Final Report

June 28, 2022

IEA HEV Task 35 – The State of Art on Fuel Cell Vehicle and Technology

Chief Editor :

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Acknowledgments: *The Management of the IEA HEV Task 35 "The State of Art on Fuel Cell Vehicle and Technology" was financed by the common fund of the IEA Technology Cooperation Programme (TCP) on Hybrid and Electric Vehicles (HEV) within the framework of the International Energy Agency (IEA).*

IEA HEV Task 35

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The State of Art on Fuel Cell Vehicle and Technology

Authors:

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SESSION 1. GLOBAL HYDROGEN ROADMAP

SESSION 2. HYDROGEN MOBILITY

SESSION 3. FUEL CELL APPLICATIONS

SESSION 4. HYDROGEN INDUSTRY VALUE CHAIN

CLOSING

1 Introduction

The IEA Implementing Agreement for co-operation on Hybrid and Electric Vehicle Technologies and Program (IA-HEV) was set up in 19 as a basis for collaboration on pre-competitive research and the production and dissemination of information. In 2016 the name of the agreement changed to Hybrid and Electric Vehicles Technology Collaboration Program (HEV-TCP). The work of the IEA-HEV-TCP is governed by the Executive Committee (ExCo), which consists of one delegate from each member country. The work is performed through a variety of Tasks that are focused on specific topics.

This report is the final deliverable of Task 35: *The State of Art on Fuel Cell Vehicle and Technology*. In 2021, Task 35 seminars were held. The first Task 35 was held at University of Ulsan, Ulsan, Republic of Korea on 25th November 2021.

Worldwide, policy makers are implementing supportive measures to facilitate the introduction or implementation of electric mobility in their region for many different reasons. Electric mobility has a great potential to solve some of our environmental, societal and economic challenges.

Task 35 Fuel Cell Electric Vehicles of the IEA TCP Hybrid and Electric Vehicles" (HEV) aims at supporting a broader commercialization, acceptance and a further development of fuel cell electric vehicles (FCVs) by collecting and sharing pre-competitive information, exchange about framing conditions, best practices and ideas, how to develop the market conditions and mobility concepts further.

Many IEA-HEV-TCP member countries and some observer countries were interested in the topic addressed by Task 35, which is in fact a new theme for the IEA-HEV- TCP, and eight countries decided to work together on this Task.

The main approach of Task 35 is to collect and exchange information, opinions and concerns in workshops and to disseminate the results amongst stakeholders and policy makers. Three major topics are distinguished:

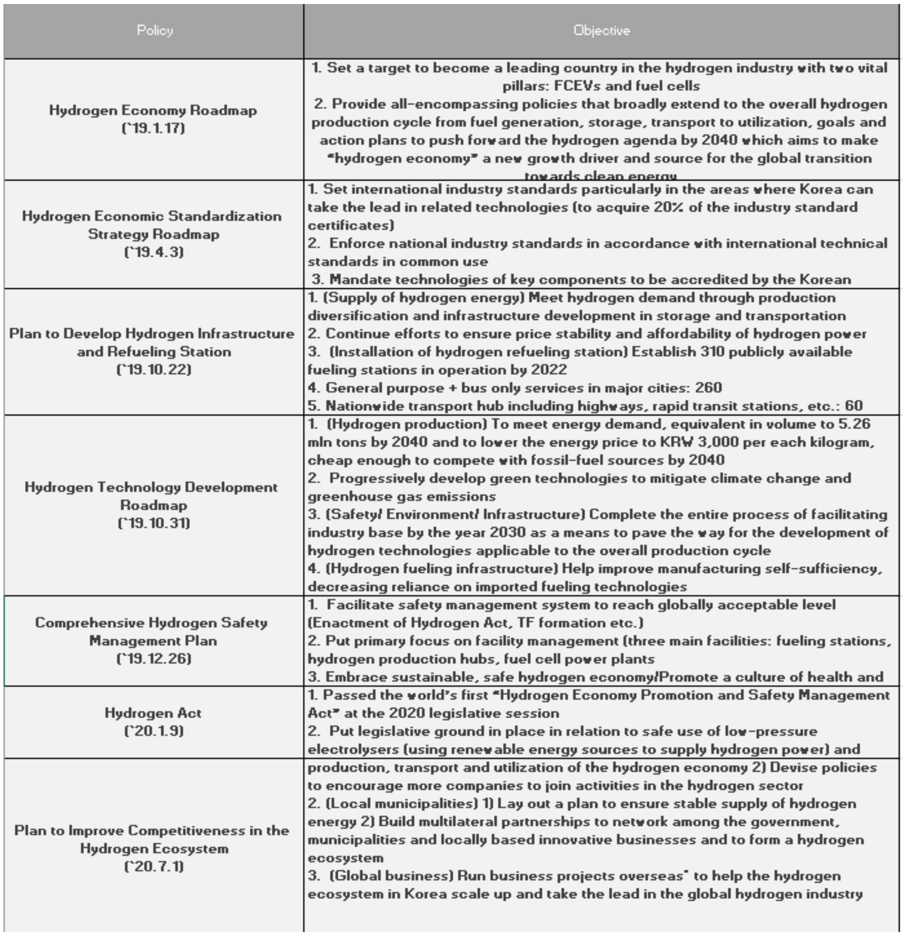
- FCVs concepts: Technologies, prospects and research needs.
- Hydrogen station for FCVs concepts: Technologies, prospects and research needs
- Market condition for FCVs and hydrogen station: international differences and best practices

GLOBAL HYDROGEN ROADMAP

1. Policy Status and Goal on Korea’s Hydrogen Economy

1.1 The Korean government efforts for a hydrogen economy

Since announcing the state-led plan titled "Hydrogen Economy Roadmap “in January 2019, the Korean government has sought a more active role in assisting hydrogen company growth. The government's effort to enact the world's first legislation on the hydrogen industry, dubbed the "Hydrogen Economy Promotion and Safety Management Act" (Hydrogen Act),which recently entered into force on Feb. 5, 2021, was deemed to be the very first step toward a transition toward the hydrogen economy. [1]



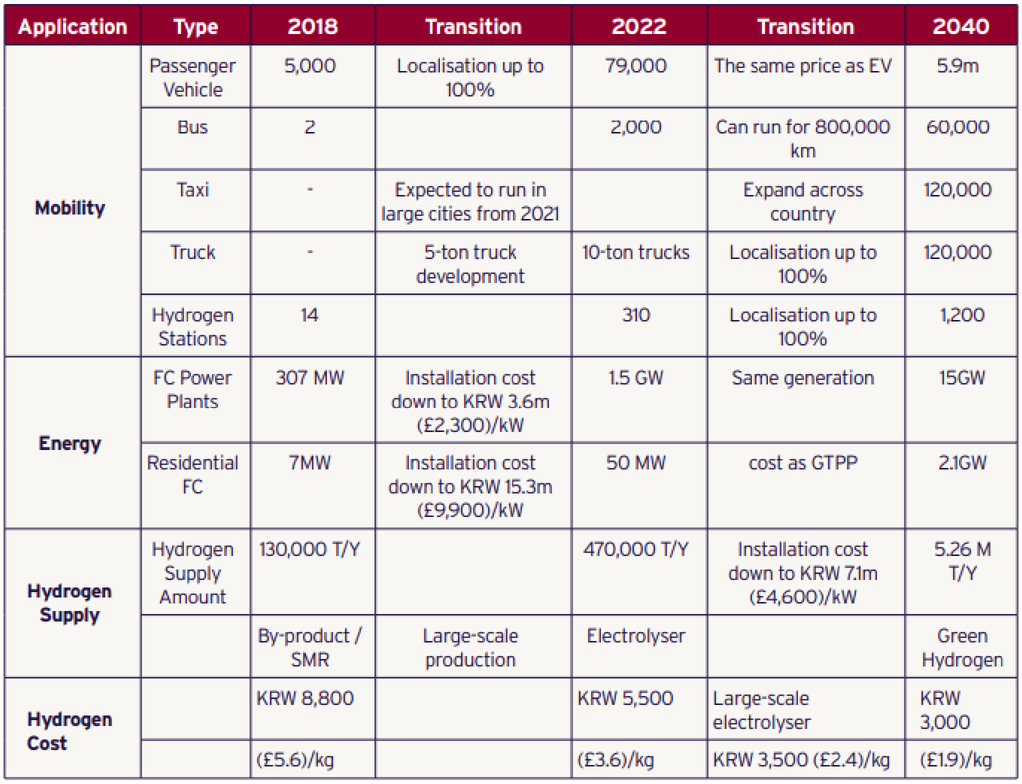
Policy	Objective
Hydrogen Economy Roadmap (`19.1.17)	1. Set a target to become a leading country in the hydrogen industry with two vital pillars: FCEVs and fuel cells 2. Provide all-encompassing policies that broadly extend to the overall hydrogen production cycle from fuel generation, storage, transport to utilization, goals and action plans to push forward the hydrogen agenda by 2040 which aims to make "hydrogen economy" a new growth driver and source for the global transition towards clean energy
Hydrogen Economic Standardization Strategy Roadmap (`19.4.3)	1. Set international industry standards particularly in the areas where Korea can take the lead in related technologies (to acquire 20% of the industry standard certificates) 2. Enforce national industry standards in accordance with international technical standards in common use 3. Mandate technologies of key components to be accredited by the Korean
Plan to Develop Hydrogen Infrastructure and Refueling Station (`19.10.22)	1. (Supply of hydrogen energy) Meet hydrogen demand through production diversification and infrastructure development in storage and transportation 2. Continue efforts to ensure price stability and affordability of hydrogen power 3. (Installation of hydrogen refueling station) Establish 310 publicly available fueling stations in operation by 2022 4. General purpose + bus only services in major cities: 260 5. Nationwide transport hub including highways, rapid transit stations, etc.: 60
Hydrogen Technology Development Roadmap (`19.10.31)	1. (Hydrogen production) To meet energy demand, equivalent in volume to 5.26 mln tons by 2040 and to lower the energy price to KRW 3,000 per each kilogram, cheap enough to compete with fossil-fuel sources by 2040 2. Progressively develop green technologies to mitigate climate change and greenhouse gas emissions 3. (Safety/ Environment/ Infrastructure) Complete the entire process of facilitating industry base by the year 2030 as a means to pave the way for the development of hydrogen technologies applicable to the overall production cycle 4. (Hydrogen fueling infrastructure) Help improve manufacturing self-sufficiency, decreasing reliance on imported fueling technologies
Comprehensive Hydrogen Safety Management Plan (`19.12.26)	1. Facilitate safety management system to reach globally acceptable level (Enactment of Hydrogen Act, TF formation etc.) 2. Put primary focus on facility management (three main facilities: fueling stations, hydrogen production hubs, fuel cell power plants 3. Embrace sustainable, safe hydrogen economy/Promote a culture of health and
Hydrogen Act (`20.1.9)	1. Passed the world’s first "Hydrogen Economy Promotion and Safety Management Act" at the 2020 legislative session 2. Put legislative ground in place in relation to safe use of low-pressure electrolysers (using renewable energy sources to supply hydrogen power) and
Plan to Improve Competitiveness in the Hydrogen Ecosystem (`20.7.1)	production, transport and utilization of the hydrogen economy 2) Devise policies to encourage more companies to join activities in the hydrogen sector 2. (Local municipalities) 1) Lay out a plan to ensure stable supply of hydrogen energy 2) Build multilateral partnerships to network among the government, municipalities and locally based innovative businesses and to form a hydrogen ecosystem 3. (Global business) Run business projects overseas" to help the hydrogen ecosystem in Korea scale up and take the lead in the global hydrogen industry

Table 1. Policy and Objective

The Hydrogen Act includes a two-pronged approach: a legal framework to encourage and explore the hydrogen economy's potential, as well as preventive and protective measures for safety management. Following the passage of the Hydrogen Act, the Ministry of Trade, Industry, and Energy (MOTIE) intends to support the ratification of the "Hydrogen Roadmap 2.0" an the table 1.

1.2Progress and accomplishments in Korea’s hydrogen economy

Over the last few years, confidence about the hydrogen economy has resurfaced, and Korea is well positioned to lead that shift. The government announced the Hydrogen Economy Roadmap in January 2019, outlining its aims until 2040. The strategy seeks to raise the number of fuel cell automobiles to 79,000 by 2022 and 5.9 million by 2040, with 310 HRS deployed by 2022 and 1,200 HRS installed by 2040 to support this expansion as shown in the table 2. It also intends to significantly boost the installed capacity of utility-scale and residential fuel cells to 15GW and 2.1GW, respectively, by 2040. [2]



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 (£2,300)/kW	1.5 GW	Same generation	15GW
	Residential FC	7MW	Installation cost down to KRW 15.3m (£9,900)/kW	50 MW	cost as GTPP	2.1GW
Hydrogen Supply	Hydrogen Supply Amount	130,000 T/Y		470,000 T/Y	Installation cost down to KRW 7.1m (£4,600)/kW	5.26 M T/Y
		By-product / SMR	Large-scale production	Electrolyser		Green Hydrogen
Hydrogen Cost		KRW 8,800		KRW 5,500	Large-scale electrolyser	KRW 3,000
		(£5.6)/kg		(£3.6)/kg	KRW 3,500 (£2.4)/kg	(£1.9)/kg

Source: Ministry of Environment

Table 2: Hydrogen Economy Roadmap

In addition, the plan defines the National Core Technology Development Plan for hydrogen generation. Hydrogen is a critical industry for Korea, and the country has worked hard over the last two decades to guarantee that it has access to the necessary technologies. While the country has made significant success in creating or purchasing foreign fuel cell technology, it has not made the same development in hydrogen production or handling technologies. One of the primary objectives of the National Core Technology Development Plan is to guarantee that the country is globally competitive in small-scale SMR and electrolysis (both PEM and alkaline) technologies. [2]

1.3Korea hydrogen economy strategy

A. Production

- **Grey Hydrogen (fossil fuel-based) production**

Grey hydrogen is made from natural gas, which emits carbon emissions throughout the manufacturing process, but blue hydrogen is cleaner because the carbon emissions are absorbed and stored. Green hydrogen is created by using renewable energy electricity. To attain this goal, the government intends to build large-scale green hydrogen production plants and reduce production costs. It also intends to secure carbon storage facilities with a capacity of 900 million tons or more by2030, with the goal of producing 2 million tons of blue hydrogen annually by 2050. [3]

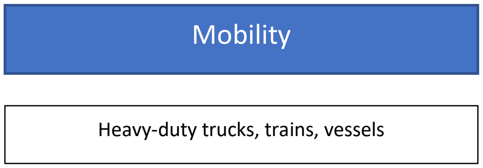
B. Distribution

- Lack of HRS Compressed Hydrogen R&D Stage

When it comes to distribution regarding the hydrogen charging stations were liquidities hydrogen. All of infrastructure and technology should be enhanced and need to be mature further.

C. Utilization

FCEVs and fuel cells are heavily focused so in the future from production to distribution to utilization across all board we need to promote these fields as shown in Fig.1.



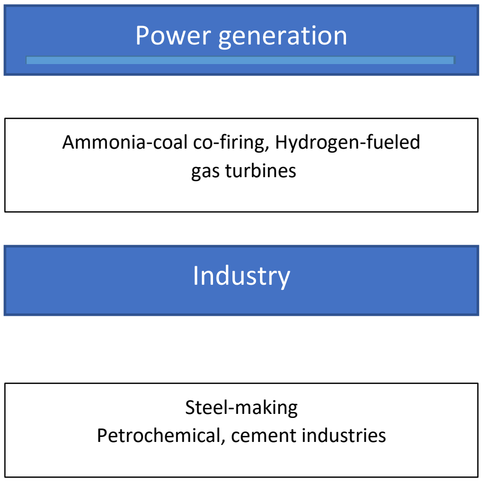


Fig.1. flowchart of Utilization Korea Hydrogen Strategy

1.4Korea’s vision for clean hydrogen production

Korea’s vision is to establish a world-leading clean hydrogen economy. The key is an ecosystem that covers the entire life cycle, from production to distribution and utilization. In each sector, we are planning to produce clean H2, distribute liquid H2, pipe-lines, ships, and utilize mobility(Heavy-duty trucks, trains, vessels), power generation(Ammonia-coal co-firing, hydrogen-fueled gas turbines), industry(Steel-making, petrochemical, cement industries). In addition, Korea will lead the establishment of a global hydrogen supply chain. Korea will raise its hydrogen self-sufficiency level to 50% by 2050.

1.5 A global hydrogen supply chain

Fig.2. global hydrogen supply chain

Korea will raise its hydrogen self-sufficiency level to 50% by 2050 as shown in Fig.2 Korea want to establish electro blindly cis pilot projects with other industries not only the local production but also overseas production have been encouraged many areas in the world have utilizing the renewable energy sources and as we know that every country has a different geological conditions so Korea want to look for the places where it will be the better conditions then the facilities can be created.

1.6Establishment of hydrogen infrastructure

At the same time regarding the fuel charging stations Korea plans to establish 660 by 2030 and over 1000 by 2040 and Korea plans also to increase more charging stations more than LPG charging stations eventually at the same time regarding the pipelines near the port and near the power plant areas, Korea want to develop the pipelines accordingly to increase the efficiency.

2. Canada’s Hydrogen Landscape

2.1 Hubs are Central to the Hydrogen Strategy for Canada

The Strategy examines Canada's hydrogen strengths, vulnerabilities, opportunities, and threats in depth, highlighting that Canada: [4] has a remarkable mix of natural and energy resources that provide myriad opportunities for clean hydrogen using diversified technologies; and is currently one of the top 10 hydrogen producers in the world, with over 3 million tone of annual hydrogen production, providing an excellent foundation on which to build out clean hydrogen infrastructure; and has a remarkable mix of natural and energy resources that provide myriad opportunities for clean hydrogen using diversified technologies. Hydrogen from natural gas, particularly in northeast B.C., Alberta, and Saskatchewan, where geology supports carbon capture, utilization, and storage; hydrogen from electrolysis using nuclear power, particularly in Ontario; and hydrogen from electrolysis using renewable power, particularly in B.C., Manitoba, and Quebec.

The Strategy also cites a number of obstacles to the scale-up of clean hydrogen development, including: the global attraction of huge projects to Canadian talent pools (for more information on international developments, read our previous blogs on Australia, Germany, and the EU, as well as Japan and South Korea); Canadian regulatory rules and standards to assist hydrogen deployment are lagging; and various emerging hydrogen usage have different technological hazards.

2.2 PEM Fuel Cell Cluster

Fuel cell technologies developed in Canada are being utilized to improve the performance of clean energy systems by balancing changes in energy loads, so contributing to the global growth of the renewable energy sector. The industry makes a significant contribution to the development of clean, efficient, and dependable alternative energy sources. The hydrogen and fuel cell industry in Canada is a global leader in terms of innovative technology development and industry experience. Canada has a large concentration of worldwide hydrogen and fuel cell expertise, which includes all aspects of the supply chain. Years of research, supply chain development, and demonstration operations have helped Canadian businesses create a competitive global position. British Columbia is home to Canada's largest cluster of hydrogen and fuel cell enterprises.

Large business and institutional institutions in Canada are leading the way in commercializing hydrogen and fuel cell technology. Walmart and Canadian Tire are converting their fleets of material handling equipment to run on hydrogen fuel cells. Fuel cell technology is being used by Enbridge Gas Distribution and Hydrogenous to provide regulating services to the Independent Electricity System Operator (IESO) of Ontario. Wind Mobile's communications backup power is provided by fuel cells. The sector's leadership in Canada is drawing major investment.[5]

- **Fuel Cell Buses**

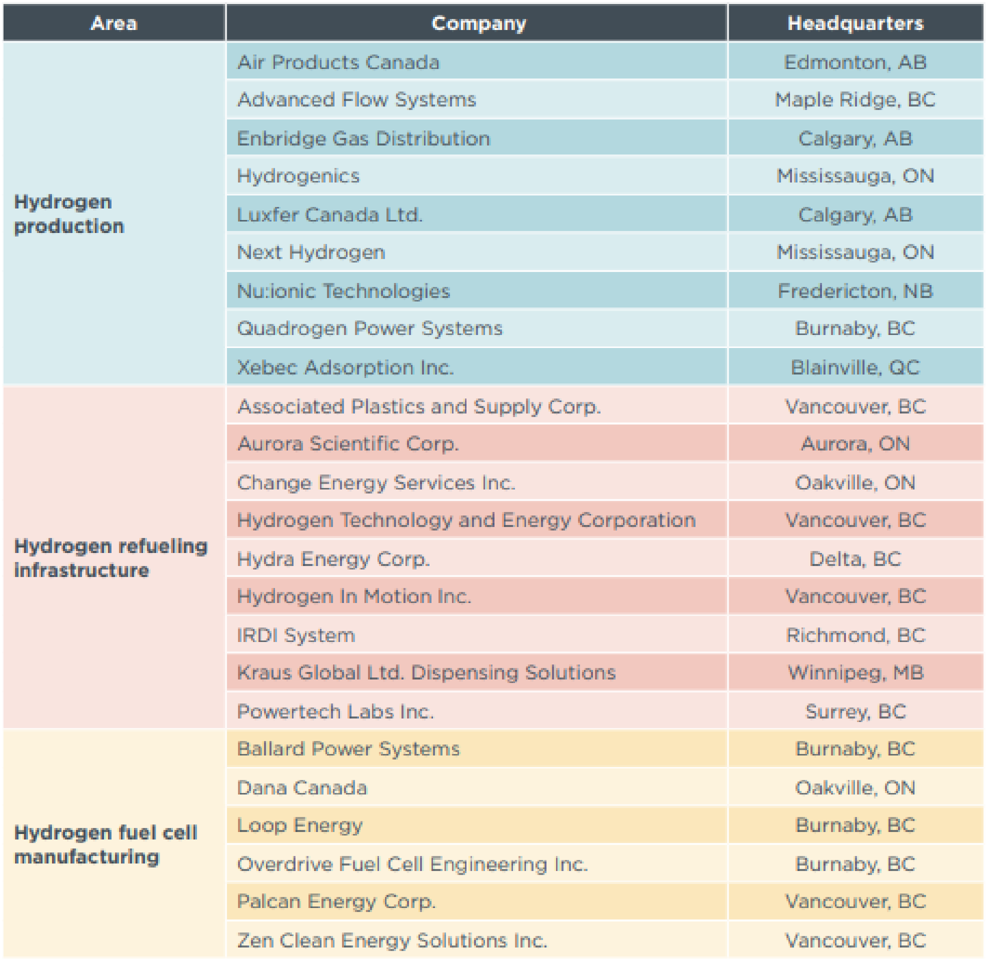
New Flyer a leading North America transit bus manufacturer, successfully demonstrated their XHE60 Fuel Cell transit bus during a 22-month test period in California. The XHE60 is powered by Ballard Power Systems’ seventh generation FC velocity hydrogen fuel cell propulsion system. First commercial delivery of two XHE60 buses to the Champaign Urbana Mass Transit Districts is scheduled for early 2019.

2.3FCEV Vehicles in Canada

There are various reasons why hydrogen fuel cell vehicles could be especially beneficial to Canada's economy and contribute to the country's transition to a more sustainable on-road transportation future. For starters, Canada has a large number of hydrogen and fuel cell enterprises that cover every aspect of the transportation supply chain, including hydrogen production and delivery, refueling stations, and fuel cell car engineering and manufacturing. Table 5 summarizes the activities of a number of Canadian companies in these three sectors. British Columbia has the largest cluster of hydrogen and fuel cell companies in Canada, but there are other companies in Ontario, Alberta, New Brunswick, and Manitoba. [6]

2.4 Fueling Infrastructure

Hydrogen-related demonstration projects, research activities, and commercialization efforts in Canada have been aided by a variety of regulations, incentive schemes, and industrial alliances. Table 3 outlines some of the changes that have occurred in the last two years. The Electric Vehicle and Alternative Fuel Infrastructure Deployment Initiative (EVAFIDI), a program that encourages the creation of a nationwide refueling network for zero-emission and other alternative-fuel cars, received funding from Natural Resources Canada's Green Infrastructure Fund. In terms of hydrogen, Phase 1 saw the installation of three refueling stations, with another 12 planned for Phase 2. (Natural Resource Canada, 2019e). [6]



Area	Company	Headquarters
Hydrogen production	Air Products Canada	Edmonton, AB
	Advanced Flow Systems	Maple Ridge, BC
	Enbridge Gas Distribution	Calgary, AB
	Hydrogenics	Mississauga, ON
	Luxfer Canada Ltd.	Calgary, AB
	Next Hydrogen	Mississauga, ON
	Nu:ionic Technologies	Fredericton, NB
	Quadrogen Power Systems	Burnaby, BC
	Xebec Adsorption Inc.	Blainville, QC
Hydrogen refueling infrastructure	Associated Plastics and Supply Corp.	Vancouver, BC
	Aurora Scientific Corp.	Aurora, ON
	Change Energy Services Inc.	Oakville, ON
	Hydrogen Technology and Energy Corporation	Vancouver, BC
	Hydra Energy Corp.	Delta, BC
	Hydrogen In Motion Inc.	Vancouver, BC
	IRDI System	Richmond, BC
	Kraus Global Ltd. Dispensing Solutions	Winnipeg, MB
	Powertech Labs Inc.	Surrey, BC
Hydrogen fuel cell manufacturing	Ballard Power Systems	Burnaby, BC
	Dana Canada	Oakville, ON
	Loop Energy	Burnaby, BC
	Overdrive Fuel Cell Engineering Inc.	Burnaby, BC
	Palcan Energy Corp.	Vancouver, BC
	Zen Clean Energy Solutions Inc.	Vancouver, BC

Table3. Fueling Infrastructure in Canada

2.5 Plan to collaborate with Korea

Fig. 3 Exploring the possibility of hydrogen collaboration between Korea and Canada in the era of climate change- [7]

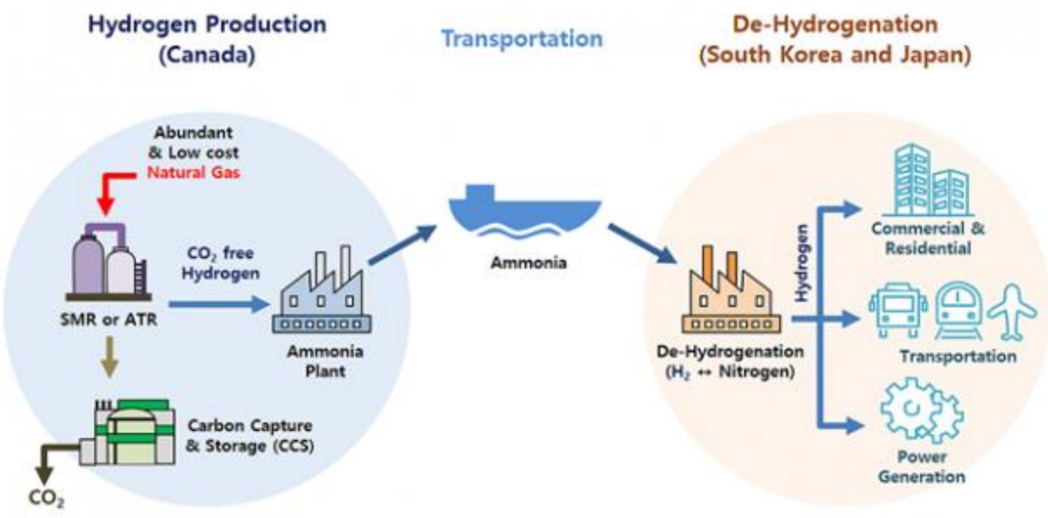


Fig.3. Canada’s Hydrogen Collaboration Plan

The Embassy of the Republic of Korea in Canada (Ambassador, Keung Ring Chang) will co-host the 'Korea-Canada Energy Forum 2021'online on July 20th (Tuesday) at 7 p.m. (EST) to explore ways to collaborate on the topic of hydrogen.

Korea and Canada, in opposition to global climate change, have designed and executed aggressive greenhouse gas reduction strategies with the goal of reaching carbon neutrality by 2050. It is investing heavily in each country's efforts to transition energy from existing fossil fuels to clean fuels. Hydrogen is another alternative energy that has been highlighted as a next-generation clean fuel, and both Korea and Canada are paying attention to the ripple effect of hydrogen, creating a national hydrogen policy and marketing it aggressively. As a result, each of the two countries' important role enterprises is increasing investment and actively seeking partnership in the hydrogen industry. [7]

The Korea-Canadian Energy Forum has chosen hydrogen as its topic in 2021 to highlight both countries' strong interest in the sector, with welcoming statements from Mollie Johnson, Assistant Deputy Minister of Natural Resources Canada, and Jade Moon, Chairman of the H2Korea. Furthermore, industry experts and stakeholders from both Canada and Korea have been asked to speak on each stage of hydrogen policy, production, transportation, storage, utilization, and investment, as well as potential collaborations on the hydrogen ecosystem between the two countries.

3 Hydrogen Economy Development: A UK Perspective

3.1UK National Hydrogen Strategy Launched

In developing a UK hydrogen economy, it will be critical that we set clear and consistent direction to give industry and investors' confidence and certainty, while remaining flexible to ensure that we act on learning from early projects and can make long-term decisions that provide the greatest decarburization and economic value. Our strategic framework influences the policy direction

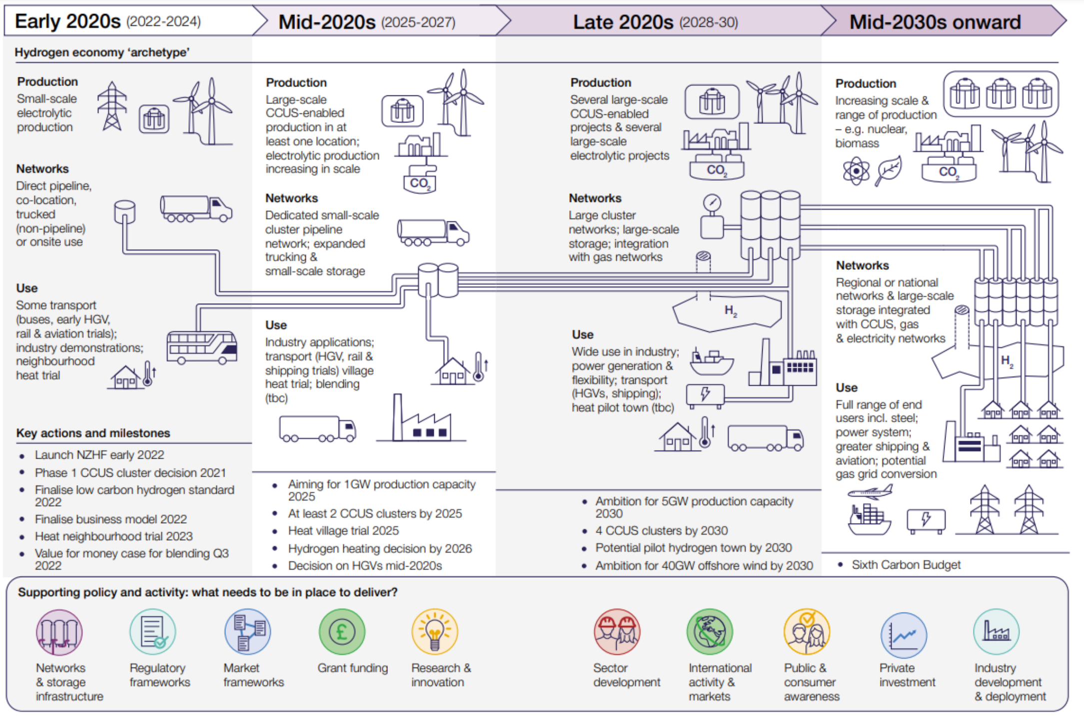
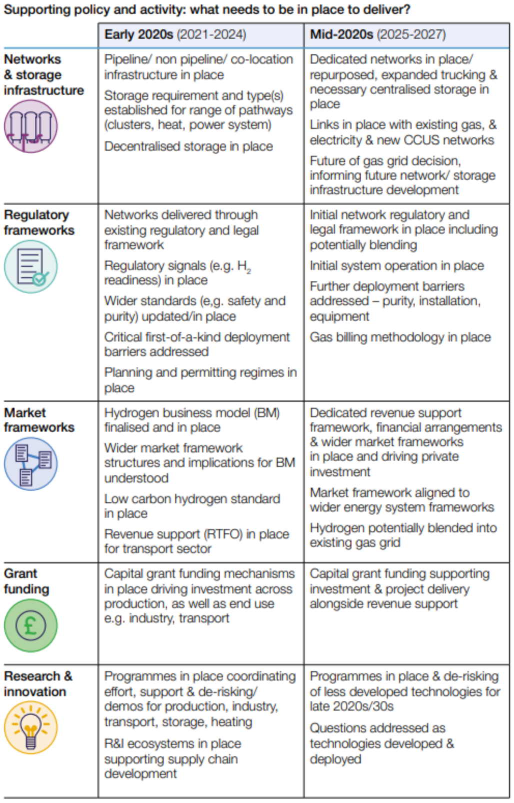


Fig.4. Policy of UK Hydrogen

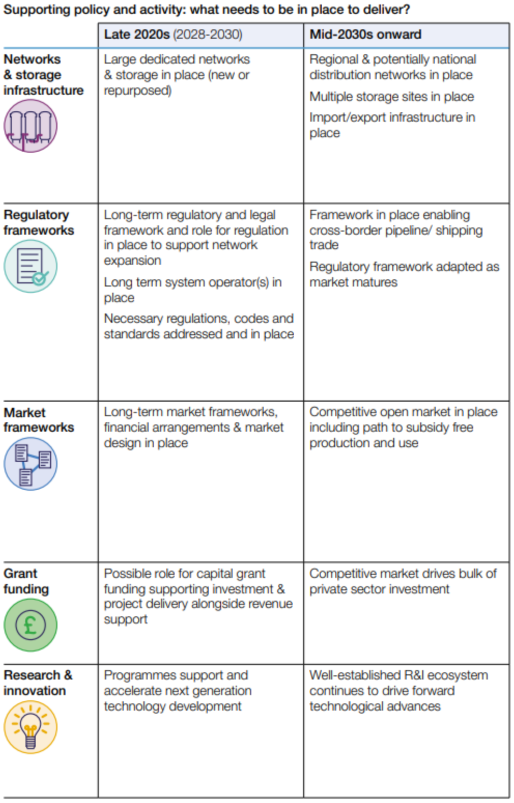
As shown in Fig.4 and pledges outlined in this strategy, and it will guide our efforts throughout the 2020s to ensure a consistent long-term approach. [8]

FUEL CELL TECHNOLOGY



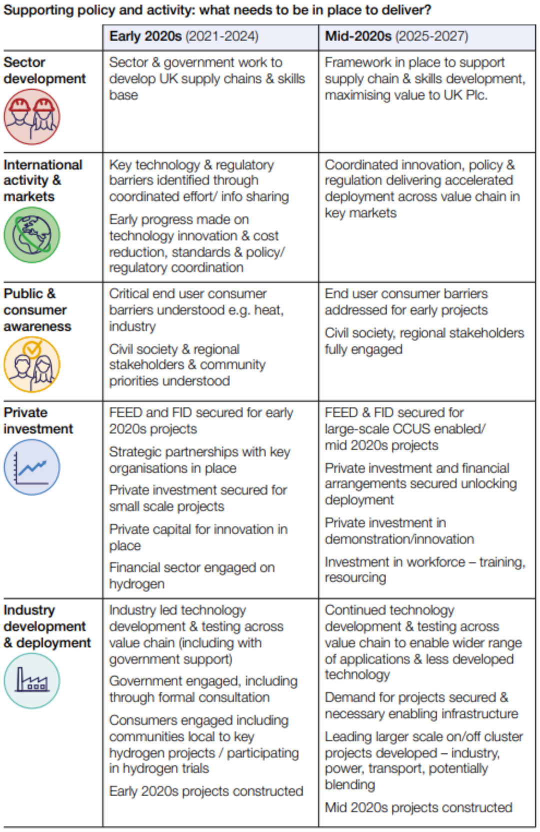
Supporting policy and activity: what needs to be in place to deliver?

	Early 2020s (2021-2024)	**Mid-2020s** (2025-2027)
Networks & storage infrastructure	Pipeline/ non pipeline/ co-location infrastructure in place Storage requirement and type(s) established for range of pathways (clusters, heat, power system) Decentralised storage in place	Dedicated networks in place/ repurposed, expanded trucking & necessary centralised storage in place Links in place with existing gas, & electricity & new CCUS networks Future of gas grid decision, informing future network/ storage infrastructure development
Regulatory frameworks	Networks delivered through existing regulatory and legal framework Regulatory signals (e.g. H_2 readiness) in place Wider standards (e,g. safety and purity) updated/in place Critical first-of-a-kind deployment barriers addressed Planning and permitting regimes in place	Initial network regulatory and legal framework in place including potentially blending Initial system operation in place Further deployment barriers addressed – purity, installation, equipment Gas billing methodology in place
Market frameworks	Hydrogen business model (BM) finalised and in place Wider market framework structures and implications for BM understood Low carbon hydrogen standard in place Revenue support (RTFO) in place for transport sector	Dedicated revenue support framework, financial arrangements & wider market frameworks in place and driving private investment Market framework aligned to wider energy system frameworks Hydrogen potentially blended into existing gas grid
Grant funding	Capital grant funding mechanisms in place driving investment across production, as well as end use e.g. industry, transport	Capital grant funding supporting investment & project delivery alongside revenue support
Research & innovation	Programmes in place coordinating effort, support & de-risking/ demos for production, industry, transport, storage, heating R&I ecosystems in place supporting supply chain development	Programmes in place & de-risking of less developed technologies for late 2020s/30s Questions addressed as technologies developed & deployed



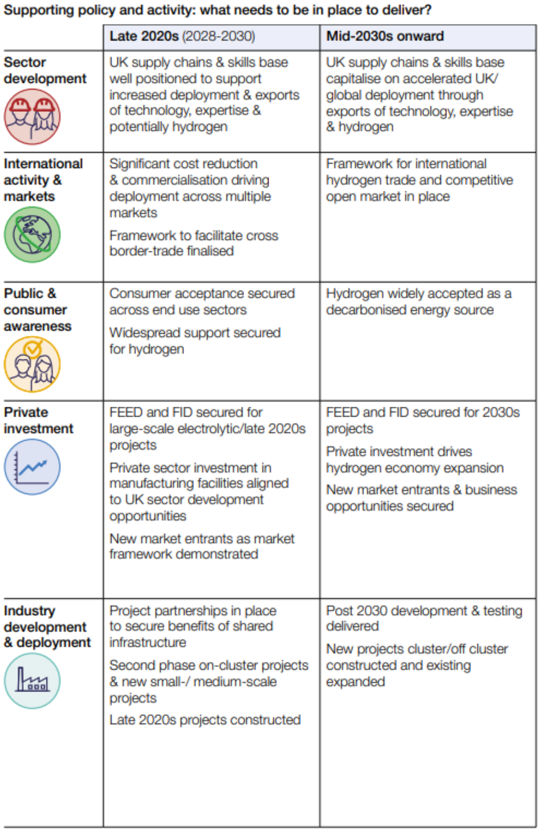
Supporting policy and activity: what needs to be in place to deliver?

	Late 2020s (2028-2030)	**Mid-2030s onward**
Networks & storage infrastructure	Large dedicated networks & storage in place (new or repurposed)	Regional & potentially national distribution networks in place Multiple storage sites in place Import/export infrastructure in place
Regulatory frameworks	Long-term regulatory and legal framework and role for regulation in place to support network expansion Long term system operator(s) in place Necessary regulations, codes and standards addressed and in place	Framework in place enabling cross-border pipeline/ shipping trade Regulatory framework adapted as market matures
Market frameworks	Long-term market frameworks, financial arrangements & market design in place	Competitive open market in place including path to subsidy free production and use
Grant funding	Possible role for capital grant funding supporting investment & project delivery alongside revenue support	Competitive market drives bulk of private sector investment
Research & innovation	Programmes support and accelerate next generation technology development	Well-established R&I ecosystem continues to drive forward technological advances



Supporting policy and activity: what needs to be in place to deliver?

	Early 2020s (2021-2024)	**Mid-2020s** (2025-2027)
Sector development	Sector & government work to develop UK supply chains & skills base	Framework in place to support supply chain & skills development, maximising value to UK Plc.
International activity & markets	Key technology & regulatory barriers identified through coordinated effort/ info sharing Early progress made on technology innovation & cost reduction, standards & policy/ regulatory coordination	Coordinated innovation, policy & regulation delivering accelerated deployment across value chain in key markets
Public & consumer awareness	Critical end user consumer barriers understood e.g. heat, industry Civil society & regional stakeholders & community priorities understood	End user consumer barriers addressed for early projects Civil society, regional stakeholders fully engaged
Private investment	FEED and FID secured for early 2020s projects Strategic partnerships with key organisations in place Private investment secured for small scale projects Private capital for innovation in place Financial sector engaged on hydrogen	FEED & FID secured for large-scale CCUS enabled/ mid 2020s projects Private investment and financial arrangements secured unlocking deployment Private investment in demonstration/innovation Investment in workforce – training, resourcing
Industry development & deployment	Industry led technology development & testing across value chain (including with government support) Government engaged, including through formal consultation Consumers engaged including communities local to key hydrogen projects / participating in hydrogen trials Early 2020s projects constructed	Continued technology development & testing across value chain to enable wider range of applications & less developed technology Demand for projects secured & necessary enabling infrastructure Leading larger scale on/off cluster projects developed – industry, power, transport, potentially blending Mid 2020s projects constructed



Supporting policy and activity: what needs to be in place to deliver?

	Late 2020s (2028-2030)	**Mid-2030s onward**
Sector development	UK supply chains & skills base well positioned to support increased deployment & exports of technology, expertise & potentially hydrogen	UK supply chains & skills base capitalise on accelerated UK/ global deployment through exports of technology, expertise & hydrogen
International activity & markets	Significant cost reduction & commercialisation driving deployment across multiple markets Framework to facilitate cross border-trade finalised	Framework for international hydrogen trade and competitive open market in place
Public & consumer awareness	Consumer acceptance secured across end use sectors Widespread support secured for hydrogen	Hydrogen widely accepted as a decarbonised energy source
Private investment	FEED and FID secured for large-scale electrolytic/late 2020s projects Private sector investment in manufacturing facilities aligned to UK sector development opportunities New market entrants as market framework demonstrated	FEED and FID secured for 2030s projects Private investment drives hydrogen economy expansion New market entrants & business opportunities secured
Industry development & deployment	Project partnerships in place to secure benefits of shared infrastructure Second phase on-cluster projects & new small-/ medium-scale projects Late 2020s projects constructed	Post 2030 development & testing delivered New projects cluster/off cluster constructed and existing expanded

4. Netherlands Hydrogen Industry

4.1 Hydrogen Policy and Roadmaps

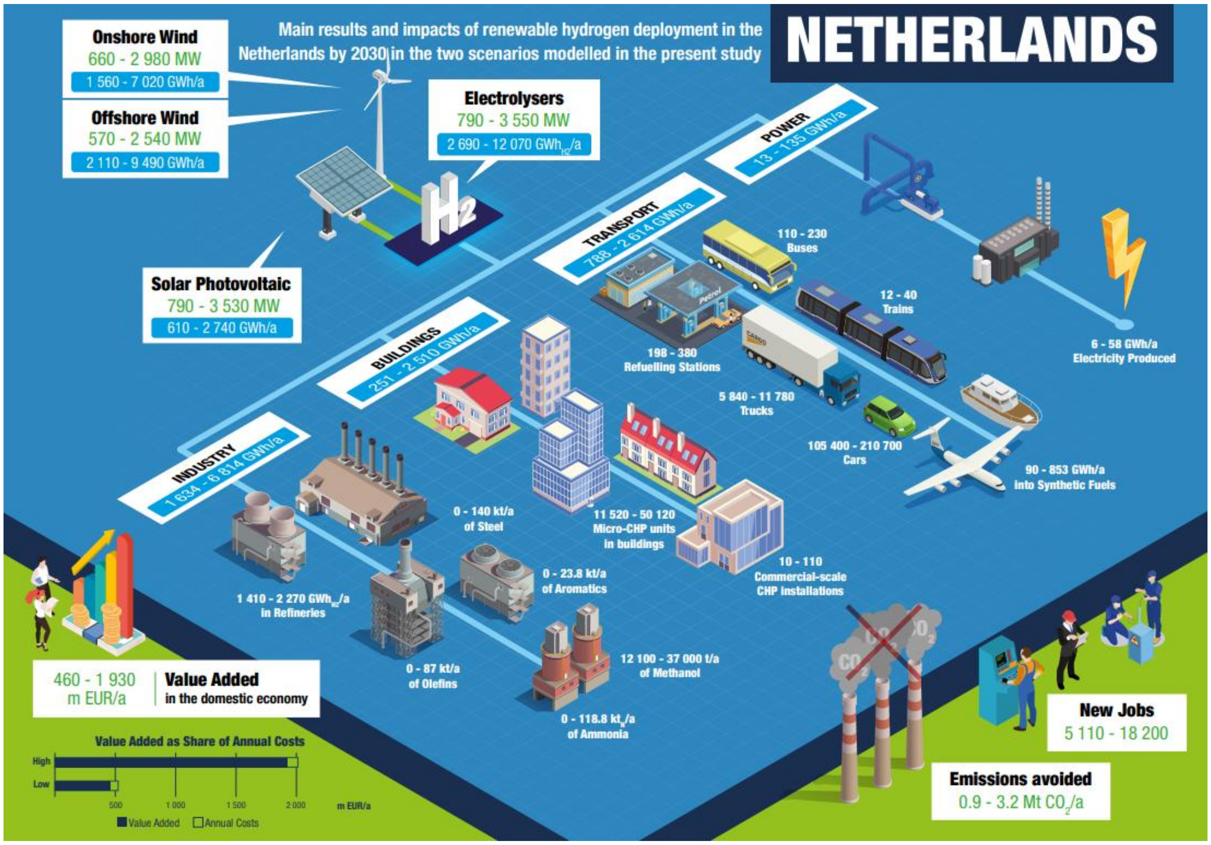


Fig.5. Renewable Hydrogen Deployment in the Netherland [9]

- **Hydrogen demand**

Based on differing levels of ambition linked to the national context, two (high and low) scenarios of hydrogen demand in 2020-2030 were generated. The obtained values are summarized in the previous page's scheme. In the analyzed scenarios for the Netherlands, a large increase in hydrogen demand is projected in transportation, particularly for passenger vehicles, buses, trucks, and trains, and to a lesser extent in aviation (through hydrogen-based liquid fuels or Pt.) and navigation9. In the scenarios for industry, a large increase in hydrogen consumption is also projected, particularly in methanol production and refining. Some industries use fossil-based hydrogen as a feedstock or reducing agent, which renewable hydrogen might replace.

Switching high-temperature heat-process fuels to renewable hydrogen could be another key potential usage in the situations under consideration. [10]

- **Hydrogen production**

To meet the expected hydrogen demand from new applications and the replacement of fossil-based hydrogen, 2 to 9 GW of dedicated renewable power capacity would need to be deployed to manufacture green hydrogen via electrolysis. While "surplus" electricity may be available during periods of strong renewable electricity production, the majority of the demand will have to be met by dedicated sources. In all scenarios, a portion of the 2030 hydrogen demand would be fulfilled by fossil-based hydrogen produced through the steam-methane reforming of fossil fuels.

The Netherlands predicts an installed capacity of 16.6 GW in wind and 26.1 GW in solar PV in 2030, providing more than 91 Tw of renewable electricity. However, the technical potential for renewable energy production in the Netherlands appears to be substantially higher10. Adding more renewable electricity generation dedicated to hydrogen production could thus be a viable option.

- **Estimated socio-economic and environmental impacts**

In the considered scenarios, the annual costs of producing green hydrogen (including the cost of dedicated renewable electricity sources), developing transportation infrastructure (or adapting existing infrastructure), and developing end-user applications would total 520 and 2 000 million EUR, respectively. These operations will provide value to the domestic economy by, among other things, providing jobs in the manufacturing, building, and operation of hydrogen technology, as well as helping to reduce greenhouse gas emissions. This is especially crucial in difficult-to-decarbonize industries. According to the European EUCO3232.5 scenario11, Dutch GHG emissions in 2030 should be decreased by 60 Mt CO2 compared to 2015. In the scenarios analyzed, hydrogen deployment might contribute 0.9 – 3.2 t CO2 to this objective, which is comparable to 2% – 5% of the required emission reduction. [10]

5. Japan’s Current Policy and R&D Activity on Hydrogen

5.1 Background and Policy Update

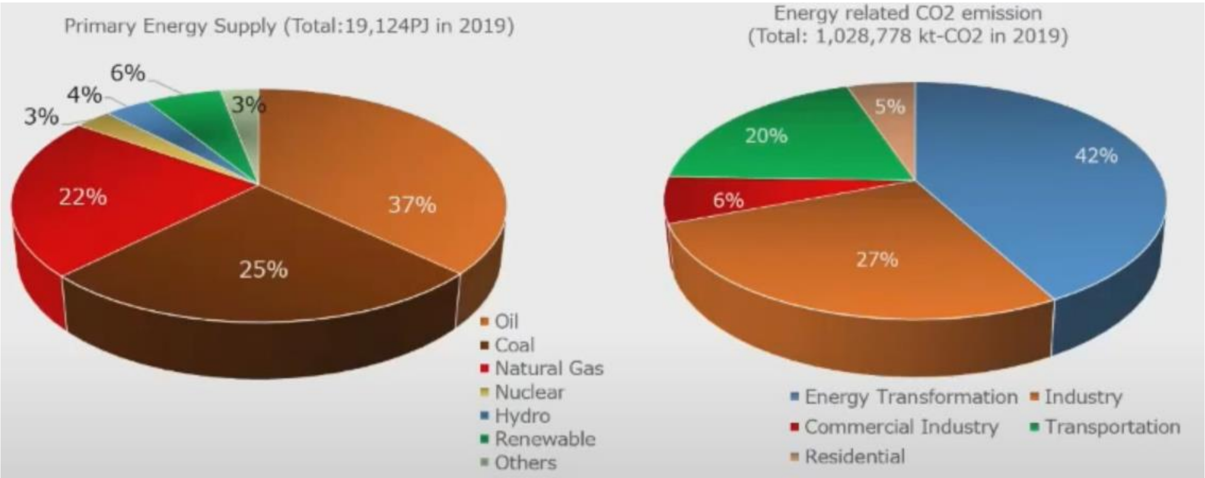
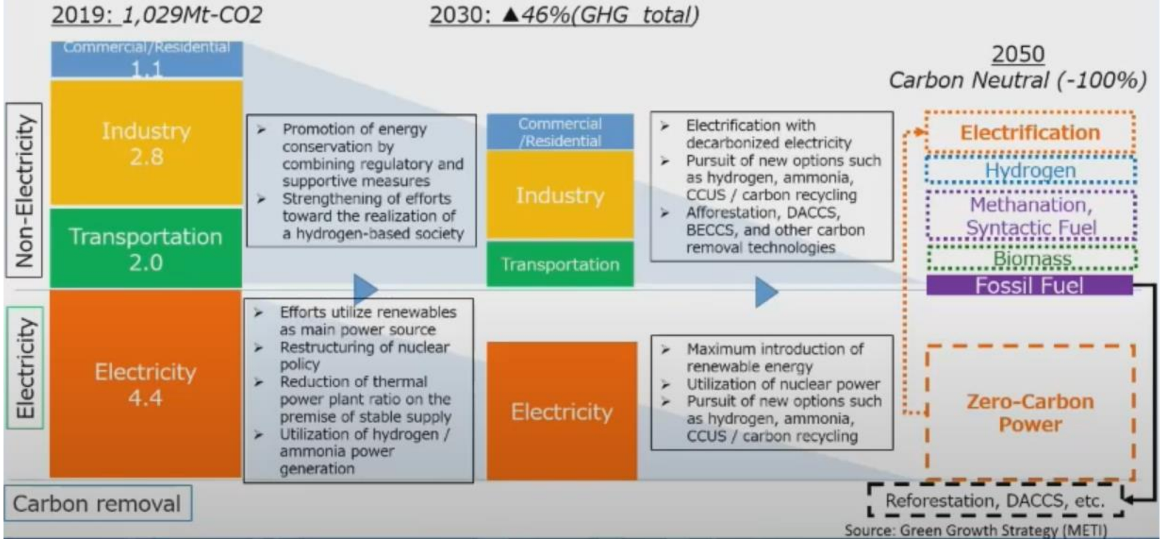


Fig.6. Primary Energy Supply Japan 2019



- Promotion of energy conservation by combining regulatory and supportive measures
- Strengthening of efforts toward the realization of a hydrogen-based society

- Efforts utilize renewables as main power source
- Restructuring of nuclear policy
- Reduction of thermal power plant ratio on the premise of stable supply
- Utilization of hydrogen / ammonia power generation

- Electrification with decarbonized electricity
- Pursuit of new options such as hydrogen, ammonia, CCUS / carbon recycling
- Afforestation, DACCS, BECCS, and other carbon removal technologies

- Maximum introduction of renewable energy
- Utilization of nuclear power
- Pursuit of new options such as hydrogen, ammonia, CCUS / carbon recycling

Source: Green Growth Strategy (METI)

Fig.7. Policy Update of Japan Hydrogen

In October 2020, the Japanese government declared its ambition to reduce greenhouse gas emissions to net zero by 2050

To achieve the target, METI formulated a “Green Growth Strategy through Achieving Carbon Neutrality in 2050” as industrial policy to lead the challenging goal of carbon neutrality to a “Positive cycle of economic growth and environmental protection”

Uploading high goals for each of the 14 priority fields including hydrogen, the strategy makes explicit current challenges and future actions by the field to support R&D activity, METI established the “Green Innovation Fund” (approx. us$ 19 billion for 10 years)

HYDROGEN MOBILITY

1. The Hydrogen Economy and Vision of Hyundai Motor Company

Hyundai Motor Group reveals 'FCEV Vision 2030'

“Hyundai Motor Group, the global pioneer of the commercial production of FCEV, is taking a bold step forward to expedite the realization of a hydrogen society. Hyundai will expand our role beyond the automotive transportation sector and play a pivotal role in global society’s transition to clean energy by helping make hydrogen an economically viable energy source. Hyundai are confident that hydrogen power will transcend the transportation sector and become a leading global economic success.”

Hyundai Motor Group, which includes automotive brands Hyundai Motor Company and KIA Motors Corporation, today announced its long-term roadmap ‘FCEV Vision 2030’ plan, as the group reaffirms its commitment to accelerate the development of a hydrogen society by leveraging the group’s global leadership in fuel-cell technologies.

Aligned with the roadmap, Hyundai Motor Group (The Group) will drastically boost its annual fuel-cell systems production capacity to 700,000 units by 2030 and explore new business opportunities to supply its world-class fuel-cell systems to other transportation manufacturers of automobiles, drones, vessels, rolling stocks and forklifts. The demand for fuel-cell systems from sectors beyond transportation such as power generation and storage systems is also expected to emerge quickly.

HMG is the only company to establish a dedicated plant for commercial production of fuel cell systems. With the construction of an additional fuel cell plant, Hyundai can quickly target market success on a global scale.

The Hydrogen Council, a global initiative of leading energy, transport and industry companies including Hyundai Motor, predicts the annual demand for hydrogen would increase tenfold by 2050, thereby creating diverse opportunities for sustainable economic growth.

1.1 Energy paradigm shift

Energy security evolved from ensuring oil, gas and electricity supplies into a more interdisciplinary issue that is far more challenging, as it includes climate change risks, uncertain impacts of energy efficiency and decarburization. In the EU, energy security, often referred to as "security of supply", was one of the three pillars of the first EU energy policy in 2007. Later in 2015, the Energy Union strategy confirmed the importance of this pillar by including energy security, solidarity and trust as one of its five dimensions.

In this second installment of the **blog series in June on security of supply**, Hyundai present the energy mix situation and the role of oil prices. Hyundai also discuss the issues related to the future role of hydrogen and the challenges related to critical minerals and cybersecurity. Hyundai conclude by introducing the possible paths to address the paradigm shift in the energy security agenda.

a. The energy mix and the role of oil prices

Fossil fuels, in particular crude oil, still dominate the EU and the global energy mix, even though their shares have been decreasing recently with renewables gaining ground. Crude oil, natural gas and coal provided about 69.3 % of all energy in the EU in 2019, for which oil and petroleum products had the most significant share. The situation is similar globally, where fossil fuels account for about 84% of the energy mix.

Worldwide, oil prices, determined by global supply and demand, have often been in the spotlight over the past decades. Their impact goes beyond the energy sector, as high oil prices could affect the production and transport costs of a wide range of consumer goods and therefore causing inflation. Also, higher oil prices make renewables deployment more attractive as they become more competitive to produce electricity and power transport.

Will the oil continue to run the world if 50% of energy demand will come from (low-carbon) electricity and gases, e.g. bio methane?

In such a scenario, it would be expected that oil prices would fall due to lower demand. This will make oil production only attractive for the low cost producing countries. Oil production would become more concentrated and exported by a smaller number of countries with high market shares. In addition, dropping oil prices would make investments in new infrastructure less attractive. However, it can create adverse effects, increasing oil consumption in countries with less stringent climate policies.

b. Would hydrogen be the new oil?

Different scenarios and studies contain predictions of the future hydrogen demand. Most of them expect that hydrogen will play a central role in the future of energy, particularly as a decarburization option for the hard-to-abate industrial sectors. According to the IEA Energy Technology Perspectives 2020, hydrogen demand will increase four-fold by 2050, and by 2070, electricity, hydrogen, synthetic fuels and bioenergy would have the same shares as fossil fuels in today’s energy mix.

Would the hydrogen price be as crucial for the global economy as oil prices are today?

It is difficult to predict. The European Commission Hydrogen Strategy states that *'by 2030 the EU will aim at completing an open and competitive EU hydrogen market, with unhindered cross-border trade and efficient allocation of hydrogen supply among sectors.'* With the US and China massively investing in hydrogen R&D and the potential opportunities to import green hydrogen from neighboring regions, e.g. Africa, the international hydrogen trade market is likely to develop. This could, over time, have important geopolitical implications and create new international alliances. New supply chain and security of supply challenges would emerge.

c. Will there be a sufficient, sustainable supply of mineral to support the energy transition?

According to the IEA report on 'The Role of Critical Minerals in Clean Energy Transitions' *'mineral demand for clean energy technologies would rise by at least four times by 2040 to meet climate goals, with particularly high growth for EV-related minerals.'* The demand for minerals will arise from multiple clean energy technologies, e.g. renewables, electricity networks, EVs, battery storage and hydrogen (electrolysis and fuel cells). Today, their production is more concentrated than oil and natural gas, with Chile leading in copper, Australia in lithium, Indonesia in nickel, the Democratic Republic of the Congo for cobalt, and China for rare earth elements (REE). For processing operation, the level of concentration is similarly high with the significant presence of China for processing the different minerals.

d. Emerging issues: reliability for electricity infrastructure and new cybersecurity challenges

In electricity grids, loop flow issues have emerged in recent years in countries like Belgium and Poland due to electricity from neighboring bidding zones or control areas flowing in their networks. They create extra costs for the hosting area/country related to security of supply and system services, as well as from reduced capacities for commercial exchanges within the host country or between the host country and other areas. The question is who should bear the extra operational costs associated to loop flows and who should pay in the future the potentially needed investments. The recent ACER decision brought some clarification on the cost-sharing of remedial actions but did not investigate the case of financing future investments that might be needed.

e. Hydrogen security and the defense industry

Hydrogen security is also another challenge that is closely linked with industry and transport. There are not many studies analyzing the security of energy systems with high hydrogen integration. A recent security analysis for a hydrogen fueling station identified 93 attack scenarios and highlighted the importance of adopting countermeasures to prevent and mitigate deliberate attacks. Suppose such attacks on hydrogen infrastructure have the potential to create similar disruptions as the ones caused by attacks in the oil sector. Would strategic hydrogen reserves be necessary for industry and transport?

Another related issue for the use of hydrogen is whether armed forces would follow the decarburization trend or keep a parallel supply system for armies running on traditional fuels. In this context, the NATO report 'Energy Security: Operational Highlights' states *'energy consumption for armed forces will be a crucial issue for the years to come.'* Lately, there has been an increasing interest from NATO's countries in fuel cell applications, producing electricity from fuels such as hydrogen. While remaining costly and complex, NATO members are developing military capabilities that are fuel cell-based and hydrogen-powered. The 'Energy Security' report provides an overview of the recent hydrogen fuel cell R&D works in the military domain.

1.2 Hyundai's net zero declination

As Hyundai enter this new phase, we're focusing on positive energy. Unlike other automotive companies which are focusing solely on electrification and switching to sustainable energy, we're focusing our efforts on pioneering hydrogen energy. Hyundai will use this hydrogen fuel cell technology in everything from consumer vehicles to trucks and busses. This combined with our new mobility platforms, including robot axis and urban air mobility, will bring the mankind one step closer to the carbon neutral future.

The trend is clear - electricity is our new fuel and we're fully onboard. We're driven by positive energy and we're not only transforming our vehicles but also the entire ecosystem they move in. With our innovative vehicle-to-grid (V2G) technology, Hyundai customers can charge their car batteries at cheaper, off-peak rates and then they can push power from their car batteries back into the grid at a profit during expensive peak periods. This will contribute to a more stable power grid and ultimately reduce our dependency on fossil fuels.

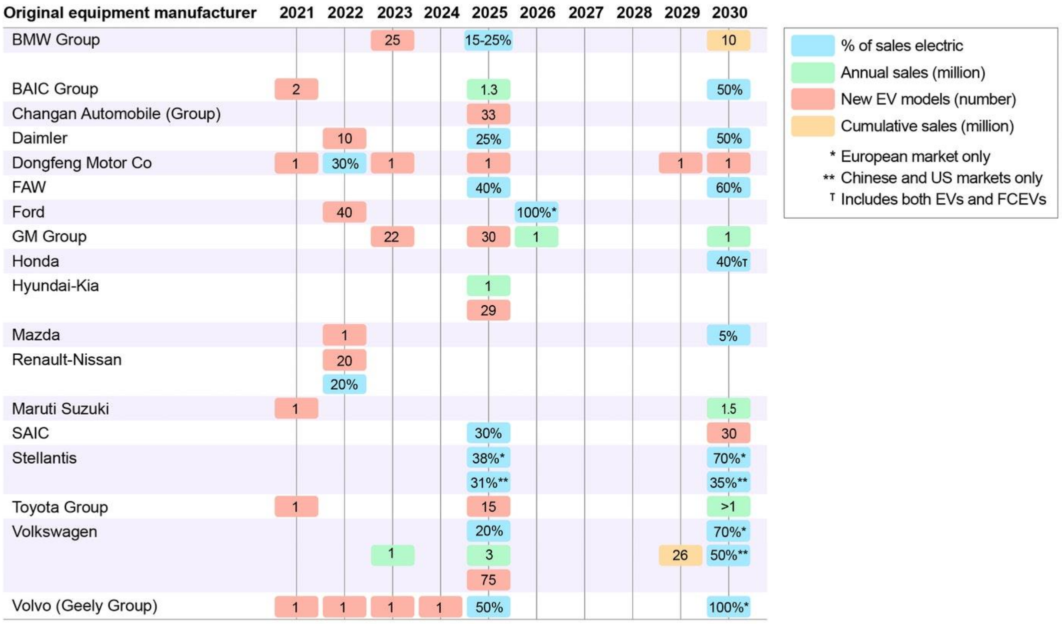
It starts with green hydrogen. Solar and wind energy are used to make renewable electricity. This clean power is then used to split water into oxygen and hydrogen - or green hydrogen.

Green hydrogen is expected to reduce 6 gig tons of CO_2 by 2050 annually and create a market worth $2.5 trillion, which employs 30 million people. That's why we're investing 6.8 billion dollars in hydrogen related startups to nurture hydrogen ecosystems. And why we're planning to establish green hydrogen infrastructures in countries with strong government support and abundant renewable energy sources like Australia.

We're building climate neutrality into everything Hyundai do, including the way Hyundai operate in our own factories. Starting with our factory in the Czech Republic, we're aiming to run all our factories around the world on 100 percent renewable energy.

1.3 OEM trend of the hydration electronic vehicle

18 of the 20 largest OEMs have committed to increase the offer and sales of EVs[11]



Original equipment manufacturer	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
BMW Group			🟥 25		🟦 15-25%					🟨 10
BAIC Group	🟥 2				🟩 1.3					🟦 50%
Changan Automobile (Group)					🟥 33					
Daimler		🟥 10			🟦 25%					🟦 50%
Dongfeng Motor Co	🟥 1	🟦 30%	🟥 1		🟥 1				🟥 1	🟥 1
FAW					🟦 40%					🟦 60%
Ford		🟥 40				🟦 100%*				
GM Group			🟥 22		🟥 30	🟩 1				🟩 1
Honda										🟦 40%ᵀ
Hyundai-Kia					🟩 1 🟥 29					
Mazda		🟥 1								🟦 5%
Renault-Nissan		🟥 20 🟦 20%								
Maruti Suzuki	🟥 1									🟩 1.5
SAIC					🟦 30%					🟥 30
Stellantis					🟦 38%* 🟦 31%**					🟦 70%* 🟦 35%**
Toyota Group	🟥 1				🟥 15					🟩 >1
Volkswagen			🟩 1		🟦 20% 🟩 3 🟥 75				🟨 26	🟦 70%* 🟦 50%**
Volvo (Geely Group)	🟥 1	🟥 1	🟥 1	🟥 1	🟦 50%					🟦 100%*

🟦 % of sales electric
🟩 Annual sales (million)
🟥 New EV models (number)
🟨 Cumulative sales (million)

* European market only
** Chinese and US markets only
ᵀ Includes both EVs and FCEVs

Fig.8. Original equipment manufacturers in European

OEMs are expected to embrace electric mobility more widely in the 2020s. Notably 18 of the 20 largest OEMs (in terms of vehicles sold in 2020), which combined accounted for almost 90% of all worldwide new car registrations in 2020, have announced intentions to increase the number of available models and boost production of electric light-duty vehicles (LDVs).

A number of manufacturers have raised the bar to go beyond previous announcements related to EVs with an outlook beyond 2025. More than ten of the largest OEMs worldwide have declared electrification targets for 2030 and beyond.

Significantly, some OEMs plan to reconfigure their product lines to produce only electric vehicles. In the first-trimester of 2021 these announcements included: Volvo will only sell electric cars from 2030; Ford will only electric car sales in Europe from 2030; General Motors plans to offer only electric LDVs by 2035; Volkswagen aims for 70% electric car sales in Europe, and 50% in China and the United States by 2030; and Stellates aims for 70% electric cars sales in Europe and 35% in the United States.

Overall, the announcements by the OEMs translate to estimated cumulative sales of electric LDVs of 55-72 million by 2025. In the short term (2021-2022), the estimated cumulative sales align closely with the electric LDV projections in the IEA's Stated Policies Scenario. By 2025, the estimated cumulative sales based on the OEMs announcements are aligned with the trajectories of IEA Sustainable Development Scenario.

1.4 Hydrogen Wave

Hyundai Motor Group (the Group) has detailed its vision for a global hydrogen society, one it expects to help popularize by 2040. Under a broad mission statement that calls for hydrogen to be made available to everyone and for everything, everywhere, the Group calls its contribution to the coming surge of fuel cell-powered transportation, industry, and societal solutions the "Hydrogen Wave."

"Hyundai Motor Group's vision is to apply hydrogen energy in all areas of life and industry such as our homes, workplaces, and factories," said Chairman of the Group, Suisun Chung. "We want to offer practical solutions for the sustainable development of humanity, and with these breakthroughs, we aim to help foster a worldwide Hydrogen Society by 2040."

FUEL CELL TECHNOLOGY

Currently, and especially in the U.S., hydrogen as a power source is a curiosity among consumers. Plus, fuel cells are hard for people to understand, even if the science behind them is simple. However, the Group has been working undeterred on hydrogen **fuel cell electric vehicles** (FCEV) since 1998 and began mass-production of its Hyundai Tucson Fuel Cell in 2013.

The Group admits that fuel cells are expensive and that a global hydrogen infrastructure barely exists. Nevertheless, the company claims that since 2003, the cost of fuel cells has dropped by 98%. By 2030, the automaker predicts, FCEVs will reach cost parity with **battery electric vehicles** (BEVs).

Today, Hyundai's FCEV models include **the Next crossover SUV** and the Client heavy-duty truck. New 100-kW and 200-kW fuel cells will be available starting in 2023, more compact and powerful than before and at half the cost of those currently used in the Next and Client.

Future fuel cell applications could include a variety of transportation solutions. From performance cars like the Vision FK Prototype (shown in camouflage above), which the Group co-developed with Rima Automobile, to an **autonomous vehicle** called the e-Bogie (shown as a Rescue Drone below) that the automaker likens to a smart robot with wheels that can be used in a wide variety of situations, fuel cells are practical and applicable.

The Group has even devised the H-Two, a portable hydrogen-fueled power charger designed to provide zero-emission electricity in remote and emergency situations. Assemble them like Lego blocks, and the company's vision suggests these fuel cell generators could collectively power entire cities.

In the short-term, in addition to rolling out its new fuel cell stacks for passenger and heavy-duty trucks in the middle of the 2020s, the Group says it will electrify all of its new commercial vehicles by 2028. After that, the company's buses and heavy-duty trucks will have either battery-electric or fuel cell power. By doing so, it can cut emissions faster while perfecting the technologies for heavy-duty, long-range use.

In the long-term, the Hydrogen Council predicts that hydrogen energy will account for 18% of global energy demand by 2050, cut carbon dioxide (CO2) emissions by six billion tons annually, and create over 30 million new jobs worldwide. Whether such predictions come true is yet to be seen, but the Group plans to work overtime to make it happen.

Hyundai believes its broad business portfolio in global transport and logistics positions it to lead the change to hydrogen through rapid scaling of innovative technologies. From personal and commercial transport to shipping via rail and by sea, the Group sees a blank-slate opportunity to transform the world with hydrogen in the same way Apple and other tech companies did with smartphones.

Success, however, is dependent on clean hydrogen production, hydrogen storage solutions, continued improvements in fuel cell technology, and the infrastructure to support a hydrogen economy. The Group's Hydrogen Wave strives to solve this puzzle, and no later than 2040.

2. The Future of Zero-Emission Marine Propulsion

2.1. One a global scale, the shipping industry contributes a significant share of GHG emissions

Shipping could be responsible for 17% of global CO2 emissions in 2050 if left unregulated, according to a new scientific study. Any agreement at the Paris Climate Summit must therefore send a clear signal to the International Maritime Organization (IMO) that CO2 reduction targets and measures for shipping are needed to help keep warming below dangerous levels, according to NGOs Seas at Risk, Transport & Environment (T&E) and the Marine Conservation Society.

Almost 40% of all CO2 emissions in 2050 will be caused by shipping and aviation if left unregulated, the study published by the European Parliament found. However the IMO, the UN body tasked with tackling the climate impacts of shipping, has so far failed to grasp the nettle on shipping's growing contribution to greenhouse gas (GHG) emissions [12], while the proposal for emissions cuts from industry – as represented by the International Chamber of Shipping – would fall short of what shipping needs to do to help meet the 2°C warming target limit by some 121%.

The European Parliament's study took into account the IMO's own research which found that shipping GHG emissions are up 70% since 1990 and are projected to grow by up to a further 250% by 2050 [2]. Shipping currently accounts for nearly 3% of global CO2 emissions – higher than those of Canada, Brazil, Indonesia, Mexico, France or the United Kingdom. Without inclusion of ship GHG emissions in the Paris agreement and significant additional action to reduce emissions, shipping will consume a growing proportion of the 2 degree carbon budget and ultimately make it all but impossible to meet climate stabilization targets.

Seas at Risk and T&E are members of the Clean Shipping Coalition, which has Observer status at the IMO. They are calling urgently on the IMO Assembly delegates to set a major course correction. Countries participating in the Paris Climate Change Conference (COP21) need to agree that the IMO should set targets and agree emissions re-duction measures that are consistent with shipping making a fair and pro-portionate contribution to keeping warming below 1.5/2 degrees.

Sotiris Rapt is, shipping policy officer at T&E, said: "Now we know that, left unregulated, ships and airplanes could be responsible for almost 40% of global emissions in 2050 if other sectors decarbonize. Any deal in Paris must lead to an emissions reduction target and measures for shipping and aviation, otherwise the efforts of all other sectors of the global economy to meet the 2 degree target could be derailed."

John Moggs, policy advisor at Seas at Risk and President of the Clean Shipping Coalition said: "Paris should be the moment when the world sets itself on a course that avoids dangerous climate change. To achieve this all will have to play their part; there is no room for shirking responsibility or special pleading, least of all from an industry like shipping that has so much untapped potential to reduce emissions and move to a low carbon business model."

2.2. Zero-emission requirements are coming to the marine industry

FUEL CELL TECHNOLOGY

According to the International Energy Agency (IEA) just 0.1% of energy consumed in shipping comes from low-carbon fuels. Under their current policy framework scenarios low and zero-carbon fuels will only make up less than 3% of shipping's total energy consumption by 2030 and roughly one third by 2050, significantly short of the net-zero target. Despite some promising announcements and plans there continues to be a lack of investment in zero-emission technologies, with the IEA highlighting that the total amount of corporate R&D investment for maritime decreased, from $2.7 billion in 2017 to $1.6 billion in 2019. To accelerate the shift to zero-carbon fuels, multiple nascent technologies need to be developed to reach large scale deployment. Shifting to alternative fuels such as hydrogen, ammonia, biofuels and electrification from renewable sources could cut 80% of emissions from maritime transport. The current pipeline of solutions and projects while welcome are not enough to deliver the paradigm shift in the technologies needed and at the scale required to decarbonize shipping. The shipping sector will experience a new technological revolution – as previous from wind to coal and then from coal and steam to fossil fuel combustion – that will need to meet maturity in less than three decades. This necessitates a complete transformation of the current dominant technology and a major scaling up of finance for technology development in addition to regulatory policies and effective public-private alliances. Only then can we deliver the thousands of zero-emission ships required to be in the water by 2030 and to meet our 2050 net zero ambitions. Significant and long-term, high-risk investments will be required to trigger the step-change to advance technology readiness levels and pilot these technologies[13].

- The report identifies 265 projects that address key technical and systemic challenges that need to be overcome to kick-start and accelerate the transition to zero-carbon emissions.
- It highlights the 20 high-priority example projects requiring immediate investment.
- $5 billion is needed to advance alternative technologies towards pre-commercial deployment stage.
- Projects identified may take between 1–6 years to mature, so action is required if we are to deliver significant numbers of zero-emission ships by 2030.

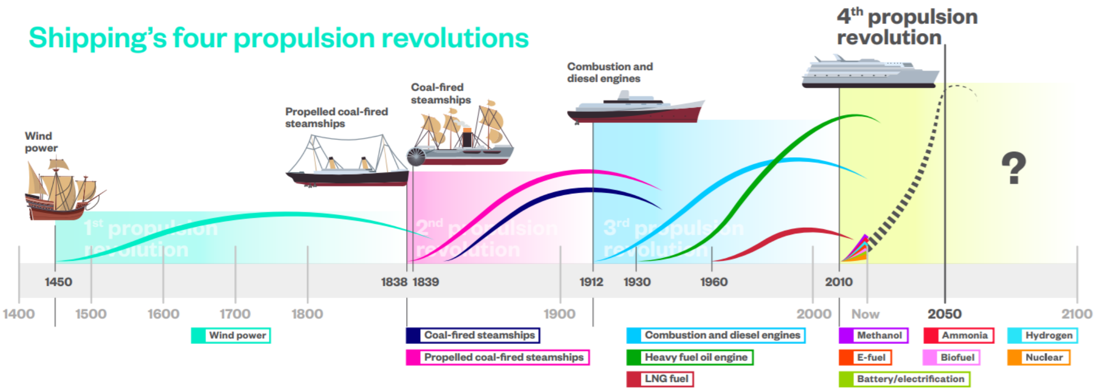


Fig.9. Shipping's four propulsion revolutions

2.3. Deliver fuel cell power for a sustainable planet

Safe, environmentally friendly, and reliable energy supplies are essential to mankind for sustainability and a high quality of life, although their provision is subjected to social, political, environmental, and economic challenges. It is generally acknowledged that there is no single energy source that can dominate and govern the global energy market, and thus an energy-mix model has been widely accepted, which benefits from the availability of usable resources in each country/region or the choice of importing energy resources. Hydrogen, a clean energy carrier, is the most abundant chemical element in the universe, accounting for 75% of normal matter by mass and over 90% by number of atoms. When hydrogen gas is oxidized electrochemically in a fuel cell system, it generates pure water as a by-product, emitting no carbon dioxide. Hydrogen has emerged as a new energy vector beyond its usual role as an industrial feedstock, primarily for the production of ammonia, methanol, and petroleum refining. There are expanding applications for hydrogen to be used in many other fields, like transportation, power generation, and militarized equipment for its advantages of high efficiency and low emission.

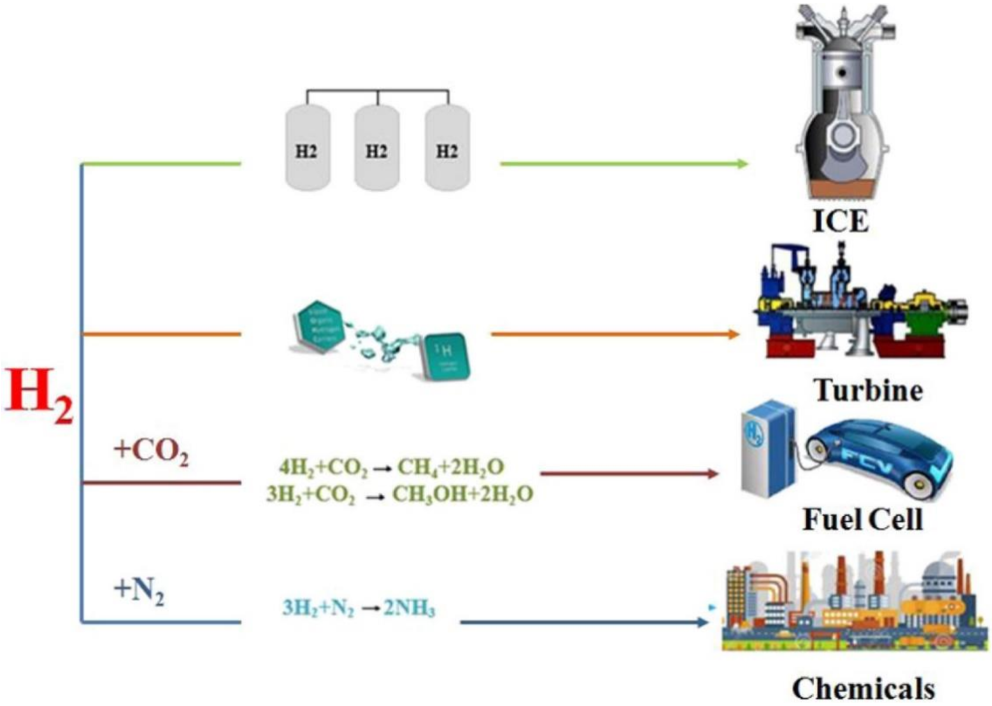


Fig.10. Hydrogen Technology

The rapid development of hydrogen technology and growing energy needs drive many countries to set domestic hydrogen roadmap. It is obvious that hydrogen and fuel cells can meet the rising demands for societal development and provide the possibility of covering most energy fields. Therefore, many countries include hydrogen development in their national strategies and implement measures to promote the fuel cell industry. For example, in Japan, the government has elevated hydrogen energy to a national strategy, including a mature industrial chain leading in technology and commercialization, with a production capacity of over 10,000 units of Toyota Mirani, more than 300,000 sets of Eni-farm cogeneration systems, and more than 100 HRS

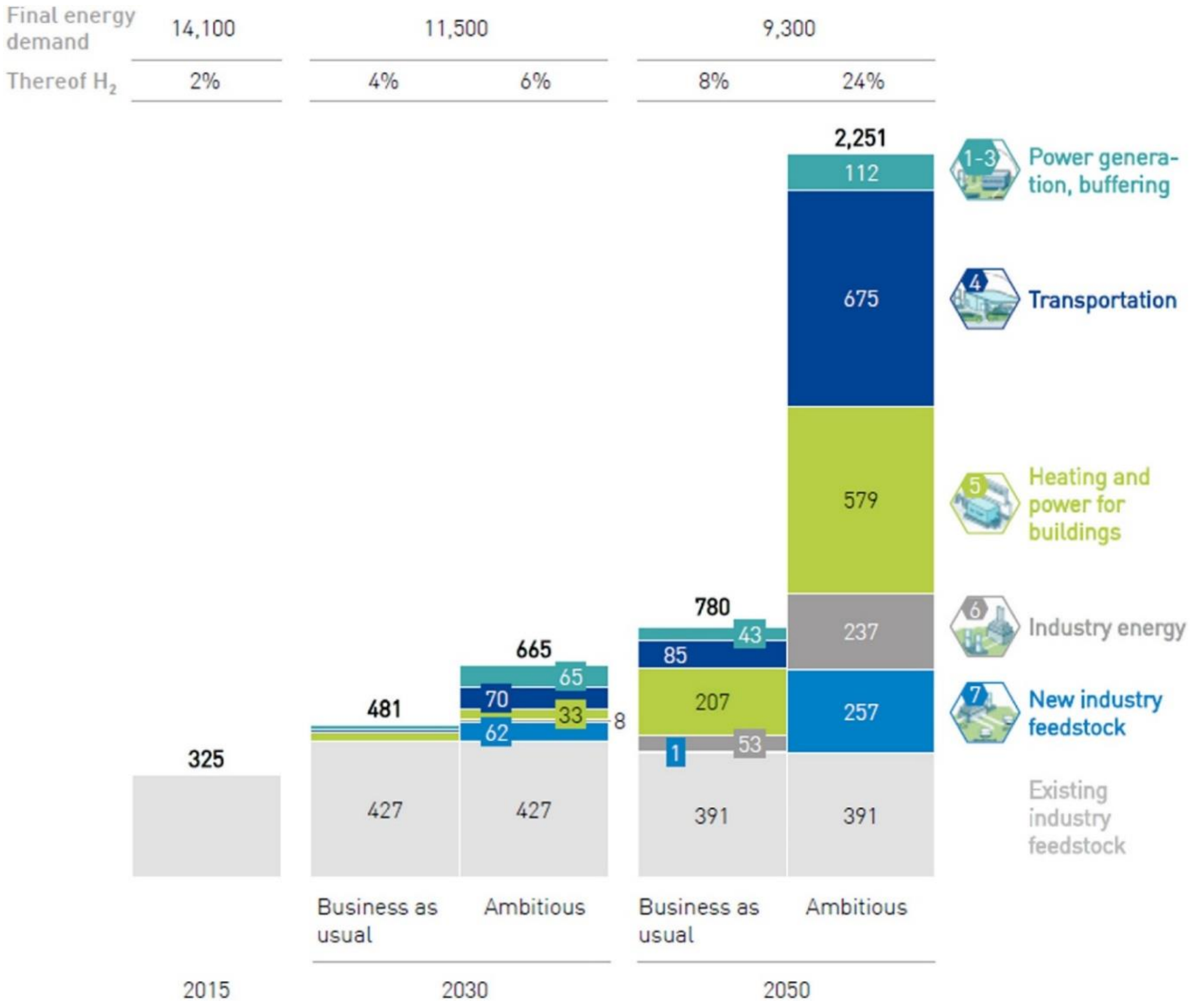


Fig.11. Ambitious scenario for Energy demand and the Hydrogen deployment For Europe from 2015 to 2050[14]

2.4. Leading independent Proton Exchange Membrane (PEM) fuel cell developer and manufacturer

Hydrogen has emerged as a new energy vector beyond its usual role as an industrial feedstock, primarily for the production of ammonia, methanol, and petroleum refining. In addition to environmental sustainability issues, energy-scarce developed countries, such as Japan and Korea, are also facing an energy security issue, and hydrogen or hydrogen carriers, such as ammonia and methyl cyclohexane, seem to be options to address these long-term energy availability issues. China has been eagerly developing renewable energy and hydrogen infrastructure to meet their sustainability goals and the growing energy demand. In this review, we focus on hydrogen electrification through proton-exchange membrane fuel cells (PEMFCs), which are widely believed to be commercially suitable for automotive applications, particularly for vehicles requiring minimal hydrogen infrastructure support, such as fleets of taxies, buses, and logistic vehicles. This review covers all the key components of PEMFCs, thermal and water management, and related characterization techniques. A special consideration of PEMFCs in automotive applications is the highlight of this work, leading to the infrastructure development for hydrogen generation, storage, and transportation. Furthermore, national strategies toward the use of hydrogen are reviewed, thereby setting the rationale for the hydrogen economy.

A PEM has the main functions of conducting protons, separating fuel oxidizer and insulating protons, and its performance directly affects the performance of PEMFCs. An ideal PEM should exhibit a high proton conductivity rate, proper water content and gas molecular permeability, good electrochemical stability and mechanical stability, with ideal characteristics of a decomposition temperature of 250–500 °C, water absorption rate of 2.5–27.5 H_2O/SO_3H, and conductivity in the range of 10^{-5}–10^{-2} S cm^{-1}.

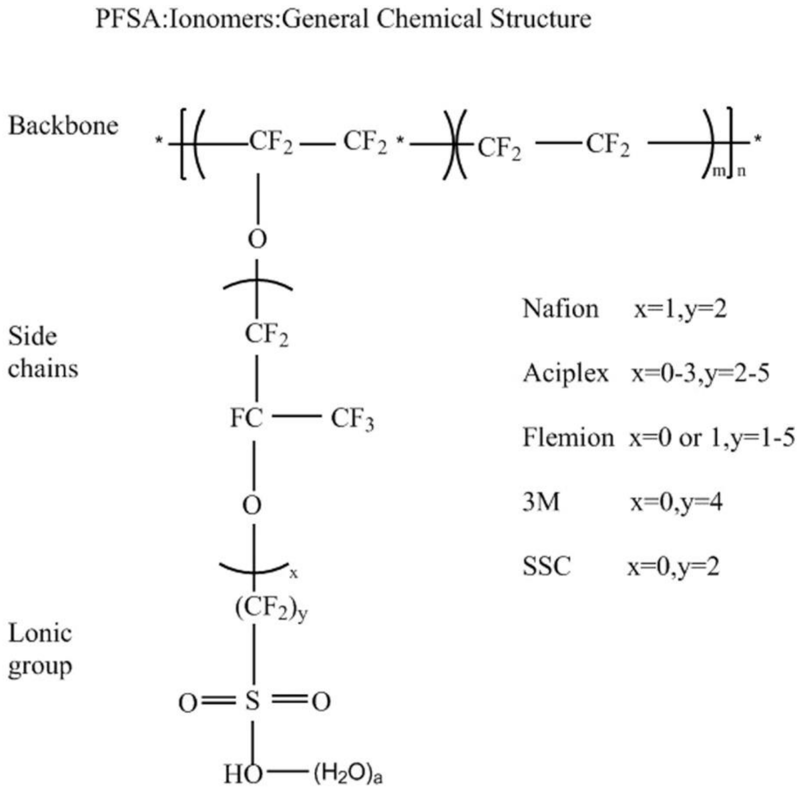
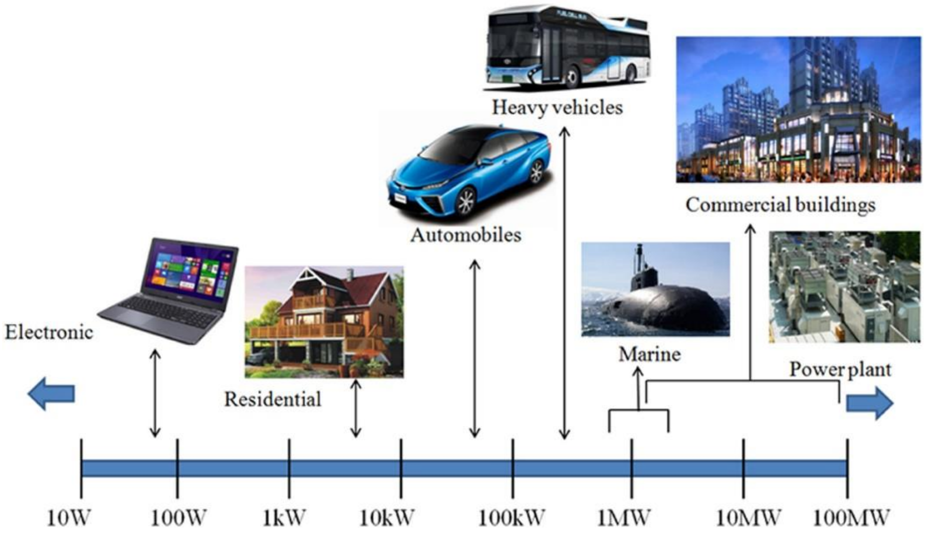


Fig.12 General chemical formula for PFSA ionomers in various forms[14]

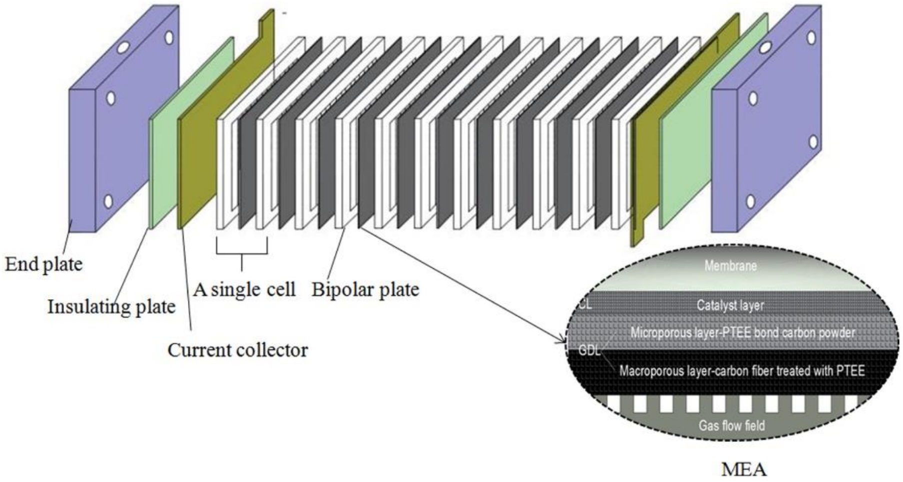
Most fuel cells use Nation membranes manufactured by DuPont, and figure shows a general chemical formula for the perfluoro sulfonic acid membrane (PFSA) ionomers (Kusoglu and Weber, 2017)[14]. The production process of a membrane is relatively complicated, and the current market price is relatively expensive (approximately 2000 \$ m^{-2}). Reducing production costs and improving chemical and mechanical stabilities are important goals in the development of PEMs. In recent years, with the continuous advancement of Nation membranes and the development of new membranes, Ballard developed a PFSA membrane with properties comparable to those of Nation membranes. The production process of such a PFSA membrane is relatively simple and the processing cost is low. If the market demand continues to increase, the cost of the membrane could be significantly reduced by mass production.

2.5. Hydrogen fuel cells for zero-emission vessels

A fuel cell is an energy conversion device that continuously converts chemical energy in a fuel into electrical energy, as long as both the fuel and oxidant are available. It exhibits advantageous characteristics exceeding conventional combustion-based technologies that are currently applied in certain critical fields, such as electronic, housing power, power plants, passenger vehicles, as well as military applications. Operating with higher efficiency than combustion engines, fuel cells demonstrate an electrical energy conversion efficiency of 60% or more, with lower emissions. Water is the only product of the power generation process in hydrogen fuel cells, and thus there are no carbon dioxide emissions or air pollutants that create smog and cause health problems during operation. Moreover, fuel cells emit low noise during operation, because they contain fewer moving parts. Fuel cells come in many varieties, but they all work in generally the same manner. In essence, a fuel cell consists of three adjacent segments, namely, the anode, electrolyte, and cathode. When hydrogen undergoes an oxidation reaction at the anode ($H_2 \rightarrow 2H^+ + 2e^-$), it generates cations that migrate to the cathode through the electrolyte and free electrons that flow the external circuit. Contrarily, a reduction reaction occurs at the cathode, where oxygen is reduced to water by the cations and electrons [15]. The electrochemical reaction that occurs at the cathode is $4H^+ + O^2 + 4e^- \rightarrow 4H_2O$. Based on the type of electrolyte used, fuel cells can be categorized into alkaline fuel cells (AFCs), PEMFCs, phosphoric acid fuel cells (PAFCs), molten carbonate fuel cells (MCFCs), and solid oxide fuel cells (SOFCs). The electrolytes of AFCs are KOH with OH^- serving as mobile ions under lower oxygen reduction over potential and lower operating temperature (20∼80 °C). The mobile ions of PEMFCs are H^+ with the operating temperature from −40 °C to 90 °C, air and oxygen can be the oxidants in the cathode. PAFCs and MCFCs are utilized in power station for its large output range. Ceramic materials, like Y_2O_3 ___Zero $_2$, served as electrolyte during the operation of SOFCs under high temperature (600∼1000 °C). As shown in Scheme of some typical applications of fuel cell, fuel cells can be used in different scenes based on the required power output scale. The distinctive advantages of rapid start-up time, wild range operating temperature (−40–90 °C), high specific energy have made PEMFC stand out from all types fuel cell and wildly be used in fuel cell vehicles and stationary applications. The typical structure of a PEMFC is illustrated in figure and the detailed explanation of these components and related researches are introduced in following parts. Additionally, water management and thermal management are the key issues of PEMFC, which are introduced in detailed.



Scheme of some typical applications of fuel cell.



Basic structure of typical integrating PEMFC stack with end plate, insulating plate, current collector, bipolar plate, MEA, and the image of MEA structure

2.6. The future of zero-emission marine vessels

Emissions from international shipping and aviation are not explicitly mentioned in the 2015 Paris Agreement – a legally binding international treaty on climate change that was signed at COP21 in 2015 - but efforts to decarbonize shipping have intensified since the adoption of the International Maritime Organization's (IMO) Initial Strategy on GHG Reduction in 2018. The IMO's greenhouse gas (GHG) strategy called for at least a 50% reduction (compared to 2008) of CO2 emissions from shipping by 2050.

In measuring the progress of both the Paris agreement and the maritime organization's GHG strategy, the Getting to Zero Coalition - a group founded by the Global Maritime Forum, Friends of Ocean Action, and the World Economic Forum - has launched A Strategy for the Transition to Zero-Emission Shipping, an analysis prepared by University Maritime Advisory Services (UMAS) on how the sector can move away from the use of fossil fuels.

The analysis identifies key aspects needed to enable the transition including how political and economic factors can impact the shipping industry' commercial and technical capacity to deploy zero-emission vessels and fuels. The transition strategy also analyzes how policy-making, at the national, regional, and global levels, plays a critical role in the transition towards net-zero shipping.

A recent industry-led Call to Action for Shipping DE carbonization, coordinated by the Getting to Zero Coalition, has also amassed around 200 signatories with industry members committing to rapidly scaling the deployment of zero-emission vessels and fuels so that they reach 5% by 2030, and zero emissions by 2050.

The question now is how to go about the transition and ensure that industry and government can collaborate in the delivery of the objectives.

Transitioning to net zero

Our analysis drew on key outcomes and lessons learned from other technological and supply chain transitions to form insights on what a shipping energy transition could look like. While several parallels can be drawn between transitions that have already taken place, there are certain nuances specific to the shipping industry that should not be ignored.

First, current policy and industry actions are insufficient to support the shipping industry's transition because it will require large-scale, rapid, and transformative deployment. Policymakers need to prepare today to avoid disruptions later. Some key preparations include efficiency improvements and optimizing wind assistance. This will help to lower the fuel bill for the zero-emission shipping of the future, which will be essential to the economics of the transition.

The urgent need for cross-cutting action towards achieving net-zero targets should not be underestimated. Although the IMO has taken important first steps, the next steps to kickstart the transition – testing, collaboration, early-stage investment -- are likely to be taken by national governments and industry actors.

As zero-emission solutions scale up globally, the IMO will play another key role in driving the later stages of the transition. But for that to happen effectively, national governments and industry actors need to start now.

The IMO's GHG strategy supports every actor along the zero-emissions supply chain by placing as much weight on equity as it does on emissions reduction. Industry actors and national governments are empowered to suggest creative ways to make the transition both equitable and impactful.

Zero-emission shipping

Alternative fuel pathways may emerge over time – but scalable, zero-emission fuels are the key to managing greenhouse gases and cooling our warming planet.

Actors in the shipping industry have worked hard to seek out alternative fuels to shift away from carbon-intensive sources of energy. In so doing, the cost of fuels has been a key consideration, but not the only one. While techno-economic analyses have shown that green ammonia is the cheapest alternative right now, cheaper options could dominate the transition in future.

Fuels that don't depend on carbon inputs, like green hydrogen for example, will have an advantage during the period of rapid scale-up.

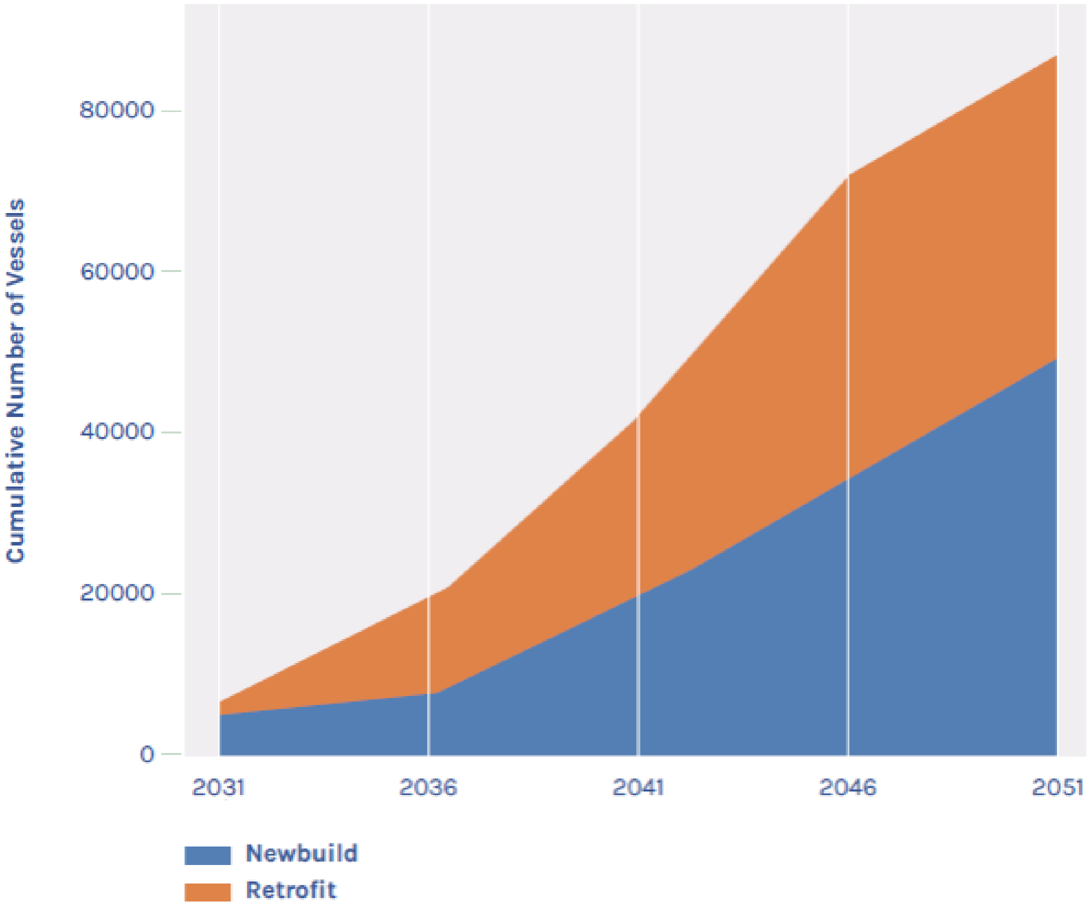


Fig.13. Cumulative number of vessels until 2051

Similar magnitudes of newbuilding and retrofitting to SZEF use will be needed, unless ship lives are significantly reduced for the fossil fueled fleet

In terms of investment in vessels, our analysis finds that the number of ships needing retrofits to use zero-emission fuels may be roughly the same as the number of zero-emission vessels being newly built over the course of the transition. As seen in the graph above, ship-owners and investors will need to scale up their retrofitting efforts in the early 2030s, something that they should be planning for today.

Ships entering fleets in the near term can be retrofitted to use scalable, zero-emission fuels (SZEFs). This will mitigate risks during the transitional phase. All things considered, to scale up zero-emissions vessels by 2030, we must act now. Early action is needed to achieve 5% SZEF use in international shipping by 2030, a prerequisite to reaching zero GHG emissions by 2050.

Our analysis finds that those who transition to SZEFs in this decade will likely be operating vessels that make regular journeys along specific geographical routes. These early adopter vessels include ferries, container ships, tankers, and bulk carriers. Their most likely routes would be those with simple and predictable operation patterns between two or more countries with the capacity for low-cost green hydrogen production.

Given that they will operate only between a small numbers of countries, national or plurilateral action may be able to create the incentives necessary for a quicker transition to green energy. Our analysis points to actors like Japan, China and the US, European Union, and Norway as possible leaders for national and regional action.

3. Hydrogen Mobility Application: Hydrogen Tram

3.1. About Hyundai Rote

Hyundai Rote is at the center of communication that connects people to people and countries to countries. Hyundai Rote manages the business in railroads, plants, and defense industry. It produce and operate railroad cars and a total railroad system. We have been acknowledged for our technology in the defense industry such as tanks and weapons systems, and in the plant engineering, such as iron and automobile facilities.

Fig.14. a. Korea's representative railway system supplier

Fig.14. b. Korea's representative railway system supplier

Hyundai Rote is a comprehensive heavy industry company known for its advanced technological capabilities worldwide in the fields of manufacturing, operating and maintaining rolling stock and railway systems, manufacturing defense related products, and plant engineering consisting of constructing steelmaking and automobile facilities. As Korea's leading total railway system supplier, it has exported over 40,000 railway vehicles to 36 countries worldwide. The company is one of the world's top 10 manufacturers of railway vehicles, being able to produce all types of vehicles, including EMUs, high speed trains, LRVs, DMUs, locomotives, and passenger coaches and freight wagons. Hyundai Rote has contributed greatly to Korea's rail exports through its global networks, including production bases in Turkey and Brazil, as well as its cooperative production bases and overseas branches in India, Egypt, Iran and Malaysia. Recently, the company has been active in entering countries in the Middle East, Africa and Southeast Asia. It is also focusing on developing new models while working to increase its competitiveness for future growth in the field of eco-friendly transportation such as EMU high speed trains, magnetic levity ton trains (MAGLEVs), and wireless low floor trams. As a comprehensive railway solution provider, the company is further expanding its business in railway systems, which involves signaling, telecommunications, power supply and PSD systems, as well as industry wide businesses such as E&M systems and electric equipment, system engineering and maintenance.

Leading the defense industry through independent research and development

Hyundai Rote's defense industry division, known for its ground weapons systems, has successfully developed wheeled armored vehicles and has also achieved exports and strategic positioning of the K2 main battle tanks. In addition, the company will increase competitiveness in future battle environments through the acquisition of core technologies for manned and unmanned weapons systems. In line with this strategy, the company is expanding its future weapons systems business which includes the development of future combat vehicles, explosion detection robots and wearable robots.

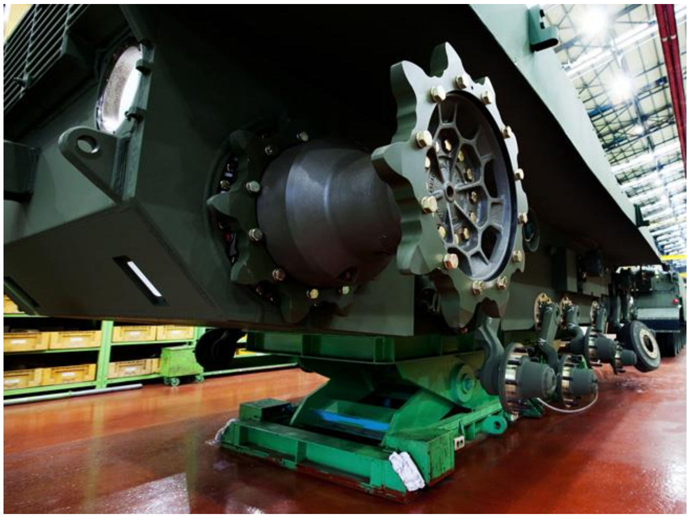


Fig.15. Hyundai Rote

As for its plant business, which serves as the basis for the nation’s industries, Hyundai Rote has carried out a wide range of projects involving the production, procurement, installation and test run of steel making facilities, auto plants and airport facilities on a turnkey basis. Through continuous research and development, the company will enter the renewable energy sector to solidify its position as a total eco-friendly plant engineering company.

3.2. Power Source Category

Fuel cells in power plants that produce large amounts of electricity

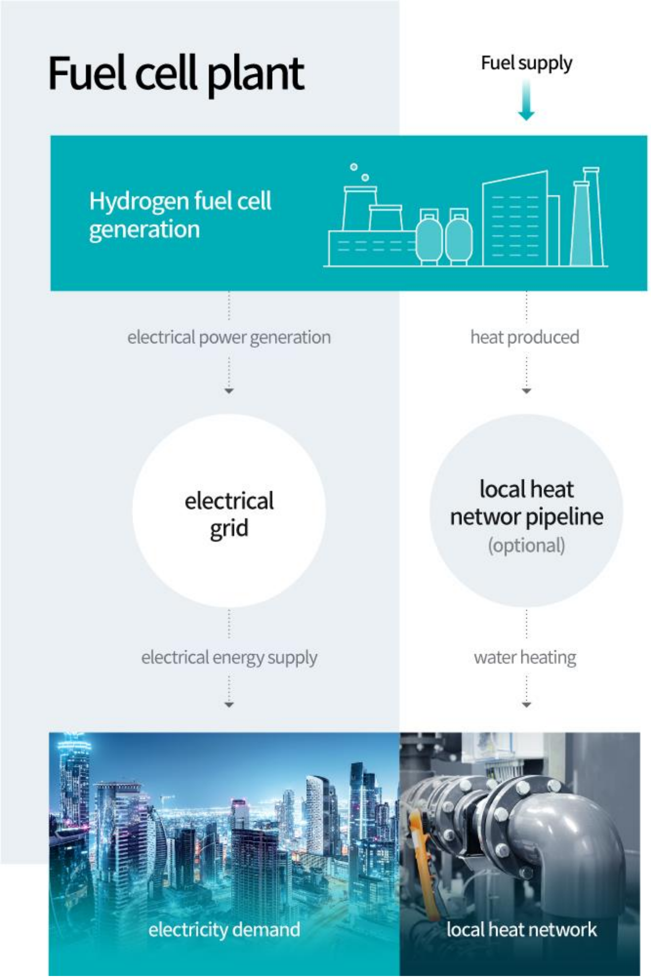


Fig.16. Fuel cell plant

Currently, the field where fuel cells are most common is in the power generation sector. Korea South-East Power Colt. Was the first to establish fuel cell power plants, and they began to be widely utilized since 2012, starting with the 250kW-plant in 2006. In addition to these who operate fuel cell power plants in Sonogram and Ansa in Gyeonggi-do, Korea east-West Power in Islam and Ulsan, and POSCO in Seoul, Incheon, and Gyeongbuk are operating fuel cell power plants.

Fuel cells used in power plants also produce electricity through a chemical reaction between hydrogen and oxygen. The electric energy produced in this way is boosted and sent to a consumer that requires it. What distinguishes it from that in the mobility sector is that it focuses on high efficiency and power generation through continuous operation over a long time. In addition, it is possible to produce steam using waste heat, and if there is demand nearby, it can also supply heat energy by getting connected to the local heat networks.

Fig.17 Hyundai Motor Company

Hyundai Motor Company, which developed hydrogen-electric vehicles and has the know-how on fuel cells, also built a fuel cell power plant to expand the hydrogen industry and started pilot operation this year. The 1MW-fuel cell power generation system devised by Hyundai Motor Company consists of two container modules capable of producing 500kW of electricity, and the most notable feature is that it utilized the fuel cell module equipped for hydrogen-electric Next. The annual electric energy production of the facility is about 8,000MWh, which is the amount that can supply power to about 2,200 households, based on monthly consumption of 300kWh.

The fuel cell container module derived from Next developed by Hyundai Motor has the capacity to generate tens to hundreds of megawatts depending on the number of containers. Not only that, in the past, most of the fuel cells for power generation in Korea were based on overseas technology, so replacement and maintenance costs were high. However, the fuel cell power plant, which Hyundai is piloting, was developed with its own technology. As the future domestic fuel cell power generation market expands, it is expected to lower the fuel cell prices for power generation.

3.3. Introduce Hydrogen Tram

Fig.18 Hydrogen Tram

Under government backing, Hyundai Rote, a locomotive arm of Hyundai Motor Group which is betting high on hydrogen economy, aims to introduce hydrogen-powered electric trams at home and abroad by 2027. According to sources on Wednesday, Hyundai Rote has been conducting a test run of a model hydrogen tram on a 235-meter-long test road within its Changwon plant since related regulations were lifted in October last year. The company developed a concept car with two 95kW hydrogen fuel cells used in Hyundai's hydrogen vehicle next inside the tram and eight hydrogen tanks mounted on the roof. A test run was successful with hydrogen charged at about 61 percent of capacity. Hyundai Rote also developed a dedicated user interface to control and monitor the vehicle. In particular, the fuel cell performance was verified through a driving load test designed to test increase and decrease the speed between 5 and 30 km/h. A power generation function capable of operating from a minimum of 5 kW to a maximum of 100 kW of instantaneous output was also verified. Behind this technology development was a regulatory sandbox system of the Ministry of Trade, Industry and Energy. Under the current law, there were no separate regulations for the pressure vessel and fuel system of a hydrogen electric tram, so it was impossible to create a test platform. Since the tram is not a hydrogen car, it was impossible to refill it with hydrogen. To address these regulatory challenges, a special deregulation review committee held in October last year granted approval of a hydrogen charging station in Changwon along with a test run of the tram. After confirming the potential of the hydrogen tram in test runs, the government is pushing for a full-scale commercialization project. The ministry will invest 42.4 billion won ($36.1 million) in total by 2023 to carry out a demo project across the hydrogen tram infrastructure with a goal of commercializing a 380kW hydrogen tram. Hyundai Rote plans to establish a full-scale mass production system from 2024 while exploring sales channels at home and abroad.

3.4. Tram in Korea has been planned

Busan’s Yogh-dong district was recently selected by the government to have the first low-rise, low-floor tram built in the country. The first section, a 1.9-kilometer track will run from Kyungsung University to Giada Station, just past LG Metro City and will be known as Oryukdo Line. It’s expected to have five stops, including Pukyoung National University, Daeyeoncheon, and Bono. The cost of the project is estimated at KRW 47 billion which will be paid by the government and sponsored by the Korea Railroad Research Institute. The new tram is hoped to revitalize the commercial areas and to increase tourism in the district. The original plans were to include an additional 3.25km of tracks to extend the route to Oryukdo in front of SK View Apartments, which would be built with four more stops. The extended line is likely to be built with public funding.

Locals in the Oryukdo area have long hoped for the tram as few buses in the area have been a major inconvenience for residents. The Busan government won the bid over four other cities by promoting eco-friendly public transport, reducing carbon dioxide emissions, increasing public transportation demand, and increase traffic flow on the ground. However, there is also concern among locals that trams may cause adverse effects such as traffic congestion as Yogh-dong has a high proportion of car use due to traffic inconvenience. The low-rise low-floor tram is a roadside tram that can run over 35 km with a built-in battery system. There is no high-pressure line, is good for the city aesthetic, and it is a new transportation system that is environment-friendly and without noise and smoke. A 430-meter long walking park named "Tram Park" is also expected to be built from Bongos junction to Pukyoung National University. The project is expected to be completed by 2022. Domestic trams have been built in Korea since 2012 and exported to Turkey in 2014 and 2015 though none currently operate within the country. Tram service was used from 1915 to 1968 in Busan but was stopped due to traffic overflow.

3.5 Benefit of Hydrogen Tram

A. Renewable and Readily Available

Hydrogen is the most abundant element in the Universe and despite the challenges associated with its extraction from water, is a uniquely abundant and renewable source of energy, perfect for our future zero-carbon needs for combined heat and power supplies.

B. Hydrogen is a Clean and Flexible Energy Source to support Zero-Carbon Energy Strategies

Hydrogen fuel cells provide an inherently clean source of energy, with no adverse environmental impact during operation as the byproducts are simply heat and water. Unlike biofuel or hydropower, hydrogen doesn't require large areas of land to produce. In fact, NASA have even been working on using hydrogen as a resource with the water produced as a byproduct being used as drinking water for astronauts. This shows that hydrogen fuel cells are a non-toxic fuel source and therefore superior in this way to coal, natural gas and nuclear power which are all either potentially dangerous or hard to obtain. Production, storage and use of hydrogen will play an important role in driving further development of renewable energy, by balancing their intermittent supply modalities with the challenging end-user demands, avoiding the need for significant early investment to upgrade grid infrastructure.

1. More Powerful and Energy Efficient than Fossil Fuels

   Hydrogen fuel cell technology provides a high-density source of energy with good energy efficiency. Hydrogen has the highest energy content of any common fuel by weight. High pressure gaseous and liquid hydrogen have around three times the gravimetric energy density (around 120MJ/kg) of diesel and LNG and a similar volumetric energy density to natural gas. These

2. Highly Efficient when Compared to Other Energy Sources

   Hydrogen fuel cells are more efficient than many other energy sources, including many green energy solutions. This fuel efficiency allows for the production of more energy per pound of fuel. For example, a conventional combustion based power plant generates electricity at 33-35% efficiency compared to up to 65% for hydrogen fuel cells. The same goes for vehicles, where hydrogen fuel cells use 40-60% of the fuel's energy while also offering a 50% reduction in fuel consumption.

3. Almost Zero Emissions

   Hydrogen fuel cells do not generate greenhouse gas emissions as for fossil fuel sources, thus reducing pollution and improving air quality as a result.

4. Reduces Carbon Footprints

   With almost no emissions, hydrogen fuel cells do not release greenhouse gases, which means they do not have a carbon footprint while in use.

5. Fast Charging Times

   The charge time for hydrogen fuel cell power units is extremely rapid, similar to that for conventional internal combustion engine (ICE) vehicles and markedly quicker in comparison to battery-powered electric vehicles. Where electric vehicles require between 30 minutes and several hours to charge, hydrogen fuel cells can be recharged in under five minutes. This fast charging time means that hydrogen powered vehicles provide the same flexibility as conventional cars.

6. No Noise Pollution

   Hydrogen fuel cells do not produce noise pollution like other sources of renewable energy, such as wind power. This also means that, much like electric cars, hydrogen powered vehicles are much quieter than those that use conventional internal combustion engines.

7. No Visual Pollution

   Some low-carbon energy sources, including wind energy and biofuel power plants can be an eyesore, however, hydrogen fuel cells do not have the same space requirements, meaning that there is less visual pollution too.

8. Long Usage Times

   Hydrogen fuel cells offer greater efficiencies with regard to usage times. A hydrogen vehicle has the same range as those that use fossil fuels (around 300 miles). This is superior to that currently offered by electric vehicles (EVs), which are increasingly being developed with fuel cell power units as ‘range-extenders’. Hydrogen fuel cells are also not significantly impacted by the outside temperature and do not deteriorate in cold weather, unlike EVs. This advantage is increased further when coupled with the short charging times.

9. Ideal for Use in Remote Areas

   Where local conditions allow, the availability of hydrogen through local generation and storage could prove to be an alternative to diesel-based power and heating in remote areas. Not only will this reduce the need to transport fuels but will also improve the lives of those living in distant regions by offering a non-polluting fuel obtain from a readily-available natural resource.

10. Versatility of Use

    As the technology advances, hydrogen fuel cells will be able to provide energy for a range stationary and mobile applications. Hydrogen powered vehicles are just one example, but it could also be used in smaller applications such as domestic products as well as larger scale heating systems. Similar to ICE power plants, the functions of energy storage capacity (i.e. the fuel tank) and engine size are decoupled, in contrast to battery-based power (i.e. for which power scales linearly with mass), thus providing great flexibility in design.

11. Democratization of Power Supply

    Hydrogen fuel cells have the potential to reduce the dependency of a nation on fossil fuels, which will help democratize energy and power supplies around the world. This increased independence will prove a benefit for many countries who are currently reliant on fossil fuel supply. Of course, this will also avoid the problem of rising fossil fuel prices as stocks reduce.

3.5. Principle of Hydrogen Tram

Fuel cells: Generating electricity from hydrogen

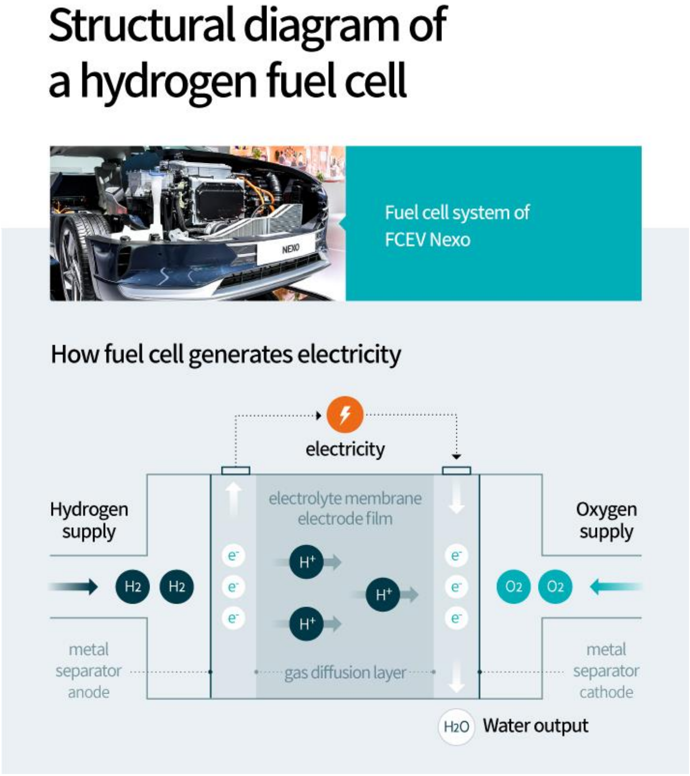


Fig.19 Structural diagram of a hydrogen fuel cell

Even in a hydrogen society, electricity is a key source that would power the world as it does now. The difference is that in a hydrogen society, electricity will be generated from hydrogen. And fuel cells get to play a huge role here.

A fuel cell refers to a device that directly converts and generates electricity through electro-chemical reactions with oxygen in the atmosphere using hydrogen as a power source. Here is how it works: the hydrogen supplied to the anode is separated into hydrogen ions and electrons, and then the hydrogen ions move to the cathode through the electrolyte layer and the electrons to the cathode through the external circuit. In this process, electrons generate electricity, and oxygen ions and hydrogen ions met at the cathode produce water and heat. In a fuel cell, hydrogen and oxygen are combined through a chemical reaction to generate electricity, water, and heat.

Generally, a fuel cell consists of an anode, an electrolyte layer, and an air electrode, an electricity production device that holds stacks of these cells, and an electrical/mechanical peripheral device (Balance of Plant, BOP). The BOP houses electrical devices such as system controllers and power converters, and the machines for optimized durability and operation such as fuel/air supply, heat exchanger, and water treatment systems.

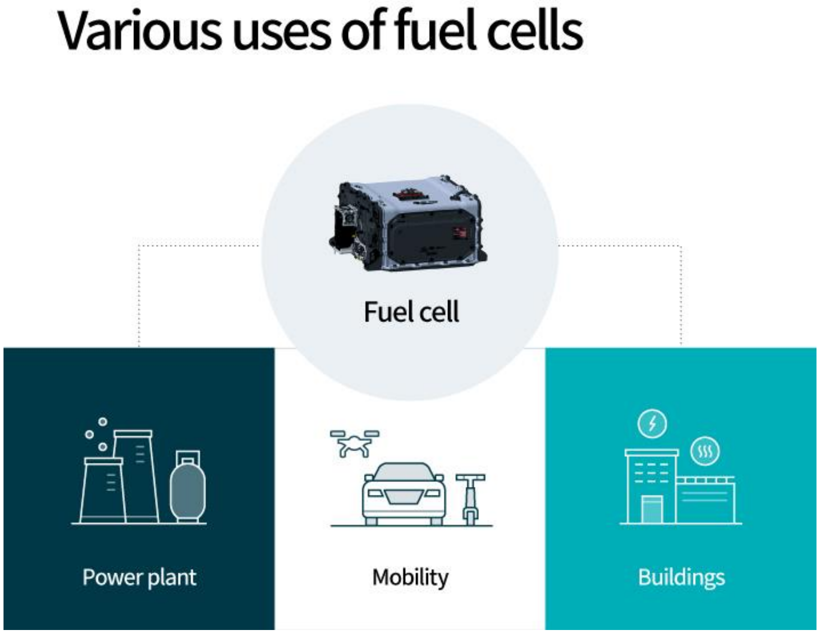


Fig.20 Various uses of fuel cells

Fuel cells have long been used in the aerospace field. It is well known that astronauts used fuel cells on the Apollo 11, the first mankind to land on the moon. In recent years, Hyundai Motor Company succeeded in mass-producing hydrogen-electric vehicles using fuel cell systems for the first time in the world, drawing worldwide attention. This became the moment people actually started to use fuel cells in their daily lives.

The mass production of hydrogen-electric vehicles seems like the application of fuel cells is only limited to automobiles, but it is never true. The amount of electricity generated by fuel cells can be adjusted depending on the size and number of cells, so it can be used for small and large mobility other than automobiles, and it can even support a huge power plant that produces a large amount of electricity. Of course, it can also be used in the houses, apartment buildings, and other places that we live in.

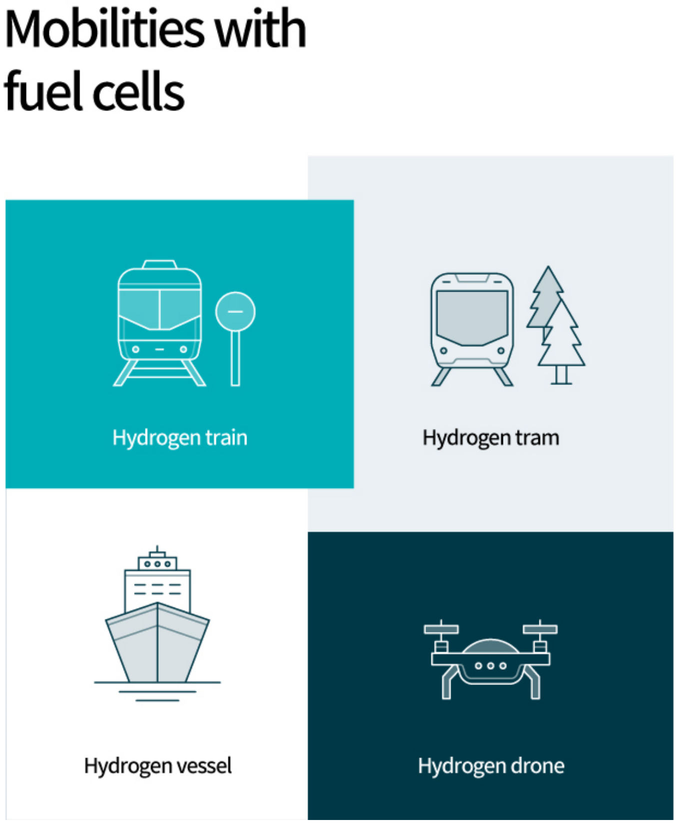


Fig.19 Mobility's with fuel cells

Fuel cells basically use electricity, so most electric vehicles could utilize fuel cells. In fact, mobility such as hydrogen trains, hydrogen trams, hydrogen ships, and hydrogen drones powered by fuel cells are actually under development.

4. The Strategy for Attracting Hydrogen Business Investment

How will South Korea transition from pilot projects and feasibility studies to larger-scale operational initiatives during the next decade? Not only does progress in legislation and regulation need to be achieved, but more clarity is also required to understand the cost competitiveness of various hydrogen production, transportation, and storage technologies, cost-cutting prospects, and the magnitude of investment required. These considerations will be important for making policy choices on support mechanisms targeted at attracting timely investment in hydrogen infrastructure, as well as constructing and developing efficient supply chains to fulfill the net zero objective Free Economic Zone (FEZ) Incentives.

4.1. Free Economic Zone (FEZ)

The Free Economic Zone (FEZ) in Korea is designated by law to facilitate foreign investment, and thereby to strengthen national competitiveness and seek balanced development among regions by improving the business environment for foreign-invested enterprises and living conditions for foreigners.

4.2 Free Economic Zone Incentives

Table 4.1 Free Economic Zone Incentives

Incentives		Main Contents	Applicable Laws
Tax Reduction	Condition	• Manufacturing · tourism industries (over $10 million), logistics industry · medical institutions (over $5 million), R&D (over $1	The Free Economic Zone Act, Sec. 16, ①.

Incentives		Main Contents	Applicable Laws
		million and regular employment of more than 10 researchers with MA degree or higher) • Development agencies (over $30 million or total project cost over $500 million with more than 50% of Foreign Investment Ratio)	The Special Tax Treatment Control Law, Sec. 121, 2,3
	Reduction	• Tariff: tariff cuts by 100% for 5 years (applies to imported capital goods) • Acquisition · Property taxes (local tax): tax cuts by 100% for first 7 years and by 50% for next 3 years	
Support for Infrastructure		• Priority support of national treasury for infrastructure within the Free Economic Zone (government expenditure 50%, province and city expenditure 50%). ※ If Free Economic Zone Council considers and votes on agendas, up to 100% tax/tariff cuts.	The Free Economic Zone Act, Sec. 18.
Freedom of Foreign Exchange Transaction		• Foreign exchange transaction without reporting is permitted up to 20,000 dollars.	The Free Economic Zone Act, Sec. 21.

Source: https://www.efez.go.kr/hb/eng/Investmment-incentive

5. Fuel cells for Civil and Military Applications-Challenges and Solutions

Clearly, there is a need to develop projects involving the optimal use of hydrogen as a transport fuel in the defense sector. Current analyses indicate that hydrogen fuel is less efficient than the use of petroleum fuel in, for example, military turbojet engines. A comprehensive life cycle assessment (LCA) should also consider the environmental impact of greenhouse gases, which are noticeably less when using H2 hydrogen fuels compared to the traditional approach-the use of military aviation paraffin (JP-8). Research is currently underway into safe and cost-effective technologies for the production, storage, and use of hydrogen, which would justify the transfer of developed solutions from the civil to the military sector. The literature highlights the dual use of the innovations in question. Individual solutions used in the civilian sector, following prior adaptation, can be successfully used in the military sector [16].

5.1. Motivation to use Fuel Cells

This article aims to identify and analyses existing barriers to the introduction of P2H technologies that use hydrogen. The holistic approach used, which was based on a literature survey, identified obstacles and possible strategies for overcoming them. The research conducted presents an original research contribution at the level of hydrogen strategies considered in leading countries around the world. The research findings identified unresolved regulatory issues and sources of uncertainty in the armed forces. There is a lack of knowledge in the armed forces of some countries about the process of producing hydrogen energy and its benefits, which raises concerns about the consistency of its exploitation [16].

5.2. Focus areas of current Fuel Cells developments

The Defense Ministry will provide an area for the station, and the Commerce Ministry will provide necessary policy support, while the Environment Ministry will oversee running the construction project. Also under the agreement, the Defense Ministry will review using hydrogen-run drones made by Doosan Mobility Innovation for military operations. The ministry said Doosan's hydrogen-run drones can fly around for more than two hours, compared to 30 minutes for regular drones out on the market.

5.3. AVL Fuel Cell Technology Roadmap 2040

There are over 20 UAV companies in Korea and apart from DMI, Giant drone is known to have FC-based product line at the R&D stage. The company recently developed a 2kW FC drone with a 2-hour flight time. Current regulations in Korea allow drones with a total weight up to 25kg (including FC system and storage tank) to fly over residential areas. Drone taxis are also on the government's long-term agenda which will require much broader regulations.

Under the National Hydrogen Technology Roadmap (NHTR), the government aims to achieve 1kW/kg for general purpose drones, and 2kW/kg power density for drone taxis by 2040 [2]. 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.

5.4. General advantages and disadvantages of PEM technologies

Table 5.2. Advantages and disadvantages of PEMFCs

Advantages	Disadvantages
High energy density	Needed to pure hydrogen
Compact design	Needed to pure oxygen
Max values of specific power per unit volume and weight	Water flooding
Fast-start-up time	Expensive
Low operating temperature	Platinum catalyst poisoning(CO)
Easy and safety handling	
Min maintenance (no moving parts)	
Continuous electrical energy supply	

5.5. Challenges Introducing Fuel Cells

Key challenges must be overcome before the military and commercial aviation industry can realize the full energy- and emissions-reducing potential of hydrogen and fuel cell technology applications. Challenges for hydrogen and fuel cell technology applications in aviation include the following:

1. Technical issues such as managing waste heat, improving fuel cell durability, improving inverter efficiency, increasing system power densities and system energy densities (including fuel storage), and ensuring reliable power quality. Another significant technical challenge is addressing the differing requirements (packaging, location, and functions) for military and commercial aviation use of APUs. APUs are used for non-propulsion power like cabin pressure, avionics, and gallery power.
2. Fuel issues such as increasing fuel flexibility and tolerance of high-sulfur fuels. The move toward bio aviation fuels may also pose challenges in terms of tolerance to sulfur and heavy metals.
3. Cost challenges for hydrogen and fuel cell technology applications in aviation, including the need to reduce fuel cell, hydrogen, and balance of plant costs.
4. Certification challenges, particularly coordinating certification, and approvals for storage of high-pressure hydrogen on aircraft.
5. The lack of a refueling infrastructure for bases and airports.

5.6. Solutions Introducing Fuel Cells

Smart energy storage is supplementing renewable energy in the global energy and transportation sector, which is continually evolving. Fuel cells will be an essential component of smart energy infrastructure, generating energy locally for fixed and mobile applications. In the transportation sector, electric cars powered by hydrogen fuel cells are gaining popularity and will soon be able to compete with battery-powered electric cars. Unlike battery-powered automobiles, which take at least 30 minutes to completely charge, fuel cell cars offer the advantage of quick charging.

6. Developing High Power Fuel Cells Systems for Automotive Applications

Hyundai Motor Group’s fuel cell systems are also rapidly improving in terms of durability. The very first fuel cell system was durable for 30,000 km (800 hours), but the first-generation fuel cell system secured the level of the internal combustion engine with 100,000 km (3,000 hours) and 160,000 km (5,000 hours) for the NEXO. Among the next-generation fuel cell systems, the high-endurance fuel cell system for commercial vehicles aims to achieve a driving range of about 500,000 km [17].

6.1. Background of Fuel Cells

A fuel cell vehicle (FCV) or fuel cell electric vehicle (FCEV) is an electric vehicle that uses a fuel cell, sometimes in combination with a small battery or super capacitor, to power its onboard electric motor. Fuel cells in vehicles generate electricity generally using oxygen from the air and compressed hydrogen. Most fuel cell vehicles are classified as zero-emissions vehicles that emit only water and heat. As compared with internal combustion vehicles, hydrogen vehicles centralize pollutants at the site of the hydrogen production, where hydrogen is typically derived from reformed natural gas. Transporting and storing hydrogen may also create pollutants.

6.2. The EU-funded STASHH project

A European consortium consisting of 25 leading organizations in the hydrogen sector are joining forces to define, develop and test the first European standard for fuel cell modules for heavy duty applications. This standard for fuel cell modules may be the game changer that the fuel cell industry requires to enhance market competitiveness by enabling competition, cost reduction and mass production. The consortium operating together as “Stash” comprises 11 fuel cell module suppliers, 9 original equipment manufacturers and 5 research, test, engineering and/or knowledge institutes and will standardize physical dimensions, flow and digital interfaces, test protocols and safety requirements of the fuel cell modules that can be stacked and integrated in heavy duty applications like forklifts, buses, trucks, trains, ships, and construction equipment. The consortium receives 7.5 M€ funding from the European Union, through the Fuel Cells and Hydrogen Joint Undertaking, in order to kick start the adoption of fuel cells in the heavy-duty sector. The total budget is 15.2 M€ [18].

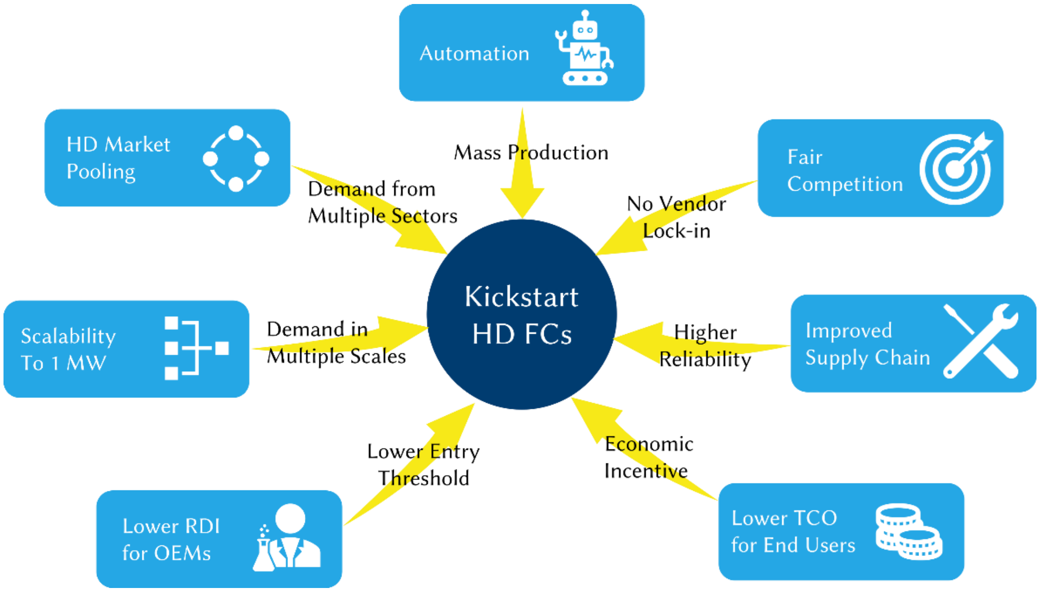


Figure 6.1. Objectives of the Stash project [18].

The size nomenclature for batteries has been well established over time and became known as the “AA-series” nomenclature and has resulted in a rapid adoption of battery technologies into a wide variety of applications. A similar nomenclature, denoted as the “HH-series” is envisioned by the Stash consortium for fuel cell modules, which are at the heart of any fuel cell system. Upon reaching an industrial consensus between fuel cell module suppliers and OEMs regarding the standard, the fuel cell module suppliers in the consortium will design and develop standardized modules for different power classes. The modules will be tested by the test centers in the consortium upon key indicators to benchmark performance and safety. Meanwhile the consortium will make a committed and devoted effort to promote the standard at the appropriate European and international regulation, codes and standards platforms to enable the worldwide adoption of the standard. Proper dissemination is guaranteed and exploitation efforts to external fuel cell module suppliers and OEMs is foreseen [18].

6.3. Feasibility Study

The core idea of Stash is the realization of a comprehensive standard for fuel-cell modules: Stash will define this standard, build prototypes implementing it and test them thoroughly. The extensive test campaign on multiple prototypes is meant to validate the standard and prove that all FCM suppliers can provide standard-compliant modules. The Stash standard will encompass physical size ("as few as possible, as many as needed"), but also flow interfaces (air, hydrogen, coolant and power), digital interface (API for control, monitoring, diagnostics), testing protocols and safety requirements.

Such a module will have the following characteristics [19]:

1. it shall include at least the FC stack, the air supply system, the hydrogen system (storage excluded) and the cooling system (excluding radiators and coolers);
2. it shall deliver from 30 to 100 knit
3. it shall be scalable to at least 1 MW by integrating multiple units;
4. it shall be employable in different heavy-duty applications;
5. Its mechanical size shall be designed to fit common battery pack sizes and the available space in different heavy-duty applications, to facilitate switching between battery and hydrogen technologies both technically and economically.

Comprehensive tests will be run on each of these systems according to the standard test protocols defined in Stash. Stash will also consider the safety aspects related to the standard with a work package entirely dedicated to RCS and Safety. Stash' standard will be disseminated worldwide

6.4. Intelligent Energy Overview

PEM (proton exchange membrane) fuel cells are a type of hydrogen fuel cell being widely commercialized across multiple applications and business sectors. They convert the chemical energy of hydrogen fuel directly into electricity via a solid conducting membrane sandwiched between two electrodes. Below is a simplified illustration of a working PEM fuel cell.

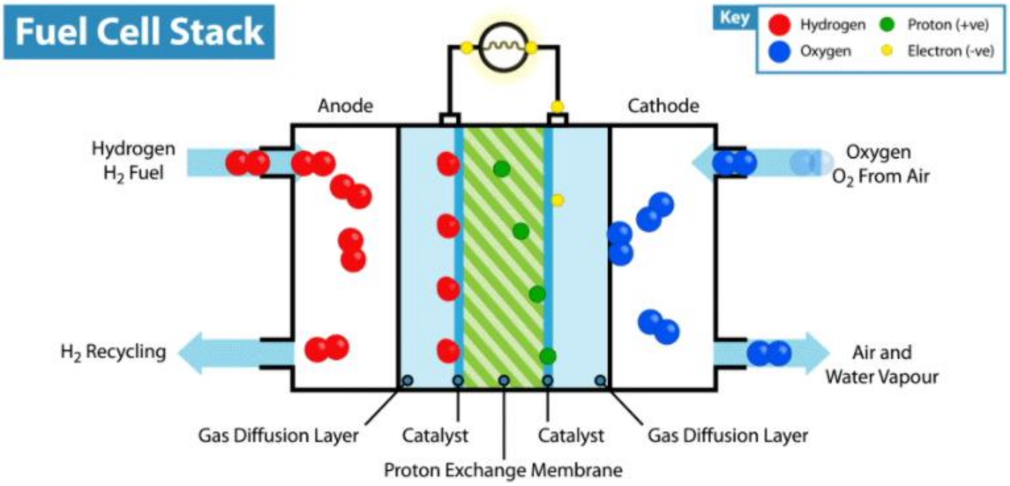


Figure 6.2. Fuel Cell Stack [20].

The hydrogen molecule donates its electron at the anode, leaving positively charged protons. Electrons travel through the circuit and protons through the membrane to the cathode, where they form water. The flow of electrons or electricity is the primary product of the fuel cell with pure water the only by product.

7. Development and Production of Fuel Cell Shipment Hybrid Power Management System

A hybrid power management scheme for the propulsion system of a small leisure ship, which is operated with a load variation according to the state of the sea. When the pulse load is generated, the power source supplies a considerably higher peak current than that in the case of a constant load. Once the peak load is generated, the battery is damaged by the rush current. Therefore, the power flow of the proposed hybrid power system is controlled with a BDC. Finally, the simulator for the hybrid power system was developed for analyzing the operating characteristics according to the load.

His hybrid power system operates well under various load conditions (e.g., steady, cold start, and overload). The operation of the battery system can be controlled by the battery voltage and the DC bus. The battery system is connected to the DC bus through the BDC, which can be controlled according to the voltage level. The voltage level of the battery is categorized into three types: over-discharge, normal, and over-charged. The battery system is connected to the DC bus, which is operated in either the buck mode, the boost mode, or the stop mode [21] .

7.1. International Maritime Organization

The IMO FAL MIG provides additional technical information, in addition to the semantic definitions, for implementing ship reporting formalities outlined in the Convention on Facilitation of International Maritime Traffic (FAL). The MIG has been developed following cooperation between the WCO and the IMO.

The IMO Compendium is a tool for software developers that design the systems needed to support transmission, receipt, and response via electronic data exchange of information required for the arrival, stay, and departure of the ship, persons, and cargo to a port.

The IMO Compendium consists of an IMO Data Set and IMO Reference Data Model agreed by the main organizations involved in the development of standards for the electronic exchange of information related to the FAL Convention: the WCO, the United Nations Economic Commission for Europe (UNECE) and International Organization for Standardization (ISO). Watch the video here [22].

7.2. Engine Market Volume (Ship)

he Marine Propulsion Engine Market (hence referred to as market studied) was valued at USD 33.82 billion in 2020 and is anticipated to reach USD 39.99 billion in 2026 by registering a CAGR of 2.63% during the forecast period (2021-2026) [23].

The Outbreak of COVID-19 has hindered the growth of the marine propulsion engine market with continuous lockdowns and the subsequent economic slowdown across the world. The most significant near-term impact on marine engines will be felt through supply chains. However, post-pandemic as restrictions eased market expected to gain momentum during the forecast period.

The Marine propulsion engine market is driven by the need for faster, cleaner, and fuel-efficient engines. The International Maritime Organization (IMO) has drafted a new rule where the sulfur content in marine fuel will be reduced to 0.5% from 3.5%. This new regulation is expected to cut off emissions from ships by 77%. This has caused the ship operators to low sulfur content fuels, such as marine gas oil, and it has also driven the demand for electrification of marine vessels.

Asia-Pacific region is anticipated to observe rapid growth over the tenure of assessment due to augmented international trade and export from the region. Both India and China have come up as major hubs of business in the region, with an increased pace of activities in the marine manufacturing sector.

7.3. High End Technology

According to the Hydrogen Council, hydrogen represents a central pillar of the energy transformation required to limit global warming. It can play several major roles in this transformation and one of them is decarbonizing transportation. Namely, hydrogen can be considered as a possible solution for future zero-carbon marine vessels as it offers the highest energy content per mass when compared to other fuels, high diffusivity and high flame speed.

The market for hydrogen and hydrogen technologies is estimated to be worth $2.5 trillion by 2050, creating 30 million jobs globally and taking up 18% of total energy demand, Hydrogen Council said a report published in 2017.

Last year, the Korean government also announced the Road Map for Activating the Hydrogen Economy and is spurring the revitalization of the hydrogen economy in various industries such as shipbuilding, automobiles and batteries [24].

FUEL CELL APPLICATIONS

The fuel cell for ships can replace not only the existing power generation engine but also the main propulsion engine, and through EMS*, energy efficiency can be improved. Doosan Fuel Cell signed an MOU with Korea Offshore & Shipbuilding, a shipbuilding holding company of Hyundai Heavy Industries Group, and jointly develops an eco-friendly ship fuel cell. A marine fuel cell is a high-efficiency power generation source that generates electricity from raw materials such as hydrogen and liquefied natural gas (LNG) and can increase the power generation efficiency by about 40% or more compared to existing marine engines. In addition, it is a key technology in the era of eco-friendly ships in that it emits less various pollutants such as sulfur oxides (Sox) and nitrogen oxides (NOx) and can reduce greenhouse gases [25].

1. H2Fuel Cell powered Electric Propulsion Systems for Ships

The International Maritime Organization (IMO) foretold to reduce greenhouse gas emissions by 50% or less compared to 2050 and 2008, the two companies will preemptively develop fuel cells for ships to secure a competitive advantage in the shipbuilding industry.

1.1 Global Markets of ABB

Building on an existing collaboration announced on June 27, 2018 with Ballard Power Systems, the leading global provider of proton exchange membrane (PEM) fuel cell solutions, ABB and HDF intend to optimize fuel cell manufacturing capabilities to produce a megawatt-scale power plant for marine vessels. The new system will be based on the megawatt-scale fuel cell power plant jointly developed by ABB and Ballard and will be manufactured at HDF's new facility in Bordeaux, France [26].

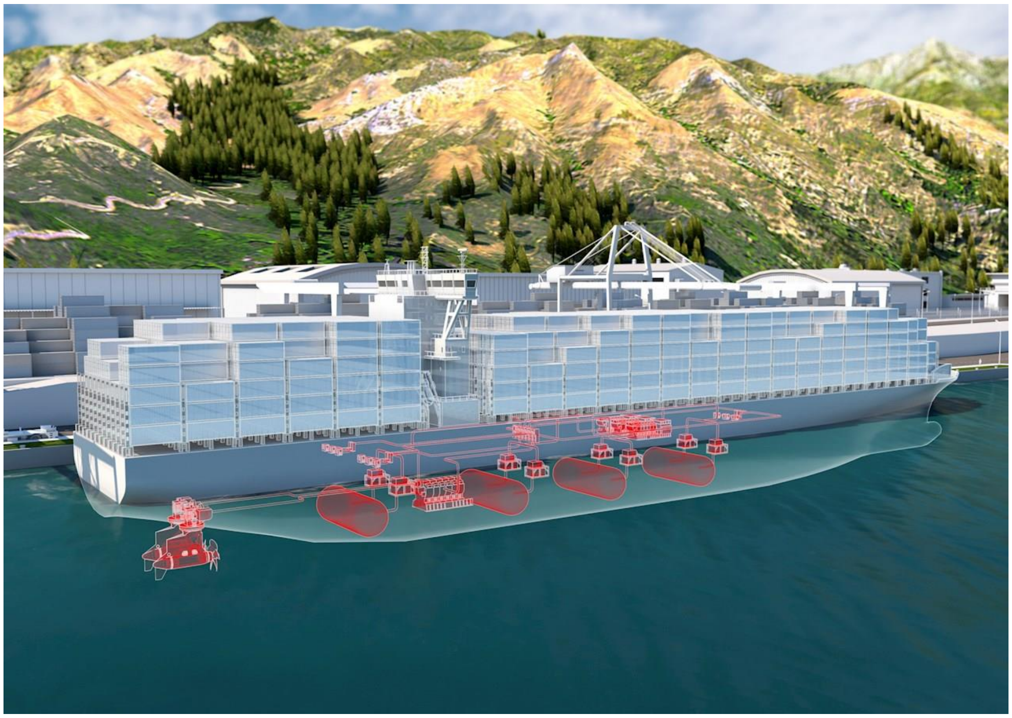


Figure 8.1. The new system will be based on the megawatt-scale fuel cell power plant jointly developed by ABB and Ballard, and will be manufactured at HDF's new facility in Bordeaux, France [26].

1.2 Main sustainability targets

Fuel cells turn the chemical energy from hydrogen into electricity through an electrochemical reaction. With the use of renewables to produce the hydrogen, the entire energy chain can be clean. HDF is very excited to cooperate with ABB to assemble and produce megawatt-scale fuel cell systems for the marine market based on Ballard technology with the ever-increasing demand for solutions that enable sustainable, responsible shipping, we are confident that fuel cells will play an important role in helping the marine industry meet CO2 reduction targets with shipping responsible for about 2.5 percent of the world's total greenhouse gas emissions, there is an increased pressure for the maritime industry to transition to more sustainable power sources. The International Maritime Organization, a United Nations agency responsible for regulating shipping, has set a global target to cut annual emissions by at least 50 percent by 2050 from 2008 levels [26].

Among alternative emission-free technologies, ABB is already well advanced in collaborative development of fuel cell systems for ships. Fuel cells are widely considered as one of the most promising solutions for reducing harmful pollutants. Already today, this zero-emission technology is capable of powering ships sailing short distances, as well as supporting auxiliary energy requirements of larger vessels.

1.3 Electric and Hybrid Propulsion

Diesel engines, the standard method of propulsion for merchant ships, contribute heavily to greenhouse gas emissions. Thermal efficiency for these engines can be as low as 50 per cent, resulting in unnecessary use of fossil fuels and polluting emissions. Electric and hybrid ship propulsion systems are a promising solution, but until recently the batteries have been weighty, with limited capacity.

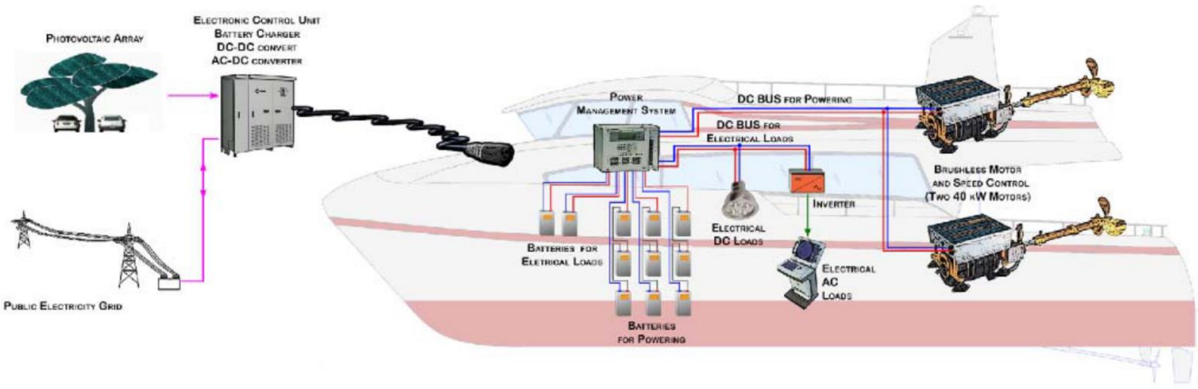


Figure 8.2. Electric propulsion system [27].

Over 80% of freight is transported by sea, and maritime transport contributes with 30% of CO2 emissions in the transport sector. Greenhouse gas emissions related to ships represents a big problem. Reduction of fuel consumption and emissions is one of the main goals for ship designers. It is important to improve the efficiency and to optimal manage the energy chains, to upgrade propulsion and protect the environment.

Hybrid marine systems include an internal combustion engine (ICE), an electric generator, an electrical storage unit and an electric motor. The performance of a marine hybrid propulsion system is given by how the energy is supplied to the propeller. In a series configuration, the electric motor is the only one to supply the propeller (Figure 8.2.). The engine receives power either from the storage unit or from a generator powered by an ICE, the ship operating either classically or electrically. In a parallel hybrid system, both the combustion engine and the electric motor can provide power to the propeller (Fig. 3). The diesel engine / electric generator can directly drive the power plug from the storage unit or be used to charge the battery.

1.4 Onboard DC Grid

The Onboard DC Grid is a step forward in optimized propulsion-on and is an extension of multiple DC links that already exist in propulsion and thruster drives. Onboard DC Grid enables us to combine the advantage of AC components with a new smart DC distribution. Just as variable speed drive allows the electric propulsion motors to be run at their optimum working point, Onboard DC Grid allows the diesel engines to run at variable speed for top fuel efficiency at each load level. And, the Onboard DC Grid enables full flexibility in combining energy sources, including renewables [28][29].

To the ship owner Onboard DC Grid means[28]:

a. Up to 27% reduction of specific fuel consumption
b. Less maintenance of generator sets
c. Improved dynamic response and maneuverability
d. Increased space for payload
e. Ready for new energy sources

To yard and designer Onboard DC Grid means[28]:

a. Fewer components to be installed
b. Reduced equipment footprint and weight
c. Easier cable installation
d. More flexible placement of components

Each power source and consumer on the Onboard DC Grid is an AC or DC “island” and the only connection between them is the DC bus. This yields two advantages: each power source and consumer can be controlled and optimized independently, and complex interactions that can arise between units that share an AC connection will never occur. Consumers fed by the Onboard DC grid are designed not to interact even under fault conditions.

In the Onboard DC Grid solution, energy storage may be included to improve the system’s dynamic performance. Diesel engines are slow to handle large, quick load changes. By using batteries or super capacitors to provide power for a short time, the ship‘s control capabilities can be improved. This will benefit especially vessels with Dynamic Positioning. Energy storage can also be used to absorb rapid power fluctuations seen by the diesel engines, thereby improving their fuel efficiency.

In its simple way the Onboard DC Grid is just an extension of the already multiple DC-links already existing in all propulsion and thruster drives accomplishing for usually more than 80% of the electrical power consumption on electric propulsion vessels. This extension means that we keep all the good and well pro-vent products already used in today's electric ships like AC generators, inverter modules, AC motors, etc. All main AC SWBDS and transformers are however no longer needed and you have the most flexible power and propulsion system to date. The main innovations with this new Onboard DC Grid are the design and control of the protection system and optimized energy flow. This technical note describes the design and configuration of the Onboard DC Grid system, with a discussion of the various benefits[28].

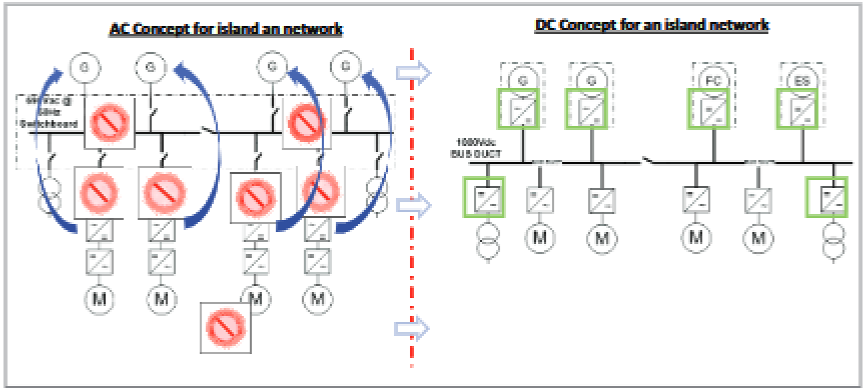


Fig. 1.4.1 From AC to DC (single line old vs. new design)[28]

There are several ways of configuring the Onboard DC Grid from a multidrive approach (figure 2) to a fully distributed system (figure 3). In the multidrive approach all converter modules are located in the same lineup within the same space layout as today's main AC switchboard. For the distributed system each converter component is located as near as possible to the respective power source or load. Common for both alternatives is that the main AC SWBD and all thruster transformers are omitted in the new concept. Instead all generated electric power is fed directly or via a rectifier into a common DC bus that distributes the electrical energy to the consumers. Each main consumer is then fed by a separate inverter unit. The 220V AC distribution (e.g. “hotel load”) will be fed using island converters, specially developed to feed clean power to these more sensitive circuits. Further converters for energy storage can be added to the grid. This energy storage could for example be batteries or super capacitors for leveling out power variations. The main benefits of this approach is a reduction of the fuel consumption - up to 27% reduction of specific fuel oil consumption. In addition the system allows for considerably weight and space savings thus leading to increased cargo capacity.AC Concept for island an network DC Concept for an island network AC Concept for island an network DC Concept for an island network Fig. 1 From AC to DC (single line old vs. new design).

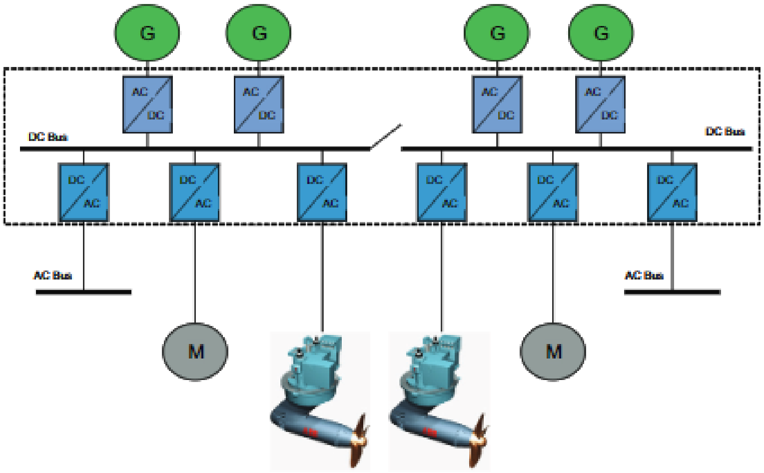


Fig. 1.4.2 Onboard DC Grid; Multidrive approach[28]

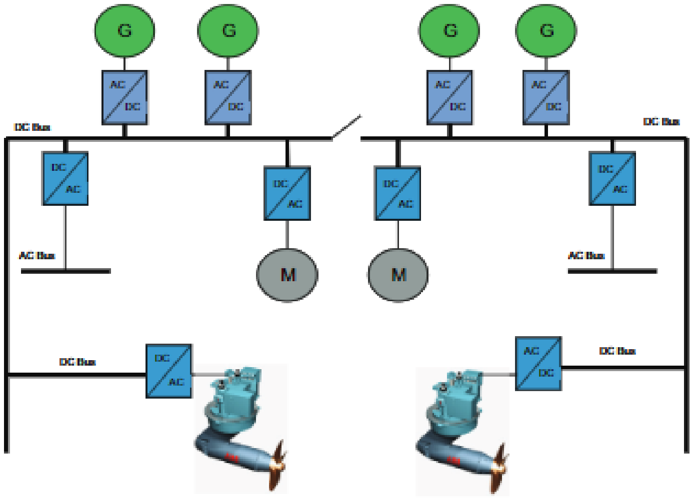


Fig. 1.4.3 Onboard DC Grid; Distributed approach[28]

The major breakthrough in the development of the DC grid was the development of an innovative protective system. AC currents are by nature far simpler to break because of their natural zero crossing every half cycle. DC circuit breakers do exists to some extent but are more complex, larger and more expensive than comparable AC circuit breakers.

Onboard DC Grid is a new electric power distribution concept that, while utilizing the well proven AC generators and motors, opens new opportunities for efficiency improvements and space savings. The efficiency improvement is mainly accomplished by the fact that the system is no longer locked at a specific frequency (usually 60Hz on ships), even though any 60Hz power source also would be connectable to the Grid. The new freedom of controlling each power consumer totally independently opens up numerous ways of optimizing the fuel consumption. Today almost all energy producers on electric ships are combustion engines, most operating on liquid oil (HFO/MDO), some on gas (from LNG mainly), and even some with Dual Fuel capability (liquid fuel or gas)[28].

Since the main AC SWBD with its AC circuit breakers and protection relays is omitted from the new design, it has been essential to devise a new protection philosophy that fulfills class requirements for selectivity and equipment protection. In doing so it has also been a key requirement to minimize use of expensive and space consuming DC circuit breakers. Proper protection of the Onboard DC Grid is achieved by a combination of fuses and controlled turn-off of semiconductor power devices. Since all energy producing components have controllable switching devices (either thermistor rectifier for AC producers and DC/DC converters for DC producers) the fault current can be blocked much faster than what is possible with traditional circuit breakers with associated protection relays[30].

1.5Current and future compliant fuels

Environmental regulations have always been an essential component in the natural gas supply chain, with recent and greater emphasis on shipping operations. Recently more stringent regulations have been imposed by the International Maritime Organization on global maritime shipping operations [31].

On 1 January 2020, new reduced limits on Sulphur in fuel oil brought about a 70% cut in total Sulphur oxide emissions from shipping, ushering in a new era of cleaner air in ports and coastal areas by using less polluting fuels. One year on, indications are that the transition has been extremely smooth, a testament to the preparations of all stakeholders prior to the new rules entering into force. The upper limit of the Sulphur content of ships' fuel oil was reduced to 0.5% (from 3.5% previously) - under the so-called "IMO 2020" regulation prescribed in the MARPOL Convention. This significantly reduces the amount of Sulphur oxide emanating from ships[32].

Compliant fuels include very low Sulphur fuel oil (VLSFO) and marine gas oil (MGO). Some ships limit their air pollutants by installing exhaust gas cleaning systems, also known as "scrubbers". This is accepted under the MARPOL Convention as an alternative means to meet the Sulphur limit requirement. Around 3,100 systems have formally been reported to IMO as an approved "equivalent method" by Administrations (flag States), by the end of 2020.

Ships can also have engines which are able to use different fuels, which may contain low or zero Sulphur, such as liquefied natural gas or biofuels. The majority of ships trading worldwide switched from using heavy fuel oil (HFO) to using VLSFO. Generally speaking, these are new blends of fuel oil, produced by refineries to meet the new limit, in accordance with IMO guidance and ISO standards.

Guidance issued by IMO on dealing with the new fuel blends in advance of the new requirement addressed implications of switching to VLSFO, including assessing and managing risks and highlighting potential safety risks, so that the risks can be mitigated.

Through 2020, and into 2021 to date, IMO has not received any reports of safety issues linked to VLSFO. Nonetheless, during 2020, an IMO correspondence group considered fuel oil safety issues in general and the need for further mandatory requirements to ensure fuel oil supplied meets the required standards and quality. The report of the group (MSC 102/6) is available on IMODOCS and will be discussed at the next session of IMO's Maritime Safety Committee (MSC), MSC 103 in May 2021[32].

Prior to that, the eighth session of the Sub-Committee on Prevention of Pollution from Ships (PPR 8), scheduled to meet remotely from 22 to 26 March 2021, will further consider VLSFO fuel quality issues, including possible effects on black carbon emissions. Provisions in regulation 18 of Annex VI of the International Convention for the Prevention of Pollution from Ships (MARPOL) regulate fuel oil quality. The International Convention for the Safety of Life at Sea (SOLAS) covers issues such as flashpoint (SOLAS regulation II-2/4.2.1).

Apart from the requirements in MARPOL Annex VI and SOLAS, VLSFO is required to meet ISO standard 8217 as well as ISO Publicly Available Specification (PAS) 23263, providing guidance as to the application of the existing ISO 8217 marine fuel standard to 0.50% Sulphur limit compliant fuel oils. These measures and standards are designed to ensure ships' safety and the protection of the marine environment and oceans.

1.6 Fuel cells for marine

Although most of the fuel cell technologies have higher energy efficiency than traditional marine diesel engines or dual-fuel engines, the advantage are not overwhelming when costs and technical maturity are taken into account [33]. Considering low carbon or zero carbon future shipping, the scenario of fuel cell applications in the maritime industry is assumed to utilize zero carbon or carbon-neutral fuels. That is to say, there is a basic assumption in this paper that carbon capture and storage (CCS) is regarded as being unavailable onboard ships. Therefore, conventional marine fossil fuels are excluded due to limited long-term prospects, but hydrogen, ammonia and synthetic natural gas (SNG, predominantly methane) and methanol from renewable sources are regarded as marine fuels with long-term prospects and will be investigated in this section. As a transition, short-term applications of fossil raw materials being used as feed stocks for hydrogen, ammonia, SNG and methanol are assumed to be acceptable.

1.6.1 Hydrogen

Hydrogen is the most abundant element on earth, but due to its high reactivity, it is only found in usable quantities within chemical compounds. Consequently, in order to obtain hydrogen in its pure form, energy must be expended for the purposes of extraction. The feed stocks of hydrogen include fossil fuels, biomass and water. However, natural gas (NG) and coal are currently the primary feed stocks. The typical production processes of hydrogen include thermochemical conversion and electrolysis at present, as well as photo electrochemical and biological conversion in the future [33]. Currently, thermochemical conversion is the primary process of hydrogen production from fossil and biomass feed stocks, and it can be classified into steam reforming, partial oxidation, auto thermal reforming and coal/biomass gasification [34]. The product of thermochemical conversion of hydrocarbon fuels is known as syngas, a mixture of H2 and CO.

1.6.2 Ammonia

Ammonia is one of the most abundant synthetic chemicals in the world. The Haber–Bosch process is the most typical method of ammonia production. At 300–500 ◦C and 200–350 bar over a Fe-, Ni- or Ru-based catalyst, the chemical reaction could be expressed as follows:

$N_2 + 3H_2 = 2NH_3$

The air is usually used for nitrogen production by the pressure swing absorption or membrane filtration method, whilst hydrogen production is as discussed in the previous Section. The ammonia is stored at ambient temperature and 8 bar vapor pressure. Due to the toxicity of liquid ammonia, ammonia storage in solid form such as metal amine salts, ammonium carbonates or urea has been proposed [35]. However, the slightly increased storage mass and additional energy consumption for ammonia release would result in extra costs. In spite of this, ammonia is easier and less expensive to transport and store than hydrogen, and it is feasible to use ammonia as a hydrogen carrier. As a hydrogen carrier, ammonia could be decomposed or cracked to release the products of hydrogen and nitrogen. Since no carbon and Sulphur are contained, there is no the risk of CO or S poisoning [33]. Ammonia could be used as direct fuel for fuel cells, where ammonia-fueled SOFC arouses significant research interest due to the decomposition of ammonia under high operating temperature and over catalysts [36]. Direct ammonia alkaline/alkaline membrane fuel cells and direct hydrazine/ammonia borane fuel cells are also possible options [37].

1.6.3 Synthetic Natural Gas

NG has already seen use as an alternative marine fuel to reduce SO_X and NO_X emissions. In parallel with this, NG also has the potential to reduce CO2 emissions owing to its minimum carbon emissions per unit of energy release among hydrocarbon and alcoholic fuels. NG can be synthesize from syngas using the thermochemical conversion of fossil raw materials. The exothermic reactions can be expressed as follows:

$3H_2 + CO = CH_4 + H_2O$

Apart from fossil-based NG, SNG from renewable sources could have a more favorable climate impact. Carbon-neutral SNG can be synthesized from biomass or power-to-gas systems [38]. Anaerobic digestion is the predominant process for SNG production from biomass compared to thermal gasification of organic biomass or the Sabatier reaction [39]. Power-to-gas systems produce SNG through a catalytic or biological metalation reaction, where hydrogen produced by water electrolysis from renewable energy and CO2 captured from industrial processes are combined together [40].

1.6.4 Renewable Methanol

Methanol is traditionally produced from NG and coal, but oil, biomass, wastes and even CO2 can also be taken as feedstock's [41]. The chemical reactions of fossil methanol synthesis from syngas can be expressed as follows:

$2H_2 + CO = CH_3OH$

$3H_2 + CO_2 = CH_3OH + H_2O$

Renewable methanol is mainly produced from second generation biomass, such as forest residues, agriculture residues, municipal solid waste and black liquor produced from pulp and the paper industry. The production process is the same as fossil methanol production, where syngas production, methanol synthesis and processing of crude methanol are covered. Renewable methanol could be regarded as carbon-neutral if renewable energy is used for the production processes [41]. Methanol can be produced by catalytic synthesis of CO2 captured from industrial processes and hydrogen electrolyzed by renewable electricity, so called power-to-liquid (Pt.) [42]. Methanol is liquid at ambient temperatures, making it easier to transport and store than NG, hydrogen and ammonia. The methanol industry is global and fuel methanol could be available in major port terminals globally with minimal infrastructure changes. Hence, as an important hydrogen carrier, renewable methanol has several advantages with regard to transportation, storage and energy density

1.6.5 Onboard Pre-Processing of Marine Fuels

The electrochemical reaction of fuel cells happens between hydrogen and oxidizing agents. Hence, pre-processing is required for marine fuels other than hydrogen. Although several marine fuels could be converted into hydrogen, a complex pre-processing system installed onboard a ship means complicated operation and probably expensive operational costs. Moreover, fossil fuels supplied onboard ships mean that an onboard CCS system is required for low carbon or zero carbon shipping. Therefore, only hydrogen, ammonia, SNG and renewable methanol are suggested to be supplied onboard ships directly in this paper. However, large-scale fuel conversions from fossil raw materials, biomass or renewable energy sources are suggested to be conducted on land. Meanwhile, sulfur would poison the catalysts used for steam reforming, water gas shift and the electrochemical reaction of fuel cells. Hence, a desulphurization process is suggested to be conducted on land as much as possible, before the fuels are supplied onboard ships. However, onboard pre-processing for converting ammonia, SNG and renewable methanol into hydrogen is still required. Sustainability 2021, 13, 1213 11 of 34 Apart from conversion to a hydrogen-rich mixture, there are requirements for hydrogen purity, especially for low temperature fuel cells.

1.7 ABB fuel cell systems for hydrogen

ABB’s fuel cell solution is a modular power supply system developed for marine use. The system is based on the hydrogen proton exchange membrane (PEM) fuel cells. The fuel cell technology is applicable to high and low voltage, as well as AC and DC power systems, and can be used in combination with batteries or engines. The system can be fully hydrogen-electric or integrated as part of a hybrid power system.

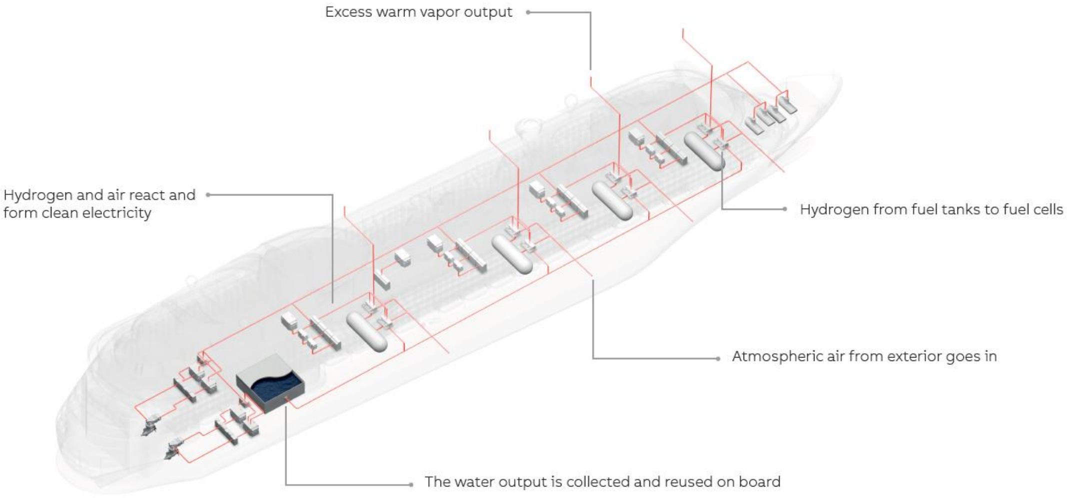


Fig. 1.7.a. The system can be fully hydrogen-electric or integrated as part of a hybrid power system.

With the use of renewables to produce the hydrogen, the entire energy chain can be clean.

Fuel cells generate energy through an electrochemical reaction. There's no combustion involved, as the fuel cell converts fuel directly to electricity and heat. There are several fuel cell technologies available. One of the most promising zero-emission technologies is the Proton exchange membrane fuel cell (PEMFC). The PEM fuel cell converts the chemical energy from hydrogen into electricity through an electro chemical reaction with oxygen, emitting only clean water and heat.

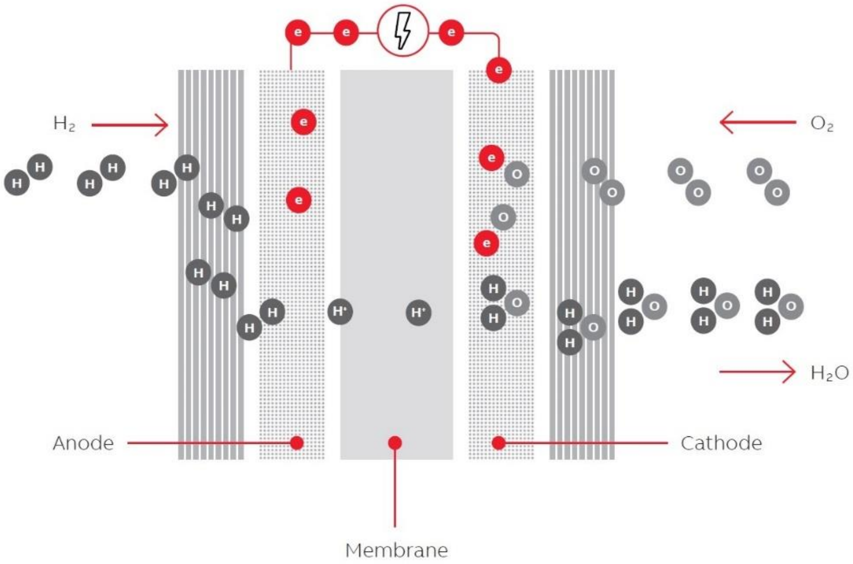


Fig.1.7.b Fuel cells generate energy through an electrochemical reaction

Fuel cells have higher efficiency than combustion engines, and the technology allows energy to be concentrated more densely than in petroleum fuels. If renewables are used to produce the hydrogen fuel, the entire energy chain will be clean, providing a true zero-emission fuel.

2 The Status of Hydrogen Fuel Cell Development of Doosan

2.1 ESG and Hydrogen Energy

South Korea's priorities are leadership in fuel cell cars and large scale stationary fuel cells for power generation. According to the "Hydrogen Economy Roadmap of Korea", the government aims to reach the production of 6.2 million FCEVs by 2040 with 2.9 million units for the domestic market and 3.3 million for export. The target for fuel cell power generation is 15 gigawatts (GW) by 2040, including 7 GW for export. The roadmap also sets a target for stationary fuel cell's application in buildings (2.1 GW by 2040)[43].

From a total cost of ownership (TCO) perspective (including hydrogen production, distribution and retail costs) hydrogen can be the most competitive low-carbon solution for 22 end applications, including long haul trucking, shipping and steel. However, pure TCO is not the only driver of application adoption: future expectations on environmental regulations, demands from customers and associated “green premiums,” as well as the lower cost of capital for ESG-compliant investments will all influence investment and purchase decisions. In industry, lower hydrogen production and distribution costs are particularly important for cost competitiveness as they represent a large share of total costs. Refining is expected to switch to low-carbon hydrogen over the next decade. For fertilizer production, green ammonia produced with optimized renewables should be cost competitive by 2030 against gray ammonia produced in Europe at a cost of less than USD 50 per ton of CO2e. Steel, one of the largest industrial CO2emitters, could become one of the least-cost decarburization applications. With an optimized setup using scrap and hydrogen-based direct reduced iron (DRI), green steel could cost as little as USD 515 ton of crude steel, or a premium of USD 45 per ton of CO2e by 2030.

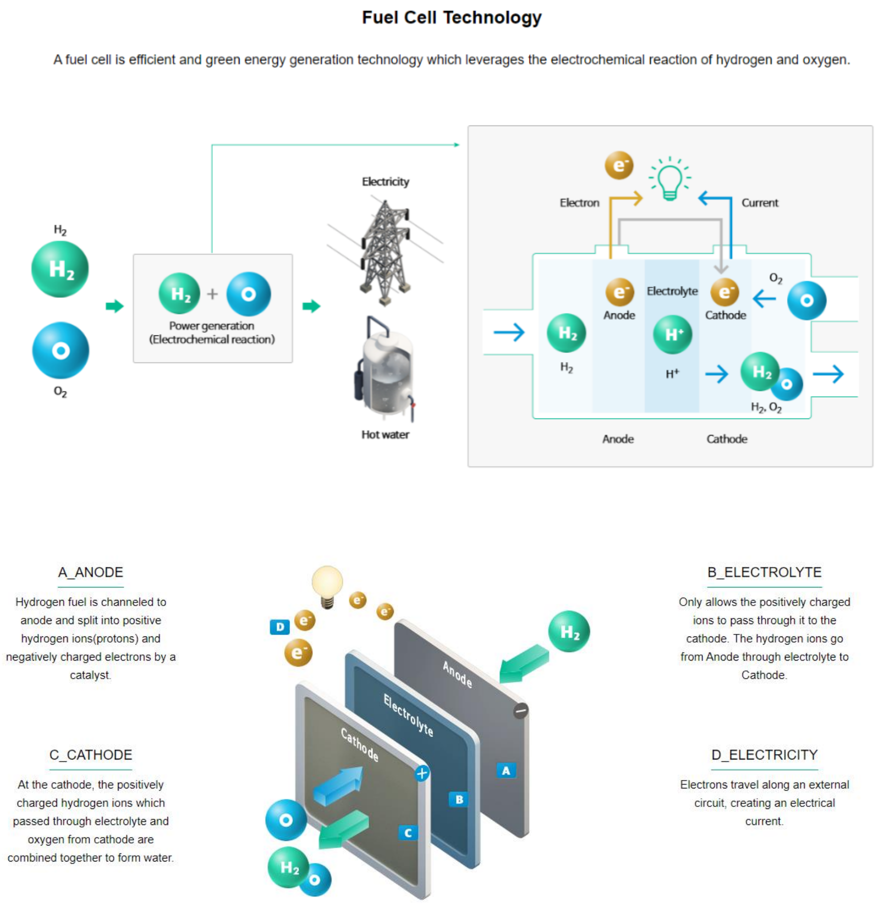
In transport, lower hydrogen supply costs will make most road transportation segments competitive with conventional options by 2030 without a carbon cost. While battery technology has advanced rapidly, fuel cell electric vehicles (FCEVs) are emerging as a complementary solution, in particular for heavy-duty trucks and long-range segments. In heavy-duty long-haul transport, the FCEV option can achieve breakeven with diesel in 2028 if hydrogen can be made available for USD 4.5 per kg at the pump (including hydrogen production, distribution and refueling station costs). Furthermore, hydrogen combustion (H2 ICE) offers a viable alternative in segments with very high power and uptime requirements, including heavy mining trucks. Hydrogen is likewise advancing in trains, shipping, and aviation. Clean ammonia as a shipping fuel will be the most cost-efficient way to decarbonize container shipping by 2030, breaking even with heavy fuel oil (HFO) at a cost of about USD 85 per ton of CO2e.3 Aviation can achieve competitive decarburization via hydrogen and hydrogen-based fuels. The aviation industry can decarbonize short- to medium-range aircrafts most competitively through LH2 directly, at a cost of USD 90-150 per ton of CO2e. Long-range aircrafts can be decarbonized most competitively using sinful, at a cost of about USD 200-250 per ton of CO2e, depending on the CO2 feedstock chosen. Other end-applications such as buildings and power will require a higher carbon cost to become cost competitive. However, as large-scale and long-term solutions to decarbonize the gas grid, they will still see strong momentum. In the United Kingdom, for example, multiple landmark projects are piloting the blending of hydrogen into natural gas grids for residential heating. Hydrogen as a backup power solution, especially for high power applications like data centers, is also gaining traction [44].

2.2 Introduction of Doosan fuel cell business

Doosan Corporation has completed construction of its new fuel cell manufacturing facility in South Korea, at the second General Industrial Complex in Iksan-si, North Joelle Province. The plant, which cost some KRW40 billion (US$35 million) to build, has a production capacity of 63 MW per annum, and is the focal point of a partnership with 80-plus domestic suppliers. The 10700 m2 (116000 ft2) Kian factory is capable of producing 144 units of the company's 440 kW Purcell 400 phosphoric acid fuel cell system per annum, which adds up to an annual production capacity of 63 MW, the highest in Korea. (POSCO Energy has a molten carbonate fuel cell manufacturing facility in Pohang [FCB, September 2015, p4].) Doosan says that, combined with its US fuel cell factory in Connecticut, it will be able to respond more promptly to global demand. The Kian factory features an automated stack production system, which dramatically. Improves product quality and manufacturing capacity. Furthermore, domestic production has allowed Doosan to include efficient balance-of-plant, and improve its cost-competitiveness. The company has also established a stable supply and demand system by producing the electrodes in-house, rather than depending on electrode suppliers overseas. Doosan plans to initially supply fuel cell systems to the Desean Petrochemical Complex in South Chungcheong Province, which will operate on industrial by-product hydrogen.

Doosan has been developing hydrogen fuel cells as part of its effort to diversify fuel sources for its fuel cells. In 2014 the company acquired phosphoric acid fuel cell company Clear Edge Power (formerly UTC Power) in Connecticut, as well as PEM fuel cell producer Fuel Cell Power in Seoul, Korea[45].

2.3 Building fuel cell technology



Fuel Cell Technology

A fuel cell is efficient and green energy generation technology which leverages the electrochemical reaction of hydrogen and oxygen.

A_ANODE

Hydrogen fuel is channeled to anode and split into positive hydrogen ions(protons) and negatively charged electrons by a catalyst.

C_CATHODE

At the cathode, the positively charged hydrogen ions which passed through electrolyte and oxygen from cathode are combined together to form water.

B_ELECTROLYTE

Only allows the positively charged ions to pass through it to the cathode. The hydrogen ions go from Anode through electrolyte to Cathode.

D_ELECTRICITY

Electrons travel along an external circuit, creating an electrical current.

Fig.2.3 Fuel cells generate energy through an electrochemical reaction

3. Ulsan Technology Small to Medium Enterprises Investment Session

3.1 About Ulsan

Ulsan, South Korea is home to the world's largest auto production complex and fifth largest automaker, its biggest shipyard and shipbuilder, and the globe's second largest petrochemicals combine. In addition, these firms have export linkages on six continents. Yet, since it does not qualify as a center of international finance, the city never has been or will be ranked among the world's most important cities by Global/World City theorists. Nevertheless, similar to other past and present Great Industrial Cities, such as Manchester, Essen, Detroit, Nagoya-Toyota, and Bashan, Ulsan has become a vital cog in, and instrument of, global capitalism[46].

Ulsan Metropolitan City is situated along the East Sea, within South Korea's newly defined Donna (Southeast) Economic Zone and the larger Gyeongsang Region. As shown in Fig. (1), the latter also includes the Daejeon Economic Zone. Originally settled as a fishing port, Ulsan's rise to industrial catalyst in its nation's economic development began on January 27, 1962, when in accordance with the First National Five-Year Economic Plan or NEP (1962-66), and Cabinet Order 403, the area was designated as a Special Industrial District (SID). A few months later, on June 1, under National Law 108, Ulsan Township was authorized as a city (is).

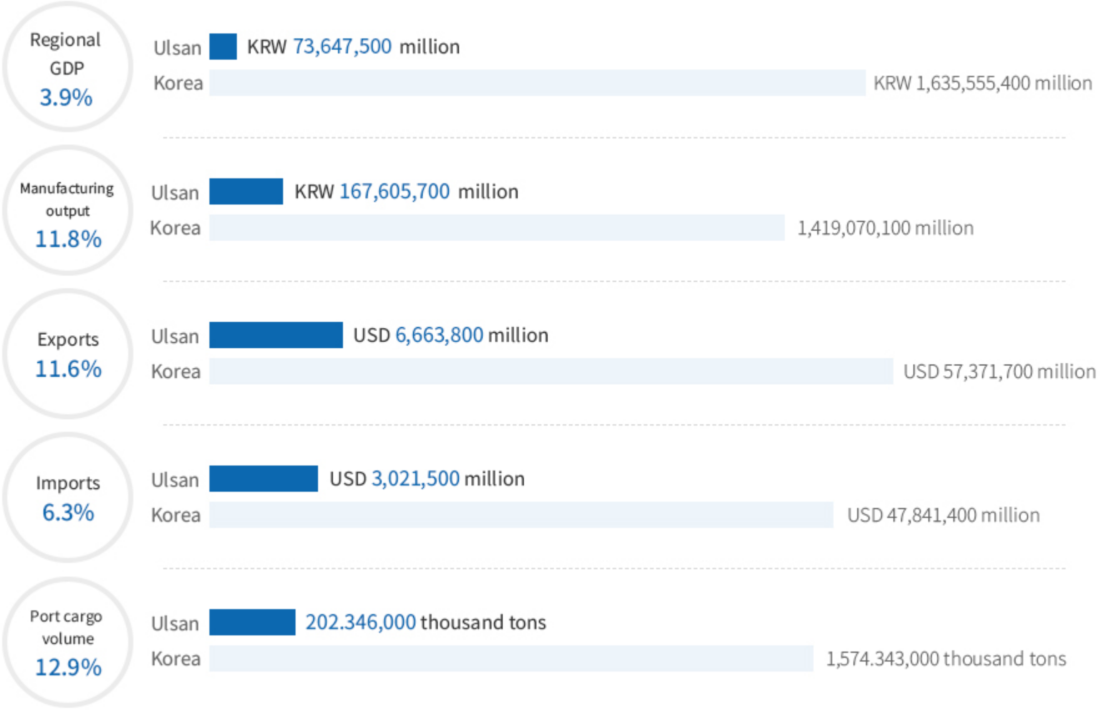


Fig. 3.1 Figure Ulsan's share of the national economy

Over the next 15 years the Ulsan-sir's population grew steadily, reaching 252,570 in 1975, before doubling to 550,207 in 1985 [28]. Then, on 1 January 1995, after merging with Ulsan-gun (county) and adding roughly 150,000 new residents, the city's Census population rose to 967,429. Two years later, Ulsan surpassed one million inhabitants and was authorized under National Law 5243, as the country's sixth Gwangyeok-si or Metropolitan City. This designation placed it in South Korea's second highest municipal status category, behind only the National Capital of Seoul. It also granted it functional independence from its province, South Gyeongsang. With 1,126,879 residents within an area of 1,056 sq. km (408 sq. miles) in 2008, Ulsan was its nation's seventh most populous city[46].

The Korean government has announced the Hydrogen Economy roadmap with ambitious numbers such as 81,000 hydrogen fuel cell vehicles (310 refueling stations) and 1.5GW stationary fuel cell power plants in Korea by 2022. According to the roadmap, 6.2 million hydrogen vehicles (1,200 refueling stations) and 15GW plants will be deployed in Korea by 2040 so that 4.9% of energy consumption will be supplied from hydrogen. Target for hydrogen production is 50% from by-product + electrolysis + import and 50% from reforming of natural gas by 2030. The focus of the roadmap is more of utilization of hydrogen because Korea has fuel cell automaker and stationary fuel cell manufacturers. On the other hand, technologies for hydrogen production, storage, transport and refueling station are mostly outsourced[47].

Ministry of Land, Infrastructure and Transport (MOLIT) announced three cities (Ansa, Ulsan and Wanju-Jeonju) to be the Hydrogen Pilot City and Sachiko as national R&D center in December 2019:

a. Ansa: Green Hydrogen production together with tidal power plant + LNG reformer and hydrogen ship

b. Ulsan: Hydrogen pipeline infrastructure and utilization pilots using by-product hydrogen

c. Wanju-Jeonju: Hydrogen production/promotion/utilization

d. Sachiko: Liquefied hydrogen storage/transport R&D/pilot

Ministry of Environment (Moe) has doubled its subsidy budget for hydrogen vehicles/refueling stations this year from 2019 to support 10,100 passenger vehicles, 180 buses and 40 refueling stations8 (max. 50% of equipment cost for 27 general stations and 70% of 13 bus refueling stations) 7,000 hydrogen fuel cell cars are already accumulatively sold in Korea. Hydrogen taxi/bus is already operational in Korea and 10 ton trucks will be deployed in late 2021-early

2022. MOTIE/MOLIT/Moe and Hyundai Motors made a deal with logistics companies (CJ, Cooping, etc.) to run the hydrogen logistics infrastructure by 2021[47].

Regional governments have plans and activities[47]:

a. Ulsan city is the most active as USD 1 billion investments for 11 years (2020-2030) to build a manufacturing complex for fuel cell and vehicles, R&D pilots and city run with hydrogen energy. It is also home of the Korea Hydrogen Industry Association (KHIA: http://www.h2.or.kr/)

b. Busan city, the 2nd most populated city in Korea, is planning to build logistic hub for imported hydrogen using its liquefied d ammonia and bunkering infrastructure. The city is also looking into maritime usages of hydrogen.

c. Hungnam province, where most of coal-fired plants are located, plans to invest USD 20 million to build residential fuel cell infrastructure and hydrogen drones for coastal surveillance/logistics from 2020 to 2022.

d. Pohang city joined with Doosan Fuel Cell, Korea Hydro-Nuclear Power (in Gyeonggi) and Postiche to build national R&D/testing cluster from 2020 to 2025 by investing USD 200 million.

e. Saemanguem Green Hydrogen Production Cluster Program (2022-2031, USD 500 million) is under feasibility study with 3GW renewable energy plant in Jeunbuk Province. 2.Private Sector[Chaebol]Hyundai Motors Group: The Company is looking for partners to invest or joint venture in order to stimulate the ecosystem.8 Moe policy announcement.

3.2 Industrial Conditions of Products

Ulsan is home to the largest industrial cluster of petrochemical, shipbuilding & marine, and automobile industries[48]. All industries closely cooperate to create a dynamic and innovative synergy with the connection of industries such as steel, machinery and port service in neighboring cities like Pohang, Changwon and Busan. Ulsan has the unique distinction of being the home to the world's[46]:

a. largest automotive assembly complex and fifth biggest automaker, Hyundai Motor (Him);

b. largest dockyard and shipbuilder, Hyundai Heavy Industries (Hypha);

c. fourth largest producer of medium-sized container vessels, Hyundai Milo Dockyard Co. (Hid); and

d. Second largest petrochemicals complex. It also hosted two of the globe's top eight refineries, operated by SK Energy and S-Oil, which combined to process more crude oil daily, 1.4 million barrels in 2010, than any other city on earth.

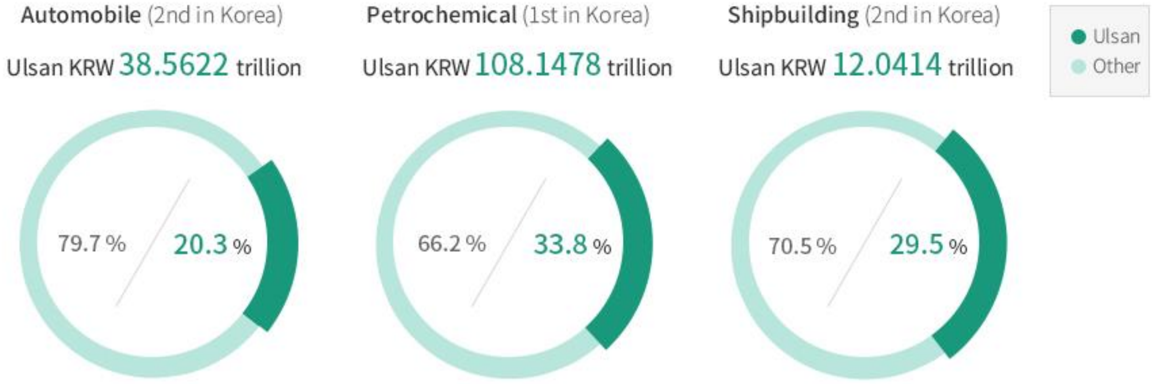


Figure 3.2 Key industries in Ulsan

As a result, Ulsan ranked first among South Korean cities in employment in four manufacturing sectors: Motor Vehicles, Motor Vehicles Parts & Trailers (MVM); 'Other' Transportation Equipment Manufacturing (OTEM), including shipbuilding; Chemicals & Chemical Products; and Coke & Refined Petroleum Products.

Finally, all of Ulsan's manufacturing sectors were tremendously supported by the city's extensive port system, whose four harbors annually handled[46]:

1) Approximately 16% of South Korea's cargo tonnage;

2) More than 50% of the nation's crude oil imports;

3) Almost 50% of the country's automobile exports; and

4) More than 40% of South Korea's shipbuilding exports.

In concert with the city's industrial prowess, the port system has helped transform Ulsan into Asia's fourth largest manufacturing hub in terms of value of exports, and into a major catalyst in South Korea's economic growth over the past 35 years. Although not a focus of this article, the city's dense clustering of heavy and chemical factories unfortunately also have made the city infamous for its combative management-labor relations and its environmental pollution. Nonetheless, similar to its positive achievements, these negative externalities were fostered by a combination of global and nested factors.

3.3 Major Projects in Ulsan [49]

i. Ulsan Free Trade Zone

The Ulsan Free Trade Zone is specialized for export-oriented and foreign-invested companies, and located close to the existing industrial complexes including automobile, shipbuilding and petrochemical industries while railways, airport, port and express way are just nearby the FTZ. The location will bring about both synergy and excellent output related to those industries.

ii. KTX Ulsan Station Area

Located near Gyeongbuk Expressway West Ulsan IC, the KTX Ulsan Station Area will become a new place where people, capital and technologies are integrated, as an important traffic hub and center of logistics and distribution once the development projects of establishing Exhibition and Convention Center and Complex Transfer Center are complete.

iii. Ulsan Techno Industrial Complex

Ulsan Techno Industrial Complex is a future-oriented, cutting-edge industrial complex where production and research functions meld. Its green energy parts and materials production and research facilities are fostered to advance traditional major industries such as automobile, shipbuilding and marine and chemical industries, to nurture creative industry and to establish its R&D infrastructure.

The Complex is located in the downtown with good accessibility, and is close to national industrial complexes including Ulsan Milo and Wonsan. It will play the role as Ulsan-style Silicon Valley by creating Ulsan Industry-University Convergence Campus in the Complex.

iv. Ulsan High-Tech Valley

High Tech Valley is located in the southeastern part of the country and accessible to Busan and Pohang. It will create a cooperative network with Samsung SDI and serve as a base for the growth industries of the future including semiconductor, electric, electronics and new material.

v. Guangdong Tourism Complex

Guangdong Tourism Complex project has been creating resorts and the Civil Safety Experience Center and it will serve as a foothold of recreational culture in all seasons by active investment in all eight areas.

vi. Janghyeon Urban High-Tech Industrial Complex

Janghyeon Urban High-Tech Industrial Complex plans to attract Green Car and high-tech businesses, such as energy component materials and 3D printers. The great geographical condition of the Complex will create more jobs and bring added values since it is in the automobile-related industrial complex region like Jong Innovation City, Ulsan Airport and Singeing Area, Iowa and Jungian Industrial Complex.

vii. Energy Convergence Industrial Complex

As the Shin Kori Nuclear Power Plant is expanded and the demand in the nuclear power industry has been increasing, the Energy Convergence Industrial Complex will become the base of nuclear power and energy industry in the southeastern part of the country through establishment of related infrastructure. The Complex has the best conditions with abundant infrastructure, broad market, great accessibility and excellent traffic network.

viii. The Northeast Asia Oil Hub Project

The Northeast Asia Oil Hub Project is a core project of creative economy in energy sector that will make Korea the hub of oil logistics and finance by building and operating oil storage facilities at the North Port of Ulsan with a capacity of 9.9 million barrels and at the South Port with a capacity of 18, 5 million barrels. The first phase of the project at the North Port is now under construction of the tank terminal and the second phase of the project at the South Port is under a government feasibility review. Organizations including the Korea National Oil Corporation and the Ulsan Port Authority are implementing the project with the aim to complete it by 2025. Development of supplementary industry including petrochemical industry, petroleum related trade and financial service industry will bring economic benefits, adding high value to the industry.

3.4 Industrial Location

The city of Ulsan is home to large industrial complexes, world-class logistics infrastructure such as harbors, airports, high-speed railways (KTX), abundant industrial utilities and outstanding human resources. Its major industries, including automobile, shipbuilding and marine and petrochemical, makes Ulsan Korea's largest industrial cluster. The city is also home to many large industrial complexes such as Ulsan Milo National Industrial Complex, Wonsan National Industrial Complex, Ulsan Free Trade Zone and Sicilian Industrial Complex [50].

Ulsan will further advance its major industries by encouraging technological convergence with ICT industries, and work toward establishing the city as a logistics and financial hub for the oil industry of Northeast Asia. It also will speed up the development of secondary cells, bio-chemical and new materials. Ulsan will nurture a new creative economy and industry by converging an internationally-competitive infrastructure with mountains, marine and urban tourism resources.

Ulsan is currently witnessing brilliant growth and development with the investment of USD 9 billion from 160 global enterprises from 34 countries. These include representative Korean conglomerates including Hyundai, SK, Samsung and LG, as well as global companies such as DuPont, BASF, Solvay and JX Energy.

Figure 3.4 Industrial investment location in Ulsan

3.5 Incentives[51]9

i. Tax Exemption

Possible candidates

a. Businesses developing technologies of future growth driver*: future mobility, energy- environment etc. and whose investments amount to more than USD 2 million.
b. FIZ (individual / independent types): Manufacturing: USD 30 million Tourism: USD 20 million Logistics: USD 10 million, R&D: USD 2 million
c. Resident businesses in Free Economic Zone(FEZ): Manufacturing: USD 10 million Tourism: USD 10 million Logistics: USD 5 million, R&D: USD 1 million

Support

a. Acquisition Tax : 100% exemption for 15 years
b. Property Tax : 100% exemption for 7 years and 50% for the following 3 years in Jung-go, Nam-go, Dong-go, Buk-go, 100% exemption in Ulu-gun
c. tariff, special consumption tax, value added tax exemption

ii. Ulsan Free Trade Zone

Corporate & income taxes: 100 percent exemption for three years and 50 percent for the following two years Acquisition & property taxes: 100 percent exemption for 15 years

iii. Special Support for Large-Scale Investments

i. Financial support within 20 percent of total investment for land purchase and factory construction
ii. Full or partial financial support for building of infrastructure such as roads, ports, water, sewage and waste water treatment facilities, power, communication or gas facilities

iv. Subsidies

- 3.5.1 Subsidies for Employment
- 3.5.2 Subsidies for Employee Training
- 3.5.3 Subsidies for Facility Construction and Expansion

v. Cash Grants

i. Businesses whose FDI share takes up more than 30% of the controlling ownership

ii. Businesses developing technologies of future growth driver or cutting-edge technologies / applications, Businesses newly establishing or building up manufacturing facilities to produce materials / parts / equipment

iii. Businesses creating massive employment opportunities by establishing or building up new manufacturing facilities (manufacturing: 300, financial services: 200, environment: 100, real estate: 50)

iv. Businesses newly establishing or building up R&D facilities or an entity financing non-profit research bodies

vi. Designation for Foreign Investment Zone

100 percent exemption(Exemptions will only apply to capital goods that are directly used in tax-free projects, and that have completed the import notification five years after the date of the foreign investment notification. Under unavoidable circumstances, one year extension will be granted.)

vii. One-Stop Service

- A strategic cooperation network has already been established among related organizations so that foreign investors are provided with one-stop service in the administrative process. Project managers are assigned to each investor to offer the best help possible

- Ulsan offer necessary information related to land purchase, current status of Ulsan businesses, etc. Comprehensive services are also provided including investment counseling, permission process, and resolution of business-related problems.

4 The Ceres Experience & Korea's Leadership in the Energy Transition

4.1 Background

In recent times, several companies have advanced their fuel cell development efforts for ever more increases in system performance and reductions in manufacturing cost. A company called Ceres has developed a SOFC called the "Steel Cell®" which is a fuel cell that has multi- fuel capability allowing it to operate on several different fuels from natural gas to hydrogen allowing for a smooth transition to a hydrogen economy from a fossil fuel one. Key advantages include the manufacturing of steel to allow it to be cost-effective, robust, and scale-able. In CHP configurations, claimed efficiency of the fuel cell is up to 90% which is better than conventional SOFCs. Another organization called Bramble Energy has developed a novel PEM fuel cell called the printed circuit board fuel cell (PCBFC). The key advantage of this approach is the design of the fuel cell on a printed circuit board which allows for a reduced number of fuel cell stack components allowing for a more affordable fuel cell. The PCBFC has 3.8x fewer components than a traditional fuel cell. Additionally, the cost of manufacturing a printed circuit board is significantly reduced compared to the manufacture of components of a traditional fuel cell [52].

4.2 Single product to multiple applications and customers

Made from mass-market and widely available materials, the Steel Cell® is inherently cost-effective, robust and scalable. It is an ideal technology to tackle air pollution and climate change as it significantly lowers carbon emissions and pollutants, lowers running costs and can enable renewables[53].

4.3 Ceres Technology[54]

Steel Cell® is ideally suited to commercial combined heat and power (CHP) applications. Today, our customer systems operate on mains natural gas to provide clean energy and hot water in a highly efficient low-carbon manner. In collaboration with Ceres, Miura launched a new product in October 2019 with 50% electrical efficiency and by capturing exhaust heat an overall efficiency of 90% is reached. Commercial CHP systems with Steel Cell® technology offer greater resilience as they continue to operate to supply electricity and hot water even during power outages.

Steel Cell® technology is best suited to heavy payload and long-range transportation applications. In partnership with Weichel Power, Ceres has developed a unique electric vehicle (EV) range extender system operating at high efficiency and with very low emissions. By exploiting existing liquid and gas refueling infrastructure, it is able to significantly increase fleet operating effectiveness compared with pure EV. The highly durable and low cost Steel Cell®, which can be operated on a wide range of fuels, is a technology that will become an important part of the diverse make up of future power trains.

4.4 Power Cell market leader with Korea

Steel Cell® is more stable and durable in the face of real-world operating conditions than other Solid Oxide Fuel Cell (SOFC) designs and unlike some fuel cells is not inhibited by the lack of a hydrogen infrastructure. One of the key drivers of the shift towards distributed power generation is the need for reliable power and this evolution is being enabled by maturing technology and abundant gas reserves. By balancing overall energy output, fuel cells can also help integrate growing, but intermittent, renewables into the energy mix to secure flexible low-carbon supply.

4.5 Electrolysis building on mature fuel cell capability and technology

Fuel cells can benefit the electricity system in several ways: they are flexible, controllable, typically co-located with demand (minimizing losses in transmission and distribution), and likely to generate when demand for electricity is highest if used for combined heat and power (thus helping to cope with peak demand). Additionally, hydrogen feedstock may be produced from power-to-gas, providing the large-scale long-term storage required to shift electricity from times of renewable surplus to those of shortfall.

A fuel cell is an energy conversion device that continuously converts chemical energy in a fuel into electrical energy, as long as both the fuel and oxidant are available. It exhibits advantageous characteristics exceeding conventional combustion-based technologies that are currently applied in certain critical fields, such as electronic, housing power, power plants, passenger vehicles, as well as military applications. Operating with higher efficiency than combustion engines, fuel cells demonstrate an electrical energy conversion efficiency of 60% or more, with lower emissions. Water is the only product of the power generation process in hydrogen fuel cells, and thus there are no carbon dioxide emissions or air pollutants that create smog and cause health problems during operation. Moreover, fuel cells emit low noise during operation because they contain fewer moving parts. Fuel cells come in many varieties, but they all work in generally the same manner.

With growing deployment of variable renewables and distributed generation, flexibility, and control to balance supply and demand becomes increasingly valuable. There are already several technologies in various stages of maturity that allow the temporal shifting of electrical energy over time periods of hours to a few days (e.g. pumped hydro, batteries and compressed air electrical storage (CAES)). None of these can provide spatial redistribution of energy or storage on the week-month timescale that is required for balancing the output from wind generation.195, 196 Hydrogen technologies have the potential to meet both these needs.

The recently development fuel cell technologies: Membrane-electrode assembly, Proton-exchange membrane (PEM), Catalyst, Gas diffusion layer, Bipolar plate, Flow channel, Thermal management, Water management.

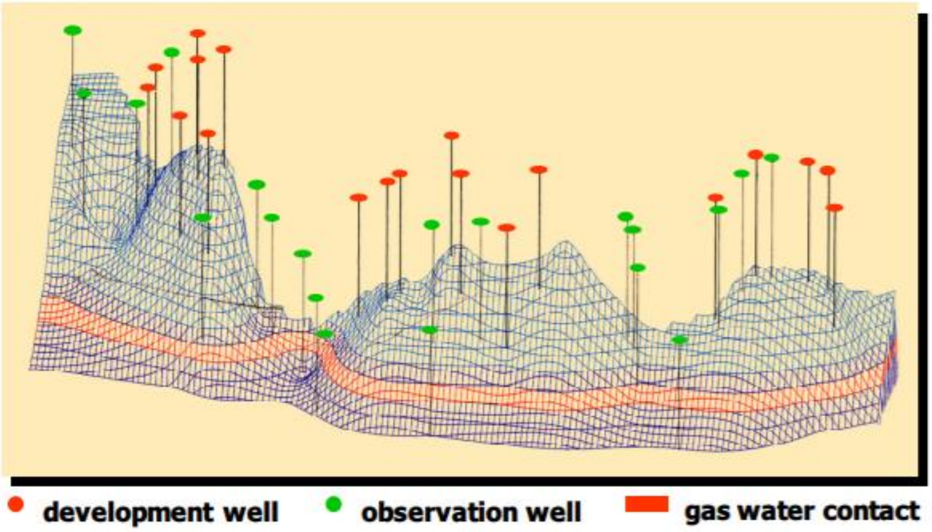
5. Developments of a NTI Competence Center of IPCP RAS in the field of Fuel Cells and Hydrogen Energy

5.1 Metal hydride hydrogen storage

Utilization of organic fuel for covering the increasing demand for energy leads to global environmental pollution, greenhouse effect and lack of oxygen for the civilization. Therefore, there is the necessity of reorientation from hydrocarbon to new universal energy resource. In this connection hydrogen is considered to be one of the most acceptable energy resources in the future. Hydrogen is a fuel for different purposes, it can be used as fuel and as chemical material. The conversion of transport, industry and household consumers to hydrogen doesn’t request drastic changes in modern technology of fuel utilization. The important thing is that being burned hydrogen comes back to the atmosphere in the form of water. Increasing hydrogen consumption requires new kinds of hydrogen storage.

At present the following methods of hydrogen storage are realized: gas bottles, gasholders (compressed gaseous hydrogen under the pressure of 40-100 MPa), stationary or transport cryogenic containers (liquid hydrogen under the pressure of 20 MPa), metal hydrides (metal absorption), underground storage. To evaluate the effectiveness of each particular method of hydrogen storage the functioning of the whole chain from production to consumption, including storing, transport and distribution, has to be analyzed. Underground hydrogen storing will be necessary for regulation of seasonal, monthly and daily fluctuation of energy consumption and production when moving to the industrial use of hydrogen. The irregularity of gas consumption depends on the industry, way of life of the population and the climatic conditions of different regions of the country. The most effective ways of large-scale hydrogen storage is underground storage in depleted oil and gas fields, the subterranean aquifers, underground reservoirs in salt deposits, permafrost grounds. These methods should be located close to its heavy consumers. Due to less viscosity and density hydrogen has got greater mobility than natural gas does. Therefore, hydrogen leaks through different seals or the storage cap are more probable.

The geological model of Yakshunovskoe UGS is on fig.3. The red zone is gas-water contact (Fig.3). Green is for the observation wells, red is for developing well. Fig.4. shows the dependence between pressure and time for methane and hydrogen while injection and producing,



calculated in Goblin Russian State University of Oil and Gas. Geotechnological methods of cavern production through drill holes allowing to create steady caverns of given geometrical proportions and shape are developed in Russia (underground desalinization of salt cavern by water, underground explosions).

Fig.5.1. developed in Russia

Yakshunovskoe UGS.

The underground desalinization technology is realized by four methods: desalinization in the bottom-up direction, desalinization in the top-down direction, combined method, cavern production without using no solvent. When designing the underground reservoirs in salt deposits it is very important to determine the permissible width of the cavern subject to production pressure, laying depth and its expected design shape [55].

5.2Materials and components for fuel cell stacks.

Fuel cell stacks and assemblies consist of individual fuel cells that are combined either in series to provide a higher usable voltage, or in parallel to provide a higher usable current. Each cell in the stack converts the chemical energy from a liquid r gaseous fuel with an oxidant such as air into electricity.

Unlike batteries, fuel cell stacks do not run down, and they do not require recharging. Rather, these electromechanical devices generate electricity as long as a fuel and oxidizer are provided; however, corrosion can reduce efficiency over time. Selecting fuel cell stacks involves a consideration of available electrolytes, as well as an analysis of temperature, cost, and application requirements.

The type of electrolyte determines the operating temperature, typical stack size, and efficiency for the fuel cells in the stack.

- Polymer electrolyte membrane (PEM) or proton exchange membrane fuel cells use hydrogen as a fuel and a solid polymer as an electrolyte. They require a more expensive catalyst (typically platinum) and are limited to low-temperature applications. Advantages include fast startup times, low sensitivity to orientation, and a favorable power-to-weight ratio, making them favorable in automotive applications. The barrier to these fuel cells is hydrogen storage, as low energy density hydrogen cannot be stored in energy amounts comparative to gasoline or other fossil fuels.
- Direct methanol fuel cells (DMFC) use pure liquid methanol as the electrolyte. Fuel conversion of hydrogen rich fuels takes place within the cell system itself. Because methanol has a higher energy density than hydrogen, fuel storage and transportation problems common to other fuel cells that use hydrogen as a fuel do not exist. DMFC technology is years behind that of other fuel cells however, making the cells less efficient.

- Alkaline fuel cells (AFC) use a solution of potassium hydroxide in water as the electrolyte. AFC stacks can run for as many as 8000 operating hours but lack the material durability for longer-running applications. Because of this, alkaline cells lack the economic viability for large-scale applications. Some newer products are suitable for both low-temperature and high-temperature use.
- Phosphoric acid fuel cells (PAFC) use phosphoric acid as an electrolyte. Because they handle impurities well, PAFCs are suitable for converted fossil-fuel utilization when other cells might be damaged by carbon monoxide. They can be costly because they require platinum as a catalyst and are less efficient when not used in cogeneration plants (heating and power). They are also larger and heavier than other fuel cells.
- Molten carbonate fuel cells (MCFC) have an electrolyte that consists of a molten carbonate salt mixture suspended in a porous, chemically inert ceramic lithium-oxide matrix. They operate at high temperatures of roughly 1,200°F and above and do not require an external reformer for fuel conversion, a fact which helps contain costs. They can even utilize carbon oxides as fuel. MCFC fuel stacks are, susceptible to corrosion, however, due to the high operating temperatures and the corrosive electrolyte used. This accelerates component breakdown and significantly decreases cell life.
- Solid oxide fuel cells use a hard, non-porous ceramic compound as the electrolyte. SOFCs can operate at very high temperatures but require thermal shielding. Because they do not require a precious metal as the catalyst, they are usually lower in cost. This type of fuel cell is also the most sulfur-resistant, a fact that makes SOFC fuel stacks suitable for use with coal-based gases.

5.3Development of the fuel cells mobile applications

Consumer applications: This market covers mainly the 4C applications (Computer, Cordless Phone, Camera, and Cordless Tools). Power supplies for notebooks and mobile phones are based on DMFCs and H2-PEFCs in the power region of ~5 W and 75 W. Demonstrations for notebooks have been developed by Toshiba, NEC, Hitachi, Panasonic, Samsung, Sanyo and LG (50–250 cm^3, 10–75 W mostly driven direct by methanol).

Industrial Applications: The main applications for the industrial use of FCs are prime power, CHP, and tri-generation, mainly for new office builds, retail parks, and hospitals, universities, or data centers. Because of the higher electrical efficiency of HT-FCs, MCFCs and SOFCs are usually used for such applications. PAFCs, PEFCs, and recently AFCs have been used to a lesser extent. Furthermore, the reduced gas reforming effort in HT-FCs allows using biogas from landfills, biomass, and digester sources to be used as fuel. Natural gas, however, is the dominant fuel. The prime power market of large stationary fuel cells is led by three players — Bloom Energy, FCE, and Clear Edge Power (now Doosan).

Residential applications: Residential CHP units produce heat and power mainly for single-family houses. In comparison to conventional CHP technologies (ICE, Sterling Engine) FC systems lead to significant reductions in CO2-emissions (about 1–2.5 tons/ annum/house).9 NG is primarily used as the fuel for residential CHP applications. Both PEFCs (quick start-up, power modulation, direct hot water) and SOFCs (internal reforming, high temperature heat) are used for this application.

Back-up and off-grid Power: FC systems for back-up and off grid applications are quite similar, with the exception of the fuel tank capacity; back-up systems for emergency use need lower fuel capacity. Back-up systems are used for areas as server banks, data centers, telematics, traffic controls, tunnels, mines, hospitals, environmental protection, pipelines, disaster control, IT, tele-communications, or signaling. In contrast to the competing battery technologies, FCs decouple energy and power Furthermore, they have a longer lifetime, lower service requirements, and lower operating costs than batteries and do not suffer from self-discharge. Moreover, due to the short operating time of power backup systems, FC-durability issues are less important compared to CHP-applications [56].

Clean and efficient transportation can become a reality for everyone with hydrogen fuel cell electric vehicles.

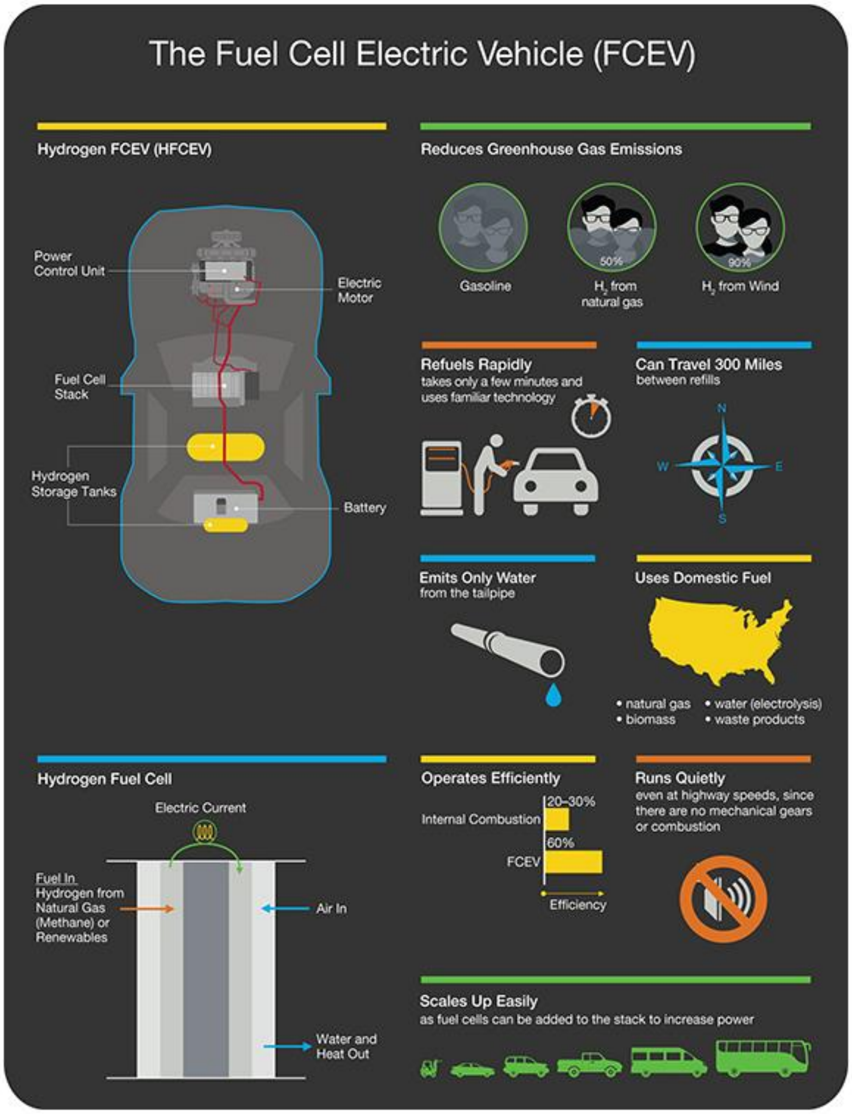


Fig. 5.3 the Fuel Cell Electric Vehicle (FCEV)

Hydrogen fuel cell electric vehicles (HFCEVs) are more energy efficient than conventional gasoline internal combustion engine vehicles (ICEVs), which are limited by the Carnot thermal engine efficiency, and they produce no tailpipe emissions other than water vapor. Hydrogen fuel can be produced from a variety of non-fossil and renewable feedstock's that are widely available and could help to reduce the transportation sector's dependence on petroleum-based fuels and increase the security of the energy supply

5.4 Fuel cells for UAVs

With a higher energy-to-mass ratio than traditional battery systems, hydrogen fuel cells can provide commercial UAVs with over three times the flight endurance, allowing you to maximize productivity, minimize downtime and achieve more in a single drone flight.

Furthermore, hydrogen is the lightest fuel available to mankind and yet one of the most energy dense fuel. No compromise on the safety because there is a decade of scientific research behind the fuel cell system. Combination of PEM fuel cell and hydrogen fuel provides the best of both worlds and enables long flight time for any UAVs. Recent investigations shows that 2X to 6X improvement can be achieved depending on the UAV platform and hydrogen storage tank compared to the same weight of Lip batteries. (Source: https://www.energy.gov/sites/prod/files/2020/12/f81/hfto-h2-airports-workshop-2020-dudfield.pdf.)

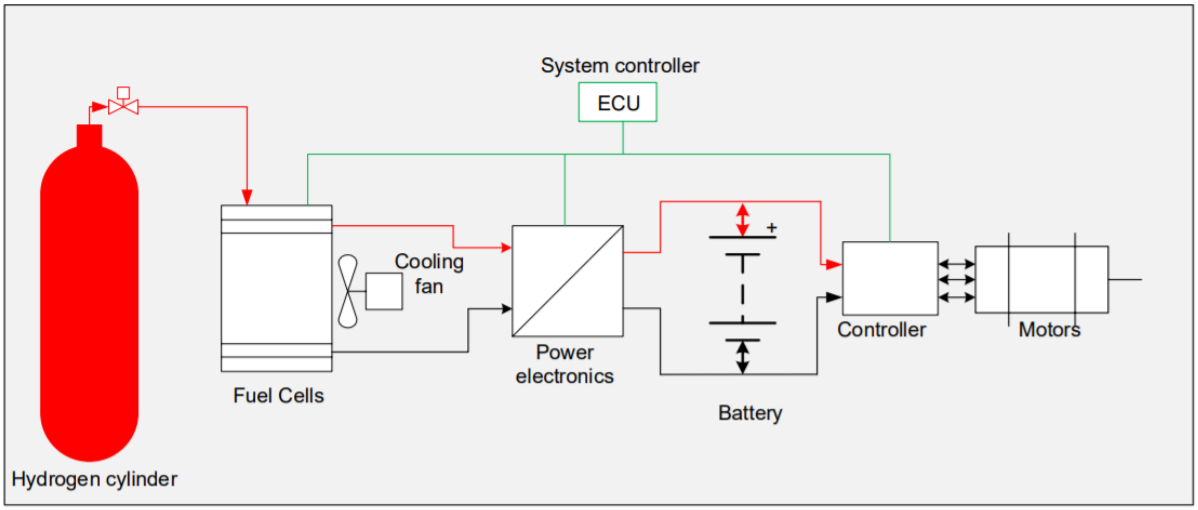


Fig. 5.4. Fuel cell system

5.5Energy sources for transport

Hydrogen and fuel cells have arguably suffered a ‘lost decade’ after high expectations in the 2000s failed to materialize. Three factors are enabling the sector to regain momentum. Firstly, improvements in technology and manufacturing mean that systems which cost $60 000 in 2005 are now cost $10 000. Secondly, commercial products are becoming widely available, and significant uptake is occurring in specific sectors such as Japanese microgeneration and US forklift trucks. Thirdly, a strengthened global resolve to mitigate climate change is coupled with increasing realization that clean power alone is insufficient, due to the complexity of decarbonizing heat and transport. This paper provides a comprehensive state-of-the-art update on hydrogen and fuel cells across transport, heat, industry, electricity generation and storage, spanning the technologies, economics, infrastructure requirements and government policies. It defines the many roles that these technologies can play in the near future, as a flexible and versatile complement to electricity, and in offering end-users more choice over how to decarbonize the energy services they rely on. While there are strong grounds for believing that hydrogen and fuel cells can experience a cost and performance trajectory similar to those of solar PV and batteries, several challenges must still be overcome for hydrogen and fuel cells to finally live up to their potential.

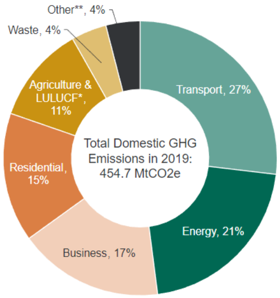
The suitability of hydrogen and fuel cells varies between transport modes and reflects the diverse nature of the transport sector, which spans land, sea and air, plus freight and passengers, as shown in Fig. 2. Nearly half of energy demand for global transport is from light duty vehicles and the number of passenger cars worldwide is expected to rise from 1 to 2.5 billion by 2050[57]

“Other” is primarily passenger rail and air freight. The middle and inner rings aggregate these uses by mode and function. Data from EIA.35 Total consumption was 110 million TJ in 2015 worldwide, equivalent to 37 kW h per person per day in OECD countries and 7 kW h in non-OECD countries.

22 Emissions have increased though, and the share of renewable energy in UK transport has fallen to 4.2% versus a target of 10%, 36 bringing calls for stronger action.37 Hydrogen represents one of three main options for low-carbon transport alongside biofuels and electric vehicles (EVs). Hydrogen avoids the land-use and air quality impacts of biofuels, and the limited range and long recharging times associated with EVs.5 However, electric cars are several years ahead of hydrogen in terms of maturity due to their lower costs and readily available infrastructure. Plug-in electric vehicles now account for 30% of new vehicle sales in Norway and 2% in the UK.

- *In 2021, 327,000 plug-in vehicles (PiVs) were registered for the first time in the UK, an increase of 77% on 2020 and 303% on 2019 (around 4 times higher). PiVs accounted for 14.7% of all UK new vehicle registrations in 2021, up from 8.7% in 2020. (VEH1153a)*
- *For cars only, In 2021, new car registrations in the UK (VEH1153a), comprised of:*
    - *912,000 (54%) petrol cars*
    - *264,000 (16%) HEV cars*
    - *195,000 (12%) diesel cars*
    - *190,000 (11%) BEV cars*
    - *114,000 (7%) PHEV cars*
    - *2,000 (0.1%) using other fuel types* [58]

In addition to tackling climate change, hydrogen vehicles can improve air quality. This is an urgent priority with over half a million premature deaths per year across Europe due to particulates and NOx emissions.40,41 The direct cost of air pollution due to illness-induced loss of production, healthcare, crop yield loss and damage to buildings is around €24b per year across Europe with external costs estimated to be €330–940b per year.42 92% of the world's population are exposed to air quality levels that exceed World Health Organization limits.43,44 Major cities have recently announced bans on all diesel-powered cars and trucks by 2025,45 and UK and France have announced nationwide bans on all pure combustion vehicles by 2040 [59] (Source: https://pubs.rsc.org/en/content/articlelanding/2019/ee/c8ee01157e.)



Greenhouse gas emissions by sector, 2019, by proportion (BEIS, 2020)

5.6 Energy storage with a hydrogen cycle

Hydrogen energy storage is another form of chemical energy storage in which electrical power is converted into hydrogen. This energy can then be released again by using the gas as fuel in a combustion engine or a fuel cell. Hydrogen can be produced from electricity by the electrolysis of water, a simple process that can be carried out with relatively high efficiency provided cheap power is available. The hydrogen must then be stored, potentially in underground caverns for large-scale energy storage, although steel containers can be used for smaller scale storage. Hydrogen can be used as fuel for piston engines, gas turbines, or hydrogen fuel cells, the latter offering the best efficiency. Hydrogen energy storage is of interest because the gas forms the basis for the hydrogen economy in which it replaces fossil fuel in many combustion applications [60]

Electricity can be converted into hydrogen by electrolysis. The hydrogen can be then stored and eventually re-electrified. The round trip efficiency today is lower than other storage technologies. Despite this low efficiency the interest in hydrogen energy storage is growing due to the much higher storage capacity compared to batteries (small scale) or pumped hydro and CAES (large scale).

HYDROGEN INDUSTRY VALUE CHAIN

1. Measures to revitalize Hydrogen Distribution Market

1.1Current status of domestic and overseas hydrogen market

South Korea adopted the Hydrogen Economy Roadmap in 2019. In order to lay the legal foundations for the government's promotion of hydrogen and the implementation of safety standards for facilities, the Korean National Assembly passed the Hydrogen Economy Promotion and Hydrogen Safety Management Law ("Hydrogen Law") in January 2020. The Hydrogen Law, which went into effect in 2021, stipulates several important industrial strategy elements, such as supporting hydrogen-focused companies through research and development (R&D) subsidies, loans, and tax exemptions.

South Korea's efforts also include R&D on liquefied hydrogen storage technology and the reduction of transportation costs. Additionally, the roadmap notes the government's long-term aim of building a specialized hydrogen pipeline network across the country while the development of hydrogen-receiving infrastructure is set to begin in 2022. While about one-third of the country's hydrogen consumption in 2040 is estimated to be based on imported liquefied natural gas (LNG), KOGAS—South Korea's state-run utility—plans to invest $37 billion overseas by 2040 to establish renewable power generation facilities that produce hydrogen.

Large government funding underpins South Korea's effort to develop a hydrogen economy. The spending for FY2021 is $701.9 million, a 40 percent increase from 2020. Also, the government has committed $2.34 billion to establish a public-private hydrogen vehicle industry by 2022. At present, about half the cost of installing HRSs is subsidized by the government. Moreover, in 2019, the national and local governments provided subsidies for an FCEV purchase ranging from $27,300 to
$30,300.

Since 2012, South Korea's renewable portfolio standard (RPS) has supported the deployment of large-scale stationary fuel cell power generation. Under the RPS, large power producers are mandated to meet a minimum portion of their power generation from new and renewable technologies, including fuel cell power generation. Additionally, the government has reduced the price of natural gas from the grid if it is used to produce fuel cells.

According to South Korea's economic ministry, five South Korean conglomerates have plans to invest $38 billion in hydrogen technology by 2030.

1.2Main tasks of hydrogen distribution agency.

As the world increasingly looks to renewable energy sources to deal with climate change, South Korea is aiming to become a leader in the development of hydrogen as an alternative energy source. In developing an ecosystem for a hydrogen economy, South Korea is focused on increasing the production and use of hydrogen vehicles, establishing an ecosystem for the production and distribution of hydrogen and related technologies, and expanding the production of fuel cells. The government's vision has the backing of key industrial firms, most importantly the Hyundai Motors Group which plans on investing 7.6 trillion won ($6.7 billion) under its "FCEV Vision 2030" and is part of the Hint consortium to build 100 new hydrogen refueling stations in South Korea by 2022. If South Korea's vision is successful, it expects hydrogen to account for 5% of its projected power consumption in 2040, to see its economy grow by 43 trillion won, 420,000 new jobs created, and significant reductions in both fine dust and greenhouse gas emission.

While the Hydrogen Economy Roadmap developed by the Moon administration covers different components of developing a hydrogen-based economy, much of the plan will rest on South Korea's ability to expand the acceptance of fuel cell electric vehicles (FCEVs) first in South Korea's domestic market and in time in markets around the world

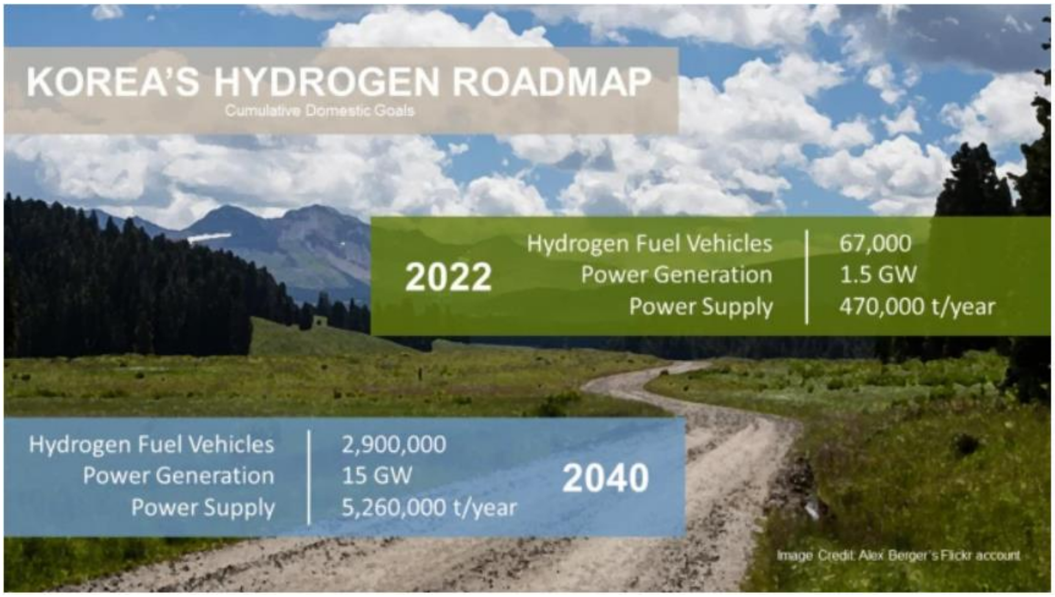


Fig. 1.2 Korea's Hydrogen Roadmap

1.3 Prospect of domestic hydrogen distribution market

If we look at whether or not we have R&D organizations for the evaluation of industrial innovation resources, the R&D base of domestic companies is considered relatively high. According to the survey, 79.5 percent of the respondents have R&D organizations, 73.1 percent of them have corporate research institutes and 6.4 percent have dedicated departments. When looking at whether the subsectors of the hydrogen industry have R&D organizations, 89 percent of firms in the hydrogen fuel cell sector reported having R&D organizations, which is the highest mark among survey respondents. As of 2018, the number of dedicated R&D personnel is estimated to be 5.9 workers per firm on average, while R&D personnel account for 44 percent of the total workforce in the hydrogen industry.

Second, looking at the level of innovation activities, respondents assessed the scale of their R&D investments and the ratio of R&D to sales. The average amount of R&D investment in the domestic hydrogen industry in 2018 was about 3.8 billion KRW. The average amount of R&D investment has been increasing since 2016 but the scale remains small. By sector, the hydrogen mobility sector recorded the highest average R&D investment, at about 5.5 billion KRW in 2018. The charging sector posted the lowest amount. R&D spending on sales was relatively low, at 5.5 percent on average as of 2018.

Examining research and development promotion at companies, about two-thirds of domestic companies are conducting R&D cooperation with the outside world. Only one-third are pursuing R&D activities independently. 73.6 percent of companies set up mid- to long-term development visions and strategies in their respective fields, the report showed. This means that they are aware of the importance of the hydrogen industry and have a high willingness to promote or innovate their businesses [2].

2. The Development Trend of Automation Technology for the safety in Hydrogen Society

2.1 Introduction of Emerson

ENERCON has been one of the technology leaders in the wind power sector for more than 35 years. As the first manufacturer of wind turbines, the company used a gearless drive concept that is a characteristic of all ENERCON wind turbines. ENERCON is also at the forefront in other areas, such as rotor blade design, control technology, grid connection technology, and, with its wide range of technological new developments, proves its innovative strength time and again.

Continual research and development are guarantees of the ongoing success of the company. The same applies to production and service. All the key components, such as the rotor, annular generators and grid feeding system, are manufactured by exclusive suppliers. This ensures the high quality and extreme reliability of ENERCON wind turbines.

2.2 Introduction of Hydrogen

By their nature, all fuels have some degree of danger associated with them. The safe use of any fuel focuses on preventing situations where the three combustion factors—ignition source (spark or heat), oxidant (air), and fuel—are present. With a thorough understanding of fuel properties, we can design fuel systems with appropriate engineering controls and establish guidelines to enable the safe handling and use of a fuel.

A number of hydrogen's properties make it safer to handle and use than the fuels commonly used today. For example, hydrogen is non-toxic. In addition, because hydrogen is much lighter than air, it dissipates rapidly when it is released, allowing for relatively rapid dispersal of the fuel in case of a leak.

Some of hydrogen's properties require additional engineering controls to enable its safe use. Specifically, hydrogen has a wide range of flammable concentrations in air and lower ignition energy than gasoline or natural gas, which means it can ignite more easily. Consequently, adequate ventilation and leak detection are important elements in the design of safe hydrogen systems. Because hydrogen burns with a nearly invisible flame, special flame detectors are required.

In addition, some metals can become brittle when exposed to hydrogen, so selecting appropriate materials is important to the design of safe hydrogen systems. In addition to designing safety features into hydrogen systems, training in safe hydrogen handling practices is a key element for ensuring the safe use of hydrogen. In addition, testing of hydrogen systems tank leak tests, garage leak simulations, and hydrogen tank drop tests shows that hydrogen can be produced, stored, and dispensed safely.

2.3 H2 Value Chain

South Korea’s Hyundai Heavy Industries Group will complete a hydrogen value chain from production to transport, storage and sale of fuel cell by 2030.

Hyundai Heavy Industries Group with mainstay in shipbuilding, robotics and rolling stock, on Thursday unveiled its hydrogen roadmap 2030 during an online conference, with focus on establishing its own value chain for hydrogen based on infrastructure and technical competitiveness of each affiliated unit.

KSOE will team up with Hyundai Oil bank Co. to establish the hydrogen production infrastructure. KSOE will be responsible for green hydrogen plant business, and Hyundai Oil bank blue hydrogen project.

Business related to storage, use and sale will be led by Hyundai Oil bank. Blue hydrogen can be used in desulfurization facilities or sold as fuel for vehicles and power generation. The company earlier decided to build 180 hydrogen charging stations across Korea by 2030.

Hyundai Electric & Energy Systems Co. and Hyundai Construction Equipment Co. will back other hydrogen-related businesses using fuel cells.

2.4 Transition to Hydrogen Requires a Credible Partner

If not produced at the consumption site, hydrogen needs to be transported and stored to eventually be delivered to final users. Different means of transportation are available:

- Pipelines: used to transport either gaseous hydrogen or hydrogen converted into ammonia;
- Trucks: used to transport either gaseous hydrogen, or liquid hydrogen, or hydrogen converted into Ammonia or into a Liquid Organic Hydrogen Carrier (LOHC);
- Shipping: transporting liquid hydrogen at temperatures below -253°C (requiring a considerable amount of energy for cooling), or through an intermediate hydrogen carrier such as ammonia or a liquid organic hydrogen carrier.

Based on the distances and volumes of hydrogen, transport costs can widely vary. Newly built pipelines are widely assumed to be the cheapest method to transport hydrogen per unit transported.

Instead, no agreement has been reached on whether either building a dedicated hydrogen network, or repurposing the existing natural gas network, or doing a combination of both options would be the optimal solution. Sometimes, blending hydrogen into the natural gas grid is seen as an option, but then the resulting gas mix would only be used for “energy” uses. Hydrogen can be stored in different ways, depending on its state (gaseous, liquid or solid). Gaseous hydrogen can, for example, be stored in rock cavern storages or pressurized tanks. There are also storage options that use an intermediate hydrogen carrier. Based on the storage duration and volume of hydrogen, storage costs can widely vary.

2.5 Emerson’s Hydrogen Value Chain Solution Overview

Scale, investment, and policy changes are the key drivers behind the renewed interest and adoption of hydrogen as a viable decarburization pathway. The past two years, and specifically the past six months, have been game-changing for green hydrogen policies (i.e., generated from renewable / low-carbon sources), with interest rising globally.

In Europe, the summer of 2020 brought about the European and German Hydrogen Strategies, focused on funding the industrial scale decarburization of hard to abate sectors such as steel, ammonia, chemicals and mobility. Industrial offtake volumes for hydrogen are known, what is new is the way that the hydrogen is being produced. For background, Bloomberg provides a good overview of the various types of available hydrogen and the IEA tracks global installed capacity. Europe is taking a leading stance and in doing so has formed a public-private group, the European Clean Hydrogen Alliance, which Emerson became part of in 2020. By joining this alliance, we will be at the forefront of hydrogen deployment and innovation.

Governments have clearly stated their support to reach cost-parity with fossil production (e.g., via steam methane reforming), and players along the new green hydrogen value chain are following suit by doubling down on their investments. The number of global industry consortia and partnerships that have announced their ‘green hydrogen’ strategies has been exponential the past couple of years.

2.6 Online Digital Twin for Electrolysis Projects

The COGNITWIN project aims to develop several enabling technologies that collectively realize the vision of cognitive production plants. These technology blocks will be integrated in the so-called COGNITWIN toolbox. To realize this vision, several steps have to be performed. We started by clarifying the concept of digital, hybrid and cognitive twins. The dependencies between different types of digital twins are shown in figure below and reported in our paper”COGNITWIN – Hybrid and Cognitive Digital Twins for the Process Industry”.

The next issue is how to represent a digital twin. The general idea of the digital twin concept is to have a digital representation of a physical system a (standardized) interface interface for digital interaction with the system. On a conceptual level, such digital twins are envisioned to provide a multitude of functionality, e.g., management of documents related to the system, provide visualization and 3D representation, access to (historical) data about the system, and methods to interact with the system, etc. An overview of the standards is reported in our journal paper “Digital Twin and Internet of Things-Current Standards Landscape”. The table below provides an overview on the classification of the different standards analyzed. Although the standards were developed independently by different standards developing organization, they ended up with quite similar approaches/solutions to some aspects[61]

As digital twins are not intended to be used by end-users directly but rather by software systems, standardization of APIs is essential. Based on the analysis shown above, we decided to base our work on the Asset Administration Shells (AAS), mainly because there is support for the key protocols used in industry (e.g. OPC UA). The Joint working group Industrial Internet Consortium and Platform Industry 4.0 came to the same conclusion: the Asset Administration Shell could be used for the implementation of the digital twins for Industry 4.0 as well as for use cases beyond manufacturing. This is reported in the white paper “Digital Twin and Asset Administration Shell Concepts and Application in the Industrial Internet and Industry 4.0”4 to which we also contributed.

However, the Asset Administration Shell model and APIs are not enough to realize the COGNITWIN vision. There is a need to run the models (e.g. data-driven and physics-based models), to “combine” different models, to integrate components developed by companies using different technologies, etc. Both the models and components are part of the COGNITWIN toolbox and should be reusable. In order to deal with this issue by minimizing the number of interfaces to be implemented and by ensuring reusability, we decided to use Stream Pipes, an open source toolbox for the Industrial Iota.

An example pipeline created by using Stream Pipes. Main purpose of developed pipeline is to create a path from sensory data to the neural network output, depicting state of the tool, through several pipeline elements. In addition, this pipeline triggers notification when value of particular property goes above certain threshold and shows results.

The dependencies between all above mentioned entities are shown in figure below. COGNITWIN covers all building blocks for digital twins: whereas Abases will be used for the asset management and the standardized interfaces, the Stream Pipes will provide an environment to host and orchestrate different models, components, services.

2.7. Industries are Adopting Remote & Autonomous Enabling Technologies at an Accelerating Pace

In the past few decades, there has been a decline in the dominance of traditional manufacturing. Traditional manufacturing is an industrial process that converts materials into a finished product using a labor-intensive low-end operation, low precision, average resource utilization and efficiency for economic value. The shortcomings of traditional manufacturing are articulated and documented in when compared to other sustainable forms of manufacturing that rely on modern technologies and digital innovations. Over the last two decades, manufacturing has transformed into something complex, automated, and new. In their evolution, manufacturing systems must retain the ability to respond to disruption quickly while possessing a good control structure. Response to disruption involves intuitive knowledge about what to do in a changing situation, even when it has never been implemented before. Through the described manufacturing approach, flexibility and configurability are introduced into traditional manufacturing systems. Reconfigurable manufacturing systems (RMS) and flexible manufacturing systems (FMS) are two popular central forms of such transformed manufacturing. Each of these forms of manufacturing possesses features that make them unique and distinct from traditional manufacturing. According to, a smart factory incorporates existing production/manufacturing into broadly existing and future communication technologies. An intelligent production environment integrates manufacturing technology and cyber-physical systems and creates more complex and detailed models than traditional architectures by integrating previously independent and disconnected systems. Another description of the smart factory relies on its creating connections between digital and physical environments while enlarging the digital space through the Internet of Things (Iota) technologies to enhance the quality and precision of manufacturing processes this extension exhibits superior information processing support structures in data analytics, cloud systems, and machine/deep learning. This intelligent system outlines a context-sensitive industrial environment in which dispersed communication structures are used to improve production processes while allowing for minimal unpredictability. Adapting to various changes and conditions is also handled in such a system, mostly instinctively. [62]

3. Advances Compression Technology for Clean Hydrogen

3.1 Introduction

The growing global energy demand, as well as the increasing concerns about environmental pollution, has made hydrogen a realistic alternative to the traditional fossil fuels. The world energy consumption is indeed expected to double over the next half century, so significant changes in producing, distributing, storing and using energy are necessary. Hydrogen can be the ideal solution to all these issues [1]. Hydrogen is the most abundant element in the universe, thus being a never-ending and renewable source of energy. Furthermore, hydrogen can be produced from renewable and sustainable resources, thus offering a promising eco-friendly solution for the energy transition expected in the next decades. Hydrogen production from water by electrolysis is nowadays considered the main sustainable alternative to hydrogen synthesis from fossil fuels. Hydrogen production from biomass has shown to be a cost effective solution as well, both by using supercritical water gasification and fermentative processes. Solar energy is also another sustainable and environmentally friendly way to produce hydrogen [2-3]. Hydrogen exhibits the largest gravimetric energy density among non-nuclear fuels, and can be easily converted into thermal, mechanical and electrical energy. Its use in both stationary and automotive applications, such as fuel cells, offers a promising way to use electrical and thermal energies without impact on the environment, opening a new scenario in the use of sustainable energy all over the world.

Despite such advantages, two main issues prevent the generalized use of hydrogen as an efficient fuel, and with this, the energy transition towards a compelling fossil-free solution. Firstly, hydrogen is an energy vector, and this means that it is necessary to produce it before use, so energy is needed to synthesize hydrogen. Secondly, hydrogen exhibits the lowest volumetric energy density among the commonly used fuels, 0.01079 MJ/L at standard temperature and pressure, much lower than that of gasoline, 34 MJ/L. In order to increase this value, several methods have been developed: (I) compression in gas cylinders; (ii) liquefaction in cryogenic tanks; (iii) storage in metal hydride alloys; (iv) adsorption onto large specific surface area-materials and (v) chemical storage in covalent and ionic compounds (formic acid, borohydride, ammonia..). Among them, compression of hydrogen is the most widespread method to store hydrogen, even if it is not the cheapest one. Gaseous hydrogen at high pressures is particularly used in the frame of the Haber process for ammonia production, as well as to carry out hydro-cracking of heavy petroleum fractions in order to produce lighter hydrocarbons [4-6].

During the last years, a significant attention has been paid to the efficient use of hydrogen in automotive applications. Moreover, a “Hydrogen Economy” is often advocated as a potential way to deliver sustainable energy through the use of hydrogen. In this context, after being produced and before using it, hydrogen is packaged, distributed, stored and delivered, the most complex issues to solve related especially to the latter two steps. It has been shown that the cheapest hydrogen storage-delivery mode is obtained by compression and delivery with a truck, especially for small stations and low demands. For this reason, efforts have been carried out in order to improve compression solutions for hydrogen storage. It has been also shown that the introduction of new and sophisticated materials, like carbon fiber- and glass fiber-reinforced tanks, allowed a significant reduction of the storing system weight, increasing in turn the hydrogen volumetric energy density [7-10]. Commercial vessels available nowadays achieve an average hydrogen content of 1-2 wt.% at pressures of about 20-25 MPa, but composite pressure tanks up to 70

MPa have also been successfully developed, reaching a gravimetric storage density of 6 wt. % and a volumetric storage density of 30 g/L. These values still don’t meet the two U.S. Department of Energy targets, which set the ideal gravimetric and volumetric capacity for hydrogen automotive systems to 40 g/L v/v and 5.5 wt. % for 2017, respectively, to be achieved in the temperature range 233-358 K. Moreover, not only the weight of the storage material but also that of the entire system should be taken into account [11]. At present, current compression methods are unlikely to satisfy these targets, but at the same time they are mature enough to ensure the 70 MPa required by the on-board hydrogen storage systems used in the Fuel Cells Vehicles as well as by the hydrogen refueling stations [12-13].

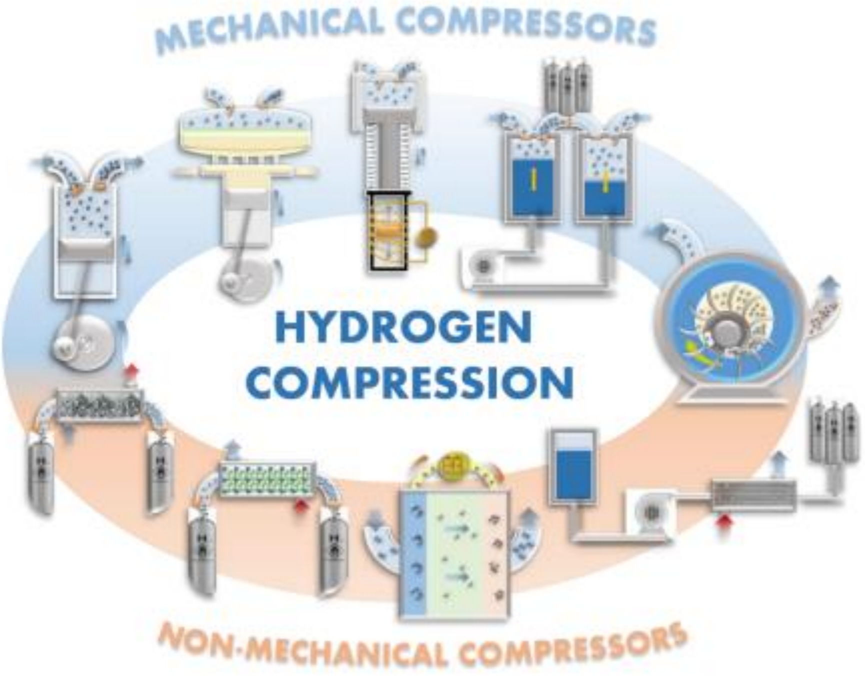


Figure.3.1 Summary of the hydrogen compression technologies currently used for stationary and automotive applications

3.2 Challenges related to compression of hydrogen

When designing a centrifugal compressor for hydrogen service, several process parameters must be considered (Figure). These include, but are not limited to, suction pressure, temperature, discharge pressure, volumetric flow rate, impeller operating speed, etc. Operating speed is especially relevant because the polytrophic head and pressure ratio that a compressor or stage produces is proportional to the square of the speed [15-17].

Because of hydrogen's low molecular weight and high sonic velocity, it will have a comparatively lower pressure rise per stage of the compressor relative to heavier gases. This means that in applications with high discharge pressures, the impeller operating speed must be increased, or additional compressor stages must be added. The latter can significantly increase rotor dynamic complexity. In some instances, the maximum permissible shaft length may not provide sufficient space to incorporate the required number of stages. In such cases, the only option is to increase impeller operating speed. However, this then requires consideration of material strength limits.

Mechanical strength limits of the impellers are directly correlated with tip speed. The maximum allowable impeller tip speed varies depending on the specific material used and the geometry of the impeller. These material strength limitations typically are not a concern when designing compressors for service with higher molecular weight gases because the Mach numbers limit the operating speed. However, in the case of hydrogen, the mechanical strength and impeller stress levels can become limiting factors. This issue is further complicated by the potential for hydrogen embrittlement, i.e. hydrogen-induced cracking (HIC). HIC occurs when atomic hydrogen diffuses into an alloy. Depending on the material used, this can reduce toughness and lead to failures below documented yield stresses. Titanium impellers with specialized surface coatings have proven to be successful in mitigating the risk associated with HIC. Other design enhancements, such as interstate cooling, can also reduce its likelihood [18-20].

It is important to note that there are currently no available test methods that can accurately simulate the conditions that a high-speed impeller may experience in a centrifugal compressor operating in 100% hydrogen service. Siemens Energy has developed a novel test method for this purpose to provide guidance on a new NACE standard for testing HIC, much like the limits for stress corrosion cracking (SCC) in NACE MR0175.3

Extensive studies on the design of blades and impeller geometry have shown that when high-strength titanium alloys are used, these stress levels can be reduced to allow for pressure ratios of up to 1.45:1 per stage.4 Therefore, a six-stage machine with a total pressure ratio of 4:1 with 100% hydrogen is technically possible. It can be assumed that the commercial availability of these machines will increase in the coming years when the market demands them.

Despite these challenges, it is possible to safely meet high discharge pressures with centrifugal compressors in hydrogen-rich service [21-24]. For example, at one Gulf Coast refinery, Siemens Energy supplied a nine-stage, constant speed centrifugal machine for a hydro treating unit.

The compressor, a DATUM D16R9S, is powered by a 16 000 hip motor and is based on a well-proven design, with no special modifications in a straight-through configuration. All nine stages are contained within a single casing fitted with a single inlet nozzle and a single discharge nozzle to accommodate the hydrogen gas flow. In preliminary performance testing at a Siemens Energy manufacturing facility, the compressor achieved a polytrophic head of 169 954 ft-lbf/lb. (approx. 18 880 ft-lbf/lb. per stage) – the highest level ever recorded with a DATUM unit.

Figure.3.2 A typical Siemens Energy hydrogen recycle centrifugal compressor package

3.3 Technical challenges of Hydrogen compression in fueling stations

For transportation, the overarching technical challenge for hydrogen storage is how to store the amount of hydrogen required for a conventional driving range (>300 miles) within the vehicular constraints of weight, volume, efficiency, safety, and cost. Durability over the performance lifetime of these systems must also be verified and validated, and acceptable refueling times must be achieved [63]. Requirements for off-board bulk storage are generally less restrictive than on-board requirements; for example, there may be no or less-restrictive weight requirements, but there may be volume or "footprint" requirements. The key challenges include:

- **Weight and Volume.** The weight and volume of hydrogen storage systems are presently too high, resulting in inadequate vehicle range compared to conventional petroleum fueled vehicles. Materials and components are needed that allow compact, lightweight, hydrogen storage systems while enabling mile range greater than 300 miles in all light-duty vehicle platforms.

- **Efficiency.** Energy efficiency is a challenge for all hydrogen storage approaches. The energy required to get hydrogen in and out is an issue for reversible solid-state materials. Life-cycle energy efficiency is a challenge for chemical hydride storage in which the byproduct is regenerated off-board. In addition, the energy associated with compression and liquefaction must be considered for compressed and liquid hydrogen technologies.

- **Durability.** Durability of hydrogen storage systems is inadequate. Materials and components are needed that allow hydrogen storage systems with a lifetime of 1500 cycles.

- **Refueling Time.** Refueling times are too long. There is a need to develop hydrogen storage systems with refueling times of less than three minutes over the lifetime of the system.

- **Cost.** The cost of on-board hydrogen storage systems is too high, particularly in comparison with conventional storage systems for petroleum fuels. Low-cost materials and components for hydrogen storage systems are needed, as well as low-cost, high-volume manufacturing methods.

- **Codes and Standards.** Applicable codes and standards for hydrogen storage systems and interface technologies, which will facilitate implementation/commercialization and ensure safety and public acceptance, have not been established. Standardized hardware and operating procedures, and applicable codes and standards, are required.

- Life-Cycle and Efficiency Analyses. There is a lack of analyses of the full life-cycle cost and efficiency for hydrogen storage systems.

The safety challenges result not only from the implementation of hydrogen technology for use directly by the public in a non-industrial context and for a completely new application. It lies also in the demanding performance and cost targets imposed by the applications leading to: the excursion to new domains of service conditions (e.g. 700 bar, 85°C.) the introduction of new physical processes (e.g. Hydride storage, fast filling.) the use of new materials (e.g. composite materials.)The safety challenge is hence two-fold:

1. Address the known risks (e.g. H2 leak) in a way that is compatible with the operation of a public fueling station: the conventional methods used by industry (large clearance distances, personnel protective equipment…) are not easily applicable here;

2. Discover and address all the new risk factors brought in by the new elements above and their combination.

The fact that multiple actors are involved (cylinder and accessory manufacturers, vehicle manufacturers, refueling station designers and operators, industrial gas companies...) further underlines this challenge. More specifically the challenges include: the reliability/safety of the 350 - 700 bar vehicle connection ensuring the user’s safety despite his presence in an area normally classified as hazardous according to industry standards perform the filling function well and safely, i.e. fill quickly to 100% exactly inside the safe operating limits, through correct management of the heat generated by the fast filling process secure/safeguard the user(ensure safety despite limited knowledge and training and his/her potential “impatience”) Prior to generalization/public use of such stations, further work is needed to fully validate critical dispenser components, such as the fueling nozzles, the hose and the break-away coupling enhance prevention of leaks and potential ignition establish qualification protocols of dispensing stations

3.4 Diaphragm compressors for hydrogen compression in fueling stations

Several demonstration projects involving hydrogen refueling stations are in operation. Examples from Europe are the CUTE and HyFleet: ECTOS projects, ECTOS project and the CEP Berlin project. In the large European demonstration project, CUTE, 30 hydrogen operated fuel cell buses have been test-driven in 9 European cities. Hydrogen refueling stations have also been located in these 9 cities. The following descriptions and technology examples from hydrogen refueling stations are mainly based on such demonstration projects as the CUTE, ECTOS and the CEP Berlin project.

Today's hydrogen gaseous stations are usually based on a few main components:

Hydrogen on site production or supply by pipeline or truck delivery Purification/Drying in case of on-site production (often included in the production unit) Compression Storage and gas distribution Hydrogen dispenser, including station/vehicle interface A 3D drawing illustrating the main system components at the refueling station at Iceland in the ECTOS project is illustrated in figure.

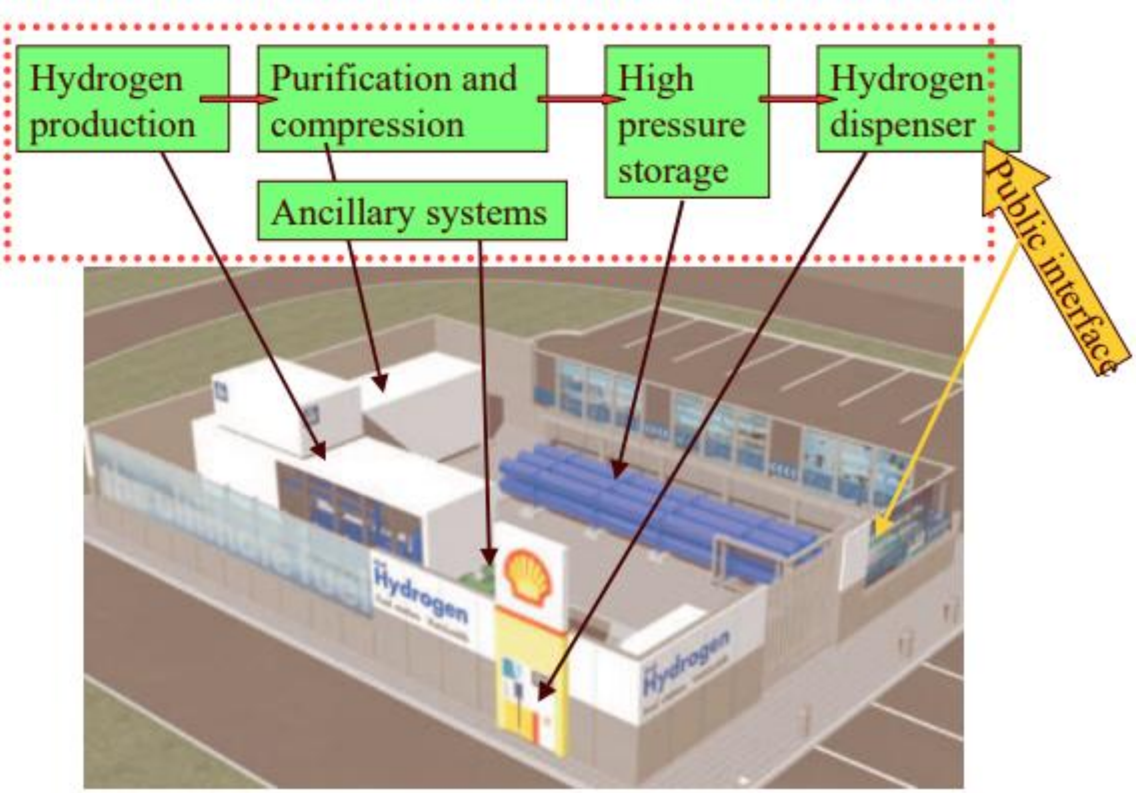


Figure.3.4 an Illustration of main blocks of a hydrogen filling station based on onsite hydrogen production

The concept in Hamburg is illustrated below in figure. At the Hamburg station hydrogen is produced on-site by electrolysis using electricity.

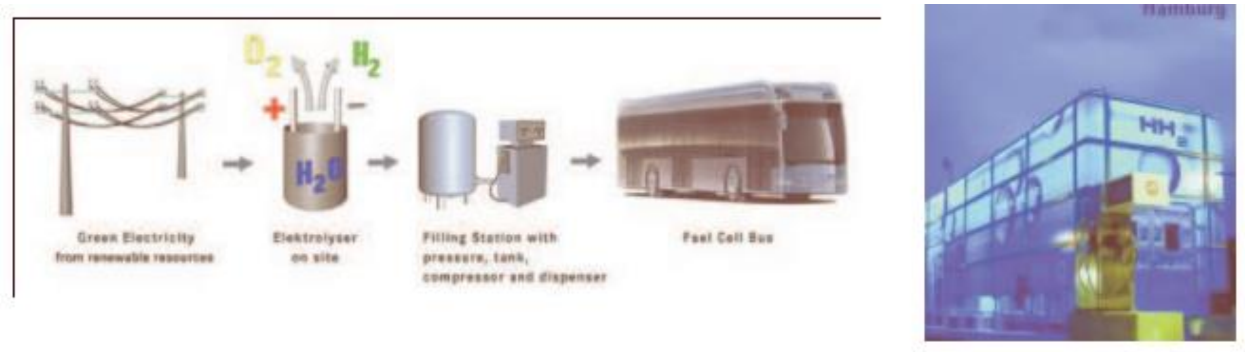


Figure.3.4.b Illustration of hydrogen station concept in Hamburg.

The filling station and production facilities are located at HOCHBAHN's bus depot in Hamburg Hummelsbüttel. Using electricity from the grid and combining this with the production from certified green electricity for the hydrogen production on-site is fulfilling all goals of ecology and sustainability [24-27]. A pressurised electrolyze (15 bar) produces high purity hydrogen with high efficiency which is then compressed to 450 bar and stored in on-site storage tanks. Busses can be filled up with 40 kg of hydrogen in 10 minutes which enables them to operate up to a range of 250 -300 km.

At the station in Madrid there are two options for hydrogen supply: on-site production by natural gas reforming and gaseous hydrogen. Delivered by truck.

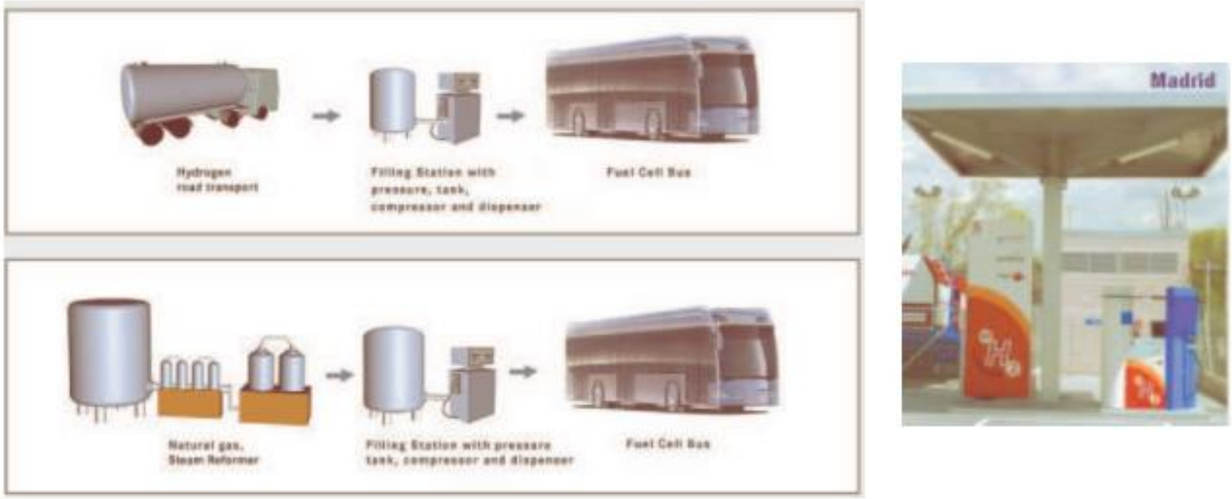


Figure.3.4.c Illustration and picture of hydrogen station concept in Madrid

Hydrogen is delivered by 200 bar by tube trailers. Each one of them contains 3960 Nm3, composed of 264 small cylinders (85 liters) with hydrogen compatible with fuel cell requirements. Gas compression from these tube trailers to the bus is done by a water cooled membrane compressor. In Madrid Hydrogen is also produced on-site by a natural gas steam reforming process.

3.5 Addressing design challenges for diaphragm compressors in fueling stations

Hydrogen is widely considered a clean source of energy from the viewpoint of reduction in carbon dioxide emissions. If hydrogen can be produced from renewable energy, it can make a big contribution to the realization of a sustainable society. Various efforts have been made to develop a hydrogen energy society. Among them, the pioneering work has been on social implementation of fuel cell vehicles (FCVs) and hydrogen fueling stations. Hydrogen fueling stations are essential for operating FCVs. FCVs have been sold commercially since December 2014, and several hydrogen-fueling stations have been constructed and are in operation worldwide. However, approximately 50 accidents and incidents involving hydrogen-fueling stations have been reported. Sakamoto et al. analyzed accidents and incidents at hydrogen fueling stations in Japan and the USA to identify the safety issues. Most types of accidents and incidents are small leakages of hydrogen, but some have led to serious consequences, such as fire. Most of the leakages occurred at the joint parts due to inadequate torque and inadequate sealing. Other causes include design error of the main bodies of apparatuses and human error. For the commercialization of FCVs, it is essential to identify and assess the overlooked risks.

Figure shows a schematic of the risk assessment of hydrogen fueling stations. The risks involved in two types of hydrogen fueling stations were identified using a hazard identification (HAZID) study. The leakage of hydrogen due to an accident is important for the consequence analysis. Many studies focused on the hydrogen release behavior [28-29]. It is necessary to evaluate the maximum amount of hydrogen released from each facility to conduct the consequence analysis of the worst-case scenario for which the consequence is the highest. The risk assessment based on the maximum amount of hydrogen released was conducted. Moreover, the rate of hydrogen released from each facility is necessary for risk assessment considering the frequency. With regard to the hydrogen release rate, experiments were conducted and the results were reported. Although the risk assessments of each component, such as pipes and accumulators, have been conducted, quantitative risk assessments considering the entire hydrogen fueling station are lacking. For example, if multiple safety measures in a hydrogen fueling station fail simultaneously, it could lead to serious accidents. Only a few studies have been conducted regarding the relationship of operative and/or inoperative safety measures with the hydrogen release behavior

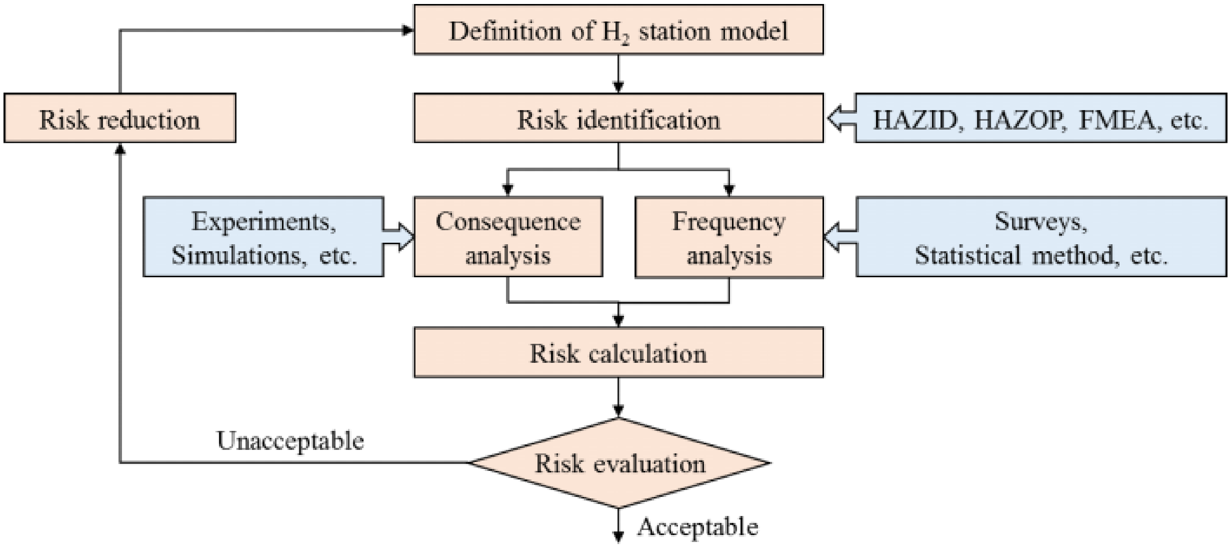


Figure. 3.5 Schematic of risk assessment of hydrogen fueling stations.

3.6 Reciprocating compressor for medium pressure

Reciprocating compressors, especially the oil-free ones, are commonly used for hydrogen applications when the desired level of pressure is higher than 3 MPa. They are ideal for moderate flow and high-pressure applications: the required power consumption can be as large as 11.2 MW, with a resultant hydrogen flow as high as 890 kg/h and a discharge pressure of 25 MPa. Higher discharge pressures up to 85 MPa are achieved by Hydro Pac, Inc. reciprocating hydrogen compressors, with an inlet pressure of 35 MPa and a capacity of around 430 kg/h.

Basically, a single-stage reciprocating compressor consists in a piston-cylinder system (Fig.), equipped with two automatic valves, one for intake and one for delivery [30-31]. The piston is linked to a crankshaft through a connecting rod, converting the rotary motion of the moving units into the almost linear motion of the piston. This movement is known as reciprocating motion. The energy necessary for the compression is given by either an electrical or a thermal machine. The piston movement towards the upper side of the cylinder, i.e., the Top Dead Centre (TDC), creates a partial vacuum in the lower part of the cylinder itself, opening the intake valve and allowing the gas to enter it. The consequent suction phase lasts until the piston reaches the Bottom Dead Centre (BDC), then the intake valve is closed. Moving again towards the TDC, the gas is compressed until the pressure reaches the desired level, then the delivery valve is opened, discharging the gas.

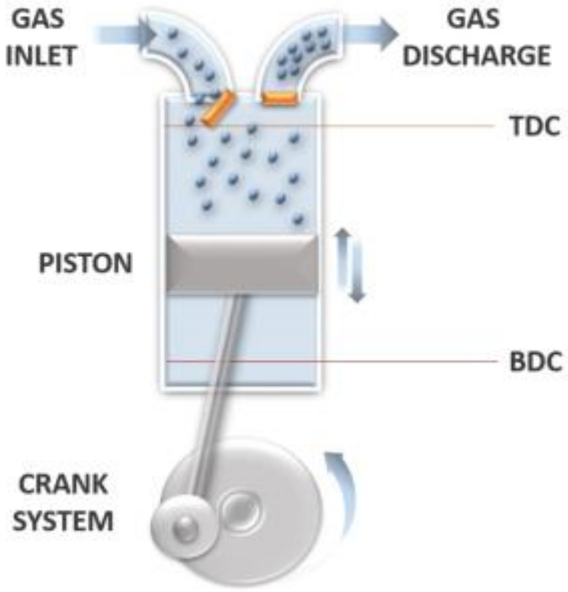


Figure.3.6 Scheme of a reciprocating piston compressor

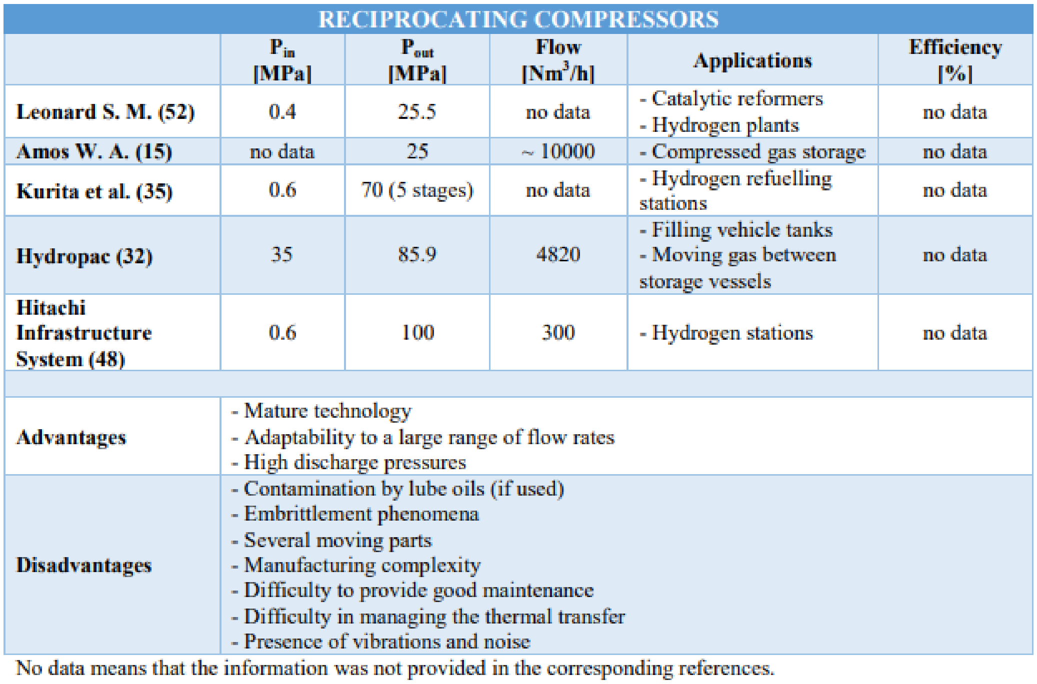
Reciprocating compressors produce high-pressure hydrogen especially when a multistage configuration is adopted: a first stage of compression increases the hydrogen pressure up to a couple of atmospheres, before reaching the target value through the next stages [32-34]. Actually, this configuration is particularly preferred in on-site hydrogen refueling stations, where hydrogen is generated at a pressure around 0.6 MPa, making necessary in turn the use of an efficient compressor system in order to supply hydrogen to a fuel cell vehicle. On the other hand, reciprocating compressors are not efficient for high flow rates. In fact, the flow rate depends on the dimension of the cylinder, as well as on the number of cycles per unit time, called speed of compression. An increase of the cylinder dimension results in bigger and heavier components, increasing in turn the inertia forces. In order to limit the resulting mechanical stresses, a decrease of speed is thus recommended. Hence, high compression speeds are achievable only in small cylinders, then causing a reduction of the allowable flow rates.

The embrittlement phenomena are the main drawback to overcome in hydrogen reciprocating compressors, making necessary a careful selection of the material used, as well as a sophisticated design. Several guidelines have to be followed, according to the API Standards 618, in which all the minimum requirements for reciprocating compressors are included. The cylinders, commonly made of cast iron, nodular cast iron, cast steel and forged steel are covered by a liner coat, ensuring the walls protection. Being easily removable, the liner reduces repair costs in case of accident, and facilitates the adjustment of the cylinder diameter, depending on the operational requirements, thus providing an advantageous versatility to the system.

Since the use of lube oils can affect the durability of the compressor components, oil-free compressors are preferred, offering high performances operation and high-purity compressed gas. Hence, in order to prevent the contact between the piston and the cylinder, pistons are equipped with wear bands, usually known as rider bands, made of thermoplastic materials. In order to reduce as much as possible hydrogen leakages, piston rings are also used. Nevertheless, it has been proved that high-pressure oil-free hydrogen reciprocating compressors are particularly affected by the early failure of the sealing rings, because of a large non-uniformity of the pressure distribution inside the compression chamber. For this reason, a two-compartment distance piece has to be included in the design of the compressor to facilitate gas venting, avoiding in this way the embrittlement of the steel due to hydrogen escaped from the compression chamber.

Nowadays, the 94/9/EC European Directive concerning equipment used in potentially explosive atmospheres is also complied by the Member States of the European Union for manufacturing reciprocating compressors. By choosing carefully the wear materials, by adopting a conservative design as well as by reducing the piston speed, good performances can be reached. During the last years, better reciprocating compressors have been developed for hydrogen applications, improving significantly the operating parameters: discharge pressures of 100 MPa and flow capacities of 300 Nm3 /h have indeed been reached.

Although reciprocating compressors are widely used for applications involving hydrogen, several limitations make them not perfectly appropriate for such purpose. Firstly, the presence of several moving parts increases the cost, because of the manufacture complexity as well as the difficulty to provide a good maintenance. Moreover, such typology prevents the efficient cooling of hydrogen during the compression because of the presence of moving parts, like the piston, resulting in an increase of the heat produced and in a more difficult management of thermal transfers. In addition, the back and forth movement of the piston causes pressure fluctuations inside the compression chamber, which can be detrimental since they may cause vibrations, noises, even explosions, and hence lead to a decrease of the system life of the overall hydrogen plant. Anyway, it is noteworthy that the reciprocating compressors exhibit very good performances especially when the multi-stage configuration is used, because of the high value of the discharge pressure reached and because of their flexibility in size and capacity. Several improvements have been achieved in their design, like the upgrading to non-metallic ring and valves materials, the use of a tungsten carbide piston rod coating, and the implementation of continuous monitoring systems to predict possible failures. However, the aforementioned drawbacks attract interest for other devices aimed at compressing hydrogen more efficiently. Table gathers the main characteristics of a few representative examples of reciprocating compressors.



RECIPROCATING COMPRESSORS

	P_{in} [MPa]	P_{out} [MPa]	Flow [Nm^3/h]	Applications	Efficiency [%]
Leonard S. M. (52)	0.4	25.5	no data	- Catalytic reformers - Hydrogen plants	no data
Amos W. A. (15)	no data	25	~ 10000	- Compressed gas storage	no data
Kurita et al. (35)	0.6	70 (5 stages)	no data	- Hydrogen refuelling stations	no data
Hydropac (32)	35	85.9	4820	- Filling vehicle tanks - Moving gas between storage vessels	no data
Hitachi Infrastructure System (48)	0.6	100	300	- Hydrogen stations	no data
Advantages	- Mature technology - Adaptability to a large range of flow rates - High discharge pressures				
Disadvantages	- Contamination by lube oils (if used) - Embrittlement phenomena - Several moving parts - Manufacturing complexity - Difficulty to provide good maintenance - Difficulty in managing the thermal transfer - Presence of vibrations and noise				

No data means that the information was not provided in the corresponding references.

Table.3.6 Hydrogen reciprocating compressors

3.7 Online performance diagnosis in real time

Thirteen international corporations recently formed the Hydrogen Council “to position hydrogen among the key solutions of the energy transition”.6 Doing so involves challenges around its complexity and diversity:

(1) Hydrogen can be produced from many feedstocks and processes, with varying greenhouse gas and other emissions, costs and infrastructural requirements;

(2) Hydrogen can be used in many ways, including without fuel cells, whilst fuel cells can operate using fuels other than hydrogen;

(3) Hydrogen and fuel cells can contribute in many ways spanning the whole energy system;

(4) Hydrogen infrastructure may be costly, but pathways include several low-cost incremental routes that ‘piggy-back’ off established networks, which are often neglected.

In March 2017, the UK's Hydrogen and Fuel Cell Supergene Hub published a white paper that systematically assessed the current status and future prospects of hydrogen and fuel cells in future energy systems. This article synthesizes and updates that white paper, broadening its scope to a global focus. It builds upon previous holistic reviews of hydrogen and fuel cells, and takes the novel approach of considering how they might be integrated together across the energy system.

This review covers the following:

- The transport sector, both personal vehicles and larger heavy-duty freight and public transit vehicles;
- Heat production for residential, commercial and industrial users;
- Electricity sector integration, balancing intermittent renewable energy;
- Infrastructure needs, options for using existing gas grids, compression and purity requirements; and

- Policy challenges, global support and targets for hydrogen and fuel cells.

3.8 Addressing hydrogen transportation and storage future needs

The suitability of hydrogen and fuel cells varies between transport modes and reflects the diverse nature of the transport sector, which spans land, sea and air, plus freight and passengers, as shown in Fig. Nearly half of energy demand for global transport is from light duty vehicles and the number of passenger cars worldwide is expected to rise from 1 to 2.5 billion by 2050. [64]

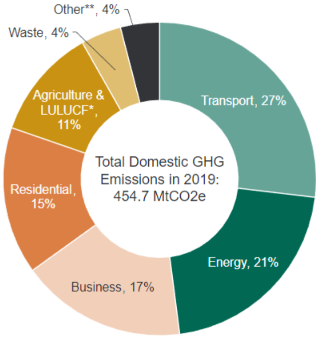


Figure.3.8 Greenhouse gas emissions by sector, 2019, by proportion (BEIS, 2020)

Overall transport emissions increased until a peak in 2007, before decreasing year-on-year until 2013, when emissions started increasing again. Emissions only started declining again in 2018. 2019 transport emissions are equivalent to those of 2011. Transport contributed a substantial portion of these air pollutants to the UK's domestic total: 34% of NOx emissions, 13% of PM2.5 emissions, 11% of PM10 emissions came from transport in 2019. (Source : www.gov.uk). Hydrogen represents one of three main options for low-carbon in the UK low carbon and renewable energy economy (LCREE) transport alongside biofuels and electric vehicles (EVs). Hydrogen avoids the land-use and air quality impacts of biofuels, and the limited range and long recharging times associated with EVs.5 However, electric cars are several years ahead of hydrogen in terms of maturity due to their lower costs and readily-available infrastructure. Plug-in electric vehicles in 2020 account for 74.8% of new vehicle sales in Norway and 10.7% in the UK. (*source: ACEA, CAAM, EV-Volumes)*

(comments :
Page 139:

"The UK must halve its transport CO2 emissions between 2015 and 2030 to meet national carbon budget commitments." *Is there a reference for this?* -> has been deleted and changed to important explanation

Page 139:
"Emissions have increased though, and the share of renewable energy in UK transport has fallen to 4.2% versus a target of 10%, 36 bringing calls for stronger action. Hydrogen represents one of three main options for low-carbon transport alongside biofuels and electric vehicles (EVs)." *Reference 36 is from a 2014 paper – this feels very out of date to reflect on the energy mix when the UK, like many other countries has brought significant renewable sources online in the last 10 years* -> has been changed to The UK Low Carbon Hydrogen Standard Government response to consultation (30)

In addition to tackling climate change, hydrogen vehicles can improve air quality. This is an urgent priority with over half a million premature deaths per year across Europe due to particulates and NOx emissions. The direct cost of air pollution due to illness-induced loss of production, healthcare, crop yield loss and damage to buildings is around €24b per year across Europe with external costs estimated to be €330–940b per year. 92% of the world's population are exposed to air quality levels that exceed World Health Organization limits. Major cities have recently announced bans on all diesel-powered cars and trucks by 2025, and UK and France have announced nationwide bans on all pure combustion vehicles by 2040.

Whilst FCEVs face strong competition from ICE and BEV passenger cars, they may be the best (and perhaps the only) realistic zero-carbon option for high-utilization, heavy-duty road transport vehicles such as buses and trucks. These are significant sectors, accounting for a quarter of transport energy usage. Growing calls to minimize urban air and noise pollution are major drivers for hydrogen bus rollout. Back-to-base operation means fewer refueling stations are needed and are more highly utilized, reducing initial refueling costs.

Three key differences for heavy-duty transport are low manufacturing volumes (meaning the cost gap with ICE is smaller), and the need for greater longevity and energy density. The US DOE targets 25 000 hour operating lifetime for fuel cell buses, versus just 8000 for passenger cars. Greater vehicle weight and driving range mean battery technologies are likely to remain unsuitable outside of urban environments; for example, fuel cell buses consume 10 times more hydrogen per kilometer than passenger cars – amplifying range limitations.

Fuel cell buses Fuel cell buses in particular have attracted significant attention and are relatively mature, at Technology Readiness Level (TRL) 7.84 On-board tanks typically hold around 40 kg of hydrogen stored in the bus roof, and reduced space restrictions mean this can be stored at 350 bar, reducing tank and compression costs. Fuel cell buses may have a 10–20% higher total cost of ownership (TCO) than diesel by 2030 and could be cheaper if deployed at scale.

Fuel cell buses have seen substantial early deployment, with 7 million kilometers of operational experience so far in Europe. Europe has 83 operating fuel cell buses, with 44 in North America. Toyota is planning to introduce over 100 fuel cell buses before the Tokyo 2020 Olympic Games. China has the world's largest bus market, with 300 fuel cell buses ordered for Foshan City (quadrupling the global fleet of hydrogen powered buses). For context, Shenzhen City has electrified its entire fleet of over 16 000 buses using BEVs.

Good progress is being made with longevity, with four London buses operating more than 18 000 hours. Ten buses in California have passed 12 000 hours of operation with one reaching 22 400 hours: close to the DOE's ultimate target of 25 000 hours. Fuel cell bus availability has exceeded 90% in Europe (versus an 85% target), with refueling station availability averaging 95%.

Trucks Trucks show considerable potential for fuel cell adoption as high energy requirements mean few low-emission alternatives exist. Light goods vehicles with short low-speed journeys could be managed with batteries and range-extender vehicles; 48 however, long-haul heavy vehicles which require high utilization are likely to require hydrogen. Competition from batteries is nonetheless increasing, with the Tesla Semi expected to offer 300–500 mile range for ~$200 000. Cost parity of fuel cell trucks with other low-carbon alternatives could be achieved with relatively low manufacturing volumes. Return-to-base delivery vehicles could see lower fuel costs with a single refueling depot, although long-range HGVs need an adequate refueling network.

Higher longevity is required than for other applications due to the high mileage expected of trucks, with one program targeting 50 000 hour stack lifetime.48 High efficiency and low fuel costs are also essential. Kenworth and Toyota are considering hydrogen truck production, and Nikola is also developing a long-distance HGV using liquefied hydrogen in the US. Fuel cells are also being developed as Auxiliary Power Units (APUs) for HGVs. These could power refrigeration units and 'hotel' loads on stationary HGVs (e.g. cabin heating, cooling, lighting, and electrical devices) to avoid engine idling.

FCEV trucks have seen lower adoption than buses due to the HGV market being highly cost sensitive with limited government support or intervention, and highly conservative with haulers wary of being pioneers. However, Anheuser-Busch Inbred (an international drinks company), recently ordered 800 FCEV trucks to be in operation in 2020. Interest could grow as diesel trucks begin to be banned from major city centers.

Motorbikes Two-wheeled vehicles are dominant for passenger transport in many regions. Intelligent Energy has developed a 4 kW fuel cell system in cooperation with Suzuki, now being trialed in the UK.100 Their low fuel consumption allows them to be refueled using hydrogen canisters from vending machines. FCEV motorbikes could contribute toward air quality and noise pollution targets.

Off-road transport

Trains Electrification can replace diesel trains but progress has slowed recently across Europe. Hydrogen trains could be used on routes which are difficult or uneconomic to electrify due to route length or lack of space in urban areas. A fuel-cell powered train with roof-mounted hydrogen tanks and a range of 500 miles has begun testing in Germany, 101 and 40 trains could be in service by 2020.102 Alstom announced plans to convert a fleet of trains in the UK from electric to hydrogen to negate the need for line electrification and meet the government target of eliminating diesel trains by 2040.

Light rail also presents opportunities for hydrogen, with fuel cell-powered trams being developed and operated in China. Low volumes mean that hydrogen trains are expected to use the same stacks and storage tanks as buses and trucks, so cost reductions will be consolidated with the automotive sector. Hydrogen powertrains may be 50% more expensive than diesel, but economic viability will depend on lower-cost fuel, and hydrogen costing under $7 per kg. One study concludes that FCEV trains are already cost competitive with diesel trains from a TCO perspective.

Ships Marine applications hold promise for hydrogen deployment, with fuel cells already being trialed for propulsion in a handful of projects including ferries. Hydrogen is not expected to gain traction until after 2030, although the growth of emissions controlled zones (such as the Baltic Sea and urban ports) and hydrogen's higher efficiency than LNG could drive early niches.48 Most vessels have long lifetimes, are built in small numbers highly tailored to specific applications; this could hamper the rollout of new propulsion systems. With ferries potentially consuming 2000 kg of hydrogen per day, cryogenic storage is necessary, and fuel costs are more important than up-front capital, with hydrogen significantly below $7 per kg needed. Fuel cells for auxiliary power could be adopted earlier than for propulsion, and port vehicles could also be early adopters, improving local air quality with a single refueling depot.

Aero planes Aviation is one of the hardest sectors to decarbonize and reducing emissions from aircraft propulsion has seen little progress. In 2016 the International Civil Aviation Organization agreed to cap aviation emissions at 2020 levels, but primarily through carbon offsetting rather than low-emission fuels. Some hybrid electric concepts are being studied, though emission reductions will be limited. Biofuels could be suitable due to their higher energy density than hydrogen or batteries but are not completely emission-free and could remain costly with limited availability. Hydrogen could be used as a propulsion fuel but needs to be liquefied to supply the required range. Combustion turbines are likely to be needed as fuel cells lack the power required for take-off. However, the climate benefits of hydrogen for aviation have been questioned because it produces more than double the water vapor emissions of kerosene; water vapor at high altitudes, although short lived in the atmosphere, causes radiative forcing and thus contributes to net warming. Significant hydrogen deployment is thought unlikely before 2050 except perhaps for small or low-flying aircraft. Hence much work remains on developing options for low-emission aircraft propulsion.

Other aviation-based sectors are more promising Fuel cells have been tested for aircraft auxiliary power units and for taxiing aircraft to/from airport terminals. There is an increasing motivation to improve air quality around airports and fuel cells could play an important role in powering ground vehicles and buses in the next 10 to 20 years, aided by the need for a low number of refueling stations experiencing high utilization. Unmanned aerial vehicles (UAVs) are also attracting considerable interest for both civilian and military applications. Fuel cell UAVs are quieter, more efficient, and have lower vibration and infrared signatures than fossil fuel-powered UAVs, and are lighter than battery systems, offering longer range. Fuel cell UAVs are currently considerably more expensive than battery UAVs; but the cost gap will close with manufacturing volume, and fuel cells retain the advantage in long-duration or high energy applications.

Forklift trucks and others other promising applications include forklift trucks, with around 12 000 fuel cell units deployed in the US and a handful elsewhere. Plug Power supplies 85% of FC forklifts in the US. The zero emissions from FC forklifts allow them to operate indoors, and their faster refueling than batteries can lead to TCO savings of 24% in a typical high throughput warehouse.113 FC forklifts also have a wide temperature range, capable of operating in temperatures as low as −40 °C. PEMFCs are most widely used with longer lifetimes, but direct methanol fuel cells (DMFCs) are also found in lower usage applications with shorter lifetimes and lower cost of ownership. Fuel cells could also see adoption in agricultural equipment such as tractors and recreational applications such as caravan APUs and golf carts, one of the few sectors that are proving profitable.

4. H-Town: Carbon-Free 2030 Challenges of Korea

4.1 Hydrogen energy futures

In achieving the 2050 Vision, the most important key element is accelerated energy transition towards carbon neutrality. Solar, wind, hydro, and other types of renewable energy should be the central sources of energy supply. CCUS technologies should be employed in the use of coal and other fossil fuel-powered energy and LNG power generation to significantly cut down on GHG emissions in the long-term. [65]

Evidently, it is important to reorient the existing energy supply system. Technological innovation could help bring about this fundamental change by making renewable energy more affordable. Continued efforts are needed to bolster market-based policies such as carbon pricing and to advance the power system at the national level. The intermittency issue remains a challenge for some renewable energy sources, which should be addressed considering Korea's geographical difficulty of supplying electricity from overseas. As the percentage of renewable energy in the power mix gradually increases, it is essential to keep the electricity output predictable and reliable throughout the entire power grid.

A system-wide integration of EVs, ESS and hydrogen technologies is another viable option, which could be achieved by utilizing advanced ICT and Industry 4.0 technologies. With this, consumers will be able to communicate with each other and trade the electricity they produced from distributed power sources on a smart grid. This will change the traditional concept of consumers into "prosumers," who both produce and consume energy.

Most sectors of our society – transportations, cooling and heating systems and industrial processes – that are using fossil fuels need to use clean electricity in the future.

To achieve Korea's 2050 Vision, most of the current means of transportation running on fossil fuels should be replaced with alternative modes of transport powered by electricity, hydrogen and other clean energy sources.

These gradual changes will form a dominant trend by 2050 especially in road transportation. By 2050, electric and hydrogen-powered vehicles are expected to become widely popular, and other modes of transportation including air, sea and rail could also experience a similar transition.

4.2 Definition of T-Hydrogen

Introduction of internal combustion engine and electricity system has opened up the era of mass production, symbolized by the 2nd Industrial Revolution. Advancement of internal combustion engine has made a remarkable progress in achieving convenience and mobility for people and goods and shortening travel time. The progress has removed all distance-related obstacles in human history. [66]

Another paradigm shift in the transportation sector that could be on a par with the 2nd Industrial Revolution is now underway. This paradigm shift is led by growing demand for carbon neutrality as well as advancement of Industry 4.0 technologies. Unlike the previous modal transformation that has focused on increasing convenience and shortening travel time, eco-friendliness and smart intelligence are the two keys to the ongoing paradigm shift. This modal transformation seeks to move away from the existing petroleum-based mobility and progress towards future mobility characterized by eco-friendly and autonomous vehicles. At the core of paradigm shift is the transformation into clean energy sources with zero-emissions – electricity, hydrogen and bio-fuels – and into green mobility using such zero-emissions energy sources. Deploying EVs and hydrogen vehicles operating on a clean energy supply system is the key mitigation option in the transportation sector.

Low-carbon transition in the transportation sector will fundamentally change the entire energy demand and supply system in Korea, which highly depends on imported oil. The transition will significantly reduce air pollutants as well, improving people’s quality of life and health.

Korea will significantly reduce GHG emissions in the transportation sector from the current level with the main sectoral strategies of increasing deployment of eco-friendly vehicles such as EVs and hydrogen cars, and improving vehicle fuel efficiency. The transportation sector’s 2050 vision presented in this section also aims to further accelerate this with four key strategies: scaling up deployment of eco-friendly vehicles, increasing low-carbon fuel use, promoting green logistics and managing transportation demand.

4.3 Hydrogen! Happy Town Model

South Korea will provide 27.9 million MT/year of "clean hydrogen" by 2050, all of which will be either green or blue hydrogen, excluding grey hydrogen, as part of efforts to expand hydrogen production and consumption in order to make it the country's number one energy source by 2050, replacing oil, the energy ministry said Nov. 26.[67]

Under the plans, the country will provide 3.9 million MT/year of hydrogen in 2030 -- 940,000 MT/year of grey hydrogen, 750,000 MT/year of blue hydrogen and 250,000 MT/year of locally-produced green hydrogen -- while importing 1.96 million MT/year of green hydrogen from overseas, according to the Ministry of Trade, Industry and Energy.

South Korea currently does not produce any clean hydrogen, with all of the 220,000 MT produced in 2020 being fossil fuel-based grey hydrogen.

By 2050, South Korea will provide 27.9 million MT/year of hydrogen -- by producing 3 million MT/year of green hydrogen and 2 million MT/year of blue hydrogen, while importing 22.9 million MT/year of green hydrogen from overseas, without any grey hydrogen.

"South Korea will increase investments in overseas projects to produce clean hydrogen projects with its own capital and technologies," the ministry said in a statement, adding that the country will boost cooperation with hydrogen producing countries to secure around 40 hydrogen supply channels by 2050.

The massive supply plans would lower production prices of green hydrogen to Won 3,500/kg ($3/kg) by 2030 and Won 2,500/kg by 2050, the ministry said.

The country also plans to secure carbon storage facilities with a capacity of more than 900 million MT/year by 2030 so as to produce 2 million MT/year of blue hydrogen by 2050.

"South Korea's clean hydrogen self-sufficiency ratio will rise to 34% in 2030 and 60% in 2050," it said.

In line with the government-led push, private power utility and city gas provider SK E&S signed an agreement with a provincial government and state-run power utility Nov. 26 to build South Korea's first blue hydrogen production plant with a capacity of 250,000 MT/year by 2025 on the country's west coast.

Of them, 200,000 MT/year will be provided for hydrogen fuel cell electricity generation and 50,000 MT/year will be used for vehicles.

The MOTIE forecasts South Korea's hydrogen demand to rise to 3.9 million MT/year in 2030 -- 3.53 million MT/year for power production and 370,000 MT/year for vehicles, according to the ministry.

Hydrogen demand would further rise to reach 27.9 million MT/year in 2050 -- 13.5 million MT/year for power production, 2.2 million MT/year for vehicles and 12.2 million MT/year for industrial use.

In order to spur demand and improve hydrogen infrastructure, more than 2,000 charging stations will be set up nationwide by 2050, with at least one charging station to be established at 226 wards and counties nationwide, according to the ministry.

The government also plans to encourage such sectors as steel and chemical to turn to hydrogen-based production processes and apply the clean energy source to various means of transportation, including drones, trams and vessels.

"Hydrogen will become our largest single energy source in 2050, which will account for 33% of the total energy consumption, replacing oil that accounts for 49.3% currently," the ministry said.

"Hydrogen is the most powerful means of achieving the zero-carbon goal," it said. In October last year, President Moon Jae-in declared that South Korea will achieve carbon neutrality by 2050 by replacing coal-fired power generation with renewable sources and internal combustion engines vehicles with hydrogen-powered and battery-based electric vehicles.

5. Korea Hydrogen Technology Competitiveness and R&D Strategy in KIPO's Perspective

5.1 Hydrogen Ecosystem

There are three large petrochemical complexes in Korea each centered on a large refiner: 1) Ulsan (SK Energy and S Oil), 2) Yeosu (GS Caltex) and 3) Season/Desean (Hyundai Oil bank). About 90% of the local hydrogen production comes as a by-product from naphtha cracking which is cleaned and distributed to customers. Around 9% of the hydrogen produced in Korea comes from large-scale steam methane reformers (SMR) built to order and constructed on or next to customers' sites. [2]

Decoying is Korea's largest supplier of hydrogen. As with the other domestic hydrogen suppliers, Decoying sources much of its hydrogen by taking by-product gas supplied at one of the three industrial complexes, cleaning it through pressure swing adsorption (PSA) equipment and distributing it to customers through pipeline or tube trailers.

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 recently began construction of a fourth plant specialized in hydrogen production from polyurethane. Linde established its Korean subsidiary in 1988 and is one of the largest industrial gas specialists in Korea.

The broader 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 subsector accounts for the highest share at around 30%.

As hydrogen moves from being purely an industrial gas concern to a broader fuel to power and heat the economy, questions around the roll out of infrastructure come to the fore. For now, hydrogen is trucked via tube trailers to Korea's nascent HRS network, but this is not sustainable: of the 130,000 tons of by-product hydrogen produced in 2019, only 50,000 tons was available for hydrogen refueling stations (HRS) or fuel cell power generation. Further, while the world's largest industrial fuel cell plant (50MW) was completed in July 2020 at Hanwha Energy's site in Desean using Doosan's phosphoric acid fuel cells (PAFC), there is a limit to the transformation that can be achieved by relying purely on by-product hydrogen from petrochemical sites.

In the medium to long 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 pipeline 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 in to hydrogen for use in fuel cell vehicles. 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.

In light of this, the natural gas industry is set to play a critical role in the early hydrogen economy. The industry is dominated by 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 slightly by region and by application.

5.2 Explanation of Patent Trend

Companies and experts were surveyed to identify the current status, foundation of development and competitiveness level of the domestic hydrogen industry, and to analyze matters to be prepared bring about the era of the hydrogen economy. The enterprise survey was conducted on firms in six ecosystems of the hydrogen energy industry: production, storage, transport, charging, mobility and fuel cells. The survey was conducted on a total of 372 companies, of which 220 responded. The survey of experts was conducted on 35 industry-academic experts in the hydrogen industry.

Based on the assessment indicators used in industrial research and analysis, the growth potential and level of the industrial ecosystems of the domestic hydrogen industry were evaluated. In particular, the hydrogen industry was evaluated through R&D-related indicators in the survey, which reflect key elements of innovation, and showed that innovations for industrial creation were still in their early stages of development. Each evaluation index evaluated the results of an entity. The survey questions asked respondents to rate various items on a five-point scale.

The evaluation of the ecosystem of hydrogen industry is divided into industrial innovation resources in the hydrogen sector and innovative activities evaluation, industrial competitiveness levels and policy support levels in the hydrogen industry. Here, the Industrial Innovation Resources measure was based on whether or not survey respondents had a R&D organization and R&D personnel, while the Innovation Activity Evaluation index was based on the scale and weight of R&D and R&D cooperation. The purpose of cross-national levels evaluation was to compare levels of technology, quality competitiveness, new product development, price, and the ability to create business models across major countries including Korea, Japan, Germany and China. The comparison is based on a scale of 100, a score that represents the country possessing the highest level of competitiveness, the U.S.

The level of policy support for the domestic hydrogen industry was divided into levels of support for industrial innovation resources, industrial innovation activities and growth base. In this regard, the assessment of support for industrial innovation resources is a composite index of indicators of technology, corporate development, industry-academic cooperation and the level of support for overseas advancement. In addition, the level of support for industrial innovation resources is a combination of professional labor, financial and government subsidies and infrastructure support. The level of support for the growth base is a set of assessment indicators for laws, systems and regulations, support for commercialization and the promotion of hydrogen.

If we look at whether or not we have R&D organizations for the evaluation of industrial innovation resources, the R&D base of domestic companies is considered relatively high. According to the survey, 79.5 percent of the respondents have R&D organizations, 73.1 percent of them have corporate research institutes and 6.4 percent have dedicated departments. When looking at whether the subsectors of the hydrogen industry have R&D organizations, 89 percent of firms in the hydrogen fuel cell sector reported having R&D organizations, which is the highest mark among survey respondents. As of 2018, the number of dedicated R&D personnel is estimated to be 5.9 workers per firm on average, while R&D personnel account for 44 percent of the total workforce in the hydrogen industry.

Second, looking at the level of innovation activities, respondents assessed the scale of their R&D investments and the ratio of R&D to sales. The average amount of R&D investment in the domestic hydrogen industry in 2018 was about 3.8 billion KRW. The average amount of R&D investment has been increasing since 2016 but the scale remains small. By sector, the hydrogen mobility sector recorded the highest average R&D investment, at about 5.5 billion KRW in 2018. The charging sector posted the lowest amount. R&D spending on sales was relatively low, at 5.5 percent on average as of 2018.[66]

Examining research and development promotion at companies, about two-thirds of domestic companies are conducting R&D cooperation with the outside world. Only one-third are pursuing R&D activities independently. 73.6 percent of companies set up mid- to long-term development visions and strategies in their respective fields, the report showed. This means that they are aware of the importance of the hydrogen industry and have a high willingness to promote or innovate their businesses

5.3 Patent Application

In 2019, South Korea published a roadmap for promoting a hydrogen-based economy that focuses on the transportation sector, decarbonizing industry and buildings, and managing the production and distribution of hydrogen. The roadmap and subsequent legislation passed by the National Assembly are designed to provide objectives, outlines for industry support, and a legal foundation for South Korea’s efforts to pursue the development of hydrogen as a fuel source.

At the center of South Korea’s strategy is an effort to “prime the pump to create a bigger market” for hydrogen and provide the support needed at this early stage for the private sector to grow the market for hydrogen in the long-term and reach the economies of scale to reduce prices (Cheong WA Dee 2019a, b). In addition to providing support to the private sector in the form of subsidies for hydrogen projects, R&D, and regulatory reform, South Korea is working to develop and demonstrate the viability of hydrogen fuel cells. As part of its demonstration efforts, South Korea plans to establish three hydrogen demonstration cities by 2022. These cities would use hydrogen for transportation, electricity, heating, and cooling, while serving as an initial step in transitioning 30% of South Korea's cities to hydrogen by 2040 (Edmond 2019).

The roadmap places significant emphasis on the transportation sector. Despite efforts to reduce greenhouse gas emissions, vehicles with combustion engines still dominate the global market. Global sales of electric vehicles, the leading alternative to the combustion engine, only amounted to 2.1 million units in 2018 and just 2.2% of all vehicles sold (Hertz 2019). Hydrogen vehicles account for a much small part of the market with sales of only about 7500 vehicles in 2019 (Kane 2020a). However, the South Korean government estimates that if just 10% of the global automobile market shifts to hydrogen, the new market for hydrogen vehicles would be worth around $125 billion.

Despite the current low sales volume for hydrogen vehicles, South Korea hopes to expand domestic production of hydrogen FCEVs to 35,000 units by 2022 and 65,000 hydrogen FCEVs on South Korean roads. By 2025, it has targeted production of 100,000 units with 40,000 units for export. It also estimates that at volumes of 100,000 units the price of hydrogen vehicles would be competitive with internal combustion engine vehicles (Government of Korea 2019). By 2030, hydrogen and electric vehicles are expected to make up a third of all new cars sold domestically (Kang 2020b).

To encourage the sale of hydrogen vehicles domestically, South Korea's roadmap calls for subsidizing the purchase price of vehicles and investing in R&D. Under South Korea's subsidy scheme, the level of subsidy would fall as the price of vehicles declines with increased production. In 2020, South Korea has adjusted its subsidy scheme for eco-friendly vehicles and will provide upwards of 42.5 million won ($34,715) for the purchase of a hydrogen vehicle (Yunshan News Agency 2020d), while under its current budget, it is set to spend 43.1 billion won in R&D on hydrogen-related technologies in 2020 (Yunshan News Agency 2020e).

In addition to passenger vehicles, South Korea's roadmap also calls for the expansion of hydrogen into other areas of transport. For personal travel, the roadmap calls for the introduction of 80,000 hydrogen taxis and 40,000 hydrogen buses by 2040. It also calls for the introduction of 30,000 hydrogen trucks over the same period for the transportation of freight.

The roadmap also includes steps for research into utilizing hydrogen to power ships, trains, drones, and construction equipment, but these areas are more focused on R&D with the goal of being able to commercialize the technology before 2030.

South Korea currently generates 307.6 MW from fuel cells, but has targeted expanding that production to 15GW by 2040. The expectation in the roadmap is that 8GW would be for domestic use, while 7GW would be dedicated to exports. To foster the production of power through fuel cells, the government would implement an LNG price exclusively for fuel cells and maintain renewable energy certificates (RECs) over a period of time to provide investors with a degree of certainty. It would also provide additional value to RECs for green hydrogen projects and is considering a long-term, fixed price system for power generated from fuel cells.

The roadmap has also set the goal of providing households and other buildings 2.1GW of power from fuel cells by 2040. This market would be grown through a mixture of incentives such as a special electricity tariff and mandatory steps such as the replacement of cooling systems at public institutions with fuel cell systems.

If the demand for hydrogen grows in line with South Korea’s hydrogen roadmap, demand for hydrogen would increase from 130,000 tons in 2019 to 5.36 million tons a year in 2040. Currently, South Korea’s hydrogen needs are supplied from byproducts in the petrochemical process. As demand grows in the early stages, South Korea would produce hydrogen using LNG. However, in the longer term it is also considering options for producing green hydrogen. These include using surplus renewable energy and hydrogen produced in conjunction with the development of new large-scale renewable energy projects. The roadmap also expects South Korea to begin importing green hydrogen by 2030. To ease the domestic shipment of imported hydrogen, South Korea is considering installing pipelines at the point of import. These and other potential pipeline initiatives would add to South Korea’s current 200-km hydrogen pipeline.

The Korea Gas Corporation (KOGAS) has also developed its own hydrogen plan. The state owned KOGAS plans to invest 4.7 trillion won ($4.06 billion) by 2030 on R&D the construction of 25 hydrogen production facilities and 700 km of new pipeline. With increased domestic production and imports of hydrogen beginning in 2030, KOGAS hopes to bring the domestic price of a kilogram of hydrogen down to 3000 won from its current price of 6500–7500 won by 2040 (Kim and Suh 2019).

5.4 Core Technology Trend for Transportation and Storage

Although hydrogen is projected to replace fossil fuels in the near future, there are many unresolved technical issues regarding its storage and transportation. In recent studies at Pusan National University, Korea, Prof Jae-Mung Lee's group has found promising solutions to two important problems: steel embrittlement and insufficient insulation. Their findings will help us repurpose existing liquefied natural gas containers for transporting hydrogen overseas, thus laying the foundations for a fully-fledged hydrogen economy. [68]

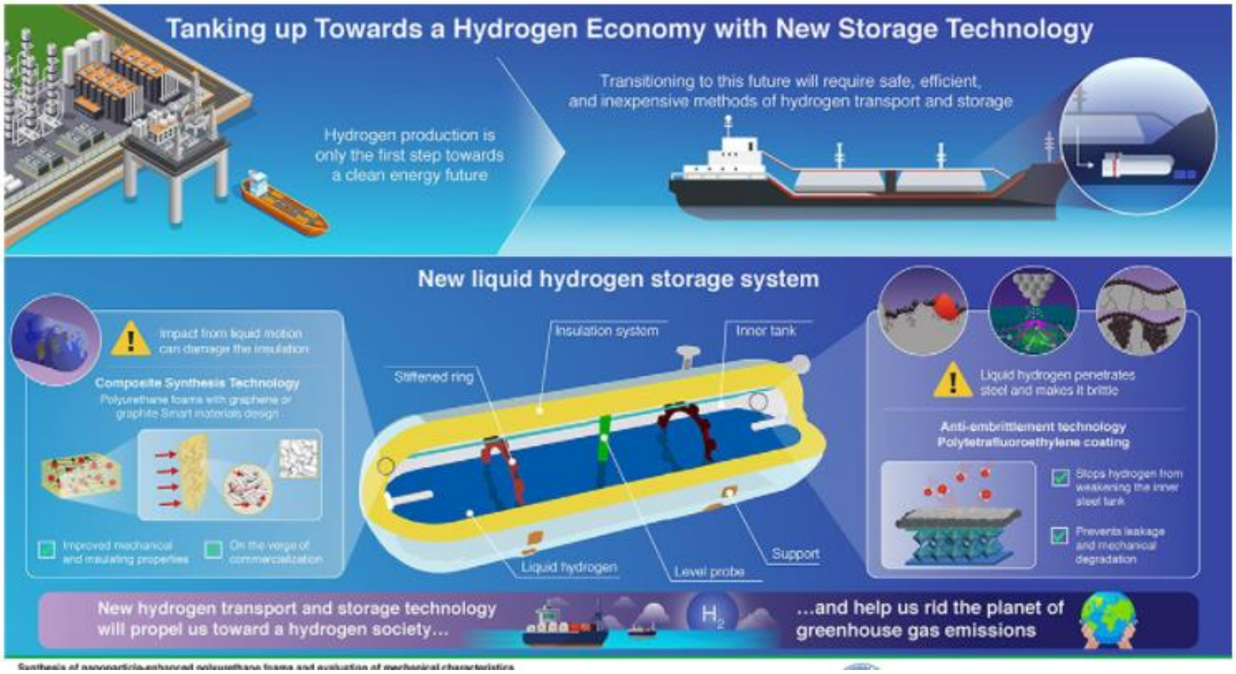


Fig. 5.4.a A hydrogen economy with new storage technology

Hydrogen is globally viewed as one of the best alternatives to fossil fuels and is projected to become the main way of storing energy by 2030. But, if we are to make these future hydrogen societies a reality, we need not only inexpensive methods to produce hydrogen, but also efficient and safe ways to transport it overseas. The issue of hydrogen storage and transportation is not an easy one; liquefied hydrogen has to be kept at −253°C, which entails a variety of technical problems to which no one has found definitive solutions.

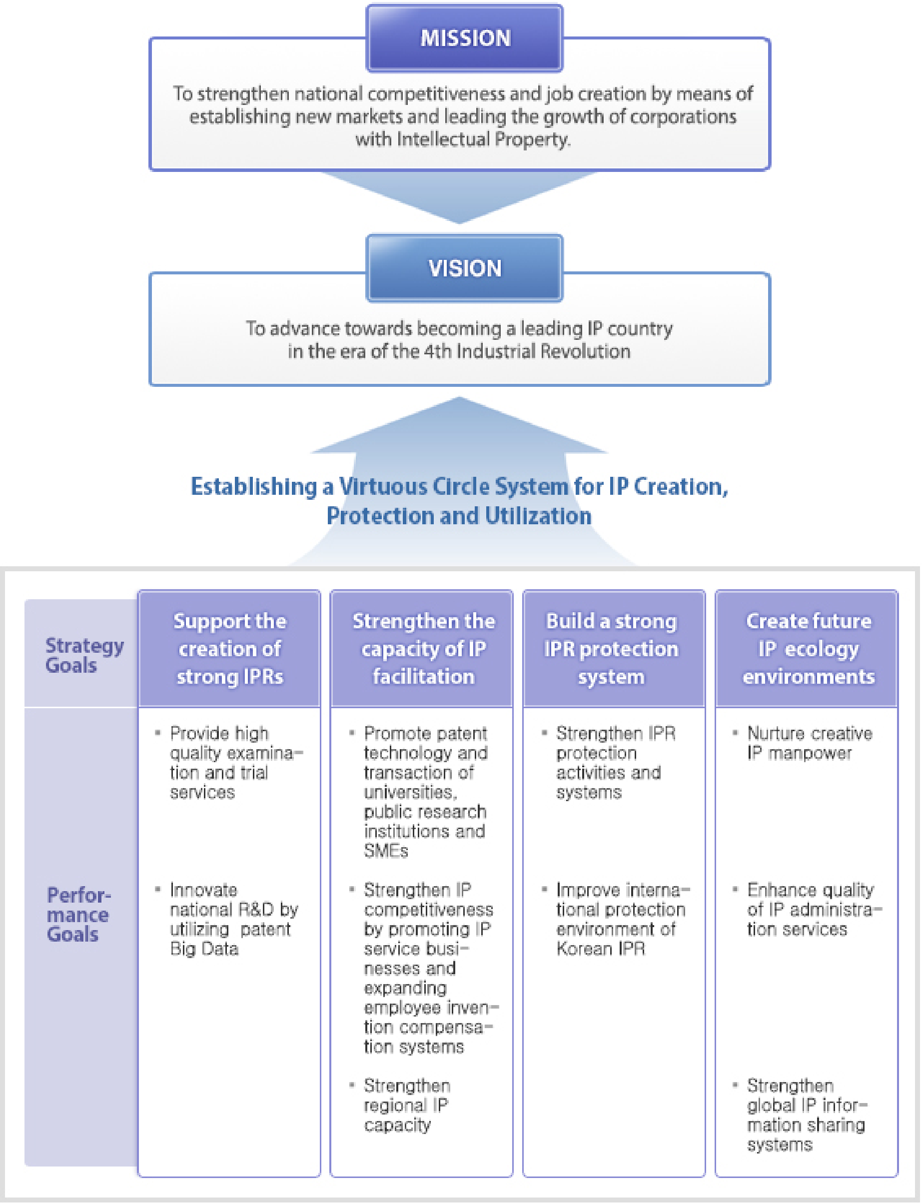
Motivated by this challenge, Professor Jae-Mung Lee's research group at Pusan National University, Korea, have been conducting research to find commercially feasible ways to store and transport liquefied hydrogen. Prof. Lee is actively working with over 20 researchers to replace liquefied natural gas technology and make existing systems suitable for liquefied hydrogen. In his group's most recent studies, published in the International Journal of Hydrogen Energy and Composites Part B: Engineering, they propose innovative solutions to two of the main problems that make transporting hydrogen in steel containers difficult: "embrittlement" and insulation.

Hydrogen embrittlement is a well-known phenomenon by which hydrogen atoms penetrate the inner walls of steel containers and cause the appearance and enlargement of cracks, which can result in leakage accidents. To tackle this issue, Prof. Lee's group has developed a practical solution in the form of a polytetrafluoroethylene (PTFE) coating. This polymer prevents hydrogen from penetrating the steel and thereby reduces embrittlement on the inner walls of the containers.

On the other hand, the problem of insulation stems from the fact that existing liquefied natural gas containers are not suitable for carrying liquefied hydrogen unless the thickness of their insulating polyurethane foam is substantially increased. Moreover, increasing the insulation of polyurethane materials generally comes at the cost of material strength, making it particularly difficult to improve upon existing technology. To address this issue, Prof. Lee's group has developed advanced theoretical models and novel concepts in polyurethane foam insulation, including foam enhancement with graphene nanoparticles. Excited about their results, Prof. Lee remarks, "Our best additives improved both the strength and insulation performance of polyurethane foams by 38% and 8%, respectively. In addition, our predictive models for materials design can greatly reduce the initial investment for developing novel insulation materials in terms of time and cost.

Overall, the research efforts by Prof. Lee’s group are getting us closer to the transition into a hydrogen economy. With eyes on the future, Prof. Lee concludes, “Efficient and economical hydrogen storage technology is widely recognized as the backbone of the realization of a hydrogen economy. Our work will contribute to the establishment of a value chain for the transport, storage, and utilization of hydrogen and help us create a cleaner environment for everyone to live in.”

5.5 Develop A Strategies



MISSION

To strengthen national competitiveness and job creation by means of establishing new markets and leading the growth of corporations with Intellectual Property.

VISION

To advance towards becoming a leading IP country in the era of the 4th Industrial Revolution

Establishing a Virtuous Circle System for IP Creation, Protection and Utilization

Strategy Goals	Support the creation of strong IPRs	Strengthen the capacity of IP facilitation	Build a strong IPR protection system	Create future IP ecology environments
Performance Goals	• Provide high quality examination and trial services • Innovate national R&D by utilizing patent Big Data	• Promote patent technology and transaction of universities, public research institutions and SMEs • Strengthen IP competitiveness by promoting IP service businesses and expanding employee invention compensation systems • Strengthen regional IP capacity	• Strengthen IPR protection activities and systems • Improve international protection environment of Korean IPR	• Nurture creative IP manpower • Enhance quality of IP administration services • Strengthen global IP information sharing systems

Source: https://www.kipo.go.kr/en/HtmlApp?c=91001&catmenu=ek02_01_02

Fig. 5.4.b Develop a strategy

South Korea has put forward a comprehensive plan to create the initial infrastructure, R&D, and investment needed to speed the development of a hydrogen economy, building on a foundation of hydrogen fuel cell vehicles and test projects such as the development of hydrogen cities. However, there are additional steeps it should consider. To further encourage the adoption of hydrogen as a fuel source, South Korea could either increase the weighting for hydrogen fuel cells or include a mandatory requirement similar to the RPS' obligations for solar power. [69] It could also consider a phase out of the sale of new combustion engine vehicles similar to France and the UK to encourage the development of vehicles that run on alternative energy sources. South Korea's ultimate success will most likely come down to policy consistency. Nurturing hydrogen as a viable power source for the South Korean economy will require long-term support from the Korean government and industry. The current roadmap runs through 2040. However, the nature of South Korea's single-term presidency means that policies are vulnerable to being minimized or reversed by even administrations of similar political ideology. For the moment, there seems to be cross-party support for developing hydrogen as a fuel source. But South Korea has seen prior shifts in policy emphasis. The Rohm Moo-hymn administration began supporting research into hydrogen in the late 1990s, but his successor shifted the emphasis to nuclear power—an energy source that the current administration hopes to phase out. If South Korea is to be successful in creating the ecosystem necessary to develop a hydrogen economy, there will need to be policy consistency in the years ahead.

6. Siemens Energy's Green Hydrogen Production and P2G Solutions

6.1 Introduction of Siemens Company

Siemens is a global powerhouse focusing on the areas of electrification, automation and digitalization. One of the world's largest producers of energy-efficient, resource-saving technologies, Siemens is a leading supplier of systems for power generation and transmission as well as medical diagnosis. In infrastructure and industry solutions the company plays a pioneering role. Siemens makes real what matters. With innovations that improve life. For customers, for society and for each individual. This is Ingenuity for life. From building technologies and integrated mobility to efficient power distribution and smart grids, the digitalization of infrastructures leads our cities in the future. With global demand for energy growing fast, innovation and ingenuity are required to take us into a sustainable energy future. With technological innovations Siemens supports industrial enterprises to become more productive, efficient and flexible. Even today, Siemens offers digital solutions to the economy, industry, and urban infrastructure of tomorrow – for more efficiency, sustainability and security. Financial Services is an international provider of financing solutions. Our financial and industry know-how creates customer value and enhances customer competitiveness. [70]

6.2 New Energy Business

Siemens Energy as currently organized is a fairly new entity. The company was spun off from Siemens AG and began trading on the Frankfurt stock exchange on Sept. 28, 2020. When the spin-off was approved by Siemens shareholders in July that year, Joe Kaiser, president and CEO of Siemens AG, said, “The spin-off enables us to build two focused companies, both of which will be strong players in their respective sectors.”

Siemens Energy also has a New Energy Business, or NEB, that is focused on the future, including on research and development (R&D) of hydrogen technology. “NEB really focuses on what’s next,” Overberg said. “And that’s probably the most exciting part of our business is what’s next—where do we go from where we are today to where we’re going to be in the future?”

Beyond hydrogen, Siemens Energy is investing in improvements to its gas turbine technology. “We’re still doing quite a bit on gas turbines, believe it or not. You know, better efficiency upgrades to look at the installed fleet,” Holt said.

A lot of effort is also going into energy storage R&D. “We believe storage will be the game changer,” Holt said, noting that the exact technology that could revolutionize the industry is not yet decided. He said there are different options for short-term versus long-term storage, as well as maximum output systems. Lithium-ion batteries are likely to be part of the answer, but other technologies, including heat storage, could also be important. “We’re putting quite a bit of effort into it,” said Holt. Concerning the transmission and distribution business, Siemens Energy’s R&D efforts are focusing on grid resilience and high-voltage direct-current (HVDC) systems. “How do you connect these offshore wind farms? How do you transport the electricity over long distances?” Holt asked. “On the switching side, they have SF_6 [sulfur hexafluoride], which is even, I think, 20,000 times worse than CO_2 [as a greenhouse gas]. How do we convert that portfolio into a clean product?” [71]

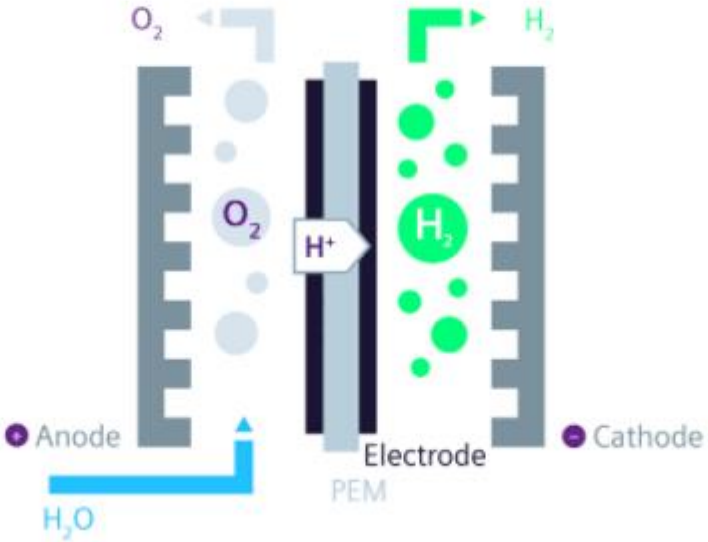
6.3 Focus on Proton Exchange Membrane (PEM) Electrolyze system technology

J. H. Russell and his colleagues first recognized the enormous potential of PEM electrolysis for the energy industry in 1973.

PEM takes its name from the proton exchange membrane. PEM’s special property is that it is permeable to protons but not to gases such as hydrogen or oxygen. As a result, in an electrolytic process the membrane takes on, among other things, the function of a separator that prevents the product gases from mixing.

On the front and back of the membrane are electrodes that are connected to the positive and negative poles of the voltage source. This is where water molecules are split. In contrast to traditional alkaline electrolysis, the highly dynamic PEM technology is ideally suited to harvest volatile energy generated from wind and solar power. PEM electrolysis also has the following characteristics:

- High efficiency at high power density
- High product gas quality, even at partial load
- Low maintenance and reliable operation
- No chemicals or impurities



Source :(https://www.siemens-energy.com/global/en/offerings/renewable-energy/hydrogen-solutions.html)

Fig. 6.3. PEM electrolysis

6.4 H2 Future (A European Flagship project for generation and use of green hydrogen)

H2FUTURE is a European flagship project for the generation of green hydrogen from electricity from renewable energy sources. Under the coordination of the utility VERBUND, the steel manufacturer voestalpine and Siemens Energy, a proton exchange membrane (PEM) electrolyze manufacturer, a large-scale 6 MW PEM electrolysis system will be installed and operated at the voestalpine Linz steel plant in Austria. The Austrian transmission system operator (TSO) Austrian Power Grid (APG) will support the prequalification of the electrolyze system for the provision of ancillary services. The Netherland's research Centre TNO and K1-MET (Austria) will study the replicability of the experimental results on larger scales in EU28 for the steel industry.

H2FUTURE is structured into 10 work packages:

- WP01 Project Management and Coordination (lead: VERBUND)
- WP02 Specification of Pilot Tests and Operation Phase (lead: VERBUND)
- WP03 Detailed Engineering of the Critical Building Blocks (lead: Siemens Energy)
- WP04 Manufacturing and Factory Testing of the Electrolyze System (lead: Siemens Energy)
- WP05 Development and Validation of the Link with Power and Energy Markets (lead: VERBUND)
- WP06 Installation of the Infrastructure for the Electrolyze System (lead: voestalpine)
- WP07 Unit Integration and on-site Validation of the full Pilot (lead: voestalpine)
- WP08 Two Year Demonstration (lead: VERBUND)
- WP09 Impacts of the Project Results and Exploitation (lead: TNO)
- WP10 Dissemination of the Project Results (lead: VERBUND)

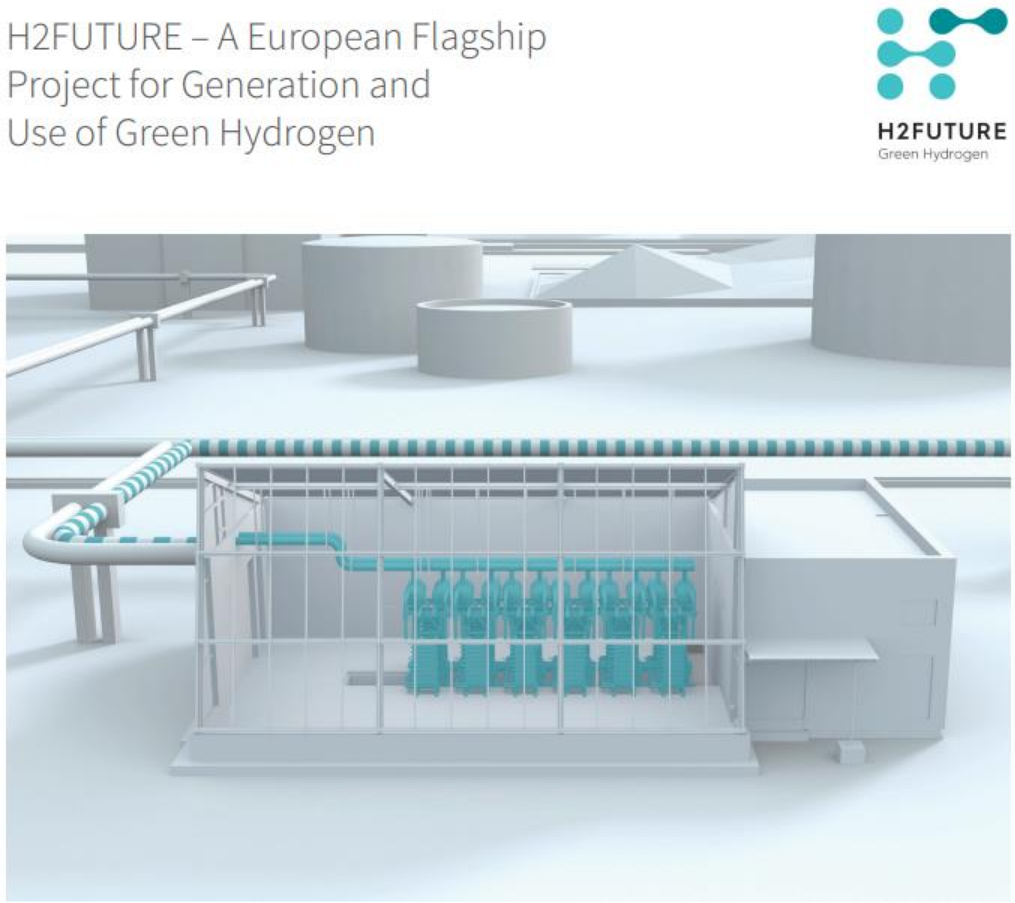
The H2FUTURE project has started on 1st January 2017 and has a duration of 4.5 years.

H2FUTURE has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking under grant agreement No 735503. This Joint Undertaking receives support from the European Union’s Horizon 2020 research and innovation programme and Hydrogen Europe and N.ERGHY.

The EU flagship project “H2FUTURE – Hydrogen meeting future needs of low carbon manufacturing value chains” brings together energy suppliers, the steel industry, technology providers and research partners, all jointly working on the future of energy. With a capacity of 6 megawatts and a production of 1,200 cubic meters of green hydrogen per hour, H2FUTURE is currently the world’s largest and most advanced hydrogen pilot facility using PEM (proton exchange membrane) electrolysis technology for producing green hydrogen from renewable electricity. The PEM electrolyze plant is scheduled to be fully operational in 2019.

Under the coordination of Austrian utility company VERBUND and with PEM technology developed and provided by SIEMENS, Germany, the electrolyze is currently being built and will be operated at the largest steel production site of voestalpine Group in Linz, Austria. VERBUND will provide electricity from renewable energy sources and is responsible for developing and testing grid-services with the electrolyze. Using demand side management, the PEM electrolyze will help to compensate fluctuations in an increasingly volatile power supply and enable higher shares of wind and solar energy. The Austrian transmission system operator Austrian Power Grid (APG) will provide support in integrating the plant into the power reserve markets. Scientific partners are the research institution ECN part of TNO (The Netherlands), responsible for the scientific analysis of the demonstration operation and the transferability to other industrial sectors, and the Austrian COMET Competence Center K1-MET, which will demonstrate the potential applications in the European and global steel sectors.

In a nutshell, the fundamental goal of H2FUTURE is to demonstrate that an industrially integrated PEM electrolyze is able to produce green hydrogen and supply grid services at the same time. In this way, the potential for “breakthrough” steelmaking technologies which replace carbon by green hydrogen can be examined and the basis for further upscaling to industrial dimensions and in the long run for decarbonizing the economy is created. H2FUTURE will also address regulatory challenges that need to be solved to create a sustainable environment for European industry players.



Source: (https://www.h2future-project.eu)

Fig. 6.4. H2 future

6.5Hare Oni Pilot Project

6.5.1 Turning wind and water into hope

Synthetic fuels and optimism will soon be flowing from Hare Oni.

With its huge potential for wind-based energy production, it has been estimated that the Magallanes region could generate **sevenfold the amount of electricity currently being produced by Chile's entire electricity matrix**.

Many areas and their populations all over the world would profit by becoming players in an e-methanol economy – including desert areas with no resources producing green energy from biomass, wind-filled regions with little or no industrial development, and oil-exporting countries that are looking for new business opportunities.

6.5.2 Bringing green life to old cars

It's somehow ironic that a part of the world where there are very few roads is playing a huge role in keeping modern and classic sports cars on the road.

70% of all Porsches ever made are still in use, and Porsche sees synthetic fuel as a solution for keeping vintage cars going for decades to come. This is one of the reasons the automaker is investing in the Hare Oni project.

As the fuel’s primary user, Porsche is planning in the first phase to use the e-fuels from Chile in beacon projects. These include using e-fuels in Porsche’s motorsport fleet, at Porsche Experience Centers and, later, in series production sports cars. The sports car maker will start with an initial investment of roughly 20 million euros.

6.5.3 Substantial benefits from thin air

The Hare Oni project demonstrates a broad spectrum of innovative, climate-relevant technologies at one location.

Synthetic fuel is produced from water, wind energy and CO_2 captured from the air. It is a liquid energy carrier that emits about 90% less CO_2 than the fossil counterpart. In case of e-gasoline, it is simultaneously compatible with existing liquid fuel infrastructure.

6.6 The Plan for the Future

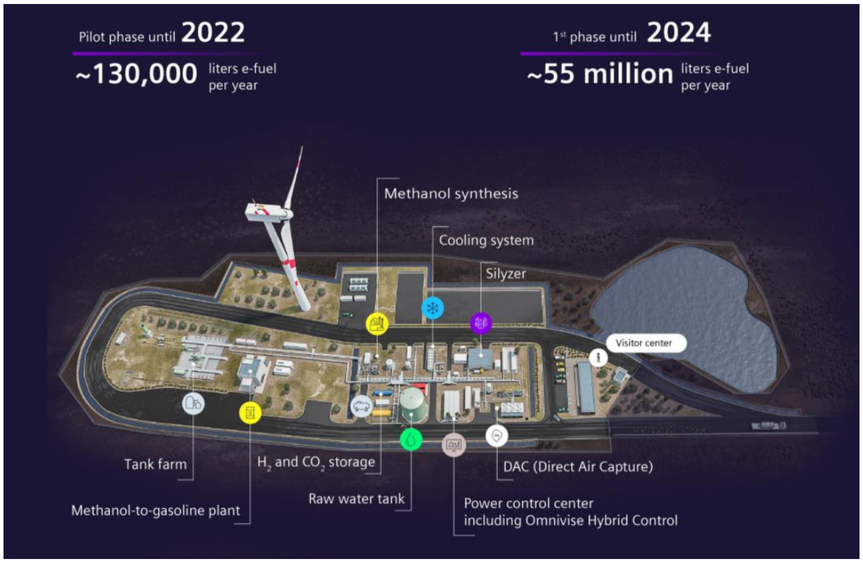


Fig. 6.6. Plan of Fuel Infrastructure

In the pilot phase, e-methanol production will initially reach around 750,000 liters per year by 2022. Part of the e-methanol will be converted to e-gasoline (130,000 liters per year). A further two phases will increase capacity: first to 55 million liters of e-gasoline per year by 2024, and then to over 550 million liters per year by 2026. That's enough fuel for over one million people to drive their cars climate-neutral for nearly a year. [72]

7 Hydrogen Value Chain by Mott MacDonald

7.1 Overview (Why Hydrogen?)

Zero carbon is a goal for a growing number of countries. Achieving it will require a transformation of energy systems. How we fuel our transport, power our industries, heat our homes, electrify our towns and cities must all change. It’s complex and will take time.

Countries and businesses around the world are exploring how hydrogen, when combined with other solutions, can help meet net-zero targets.

The EU is investing heavily to build electrolyze capacity to produce hydrogen using renewable electricity, while the US is accelerating R&D and deployment of hydrogen technologies. Elsewhere, Australia is looking to advance its hydrogen industry, while Japan aims to become a hydrogen-powered society.

As the world shifts away from burning fossil fuels to a low-carbon future, hydrogen is key to de carbonizing heavy industry, long-haul transport and heating systems.

It is also a solution to balancing supply and demand from intermittent sources of electricity generation.

Hundreds of terawatts of surplus renewable electricity a year can be stored in the form of hydrogen to manage seasonal fluctuations and provide electricity at peak times when the wind isn't blowing, or the sun isn't shining. By utilizing the existing gas grid infrastructure as well as salt caverns and depleted gas fields, large-scale, low-cost, long-term hydrogen energy storage is cost effective. Europe is already beginning to exploit its 18Bnm^3 of salt caverns to store about 40TWh of hydrogen, while a project is underway in the US state of Utah to build the world's largest salt cavern hydrogen storage facility.

7.2The Hydrogen Value Chain

Hydrogen as a key counterpart of renewable energy

Hydrogen has the ability to act as an energy storage medium and as an energy carrier.

Steelmaking, cement manufacture and other industrial processes need high temperatures and hydrogen, in some cases, is better able than electricity to deliver it. The Committee on Climate Change, the independent body advising the UK government, believes that hydrogen will be the cheapest or only way to replace fossil fuel energy in heavy industry over the next 20 years.

On the roads, hydrogen fuel cells will power trucks and buses for long distances and can be refueled as quickly as diesel engine vehicles. In the not too distant future, hydrogen and captured carbon dioxide will be turned into carbon-neutral liquid fuels for aircraft, while hydrogen fuel cells will be common in planes flying short-haul routes.

In the built environment, a combination of hydrogen, electric heat pumps and district heating networks will provide heating in the future. Countries with extensive gas networks must repurpose and modernize their systems for hydrogen, first blending it with natural gas before switching entirely. In the UK, the National Grid is currently testing the conversion of the gas network to hydrogen, possibly completing the transition by 2035.

7.3 Scale Issues

Hydrogen is already used in huge quantities to refine oil and to produce methanol, ammonia and other chemicals, and is produced mostly from natural gas. But the carbon emissions from the process – called steam methane reforming (SMR) – contributes to global warming. Hydrogen from natural gas is known as grey hydrogen. Capturing the carbon dioxide from the SMR process and utilizing it to produce sustainable fuels or chemicals or storing it in depleted gas fields offshore is called blue hydrogen. Green hydrogen is produced using renewable sources or nuclear power in an electrolysis plant to split clean water into hydrogen and oxygen.

A key problem with the hydrogen economy is that pollution-free sources of hydrogen are unlikely to be practical and affordable for decades. Indeed, even the pollution-generating means of making hydrogen are currently too expensive and too inefficient to substitute for oil.

From the perspective of global warming, electrolysis makes little sense for the foreseeable future. Burning a gallon of gasoline releases about 20 pounds of CO_2. Producing 1 kg of hydrogen by electrolysis would generate, on average, 70 pounds of CO_2. Hydrogen could be generated from renewable electricity, but that would be even more expensive and, as discussed below, renewable electricity has better uses for the next few decades.

Stranded investment is one of the greatest risks faced by near-term hydrogen production technologies. For instance, if during the next two decades we built a hydrogen infrastructure around small CH_4 reformers in local fueling stations and then decided that U.S. greenhouse gas emissions must be dramatically reduced, we would have to replace that infrastructure almost entirely.

Centralized production of hydrogen is the ultimate goal. A pure hydrogen economy requires that hydrogen be generated from CO_2-free sources, which would almost certainly require centralized hydrogen production closer to giant wind farms or at coal/biomass gasification power plants in which CO_2 is extracted for permanent underground storage. That will require some way of delivering massive quantities of hydrogen to tens of thousands of local fueling stations.

Tanker trucks carrying liquefied hydrogen are commonly used to deliver hydrogen today, but make little sense in a hydrogen economy because of liquefaction's high energy cost. Also, few automakers are pursuing onboard storage with liquid hydrogen. So after delivery, the fueling station would still have to use an energy-intensive pressurization system. This might mean that storage and transport alone would require some 50 percent of the energy in the hydrogen delivered, negating any potential energy and environmental benefits from hydrogen.

Pipelines are also used for delivering hydrogen today. Interstate pipelines are estimated to cost $1 million per mile or more. Yet we have very little idea today what hydrogen generation processes will win in the marketplace during the next few decades, or whether hydrogen will be able to successfully compete with future high-efficiency vehicles, perhaps running on other pollution-free fuels. This uncertainty makes it unlikely anyone would commit to spending tens of billions of dollars on hydrogen pipelines before there are very high hydrogen flow rates transported by other means and before the winners and losers at both the production end and the vehicle end of the marketplace have been determined. In short, pipelines are unlikely to be the main hydrogen transport means until the post-2030 period.

Trailers carrying compressed hydrogen canisters are a flexible means of delivery but are relatively expensive because hydrogen has such a low energy density. Even with technology advances, a 40-metric-ton truck might deliver only about 400 kg of hydrogen into onsite high-pressure storage. A 2003 study by ABB researchers found that for a delivery distance of 300 miles, the delivery energy approaches 40 percent of the usable energy in the hydrogen delivered. Without dramatic improvement in high-pressure storage systems, this approach seems impractical for large-scale hydrogen delivery.

Producing hydrogen onsite at local fueling stations is the strategy advocated by those who want to deploy hydrogen vehicles in the next two decades. Onsite electrolysis is impractical for large-scale use because it would be highly expensive and inefficient while generating large amounts of greenhouse gases and other pollutants. The hydrogen would need to be generated from small CH_4 reformers. Although onsite CH_4 reforming seems viable for limited demonstration and pilot projects, it is impractical and unwise for large-scale application, for a number of reasons.

7.4 Hydrogen Economics

Globally, interest in hydrogen as an alternative to fossil fuels is soaring. Making the transition is complex, however. Let’s look at the important questions to consider and how to successfully navigate the complexities to ensure viable project development and outcomes. Hydrogen has a unique set of properties that make it an attractive alternative to fossil fuels.

There is huge and growing momentum around hydrogen (H_2). The Hydrogen Council is a good barometer for the exponential interest in exploiting H_2 as an energy carrier. Formed in 2017, this global CEO-led initiative already has 109 members. These energy, transport, industry, and investment companies collectively have total revenues of more than $23.2 trillion and employ more than 6.5 million people worldwide.

The United States, Australia, Canada, Chile, China, Finland, Germany, Japan, the Netherlands, New Zealand, Norway, Portugal, Russia, South Korea, Spain, and the UK among others have established R&D programs, hydrogen vision documents, roadmaps, and strategies. In the US, the Fuel Cell and Hydrogen Energy Association released its “Roadmap to a US Hydrogen Economy” in October 2020, while the Department of Energy published its “Hydrogen Program Plan” in November 2020. With appropriate steps, the DOE estimates that H_2 could add up to $140 billion a year to the US economy by 2030, and as much as $750 billion a year by 2050. US employment in the hydrogen space could be increased by up to 700,000 jobs by 2030 and up to 3.4 million jobs by 2050.[73]

7.5 Hydrogen Vehicles

Converted back to electricity via fuel cells or direct combustion in thermal power units, hydrogen would respond rapidly to meet peaks in demand, or fill longer troughs in supply. It would also supply residential, commercial and industrial customers with energy in the form of hydrogen for heating, cooking and industrial processes – creating, by 2050, a zero-carbon system across heating as well as power. Meanwhile, in the transport sector hydrogen fuel cell vehicles would compete with those powered by electric battery.

“Hydrogen can act as a storage medium and as an energy carrier – like conventional hydrocarbons. As an energy carrier, it has different uses in a variety of sectors, including the ability to take surplus renewable energy generated during the summer and store it for winter, reducing dependence on natural gas as a backup to renewables in the power sector,” says Chris De Beer, energy storage engineer at Mott MacDonald. To get there, large-scale hydrogen production plants must be piloted, while pipeline networks and end-use appliances need to be converted to use hydrogen. [74]

7.6 What’s happening around the world?

Hydrogen is the most abundant element in the universe — and the lightest. It is odorless and nontoxic. It has the highest energy content by weight — almost three times that of gasoline — and when burned, its only byproduct is water.

A key challenge is producing H_2 at a competitive price, without adding carbon to the atmosphere. Others are around the safe storage and transport of hydrogen.

Given all these characteristics, it is logical that hydrogen (H_2) has been talked about over the past 100 years as a potential replacement for burning hydrocarbons to generate electricity and power transportation.

Over the past decade, electric vehicles (EVs) have become more popular and this trend is set to continue. At the same time, auto manufacturers are developing hydrogen fuel cell electric vehicles, as these can travel further without refueling and are quicker to refuel than recharging an EV.

Around the world, there are currently few hydrogen fuel cell EVs on the roads compared with millions of standard and hybrid EVs. Some challenges must be overcome before hydrogen fuel cell EVs become equally common.

7.7Asia Pacific Initiatives

Carbon neutral

The first company in the class to become carbon neutral globally. Global carbon footprint was cut by 45% per employee between 2015 and 2019 and are on track to reduce total emissions by a further quarter by 2024.

In 2020 investigation in the restoration of peatland in Sumatra, Indonesia will be conducted. CO2 is sequestered from the atmosphere as plants grow and, as they decompose and convert to peat, that carbon is locked into the ground.

The Asia Pacific are committed to being a net-zero organization by 2040, meaning that we will achieve a scale of value-chain emissions reduction consistent with pathways that limit global warming to 1.5°C above pre-industrial levels. Neutralizing on the impact of any residual emissions by permanently removing an equivalent amount of atmospheric CO2.

The Asian context

The Asian Subcontinent division includes over 1000 qualified professionals engaged across a range of sectors, such as transport, industry, energy, water, environment, urban infrastructure and social development.

The breadth of India projects employ professionals working in an array of different roles, including design engineering, project management, planning, site engineering covering different disciplines like civil, architect, MEP, infrastructure engineering, mechanical, electrical, piping/pipeline, process engineering, environmental engineering, instrumentation, HVAC, fire protection system and safety.

Provision of opportunities on challenging and exciting projects that are key to the visionary development of the Subcontinent, such as design and development of metro stations in major Indian cities, planning of major airports, port developments, urban construction, inter-urban and industrial estates, and numerous other urban infrastructure development projects. Projects on which provide advisory, basic engineering, conceptual design, detail design/engineering, project and construction management including EPCM assignment include chemical, pharmaceuticals, FMCG, capital goods industry, synthetic fiber, agro industry, oil/gas and petrochemical sectors.

7.8 Where are we on the journey?

7.8.1 Social outcomes

We have a proud history of working with the poorest and most vulnerable people in low-, medium- and high-income countries. We have social inclusion specialists based around the world. In 2017, we created our global social practice, providing an international platform for the growth of our social skills and capabilities. Our network of social inclusion specialists – with over 500 members from more than 35 countries – makes us unique among our competitors. We provide services to clients in the areas of equality, diversity, accessibility, participation, social care, social protection, women’s empowerment, human rights, impact assessment and due diligence. The core business of our social practitioners is to make a positive difference to people’s lives. Our business leaders recognize that inclusion skills and expertise are relevant not only to social practice projects but to all of our projects. The delivery of community-responsive solutions is at the heart of all that we do. Delivering better, more inclusive social outcomes is a central element of our value proposition. To deliver on our ambitions we have developed our social outcomes framework. It defines what we are aiming to achieve: communities characterized by accessibility, inclusion, empowerment, resilience and wellbeing. Our social transformation model sets out the steps of a major project and identifies actions that can be taken at each stage to maximize the benefits we deliver for people. We are working with colleagues across the business to identify the most appropriate ways to use these tools, and the expertise of our social practice, so that we can influence our clients and partners from thought leadership through to every stage of project delivery.

7.8.2 Green-house emissions

We have been tackling the root causes and implications of greenhouse gas emissions since the evidence showed that greenhouse gas concentration in the atmosphere could lead to significant problems. In the last decade, we have been instrumental in setting the agenda to reduce carbon dioxide in infrastructure asset delivery and management, recognizing that this also makes good business sense by cutting cost and unleashing innovation. We have reduced our global carbon footprint by 45% per employee over the last five years and are on track to reduce the absolute figure by a further 25% by 2024. We are demonstrating our future intent by identifying particularly polluting industries, such as coal-fired power generation, and withdrawing from those markets.

7.8.3 Climate change

Our global climate resilience team was established in 2014 to address the growing climate change needs of our clients and manage our own exposure to the risk of climate change. Resilience services focus on helping clients understand and control their risks, considering robustness, redundancy, recovery and responsiveness in their systems and the way they deliver and manage their assets. Our approach links our knowledge of climate science and hazards to the design and management of social and economic infrastructure. We assist our clients in assessing their exposure to risk from the physical impacts of climate change. And we develop resilience strategies involving changes to our clients' assets and operating systems, to reduce losses. This helps our clients justify investment in climate resilience, understand their residual risks, develop adaptation pathways which allow investment in planned stages rather than all at once, and disclose their financial risks. Our Group's interdisciplinary skills support this approach, including consideration of how our projects affect the resilience of the environments and communities in which they are located. We have supported our clients in innovating on their projects and in becoming industry leaders across sectors and in all regions of the world. Our thinking on how business, infrastructure and society must respond to climate change is set out in two key publications: Climate change and business survival and Mission possible. We have demonstrated our expertise in key international forums by contributing to the latest reports published by the Intergovernmental Panel on Climate Change, as well as by presenting our work at the international climate summits. Awareness of the increasing risks posed by climate change is also driving changes to our own business management processes – we are working on a program to manage our own exposure to climate risks.

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