Australian Government
Department of Climate Change, Energy, the Environment and Water

AHRN
THE AUSTRALIAN HYDROGEN RESEARCH NETWORK

CSIRO

Australia's National Science Agency

Australian hydrogen research delegation to the Republic of Korea

4-8 September 2023

Final Report

Contents

1 Executive summary

The 2023 Australian hydrogen research delegation to the Republic of Korea (ROK) marks an important first step in fostering international collaboration, with a core focus on hydrogen technology exchange, funding initiatives, and researcher engagement. The delegation was based upon the mutual interests in finding sustainable energy solutions, which requires cross-border R&D partnerships for leveraging expertise, pooling resources, and accelerating progress towards a hydrogen-based economy.

At the heart of this delegation lay the recognition of Korea's strong manufacturing industry, pioneering efforts in hydrogen technology development and its alignment with Australia's ambition to become a key player in the global hydrogen market. The delegates saw hydrogen engines, fuel cell vehicles and 720 Bar charging stations at the Hyundai-Kia Global R&D Centre. At the centre of Seoul, KOMIPO built an underground gas powerplant with 800 MW combined cycle operation, which impressed the delegates with its scale and flawless operations. The delegates exchanged knowledge and presented capabilities at Korea Hydro and Nuclear Power (KHNP) Central R&D Centre, which was followed by a site visit to 39.6 MW hydrogen fuel cell power plant near Incheon Metropolitan Area.

The delegation included Korea’s top universities where academics gave technical overview talks and provided tours of the lab facilities. A broad range of technical areas were covered including hydrogen production, materials, electrolysers, storage systems and utilisation technologies. Undertaking an international exchange of researchers between our countries was frequently discussed to identify key requirements for the best outcomes. The top four universities of Korea hosted the delegation including Korea Advanced Institute of Science and Technology (KAIST), Seoul National University, Yonsei University and Korea University.

A major highlight of the delegation was a full-day workshop hosted by the Korea Institute of Energy Research (KIER). Eminent researchers across Korea made their way to the city of Daejeon to present their state-of-the-art hydrogen technologies and products in development, and to learn about Australian hydrogen research strength presented by the delegates. Korea Institute of Science and Technology (KIST), the oldest national research institute of Korea, also hosted a half-day session to update on their latest innovations in hydrogen technologies and give a tour of the world-class research facilities.

Opportunities for collaboration were identified in the areas of electrolysis, transport of hydrogen and its derivatives, large scale storage, demand creation and many other areas. However, with Korea’s strong focus and existing partnerships in hydrogen research, Australia should focus future proposals around areas of our unique expertise. Creative partnerships will be needed at times to share IP on win-win opportunities.

This delegation saw the growing momentum in hydrogen as a clean, versatile energy carrier with immense potential to address global energy challenges. Through collaboration, innovation, and shared commitment, Australia and Korea bring tremendous opportunities to partner our transitions towards a hydrogen-powered future, driving positive environmental and economic outcomes for generations to come.

2 Opportunities for collaboration

Korea's hydrogen push is driven primarily by economic growth, emissions reduction, and energy security. Korea has a strong history in industrial competitiveness which is likely to continue with the energy transition including green vehicle manufacturing. With limited natural resources, hydrogen provides a way to help meet these objectives. ROK's mountainous terrain and small landmass make it a challenge to develop renewable energy in Korea. ROK imports large volumes of energy to provide for their population of 50 million, and many active large industrial centres, and are heavily involved in the energy transition to low emission technologies. Many of their power stations are in or near the populus. Many of the gatherings during the delegation discussed the idea of Korea relying on Australia for energy supplies, even if this takes the form of heavy investments in Australia by Korean compagnies to fully own the land and assets in Australia.

This background creates a series of problems to overcome and therefore opportunities for ROK and its energy partners to work together. ROK has many applications moving towards hydrogen and a growing emphasis for cleaner energy.

Participants in this delegation and the hosts we met see value in the following:

- a two-way energy research program between our countries
- pilots and demonstrations to raise confidence in potential development pathways, to urgently secure energy in Korea
- further creation and use of international collaboration techniques and tools to assist with the planning and implementation of research and shared knowledge along the way.
- ongoing coordination and governance of the research at the multilateral level, under technology-based groups, or under aspiration goals such as exporting hydrogen, could assist research efficiencies.

Further work is now needed to refine R&D opportunities, especially to jointly work on:

- electrolysis pathways
- hydrogen conversion and power generation
- exporting hydrogen and its carrier derivatives
- heavy vehicles
- large scale storage identifying sizes required, locations, materials, and performance standards
- demand creation, hydrogen finance and investment decisions, being able to raise capital quickly
- establishing frameworks, standards, certification systems and regulatory research to fast-track hydrogen trading
- labour, skills, and planning.

At the fundamental level there is interest for collaboration with the research institutions we met especially in the fuel cell, electrolyser, and hydrogen storage space. The level of funding available to foster the hydrogen program in Korea is impressive. Companies also have strong hydrogen agendas and dedicated budget to directly fund the research in universities and research institutions. This creates significant long-term value for the country and also develops helpful applied research ecosystems at important junctions for testing innovation with key sectors of the hydrogen technology supply chains. Korea does not hesitate to fund large scale projects and subsidise hydrogen which supports their automotive industry. By doing so, Korea is transitioning its society and workforce to be at the front of the hydrogen innovation curve.

Bilateral arrangements such as the Australia-Republic of Korea Comprehensive Strategic Partnership and the New Colombo Plan may assist with collaboration, along with the Korea-Australia Business Council.

Collaboration opportunities by institution (in Appendix 1):

- Opportunities with Korea Advanced Institute of Science and Technology
- Opportunities with Korea Hydro and Nuclear Power
- Opportunities with Hyundai
- Opportunities at Korea Institute of Science and Technology
- Opportunities with Seoul National University
- Opportunities with Korea University

3 Risks and barriers

South Korea has abundant research facilities and resources going towards energy research. Korea has made prominent steps towards owning and reaping the advantages of its high innovation levels and flow on technological developments. This is likely to see ROK gain sovereignty in the hydrogen space and may rely on Korean investment to do so. South Korea also has strong linkages with global research organisations and universities translating to high direct competition in any future research.

Australia will need to push forward on unique methods and niche technologies to differentiate from competitors and look for industry linkages between Australia's energy supplies and Korea's energy needs, and continued trading opportunities in vehicle manufacturing. Creative partnerships will be needed at times to share IP on win-win opportunities and look for multilateral arrangements that can offer more leverage and advantages of pooled resources.

4 Australian delegation participants

NAME	ROLE	ORGANISATION	LOCATION
Professor Francois Aguey-Zinsou	Head of the MERL in research lab at the School of Chemistry	University of Sydney	Sydney NSW Australia
Professor Rachel Caruso	Director of the Enabling Capability Platform for Advanced Materials	RMIT University	Melbourne VIC Australia
Andrew Feitz	Director of Low Carbon Geoscience and Advice at the Australian Government's national geoscience agency, Geoscience Australia	Geoscience Australia	Canberra ACT Australia
Dr Sarb Giddey	Senior Principal Research Scientist and currently Group Leader in the Energy Technologies Program at CSIRO	Commonwealth Scientific and Industrial Research Organisation (CSIRO)	Clayton VIC Australia
Dr Patrick Hartley	Leader of CSIRO's Hydrogen Industry Mission	Commonwealth Scientific and Industrial Research Organisation (CSIRO)	Clayton VIC Australia
Professor Zhenguo Huang	Heads a team of cross-disciplinary experts working on the Hydrogen Energy Program. Chair of the International Hydrogen Carriers Alliance and a Chief Investigator on > 6 research projects on hydrogen storage and delivery (ARC DP, CRC-P, KOGAS, etc),	University of Technology Sydney (UTS)	Ultimo NSW Australia
Professor Shawn Kook **Delegation Lead**	Korean-Australian engineering professor at The University of New South Wales (UNSW) where he directs the UNSW Engine Research Laboratory	University of NSW	Sydney NSW Australia
Professor Ian Mackinnon	Founder and former Executive Director of the Institute for Future Environments, and currently Director of the Centre for Clean Energy Technologies, at QUT	Queensland University of Technology (QUT)	Brisbane QLD Australia
Professor Eric May	CEO of the Future Energy Exports (FEnEx) CRC and was named the 2021 Western Australian Scientist of the Year	University of Western Australia (UWA)	Crawley WA Australia
Dan O'Sullivan **Delegation Co-ordinator**	Program Manager International Hydrogen Research Collaboration	Commonwealth Scientific and Industrial Research Organisation (CSIRO)	Brisbane QLD Australia
Dr Sasha Simonov	ARC Future Fellow - a physical chemist specialising in (photo)electrochemistry and (photo)electrocatalysis	Monash University	Clayton VIC Australia
Professor Paul Webley	Professor and Director Monash University and Woodside Monash Energy Partnership	Monash University	Clayton VIC Australia

5 ROK organisations visited

Australia Korea Business Council (AKBC)

H2 Station at Parliament

Hyundai Motor Company Fuel Cell

Hyundai Namyang Global R&D Centre

Korea Advanced Institute of Science and Technology (KAIST)

KOMIPO Underground Plant

Korea Hydro & Nuclear Power Central Research Institute (KHNP)

Korea Hydro and Nuclear Power Fuel Cell Power Plant

Korea Institute of Energy Research (KIER)

Korea Institute of Science and Technology (KIST)

Korea University

Seoul National University (SNU)

Yonsei University

Appendix 1: Daily insights

A special thank you to the Austrade Seoul office, DFAT, and to KIER, Elecseed and eTour who helped organise this comprehensive itinerary. The following key insights were identified by the Australian delegates during their visit to the following organisations and sites.

Monday, 4 September 2023

Australian Embassy

After a tour of the National Museum the delegates headed to the Australian Embassy in Seoul and were provided with an overview of Australian Korean economic and diplomatic relations focusing on energy production and trade.

Dr Alexandra Siddall, Deputy Head of Mission (DHOM)

Alexandra Siddall (DHOM) provided an overview of Australia's relationship with Korea, which is of escalating importance to both countries. The Australia-Republic of Korea Comprehensive Strategic Partnership is a program of enhanced bilateral cooperation under three pillars – strategic and security; economic, innovation and technology; and people-to-people exchange (which is where research sits). An example is Australia's new international student program, the New Colombo Plan.

Industry standards setting has become a great interest to set boundaries for science and technology, as has other cooperative actions such as AUKUS and QUAD. Korea is Australia's third largest trading partner. Australia is Korea's Fifth largest trading partner. Investment between the countries though is considered low. Korea's decarbonisation ambitions are strategically aligned with Australia, and also have a focus on working with regional neighbours.

Mr BAEK Sang-joo, International Cooperation, Korea Institute of Energy Technology Evaluation and Planning (KETEP)

Korea currently has high debt levels affecting their R&D budget, which remain globally impressive. KETEP has an energy MOU with DISR involving hydrogen projects that is being transferred to DCCEEW. KETEP are:

- Keen to consider both bilateral and multilateral programs going forward. See past outstanding international examples: Fuel Cell vehicle R&D MOTI 10-year programs & PV program
- Interested in projects with partner countries in Mission Innovation. Australia's DCCEEW is co-leading the Clean Hydrogen Mission, with support from CSIRO.
- Developing a clean certification scheme, with a threshold of 4kg CO2 / kg hydrogen well-to-gate emissions
- Coordinating a number of relevant science and technology committees with areas to cooperate in. See the Tech Bridge program. H2 is expected to be part of future programs.

- Supporting the acquisition of 400 fuel cell buses for selected cities and provinces. There was discussion about whether or not these could come from other countries. In principle yes, but unlikely in practice.

A particular emphasis on research in hydrogen safety (including refuellers) was worthy of note; there are currently 153 hydrogen refuellers operating in ROK.

The change in government has resulted in renewed interest in nuclear power (which was de-prioritised under the previous government), with three new plants under development.

Hyundai provides good industry research collaborative efforts. See for example their bus production program which brings together the shell of buses and fuel cells. Hyundai is going offshore with EVs building in Vietnam.

FCEV no longer makes sense for passenger cars, but Korea sees strong advantages for large vehicles and trains. Refuelling station numbers is a big barrier. Barriers include the number of refuelling stations and material supplies, and recycling is an emerging problem.

The HyNet consortium, which includes Woodside, have built refuelling stations here and have fully developed cost models. Anecdotally its said costs have come down a lot.

ROK aspire to progress offshore wind.

Ms YOON Ji-won, Researcher, American & Asian Affairs, National Research Foundation (NRF)

NRF sits under the ministries of science and education, and funds predominantly earlier stage research in universities and research institutes. International Affairs is one of seven divisions, with Australia sitting under the American and Asian Affairs program. They have MOUs with 81 agencies in 51 countries, including Australia with ATSE, ARC, and others. This includes research mobility programs.

Approximately 1% of NRF's budget (US$82m) is devoted to international cooperation.

The Joint Committee on Science & Technology (JCST) between the governments has meetings every few years and leads to follow up activities, such as a bilateral mobility program via ATSE. See "Bilateral Tech Bridge Program". The JCST will meet next year and can expect new programs, with hydrogen potentially in scope.

Mobility grants are typically around 5m Won. The two tracks for funding collaboration are joint programs and mobility programs.

The Korean government has a large budget and supports programs towards international cooperation. Their exchange programs, joint research programs, and Official Development Assistance (ODA) are excellent and very transparent.

Ms Yoon advised we work with Korea under MOUs, and to connect with relevant committees and individuals.

MOTIE announced a big increase in international R&D budget on the day that we attended (US$2010 million). They are a separate ministry and these budgets run separately.

Ron Green, Trade Commissioner

Australia is looking to elevate the 'Low & Zero Emissions Technology Partnership' which includes hydrogen.

Hyundai is considering orders for ships to do the ammonia – CO2 round trip to Australia.

Korea's gas networks are more suitable for hydrogen so they will be able to use them for hydrogen distribution.

Hydrogen Cities have been established in Korea:

- Korea is producing hydrogen from nuclear power for $60/MWh. In Australia the cost of hydrogen is around $100/MWh.
- Korea cannot get enough clean electrons into the cities. So they're going to pipe hydrogen into fuel cells in the cities.

Korea is behind on their ambitions for hydrogen vehicles based on recent strategies. Hydrogen costs AU$10/kg at the bowser – perhaps the cheapest in the world. Local governments own and operate the refuellers. It's a waste product at present, and not green.

Korea has created a world's first hydrogen power bidding market.

Market development:

- Mass Balance system based on certificate trading
- Book and Claim system for hydrogen embedded in products

Clean hydrogen certification schemes are becoming more prominent. The Australian government program has connected to ROK Government and companies. Carbon 'credits' or proxies like this are increasingly being included in some way.

Emerging areas for research include: ammonia carriers, transporting CO2 back to Australia to bury; technology and social licence; and other topics. Gas companies will eventually profit from hydrogen but relationships, efforts and communications needs thought.

Alexandra Dawer, Economic Counsellor

Korean economy is export driven. The large corporations in ROK do many different things. Australia supplies a very large portion of their iron ore, coal, and gas. Trade is strong between the countries, but investment is low.

Korea is looking to improve trade diversification and supply chain stability, and Australia can assist across trade items in energy, beef, and vehicles. Austrade see a lot of potential on this front. Australia and Korea need each other.

A new DISR counsellor is about to start at the Seoul office and can assist more with R&D.

Korea ARC energy has some investment in Australian energy.

Refer to the July 2023 Minister Bowen Korean discussion on government partnerships in hydrogen.

Networking event / dinner hosted by Elecseed

In the eventing a networking dinner was held at the National Press Club hosted by Elecseed and organised by Kyu Hong Lee. Attendees included: Austrade, CARBONCO, DL E&C, EWP, Gongju University, Hanwha Energy Solution, Hyundai Motor, KAIST, KEITI, KETEP, KHNP, KISCO, KOMIPO, Mazars, MOTIE, New Electric Partners, Ron Green, SA – DTI, Samsung, SNU, TIQ Korea Yeong Park.

Presentations were provided by: Prof. Daejoom KAIST; PwC (Australia office) and Elecseed; and Dr Scott Watkins, Australia-Korea Foundation.

Tuesday, 5 September 2023

Korea Advanced Institute of Science and Technology (KAIST)

KAIST is a national research university located in Daedeok Innopolis, Daejeon, with about 6000 undergraduate and 4000 postgraduate students in science and engineering programs.

KAIST has a very strong record in research translation and commercialisation. Some academics hold more than 100 patents, which is rarely seen in Australia. They have strong connections with Korean industry and also entrepreneur culture. They are very involved in digital research and data sharing, and keen to hear more about online collaboration tools. They currently are collaborating with over 300 universities globally.

The "KAIST Science and Technology New Deal" is designed to address national and global problems. KAIST wants to be a world bridge promoting peace and prosperity between regions. This will involve sharing industrialisation experiences.

KAIST is very active in hydrogen research with programs in:

- electrochemical reactions
- hydrogen reforming from methane, petrol and diesel/biodiesel,
- hydrogen storage materials including liquid hydrogen tanks using lattice structures
- solid oxide fuel cell and proton conducting fuel cell
- hydrogen combustion engines.
- intensive barrier safety research.

The delegation was welcomed by Prof Kang Taek Lee, Associate Vice President, International Office, and key academics in a range of hydrogen research areas including Prof Choongsik Bae, Prof Joongmyeon Bae, Prof Kang Taek Lee, Prof Byungha Shin, Prof EunAe Cho, Prof WooChul Jung and Prof Hyunjoo Lee. After a brief overview talk of the Australian Hydrogen Strategy, each delegate gave a short presentation about research highlights. This was followed by KAIST academics' research presentations and then a tour of the world class lab facilities.

Opportunities for collaboration

KAIST hydrogen research is directly relevant to active Australian research, particularly in electrochemical reactions, hydrogen storage materials, solid oxide fuel cell and hydrogen combustion engines. Importantly, the commercialisation ready liquid hydrogen storage tanks developed by KAIST could provide a much-needed solution to Australia's hydrogen export and thus this new linkage should be enhanced, preferably involving the Australian shipping industry. KAIST researchers also excel in fundamental research with a large volume of high-quality papers. This aligns well with the strength of Australian research institutions. Also, collaboration with KAIST may help Australian researchers to commercialise their research built upon the strong and cutting-edge industrial activities in Korea.

KAIST operates international student exchange programs with a number of universities globally including RMIT in Australia who was one of their first exchange program partners. KAIST is experienced in hosting overseas researchers' visits with international housing and settlement support systems.

Risks or barriers

KAIST is well funded and connected as a fully government supported research university. Their industry partnership program with all the major Korean companies is also strong. Thus, establishing new partnerships would be competitive. Their interest in fundamental research is high which could be a preferable connection pathway for Australia, which can be utilised to establish long-term academic links. Australian researchers should provide clear complementary skills or research strength, so that fruitful research collaborations can be found.

Existing projects

Project / Program	*Organisations involved*	*Brief description*
Hydrogen reformer development	KAIST	KAIST developed innovative technologies for direct reformation of liquid petrol and diesel to hydrogen. Research collaboration in this space can accelerate hydrogen production volume significantly using existing resources.
Liquid hydrogen storage tankers	KAIST, Lattice Technology, Inc.	Liquid hydrogen storage tanks with innovative lattice structures for any size. This could resolve many hurdles for liquid hydrogen tankers due to a compact size and high strength.
Hydrogen storage materials	KAIST	Various hydrogen storage materials including MOF based physisorption, metal hydrides, and ammonia.

Additional elements identified:

KAIST has an entrepreneurial, venture and startup focus

Establishing partnerships to replicate energy development models

4 campuses (Daejeon is HQ, >1m m2 area.

Hydrogen combustion activities

Labs

to observe hydrogen jets & sprays during combustion

PV, perovskites and Photoelectrochemical energy conversion (PEC) water splitting

Monolithic wireless PEC cells

Electrochemical nitrogen reduction

Ionic liquid mediated approach

Heterogeneous nanoparticle catalysts

Making exotic nanoparticle catalysts

Synthesis of small clusters on supports e.g. carbon

Producing MEA's to test because fundamental rotating electrodes not very indicative of practical effectiveness

Energy Conversion & Storage Materials Laboratory (ECSM)

Nanomaterials for catalysts

Mo/TiO2 to enhance conductivity of PEM electrolysis efficiency

Metal Hydride, LOHC, Ammonia

Reformer development – used in submarines

Enhance dehydrogenation reactions

SOFC reformer system

Mobile LAVO style battery. FC fabrication, catalysts etc

Advanced Energy Conversion & Storage Laboratory

SOFC, Proton ceramic fuel cell (PCFC) – new thing

Reversible SOFC / SOEC

Ceramic systems for CO2 reduction to make syngas

3D tomography to look at materials structure

Key contacts

Professor Choongsik Bae

Prof. Man-Sung Yim (Vice President, International Office)

Prof Deajon

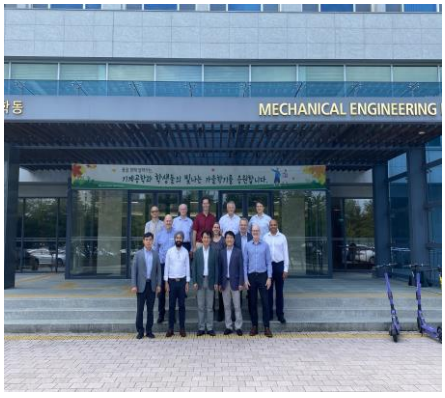
Prof. Byunsha Hin

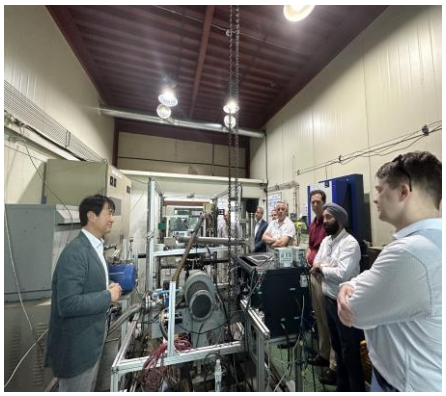
Prof. Hyunjoo Lee

Prof. Eunae Cho

Prof. Joongmyeon Bae

Prof. Kang Tak Lee





Korea Hydro and Nuclear Power and Incheon FuelCell Co. Ltd.

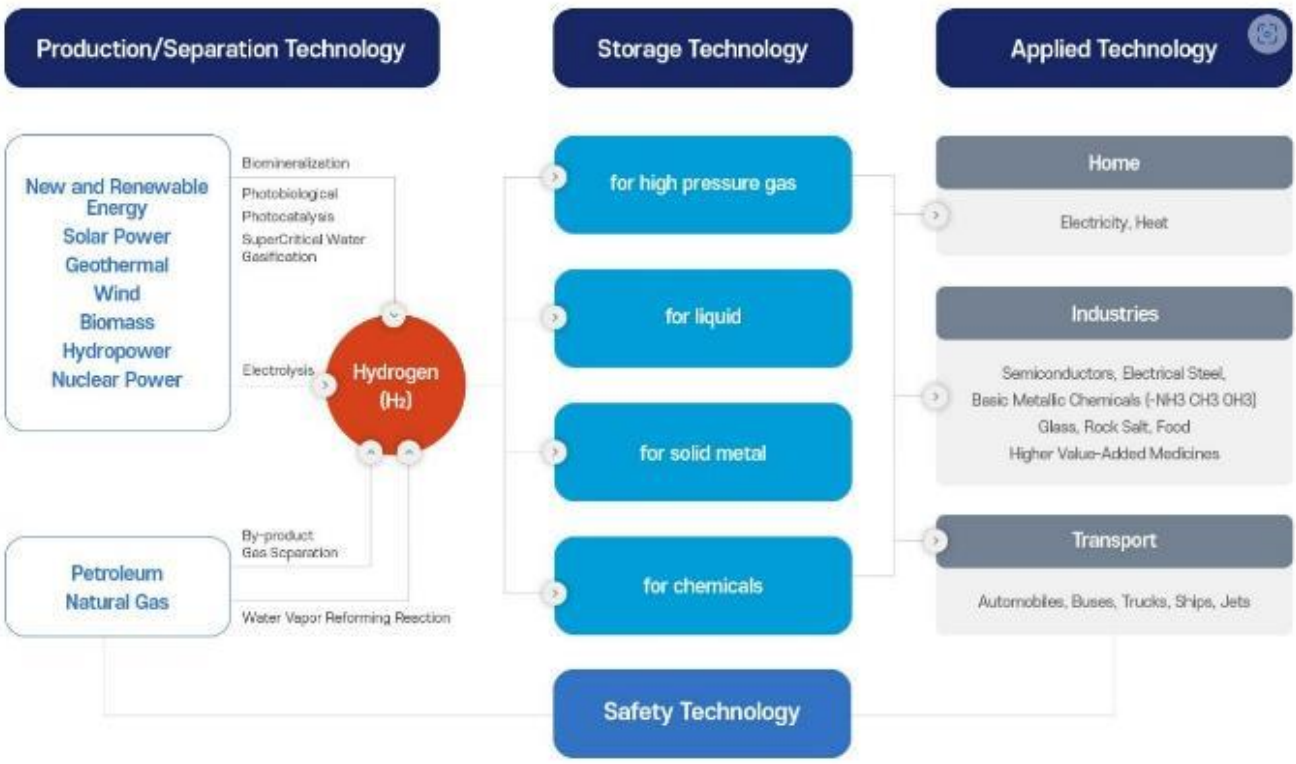
Korea Hydro and Nuclear Power Central Research Institute (KHNP)

KHNP is among the largest of Korea's electric power companies generating approximately 30% of the country's requirements in 2022. KHNP also has substantive operations in Europe (France), USA (NJ) and Egypt (Cairo). The company is AA rated by three of the four major credit ratings agencies and Aa2 by Moody's.

KNHP can trace its power industry history to 1937 with the construction of the Boseonggang Power Plant. KHNP assets total approximately US$69billion in value on a revenue of US$10.6billion. In Korea today, KHNP manages 25 nuclear, 37 hydro, 16 pumped-hydro, 59 solar and 1 wind-based power generation plants for a total of 30 GW capacity. An additional 16 nuclear power plants are either under construction or in planning stage. Two nuclear power plants have recently been placed into permanent shut-down.

Within the KHNP corporate structure, the "New Energy" section is co-located with Renewable Energy and is explicitly directed towards utilisation of hydrogen. Low emissions technologies include investments in 149MW of fuel cell power plants in Korea – predominantly based on reformed natural gas. The figure below delineates a KHNP corporate view for hydrogen within the industry value chain. This approach suggests opportunities for Australian commercial entities to engage with KHNP in segments across the value chain.

Figure KHNP technology mapping



On a subsequent day, delegates visited the Incheon FuelCell Co. Ltd., in which KHNP has a substantive ownership position (60% shareholding). KHNP also secured from Incheon FuelCell Co. Ltd a power off-take agreement which attracts a renewable energy certificate.

Incheon FuelCell Co. operates a 40 MW fuel cell farm (construction $300m) to deliver electricity to the nearby industrial and housing precinct via the local grid. This facility held a total of 90 container-sized fuel cell packs each of which was provided H_2 from an on-board natural gas reformer. Natural gas is piped to each of the 90 containers (each fuel cell is ~450kWe) at the site which occupies an area < 1 hectare. This is a quiet facility (noise level < 70dB) within a residential area – an apartment complex is within 250m. Other low emissions installations include 10MW of clean H_2 production *via* nuclear power and demonstration of 12.5MW green H_2 production on Jeju Island.

Overseas investments include 852MW in wind power in the United States, 6.6MW of solar power in Chile as well as agreements to support a South Australian cement manufacturer and a solar plus hydrogen initiative in Western Australia. Additional low emissions demonstration projects (e.g. green hydrogen refuelling station) are in discussion for other regions of Australia. This type of technology has potential for big industrial processing with high emissions and can serve as a useful storage facility.

Research and Development

The KHNP R&D Centre in Daejeon has established a hydrogen facility that includes electrolysis and fuel cell configurations supplied by local Korean manufacturers. The RD&D facility consists of two electrolysers (PEM and alkaline; total ~150kWe) coupled to a PEM fuel cell (50kWe) and additional AC load. Hydrogen is stored at 8bar up to a volume of 6Nm^3. A solar and/or wind emulator provides AC power to the facility via DC-AC inverters. Hydrogen is supplied to the fuel cell at 99.999% purity after processing by a locally made dryer system.

The alkaline electrolyser can deliver hydrogen at 20 Nm^3/hr and the PEM electrolyser at ~10Nm^3/hr. Dual dryers are utilised for fail safe operation and maximum safety. Electrolyser load follows facility operation using an automatic energy safety system that targets stabilised power to the electrolysers. A substantial nitrogen flood system ensures safety of the overall system and extensive sensing and monitoring enables effective modelling of overall process.

On arrival at KHNP R&D Centre, Kong Young-gon (Vice President, Head of H2 and Smart Business Department) and Lee Yun-Sang (Vice President, H2 and Smart Business Department) greeted the delegation along with three other key staff. Kong Young-gon provided a brief introduction to the company while Im Woo Hyun (Senior Manager, H2&SBD) provided details on the R&D activities on site. Im Woo Hyun led the subsequent tour of the demonstration facility; taking photos during the site tour was not encouraged. Other staff members: Han Sang-Jin (General Manager, H2&SBD) and Seo Jun Seok (Senior Research Engineer, H2&SBD).

Incheon FuelCell Co: Hyoung-seop Kim (CEO).

Opportunities for collaboration

Opportunities for future R&D with KHNP discussed in question time during the presentations suggest the following:

- KHNP team have an emulator that can accept real/actual data from renewable energy generators such as wind or solar farms, hydro-electric sites etc. Potential projects could include sharing data from existing renewable energy sites in Australia delivered to the KHNP emulator. This data could enable assessment of the electrolyser/fuel cell configuration at KHNP under Australian conditions. This would be a useful contribution to

the low emissions industry in both countries; and enhance trade potential through certainty of operation.

- Evaluation of O_2 quality assessed as an additional by-product of the electrolyser configuration; compare data for each electrolyser – assuming capture from each electrolyser can be achieved. Variation under different emulator conditions could be evaluated. This understanding may lead to broader utilisation of electrolysis in Korean domestic market due to effective use of a second product from electrolysis.
- Fundamental system studies – albeit limited by emulated power – on integration of electrolysers and fuel cells and/or overall control systems to enable (automated) interoperability of system components. Comparison of algorithms/software may provide useful innovations in control systems and/or optimum configurations for system stability.

Public display for fuel cell farm parameters on arrival at Incheon site; shows date, output power (37.61 MW), total MWh.

One segment of Incheon FuelCell Co. Ltd fuel cell farm containing ~42 container-sized units with ~450kW capacity. Note that double capacity can be obtained by "stacking" the containers vertically.

Contacts

Kong Young-gonHan Sang-jin

Wednesday, 6 September 2023

Korea Institute of Energy Research (KIER)

KIER hosted an Australia-Korea Hydrogen Research Workshop at KIER in Daejeon in collaboration with CSIRO and the Australian Hydrogen Research Network. A number of experts of hydrogen related research from the two countries, government, and industry representatives attended the workshop with the aim to foster research mobility between the two countries and collectively share resources and research talent.

Dr Chang-Keun Yi, President, KIER, provided the Opening Remarks, and the day was moderated by Dr Sangjin Choi, Chief of Global Strategy Team and Dan O'Sullivan, Program Manager of the CSIRO International Hydrogen Research Program. A summary of the program is as follows, and the full program can be found at the following KIER link **here**.

Topic	**Presenters**
Hydrogen production: What are the current breakthroughs and scaling problems when producing hydrogen from renewables and fossil fuels with and without carbon capture and storage?	Dr Hyunku Joo, KIER, Dr Hyun Seok Cho, KIER, Dr Doo Wook Kim, KIER, Prof Ian Mackinnon, Queensland University of Technology, Prof Alexandr Simonov, Monash University, Dr Sarbjit Giddey, CSIRO.
Hydrogen trade: Exporting hydrogen and its derivatives from Australia to Korea: What are the optimal carriers (ammonia, MCH, LOHCs, and liquid hydrogen)? What decision tools are needed to help determine optimal choices over time as a source of hydrogen or direct use in co-firing and power generation. What infrastructure and market mechanisms are needed on both sides?	Dr Hyung Chul Yoon, KIER, Prof Kwang Hyo Jung, Pusan National University, Prof Daejun Chang, KAIST, Prof Eric May, The University of Western Australia, Prof Zhenguo Huang, University of Technology Sydney, Prof Paul Webley, Monash University
Critical minerals and materials: What materials and minerals does the hydrogen economy require now and what are potential supply demand scenarios into the future?	Dr Sujeong Lee, KIGAM, Dr Andrew Feitz, Geoscience Australia, Prof Rachel A. Caruso, RMIT University
End uses: What technologies can be applied now, and into the future? Who are the current and potential end users of technologies such as fuel cells, heavy vehicle applications, and power generation? What R&D is needed to accelerate their uptake and avoid impediments and research translation issues?	Dr Gugon Park, KIER, Mr Hyungsung Kim, Doosan Mobility Innovation, Dr Patrick Hartley, CSIRO, Prof Francois Aguey-Zinsou, University of Sydney.

Key Takeaways

Production:

- In common with most countries we have visited, KIER has considerable focus on electrolysis research, ALK, PEM, AEM. Membranes, Separators and electrodes are all active research area.
- KIER has active research in blue hydrogen, including technoeconomic analysis and the development of demo- scale small reformer systems. While the issue of CO2 emissions from these systems was mentioned, it was not clear how the small units dealt (economically) with the CO2. One of the demo units is/could (?) operate at 2t / day (see slides).
- KIER has capabilities in quite large stack development and integration (up to ~30-100kW)

Trade:

- Dr Yoon (KIER) highlighted activities in the ammonia area. Based on Australian activities in this area, this could be a fruitful area of collaboration.
- KIER have demo scale facilities for both ammonia synthesis (low pressure Haber Bosch, and lithium mediated electrochemical), and ammonia decomposition (catalytic column with PSA purification to 5 9's fuel cell grade purity. Synthesis rate = 5Nm3/hr = 500g / hour. CSIRO's membrane reactor system appears to compete favourably with this system, at least at first glance.
- Prof Jung (Pusan National University) highlighted work on 'well to wake' lifecycle assessment for the analysis of marine trade of hydrogen and derivatives between Australia and Korea. Based on the (current) high emissions intensity of electricity in Australia, the LH2 was seen as being much more emissions intensive than LNG. The emissions assumptions used in the lifecycle analysis for natural gas (e.g. fugitive emissions) may warrant further examination (see slides). The Pusan group is also looking at fuel cell applications for power supply on ships.
- Professor Daejun Chang (KAIST) presented on the prismatic LH2 tank developments which are being developed by spinoff Lattice Technology. The key benefits of the technology appear to be reduced wall thickness and the potential for more 'space filling' (i.e. rectangular) tanks, which in principle allow up to 4.6t per trailer, as compared to 3t for conventional LH2 tanker trailers, and less than 1t per 450 Bar tube trailer. Lattice id pursuing pre-FEED for marine tankers using the technology.

Critical Metals:

- Critical metals as a supply-demand partnership between Australia and Korea is an obvious area for collaboration in hydrogen and other renewable energy technologies. Dr. Lee (KIGAM) promoted government support for hydrogen technology critical mineral supply chain efforts with Australia.

End use:

- Various Australian speakers emphasised the importance of this area, as building demand is a determinant of the bankability of hydrogen production projects.

- Dr Park (KIER) spoke to the 40 year history of fuel cell research at KIER. All stack components (including polymer membranes) are/have been developed, and KIER has test facilities (we did not see these but expect them to be of a high standard). The group has had an excellent publication and patent output over the years.
- A company presentation by Doosan Mobility Innovation showcased their work on fuel cell powered drones and other small vehicles. Demonstration partnerships in Australia with Swinburne University and Coregas (hydrogen tanks/refuelling) are underway.

Next steps were briefly discussed during the meeting. Based on the recent significant announcements of international R&D collaboration support from both governments, parties undertook to consider how a mobility program between Australia and Korea for scientists (including PhD students) could be developed in specific areas (to be considered in discussion) between the countries and potentially put forward as part of Australia's National Hydrogen Strategy refresh.

Following a tour of fuel cell and ammonia decomposition demonstration facilities at KIER, we departed KIER with great thanks for all of the effort which they had gone to welcome us to Korea.

Thursday, 7 September 2023 – Industry Visits

H2 Station at Parliament

The team got to explore one of ROK's first refuelling stations at Parliament House. The national hydrogen roadmap set a goal to expand the number of refuelling stations 1200 by 2040 and currently sits at 152. South Korea provides generous subsidies and reducing regulations to encourage the construction of new refuelling stations to facilitate this expansion.

Hyundai

Hyundai Namyang Global R&D Centre & the Hyundai Motor Company Fuel Cell Development Centre

Hyundai-Kia Global R&D Centre was established in 1995 to expand its original R&D Centre built in Ulsan in 1975. In a 860-acre space, over 13,000 researchers and supporting staff work at the centre for the development of new vehicle technologies. The delegation was granted for a VIP access into the electrified powertrain division building. The delegation toured the exhibition room where a range of combustion engines, electric motors and transmission systems are displayed. Following this, Hyundai's recent development on hydrogen spark-ignition engines and ammonia spark-ignition engines were presented by Hyundai researchers including Hong-kil Baek, Seung Woo Lee, Chanki Min and Kyung Hyun Lee.

The delegation had the opportunity to sight the hydrogen refilling station where 200 bar tube trailers are used to pump up the compressed hydrogen pressure to 1000 bar for filling of 700 bar storage tanks. The delegation also saw Hyundai's Xcient fuel cell semi-truck carrying a 67 kg of hydrogen in 10 x 700 bar tanks and the filling station facility. We toured the hydrogen engine test facility and sighted the hydrogen engine powered SUV.

A highlight of the visit was Hyundai's R&D centre in Namyang and their fascinating and important research into Hydrogen and Ammonia (ignition) combustion engines.

Aspects of the corporate presentations included highlighting Hyundai's 19 R&D centres worldwide, the staff complement of 13,700 (~10,000 researchers) and a video introduction to their 'Experience and value beyond expectations' catch cry are as follows:

- Hyundai is aiming to achieve carbon neutrality by 2045.
- Hyundai has set specific emissions related targets, such as <1g/kWh CO2, and efficiency, power, cost/investment.
- H2 ICE development requires innovation in the key areas of injection and ignition systems.
- H2 ICE is better than the gasoline engine baseline for benzene, toluene, ethylbenzene and NOx, and CO2 emissions are almost nothing.
- Total cost of ownership is 29% superior to FCEV based on an 8 year / 100,000 km measure, and similar to BEV due to upfront vehicle capex.
- As we heard elsewhere, bowser cost for hydrogen is approximately US$10/kg, though the extent of the government subsidy is unclear. Given that the current dominant form of hydrogen is by-product (grey), it is thought the subsidy is low but would need review to fully incentivise green hydrogen.
- Lifecycle assessment has been completed showing that H2 ICE is comparable with FCEV and BEV for blue and green hydrogen.
- A clear benefit for ICE is the lower purity requirement for hydrogen relative to FCEV.
- A particular area of interest is the 'HEV' hybrid concept, where the hydrogen combustion charges a battery and electric drivetrain. According to our hosts, this results in a similar range for vehicles relative to their fuel cell counterparts for the same amount of on-board storage.
- Quite advanced technology innovations were on show at the onsite refueller station including: 700Bar truck with 10 x 6kg carbon fibre; and 'Back room' with 200Bar tube trailer bay, compression and storage in 1000Bar carbon fibre cylinder pack (8 cylinders,

50kg per cylinder = 400kg; approximately a 1.5m x 1.5m footprint). We also saw a hydrogen combustion engine retrofitted Hyundai Santa Fe.

- Ambitious efforts are also underway to develop ammonia ignition engines (NH3ICE). Igniting ammonia is harder and the combustion different, which requires improvements to ignition coil energy, higher compression ratio, and adding hydrogen to increase flame speed.
- The use of an on-board hydrogen cracking system is a likely requirement here.
- Ammonia only engines can operate at <1500rpm, but above this, hydrogen must be added.
- The efficiency of ammonia engines is around 35%, similar to Hydrogen ICE
- Whilst ammonia engines for mobile applications might be a challenge for the above reasons and the real/perceived safety risks, stationary small-scale options (e.g. remote area power systems to displace diesel) could make sense.

Existing projects

Project / Program	**Organisations involved**	**Brief description**
Low pressure hydrogen direct injection spark ignition engine	Hyundai Motor Company	Hyundai has made a significant development of hydrogen spark-ignition engine, which has been installed in one of their SUVs for operational tests. An engine dynamometer facility dedicated for hydrogen engine development has also been built and is now ready for use.
Ammonia direct injection spark ignition engine	Hyundai Motor Company	Hyundai currently develops ammonia fuelled spark ignition engines. The engines use an innovative hydrogen cracking system installed on the exhaust pipe, which provides hydrogen enriched ammonia combustion for stable engine operations.

Opportunities for collaboration

Hyundai Motor Company is internally funded for all their research activities and seeks international contract research to acquire and apply overseas developed innovative technologies. Hyundai is keen to continue its existing research projects with Australian researchers for further development of hydrogen and ammonia fuelled engines. The collaborative platform is of course Australia's ambition to competitively produce renewable hydrogen and accelerate the market penetration of hydrogen fuelled vehicles in countries like Korea.

Risks and barriers

Hyundai Motor Company is a mega company with all possible future vehicle technologies pursued for commercialisation. These include battery electric vehicles, fuel cell vehicles and combustion engine vehicles. They are abundant in research facilities and resources, and already have a strong linkage with global research organisations and universities. There would be high direct competition with universities and research institutes with much more significant funding and

resources than Australian universities and research institutes. A unique method and technology clearly differentiated from competitors will be required to establish a new research collaboration linkage with the world's third largest vehicle manufacturer.



Key contacts

Seung Woo Lee, Senior Engineer, CO2 Zero Engine Research Laboratory, Namyang Global R&D Centre, Hyundai Motor Group

Korea Midland Power (KOMIPO)

Korea Midland Power (KOMIPO) produces electricity through thermal power generation (i.e. coal, liquefied natural gas, heavy oil) as well as wind, photovoltaic, solid refuse fuel, and fuel cell power generation. KOMIPO has a number of Korean electricity power plant assets and are expanding into overseas markets, particularly in Indonesia. KOMIPO operate additional power plants in Vietnam, USA, Singapore, Thailand and have built plants in Mongolia, Lebanon, and the UAE.

The delegation had the opportunity to visit KOMIPO's new large-capacity urban underground LNG-fired combined cycle power plant in Seoul, a world first. This impressive (and exceptionally clean) compact 800 MW power plant is equipped with two large turbines, situated 24 m underground. LNG is supplied by KOGAS (including inputs from Australia), and excess heat is supplied to 100,000 households for domestic heating. Low land availability and high land costs mean there is no scope to completely provide Korea's energy from renewable energy. Korea is therefore looking to import clean energy in the form of hydrogen or ammonia.

The facility replaces Korea's historic first coal fired power station, which is undergoing renovation into a cultural centre. A park is located above the underground LNG power plant which includes a small ski slope. Also located above the facility is a 30 MW fuel cell installation. Natural gas (pipeline) is reformed on site to produce the hydrogen, with a portion of the natural gas network supplied by landfill biogas. The fuel cells were purchased from US company Bloom Energy. Renewable portfolio certificates provide compensation for renewable assets given the fuel cell electricity price is double compared to present electricity generation costs. Community acceptance was positive regarding the fuel cells (not noisy, not very big) and the heat could be captured for residential heating.

KOMIPO is building a green hydrogen plant in southern Queensland, the Kumbarilla Renewable Energy Park (K-REP), a 200 megawatt (MW) solar farm with green hydrogen facilities in the Western Downs region of Queensland. KOMIPO also signed a Memorandum of Understanding with Perth-based Progressive Green Solutions (PGS) and Samsung C&T in 2023 to develop a 1 million tonne per annum green hydrogen project at the Narngulu Industrial Estate in Geraldton, Western Australia. The aim is to produce 200,000 tonnes of green hydrogen by 2027 and be exporting green ammonia to ROK by 2029.

One of two underground gas turbines powering the 800 MW KOMIPO power station in the heart of Seoul.

KABC-AKBC Dinner

While in Korea our delegates were able to attend the 44th Australia-Korea Business Council (AKBC) Joint Meeting which was held for the first time since 2018 due to delays from COVID. Prof Eric May, CEO of Future Energy Exports (FENEX) CRC, gave a keynote presentation on promoting research and industry cooperation. The Joint Meeting took place on September 7th and 8th at the JW Marriott Hotel in Seoul, *ROK* bringing together business leaders, policymakers, and experts

from both countries to discuss opportunities for collaboration and partnership in key sectors such as Energy, Critical Minerals, Hydrogen, Financial Services, Defence, Education, Food & Agriculture and Health and Biotechnology. This year's focus was on innovation and sustainability. The Korea-Australia Free Trade Agreement (KAFTA) came into force on 12 December 2014 with energy resources being an important component with hopes to significantly expand on its objectives.

Friday, 8 September 2023

Korea Institute of Science and Technology (KIST)

KIST is a government funded multidisciplinary research institute. The institute has around 1300 research staff, 1000 students, 460 support staff and a yearly budget of A$400M (~ 60:40 government: public/private funds ratio). KIST's major R&D centre is in Seoul and also has overseas research centres – KIST-DFC (Boston, USA), KIST Europe (Germany) and Indo-Korean Science and Technology Centre (Bangalore, India).

KIST was founded in 1966 and has a broad remit, spanning areas such as biology, brain science, AI. Whilst energy was not highlighted within the KIST Grand Challenge programs, hydrogen research is a historical strength of the institute. The desire and opportunity for mobility of researchers between Australia and KIST was discussed during the meeting, with the possibility that the Korean Government's recently announced international collaboration funding might support this.

Clean Energy Research Division (CERD) is one of the 10 divisions and institutes within KIST. CERD is developing technologies for carbon neutrality by conducting research on next-generation solar cells, secondary batteries, hydrogen and CCU technologies. This R&D work is carried out in the established R&D Centres: Clean Energy Research Centre, Advanced Photovoltaics Research Centre, Energy Materials Research Centre, Energy Storage Research Centre and Hydrogen Fuel Cell Research Centre.

The agenda of the visit consisted of a welcome and introductory session, lab visits and technical presentations. Delegates were greeted by Dr Ji-Won Son (Director – Technology Policy Research Institute) and other KIST staff and scientists (Mr Don Jae Lee, Manager Global Strategy Department), Mr Jongseung Ahn, Team Leader International Cooperation Team), Dr Hyangsoo Jeong (expertise in LOHC, ammonia), Dr Jin Young Kim (Electrochemistry / Photo electrolysis), Dr Jong Hyun Jang (Head of Hydrogen Fuel Cell Research Centre), Dr Hyuntae Sohn (H2 / fuel cell research), Dr Kyung Joong Yoon (SOFC), and Dr Katie H Lim (H2 / fuel cells).

Mr Jongseung Ahn provided the information on international R&D programs. Dr Shawn Kook briefed KIST on the purpose of the Australian delegates visit, and Dr Patrick Hartley briefed on Australian government's initiatives on decarbonisation of the energy sector including the objectives of the Hydrogen Industry Mission.

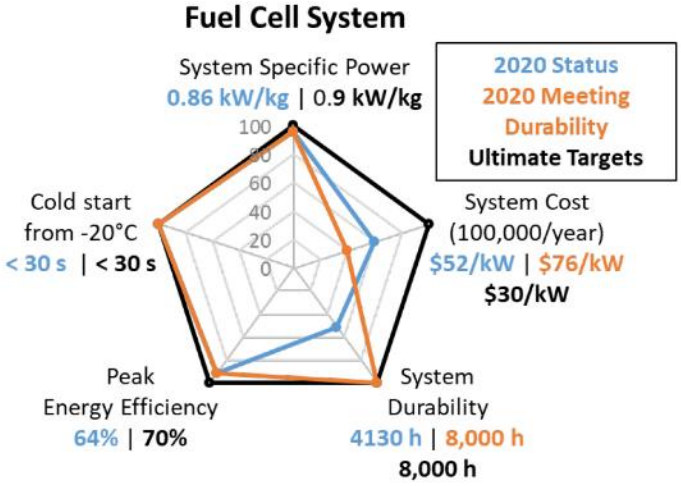
Other high-level points on KIST include:

- Combines energy and other areas with the Climate Change and Environment Research Institute within KIST
- Develops technologies to achieve zero emissions, carbon neutral society, sustainable water supply
- Advocates a "Linking Lab" established to connect researchers with entrepreneurs

- K-DARPA – focused on public order and safety
- KISTANDARD – Award “not only what people achieve” but also focuses on the wellbeing of people.
- Is active in sharing its operating model to assist establishment of research capability in developing countries in the region.

Next, the delegation adjourned for a more focussed research workshop and took the following summary notes.

- In terms of utilisation, the focus is on fuel cell research, with membrane electrode assembly (MEA) development (membrane + catalyst) a priority. R&D challenges being addressed are reducing resistance, lightweighting (esp. for drones/aviation), cost reduction and durability.
- The US DOE has produced a nice spider diagram to articulate these needs (Papageorgopoulos et al).



DOE Fuel cell technologies overview 2021 (Dimitrios Papageorgopoulos)

- We also learned of a DOE 5 hour accelerated lifetime test protocol which has been developed by US DOE and deployed at KIST
- Hyuntae Sohn introduced us to work on hydrogen storage and transportation, with emphasis on ammonia and LOHC.
- Korea’s focus on ammonia utilisation is in combustion and/or partial decomposition to improve combustion properties.
- KIST worked with Hyundai and KIER on the development of the small-scale cracker and hydrogen thermal swing absorption/pressure swing absorption purification technology which we saw at KIER, and later at H2MEET. The purification technology is developed by Hyundai.
- Prof. Kyung Joon Yoon introduced us to work on reversible SOEC/SOFC with internal reforming technology, which utilises oxygen ion conduction (O^{2-}).
- KIER is working on ceramic processing technologies to develop multilayer structures to optimise the solid oxide systems.
- NIST has a direct ammonia fuel solid oxide fuel cell.

- Membrane (ie electrolyte) degradation is a key challenge in solid oxide systems. KIST is using in situ and in operando analytical techniques to look at this. There are 8 staff and 30-40 postdocs and grad students in this group.

Lab visits:

We then visited the following labs:

- LOHC / ammonia Lab: The work in this lab was related to MCH / Toluene dehydrogenation and hydrogenation, building a 5kg/day system; and ammonia cracking – co-firing applications.
- Fuel cell labs: Mainly focussing on PEM fuel cell technology development; 25 test stations for simultaneous evaluation of cells / stacks.
- PEM electrolysis lab: Seven stations for electrolysis cell / stack evaluation; 5 auto-spray coating machines for electrode coatings and fabrication.

Opportunities for collaboration

- PEM fuel cells and electrolysis cells (contact: Dr Jong Hyun Jang, Head of Hydrogen-Fuel Cell Research Centre).
- LOHC hydrogenation and dehydrogenation; and ammonia cracking (Dr Hyuntae Sohn, Senior Researcher, Hydrogen-Fuel Cell Research Centre)
- SOFC including Ammonia SOFC (Dr Kyung Joong Yoon)

Risks or barriers

KIST has strong relationships with companies like HMC, Amogy, and also with KIER in the hydrogen and ammonia technologies space. There are well established facilities for R&D in the fuel cells (both PEM and SOFC), electrolysers (PEM), and LOHC / ammonia cracking. The R&D work relates to both fundamental studies as well as building prototype systems. Thus, there could be opportunity for Australian organisations to assist KIST and others in these areas. However, there are few established mechanisms or relationships to do so. Some of the ways discussed for collaboration are as follows.

- One-on-one scientist contact basis leading to joint proposal / project development
- International Collaboration Program – Exchange / workshops
- Hydrogen Industry Mission – early career researchers (PhD / PDFs) from Australia visit KIST labs (3 months duration)
- KIST School – there is already a framework for PhD students to work in the hydrogen R&D areas and with other organisations.

Existing projects

Existing projects were captured in presentations made by the three scientists from KIST:

Dr Jin Young Kim – MEAs for fuel cells and electrolysis

- KIST is involved in developing membranes, electrodes, cells and stacks, including complete system to domestically make all materials required for the fuel cells and electrolysis systems.
- Discussed Figure of Merit (FOM) for fuel cells: high performance (E-chem resistance), light weight (BOP) and low cost ($55/kW).
- Current collaboration with Hyundai – Nexo.
- Fuel cell technology demonstrated for drones.

Dr Hyuntae Sohn – LOHC and ammonia cracking

- Amogy (fuel cell grade hydrogen production – US based company) founder is from this group; Tech transfer from KIST; and team has currently collaboration with them.
- Current work on ammonia cracking is focussing on combustion of ammonia / co-firing with other fossil fuels like NG and coal.
- KIST and KIER are collaborating in the ammonia cracking technology. Hydrogen separation is pressure swing absorption based (Gens Eng.) – 1.8 kg/h system. Some work also carried out on ammonia adsorption for hydrogen purification, for Hyundai.
- Work on LOHC is mainly focussing on MCH / Toluene – eutectic mixture of Biphenyl and Diphenyl Ether; Aim is 99.9% H2 / 2.3 NM^3/h (5 kg/day) hydrogen production.

Dr Kyung Joong Yoon – Fuel cells (SOFC)

- Developing oxygen ion and proton conducting SOFCs.
- Fuels being tested are H2, HC and ammonia.
- Well established facilities for ceramic processing, catalyst synthesis, cell fabrication (5x5 to 20x20 cm^2 planar cells)
- Actively pursuing direct ammonia SOFC technology.

Key contact

Dr Hyangsoo Jeong, Senior Research Scientist, Fuel Cell Research Centre, Korea Institute of Science and Technology (KIST)

Seoul National University (SNU)

SNU is among the highest ranked (ranked 41st in the world; QS rankings) and largest universities in Korea with more than 2,000 full-time faculty staff and ~30,000 students. The AHRN delegation was hosted by the College of Engineering (CoE) – the largest college at the SNU with 6,500 students and 319 full-time faculty members. The CoE includes 14 departments, some of which were highlighted in the presentations from the SNU staff briefly summarised below.

Figure small workshop with the hydrogen leads at SNU

A/Prof Jungwon Park presented catalysts for the liquid organic hydrogen carriers, ammonia splitting into nitrogen and hydrogen, and CH_3OH conversion to H_2.

Prof Kyoungdoug Min showcased the CoE capabilities in modelling and experimental studies of the fuel cell stability, including for the FCEVs, the battery electric vehicles (collaboration with Hyundai), and hydrogen combustion engines (collaboration with Hyundai).

A/Prof Sang Gyu Kang highlighted a broad range of modelling developments for process optimisation, development, and prediction as well as techno-economic analysis for a broad range of energy storage systems, including various modes of water electrolysis, hydrogen storage tanks, solid oxide fuel cell systems (including ammonia fed), hybrid fuel cell + battery- systems, etc.

Prof Yutaek Seo discussed experimental and modelling developments in the development of the ammonia fuel engine (5-year project in collaboration with MAN), transport of ammonia mixed with LPG and/or CO_2, hydrogen generation from hydrocarbons, CO_2 sequestration and storage technologies, including detailed physicochemical analysis of the process and development of new capture materials and process optimisation, like the Donghae offshore CO_2 injection project.

Prof Ki-Bok Min overviewed the CoE developments in the CO_2 storage and transportation, focusing on the pipeline system modelling, CO_2 geomechanics, and monitoring of carbon dioxide in the crust.

A/Prof Sangwook Park presented some of the recent developments in electrocatalysts for water electrolysis and dry reforming of methane and carbon dioxide by heat and plasma to produce hydrogen and carbon monoxide.

Prof Ho Won Jang concluded the presentations from the SNU by presenting an overview of the university and the College of Engineering.

Prof. Yutaek Seo and A/Prof Sang Gyu Kang led the tour to the laboratory exploring the CO_2 geophysics and off-shore technologies relevant to the low-carbon energy systems.

Delegation visit to SNU hydrogen transport and storage testing facilities

Example of forward energy infrastructure planning interactive model

Opportunities for collaboration

Overall, SNU, and CoE in particular, brings together world-class experts in a broad range of sustainable energy technologies. This includes much needed capabilities in different modes of modelling of energy systems and processes. Presentations and discussions during the delegation meeting highlighted outstanding modelling capabilities and expertise available at the SNU, encompassing all key areas of the green hydrogen generation/storage/use cycle. Collaborative

projects could be established between SNU and Australia in this domain focusing on technological aspects and challenges of the hydrogen supply chains between Australia and Korea.

Risks and barriers

Existing collaborations between SNU and Korean and international industry could be a limitation because of existing IP issues.

Existing projects

Prof Eric May has an established collaboration with SNU that spans 10 years, working with the Korean heavy-industry and shipbuilding sector. Current research activities are aligned with the transport and storage of liquid CO_2 and liquid hydrogen. The key collaborator is Prof Yutaek Seo.

Key contacts:

Prof Ho Won Jang, Associate Dean of Student Affairs

Prof Yutaek Seo

Korea University

Founded in 1905 as a technical college "Bosung College", in 1946 became Korea University. It is the highest ranked private university in Korea. Has 152 research institutes, 46 graduate schools. Current student numbers ~26,000 undergraduates and ~10,000 postgraduates and faculty members ~5,000. The university keeps good contact with 330+ million alumni and pride themselves on their achievements, for example over 10% of Congress are graduates from KU. This gives the university very good connections with government, business, and other stakeholders.

Delegates Rachel Caruso, Andrew Feitz, Zhenguo Huang, Ian Mackinnon, Shawn Kook and Paul Webley were met and escorted by William Stewart (Associate Director, International Cooperation) and Professor Jong Ug Jeon (Office of Research Planning) to the meeting room. Welcomed by Prof Sang Kee Song, Vice-President for International Affairs, who informed us he would be visiting UNSW in late September. Joined by academics from Chemical and Biological Engineering: Ki Bong Lee, Sang Hyuk Im, Wangyun Won; Smart Mobility: Jun Hyuk Moon; Institute for High Technology Materials and Devices: In Kook Suh; and Chemistry Kwang Yeol Lee, Kyoung Suk Jin.

Delegates and Korea University academics gave short presentations on their research areas, followed by a brief discussion on the possibility of visits from Australian Research Fellows.

Brief notes on presentations:

Professor Ki Bong Lee (Chemical and Biological Engineering) Energy and Environmental Materials and Processes Laboratory.

- Separation
- H_2 production from natural gas – enhance reaction
- Greenhouse gas capture – adsorbent and adsorption process. Looking at high temperature CO_2 capture.
- Looking at Water Gas Shift reaction to produce H_2 while separating off CO_2.

- Prof Sang Hyuk Im (Chemical and Biological Engineering) Nano Energy Convergence System Lab.
- Perovskite solar cell driven H2 production, using $CsPbI_3$ perovskite/Mxene composite. Constructing tandem cell with Si. Currently obtain 25% solar to H2 efficiency, trying to achieve 30%.

Professor Wangyun Won (Chemical and Biological Engineering) Kyunghee University

- Process systems engineering and simulations. Techno economical analysis and lifetime evaluation, carbon foot print across the H_2 value chain, and wider.

Professor Jun Hyuk Moon (Smart Mobility) Advanced Battery and Electrochemical Catalysts Lab, Sogang University

- Advanced electrochemical methane conversion for H_2 production.
- Catalytic reactors and scalable demonstrators. Electrocatalysis for water splitting and methane to methanol or ethanol. Nanostructural control to produce porous materials: $NiCo_2O_4$, $CuCO_2O_4$, … engineering the bandgap, determining energy mechanism for reaction.
- Room temperature CH_4 activation and oxidation, use perovskite solar cells (ACS Energy Lett 2020). Catalyst is copper oxide on cerium oxide.
- Heterojunction nanorod catalysis, NiO/ZnO shell/core nanorod (Appl Cat. B, 2022)
- Methane to ethanol using IrO_2 catalyst (EES 2023) water splitting and use oxygen to oxidise methane single atom catalyst: Fe
- Using “real” gas experiments, running for a month, showing scalable small reactor.

Professor In Kook Suh Institute for High Technology Materials and Devices

- Green steel production with the use of H_2

Professor Kwang Yeol Lee (Chemistry) Research in Techtonics Lab

- Fundamental science, understanding nanocrystal growth, e-TEM and use ML to understand growth kinetics, phase transition, catalytic applications: H_2, CO_2, NH_3
- Water splitting and fuel cell, PEM water electrolysis, oxygen evolution reaction (OER) in acidic electrolyte
- Use Ir – good OER
- Decrease cost, mix Ru and Pt - Pt/Ni doped RuO_2 nanoframe (Adv. Mater. 2019 31, 1805546)
- Pt doped RuO2 nrod (En. Env. Sci. 2022, 15, 1119)
- Pt(Co)@Ru – migration of Co decreases overpotential
- Engineering perovskites to increase stability with nanoscale coating
- Operando experiments determine catalyst performance and reaction kinetics

Professor Kyoung Suk Jin (Chemistry)

- Electrically driven synthesis toolkit for chemical transformations
- Electrochemical approach for chemical manufacturing: oxidative olefin activator, reductive C(sp3)-C(sp3) bond formation, sea water splitting, water purification.

Opportunities for collaboration

A range of key areas for collaboration are noted from catalyst design, (solar driven) electrolytic H_2 production, gas capture, green steel to techno economic analysis. While collaboration would be

academic (more fundamental) the links Korea have to potential industry partners would also be beneficial to Australian researchers. Delegates that are interested should follow up with relevant Korean University Academics to determine possible project interests and whether student or ECR exchange is a way to initiate such projects.

Risks and barriers

While the KU academics are eager to collaborate and visit Australia, there is no strong motivation or mechanisms for KU researchers to directly collaborate with Australian researchers. However, their interest and participation in fundamental research is high, which can be utilised to establish necessary long term academic linkages.

Week 2

H2MEET

Patrick Hartley and Sarb Giddey from CSIRO stayed on a second week to attend H2MEET, the world's largest hydrogen trade show, during 13-15 September 2023, covering mobility, energy, environment and technology sectors, supported by Korean government and industry.

Appendix 2: Acronyms

AKBC	Australia - Korea Business Council
BEV	Battery electric vehicle
CERD	Clean Energy Research Division, a division of KIST
CoE	College of Engineering at SNU
FCEV	Fuel cell electric vehicle
HEV	Hybrid electric vehicle
ICE	Internal combustion engine
KAIST	Korea Advanced Institute of Science and Technology
KHNP	Korea Hydro & Nuclear Power Central Research Institute
KIER	Korea Institute of Energy Research
KIGAM	Korea Institute of Geosciences and Mineral Resources
KIST	Korea Institute of Science and Technology
KOGAS	Korea Gas Corporation
KOMIPO	Korea Midland Power
KU	Korea University
LOHC	Liquid organic hydrogen carrier
MOTIE	South Korean Ministry of Trade, Industry and Energy
ROK	Republic of Korea (also referred to as South Korea in this document)
SNU	Seoul National University