Proposal for an economic study into:

*Producing hydrogen and ammonia*
*for domestic use and export,*
*from renewable energy*
*in the Spencer Gulf region*
*of South Australia*

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*Tim Forcey - Energy Advisor, Melbourne Energy Institute*

Table of Contents




McCoy Building, School of Earth Sciences, University of Melbourne, Victoria 3010, Australia
T: +61 3 8344 3519 F: +61 3 8344 7761 E: info-mei@unimelb.edu.au W: www.energy.unimelb.edu.au

## 1. Purpose of this document

The University of Melbourne Energy Institute (MEI) seeks funding for a economic study into producing hydrogen and ammonia, for domestic use and export, from renewable energy in the Spencer Gulf region of South Australia. This document describes the aims of this study, its scope, technology pathways, the organisations involved, other potential stakeholders, study timing, and funding requirements.

## 2. Why study renewable hydrogen?

As the world decarbonises its energy supplies, some countries may find that their in-country renewable energy resources are limited or uneconomic. These countries may then consider renewable energy imports. Clearly Australia possesses remarkable renewable energy resources that may supply such markets[1].

Leading in this area is Japan. In June 2014, Japan's Ministry of Economy, Trade and Industry (METI) published a "Strategic Road Map for Hydrogen and Fuel Cells" [2]. Japan considers its many years of research into hydrogen fuel cells to be a strategic advantage as Japan and other countries increase their use of greenhouse-gas-emission-free energy sources. The METI road map envisions using hydrogen in:

- mobile fuel cells - for cars and larger transport vehicles
- stationary fuel cells - providing distributed electricity and heat to buildings
- combustion gas turbines for large-scale electricity generation.

While Japan will continue to develop its own renewable energy resources and will direct some of these to hydrogen production, studies have shown that at high renewables penetration, Japan would have to rely on variable and expensive-to-develop offshore wind[3]. Therefore in the METI road map, Japan expressed the desire to also source renewable energy from geopolitically-stable trading partners. At present Australia provides 20% of Japan's energy and Japan consumes 40% of Australia's energy exports. Therefore, Australia is well-placed, as an early mover in hydrogen and ammonia, to continue and expand its long-held role as a key energy supplier as Japan moves toward an economy increasingly based on renewable-energy-derived hydrogen.

As further signs of Japan's development of hydrogen, Toyota recently launched the Mirai[4] - its first hydrogen fuel cell-electric car. Furthermore, Japan has committed to spend $A 400 million for hydrogen fuel infrastructure in time for the 2020 Tokyo Olympics[5].

[1] For example, presentation by Dr. Keith Lovegrove, 5 March 2015, http://www.energy.unimelb.edu.au/files/site1/docs/2323/Keith_Lovegrove_presentation.ppt
[2] http://www.meti.go.jp/english/press/2014/0624_04.html
[3] "Asia-Pacific Renewable Energy Assessment", Australian Government Bureau of Resources and Energy Economics (BREE), July 2014.
[4] http://www.toyota.com/fuelcell/fcv.html
[5] http://www.bloomberg.com/news/articles/2015-01-19/tokyo-to-get-385-million-hydrogen-makeover-for-olympics

Other global manufacturers of hydrogen-electric cars include Honda of Japan, Volkswagen and Audi of Germany, and Hyundai of Korea who launched the first hydrogen/electric car in Australia in April this year[6].


***Hyundai hydrogen car – launched in Australia, April 2015***

In the zero-carbon-emission transport sector, hydrogen-electric cars are being introduced because they can have greater range than electric-only cars and can be re-fuelled (or re-charged) more quickly. For these reasons, hydrogen-electric technology is seen to have good potential for fleets and also for larger vehicles[7]. China has just announced construction of the first hydrogen-electric tram. The city of Perth demonstrated hydrogen buses over the period 2004 to 2007.

***Hydrogen tram - launched in China, March 2015***

6 "Hyundai ix35 Fuel Cell vehicle arrives in Australia to pioneer hydrogen technology", http://www.caradvice.com.au/324096/hyundai-ix35-fuel-cell-vehicle-arrives-in-australia-to-pioneer-hydrogen-technology
7 "The role of hydrogen in Australia's transport mix", Ally, J., Pryor, T., Pigneri, A., International Journal of Hydrogen Energy, 6 March 2015.

Outside of Japan and beyond just the transport sector, significant investigation of and investment in all aspects of producing and using renewable hydrogen (and its derived-product, ammonia) are underway in countries such as:

- Germany – injection of wind-derived hydrogen into the gas system (power to gas)[8] using UK electrolysis technology from ITM power[9]
- UK – recent announcement of a £6.6 million funding for 12 hydrogen refuelling stations[10]
- Scotland – with Toshiba, the Levenmouth Community Energy Project will create hydrogen from solar and wind for use in hybrid commercial vehicles[11], Aberdeen hydrogen bus project
- France – operation of hydrogen-fueled forklift trucks[12], and longer-range postal truck trial
- the Netherlands – hydrogen generation for transport[13] and ammonia fuel concept [14]
- U.S. and Canada – hydrogen and ammonia production from wind[15, 16], the operation of 2,000 hydrogen-fuelled forklifts at Wal-Mart[17], and various vehicle trials. (See map of hydrogen fuelling stations below.)


*Hydrogen refuelling stations in the U.S. and Canada*

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8 http://www.greentechmedia.com/articles/read/Wind-Power-Makes-Hydrogen-for-German-Gas-Grid
9 ITM Power – "Sale of second major power-to-gas plant", http://www.itm-power.com
10 http://www.express.co.uk/life-style/cars/567344/Government-announced-funding-seven-new-hydrogen-fuelled-car
11 https://www.toshiba.co.jp/about/press/2015_03/pr1801.htm
12 http://www.gasworld.com/air-liquide-installs-hydrogen-station-at-logistics-hub/2007044.article
13 http://www.hydrogenics.com/about-the-company/news-updates/2013/12/04/new-hydrogen-fueling-station-and-bus-launched-in-the-netherlands-with-hydrogenics-technology
14 Proton Ventures NFuel concept. http://www.protonventures.com/NFUEL.html
15 University of Minnesota, http://discover.umn.edu/news/environment/wind-power-helps-make-agriculture-more-sustainable
16 NH3 Fuel Association: http://nh3fuelassociation.org/2013/08/28/ammonia-production-using-wind-energy/
17 http://gas2.org/2014/03/18/wal-mart-buys-50-million-worth-hydrogen-forklifts/

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In Australia today, hydrogen and fuel cells are being deployed as a way to provide back-up electricity supply in remote areas[18]. The Australian Renewable Energy Agency (ARENA) has funded research into solar hydrogen synthesis[19] and storage[20].


*Remote power-supply back-up, using hydrogen (Australia)*

**Hydrogen electro-chemistry**

Using electrolysis, hydrogen (chemical formula $H_2$) can be produced from water (fresh or desalinated) and renewables-derived electricity. Renewable energy essentially becomes stored in the hydrogen molecule. Oxygen ($O_2$) is a by-product of this process, as shown by this chemical reaction formula:

$$2\ H_20\ (\text{water}) + \text{electricity} \Rightarrow 2\ H_2 + O_2$$


*Hydrogen generator by ITM (UK)*

[18] http://www.sefca.com.au/backup-power
[19] http://arena.gov.au/project/new-photocathodes-for-solar-hydrogen-production/
[20] http://arena.gov.au/media/advancing-renewable-energy-storage-options/

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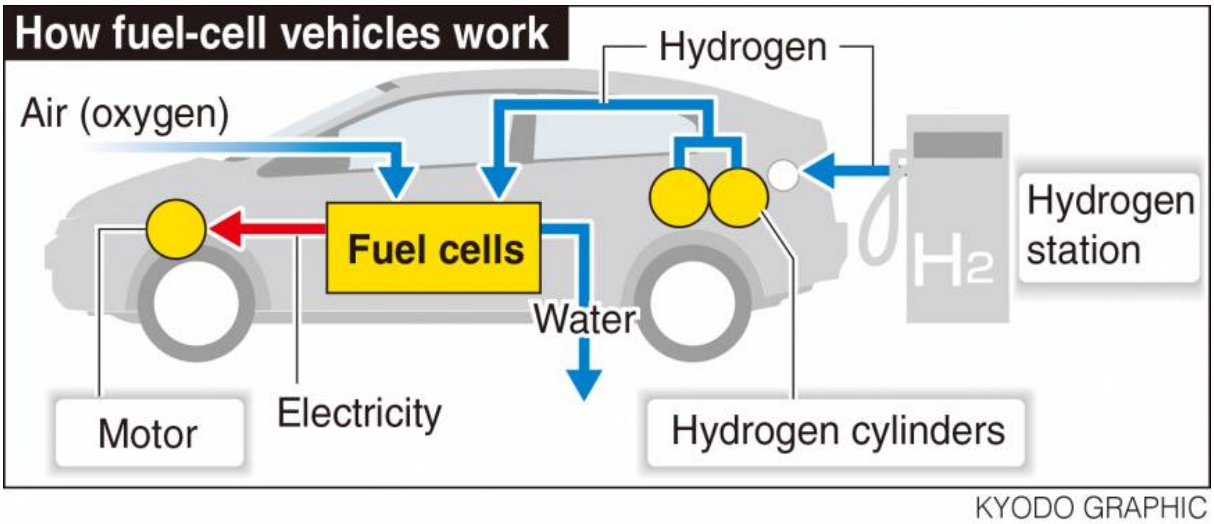
Later, when electricity is needed, the above reaction can be reversed and the energy stored in the hydrogen molecule is released as shown here:

$$2\ H_2 + O_2 \text{ (from the air)} \Rightarrow 2\ H_2O + \text{electricity}$$

The energy contained in the hydrogen molecule can be liberated by using fuel cells - famously used years ago during the early NASA space missions - or by burning hydrogen in an electricity-generating power station. No air pollutants are produced from hydrogen, because other than energy, the only other product of this operation is water.

*Fuel cell "stack"*




*Components of a fuel cell vehicle*

## 3. Why study renewable hydrogen *and ammonia*?

At room temperature and pressure, hydrogen is a very light gas that is costly to store and transport. Methods used include compressing hydrogen to very high pressures (to 350 or 700 bar) or liquefying hydrogen at very low temperature (to minus 250 deg C). However, a more-economical way to transport hydrogen by ship, especially across long distances such as between Australia and Japan, is to convert the hydrogen to ammonia – a chemical that today is stored and transported in ways similar to how LPG is handled. (LPG is well known in Australia for use as barbeque gas and as a widely-used vehicle fuel.)

***Ammonia carrier***

Consisting of one atom of nitrogen and three atoms of hydrogen, ammonia (chemical formula $NH_3$) is a common bulk-commodity chemical used widely today in minerals processing, as a fertiliser, as a pre-cursor for other fertilisers and chemicals, in air and water pollution treatment, and as a fuel source in its own right. In recent years, Australia produced and consumed around 1.2 million tonnes of ammonia[21]. Globally, 140 million tonnes per year of ammonia was produced. (Today, given the low costs associated with using fossil fuels, the ammonia manufacturing process involves converting fossil gas to hydrogen rather than using renewable energy.)


***Direct application of ammonia as fertiliser (IncitecPivot "Big N")***

[21] "The Australian fertilizer industry – values and issues", Terry Ryan, Australian Fertilizer Industry Conference 2010.

Ammonia is made commercially via the well-known and widely-used Haber-Bosch process that combines hydrogen with nitrogen ($N_2$, derived from the air) as shown here:

$$3 H_2 + N_2 \Rightarrow 2 NH_3 + energy$$

Upon delivery to a country such as Japan, ammonia can be converted back to hydrogen (and nitrogen) by reversing the above reaction as shown here:

$$2 NH_3 + energy \Rightarrow 3 H_2 + N_2$$

Using ammonia in this way as an "energy carrier" for transporting hydrogen over long distances uses proven and commonly-used technology and avoids the need to transport hydrogen at high pressure or cryogenic temperatures.

To supply just 5% of Japan's current energy needs would require producing and shipping approximately 50 million tonnes of ammonia per year, and a capital investment within Australia of greater than $A 200 billion for renewable energy and ammonia synthesis equipment and facilities. In other words, a future Australian ammonia export industry could require capital investment similar to or larger than Australia's liquefied natural gas (LNG) industry.

*Export ammonia complex – Karratha, Western Australia (operational in 2006)*


McCoy Building, School of Earth Sciences, University of Melbourne, Victoria 3010, Australia
T: +61 3 8344 3519 F: +61 3 8344 7761 E: info-mei@unimelb.edu.au W: www.energy.unimelb.edu.au

## 4. Why centre this study on the Spencer Gulf region of South Australia?

The concept of producing renewable hydrogen and ammonia can be applied to every Australian state and territory[22]. However, in order to concentrate this initial study effort, the Spencer Gulf region of South Australia has been selected as a target location for the following reasons:

- renewable energy resources - the Spencer Gulf region of South Australia has extensive wind, solar (photovoltaic (PV) and thermal), bioenergy, wave, and geothermal resources[23] and also potential for pumped hydro energy storage[24].
- renewable energy deployment track record - South Australia leads the other Australian states in renewable energy development over the last decade. Using mainly wind and roof-top solar PV, approximately 37% of the electricity generated in South Australia in the financial-year 2013-14 came from renewables. The state government has committed to achieving a level of 50% renewables by 2025.
- Industrial track record and capability in the Upper Spencer Gulf region
- in-state ammonia needs – South Australia has existing and potential domestic markets for ammonia in agriculture (fertilisers and tractor fuel), minerals processing (e.g. BHP Billiton Olympic Dam[25]), and remote electricity generation (as a substitute for diesel fuel).
- the availability of industrially-zoned land
- port facilities – the Spencer Gulf region of South Australia has port facilities near sources of renewable energy and existing / potential domestic ammonia consumers (e.g. Port Bonython, near Whyalla). Port facilities are required for eventually shipping ammonia to other Australia ports and/or overseas.
- early stakeholder support.

*Port Bonython - on the Spencer Gulf of South Australia*

[22] For example, see the Pilbara (Western Australia) Hydrogen Renewable Export Project: https://northernaustralia.dpmc.gov.au/sites/default/files/online-submissions/renewableh2.docx
[23] http://www.environment.gov.au/climate-change/publications/aemo-modelling-outcomes
[24] http://www.energy.unimelb.edu.au/opportunities-pumped-hydro-energy-storage-australia
[25] http://www.world-nuclear.org/info/Country-Profiles/Countries-A-F/Appendices/Australia-s-Uranium-Mines/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## 5. Study cost, timing, scope, and deliverables

The University of Melbourne Energy Institute (MEI) seeks funding of **$200,000** to produce a study of the economics of producing hydrogen and ammonia, for domestic use and export, from renewable energy in the Spencer Gulf region of South Australia. The study deliverables will be completed **nine months** after commencement. Work can begin as soon as funds are available.

The deliverable of this study will be a report containing:

- a review of academic and industrial literature relevant to this study
- a review of hydrogen and ammonia technology pathways and factor-based costs: for both existing and developing technologies
- an analysis of solar and wind resources in the region, output profiles and development costs
- regional pumped hydro energy storage development possibilities and factor-based costs
- cost optimisation of renewable energy supply, hydrogen synthesis plant, intermediate hydrogen storage volume, and ammonia synthesis plant
- a discussion of cost uncertainties and risks, and the potential for future cost reductions and process improvements
- an assessment of local South Australian markets for hydrogen and ammonia, present and future
- an assessment of interstate and export markets for ammonia, present and future
- an analysis of the cost of available finance and financing options including infrastructure bonds such as Climate Bonds[26]
- economic analysis of future large-scale South Australian renewable hydrogen and ammonia projects, including sensitivity analysis of technology improvements
- economic analysis of the "SA Renewable Hydrogen and Ammonia Commercialisation Facility" (see below)
- description of future required industry development steps and potential barriers.

[26] NAB launched first Australian climate bond: http://www.abc.net.au/news/2014-12-05/nab-launches-first-australian-climate-bond/5945968

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## 6. SA Renewable Hydrogen and Ammonia Demonstration Plant

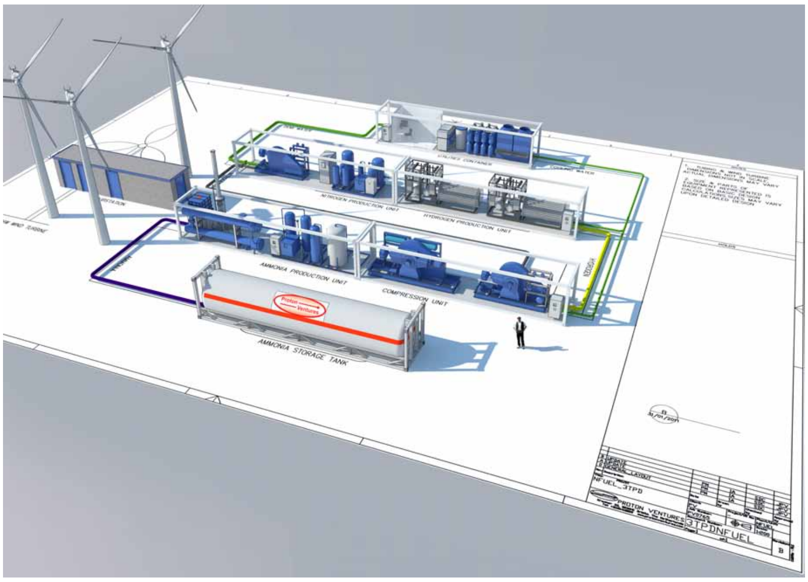
Following the completion of this study and stakeholder briefings, a next step would be to consider design and construction of a demonstration plant. This plant could be sized to supply the ammonia market around the Spencer Gulf region (e.g. 5,000 tonnes per year / 20 tonnes per day).

A plant site of around 10 hectares would be required, potentially in areas zoned for industry around Whyalla such as near the site of the Muradel[27] algal-fuel demonstration plant.

This plant would require electricity supply of approximately 10 megawatts. Depending on the research and operational objectives of this plant, this electricity could be supplied completely or in part from dedicated renewable energy sources and energy storage devices, or simply from the grid.

In addition to producing ammonia, the plant could produce and store hydrogen for use in Whyalla for transport or other purposes.

This demonstration plant would be based on widely-available hydrogen and ammonia synthesis technologies but in addition would provide the infrastructure to allow parallel demonstration and operation of developing technologies.




*Proton Ventures (Netherlands) – concept for a small-scale hydrogen/ammonia plant*

[27] http://www.muradel.com.au/facilities.html

## 7. Timeline to commercial development

The following provides a timeline to commercial development of renewable hydrogen and ammonia in South Australia.

- 2015: This proposed economic study.
- 2016 to 2019: Design and construct demonstration plant to supply SA ammonia market
- 2020 to 2025: Design and construct first billion-dollar export-based plant
- 2025 to 2040: Expansion of the industry

*World's largest solar photovoltaic farm – California (500 megawatts, operational in 2014)*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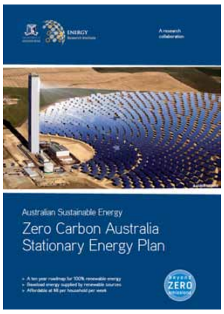
T: +61 3 8344 3519 F: +61 3 8344 7761 E: info-mei@unimelb.edu.au W: www.energy.unimelb.edu.au

## 8. Why is MEI an appropriate organisation to execute this study?

MEI has a track record of producing significant studies on the leading edge of strategic Australian energy developments whilst involving academic, industry, government, and NGO stakeholders, including:

- the Zero Carbon Australia project, led by Beyond Zero Emissions (BZE) [28]
- a review of renewable energy technology costs (commissioned by the Garnaut Review) [29]
- a study into the merit-order-effect of solar PV in the National Electricity Market (with BZE, the Australian National University, and Clean Technology Partners; supported by the Consumer Advocacy Panel) [30]
- a study into the “Opportunities for Pumped Hydro Energy Storage in Australia”, with particular focus on South Australia (supported by Arup) [31]
- the development of a New South Wales gas demand scenario [32]
- the development of a tool for modelling “least-cost emissions abatement” (with UNSW, AEMO, BOM, GE, and Market Reform, with support from ARENA) [33]




*Zero Carbon Australia Stationary Energy Plan (published in 2010)*

MEI is well-placed to involve other University of Melbourne experts in the fields of chemical engineering, combustion, agriculture, economics, etc. To lead the study, MEI has available Tim Forcey, a researcher, project manager, and study leader with 30+ years of experience in petrochemicals, oil and gas, and renewable energy. Tim contributed to three of the studies listed above and was previously employed by Exxon Chemicals, BHP Billiton, and with the Australian Energy Market Operator where in 2012 he led a study into producing 100% of eastern Australia’s electricity from renewable energy[34].

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[28] http://www.energy.unimelb.edu.au/documents/zero-carbon-australia-stationary-energy-plan
[29] http://www.energy.unimelb.edu.au/documents/renewable-energy-technology-cost-review
[30] http://www.energy.unimelb.edu.au/documents/retrospective-modelling-merit-order-effect-wholesale-electricity-prices-distributed
[31] http://www.energy.unimelb.edu.au/opportunities-pumped-hydro-energy-storage-australia
[32] “The Dash from Gas – could demand in New South Wales fall to half?”,Tim Forcey and Mike Sandiford – University of Melbourne Energy Institute. January 2015.
[33] http://arena.gov.au/project/least-cost-carbon-abatement-modelling/
[34] http://www.slideserve.com/shino/100-per-cent-renewables-study-supply-side-modelling-assumptions-and-input-stakeholder-information-forum-28-september-2012

## 9. Who has expressed interested in being involved with this study?

Organisations and/or individuals expressing an interest in being involved with this study include the following.

The University of Adelaide Centre for Energy Technology (CET) has and is conducting research relevant to this study into energy generation, transmission and storage. CET is well-connected with stakeholders in South Australia.

RenewableH2 (RH2) is a commercial organisation with executives experienced in the delivery of energy projects. RH2 has been actively developing renewable Australian hydrogen and ammonia concepts for over three years with focus on the expanding Japanese market. RH2 has developed intellectual property relevant for later, large scale projects. RH2 has developed strategies for land acquisition and for creating a strong social license to operate renewable energy projects. It has also been closely researching funding strategies for harnessing instruments such a Climate Bonds to fund the later stage roll-out of renewable energy projects at scale. In developing these strategies RH2 has built a data base of contacts with Australian and international entities capable of designing and constructing key elements of the infrastructure required for renewable hydrogen and ammonia projects. RH2 has been discussing with MEI the scope for how these new applications of renewable energy could emerge as an important new industry for South Australia.

Dr Keith Lovegrove (formerly of the Australian National University and presently with IT Power) has extensive experience particularly in solar thermal and in the use of hydrogen and ammonia as means to store renewable energy.

The expertise of fertiliser and other consultants and specialists will also be engaged as required.

## 10. Who are potential study funders?

Stakeholders that will be engaged as knowledge sources and that may also be sources of funding include:

- South Australian Government departments (renewable energy, regional development, mining support, agriculture support)
- ammonia producers and marketers
- current and possible future ammonia and hydrogen consumers (including overseas companies)
- mining and minerals processing companies
- agricultural companies
- renewable energy producers and marketers
- technology and equipment supply companies
- infrastructure developers
- engineering companies
- the Australian Commonwealth Government (via ARENA, agricultural and regional development bureaus, etc.).
- Japanese industrial and trading companies with interests in energy and agricultural commodities, and in the development of Japan's 'hydrogen society' [35]
- Japanese government agencies such as METI, the New Energy and Industrial Technology Development Organisation (NEDO), the Ministry of Education and Science (MEXT), and Ministry of Environment

[35] http://www.japantimes.co.jp/news/2014/10/12/national/japan-rises-challenge-becoming-hydrogen-society/

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McCoy Building, School of Earth Sciences, University of Melbourne, Victoria 3010, Australia
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## 11. Who are other study stakeholders?

Other stakeholders are or may be key to the successful production and use of renewable hydrogen and ammonia in South Australia. These stakeholders may not necessarily be sources of funding but could provide in-kind support. These include:

- local government councils
- regional development groups (e.g. Regional Development Australia - Whyalla and Eyre Peninsula (RDAWEP), Upper Spencer Gulf Common Purpose Group (USGCPG))
- Aboriginal community and other community organisations
- universities and research institutes (e.g. UCL, South Australian Research and Development Institute (SARDI), Minnipa Agricultural Research Facility)
- Japanese research institutions such as Tokyo Institute of Technology, Tokyo University's Research Centre for Advanced Science and Technology, Panasonic's Renewable Energy Laboratories, others
- European agencies, research institutions, and private concerns undertaking research into renewable power-to-gas, renewable hydrogen productions and ammonia synthesis
- other NGO’s.