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Hydrogen Export Industry in Australia: Requirements of Further Technical Research

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Abstract

Hydrogen has been identified as central to the decarbonisation of the energy and industrial sectors. Significant efforts in research and development (R&D) are underway to promote hydrogen production, distribution and utilisation within Australia. Tremendous opportunities also exist to establish a hydrogen (H_2) export industry that builds upon Australia world-leading track record as global supplier of liquefied natural gas (LNG). However, many technical challenges exist regarding the most cost-effective methods of exporting H_2 from Australia to the large prospective markets in Japan, Korea, China and Europe. Overcoming these challenges efficiently will require Australia to *develop systematic and coordinated R&D programs*, informed by industry and the experience of other countries that builds upon existing strengths while minimising duplication. The design and use of coordinated research infrastructures that allows for industrial-scale validation of H_2 export technologies will be central to this program.

This project hosted few workshops sittings and meetings which brought together global and local experts on H_2, natural gas and LNG, representing industry organizations, government agencies, and research institutions, to identify knowledge and capability gaps for H_2 export industry. This abstract aims to give comprehensive overview of the current and required R&D activities in Australia to accelerate the H_2 export industry, focusing in particular at:

- Presenting driving forces, current efforts and future plans for industrially-focussed H_2 research in Australia
- Illustrating the recently established LNG Futures Facility, its capabilities for industrial-scale testing at high-pressures and cryogenic temperatures, and the proposed R&D program
- Presenting an industry-led R&D plan to accelerate the growth of H_2 exports from Australia, avoiding duplicating existing research initiatives.

Keywords—LNG, H_2 export, LNG Future Facility, Australia, R&D

I. Introduction

Australia is already a global leader in the export of liquefied natural gas (LNG), which is central to the global energy transition away from coal that is now underway. Hydrogen (H_2) has been identified as central to the decarbonisation of the energy and industrial sectors. By building upon our world-leading track record as global supplier of LNG, Australia is uniquely poised to take the lead in establishing a large-scale, international trade in hydrogen. If adequately supported, this nascent hydrogen trade could readily become a key pillar of Australia's future energy export industry alongside LNG.

However many technical challenges exist regarding the most cost-effective methods of exporting H_2 from Australia to the large prospective markets in Japan, Korea, China and Europe. The demonstration of new technologies and the adoption of innovation is also a significant problem within the LNG sector. Fundamental barriers to the adoption of research & development exist because of the incompatibility of two implicit principles central to all large-scale industries involved in the export of energy.

I. New technologies must be validated at industrially-relevant scales to mitigate risk adequately before operational deployment.

II. Interruptions to operations at existing production facilities are kept to a minimum.

Recently, a flagship project [1], an LNG Futures Facility (LNG FF), was established, which consists of a small scale LNG plant (10 tonne per day). The facility has already been through a pre-FEED process and is well defined in terms of location, source and disposal of natural gas, unit operation definition, storage facilities, power supply and utilities. Phase 1, which was completed in 2018, consists of the pre-FEED design of a 10 tonne-per-day LNG plant that will serve as an open-access national facility for industrial-scale research and technology validation. The facility will enable research & development programs in natural gas processing, liquefaction, storage and re-gasification. An extensive research and development program that will utilize this unique infrastructure has also been defined, together with robust business and governance models. Currently, the LNG FF is extended to include a hydrogen export train, including conversion, liquefaction and storage.

The proposed LNG FF and current work presents list of research programs and the associated key infrastructure for testing technologies that is required to accelerate the launch of a future Australian H_2 export industry. The key research themes & questions that will be addressed by this facility:

1) LNG and Natural Gas Processing
2) H_2 Processing, Liquefaction and Utilisation
3) Storage, Transport and Regasification for H_2 and LNG.
4) Large scale Renewable Hydrogen

Theme 1: LNG and Natural Gas Processing.
This theme targets projects that seek to improve the efficiency with which natural gas from a variety of sources is treated and/or liquefied to maximise value associated with Australia's gas reserves. Projects will be drawn from the following areas:

- *Advanced Gas Separations*, including reduced foaming in acid gas removal, high-throughput dehydration, non-cryogenic helium recovery and N_2 rejection.
- *Cryogenic Fluids & Refrigerants*, including solids freeze-out prevention & remediation, refrigerant optimisation, efficient liquefaction technologies.
- *Data Analytics & Digital Twins*, including validation of online data monitoring and analysis software; improved predictive physical models scalable to large facilities.

Theme 2: H_2 Processing, Liquefaction & Utilisation.
This theme targets projects that allow efficient generation and/or processing of blue or green hydrogen, as well as those that identify how best to get the H_2 from its source to its point of use. Projects will be drawn from the following areas:

- *Processing & Conversion*, including the optimisation of large-scale H_2 production or conversion methods with low, neutral or negative carbon foot-prints, and the efficient separations processes required.
- *Liquefaction and Liquid Carriers*, including identification of the most cost-effective ways of achieving energy densities necessary for intercontinental trade, including any application specific re-conversion costs.
- *Hydrogen Utilisation*, including optimisation of hydrogen powered engines as well as the use of solid-state and porous media storage technologies in vehicles.

Theme 3: Storage, Transport and Re-gasification for H_2 and LNG.
This theme targets projects that minimise hazards and/or energy loss in large-scale, long term storage and maximise energy or value recovery upon re-gasification. Projects will be drawn from areas such as:

- *Optimised H_2 Storage for Transport*, including evaluation of context-specific hydrogen storage options for transport of various distances such as liquid H_2, NH_3, liquid organic carriers and in solid state storage materials.
- *Boil-off and Rollover*, including the validation of boil-off and LNG rollover modelling, optimised ortho-para conversion in liquid H_2 and the reduction of re-liquefaction compressor duty.
- *High-efficiency re-gasification*, including elimination of combustion-based vaporisers and Stirling cycle co-generation of electricity or additional green H_2.

Theme 4: Large Scale Renewable Hydrogen.
This theme concentrates specifically on using renewables to produce green hydrogen for export and the domestic market. Projects will be drawn from areas such as:

- *Reduced Cost Renewable Hydrogen*, including technical and economic assessments of how renewable energy can be optimised for production on the large scales necessary for export.
- *Demonstration of Hydrogen Refuelling Stations (HRS)*, including the promotion of public acceptance for wide spread hydrogen use in cars, buses and trucks and the development of codes and standards for safe re-fuelling.

II. Discussion

Currently, tremendous R&D activities are being conducted in Australia to accelerate the launch of a future Australian H_2 export industry. Here, we report examples, but not limited to, of the major observations gathered during this work:

- LNG Futures Facility could readily be extended to provide unique infrastructure for industrial scale R&D on liquid H_2 and/or high-pressure H_2 (70 MPa).
- Although there is considerable scope for further R&D in H_2, the current technological maturity means the narrative is shifting to market activation and what is needed to make that happen.
- Barriers to market activation stem from both a lack of infrastructure supporting markets and/or the cost of hydrogen supply. This requires development of an appropriate policy framework which could create a 'market pull' for hydrogen.
- There is need for techno-economic modelling of hydrogen export to identify most prospective routes, and also a need for R&D to establish and support demonstration projects.
- Existing R&D plans should include Type-A testing to determine which domestic appliances can be accredited for operation on natural gas with 10% H_2 blends or more.
- Existing R&D plans should include investigating the compatibility of steel pipes (including those with

internal coating) and components in gas networks with hydrogen-based energy fluids.

- Hydrogen generation by hydrolysis can be used to ensure utilization of excess renewable power. The driving force for H_2 economy is environmental benefit but the cost of H_2 also matters.

- If methods applied by natural-gas industry are to be applied in distributed gas-grids with increased hydrogen concentrations, uncertainties in fluid properties as low as those in the natural-gas industry have to be targeted. This requires highly accurate thermodynamic modelling based on high-quality experimental data measured at relevant conditions.
- Liquid fuels are broadly preferred and NH_3 has many advantages, including potential for direct combustion and the existence of long-standing industry practice for safe handling.
- The HAZER process [2] is used to produce hydrogen and graphite from natural gas with virtually no CO_2 emissions with several advantages relative to other processes for producing hydrogen from fossil fuels. Graphite generated by the Hazer process is a high-grade product of value to battery markets.
- Significant consideration needs to be given to the efficiency and safety of liquid H_2 storage due to diffusion (3 times faster than hydrocarbon in air), low ignition energy, and high thermal conductivity. Technical issues with H_2 liquefaction include the need for new infrastructure, understanding H_2 boil off, and high cost.
- Hydrogen in metal hydrides can be used for heat storage to produce electricity, particularly in the context of concentrated solar thermal energy.
- Developing effective technologies for H_2 production coupled with CCS will enable a low carbon economy. This will also enable H_2 production from SMR with minimal carbon emissions.
- Temperature management is obviously a challenge for liquid hydrogen, there should be a scope to study other storage mechanisms.

Table 1 gives examples of proposed core ideas on priority R&D areas to support a H_2 export industry that will need to be developed while in Table 2, examples of proposed core ideas for infrastructure needed to support industry driven R&D programs for H_2 export industry are given.

III. Conclusion

We conclude that for Australia to be a leading H_2 export nation, coordinated R&D programs, informed by industry and the experience of other countries must be developed. The recently established LNG Futures Facility will allow for industrial-scale research and technology validation and enable research & development programs in hydrogen processing, liquefaction, storage and re-gasification.

This work matters directly to both (***A***), "reducing capital and operating costs, managing social dynamics, and minimizing environmental impact while maintaining extreme productivity are key; automation, artificial intelligence, social mobilization, governmental actions, and international coordination will provide essential boosts" and (***B***), "we seek new concepts and emerging technologies (e.g. in energy storage, superconducting transmission, etc.) that stand a chance to scale to terawatts within 30 years." Current activities undertaken by this project and proposed R&D programs will not only help Australia minimizing environmental impacts (by reducing CO_2 emission) but will also accelerate for the emerging of new technologies and most cost effective free-CO_2 hydrogen export paths.

IV. References

1. *LNG Future Facility*. 2018; Available from: http://lngfutures.edu.au/lng-futures-facility/.

2. *HAZER Process*. 2018; Available from: http://www.hazergroup.com.au/.

Table 1. Examples of proposed core ideas on priority R&D areas to support a H_2 export industry

<table>
<tr><th>Production, Processing and Conversion</th><th>Liquefaction (cryogenic or carrier)</th><th>Storage and Transport</th><th>Re-gasification and Use</th></tr>
<tr>
<td>▪ PSA separation for CH_4/H_2 mixtures
▪ Low pressure TSA membrane technology for separation
▪ Direct electro-chemical synthesis of NH_3
▪ H_2 + NG separations: full life cycle analysis, separation efficiency, alternative technologies
▪ Alternative novel means of hydrogen production and separation technologies.
▪ Development of fundamental EOS and Standards and regulations regarding product purity
▪ Direct use of sea water electrolysis in hydrogen production
▪ Impurity and compatibility of H_2-based mixtures with process units
▪ H_2 from SMR coupled with CCS: Integration with existing gas infrastructure, mixture behavior, corrosion, sequestration systems, CO_2-H_2 stratification in geological systems.</td>
<td>▪ Increasing efficiency of hydrogen liquefaction process
▪ Reduce liquefaction process cost
▪ Low cost catalysts for improved ortho-para conversion, and ortho-para ratio measurement capability, to reduce boil off rate
▪ Need for studies of impurity freeze-out in H_2 production
▪ New liquefaction cycles: N_2/LNG synergy and/or helium cycles, mixed refrigerant development and cascade refrigeration optimization
▪ Compare round-trip energy efficiency of LH_2 vs NH_3 vs MeOH vs MCH.</td>
<td>▪ Standard and practices for H_2 fuel stations, and hydrogen safety and handling standards
▪ Solar thermal energy storage
▪ Evaluate H_2 liquid vs NH_3 vs MeOH vs LNG vs solid state storage (in various customer contexts)
▪ Use of NH_3/DME/MEOH in H_2-vehicles (to replace diesel)
▪ Potential for H_2 liquid storage: study important factors such as materials compatibility and boil-off
▪ Systems modelling and port handling facilities
▪ H_2 transported in NG grid in WA: capacity, on-line H_2 tools (sensors development) for grids and vehicles, advanced thermodynamic models for custody transfer and fiscal metering.</td>
<td>▪ Effective conversion of NH_3 which can be used in fuel cells, and displace coal fired power stations (turbines)
▪ Industrial integration of CO_2 utilization
▪ Co-location of energy systems and heat management
▪ Demonstration of hydrogen refueling stations and hydrogen-powered vehicles; build public understanding and acceptance.</td>
</tr>
<tr><td colspan="4">Economic, Social & Educational Priorities</td></tr>
<tr><td colspan="4">▪ Develop full life cycle sustainability analysis (techno-economic approach) evaluating alternatives H_2 generation/storage/transport and use, cost, energy efficient, energy cost of materials, fabrication and so on. Carbon used to develop hydrogen economy should be included in analysis.
▪ Develop outreach and public demonstration programs to secure social acceptance and adoption, plus local market uptake.
▪ Technical education programs to stimulate SMEs and larger companies to engage with and enter H_2 export industry; make Australia a H_2 knowledge exporter. Economic analyses regarding how H_2 export and trade can accelerate energy transition without social disruption.</td></tr>
</table>

Table *2*. Examples of proposed core ideas for infrastructure needed to support industry driven R&D programs for H_2 export industry

Processing and Conversion	Liquefaction (cryogenic or carrier)	Storage and Transport	Re-gasification and Use
▪ Pilot scale (or larger) H_2 generation process, (e.g. Hazer, SMR and eventually Renewable) ▪ HAZER process to produce H_2 from treated natural gas taken as slip stream from LNG FF ▪ Solar panels to power electrolysis-driven H_2 generation ▪ Separation testing facilities (PSA, TSA…) and membrane modules	▪ Benchmark liquefaction facility with offtake connections that allow new liquefaction technologies to be tested and validated relative to a known baseline. ▪ Ability to integrate H_2 liquefaction system with LNG refrigeration cycles to maximize thermal efficiency and lower capital cost ▪ Slip stream facilities to enable testing and benchmarking of catalytic or other processes for converting H_2 (or natural gas) into liquid carriers.	▪ Hydrogen loading facilities; heavy vehicles transport and H_2 highways to use ▪ Local demonstration site for public education and acceptance ▪ Slipstream facilities with take-off points to enable testing and validation of fiscal metering and custody transfer measurements for natural gas and H_2 blends.	▪ High pressure fueling station for code development ▪ NH_3-based turbines that can handle composition fluctuation ▪ Natural gas turbines and distribution grid handling facilities that can help establish allowable H_2 contents in mixtures.