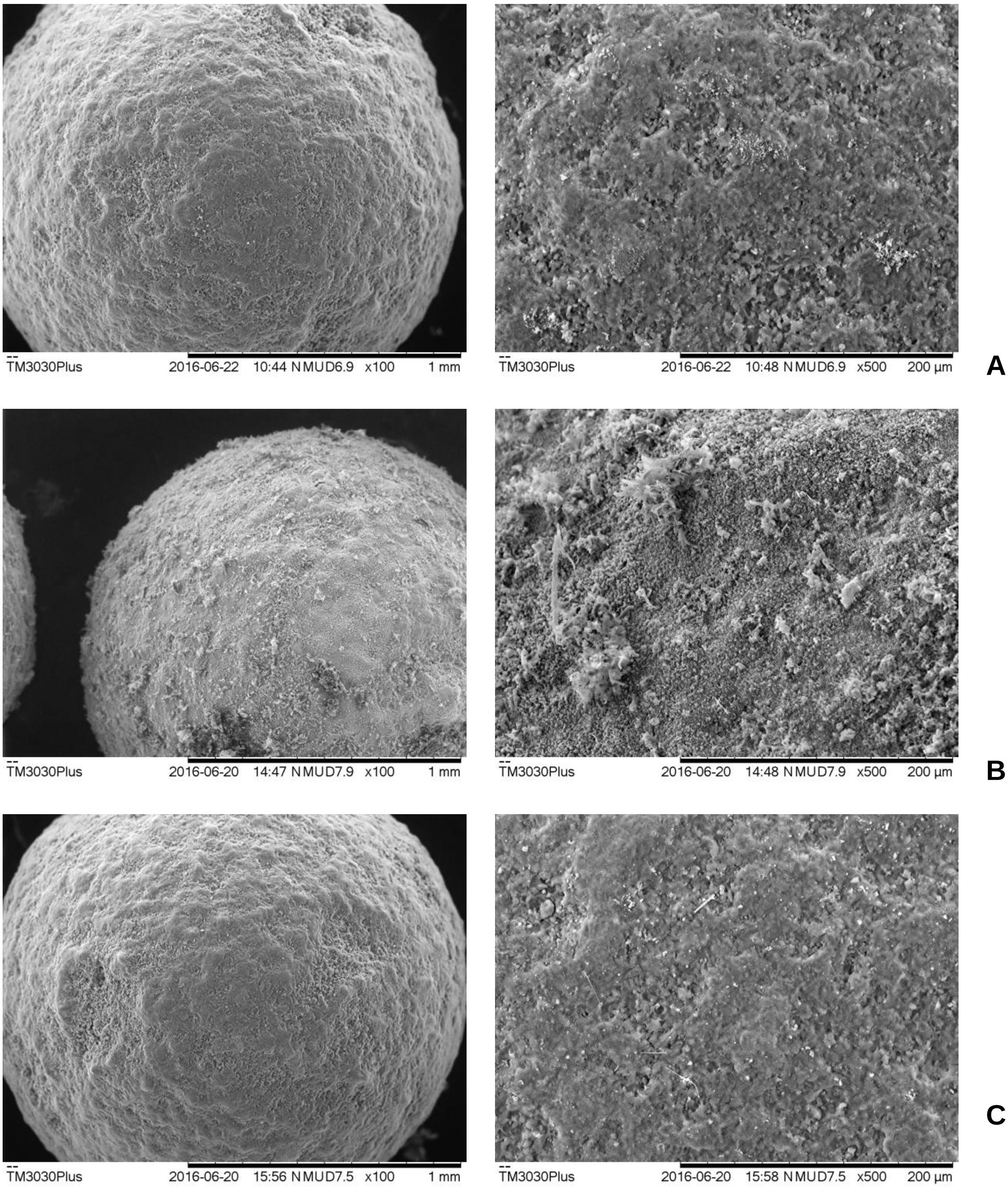
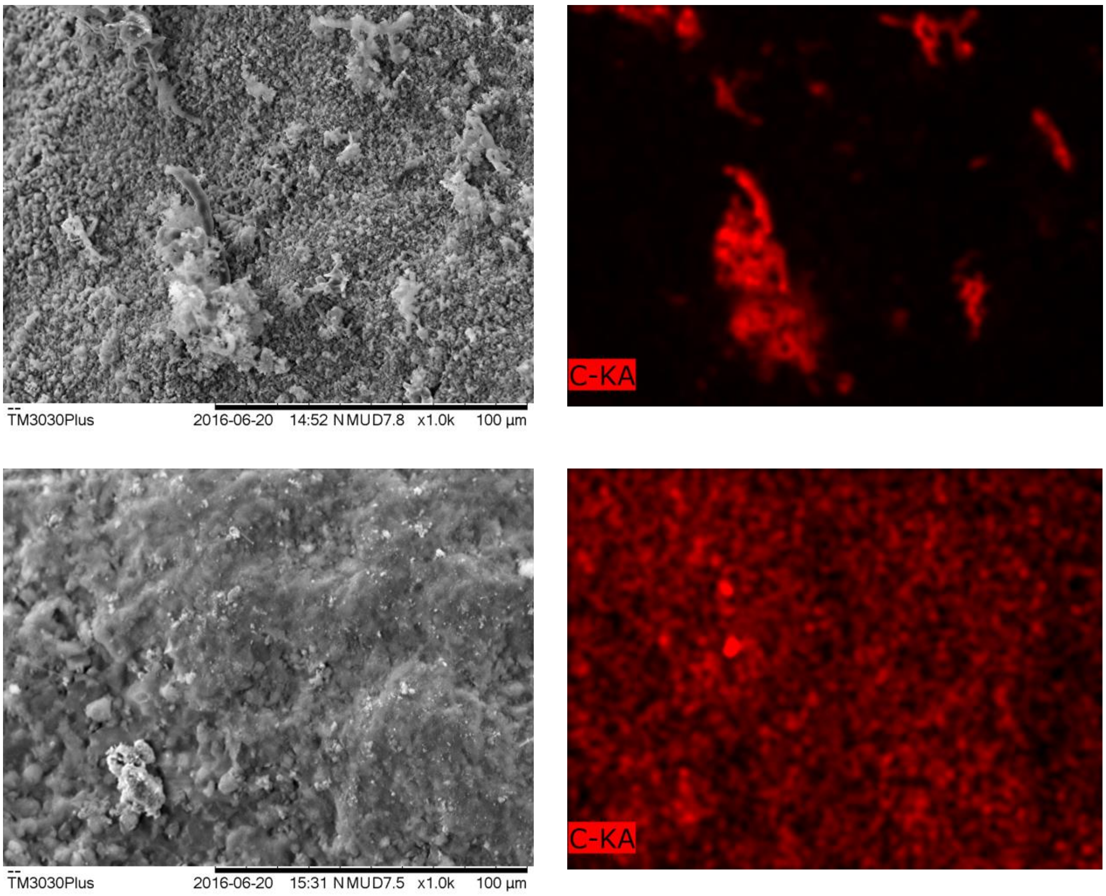


Figure 46 SEM scans of AB10 catalyst. A - fresh catalyst, B-D catalyst after 1000 h at 750°C with GHSV 1.5x10⁵ ml/h g_cat CH4:air 1:2.6, B - reactor inlet, C - reactor exhaust.

The surface of catalyst particles (Fig 46) become smoother probably caused by sintering, with the exception of reactor inlet where particles were covered by coke flakes. On the surface of some catalyst particles after the reaction were visible particles of Fe from the oxidation of stainless steel reactor.

The coke deposition was much lower than expected. The structure of deposited coke at the reactor inlet differed from the rest of reactor. At the inlet, coke had a structure of flakes (Fig 47B and Fig 47A). Coke agglomerated in big particles. The catalyst in the middle of the reactor and at the exhaust was coated with very small coke particles relatively equally distributed on the catalyst surface.



A

B

Figure 47 SEM scans of AB10 catalyst showing carbon in red. A – reactor inlet, B – middle of the reactor. Catalyst after 1000 h at 750°C with GHSV 1.5x10^5 ml/h g_{cat} CH_4:air 1:2.6.

For samples of the catalyst from the reactor inlet, the only change of mass was at 680^oC caused by coke oxidation. However, samples from the middle had a significant change of mass at 100-150^oC caused by moisture removal and a slow steady linear reduction of mass between 300 and 1000^oC. Samples of catalyst from reactor outlet gave moisture removal at 100-150^oC and had a slow linear change of mass between 300 and 600^oC, after which the mass was stable. This phenomenon was difficult to explain.

Table 4 Coke deposition on AB10 catalyst - TGA. Catalyst after 1000 h at 750^oC with GHSV 1.5x10^5 ml/h g_{cat} CH_4:air 1:2.6.

Position in reactor	Coke mg/g_{cat}
Inlet	14.8
Middle	12.8
Outlet	6.0

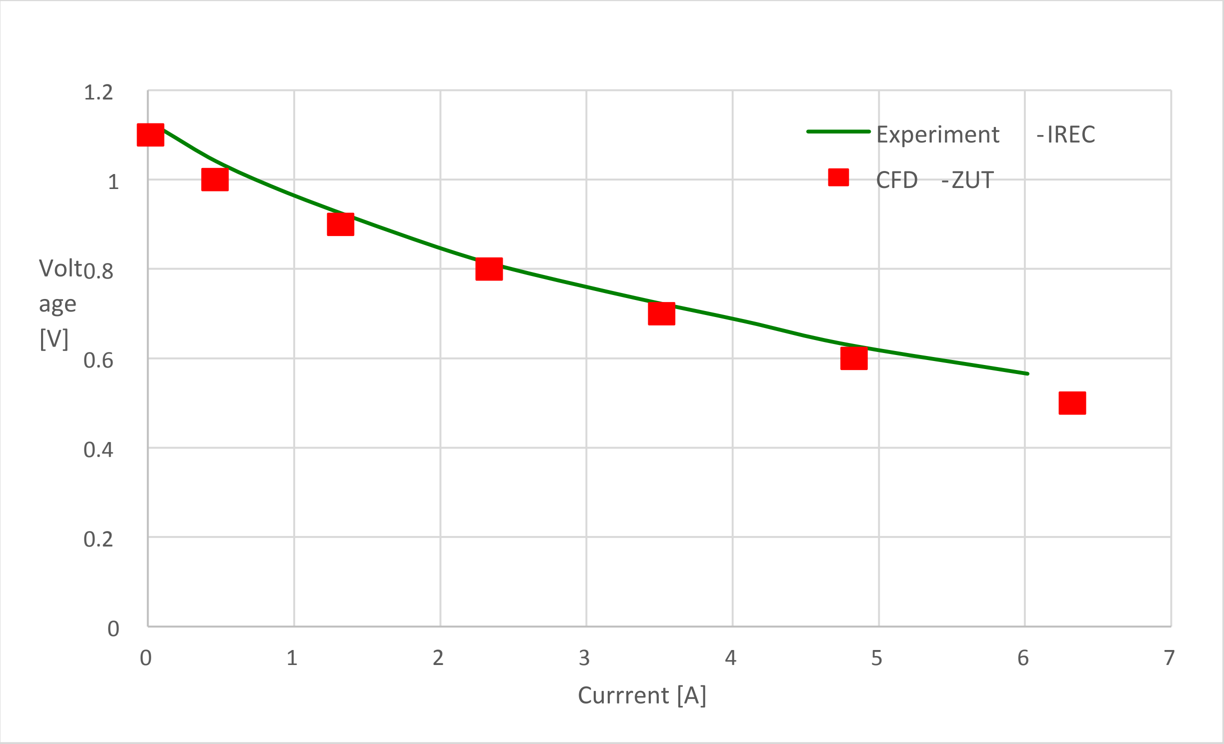
Coke deposition decreased along the catalyst from inlet to outlet (Table 4). The colour of catalyst changed after the reaction. Fresh catalyst was brown. After 1000 h of partial oxidation at 750^oC, all particles of the catalyst at the reactor inlet (up to 2 cm from inlet) oxidation, there was always hot-spot formation at the reactor inlet, helping to warm-up the anode gas.

Theoretical modelling

Computer modeling was carried out by ZUT and the results helped with optimisation of hardware designs and operating conditions for both tubular and planar SOFCs

Single m-tubular SOFC modelling

The modelling approach at the cell level was based on the Membrane Electrode Assembly (MEA) approach with pure hydrogen as a fuel. The CFD code enabled prediction of the electric current and temperature as well as mole-fraction of species distributions in the single SOFC. Figure 48 shows the V-I curve obtained from the CFD model and compared with the experimental data obtained by IREC under the same operating conditions. The fuel cell was tested at 680^oC for the cell operating voltage in the range of 0.5 – 1.15 [V] and 60% of fuel utilization. It can be seen in Figure 48 that general agreement between the predicted CFD V-I curve for m-tubular SOFC with the experimental data [IREC – 6th month progress meeting presentation from Szczecin] is good. Fig 49 showing the power versus current density also gave fair agreement with experiment.



mSOFC, FU=60%, hydrogen

Figure 48 Voltage [V] vs. current density [A] curve for the single mSOFC at temperature of 680^{o}C and for pure hydrogen

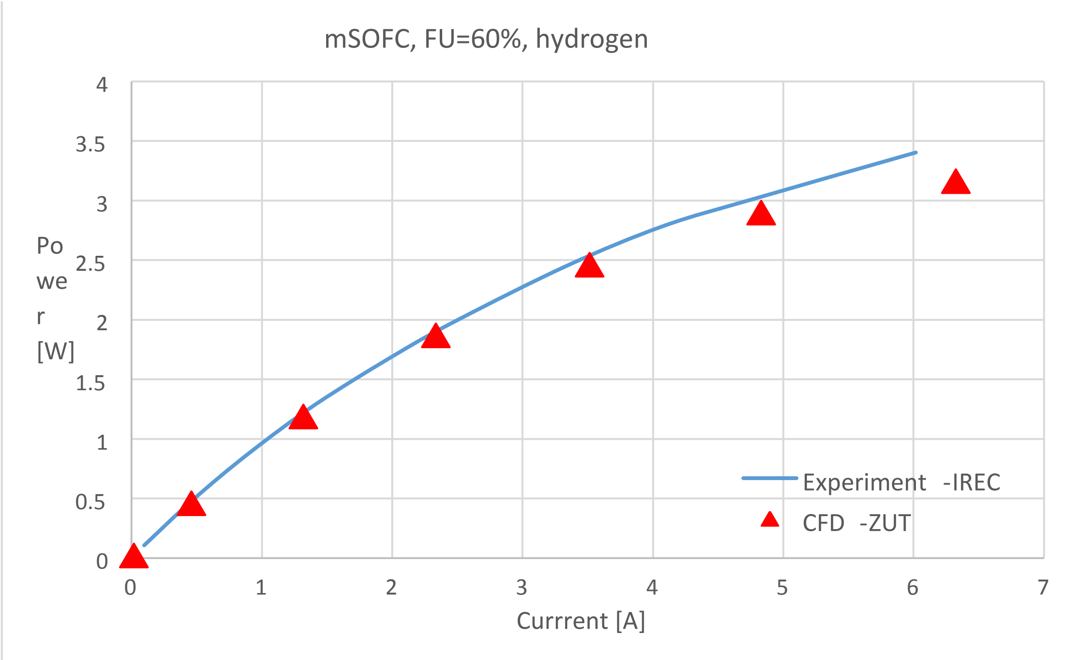


Figure 49 Power [W] vs. current density [A] curve for the single mSOFC at temperature of 680ºC and for pure hydrogen

Fig 50 shows that the predicted CFD values of temperature along the substack were in good agreement with the experimental values measured by ADELAN in a 4tube substack test operated on hydrogen. The 200C temperature gradient will be reduced by the CPOX exotherm with CH_4 fuel.

SAFARI

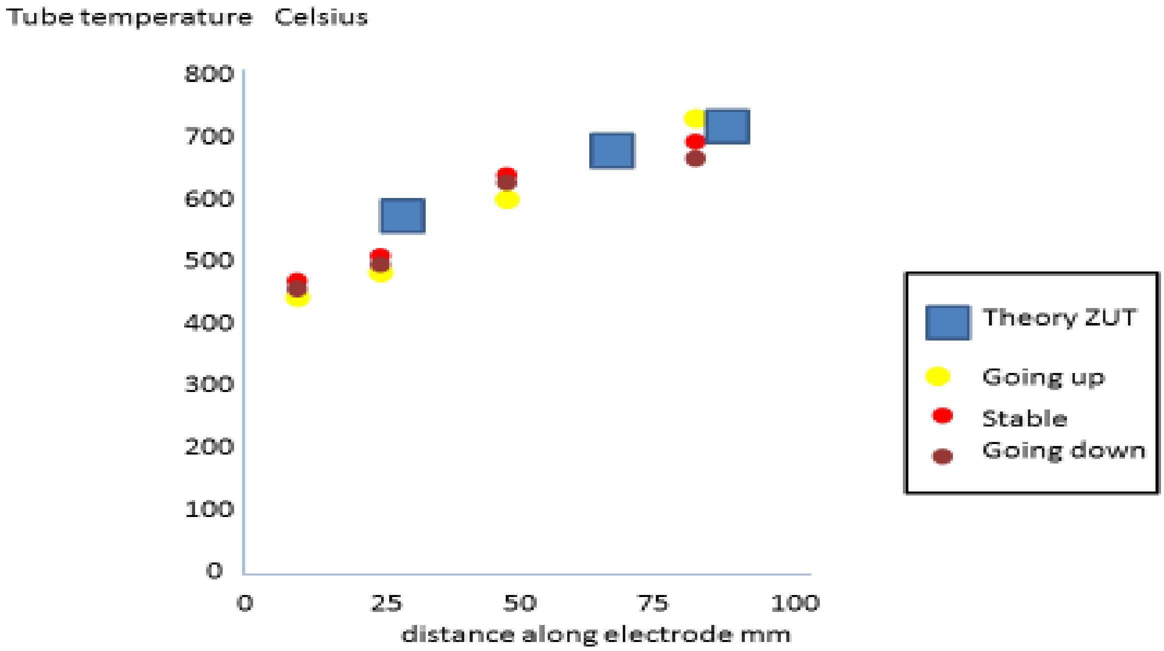


Figure 50 Comparison of the experimental [ADE] and CFD results for the temperature inside the m-tubular SOFC sub-stack

Planar SOFC models

In order to estimate appropriate values of the mass flow rates of the hydrogen and oxygen for the new planar SOFC design, a new case was analysed. The only difference was the value of mass flow rate of the hydrogen which was increased twofold, while the mass flow rate of the oxygen one and a half of that in the base case. The CFD results are shown in Fig 51. When the mass flow rate of the oxygen was increased 1.5 fold in comparison to the base case and assuming that the mass flow rate of the hydrogen was increased 2-fold it was noticed that the current density decreased and a lower degree of utilization of hydrogen from 67 to 55% was achieved. The oxygen consumption was at a similar level and exceeded 98%.

The experimental results were shown by the coloured lines, while the theoretical predictions were given by the symbols. The results at 760°C came higher than the model predictions but reasonably fitted the N8 predictions for 700°C. The conclusion was that the planar model requires more work, but that it gives fair predictions of current/voltage curves depending on fuel and air flows at various temperatures.

SAFARI

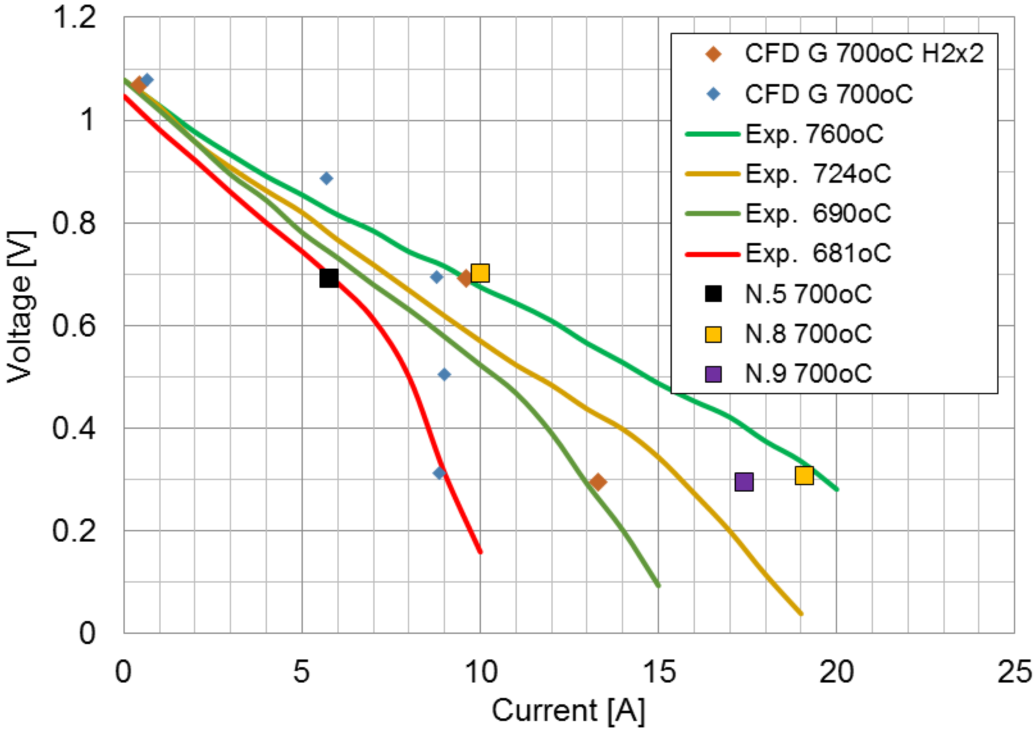


Figure 51. Voltage [V] vs. current [A] curves for the single planar SOFC new design for the case - 2 x hydrogen – 1.5 x oxygen, at the cell voltage of 0.3 V

Models of temperature and flow distributions

One of the best results from the tubular modelling was the result for temperature distribution along the SOFCs including the air preheater, that is the new patented recuperator design which used the hot exhaust to warm the incoming cathode air.

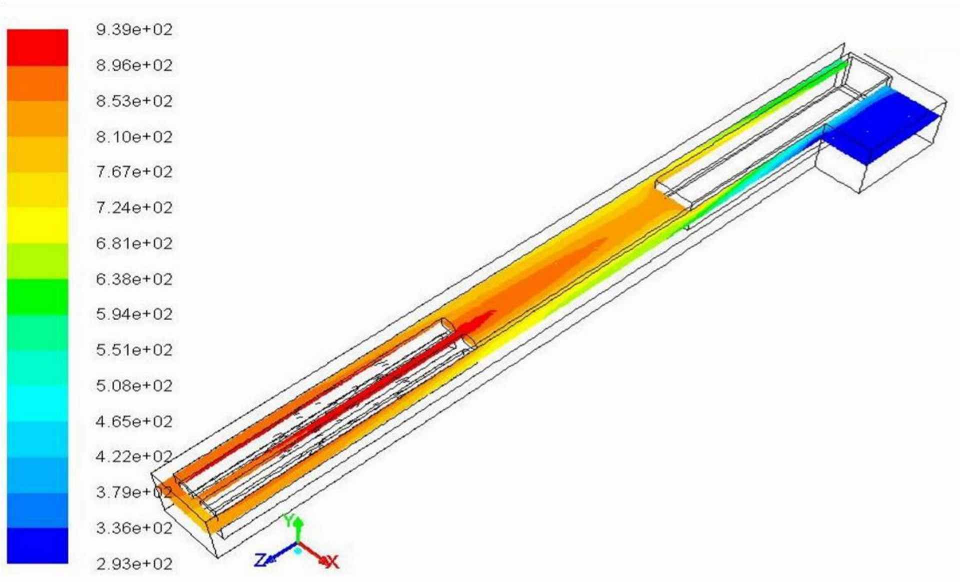


Figure 52 Temperature distribution in the tubular SOFC 4-tube substack

Fig 52 shows the computed results for a 4 tube substack with the cold air entering in the blue right hand top corner. This air at 393K room temperature moved left along the stainless steel recuperator and quickly got warmer as it reached the entry to the cathode on the left about 850K. The gas was then heated by the SOFC reaction as it moved along the cathode surfaces towards the exit on the top right. The maximum temperature was 930K as the reaction was finished and the gas then cooled as it passed along the recuperator to the exhaust at 594K.

When these models were compared in detail with experiment, the graph of Fig 50 was obtained which showed reasonable agreement with the experimental results on pure hydrogen.

For the planar system, detailed modelling of the stack (Fig 53) was carried out and temperature distributions were calculated. The ANSYS Workbench was used to build a 3D geometry, while the ANSYS Meshing was employed to create a numerical grid with 762 thousands of computational cells for the 16 plate stack. In the first stage of investigations, uniform distribution of heat flux was assumed along the active surface of the cells. Thus, for the surfaces between the fuel channels and anodes the heat flux value was equal to 61 W/m^2, while for the surfaces between the air channels and cathodes it was 82 W/m^2 at the fuel cell voltage of 0.7 V. Those heat flux values were calculated during the CFD modelling at the cell modelling level.

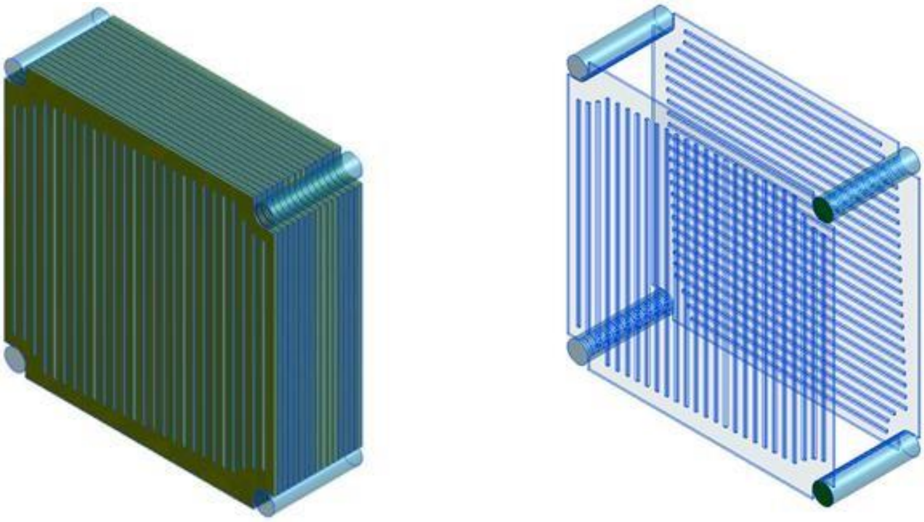
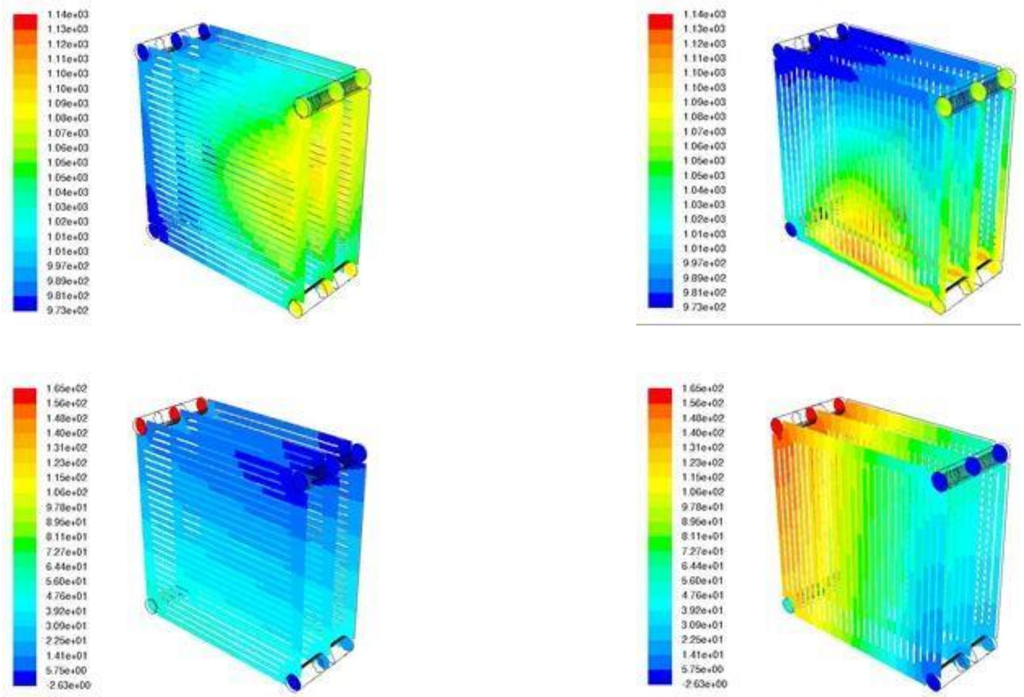


Figure 53 Geometry of the planar stack with 16 plates

Figure 54 shows the temperature and pressure distributions at various places in the planar stack, showing clearly the cross-flow effects in both the fuel and air channels.



(a)

(b)

Figure 54 Temperature (a) and pressure (b) distributions at half thickness of the first, eight and sixteen fuel channel (left) and air channel (right) for the 16 plate sub-stack

SAFARI

System models

To obtain the system model (Fig 55), the commercially available Aspen Plus process simulator was chosen for BoP modelling of the SOFC sub-system. The effect of O_2/CH_4 ratio at the inlet to the CPOX reactor was investigated. According to thermodynamic literature data for methane–air composition, in previous calculations O_2/C = 0.6 was assumed to avoid carbon formation. It was a fair value, but the air stream value affects CPOX temperature, and finally stack temperature. The O_2/C ratio equal to 0.4; 0.50 and 0.55 was used and results of such BoP simulations are presented in Table 5 and in Figure 55. The methane flow stream was the same in all cases. Decreasing O_2/C ratio resulted in the temperature decrease of each stream, but at the same time the electric power decrease was also observed. However, the lower value of CPOX temperature with the O_2/C = 0.4 and 0.5 causes soot formation and finally fuel cell destruction.

Table 5. Results of BoP simulations; **Fuel - methane**; 100W system, constant inlet fuel stream

Fuel = CH_4	T [°C]						
O_2/CH_4 ratio	Wel [W]	reformate	after ANODE	after recuperator	after CATHODE	after burner gas	exhaust gas
0.60	100.10	694.78	785.31	650	696.28	845.93	290.62
0.55	92.65	672.22	760.06	650	692.32	829.40	269.84
0.50	84.00	655.21	738.81	650	688.39	812.05	248.07
0.40	65.56	626.08	698.51	650	679.98	775.42	202.09

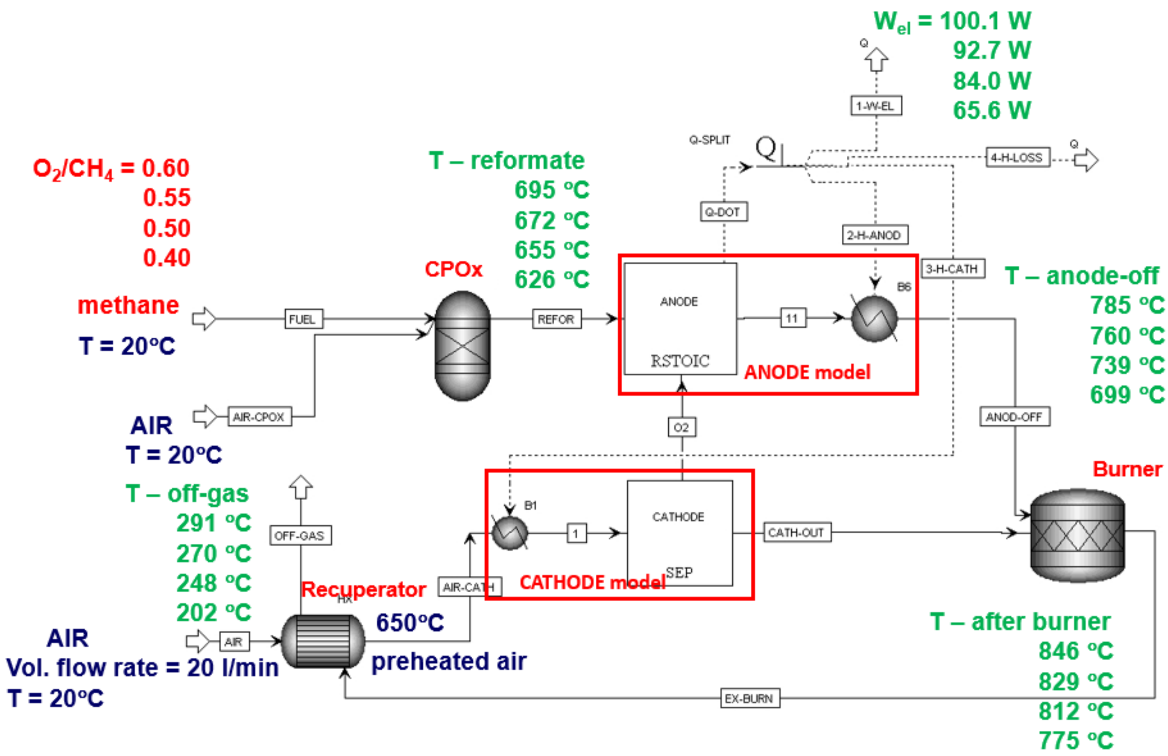


Figure 55. The effect of O_2/CH_4 ratio at the inlet to the CPO_x reactor; the same inlet fuel stream

The convergence criterion of the iterations was to obtain electric power of 100 W of the SOFC stack. The air flow rate at the inlet to the CPO_x reactor was also adjusted to result in O_2/C = 0.6 to avoid carbon formation. It led to a lower temperature value at the anode outlet equal to 913 °C and a higher temperature of afterburner gases equal to 1140 °C.

Truck Experiments

The only test of the SOFC in an LNG truck was carried out in February 2015 on the day that HAR went bankrupt (Fig 56). Shortly after this interesting test, the project was suspended by the PO. Although ADE managed at their own expense to find another partner in VAY, and the project restarted on 1 Nov 2015 with excellent support from the other 4 partners, the report of the 23 Feb review meeting from the PO was so negative that VAY dropped out, even though they had a truck ready to accept the two demonstration SOFCs. Therefore the picture below is the only record that this project was on the right track with no show-stopping barriers to commercialisation.

SAFARI

Figure 56 Fuel cell in protective box, positioned at the back of the truck cab

However, a key result of the work in Period 3 was the development and improved design of the ADE microtubular SOFC unit, lower in weight and volume than that shown earlier in Fig 11. The final design is shown in Fig 57 from front and back. This is much more convenient to install on the truck than that shown earlier.

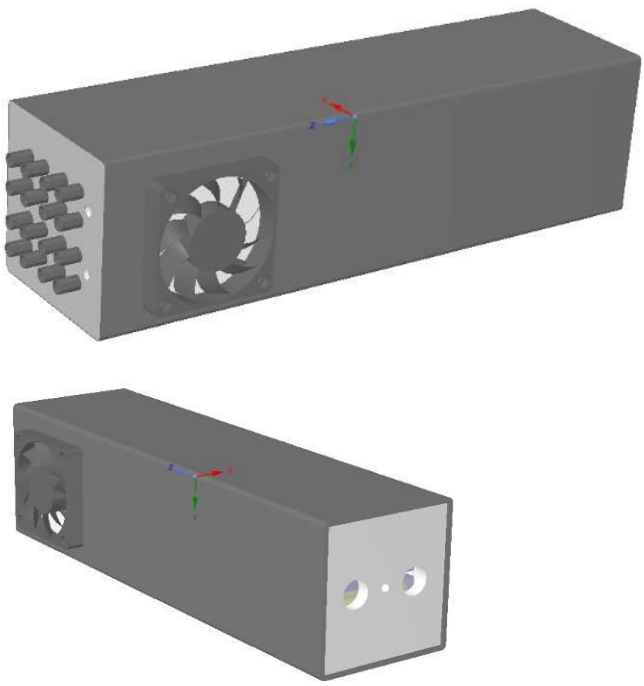


Figure 57 Improved design of ADE microtubular unit

The platform tests which were planned in the EU had to be cancelled when the project was stopped by the PO.

Main dissemination activities and exploitation of results

From the start of the project, it was made clear to the Consortium members that each and every partner was responsible for dissemination of the results and outcomes. No industry exhibitions were attended because HAR became insolvent and VAY resigned. At the 12 month project meeting hosted by ZUT in 2014, the dissemination was emphasised and the team shown in Fig 58 responded well by listing papers in preparation for publication.

Figure 58 Meeting of SAFARI partners in Poland during 2014 before HAR went bankrupt

Project meetings

Regular project meetings were convened by the coordinator ADE as shown

Period 1

- Project Kick-off Meeting, Birmingham UK, 21 January 2014
- 12 Month Progress Meeting, ZUT 18 September 2014

Period 2

- Partner meeting 18^{th} March 2015 UOB

- Review meeting April 29th Brussels
- 10th Dec Re-start meeting UOB

Period 3

- Partner meeting 26th Jan 2016 VAY, Leyland UK
- Pre-meeting of partners for review 22nd Feb 2016 VAY
- Review meeting Feb 23rd VAY
- Project meeting with partners on 12 April 2016 at UOB to produce response to suspension letter from FCH-JU

Conferences

Academic conference presentations were delivered by Adelan, ALM, IREC, UOB and ZUT. Posters were also widely disseminated at these conferences, as shown below:

- M Torrell, 'Long-Term Degradation Performance of militubular SOFC cells' EMRS Boston 2015
- K Kendall, JE Newton, M Kendall, Microtubular SOFC system in truck applications, Abstract to SOFCxiv, Glasgow 2014
- U Bossel Small Scale Power Generation for Road Trucks with Planar SOFC System Abstract to SOFCxiv, Glasgow 2014
- Project with Gaz de France (ADE). Project management Dissemination to GDF because they are a very large company interested in using natural gas in trucks and other applications. Such dissemination should help commercialization in Y3 and following.
- P. Pianko-Oprych, T. Zinko, Z. Jaworski, Three-Dimensional Computational Fluid Dynamics Modelling for a Planar Solid Oxide Fuel Cell of a New Design, Electrochemical Energy & Conversion Storage with SOFC-XIV, submitted abstract, poster, 26-31/07/2015, Glasgow, UK.
- M Kendall, paper at the 11th international Hydrogen and Fuel Cell conference on 17th March 2015, Birmingham UK
- P. Pianko-Oprych, T. Zinko, Z. Jaworski, CFD analysis of a new planar Solid Oxide Fuel Cell in SAFARI project, poster at the 11th international Hydrogen and Fuel Cell conference on 17th March 2015, Birmingham, UK.
- T. Zinko, P. Pianko-Oprych, Z. Jaworski, Modelling of thermal stress in a planar Solid Oxide Fuel Cell in varying operating conditions, European Technical School on Hydrogen and Fuel Cells 2015, poster, 22-26/06/2015, Crete, Greece.

SAFARI

- T. Zinko, P. Pianko-Oprych, Z. Jaworski, Three-dimensional modelling of thermal stresses in a planar Solid Oxide Fuel Cell of a novel design, IIPhDW Interdyscyplinary International PhD Workshop I^{2}PHDW 2015, 14-17/05/2015, Międzyzdroje, Poland.
- K Kendall, K Afzal, M Kendall, Microtubular SOFCs for mobile applications, SOFC xv, Florida, ECS 2017
- M Kendall, paper at the 12th international Hydrogen and Fuel Cell conference, March 2016, Birmingham UK
- M Kendall, paper at the 13th international Hydrogen and Fuel Cell conference on 14th March 2017
- T. Zinko, P. Pianko-Oprych, Z. Jaworski, 12th European Solid Oxide Fuel Cells and Electrolysers Forum, Luzern, Switzerland, Numerical investigation of fuel starvation effect at high current in novel planar SOFC design, poster.
- P. Pianko-Oprych, T. Zinko, Z. Jaworski, 22nd Polish Conference of Chemical and Process Engineering, Spała, Poland, Computational Fluid Dynamics calculation of a novel planar Solid Oxide Fuel Cell design running on reformed gas, poster.
- A.J. Majewski, U. Bossel, R. Steinberger-Wilckens: “Catalytic Reforming System Suitable for Transportation Applications” - “5th International Conference on Hydrogen and Fuel Cells”, 11-13 December 2016, Hyderabad, India
- P. Pianko-Oprych, T. Zinko, Z. Jaworski, Three-dimensional CFD modelling of transport phenomena in microtubular and planar anode supported Solid Oxide Fuel Cells, submitted abstract, 8th Congress of Chemical Technology: “Raw materials – energy – materials”, 30/08 – 4/05/2015, Rzeszów, Poland.
- A Majewski, A Dhir, Microtubular SOFC for Auxiliary Road-truck Installations, “Progress in Fuel Cell Systems, 8th Workshop”, 2nd-3rd June 2015, Bruges, Belgium
- A Majewski, A Dhir, Palladium/Barium based catalyst for partial oxidation of methane to syngas, “Fuel Cell and Hydrogen Technical Conference”, 19th-21st May 2015, Birmingham, UK

The largest SOFC conference in the world in 2015 was held in Glasgow hosted at the SECC by the American Electrochemical Society. All the SAFARI partners attended and discussed the truck SOFC project. 200 handouts were distributed. ADE will give a presentation at the next ECS meeting in Florida in July 2017. The only partners not giving presentations at exhibitions or conferences were HAR and VAY

Printed Papers

Several papers were published by the partners from the SAFARI project:

- K Kendall, Portable SOFCs, Chapter in book, High Temperature SOFCs, ed K&M Kendall, Elsevier, 2015
- Z. Jaworski, P. Pianko-Oprych, K. Kendall, SOFC modelling, chapter in book, High Temperature SOFCs, ed. K&M Kendall, Elsevier, 2015.
- A.J. Majewski, A. Dhir, “Direct Utilization of Methane in Microtubular-SOFC”, Journal of The Electrochemical Society, pp F272-F277 , volume 163 No 3, 2016
- A.J. Majewski, A. Dhir, “Direct Utilization of Methane in Microtubular-SOFC”, ECS Transactions, pp 2189-2198, volume 68 (1), 2015
- A. Hornés, M. Torrell, A. Morata, M. Kendall, K. Kendall, A. Tarancón, Towards a high fuel utilization and low degradation of micro-tubular Solid Oxide Fuel Cells, Int J Hydrogen Energy, 2017
- M.Torrell ;A. Hornés ;J. Newton ;A. Morata ;K. Kendall ;A. Tarancón, Electrochemical and microstructural characterization of Micro-Tubular SOFC: The effect of the operation mode". 12th European SOFC & SOE Forum 2017, submitted.
- Aneta Slodczyk, Marc Torrell, Aitor Hornés, Alex Morata, Kevin Kendall, Albert Tarancón, Understanding the (longitudinal) degradation mechanism of the microtubular solid oxide fuel cell - Raman and SEM/EDX study, to be submitted.
- K Kendall, JE Newton, M Kendall, Microtubular SOFC system in truck applications, Electrochemical Society Proceedings, SOFCxiv Glasgow, 2015.
- K Kendall, K Afzal, M Kendall, Microtubular SOFC system in mobile applications, Electrochemical Society Proceedings, SOFCxv Florida, 2017.
- A.J. Majewski, A. Dhir: “Silver as current collector for SOFC” – submitted to Journal of The Electrochemical Society (Jan 2017)
- A.J. Majewski, U. Bossel, R. Steinberger-Wilckens: ‘Catalytic Reforming System Suitable for Transportation Applications’ – submitted to Fuel Processing Technology (Jan 2017)

The website www.safari-project.eu for the project was set up during the first six months and has been successful in both the public and private pages, in which the partners could record their reports.

ADE visited AVL in Austria to discuss the DESTA results (DESTA was the FP7 SOFC APU project on trucks funded through FCH-JU) and to talk about possible future collaborations, in particular to ask whether they could join the project after HAR went bankrupt. They declined our offer.

A SAFARI poster has been shown at the FCH-JU General Assembly in Brussels in November 2014.

As predicted in the original SAFARI bid, three special conferences were convened by ADE in Birmingham where APUs for trucks were discussed. ADE, ALM, IRE, UOB and ZUT were present at these meetings as suggested in the DOW.

Special Conferences for SAFARI

During the SAFARI project, the coordinator Dr K Kendall has been involved in organising three Hydrogen Fuel Cell Conferences in Birmingham, with posters, presentations and official project meetings held during the proceedings.

The first in 2014 was bringing out new fuel cell concepts. Dr Kendall organised and chaired a session on Transport Applications and delivered a paper on ‘Fuel Cells in Transport’. The Conference was held at Millenium Point in the city centre, where Dr M Kendall gave a talk which was attended by 250 people from all sectors of the fuel cell community in the EU, while the SOFC APU was exhibited at the conference centre entrance.

THE COMMERCIALISATION OF HYDROGEN AND FUEL CELL TECHNOLOGY
12th International Hydrogen and Fuel Cell Conference 15 March 2016

Figure 59 Brochure for the 2016 Hydrogen Fuel Cell Conference at Birmingham NEC

Fig 59 Shows the Brochure for the 2016 Birmingham conference organised by the authors.

Links with Companies and Patenting

When Dr Kendall heard the DESTA presentation from the coordinator AVL List, it was a great opportunity to foster links with related project teams. Although AVL was working on truck APUs with Volvo and other companies, with diesel as the fuel fed to the SOFC reformer, and also used a different stack technology based on planar SOFCs, there was distinct common interest in the problems of cost, fuel procressing, warm-up time etc. The outcome of this meeting was the ADE visit to Graz Austria on 17 June 2015 to meet the DESTA group and to present data on the respective projects. In particular, AVL had experienced the problem of Topsoe Fuel Cell dropping out of the stack building defined in DESTA. These issues were discussed in detail and should lead to future collaborations..

Patent

One patent was filed on SAFARI

PCT application No 1200196493 Solid oxide fuel cell unit K Kendall July 2016

Patenting has also been successful for Adelan. The PCT application was filed in 2015 and then finalised in July 2016. This invention arose from experiments on preheating the incoming cathode air by using the hot exhaust gas. When a standard heat exchanger was built and tested, it was found to be much too heavy and expensive. Therefore a novel stainless steel component was designed and proved. This was ten times less costly, also much lighter, and was stackable. This IP is now being marketed worldwide by ADE.

No other patents have been filed by the consortium partners during the project.

4.2 Use and dissemination of foreground

Section A (public) Dissemination measures, science publications

SAFARI started in 2014 with clear technical objectives for short and medium term results relating to the contributing industry SMEs. However, the effect on truck companies, having seen the product potential and the benefits to LNG vehicles will be noticed within the next two years. Therefore, raising public participation and awareness on the specific techniques of this project is important. It is of pivotal priority to begin raising awareness on the positive aspects and advantages of fuel cells now so that when fuel cells with this new technology are commercialized, the public will already be educated on the topic and therefore be more eager to purchase this innovative product. IREC was to lead the lifetime studies but these were cancelled when FCH-JU terminated the project.

Adelan with the assistance of the University of Birmingham has been the main conduit of dissemination to the public through their web sites (www.adelan.co.uk; www.SAFARI-project.eu) and with their Birmingham Hydrogen Fuel Cell conferences and expositions held annually.

Section B Public
Part B1

TEMPLATE B1: LIST OF APPLICATIONS FOR PATENTS, TRADEMARKS, REGISTERED DESIGNS					
Type of IP Rights[3]:	Confidential Click on YES/NO	Foreseen embargo date dd/mm/yyyy	Application reference(s) (e.g. EP123456)	Subject or title of application	Applicant (s) (as
PATENT	no	none	UK PCT 1200196493,	Solid Oxide Fuel Cell Unit	Adelan Ltd

[3] A drop down list allows choosing the type of IP rights: Patents, Trademarks, Registered designs, Utility models, Others.

Part B2

Please complete the table hereafter:

Type of Exploitable Foreground[4]	Description of exploitable foreground	Confidential NO	Foreseen embargo date dd/mm/yyyy	Exploitable product(s) or measure(s)	Sector(s) of application[5]	Timetable, commercial or any other use	P o e (I
Patent	*Recuperator design*	*No*	*none*	*SOFC APUs*	*Energy*	*2015 onwards*	*P*

- Its purpose; The purpose of this patent is to protect a novel way of preheating the cathode air in microtubular solid oxide fuel cells.
- How the foreground might be exploited, when and by whom; Adelan will exploit this patent from 2015 onwards
- IPR exploitable measures taken or intended; companies contacted for joint ventures
- Further research necessary; More research is needed on durability aspects
- Potential/expected impact; Market is for 100Meuro/a by 2030

4.3 Report on societal implications

The societal implications of portable fuel cell use, particularly in commercial vehicles like trucks are very significant in the view of this consortium. At present, most trucks in the EU are powered by diesel and cause severe pollution, especially when idling and when the driver is resting or asleep. At these times, the driver and nearby public wish to be free of air pollution and engine noise. This can be achieved by moving to clean power sources such as LNG SOFCs without noise and toxic engine emissions. This gives several societal strands as follows.

The first strand impacting this project is commercialisation in the LNG (Liquid Natural Gas) truck market which is increasing and is a coherent high value niche. LNG is a much cleaner fuel than diesel, is more available long-term, and may eventually be sourced from biomass to become fully renewable. Recent market reports show that global LNG in trucks will be about 45Mte in 2025 and 96Mte in 2035, starting from zero in 2010. China is leading, with almost half the total of LNG trucks, about 100,000 LNG trucks in 2013, fed by 1100 LNG fuelling stations. The demand in the EU depends on the high relative cost of diesel compared to natural gas, and this has fallen off in recent years. But predictions are that the overall use of LNG will increase by a factor 9 by 2025, not only in trucks but also in locomotives and ships.

[19] A drop down list allows choosing the type of foreground: General advancement of knowledge, Commercial exploitation of R&D results, Exploitation of R&D results via standards, exploitation of results through EU policies, exploitation of results through (social) innovation.

[5] A drop down list allows choosing the type sector (NACE nomenclature) : http://ec.europa.eu/competition/mergers/cases/index/nace_all.html

Compared to CNG, which is commonly moved through pipeline networks and requires additives for transport safety, LNG is much purer and this pays off in SOFC use, where the sulfur trap is smaller and lasts longer. The proving ground for LNG trucks is China, where LNG trucks have increased to more than 330,000 medium- and heavy-duty trucks on the road. That number is expected to triple in the next five years. That compares to about 23,000 in the U.S. and only 2,000 in Europe. So a key societal influence depends on EU learning how China has succeeded in this cleaner technology.

Dissemination impact is the second strand. Vayon had access to hundreds of customer industries such as supermarket delivery companies. When they resigned because of the negative FCH-JU report, we lost the link to the consumer. Their view was that a fuel cell at the right price and performance will be a successful commercial product in the current market. Their task was to start the market stimulation in the UK by carrying out specific trials and relaying the positive message to their industry customers. members. This has now stopped.

In the third strand, environmental impact will certainly occur as these generators take hold, especially as the niche truck market can be widened to locomotives and ships. Typical savings of emissions include COx, NOx, SOx, VOCs and particulates, more than 1te/a in total per portable fuel cell unit. Reducing noise is the second major benefit. Such savings apply further to locomotives, the second priority of SAFARI after trucks. The first need is to identify and satisfy the needs of specialist vehicles. The underlying fuel cell product technology is expected to be virtually identical. This very large market cannot now be addressed.

A General Information *(completed automatically when **Grant Agreement number** is entered.*

Grant Agreement Number:	325323
Title of Project:	SAFARI
Name and Title of Coordinator:	Dr Kevin Kendall

B Ethics

1. Did your project undergo an Ethics Review (and/or Screening)? • If Yes: have you described the progress of compliance with the relevant Ethics Review/Screening Requirements in the frame of the periodic/final project reports? Special Reminder: the progress of compliance with the Ethics Review/Screening Requirements should be described in the Period/Final Project Reports under the Section 3.2.2 *'Work Progress and Achievements'*	***No***
2. Please indicate whether your project involved any of the following issues (tick	***No***

box) :	
RESEARCH ON HUMANS	
• Did the project involve children?	
• Did the project involve patients?	
• Did the project involve persons not able to give consent?	
• Did the project involve adult healthy volunteers?	
• Did the project involve Human genetic material?	
• Did the project involve Human biological samples?	
• Did the project involve Human data collection?	
RESEARCH ON HUMAN EMBRYO/FOETUS	
• Did the project involve Human Embryos?	
• Did the project involve Human Foetal Tissue / Cells?	
• Did the project involve Human Embryonic Stem Cells (hESCs)?	
• Did the project on human Embryonic Stem Cells involve cells in culture?	
• Did the project on human Embryonic Stem Cells involve the derivation of cells from Embryos?	
PRIVACY	
• Did the project involve processing of genetic information or personal data (eg. health, sexual lifestyle, ethnicity, political opinion, religious or philosophical conviction)?	
• Did the project involve tracking the location or observation of people?	
RESEARCH ON ANIMALS	
• Did the project involve research on animals?	
• Were those animals transgenic small laboratory animals?	
• Were those animals transgenic farm animals?	
• Were those animals cloned farm animals?	
• Were those animals non-human primates?	
RESEARCH INVOLVING DEVELOPING COUNTRIES	
• Did the project involve the use of local resources (genetic, animal, plant etc)?	
• Was the project of benefit to local community (capacity building, access to healthcare, education etc)?	
DUAL USE	
• Research having direct military use	0 Yes 0 No
• Research having the potential for terrorist abuse	

C Workforce Statistics

3. Workforce statistics for the project: Please indicate in the table below the number of people who worked on the project (on a headcount basis).

Type of Position	Number of Women	Number of Men
Scientific Coordinator		1
Work package leaders	3	6
Experienced researchers (i.e. PhD holders)	6	12
PhD Students		
Other		

4. How many additional researchers (in companies and universities) were recruited specifically for this project?	**10**
Of which, indicate the number of men:	6

SAFARI

D Gender Aspects

5. Did you carry out specific Gender Equality Actions under the project? — Yes

6. Which of the following actions did you carry out and how effective were they?

	Not at all effective → Very effective
❑ Design and implement an equal opportunity policy	○ ○ ○ ○ ◉ (5)
❑ Set targets to achieve a gender balance in the workforce	○ ○ ◉ ○ ○ (3)
❑ Organise conferences and workshops on gender	○ ◉ ○ ○ ○ (2)
❑ Actions to improve work-life balance	○ ○ ○ ◉ ○ (4)
○ Other:	

7. Was there a gender dimension associated with the research content – i.e. wherever people were the focus of the research as, for example, consumers, users, patients or in trials, was the issue of gender considered and addressed?

- ○ Yes- please specify
- ◉ No

E Synergies with Science Education

8. Did your project involve working with students and/or school pupils (e.g. open days, participation in science festivals and events, prizes/competitions or joint projects)?

- ◉ Yes- please specify: Several conferences were organised and students invited
- ○ No

9. Did the project generate any science education material (e.g. kits, websites, explanatory booklets, DVDs)?

- ◉ Yes- please specify: Handouts given to students
- ○ No

F Interdisciplinarity

10. Which disciplines (see list below) are involved in your project?

- ◉ Main discipline[6]: 2.3 Energy
- ○ Associated discipline[6]:
- ○ Associated discipline[6]:

G Engaging with Civil society and policy makers

11a Did your project engage with societal actors beyond the research community? *(if 'No', go to Question 14)*

- ◉ Yes
- ○ No

11b If yes, did you engage with citizens (citizens' panels / juries) or organised civil society (NGOs, patients' groups etc.)?

[6] Insert number from list below (Frascati Manual).

- ○ No
- ○ Yes- in determining what research should be performed
- ○ Yes - in implementing the research
- ○ Yes, in communicating /disseminating / using the results of the project

11c In doing so, did your project involve actors whose role is mainly to organise the dialogue with citizens and organised civil society (e.g. professional mediator; communication company, science museums)?	○ ○	Yes No

12. Did you engage with government / public bodies or policy makers (including international organisations)

- ○ No
- ○ Yes- in framing the research agenda
- ○ Yes - in implementing the research agenda
- ○ Yes, in communicating /disseminating / using the results of the project

13a Will the project generate outputs (expertise or scientific advice) which could be used by policy makers?

- ○ Yes – as a **primary** objective (please indicate areas below- multiple answers possible)
- ○ Yes – as a **secondary** objective (please indicate areas below - multiple answer possible)
- ○ No

13b If Yes, in which fields?

Agriculture Audiovisual and Media Budget Competition Consumers Culture Customs Development Economic and Monetary Affairs Education, Training, Youth Employment and Social Affairs		Energy Enlargement Enterprise Environment External Relations External Trade Fisheries and Maritime Affairs Food Safety Foreign and Security Policy Fraud Humanitarian aid		Human rights Information Society Institutional affairs Internal Market Justice, freedom and security Public Health Regional Policy Research and Innovation Space Taxation Transport	

13c If Yes, at which level? ○ Local / regional levels ○ National level ○ European level ○ International level	

H Use and dissemination

14. How many Articles were published/accepted for publication in peer-reviewed journals?	**8**
To how many of these is open access[7] provided?	**none**
How many of these are published in open access journals?	
How many of these are published in open repositories?	
To how many of these is open access not provided?	
Please check all applicable reasons for not providing open access:	
❑ publisher's licensing agreement would not permit publishing in a repository ❑ no suitable repository available ❑ no suitable open access journal available ❑ no funds available to publish in an open access journal ❑ lack of time and resources ❑ lack of information on open access ❑ other[8]: ……………	
15. How many new patent applications ('priority filings') have been made? *("Technologically unique": multiple applications for the same invention in different jurisdictions should be counted as just one application of grant).*	**1**

16. Indicate how many of the following Intellectual Property Rights were applied for (give number in each box).	Trademark	**1**
	Registered design	**0**
	Other	**0**

17. How many spin-off companies were created / are planned as a direct result of the project?	**0**
Indicate the approximate number of additional jobs in these companies:	

18. Please indicate whether your project has a potential impact on employment, in comparison with the situation before your project:

❑	Increase in employment, or	❑	In small & medium-sized enterprises
❑	Safeguard employment, or		In large companies
❑	Decrease in employment,	❑	None of the above / not relevant to the project
❑	Difficult to estimate / not possible to quantify		

[7] Open Access is defined as free of charge access for anyone via Internet.
[8] For instance: classification for security project.

19. For your project partnership please estimate the employment effect resulting directly from your participation in Full Time Equivalent (*FTE = one person working fulltime for a year*) jobs:	*Indicate figure:* *10*
Difficult to estimate / not possible to quantify	❑

I Media and Communication to the general public

20. As part of the project, were any of the beneficiaries professionals in communication or media relations?

○ Yes ○ No

21. As part of the project, have any beneficiaries received professional media / communication training / advice to improve communication with the general public?

○ Yes ○ No

22 Which of the following have been used to communicate information about your project to the general public, or have resulted from your project?

❑	Press Release	❑	Coverage in specialist press
❑	Media briefing	❑	Coverage in general (non-specialist) press
❑	TV coverage / report	❑	Coverage in national press
❑	Radio coverage / report	❑	Coverage in international press
❑	Brochures /posters / flyers	❑	Website for the general public / internet
❑	DVD /Film /Multimedia	❑	Event targeting general public (festival, conference, exhibition, science café)

23 In which languages are the information products for the general public produced?

❑	Language of the coordinator	❑	English
❑	Other language(s)		

Question F-10: Classification of Scientific Disciplines according to the Frascati Manual 2002 (Proposed Standard Practice for Surveys on Research and Experimental Development, OECD 2002):

FIELDS OF SCIENCE AND TECHNOLOGY

1. NATURAL SCIENCES

1.1 Mathematics and computer sciences [mathematics and other allied fields: computer sciences and other allied subjects (software development only; hardware development should be classified in the engineering fields)]

1.2 Physical sciences (astronomy and space sciences, physics and other allied subjects)

1.3 Chemical sciences (chemistry, other allied subjects)

1.4 Earth and related environmental sciences (geology, geophysics, mineralogy, physical geography and other geosciences, meteorology and other atmospheric sciences including climatic research, oceanography, vulcanology, palaeoecology, other allied sciences)

1.5 Biological sciences (biology, botany, bacteriology, microbiology, zoology, entomology, genetics, biochemistry, biophysics, other allied sciences, excluding clinical and veterinary sciences)

2 ENGINEERING AND TECHNOLOGY

2.1 Civil engineering (architecture engineering, building science and engineering, construction engineering, municipal and structural engineering and other allied subjects)

2.2 Electrical engineering, electronics [electrical engineering, electronics, communication engineering and systems, computer engineering (hardware only) and other allied subjects]

2.3. Other engineering sciences (such as chemical, aeronautical and space, mechanical, metallurgical and materials engineering, and their specialised subdivisions; forest products; applied sciences such as geodesy, industrial chemistry, etc.; the science and technology of food production; specialised technologies of interdisciplinary fields, e.g. systems analysis, metallurgy, mining, textile technology and other applied subjects)

3. MEDICAL SCIENCES

3.1 Basic medicine (anatomy, cytology, physiology, genetics, pharmacy, pharmacology, toxicology, immunology and immunohaematology, clinical chemistry, clinical microbiology, pathology)

3.2 Clinical medicine (anaesthesiology, paediatrics, obstetrics and gynaecology, internal medicine, surgery, dentistry, neurology, psychiatry, radiology, therapeutics, otorhinolaryngology, ophthalmology)

3.3 Health sciences (public health services, social medicine, hygiene, nursing, epidemiology)

4. AGRICULTURAL SCIENCES

4.1 Agriculture, forestry, fisheries and allied sciences (agronomy, animal husbandry, fisheries, forestry, horticulture, other allied subjects)

4.2 Veterinary medicine

5. SOCIAL SCIENCES

5.1 Psychology

5.2 Economics

5.3 Educational sciences (education and training and other allied subjects)

5.4 Other social sciences [anthropology (social and cultural) and ethnology, demography, geography (human, economic and social), town and country planning, management, law, linguistics, political sciences, sociology, organisation and methods, miscellaneous social sciences and interdisciplinary , methodological and historical S1T activities relating to subjects in this group. Physical anthropology, physical geography and psychophysiology should normally be classified with the natural sciences].

6. HUMANITIES

6.1 History (history, prehistory and history, together with auxiliary historical disciplines such as archaeology, numismatics, palaeography, genealogy, etc.)

6.2 Languages and literature (ancient and modern)

6.3 Other humanities [philosophy (including the history of science and technology) arts, history of art, art criticism, painting, sculpture, musicology, dramatic art excluding artistic "research" of any kind, religion, theology, other fields and subjects pertaining to the humanities, methodological, historical and other S1T activities relating to the subjects in this group]

1. FINAL REPORT ON THE DISTRIBUTION OF THE EUROPEAN UNION FINANCIAL CONTRIBUTION

This report shall be submitted to the Commission within 30 days after receipt of the final payment of the European Union financial contribution.

Report on the distribution of the European Union financial contribution between beneficiaries

Name of beneficiary	Final amount of EU contribution per beneficiary in Euros
1. *Adelan*	
2. Vayon	*0*
3. *Almus*	
4. *UOB*	
5. *IREC*	
6. *ZUT*	
TOTAL	

REFERENCES

1. **SAFARI Period 1 report 2015**
2. **SAFARI Period 2 report 2016**
3. **SAFARI Period 3 report 2017**
4. **11th International Conference on Hydrogen & Fuel Cells 2015, Birmingham UK**
5. **12th International Conference on Hydrogen & Fuel Cells 2016, Birmingham UK**
6. **13th International Conference on Hydrogen & Fuel Cells 2017, Birmingham UK**

Acknowledgements

The SAFARI partners thank FCH-JU for the project and its partial financial support. The bankruptcy of one of the partners after 13 months caused serious problems. But there were several difficulties caused by FCH-JU which should be avoided in future:-

- FCH-JU should have adhered to the project contract
- Bankruptcy of a partner is not a normal reason for termination

- Bankruptcy and poor performance should not be confused with each other.
- Finance problems were significant; eg no FCH-JU prepayments for the SMEs ADE and ALM. It turned out that both these small companies were subsidising FCH-JU when it should have been the other way around.
- Cash flow was the worst ever experienced by the coordinator in an EU project; FCH-JU inept accounting policies were responsible
- Negative and non-factual reports from the PO were not helpful and eventually destroyed the project when VAY found them too depressing