Alternative Fuels: Hydrogen Fuel Cells

Dmitri Bessarabov
DST HySA Infrastructure Center of Competence, NWU/CSIR

http://www.hysainfrastructure.org/
1. Author: Brief Introduction
2. SA energy profile
3. HySA: relevance to South Africa
4. World hydrogen landscape and markets
5. HFCT sector: selected international organizations
6. Application landscape: alternative fuel examples
7. South African case: solving real problems for people
8. Emerging technologies: Power-to-Gas projects
9. Conclusions
• 1991- Moscow State University – M.Sc. (Physical Chemistry and Chemical Technology)
• 1991-1993- Russian Academy of Sciences (Membranes for Gas Separation)
• 1999 – 2001: Senior lecturer – U. Stellenbosch
• 2001-2006: Aker Kvaerner Chemetics (AKC) - novel membrane processes for chlor-alkali industry (OMD, NF, HAD)
• 2006-2010: Ballard/AFCC (Fuel Cell MEA research for automotive industry)
• ~ 20 years of applied membrane research experience; former “Y” SA NRF rating, current “C” rating; more than 100 papers and presentations/proceedings; international patents; Editorial Board member for Membrane Technology journal; Canadian PEM academia-industry network coordinator.
• 2010- present: SA Hydrogen Infrastructure (HySA) CoC: Director (NWU/CSIR)
• 2014 – present: Co-founder and Co-Director: SAHA
“We have not inherited this world from our parents, but we have it on loan from our children”
Evidence of the global warming....

- **Land surface air temperature** as measured by weather stations.
- **Sea surface temperature.**
- **Air temperature over the oceans.**
- **Sea level.**
- **Glaciers.** (2009 was the 19th consecutive year in which there was a net loss of ice from glaciers worldwide).
- **Northern Hemisphere snow cover,** (has also decreased in recent decades).
- **Arctic sea ice.** Satellite measurements are available back to 1979 and reliable shipping records back to 1953. September sea ice extent has shrunk by 35% since 1979.
US: transportation generates about a third of the CO$_2$ and production of electricity generates about 40%. For oil consumption, transportation consumes $\sim \frac{2}{3}$ of the oil used in US, and $\sim \frac{2}{3}$ of that is for light duty vehicles.
South African Energy Profile

- **Coal** supplies ~75% of South Africa’s primary energy and ~90% of its electricity requirements.

- South Africa has estimated coal reserves of 35 billion tons.

- Annually ~285 million tons is mined from 73 mines in 19 coalfields.

- Domestic consumption of coal amounts to ~171 million tons (~100 mt for electricity and ~70 mt for synfuels) and ~69 million tons is exported.

- RSA has an energy-intensive economy.

- RSA has a large SO₂/CO₂ footprint.

- RSA’s CO₂ footprint per capita ranks among the top 12 in the world.

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*CR&W: Combustible Renewable and Waste

Source: International Energy Agency (IEA)
## South African SO$_2$ footprint

(new SO$_2$ emission regulations are coming soon)

<table>
<thead>
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<td>225,000</td>
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<td>15,340</td>
<td>17,650</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

1. Eskom Annual Report 2010
2. Sasol Sustainable Development Report 2010
3. Implats Annual Report 2010

**Annual emission of SO$_2$ (t)**
In SA:
- **AVERAGE**: 4.5 – 5 kWh/m²/day
- 1 kW/m² for a 5.5 hour day
- 245 GW capacity
- 834 TWh @ 39% capacity factor

South Africa is the dominant PGM supplier

PGM Supply by region

- South Africa: 79%
- Russia: 12%
- North America: 5%
- Others: 4%
Facts about SA

South Africa has nearly 80% of the world’s PGMs

Population: ~ 50 m
~ 25% plus unemployed
~ 5 m tax-payers
HySA: Strategic Goals

- Develop local cost competitive hydrogen generation solution based on renewable resources

- Wealth creation through value added manufacturing of PGM catalysis, goal- supply 25% of PGM catalysts demand by 2020

- Promote equity and inclusion in the economic benefits of South Africa’s resources, SMEs to play an important role

HySA Infrastructure Successful Launch (2013)
Commercial scale solar-to-hydrogen system: fuel for FC

- Upgrade:
  - 6 kW PV to 15 kW PV
  - 30 kWh to 90 kWh battery storage
  - 0.56 kg to 2.5 kg production of high purity hydrogen per day
  - Air-driven hydrogen booster provides filling pressures up to 200 bar
  - Solid-state H2 compression development
Proton exchange membrane fuel cell

1. Hydrogen fuel is channeled through field flow plates to the anode on one side of the fuel cell, while oxidant (oxygen or air) is channeled to the cathode on the other side of the cell.

2. At the anode, a platinum catalyst causes the hydrogen to split into positive hydrogen ions (protons) and negatively charged electrons.

3. The polymer electrolyte membrane (PEM) allows only the positively charged ions to pass through it to the cathode. The negatively charged electrons must travel along an external circuit to the cathode, creating an electrical current.

4. At the cathode, the electrons and positively charged hydrogen ions combine with oxygen to form water, which flows out of the cell.
The petroleum refining industry is the primary driver of hydrogen (H₂) consumption around the world.

9% of global H₂ demand by volume is consumed in applications other than petroleum refining and chemical production. In 2011, these markets accounted for 21 billion m³ of H₂. This includes H₂ used in manufacturing applications such as semiconductors, food products, glass, and metal products. All the H₂ consumed by technologies emerging within the new H₂ economy (fuel cells and fuel cell vehicles, predominantly) are in this category. Non-manufacturing applications for H₂, such as rocket fuel, are also included.

World demand for H₂ is forecast to advance 4.1 % annually to 286 billion m³ in 2016. In value terms, H₂ consumption will expand 8.2 % annually to $43 billion. Between 2001 and 2011, world H₂ demand by volume increased a total of 47 percent to 234 billion m³. Of this 75 billion m³ increase, two-thirds was accounted for by the world’s refineries, which are increasingly producing cleaner-burning fuels that require more H₂ to produce.
H2, a valuable commodity gas, is increasingly recognized as an important fuel and energy storage vector of the future. Demand for H2 as a fuel for FC, in both transport and stationary applications (the power-to-transport and power-to-power vectors, respectively) will continue to grow, alongside hydrogen for energy storage (the power-to-gas vector). The power-to-power, power-to-transport, and power-to-gas vectors are forecast to consume nearly 31 billion kg of merchant hydrogen between 2013 and 2030. The majority of this demand will come from the power-to-power sector, with the hydrogen fuel for telecommunications primarily providing backup and prime power to mobile base stations, leading global demand by 2021. Power-to-gas, the current darling of the hydrogen industry, is expected to account for a conservative 45 million kg in 2030.
**H₂ Landscape: Current and Future Markets: sustainable mobility**

**The Markets**

**Industry**
- Alternator cooling
- Float Glass
- Heat Treatment

**Hydrogen Mobility**
- OnSite H₂ for HRS

**Renewable Energy Storage**
- Power2gas
- FC Re-electrification

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*HySA Infrastructure*  
*Hydrogen South Africa*  
*CSIR*
Where is the “killer application” for HFCT? - Electric Power Analogy (sales by volume)

≈$300/kW Hr

≈$0.10/kW Hr
Hydrogen for sustainable mobility: Emerging markets

Brazilian Fuel Cell Bus Market Opportunity

- **Largest transit bus market in the world**
  - Approximately 35,000 buses purchased each year
  - Sao Paulo, Brazil’s largest city, has a fleet of 16,000 buses

- **Significant air pollution**
  - Sao Paulo is one of the most polluted cities in the world...
    - ~6 deaths per day attributed to air pollution
  - 85% of emissions are attributed to vehicles

- **Government initiatives**
  - National Plan on Climate Change: Gov’t commitment to significant use of zero-emission transit technology
  - Upcoming events: 2014 World Cup and 2016 Summer Olympic Games
Operating experience

Phase IIa Verification Test Results

- **Performance:**
  - Fuel cell bus performance superior to existing diesel fleet
  - Drivers praised ease of operation & comfort

- **Fuel efficiency:**
  - Average hydrogen consumption of 13.3kg/100km, exceeding goal of 15kg/100km

- **Challenges:**
  - Some system failures due to operating environment (humidity, dust & weather conditions), to be addressed in Phase IIb
Why Fuel Cell Buses?

- **Completely eliminates tailpipe emissions**
  - Nox, Sox, PM

- **Noise reduction and comfortable ride**

- **Improved fuel efficiency**
  - 1.5-2.5x improvement over conventional diesel buses on an energy equivalent basis

- **Reduced Greenhouse Gas Emissions**
  - Demonstrated on a well to wheel basis

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BC Transit has calculated* a WTW reduction in CO$_2$ emissions of 62% for the Whistler buses.
Hydrogen for mining operation
### 2013 Comparative Operating and Capital Costs for Underground Mine Loaders

**Annual operating cost comparison 8 LHD's, Louvicourt.**

<table>
<thead>
<tr>
<th></th>
<th>Diesel</th>
<th>Fuel cell-hybrid</th>
<th>Difference between diesel and fuel cell-hybrid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maintenance, fuel, hydride, bed cooling</td>
<td>$2,800,000</td>
<td>$3,016,500</td>
<td>$(216,500)</td>
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<td>Ventilation</td>
<td>$2,200,000</td>
<td>$1,650,000</td>
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<tr>
<td><strong>Total</strong></td>
<td>$5,000,000</td>
<td>$4,666,500</td>
<td>$133,500</td>
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</table>

**Underground Loaders (LHDs) – term used to describe load and haul equipment**
Example of potential large-scale niche application of H₂ and FC technology in SA mining industry

Fuel Cells and associated H₂ Infrastructure represent an exciting new market which could drive growth for platinum as well as spark significant new opportunities for SA.

Benefits of developing H₂ infrastructure and fuel cell market in South Africa: means of meeting increasing demand for energy, reduction of carbon footprint, platform for beneficiation, opportunity for job creation, increase demand for platinum group metals.
Mechanisation opportunity

THE FUEL CELL DOZER WILL REVOLUTIONISE MECHANISED MINING AND IS A PRECURSOR FOR LARGER MACHINES

Why fuel cell dozer?

- **Safety through automation** - LHD operation presents a case for automation since the roof of tunnels in open stope areas are unstable
- **Entry point for diesel equipment** - the commercialisation of Dozer ‘opens the door’ to convert other, larger diesel-driven equipment
- **First Ultra Low Profile fuel cell mining application**

What is the fuel cell dozer?

- Ultra low profile stope dozer for fully mechanized mining capable of cleaning the entire face within 45 minutes (174 tons)
- Easy to manoeuvre in tight spaces and capable of ascending steep inclines (18°)
- Refuels in 15 – 45 minutes / shift and machine availability of 95%
- Continuous max power of 33 kW and average energy for pushing cycle of 5.6 kWh
Off-grid telecommunication base stations without possibility of being connected to the grid offer high value proposition for the near-term hydrogen fuel cell market.

There are approximately 640,000 off-grid cell-phone towers worldwide, while new off-grid installations are growing at 12% per annum.

To a large extent, this growth is attributed to the dynamic economic expansion and emergence of developing countries.

Telecommunication networks have resolved to use large battery banks and diesel generators as prime power sources at these remote locations.

Unfortunately, diesel generators and battery banks have reportedly been vandalised at isolated telecommunication base stations and valuable items such as diesel fuel and important battery components have become targets for theft.
Amplats, partner launch trailblazing platinum-using fuel cell mini-grid: FIRST EVER The world’s first platinum-using fuel cell minigrid prototype was developed for use in an off-grid residential application, where the cost of electrification through grid expansion might be too expensive or technically prohibitive: http://www.miningweekly.com/article/platinum-first-as-fuel-cells-power-rural-homes-in-free-state-2014-08-15

Speaking at the launch, Department of Mineral Resources Deputy Minister Godfrey Oliphant said there were 3.4-million households in South Africa without access to electricity from the national grid, with 1.4-million of these being in rural areas.
Honda’s hydrogen production, storage and fueling station in Torrance, CA
Overall costs for infrastructure are similar, shape is different.

- **Investment for the charging infrastructure depends on vehicles sales**
- **H₂-infrastructure requires start-up investments**

AFCC, A. Truckenbrodt
125 4-5 MILES AN HOUR.

Electric Car on Marienfelde-Zossen Line Breaks All Records.

BERLIN, Oct. 6.—An electric car on the Marienfelde-Zossen experimental line reached a speed of 125 4-5 miles an hour to-day, or a kilometer more than the highest previous record. The machinery and roadbed were unimpaired. The engineers are determined to try for still higher speeds and venture the opinion that they will be able to attain the rate of 140 miles per hour.

ELECTRIC CAR RECORD;
MAKES 100-MILE RUN

Remarkable Test for Stock Run-about on Single Charge.

PHILADELPHIA, Oct. 12.—A run of 100 miles was made to-day by an electric car from Jersey City to Philadelphia on a single charge and using only its regular stock batteries. It was the most severe and satisfactory test to which a stock electric car has ever been put.
H₂ Landscape: Current and Future Markets: Energy Storage

**The Markets**

**Industry**
- Alternator cooling
- Float Glass
- Heat Treatment

**Hydrogen Mobility**
- OnSite H₂ for HRS

**Renewable Energy Storage**
- Power2gas
- FC Re-electrification
### Power-to-Gas Demonstration Projects
**Power-to-Gas Demonstration Projects, World Markets: 2010-2012**

<table>
<thead>
<tr>
<th>Project Location</th>
<th>Country</th>
<th>Companies Involved</th>
<th>Installed Power (kW)</th>
<th>PEM/A</th>
<th>Power Load</th>
<th>Hydrogen or SS reaction</th>
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<td>Werlte</td>
<td>Germany</td>
<td>Audi</td>
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<td>TBC</td>
<td>Base Load</td>
<td>Sabatier reaction</td>
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Fuel Cells and associated H₂ Infrastructure represent an exciting new market which could drive growth for platinum as well as spark significant new opportunities internationally and locally in SA.

- HFCT organizations depend on the government funding.
- Power-to-Gas is a new complex technology that uses renewable H₂ and could become fastest growing technology utilizing electrolytic hydrogen, thus significantly increasing demand for large electrolyzes.

Benefits of developing H₂ infrastructure and fuel cell market in SA:

- Means of meeting increasing demand for energy,
- Reduction of carbon footprint,
- Platform for mineral beneficiation,
- Opportunity for job creation,
- Export opportunities,
- Increase demand for platinum group metals.