OUTLOOK ON HYDROGEN ECONOMY & ROADMAP

REPUBLIC OF KOREA

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Ministry of Higher Education and Science Denmark

MINISTRY OF FOREIGN AFFAIRS OF DENMARK

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CONTENTS

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INNOVATION
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TABLE OF FIGURES

TABLE OF TABLES

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INNOVATION
CENTRE
DENMARK

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1. FOREWORD

Hydrogen is emerging as a key driver to reach net zero worldwide while maintaining energy security. The Republic of Korea is one of the most proactive advocates of hydrogen society, passing the world's first hydrogen economy law in 2020.

In 2020, the Korean government committed to achieving net zero emissions by 2050 in the Korean Green New Deal, which includes a plan to invest approximately €127bn and create 1.9 million jobs by 2025. This national strategy focuses on promoting renewable energy, green infrastructure, and industries as these will unleash the hydrogen transition in Korea.

With the 2050 Carbon Neutral Strategy of Korea highlighting a phase-out of coal power plants or conversion to those of liquefied natural gas by 2050, this requires the country to accelerate the innovation and development of new and clean technologies.

As this publication outlines, the hydrogen market in the Republic of Korea will almost double in size from €10.9bn in 2020 to €20.7bn by 2030, with the growth driven largely by investment from local players such as Hyundai, POSCO, Doosan and other conglomerates.

Over the past 30 years, Denmark has drastically transitioned its energy supply and renewable energy towards green technologies. To reach the target of a 70% reduction in green house emission by 2030 and net zero by 2050, Denmark will continue the expansion of renewable energy production, increase the numbers of electric vehicles on the roads and accelerate electrification of buildings and industries.

Throughout this report you will find an overview of Korea´s hydrogen economy initiatives. It is my sincere view, that there is great potential for both the Republic of Korea and Denmark to collaborate bearing in mind the level of investment coming into the arena as well as the obvious match of Korean and Danish technology.

As is the case for Korea, Denmark is ambitious on the agenda. In December 2021, the Danish government announced its own Power-to-X Strategy. With this strategy, we are setting ambitious targets to complement hydrogen to our other sustainable energy sources. Combined with our state-of-the-art technologies, this policy offers huge opportunities for further hydrogen based Green Growth collaboration between Denmark and Korea in many years ahead.

This report marks the first step in the establishment of new Korean-Danish Green Hydrogen Alliance that will raise awareness of the importance on cooperation in the production, storage, transportation and utilisation of hydrogen and other energy storage solutions.

Danish Ambassador to the Republic of Korea

H. E. Einar H. Jensen

The Republic of Korea is transforming itself to be a front-runner in low carbon economy.

The Republic of Korea and the Kingdom of Denmark have demonstrated leadership in supporting climate action by implementing policies and initiatives for deep decarbonisation of their respected economies. Our green partnership is at a strategic level, which shows the significance of our close friendship. Furthermore, we are both partners in the race to reach net zero by 2050.

I wish to offer my sincere congratulations to the Innovation Centre Denmark and the Embassy of Denmark in Korea on the release of the report “Outlook on Korean Hydrogen Economy & Roadmap”. I believe this will be a cornerstone to facilitate hydrogen cooperation between the two countries, considering the role of hydrogen as an alternative energy carrier in our endeavour for net zero economy.

The Korean Government has actively promoted the hydrogen economy since the mid-2000s. In 2005, the government announced its masterplan for realizing an environmental-friendly hydrogen economy. Further, in 2019, the Korean Government announced the Hydrogen Roadmap for Korea. The Economic Promotion and Safety Control of Hydrogen Act was passed in January 2020 and is the first hydrogen economy law in the world. The act was followed by adoption of the Basic Plan for Implementing the Hydrogen Economy of Korea in November 2021. It is intended to drive the hydrogen usage and production by implementing a transparent pricing system, compulsory installation of charging stations and obligatory periodic safety checks for hydrogen equipment.

The government’s strong push for hydrogen has accomplished outstanding results. For example, in 2020, the Republic of Korea has the largest market share of 60% for hydrogen vehicles in the world. Furthermore, the country has the highest number of hydrogen stations, 127 as of today (March 2022), and plans to raise up to 1,200 by 2040. Nevertheless, the Republic of Korea faces the task of developing and expanding hydrogen production technology beyond hydrogen use technology.

A business council called the Korea H2 Business Summit was officially launched on September 2021, led by 15 corporations including Hyundai Motor, SK Group and POSCO. It aims to nourish the hydrogen economy by collaborating on production, financing, and export of hydrogen technology and commodities.

International collaboration is essential for sustainable green transition and creating new industries and jobs across hydrogen value chain. Korea and Denmark, as Green Growth Alliance partners, will further strengthen cooperation to build a successful hydrogen supply system.

I sincerely hope that this report will raise awareness of the importance on cooperation in the production, storage, transportation and utilisation of hydrogen and other energy storage solutions.

Ambassador and Deputy Minister for Climate Change

H. E. Hyoeun Jenny Kim

Ministry of Foreign Affairs of the Republic of Korea

2. EXECUTIVE SUMMARY

The Republic of Korea (Korea) has set ambitious goals for the hydrogen economy. Although Korea is still some way from achieving its hydrogen economy targets, the country already accounts for fully one-third of the world's installed capacity of utility-scale stationary fuel cells and its largest automotive company, Hyundai Motors, has supplied almost 60% of the world's fuel cell electric vehicles (FCEV) since launching its first model in 2013. Huge capital investment – both private and public – aimed at building out a sustainable hydrogen ecosystem in Korea along with early success in the commercialisation of key hydrogen technologies create strong opportunities for Danish businesses and research organisations in the space.

Korea's hydrogen industry is forecast to almost double in size from KRW 14.1 trillion (€10.5bn) in 2020 to KRW 26.8 trillion (€20bn) by 2030. This growth will be driven by investments from large local players who increasingly see hydrogen as a key growth engine. Five of Korea's largest conglomerates – Hyundai Motors, SK, POSCO, Hanwha, and Hyosung – recently announced KRW 42 trillion (€31.5bn) investment commitment into the hydrogen economy by 2030. Hyundai Motors alone intends to spend KRW 7.6 trillion (€5.7bn) under its 'Fuel Cell Vision 2030' and 'Hydrogen Wave 2040' programmes and looks well placed to capitalise on its early-mover advantage in fuel cells, both by selling its own vehicles, and by licensing its fuel cell systems to mobility OEMs around the world.

This level of ambition is matched by government strategies that see hydrogen as part of the solution to the high carbon intensity of the country's economy. In 2017, President Moon announced his 'New and Renewable Energy 3020' policy which looks to increase the proportion of new and renewable energy in the overall generation mix to 20% by 2030. This difficult target - the current figure is 6.6% - reflects the action required to reduce emissions 40% against business-as-usual levels by 2030, the pledge that Korea made at the United Nations Climate Change Conference (COP 26) in Glasgow in October 2021.

The Korean government announced its Hydrogen Economy Roadmap in 2019. The roadmap aims to deploy 15GW of utility-scale and 2.1GW of commercial and residential fuel cells by 2040. In terms of mobility, the goal is to have 5.9 million fuel cell cars and 60,000 fuel cell buses on the road by 2040 all supported by 1,200 hydrogen refuelling stations. The announcement of Korea's Green New Deal in July 2020 – a coronavirus stimulus plan outlining KRW 74 trillion (€55bn) in 'green' public-private capital investment by 2025 – should help the country on its way to achieving these aggressive long-term goals. However, a new government has taken office in May 2022 which means future Korean government strategies on the use of renewable energy sources in the production of hydrogen are somewhat unknown.

The hydrogen economy is of key strategic importance to Korea, a country lacking in both conventional and easily exploitable renewable energy resources. Its industrial gases industry has long been dominated by Japanese, American and European technologies, and standards. As hydrogen begins to play a more transformative role in the broader economy, Korea is keen to ensure it has greater control over the technologies that will underpin that transition, but the country still lags behind countries such as Denmark in many core hydrogen technologies which means there are strong opportunities for Danish companies in the Korean market. Closer collaboration therefore between Denmark and Korea across policy, R&D and innovation, and commercial opportunities should prove profitable to both countries.

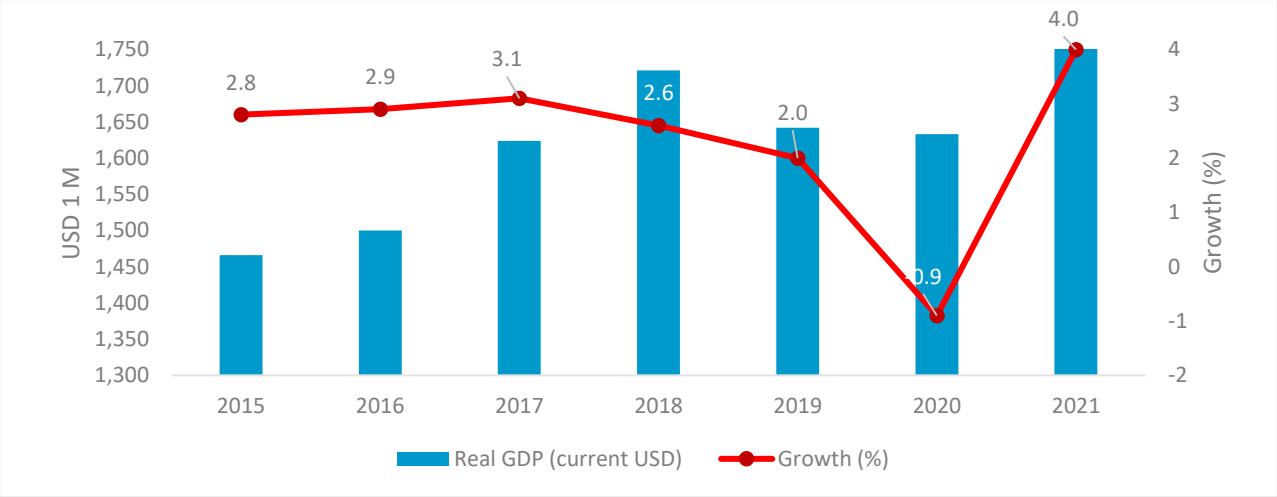
3. KOREA: AN OVERVIEW

In the space of just 60 years, Korea has transitioned from an agricultural economy to one driven by high value industries such as automotive, shipbuilding and advanced manufacturing. Perhaps most remarkable of all is the country's success in the area of information communications technology where the country has become world class in terms of semiconductor, consumer electronics and ICT infrastructure.

With a population of 51 million people, Korea boasts the 10th largest economy in the world, a GDP of €1.52 trillion in 2021 and a per capita GDP of €29,300 that same year. Whilst no longer experiencing the dizzying growth rates that characterised its early growth phase in the second half of the twentieth century, Korea has maintained strong growth for a developed economy of close to 3% in the years before the COVID pandemic.

Korea's trade dependency ratio is extremely high at over 80% and its economic performance is heavily affected by the economies of China, the US and Japan. Trade and investment flows between Korea and the EU are growing as a result of the FTA that came into effect in 2011. The trade volume between Denmark and Korea has grown rapidly over that period and surpassed €1bn in 2020.

Figure 1: GDP and growth rates (2015-2021)



Source: Intralink research

4. THE HYDROGEN INDUSTRY

4.1. ECOSYSTEM

Hydrogen production

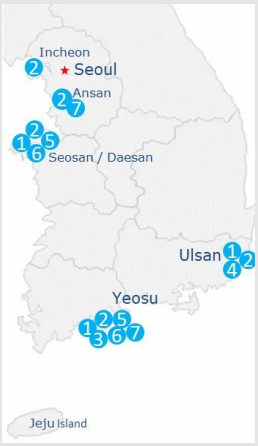
Hydrogen is mainly sourced as a by-product gas from oil refineries located in the south of the country. There are three large petrochemical complexes: 1) Ulsan (SK Energy and S Oil), 2) Yeosu (GS Caltex) and 3) Seosan/Daesan (Hyundai Oilbank) where 85% of the local hydrogen production comes as a by-product from naphtha cracking which is then cleaned and distributed to customers. Around 14% of the hydrogen produced in Korea comes from large-scale steam methane reformers (SMR) built to order and constructed on or next to customer's sites. Less than 1% of hydrogen is currently sourced through water electrolysis.

In the medium to longer term, one of Korea's hydrogen strategies involves moving towards green hydrogen with renewable energy-powered electrolysis but for now, the strategy is to use the extensive natural gas network as the main source of hydrogen for both power and mobility applications. This means the roll-out of fuel cells with in-built reformers for power generation and the roll-out of steam methane reformers (SMR) which reform the natural gas into hydrogen for use in fuel cell vehicles and hard to abate sectors such as steel and cement production. In this sense, Korea's strategy is to build out the most cost-effective hydrogen infrastructure in the short term and 'green' the supply of the hydrogen at a later point rather than trying to start with a green hydrogen strategy from the start.

This approach received a lot of criticism and the Korean government announced 'Hydrogen Economy Action Plan' in November 2021 to focus more on the production and importation of green hydrogen. The government assessed that there is a gap of between 4 and 7 years between itself and countries that lead in green hydrogen, meaning Korea is clearly behind the international competition in terms of electrolysis competency. Moving forward, the government aims to invest in large-scale water electrolysis technologies, shifting the focus of supply to green hydrogen, and this will inevitably create demand for overseas technologies.

Table 1: Key hydrogen suppliers (2021)

	Company	Capacity (Nm3/h)	Market Share (%)	Type of Hydrogen
1.	Deokyang	180,000	47.7	
2.	SPG	98,000	26.0	
3.	Air Liquide	75,000	19.9	
4.	Linde	13,000	3.4	
5.	SDG	7,000	1.8	
6.	Changshin	3,000	0.8	
7.	Daesung	1,000	0.2	



Source: Korea Hydrogen Industry Association (KHIA)

Hydrogen demand

Hydrogen is rapidly moving from being purely an industrial gas concern to a broader fuel used to generate power, heat, and energy for mobility. The current hydrogen supply model which involves hydrogen being trucked via tube trailers to Korea's nascent Hydrogen Refuelling Stations (HRS) network, faces problems of sustainability and scalability. Out of almost 320,000 tons of hydrogen produced in 2020, only a small fraction was available for HRS or fuel cell power generation. As most of the by-product hydrogen is produced and consumed by the petrochemical complexes, industry experts believe that even today there are only about 80,000 tons of hydrogen available to supply to the energy and mobility sectors. On average, the oil refineries in Korea consume about 3,000-5,000 Nm^3/h of hydrogen while steel manufacturers use between 1,000 Nm^3/h and 2,000 Nm^3/h. For example, Ulsan Petrochemical Complex only, where almost half of Korea's total by-product hydrogen is produced, accounts for a quarter of the total hydrogen demand in the country.

According to KHIA, hydrogen demand will increase by 30% in the power generation and 50% in the mobility sector by 2025. Further, while Korea's total installed capacity of fuel cell power plants is nearing 600MW, clearly there is a limit to the transformation that can be achieved by relying purely on by-product hydrogen from petrochemical sites.

4.2. KEY STAKEHOLDERS

The hydrogen ecosystem consists of hydrogen producers and users, gas and power utility companies, gas and fuel cell equipment manufacturers and integrators, EPC companies, regulatory bodies, and R&D institutions. It is estimated that there are almost 400 companies in the Korean hydrogen industry, of which the fuel cell sub-sector accounts for the highest share at around 30%, and 52 research institutes conducting R&D in the upstream and down-stream hydrogen sectors.

Deokyang is Korea's largest supplier of hydrogen. As with the other domestic hydrogen suppliers, Deokyang sources much of its hydrogen by taking by-product gas supplied at one of the three petrochemical complexes, cleaning it through pressure swing adsorption (PSA) equipment and

distributing it to customers through pipeline or tube trailers. The second largest hydrogen supplier, SPG Hydrogen, on the other hand is increasing the hydrogen production from SMRs, due to limited by-product gas available from petrochemical complexes.

In light of the recent shift towards SMRs, the natural gas industry is set to play a critical role in the nascent hydrogen economy. The industry is dominated by Korea Gas Corporation (KOGAS) which, with the exception of gas power plant operators, has a monopoly on the importation of natural gas. KOGAS distributes the gas to a network of 34 gas retailers that have the exclusive right to distribute the gas within their geographical region. The price of natural gas is heavily regulated and varies between KRW 18-20 (€0.013-0.015)/MJ depending on the application and region.

Figure 2: Key stakeholder map

Source: Intralink research

Among the established international industrial gas companies Linde and Air Liquide are strong in Korea. Since 1996, Air Liquide has operated three industrial gas plants in Yeosu and in 2019 began the operation of a fourth plant specialised in hydrogen production from polyurethane. Linde established its Korean subsidiary in 1988 and is one of the largest industrial gas specialists in Korea. In 2020, Linde and Hyosung Heavy Industries, a local heavy machinery producer, established a joint venture to construct liquid hydrogen plant in Ulsan, with an expected annual capacity of 13,000 tons of liquid hydrogen.

Local R&D institutes such as Korea Institute of Energy Research (KIER) are regularly funded by the government-level organisations such as ministries and occasionally by municipal authorities such as technoparks for small-scale green hydrogen projects. The majority of R&D institutes are tasked by the government to develop a core technology with a view to licensing that technology to domestic SMEs. For example, KIER developed an on-site SMR with 500kg/day hydrogen production capacity in 2020, and successfully licensed the technology to Wonil T&I, a local gas equipment producer.

There are also other R&D institutes such as Korea Automotive Technology Institute (KATECH) equipped with cutting-edge testing technologies who help local automotive companies conduct durability and performance evaluations on newly developed fuel cell designs, fuel cell components such as bipolar plates, MEA, gaskets, etc. Local R&D institutes partner not only with SMEs but also with large conglomerates as shown by the recent MOU signed between Doosan Heavy Industries & Construction and Korea Institute of Energy Technology Evaluation and Planning (KETEP). According to the MOU, the two organisations will collaborate on the development and demonstration of green hydrogen projects based on wind power in Jeju island.

Industry Insider's Thoughts

There is a great potential for the R&D collaboration in the hydrogen energy storage field between Denmark and Korea. We are already working with numerous Danish R&D institutes and companies to develop independent smart grid solutions using hydrogen as energy storage system (HESS). Korea offers various incentives for the commercialisation of early hydrogen technologies, and we are ready to help Danish and Korean companies develop joint programmes in this space.

Dr. H. WOO, Director – Energy Technology Support Agency, Ulsan Technopark

5. NEW AND RENEWABLE ENERGY (NRE) POLICY

5.1. HYDROGEN ECONOMY ROADMAP

The first comprehensive hydrogen economy vision of Korea dates back to September 2005 when Ministry of Trade, Industry and Energy (MOTIE) announced the 'Masterplan for the Realisation of Hydrogen and New Renewable Energy Economy'. The early 2000s was characterised by optimism around the hydrogen economy and the plan's goals were ambitious: the production target of fuel cell vehicles (FCEVs) by 2020 was 2 million units, however, as of May 2021, the cumulative sales volume of FCEV was about 15,286 units (including exports). The target for total installed capacity of fuel cells for power generation by 2020 was 3,100 MW, whereas in fact the total installed capacity of fuel cell power plants in Korea is about 600 MW as of 2021. Despite falling short of its early goals, Korea still accounted for fully 40% of global installed utility-scale fuel cell capacity in 2021.

Over the last few years, optimism surrounding the hydrogen economy has returned. In January 2019, the government announced the Hydrogen Economy Roadmap that set out its targets to 2040. The roadmap aims to increase the number of fuel cell cars to 79,000 by 2022 and to 5.9m units by 2040 and will support this growth with 310 HRS installed by 2022 and 1,200 HRS by 2040. It also aims to increase massively the installed capacity of utility-scale and residential fuel cells by 2040 to 15GW and 2.1GW respectively.

Table 2: Hydrogen Economy Roadmap

Application	Type	2018	Transition	2022	Transition	2040
Mobility	Passenger Vehicle	5,000	Localisation up to 100%	79,000	The same price as EV	5.9m
	Bus	2		2,000	Can run for 800,000 km	60,000
	Taxi	-	Expected to run in large cities from 2021		Expand across country	120,000
	Truck	-	5-ton truck development	10-ton trucks	Localisation up to 100%	120,000
	Hydrogen Stations	14		310	Localisation up to 100%	1,200
Energy	FC Power Plants	307 MW	Installation cost down to KRW 3.6m (€2,600)/kW	1.5 GW	Same generation cost as GTPP	15GW
	Residential FC	7MW	Installation cost down to KRW 15.3m (€11,300)/kW	50 MW	Installation cost down to KRW 7.1m (€5,300)/kW	2.1GW
Hydrogen Supply	Hydrogen Supply Amount	130,000 T/Y		470,000 T/Y		5.26 M T/Y
		By-product / SMR	Large-scale production	Electrolyser	Large-scale electrolyser	Green Hydrogen
Hydrogen Cost		KRW 8,800 (€6.5)/kg		KRW 5,500 (€4.0)/kg	KRW 3,500 (€2.6)/kg	KRW 3,000 (€2.2)/kg

Source: Ministry of Environment

The Roadmap also identifies the National Core Technology Development Plan with respect to hydrogen production. Hydrogen is a strategic industry for Korea, and it has worked over the past two decades to ensure that it has access to the enabling technologies. While it has made great strides in developing or buying foreign companies with fuel cell technologies, the country has not made the same progress with hydrogen production or handling technologies. One of the key goals of the National Core Technology Development Plan is to ensure the country becomes globally competitive in small-scale SMR and electrolysis (both PEM and alkaline) technologies.

Table 3: National Core Technology Plan

Technology	Current Status	Short-term						Mid-term		Target
		2020	2021	2022	2023	2024	2025	~2028	~2030	
SMR	System design, small-scale system demonstration stage	Small-scale SMR system development								System Efficiency 78% (HHV) by 2030
			Medium-scale SMR system development							
Water Electrolysis	Design stage of the development of 1MW original technology and stack technology	Alkaline water electrolysis system development								100MW system; System Efficiency 50kWh/kg-H2; Dozens of MWs of P2H technology development connected to RE by 2030
		PEM electrolysis system development								
				Development of P2H technology connected to renewable energy						

Source: MOTIE

Although the Hydrogen Roadmap is a key guideline for the development of the hydrogen economy in Korea, some targets are regarded as 'too ambitious to achieve'. For example, the target to roll out 310 HRS by 2022 could be unfeasible as there are only about 100 HRS both operational and under construction as of 2021. The Korean government understands that some of the targets are too ambitious, and in order to come up with more realistic goals the government is considering the introduction of revised Hydrogen Economy Roadmap in 2022.

Hydrogen Law

The National Assembly passed the Hydrogen Law in February 2020 with a view to creating a legal framework for the realisation of Hydrogen Economy Roadmap. The law came into effect in February 2021 and makes provisions for hydrogen equipment safety requirements, certification processes and clarifies the roles and responsibilities of various government agencies.

5.2. VISION 3020

In December 2017, the Korean government announced the Renewable Energy 3020 Implementation Plan, known as 'Vision 3020'. The plan sets the goal of sourcing 20% of the country's energy from New and Renewable Energy (NRE) by 2030 and increase job creation in the NRE sector. According to the plan, the primary instrument used to incentivise the roll-out of large-scale NRE – Korea uses the term 'new and renewable' precisely because natural gas-powered fuel cells cannot be considered a renewable energy resource – is the Renewable Portfolio Standard (RPS).

Under the RPS, power generators with installed capacity larger than 500MW are obliged to meet an increasing proportion of their power generation from new and renewable energy sources each year. The 22 obligators, both public utilities and IPPs, must source at least 8% of their total power production from such sources in 2021, a figure which rises by 1% each year up to 10% in 2023.

Each MWh of new and renewable energy produced secures one Renewable Energy Certificate (REC). To secure RECs, obligators can develop projects themselves, invest in projects developed by third parties, sign REC contracts with third party developers or buy RECs on the spot market. To control the direction of the market and incentivize certain technologies, a multiplier is used. For example, solar farms under 100kW capacity receive 1.2 RECs/MWh whereas solar farms over 3MW receive 0.8 RECs/MWh. For fuel cells the multiplier has been upgraded from 2.0 in 2020 to 2.5 in 2021, so a fuel cell plant receives 2.5 RECs per MWh of energy produced on top of the value of the electricity.

The REC price and the system marginal price (SMP) for electricity fluctuate, but the incentives ensure fuel cells generate revenues more than the SMP which is the market price of generated electricity. For example, assuming an average long-term REC contract price of KRW 50,000 (€37) and an SMP price of KRW 160,000 (€120)/MWh, this means a utility-scale fuel cell power generator would make about KRW 285,000 (€214) (SMP KRW 160,000 + REC 2.5 x KRW 50,000) of revenue for each MWh of electricity generated through fuel cells.

This policy has led to 578MW of utility-scale fuel cells being installed across the country or approximately 0.6% of the total domestic power generation. This is a long way from the 15GW target by 2040 set out by the Hydrogen Roadmap but it has made the Korean utility-scale fuel cell market one of the most competitive in the world.

5.3. GREEN NEW DEAL

In July 2020, the Korean government announced a Korean New Deal with the aim of creating 1.9m jobs by 2025. The New Deal consists of almost KRW 160 trillion (€118bn) worth of total investment in the digital, green economy and ‘safety net’ spaces. Central government expenditure will account for KRW 115 trillion (€85bn), while the remainder will be sourced from local governments and the private sector.

The Green New Deal is the term used to describe projects aimed at reducing the economy’s carbon intensity and hydrogen is set to play a key role. The government has selected 5 key areas of investment: Green Smart Schools, Smart Green Industrial Complexes, Green Remodelling, Green Energy, and Green Mobility. Of the KRW 74 trillion (€55bn) total capital investment under the Green New Deal, the largest portion, KRW 20 trillion (€15bn), will be used for green mobility, particularly hydrogen projects. Public organisations such as KOGAS, KEPCO and related ministries are tasked with developing plans to channel the funds.

Green New Deal funding will be applied to overcome the lack of short-term profitability with hydrogen infrastructure. For example, operating a hydrogen refuelling station (HRS) is not yet profitable due to low volumes and the high price of delivered hydrogen through tube trailers so attracting investment has proven difficult. To remedy this, the government is considering adopting a Build-Transfer-Lease (BTL) model under the Green New Deal whereby the private sector builds the infrastructure, transfers the ownership to the government and then leases the infrastructure back from the government over a 30 or 50-year period.

It is important to note, however, that a new government has taken office in May 2022 which means that the future implementation of the Korean New Deal and the Green New Deal is somewhat unknown.

5.4. REGULATIONS AND CERTIFICATION

Korean hydrogen law designated Korea Standards Association (KSA) as the central organisation to certify fuel cell and other downstream hydrogen technologies. However, the certification of the upstream hydrogen technologies still remains with Korea Gas Safety Corporation (KGS) which is the central government authority that tests and certifies high-pressure gas equipment. Currently there is no specific law that regulates the certification of hydrogen production and handling equipment such as SMRs and compressors, storage tanks, etc. Instead, the 'High-pressure Gas Safety Law (HPGSL)' is temporarily applied for the certification of these equipment.

KGS and MOTIE are currently working on the Hydrogen Safety Act which is expected to be announced in 2022. According to the HPGSL, all hydrogen-related equipment rated at over 10 bar design pressure is considered high-pressure gas equipment and will need to be certified by KGS. On the other hand, equipment below 10 bar design pressure is considered low-pressure gas equipment. Low-pressure gas equipment and fuel cell certification are regulated by Korea Occupational Safety and Health Agency (KOSHA).

More information on the KGS and KSA regulations can be found at:

http://www.kgs.or.kr/kgsmain_eng/kgs_services/manufactural_sys.jsp

https://eng.ksa.or.kr/ksa_kr/index.do

6. UPSTREAM AND MIDSTREAM HYDROGEN SECTORS

6.1. DISTRIBUTED HYDROGEN PRODUCTION

Steam Methane Reformers (SMR)

Korea ultimately aims to secure its hydrogen from renewable energy-powered electrolysis or to ship in hydrogen from, for example, Australia, the Middle East or potentially Norway or Denmark. But it is recognised that doing this safely, cheaply and at scale is still some way off. In the meantime, the government has identified on-site natural gas reformation through SMRs as a 'bridging' technology for the next decade or so.

In order to encourage the roll-out of on-site SMRs, MOTIE announced in November 2021 a separate 25% lower tariff for natural gas used to generate hydrogen through on-site SMRs. For example, in Seoul, from December 2021 KRW 14 (€0.10)/MJ natural gas tariff is applied for hydrogen generation, 25% lower than the regular tariff of KRW 18.6 (€0.14)/MJ. Local companies are racing to develop on-site SMR offerings but currently only have early-stage commercial units.

Although the government's focus remains on the natural gas or LPG-sourced hydrogen, local research institutes, such as KIER, and private sector players such as POSCO Energy and GS Energy, are increasingly shifting their R&D focus towards ammonia-based solutions. In September 2021, POSCO announced plans to import ammonia from abroad and roll out large-scale ammonia-based hydrogen production hubs in four locations (Incheon, Daejeon, Yeosu and Ulsan) by 2025.

Electrolysis

Korea is clearly behind the international competition in terms of electrolysis solutions. While the government and industry see renewable energy powered electrolysis as an important component of its long-term hydrogen production strategy, it does not see this production method making a large contribution – at least to HRS – in the near term.

Due to the country's small footprint and other geographical constraints, offshore wind is considered one of the most feasible sources for electricity to produce hydrogen through electrolysis in Korea. In terms of the project development local conglomerates are collaborating with global offshore wind specialists as seen in POSCO's recent MOU signed with the Danish offshore wind specialist Ørsted to develop 1.6GW capacity offshore wind and green hydrogen complex in Incheon by 2026.

A small percentage (<1%) of hydrogen is currently produced through electrolysers, at 5 locations across the country. Investment is being made into electrolysis both by the private and public sector. Elchemtech has a PEM electrolysis solution on the market and large players such as Hyundai Motors are also looking at electrolysis technology. Other players such as Acro Labs and Wespe are developing PEM and AEM (Anion Exchange Membrane) technologies with a view to bringing units to the market by 2022. By 2030, the government aims to have a domestic champion with a high-efficiency (50kWh/kg), large-scale (up to 100MW) electrolysis technology.

Industry Insider's Thoughts

Korea is very strong in downstream hydrogen applications such as power generation and mobility while Europe, and Denmark in particular, is more focused on upstream hydrogen production. Korean companies and institutes are well aware of the R&D strength of Denmark in electrolysis technologies, and we would welcome any cooperation in this space with Denmark.

Mr S. LEE, General Manager – Hydrogen Convergence Alliance (H2Korea)

6.2. HYDROGEN HANDLING AND TRANSPORTATION

Hydrogen handling equipment for mobility such as compressors, storage tanks and dispensers are largely sourced from abroad. The high-pressure methane and propane/butane gas compressor supply chain is mature as most of Korea's bus and taxi networks use CNG and LPG fuels respectively. However, as the hydrogen economy is in its infancy, local companies still rely on foreign hydrogen compressor equipment.

Korea recently allowed the installation of bundle-type hydrogen storage tanks instead of cartridge-type tanks, which generally have a larger footprint. However, owing to increased weight and safety concerns, bundle-type storage is allowed only with Type 3 or 4 storage tanks, which are strengthened with non-metallic fibre liners.

Japanese companies partnering with local firms dominate the hydrogen dispenser market. A local company called Saemchan has succeeded in developing a domestic hydrogen dispenser, but customers maintain a preference for foreign equipment with stronger track records – industry experts believe this will continue as dispensers and compressors account for 20% and 40% of station downtime respectively ensuring that reliability is critical.

Most of the research around Liquid Organic Hydrogen Carriers (LOHC) in Korea is led by R&D institutes and state-owned companies. Korea Institute of Science and Technology (KIST) developed a new LOHC with the support of MOTIE in 2017. The LOHC is a liquid in which biphenyl and diphenylmethane are mixed in a specific ratio. A ruthenium catalyst is used to store the hydrogen at 50 bar and a palladium catalyst is then used at atmospheric pressure to extract the hydrogen. Although KEPCO also claims to have developed LOHC technology that can store 20Nm^3/h hydrogen, most of the research in Korea remains at the basic R&D stage.

In 2019, the Korea Institute of Machinery and Materials (KIMM) launched a liquid hydrogen technology research group with the aim of developing domestic liquification technology. Until then, Korea has no option but to use foreign technology. In April 2020, Hyosung Corporation announced a partnership with Linde Group for a 13,000 tons/year capacity hydrogen liquification plant which will be the world's single largest liquid hydrogen facility. One month prior to the Hyosung-Linde project announcement, Doosan Heavy Industries & Construction (DHIC) announced a 5 ton/day capacity project with Changwon Industry Promotion Agency. DHIC is currently considering several options for the liquification technology supplier.

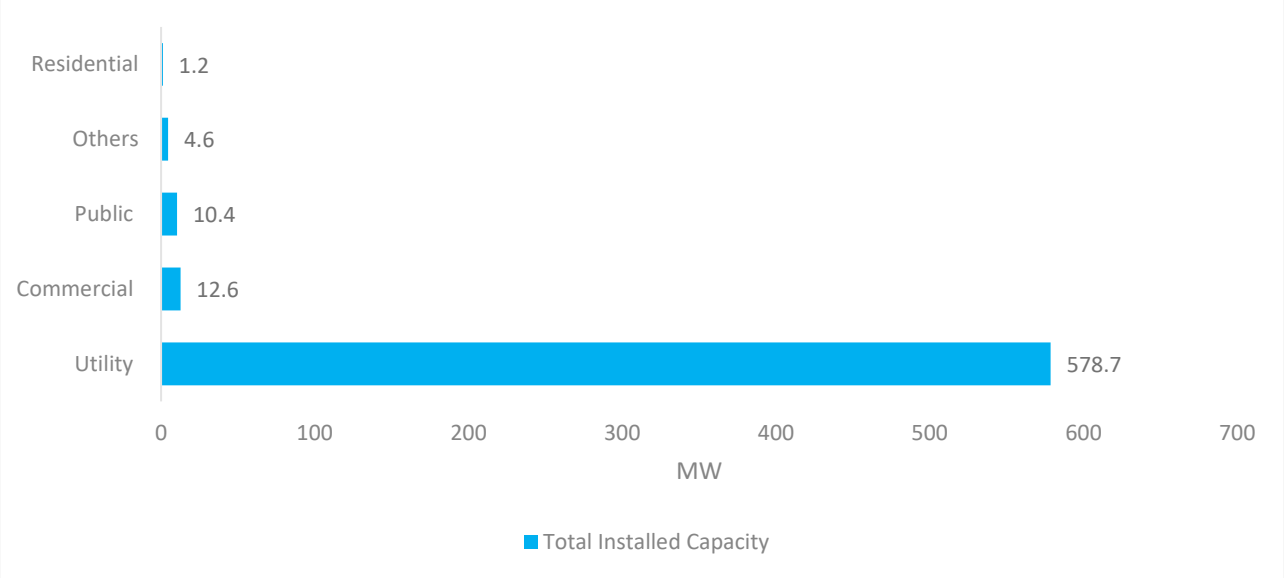
7. DOWNSTREAM HYDROGEN SECTORS

7.1. STATIONARY POWER GENERATION

Although the RPS policy under Vision 3020 has already led to 578MW of utility-scale fuel cells being installed across the country, MOTIE recently announced plans to introduce a new Hydrogen Portfolio Standards (HPS) from 2022, which separates hydrogen from the existing RPS. Although it is not official yet, HPS is expected to be applicable only to the state-owned KEPCO and other gencos (subsidiaries of KEPCO), not IPPs in the short-term. That means the gencos will be obligated to source a certain percentage of their power generation from hydrogen fuel cells, invest in projects developed by third parties or purchase credits.

According to the preliminary draft of HPS, gencos should aim to source at least 20% of their power generation from hydrogen fuel cells by 2035. In addition, there will be separate credits for each MWh of power generated with fuel cells, that IPPs can sell to gencos on the spot market. It is not clear yet if the IPPs who are reliant on fuel cell with natural gas reformers will also be entitled to credits. However, with so much focus on fuel-flexible solutions such as SOFC systems and reduced tariffs on natural gas, it is highly likely that natural gas-powered fuel cells will also be entitled to HPS credits, albeit with possibly lower applied rates compared to fuel cells generating power with pure hydrogen.

Figure 3: Fuel cell stationary power generation by application (2021)



Source: Korean Statistical Information Service

The residential and commercial fuel cell markets in Korea have not been so successful and stand in contrast to Japan's success in these sections of the market. Buildings with a total floor area over 1,000m^2 are required to generate at least 30% of their energy consumption from new or renewable energy. MOTIE provides subsidies for 5 types of installations for residential and commercial building

end-users: solar power, solar heat, fuel cells, geothermal and wind. For fuel cells, 80% of the installation cost is covered up to a maximum of €11,500/kW. Similar subsidies apply to residential fuel cells up to a maximum of €11,700/kW.

Table 4: Key players - Power generation market (2021)

Company	Product Type	Capacity	Original Technology	Application Field
POSCO Energy	MCFC	300kW, 2.5MW	FuelCell Energy	Utility
Doosan	PEMFC	600W, 1kW, 5kW, 10kW	Fuel Cell Power	Residential/Commercial
	PAFC	400kW	Clearedge Power	Utility
	SOFC	5~20kW	Ceres Power	Commercial
SK Ecoplant	SOFC	300kW	Bloom Energy	Utility
S-FuelCell	PEMFC	1~10kW	CETI, GS Fuel Cell	Commercial
	PAFC	100kW	S-FuelCell	Utility

Source: Intralink research

7.2. PASSENGER MOBILITY

Consumer Fuel Cell Electric Vehicles (FCEV)

Hyundai Motor Company has maintained its leading position in the commercial FCEV market in 2021 with a 60% global market share. In the domestic market, FCEV sales are growing more rapidly than battery electric vehicles (BEV), albeit from a much smaller base, thanks to government subsidies. The central and local governments allocate subsidies for consumer FCEV and while the subsidies apply to any make, almost all FCEVs in Korea are supplied by Hyundai.

The starting price of Hyundai's most recent FCEV model 'Nexo' is KRW 70m (€53,000). The central government offers a subsidy of KRW 22.5m (€17,000) and local governments offer subsides ranging from KRW 10-20m (€7,500-15,000). In Seoul, after subsidies the consumer pays around KRW 30m (€22,500) for the basic Nexo model. Apart from the end-user subsidies the government provides further incentives in the form of tax benefits. As Type 1 low-emission vehicles, FCEVs are also eligible for up to a 50% discount on public parking spaces and the Korea Expressway Corporation (KEC) provides a 50% discount on highway tolls.

Industry Insider's Thoughts

It is important to trade the know-how in the hydrogen infrastructure space between Korea and Denmark. I expect to see a potential synergy effect if we combine Danish companies' expertise in the electrolysis and Korean companies' strength in the high-pressure gas handling areas.

Mr W. KIM, Head of Infrastructure Division – Hydrogen Energy Network (HyNet)

Fuel Cell Electric Buses (FCEB)

Hyundai Truck & Bus is the only fuel cell bus (FCEB) OEM in the market, although Edison Motors announced a tie-up with Plug Power in December 2021 to develop FCEBs for cities. The original price of Hyundai's FCEB is around KRW 630m (€474,000) but this receives subsidies of around KRW 150m (€113,000) from the central, and KRW 150m (€113,000) from local governments, bringing the price down to KRW 330m (€250,000).

Despite government subsidies, Korea is far from achieving the country's goal of 2,000 units running by 2022. As of December 2021, there are only about 150 FCEBs on the road in Korea, and only 30% of the subsidy budget allocated by local governments for 2021 has been used. The slow roll-out of FCEBs is often explained by the lack of refueling infrastructure and maintenance service for such vehicles which are the main discouraging factors cited by bus operators.

In 2019, HMC announced that as well as supplying Hyundai Bus & Truck, they would also supply fuel cell systems to other local bus manufacturers. However, since no progress has been made so far there is suspicion among the bus OEMs as to whether Hyundai will deliver its systems on terms that would allow them to compete with Hyundai Truck & Bus. On the other hand, Doosan Group, recently announced the development and supply of fuel cell systems for commercial vehicles, signalling the company's entry into the FCEB and heavy-duty vehicle markets.

7.3. FREIGHT MOBILITY

FC Trucks

In 2020, Hyundai Truck & Bus began mass production of the world's first FC trucks – XCIENT Fuel Cell. The trucks are powered by 190kW FC stacks (2 x 95kW Nexo FC stacks) with a combined hydrogen storage capacity of approximately 32kg. In 2019, Hyundai Motors formed Hyundai Hydrogen Mobility (HHM), a joint venture with the Swiss company H2 Energy, which will lease the trucks to commercial truck operators on a pay-per-use basis. Following delivery of the initial 10 units of its FC trucks to Switzerland, Hyundai signed an agreement to provide two test-run FC garbage trucks and these trucks have been in operation in the Korean city of Changwon since January 2021. The Ministry of Environment is soon expected to announce end-user subsidies starting from 2022.

There are two local domestic OEMs in the market: Hyundai Truck & Bus and Tata Daewoo. Although Hyundai is currently the only supplier of FC trucks in Korea, Tata Daewoo also has medium to long-term plans to develop FC trucks. According to a representative at Tata Daewoo, the company is

closely monitoring the potential government subsidies for FC trucks and potential demand in the market.

FC Drones

Korea has more than 3,300 islands and delivering goods to these rural areas is challenging and drones are seen as one solution for this. In April 2020, Doosan Mobility Innovation (DMI) distributed protective masks to three islands using its FC drone. Apart from 'last mileage delivery' services, FC drones are also being used in the plant inspection (industrial, power generation), solar farm monitoring as well as for military and agriculture purposes.

There are over 20 UAV companies in Korea and DMI and Giantdrone are known to have FC-based product lines at the commercial stage. DMI recently developed a 2kW FC drone with a 2-hour flight time and the company is focusing on the development of fuel cell stacks with titanium plates rather than stainless steel, due to the lighter weight and durability of titanium.

Under the NHTR, the government aims to achieve 1kW/kg for general purpose drones, and 2kW/kg power density for drone taxis by 2040. The largest FC drone currently available in Korea has a 5kW air-cooled PEMFC system but local drone manufacturers such DMI are open to licensing technology for larger scale, liquid cooled systems and are keen to secure or develop lightweight, cost-effective hydrogen storage tanks for those drones.

FC Water Vessels

Korea is currently the world's largest shipbuilder and boasts major shipbuilding companies such as Hyundai Heavy Industries, Daewoo Shipbuilding and Marine Engineering and Samsung Heavy Industries. The country currently requires only Tier II marine standards (less strict control of CO_2 and NO_x emissions) rather than Tier III, meaning vessel operators have no obligation to electrify the vessel engines.

Despite this, Korean shipbuilders are already working on early-stage projects with global players, as shown by the agreement signed between Hyundai Mipo Dockyards and Maersk in July 2021 to a build a feeder vessel capable of sailing on methanol through DMFC systems. In addition, Samsung Heavy Industries and Bloom Energy have also signed an agreement in 2020 to develop a fuel cell system to replace the main engines and generators on LNG carriers. The Korean government's aim is to encourage the domestic development of a fuel cell system for marine applications by 2030 at a price point of KRW 0.5m/kW (€376/kW).

7.4. MATERIAL HANDLING AND HEAVY EQUIPMENT

Forklift subsidies from central government are expected in 2022 but current subsidies are only available at the local government level and differ by region. For instance, South Chungcheong Province provides 40-50% end-user subsidy for FC forklifts depending on the volume and application, while the subsidies in South Gyeongsang Province were fixed at 70% in June 2021. The subsidies mean that currently forklift end-users should pay about KRW 20-24m (€15,000-18,000) per vehicle.

Hyundai Material Handling (HMH) is currently the only OEM producing FC forklifts in Korea. Hyundai Mobis has developed special fuel cell systems with 15kW capacity downsizing the original 45kW

systems to supply HMH and other forklift OEMs in Korea and abroad. The largest port in Korea, Busan Port is looking to procure 300 units of FC forklifts by 2025 and according to the port authority, a subsidy amount of KRW 30m (€22,500) per vehicle has been approved for by the government.

7.5. HYDROGEN REFUELLING STATIONS

Currently, there are 100 HRS operating in Korea. The vast majority of these are 'truck-in' stations where the hydrogen is brought in by tube trailer from a supplier such as Deokyang or SPG. There are three operational HRS with on-site SMRs commissioned in 2020 and 2021. In terms of capacity, HRS are divided into two broad categories: regular HRS with 650kg/day and bus HRS with 1,000kg/day refuelling capacity. Due to the low profitability of HRS operation, almost all HRS are being operated by the municipalities. HRS are often built close to CNG stations (most Korean buses run on CNG) or LPG stations (most Korean taxis run on LPG) as permits are easier to secure and some costs, such as safety protocols, can be shared across the stations.

The hydrogen price at HRS falls within the range of KRW 7,100 and KRW 8,800/kg (€5.3 and €6.6/kg) which includes 10% VAT. Hydrogen is substantially cheaper than gasoline, diesel, or LPG on a cost/km basis. While there is no government-mandated ceiling for the price of hydrogen that the end-user pays, 8,800 KRW/kg (£5.7/kg) has become the standard price that HRS operators are reluctant to go beyond. This price makes it difficult to attract operators into the HRS industry, an issue the government is looking to address.

HyNet

In 2019, 13 hydrogen companies with interests in the hydrogen space established a special purpose company (SPC) with the goal of building 100 HRS by 2022. Those companies were KOGAS, Hyundai Motors, Woodside, Nel, Valmax, Bumhan, SPG Hydrogen, JNK Heaters, Kolon Industries, Hyosung Heavy Industries, Air Liquide, Deokyang and Ecobio Holdings and together they invested a total of KRW 135bn (€101m) into the SPC. However, Deokyang and Ecobio withdrew from the SPC in 2020, leaving 11 companies in the consortium.

HyNet has built 40 HRS in 2020, currently building 30 and plans to build 30 more in 2022. Despite a degree of government involvement, HyNet acts as a private sector player investing 50% CAPEX on top of the government's 50% subsidy for HRS.

KOHYGEN

There were plans to copy the HyNet model with the formation of another SPC to build HRS for FCEB and trucks. Finally, in March 2021, 9 companies, mainly the operators of petrol and LPG stations such as GS Caltex, S-Oil, Hyundai Oilbank and SK Gas have formed an SPC called 'KOHYGEN' with the goal of building and operating HRS for passenger and heavy-duty hydrogen vehicles such as buses and trucks. KOHGYEN plans to build HRS across Korea with refuelling capacity of 1,000 kg/day and higher. Although there is no target for the number of HRS as there is with HyNet, KOHGEN is in the process of building three HRS with capacity of 1,000 kg/day each and has applied for government approvals for an additional six HRS to be built in 2022.

Industry Insider's Thoughts

KOHYGEN is a unique structure designed to roll out hydrogen refueling infrastructure for FCEB and trucks. On the back of our success in Korea, we are planning to invest in HRS in Middle East and Europe. SPCs such as KOHYGEN will enable countries like Denmark to build hydrogen refueling infrastructure which is a key in decarbonisation of public transport sector.
Mr C. LIM, General Manager – KOHYGEN

7.6. HYDROGEN FOR INDUSTRY

The industrial hydrogen market in Korea is dominated by established players. Many of the applications are 'mission-critical' so commercial track records are extremely important for customers. By-product hydrogen is limited as it is directly linked to the load capacity of petrochemical complexes so industrial users of hydrogen tend to install large-scale SMRs to guarantee supply.

Due to the limited hydrogen, industrial users especially in the hard to abate sectors such as steel, cement, chemicals and fertiliser production are increasingly moving towards substituting pure hydrogen with ammonia creating more demand for ammonia cracking solutions. In May 2021, POSCO announced partnership with KIST and the Research Institute of Industrial Science & Technology (RIST) to develop green ammonia synthesis solutions.

In addition, the largest players in Korea's hard-to-abate sectors such as Hyundai Merchant Marine (HMM), Lotte Fine Chemical, POSCO, and Korea Shipbuilding & Offshore Engineering (KSOE) formed a consortium in May 2021 for the purpose of marine transport and bunkering of green ammonia. According to the consortium agreement, KSOE will develop ammonia-fuelled ships and Korean Register of Shipping will be in charge of certification. HMM and Lotte Global Logistics will run the vessels, POSCO will produce green ammonia abroad and import to Korea, and Lotte Fine Chemical will transport, store, and bunker the green ammonia. The government is also supporting this initiative through deregulation of ammonia import and allocating more funds for R&D on ammonia technologies.

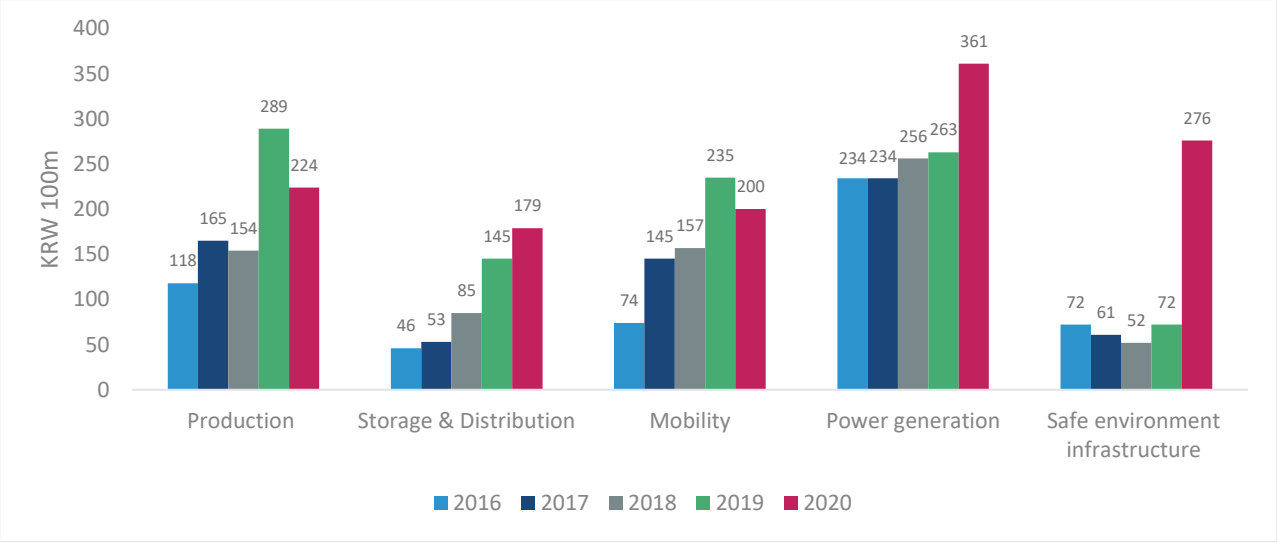
Although injecting hydrogen into the natural gas grid can be very effective as a decarbonisation strategy, Korea is not currently working on blending hydrogen into the gas grid. According to one local KOGAS official the natural gas pipeline could take no more than a 3% blend of hydrogen, so it's not a major focus for the organisation.

8. HYDROGEN TECHNOLOGY R&D TRENDS

Korea is mainly focusing its R&D efforts on blue and green hydrogen production, liquefied hydrogen storage and transportation technologies. Additionally, the government is aiming to build hydrogen pipeline networks across the country by 2025 and several R&D institutes such as KIER and KETEP are working on the technological development and economic feasibility of pipeline infrastructure. While about one-third of the country's hydrogen consumption in 2040 is estimated to be based on imported LNG, KOGAS plans to invest €32bn in green hydrogen R&D, and NRE projects both in Korea and abroad.

Large government funding underpins Korea's effort to develop technological competence in the hydrogen economy. Public R&D spending on hydrogen technologies for FY2021 was KRW 834bn (€614m), a 40% increase from 2020. In addition, the investment in broader hydrogen-related R&D from across five ministries (Ministry of Science and ICT, Ministry of Trade, Industry and Energy, Ministry of Land, Infrastructure and Transport, Ministry of Oceans and Fisheries, and Ministry of Environment) has been steadily increasing from KRW 544bn (€409m) in 2016 to KRW 705bn (€530m) in 2018.

Figure 4: R&D investment trend by hydrogen technology fields (2016-2020)



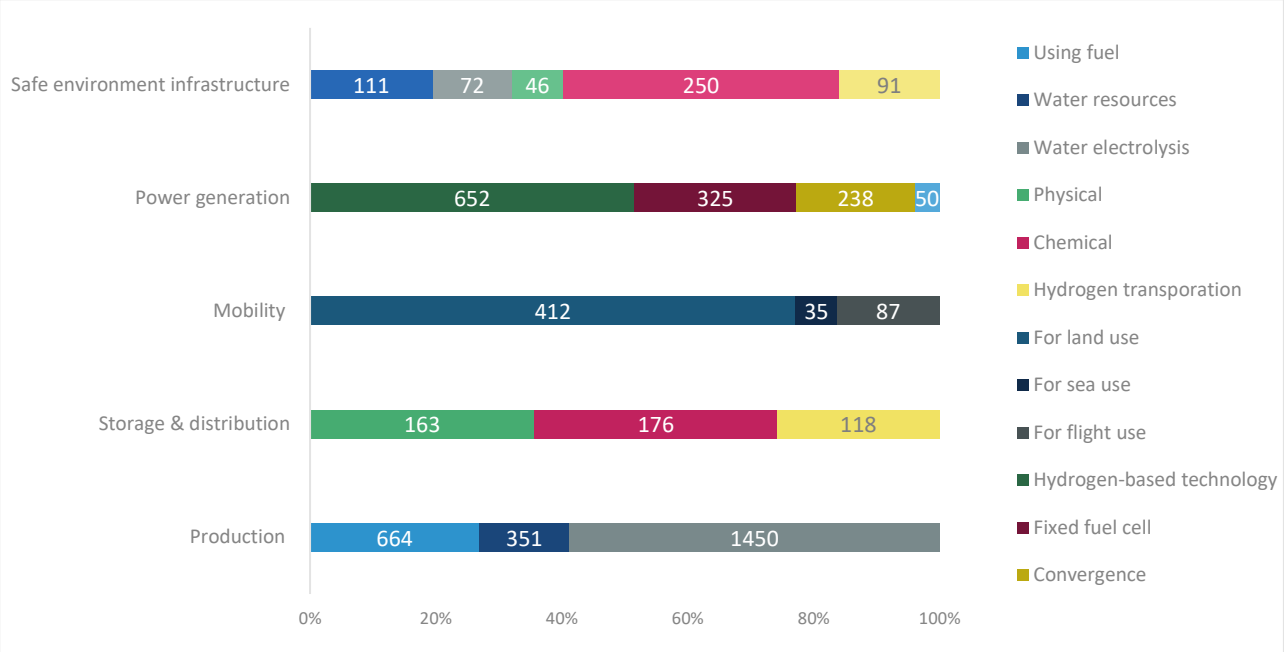
Source: Status of hydrogen technology development roadmap and future plans (Related ministries, 2020)

Hydrogen technology R&D in universities

There are numerous universities in Korea with hydrogen technology related R&D and higher education programmes. The government, with the commitment to invest KRW 7.1bn (€5.2m) by 2025, selected Changwon University, Yonsei University, Chungnam National University, and Korea Polytechnic University to establish special graduate and R&D courses.

Domestic research papers in Korea are mainly focused on water electrolysis, hydrogen production, chemical storage, land transportation, hydrogen-based technologies, and hydrogen infrastructure.

Figure 5: Number of research papers by hydrogen technology fields (2018)



Source: Status of hydrogen technology development roadmap and future plans (Related ministries, 2020)

Key R&D topics in private sector

Private sector R&D mainly focuses on hydrogen liquification, transportation, and storage technologies. Korean companies are conducting R&D in the hydrogen liquification sector first and foremost with the goal of commercialisation, since liquefied hydrogen can be transported and stored in large quantities and secure high economic efficiency. In 2020, Hyosung Heavy Industries announced its partnership with Linde to build a liquified hydrogen production facility in Ulsan with 30 tons/day capacity by 2023. Despite the early success in the liquified hydrogen production sector, hydrogen storage technology is currently at the pre-commercialisation stage centred around high-pressure gas storage.

The liquified hydrogen storage and distribution at cryogenic temperatures are also at the early R&D stage. Industry experts believe that there is no technological gap between domestic and foreign producers in the case of hydrogen storage under less than 200 bar pressure. However, local companies are in the process of developing and licensing high-pressure (over 400 bar) storage technologies from US and European companies. Although local OEMs such as NKTECH and Iljin are gaining strength, the majority of equipment continues to be imported from abroad and JSW (Japan) and Fibatech (the US) control almost 50% of the hydrogen storage equipment market. See Appendix B for research fields in public and private sectors.

9. OPPORTUNITIES

The Korean government is supporting upstream, midstream, and downstream hydrogen industries through deregulation and investment in technology R&D. Meanwhile, the private sector is playing a critical role in the commercialisation of early-stage technologies which have made FCEVs, utility-scale fuel cells and other applications key engines of the Korean hydrogen industry. Despite the early success in these sectors, there is a significant technology gap between Denmark and Korea in the upstream and midstream sectors which create substantial commercial opportunities for Danish companies in hydrogen production and handling, general equipment, power generation and other areas.

Upstream and midstream hydrogen sectors

There are two essential procurement authorities in the hydrogen production market for HRS in Korea: MOTIE and KOGAS. Although the purpose is the same, generally, MOTIE-sponsored projects are called 'base-type stations' and KOGAS-sponsored projects are called 'mother stations" (*Please see Appendix A*). Both MOTIE and KOGAS are planning to install SMR equipment in these stations with a view to transporting hydrogen to the nearby stations. The technology requirement for base-type or mother stations are usually announced 2-3 months prior to the announcement of actual tender.

There are separate tenders to obtain the budget from MOTIE for base-type projects among local technoparks – industry project coordinating arms of municipal governments. After receiving the budget by winning a project from MOTIE Technoparks announce tenders for the procurement of hydrogen station equipment such as on-site SMRs, compressors, storage tanks, chillers, dispensers etc.

On the other hand, KOGAS organises such tenders either independently or in cooperation with local governments. KOGAS projects are fully sponsored by KOGAS only, whereas some technoparks allocate a certain amount of capital in addition to the MOTIE funding for base-type projects. Local governments provide land or permitting, tax, or other administrative assistance in return for KOGAS building hydrogen facilities in their respective territories.

Although Korea lags significantly in terms of the roll out electrolysis-based hydrogen production facilities, there is an increasing demand in the market for alkaline water electrolysis technologies connected to renewable energy with on/off operation characteristics. However, with the current high price of electricity generated through renewable energy, it is very challenging to make hydrogen production competitive relative to methane reforming or extraction from by-product hydrogen methods.

Korea largely sources hydrogen handling equipment from abroad. There are ample opportunities for Danish companies in the hydrogen compressor, dispenser, transportation and liquification spaces. The localisation of equipment manufacturing is high on the government's agenda, especially for hydrogen transportation and liquification areas, so licensing best-in-class technologies to local Korean manufacturers is an option for Danish companies that are comfortable with that model.

For the transportation of hydrogen to nearby refuelling stations tube trailers are often the only available option; however, the government is planning to introduce hydrogen pipelines for some locations. Currently, hydrogen is transported from extracting plants to refineries and other end users through a total of 200km hydrogen pipelines mainly around the south of the country. The old pipeline is based on conventional metallic-type pipes which operate at 60 bar pressure. Industry experts are increasingly thinking that compressing hydrogen from the reformer outbound pressure which is

around 10 bar up to 60 bar in order to transport it, is dangerous and inefficient. Therefore, there is a demand for flexible, low pressure (under 40 bar) hydrogen pipelines in the market. There is no robust hydrogen pipeline technology in Korea.

There is also an increasing demand for general equipment such as hydrogen storage, compressor / dispenser and liquification technologies, LOHC solutions, control valves, filters, pumps, water flow sensors, flow controllers, desulpherisers, heat exchangers, and others that are key for the development of midstream hydrogen sector. As Korea is aiming to localise the production of this equipment, there will be more demand for advanced materials with properties related to thermal and pressure management, fibre composites, materials for cryogenic liquid storage of hydrogen, and graphene solutions.

Downstream hydrogen sector

One of the key strengths of the Korean hydrogen economy is its ability to rapidly commercialise new technologies, especially in the downstream hydrogen sector. There are strong opportunities to license and commercialise technologies such as efficient fuel cell stacks, SOFC for power generation, polymer membranes, modular air filters, liquid cooled PEMFC systems and hydrogen tanks for drones, and other enabling materials.

Opportunities for joint research

The Danish government has allocated substantial R&D investments to four mission-driven green innovation partnerships in order to achieve the government's climate goals for 2030 and 2050. One of these challenges is a mission-driven green partnership on green fuels in transport and industry. With the Danish ambitions in this area, there is potential for increased R&D collaboration between Danish and Korean stakeholders related to the production and use of green hydrogen.

Referring to the Danish Roadmap for Green Fuels in Transport and Industry (Innomission 2), potential collaboration could include research on electrolysis, offshore windpower, energy storage and energy system integration. Also research related to social issues and increasing public acceptance and uptake could be of mutual interest.

Korea has recently kicked off official talks with the EU on joining the Horizon Europe programme as an associated country. This could be a platform for future R&D collaboration between Denmark and Korea alongside bilateral calls.

APPENDICES

A. KEY HYDROGEN PRODUCTION PROJECTS

Table 5: MOTIE-sponsored projects (2021)

	Tender Name	Capacity (Nm3/h)	Status
1.	Incheon Hydrogen Cluster	460	Planned
2.	Ansan Refuelling Station	300	On-going
3.	Daejeon Refuelling Station	300 x 2	On-going
4.	Daegu Hydrogen Facility	460 x 2	Planned
5.	Gwangju Hydrogen Facility	300	Planned
6.	Busan Hydrogen Station	300 x 2	On-going
7.	Samcheok Hydrogen Facility	300	On-going

Source: Intralink Research

Table 6: KOGAS-sponsored projects (2021)

	Tender Name	Capacity (Nm3/h)	Status
1.	Ansan Hydrogen Facility	460	On-going
2.	Pyeongtaek Hydrogen Facility	3,000	On-going
3.	Daejeon Hydrogen Facility	460	Planned
4.	Jeonju Hydrogen Facility	460	Planned
5.	Gwangju Hydrogen Facility	1,830	Planned
6.	Changwon Hydrogen Facility	1,830	On-going
7.	Gimhae Hydrogen Facility	300	Planned
8.	Busan Hydrogen Facility	460	On-going
9.	Ulsan Hydrogen Facility	1,830	On-going

Source: Intralink Research

B. RESEARCH FIELDS IN PUBLIC AND PRIVATE SECTORS

Research fields by ministries

Ministry of Science and ICT (MSICT)

- Research on the basic sources of hydrogen production, storage, and utilisation
- Electrolysis (low and high temperature and photochemical), liquid organic hydride
- LOHC-based chemical storage, next generation fuel cell material (electrode, separator, electrolyte membrane, etc.)

Ministry of Trade, Industry and Energy (MOTIE)

- Development of hydrogen production, storage, utilisation, and charging technologies
- Fuel reforming and low temperature electrolysis systems, storage tanks for FCEV and charging stations, ammonia-based chemical storage, mobility fuel cell material parts and systems, fuel cell systems for buildings and power generation, charging station parts (valves, compressors, etc.)

Ministry of Land, Infrastructure and Transport (MOLIT)

- Liquid hydrogen storage, utilisation (railroad, bus) and urban infrastructure technology development
- Commercial liquid hydrogen plant parts and processes, hydrogen railway vehicle operation, hydrogen bus safety evaluation, hydrogen pilot city (hydrogen-based energy prosumer housing complex, etc.)

Ministry of Oceans and Fisheries (MOF)

- Development of technology for sea-based hydrogen production and utilisation (ship safety)
- Safety standards for marine biohydrogen and hydrogen ships (hydrogen propulsion vessel bunkering, fuel supply, etc.)

Ministry of Environment (ME)

- Development of organic waste-based hydrogen production technologies

Table 7: Research topics in private sector and research institutes

Category		Organisation
Liquification	Process	Korea Institute of Science and Technology Korea Institute of Machinery & Materials
	Expander	Hanwha
	Cryogenic Heat Exchanger	Doosan Heavy Industries & Construction Innowill Donghwa Entec
	Ortho-Para Converter	Korea Institute of Science and Technology Korea Institute of Machinery & Materials
	Tank	Doosan Heavy Industries & Construction Iljin Korea Institute of Energy Research
	Cryogenic Valve	PK Valve Korea Institute of Machinery & Materials
	Cold-box	DIG Airgas
Hydrogen handling	Transport	Doosan Heavy Industries & Construction NKTECH
	Tank	
	Carburettor	
	High-Pressure Cryogenic Pumps	Korea Institute of Machinery & Materials Hyosung Goodspings Sewon E&C

Source: Korea Energy Economics Institute & Ministry of Trade, Industry and Energy. (2020)

C. ABBREVIATIONS

Table 8: Abbreviation definitions

BEV	Battery Electric Vehicle
BTL	Build, Transfer, Lease
CNG	Compressed Natural Gas
EPC	Engineering, Procurement, Construction
FC	Fuel Cell
FCEB	Fuel Cell Electric Bus
FCEV	Fuel Cell Electric Vehicle
FiT	Feed-in-Tariff
HPGSL	High Pressure Gas Safety Law
HRS	Hydrogen Refuelling Station
KEPCO	Korea Electric Power Corporation
KGS	Korea Gas Safety
KOGAS	Korea Gas Corporation
KSA	Korea Standards Agency
LNG	Liquified Natural Gas
LOHC	Liquified Organic Hydrogen Carrier
LPG	Liquified Petroleum Gas
ME	Ministry of Environment
MEA	Membrane Electrode Assembly
MOTIE	Ministry of Trade, Industry and Energy
NRE	New and Renewable Energy
PEM	Proton Exchange Membrane
PSA	Pressure Swing Adsorption
REC	Renewable Energy Certificate
RPS	Renewable Energy Portfolio
SME	Small and Medium-sized Enterprise
SMP	System Marginal Price
SMR	Steam Methane Reformer

About Intralink

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Intralink does not just develop its clients' strategies but plays a hands-on role in building their businesses. Its teams in Asia – immersed in the cultures and business practices of their local markets – identify opportunities, negotiate deals, and generate revenues. And when the client is ready, they will help set up an in-country presence through a local subsidiary, partnership, or acquisition.

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