1. Executive summary

1.1 Introduction

As a contribution towards development of An Australian scientific roadmap for the hydrogen economy, this project provides an assessment of current Australian research into hydrogen as a future energy carrier in comparison with international research efforts. The assessments are also used to identify the most likely areas in which Australian hydrogen research could make significant contributions to hydrogen utilisation as a future fuel for transport and power requirements in Australia and internationally.

The report is based on analyses of hydrogen research publications by Australian and other researchers cited in the Thomson ISI Web of Knowledge Science Citation Index Expanded database; and on the proceedings from *Science on the way to the hydrogen economy*, a symposium organised by the Australian Academy of Science and held in Canberra, on 5 May 2006 (www.science.org.au/sats2006/symposium.htm).

The project, funded by the Australian Research Council in 2006, preceded the decision by the Council of Australian Governments (COAG) in April 2007 for development of four technology road maps for hydrogen, geothermal, solar-thermal and coal gasification.[1] The COAG Roadmap for the Development of Hydrogen Technology in Australia is to be produced by April 2008.[2]

1.2 Background

Hydrogen is attracting considerable research globally as a possible longer term, renewable energy carrier. Its particular appeal is as a clean energy source, when derived from renewable sources, for fuel cell systems. When fuelled by pure hydrogen and oxygen/air, these produce electric power with water as the chemical by-product and no carbon-based greenhouse gas emissions. There are a number of hydrogen fuel cell prototypes in test and field-trial operations for both stationary and vehicle applications, but considerable scientific, technical and economic challenges have to be addressed before hydrogen could become a widespread energy alternative in the next 20 to 50 years.[3,4,5] The challenges include:

- large-scale hydrogen production from coal and natural gas together with sequestration of the CO_2 by-product until hydrogen can be obtained economically from renewable sources; (deleted additional words)
- infrastructure for hydrogen delivery and filling stations;
- improved hydrogen storage technologies;
- fuel cells with improved reliability and lower costs; and
- codes for safe handling of hydrogen and addressing public safety concerns.

The different national priorities for hydrogen energy R&D depend on each country's relative dependence on other energy sources, especially fossil fuels, and strategies to ensure security of supply and to combat climate change by reducing greenhouse gas emissions. Australia enjoys relatively low-cost power for industry and

domestic requirements based largely on its vast reserves of coal and natural gas. Not surprisingly, therefore, early federal and state government initiatives have been directed towards more efficient utilisation of coal and gas, but there is also support for the development of alternative renewable energy sources such as wind, solar and geothermal.

This project was based on a bibliometric analysis of hydrogen research in key fields, such as hydrogen production, storage and utilisation in fuel cells, using a comprehensive search list of key words. It used a benchmarking methodology piloted by the Australian Academy of Science for assessing emerging areas of science and technology in Australia, such as nanotechnology.

The bibliometric analysis shows that Australia produced 1.69% of the world's hydrogen publications from 1980 to 2006 (and 1.78% from 1998 to 2006), and the country is the 16th largest producer of hydrogen research papers. This output is lower than for science as a whole, for which Australia produced 2.89% of the world's science publications in 2004. Nevertheless, the number of Australian hydrogen energy publications has been increasing steadily since 1991 and then more rapidly since 2003, and they receive similar citation ratings for other country hydrogen energy research publications.

Australia does not have a specific national hydrogen R&D initiative, but there are a number of active hydrogen research groups in CSIRO and the universities. These include the Australian Research Council (ARC) Centre for Functional Nanomaterials at the University of Queensland, and the National Hydrogen Materials Alliance which comprises a consortium of 11 universities, Australian Nuclear Science and Technology Organisation (ANSTO) and CSIRO. The 2005 Department of Innovation, Industry, Science and Research (previously the Department of Industry, Tourism and Resources) Hydrogen Activity Database lists over 120 projects.[6] Australia also has membership of multilateral hydrogen initiatives such as The International Energy Agency Hydrogen Implementing Agreement (IEA HIA) with 21 member countries,[7] The IEA Advanced Fuel Cells Implementing Agreement, and The International Partnership for the Hydrogen Economy which was established in 2003 with 16 other countries to accelerate the development of hydrogen and fuel cell technologies.[8]

1.3 Summary of key findings

The key findings from this project are:

1. Australia will continue to use the fossil fuels coal, oil and gas to provide base power generation for industry and domestic electricity requirements for the next 15 to 20 years, with research into clean coal technologies to continue in Australia, and internationally.
2. Australia is well-placed to contribute significantly to research into clean coal technologies, including CO_2 capture and storage, as a result of significant government funding and industry participation. Australian research success in this area and collaboration with key export market countries, will contribute to:
    a. continuing exports of these economically-important commodities and their use for power generation with low greenhouse gas emissions;
    b. the transition to fossil fuel energy alternatives, including hydrogen; and
    c. national and international initiatives for lowering greenhouse gas emissions.
3. Australian research into hydrogen energy applications will be in niche areas, since there is very limited research-based or technology-based industry being established for market-driven opportunities.
4. Australian hydrogen energy research in a number of sectors is high-quality, but it is spread over a range of basic and applied research areas. It is also lacking in critical mass in most sectors other than clean coal technologies, and research into hydrogen storage materials.

5. Australian hydrogen research will make important contributions in research-intensive areas such as CO_2 separation and sequestration, hydrogen storage materials, solar-thermal reforming of fossil fuels and biomass for hydrogen production, and distributed energy supply for remote areas.
6. There has been significant research funding for hydrogen energy technologies by the Australian Research Council, but there is a need for federal and state government initiatives to support early-stage startup companies and industry participation for commercialisation of the promising research to ensure that Australia can participate in the development of this important emerging energy sector.
7. There is a need for continuing Australian R&D into hydrogen energy technologies and applications to ensure that Australia can both contribute to this sector in areas of niche strengths, and also develop the necessary expertise to incorporate international hydrogen energy developments into Australia's energy strategies in a timely manner.
8. The Australian Government should consider a revised energy technology assessment for hydrogen from the 'reserve' to 'fast follower' category based on the present speed of global developments for hydrogen energy R&D and applications.
9. The COAG Roadmap for the Development of Hydrogen Technology in Australia, due in April 2008, will provide more detailed guidance for government and industry on hydrogen energy R&D capabilities in Australia and priority areas for research and applications development. In addition, the roadmap could identify mechanisms to foster Australian R&D in energy alternatives to fossil fuels, including hydrogen, which is likely to be the next major global research-based technology and industry development sector to follow the ITC and biotechnology sectors.
10. The coordinated development of Australian hydrogen energy R&D and applications as part of Australia's future energy strategies would benefit from the development of an 'Australian Hydrogen Energy Initiative' which could incorporate support for:
    a. continuing hydrogen energy R&D with particular attention to building critical mass in areas of Australian expertise through a CRC or other consortia;
    b. early-stage startups for proof-of-concept of promising hydrogen energy research discoveries;
    c. commercialisation through existing AusIndustry and other government programs;
    d. demonstration projects; and
    e. the establishment of an effective Hydrogen Energy Industry Group or Association to foster sector collaboration and community awareness about the transition to a hydrogen economy.