REPORT R99/2013

FUEL CELLS AND THE FUTURE ROLE OF SOUTH AFRICA THROUGH ITS PLATINUM RESOURCES

DIRECTORATE: MINERAL ECONOMICS

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Mineral Resources
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Cover picture: A fuel cell vehicle, sourced from www.platinum.matthey.com

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ABSTRACT

This report aims to assess the country's future role through its platinum-group metals (PGMs) resources, in the global fuel cell market. In line with the global trend, South Africa (SA) is researching alternative energy sources to fossil fuels, to both reduce the dependence on these resources and to find cleaner, more sustainable alternatives. The Department of Science and Technology (DST) has established three national competence centres through its National Hydrogen and Fuel Cell Technologies (HFCT) flagship project, also known as Hydrogen South Africa or HySA. Although the country is unlikely to be an early adopter of large-scale hydrogen energy technologies, it could still benefit in terms of business and jobs, in servicing the emerging hydrogen economy segments around the world. The use of fuel cells can be categorized into three broad areas; portable power generation, stationary power generation and power for transportation. Commercialization of fuel cells globally has been a slow but steady progress, with several sales experiencing delays and cancellations. However, a change in certain sectors began in 2011, particularly in the stationary market when large orders were announced and completed on time, even exceeding expectations at times. Almost all of the fuel cells sold to date use platinum as a catalyst, with smaller amounts of ruthenium, both of which impart unique characteristics of durability, power density and efficiency.

According to HySA, the main goal is not to prepare SA markets for the hydrogen economy, but to prepare the country to be an exporter of value-added technologies that include PGMs. However, hydrogen and fuel cell technologies also offer SA an opportunity to develop the local market for PGMs, particularly after the local PGMs industry endured significant challenges related to subdued demand for platinum. The development of technologies for fuel cell production in SA is expected to naturally thrive on the back of the catalytic converters industry with its currently installed capacity for coating of PGMs. Cellphone companies and underground mine locomotives are touted as the potential large scale entry points for a SA's platinum fuel cell industry. It must be mentioned, though, that plans to reduce high capital costs by decreasing the platinum dependency of fuel cells presents a challenge since utilizing platinum resources is part of the reason for the country's rigorous approach towards capturing a portion of the fuel cell market, although platinum-mediated reactions may remain at the core of fuel cell technologies for the fore-seeable future. However, the fact that fuel cell commercialization has been well below expectations poses a serious challenge, and perhaps the emphasis should be on the level to which the country needs to increase locally beneficiated platinum by 2020, rather than on the portion of the unreliable fuel cell market.

CONTENTS

ABBREVIATIONS AND SYMBOLS

APU	Auxillary Power Units
CHP	Combined Heat and Power
CSIR	Council for Scientific and Industrial Research
DST	Department of Science and Technology
FCVs	Fuel Cell Vehicles
HFCT	National Hydrogen and Fuel Cell Technologies
HySA	Hydrogen South Africa
kW	kilowatts
LDVs	Light Duty Vehicles
MEAs	Membrane Electrode Assemblies
MW	Megawatts
NWU	North West University
oz	ounces
PEM	Polymer Electrolyte Membrane
PGMs	Platinum Group Metals
Pt	Platinum Group Metals
SA	South Africa
TUT	Tshwane University of Technology
UAVs	Unmanned Aerial Vehicles
UPS	Uninterrupted Power Systems
UUVs	Unmanned Undersea Vehicles
W	Watts

1. INTRODUCTION

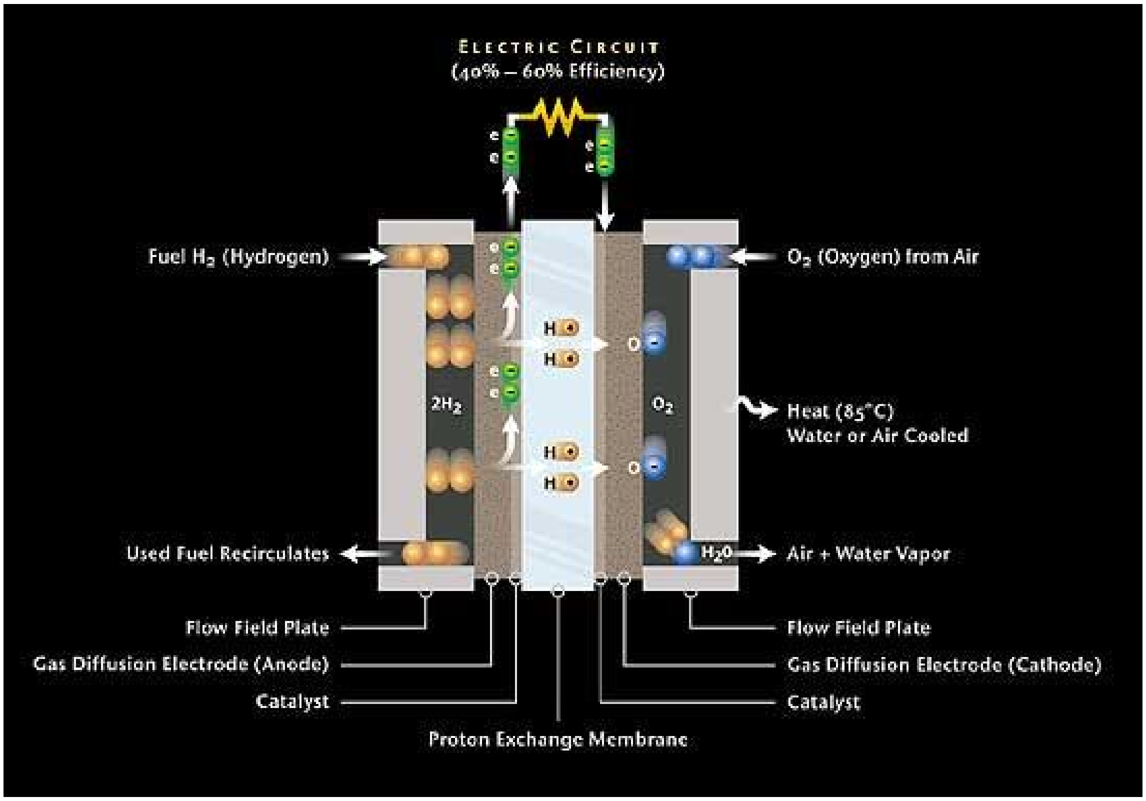
The abundance and affordability of fossil fuels have made them major sources of energy around the world and South Africa (SA) is no exception. However, with the global energy demand expected to grow more than 60 percent by 2030 and green evolution posing the main challenge to fossil fuels as energy sources, security of energy supply has become a concern, leading to the need to diversify energy sources. This has opened doors for fuel cell technology, a pollution-free electricity generation technology that is expected to compete with traditional fossil fuels and hydrocarbon combustion. Because fuel cells have no moving parts and do not involve combustion, they can achieve up to 99.99 percent reliability and are therefore seen as energy solutions for the 21st century. For South Africa, this has opened up new opportunities for platinum group metals (PGMs), particularly platinum. Fuel cells use a variety of feed streams such as hydrogen, ammonia and liquid petroleum gas to generate electricity, and uses platinum as a catalyst for the conversion of hydrogen into electricity. Fuel cells therefore have the potential to become one of the main drivers of global platinum demand in the future and SA's abundant PGMs resources are expected to position the country in a good stead to be both an active participant and a beneficiary. This report aims to assess the country's future role, through its PGMs resources, in the global fuel cell market. The report will address issues such as the science of the fuel cell technology, fuel cell market dynamics as well as opportunities and challenges facing the country with regards to application and commercialization of fuel cells.

2. FUEL CELL TECHNOLOGY

Fuel cells generate electricity by an electrochemical reaction between oxygen and hydrogen (or hydrogen-rich fuel), generating water and heat as waste products. A fuel cell unit consists of a stack, which is composed of a number of individual cells. Each cell within the stack has two electrodes, a positive cathode and a negative anode, separated by an electrolyte (Figure1). The reactions that produce electricity take place at the electrodes, with the electrolyte carrying ions from one electrode to the other. The electrolyte substance usually defines the type of a fuel cell e.g. Polymer Electrolyte Membrane (PEM) fuel cell. At the anode, a catalyst, usually made up of very fine platinum powder, breaks down the fuel into electrons and ions, while the cathode catalyst, often made up of nickel, turns the ions into waste products such as heat and water. Unlike internal combustion engines, the fuel is not combusted; the energy is instead released through a catalyzed chemical reaction. This allows fuel cells to be highly energy efficient, especially if the heat produced by the reaction is also utilized for other purposes.

Fuel cells are similar to batteries in that they generate electricity from an electrochemical reaction. Both batteries and fuel cells convert chemical potential energy into electrical energy and also, as a by-product of this process, into heat energy. However, a battery holds a closed store of energy within it and once this is depleted the battery must be discarded, or recharged by using an external supply of electricity to drive the electrochemical reaction in the reverse direction. A fuel cell, on the other hand, uses an external supply of chemical energy and can run indefinitely, as long as it is supplied with a source of hydrogen and a source of oxygen (usually air). The power output from a single cell is relatively low, but a stack arrangement makes fuel cells a very versatile technology, allowing them to power a broader range of applications than any other currently available power source.

FIGURE 1: A SCHEMATIC DIAGRAM OF HOW A FUEL CELL WORKS.



Source: energyinformative.org

3. APPLICATIONS

There are several fuel cell technologies currently in various stages of development. The demand for a particular application generally determines the choice of technology to be applied. For example, phosphoric acid fuel cells are commercially available today, mainly in larger stationary power generation applications. However, these fuel cells operate at relatively high temperatures, so they are not practical in many applications. Other types include molten carbonate, solid oxide, and alkaline fuel cells. Each fuel cell type also has its own operational characteristics, offering advantages to particular applications.

The use of fuel cells can be categorized into three broad areas; portable power generation, stationary power generation and power for transportation (Table 1). Portable fuel cells encompass those designed to be moved, while stationary power fuel cells are designed to provide power to a fixed location. Transport fuel cells provide propulsive power to vehicles, directly or indirectly (as range-extenders).

TABLE 1: APPLICATIONS OF FUEL CELLS CATEGORISED INTO THREE BROAD AREAS.

PORTABLE	STATIONARY	TRANSPORT
Applications for portable fuel cells include military applications (Portable soldier power, skid mounted fuel cell generators etc), Auxiliary Power Units (APU, e.g. for the leisure and trucking industries), portable products (torches, vine trimmers etc), small personal electronics (mp3 players, cameras etc), large personal electronics (laptops, printers, radios etc), education kits and toys.	UPS systems can be divided into five sub-sectors; telecommunication base stations, critical communication base stations, On-line and off-line mountable systems for data centres and off-line systems for residential use.	Applications for fuel cells for transport include forklift trucks and other goods handling vehicles such as airport baggage trucks etc, two- and three-wheeler vechicles such as scooters, light duty vehicles (LDVs), such as cars and vans, buses and trucks, trains and trams, ferries and smaller boats, manned light aircraft and unmanned aerial vehicles (UAVs) and unmanned undersea vehicles (UUVs), for example, for reconnaissance. PEM technology is seen as the most likely fuel cell for automotive applications.

Source: Fuel Cell Today.

For portable applications, portable fuel cells are being developed in a wide range of sizes ranging from less than 5 W up to 500 kW. The difference between small and large personal electronics is that the smaller devices, such as cameras or mobile phones only draw around 3 W of power, whereas a laptop can use up to 25 W, requiring a fuel cell of higher power density. The main drivers for fuel cells in portable applications are off-grid operation, longer run-times compared with batteries, rapid recharging, significant weight reduction potential (for soldier-borne military power) and convenience, reliability, and lower operating costs.

Stationary fuel cells include combined heat and power (CHP), uninterruptible power systems (UPS) and primary power units. CHP units are sized between 0.5 kWe and 10 kWe, and take advantage of the fact fuel cells generate heat alongside electricity, while UPS systems provide a guaranteed supply of power in the event of grid interruption. Fuel cell light duty vehicles (LDVs) have so far seen limited use but this is set to change as most major automakers have targeted 2015 for initial commercial sales of their fuel cell vehicles. The fuel cell bus sector is showing year-on-year growth, with more prototypes being unveiled, while niche transport consists of a number of sub-applications with differing levels of commercial success to date.

4. FUEL CELL MARKET DYNAMICS

4.1 Global Sales

Fuel cells were invented more than a hundred years ago, but were only commercialized in 2007. It has been a slow but steady progress, with several sales experiencing delays and cancellations. However, a change in certain sectors began in 2011, particularly in the stationary market when large orders were announced and completed on time, even exceeding expectations at times. As a result, fuel cell system sales continued to grow world-wide in 2011, rising by 39 percent to reach a high of 24 600 units (Table 2). In terms of megawatts (MW), a 20 percent increase was recorded in 2011 to exceed 100MW for the first time.

TABLE 2: NUMBER OF FUEL CELL UNITS SOLD BY APPLICATION AND REGION, 2008 – 2011.

		2008	2009	2010	2011
Application	Portable	5 100	5 700	6 800	6 900
	Stationary	3 600	6 700	8 300	16 100
	Transport	800	2 000	2 600	1 600
	Total	***9 500***	***14 400***	***17 700***	***24 600***
Region	Europe	3 300	4 400	4 800	3 900
	N. America	1 700	3 200	3 300	3 300
	Asia	4 500	6 700	9 500	17 000
	Rest of World	0	100	100	400
	Total	***9 500***	***14 400***	***17 700***	***24 600***

Source: Fuel Cell Today Industry Review 2011.

In 2011, sales of fuel cell systems for stationary power grew to more than 16 000 units in excess of 81MW, increases of 94 percent and 133 percent, respectively when compared with 2010. Portable system sales grew by 1.5 percent to 6 900 units while remaining at 0.4MW. Sales for transport applications dropped nearly 40 percent in 2011 to 1 600 units, mainly due to the launch of relatively smaller scale fuel cell vehicles (FCVs) demonstration fleets. Regionally, Asia was responsible for 69 percent of all fuel cell unit sales, while the Rest of World, which includes Africa among others, accounted for just 1.6 percent.

4.2 Fuel Cell Demand for Platinum

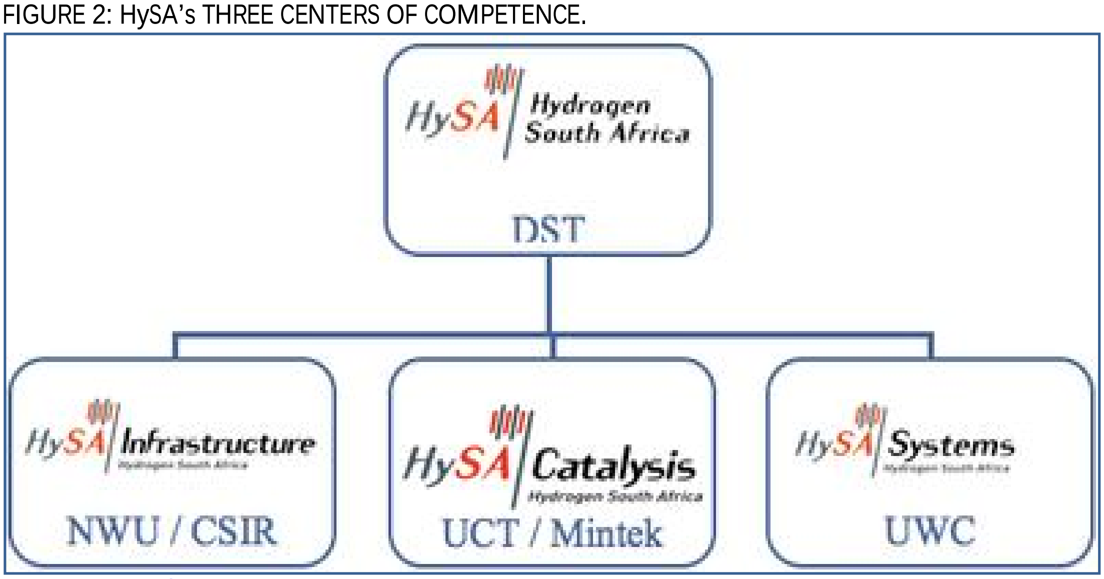
Almost all of the fuel cells sold to date use platinum as a catalyst, with smaller amounts of ruthenium, both of which impart unique characteristics of durability, power density and efficiency. Of all the various fuel cell applications, the largest amount of platinum is used in FCVs. Total demand for platinum in fuel cells reached 20 000 ounces (oz) for the first time in 2010, accounting for less than 1.0 percent of total platinum demand. Part of the reason is that although fuel cells have been invented for over a century now, they are not yet used on a large commercial scale. However, commercialization in a number of early niche markets has been successful and fuel cells are becoming increasingly more important. Moreover, they are becoming more affordable, owing to reduced production costs and the industry's ability to reduce the loading (amount of PGMs per unit) used in the application. For example, platinum loading has decreased by more than 80 percent between 2005 and 2010, while the US Department of Energy targets for automotive fuel cells were 0.33 g Pt/kW in 2010 and 0.125 g Pt/kW in 2015. This is a similar trend to that experienced by the autocatalysts industry over 30 years ago. Less metal was progressively used in vehicles to achieve an equivalent amount of emissions, resulting in more control over the costs of production and success in meeting the operational challenges of using platinum and palladium in catalysts. However, if the global market for fuel cells grows, they will form an increasingly important part of industrial demand for associated PGMs, which are platinum and ruthenium.

5. FUEL CELL DEVELOPMENTS IN SA

In line with the global trend, SA is researching alternative energy sources to fossil fuels, to reduce the dependence on these resources and to find cleaner, more sustainable alternatives. The Department of Science and Technology (DST) has established three national competence centres through its National Hydrogen and Fuel Cell Technologies (HFCT) flagship project, also known as Hydrogen South Africa or HySA. The three centres are: HySA Systems Intergration and Technology Validation co-hosted by the SA Institute for Advanced Materials Chemistry (SAIAMC) and the University of the Western Cape, HySA Infrastructure co-hosted by the North-West University (NWU) and the CSIR, as well as HySA Catalysis co-hosted by the University of Cape Town and Mintek. Possible products the three Centres of Competence will endeavour for as objectives of HySA are portable sources of power (that are cleaner and less noisy than power generators), combined heat and power sources (for heating buildings and industries) and possibly also for fuel cell driven vehicles. The overall vision of the

HFCT Research, Development and Innovation strategy is to bring about wealth and job creation through the initiation of new high technology industries based on minerals found in South African soil, particularly PGMs. The objective is to ultimately supply 25 percent of the future global fuel cell market with locally developed and fabricated PGMs components by 2020.

FIGURE 2: HySA's THREE CENTERS OF COMPETENCE.



Source: www.dst,gov.za

HySA Infrastructure is responsible for the development of technologies related to hydrogen production using renewable energy sources and hydrogen storage and distribution technologies. Currently the centre has a functional laboratory established at NWU Potchefstroom campus and CSIR in Pretoria, and there are currently 21 active students involved in research and development projects. HySA Catalysis mainly focuses on the development of fuel cell catalysts, membrane electrode assemblies (MEAs) for low temperature PEM fuel cells, and fuel processors. HySA Systems is an industry, technology and product development oriented competence centre, which has demonstrated its ability to develop, build, commission and validate prototype systems. Its objectives are to develop key components for hydrogen and fuel cell technologies, to validate technology and systems for both domestic and automotive applications, and to facilitate the export of new technology from SA to international markets. The centre has successfully assembled the first fuel cell comprised fully of components manufactured in SA (Figure 3). The system, a 2 kW high temperature PEM fuel cell, is a collaboration between HySA and the German Center for Solar Energy and Hydrogen Research, whose stack technology was used in the project.

FIGURE 3: THE HIGH TEMPERATURE PEM FUEL CELL, ASSEMBLED BY HYSA SYSTEMS.

Source: www.fuelcelltoday.com

The SA government has also partnered with the private sector to establish a new company which will initially market and distribute fuel cells in South Africa, before manufacturing locally for the Sub-Saharan African market by 2013. The company, currently in its market development stage, has reportedly supplied eighteen fuel cell backup power systems to one mobile phone service provider, which has an estimated market share in South Africa of over 55 percent. Another product of the government-private sector partnership is a hydrogen fuel cell powered bicycle, Ahi Fambeni (meaning “let’s go” in Tsonga language), which was launched in August 2010 to promote hydrogen and fuel-cell technology. The bicycle (Figure 4), built by students from the Tshwane University of Technology (TUT) in Pretoria, is made from light and strong advanced materials. It is intended to provide cheap powered transport for people living in rural villages, and is expected to be followed by a hydrogen fuel cell powered tricycle and, ultimately, by a hydrogen fuel cell powered car.

FIGURE 4: A HYDROGEN FUEL CELL POWERED BICYCLE BUILT BY TUT STUDENTS IN PRETORIA.

Source: Taken at the IPHE exhibition, Cape Town, 03 May 2012.

6. SA'S POTENTIAL AS A MAJOR PLAYER IN THE GLOBAL FUEL CELLS INDUSTRY

6.1 Opportunities

Major drivers for hydrogen and fuel cell technologies include energy security, climate change, sustainable energy generation and economic growth. By having more than 90 percent of the world's known PGMs reserves and accounting for approximately 75 percent of global platinum supply, South Africa has a dominant position in the ownership and supply of the natural resources needed for fuel cells and, therefore, it has the opportunity to play a part in their global provision and in providing expertise. According to HySA, the main goal is not to prepare SA markets for the hydrogen economy, but to prepare the country to be an exporter of value-added technologies that include PGMs. Currently, SA is the world's largest platinum exporter and there is a strong opportunity to add value to its exports through the production of platinum-containing fuel cell catalysts.

Hydrogen can be produced from diverse domestic sources and processes, freeing it from the political instabilities normally associated with oil and gas. Furthermore, over a century of safe production, transportation and use of hydrogen shows that it carries no more risk than the afore-mentioned fossil fuels. According to HySA Infrastructure, for the SA market, hydrogen will be derived from renewable sources, but can also be sourced from coal-bed methane. However, the latter will require additional technology in order to purify hydrogen, or the unpurified fuel will have to be used in special types of cells only. The challenge is the reduction of costs of the technology but fortunately for SA, HySA Infrastructure is already working on such a strategy and has identified cost reduction enablers.

Hydrogen and fuel cell technologies also offer SA an opportunity to develop the local market for PGMs, as relying on foreign markets has got its drawbacks. The local PGMs industry endured significant challenges after the Euro zone crisis resulted in subdued demand for platinum from the autocatalysts market, the major consumer of the metal, resulting in significant decline in prices. To a certain extent, the industry struggled to cope with the challenges, resulting in some mines shutting down due to low profit margins while smaller operators mothballed their development plans, leading to significant job losses. Such developments highlighted the need to develop local, and perhaps regional PGMs markets and diversify the metals' applications in order to derive maximum value from the country's resources.

Cellphone companies are touted as potential large scale entry points for a SA platinum fuel cell industry. A firm has already been lined up to establish a local fuel cell factory once sufficient demand exists. According to a report, the firm will need sales of 800 to 1 000 fuel cells per annum to justify the construction of a plant in SA. But that is not impossible as the cellphone industry in South Africa has about 20 000 relay stations, all with diesel generators, while in Africa there are about 70 000 cellphone base stations that require generators. The challenge is to convince operators on the advantage of fuel cells, as they are more reliable and provide steady current, while the current from an internal combustion engine fluctuates a great deal.

The other likely market is underground locomotives in mines, a prototype of which was put into operation recently at one of the PGMs mines in the country to establish the viability of commercialization. Rising energy costs are putting a lot of pressure on the mining industry, while the clean energy of a fuel cell has great benefits, particularly underground. Using the platinum-based hydrogen-powered fuel-cell locomotives would reduce the energy dependence of the mines on the state-owned power utility, and would be more environment-friendly than traditional rail transport. For a mine in SA, solar power is an attractive primary energy source for producing hydrogen on site in order to mine platinum in a more economical, energy secure and environmentally-friendly manner.

The development of technologies for fuel cell production in SA is expected to naturally thrive on the back of the catalytic converters industry with its currently installed capacity for coating of PGMs. Additionally, companies involved in the production of auto catalysts already have a footprint in the country, and these are the same companies involved in the development of fuel cells. The success of the auto catalysts industry is therefore expected to rub off on the fuel cells industry and for South Africa, such a success has a huge potential to go beyond just energy diversification. Through job creation, not only in manufacturing but also in the maintenance of various installations, and skills development due to their multi-faceted nature, fuel cells also provide opportunities for sustainable socio-economic development and enable the country to transition from a resource-based economy to a knowledge-based economy.

6.2 Challenges

South Africa's recent experience with platinum and other resources shows that amount of minerals in the ground does not automatically translate into a competitive manufacturing industry. The fact that PGMs have global dollar prices means that platinum costs the same in South Korea as in South Africa, which in turn means that local technology developers gain no benefit from being located close to the mines extracting the metals. For fuel cells, the cost is an important factor to consider, as do platinum substitution and the extent of commercialization. These are not unique to SA but affect global market dynamics.

The high capital cost for fuel cells is by far the largest factor contributing to the limited market penetration of fuel cell technology. In order for fuel cells to be competitive, there is a need to reduce both capital and installation costs (the cost per kilowatt required to purchase and install a power system). However, the usage of platinum as a catalyst in most designs escalates the operating costs due to the high price associated with platinum. As a result, research towards decreasing this dependency on platinum is currently underway. For SA, this presents a challenge since utilizing platinum resources is part of the reason for the country's rigorous approach towards capturing a portion of the fuel cell market. According to the International Platinum Association, there is no substitute for platinum that has proved to be as effective, particularly for PEM fuel cells. Platinum-mediated reactions may therefore remain at the core of fuel cell technologies for the fore-seeable future, which could be beneficial for SA in the long term.

The other factor to consider is how soon and to what extent the commercialization of fuel cells will start to impact significantly on the future platinum demand. Global platinum demand is expected to be increasingly affected in future by the extent to which fuel cell technology will become embedded in various applications. However, the debate over fuel cell technology and the associated platinum demand has been around for years, even stretching back to the 1980's. In fact, in 2004, fuel cells were poised to stimulate platinum demand from 2010 onwards. However, platinum demand from fuel cells still accounts for less than 1.0 percent of total demand. The level of fuel cell commercialization has therefore been well below expectations, moving at a snail's pace during the past decade. This poses a serious challenge, as SA intends to

supply 25 percent of the fuel cell market by 2020. Fuel cell demand for platinum could be around only 2 percent by then, and even capturing 25 percent of the market could be insignificant as far as local beneficiation is concerned. Perhaps the emphasis should be on the level to which the country needs to increase locally beneficiated platinum for other applications by 2020, rather than on the portion of the unreliable fuel cell market.

7. CONCLUSIONS

Fuel Cell technology has opened up new opportunities for platinum group metals (PGMs) and platinum in particular, since it uses the metal as a catalyst for the conversion of hydrogen into electricity. SA's abundant PGMs resources are therefore expected to put it in a good stead to be both an active participant in, and a beneficiary of the global fuel cell industry. Although the country is unlikely to be an early adopter of large-scale hydrogen energy technologies, it could still benefit in terms of business and jobs, in servicing the emerging hydrogen economy segments around the world. According to HySA, the main goal is not to prepare SA markets for the hydrogen economy, but to prepare the country to be an exporter of value-added technologies that include PGMs. However, hydrogen and fuel cell technologies also offer SA an opportunity to develop the local market for PGMs, particularly after the local PGMs industry endured significant challenges related to subdued demand for platinum. If successful the development of technologies for fuel cell production in SA is expected to naturally thrive on the back of the catalytic converters industry with its currently installed capacity for coating of PGMs. Cellphone companies and underground mine locomotives are touted as the likeliest large scale entry points for a SA platinum fuel cell industry. It must be mentioned, though, that reducing high capital costs by decreasing the platinum dependency of fuel cells presents a challenge since utilizing platinum resources is part of the reason for the country's rigorous approach towards capturing a portion of the fuel cell market, although platinum-mediated reactions may remain at the core of fuel cell technologies for the fore-seeable future. However, the fact that fuel cell commercialization has been well below expectations means that for local value-addition to platinum resources, relying on the success of fuel-cell commercialization could be detrimental to the country. The emphasis should therefore be on the level to which the country needs to increase locally beneficiated platinum by 2020, rather than on the portion of the unreliable fuel cell market.

8. RECOMMENDATIONS

The following recommendations are made:

- Continued participation in hydrogen and fuel cell research and development is vital, particularly for the purposes of energy diversification and ultimately capturing a significant portion of the fuel cell market.
- The focus should not just be on fuel cell technology. Strategies for various applications should be implemented in order to achieve the desired target.

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