HySA Public Awareness
Hydrogen South Africa

HYDROGEN AND FUEL CELL TECHNOLOGIES

FREQUENTLY ASKED QUESTIONS

(FAQ)

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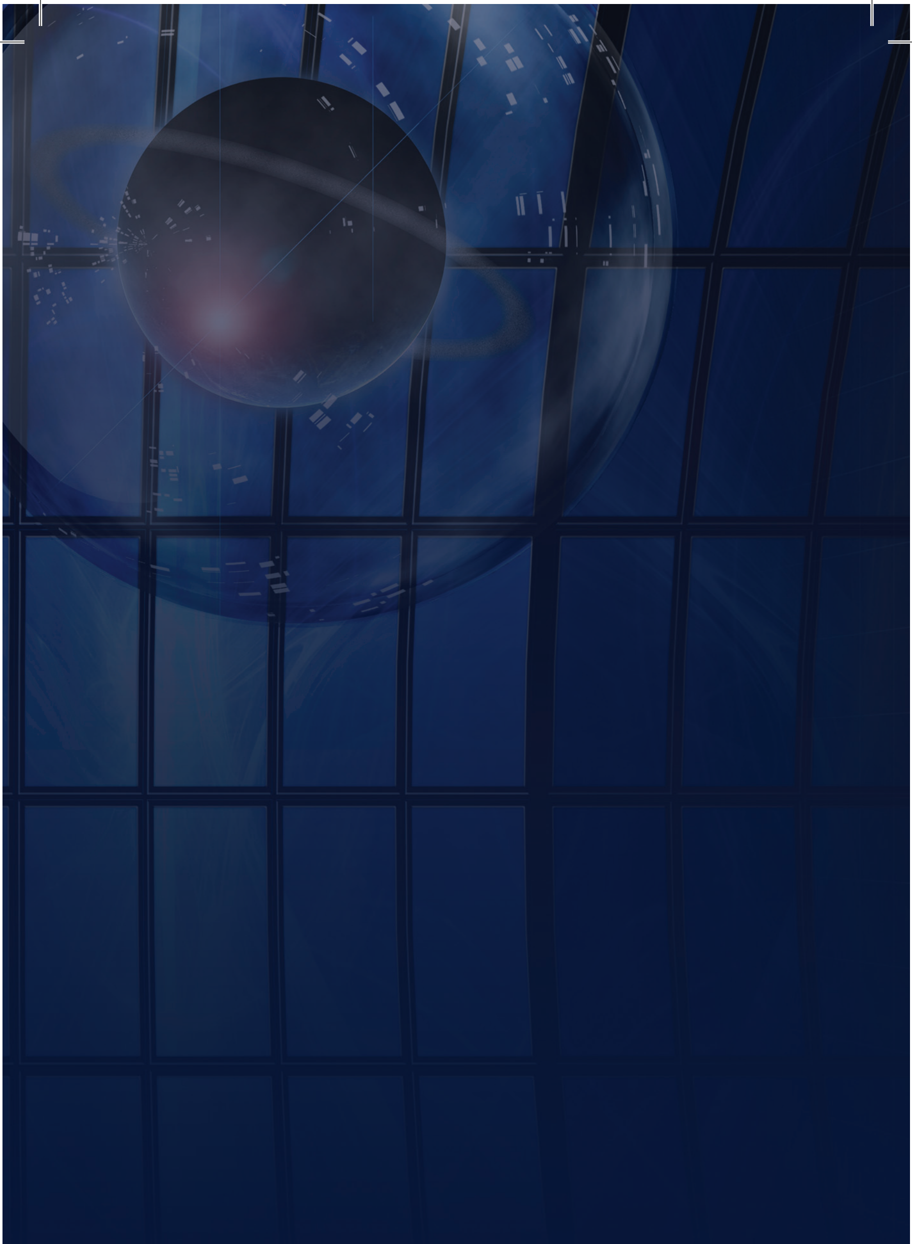

The Department of Science and Technology's
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What's the problem?

All nations across the globe face a severe energy crisis. Our current energy systems are based on fossil fuels, which not only have adverse effects on the environment, but are also depleted and running out. With the growing demand for energy predicted to increase by more than 50% by 2025 due to the rising world population, pressure is mounting to find alternative, renewable sources of energy.

The energy crisis is becoming more visible every day. At the political level, tensions continue to rise over access to oil as demand increases. The increasing cost of oil and other fossil fuels also impacts each of us on a daily basis with the cost of groceries and other basic goods escalating.

What system are we currently using?

The current economy implemented around the world is based on the burning of fossil fuels, including coal, oil and natural gas.

When fossil fuels are burned, they release carbon dioxide (CO_2), as well as many other toxic Greenhouse Gases (GHG) and particulates, which trap heat close to the earth's surface instead of allowing it to radiate out to space. Emissions of GHG, which also include water vapour, methane and nitrous oxide, have grown significantly since pre-industrial times, with an increase of 70% between 1970 and 2004. These increased emissions have caused the temperature of the earth to rise, an effect known as global warming. In 2007, scientists from collaborating nations around the world finally confirmed the link between human activity, increased GHG emissions and climate change.

Reducing reliance on fossil fuels and replacing them with renewable energy sources is a priority across the globe, and countries are implementing policy and research to develop suitable alternatives.

The burning of fossil fuels, including coal, oil and natural gas (www.shutterstock.com).

What is the Hydrogen Economy?

The Hydrogen Economy is one option to develop an energy system based on safe, clean and reliable alternative energy sources – by using hydrogen to store and deliver energy. The term "Hydrogen Economy" was coined by John Bockris in 1970 during a talk at General Motors. Within this economy, hydrogen gas is the universal carrier of energy and links all sources of energy production with all points of energy consumption. If only renewable sources of energy are used, there are no net emissions of CO_2 resulting from this system.

History has seen many new technologies and inventions that were initially expensive become more affordable, as the underlying markets matured and advanced Research and Development (R&D) resulted in increased efficiencies and productivities. It is likely that this will also be the case for using hydrogen, which will become more viable as the benefits, especially for the environment and human health, are seen against the negative impacts of the current system, which is based on limited natural resources.

Within this proposed system based on hydrogen, Hydrogen and Fuel Cell Technologies (HFCT) are potential solutions for the 21st century and will enable both power and heat to be produced cleanly and efficiently from alternative sources of energy.

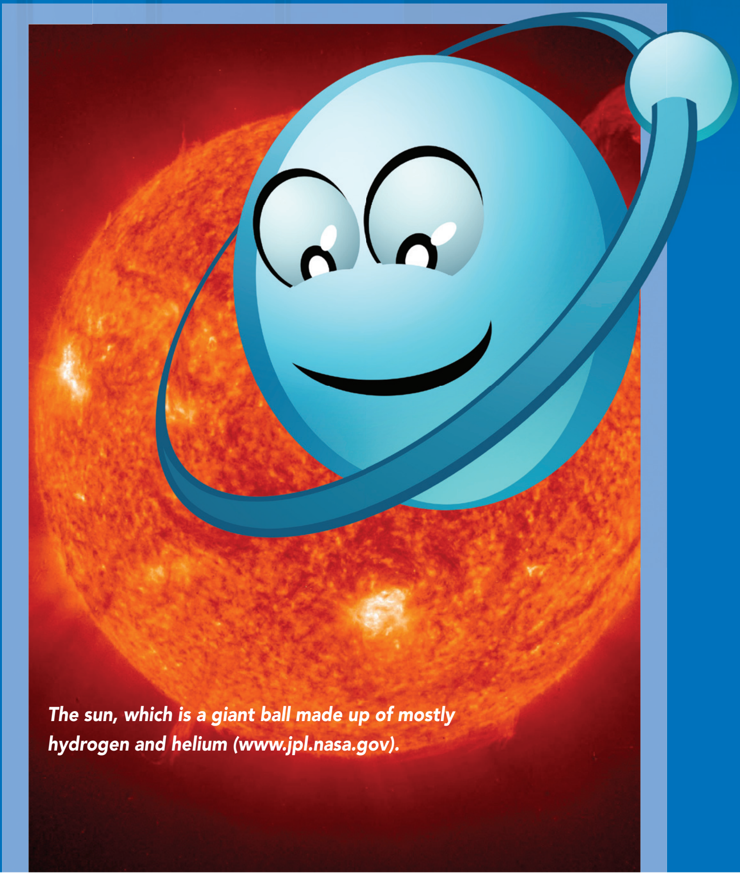
Concept for hydrogen household fuel cells (www.shutterstock.com).

What is hydrogen?

Hydrogen is the most abundant element in the universe. Hydrogen itself is not an energy source - it is an *energy carrier*. It can store and move energy in a usable form from one place to another. Hydrogen can be produced by converting fossil fuels, or using energy from renewable sources such as wind, solar or biomass.

Hydrogen is:

- The lightest gas and much lighter than air.
- A substance with no colour, smell or taste.
- A gas at normal temperature and pressure and condenses from a gas to a liquid at a temperature of -253°C.
- The first element in the periodic table of chemical elements.
- The most abundant element in the universe, comprising some 90% of all atoms.
- A major constituent of the sun which is a giant ball made up of mostly hydrogen and helium.
- One of the most reactive substances in the world and highly flammable.



The sun, which is a giant ball made up of mostly hydrogen and helium (www.jpl.nasa.gov).

Where is hydrogen found?

Although hydrogen is the most plentiful element in the universe, it is rarely found alone in nature because it tends to form compounds with other elements. For example, it joins with oxygen to form water (H_2O). Separating the hydrogen from these compounds is one of the challenges of using hydrogen as an energy carrier.

One of the most common current methods to produce hydrogen uses steam to separate it from hydrocarbons found in petroleum and natural gas – a process which still emits CO_2. A longer term option to produce hydrogen will be to extract it from water, a process known as "water splitting". This process uses either heat (thermolysis) or electricity (electrolysis) to separate out the hydrogen from the oxygen in water – both methods can directly use renewable energy sources.

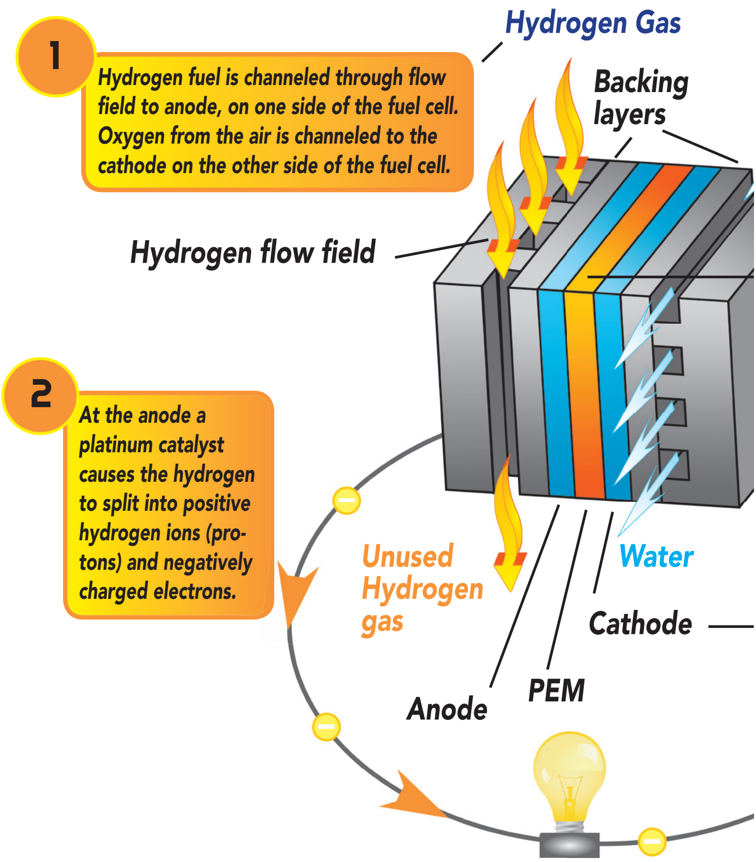
Once hydrogen has been produced or extracted the energy it stores is transportable. This energy can be converted into electricity or heat as needed at the point of use through using a device such as a fuel cell.

What is a fuel cell?

Fuel cells convert chemical energy into electrical energy (electricity), using hydrogen or other fuels and oxygen from the surrounding air. In simple terms, a fuel cell operates like a "battery", except that it does not run down or need electrical recharging. Hydrogen Fuel Cells (HFC) use a quiet, efficient process that can be repeated over and over, and converts the hydrogen's energy to electricity, with heat and pure water as the only emissions.

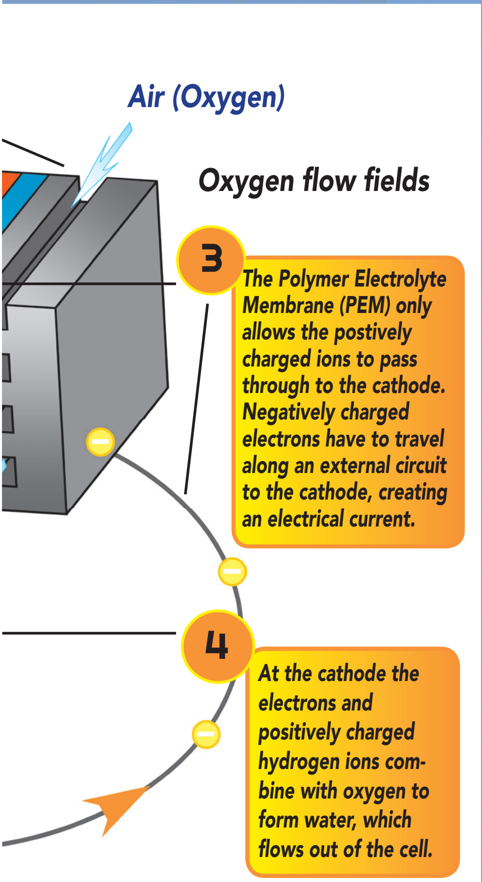
Fuel cells were invented about 150 years ago by Welshman William Grove and they work by reverse electrolysis. Instead of splitting water molecules into hydrogen and oxygen, fuel cells combine hydrogen and oxygen to form water to release the energy content.

The three basic elements of a fuel cell are the catalyst-containing anode and cathode, and the electrolyte.



How does a hydrogen fuel cell work?

A fuel cell consists of three segments sandwiched together: the anode, the electrolyte (which is a membrane in the most common fuel cell type), and the cathode. The anode and cathode are coated with catalytic material, causing two chemical reactions to happen at the interfaces between the three segments. Hydrogen gas and oxygen (in air) are introduced to opposite sides of the separating membrane. As the hydrogen enters the fuel cell, the catalyst on the anode breaks down the hydrogen molecule into protons (H^+) and electrons (e^-). The protons (carrying a positive charge) released are able to pass through the membrane to the oxygen on the other side. The membrane does not allow the electrons (that carry a negative charge) through, and instead they flow through an external circuit thereby creating an electrical current that can be used as a source of power. The catalyst at the cathode combines the protons with oxygen to form water.



HFC are usually named according to the electrolyte used, such as the Proton Exchange Membrane (PEM) and can be a variety of sizes. Since individually they produce a very low voltage (about ± 0.7 volts), they are usually "stacked" and connected in a series, one on top of another to increase the power output. The energy efficiency of a complete fuel cell system is generally between 40-60%, and can be up to 85% if waste heat is captured for use.

What are the uses of Hydrogen Fuel Cells?

HFC can potentially be tailored for use wherever needed, for stationary and portable uses as well as in transportation, and applications range from powering cell phones to cars and houses and even entire neighbourhoods. They are especially useful in remote locations, such as for remote weather stations, nature reserves, military operations or even in submarines and space craft. HFC have the potential to replace the internal combustion engine in vehicles, and could radically change transportation.

Around the world, fuel cells are being developed for:

- Car and buses.
- Motorbikes, scooters and bicycles.
- Utility vehicles (e.g. forklift trucks, golf carts and tractors).
- Aircraft/aviation.
- Locomotives.
- Boats and submersibles.
- Combined heat and power (CHP) domestic and commercial energy needs.
- Back-up power, including Uninterrupted Power Supply (UPS) technology.
- Portable power (to replace power in portable electronic devices such as cell phones and laptop computers).
- Off grid power supply.
- Base load power plants.

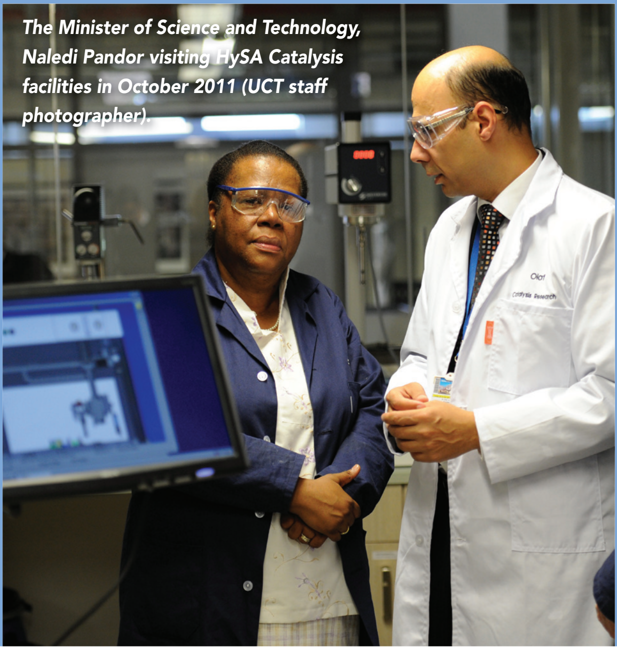
Toyota Hybrid Green Concept Car (www.shutterstock.com).

What is happening in South Africa in HFCT?

Countries around the world have different motivations for investing in R&D in the area of HFCT. For example, Canada is investigating HFCT related to environmental protection and the United States of America is doing likewise, but for reasons of energy security. Japan plans to offer domestic fuel cells commercially soon and aims for a quarter of all Japanese homes to be powered by fuel cells by 2020. Some more advanced countries are also building up hydrogen fuelling infrastructure for hydrogen powered vehicles.

The South African government is driving the R&D on HFCT and related technologies for three main reasons:

- South Africa has an abundance of Platinum Group Metals (PGM), which are the key catalytic materials used in most fuel cells. This provides great potential for socio-economic benefits to be obtained from these natural resources due to the increased global demand for PGM products.
- The Human Capital Development (HCD) required to develop this sector will lead to job creation in South Africa – in order to supply the rest of the world with a much needed resource.
- R&D of HFCT as a viable alternative, renewable energy source is essential to reduce CO_2 and GHG emissions and help meet the country's commitment to the global targets.



The Minister of Science and Technology, Naledi Pandor visiting HySA Catalysis facilities in October 2011 (UCT staff photographer).

Hydrogen South Africa

Considered as a "frontier science and technology" platform, the Hydrogen and Fuel Cell Technologies Research, Development and Innovation Strategy was approved by the Department of Science and Technology (DST) in May 2007. Branded as Hydrogen South Africa (HySA) in 2008, the strategy stimulates and guides innovation along the value chain of HFCT in South Africa. A budget of R400 million was allocated to HySA by DST in the launch period between 2007 and 2011, and the timeline of the programme is 15 years. The ultimate goal of HySA is to facilitate the establishment of a South African HFCT industry that captures a significant share of the global market. The ambitious national target is to supply 25% of the PGM content in the form of value-added products to the international fuel cell markets by 2020.

Miner walking in a mine (www.shutterstock.com).

What are Platinum Group Metals?

PGMs are the key catalytic materials used in PEM fuel cells. The platinum catalyst is vital because it causes the atoms of hydrogen gas to break down into protons and electrons, releasing the energy it contains. One of the main motivators for South Africa's investment into R&D of HFCT is because over 75% of the world's platinum reserves are found in South Africa. Other facts about PGM:

- PGMs include platinum, iridium, osmium, palladium, rhodium and ruthenium – and all of these play important roles in PEM technologies.
- PGMs are renowned for their catalytic qualities and are also resistant to corrosion, chemically inert and have high melting points, making them useful in a number of applications.
- PGMs are predominantly mined in an area called the Bushveld Complex, discovered in the north of South Africa in 1897.
- The Bushveld Complex, which is a two billion year old igneous intrusion, contains some of the richest ore deposits on earth, including PGMs, tin, iron, titanium and chromium.
- South Africa's platinum mines are found mainly in the North-West, Limpopo and Mpumalanga Provinces.

Mine workings (www.shutterstock.com).

Hydrogen research in South Africa

Three Centres of Competence (CoCs) have been established by DST to implement the HySA strategy and are charged with unique responsibilities collectively geared towards attaining the goal of supplying 25% of global PGM based catalyst demand by 2020. The three CoCs are:

- **HySA Catalysis:** Focusing on catalysts and catalytic devices for fuel cells and hydrogen production, co-hosted by the University of Cape Town and MINTEK.
- **HySA Infrastructure:** Focusing on technologies for hydrogen generation/production, storage and distribution, co-hosted by the North-West University and the Council for Scientific and Industrial Research (CSIR).
- **HySA Systems:** Focusing on systems integration and technology validation, hosted by the University of the Western Cape.

Since HFCT is currently too expensive and "young" to be a viable alternative for the South African market, the HySA programme is export oriented. It focuses on developing marketable systems and critical system components that are needed around the world. This will help South Africa to capitalize on the increasing demand for PGM products globally.

The initial focus has been upon establishing the facilities and infrastructure required for fuel cell R&D. This includes a world class 2000 m^2 laboratory at the University of the Western Cape, the fitment of dedicated laboratory space on the campuses of MINTEK, CSIR and North-West University, as well as newly constructed laboratory and office space on the campus of the University of Cape Town. HySA now boasts in excess of 5000 m^2 dedicated laboratory and office space in five locations across the nation and additional access to shared facilities at host institutions.

The combined efforts of the three CoCs are focused on the R&D on a variety of HFCT. This involves "tailor making" or customising fuel cells, usually PEM, for specific uses and applications, resulting in very different fuel cells for the different uses.

Combined Heat and Power

As well as producing power, fuel cells also produce heat as a by-product. This heat can be exploited by customising fuel cells for use as a Combined Heat and Power (CHP) source, and supply decentralised power and heating for buildings and industries. Popular in colder countries where heating is required more often, these CHP systems offer high efficiency and low emissions. Operating from modified existing natural gas distribution networks, they provide up to 10 kW power for domestic and up to 150 kW for industrial buildings.

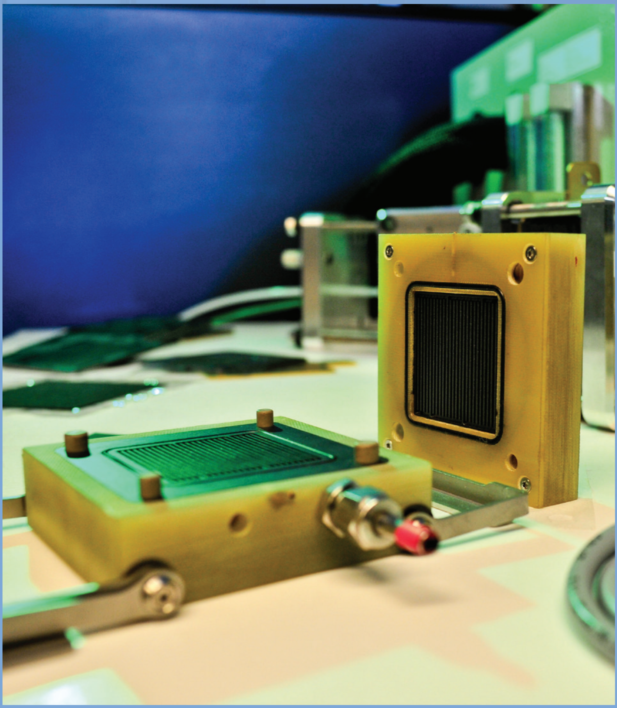
Globally, efforts are underway to implement domestic CHP (dCHP) technology on larger scales, for heating entire communities. In South Africa, the emphasis is upon developing internationally competitive and marketable CHP systems and components – to meet the needs of the global market. The current focus is upon designing the complete CHP systems, based on High Temperature (HT) PEM fuel cells and the necessary fuel processing technology to extract hydrogen at suitable quality from natural gas.

Scientist working on fuel processing technology to produce hydrogen for CHP systems (UCT staff photographer).

Portable power sources

Based on fuel cells, these portable power sources offer backup power supplies that are a quieter and cleaner alternative to generators. Generating power in the range of 0.5-5 kW, these backup "batteries" can range from lightweight portable power units (<1 kW) to larger stand-alone power systems (<5 kW), or Uninterrupted Power Systems (UPS) for telecommunication systems. Portable power is a niche market where customised PEM fuel cells and on-site hydrogen storage technology will quickly become commercially competitive against alternative solutions. It is especially useful in remote areas, where reliable, efficient fuel systems are needed to minimize maintenance and fuel delivery costs.

The aim of the HySA projects on portable power is to develop small-scale reformers, hydrogen storage and low temperature PEM fuel cells that are suitable for a wide range of applications and fuels.



Fuel cell components for portable power systems (UCT staff photographer).

Hydrogen Fuelled Utility Vehicles

Hydrogen Fuelled Vehicles (HFV) could provide a viable alternative to hybrid and pure electric vehicles. Using PEM technology, research over the next 20 years will focus on hydrogen storage density and extending fuel cell life – so that such vehicles could drive further/last longer.

The PEM fuel cell stack is the most important component in a HFV and is equivalent to the "engine" in a conventional vehicle. Although PEM fuel cell technologies are developing at a good pace, two key limitations still remain: cost and durability.

The cost of an Internal Combustion Engine (ICE) in a conventional vehicle is about US$25-35 per kW. Current fuel cell systems are estimated to be about five times more expensive, even taking into account cost savings for high-volume manufacturing. This is because materials and manufacturing costs for PEM fuel cell components are currently too high. Conversely, the fuel cell stack as an "automotive engine" is expected to be as durable and reliable as current automotive engines, i.e. with 5000 hours lifespan or 150 000 miles (approximately 240 000 km) equivalent under a range of operating conditions, including different temperatures and climates.

Costs for PEM components are falling rapidly, with a 90% decrease in manufacturing costs of HFV since 2005 - and this drop is expected to continue for the next five to ten years. This means the goal of US$50,000 for a luxury car is now within reach. The more immediate focus for HySA is on utility vehicles, such as forklift trucks, tractors and golf carts which require lower energy dense storage than passenger cars/HFV.

Force Fuels custom built Hydrogen Fuel Cell powered Hummer H2 (www.shutterstock.com).

Producing hydrogen using renewable energy sources

Relevant infrastructure for hydrogen and HFCT is essential to develop and sustain this technology and its applications. This includes developing cleaner and more economical methods to produce high quality hydrogen from renewable energy sources. Integrating renewable energy sources (wind and photovoltaics) with hydrogen production through water electrolysis is due for completion at the end of 2012, and will include the development of a South African water electrolyser producing hydrogen at a set cost.

Other key areas of research include increasing the energy density of hydrogen, so that more hydrogen can be more practically and economically stored and distributed for the various applications. The responsible development of efficient and safe infrastructure strategies is vital to facilitate the deployment of hydrogen energy technologies.

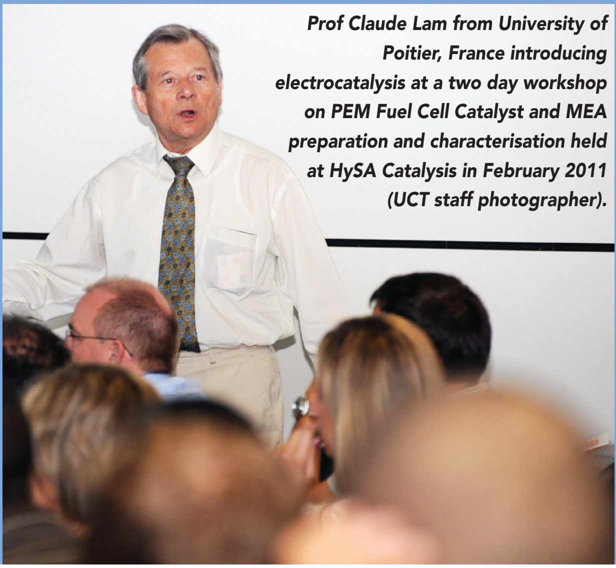
Solar energy panels and wind turbines (www.shutterstock.com).

Who is working on HFC?

As with any new technology, people with relevant qualifications and expertise are needed. To accelerate the development of this technology over the next two decades, high-end South African post graduates with relevant degrees in Science and Engineering need to be recruited to the sector. Developing the required human skills and expertise at various levels, more formally known as Human Capacity Development (HCD), is essential to the sustainable growth of the sector.

HySA is promoting collaborative and inter-disciplinary research and is developing a creative research training environment that is world class and internationally competitive. Increasing the number of South African students in the postgraduate pipeline, ranging from MSc to post-doctoral level is being tackled through the HySA HCD programme. Workshops, seminars, short courses and training manuals are being developed to promote learning of critical and basic scientific skills and knowledge related to HFCT as well as project management, basic leadership and relevant financial management where appropriate.

Both short and long-term exchange programmes and visits from world-renowned experts, and other international and national linkages are promoting knowledge transfer and mutual information exchange, and exposure to cutting edge research and alternative research and education systems. National internships and mentor programmes are also a part of this process.



Prof Claude Lam from University of Poitier, France introducing electrocatalysis at a two day workshop on PEM Fuel Cell Catalyst and MEA preparation and characterisation held at HySA Catalysis in February 2011 (UCT staff photographer).

Advantages of HFCT

- **Low to zero emissions** – When hydrogen produced from clean technologies ("green" hydrogen) is used in fuel cells, there is zero pollution.
- **Reliability** – HFC are very reliable which is essential when high quality, uninterrupted power supply is needed.
- **Quiet** – Fuel cells operate silently, mainly due to the lack of moving parts, which also minimizes maintenance and operating costs.
- **Efficient** – Fuel cells are highly efficient at converting fuel to electrical energy, when compared to other electrical generating technology.
- **Flexible** – Not only can HFC be used for a variety of applications, they can also operate on a wide load range and scale from micro production to megawatt production.

State-of-the-art fuel cell testing facility at HySA Catalysis Centre of Competence (UCT staff photographer).

Challenges of HFCT

A lot of research is needed before fuel cells will become a practical alternative to current energy production methods – and it could be several decades before a hydrogen fuel cell-based energy system is a viable alternative. Some of the key challenges in this process are:

- **High cost** – The current high cost of producing fuel cells and related components will need to be reduced considerably if this technology is to be competitive. Although fuel cells will become more affordable when they are mass produced, the cost of the catalyst (i.e. the amount of platinum), also needs to be reduced.
- **Storage and distribution** – The low volumetric energy density of hydrogen gas requires new storage and distribution strategies, especially for use in cars i.e. a hydrogen storage tank for a hydrogen fuel cell vehicle, even at high pressures will be three times the size of an equivalent petrol tank. The availability of hydrogen is another key challenge which needs to be resolved before the technology can be scaled up and commercialised, i.e. refuelling of cars.
- **Durability** – Fuel cell powered systems in cars will need to achieve the same level of durability as current automotive engines.
- **Safety** – As for all fuels, hydrogen is potentially dangerous and is flammable if not handled properly. However, unlike gasoline or natural gas, cars powered by hydrogen would not burn during a collision as the hydrogen quickly evaporates into the air.
- **Industry linkages** – Additional links are needed with industrial manufacturers in South Africa that are interested in getting involved in the future development of HFCT and the related business opportunities. These industries need to work closely with the researchers to find innovative ways of producing cost effective components and fuel cell systems.

Careers in HFCT

The fast-tracking of HFCT means that it is a good time to consider pursuing a career in this area.

What subjects are needed at school?

At the end of Grade 9, learners choose which subjects to study for matric in Grades 10-12. If they want to consider pursuing a career in this field, they need to choose their subjects with this in mind. In order to study for a Science or Engineering degree at University, they need to choose Physical Science, which includes Physics and Chemistry. Although Maths is a compulsory subject they should choose straight Mathematics, rather than Maths Literacy. The main goal at school is to ensure a good pass in the final exams to achieve university exemption, as standards at some of the faculties of Science and Engineering are set very high.

Graduate student (www.shutterstock.com).

What degrees are needed at university?

Since the HFCT research sector requires researchers from a broad spectrum of disciplines, any of the Science degrees or diplomas could be chosen including:

- Physics.
- Chemistry.
- Applied Materials Chemistry.
- Chemical or Mechanical Engineering.
- Electrical Engineering.
- Electronics.
- Metallurgy.
- Socio-economics.
- Business and Marketing.

All of these subjects could be useful for research in HFCT. However, most universities offer a generic four-year BSc Chemical or Mechanical Engineering degree, which may provide more scope in research fields later on. Most four year degrees incorporate honours, and so qualify successful graduates for a Master's degree automatically.

Before you finally decide upon which degree to pursue at university, consider your long term career options – as your choice could drastically impact the opportunities available to you afterwards.

What about post-graduate study?

Due to the specialised nature of HFCT research, you will need to progress to a post-graduate qualification as well, either a Master's degree or a Doctor of Philosophy (PhD). If you have an honours degree in Engineering or Science, you would be eligible to apply for postgraduate study at various universities and tertiary institutions in this field.

Are bursaries available in this field?

Bursary support is available at many universities and scientific institutions around South Africa for those that have achieved excellent academic result. The criteria for these bursaries differ between institutions, although most require post-graduate academic records with an average of 75% and above.

Which universities offer post-graduate research programmes in HFCT?

Several universities and science councils in South Africa are already engaged in research on HFCT. Most of these fall within the HySA framework and are linked to the HySA CoCs. These include:

- The University of the Western Cape (UWC) – The HYSA Systems Competence Centre focuses on technology validation and systems integration in three main areas: combined heat and power, portable power and fuel cell vehicles. The research group based at UWC has been involved in HFCT R&D since the mid 1990's and holds several related local and international patents.
- University of Cape Town (UCT) – The HySA Catalysis Competence Centre is co-hosted by UCT and MINTEK and the focus of R&D is on fuel cell and fuel-processor catalysts and catalytic devices.
- North-West University (NWU) – Co-hosts of the HySA Infrastructure Competence Centre along with the Council for Scientific and Industrial Research (CSIR), the main R&D focus is to develop technologies for hydrogen production, storage and distribution.

A number of other universities in South Africa have collaborative agreements with these key centres, and are involved in R&D programmes that advance knowledge generation in HFCT. These include:

- University of Witwatersrand.
- University of Johannesburg.
- University of Limpopo.
- Tshwane University of Technology.
- Nelson Mandela Metropolitan University.
- Stellenbosch University.

The way forward

HFC technology is an option under serious consideration by South Africa as a potential alternative energy system for use in the future, when it could be integrated together with other renewable energy technologies, such as solar cells, for smaller remote area applications.

A new company, called "Clean Energy Incorporated" was established in 2010 through an agreement between DST, Anglo-Platinum and a US-based company called Altergy Systems to market and distribute fuel cells in South Africa, and to locally manufacture fuel cells for Sub-Saharan Africa. Additional links are needed with other industrial manufacturers in South Africa that are interested in being involved in the future development of HFCT and the related business opportunities. It is important that these industries work together with the researchers to find innovative ways of producing cost effective components and fuel cell systems.

This has to be accompanied by the development of the necessary human experts to make it a reality in the allocated timespan.

Solar cells (www.shutterstock.com).

Where can I learn more about HFCT?

Stationary fuel cell exhibits have been established at a number of Science Centres around the country, including:

- Sci-Bono Discovery Centre, Newtown, Johannesburg.
- Potchefstroom Science Centre, North-West University.
- Old Mutual MTN ScienCentre, Gateway Theatre of Shopping, Umhlanga Rocks.
- SAASTA Observatory, Johannesburg.
- Cape Town Science Centre.

The Centres of Competence can also be contacted:

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"What is so exciting about this technology is that by using our natural resources, everyday products can be made that are not only environmentally friendly, but can ultimately impact on and improve the lives of both South Africans and millions around the world."

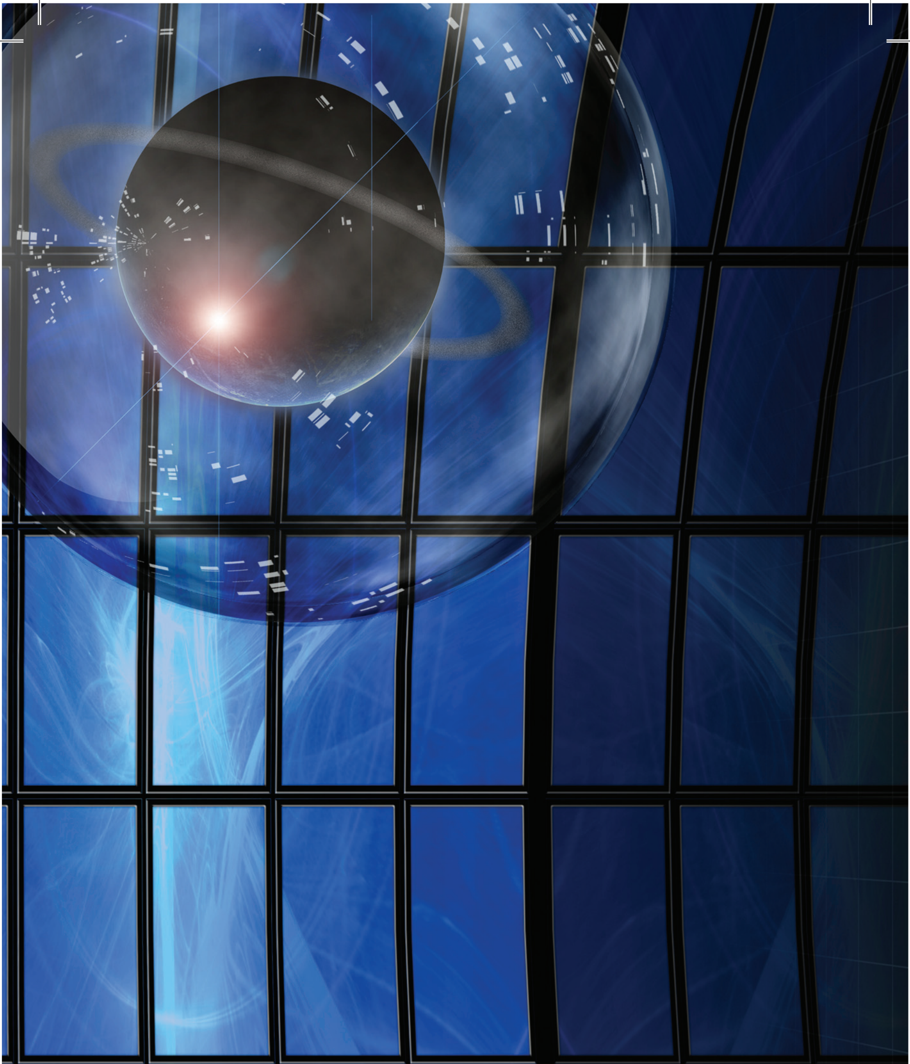
Dr Dmitri Bessarabov, Director HySA Infrastructure

"South Africa is endowed with immeasurable mineral riches; converting these into high technology products will create a prosperous future with high-quality jobs for many South Africans. The Hydrogen Economy is the most promising global aspiration and HySA is making sure that South Africa is a global exporter of value-added products into this expanding market."

Dr Olaf Conrad, Director HySA Catalysis

"Hydrogen and Fuel Cell Technologies will have an enormous impact across all energy markets around the world. South Africa will be the catalyst for this revolution in sustainable technologies by providing first-class technologies, products and skilled researchers."

Professor Bruno G. Pollet, Director HySA Systems



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