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Hydrogen Energy Research and Collaboration in Australia

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1 Background

Interest in Hydrogen Energy within Australia can be traced back to at least the 1930s when a Councillor Kemp in Brisbane considered converting vehicles to run on hydrogen generated from Queensland's plentiful supply of high grade coal. The state government ordered the construction of a high pressure plant but this was never built as the end of WWII signalled a return to relatively cheap oil and petrol. In 1962 opportunities in hydrogen were re-introduced by Professor John M O'Bockris, a former academic from Flinders University, South Australia. A leading authority in electrolytic hydrogen, Bockris influenced many Australians including the late Sir Mark Oliphant, Barbara Hardy AO and Dr Sukhvinder Badwal of the Commonwealth Scientific and Industrial Research Organisation, CSIRO. Dr Badwal was instrumental in setting up Ceramic Fuel Cells Ltd. as a spin-out from CSIRO in 1992. The 1960s also saw the start of work on alternative fuels, including hydrogen, for internal combustion engines led by Professor Harry C. Watson and colleagues from the University of Melbourne. During the last three decades of the 20th century, research within Australian universities and CSIRO on hydrogen energy and related technologies continued in a fragmented fashion.

In 2003 a National Hydrogen Study was carried out on behalf of the Department of Industry Tourism and Resources and with this a conference was held in Broome that proved to be something of a turning point for hydrogen energy in Australia. In response to renewed interest, a bid for hosting the 2008 World Hydrogen Energy Conference was presented to the IAHE in 2004 by the Australian Institute of Energy, and subsequently the 17th WHEC was held in Brisbane in June 2008. Also, stimulated by the National Hydrogen Study of 2003, the CSIRO set about bringing together various research players in the hydrogen energy space to create a critical mass of expertise. As a result of this, by end of 2006 a research cluster had become established known as the National Hydrogen Materials Alliance (NHMA). Interest has been maintained nationally and in 2009 a new Australian Association for Hydrogen Energy was established to serve as the peak body representing national interests in hydrogen and fuel cells liaising with various appropriate international bodies.

2 National Hydrogen Materials Alliance (NHMA)

The National Hydrogen Materials Alliance (NHMA) has been a cluster of twelve research groups from Australian universities and included the Australian Nuclear Science and Technology Organization (ANSTO), brought together by the CSIRO in 2006 to provide a framework for collaboration. The aim of the alliance was to tackle the major challenges in materials, in moving towards a hydrogen economy. These are associated with the safe and

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economical production of clean renewable hydrogen, solid state storage of hydrogen especially for transport applications, and efficient cost-effective fuel cell systems for conversion of the chemical energy in hydrogen into electrical energy. A cash contribution from CSIRO of almost $3AUD million over a period of 2.5 years has leveraged in-kind contributions from all of the partners to provide some $10AUD million of investment in research. The alliance project partners contributed to a matrix of eight projects. One stream of projects was concerned with materials for hydrogen storage, based on light metals (lithium and magnesium), carbons and porous materials. The second stream was devoted to materials aspects of hydrogen production and utilisation. The projects on hydrogen production included one devoted to developing catalysts for the decomposition of hydrocarbons, a project on the integration of renewable energy sources (PV and wind) with electrolysers, and a project on the direct splitting of water with photocatalysts. A final project was concerned with materials for solid oxide fuel cells.

3 Research Outcomes of the NHMA

3.1 Hydrogen generation

In the near term it is widely held that hydrogen will be produced most economically from hydrocarbon fuels such as natural gas. Two significant developments in this area have been made by alliance researchers. The first is the synthesis of highly active catalyst based on supported nickel with addition of a Pt metal for steam reforming and partial oxidation. This has been demonstrated in a compact microchannel reactor, at significantly lower temperatures (650° C or below) than normally encountered. It may find application for solar reforming. The second is the development of metal/metal oxide catalysts for generation of pure hydrogen from natural gas without the need for complex processing. In this case, doped iron/iron oxide and tungsten/tungsten oxide have been found to work well [1]. In addition to the investigation of the new catalyst materials, progress has been made in developing a catalytic gasification process for dealing with solid fuels such as biomass.

Ultimately hydrogen will need to be generated from sustainable energy sources, either by electrolysis of water or directly to split water into its component hydrogen and oxygen by a direct photocatalytic process. Research in the alliance has focused on coupling photovoltaic panels or wind turbines directly with electrolysers in a highly efficient manner without the need of expensive DC-DC converter or maximum power point tracker technology [2]. In this context computer models have been developed for a proton exchange membrane electrolyser that can also function as a fuel cell. This unitized regenerative fuel cell model has been validated against experimental data in an internationally leading study [3].

Direct water splitting has been tackled by researchers in four institutions and has led to the development of testing protocols that are to be published in peer reviewed articles. World class facilities have been set up in Queensland to measure the effectiveness of photocatalysts for water splitting. Various photocatalyst materials have been evaluated including titania (TiO_2) and its variants such as $CaTiO_3$ [4], mesoporous iron oxide films, two multi-component systems - ZnO-ZnS composite system, and dye-sensitised polymeric spheres. Gradual improvements have been made in efficiency and cost reduction has been addressed. Through collaboration and exchanging of samples, the role of TiO_2 in water splitting catalysts has been addressed by several research groups and a better understanding of the science of the materials has emerged.

3.2 Hydrogen storage materials

The development of materials for hydrogen storage is critically dependent on having access to reliable methods of measuring hydrogen uptake. For this reason, the researchers at Griffith University have constructed a variable volume manometric analyser, which will allow groups around the country to have access to a definitive unique world-class facility, enabling users to benchmark their research against other international groups. The analyser is the first phase of what is intended to be a National Hydrogen Materials Reference Facility**.**

Whilst some work was carried out on the storage of hydrogen in materials based on lithium [5], a much larger collaborative effort across seven universities has been devoted to magnesium materials. The R&D investigated cast materials as well as ball milled materials, including nanocomposites. The materials included $NaBH_4$-MgH_2, cast Mg-10%Ni alloys, Mg-$Ti_{0.4}Cr_{0.15}Mn_{0.15}V_{0.3}$, Mg-SiC-Ni, and Mg with various carbon additives. The main outcome from the research on Mg materials is that the kinetics of hydrogen desorption/absorption as well the amount of hydrogen stored in the alloys are highly dependent on the additives [6,7,8,9]. Theoretical modeling also proved to be useful in this work [10.11].

Hydrogen storage in carbon continues to be a controversial area of research. Microporous carbons prepared by a “one step” process and doped with transition metals all had high surface areas (>2000 m^2g^{-1}) and reasonable hydrogen storage capacities at low temperatures [12,13]. Doping of mesoporous carbons with nickel was found to increases storage capacity and in the case of multiwalled carbon nanotubes, storage capacity can also be improved by irradiation with gamma rays or microwaves, or by increasing defects by using high energy ball milling. Much higher storage capacities are however exhibited by carbon aerogels, with values of over 5 wt.% at 77K, depending on the method of activation.

From the work in the storage stream, it can be concluded that magnesium alloys continue to provide good prospects as practical hydrogen storage materials. It is too early to say whether porous materials or carbons are likely to fare any better, and further work would be worth pursuing in metal organic framework materials and in some classes of carbon materials, on the grounds that they may be more cost effective than magnesium alloys.

3.3 Hydrogen utilisation

One of the best ways of directly utilizing hydrogen is to convert the chemical energy in the hydrogen directly into electricity in a fuel cell. Fuel cell research is a very active field internationally and the project within the alliance has focused on one small area where maximum impact could be possible. This has concerned identifying new materials for solid oxide fuel cells (SOFCs) that can operate at much lower temperatures than the conventional natural gas fuelled systems. Lower temperature SOFCs are potentially more robust than the conventional high temperature SOFCs. Researchers at the University of Queensland have discovered 3 new materials systems in the La_2O_3-WO_3 system that with appropriate doping can produce a range of new ionic conductors that are comparable to the state-of-the-art Yttria Stabilised Zirconia (YSZ) [14]. This is a significant scientific advance that has opened new systems for consideration as ionic conductors. Tests have also shown that new ceramic electronic conductors based on the TiO_2-Nb_2O_5-Cr_2O_3 system may also be useful as catalysts for the partial oxidation or steam reforming of methane that could be used internally within an SOFC. Again this is a significant advance that could be applied to SOFC developments world-wide.

It has become clear that the strategic support from CSIRO has resulted in the establishment of a critical mass of researchers covering a wide range of interests in hydrogen energy throughout Australia. By bringing the various groups together, the NHMA has achieved some clear technical advances in materials for hydrogen storage, catalysts for hydrogen generation, photocatalysts and in new materials for solid oxide fuel cells. More than 33 peer reviewed papers and over 30 conference papers have been published describing the outcomes of the NHMA, which has served to train 13 PhD students and several masters and undergraduate students.

4 Activities after the NHMA

Towards the end of 2008 the Department of Resources, Energy and Tourism (DRET) published a *National Hydrogen Technology Roadmap* that had been developed for the Council of Australian Governments (COAG). This presents a vision for hydrogen and fuel cells in Australia that: "By 2020 Australia is effectively exploiting emerging hydrogen and fuel cell market and supply chain opportunities, locally and globally" The Roadmap also identifies the potential role of Australian governments, industry and researchers and recommends strategies in the possible development of a hydrogen economy. A companion *Australian Hydrogen Activity 2008* complements the Roadmap by outlining Australian research projects related to hydrogen and fuel cells. Copies of both the roadmap and activity report can be obtained from the DRET and online at www.ret.gov.au/energy.

One of the recommendations of the *National Hydrogen Technology Roadmap* was to set up "an appropriately-funded and well-managed, industry-led national body for coordinated sector representation and promotion of the interests of hydrogen and fuel cell-related industry and professionals." This recommendation has led to the formation of the Australian Association for Hydrogen Energy (AAHE), a non-profit company limited by guarantee and registered in 2009 for "the benefit of the Australian public, to advance the knowledge and understanding of production, storage, transport, safety, distribution and end use of hydrogen energy." It is intended that the AAHE will also provide a forum for the dissemination of research results now that the NHMA has run its course. The new association will therefore be running workshops and seminars, and an annual national conference, as well as providing a source of information on hydrogen and fuel cell activities within Australia. The AAHE will also represent Australia at the international level, interfacing with organisations such as the International Energy Agency, Hydrogen Implementing Agreement, the Partnership for Advancing the Transition to Hydrogen, and the International Partnership for Hydrogen in the Economy.

More details of the Australian Association for Hydrogen Energy can be found at www.hydrogenaustralia.com.

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