HYDROGEN TECHNOLOGY OVERVIEW

By Luigi Bonadio – Published in ENGINEERS AUSTRALIA May 2008

Update on hydrogen power and fuel cell technologies

PRODUCTION

Hydrogen is not an energy source, but an energy carrier. It can be cleaved from fossil fuels via a reformation, partial oxidation or gasification process and is commonly followed by a water-shift reaction to covert undesired CO to CO_2 and increase hydrogen yield. The reformation of natural gas supplies the majority of global hydrogen production today with the contribution from new-generation coal gasification plants likely to increase in the mid to long term. General Electric, Rio Tinto and BP are raising capital for zero-emission plants based on the integration of coal gasification, hydrogen turbine and carbon capture and storage technologies. However, the hydrogen derived from Australian plants, in the initial case, will be produced for synfuel and "cleaner" diesel production rather than for an expanded uptake of hydrogen and fuel cell (H&FC) technologies.

Hydrogen derived from fossil fuels often requires purification before it can be administered to a fuel cell. Higher purity can be achieved via electrolysis of water however this requires the supply of electricity from energy source such as renewables. Hydrogen can be produced from biomass or directly from nuclear or photochemical processes, however, these and many other production methods remain in an embryonic stage of development. Hydrogen production will continue to be dominated by fossil fuel derivation until renewable and nuclear-hydrogen routes prove to be reliable and cost-effective on a commercial scale and gain widespread public acceptance.

DISTRIBUTION

Bulk hydrogen can be transported via pipeline, shipped on a barge, or as is often the case, transported via tube trailer. Considerable energy is expended in gas compression to provide the required dynamics of hydrogen supply for pipelines, refuelling stations and some electrolyers and is an important design parameter in the operation and costing of large scale hydrogen infrastructure. A high grade of hydrogen is also required restricting compression to the use of diaphragm compressors that resist oil contamination of the hydrogen stream. Contamination in membrane-based electrolysis and FC systems reduces power conversion capacity and system durability to an impractical range.

STORAGE

Hydrogen storage poses many engineering challenges particularly for transport applications where high density on-board energy storage is required for acceptable power and driving range, and reduced frequency of refuelling. The system dynamics, or the rate at which hydrogen can be accessed form the storage medium, is also important criterion. All hydrogen storage media (compressed, liquefied and solid media) must satisfy numerous design criteria, including.

- Abundant and cheap raw materials of storage and containment media
- high density of hydrogen on both a gravimetric and volumetric basis
- rapid rate of hydrogen transfer (to minimize refuelling or recharging time)
- optimised energy management (in liquefaction and for removal of exothermic heat in metal hydrides)
- enhanced safety features

In any case, the type, scale and cost of the storage medium, is dependent on the application for which it is used. A range of storage media are under investigation to match the design requirements of various applications. The National Hydrogen Materials Alliance (11 Australian universities and ANSTO) is focused on this development.

UTILISATION

Hydrogen's properties and capabilities are diverse in nature, as reflected by the many engineering systems where it finds application. Applications are categorized by market sector; portable power, stationary power and transport. The base technologies are hydrogen fuelled fuel cells, hydrogen fuelled internal combustion engines (HICE) and gas turbines (HGT).

Fuel cells fall into six distinguishing categories each with differing technical design, operating conditions, performance characteristics and applications. system complexity hence capital & operating costs and environmental impacts of each system also differ markedly. Not all FCs require hydrogen as a reagent, and therefore not all play a role in the notional concept of a "hydrogen economy". The most common investigated is the polymer electrolyte or proton exchange membrane (PEMFC).

i) Portable devices

Leading Japanese and Canadian companies (NEC, Toshiba, Angstrom) are engaged in commercial and pre-commercial stages of development of various portable PEMFC products. Niche markets have been identified for laptops, military applications and other electronic applications.

ii) Stationary power

Significant global efforts in stationary applications are focused on PEMFCs (Plug Power), however they are not as advanced as for Solid Oxide FC (CFCL, Siemens) and Molten Carbonate FC (Fuel Cell Energy). These FC systems are utilized for small scale stationary power, back-up power, cogeneration and RAPS systems.

iii) Transport

Hydrogen can be used to fuel either a PEMFC fuel cell electric vehicle (FCEV) or an hydrogen-fuelled internal combustion engine (HICE) for either light or heavy duty vehicles. Hydrogen can also be added to natural gas to produce hythane or injected in a petrol-fired combustion engine to reduce tail-pipe emissions.

A fundamental shift in drive train from internal combustion to electric propulsion will have significant impacts on the Australian automotive manufacturing and service sector as well as in the fuels handling, storage, distribution and retailing industry.

New technologies and products must provide an adequate match with a variety of consumer demands and choices. Battery-charged full-EVs are restricted to an impractical driving range not exceeding 200 km and regions where a network of power outlets can be readily accessed. The very purpose of FC vehicle integration is to extend on this energy storage capacity and thereby provide a more practical and consumer-friendly driving range between refueling. Even if the majority (80%) of urban trips are less than 100km, consumers will not readily purchase vehicles that restrict mobility and significantly impinge on their regular life-style patterns. Batteries suffer from limited durability, cycle-life and raise a major waste disposal management and cost issues. There also exists a need for reduced hydrogen refuelling time (currently at 5 minutes) or battery charging.

Between full EV and conventional ICE technologies lie a range of hybrid (petrol-electric, diesel-electric) vehicles that are realizing greater market share. Development of electric propulsion is seen as a tremendous interim step for greater FCEV market penetration, build-up of servicing capability and consumer acceptance. The Australian automotive manufacturing industry may play a role in the development of components of FC systems rather than the entire vehicle. Engineers from Holden Australia (Melbourne) have been engaged in GM's global FC development for many years. Eden Energy is advancing Hythane fuels, a combination of hydrogen and natural gas. Toyota has recently announced plans to produce hybrid vehicles in Melbourne.

In any case, the durations for vehicle park turn over and start-up/commissioning of large scale power plants are considerable (in excess of 10-12 yr) – so major market penetration of new vehicle or power plant technology is not likely in the short to medium term. It is also important to recognize that the development of capacity to deliver new vehicle models let alone an entirely new drive train is a lengthy process.

Environmental impacts

The full environmental benefits of hydrogen technologies are only realised when utilising low emissions technologies for hydrogen production and delivery. Other existing and proposed fuels (coal, gas, syngas, petrol, LPG, CNG and biofuels) are all carbon based and will therefore yield higher life cycle emissions than FCEV and HICE. However, continuous improvements in fuel efficiency and emission performance of petrol-fuelled ICE vehicles retard market penetration of alternative electric drive trains. Gasoline and diesel are readily available, and as long as they are affordable and plentiful, there appears little economic incentive to switch to a new fuel (hydrogen) and a new powertrain (a FC system). The implementation of an emissions trading and renewable energy targets will accelerate this transition.

Code and Standards

Hydrogen has an excellent safety record, and is as safe, if not safer conventional fossil fuel derivatives. Safety remains a top priority in all aspects of hydrogen technology implementation and is addressed through stringent design and testing of storage and transport concepts, and via the development of codes and standards for i) design, ii) maintenance and iii) operation of hydrogen systems. International standards are developed by ISO technical Committee 197 and other regulatory bodies. The next ISO TC 197 meeting will be held in Brisbane, to coincide with the 17th World Hydrogen Energy Conference in June.

Costs

As is the case with most energy systems and infrastructure, indeed with most engineering systems in their infancy, the materials, manufacture and maintenance of pipelines, storage vessels and conversion technologies, represent a significant component of project costs. The significant upstream costs of hydrogen production, distribution and storage limit the commercialization path for many H&FC applications. H&FC technology costs are currently not cost-compeitive and are inherently expensive, however, rapid technological advancement leads to reduced costs - significant advances are providing incremental savings in costs. Further reductions in material and manufacturing costs, and improved system efficiencies, will in time, reduce consumer costs to an acceptable level, if not lower them further.

FC capital ($\$/kW_e$) and delivered (c/kWhr) costs are decreasing steadily particularly where financial and research investments are considerable such as in the US, Japan and throughout several European states. As an indicator of progress, US, German and Japanese motor companies and the majority of oil companies are planning the widespread commercialisation of FC and HICE vehicles from as soon as 2016-18 and are committing heavy investments for the development of hydrogen infrastructure.

The down side of FCEV technology is the cost for the development and maintenance of hydrogen refueling infrastructure. However, if consumer fuel prices continue to increase, the pay back for additional capital expense for a hybrid vehicle reduces to approximately 5 years.

Investment

Over and above an increasing level of demonstrations and a scattering of commercial projects, H&FC technology projects largely remain at the R&D and pre-commercial stage of development. In many cases, project viability is dependent on significant investor subsidization and/or government grants. Investment is heavily geared towards the rapidly developing “clean tech” industry today. By comparison, the H&FC industry has seen surges of investment, rather than steady, long-term financial commitments.

Despite this, recent estimates indicate that globally up to US$ 2 billion has been invested into the development of FCs and associated technologies over the past 15 years. The lion’s share of this investment is made by the world’s leading fuel resource companies (dominated by BP and Shell), and automobile manufacturers (including BMW, DaimlerChrysler, General Motors, Honda, Toyota, Ford, Volkswagen, PSA (Peugeot/Citroen/Renault) and Nissan. The global FC industry grew by 75% over the past year, delivering over 10,000 new FC units, one third of these to the automotive sector, manufacturing capacity and installations increased and costs fell. The global market for H&FC technologies is estimated to exceed $30 million within 5 years.

Expertise

Many leading authorities in the H&FC field are Australian, particularly in academic circles. Industrial experience in bulk handling of captive hydrogen in oil refineries and chemical plants is broad. Australian engineering design, power engineering and plant commissioning capabilities are of a world-class standard. Technical/industrial expertise and capability in infrastructure development/civil engineering/design/service industry is well-established. Gas industry players, Linde/BOC, Wesfarmers and Air Liquide are engaged in many global H&FC demonstration projects. Other than the WA CUTE FC Bus Trial, which ended in 2007, there is no major Australian demonstration (let alone commercial) project geared to H&FC projects.

EA members are invited to attend the World Hydrogen Energy Conference 2008 that will cover a wide range of technical issues including hydrogen production, storage, transport and utilisation to broader topics such as national programmes, environment, education and regulatory developments. WHEC2008 will feature presentations from many global and local industry leaders, a major trades exhibition, an engaging social programme, the inaugural International Hydrogen and Fuel Cells Education Forum and a presentation of the Australian Hydrogen Technology Roadmap commissioned by the Department of Resources, Energy and Tourism in 2007.

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