Hydrogen, Fuel Cells and Renewable Energy

S.P.S. Badwal, S. Giddey and P. Bandopadhayay
CSIRO Energy Technology, CSIRO Energy Transformed Flagship
Address for authors: Private Bag 33, Clayton South 3169, Victoria, Australia
E-mail: Sukhvinder.Badwal@csiro.au

Summary

The presentation is a general presentation on hydrogen and fuel cells and covers the following main areas:

- Drivers for new energy technologies and the role of hydrogen in future energy mix
- Fuel Cells and technological challenges.
- CSIRO's R & D in hydrogen and fuel cells based on polymer electrolyte membrane technologies.
- Oreion Australia Energy – a new company in the Hydrogen / Fuel Cell space with technology license from CSIRO.
- Modelling of Hydrogen Renewable Energy Storage System based on an electrolyser, a fuel cell and a source of renewable energy.

Drivers for new energy technologies

- Global energy demand - over the period 2003-2030, the total global energy demand is forecast to increase by 71% (170% in Asia) (US-EIA- International Energy Outlook 2006). The demand for energy, including transport fuels, is increasing at an alarming level in developing countries such as India and China. For sustained economic growth, this demand has to be met from a number of sources.
- Concern over climate change - Global warming, GHG emissions and rapidly rising Carbon dioxide levels.
- Concern over deteriorating air quality and its effect on human health with increasing pollution levels (NO_X, SO_X, CO, PM_X) especially in developing countries.
- Energy security and sustainability:
    - Peak in global liquid fuel production is forecast by many experts to occur shortly within the next few years.
    - Uneven distribution of carbon based energy resources: about 58% natural gas reserves are located in Russia, Iran and Qatar; and today about 66% oil reserves are in the Middle East, growing to 83% in 2020 (US Energy Information Administration).

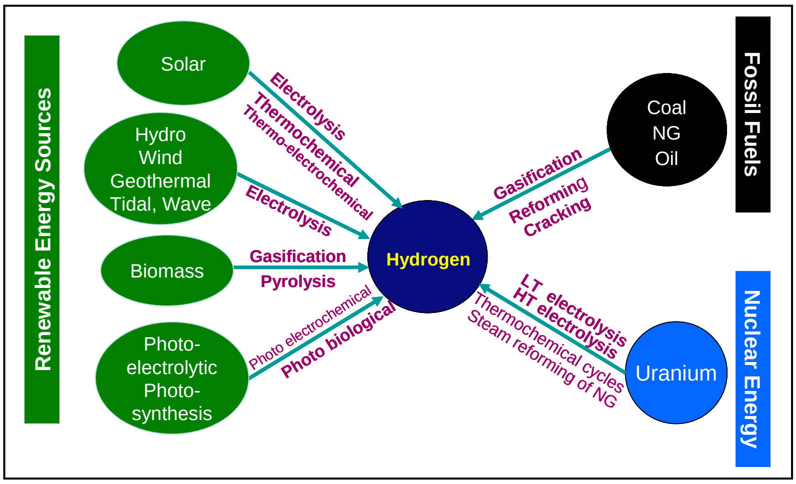
A range of energy solutions are under development globally to avoid catastrophic consequences arising from global warming, shortage of transport fuels and poor air quality. Many of these solutions point to hydrogen as an energy currency, carrier and storage media. The global investment in hydrogen R & D and technology development and commercialisation is now several billion dollars and is increasing exponentially with major initiatives announced in recent years in the USA, Europe, Japan, China and India.

Hydrogen - the role of hydrogen in future energy mix

One of the major drivers for a shift to the hydrogen economy is the looming shortage of transport fuels with a peak in oil production likely to occur within the next few years (Campbell C J (2002). *World: Oil and Gas Industry - Peak Oil: an Outlook on Crude Oil Depletion*, http://www.mbendi.com/indy/oilg/p0070.htm).

Hydrogen offers a clean and sustainable alternative to dwindling transport fuels and future energy needs. Hydrogen is the best energy carrier and a flexible storage media. Hydrogen combustion either in a fuel cell or in an internal combustion engine generates no toxic pollution or CO_2.

Hydrogen can be generated from fossil fuels (coal gasification or natural gas reforming followed by hydrogen separation), and from nuclear fuels or renewable energy sources using either the heat or both heat and electricity (thermal or thermo-chemical processes and high or low temperature water electrolysis). However, if hydrogen is to be generated from fossil fuels, it must be CO_2 neutral to reduce the impact of large scale hydrogen use on the environment. Hydrogen generation using water and renewable energy sources is greenhouse gas neutral and offers long term energy security and removes regional energy bondage.

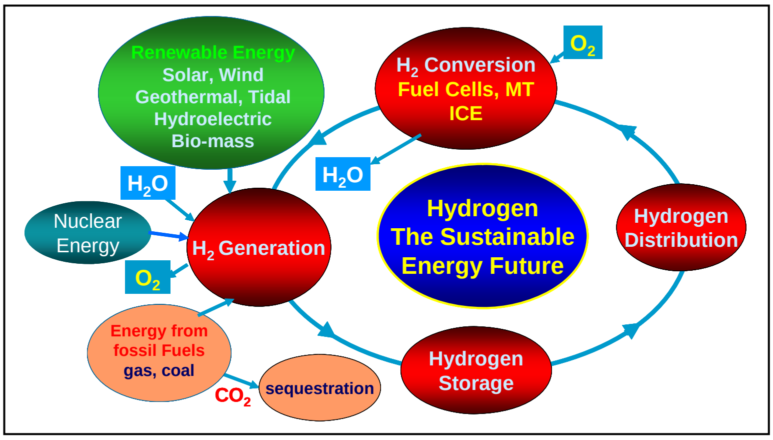


Other energy carriers such as natural gas and bio-fuels including ethanol and bio-diesel will no doubt provide some transport fuel solution but it will be short term and limited.

The major challenges for the adaptation of the hydrogen economy are the lack of hydrogen transportation and distribution infrastructure, codes and standards, and cost and reliability of technologies for its large scale generation, storage, transportation, distribution and utilisation.

Distributed hydrogen generation at demand centres has the potential to reduce or eliminate the need for costly up-front transportation / distribution infrastructure requirements and can assist with the early introduction of the hydrogen economy as well as with increased trials of the fuel cell technology. Thus there is increasing emphasis on developing technologies which reduce the hydrogen transportation / distribution infrastructure costs.

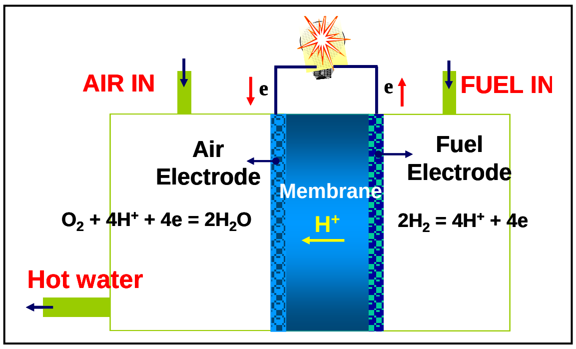
Current global hydrogen production is around 45million tons per annum, enough to meet US transport fuel demand. Most of current hydrogen production is used for ammonia (fertiliser), oil refining and other non-energy industry uses with about 1% in direct energy usage. In order to meet only global transport demand, hydrogen production has to increase by more than an order of magnitude.



Fuel Cells and Technological Challenges

Fuel cell is an electrochemical device which generates electricity continuously without direct combustion by harnessing the energy created when hydrogen and oxygen are electrochemically combined. A fuel cell consists of an electrolyte (solid, or a liquid or a molten mass held in a matrix) and air and fuel electrodes. Fuel cells are energy conversion devices like an ICE or a power plant and need no recharging. Batteries are essentially storage devices.

Fuel Cells combine the clean and quite attributes of a battery with the refueling capabilities of an internal combustion engine. Typical power output from a single fuel cell is 0.5-0.7V under load with power operating densities >300-400mW/cm^2. A number of cells are connected in series to achieve optimal power output.



The operating characteristics of four main fuel cells, efficiencies and costs are given in Table 1. A fuel cell power plant consists of a fuel cell module, balance of plant (BOP) and overall mechanical and electrical control systems. The BOP construction will vary depending on the application, fuel cell type, available fuel, and heat and electric load requirements and may consist of fuel and air delivery sub-systems, a fuel processor (desulphuriser, hydrocarbon reforming unit or a pre-reformer to remove ethane and higher hydrocarbons in the natural gas, humidifier), a power conditioning unit to convert DC into required power output and a heat management system for the entire plant (heat recovery, recycling, heat exchangers, etc.).

For the fuel cell module, typically accumulated operating times of 40000-50000h for stationary and 3000-5000h for transport and 4000h for portable power applications are required. The BOP life times of around 25 years are necessary for the system to be economical.

Table 1: Operating characteristics of four main fuel cell types.

Fuel Cell Type	Operating Temp. °C	Exhaust Temp. °C	Efficiency (%)		Cost US $ /kW	
			Electric	CHP	Current	Target
Phosphoric Acid (PAFC)	200–215	100-150	35–42	70-80	3000	1500
Polymer Electrolyte Membrane (PEMFC)	70–100	40-60	35-45	80-90	4000-6000	800-1000
PEMFC – portable power	20-50°C	-	50	-	??	3000
Molten Carbonate (MCFC)	650	500–600	50-55	80-85	30000	1500
Solid Oxide (SOFC) – Tubular	1000	800-850	50-70	80-90	10000	1200
Solid Oxide (SOFC) – Planar	700-900	600-750	>50	80-90	??	1000-1200

The alkaline fuel cell has been used in the past in space missions and some vehicular applications but most of the effort on this fuel cell has subsided. Efficiencies given in the table are based on low heating value (LHV) of natural gas. CHP efficiencies refer to combined heat and power generation. The generic name of the fuel cell is usually derived from the type of electrolyte material used.

Fuel cells offer numerous advantages over conventional power generation systems such as high energy density, high efficiency (forecast >40% well to wheel for transport, and >70% fuel life cycle with heat recovery for stationary applications), low noise, low pollution and particulate matter emissions, ability to co-generate heat and electricity at demand centres, high quality power (no spikes or electrical noise), minimum transmission / distribution infrastructure and losses, modularity and fuel flexibility.

Applications of fuel cells include:

Transport

- Electric Vehicles: Cars, Buses, Trucks, Locomotives, Sailboats.
- Small Transporters: Airports, Railway stations, Shipyards, Golf carts, Delivery vans, Wheel chairs, Hospital mobile carts, Recreational vehicles, Bikes.

Stationary Power

- Distributed Energy: Co-gen. of heat & electricity in office buildings, hospitals, apartment complexes, etc.
- Residential Power, Remote Area Power.
- Premium / Standby Power: UPSs, Internet data banks, Stock markets, banking services, computers, Variable message signs, etc.

Small and Portable Power

- Portable Power: mobile phones, laptops, PDAs, portable electronic appliances, soldier packs, emergency power, camping auxiliary power, remote & strategic communication, remote phone exchanges, etc.
- Defence, Space.

A number of companies are conducting trials of fuel cells in buses, cars and for stationary power generation. Most automotive manufacturers have a program in fuel cell vehicles (DaimlerChrysler, Ford, Toyota, GM, Volvo, Honda, Mitsubishi, Mazda, Renault, Volkswagen, BMW, Hyundai, Reva). Semi-commercial fuel cell units with limited warranties are available, however, the cost is high and lifetime short.

Major hurdles for the commercialisation of the fuel cell technology are their short lifetime, high cost and lack of hydrogen refuelling infrastructure and availability of robust and cost effective hydrogen storage technologies. Substantial materials research and development effort is still required to increase the reliability of the technology and to reduce overall fuel cell stack cost.

CSIRO's R & D in Hydrogen and Fuel Cell Space

In the hydrogen / fuel cell space, CSIRO has been performing research and development in a number of technologies which include:

- Test Stations for testing fuel cells from few watts to kW range.

- PEM Fuel cells in the kW range for small scale applications such as small transport and emergency or back-up power.
- Micro fuel cells (1-500W range) for portable electronic applinaces such as lap top computers, PDAs, mobile phones, soldier packs, remote communication, back-up power, etc.
- PEM Electrolysers for on-demand, distributed hydrogen production (efficiency >80% at $1A/cm^2$).
- Oxygen generater for homecare oxygen therapy and other medical applications.

CSIRO team involved in the project

Dr Sukhvinder Badwal, Dr Sarb Giddey, Dr Brett Sexton, Mr Robin Clarke, Mr Fabio Ciacchi, Mr Pon Kao, Mr John Beatty, Mrs Fiona Glenn, Mr Daniel Fini.
Other participants: Dr Pratish Bandopadhayay, Mr Stephen Meddings.

Oreion Australia Energy Pty Ltd

Oreion has exclusive worldwide rights to licence from CSIRO the Polymer Electrolyte Membrane (PEM) technology areas listed above. Oreion is a growing high technology company, formed to develop and commercialise in international markets sustainable enabling technologies in the fast evolving hydrogen and fuel cell space. Oreion will develop and commercialise technologies under the following registered brand names:

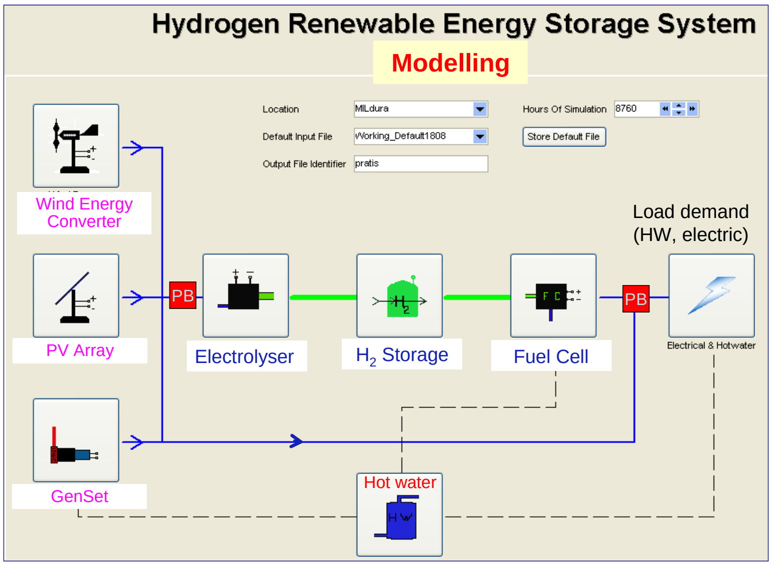
- Oreion HYTEST™ for testing evaluation of fuel cells and components.
- OREION HYGEN™ for convenient on site supply of hydrogen to end users.
- OREION HYMICRO™ - Direct hydrogen micro fuel cell (1-500W).
- OREION MEDoxyGEN™ Oxygen Generator.

Further information about the Company is available at: www.oreion.net

Modelling of Hydrogen Renewable Energy Storage System

A number of renewable energy sources are available in Australia and globally and promise to fulfil most of our future energy demands. One of the major barriers to the use of renewable energy, however, is the intermittent nature of its availability and the requirement of efficient storage system to ensure robustness of the energy supply to the user. Alternatively the renewable energy source needs a grid back-up.

A modelling / analysis package that allows the investigation of various options of hydrogen based renewable energy storage solution, such as that shown below, in terms of the overall system efficiency and economics is under development.



The basics of the simulation package are:

- The renewable energy system meets basic load demand when effective with excess stored in the form of hydrogen generated by the electrolysis unit.
- The electrolysis unit in conjunction with the fuel cell unit provide load levelling and meet load demand when the renewable energy source is fully or partially ineffective.
- The PEM electrolyser is capable of producing hydrogen at pressures up to 20bar.
- A relatively low cost storage tank is used to store hydrogen at pressures up to 20bar.
- The system is controlled by the load demand and hydrogen tank gas pressure.
- The fuel cell connected to the hydrogen tank supplies the required electrical load demand when the tank pressure is above 2bar.
- The electrolyser operates when the tank pressure is below 20bar.
- The system can also incorporate an internal combustion engine to accommodate excess load demand.
- The thermal energy from the fuel cell cooling circuit and the waste heat from the generating set are collected in the hot water tank which supplies the hot water demand.
- Available hourly data for the wind speed, solar radiation, electrical load demand and hot water consumption for a typical site are used for simulation.
- The simulation can be performed on daily, weekly, monthly or yearly basis.
- The simple simulation model developed, assists with optimisation of Hydrogen Energy Storage System components (size of fuel Cell, hydrogen storage system, the Wind Energy Converter or PV array and GenSet if required).
- Based on electricity and hot water demand of a particular site on weekly, monthly and yearly basis provides choices and assists with performance and cost optimisation.
- The model can also predict environmental benefits in terms of reduction in greenhouse gas emission.

For further information contact:

Dr Sukhvinder Badwal, Chief Research Scientist, CSIRO Energy Technology
Phone: 03-95452719, Mobile: 0402-014644, email: Sukhvinder.Badwal@csiro.au