Fuel Cell R&D at the CSIR

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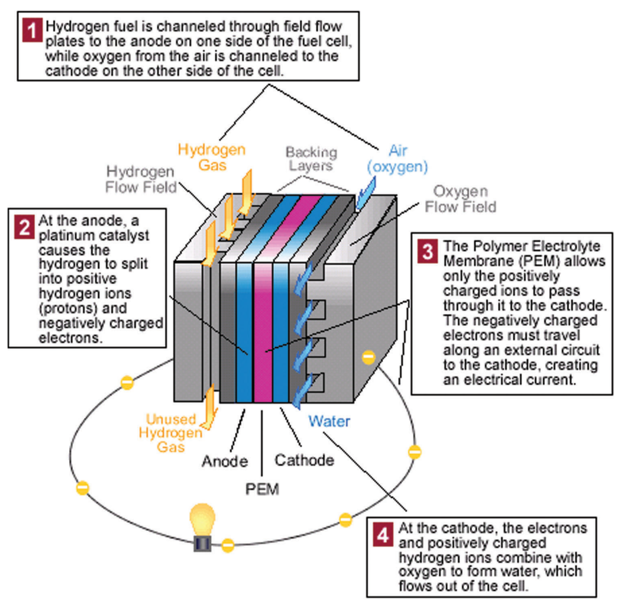
INTRODUCTION

Basic Principles of a Fuel Cell

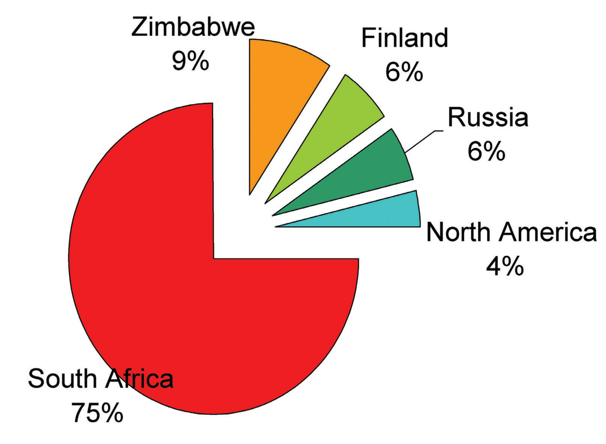


According to a dictionary definition, "A Fuel Cell is an electrochemical cell in which the energy of a reaction between a fuel, such as hydrogen, and an oxidant, such as oxygen, is converted directly and continuously into electrical energy."

A Fuel Cell is a device that converts chemical energy e.g. hydrogen directly into electrical energy, without the need of burning fuel to create steam or gas that drives a generator.

Functioning similarly to a battery, which uses electrochemical conversion, Fuel Cells take in hydrogen-rich fuel and oxygen and turn them into electricity and heat. The waste product, depending on the fuel, is water and carbon dioxide. The hydrogen can be derived from gasoline, natural gas, propane or methanol.

Rationale for Fuel Cell R&D at CSIR



Worldwide Platinum Resources (Cawthorn, 1999)

An increasing amount of funding is becoming available internationally to develop the so-called hydrogen economy. The main drivers for countries to pursue this field are the need to create more energy independence and to address environmental issues. An important aspect of the hydrogen economy is the use of Fuel Cells. Within the CSIR and within South Africa's Government and industry it has been realised that research into Fuel Cells is as important for South Africa as it is for other countries. Additionally as South Africa accounts for about 77% of platinum world supply and platinum and other precious metals are an important part of fuels cells, South Africa could become a key player in a future hydrogen economy and Fuel Cell technology. Therefore the SAFCI (South African Fuel Cell Initiative) was established during 2004. At the CSIR and at a number of TEIs, research projects have been started in a number of aspects of Fuel Cell technology development.

At the CSIR the Fuel Cell development project started with literature studies in 2004 in order to learn about the field and to help decide in which aspects of Fuel Cell technology the focus should lie. Based upon these studies it was decided that PEMFC (Polymer Electrolyte Membrane Fuel Cells) and DMFC (Direct Methanol Fuel Cells) would be the focus points. Furthermore it was decided to buy a 5 kW PEMFC in order to study performance and energy output from a commercial unit.

The first aim of the project is to increase our understanding of the different issues relating to Fuel Cells and the second is to build an operating system, preferably in co-operation with other research groups within South Africa.

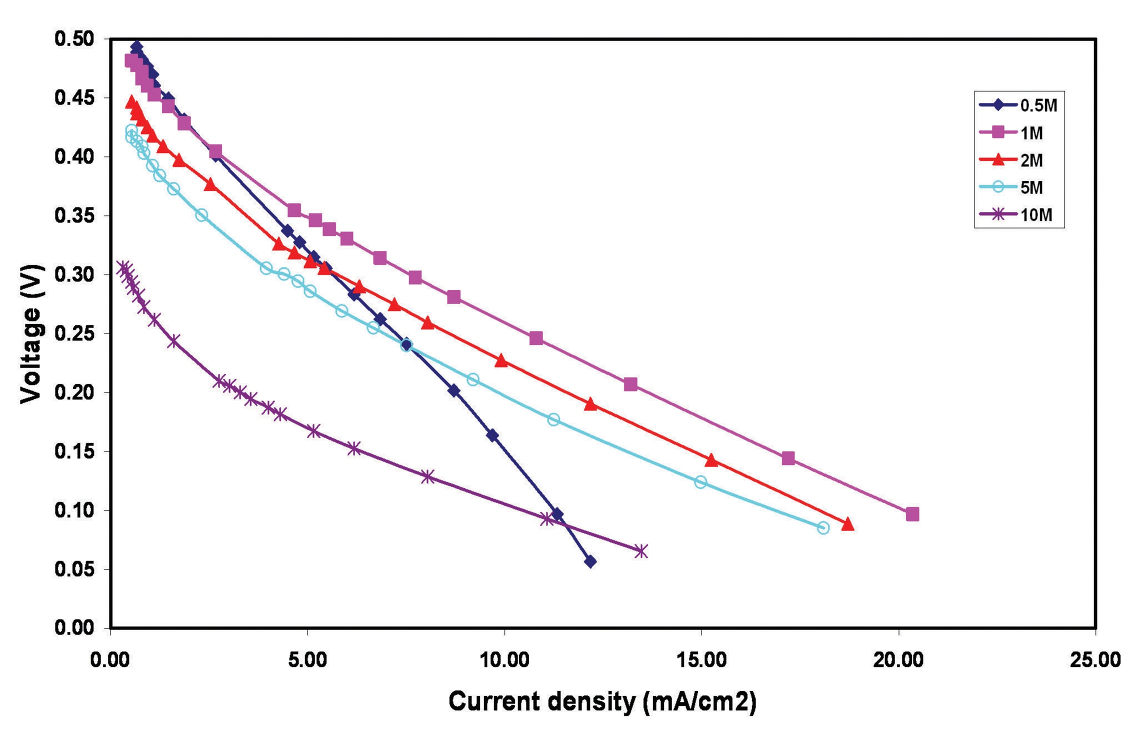
EXPERIMENTS AND RESULTS

Energy and Processes (EaP):

The hydro-Genius™ Direct Methanol Fuel Cell (DMFC) and the Hydrogen Fuel Cell (H_2FC) used in the experiments were supplied by Heliocentris Energiesysteme GmbH. The cells had an effective active area of 7.5 cm² and a volume of 6.75 cm³. The cells were wired with a multimeter and a rheostat. This setup enabled measurements of voltage (directly) and current (indirectly) in order to generate polarisation curves for both the DMFC and the H_2FC. The current was calculated from the circuit voltage and the respective resistance, using Ohm's law.

A variable resistor/rheostat with a range of 0.51 – 9.1Ω and 10 –100 Ω was used in these experiments. The open circuit voltage was measured at the beginning of all methanol and hydrogen experiments. Subsequently, the resistance was changed and the corresponding voltage readings taken at 2 minute intervals. The current-densities were calculated from J = I/A, where I (mA) is the current calculated using Ohm's law; V = IR, and A (cm²) is the area of the cell, i.e. 7.5 cm².

In order to determine whether the calculated currents were accurate, a 0.1Ω shunt was connected in series and the potential across the shunt measured. The current was then calculated using Ohm's law. This method gave results that correlated well with the original indirect current measurements.



DMFC:

MeOH solutions of different concentrations, viz. 0.5, 1.0, 2.0, 5.0 and 10.0 M were used to study the effect of concentration on voltage, current and power densities as well as efficiencies. The objective was to determine an optimum concentration that yielded maximum current and power.

IV-measurements were carried out at room temperature (~20°C) using six different methanol concentrations. It is clear from the Figure below that the best concentration is from 1 to 2 M, and the current density decreases with increasing concentration over 2 M. These results are consistent with results in literature {J. Power Sources 142 (2005) 56 -69.}

It should be noted that the temperature of the cell has a strong influence on its performance. Earlier experiments, carried out at 25 to 30°C, gave significantly higher power densities.

Furthermore, time dependency experiments were done to investigate the rate of MeOH exhaustion/ depletion, and in a range of pH studies, a 1M MeOH solution was adjusted to various pHs and used to study the effect of pH on power density and IV curves.

H_2FC:

H_2FC studies explored the Pt loading efficacy by changing between membrane-electrode assemblies with 0.1 mg/cm² and 0.3 mg/cm² Pt loading. Furthermore, the cathode side was supplied with ambient air (passive ventilation), compressed air (active ventilation) and oxygen (active ventilation) to investigate the effect of the oxidant on the current, efficiency and power output.

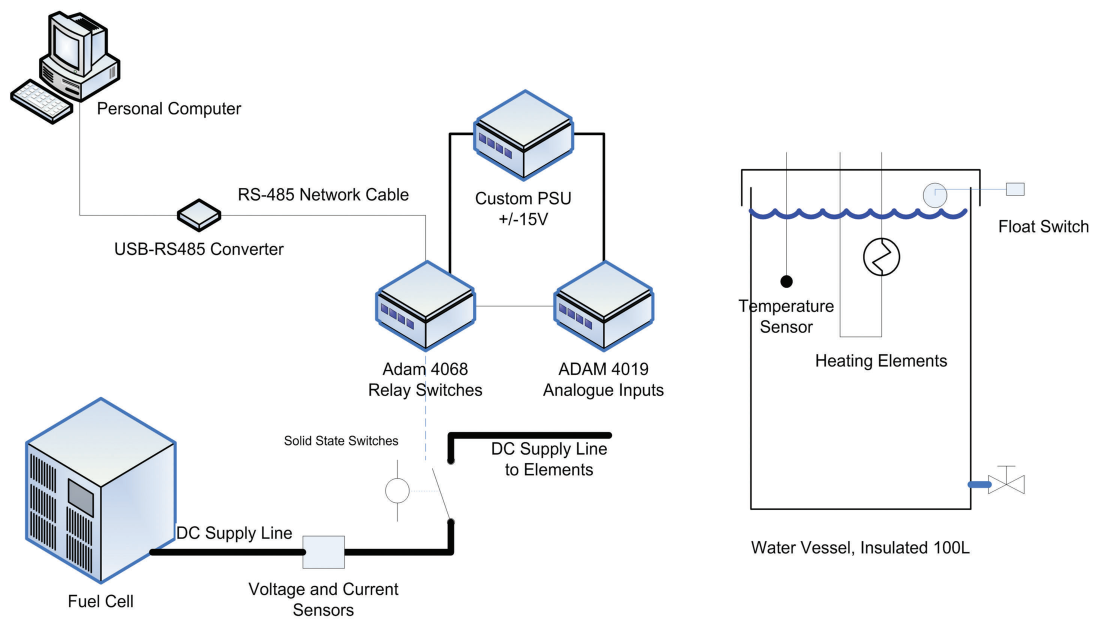
A slight increase of output can be observed when the cathode ventilation is changed from passive to active, especially under higher loads, where passive ventilation does not ensure sufficient mass flow at the cathode.

5 kW Fuel Cell:

A 5 kW Fuel Cell was purchased from PlugPower (USA), through their South African representative, IST, in order to study its fuel efficiency, stability, user interface and control systems.

The Sensor Science and Technology (SST) Competence Area was tasked with developing a system of variable loads (up to 5 kW in 500 W steps), as well as software to control the load system. More details are given under the SST section below.

The hardware and software were recently installed, and once the sensors for voltage, current and water temperature are correctly calibrated, the test runs will commence.



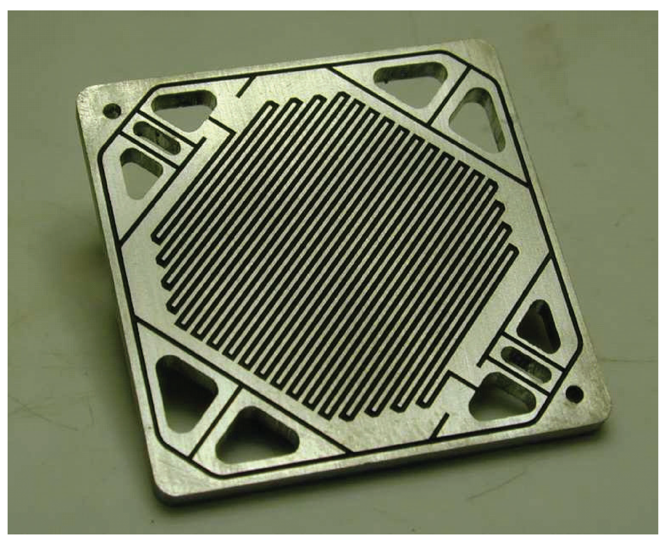
Sensor Science and Technology (SST):

A load system was developed for the 5 kW Fuel Cell, according to the following requirements:

- Construct a varying load (0.5 kW to 5 kW) which is controlled by a programme;
- Load must able to be varied in 500 W steps;
- A load profile must be set-up which is then run over a pre-programmed duration. (Test runs typically take place over 1 hour); and
- Outputs of the FC must be measured by external sensors (Current, Voltage).

The load is in the form of a water tank with submerged heating elements. As the water temperature is monitored, the amount of thermal energy transferred into the tank can be calculated.

The loads are switched by a series of solid-state switches that are controlled by the user software. The system also monitors the voltage and current delivered by the Fuel Cell. A schematic diagram of the load system is shown below:



Metals and Metals Processes (MMP):

A literature survey was done to identify available data on bipolar plates in terms of their design and manufacture. Based on the design parameters extracted from literature a preliminary requirement specification was developed.

A number of manufacturing processes were investigated in terms of the suitability for Fuel Cell prototype manufacture. They include:

- CNC Machining;
- Injection Moulding of graphite filled polymers;
- Laser Ablation;
- Carbon – Carbon composites manufacture;
- Compression Moulding; and
- Rapid Prototyping.

Each of these approaches was considered and evaluated in terms of the following criteria:

- Technical performance of manufactured components in process suitable materials;
- In-house availability of processes and related expertise;
- Novelty and further research possibilities; and
- Do-ability within the cost and time constraints of the current phase of the project.

Some prototypes were also manufactured, using Laser Ablation (see examples below), Rapid Prototyping and Die Design and Manufacture.

OVERVIEW OF SAFCI AND OTHER PLAYERS

South African institutions and companies have been late-starters in the field of FC technology research and development. Currently, there are few key players in both the research arena and the market, but the number is expected to increase. All the following institutions and companies are represented in SAFCI:

- The CSIR's research activities in Fuel Cell technology are currently in Energy and Processes, Metals and Metals Processes and Sensors Science and Technology, all part of Materials Science and Manufacturing;
- Mining Technology (Mintek) is a government research organisation that specialises in mineral and metallurgical technology. Mintek is located in Johannesburg;
- Eskom is a public utility company responsible for electricity generation, transmission and distribution;
- University of the Western Cape, located in Cape Town, has for some years conducted significant FC related research work sponsored by the DST, the National Research Foundation and Eskom;
- Vaal University of Technology and the University of Cape Town are also involved in FC research and development. The University of South Africa and Tshwane University of Technology have representation in SAFCI; and
- Intelligent Systems and IST are private companies involved in the marketing and application of FCs for off-grid and backup systems.

WHAT WE ENVISAGE FOR THE FUTURE

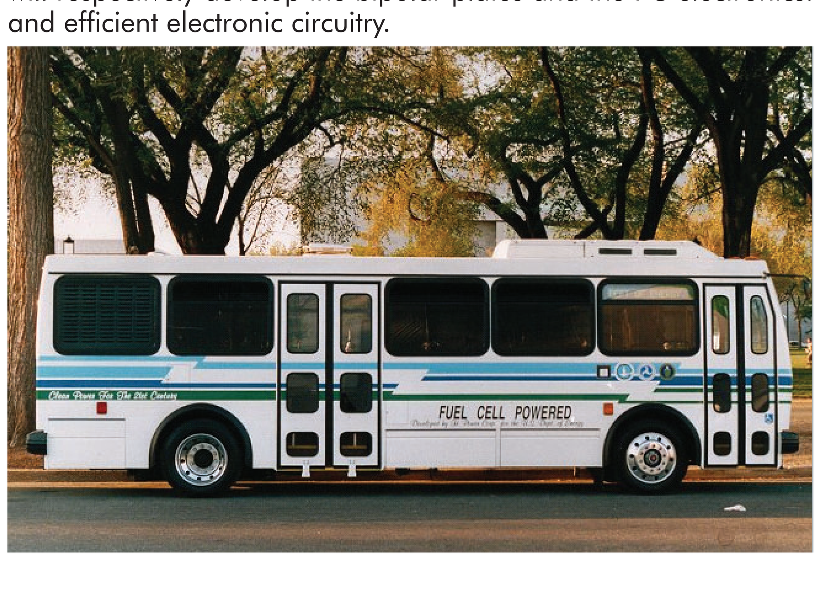
Present Fuel Cell research activities are concentrated on:

- Stationary 5 kW Plug Power Hydrogen Fuel Cells; and
- Proton Exchange Membrane Fuel Cells (PEMFC) with concentration on Direct Methanol Fuel Cells (DMFC) and Hydrogen Fuel Cells (H_2FC).

Future plans on the stationary 5 kW hydrogen Fuel Cell include fuel consumption studies under varying loads and investigation of operating electronics. Successful completion of these studies could result in a pilot demonstration project for household use.

For PEMFC, the fabrication and characterisation of membrane electrode assemblies (MEAs) will be developed as our niche area. Present MEA fabrication methods use commercially available electrodes. It is envisaged by this group that local natural materials will be explored as alternative electrodes. The reduction of the catalyst loading, using alternative electrode materials, will be pursued as it impacts on the cost of the Fuel Cells in general. The use of nanotechnology in Fuel Cells will most probably reduce the catalyst loading, especially when carbon nanotubes can be used as substitute electrode materials in MEA fabrication. MEAs will be fabricated to achieve power outputs that can be used with small electronic gadgets.

Integration of the MEAs into a complete Fuel Cell will be done in co-operation with the Metals and Sensors group at the CSIR, who will respectively develop the bipolar plates and the FC electronics. System integration will include using light material bipolar plates and efficient electronic circuitry.



It is also expected that the Fuel Cell durability testing will be undertaken in collaboration with local as well as international institutes. These collaborations will help develop human capital and skills through exchanges of scientists and students.

The experimental work undertaken will be accelerated and directed through the additional approach of systems modelling, a project that will be done with local expertise.
The human resource development component of the project will be realised through training of students and establishment of collaborations with internationally competitive experts in FC research and development. Publications and Intellectual property development that will give South Africa a competitive advantage in the development and manufacture of Fuels Cells or parts thereof will ensue from these efforts.