# THE SOUTH AFRICAN PERSPECTIVE IN THE VISION OF THE GLOBAL TECHNOLOGY DEVELOPMENT OF HYDROGEN FUEL CELLS

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## Abstract

The South African hydrogen fuel cell technology (HFCT) initiatives is a national strategy response to the globally emerging HFCT sector. Among the currently developing renewable technologies, which includes wind powered energy systems, bio-fuels and ethanol production plants, hydrogen fuel cell technology, may be one of the most promising. The world population is increasing exponentially and the need for sufficient and uninterrupted energy supply continues to rise. The opportunity which hydrogen fuel cell technology contribute to this dilemma would alleviate some of the speculative demand in energy use. As a part of this general thrust, the South African Department of Science and Technology is encouraging and funding the development of fuel cell technology. If successful within the sustainability and financial constraints, a well-developed hydrogen fuel cell technology for South Africa and the region, can decrease strain on the national economy, and cut down the country's carbon footprint from coal-fired power generation. There is also the potential to improve the lifestyle and the economy in the remoter parts of the nation and the region by enabling on-site generation of electricity. The paper outline entails and locates the South African HFCT in the global project initiative, highlighting the current stage of its development, and the know-how as well as the endeavour towards its goals and the achievements up to date. This initiative gives South Africa an advantage over other countries given that it is the wealthiest country in platinum group metals (PGM). PGM are the key elements to the HFCT system efficiency; these are mainly used in the most performing fuel cell system known as the proton exchange membrane (PEM) fuel cell system. The achievements highlighted in the first five-year phase (2008-2013) by the SA hydrogen fuel cell technology initiative are discussed in detail emphasising trends already developed by international scientists and institutions involved in the HFCT initiative. This paper address concerns of policy makers, government regulatory bodies, the current large automotive manufacturers in the country, the clean energy production investors, and other renewable energy investment stakeholders to promote the implementation of hydrogen fuel cell technology in South Africa.

**Key words:** South African HFCT Development, Global HFCT Strategy, (PEM) fuel cell system, PGM, Renewable Energy.

## Introduction

The South African cabinet adopted hydrogen and fuel cell technology as one of the priority technologies to be developed in a bid to reduce the country's dependence on coal-fired power generation, oil and gas. The Department of Science and Technology (DST) submitted this proposition initiated from the public and private sectors; and this has been seen as a significant competitive advantage for the global HFCT initiatives in view of the country's abundant platinum metals deposits, a key raw material in fuel cells. Its objective is to foster proactive innovation and create knowledge and human resource capacity for industrial development with a South African advantage of PGM abundance estimated of about 80% of the world's reserves (DST, 2007). PGM are the only metals used as electro catalysts for the efficiency of hydrogen fuel cell technology. Moreover, South Africa aims to establish a base in hydrogen production and storage technologies, and to develop niche applications for regional needs. The country's potential reserves in PGM might result in the sector becoming a significant part of the national economy. The investment already done in this sector is around R400 million (approximately 56 million US dollars) to put in place the required research development and education infrastructure. Of the investment, around 80% is channelled towards technology and expertise development and 20% is used to stimulate private sector funding. Part of the funding will be used to establish basic hydrogen fuelling infrastructure to attract fuel cell vehicle manufacturers (UNU-MERIT, 2010).

## Main Natural Capital of the World's PGM and South African PGM related Reserves

The sustainability of PGM-based fuel cell technology is basically subjected to the potential of the natural capital of the World's PGM. Dominant PGM producers are progressively raising a capital reserve of platinum metals for the global HFCT industry. According to Mudd (2009b), it is significant to recognise that resource issues such as ore grade declination, increase of more energy and water consumption and environmental issues are possible constraints on future PGM production. The rate of PGM production growth may also be constrained by demand which is foreseen. South Africa, for instance, prepares to make reserves available to supply 25% of the global catalyst demand for the HFCT industry by 2020 (Mange, 2010). In the current stage of HFCT development, the share of the globally produced PGM is as yet at an insignificant level for the HFCT industry (Table 2). It is obvious that the 2020 target will bring about more efforts and pressure to the South African mining industry to increase the production with more environmental responsibility and more social responsibility to handle.

The global supply of PGM (Table 1) is largely dominated by South Africa due to its large economic reserves in the stratiform deposits built with Precambrian mafic to ultramafic layered intrusions known as the Bushveld Complex. South African PGM reserves are estimated to be 71,000 tonnes whilst the global reserves are estimated to be 80,000 tonnes (Mudd and Glaister, 2010).

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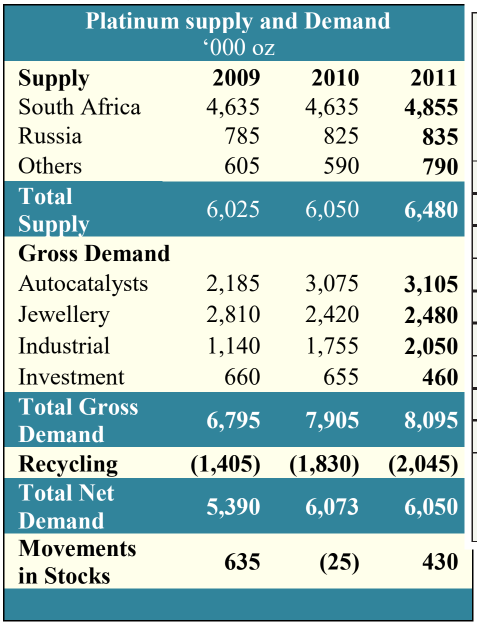
Table 1: PGM production and resources in 2007 by country (Mudd and Glaister, 2010)

| Country | Production | | | Reserves [b] | Reserve base [b] |
|---|---|---|---|---|---|
| | t Pt | t Pd | t PGM | t PGM | t PGM |
| South Africa | 165.83 | 86.46 | 310.92 | 63,000 | 70,000 |
| Russia | 27.00 | 96.80 | 138.30 | 6200 | 6600 |
| Canada | 6.20 | 10.50 | 20.20 | 310 | 390 |
| Zimbabwe | 5.30 | 4.20 | 11.00 | - | - |
| United States | 3.86 | 12.80 | - | 900 | 2000 |
| Columbia | 1.40 | - | - | - | - |
| Australia | ~0.90 a | ~0.73 a | - | - | - |
| World | 212 | 219 | 509 | 71,000 | 80,000 |

[a] Assuming Australia is credited with PGM extracted from ores and concentrates exported to Japan.
[b] They are broadly similar to reserves and resources as used in South Africa, Canada, Australia, and elsewhere. With t= tonne metric, Pt=platinum, Pd=palladium.

Table 2: Global demand for platinum:
Source: (Butler, 2012)



| Platinum supply and Demand '000 oz | | | |
|---|---|---|---|
| **Supply** | **2009** | **2010** | **2011** |
| South Africa | 4,635 | 4,635 | **4,855** |
| Russia | 785 | 825 | **835** |
| Others | 605 | 590 | **790** |
| **Total Supply** | 6,025 | 6,050 | **6,480** |
| **Gross Demand** | | | |
| Autocatalysts | 2,185 | 3,075 | **3,105** |
| Jewellery | 2,810 | 2,420 | **2,480** |
| Industrial | 1,140 | 1,755 | **2,050** |
| Investment | 660 | 655 | **460** |
| **Total Gross Demand** | **6,795** | **7,905** | **8,095** |
| **Recycling** | **(1,405)** | **(1,830)** | **(2,045)** |
| **Total Net Demand** | **5,390** | **6,073** | **6,050** |
| **Movements in Stocks** | **635** | **(25)** | **430** |

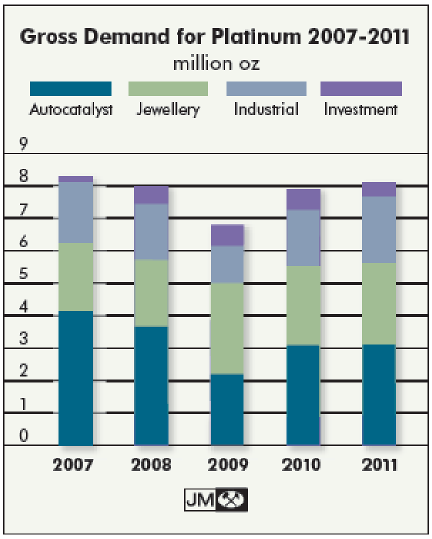


Figure 1: Gross Demand for Platinum 2007-2011. Source: (Butler, 2012)

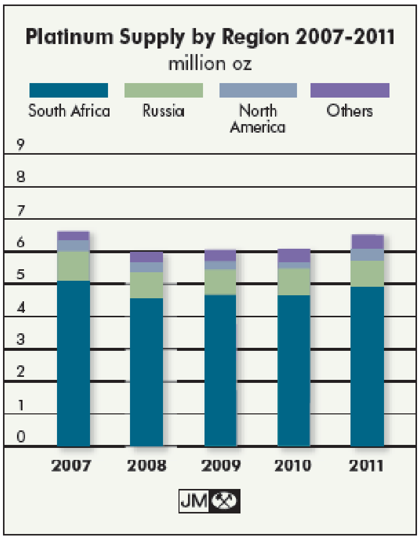


Figure 2: Platinum Supply by Region 2007-2011. Source: (Butler, 2012)

The world population is increasing exponentially and the need for sufficient and uninterrupted energy supply continues to rise. The opportunity which hydrogen fuel cell technology contribute to this dilemma would alleviate some of the speculative demand in energy use.

## South African Hydrogen Fuel Cell Initiative: Strategic Objectives

The acknowledgement by the South African Cabinet to the HFCT initiatives formulation was funded with expectancy in delivery such as thorough understanding of concepts of new technologies, developing suitable policies, mobilising innovation in support of economic growth, establishing intellectual property support platform, stimulating the development of technology-based services, products and enterprises, and encouraging investment.

With reference to South Africa's ability to improve the effective use of its PGM reserves for optimal, sustainable and equitable benefit for the country through a national HFCT initiative, the following advantages were looked at over and above PGM potential reserves (Mange, 2010; Sita, 2012):

(i) some pioneered HFCT RDI activities at some universities and science councils; HySA systems for instance, with 15 years of HFCT research at the launch of the South African HFCT initiative by DST in 2008;

(ii) some national nanotechnology strategy and expertise;

(iii) some specific catalysis expertise;

(iv) some innovative induction heating systems for processing precious and base metals;

(v) leadership in four-generation nuclear reactors;

(vi) a world-class photovoltaic RDI group;

(vii) an abundant and underutilised solar energy resource ;

(viii) The fuel cell industry is supported by thermodynamics fluids and design industries.

## Highlighted Achievements in the First Five-Year (2008-2013) Phase of the SA HFCT Initiatives

In the five years of HFCT initiative, South Africa developed a successful fast-track compared with the 10-15 years taken by the global HFCT strategy. This was done at a commercially relevant scale for low temperature proton exchange membrane (LT-PEM) applications. More achievements are as follows:

### High performance electro catalytic activities of LT-MEAs locally manufactured

The development of platinum nanophase composite electrode, with surface properties hydrophilic based catalyst layers, suitable to produce hydrogen when used in a standard electrolyser cell or in a Solid Polymer Electrolyte (SPE) electrolyser cell. The same nanophase composite electrode, with surface properties hydrophobic based catalyst layers, can be used to produce electricity from a Proton Exchange Membrane (PEM) fuel cell system. As designated, a setup composed of anode and cathode composite electrodes, combined with a specific electrolyte, forms a membrane electrode assembly (MEA) with following observations in testing (Petrik at al., 2008):

(i) The composite electrodes in low temperature (T<393K) testing at 333K achieving current densities about 600mAcm−2 at an applied potential of −2V when the standard electrode developed by Johnson Matthey Pt/C catalyst, merely reaching current density of 317mAcm−2, under same conditions applied.

(ii) Electro catalyst loadings of 0.03 and 0.04 g geometric cm−2 of gas diffusion electrode showing an increase in current and conductivity;

The following Figure 3 showing a comparative result achieved in terms of current density. All the three of the South African results far out-performed the JM Pt/C outcome. JM Pt/C showed no activity below 2 Volts applied potential.

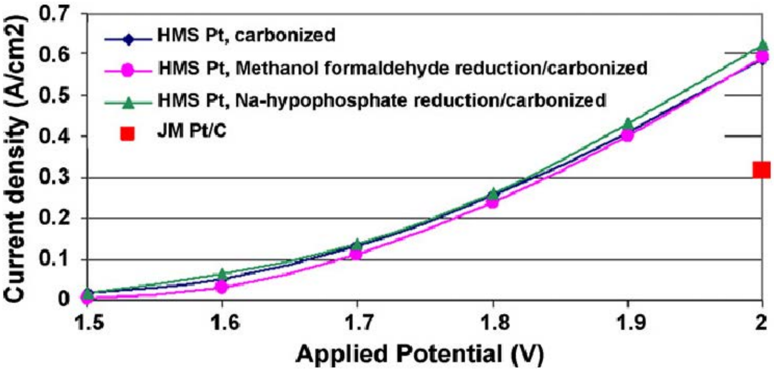


Figure 3: Comparison of electroactivity of Pt on HMS composites prepared by sequential deposition with binder (Nafion), conductive phase and nanophase upon carbon-based support for high electrolyte water electrolysis (conditions:333K; 40% KOH). Source: (Petrik et al., 2008)

Petrik et al. (2008) reported that the developed Pt nanophase electrodes were able to withstand a very high degree of hydrogen gas evolution at an applied potential of 6V. They showed that even under these aggressively accelerated testing conditions the nanophase catalyst containing thin films was stable and durable. The use of Pt composite electrodes in membrane electrode assemblies (MEA) such as solid polymer electrodes (SPE) electrolyser systems might bring better efficiencies for water electrolysis given the low cell resistance of the SPE electrolyser system which is as little as 0.075 Ohm in ultra-pure water. Alkaline systems and the like can use composite electrodes with a cell resistance of not less than 0.2 Ohm in ultra-pure water. Optimising a MEA is not a simple process given the large number of dependent variables partaking in the overall output. In the particular case of the electrolyser cell, a successful system will have to look at the following parameters as a whole:

(i) The over potential capacity of electrodes for the production of hydrogen and oxygen;

(ii) The cell potential reduction;

(iii) The maintenance of energy conversion and cell efficiency. The increase of energy efficiency requiring low operating voltage and highly active catalysts;

(iv) The electrode/electrolyte interface surface properties and energy consumed by reaction steps;

(v) The adsorption-desorption processes at the electrode surface;

(vi) The transport processes and thermal behaviour of gas diffusion electrodes;

(vii) The analysis of spatial distributions of the transport and the concentration of reactants and current density;

(viii) Other factors related to the type of MEA such as high or low temperature.

## HT MEAs catalyst development

The manufacture of the first South African high temperature MEAs (HT MEAs) which was developed in a joint venture between a local engineering company and a renowned key International partner (Sita, 2012).

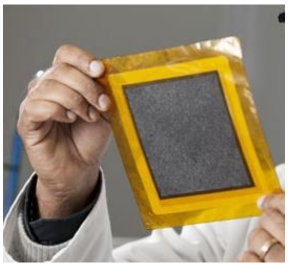


Figure 4: Figure First fuel cell electrodes (HT MEA). Source: (Sita, 2012)

## Portable power key programme

These are portable power system prototypes successfully developed at laboratory level with commercial development activities underway (Sita, 2012):

(i) The first South African Combi-Lit battery, which is an aqueous hybrid Li-ion/supercapacitor cell chemistry for high power applications such as being used as auxiliary power unit of fuel cell vehicles. These power units are manufactured on a small-scale prototype manufacturing line in South Africa. Combi-Lit is an activated carbon supercapacitor electrode and a Li-ion battery electrode of lithium manganite (HySA systems, 2011).

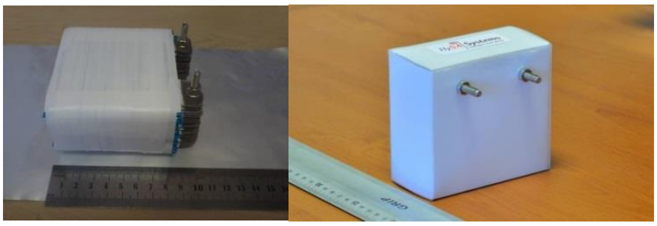


Figure 5: First Combi-lit battery manufactured in South Africa. Source: (Sita, 2012).

(ii) The manufacture of the first South African HT-PEM fuel cell stack and bipolar plates by local and key international manufacturers.

Figure 6: South African first HT-PEM fuel cell stack and bipolar plates. Source: (Sita, 2012)

(iii) The manufacture of the first 2.5kW Fuel Cell backup power system prototype in South Africa for the Telecommunication & UPS Markets

Figure 7: South African first 2.5kW Fuel Cell backup power system prototype. Source: (Sita, 2012)

(iv) The manufacture of the first 2kW HT-PEMFC combined heat & power unit for domestic applications in South Africa.

*Figure 8: South African first 2kW HT-PEMFC combined heat & power unit for domestic applications. Source: (Sita, 2012)*

(v) The manufacture the first prototype of a fuel cell powered tricycle in South Africa

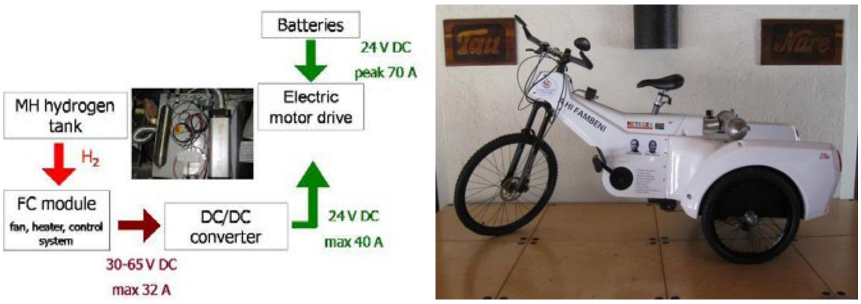


Figure 9: South African first prototype of a fuel cell powered tricycle. Source: (Sita, 2012)

(vi) The manufacturing plant and the first prototype of a fuel cell to power a fork lift in South Africa

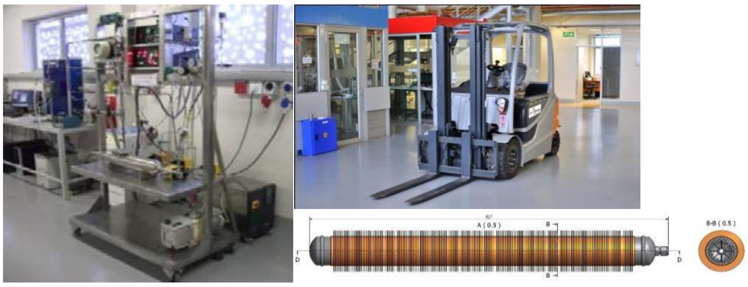


Figure 10: South African first prototype of a fuel cell powered fork lift. Source: (Sita, 2012)

## Human capital development

*Table 2: South African HFCT initiative: the human capital development (Sita, 2012)*

| Qualification | Supported (2008-2011) | Graduated (2011) |
|---|---:|---:|
| Masters | 51 | 11 |
| PhD | 21 | 2 |
| Post Docs | 5 | - |
| Total | 77 | 13 |

## South African HFCT initiative strategies and the timescale of the global estimated electrolysis plant capacity development

South Africa unlikely to be an early adopter of large-scale hydrogen energy technologies; but given its HFCT initiative achievements with maturation technology level expected within five years' time, and given the estimated timeframe of the global electrolysis plant capacity projections to oversupply hydrogen globally as expected in future (Figure 11), South Africa may be able to position its self to play a prominent role in the global HFCT.

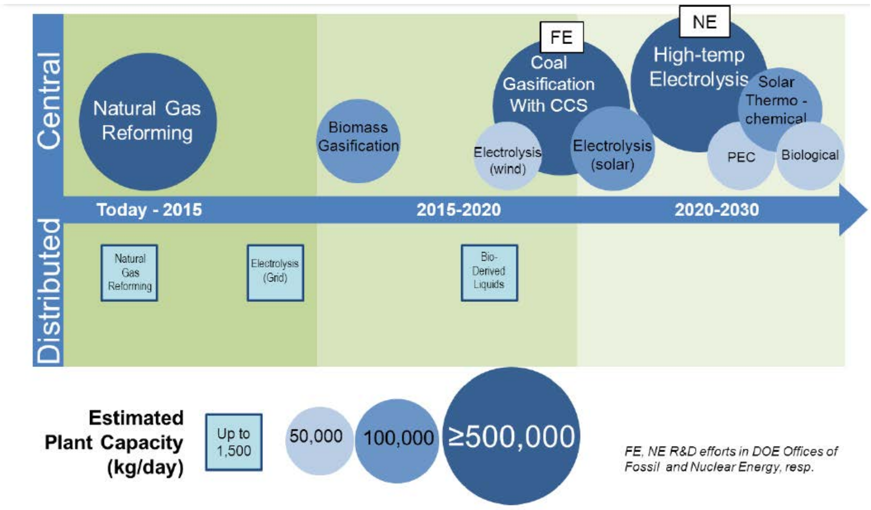


Figure 11: Estimated Electrolysis Plant Capacity. Source: (Gardiner, 2012)

## Conclusions

The South African HFCT strategy is partly invested in the creation of a path contributing to the local economy as whole to benefit from the country's natural resources. The economic benefits from PGMs resources by HFCT initiatives are to reach the poor and side-lined part of the community. In the short term, HFCT has the potential to provide a cost-effective reliable energy services for various niche applications in Southern Africa. The long-term secondary benefits would be a reliable supply of energy for the deeply remote rural zones.

South African HFCT initiatives is a ten year running project (2008-2018) which is defined as one of the edge initiatives technology piloted by DST. The primary objective of the South African HFCT initiatives was to hoist the country to the ranks of leaders in the development of HFCT technologies (Mange, 2010). The strategy of medium to long term aims to successfully implement the following indicators:

(i) Commercial application of research that results the creation of sustainable businesses and employment;

(ii) Development of a pool of skilled researchers and technicians;

(iii) Quality and quantity of intellectual property held by South African institutions; and

(iv) Measurable impact on the quality of life of affected communities through improved standards of living, a cleaner environment, better access to suitable energy services and employment.

The SA HFCT initiatives targeted to stimulate opportunities to acquire tangible benefits of high-tech values through which a reform may result to impact its society on values and competences to acquaint with global environmental trend of wealth creation through know-how to innovation and which can be extended to other scientific fields of development. The following are also indicators aiming by SA HFCT initiatives (DST, 2007; Sita, 2012):

(i) To create knowledge and human resource capacity to develop high value commercial activities in HFCT utilising local resources and existing know-how

(ii) Wealth creation through high value-added manufacturing

(iii) A shift to high-value and knowledge-intensive products of natural wealth transformation is a national objective which requires a thorough understanding of concepts of new technologies. The development of the PGM catalysis value chain will expose the country, given its potential PGM reserves, to play a prominent role in the global HFCT local industry.

(iv) Developing hydrogen infrastructure solutions

(v) The country might likely benefit by promoting the early development of hydrogen infrastructure from the existing knowledge of high-temperature gas-cooled nuclear reactors and the Fischer-Tropsch process, a coal gasification and liquefaction technology, which might assist with large-scale production and distribution of hydrogen.

(vi) Equity and inclusion

The directly above objectives rely on pre-investment in programmes in order to identify suitable human capital. Further advanced objectives of the national HFCT initiatives are as follow:

(i) Establishing a base for hydrogen production, storage technologies and processes;

(ii) Establishing a base for developing PGM-based catalysts;

(iii) Building on existing global knowledge and developing know-how to apply and build on existing HFCT for niche applications to address regional developmental challenges.

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