6th

WORLD HYDROGEN EXPO 2025

Conference

Program Book

Dec 4(Thu) – Dec 7(Sun), 2025

Kintex, S. Korea

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Hydrogen Deep Dive I : Global Hydrogen Outlook

Hydrogen Deep Dive II : International Hydrogen Technology Standardization

Hydrogen Deep Dive III : Clean Ammonia

Hydrogen Deep Dive V : Hydrogen : Future to TECH

Hydrogen Deep Dive I : Global Hydrogen Outlook

December 5 (FRI), 13:30-16:00 **Venue : Hall 6C, KINTEX II**

Time		Program	Title / Speaker
Global Business Outlook			
09:30-09:45	15'	Speech	Global State of Play of Hydrogen **Ivana Jemelkova** (Chief Executive Officer, Hydrogen Council)
09:45-10:00	15'	Speech	Global Hydrogen Policy and Market Trends **Neal Won** (Principal Analyst, S&P Global)
10:00-10:15	15'	Speech	Hydrogen for Development: 10 GW Lighthouse Initiative **Myoe Myint** (Senior Energy Specialist, World Bank)
10:15-10:30	15'	Speech	Overview of the Northeast Asia Clean Hydrogen Power Generation Market **Lim Yeon Yi** (Senior Manager, KPX)
10:30-10:45	15'	Speech	H2Global: A Novel Financing Mechanism to Accelerate Global Clean Hydrogen Trade **Markus Exenberger** (Executive Director, H2Global Foundation)
10:45-11:15	30'	Panel Discussion	Investment and Market Growth Outlook of Global Clean Hydrogen Projects Moderator : **Neal Won** (Principal Analyst, S&P Global) Panelists : **Myoe Myint** (Senior Energy Specialist, World Bank) **Lim Yeon Yi** (Senior Manager, KPX) **Markus Exenberger** (Executive Director, H2Global Foundation)
11:15-13:30	135'	**Lunch Break**	
Global Demand Outlook			
13:30-13:45	15'	Speech	LH2-based Global Hydrogen Supply Chain Development and Demand Expansion Strategy **Kenji Yoshimura** (Kawasaki Heavy Industries)
13:45-14:00	15'	Speech	Hydrogen sector in Spain **Javier Brey** (President, Spanish Hydrogen Association (AeH2))
14:00-14:15	15'	Speech	POSCO HyREX Development Status **Jang Hoi Choi** (General Manager, Posco Holdings)
14:15-14:30	15'	Speech	Power Transition in Data Centers **Inki Choi** (Senior Manager of Strategy and Marketing, Bloom Energy Korea)
14:30-14:45	15'	Speech	Green Hydrogen and Regional Decarbonisation: Helios Project at Port Augusta to Support Local Superpower Industries **Jong Hwa Lee** (Head of Ammonia Hydrogen Business and Executive Vice President, Hanwha Impact)
14:45-15:00	15'	**Break Time**	
15:00-15:15	15'	Speech	Mobility Sector Hydrogen Demand and Market Outlook **Yong Tae Kimm** (Vice President, Hyundai Motor)
15:15-15:30	15'	Speech	India's Industrial Hydrogen Demand and Market Growth Outlook **Nishaanth Balashanmugam** (CEO, GH2 India)
15:30-16:00	30'	Panel Discussion	Hydrogen Price Stability and Its Impact on Global Demand Expansion Moderator : **Nishaanth Balashanmugam** (CEO, GH2 India) Panelists : **Kenji Yoshimura** (Kawasaki Heavy Industries) **Jang Hoi Choi** (General Manager, Posco Holdings) **Inki Choi** (Senior Manager of Strategy and Marketing, Bloom Energy Korea) **Jong Hwa Lee** (Head of Ammonia Hydrogen Business and Executive Vice President, Hanwha Impact) **Yong Tae Kimm** (Vice President, Hyundai Motor) **Ralph Foong** (Chief Hgydrogen Officer, City Energy)

Hydrogen Deep Dive II : International Hydrogen Technology Standardization

December 5 (FRI), 10:00-11:15 **Venue : Room 301, KINTEX II**

Time		Program	Title / Speaker
			Global Clean Hydrogen Technology Standardization Strategy
10:00-10:15	15'	Speech	Proposed US Regulations and Impact on Global Hydrogen Compliance and Certification **Frank Wolak** (President, Fuel Cell and Hydrogen Energy Association)
10:15-10:30	15'	Speech	Status and Strategy of Korea's Hydrogen Fuel Cell Standardization (IEC/TC 105) **Hong-Ki Lee** (Chair, IEC/TC 105) (Vice President, Woosuk University)
10:30-10:45	15'	Speech	Global Clean Hydrogen Technology Standardization Strategy **Laurent Antoni** (Executive Director, IPHE)
10:45-11:00	15'	Speech	Hydrogen Technology Standardization in Europe and Germany : A Catalyst to Drive Green Hydrogen Solutions **Klemens Ilse** (Deputy Director, Fraunhofer IWMS)
11:00-11:15	15'	Speech	Commercial Hydrogen Measurement Standards Development of United States & California **Kevin Schnepp** (Director, California Department of Food and Agriculture)
11:15-11:45	30'	Panel Discussion	Investment and Market Growth Outlook of Global Clean Hydrogen Projects Moderator : **Laurent Antoni** (Executive Director, IPHE) Panelists : **Hong-Ki Lee** (Chair, IEC/TC 105) (Vice President, Woosuk University) **Klemens Ilse** (Deputy Director, Fraunhofer IWMS) **Kevin Schnepp** (Director, California Department of Food and Agriculture)

Hydrogen Deep Dive III : Clean Ammonia

December 5 (FRI), 10:00-11:15 **Venue : Room 302, KINTEX II**

Time		Program	Title / Speaker
			Global Technology and Policy Trends for the Expansion of Clean Ammonia
10:00-10:15	15'	Speech	Global Clean Ammonia Market and Outlook **Alexander Oliver Bower** (Global Head of Marketing & Sales, Gentari Hydrogen Sdn Bhd)
10:15-10:30	15'	Speech	Ammonia Cracking Technologies: Status and Outlook **SeongHoon Woo** (CEO, Amogy)
10:30-10:45	15'	Speech	Development of Ammonia Fuel System for Marine Applications **HoKi Lee** (Vice President, Samsung Heavy Industries)
10:45-11:00	15'	Speech	Progress and Outlook of the Green Ammonia Project by Hive Energy **Colin Loubser** (CEO, Hive Energy Africa)
11:00-11:15	15'	Speech	Investment Strategy for Green Ammonia Infrastructure in Korea **KwangJun Kim** (Senior Executive Director, Saman Corporation)
11:15-11:30	15'	Speech	Ammonia Adsorbents as Key Enabling Technologies for a Clean Ammonia Society **KwangBok Yi** (Professor, Chungnam National University)
11:30-12:00	30'	Panel Discussion	Technological and Economic Challenges for Clean Ammonia Utilization Moderator : **KwangBok Yi** (Professor, Chungnam National University) Panelists : **Alexander Oliver Bower** (Global Head of Marketing & Sales, Gentari Hydrogen Sdn Bhd) **SeongHoon Woo** (CEO, Amogy) **HoKi Lee** (Vice President, Samsung Heavy Industries) **Colin Loubser** (CEO, Hive Energy Africa) **KwangJun Kim** (Senior Executive Director, Saman Corporation)

Hydrogen Deep Dive V : Hydrogen : Future to TECH

December 5 (FRI), 13:00-16:15 **Venue : Room 302, KINTEX II**

Time		Program	Title / Speaker
Breakthroughs in Hydrogen Production Techniques			
13:00-13:15	15'	Speech	From Waste to Value: CCUS & Sustainable Hydrogen Pathways for Industrial Decarbonization **Marat Mayan** (Founder & CEO, Airovation Technologies)
13:15-13:30	15'		Project Helios - Cement Production Decarbonisation through Green Hydrogen **Robert Saunders** (Managing Director, Elecseed)
13:30-13:45	15'		Catalyzed heat exchanger for fuel processing **Amin Mehdipoor** (Business Development Manager, Catator AB)
13:45-14:00	15'		Precision hydrogen flow measurement in SOFC and SOEC applications **Peter Brouwer** (Market Developer Renewable Energy, Bronkhorst High-Tech B.V.)
14:00-14:15	15'		Accelerating clean hydrogen solutions with High-efficiency heat exchangers **MyoungSoo Shin** (Professional of Sales Manager,Alfa Laval)
14:15-14:30	15'		Scaling Economic Industrial Decarbonization: How Utility Global H2Gen® Technology is delivering Decarbonization without Compromise for the Hard-to-Abate Sectors **Vladimir Novak** (Chief Commercial Officer, Utility Global, Inc.)
14:30-14:45	15'	**Break Time**	
Exploring New Hydrogen Storage and Distribution Solutions			
14:45-15:00	15'	Speech	Materials challenges in the Hydrogen Economy **Jens Eichler** (Hydrogen Technology and Business Architect, 3M)
15:00-15:15	15'		Large-scale liquid hydrogen technologies enabling intercontinental hydrogen transportation:Techno-readiness & economic assessment **Sébastien Lichtle** (Director of LH2 Product Line,Air Liquide E&C)
15:15-15:30	15'		BEYOND THE BOND, ADHESIVE SOLUTION FOR HYDROGEN APPLICATION **Hyunseob Shim** (Lead Application Engineer, Henkel Korea)
15:30-15:45	15'		Case Study & Research for Hydrogen Refueling Station Performance Test Apparatus **Moonbeom Heo** (Team Leader, TÜV SÜD KOREA)
15:45-16:00	15'		"Industrializing Hydrogen Storage for Global Mobility" How OPmobility is enabling the next generation of zero-emission transport **Chanjoo Park** (Asia Managing Director, Opmobility)
16:00-16:15	15'		TBD **Mikaa Blugeon-Mered**

WORLD HYDROGEN EXPO 2025 6th
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Hydrogen Deep Dive I：

Global HydrogenOutlook

6th WORLD HYDROGEN EXPO 2025 Conference

Global Business Outlook

Global Business Outlook 1

Global State of Play of Hydrogen

Ivana Jemelkova
Chief Executive Officer, Hydrogen Council

Education
- Charles University, Master's Degree in European Studies
- Charles University, Bachelor's Degree in International Affairs

Professional Career
- Chief Executive Officer, Hydrogen Council, Jun 2024 - Present
- Senior Managing Director, FTI Consulting, 2017 – 2024, Washington, District of Columbia, United States

Speech Summary
Highlighting hydrogen's role in decarbonization, Ivana will outline industry progress, investment needs, and key insights from the Global Hydrogen Compass Report 2025 showing accelerating deployment, falling costs, and growing readiness across value chains.

Company Introduction
The Hydrogen Council is a global, CEO-led initiative that brings together leading companies with a united vision and long-term ambition for hydrogen to foster the clean energy transition.

The Council believes that hydrogen has a key role to play in reaching our global decarbonization goals by helping to diversify energy sources worldwide, foster business and technological innovation as drivers for long-term economic growth, and decarbonize hard-to-abate sectors.

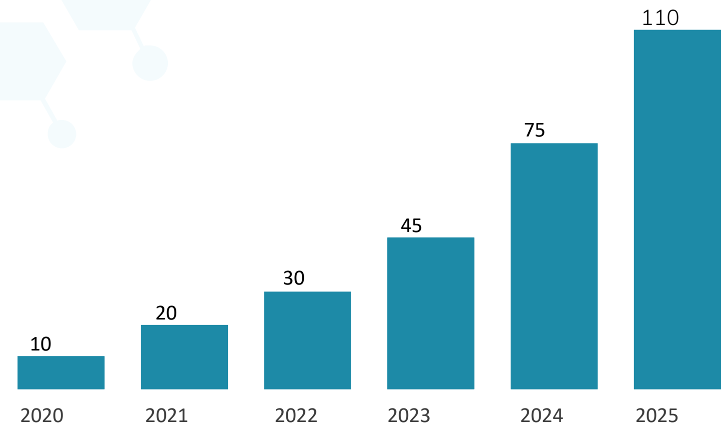
Using its global reach to promote collaboration between governments, industry and investors, the Council provides guidance on accelerating the deployment of hydrogen solutions around the world. It also acts as a business marketplace, bringing together a diverse group of 140+ companies based in 20+ countries and across the entire hydrogen value chain, including large multinationals, innovative SMEs, and investors.

The Hydrogen Council also serves as a resource for safety standards and an interlocutor for the investment community, while identifying opportunities for regulatory advocacy in key geographies.

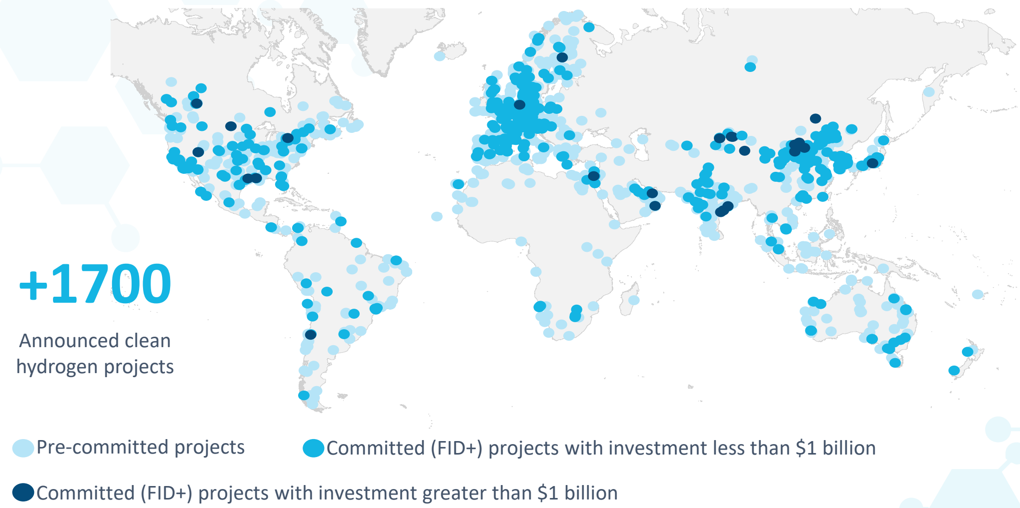
Global hydrogen industry has surpassed USD 110 billion in committed investment

Hydrogen Council

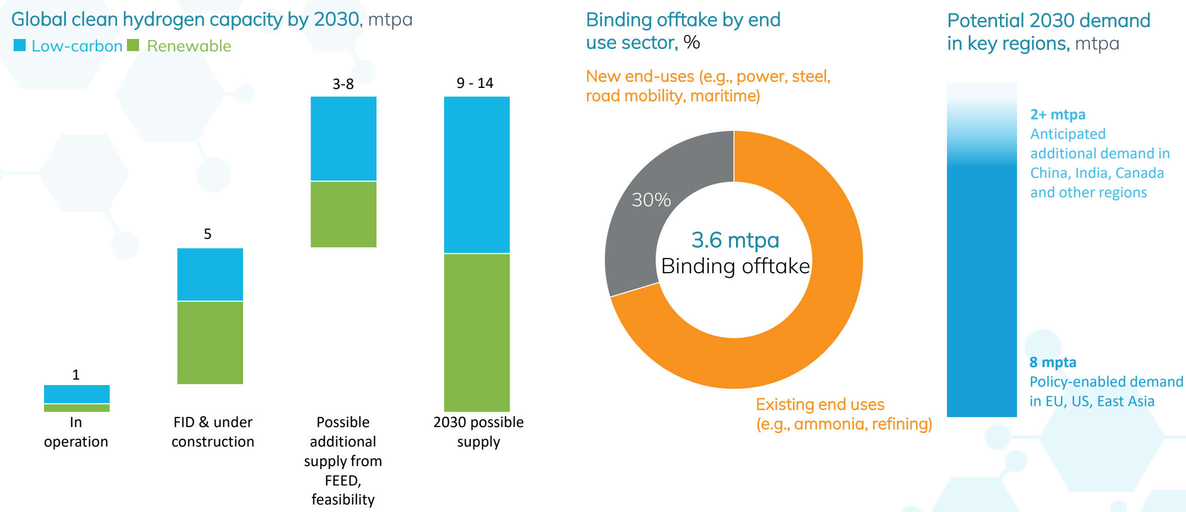
Global cumulative committed (FID+) investment in clean hydrogen projects by 2030, $ billion



There are 510 committed (FID+) projects globally (+83 since May 2024)



Supply is ready to scale, and demand is starting to materialise



China has emerged as a dominant player, followed by North America and Europe

Hydrogen Council

Committed investment by 2030

China	North America	European Union
$33 billion	$23 billion	$19 billion
Global leader in electrolysis deployment, supported almost exclusively by domestic market	Global leader in low-carbon production and exports, with limited domestic demand-side policies	Policy-backed renewable demand center with emerging regulatory clarity

Industry CEOs have a unified message of confidence, clarity, and urgency

Hydrogen Council

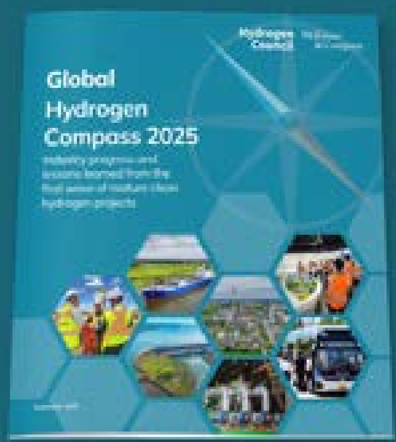
75%
CEOs report stable or increased investment appetite

97%
CEOs believe hydrogen is a critical solution for hard-to-abate sectors

65%
Across economy

83%
CEOs expect growth to continue

Learn more:
compass.hydrogencouncil.com



WORLD HYDROGEN 6th EXPO 2025 Conference

Global Business Outlook 2

Global Hydrogen Policy and Market Trends

Neal Won
Principal Analyst, S&P Global

Education
B.A., Urban Systems, McGill University, Montreal, Canada

Professional Career
Principal analyst at S&P Global Energy's Gas, Power and Climate Solutions team under CERA, based in Seoul. Focused on South Korea's evolving power market fundamentals, the energy transition toward renewables in conjunction with nuclear, and the policy frameworks shaping them. Delivers strategic insight that bridges macro policy shifts with operational realities, supporting institutional and corporate decision-making in a decarbonizing landscape.
Previous experiences include leading Asia-Pacific energy market analysis at Siemens Energy's Gas Services division and providing global macro and renewable market intelligence at Hanwha Solutions while simultaneously performing a freelancer job at S&P Global Market Intelligence covering the Korean Peninsula's geopolitical risks. Served as an intelligence officer at some of the highest echelons of Republic of Korea's military, overseeing real-time missile operations, supporting diplomatic efforts, and arms sales.
Holds a degree in urban systems and philosophy from McGill University. Fluent in English and Korean, with some passive knowledge in French. Growing focus is on the intersection of power, energy, and capital across the global energy industry.

Research Interest
- South Korea Power and Renewables market
- Global LNG Market Dynamics
- APAC LNG and Natural Gas generation
- Global Hydrogen Market Dynamics
- APAC Hydrogen and Ammonia co-firing

Speech Summary
Explore global hydrogen trends, policy frameworks, and market dynamics. Highlight emerging offtake agreements and price insights. Discuss long-term hydrogen outlooks, emphasizing the role of coordinated global policy in advancing clean hydrogen adoption across sectors by 2050.

Company Introduction
At S&P Global Energy we deliver a comprehensive view of global energy and commodities markets that enables you to make superior decisions and create long-term sustainable value for your business.
Our four core capabilities bring clarity to the kinetic: S&P Global Energy Platts delivers pricing and news; S&P Global Energy CERA delivers research and advisory; S&P Global Energy Horizons delivers energy expansion and sustainability solutions; S&P Global Energy Events deliver unparalleled thought leadership and industry collaboration. Together, these resources empower those who power the world.

S&P Global Energy

Global Clean Energy Technology

Global hydrogen policy and market trends

World Hydrogen Expo 2025

Neal Won / Global Power and Renewables / Principal Analyst

December 5, 2025.

Global policy frameworks have come together despite political challenges

Most markets globally established basic definitions and processes needed for low-carbon hydrogen markets

Region	Market	Clean hydrogen definition	Certification process	Demand mechanism	Financial support
ASIA-PACIFIC	Australia	(✓)	(✓)	(✓)	✓
ASIA-PACIFIC	China	✓	(✓)	(✓)	✓
ASIA-PACIFIC	India	✓	✓	(✓)	✓
ASIA-PACIFIC	Japan	✓	✓	(✓)	✓
ASIA-PACIFIC	South Korea	✓	✓	(✓)	✓
EUROPE	European Union	✓	✓	(✓)	✓
EUROPE	United Kingdom	✓	(✓)	(✓)	✓
NORTH AMERICA	United States	✓	(✓)	✗	✓
NORTH AMERICA	Canada	✓	✗	(✓)	✓

Legend: ✗ Conceptual → (✓) → ✓ Fully defined

Data compiled Jul. 15, 2025
Source: S&P Global Commodity Insights.

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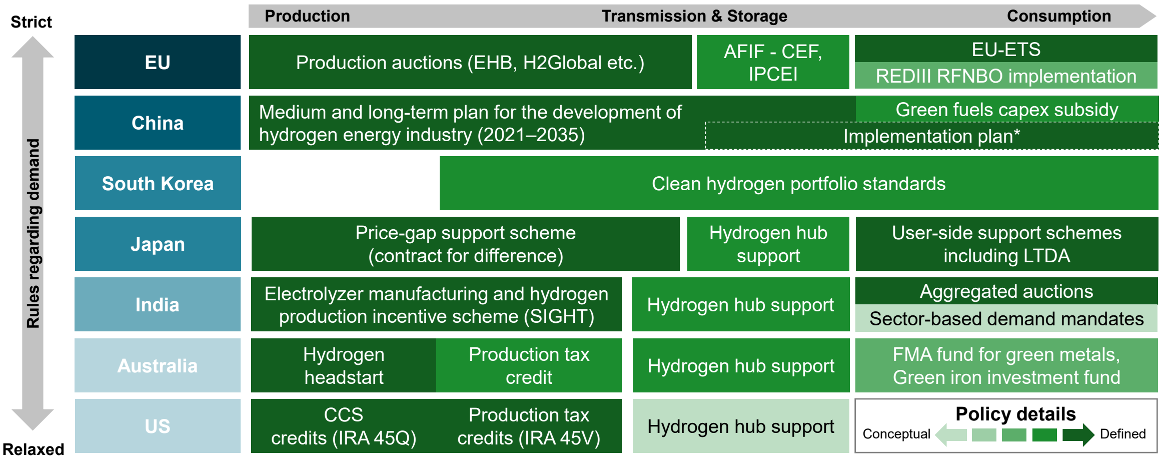
 2

Support policy frameworks are advancing across the supply chain in key markets

Hydrogen support policy landscape in key markets



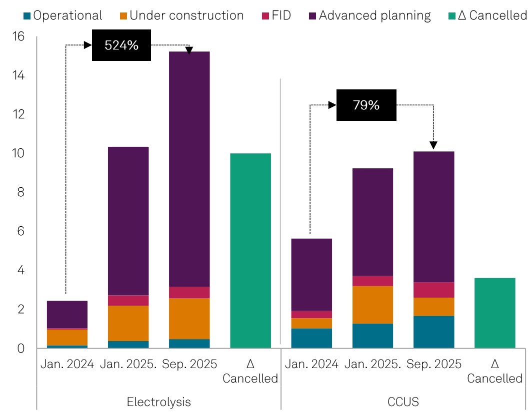
As of September 2025.
EHB = European Hydrogen Bank; AFIF – CEF: Alternative Fuels Infrastructure Facility under Connecting Europe Facility funding; IPCEI = Important Projects for Common European Interest; EU-ETS = European Union emission trading scheme; REDIII = renewable energy directive; RFNBO = renewable fuels of non-biological origin; LTDA = long-term decarbonized-power auction; CCS = carbon capture and storage; FMA = Future Made in Australia.
*Implementation Plan on Accelerating the Deployment of Clean and Low-Carbon Hydrogen in the Industrial Sector, and so on.
Source: S&P Global Commodity Insights.

S&P Global Energy

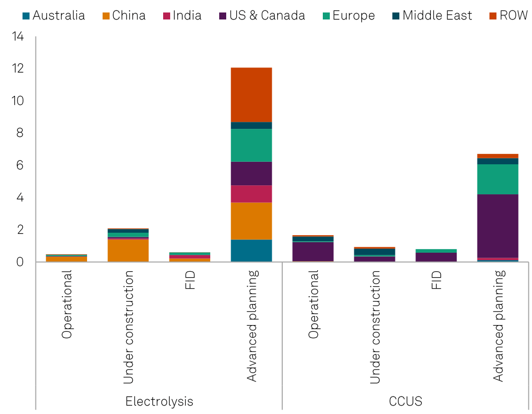
 3

The clean hydrogen project pipeline is maturing even amid geopolitical tensions, with Asia Pacific leading electrolysis and US leading CCS

Advanced and canceled clean hydrogen project capacity, January 2024 to today (MMt/y H_2-e)



Advanced clean hydrogen project capacity, by current status, technology and region (MMt/y H_2-e)



Data compiled Sept. 1, 2025.
MMt/y H_2-e = million metric tons of hydrogen equivalent including derivatives per annum; CCUS = carbon capture utilization and storage; FID = Final Investment Decision; ROW = rest of the world.
Δ Canceled refers to projects canceled" between January 2024 – September 2025. Canceled projects include projects announced as "canceled" or "on hold" by the developers and "dormant" projects where no announcements have been made in over 36 months.
Source: S&P Global Commodity Insights.

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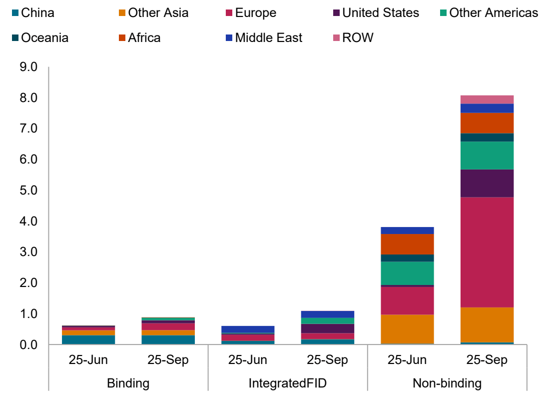
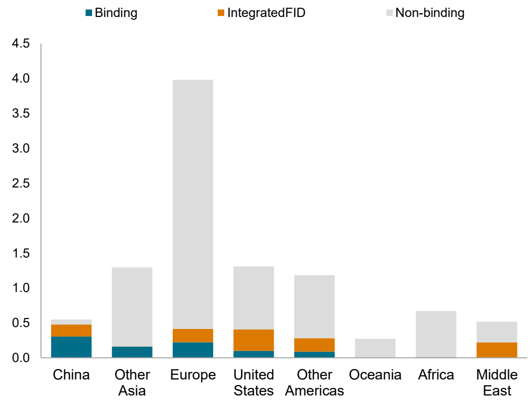
Observations from offtake agreements: Capacities are increasing with Europe leading overall and China leading the most committed agreements

Offtake agreement volumes by production country or region by status (MMt/y H_2)



Offtake agreement volumes by country or region - September 2025 (MMt/y H_2)



Data compiled Sept. 18, 2025.
Source: S&P Global Commodity Insights Clean Hydrogen Offtake Database.

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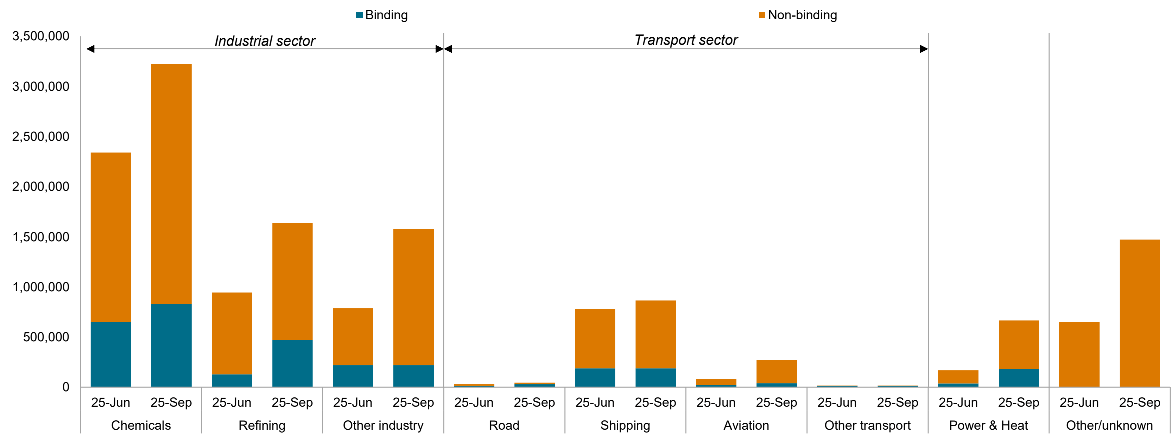
Offtake agreements in industrial applications continues to lead the absolute volume and the growth in volume

Offtake agreement volumes by end-use sector (MMt/y H_2)



Data compiled Sept. 18, 2025.
* Offtake volumes are attributed to the producing country or region to match production capacity projections. Conversion from gigawatt capacity assumes a 50% average capacity factor in China and 60% globally.
Source: S&P Global Commodity Insights Clean Hydrogen Offtake Database.

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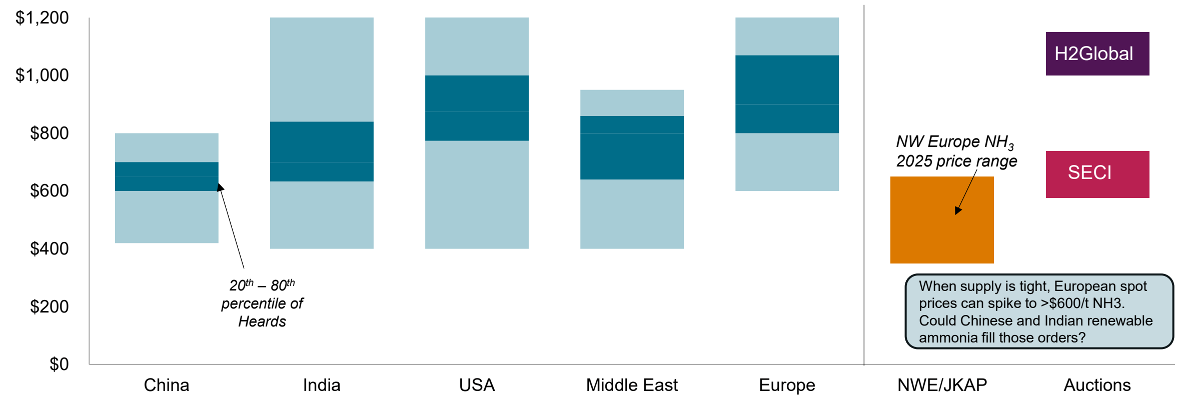
 6

Renewable ammonia indicative prices from China and India at around \$600 – 800/t NH_3 – below cost projections and auction results in the US and Europe

Indicative price Heards and auction results for renewable ammonia compared with traditional ammonia market (\$/mt NH_3)



Data compiled October 7, 2025
Graph shows indicative Heards, not traded prices. Indicative Heards are generally "at-the-gate" and do not include transportation and delivery costs. H2Global range due to fluctuating Euro-to-dollar exchange range.
Source: S&P Global Commodity Insights

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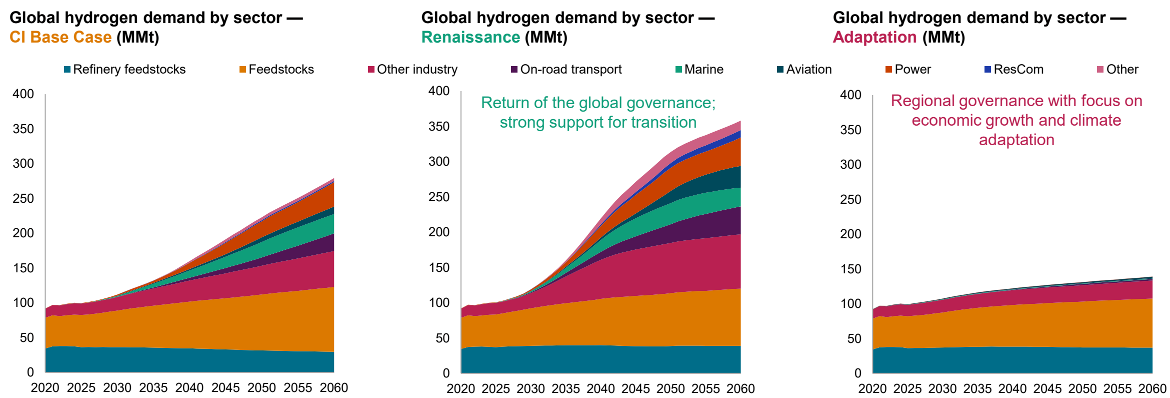
 7

Long-term demand outlook differ significantly across scenarios – adoption in new sectors will require a coordinated global support for transition



	CI Base Case	Renaissance	Adaptation
Global GDP (CAGR 2024–60)	2.4%	2.8%	2.8%
GHG emissions (vs. 2024)	-31%	-71%	+1%
Global temperature (by 2100)	2.5°C	1.9°C	3.2°C

Data compiled July 2025.
ResCom = Residential and commercial. Other consists of hydrogen demand for gas grid blending.
Source: S&P Global Commodity Insights.

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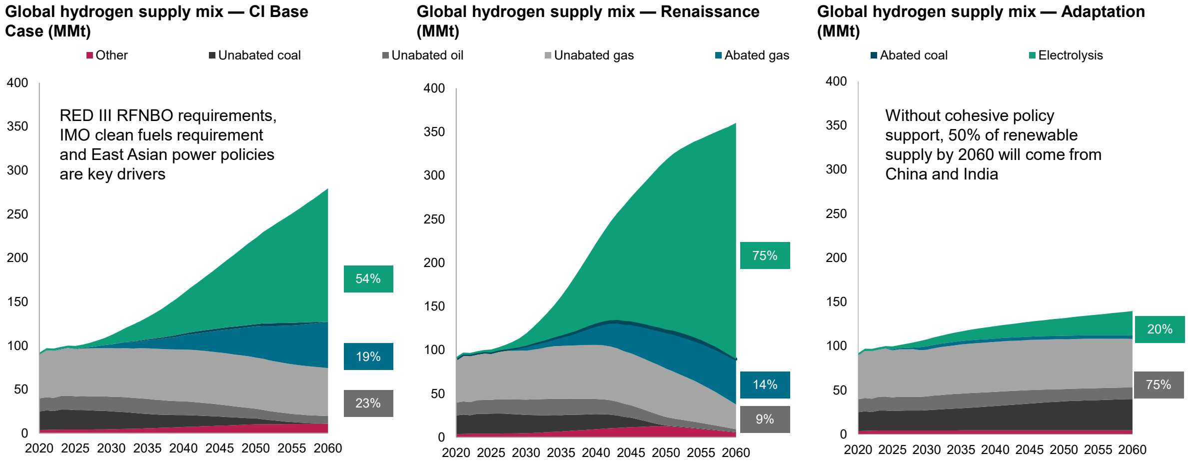
Currently discussed policies could see low-carbon hydrogen grow to 60% of the supply mix in 2050, but cessation of support could see this drop dramatically



Data compiled July 2025.
RED III RFNBO = Renewable Energy Directive III Renewable Fuels of Non-Biological Origin; IMO = International Maritime Organization.
Other consists of hydrogen produced as a byproduct from other chemical production processes, including ethylene cracking byproducts, propane dehydrogenation and ethylbenzene dehydrogenation.
Source: S&P Global Commodity Insights.

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 9

Key messages

- **The policy and regulatory frameworks for the low-carbon hydrogen market have developed in most major markets,** with auctions, grants, and tax credits facilitating project advancements. In the near term, China is expected to dominate renewable electrolysis hydrogen production.
- **Today, binding and non-binding offtake agreements primarily target incumbent sectors,** driven by policy direction, a higher willingness to pay, and ease of implementation.
- **By 2050, hydrogen demand outlooks vary widely depending on the scenario.** Globally coordinated policy will be crucial for the adoption and growth of clean hydrogen consumption in non-traditional sectors.

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 10

Contact us

Primary contact

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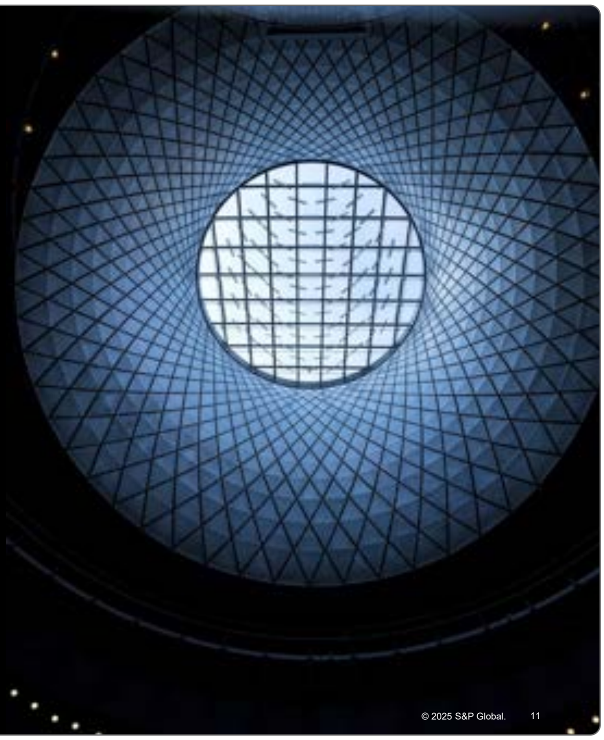

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WORLD HYDROGEN 6th EXPO 2025 Conference

Global Business Outlook 3

Hydrogen for Development: 10 GW Lighthouse Initiative

Myoe Myint
Senior Energy Specialist, World Bank

Education
2006-2007, MPA, International Energy Management and Policy, Columbia University, New York, USA
1999-2001, MBA, Yangon Institute of Economics, Yangon, Myanmar
1986-1995, B.E., Yangon Institute of Technology, Yangon, Myanmar

Professional Career
2015-Present, Senior Energy Specialist, The World Bank, Songdo, Korea
2003-2014, Energy Analyst, ITOCHU International Inc., New York, USA

Research Interest
Myoe Myint serves as Senior Energy Specialist and plays a pivotal role on the World Bank Korea energy team. He oversees initiatives to facilitate the sharing of Korea's development experience and technical expertise with developing countries throughout the East Asia and Pacific region. As the task team leader, he is responsible for the implementation of World Bank energy operations in Korea, Myanmar, Micronesia, and the Marshall Islands, as well as providing support for regional energy transition initiatives in the East Asia and Pacific region. Myoe is involved in multiple World Bank initiatives across the region, including projects in the Solomon Islands, Papua New Guinea, the Philippines, Thailand, and other Pacific Island countries.
Myoe has approximately 25 years of professional experience working in energy project development across Southeast Asia, Latin America, and North America. His expertise includes research on energy sector development in these regions. Myoe Myint is a World Bank scholar with a Master of Public Administration focused on International Energy Management and Policy from Columbia University (2007), an MBA from Yangon Institute of Economics (2001), and a Bachelor of Engineering in Electronics from Yangon Institute of Technology (1995).

Speech Summary
The 10 GW Hydrogen Lighthouse Initiative is a World Bank–led ESMAP program launched at COP28 to accelerate clean (renewable) hydrogen in emerging markets and developing countries by de-risking and financing a first wave of mid- to large-scale projects (roughly 100 MW to 1 GW each) totaling about 10 GW of electrolyzer capacity. It aims to prove commercial viability, lower costs, and create replicable models for hard-to-decarbonize sectors like steel and long-haul transport, using tailored risk mitigation instruments and coordinated support from development finance institutions and private investors.
One of the most significant barriers to clean hydrogen's growth is its high production and financing costs, particularly in developing countries. World Bank role includes designing financing mechanisms to reduce these costs and de-risk projects. By addressing uncertainties around future buyers, pricing, and regulatory conditions, the World Bank aims to attract investment and encourage the development of clean hydrogen infrastructure. World Bank is particularly focused on lowering financial risks, working with its partners to make clean hydrogen projects more commercially viable and thus paving the way for broader adoption. In FY2024 the World Bank approved 1.6 billion in funding for renewable hydrogen loans, in addition to the $1.65 billion approved in FY2023, bringing the total loan amount for hydrogen activities to $3.25 billion. Investments up to $3 billion are currently in preparation.
In partnership with other stakeholders, World Bank is also developing a digital hub to support knowledge sharing, training, and technical assistance. The platform will serve as a resource for countries and stakeholders looking to implement clean hydrogen projects. It will also help connect governments, investors, and technical experts, promoting collaboration and enabling stakeholders to benefit from shared knowledge and expertise.

Company Introduction
The World Bank is a global development bank providing finance, knowledge to reduce poverty and boost prosperity.
https://www.worldbank.org/ext/en/home

Global Business Outlook 4

Overview of the Northeast Asia Clean Hydrogen Power Generation Market

Lim Yeon Yi
Senior Manager, KPX

Education
2016-2021, Ph.D., Economics, SoongSil University, Seoul, Korea
2014-2016, M.S. Economics, SoongSil University, Seoul, Korea
2010-2014, B.S., Economics, SoongSil University, Seoul, Korea

Professional Career
2022-Present, Hydrogen Market Team, Market Innovation Department, KPX, Jeollanam-do, Korea

Research Interest
Hydrogen Policy and Clean Hydrogen Power Market Design
Energy Markets and Power System Economics
Climate and Decarbonization Policy
Energy Price Analysis

Speech Summary
This Speech provides an overview of Korea's clean hydrogen power generation bidding market and Japan's long-term decarbonized capacity auction. It outlines policy backgrounds, market design principles, bidding and evaluation structures. Through this, it offers insights into policy trends and future institutional directions for the Northeast Asian hydrogen power market.

Company Introduction
KPX is Korea's independent system and market operator, ensuring transparent electricity markets and reliable grid operations. As Asia's first ISO-style power exchange, KPX is at the forefront of the global energy transition, connecting Korea to international standards.
The Hydrogen Council also serves as a resource for safety standards and an interlocutor for the investment community, while identifying opportunities for regulatory advocacy in key geographies.


smart KPX 전력거래소 KOREA POWER EXCHANGE
Overview of the Northeast Asia Clean Hydrogen Power Generation Market
K O R E A P O W E R E X C H A N G E
2025.12.05.
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smart KPX 전력거래소 KOREA POWER EXCHANGE
Korea's Hydrogen Power Generation Bidding Market Overview
K O R E A P O W E R E X C H A N G E
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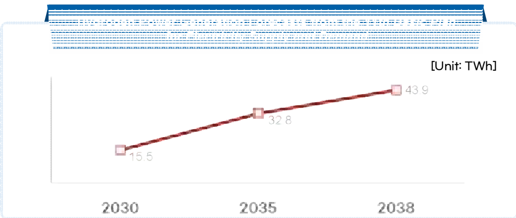
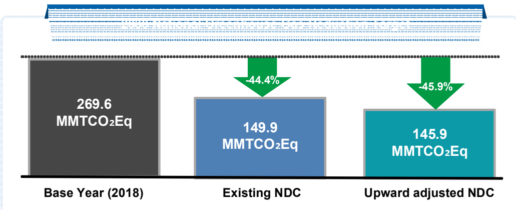
Background

KPX 전력거래소 KOREA POWER EXCHANGE

Reduction of Greenhouse Gases in the Power Generation Sector

- Use clean hydrogen as fuel to generate electricity
  →Achieving carbon neutrality through carbon-free power sources such as nuclear power and renewable energy





Establishing a Full Hydrogen Value Chain

- Complementing the limitations of the existing RPS scheme to expand hydrogen-using power plants and create stable hydrogen fuel demand
- Foster related industries and build the foundation for a hydrogen economy by generating large-scale clean hydrogen demand and ensuring stable investment and cost recovery for businesses through long-term fixed-price contracts

	Renewable Portfolio Standard	Hydrogen Power Generation Bidding Market
Legal Basis	Article 12-5 of the Renewable Energy Act	Article 25-6 of the Hydrogen Act
Subject of Trade	Renewable energy certificate (REC)	Electricity generation by Hydrogen power(kWh)
Obligated Party	Power generators	Power Sales Companies
Settlement Method	SMP + REC	Fixed price contract
Contract Duration	20 years	20 or 15 years
Competitive Factors	Price + non-price factors	Price + non-price factors

K O R E A P O W E R E X C H A N G E | 3

Progress and Foundation

KPX 전력거래소 KOREA POWER EXCHANGE

- Feb. 2021 — Enforcement of the Hydrogen Act
- Nov. 2021 — Establishment of the first basic plan for transiting to a hydrogen economy
- June 2022 — Amendment of the Hydrogen Act
- Nov. 2022 — Establishment of a plan to create a clean hydrogen ecosystem
- Dec. 2022 — Amendment of the Enforcement Decree and Enforcement Regulations
- Jan. 2023 — Designation of a management agency for the bidding market
- May 2023 — Announcement of purchase volume and enactment of management regulations
- June 2023 — The first opening of a market for general hydrogen power
- May 2024 — The first opening of a market for clean hydrogen power

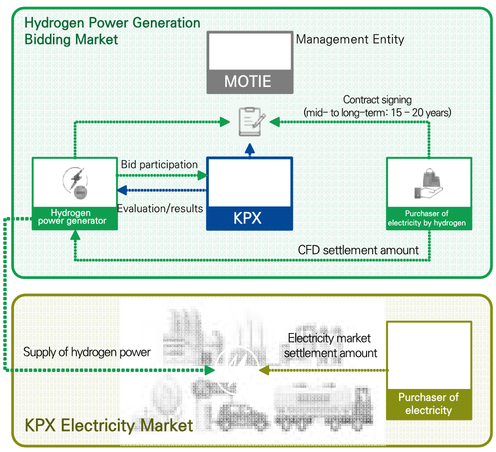
Legal Basis

Opening of Hydrogen Power Generation Bidding Market (MOTIE)

- **Article 25-6 of the Hydrogen Act (Purchase or Supply of Amounts of Hydrogen-Generated Electricity)**
  The Minister of Trade, Industry and Energy may establish a bidding market for hydrogen power generation (hereinafter referred to as "bidding market") to facilitate the implementation of the hydrogen economy. In such cases, a successful bidder in the bidding market shall be determined from among hydrogen power generation business entities meeting the standards prescribed by the Presidential Decree, such as resident acceptance.

Management Agency for the Bidding Market (KPX)

- **Article 25-7 (Designation of Agencies Managing Bidding Market)**
  To efficiently operate a bidding market, the Minister of Trade, Industry and Energy may designate an institution, an organization, or a corporation related to hydrogen business or electricity transactions that meet the standards prescribed by the Presidential Decree, such as facilities and human resources, as an agency managing a bidding market (hereinafter referred to as "management agency").



K O R E A P O W E R E X C H A N G E | 4

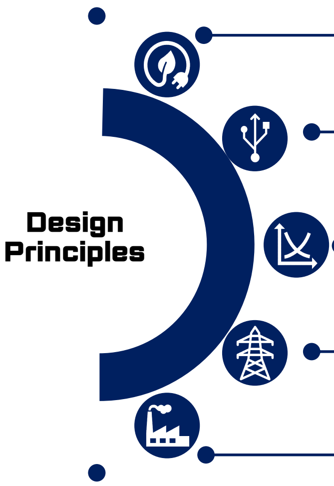
Market Segmentation

While making unnecessary classification of the market should be avoided to promote the competition of businesses, the market should be classified into a general and clean hydrogen market per policy objectives.

	General Hydrogen Market	Clean Hydrogen Market
Purpose	Maximizing the role of **distributed generation expansion**	**Reducing greenhouse gas emissions** through **mandatory clean hydrogen use**
Subject of Participation	Technology-neutral	
	New hydrogen firing plant (RPS-unregistered)	**New clean hydrogen firing and co-firing plants** (RPS-unregistered)
Fuels Used	**Clean hydrogen** Allows **reformed(grey) and by-product hydrogen**	**Clean hydrogen**
Features	▪ Opened considering the limitations of the initial introduction of clean hydrogen ▪ After the stabilization of clean hydrogen production and introduction in the future, the **general hydrogen market will be closed.**	▪ Since the beginning, the bidding market was established targeting power producers that **use clean hydrogen**

Basic Design Principles

To achieve the objectives of the Hydrogen Act, five basic principles are comprehensively considered: environmental friendliness, technology, economic feasibility, impact on electric power system, and industrial ecosystem



1. **Environmental Friendliness**
   Encouraging transition to clean hydrogen which has no greenhouse gas emissions
2. **Technology**
   Promote diverse and innovative power generation technologies through technology-neutral competition
3. **Economic Feasibility**
   Ensuring price competitiveness(Lowering the hydrogen generation cost) and formation of a stable hydrogen fuel price
4. **Impact on Electric Power System Grid**
   Strengthening site / transmission linkages and use of flexible resources
5. **Industrial Ecosystem**
   Strengthening the competitiveness of the hydrogen economy industry and establishing a growth foundation for each ecosystem

Basic Operational Framework

Application of the operating rules of the hydrogen power generation bidding market

- Market opening
- Evaluation of bids and selection of successful bidder
- Contract signing and Construction management

Application of the *Electricity Market Management Regulations*

- Commencement of commercial operation
- Linkage with spot market
- Metering, settlement, and payment

Decision-making through a committee of experts

Hydrogen Power Generation Bidding Market Committee
Making decisions on key matters such as market opening, management, contracts, and post-management, and enactment/amendment of management regulations

Working Council
Discussions on key matters related to the management of the bidding market

Design WG
Gathering the opinions of external experts related to the design of the bidding market

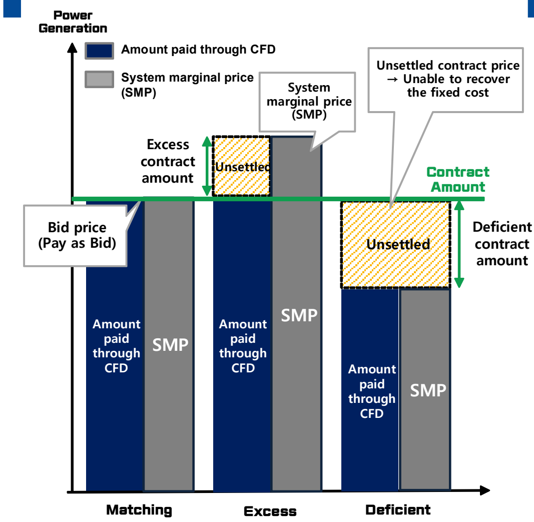
Evaluation Committee
Random selection from the expert pool
Evaluation of business proposals and Selection of successful bidder fairly and transparently

Transparent and fair management of the bidding market through multilateral decision-making.

Basic Operational Framework

1	Market opening
Volume	based on annual purchase notification in the hydrogen power generation bidding market
Contract Duration	Preparation : 3 years (up to 1-year grace period) Trading : 15 years
Require-ments	(Facility) obtained a power plant license (Financial) Credit rating, Paid-in capital etc. (Environmental) Using Clean hydrogen, at least 20% co-firing ratio etc.
Bid Amounts	Annual hydrogen power generation
Bid Price	LCOE for clean hydrogen power generation Fuel costs can be linked to the exchange rate and Henry-Hub price
Contract	A contract for difference(CfD)

Dealing with Excess/Deficient contract amount



Basic Operational Framework

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2 Evaluation of bids and selection of successful bidder

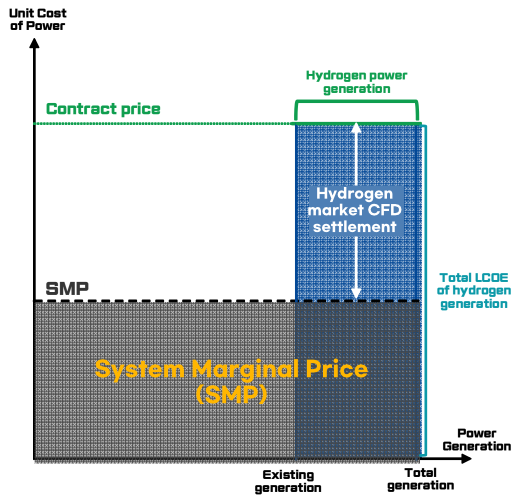
- Evaluating bid proposals meeting participation requirements and within the ceiling price
- A successful bidder is selected by comprehensively evaluating price (60%) and non-price factors (40%)
  - (Price evaluation) Evaluation based on the price proposed by the bidder within the ceiling price
  - (Non-price evaluation) Forming a separate committee to ensure the objectivity of quantitative and qualitative evaluations
- Selection of successful bidders in order of highest total score

※ Tie-breakers : Price → Environmental contribution → Fuel Supply Stability

Price (60%)	Based on lowest price(*)	- fixed costs + operating costs + fuel costs - Calculated as [Lowest bid price / Given bid price] × 60
Non-price (40%)	Quantitative and Qualitative Evaluations	- Calculated as [Overall evaluation score × 0.4] - Considering the market's purpose, greater weight is given to environmental contribution categories - Pass-fail system to ensure business capability

(*) Excluding bid prices of businesses that exceed the ceiling price or fail in non-price evaluation

3 Settlement of Hydrogen Power Generation



'24 Clean Hydrogen Power Generation Bidding Market Results

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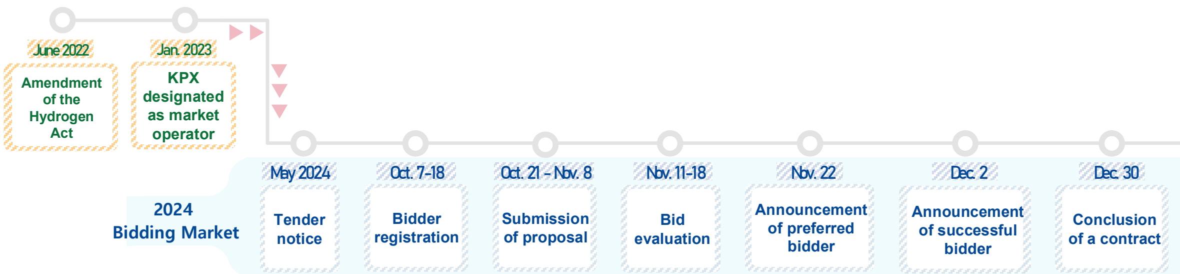
First Bidding Market Opening Progress

- After the formation of a task force for the clean hydrogen power generation bidding market in June 2023, working council management and design, working council review, and committee resolution took place, after which the first clean hydrogen power generation bidding market opened in May 2024.



Acceptance of Bids and Successful Bid Results

- Six power plants (five companies) participated in the bid with volume of 6,172 GWh, and one power plant with 750 GWh was selected as the final successful bidder.

Announced Amount	# of Participating Companies	# of Bids	Total Bid Amount	Proposal Acceptance Rate	Successful Bidder Amount
6,500 GWh	5	6	6,172 GWh	0.95 : 1	750 GWh (1 bid)

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Japan's Long-term decarbonized Power Generation Capacity Auction Overvie

K O R E A P O W E R E X C H A N G E

Background

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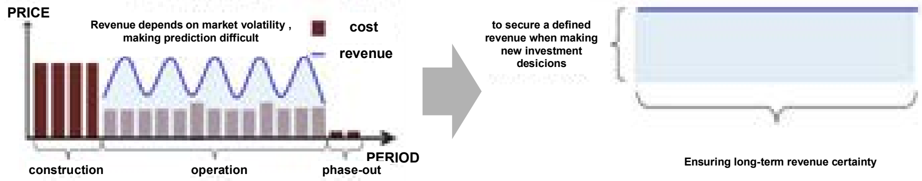
▌ **Securing supply capacity through decarbonized power sources is necessary to achieve carbon neutrality by 2050**

- The capacity market was bifurcated into **the general capacity market** and **the long-term decarbonized capacity market** according to its purpose and function.

General capacity market	To secure the supply capacity required for demand in a future specified period(single year), the auction is conducted 4years prior to the actual delivery year(real supply-demand year)

▌ **Promoting new investment in decarbonized power sources**

- When investing in new power sources, investors require a level of **revenue predictability** that allows for long-term cost recovery.
- By providing producers with greater long-term predictability for investment recovery than existing schemes, **investment in decarbonized power sources is promoted.**



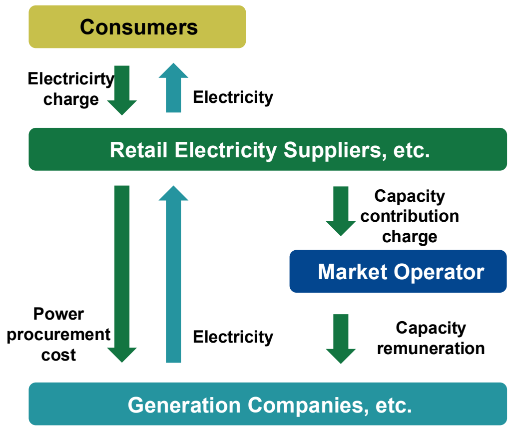
Progress and Operating Framework

KPX 전력거래소 KOREA POWER EXCHANGE

- Oct. 2023 — Registration of participants for the first auction
- Jan. 2024 — The fist opening an auction
- Apr. 2024 — Selection of awardees in the first auction — NH3/H2 820MW
- Jan. 2025 — Announcement of the second aution
- Apr. 2025 — Selection of awardees in the second auction — NH3/H2 94MW

Operating framework

- The central capacity market is operated **by OCCTO**, the cross-regional transmission system operator.
- OCCTO invoices and collects capacity contribution **charges from retail electricity suppliers, general transmission and distribution operators**, and then disburses **the payments to generation companies**.
- The costs associated with securing capacity are ultimately **passed on to end consumers**.



Fundamental elements of market design

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Bidding process

Market opening → Submission of bid proposals → Evaluation and selection of successful bidders → Contract execution → Obligation fulfillment and settlement

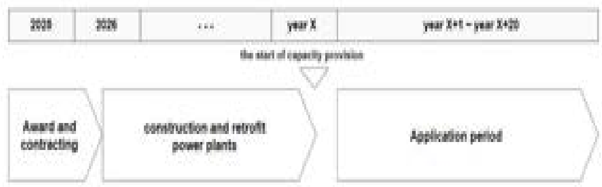
Market opening(based on the second auction market round)

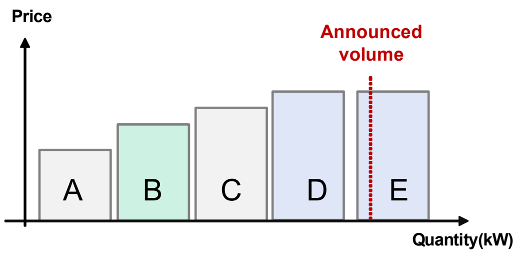
Volume	The total capacity : 5GW Decarbonized thermal capacity* : 500MW
Eligible Entities	Decarbonized stable/variable power LNG dedicated firing is temporarily included
Bid Capacity	For each generator unit, the operator sets the supply capacity(kW) New/replacement Hydrogen full-firing : 100MW or more Retrofit Hydrogen co-firing : 50MW or more Ammonia full or co-firing : 50MW or more

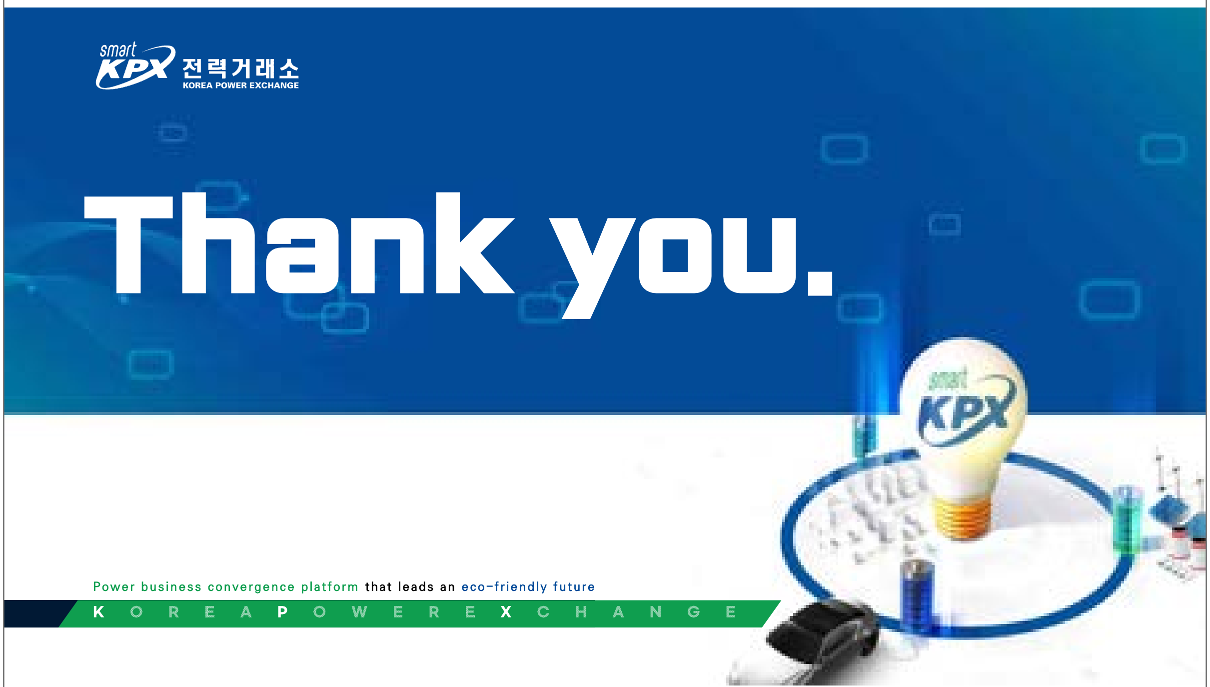
* Ammonia/Hydrogen(co-firing and full-firing), CCS

Fundamental elements of market design

Bid price	▪ Based on capital cost, O&M costs, and project margins(yen/kW/year) ▪ Decarbonized thermal plants(NH3/H2 dedicated or co-firing, CCS) may include variable costs(e.g., fuel) in their bid prices. ※ Limited to the fuel cost differential vs. LNG/coal, Capacity factor capped at 40%
Contract period	20-year period(beginning in the year following the start of capacity provision) While 20-year period is the standard across all resource types, participants may request a longer application period, in one-year increments, if desired.
Evaluation	Awarding proceeds from the lowest bid until the volume is filled To minimize the burden on consumers, ceiling prices are applied by power source and by category (new/replacement or retrofit).
Contract/Settlement	Pay-as-bid







WORLD HYDROGEN 6th EXPO 2025 Conference

Global Business Outlook 5

H2Global: A Novel Financing Mechanism to Accelerate Global Clean Hydrogen Trade

Markus Exenberger
Executive Director, H2Global Foundation

Education

He studied business administration, commercial law and supply engineering at the universities of Cologne and Hamburg.

Professional Career

Worked for Bechtel Corporation and Multiplex in Hong Kong, Singapore, Australia, and the United States.
Consultant for large companies in Germany in the field of energy transformation.
2001–2021: Senior roles at the German Federal Government (GIZ) in South-East Europe, South-East Asia, East Africa, and Brazil; managed major energy programs and advised governments on energy transition and funding mechanisms.
Co-founder and co-developer of the H2Global mechanism.
Chairman of the Executive Board of the H2Global Foundation since establishment.

Research Interest

Clean hydrogen market development
Energy transition policy and funding mechanisms
International energy cooperation
Market-based support instruments for next-generation fuels

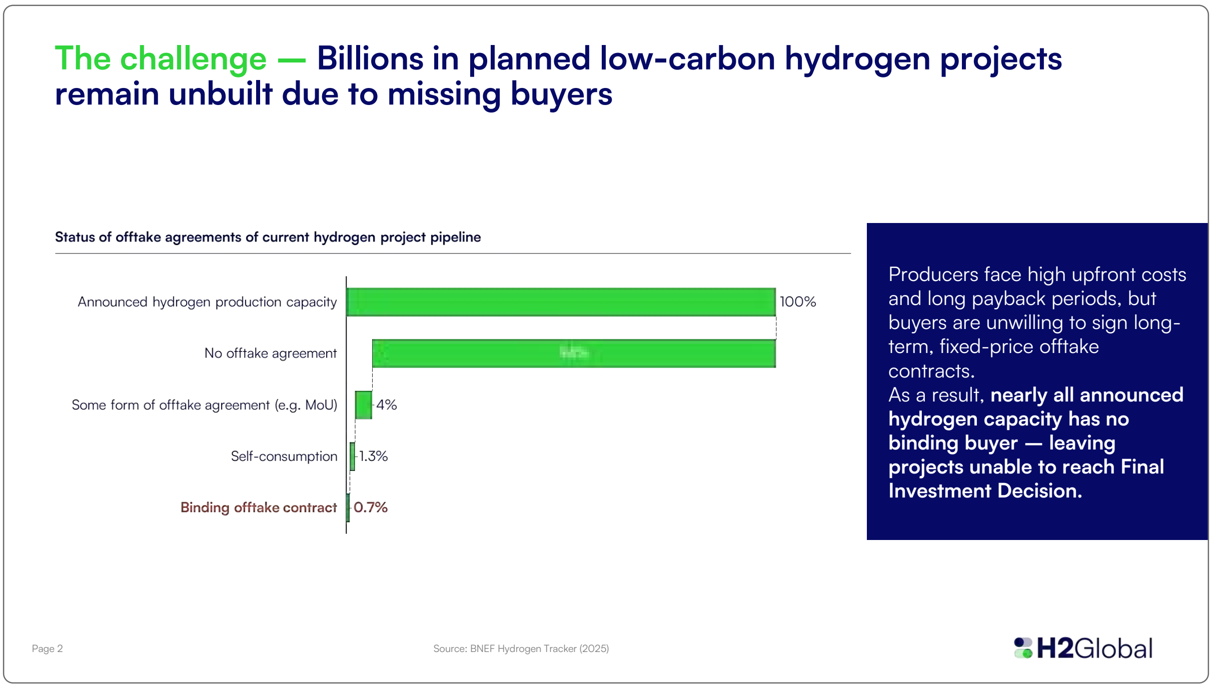
Speech Summary

With around USD 6 billion in funding commitments from four governments, H2Global is currently the world's largest green hydrogen trading platform. This keynote will introduce the H2Global model — an innovative price gap financing instrument designed to bridge price gaps between supply and demand, de-risk early market transactions, and accelerate international hydrogen trade. The presentation will also highlight lessons learned from the European experience and explore how the mechanism can support clean hydrogen market development in other regions.

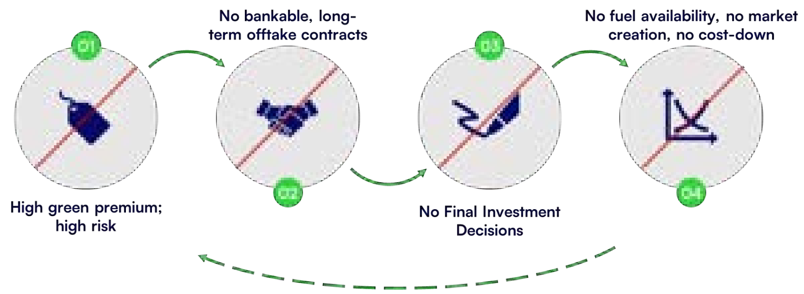
Company Introduction

The H2Global Foundation is a non-profit organization dedicated to creating a global market for clean hydrogen and other low-emission fuels. By promoting a double-auction mechanism, the foundation facilitates the efficient and transparent trade of clean fuels, helping to accelerate the energy transition.


Shaping the global
energy transition.
H2Global: A Novel Financing Mechanism to Accelerate Global Clean Hydrogen Trade
December 2025
H2Global


The challenge — Billions in planned low-carbon hydrogen projects remain unbuilt due to missing buyers
Status of offtake agreements of current hydrogen project pipeline
Announced hydrogen production capacity
100%
No offtake agreement
Some form of offtake agreement (e.g. MoU)
4%
Self-consumption
1.3%
Binding offtake contract
0.7%
Producers face high upfront costs and long payback periods, but buyers are unwilling to sign long-term, fixed-price offtake contracts.
As a result, nearly all announced hydrogen capacity has no binding buyer — leaving projects unable to reach Final Investment Decision.
Page 2
Source: BNEF Hydrogen Tracker (2025)
H2Global

The challenge — Structural market failures prevent low-carbon projects to move forward

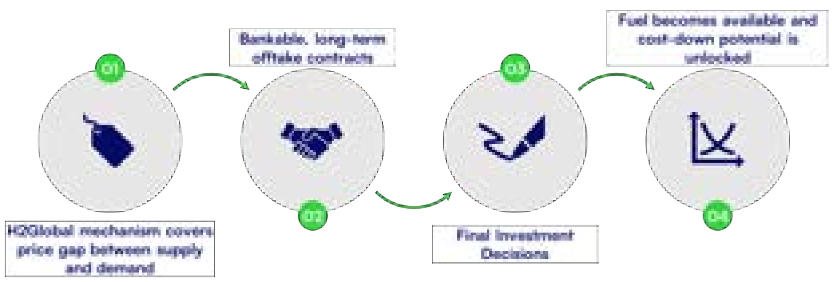


Even when governments set ambitious decarbonization targets, **private actors face too much price risk.**
Without a smart and efficient mechanism to bridge this gap, large-scale projects remain stalled, and clean energy products cannot compete with fossil alternatives.

Page 3

H2Global

The solution — H2Global's double auction mechanism resolves market failures, with the aim to accelerate the emergence of liquid markets

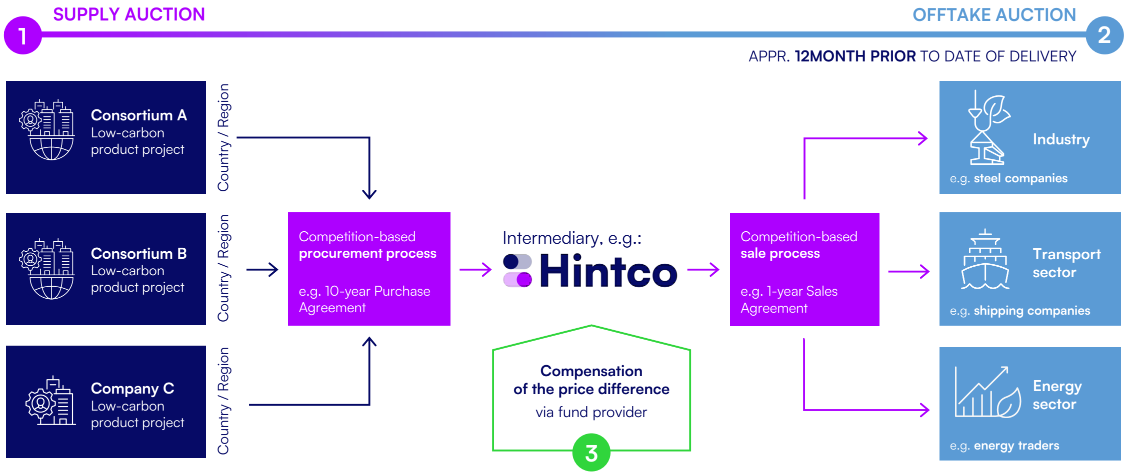


H2Global brings first movers into the market by providing the certainty needed for developers to invest, while ensuring competitively priced, low-carbon products for buyers. This coordinated market-making approach accelerates early deployment and drives long-term cost reductions.

Page 4

H2Global

The solution — H2Global's double auction mechanism in a nutshell — enabling business cases for low-carbon product projects



Page 5

H2Global

The solution — H2Global's double auction mechanism creates value for all key stakeholders

1

For producers,
it provides long-term revenue certainty and gets projects to Final Investment Decision.

2

For fund providers,
it minimizes funding needs and ensures the 'biggest bang for the buck'.

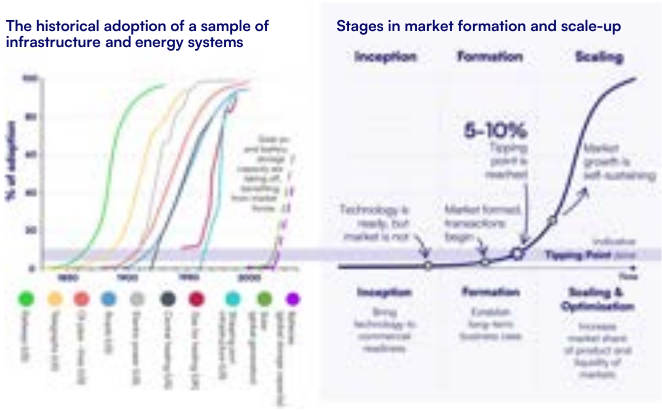
3

For offtakers,
it manages price risk and aids price discovery towards a liquid market.

Page 6

H2Global

Our role in a global context — H2Global is currently the sole active Green Market Maker in the world



KEY TAKEAWAYS

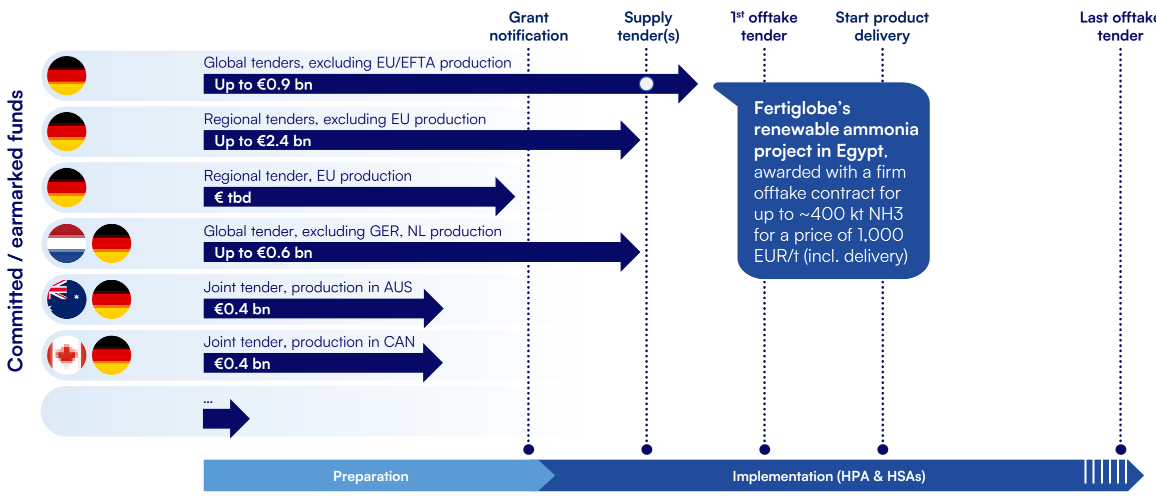
- When markets reach a **tipping point**, market forces lead to **exponential adoption** thereafter.
- **The H2Global mechanism has the power to bring markets to their tipping points** and unlock large-scale GHG emissions reductions.

Page 7

Source: MPP/BEF (2024): Unleashing market forces to scale green industry: The role of Green Market Makers

H2Global

Success to date — USD 6+ billion of public capital for H2Global tenders by Australia, Canada, Germany and the Netherlands



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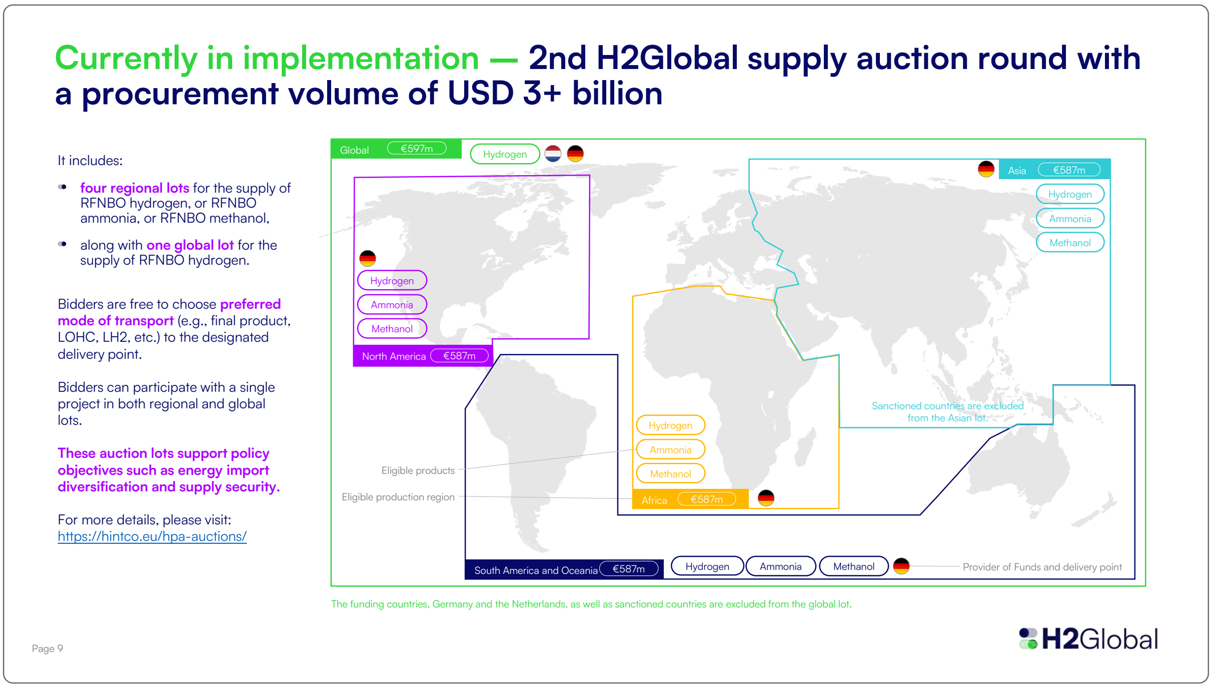
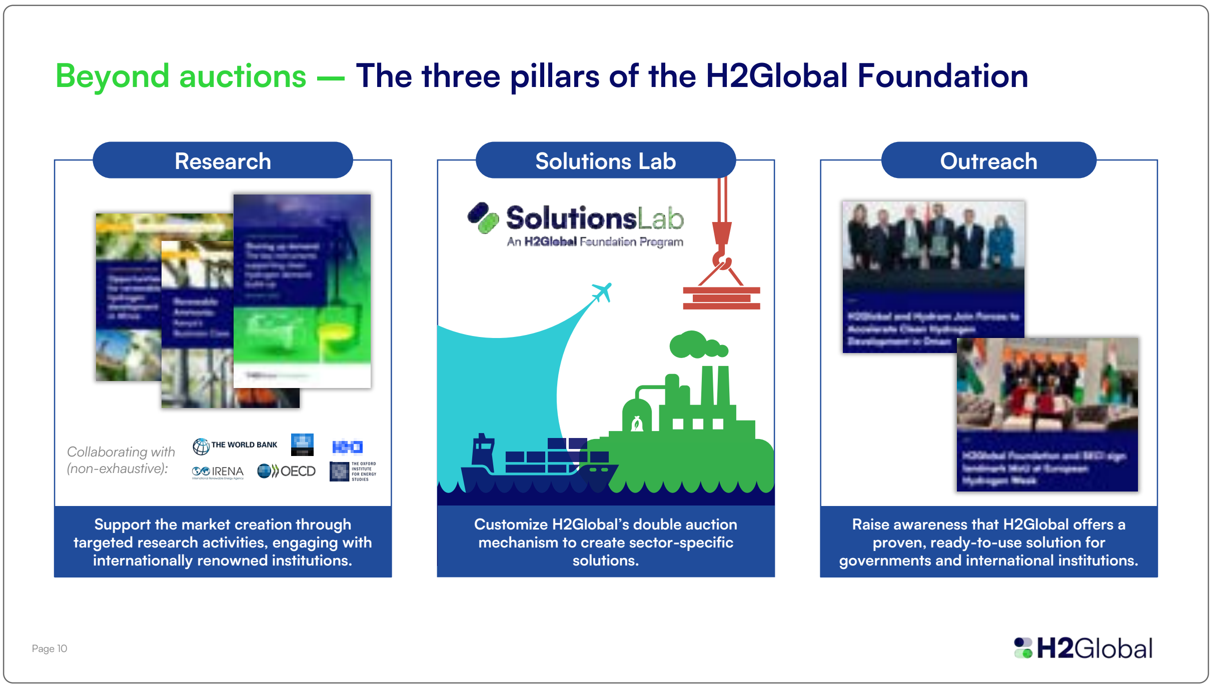
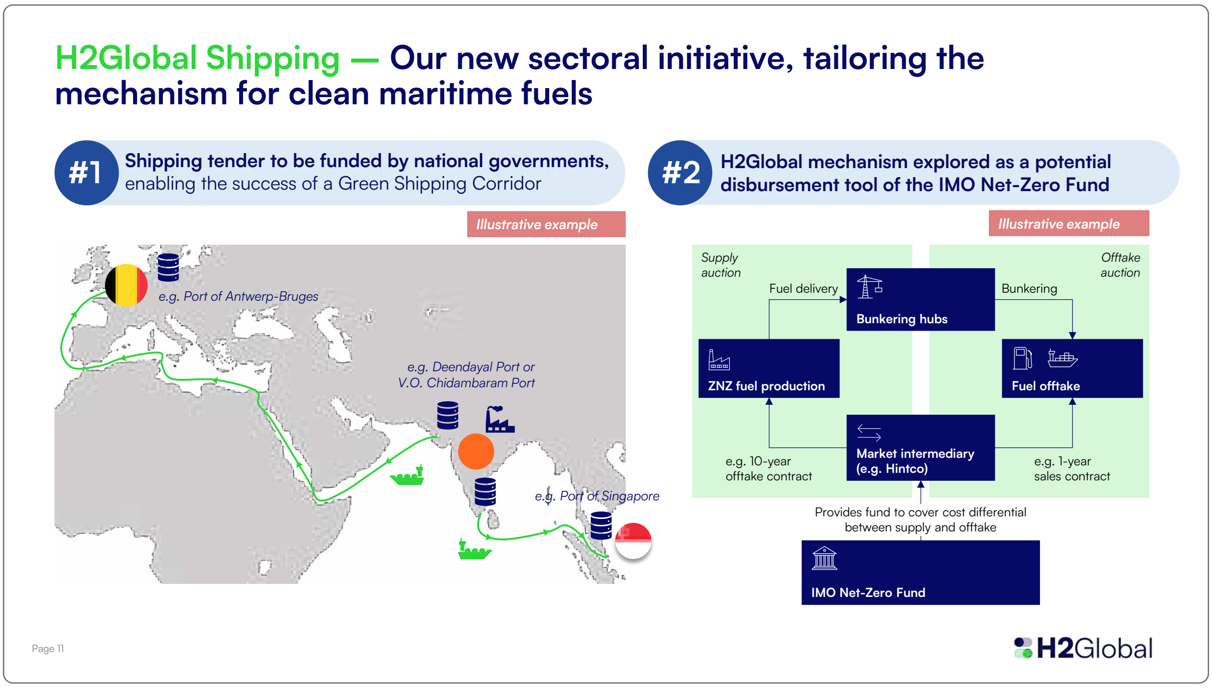
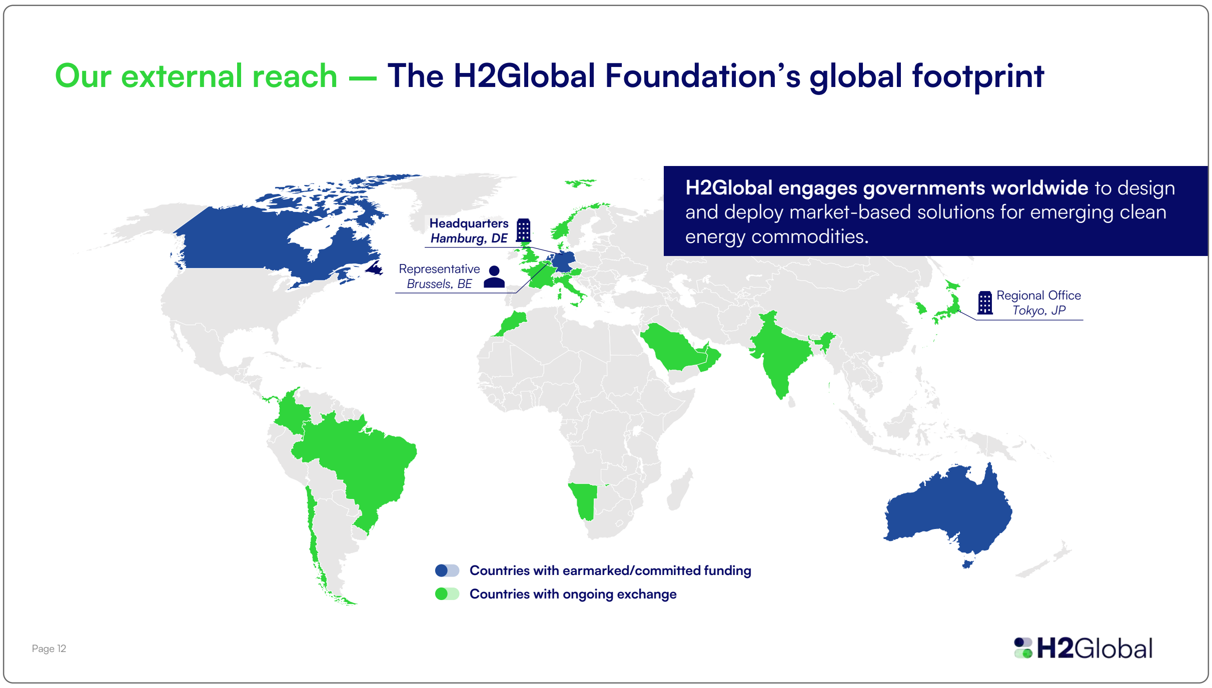
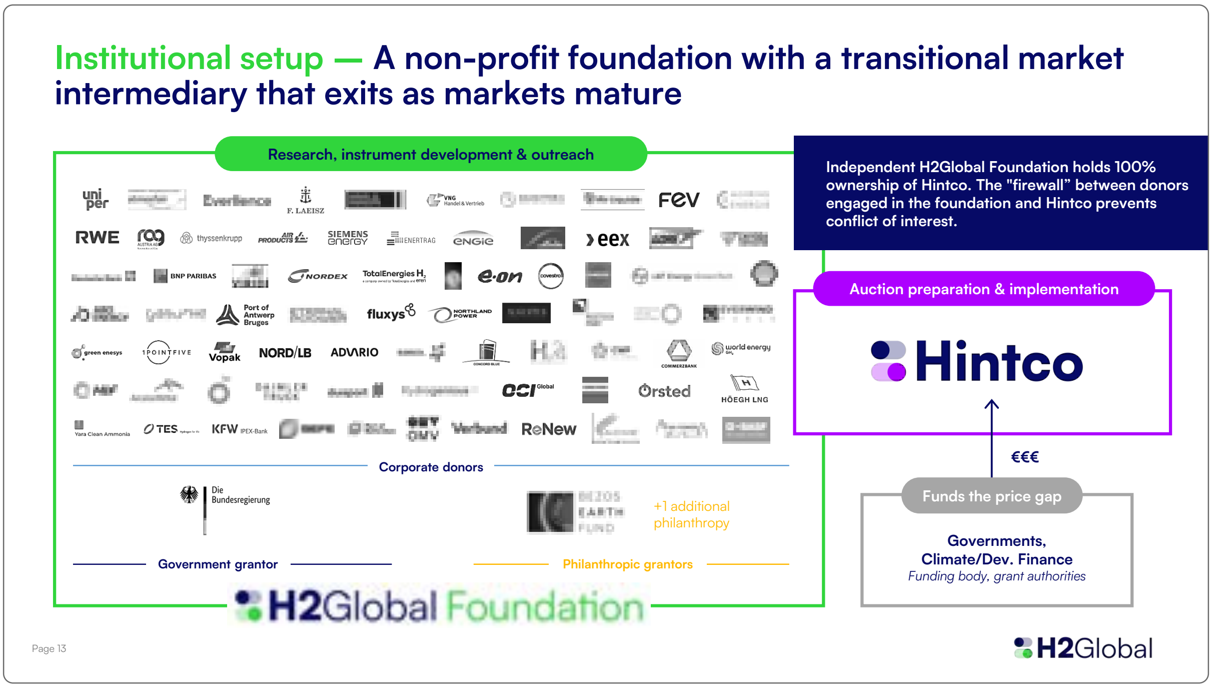
H2Global

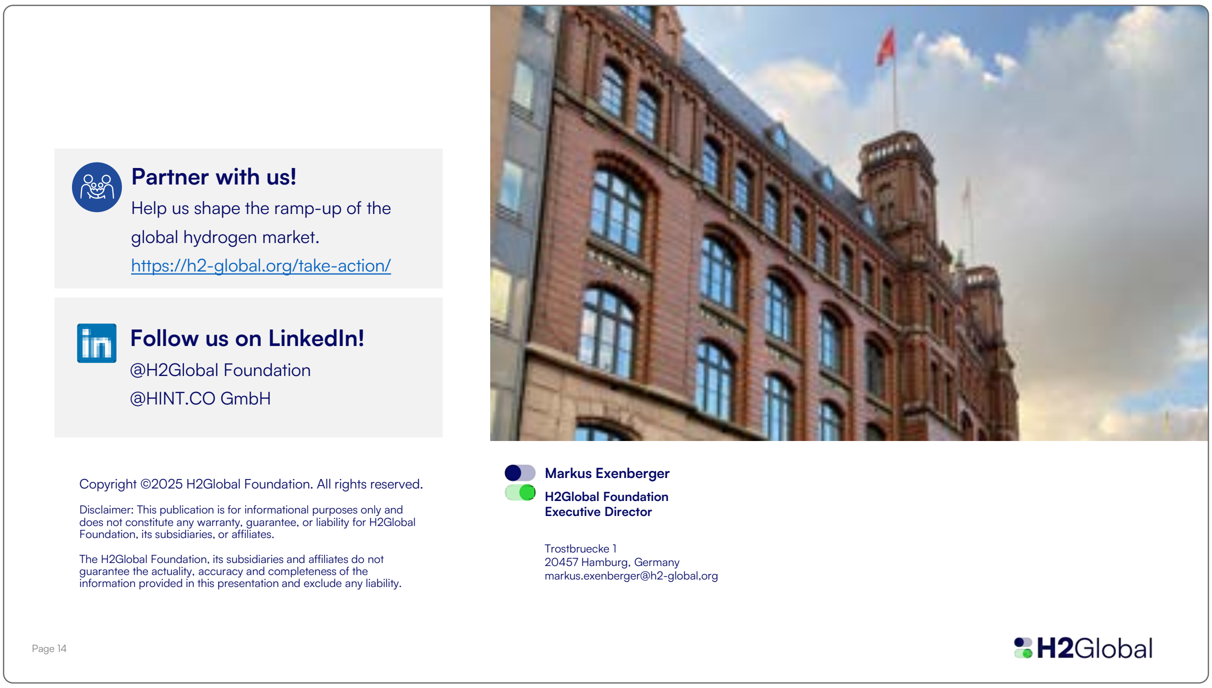

Currently in implementation — 2nd H2Global supply auction round with a procurement volume of USD 3+ billion
It includes:
four regional lots for the supply of RFNBO hydrogen, or RFNBO ammonia, or RFNBO methanol,
along with one global lot for the supply of RFNBO hydrogen.
Bidders are free to choose preferred mode of transport (e.g., final product, LOHC, LH2, etc.) to the designated delivery point.
Bidders can participate with a single project in both regional and global lots.
These auction lots support policy objectives such as energy import diversification and supply security.
For more details, please visit:
https://hintco.eu/hpa-auctions/
Global €597m
Hydrogen
Asia €587m
Hydrogen
Ammonia
Methanol
North America €587m
Hydrogen
Ammonia
Methanol
Africa €587m
Hydrogen
Ammonia
Methanol
Sanctioned countries are excluded from the Asian lot.
Eligible products
Eligible production region
South America and Oceania €587m
Hydrogen
Ammonia
Methanol
Provider of Funds and delivery point
The funding countries, Germany and the Netherlands, as well as sanctioned countries are excluded from the global lot.
Page 9
H2Global


Beyond auctions — The three pillars of the H2Global Foundation
Research
Collaborating with (non-exhaustive):
THE WORLD BANK
IRENA
OECD
Support the market creation through targeted research activities, engaging with internationally renowned institutions.
Solutions Lab
SolutionsLab
An H2Global Foundation Program
Customize H2Global's double auction mechanism to create sector-specific solutions.
Outreach
Raise awareness that H2Global offers a proven, ready-to-use solution for governments and international institutions.
Page 10
H2Global


H2Global Shipping — Our new sectoral initiative, tailoring the mechanism for clean maritime fuels
#1
Shipping tender to be funded by national governments, enabling the success of a Green Shipping Corridor
Illustrative example
e.g. Port of Antwerp-Bruges
e.g. Deendayal Port or V.O. Chidambaram Port
e.g. Port of Singapore
#2
H2Global mechanism explored as a potential disbursement tool of the IMO Net-Zero Fund
Illustrative example
Supply auction
Offtake auction
Fuel delivery
Bunkering hubs
Bunkering
ZNZ fuel production
Fuel offtake
Market intermediary (e.g. Hintco)
e.g. 10-year offtake contract
e.g. 1-year sales contract
Provides fund to cover cost differential between supply and offtake
IMO Net-Zero Fund
Page 11
H2Global


Our external reach — The H2Global Foundation's global footprint
H2Global engages governments worldwide to design and deploy market-based solutions for emerging clean energy commodities.
Headquarters Hamburg, DE
Representative Brussels, BE
Regional Office Tokyo, JP
Countries with earmarked/committed funding
Countries with ongoing exchange
Page 12
H2Global


Institutional setup — A non-profit foundation with a transitional market intermediary that exits as markets mature
Research, instrument development & outreach
Corporate donors
Government grantor
Philanthropic grantors
+1 additional philanthropy
H2Global Foundation
Independent H2Global Foundation holds 100% ownership of Hintco. The "firewall" between donors engaged in the foundation and Hintco prevents conflict of interest.
Auction preparation & implementation
Hintco
€€€
Funds the price gap
Governments, Climate/Dev. Finance
Funding body, grant authorities
Page 13
H2Global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H2Global

Panel Discussion

Investment and Market Growth Outlook of Global Clean Hydrogen Projects

Moderator

Neal Won
Principal Analyst, S&P Global

Panelists

Myoe Myint
Senior Energy Specialist, World Bank

Lim Yeon Yi
Senior Manager, KPX

Markus Exenberger
Executive Director, H2Global Foundation

WORLD HYDROGEN EXPO 2025 6th
Conference

Global Demand Outlook

Global Demand Outlook 1

LH2-based Global Hydrogen Supply Chain Development and Demand Expansion Strategy

Kenji Yoshimura
Kawasaki Heavy Industries

Education
1990-1992 Master of Engineering, Kyushu University

Professional Career
2025 Oct-Present, Executive, Chief Executive Staff Officer, Think Tank Department, Hydrogen Strategy Division, KHI
2023, Executive, Group Manager, Project Group, Hydrogen Strategy Division, KHI
2020, Senior Manager, Business Development Department, Hydrogen Strategy Division, KHI
2009, Manager, Hydrogen Project Department, Hydrogen Chain Development Center, KHI
1992, Joined in Kawasaki Heavy Industries, Ltd.(KHI)

Research Interest
Energy related equipment
Hydrogen related equipment

Speech Summary
KHI is advancing a global hydrogen strategy for carbon neutrality via large-scale production, transport, and use. Its roadmap spans pilot, commercialization, and full-scale phases, while developing power, mobility, aviation tech, and CO_2 capture to drive decarbonization worldwide.(282 characters)

Company Introduction
KHI leads hydrogen innovation with global supply chains, power systems, and CO_2 solutions.(90 characters)

World Hydrogen Expo 2025 (H2 MEET)

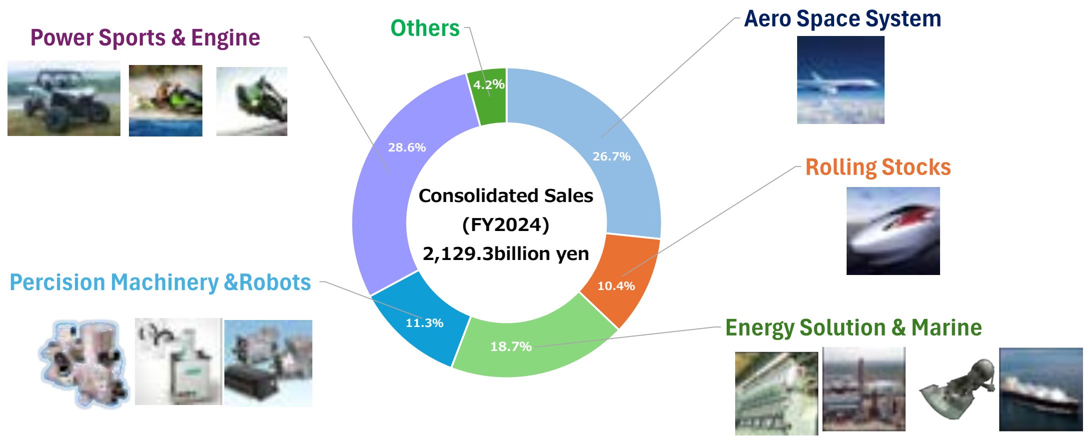
LH2-based Global Hydrogen Supply Chain Development and Demand Expansion Strategy

December 5. 2025
Kenji Yoshimura

Kawasaki Heavy Industries, Ltd
Executive, Chief Executive Staff Officer
Think Tank Department
Hydrogen Strategy Division

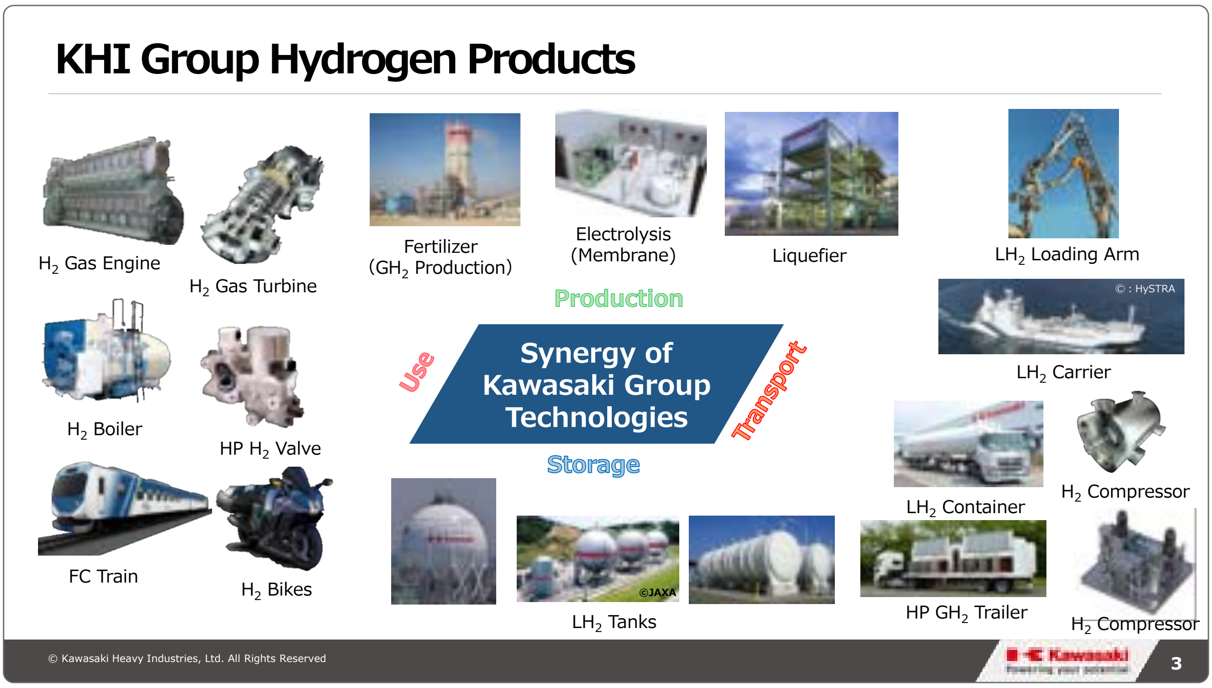
Kawasaki
Powering your potential

Kawasaki FY2024



1 USD = 140 JPY,

2


KHI Group Hydrogen Products
H_2 Gas Engine
H_2 Gas Turbine
Fertilizer (GH_2 Production)
Electrolysis (Membrane)
Liquefier
LH_2 Loading Arm
Production
© : HySTRA
LH_2 Carrier
H_2 Boiler
HP H_2 Valve
Use
Synergy of Kawasaki Group Technologies
Transport
Storage
LH_2 Container
H_2 Compressor
FC Train
H_2 Bikes
©JAXA
LH_2 Tanks
HP GH_2 Trailer
H_2 Compressor
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Kawasaki
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Expected CO2-free H2 Supply chain
Wind, Hydro, NG H_2
Hydro H_2
Hydro H_2
Oil & NG H_2
Solar H_2
Brown coal H_2
Wind H_2
NG H_2
Geothermal H_2
Wind H_2
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Liquefied Hydrogen

- Liquefaction at a cryogenic temperature of -253℃ ➔ 1/800th the volume of gas
- High-performance insulation technology (double-shelled/vacuum insulated tank)
  ➔ Long-term storage equivalent to LNG
- High purity/No need for refining
  ➔ Suitable for a wide range of applications
  from FCVs to industrial furnaces simply by evaporation

LH2 Storage Tank
at Tanegashima Space Center

Japan's biggest LH2 Tank
at Kobe LH2 Terminal

Large-scale LH2 Carrier
(to be built)

LNG Carrier

Liquefied Hydrogen Supply Chain

2015 | 2020 | 2025 | 2030 | 2040~

Pilot Demonstration
- Completed pilot demonstration

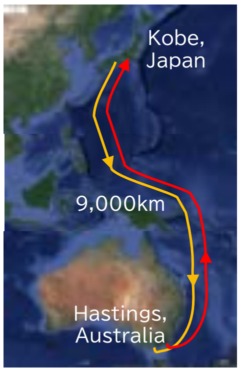
Commercialization Demonstration
- Development of commercial-scale equipment

Commercial Chain Operations

Pilot Project Demonstration

The first voyage

Departure from Kobe	24th Dec. 2021
Arrival at Hastings	21st Jan. 2022
Departure from Hastings	28th Jan. 2022
Arrival at Kobe	25th Feb. 2022

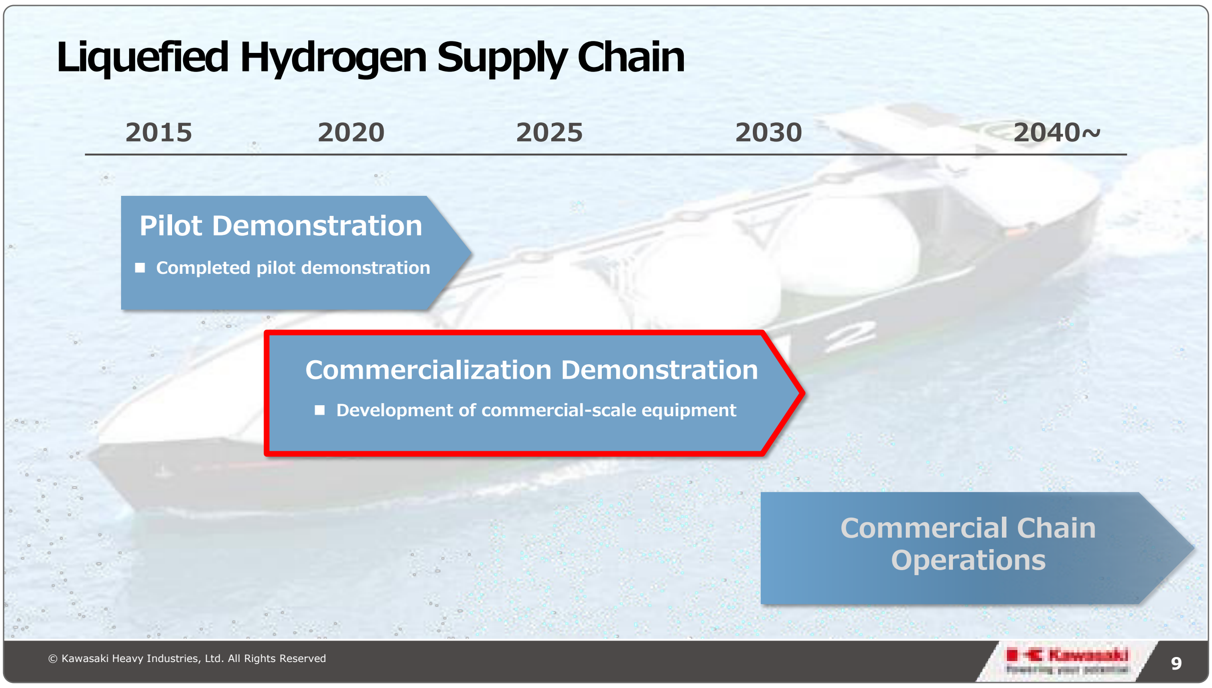


Source:HySTRA

Liquefied Hydrogen Carrier "Suiso Frontier"

Length	116 m	Speed	13 knot
Width	19 m	Draft	4.5 m
Max crew	25 person	Propulsion	Diesel electric

Vacuum Insulated Double Shell Structure


Liquefied Hydrogen Supply Chain
2015
2020
2025
2030
2040~
Pilot Demonstration
■ Completed pilot demonstration
Commercialization Demonstration
■ Development of commercial-scale equipment
Commercial Chain Operations
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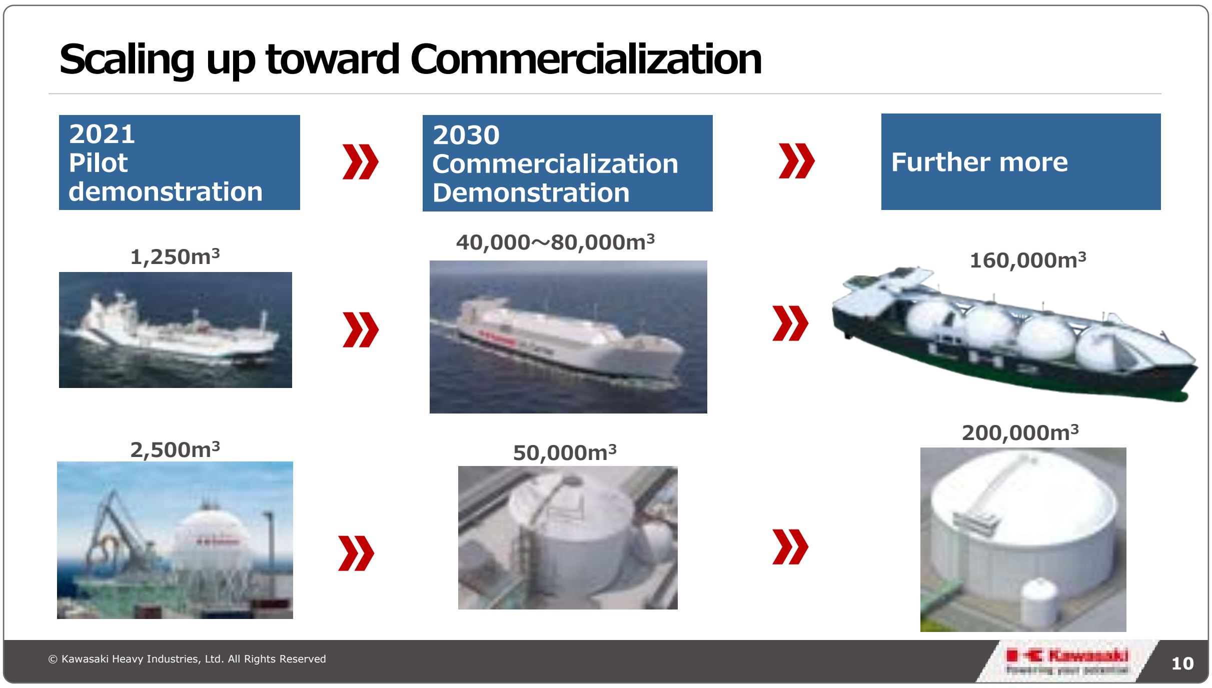
Scaling up toward Commercialization
2021 Pilot demonstration
2030 Commercialization Demonstration
Further more
1,250m³
40,000~80,000m³
160,000m³
2,500m³
50,000m³
200,000m³
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Commercialization Demonstration

NEDO Green Innovation Fund project

Organization : Japan Suiso Energy (Lead manager), ENEOS、Iwatani Corporation

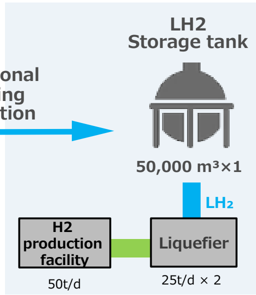
Investment : Approx. USD 2.1 Billion (Government Support Approx. USD 1.4 Billion)

Domestic terminal tests:

LH2 Carrier

40,000 m³ × 1 ship

International Sea-going examination



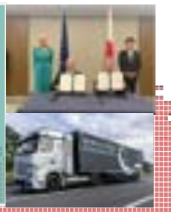
Ogijima Island, Kawasaki city

Worldwide Collaboration for Global Hydrogen Supply Chain

Daimler Truck
Daimler Truck and Kawasaki Heavy Industries signed MoU

Jointly study the optimization of liquid hydrogen supply chains

Target: Early 2030s establish LH2 supply chain



ADNOC
Strategic Collaboration Agreement with ADNOC

Signed a strategic collaboration agreement with UAE energy company (ADNOC) to build a liquefied hydrogen supply chain.

- Supplier (Green Hydrogen)
- Supplier (Bule Hydrogen)
- Off taker

Japan-Australia Pilot Demonstration Project

Supported by the government of Japan and Australia

Supported by NEDO from FY2015 to 2022.

Other application developments for Demand Expansion

FC Train

H_2 Compressor for Refueling station

H_2 Gas Engine

H_2 Gas Turbine

H_2 Aircraft

LH_2 Container for Train

H_2 Compressor for Pipeline

MHFS（Marine LH_2 Fuel System）

H_2 Bikes

Hydrogen Gas Turbine

	Diffusion / Micro-Mix	Diffusion Combustor	Micro-Mix Combustor
Type H_2 Firing	PUC17（1.8MW） 0～100% H_2/NG Firing (2018)	PUC300（34MW） 0~50% H_2 Co-firing (2021)	GPB300 (34MW) 0~100% H_2 Co-firing (2026)
Project Overview	✓Co-generation system (CGS) with 1 MW class ✓World's first 100% H_2 firing ✓Heat and power were delivered to neighborhood building  @H2CGS Demonstration Facility, Port Island, Kobe	✓Co-firing by-product hydrogen and natural gas. ✓Kerosene can also be used as a backup.  @Seibu Oil	✓Aim at Operation with flexible ratio between 100% hydrogen and 100% natural gas  @RWE Generation SE

Large scale Hydrogen Gas Engine

For power generation

H_2 Co-Firing Engine (5~8 MWe)


・Actual demonstration test in FY2024
・30 vol.% H_2 co-firing
・Market in 2025

For marine proparsion

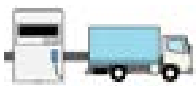
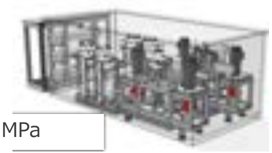
H_2 Dual Fuel Engine (2~3 Mwe)


・Op. Mode :H_2 Mode and Diesel Mode
・ Green Innovation Fund Project
「Next Generation Ship Development」
・Actual demonstration test by 2030

Hydrogen Compressors

For large scale H_2 stations


・Flow rate : 300Nm³/h
・Discharge pressure: 87.5MPa
・Market in 2025

・Flow rate : 2100Nm³/h
・Discharge pressure: 87.5MPa
・Demonstration in 2027

For H_2 pipeline

Flow rate 500,000 Nm3/hr
Inlet Pressure : 30 barA
Outlet Pressure: 60 barA
Pressure ratio: 2.0+(Plus)
Market in : 2026

Small scale Hydrogen Engine

Consortium「HySE」 established in May 2023

Kawasaki Heavy Industries, Ltd.,
Kawasaki Motors, Ltd.,
Suzuki Motor Corporation,
Toyota Motor Corporation,
Honda Motor Co., Ltd.,
Yamaha Motor Co., Ltd.,
DENSO CORPORATION

2024 Dakar Rally Saudi Arabia in Jan. 2024

HySE-X1 with a hydrogen-fueled engine showed its potential in Dakar 2024 "Mission1000"

Suzuka Circuit in July 2024

World's First Public Demonstration Run of a Hydrogen Engine Motorcycle

HySE: Hydrogen Small mobility & Engine Technology Association

Kawasaki
Powering your potential

Global Demand Outlook 2

Hydrogen sector in Spain

Javier Brey
President, Spanish Hydrogen Association (AeH2)

Education
2009 - 2015, Ph.D., Hydrogen Economy, Pablo de Olavide University, Sevilla, Spain
1999 - 2001, Postgraduate Diploma of Advanced Studies (DEA) in Electronic Communications, University of Seville, Sevilla, Spain
1992 - 1999, MSc in Telecommunications Engineering, University of Seville, Sevilla, Spain

Professional Career
2009 – Present, President, Asociación Española del Hidrógeno- Spanish National Hydrogen Association (AeH2), President
2016 - Present, Associate Professor, Loyola University, Sevilla, Spain
2016 - Present, CTO and Founder, H2B2 Electrolysis Technologies, Sevilla, Spain
2013 - 2016, General Manager, Abengoa Hydrogen, Sevilla, Spain
2003 - 2013, General Manager, Hynergreen Technologies, Sevilla, Spain

Research Interest
My research focuses broadly on the development and implementation of the hydrogen economy. I am particularly interested in the production of renewable hydrogen, as well as its transport, distribution, and end-use applications across different sectors. A significant part of my work has been dedicated to hydrogen generation technologies, including renewable electrolysis, together with the integration of fuel cell systems as a viable utilization pathway.
In addition, I am strongly engaged in understanding how hydrogen can be deployed at national and regional scales through public policy, regulatory frameworks, market design, and governmental incentive schemes. I am especially motivated by how these elements can accelerate the transition towards a decarbonized energy system and enable hydrogen to become a central vector in sustainable global energy markets.

Speech Summary
This presentation outlines the current status of the hydrogen economy in Spain, including national strategy, deployment progress, public funding, infrastructure plans such as H2Med, and updated data from the AeH2 2025 Project Census. acters

Company Introduction
Founded in 2002, the Spanish Hydrogen Association has 400 members across the value chain.

Hydrogen sector in Spain

Prof. Dr. Javier Brey

WORLD HYDROGEN EXPO 2025
December 4-7, 2025, KINTEX, KOREA

AẽH2
SPANISH HYDROGEN ASSOCIATION

The Voice of the Hydrogen sector in Spain since 2002

AẽH2 ASOCIACIÓN ESPAÑOLA DEL HIDRÓGENO

400+ members
+ 37% growth since 2021
+ 20 years supporting the sector
+ 15 years of international collaborations

MISSION

Promote and encourage the development and growth of hydrogen technologies in Spain, with the aim of strengthening and enhancing the national industrial fabric.

VISION

Hydrogen is a key energy vector in the decarbonization of the Spanish economy to achieve climate neutrality in 2050. Hydrogen allows for reactivating, redefining and transforming the national economy, through the creation of a technological and productive industrial fabric, and the generation of highly qualified employment.

Board of Directors

President
D. Javier Brey Sánchez

Vice-president
D. Antonio González García- Conde

Secretary
D. Miguel A. Peña Jiménez

Sectoral vocals

- Industrial Gases Sector.
- Renewable Gases Sector.
- Fuel Gas Sector.
- Energy Sector.
- Engineering and Construction Sector.
- Electrolyzers Sector.
- Technology Centers Sector.
- Testing, Inspection and Certification Sector.
- Public Research Organizations Sector.
- Scientific Facilities and Singular Technologies Sector.
- Industrial Development Sector.
- Demand Integration and Renewable Sector.

Our promoting members

Members

Objectives

CLUSTER

Be the key gathering place for the sector, bringing together companies, institutions, technology and research centers, and universities active in hydrogen technologies.

R&D&i

Promote research and innovation in hydrogen technologies, as well as the promotion of startups and technological knowledge.

DEVELOPMENT

Support the growth of hydrogen technologies by promoting its production, storage, distribution, and end-use applications.

EDUCATION

Provide professional education through established courses in collaboration with various universities and training centers.

LEGISLATION

Advocate for the establishment of laws and regulations governing hydrogen as an energy vector.

DISSEMINATION

Establish hydrogen as a recognized energy vector within our society

Updated monthly
www.aeh2.org

Updated yearly
www.pteh2.org

National Collaboration

- Entities
- Public Administration
- Ministeries

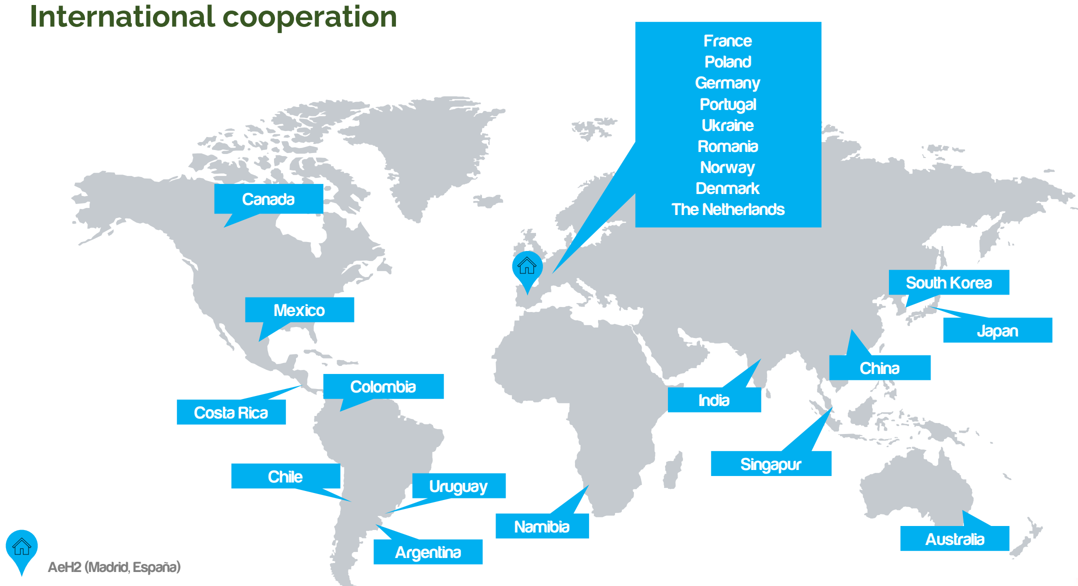
International cooperation

→ International cooperation efforts are translated into the organization of workshops, trade missions, and other activities that promote the presentation and contact between national and international entities (and initiatives).

Hydrogen Europe European Clean Hydrogen Alliance UNIDO

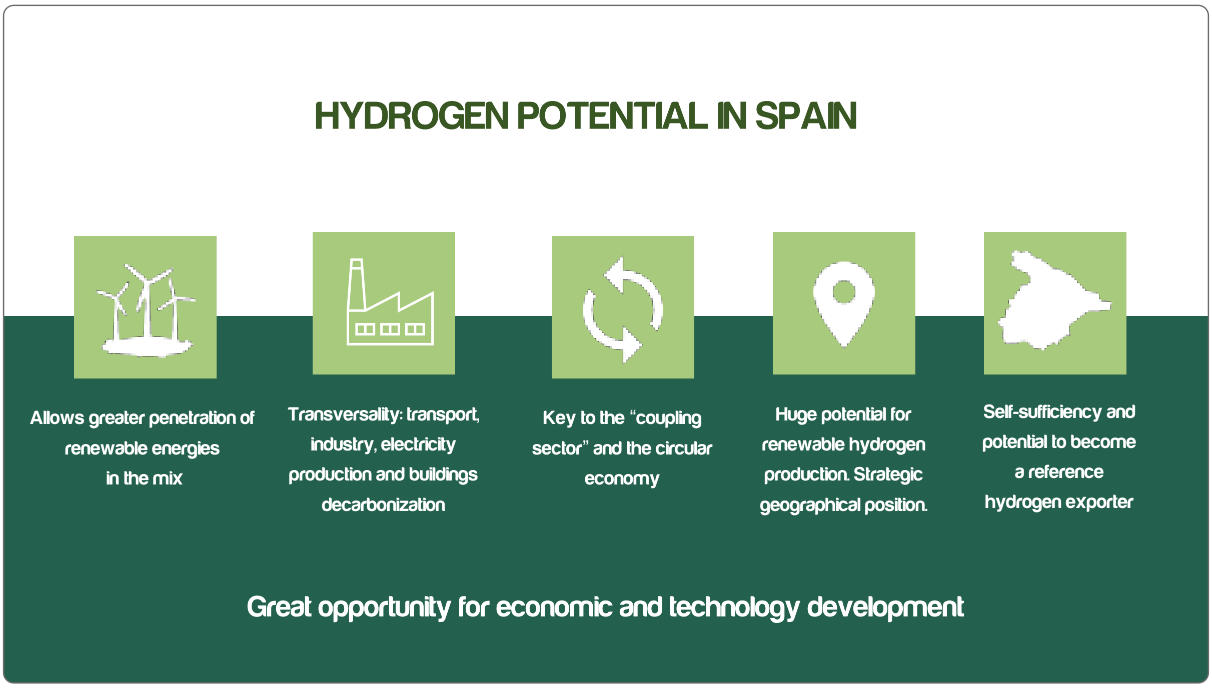
AeH2

International cooperation



AeH2


Projects and Initiatives
PTẽ H2
UNE
Normalización Española
EHEC
EUROPEAN HYDROGEN ENERGY CONFERENCE
Working Groups
H2
Census of Projects
GREEN HYSLAND
AeH2


HYDROGEN POTENTIAL IN SPAIN
Allows greater penetration of renewable energies in the mix
Transversality: transport, industry, electricity production and buildings decarbonization
Key to the "coupling sector" and the circular economy
Huge potential for renewable hydrogen production. Strategic geographical position.
Self-sufficiency and potential to become a reference hydrogen exporter
Great opportunity for economic and technology development

The Spanish Hydrogen Roadmap (2020)

"Hydrogen Roadmap: a commitment to renewable hydrogen"

6th October 2020 - Approved by the Council of Ministers

Includes **60 actions** to promote the development of hydrogen in Spain, divided in 4 blocks

1. Regulatory instruments
2. Sectoral instruments
3. Cross-cutting instruments
4. Boosting R&D

2030 GOALS

Spain has growing ambitions for renewables and hydrogen

Under the Regulation on the governance of the energy union and climate action (EU)2018/1999, all Member States must have a 10-year plan addressing decarbonization, energy efficiency, energy security, international energy market, and research, innovation and competitiveness, known as NECP (National Energy and Climate Plan, PNIEC in Spanish).

PniEC Un Plan de Hoy para el Mañana

	First PNIEC (published 2020)	Updated PNIEC (September 2024)
GHG emissions reduction by 2030	23%	32%
RE in total energy consumption by 2030	42%	48%
RE in electricity generation by 2030	74%	81%
RE in the transport sector by 2030	15%	28%
Advanced biofuels + RFNBO in transport by 2030	2,1%	**17,26%**
RFNBO in industrial hydrogen consumption by 2030	*25 % (set in the Roadmap, not PNIEC)*	**74%**
Electrolysis capacity installed	4GW	**12 GW**

Funding channeled to commercial projects in Spain

Plan de Recuperación Transformación y Resiliencia (PRTR) Componente 9. Hidrógeno Renovable

1555M€

+ IDAE's Hydrogen Valleys Call

7 projects

2,28 GW electrolysis

1214M€

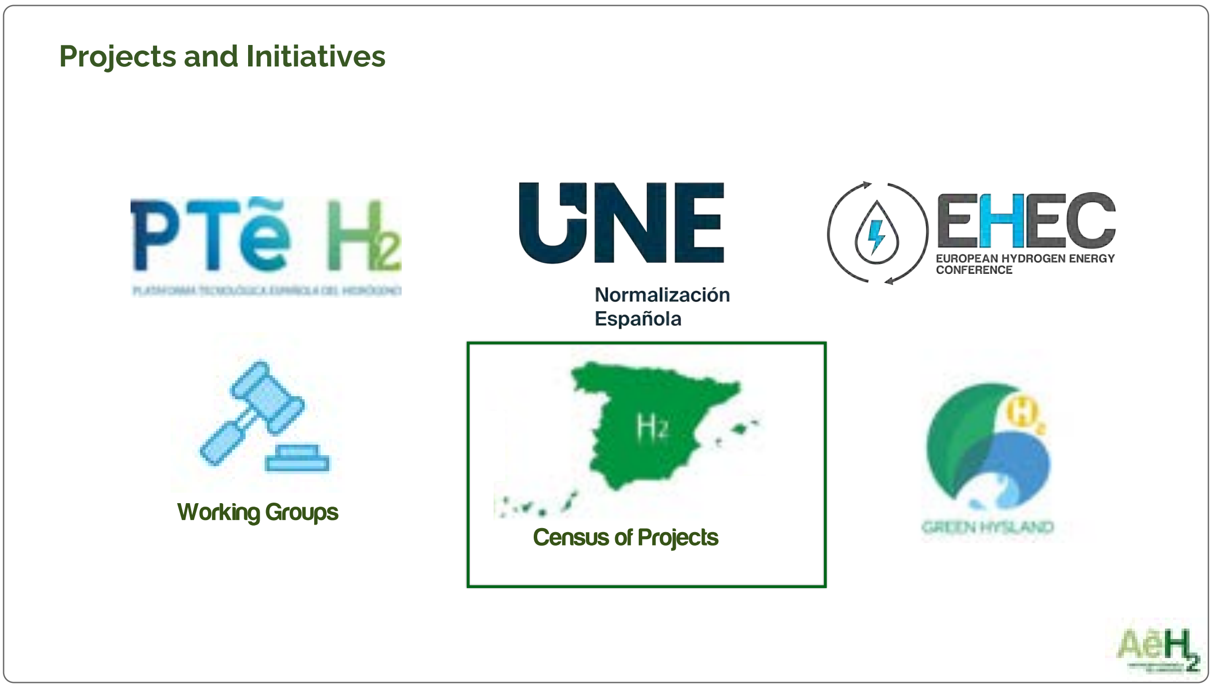
+ European Hydrogen Bank

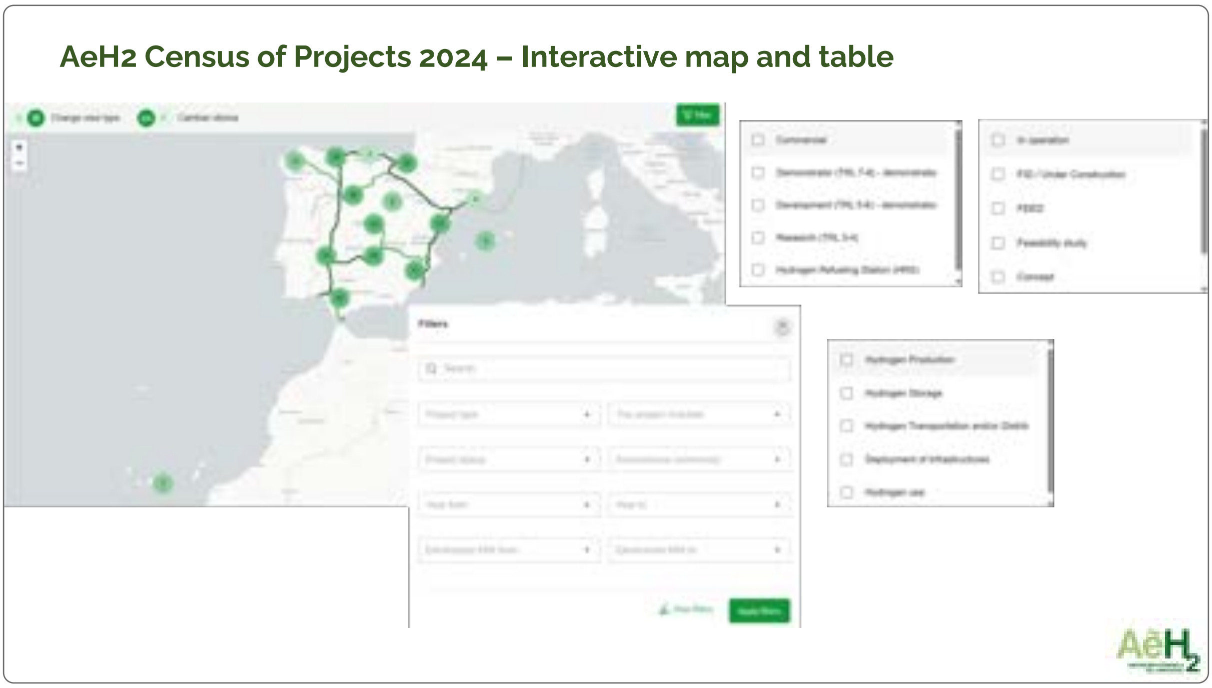
Auction as a Service – 2nd round

377M€

TOTAL >3100 M€

H2Med and Spanish hydrogen backbone (+ > 6000 M€)


Projects and Initiatives
PTẽ H2
PLATAFORMA TECNOLÓGICA ESPAÑOLA DEL HIDRÓGENO
UNE
Normalización Española
EHEC
EUROPEAN HYDROGEN ENERGY CONFERENCE
Working Groups
H2
Census of Projects
GREEN HYSLAND
AeH2


AeH2 Census of Projects 2024 – Interactive map and table
AeH2

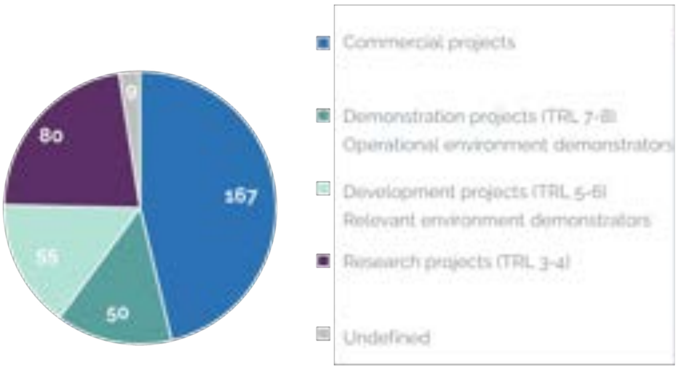
AeH2 Census of Projects 2024 – Overview

361 projects

83 AeH2 Members participated

> 36 000 M€ of total investment

≈2650 M€ public financing



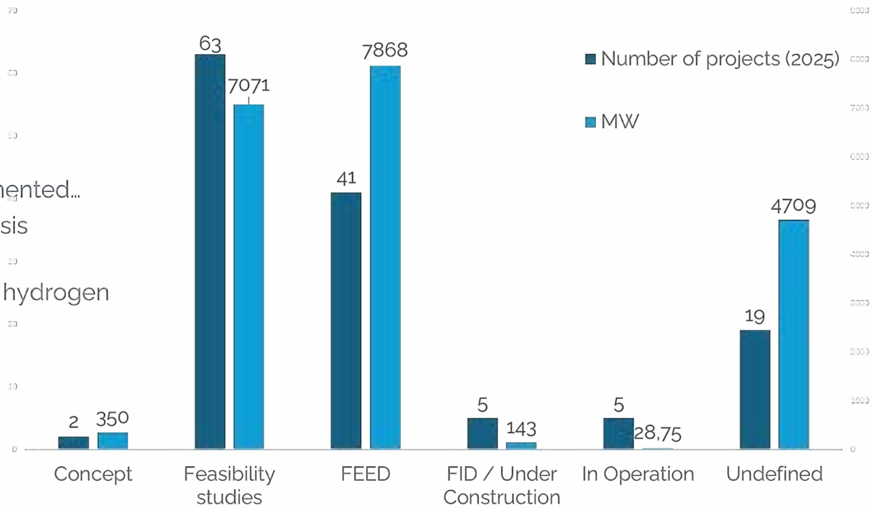
AeH2

AeH2 Census of Projects 2024 – Commercial projects

145 commercial projects

41 AeH2 members

If all of them were implemented...
20 GW, installed electrolysis capacity
2.65 million tons/year of hydrogen produced



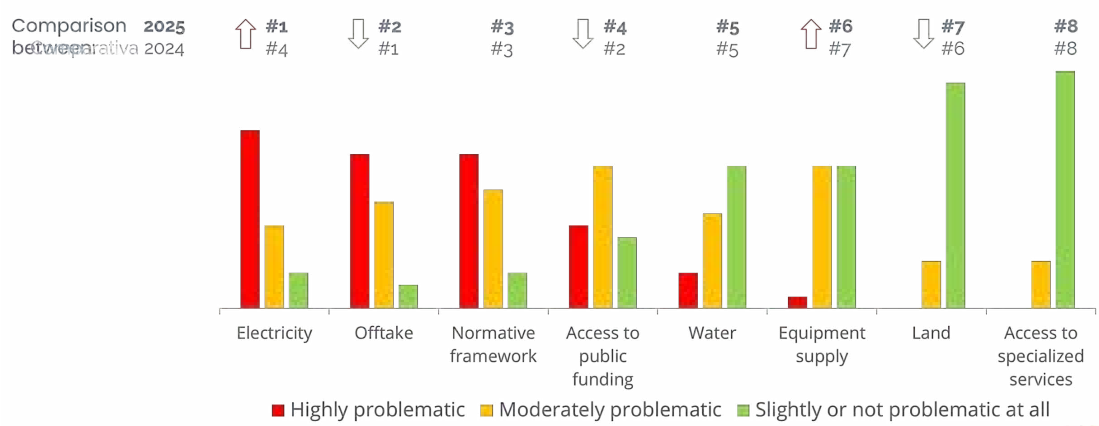
AeH2

AeH2 Census of Projects 2024 – Commercial projects

Expected timeline for commissioning of installed electrolysis capacity

AeH2 Census of Projects 2024 – Main barriers

What barriers are commercial project developers currently facing, and how have they rated the severity of these challenges—**"Very problematic," "Moderately problematic," or "Slightly or not problematic"**?



European Hydrogen Energy Conference

EHEC 2026 EUROPEAN HYDROGEN ENERGY CONFERENCE

EHEC is the European conference of reference in the hydrogen sector. Held every two years, it is **organized by the Spanish Hydrogen Association (AeH2)** and brings together experts, researchers and industry leaders in the field of hydrogen, providing a platform to share the latest advances, innovations and developments in technologies based on this energy vector.

- It is the perfect setting to showcase **advances in R&D projects and products.**
- It brings together the latest advances in research and business to a **worldwide audience** of interested parties.
- It facilitates the presentation of technologies for **strategic business collaborations** to emerge.

Following the great success of EHEC 2024, which had **+1300 attendees and +300 speakers** from across the hydrogen value chain, we are proud to announce the next edition of EHEC, to be held in Seville (Spain) in 2026.

Next edition 11-13th Seville March 2026

AeH2

Hydrogen sector in Spain

Prof. Dr. Javier Brey

WORLD HYDROGEN EXPO 2025
December 4-7, 2025, KINTEX, KOREA

AeH2 SPANISH HYDROGEN ASSOCIATION

Global Demand Outlook 3

POSCO HyREX Development Status

Jang Hoi Choi
General Manager, Posco Holdings

Education
1994-2001, B.S., Metallurgical Engineering, Jeonbuk National University, Korea

Professional Career
2001, Joining POSCO (FINEX Department)
2013, Plant leader (FINEX Department)
2016, Leader (Technology Strategy Department, POSCO)
2024-Present, General Manger (Carbon Neutral Strategy Office, POSCO Holdings Inc.)

Speech Summary
POSCO Holdings aims for net-zero by 2050 via HyREX hydrogen reduction steelmaking, leveraging FINEX and ESF tech. Plans include a 2028 demo plant, but challenges remain in clean hydrogen cost, supply, and infrastructure, requiring public-private cooperation and policy support.

Company Introduction
POSCO Holdings is a global industrial group leading steel, battery materials, and various businesses.

WORLD HYDROGEN EXPO 2025

posco HOLDINGS

1. Intro

POSCO, Growing into the World's Most Competitive Steelmaker

2024 'World's Most Competitive Steelmaker' ranking

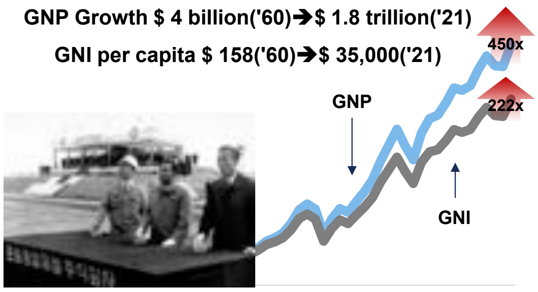
Ranking	Company (Country)	Ranking	Company (Country)
1	POSCO (Republic of Korea)	6	SDI (USA)
2	Nucor (USA)	7	Tata Steel (Europe)
3	Nippon Steel (Japan)	8	JSW (India)
4	ArcelorMittal (Multinational)	9	CSC (Taiwan)
5	BaoWu Steel (China)	10	Ternium (Mexico)

1. Intro

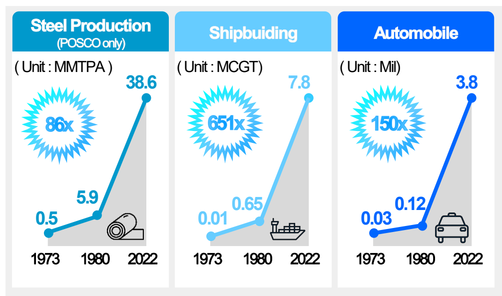
Steel – Huge Contribution to Economic Growth

Steel is the irreplaceable core of daily life and the backbone of national manufacturing

World's 8th Largest Trading Nation



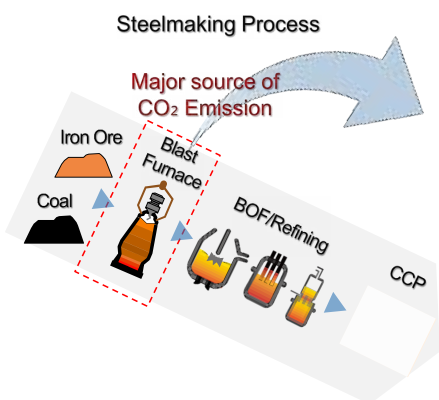
POSCO, the Driving Force of Korea's Industry

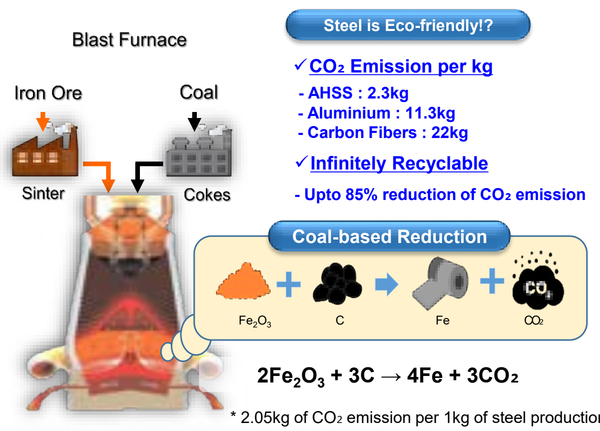


1. Intro

But Big Challenge due to High Emission through Mass Production

Coal used in traditional steelmaking inevitalbly generates substantial CO_2





$$2Fe_2O_3 + 3C \rightarrow 4Fe + 3CO_2$$

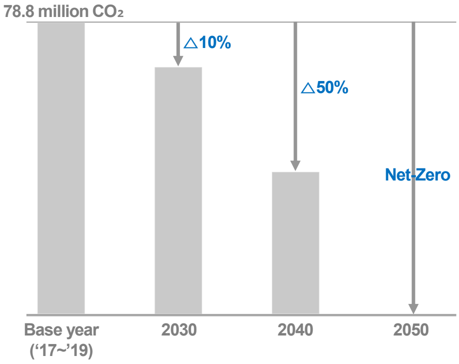
* 2.05kg of CO_2 emission per 1kg of steel production('22)

2. Decarbonization Approach

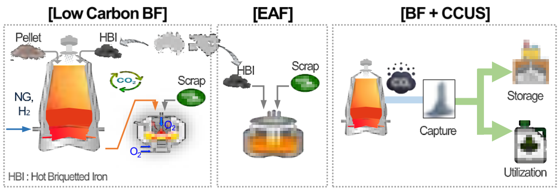
POSCO Declared to Achieve Net-zero in 2050

Through real option – based carbon reduction strategies and breakthrough decarbonization technologies

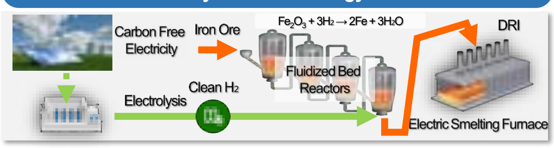
Decarbonization Approach



Carbon Reduction Bridge Technology



HyREX* Technology



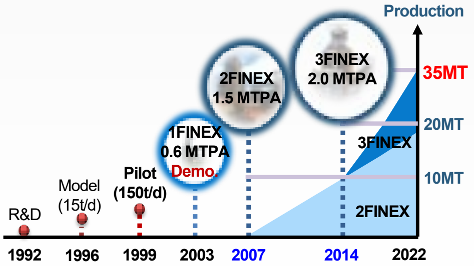
* Hydrogen Reduction

3. Technologies

POSCO already possessed the core technology for HyREX

Technology development can be accelerated by operational and equipment technology and skilled personnel

Core Tech #1 : FINEX (fine iron ore reduction)
- 3.5 mil. tons production capacity with 15 yrs of operation
- Above 96% plant factor



Core Tech #2 : ESF (Electric Smelting Furnace)
- Own and operate the world's largest facilities
- 280,000 tons of annual production(Fe-17%Ni)

No.1 ESF (Circle)
120MVA, 22mΦ

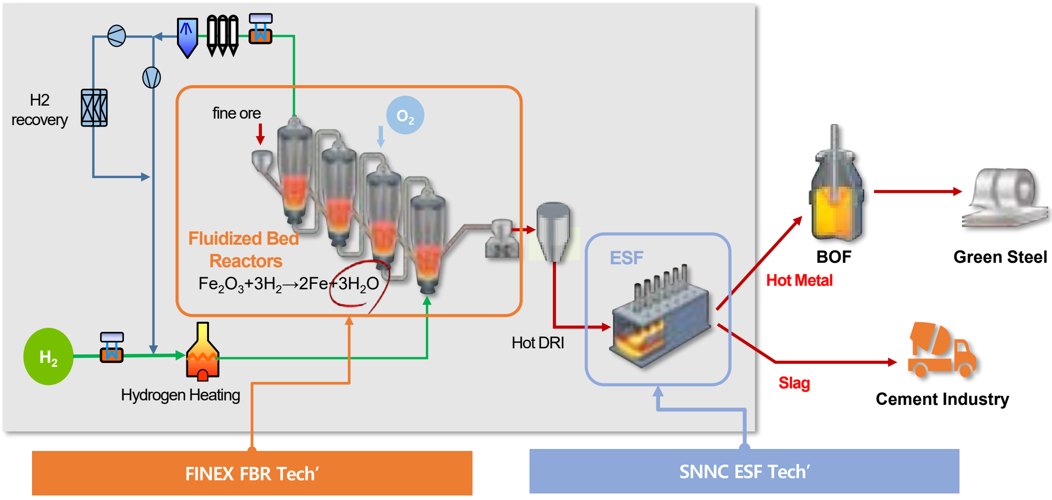
SNNC

No.2 ESF (Rectangle)
135MVA,40mX14m

3. Technologies

Korean-style hydrogen reduction steelmaking technology, HyREX

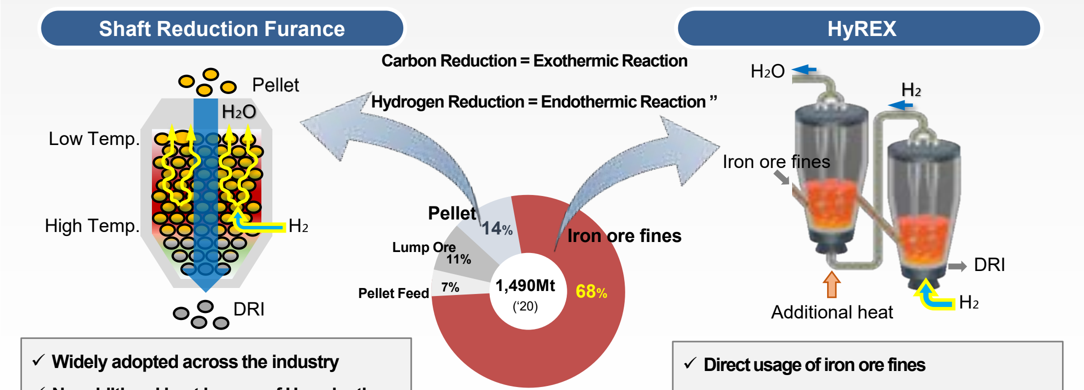
POSCO is developing the Korean-style hydrogen reduction steelmaking technology, HyREX, by leveraging its existing proprietary technologies — the FBR(Fluidized Bed Reactor) and the ESF(Electric Smelting Furnace).



3. Technologies

HyREX, Competitive Solution in terms of Costs and Quality

Flexible in raw material usage, higher quality, and cost savings compared to shaft reduction technology



- ✓ Widely adopted across the industry
- ✓ No additional heat in case of H_2 reduction
- ✓ Variability in quality linked to permeability

- ✓ Direct usage of iron ore fines
- ✓ Ease of additional heat supply
- ✓ Lower variability in quality

3. Technologies

Building HyREX Demo Plant prior to Commercialization Phase

By collaborating with leading companies, universities, and research institutes both in Korea and abroad

Basic Study

FBR

100% H_2 Reduction

Capa. 50 kg/batch

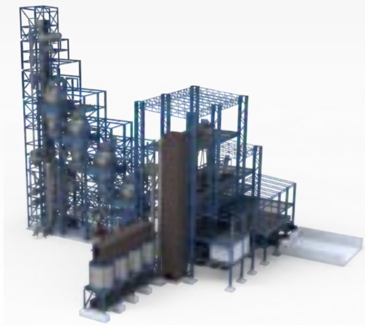
ESF

Smelting of H_2 DRI

Capa. 1.0 ton/hr

Know-how

HyREX Demo Plant



Scheduled to begin operation in 2028, The plant is capable of producing 300,000 tons per year.

4. Challenges

Clean Hydrogen is Still Very Expensive……

Across the steel industry, many pioneers are struggling due to infrastructure gaps and economic constraints.

Economic Hurdles

- High costs due to limited potential for renewables in Korea
  - Insufficient resources and high EPC costs
- Massive investment required for infrastructures such as storage tanks and pipelines
- Stranded asset risk in transition to HyREX
- Additional power costs by decreasing by-product power generation

Market Trend

- Global steelmakers are currently facing project delays and cancellations due to uncertainties in supply and economic conditions

Players	Status
ArcelorMittal (EU)	Cancellation of Hydrogen Steelmaking PJTs in Bremen and Eisenhüttenstadt, Germany (June 2025) due to limited hydrogen supply and lack of infrastructure
thyssenkrupp (EU)	Uncertainty in transition from NG-based DRI to Hydrogen-based DRI due to supply and cost competitive issues
CLIFFS (US)	Withdrawal of transition plan for EAF and hydrogen reduction facilities in Ohio state due to policy risks and market uncertainties(June 25)

4. Challenges

Low-cost Clean Hydrogen Essential for HyREX Realization

In Korea, pink hydrogen could be an answer. But several issues shall be addressed.

	Gray	Blue	Turquoise	Green	Pink
Raw Material	Natural Gas & Steam		Natural Gas	Water	Water
Energy	Thermal			Renewable	Nuclear Power
Required Technology	Steam Methane Reforming(SMR) & Autothermal Reforming(ATR)	SMR & ATR with CCS	SMR & ATR with CCUS	Electrolysis	Electrolysis
Production Cost	Low	Mid	Mid	High	**Low**
CO_2 Emission	High	Mid	Mid	Low	**Low**

- **Given Korea's renewable limitations, nuclear hydrogen is the most cost-effective option. In parallel, policy measures such as virtual PPAs should be considered.**
- **As Pink Hydrogen alone may not be sufficient to meet HyREX's full demand, It would be beneficial for the government to explore pathways to facilitate large-scale clean hydrogen imports.**

5. Conclusion

Competitive Decarbonization Calls for Strong Public-Private-Market Synergy

Achieving meaningful progress requires the participation of all members of society across every sector, and strong government support is essential to this effort.

- Providing full-cycle support for carbon reduction innovation (R&D → Demonstration → Commercialization → Construction → Operation)
- Building cost-effective, reliable power and energy infrastructure and securing large-scale clean hydrogen supply
- Driving the growth of green steel markets and promoting green premium adoption
- Implementing full value chain benefit-cost sharing for carbon reduction

POSCO HOLDINGS

Thank you

Global Demand Outlook 3

Power Transition in Data Centers

Inki Choi
Senior Manager of Strategy and Marketing,
Bloom Energy Korea

Education
M.S., California Institute of Technology, Aerospace Engineering, CA, USA
B.S., Seoul National University, Mechanical Engineering, Korea

Professional Career
2025-Present, Senior Manager, Strategy & Marketing, Bloom Energy (Korea)
2016-2024, Business Strategy/Sales/Project Management Manager, KC Cottrell (Korea)
2011-2015, Strategic Planning Analyst/Engineer, DB Group (Formerly Dongbu Group) (Korea)

Speech Summary
According to multiple reports from leading energy organizations, the rapid surge in demand for artificial intelligence (AI) has driven data center power requirements far beyond current electricity supply capacities. This session explores the critical choices the data center industry is making to secure urgently needed power amid soaring demand.

Company Introduction
Bloom Energy is a global leader in clean hydrogen energy solutions, headquartered in Silicon Valley, USA. Leveraging high-efficiency fuel technology, the company delivers clean, reliable, and resilient power. Since its listing on the New York Stock Exchange (NYSE: BE) in 2018, Bloom Energy's market capitalization has exceeded USD 33.8billion as of November 2025.
Bloom Energy develops and manufactures solid oxide fuel cells (SOFCs), which generate on-site power through an electrochemical process rather than combustion. This proprietary SOFC technology delivers optimized distributed power solutions for various sectors, including data centers, manufacturers, healthcare facilities, and power utilities.
Collaborating with leading global enterprises and public institutions, Bloom Energy is driving the development of sustainable power infrastructure. Today, the company has deployed approximately 1.5 GW of low-carbon electricity across more than 1,200 sites worldwide, driving the global transition toward cleaner energy.

More information can be found at https://www.bloomenergy.com and https://bloomenergykorea.com.

WORLD HYDROGEN 6th EXPO 2025 Conference

Global Demand Outlook 4

Green Hydrogen and Regional Decarbonisation: Helios Project at Port Augusta to Support Local Superpower Industries

Jong Hwa Lee
Head of Ammonia Hydrogen Business and Executive Vice President, Hanwha Impact

Education

1989-1982, B.S., Chemical Engineering, Sungkyunkwan University, Seoul, Korea

Professional Career

2012. team leader, Planning Division, SamsungTotal
2014-2015 Managing Director(상무), Business Planning Division, SamsungTotal
2015. Managing Director(상무), Business Planning Division, HanwhaTotal
2015-2016 Managing Director(상무), Energy & Aromatic Production Division, HanwhaTotal
2017-2020. Managing Director(상무), Energy Sales Division, HanwhaTotal
2021-2022. Managing Director(상무), Safety & Environment Division, HanwhaTotal
2022. Executive Vice President(전무), HSE Safety & Environment, HanwhaTotal
2023-Pesent Executive Vice President(전무), Ammonia/Hydrogen TF Leader, Hanwha Impact

Research Interest

Ammonia Cracking and Clean Power Generation: Industrial Demand Strategies

Speech Summary

This presentation outlines the clean hydrogen value chain and the role of ammonia cracking for power generation. It highlights efficiency gains through integrated cracking–CCPP systems, hydrogen turbine demonstrations, and pathways to scalable, low-carbon energy solutions.

Company Introduction

Hanwha Impact is an investment company dedicated to creating a sustainable planet through eco-friendly energy solutions and future-driven innovative technologies, including energy transition, life sciences, and digital/data tech. In addition to our high-purity terephthalic acid (PTA) manufacturing business, we actively pursue M&A and strategic investments.More information can be found at https://www.bloomenergy.com and https://bloomenergykorea.com.

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Clean Energy Value Chain

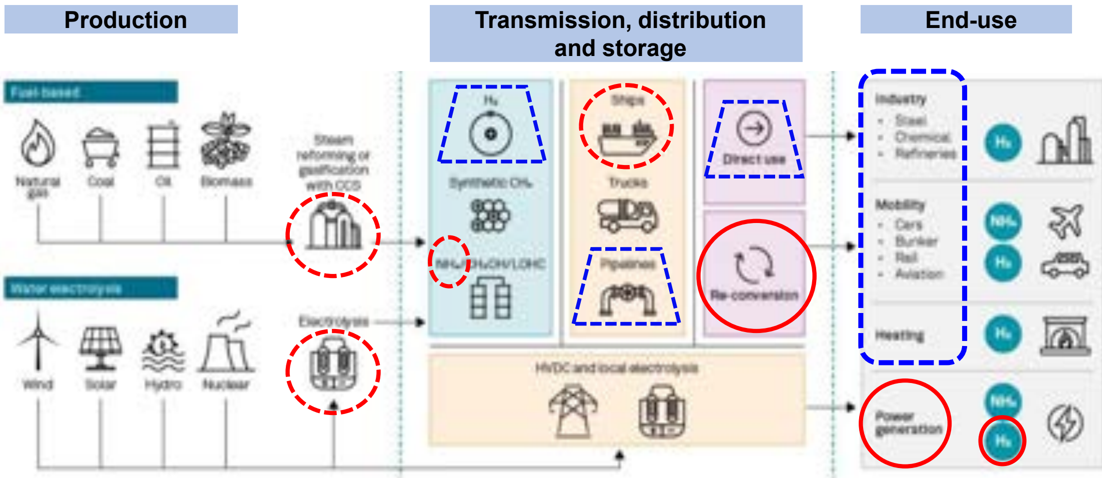
- Hydrogen Power Generation

2025. 12.

Hanwha Impact

Low-Carbon Hydrogen Value Chain

Hydrogen Value Chain



✔ Hydrogen Energy Equivalencies

1 Mt = 33 MWh of energy (LHV) = 130 MMBtu of natural gas = 1,020 gallons of gasoline = 6.434 Mt of ammonia equivalent energy

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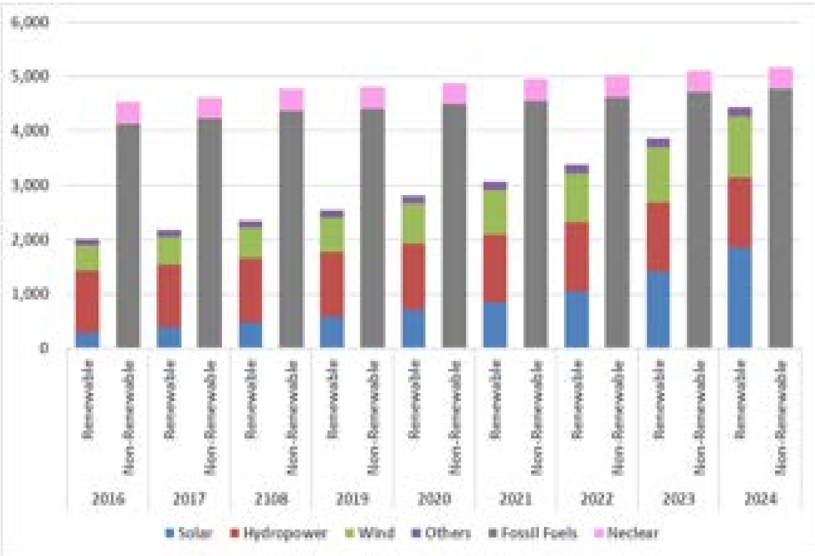
Global Electricity Capacity

Global Electricity Capacity: About 9.6TW in 2024

- Renewable Electricity: 3,073 GW(38.3%) in 2021 → 40.2% in 2022 → 43.0% in 2023 → 4,443 GW(46.2%) in 2024
- Capacity @2024: Solar 1,866 GW, Wind 1,133 GW, Hydropower 1,277 GW, Others 167 GW



(GW)	Electricity Capacity 2024		
	Total	Non-Ren.	Renewable
China	3,350	1,532	1,818
USA	1,278	851	428
India	534	329	204
Japan	367	237	130
Germany	276	97	179
Russia	251	194	57
Brazil	246	32	214
Korea	158	124	34
France	157	82	74
Canada	155	45	110
Italy	138	65	72
Spain	136	47	88
Mexico	120	86	34
Australia	115	54	60
Türkiye	116	47	69
UK	107	47	60
Indonesia	101	87	14
Iran	96	83	13
Saudi Arabia	94	90	5
Viet Nam	85	36	49
Others	1,730	1,000	730
World	9,610	5,167	4,443

Source: IRENA, Renewable Energy Statistics 2025

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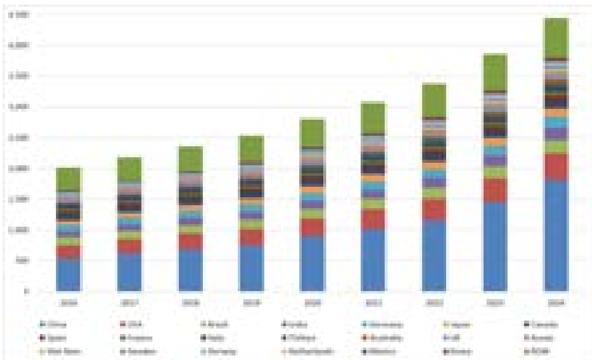
Global Renewable Electricity Capacity

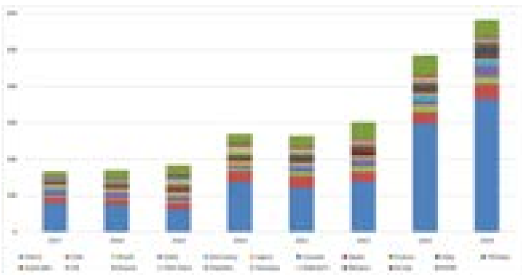
Renewable Power Capacity (GW)



	Renewable(2024)		Solar PV	Wind		Renewable	Others	Pumped
	Capa.(GW)	Ratio		Onshore	Offshore	Hydro.		Storage
China	1,818	54.3%	26.5%	14.3%	1.2%	11.3%	1.0%	1.8%
USA	428	33.5%	13.8%	11.9%	0.0%	6.6%	1.2%	1.5%
Brazil	214	86.9%	21.6%	13.4%	0.0%	44.7%	7.2%	0.0%
India	204	38.3%	18.2%	9.0%	0.0%	8.9%	2.2%	0.9%
Germany	179	64.8%	32.6%	23.1%	3.3%	2.1%	3.6%	1.9%
Japan	130	35.5%	24.4%	1.5%	0.1%	7.7%	1.8%	6.0%
Canada	110	70.8%	3.7%	11.3%	0.0%	53.9%	1.8%	0.0%
Spain	88	65.2%	26.7%	23.4%	0.0%	12.4%	2.6%	2.5%
France	74	47.4%	13.7%	14.7%	0.9%	15.7%	2.3%	1.4%
Italy	72	52.4%	26.2%	9.4%	0.0%	13.8%	3.0%	2.9%
Türkiye	69	59.3%	17.1%	11.2%	0.0%	27.9%	3.2%	0.0%
Australia	60	52.5%	31.3%	13.3%	0.0%	7.0%	0.8%	0.7%
UK	60	56.0%	16.7%	15.1%	14.8%	2.0%	7.3%	2.4%
Korea	34	21.4%	16.9%	1.3%	0.2%	1.1%	1.9%	3.0%

	Renewable(2023)		Solar PV		Wind		Hydropower		PSH	
	Capa.(GW)	Gen.(TWh)	Cap	Utilization	Cap	Utilization	Cap	Utilization	Cap	Utilization
China	1,454	2,843	609.4	10.9%	441.9	22.9%	370.6	38.0%	50.9	12.0%
USA	385	962	138.4	17.7%	147.5	33.0%	84.3	33.4%	18.9	13.4%
Brazil	194	630	37.9	15.2%	29.1	37.6%	109.9	44.2%	0.0	0.0%
India	176	370	72.7	17.0%	44.7	19.1%	47.3	38.9%	4.8	11.8%
Germany	160	270	74.9	9.7%	69.5	23.1%	5.6	40.5%	5.3	11.6%
Japan	127	227	87.1	12.6%	5.4	22.3%	28.2	30.5%	21.9	5.1%
Canada	108	419	5.3	15.1%	16.1	28.7%	83.5	49.3%	0.2	7.3%
Spain	81	144	29.6	16.8%	30.9	23.8%	16.8	17.0%	3.3	20.9%
France	67	140	17.4	14.5%	23.1	24.9%	24.6	26.3%	1.7	27.7%
Italy	65	117	29.4	11.9%	12.3	21.9%	18.9	24.4%	4.0	4.5%
Türkiye	59	140	11.3	22.3%	11.8	33.0%	32.0	22.9%	0.0	0.0%
UK	56	136	16.3	9.7%	30.2	31.2%	2.2	28.9%	2.6	8.0%
Australia	52	92	30.7	15.6%	12.9	27.8%	7.7	23.3%	0.8	12.6%
Korea	31	47	23.5	14.5%	2.2	17.9%	1.8	23.3%	4.7	9.2%

❖ Capacity Addition by Country (GW)



Source: IRENA, Renewable Energy Statistics 2025

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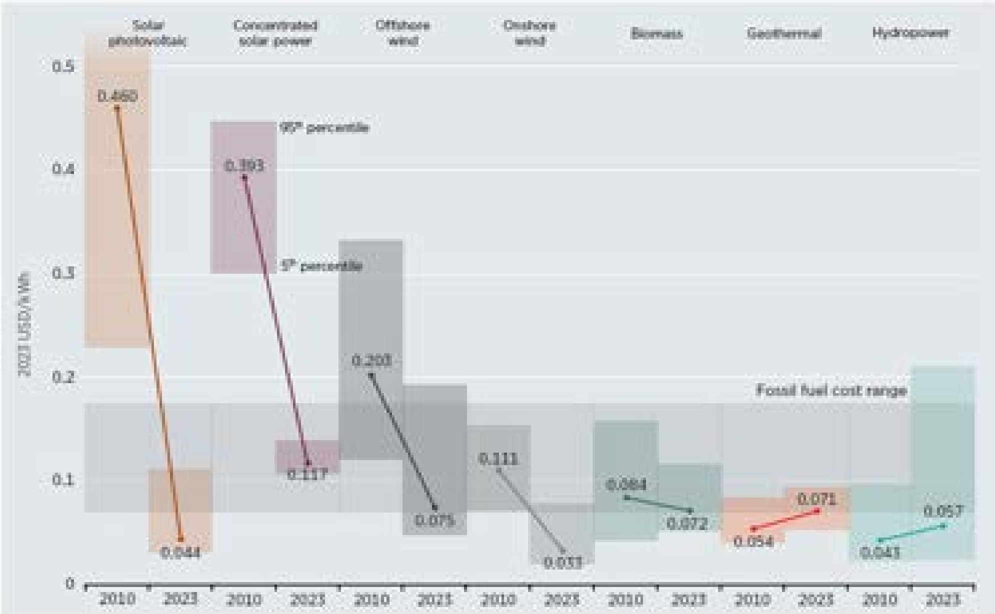
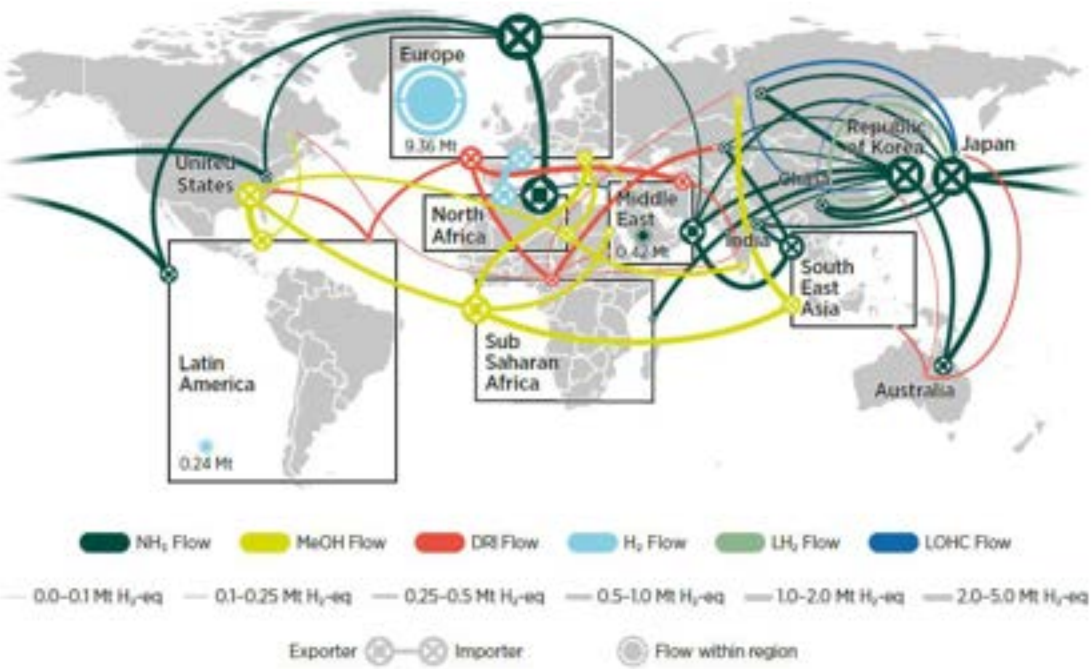
Renewable Power Generation Costs - LCOE



Note: These data are for the year of commissioning. The thick lines are the global weighted average LCOE value derived from the individual plants commissioned in each year. The LCOE is calculated with project-specific installed costs and capacity factors, while the other assumptions, including weighted average cost of capital (WACC), are detailed in Annex I. The grey band represents the fossil fuel-fired power generation cost in 2023, while the bands for each technology and year represent the 5th and 95th percentile bands for renewable projects.

5

Global Trade Flows in 2050



Source: IRENA, THE POTENTIAL FOR GREEN HYDROGEN AND RELATED COMMODITIES TRADE, July 2025

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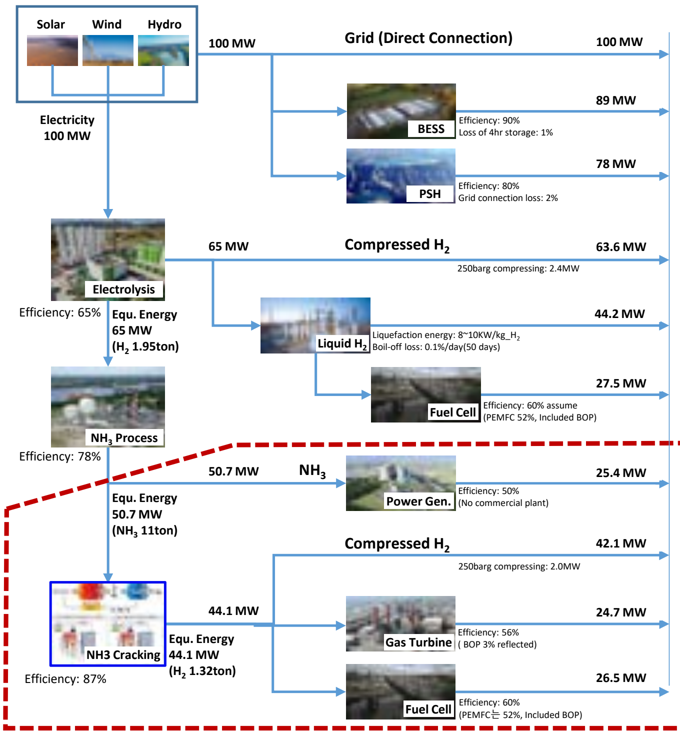
Clean Hydrogen Value Chain – NH_3



- VRE Share in Generation
- Required ESS Capacity
- Electrolysis and H_2-derived commodities

	Generation(TWh)				VRE(TWh)				
	Total	Non-Ren	Renewable		Solar		Wind		Total
France	525	385	140	27%	22	4%	50	10%	14%
Germany	512	242	270	53%	64	12%	141	27%	40%
Spain	286	142	144	50%	43	15%	64	22%	38%
UK	293	158	136	46%	14	5%	82	28%	33%

- Industry: Steel, Chemicals, Refineries, etc
- Mobility: Drones, Cars, Rail, etc
- Heating
- Low round-trip efficiency (RTE)
  Liquid H_2 < 44.2%, Fuel Cell < 27.5%
- High logistics cost for H_2 transport

- Constraints from NH_3 combustion characteristics
- H_2 for industry and mobility
- Economics challenge: very low RTE
  H_2 Gas Turbine < 24.7%, Fuel Cell < 26.5%
- **Exploring alternatives and solutions**

7

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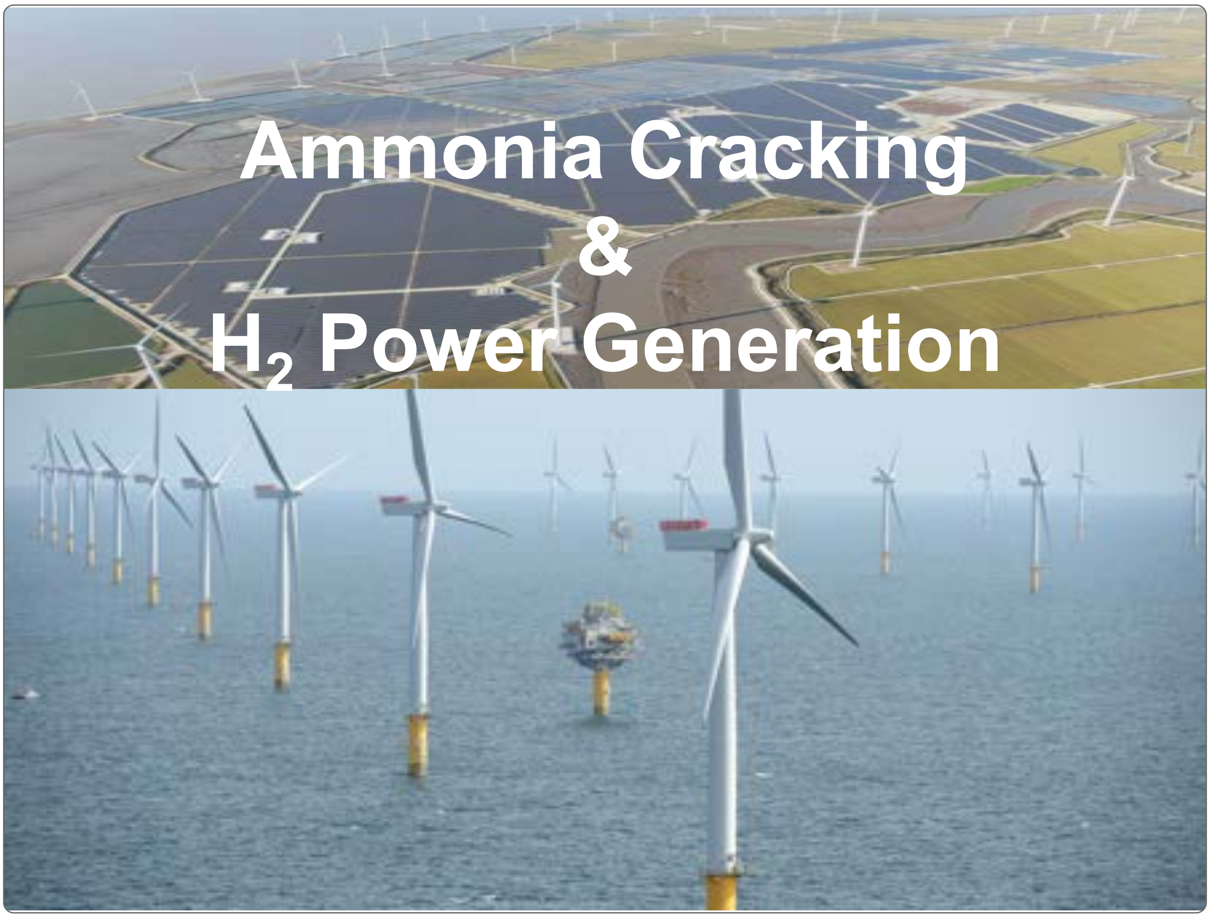
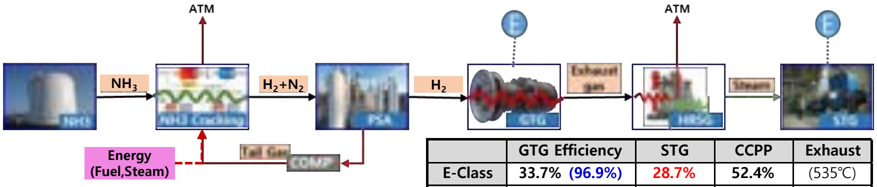


Ammonia Cracking & CCPP

"Stand-Alone Ammonia Cracking" Basic Design by KBR



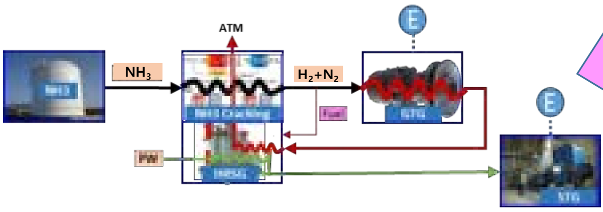
	GTG Efficiency	STG	CCPP	Exhaust
E-Class	33.7% (96.9%)	28.7%	52.4%	(535℃)
F-Class	38.5% (97.5%)	35.9%	60.2%	(593℃)
H-Class	43.3% (97.7%)	37.0%	63.9%	(600℃)

√ Limited synergy between "Stand-Alone Ammonia Cracking" and "CCPP"
- Mostly shared utilities only (steam, water, etc.); little heat/power-integration benefit

√ No clear pathway to materially improve the low "RTE Round Trip Efficiency"

"Integrated Ammonia Cracking" Basic Design by KBR

√ We can now see:
- strong synergies
- clear answers
- viable alternatives



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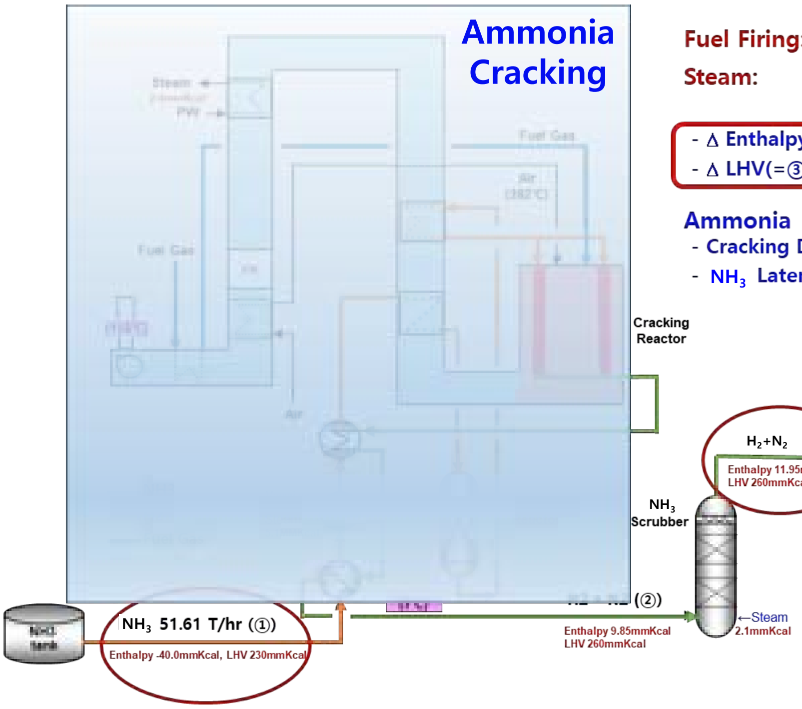
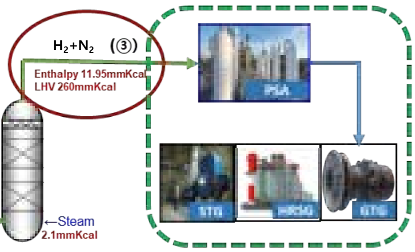
Ammonia Cracking – Stand-Alone(by KBR)



Fuel Firing: 51.5mmKCal
Steam: 4.8mmKCal
➡ Input Energy 56.3mmKcal

- Δ Enthalpy(=③-①): 51.95mmKcal
- Δ LHV(=③-①): 30.40mmKcal

Ammonia
- Cracking Duty: 33.1mmKcal
- NH_3 Latent Heat: 16.9mmKcal



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Ammonia Cracking - Gas Turbine Demonstration

Demonstrating 100% full combustion of 7E-Class with Hydrogen & Mixed Gas

Aug. '21 — Demonstration Project Agreement (Hanwha Impact-Korea Western Power)

Jun. '23 — H_2 59.5 vol% Demo. test

Nov. '23 — H_2 100 vol% Demo(FSNL)

Apr. '24 — Co-firing combustion test

Hydrogen turbine demonstration results

- Model: 7E-Class Gas Turbine Retrofit (80MW)
- Applied Hanwha's Independently Developed Combustor "Flamesheet™" (w/ PSM)

Category	Assessment Items	Target	Value	Result
50% co-firing (June. 2023)	Hydrogen co-firing ratio	50±5 vol%	59.5%	Success
	CO2 reduction ratio	20±2 vol%	22%	Success
	NOx emission	< 10 ppm	6 ppm	Success
100% hydrogen (Nov. 2023)	Hydrogen co-firing ratio	100%	100%	Success
	CO2 emission	-	0.05%	Success
	NOx emission	< 10 ppm	7.6 ppm	Success

Cracking Mixed Gas Combustion Test

- Cracking gas mixture: 75% hydrogen + 25% nitrogen (Vol.%)
- 10-day rig test at the German Aerospace Center (DLR)

"Successful Combustor Operation with New Configuration"

Results	- Good NOx control - Flashback margin secured - Good temperature control

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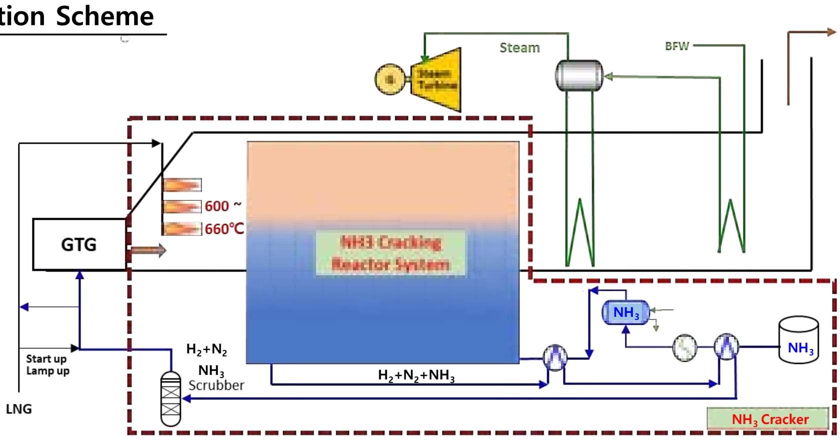
Integrated Ammonia Cracking & CCPP

Integration Scheme



◆ Key Points

- **Maximize use of GTG exhaust heat for Ammonia Cracking**
- **Minimize HRSG duct firing for Ammonia Cracking**
  - Optimize reactor configuration, GHSV, pressure, temperature profile
- **Prioritize GTG electric generation; minimize STG electric generation**
  - Divert steam/enthalpy to cracking duty.
  - GTG power attribution(energy-accounting basis): 96.9~97.7% of net electric output
  - STG electrical efficiency: 28.7~37%
- **High vaporization latent heat and endothermic reaction of Ammonia**

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Estimated Performance Comparison

The 7E-Class CCPP with Integrated NH_3 Cracking is conservatively designed and can be further optimized – e.g., reactor configuration, GHSV

- The optimized cracking design will be validated at the Daesan Hydrogen Power Plant and then deployed across advanced-class gas turbine
- Increase net CCPP efficiency with Integrated NH_3 Cracking beyond the standalone CCPP baseline

(RE100 Electricity)		E Class		F Class		H Class	
		Standalone (H_2 100%)	Integraion ($H_2 + N_2$)	Standalone (H_2 100%)	Integraion ($H_2 + N_2$)	Standalone (H_2 100%)	Integraion ($H_2 + N_2$)
NH_3 Feed (Cracker)	Ton/hr	53.0	50.4	109.7	89.5	149.1	114.7
	Gcal/hr ①	235	223	486	397	661	508
Fuel (Cracked Gas)		53.2	49.3	110.1	26.0	149.7	0.0
GTG Input (Gcal/H) ②		211.9	206.3	445.1	427.1	605.0	580.5
Generation (MWh)	GTG ③	81.4	81.4	201.0	201.0	290.0	290.0
	STG ④	41.90	44.0	104.3	80.8	142.5	95.3
	PSA	(3.6)	0.0	(7.5)	0.0	(10.1)	0.0
	Operation	(4.6)	(4.6)	(9.6)	(6.9)	(13.0)	(8.8)
	Net Power ⑤	115.1	120.8	288.2	274.9	409.4	376.5
	(Gcal/H) ⑤	99.0	103.8	247.9	236.4	352.1	323.8
CCPP Efficiency (③+④)*0.86/②		50.0%	52.3%	59.0%	56.7%	61.5%	57.1%
Total Efficiency (⑤/①)		42.2%	46.5%	51.0%	59.6%	53.3%	63.7%
NH_3 Unit (kg_NH3/MW)		460	418	381	326	364	305

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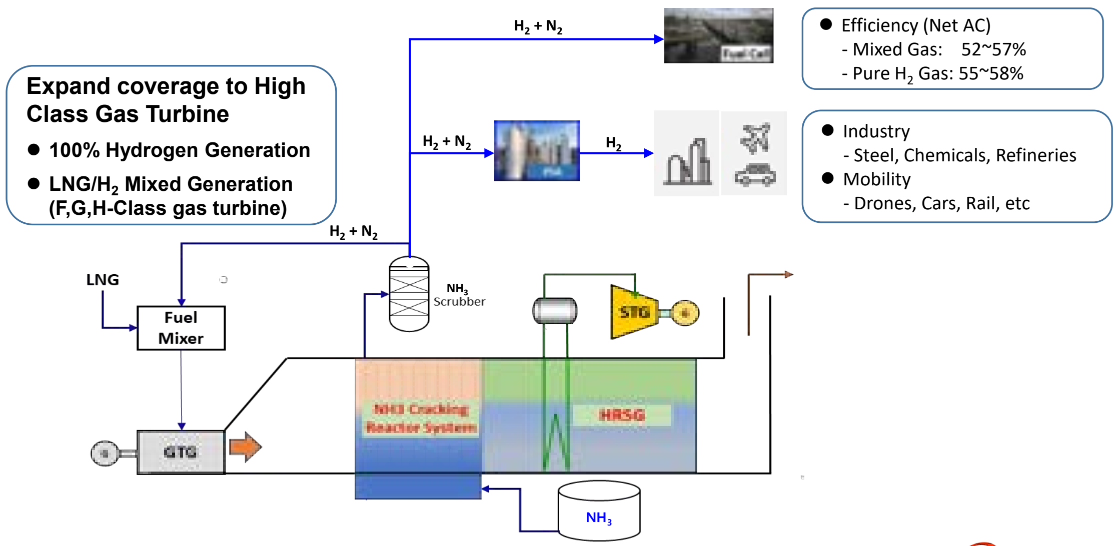
Integrated NH_3 Cracking Applications

Maximize Hydrogen Production via HRSG Heat Integration

STG Power(eff. 29~37%) ➡ GTG(eff. 97%), Fuel Cell(eff. 52~57%)



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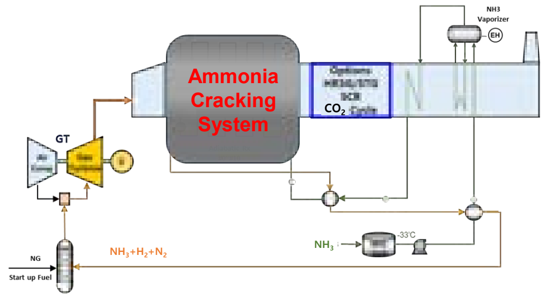
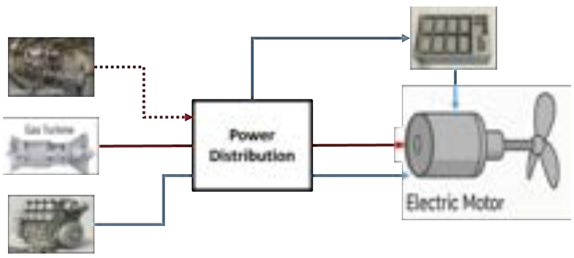
Integrated NH_3 Cracking Applications

Small Shipboard Gas-turbine Generators

- It is necessary to develop gas turbines capable of firing $NH_3/H_2/N_2$ fuel mixtures
- Estimated NH_3 cracking rate: 50~80wt%(H_2 67 vol%, NH_3 11 vol%, N_2 22 vol%)





GTG-Diesel Hybrid Applications

- **Battleship: Simple Cycle Gas Turbine**
  - Mobility, space/weight constraints
  - Efficiency 25-35%
- **Cruise ship: CCGT**
  - High efficiency, high power, maximum energy
  - Efficiency 45%-55%
- **LNG/Container Ships: CCGT/Diesel Engine**
  - IMO regulations, fuel diversification

√ **Combined-cycle gas turbines are well-suited for large, lower-emission vessels and can be installed as modular units**

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Efficiency Estimates for Small Marine GTGs

✔ **Assume simple-cycle(SCGT) due to space constraints**
- Higher overall efficiency is achievable with a combined-cycle(CCGT) configuration

✔ **Assume the same efficiency for NH_3 and mixed gas($NH_3/H_2/N_2$)**
- Utilize GTG exhaust heat for Ammonia Preheating, Vaporization and Cracking

✔ **Direct combustion of mixed gas ($NH_3/H_2/N_2$) in GT power generation**
- Utilize N_2 pressure energy for additional power generation

Efficiency estimates vs. $NH_3 \rightarrow H_2$ conversion

		700(Exhaust Temp 530℃)			400 (Exhaust Temp 529℃)		
		NH_3 100%	50% Conversion ($H_2+N_2+NH_3$)	80% Conversion ($H_2+N_2+NH_3$)	NH_3 100%	50% Conversion ($H_2+N_2+NH_3$)	80% Conversion ($H_2+N_2+NH_3$)
NH_3 Feed	Ton/hr	17.1	15.7	14.9	7.7	7.1	6.7
	Gcal/hr ①	76	70	66	35	32	30
GTG Input (Gcal/H)		76.1	76.1	76.1	34.5	34.5	34.5
GTG Generation	MWh	32.6	32.6	32.6	14.3	14.3	14.3
	(Gcal/H) ②	28.0	28.0	28.0	12.3	12.3	12.3
Total Efficiency (②/①)		36.8%	40.2%	42.3%	35.6%	38.9%	41.0%
NH_3 Unit (kg_NH3/MW)		524	480	457	542	496	471

16

Hanwha


감 사 합 니 다

Global Demand Outlook 5

Mobility Sector Hydrogen Demand and Market Outlook

Yong Tae Kimm
Vice President, Hyundai Motor

Education
2001, B.S, Chemical Engineering, Seoul National University

Professional Career
2025-Present, Vice President, Energy&Hydrogen Policy Group, Hyundai Motor Company
2023-2025, Vice President, Strategic Policy Division, Hyundai Motor Company
2021-2023, Director, Renewable Energy Industry Division, Ministry of Trade, Industry and Energy*, Korea
*Currently referred to as Ministry of Trade, Industry and Resources
2018-2021, Counselor, Permanent Mission of the Republic of Korea to the OECD

Company Introduction
Hyundai aims to be a Global Energy Transition Leader, driving hydrogen mobility via HTWO

Global Demand Outlook 6

India's Industrial Hydrogen Demand and Market Growth Outlook

Nishaanth Balashanmugam
CEO, GH2 India

Education
2013 – 2014 - Msc, International Business Management, Northumbria University, Newcastle, UK
2009- 2011 - Bachelor of Commerce, Loyola College, Chennai, India

Professional Career
2022 – Present, CEO and Founding Director, Green Hydrogen India (GH2 India), Chennai, India
2012 – Present, Dealer Principal, Honda, Tirupur, India
2018 – 2022, Authorized Dealer for Ford India, Tirupur, India
2011 – 2012, Director, KRR Bajaj, Tirupur, India

Research Interest
Industrial Demand & Market Development
Policy, Regulation & Standards
Power System & Infrastructure for Hydrogen
Financing, Risk Sharing & Business Models
Social, Skills & Just Transition Dimensions
International Cooperation & Corridors

Speech Summary
India today is one of the world's largest consumers of industrial hydrogen, with demand concentrated in refineries and fertiliser production. Until now, almost all of this has been "grey" hydrogen, produced from fossil fuels. The shift to green hydrogen is therefore not a luxury—it is central to meeting India's net-zero commitments, reducing import dependence on fossil fuels, and keeping our industrial exports competitive as global markets increasingly favour low-carbon products.
This presentation will first set out why India is pursuing green hydrogen: to decarbonise hard-to-abate sectors such as steel, refineries, fertilisers and chemicals, to create new industries and jobs, and to position India as a global hub for green molecules and derivatives.
I will then outline the policy enablers driving this transition. At the federal level, the National Green Hydrogen Mission provides the overarching framework—creating demand, supporting supply through schemes such as SIGHT, and addressing infrastructure, standards and R&D. Key ministries and agencies are working in tandem to lower the cost of renewable power, facilitate transmission and open access, and enable exports of green hydrogen, ammonia and other derivatives.
A core part of India's advantage lies in its power ecosystem. Rapidly growing renewable capacity, some of the world's most competitive solar and wind tariffs, and emerging storage solutions together create the foundation for large-scale, low-cost green hydrogen production.
The speech will also touch on state-level policies, where leading states such as Gujarat, Odisha, Andhra Pradesh, Tamil Nadu and Rajasthan are offering land, power concessions and project facilitation, creating hydrogen and e-fuel hubs linked to industrial corridors and ports.
Finally, I will provide a short project and offtake snapshot—covering major announced green hydrogen and ammonia projects, early offtake arrangements, and what this means for India's industrial hydrogen demand and market growth over the coming decade.

Company Introduction
GH2 India (Green Hydrogen Association) is a dedicated industry-led platform advancing India's green hydrogen ecosystem. We work at the intersection of policy, markets and projects to accelerate production, use and export of green hydrogen and its derivatives such as green ammonia, methanol and e-fuels. Our focus areas include policy research and consultation, industry coordination, state-level ecosystem development, standards and certification dialogues, and international partnerships. GH2 India convenes government, industry, financiers, and civil society to enable bankable projects, support offtake creation, and promote a just, inclusive transition that positions India as a global leader in green hydrogen.

Panel Discussion

Hydrogen Price Stability and Its Impact on Global Demand Expansion

Moderator

Nishaanth Balashanmugam
CEO, GH2 India

Panelists

Kenji Yoshimura
Kawasaki Heavy Industries

Jang Hoi Choi
General Manager, Posco Holdings

Inki Choi
Senior Manager of Strategy and Marketing, Bloom Energy Korea

Jong Hwa Lee
Head of Ammonia Hydrogen Business and Executive Vice President, Hanwha Impact

Yong Tae Kimm
Vice President, Hyundai Motor

Ralph Foong
Chief Hgydrogen Officer, City Energy

WORLD HYDROGEN 6th EXPO 2025 Conference

Hydrogen Deep Dive II：

International Hydrogen Technology Standardization

Global Clean Hydrogen Technology Standardization Strategy

Global Clean Hydrogen Technology Standardization Strategy 1

Proposed US Regulations and Impact on Global Hydrogen Compliance and Certification

Frank Wolak
President, Fuel Cell and Hydrogen Energy Association

Education

Western New England University, Bachelor of Science - BS, Mechanical Engineering
University of Hartford, Master of Business Administration - MBA, Finance, General

Professional Career

Fuel Cell & Hydrogen Energy Association (FCHEA), President and CEO, 2021 – 2025
FuelCell Energy, Senior Vice President, 2021 - 2019
FuelCell Energy, Vice President, 2004 - 2019
DNV KEMA, Senior Consultant, 2002 - 2004
NORESCO, Vice President, 2000 - 2002
ERI Services, Inc., Vice President, 1997 – 2000

Speech Summary

Title: Proposed US Regulations and Impact on Global Hydrogen Compliance and Certification. The session will outline global certifications of importance to hydrogen and derivative fuel production in the United States, the importance of consistent data in certification and standards utilization, the business implications of proposed US regulatory changes in greenhouse gas reporting and the growing factor of Global Warming Potential in certification development.

Company Introduction

The Fuel Cell and Hydrogen Energy Association (FCHEA) is the U.S. industry association with a mission to advance the commercial production, distribution and use of hydrogen in the United States and beyond. Based in Washington, DC, FCHEA has provided a credible, consistent, and unified industry voice for more than 35 years, driving support at federal and state levels through engagement with policymakers, regulators, and stakeholders.

Agenda

FCHEA

- **Certification for the U.S. Hydrogen Industry**
  - *Why Certifications Matter*
  - *Relevant International Certifications*
  - *Importance of Data*
- **U.S. Regulatory Landscape**
  - *Requirements for Measuring Carbon Intensity*
  - *U.S. Architecture for GHG Data*
- **Global Warming Potential (GWP) in Certifications**
  - *Growing Interest in Measuring Hydrogen*
  - *Accuracy is Necessary for True Impact*
  - *Considerations of International Standards Organizations*

Fuel Cell and Hydrogen Industry Association FCHEA

The Industry Association for Hydrogen in the United States

Based in Washington, DC

- **Advocating** for Hydrogen and Fuel Cell technology for 35 years**.**
- **Representing** leading companies, organizations, and partners that are advancing the ***production, distribution,*** *and* ***use*** of Hydrogen.
- **Providing** a consistent industry voice to regulators and policymakers at both *Federal and State* levels.
- **Educating** about the ***environmental, economic*** *and* ***societal*** benefits of Hydrogen

Fuel Cell & Hydrogen Energy Association Members FCHEA

AGC, AGFA, AIRBUS, Air Liquide, Air Products, ANGI, Ballard, Baker Hughes, Baker Botts, Bloomenergy, BMW, bosal, BOSCH, Capstone, ceres, CF, CGA Compressed Gas Association, Chart (Cooler By Design), Chemours, Clean Energy, ConocoPhillips, Cummins, Electric Hydrogen, Emerson, Engie, Evoloh, Flexitallic, Forvia Faurecia, Fortescue Future Industries, FuelCell Energy, Friem America Inc., Garrett Advancing Motion, gm, Gore, Heraeus Precious Metals, Hexagon Purus, Honda, Horiba Automotive, HyAxiom, Hydrogen & Fuel Cell Seminar, H2MOF, Hydrogen Fuel Cell Partnership, Hyundai, IHI, Ionomr, Jera Americas, Joby, John Cockerill, Johnson Matthey, Koloma, Mitsubishi Power, monolith, Nebraska Public Power District, Neeltran Inc., nel, Neuman & Esser, NeuVentus, Nuclear Energy Institute, Luxfer Gas Cylinders, Nuvera, Parker, pdc Machines, Phillips 66, pillsbury, plug, Proteum Energy, PowerCell Group, Quest One, Renewable Innovations, Schaeffler, SwRI, StormFisher Hydrogen, Topsoe, Toyota, twelve, Valterra Platinum, Wabtec Corporation, Westlake, Yamaha

Why Certification Matters to US Hydrogen

FCHEA

US Policies and International Demand enable a US Export Opportunity

- US Tax Credits reduce production costs
- Ample resources for Blue and Green hydrogen feedstock
- International demand pull (H2Global, Japan CfD) offer long-term market certainty

- **Hydrogen/ammonia export strategies require:**
  - Traceable carbon intensity (CI) values
  - Auditable MRV systems
  - Compatibility with international certification frameworks
- **CI evidence directly influences**
  - Compliance with national regulations
  - Tariff exposure
  - Bankability of projects

Certification Systems Define Compliance

FCHEA

Market – Specific Transactions Require Products Meet Regulations

- **EU RED II / RFNBO / CBAM**
  - Detailed LCA, strict electricity sourcing
  - Key for ammonia/e-fuel exports to EU
- **ISCC (International Sustainability & Carbon Certification) / CertifHy**
  - Chain of custody + audited CI
  - Common in project finance
- **TÜV SÜD CMS 70: Green Hydrogen/ TÜV Rheinland "Green Hydrogen"**
  - CI thresholds, MRV documentation
  - Basis for tariff treatment & "clean hydrogen" designation

Importance of Data in Certifications

FCHEA

- **Growing demand for "certified green hydrogen" and derivatives (ammonia, e-fuels, steel, etc.).**
- **Offtakers and financiers want**:
  - Recognized certification schemes
  - Auditable GHG data over the full life cycle
- **Without credible data: No Proof → No Premium Contract**
- **Global certification systems are converging around traceable and scientifically defensible CI data**

U.S. Regulatory Landscape: Certification

FCHEA

Key U.S. Policies Incorporating Hydrogen Carbon Intensity (CI)

- **45V Clean Hydrogen Tax Credit**
  - Requires LCA-based CI calculation (kg CO_2e/kg H_2)
  - Uses GREET-based modeling
  - Strongly shapes project design & electricity and hydrogen sourcing
- **DOE / National Lab LCA Methodology Work**
  - GREET (Greenhouse Gases, Regulated Emissions, and Energy Use in Technologies) - U.S. life-cycle assessment (LCA) model maintained by US DOE
  - Updates to H2-GREET will influence global comparisons
  - U.S. developers increasingly aligning with ISO/IPHE CI rules
  - DOE supporting development of transparent project-level MRV
- **State-Level Clean Fuel Standards**
  - California LCFS, Washington CFS, Oregon CFP
  - Require verified CI and third-party auditing
  - Commonly used as reference frameworks in early export deals

U.S. Architecture for GHG data (today)

FCHEA

- **US EPA's GHG Reporting Program (GHGRP):**
  - Provides foundational emissions data for life-cycle modeling
  - Supports harmonization with international verification and standardized methodologies
  - Auditable and transparent framework providing confidence for domestic & foreign buyers

- **Proposed changes to GHGRP may influence data granularity, and degree of consistent data**

- **Impacts from Changes to GHG Reporting Structure:**
  - Modified data collection
  - Increased reliance on estimates
  - More importance given to voluntary schemes
  - Loss of consistency: Potential for fragmentation of key data

Interest in Global Warming Potential (GWP)

FCHEA

- **H_2 has known indirect warming effects:**
  - Extends methane lifetime
  - Increases tropospheric ozone
  - Increases stratospheric water vapor

- **Scientific debate on which GWP value (timeframe in years) to use:**
  - GWP_{100} (like other gases) or GWP_{20} of H_2 in LCA models

  Latest research:
  - $GWP_{100} \approx 11 \pm 5$
  - $GWP_{20} \approx 35–40$

- **Consensus:**
  - Leakage could influence CI in the context of green H_2
  - Growing recognition of this effect in LCA and certification systems

Accuracy of GWP Impact is Critical

FCHEA

- **Environmental Defense Fund real-world measurement campaigns:**
  - Real-world hydrogen leakage rates
  - Detection instrumentation
  - Field measurement campaigns with industry partners
- **Focus areas:**
  - Pipeline & equipment leakage
  - Routine releases (venting, boil-off)
  - Improved detection instrumentation
- **Early findings & claims:**
  - Historic leakage assumptions (e.g., 10–20% in some models) appear overstated.
  - Actual pipeline and equipment leaks tend to be much lower but still relevant.
- **Early work will shape:**
  - Regulatory modeling
  - International certification bodies
  - International interest in "hydrogen-specific MRV"

GWP Considerations - ISO

- **While ISO is not a "certification body," many certification programs are built on ISO frameworks, especially:**
  - ISO 14040/44 – LCA principles
  - ISO 14064 – GHG accounting
  - ISO 14687 – Hydrogen purity / quality
  - ISO 19870-series – GHG methodology (new work)
- **New LCA standards under ISO 14040/14067 frameworks increasingly incorporate:**
  - Hydrogen leakage
  - Indirect climate warming factors
  - System boundaries for CI accounting
- **LCA frameworks working groups are increasingly discussing the incorporation of:**
  - Leakage
  - Indirect warming effects
  - Boundary consistency

GWP Considerations - IPHE

FCHEA

- **IPHE is coordinating a global methodology for calculating the carbon footprint of hydrogen.**
- **IPHE's approach aims to:**
  - Harmonize CI accounting
  - Align definitions across major markets
  - Reduce trade friction
- **Early IPHE discussions include:**
  - Whether hydrogen leakage should be mandatory
  - What GWP values should be applied
  - What system boundaries should be consistent globally

Summary

FCHEA

- U.S. Policies have opened opportunities for export projects as strong partners for global importers. Trade must consider compliance with international regulations.
- Global certification systems are converging around robust, traceable, scientifically defensible CI data.
- Proposed US GHGRP changes may influence US data as a factor in verifications for importers.
- Hydrogen's indirect climate impacts are becoming factors in global CI rules. Accuracy is critical.
- International Standards Organizations are shaping the future of how hydrogen GWP and leakage are measured


FCHEA
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1025 Connecticut Avenue, Suite 1000
Washington, DC 20036
202-355-9463 | www.fchea.org
Thank You

WORLD HYDROGEN 6th EXPO 2025 Conference

Global Clean Hydrogen Technology Standardization Strategy 2

Status and Strategy of Korea's Hydrogen Fuel Cell Standardization (IEC/TC 105)

Hong-Ki Lee
Chair, IEC/TC 105
Vice President, Woosuk University

Education
1989-1993, Ph.D., Electrochemistry,Hanyang University, Seoul, Korea
1986-1988, M.S., Industrial Chemistry, Hanyang University, Seoul, Korea
1978-1982, B.S., Industrial Chemistry, Hanyang University, Seoul, Korea

Professional Career
2023-presentL Chairman, The IEC International Fuel Cell Technology Committee
2024-present: President, The Korea Hydrogen and New Energy Society
2018-present: Chairman, Hydrogen Technology Standard Forum
2014-present: Chairman, Overseas Certification Support Committee
2008-present: Chairman, The Hydrogen Fuel Cell Mirror Committee
1994-present: Vice President(2024) , Professor, Woosuk University

Research Interest
AFC, PAFC, FEMFC system R&D
International Standard for Fuel cell
Catalysts and MEA research
Physical mobility for hydrogen fuel cell system

Speech Summary
This session presents various performance indicators to discuss key issues related to Korea's hydrogen economy roadmap established since 2018..
The session discusses the vision, target and structure of the Standards Forum, established to standardize hydrogen technology with its annual performance indicators.
Furthermore, the current status and future direction of IEC/TC 105, which develops international standards for fuel cells, are explained.

Company Introduction
Woosuk University was provate university established since 1979,and Fuel Cell Regional Innovation Center was established since 2008 by government support.
The activity is Research and development of fuel cells, Core technology construction of fuel cells, Providing of research facilities and Technical support for companies

Status and Strategy of Korea’s Hydrogen Fuel Cell Standardization

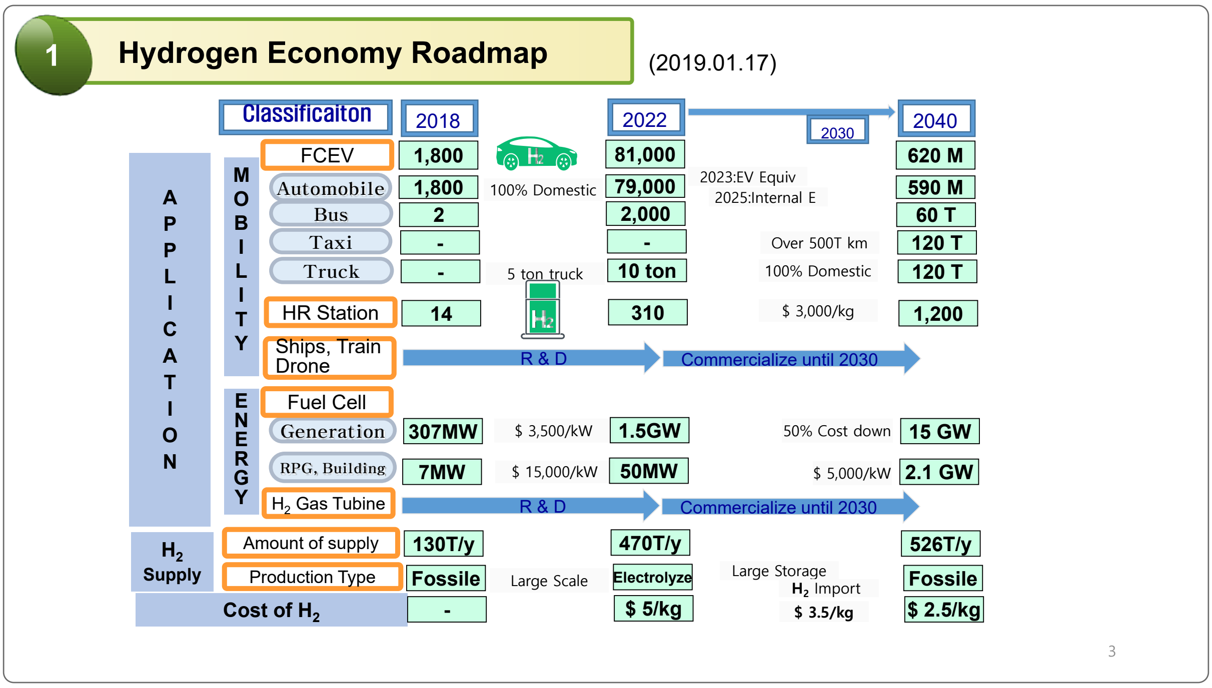
HONGKI LEE
IEC/TC 105 Chair

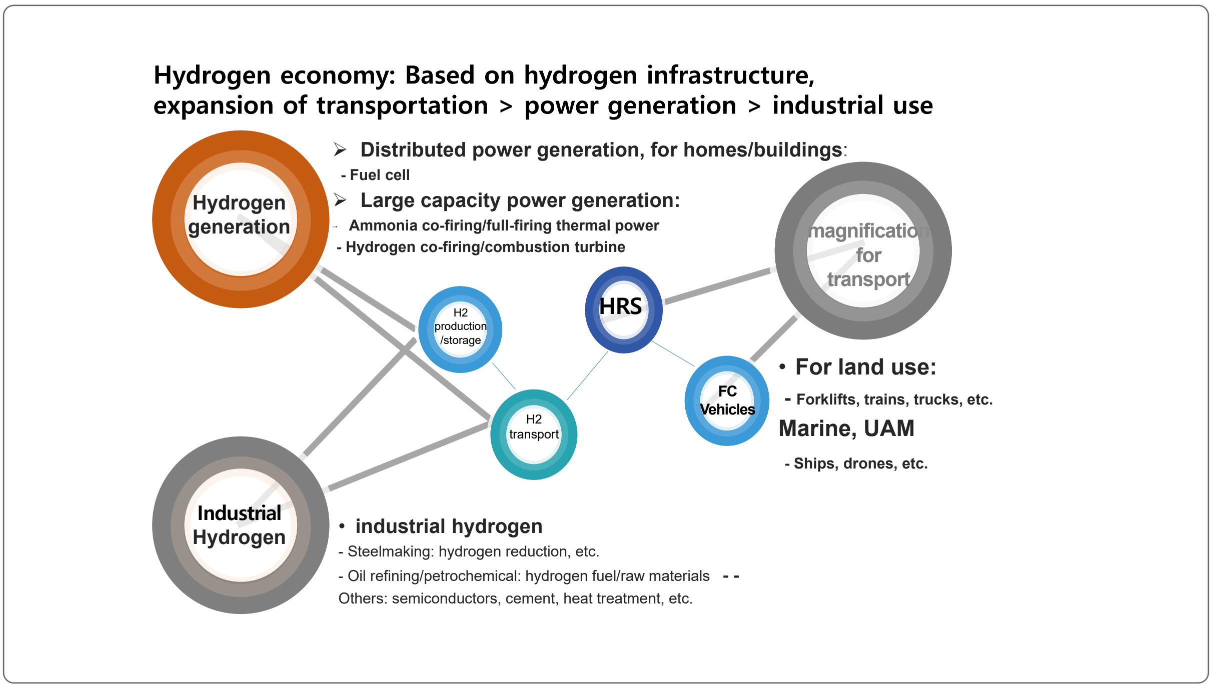
2025 Hydrogen Technology
International Standard Conference
December 5, Korea

IEC International Electrotechnical Commission

Contents

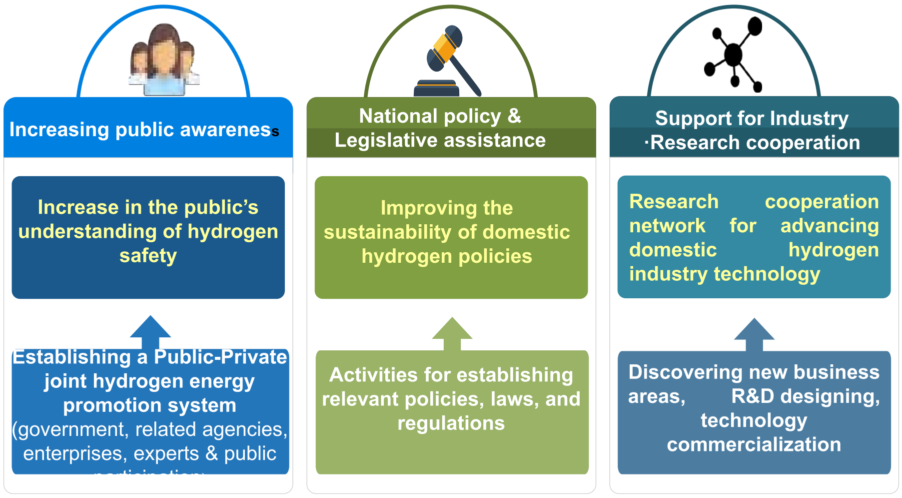
1 Hydrogen Economy Roadmap
2 Hydrogen Technology Standard
3 Status of International Standard


1
Hydrogen Economy Roadmap
(2019.01.17)
Classificaiton
2018
2022
2030
2040
APPLICATION
MOBILITY
FCEV
1,800
81,000
620 M
Automobile
1,800
100% Domestic
79,000
2023:EV Equiv
2025:Internal E
590 M
Bus
2
2,000
60 T
Taxi
-
-
Over 500T km
120 T
Truck
-
5 ton truck
10 ton
100% Domestic
120 T
HR Station
14
310
$ 3,000/kg
1,200
Ships, Train Drone
R & D
Commercialize until 2030
ENERGY
Fuel Cell
Generation
307MW
$ 3,500/kW
1.5GW
50% Cost down
15 GW
RPG, Building
7MW
$ 15,000/kW
50MW
$ 5,000/kW
2.1 GW
H2 Gas Tubine
R & D
Commercialize until 2030
H2 Supply
Amount of supply
130T/y
470T/y
526T/y
Production Type
Fossile
Large Scale
Electrolyze
Large Storage
H2 Import
Fossile
Cost of H2
-
$ 5/kg
$ 3.5/kg
$ 2.5/kg
3


Hydrogen economy: Based on hydrogen infrastructure,
expansion of transportation > power generation > industrial use
Distributed power generation, for homes/buildings:
- Fuel cell
Large capacity power generation:
Ammonia co-firing/full-firing thermal power
- Hydrogen co-firing/combustion turbine
Hydrogen generation
H2 production /storage
HRS
magnification for transport
H2 transport
FC Vehicles
• For land use:
- Forklifts, trains, trucks, etc.
Marine, UAM
- Ships, drones, etc.
Industrial Hydrogen
• industrial hydrogen
- Steelmaking: hydrogen reduction, etc.
- Oil refining/petrochemical: hydrogen fuel/raw materials - -
Others: semiconductors, cement, heat treatment, etc.

1-3. Increase in public acceptance of hydrogen industry

Improvement in public acceptance of hydrogen Industry through customized support activities for the public - policy makers - industrial technical experts



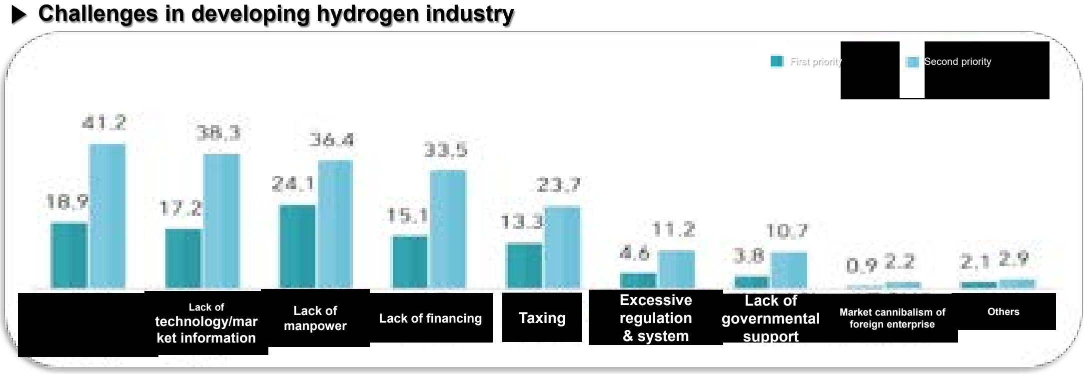
1-4 Survey Results of hydrogen Enterprises in S. Korea

Growth Potential

- **Major obstacles Lack of infrastructure**

➡ Infrastructure, technology & market information, manpower, and finance (left to right)

▶ **Challenges in developing hydrogen industry**



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2 Hydrogen Technology Standard

Vision: Leading global market share of hydrogen industry by prevailing international standard

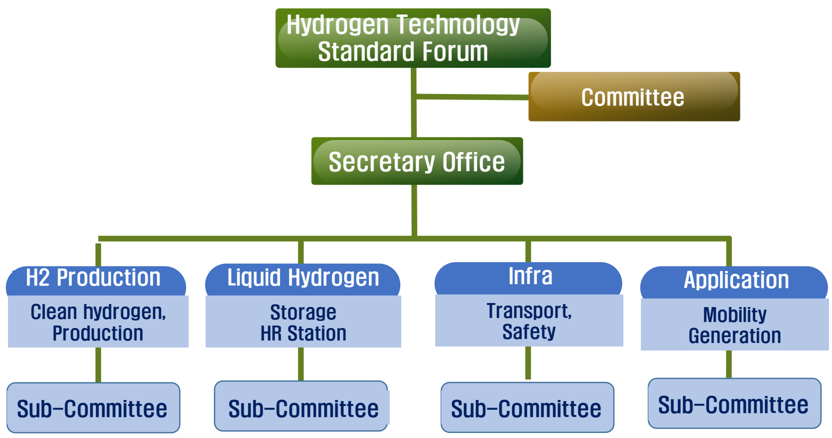
Strategy

1. Achieve the goals of the International Standardization Cooperation Project
2. Serve as a think tank for domestic hydrogen technology standards,
3. Establishing int'l standardization strategies and reviewing int'l joint research.

Action Plan

1. Active participation to present international standards WG
2. Strengthening Korea's new proposal to lead international standards
3. Standardization technology reflected in domestic R & D
4. Occupied hydrogen industry demand with Harmonization of IS
5. Fostering Standards Experts in International Standards Organizations

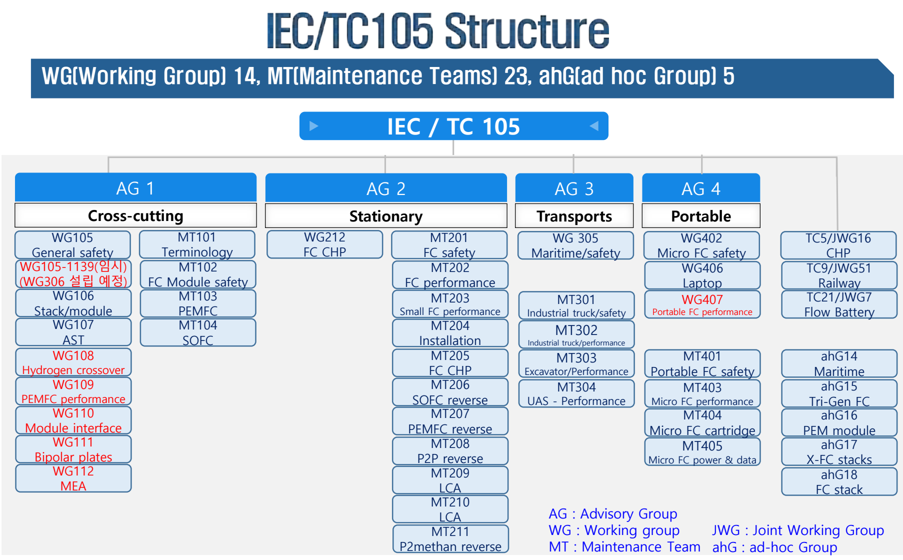
Structure of Standard Forum



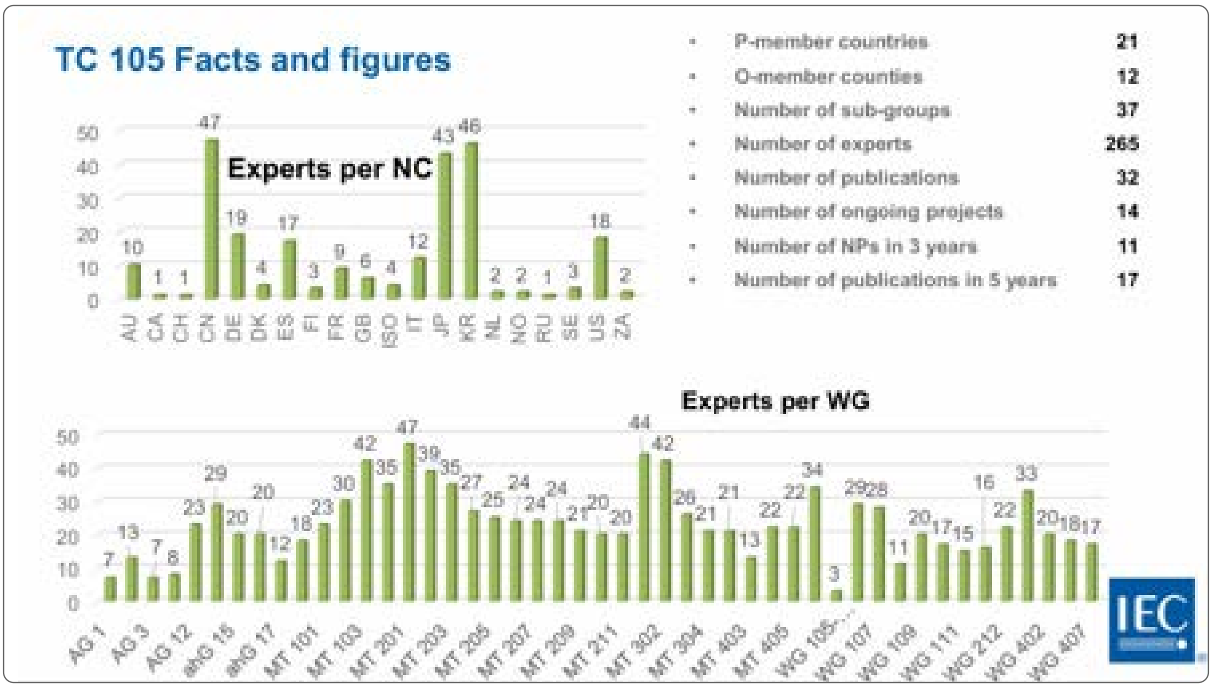
2-2 Items of H_2 Economy Standard

No.	Item	Target
1	Development of integrated standard with R & D	NWIP 25 until 2030
2	Expanded supporting system for international standard	Expanding Expert Support
3	Strengthening cooperation with multilateral IS	NE Asia standard cooperation International forum
4	Expansion of KS standard for H_2 products and services.	100% Harmonization(54)
5	Establishment of KS system for market penetration	Identification of items and KS certification
6	Supply to secure transaction reliability of H_2 charging	Technical development Regulation improvement
7	Support standard activities of small/medium sized companies	Mach-up 30 at 2022
8	**Hydrogen economy standard forum and fostering experts.**	100 Experts at 2020
9	Establishment of hydrogen safety test base	Relevant agency cooperation

3 Status of International Standard



* source : IEC/TC105 web('25.10)



❖ TC 105 Liaisons

Committee	Description	Incoming liaison	Outgoing liaison
	Internal IEC Liaison		
TC 8	System aspects of electrical energy supply	Mr Toshiki SHIMIZU	Mr Toshiki SHIMIZU
TC 9	Electrical equipment and systems for railways	Mr Julien D'ARBIGNY	
TC 18	Electrical installations of ships and of mobile and fixed offshore units		Mr Noel Dunlop
TC 21	Secondary cells and batteries		Mr Nobuo SHIGA
TC 108	Safety of electronic equipment within the field of audio/video, information technology and communication technology	Mr Bob Griffin Mr Jos Remy	Mr Toshiki SHIMIZU
TC 120	Electrical Energy Storage (EES) systems	Mr Toshiki SHIMIZU	Mr Toshiki SHIMIZU
SyC LVDC	Low Voltage Direct Current and Low Voltage Direct Current for Electricity Access		
SyC Smart Cities	Electrotechnical aspects of Smart Cities	Mr Kazuo SHIBATA	Mr Kazuo SHIBATA
SyC Smart Energy	Smart Energy		Mr Kazuo SHIBATA
	Liaison ISO		
ISO/TC 22	Road vehicles	Mr Kelvin Hecht	
ISO/TC 110	Industrial trucks	Mr Sylvain Cadou Mr David Goss Mr Andreas Scherb Mr Maxime Vinçonneau	Mr Akio Matsuura
ISO/TC 127	Earth-moving machinery	Mr Chuck Crowell	
ISO/TC 127/SC 3	Earth-moving machinery - Machine characteristics, electrical and electronic systems, operation and maintenance	Mr Minpei SHODA	Mr Hong Ki Lee
ISO/TC 197	Hydrogen technologies	Mr Hidenori Tomioka	
	Liaison A		
EC	European Commission	Mr Thomas Malkow	

IEC/TC105 Projects(14)

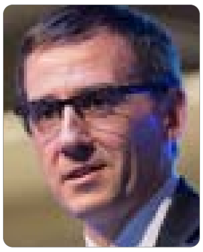
Project Reference	Title	Current Stage	WG	Project Leader
PWI 105-1	General safety standard	PWI		
PNW 105-1139 ED1	Fuel cell technologies - Part 4-601: Fuel cell power systems for propulsion other than road vehicles and auxiliary power units (APU) – Safety-Fuel cell/battery hybrid systems for excavators and wheel loaders	PNW	WG 306	Joongpyo Shim
IEC 62282-2-201 ED1	Fuel cell technologies – Part 2-201: Fuel cell modules - Performance test methods for PEM module	ACD	WG 109	Tiancai MA
IEC 62282-2-400 ED1	Fuel cell technologies - Part 2-400: Fuel cell modules - Calculation of Rated Power and Power Density of a PEM stack and PEM module	CDM	WG 106	
IEC TS 62282-2-401 ED1	Fuel cell technologies– Part 2-401: Fuel cell modules – PEM modules Size and interfaces definition (Shape, fluidic, electrical, API interfaces)	ACD	WG 110	Etienne HAVRET
IEC 62282-3-100 ED3	Fuel cell technologies - Part 3-100, Stationary fuel cell power systems - Safety	PCC	MT 201	Stephen Maurer
IEC 62282-4-401 ED1	Fuel cell technologies - Part 4-401: Fuel cell power systems for propulsion and auxiliary power units - Maritime sector - Safety of PEMFC-Systems	ACD	WG 305	Takehiro Maruyama
IEC 62282-5-200 ED1	Fuel cell technologies – Part 5-200: Portable fuel cell power systems - Performance test methods	ACD	WG 407	Toshiki SHIMIZU
IEC 62282-7-4 ED1	Fuel cell technologies - Part 7-4: Test methods - Bipolar plates for PEFC	ACD	WG 111	Zhigang qi
IEC 62282-7-5 ED1	Fuel cell technologies - Part 7-5: Test methods - Membrane electrode assembly for PEFC	ACD	WG 112	Hongmei YU
IEC 62282-8-101 ED2	Fuel cell technologies - Part 8-101: Energy storage systems using fuel cell modules in reverse mode - Test procedures for the performance of solid oxide single cells and stacks, including reversible operation	ACD	MT 206	Stephen Mc Phail
IEC 62282-8-102 ED2	Fuel cell technologies - Part 8-102: Energy storage systems using fuel cell modules in reverse mode - Test procedures for the performance of single cells and stacks with proton exchange membrane, including reversible operation	ACD	MT 207	Hongmei YU
IEC 63341-3 ED1	Railway applications - Hydrogen and Fuel Cell systems for rolling stock - Part 3: Performance test methods for fuel cell power system	BPUB	TC 9/JWG 51	Nan Liu

* source : IEC/TC105 web('25.10)

Thank you.

Regional Innovation Center for the Hydrogen Fuel-Cell Technology

Global Clean Hydrogen Technology Standardization Strategy



Laurent Antoni
Executive Director, IPHE

Education

1992-1996 PhD at Institut National Polytechnique de Grenoble (INPG), Electrochemistry and Surface Sciences. INPG PhD award 1997
1989-1992 Engineer School INP Grenoble / ENS Electrochemistry and Electrometallurgy of Grenoble

Professional Career

2003 - Commissariat à l'Energie Atomique et aux Energies Alternatives (CEA)
2023- Executive Director of the IPHE
2015-2023 Hydrogen Public Affairs Manager (LITEN)
2013-2014 Electricity and Hydrogen for Transportation Department Manager
2010-2012 Electrochemical Generators Integration Laboratory Manager
2005-2009 Low temperature fuel cell system Laboratory Manager
2003-2005 Team leader in the Fuel Cell Laboratory
1996-2003 UGINE-SAVOIE IMPHY, Mittal Group

Research Interest

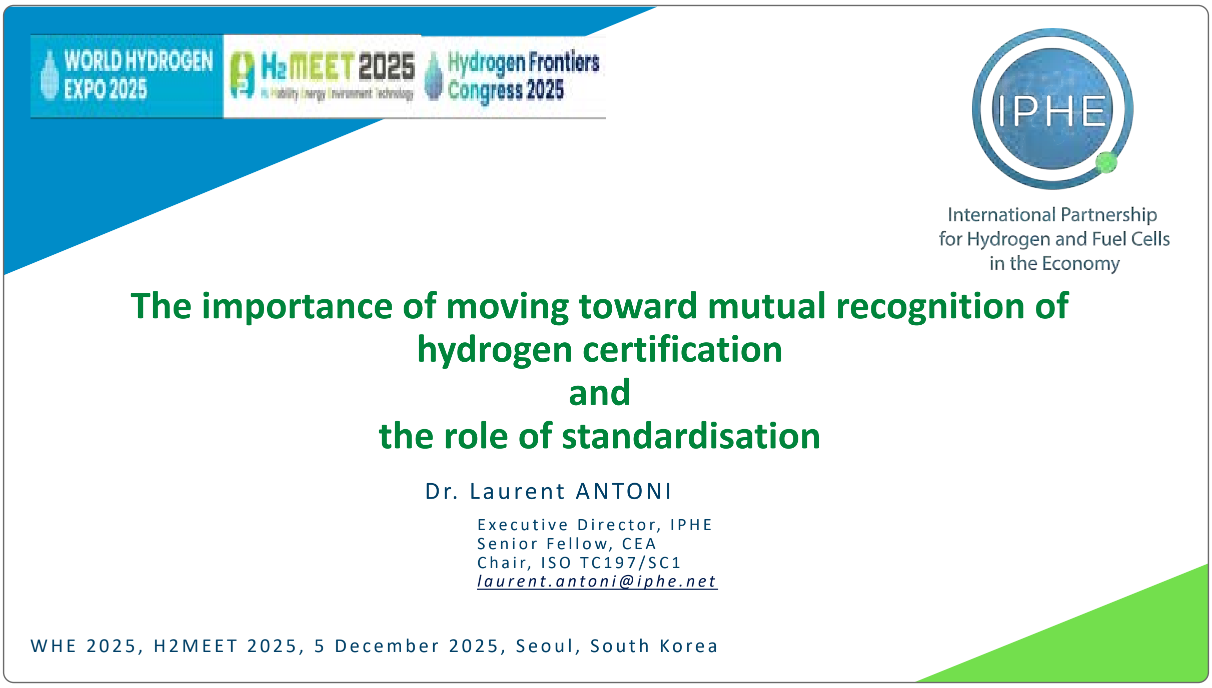
Hydrogen technologies

Speech Summary

Low-emission hydrogen is a key lever for decarbonising our economies and achieving global carbon-neutrality targets by 2050. Building trust and securing long-term commitments across the hydrogen value chain, however, requires reducing significant uncertainties—particularly regarding what qualifies as "clean" hydrogen for producers, buyers, investors, and end users. Certification schemes play a central role by verifying that hydrogen meets defined sustainability and emissions-performance criteria, thereby ensuring that emerging low-emission hydrogen markets genuinely contribute to climate-mitigation and broader sustainability goals.
To prevent market fragmentation and enable international trade, there is now an urgent need for mutual recognition of certification schemes for renewable and low-carbon hydrogen and derived products. Establishing a shared understanding of certification mechanisms among governments and stakeholders is essential.
This presentation will examine how standardisation can support this process, fostering interoperability, comparability, and confidence in global hydrogen markets.

Company Introduction

The International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE), established in 2003, is an international Government-to-Government partnership whose objective is to facilitate and accelerate the transition to clean and efficient energy and mobility systems using fuel cells and hydrogen technologies. Each of the IPHE partner countries has committed to accelerate the development of FCH technologies to enhance the security and efficiency of their energy systems, to help address environmental objectives, and to grow the economy.


WORLD HYDROGEN EXPO 2025
H2 MEET 2025
Hydrogen Frontiers Congress 2025
IPHE
International Partnership for Hydrogen and Fuel Cells in the Economy
The importance of moving toward mutual recognition of hydrogen certification
and
the role of standardisation
Dr. Laurent ANTONI
Executive Director, IPHE
Senior Fellow, CEA
Chair, ISO TC197/SC1
laurent.antoni@iphe.net
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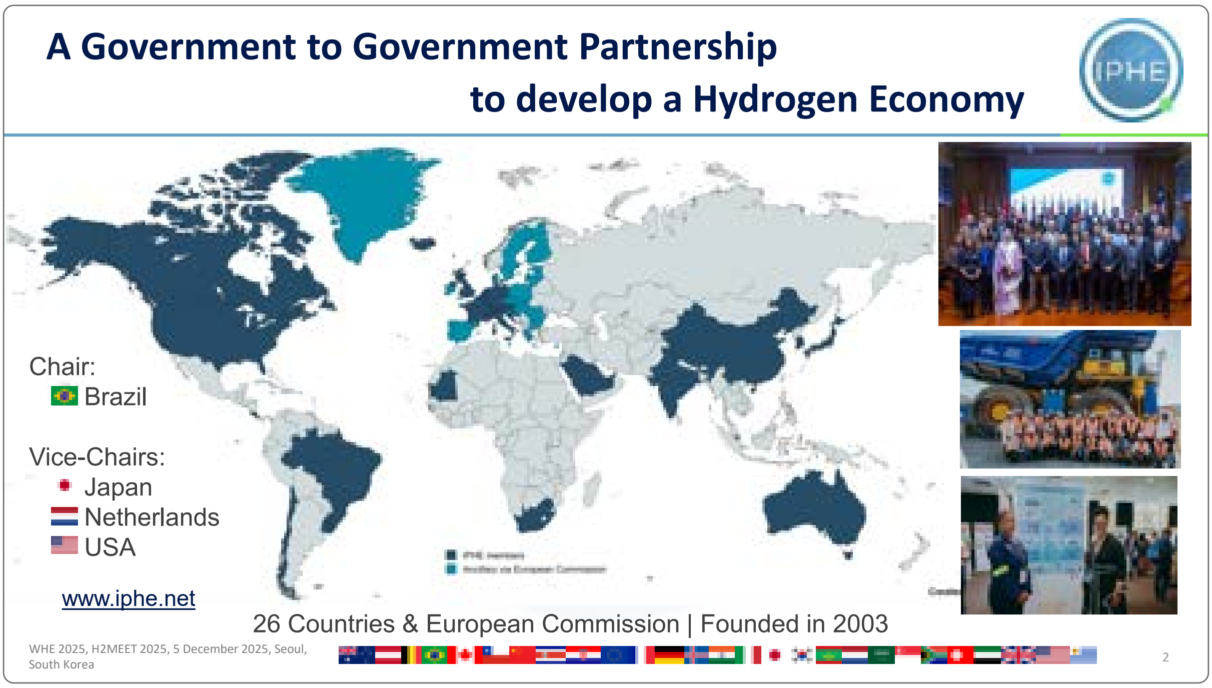
A Government to Government Partnership
to develop a Hydrogen Economy
IPHE
Chair:
Brazil
Vice-Chairs:
Japan
Netherlands
USA
www.iphe.net
26 Countries & European Commission | Founded in 2003
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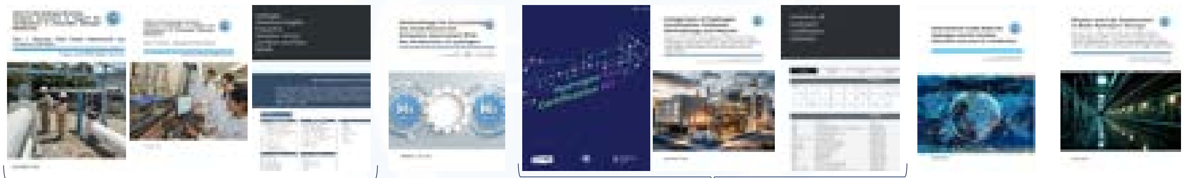
A Government to Government Partnership to develop a Hydrogen Economy

IPHE's DNA is to monitor information, perform gap analysis and subsequently produce and publish reports, databases, etc.

All documents produced by the task forces and working groups of IPHE stem from government-to-government exchanges and work **exclusively**. They are **publicly available**. They are often presented through dedicated webinars.



The IPHE Secretariat maintains database listing **national hydrogen strategies** and technology **deployments** as well.

All resources are available here: https://www.iphe.net/intelligence

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Introduction

- Hydrogen's global role in
  - Decarbonization: Hard-to-abate sectors (steel, chemicals, heavy transport, shipping, aviation)
  - Energy Security: Diversification away from fossil fuel dependencies
  - Economic Opportunity: Creation of new export industries and "green" jobs

→ Hydrogen is more than just a new fuel; it is a potential cornerstone of the future energy system.

- Current barriers
  - Cost gap versus fossil fuels, including unabated fossil hydrogen
  - Infrastructure
  - Policy uncertainty

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The Need for International Cooperation

- National strategies are necessary but not sufficient. No country can go it alone.
- Without international cooperation and coordination, there is a risk of a fragmented market with incompatible standards, hindering the economies of scale that are crucial for cost reduction.

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The Need for International Cooperation

- Four main pillars:

1. **Common Definitions and Standards**: Defining "low-emission/clean/renewable and low-carbon" hydrogen to ensure credibility & trust and to prevent any greenwashing
2. **Global Trade**: Developing trade rules and infrastructures
3. **Financing and Risk Sharing**: Role of public financing (grants, loans, guarantees), blended finance with private capital, carbon pricing mechanisms
4. **R&D Collaboration**: Shared innovation in electrolysis, CCS, storage, and safety to accelerate cost reduction for everyone.

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Harmonizing international standards, certification and trade rules is critical to avoid market fragmentation

IPHE

Global trade in low-emission hydrogen and hydrogen derivatives **helping match supply and demand** at international scale **unlocks decarbonization opportunities** and **cost-efficiency gains**.

Certification of low-emission hydrogen and hydrogen derivatives is a key priority for **multilateral cooperation to unlock this cross-border trade** while enabling **transparency, interoperability** as well as in building **consumer trust**.

At COP28, a Declaration of Intent signed by 39 countries affirmed the importance of a **mutual recognition of certification schemes** based on key principles that recognizes diverse policy choices with regards to strategies, roadmaps, policies and legislation for renewable and low-carbon hydrogen and hydrogen derivatives.

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Mutual recognition of certification schemes based on key principles

IPHE

1 **Political track**: Engage at the political level to obtain continued political endorsement of the implementation of the initiative by signatories — BREAKTHROUGH — COP

COP28

2 **Technical track**: Develop technical draft and operational program to develop the mutual recognition of certification schemes — IPHE

Long-term objectives

- Support the development of **harmonized underlying methodologies**
- Develop **mutual recognition framework and mechanism**
- Develop **technical recommendations**

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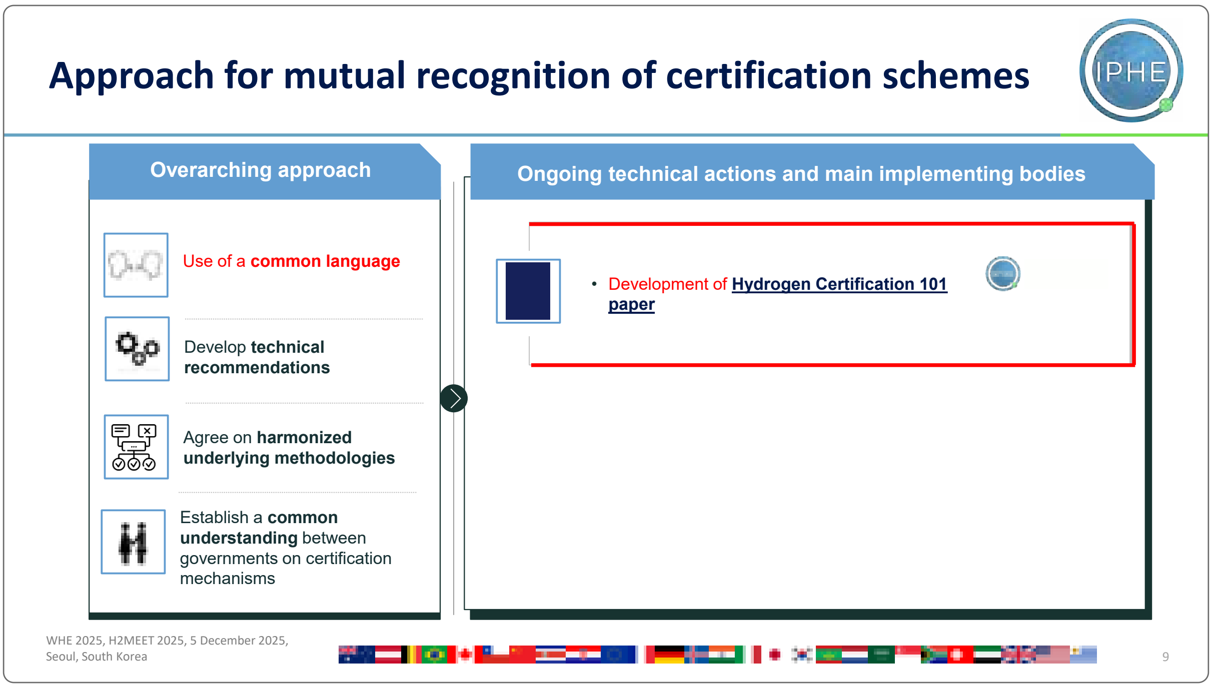
Approach for mutual recognition of certification schemes
IPHE
Overarching approach
Use of a common language
Develop technical recommendations
Agree on harmonized underlying methodologies
Establish a common understanding between governments on certification mechanisms
Ongoing technical actions and main implementing bodies
• Development of Hydrogen Certification 101 paper
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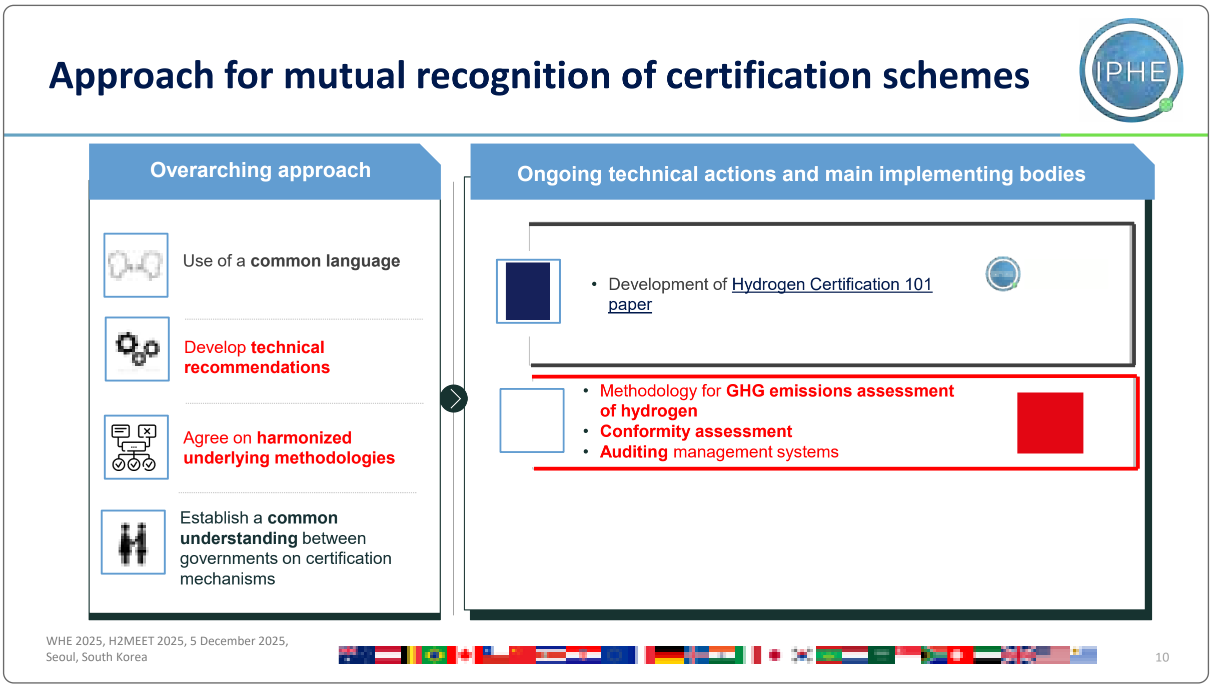
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• Development of Hydrogen Certification 101 paper
• Methodology for GHG emissions assessment of hydrogen
• Conformity assessment
• Auditing management systems
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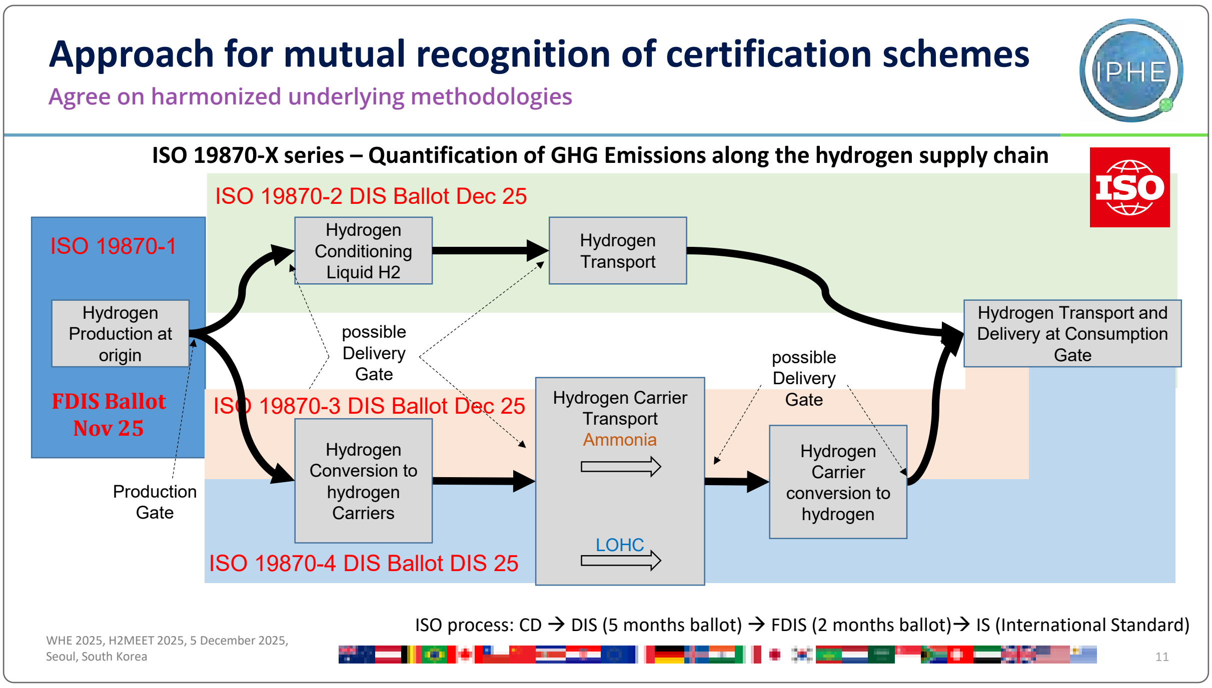
Approach for mutual recognition of certification schemes
Agree on harmonized underlying methodologies
IPHE
ISO 19870-X series – Quantification of GHG Emissions along the hydrogen supply chain
ISO
ISO 19870-2 DIS Ballot Dec 25
ISO 19870-1
Hydrogen Production at origin
FDIS Ballot Nov 25
Production Gate
Hydrogen Conditioning Liquid H2
Hydrogen Transport
possible Delivery Gate
Hydrogen Transport and Delivery at Consumption Gate
possible Delivery Gate
ISO 19870-3 DIS Ballot Dec 25
Hydrogen Carrier Transport
Ammonia
LOHC
Hydrogen Conversion to hydrogen Carriers
Hydrogen Carrier conversion to hydrogen
ISO 19870-4 DIS Ballot DIS 25
ISO process: CD → DIS (5 months ballot) → FDIS (2 months ballot)→ IS (International Standard)
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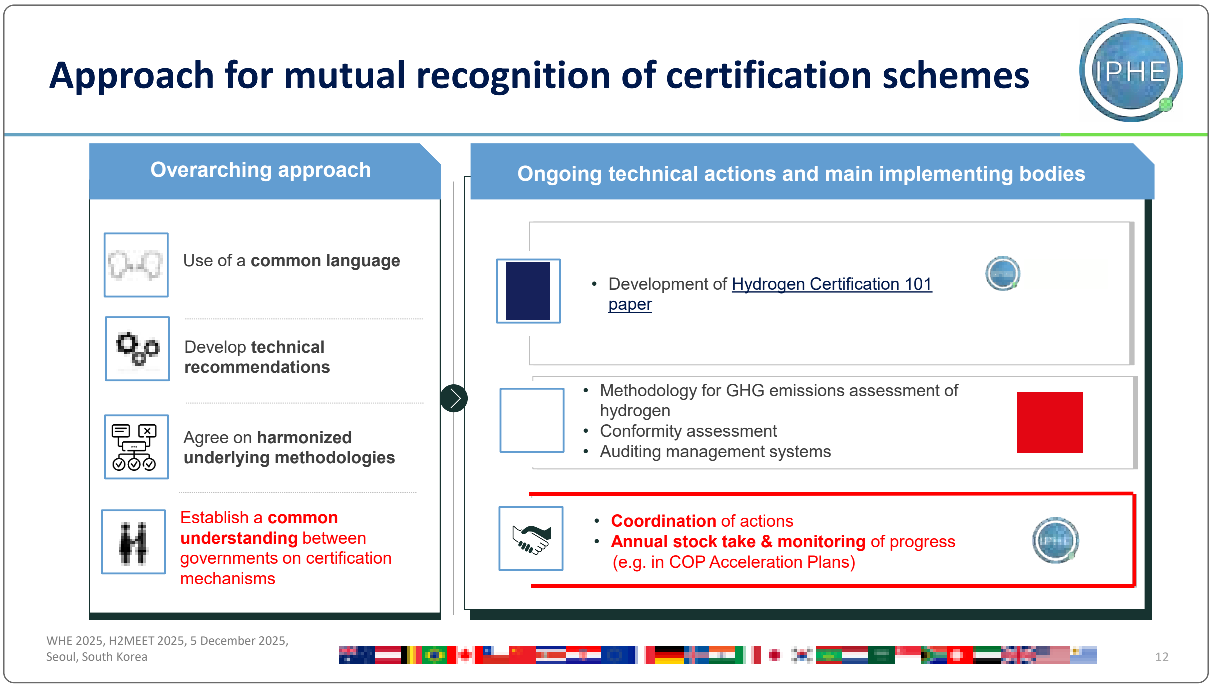
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Ongoing technical actions and main implementing bodies
• Development of Hydrogen Certification 101 paper
• Methodology for GHG emissions assessment of hydrogen
• Conformity assessment
• Auditing management systems
• Coordination of actions
• Annual stock take & monitoring of progress (e.g. in COP Acceleration Plans)
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Assessment of the existing landscape

IPHE

Hydrogen Certification 101

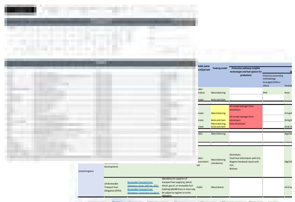
- Reference for broader audience, not a technical guidebook for experts
- Definitions of terminology and concepts
- Information on design of certification schemes and their key elements

Comparison Report

- Comparison of 21 certification schemes across 11 countries/ regions
- Comparison of:
  1. Product attributes
  2. Chain of custody model
  3. Operational setup & procedures

Inventory

- Systematic collection and mapping of hydrogen certification schemes
- Excel tool with results informing comparison report



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Results of comparison and interoperability assessment

IPHE

1. The **more detailed** the assessment, the **more differences** between schemes can be found
2. **Considerable differences** between certification schemes for hydrogen, many of which are expected to have negative impact on trade of certified hydrogen
3. **Modular approach to address the differences** and improve tradability of certified hydrogen, with common modules and modules specific to individual jurisdictions or certification schemes
4. The **more common modules**, the **higher the benefits** for trade of certified hydrogen
5. Regardless of the level of ambition, modular approach could be implemented in the form of a **hydrogen digital product passport (DPP)**

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Results of comparison and interoperability assessment

IPHE

- 28 hydrogen certification mechanisms included across 13 countries/regions
- 7 of these are pending analysis
- Information up to date as of September 2025
- Information covering 5 different areas
- Online, easily navigable tool

Product Attributes – GHG Emissions

Product Attributes – Electricity Sourcing

Product Attributes – Other Attributes

Chain of Custody Model

Operational Setup & Procedures

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Product Attributes – GHG emissions

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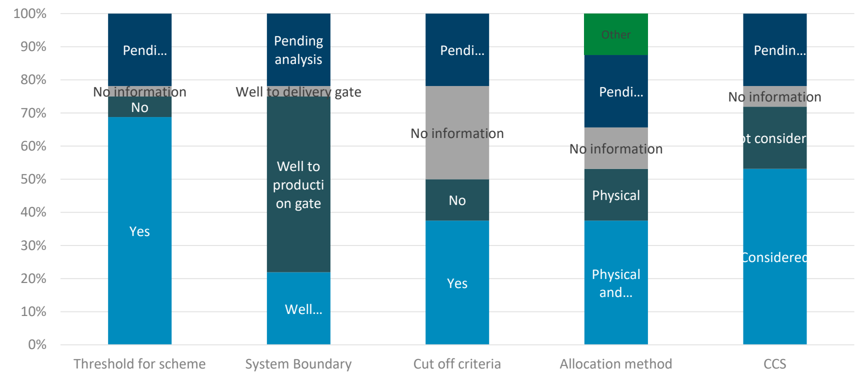

Just comparing GHG threshold values makes no sense

Key role of the ISO 19870-x series to allow interoperability and comparison (ISO TC197/SC1)

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Operational setup & procedures

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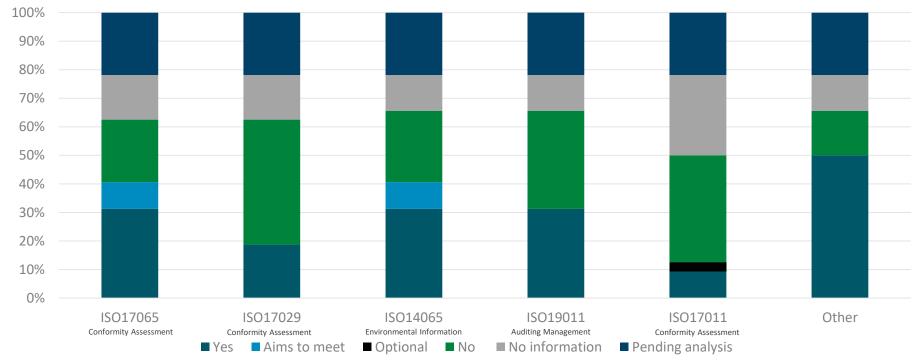

Strong need in harmonisation and in promoting whenever possible the usage of the existing ISO standards (ISO/CASCO, ISO/TMBG, ISO TC207/SC7)

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Modular approach implemented in the form of a Hydrogen Digital Product Passport (DPP)

IPHE

Content

- Affiliation, Purpose, Coverage, Data collection and management
- The main data of a hydrogen product (batch)
- Certificates
- Shall be integrated from a project design

Source: IEA Towards H2 definitions based on their emissions intensity (2023)

Almost 10 hydrogen DPPs under development (AUS, DE, FR, UAE, UK, URU)

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Conclusions

- Clean hydrogen is on the path to becoming a globally traded commodity
- **International collaboration** and coordination are key
- **International coordination** on standards, certification and trade is as important as national strategies
  - Move toward mutual recognition of certification schemes (e.g H_2 digital product passport)
  - Rely as much as possible on **international technical standards** (ISO TC197, ISO/CASCO, ISO/TMBG, ISO TC207/SC7, IEC TC105)

The coming 2-3 years are critical.
The policies we enact now will determine if low-emission hydrogen remains a niche technology or becomes the backbone of a decarbonized global economy.

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Thank you / 감사합니다

International Partnership for Hydrogen and Fuel Cells in the Economy

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WORLD HYDROGEN 6th EXPO 2025 Conference

Global Clean Hydrogen Technology Standardization Strategy 4

Hydrogen Technology Standardization in Europe and Germany : A Catalyst to Drive Green Hydrogen Solutions

Klemens Ilse
Deputy Director, Fraunhofer IWMS

Education

- PhD thesis, written at the Martin-Luther-University Halle-Wittenberg and Fraunhofer CSP. Topic: "Microstructural investigation and simulation of natural soiling processes on PV modules"
- Master of Science in Physics at the Martin-Luther-University Halle-Wittenberg. Thesis: "Fabrication and characterization of silicon nanoparticles embedded in aluminum oxide"
- Abitur (qualification for university entrance)

Professional Career

- Deputy Director of Fraunhofer CSP, a business unit of Fraunhofer IMWS
- Deputy Director of FIP-H2ENERGY@KENTECH
- Group Leader "Materials for H2 Technologies" at the Fraunhofer Institute for Microstructure of Materials and Systems IMWS
- Research associate in business unit "Hydrogen Technologies", Fraunhofer IMWS
- Head of team "Functional and optical surfaces" within the group "Diagnostics and Metrology", Fraunhofer Center for Silicon Photovoltaics CSP

Research Interest

- International cooperation on hydrogen research
- Production of green hydrogen and its derivates from renewable energy, e.g. in desert locations
- Hydrogen logistics
- Standardization and certification of electrolyzers
- New methods for degradation analysis and optimization of electrolyzer components

Speech Summary

Green hydrogen is vital for decarbonization with rapid global growth. This presentation covers evolving standards, certification, regulatory challenges, and success stories. Harmonized approaches ensure safety, trust, and bankability. Collaboration drives scalable, sustainable hydrogen economies.

Company Introduction

Fraunhofer IMWS drives material efficiency and innovation through leading microstructure research.

Fraunhofer IMWS

Fraunhofer Institute for Microstructure of Materials and Systems IMWS

Hydrogen Technology Standardization in Europe and Germany A Catalyst to drive Green Hydrogen Solutions

Dr. Klemens Ilse - International Hydrogen Technology Standardization Conference, 05.12.2025, Seoul
Head of Group – Materials Diagnostics for H2 Technologies, Fraunhofer IMWS
Deputy Director FIP-H2ENERGY@KENTECH

Fraunhofer Innovation Platform for Hydrogen Energy

KENTECH Korea Institute of Energy Technology in cooperation with Fraunhofer

The Green Hydrogen Challenge

How is green hydrogen evolving?

Timeline of progress and deployment for different countries in the years 2023-2024

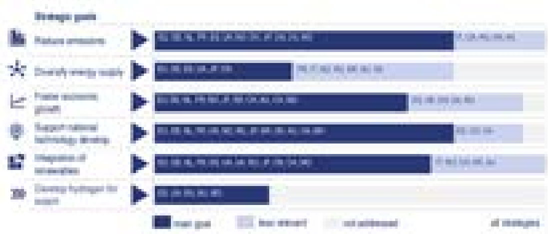
Map overview of H2 strategies and activities

Source: World Energy Council: International Hydrogen Strategies, report Sept.-2020

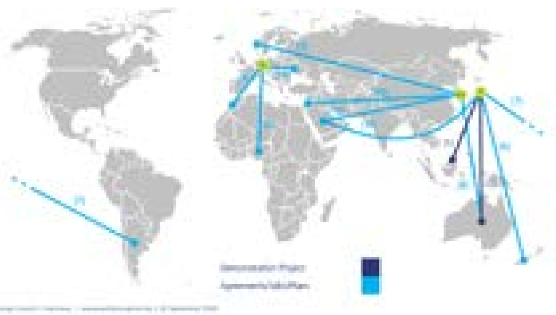
The Green Hydrogen Challenge

How is green hydrogen evolving?

H2 is clearly recognized as an essential element of a decarbonized energy system



Hydrogen Economy creating international cooperation and partnerships in the energy sector



Source: World Energy Council: International Hydrogen Strategies, report Sept.-2020

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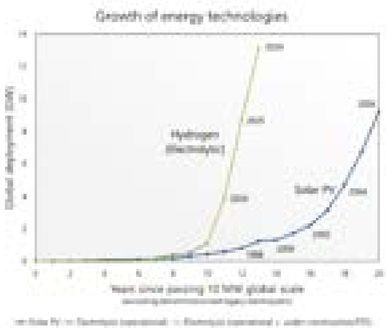
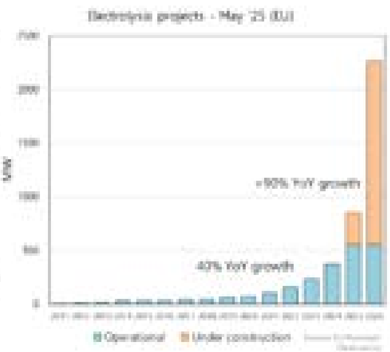
The Green Hydrogen Challenge

How is green hydrogen evolving?

- Hydrogen is growing faster than solar, fastest-growing energy technology ever
- In the EU, steady historic growth is now accelerating (based on real projects being built)
- Based on projects past FID, global growth exceeds 100%

- Growth is strongly subsidized
- To reach 500GW GH2 capacity by 2030 → annual growth must be 100% over next 5 yrs → it's extremely ambitious
- Even if achieved, 500GW replaces only about 50% of current fossil hydrogen demand → GH2 still in early growth phase.





https://www.linkedin.com/posts/janronge_green-hydrogen-growth-activity-7356560728926965760-DRZF/?utm_source=share&utm_medium=member_android&rcm=ACoAABJf120BoDN93jqcCOviLKTbOpkgUMeXKk8

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The Hydrogen Standards Gameboard

Standards Framework and Its Use in Hydrogen

Technical rules & Standards are essential for reliance, bankability, and global trade.

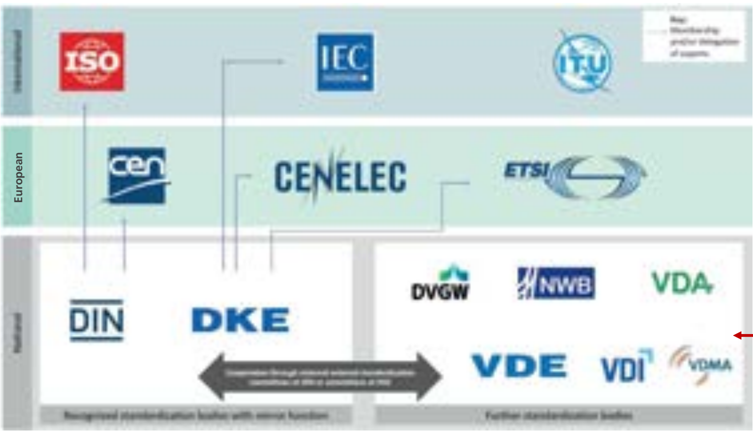
- Standards:
  - Ensure Reliability: Create a baseline for performance, quality, and comparability.
  - Guarantee Safety: Establish uniform rules for components, sensors, and operations.
  - Enable Bankability: Provide a common language to de-risk investments for funders and insurers.
  - Fulfill National Strategy: National Hydrogen Strategies (e.g., Germany) explicitly call for uniform standards.

Hierarchical Model of Legal Frameworks: The Inverse Relationship Between Binding Force and Detail

Sectoral Breakdown of the European and International Hydrogen Standards Ecosystem

The Standardization Ecosystem

Key players from national to global



Sector-specific organisations

DIN et al. „Standardization Roadmap Hydrogen Technologies 2024" (2024)

The Standardization Ecosystem

German Perspective – Published Standardization Roadmap

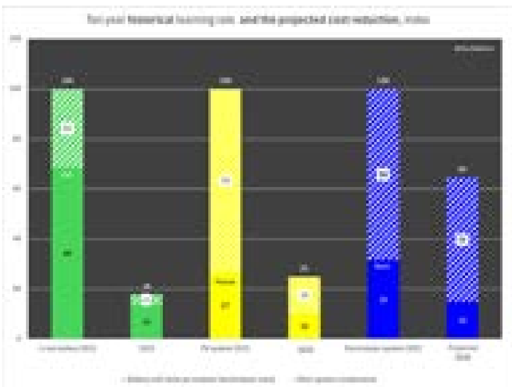
Sector specific German certification bodies DKE, DIN, DVGW, VDA, VDI, VDMA and NWB developed the „Standardization Roadmap for Hydrogen Technologies 2024“

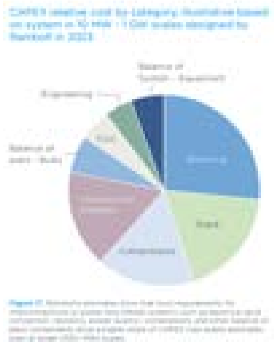
- Including recommendations for action for science, technical regulations and monitoring of their editing and implementation

The need for standardization

Standardizing safety and approval of components and systems

- GH2 BOP costs dominate total electrolyzer CAPEX and limits learning-related cost decline.
  - Li-ION batteries & PV much higher in comparison
- Clear standards and benchmarks to reduce cost and enhance deployment
- Standardization directly reduces costs by enabling component compatibility, de-risking design choices, and supporting economies of scale
- Reducing fragmented technical rules to push global value chain integration





https://observatory.clean-hydrogen.europa.eu/hydrogen-landscape/production-trade-and-cost/electrolyser-cost

The need for standardization

Performance metrics of actual devices is barely comparable

- Diversity of new designs and OEMs challenges benchmarking and quality assurance.
- Absence of common definitions for acceptable lifetime performance causes market uncertainty.
- Certification shows that the product has been tested according to comparable standardized specifications
- Certified products are easily comparable, test procedure is transparent for customers

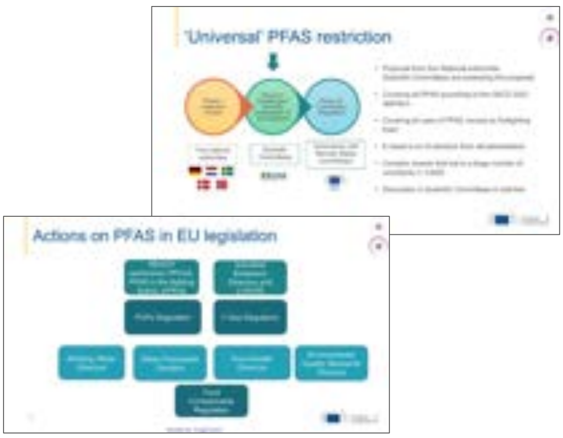
- **Established international cooperation** for joint standards:
  - **PWI proposal** on Water electrolysis technology Performance test at 33rd ISO/TC197 Plenary Meeting Dez. 2024 Seoul
  - Continuation and revision with ISO/TC197 WG4 and further international recognized institutions (**GER, KR, JP, NL**)

The need for standardization

Materials threatened by regulation

- Pending regulations (e.g., PFAS ban) threaten the availability of critical components like membranes and seals
- Changing material requirements demand rapid validation and approval protocols.
- Uncertainties in regulatory landscapes risk delaying next-generation technology introduction.

- **International research project** for fundamentals and standardization needs – **EU Horizon project**:
  - Understanding emissions of PFAS from electrolysers and/or fuel cells under product use
    - Successful project application of **European partners**, with Korean participation: **KIST**



Source: slideshare: Overview of pfas activities from the european union, https://www.slideshare.net/slideshow/overview-of-pfas-activities-from-the-european-union-pdf/274783487#6

The need for standardization

Standardizing certification and guarantee of origin

- By use of Certification processes assessing if a specific product meets established characteristics.
- Certifying the sustainability attributes of hydrogen offers trustworthy information regarding its production and delivery methods
  - Demonstrate compliance with regulatory requirements
  - Access to financial incentives
  - Demonstrate voluntary reporting and disclosure requirements
- EU perspective: Delegated Acts: Revised under the "Fit for 55" package, REDIII promotes increased use of renewable energies and RFNBOs across various sectors, particularly for defossilizing areas unsuitable for direct electrification
  - Since Dec 2024 ISCC, CertifHy & TÜV

Source: Hydrogen Certification 101, July 2023

Targets	RED II (2018)	RED III (2023)
Renewable Energy consumed (EU)	32% (by 2030)	42,5% (by 2030)
Industry (RFNBOs & H_2)	-	42% (by 2030) 60% (by 2035)
Renewable energy use in industry (annual increase)	-	1,6%/a
Renewables energy within final consumption in transport sector	14% (by 2030)	29% (by 2030)
Transport sector (advanced biofuels + RFNBOs)	3,5% (advanced biofuels)	5,5% (biofuels & RFNBO) (min 1% RFNBO) Maritime: 1,2% (by 2030)

Source: https://energy.ec.europa.eu/topics/renewable-energy/renewable-energy-directive-targets-and-rules/renewable-energy-directive_en, https://www.consilium.europa.eu/en/infographics/fit-for-55-how-the-eu-will-turn-climate-goals-into-law/: /https://www.now-gmbh.de/wp-content/uploads/2024/04/NOW-Factsheet_REDIII.pdf

Conclusions and key takeaways

Green Hydrogen: Success Through Standards and Collaboration

- Green hydrogen is rapidly advancing worldwide, supported by real projects and strong international cooperation, demonstrating the great potential for a sustainable energy future.
- Clear and harmonized standards create trust, ensure safety, and enable investment security, helping green hydrogen projects become bankable and scalable.
- Standardization lowers costs by fostering component compatibility, enabling economies of scale, and reducing risks in design and deployment.
- Certification and guarantees of origin provide transparency and unlock regulatory incentives, further accelerating market acceptance.
- International collaboration and shared technical rules are pivotal for overcoming regulatory uncertainties and speeding up technology adoption.
- Ongoing performance benchmarking and joint qualification processes build confidence in emerging technologies and support innovation.
- Collective action and standardization efforts have already begun to reduce barriers, enhancing the pace of green hydrogen deployment globally.

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- Informationsklassifizierung -

Fraunhofer IMWS

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Fraunhofer Innovation Platform for Hydrogen Energy

KENTECH Korea Institute of Energy Technology in cooperation with Fraunhofer

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Global Clean Hydrogen Technology Standardization Strategy 5

Commercial Hydrogen Measurement Standards Development of United States & California

Kevin Schnepp
Director, California Department of Food and Agriculture

Education
1996 B.A. Chemistry - California State University Sacramento
2012 Masters Business Administration with a concentration in Environmental Compliance and Sustainability - Southern New Hampshire University

Professional Career
CHEMIST (5 years) Aerojet Fine Chemicals
ASSOCIATE RESEARCH SCIENTIST II (3.5 years) Exelixis, Inc.
ENVIRONMENTAL SCIENTIST (1.5 years) California Department of Food & Agriculture - Division of Measurement Standards
SENIOR ENVIRONMENTAL SCIENTIST (3.5 years) California Department of Food & Agriculture - Division of Measurement Standards
SENIOR ENVIRONMENTAL SCIENTIST – SUPERVISOR (1.5 years) California Department of Food & Agriculture - Division of Measurement Standards
ENVIRONMENTAL PROGRAM MANAGER I (5.5 years) California Department of Food & Agriculture - Division of Measurement Standards
DIRECTOR (Current) California Department of Food & Agriculture - Division of Measurement Standards

Research Interest
Hydrogen Measuring Systems
Analytical methods for hydrogen analysis (Fuel Cell Applications)
Hydrogen Energy Storage
Hydrogen Production and Generation Life Cycle Analysis

Speech Summary

Discussion on the standards development processes in the United States for hydrogen measuring equipment used in dispensing hydrogen for fuel cell electric vehicles. Presentation will provide an overview of the roles of the National Council on Weights and Measures (NCWM); the National Institute for Standards and Technology (NIST); The National Type Evaluation Program (NTEP); the California Type Evaluation Program (CTEP); and state's authority to adopt and enforce national model regulations. Overview of California specific efforts to support hydrogen fueling infrastructure.

Company Introduction
California Department of Food and Agriculture – Division of Measurement Standards
State program responsible for the development and enforcement of performance specifications for zero-emission and near zero-emission alternative and renewable fuels. Adopts and enforces the specifications, tolerances, and user requirements for commercial weighing and measuring devices used in the dispensing of fuels, lubricants, and automotive products including hydrogen and electricity. Operates the California Type Evaluation Program where new commercial dispensing equipment is evaluated and approved for sale and commercial use in the state.

Commercial Hydrogen Measurement Standards Development

United States & California

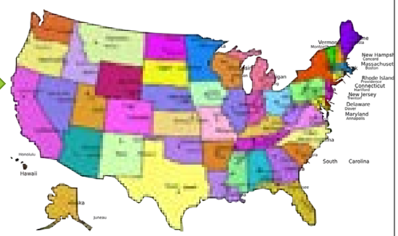
CDFA CALIFORNIA DEPARTMENT OF FOOD & AGRICULTURE

Kevin Schnepp, Director

Serving and Protecting California's consumers, businesses, economy and environment

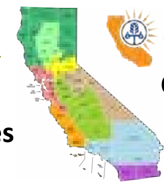
International, United States, California, and California County Metrology Relationships

International Weights and Measures System - OIML



US Weights & Measures System - NIST
National Institute of Standards and Technology

California Weights and Measures
CDFA-DMS Metrology Program



cacasa
County Sealers

U.S. Weights and Measures Requirements for Commercial Devices

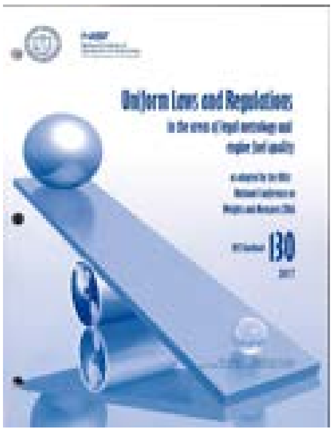
- Unlike many nations, the United States does not have any federal weights and measures laws.
- Weights and measures laws are a state's right to oversee and enforce.
- To ensure an equitable and robust marketplace, the states need to have consistent regulations.
- In the United States, the National Council on Weights and Measures (NCWM) is the consensus standard setting organization that develops the model laws published by NIST in Handbooks 44, 130 and 133.

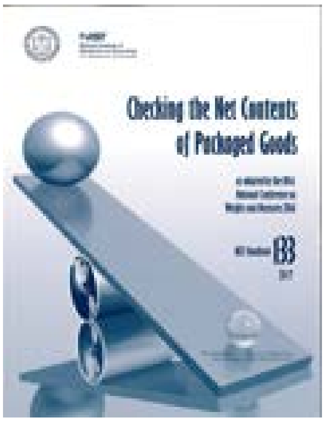
NCWM

The Consensus Standards Setting Organization for Weights and Measures Jurisdictions in the United States.

- Develops national standards for commercial measurement and method of sale requirements which are published annually by the National Institute of Standards and Technology (NIST) in Handbooks 44, 130 & 133.
- Administers the National Type Evaluation Program (NTEP)
- Collaborates with the four (4) regional weights and measures associations. (Independent and self-governing)
- Maintains a memorandum of understanding (MOU) with NIST who provide technical expertise and advice during the standards development process
- NIST Publishes the Consensus Standards Adopted by NCWM

The National Standards (Model Laws) Published by NIST





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National Council on Weights and Measures

National Type Evaluation Program (NTEP)

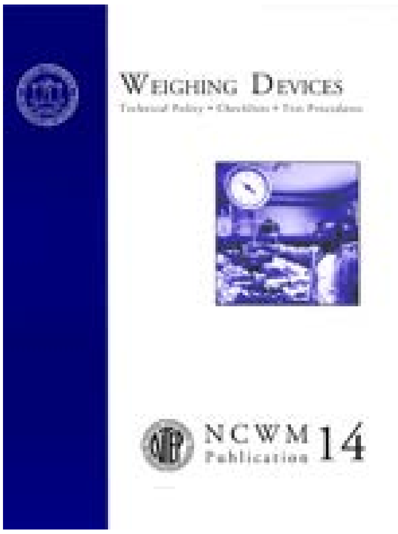
Almost every state requires that commercial weighing and measuring devices be type approved prior to be sold and placed in service.

Type evaluation ensures that a commercial weighing and measuring device meets all the specifications, tolerances, and general code requirements adopted and published in NIST Handbook 44.

Tested and approved devices are issued an NTEP Certificate of Conformance (CC)

6

NCWM Publication 14



- Administrative Policy
  - Content is developed by NTEP Committee and Board of Directors
- Technical Policy, Checklists, and Test Procedures
  - Content developed by NTEP Sectors and approved by NTEP Committee
  - –Weighing Devices
  - –Measuring Devices
  - –Grain Analyzers

California Weights and Measures Requirements

- Prior to installation and use, all commercial weighing and measuring devices must be type approved to assure that the device is accurate; measures repeatably; designed to operate in the conditions it will be exposed to; cannot be easily manipulate to defraud customers; and a fair and accurate accounting of all measurements and fees is communicated to the customer.
- The California Department of Food and Agriculture (CDFA), Division of Measurement Standards (DMS) certifies retail hydrogen dispensers prior to installation for commercial use through the California Type Evaluation Program (CTEP).

California Weights and Measures Requirements

For type evaluation to occur, there must be enforceable standards in the form of tolerances and specifications for the device in question.

CDFA-DMS chaired and sponsored a multitude of U.S. Hydrogen Working Group meetings that led to the adoption of hydrogen vehicle fueling regulations by NCWM. Published in NIST HB 44 Section 3.39 *Hydrogen Gas-Measuring Devices*

Assessment of hydrogen measuring devices required the development of a test standard. CDFA-DMS contracted with U.S. Department of Energy National Renewable Energy Laboratory (NREL) to design and build a hydrogen field standard.

Hydrogen Field Standard (HFS)
Hydrogen Dispenser Metrology Testing Device

California Hydrogen Dispenser Requirements

During type evaluation, conformance to CCR Title 4, Division 9 Section 3.39 Hydrogen Gas Measuring Devices as adopted is determined.

Must meet Acceptance Tolerance prior to being placed into commercial service.

Re-tested annually thereafter, Maintenance Tolerances are applied.

Devices are also inspected for conformance during complaint investigations and routine visits.

CA Commercial Hydrogen Dispenser Requirements

Who Enforces?

The State and County Offices of Weights and Measures

State: Establishes specifications, tolerances, user requirements. Establishes method of sale and advertising. Conducts fuel quality sampling and analysis. Takes enforcement action for non-compliant fuel. Conducts type evaluation and certification of approved devices.

Counties: Local weights and measures officials perform field inspections and enforce device compliance requirements.

State and County Officials work together on complaint investigations to ensure continued compliance with established laws and regulations for all commercial weighing and measuring devices.

Method of Sale, Advertising, and Labeling Requirements

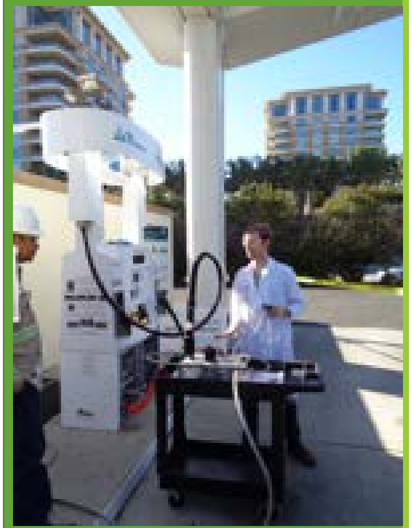
- CDFA adopts by reference NIST HB 130 method of sale for hydrogen and codifies legal requirements for retailers.
- All provisions as specified in CCR Title 4, Division 9, Chapter 1, Article 1, Section 3.39 Hydrogen Gas Measuring Devices apply.
- Conformance to requirements is evaluated during initial accuracy assessment of newly installed type-certified dispensers, during annual reinspection, and any routine/complaint testing.

Hydrogen Fuel Quality Sampling and Testing

Chapter 14 of the Business and Professions Code requires the Division of Measurement Standards to establish and enforce quality specifications for transportation fuels in California.

Quality standards for hydrogen fuel were published in 2011 as SAE International's Surface Vehicle Standard J2719 - Hydrogen Fuel Quality for Fuel Cell Vehicles.

SAE J2719 has been adopted by reference by the Department of Food and Agriculture in California Code of Regulations Title 4, Division 9, Chapter 6, Article 8, Section 4181.



Division staff conduct regular routine sampling of hydrogen fuel sold at retail. Additional sampling occurs to address any fuel quality complaints.

Division staff also include particulate sampling to ensure compliance with SAE J-2719 maximum particulate requirements.

Samples are collected in duplicate and evaluated in one of our two hydrogen fuel quality laboratories.

Hydrogen Fuel Quality Sampling and Testing Apparatus

Fuel Quality Sampling Gas Analysis

Fuel Quality Sampling Particulates

Hydrogen Fuel Quality Laboratory

JUNE 3, 2025

Hydrogen Oversight

Ongoing Efforts

- Working with particulate sample device manufacturer to develop high-flow sampling device and procedures.
- Configuring a test standard for high-flow heavy duty vehicle fueling applications.
- Updating fuel sampling SOP to include high-flow dispensers for HD fueling. Current equipment can work for collecting gas samples for analysis.
- Developing regulatory language to include an additional user requirement (UR) for dispensing equipment to conform to fueling protocols established by SAE J-2601. Joint effort with CARB to determine implementation requirements

Thank You!

California Department of Food and Agriculture
Division of Measurement Standards
dms@cdfa.ca.gov

Kevin Schnepp, Director
Kevin.schnepp@cdfa.ca.gov

Appendix Slides

The following slide detail the test data acquired during evaluation of each of test methods: Gravimetric, PVT, and Master Meter

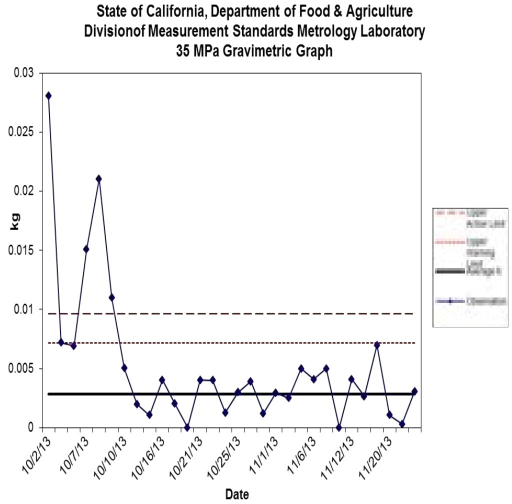
Assessing Control Chart Data

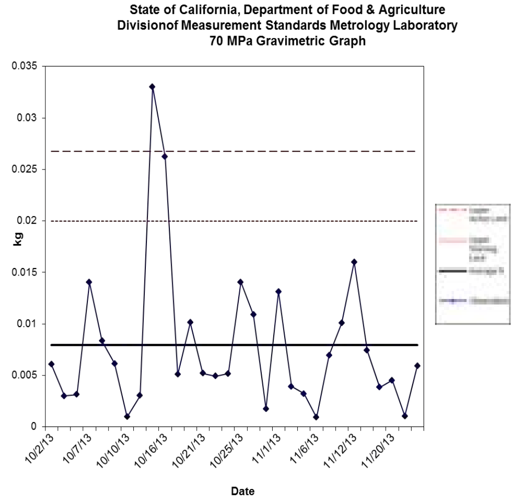
To calculate the expanded uncertainty, the measurement uncertainty was multiplied by a coverage factor, k, based on the degrees of freedom (number of data points, n – 1) to provide a level of confidence of approximately 95%

2kg 35 MPa				
Procedure	Degrees of Freedom (n-1)	Measurement Uncertainty	Coverage Factor k	Expanded Uncertainty
Gravimetric	19	2.4 g	2	4.8 g
Volume	29	15.5 g	2	31 g
Master Meter	29	144.4 g	2	288.8 g

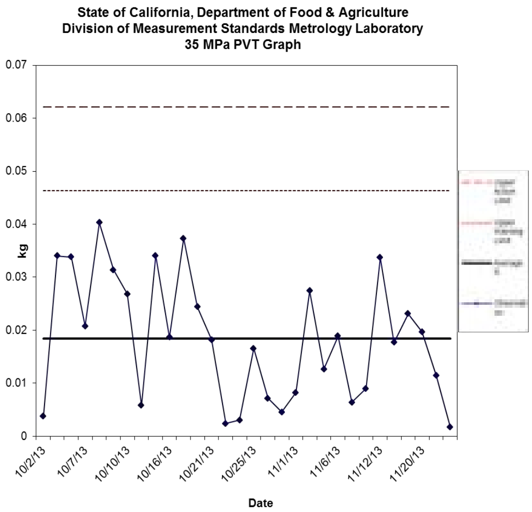
4kg 70 MPa				
Procedure	Degrees of Freedom (n-1)	Measurement Uncertainty	Coverage Factor k	Expanded Uncertainty
Gravimetric	29	7.6 g	2	15.2 g
Volume	19	16.8 g	2	33.6 g
Master Meter	29	170.0 g	2	340 g

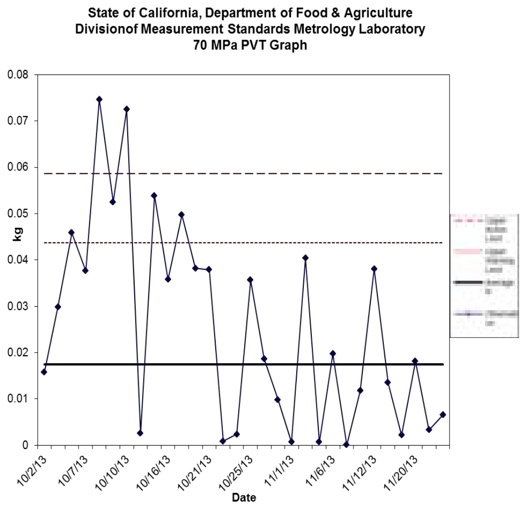
Validation of the Reference Standard Gravimetric Control Charts



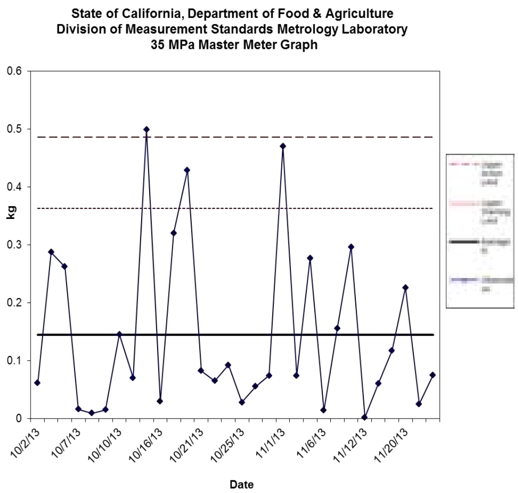


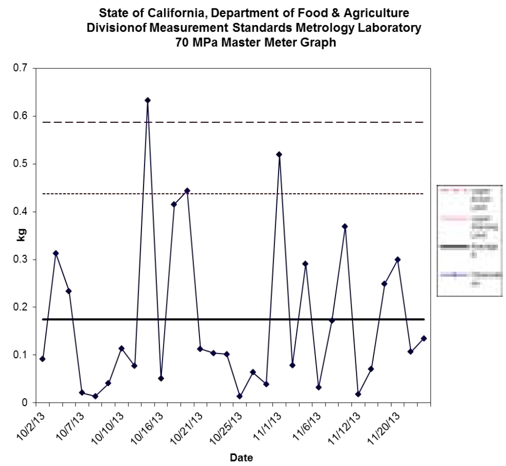
Validation of the Reference Standard PVT Control Charts





Validation of the Reference Standard Master Meter Control Charts





Panel Discussion

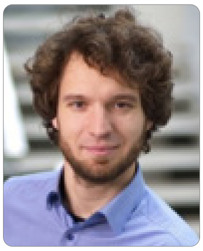
Investment and Market Growth Outlook of Global Clean Hydrogen Projects

Moderator

Laurent Antoni
Executive Director, IPHE

Panelists

Hong-Ki Lee
Chair, IEC/TC 105
Vice President, Woosuk University



Klemens Ilse
Deputy Director, Fraunhofer IWMS

Kevin Schnepp
Director, California Department of Food and Agriculture

Hydrogen Deep Dive III：

Clean Ammonia

WORLD HYDROGEN 6th EXPO 2025
Conference

Global Technology and Policy Trends for the Expansion of Clean Ammonia

Global Technology and Policy Trends for the Expansion of Clean Ammonia 1

Global Clean Ammonia Market and Outlook

Alexander Oliver Bower
Global Head of Marketing & Sales,
Gentari Hydrogen Sdn Bhd

Education
1995 – 1999, BA, Business Economics, University of Leicester, United Kingdom
2004 – 2006 MSc Energy, Trade and Finance, Bayes Business School, United Kingdom.
2017 – 2019 Global Executive MBA, INSEAD

Professional Career
1999 – 2001, Finance, Halliburton, Leatherhead, United Kingdom
2001 – 2006, Power Trading, London, United Kingdom
2006 – 2018, Senior Vice President, Head of LNG Trading, Engie, Paris, France
2018 – 2022, Senior Project Director, TotalEnergies, France & Singapore
2022 – 2023, Commercial Director, InterContinental Energy, Singapore
2023 – Present, Global Head, Marketing & Sales, Gentari Hydrogen Sdn Bhd, Singapore

Speech Summary
The speech will begin with a brief introduction to the PETRONAS and Gentari, followed by an overview of Gentari's clean ammonia projects. It will then cover key trends in the global green ammonia market and demand outlook, concluding with key points on future direction.

Company Introduction
Gentari is PETRONAS's clean energy arm, focused on clean hydrogen, renewables, and EV charging

gentari

Global Clean Ammonia Market and Outlook

World Hydrogen Expo 2025 - Green Ammonia Session

Alex Bower
Global Head, Marketing & Sales
Gentari Hydrogen Sdn. Bhd.

Friday, 05 December 2025

PETRONAS

A progressive energy and solutions partner enriching lives for a sustainable future

Open

• [Open]

CORE PORTFOLIO

Exploration & Production

Upstream

Gas & Power

Gas

Chemicals & Products

Retail & Marketing

Downstream

'STEP OUT in 2022'

Clean Energy Solutions

Gentari

A new independent entity focused fully on **clean energy solutions** to capture opportunities in the energy transition space, alongside core portfolio.

• [Open]

Our business

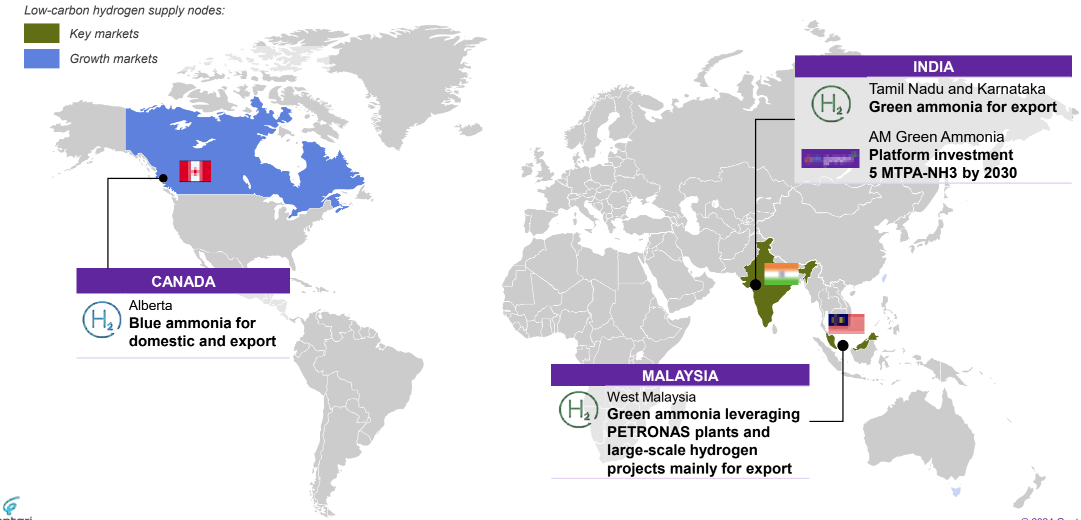
We offer **clean energy solutions** through our **three pillars** to help customers achieve their net zero ambitions – no matter how far along they are in their decarbonisation journey.

- **Renewable Energy**
  - To be the leading next-generation Commercial and Industrial (C&I) and utility- scale renewable energy developer, accelerating the adoption of renewable energy
- **Hydrogen**
  - To be a large-scale clean hydrogen producer and go-to industry partner in enabling decarbonisation
- **Green Mobility**
  - To be Asia Pacific's leading green mobility solutions partner, accelerating every driver's shift to sustainable solutions

• [Open]

Gentari's Global Low-Carbon Hydrogen/Ammonia Projects

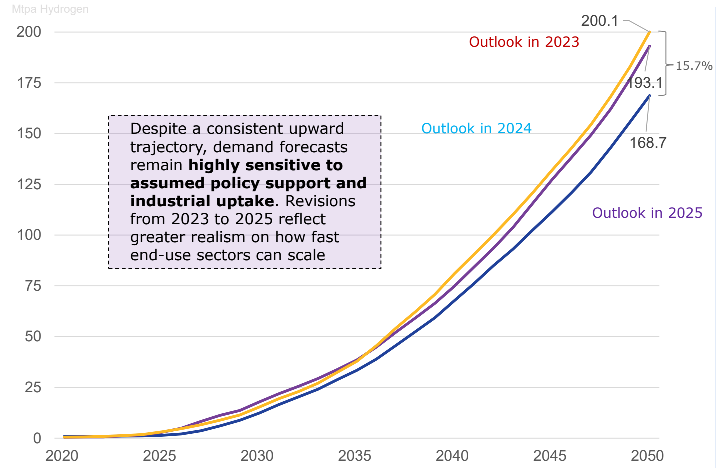
Developing hydrogen and ammonia projects globally, capitalizing on inherent capabilities in project development, molecule production, and sales & trading



gentari

Demand: Clean hydrogen demand by 2030 is now projected to be at 12 Mtpa vs last year's forecast of 18 Mtpa

An upward long-term outlook with most of today's demand remains policy-driven as the main enabler, highlighting the need for uptake through cost competitiveness and infrastructure readiness

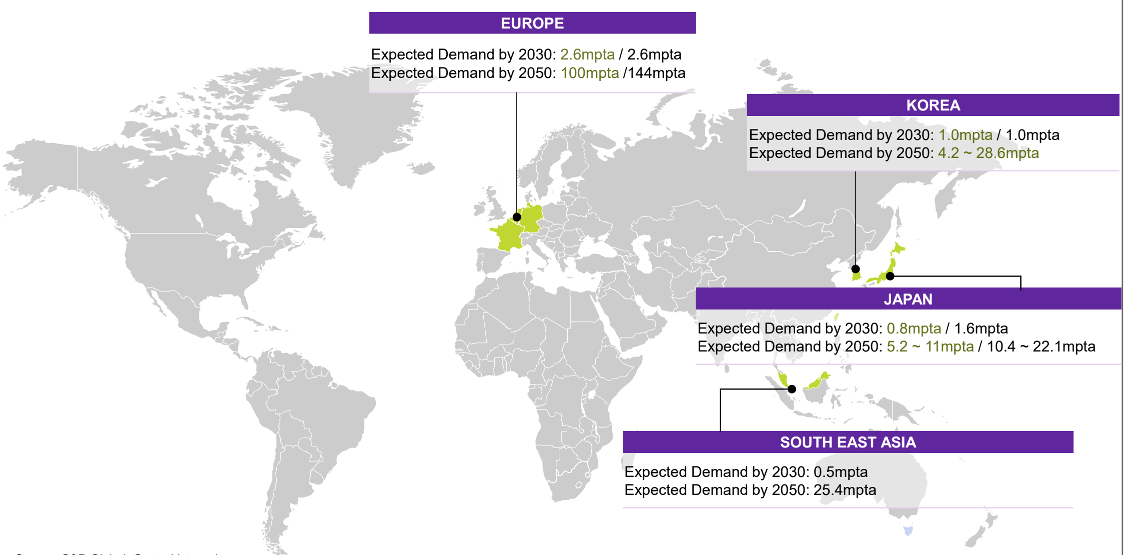


Insights

- **Most of the forecasted demand by 2030 is yet to be supported by binding offtake.** Cumulative demand (2020-Q1 2025) through binding offtake agreements was below 2 Mtpa
- **Inflection point emerges around 2029–2030**, where demand rises to 12 Mtpa, signalling possible sector activation – though this is conditional on policy and buyer readiness
- **Demand-side risks remain underappreciated**, especially if infrastructure readiness, conversion tech. or policy enforcement lag. A demand delay may undermine project bankability and offtake certainty

gentari Source: Wood Mackenzie Lens Hydrogen (May 2025)

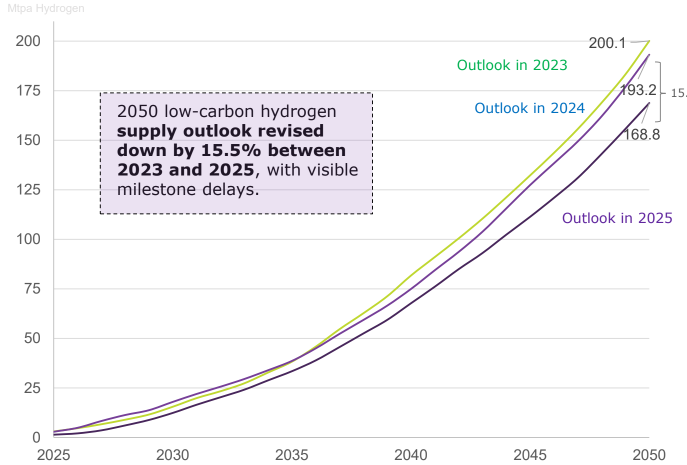
Snapshot of Key Green Ammonia Import Regions (green/blue&green combined, NH3/mpta)



gentari Source: S&P Global, Gentari internal assessment

Supply: Recent outlook revision signal a two-year shift in supply-side clean hydrogen scale-up

Downward revision of supply forecast was mainly driven by delays in projects due to high costs, market uncertainties in both policies and offtake, and macroeconomic concerns

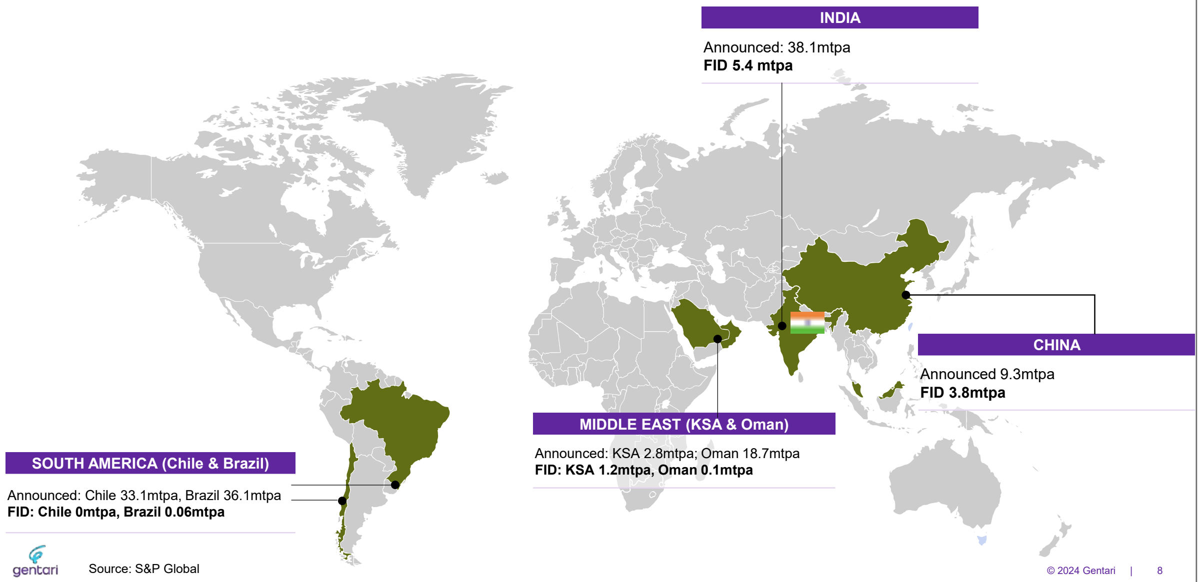


Insights

- The supply forecast for 12 Mtpa has slipped from **2028 to 2029**, and the 169 Mtpa milestone has shifted from **2048 to 2050** — reflecting a **~2-year delay** in key ramp-up points.
- This **structural lag in the projected industry build-out** suggests that early-mover projects may face both first-mover advantages and risks if their internal timelines are not recalibrated accordingly.

gentari Source: Wood Mackenzie Lens Hydrogen

Snapshot of Key Green Ammonia Export Regions



gentari Source: S&P Global

• [Op en]

Considerations on Green Ammonia Market Outlook

✓Regulatory Measures for Market Formation: Tension with Economic Viability

- Introduction of strong regulations on carbon intensity (e.g., accelerated RFNBO transposition, CBAM, etc)
- Direct carbon regulation and monetization mechanisms (e.g., delayed adoption of IMO carbon tax, ongoing ITMO discussions)

✓Competition with Blue Ammonia: Diverging Responses in Asia and Europe

- Asia: Growing preference for green ammonia in both government policy and market supply, especially in South Korea
- Europe: Adoption of the Low-Carbon Hydrogen Delegated Act, allowing blue ammonia to ease cost pressures and accelerate hydrogen market development

✓Pace of Supply Chain Development: Although dependent on demand growth, some regions show rapid, bold moves

- Subsidies for green ammonia production (e.g., China's NDRC announcing national grants covering 20% of CAPEX for decarbonization projects)
- Maturity of upstream value-chain industries: advancing technologies and economies of scale are enabling cost competitiveness versus fossil fuels

gentari

gentari

Global Technology and Policy Trends for the Expansion of Clean Ammonia 2

Ammonia Cracking Technologies: Status and Outlook

SeongHoon Woo
CEO, Amogy

Education

2011-2015, Ph.D., Materials Science and Engineering, MIT, USA
2007-2011, B.S., Materials Science and Engineering, POSTECH, Korea

Professional Career

2021-, CEO/Co-Founder, AMOGY, USA
2018-2020, Research Staff Member, IBM, USA
2015-2018, Staff Scientist, Korea Institute of Science and Technology (KIST), Korea

Research Interest

Ammonia-to-Power

Speech Summary

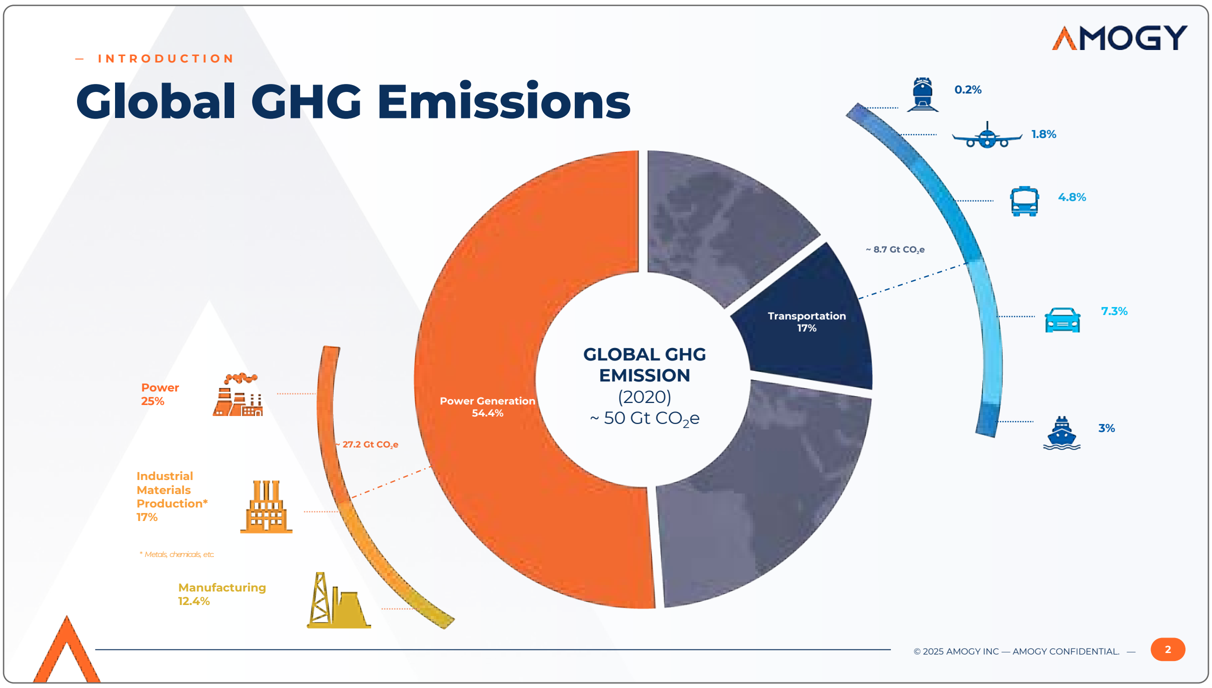
An overview of ammonia's role as a hydrogen carrier and Amogy's cracking catalyst technology to enable low-cost clean hydrogen. Highlights include catalyst advantages, commercial applications, and key global pilot projects.

Company Introduction

Amogy provides carbon-free ammonia-to-power energy solutions to decarbonize hard-to-abate sectors like power generation, maritime shipping, and heavy industry. Proven in real-world applications, its patented ammonia cracking technology offers a mature, scalable, and highly efficient method for splitting ammonia into hydrogen and nitrogen. The produced hydrogen is directed to integrated fuel cells or hydrogen engines, generating high-performance power with zero carbon emissions.

Amogy is headquartered in Brooklyn, New York, with additional locations including Houston, Texas and Seoul, South Korea. Amogy is backed by investors including Amazon, SK Innovation, Aramco, Mitsubishi Corporation, Samsung Heavy Industries, BHP Ventures, AP Ventures and more. For more information, visit www.amogy.co.


AMOGY
Ammonia Cracking Technologies:
Status & Outlook
Seonghoon Woo, Co-founder & CEO
December 2025


AMOGY
— INTRODUCTION
Global GHG Emissions
GLOBAL GHG EMISSION
(2020)
~ 50 Gt CO$_2$e
Power Generation
54.4%
Transportation
17%
~ 8.7 Gt CO$_2$e
0.2%
1.8%
4.8%
7.3%
3%
27.2 Gt CO$_2$e
Power
25%
Industrial
Materials
Production*
17%
* Metals, chemicals, etc
Manufacturing
12.4%
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AMOGY

— HYDROGEN ECONOMY

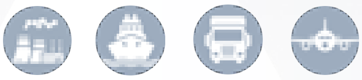
Hydrogen: the Missing Piece in Energy Transition

Will hydrogen be the best solution to decarbonize heavy industries?

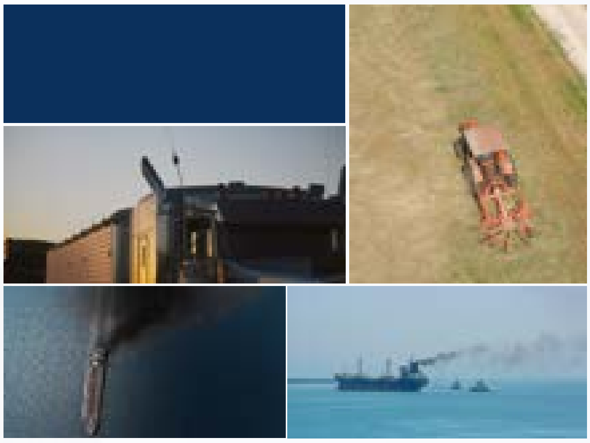
Hydrogen (H_2)
for hard-to-decarbonize industries

- Abundant material
- Technology ready
- Regulation & government support

Trillion $ Market



$830B (2019) $205B (2020) $360B (2020) $240B (2020)



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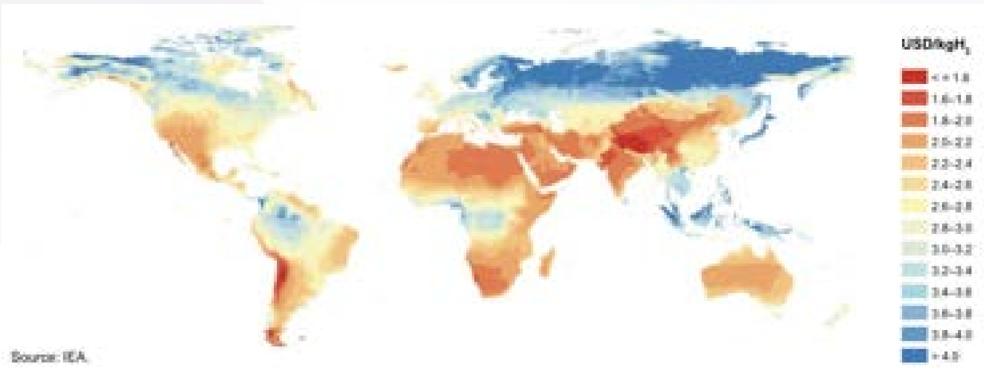
— HYDROGEN ECONOMY

HYDROGEN PROBLEM
Renewable hydrogen source is far from where it's mostly needed!



Source: IEA

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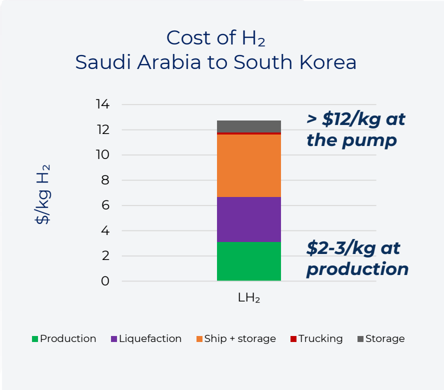
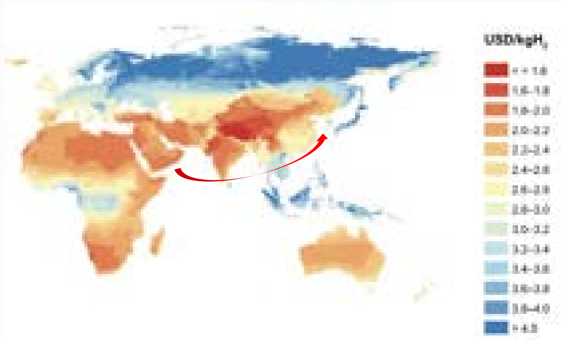
— HYDROGEN ECONOMY

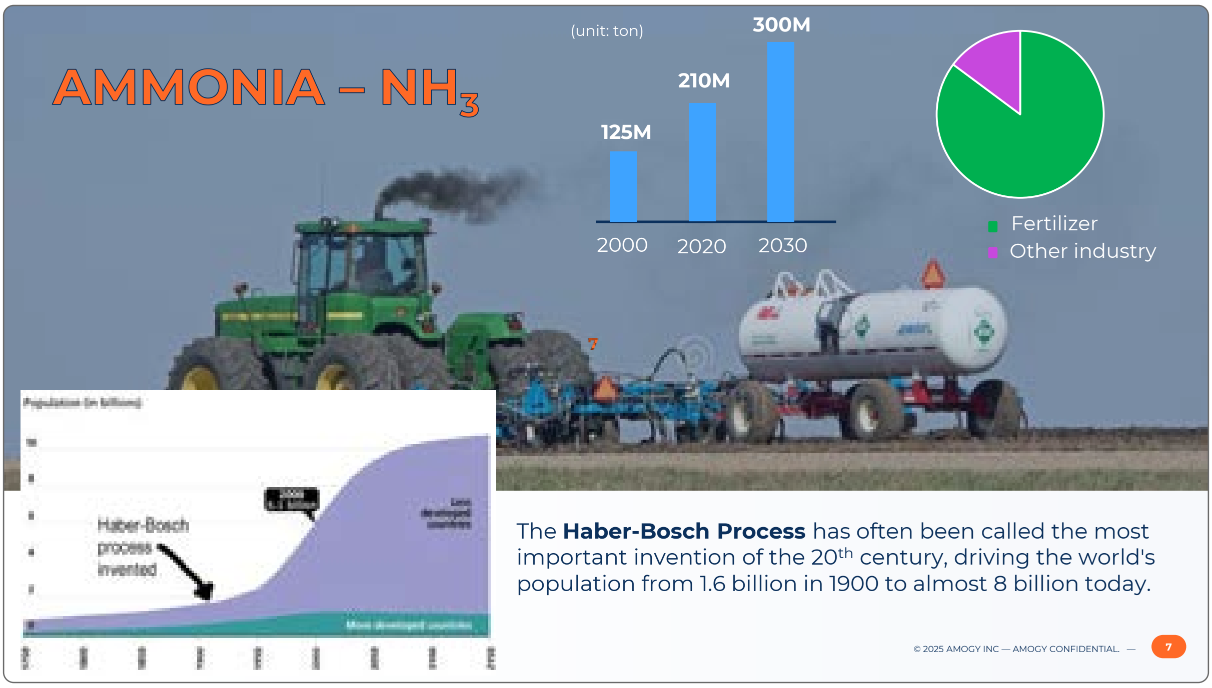
Hydrogen: High-Cost Transportation/Storage





- *Average H_2 cost in California is ~**$15/kg***
- ***4-5x more expensive** than diesel (energy-basis)*

 5


AMMONIA – NH3
(unit: ton)
125M
210M
300M
2000
2020
2030
Fertilizer
Other industry
Haber-Bosch process invented
The Haber-Bosch Process has often been called the most important invention of the 20th century, driving the world's population from 1.6 billion in 1900 to almost 8 billion today.
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— ABOUT AMMONIA
AMOGY
Ammonia Infrastructure Today
190 MTA of production
200 ports store ammonia
4,000 km+ of pipelines in U.S.
20 MTA of waterborne trading
500 vessels capable of carrying ammonia
• 100+ years of scaled industrial use of ammonia
• No ammonia-to-power technology available to date
MTA: million metric tons per annum
Sources: DNV, IRENA
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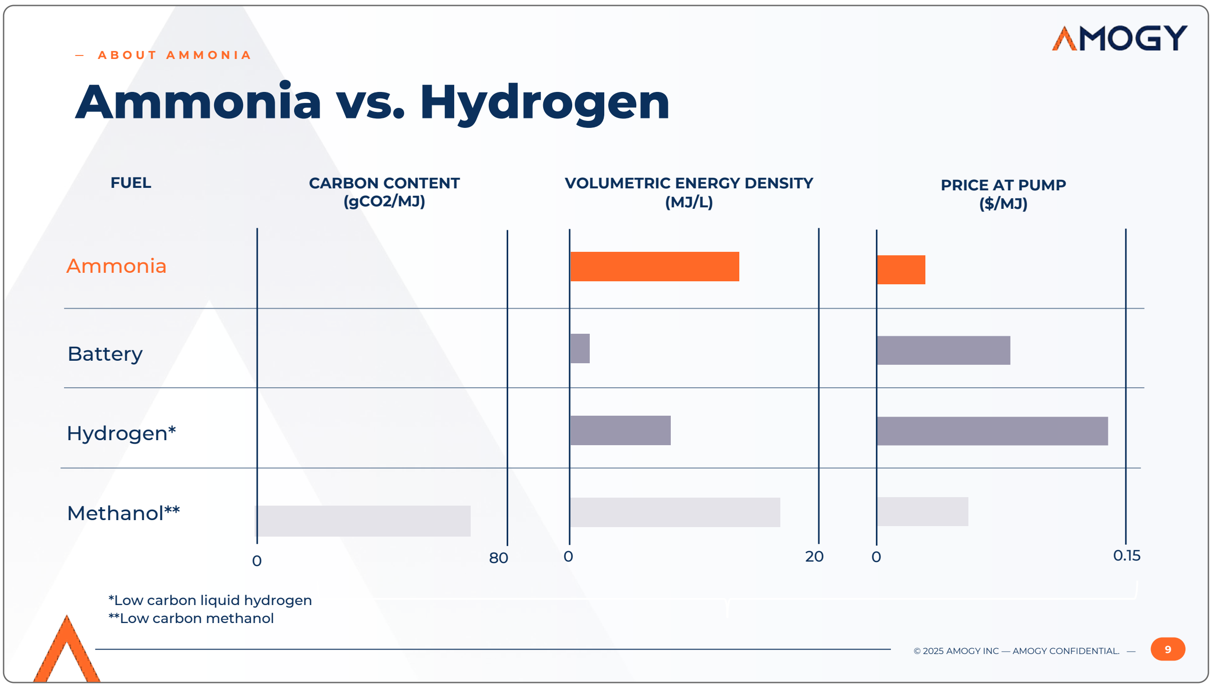
AMOGY
— ABOUT AMMONIA
Ammonia vs. Hydrogen
FUEL
CARBON CONTENT (gCO2/MJ)
VOLUMETRIC ENERGY DENSITY (MJ/L)
PRICE AT PUMP ($/MJ)
Ammonia
Battery
Hydrogen*
Methanol**
0
80
0
20
0
0.15
*Low carbon liquid hydrogen
**Low carbon methanol
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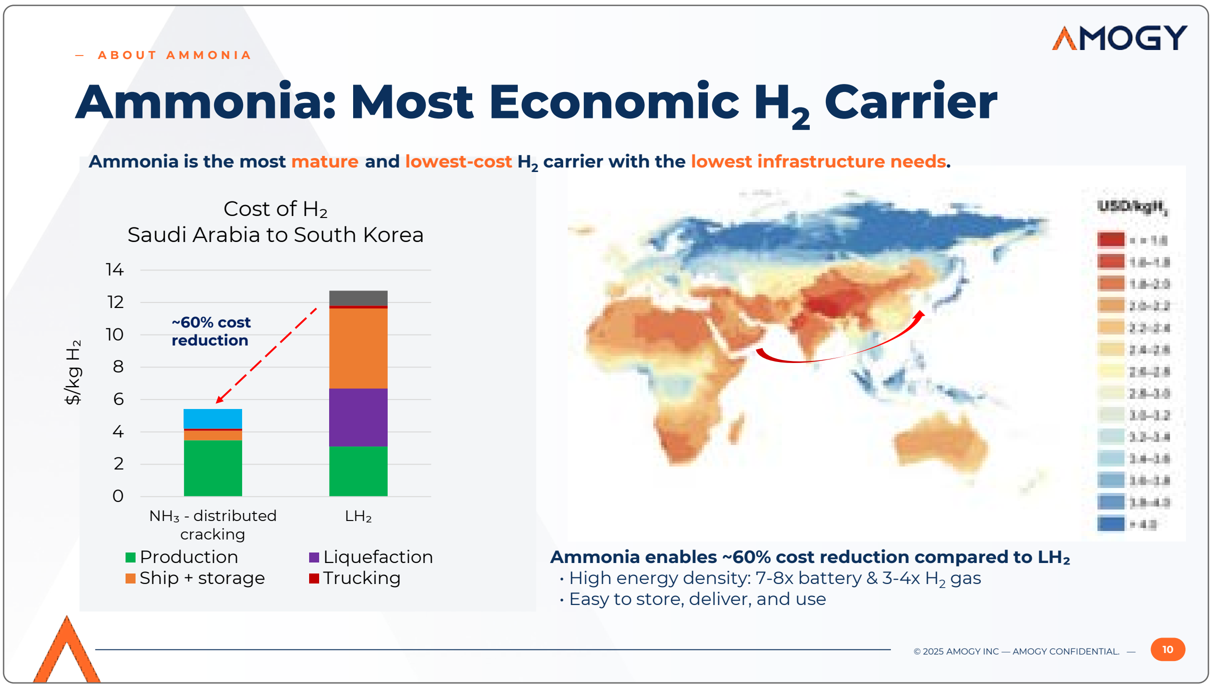
AMOGY
— ABOUT AMMONIA
Ammonia: Most Economic H2 Carrier
Ammonia is the most mature and lowest-cost H2 carrier with the lowest infrastructure needs.
Cost of H2
Saudi Arabia to South Korea
$/kg H2
14
12
10
8
6
4
2
0
~60% cost reduction
NH3 - distributed cracking
LH2
Production
Ship + storage
Liquefaction
Trucking
USD/kgH2
Ammonia enables ~60% cost reduction compared to LH2
· High energy density: 7-8x battery & 3-4x H2 gas
· Easy to store, deliver, and use
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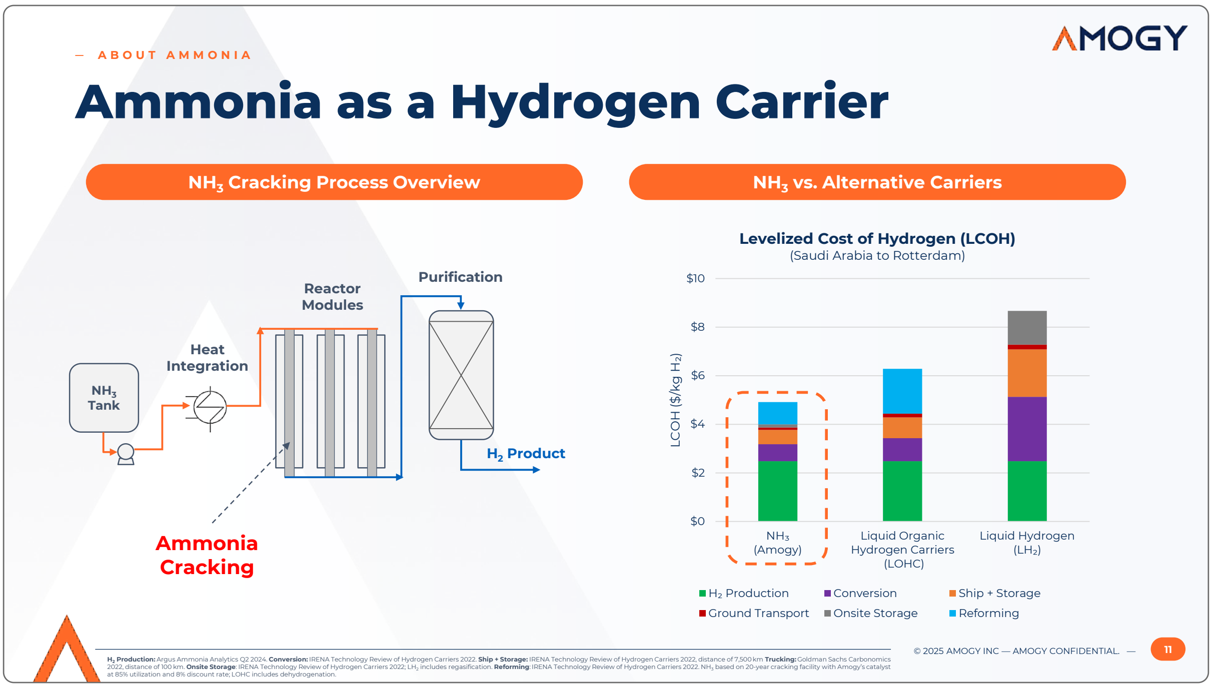
ABOUT AMMONIA
AMOGY
Ammonia as a Hydrogen Carrier
NH3 Cracking Process Overview
NH3 vs. Alternative Carriers
NH3 Tank
Heat Integration
Reactor Modules
Purification
H2 Product
Ammonia Cracking
Levelized Cost of Hydrogen (LCOH)
(Saudi Arabia to Rotterdam)
LCOH ($/kg H2)
$10
$8
$6
$4
$2
$0
NH3 (Amogy)
Liquid Organic Hydrogen Carriers (LOHC)
Liquid Hydrogen (LH2)
H2 Production
Conversion
Ship + Storage
Ground Transport
Onsite Storage
Reforming
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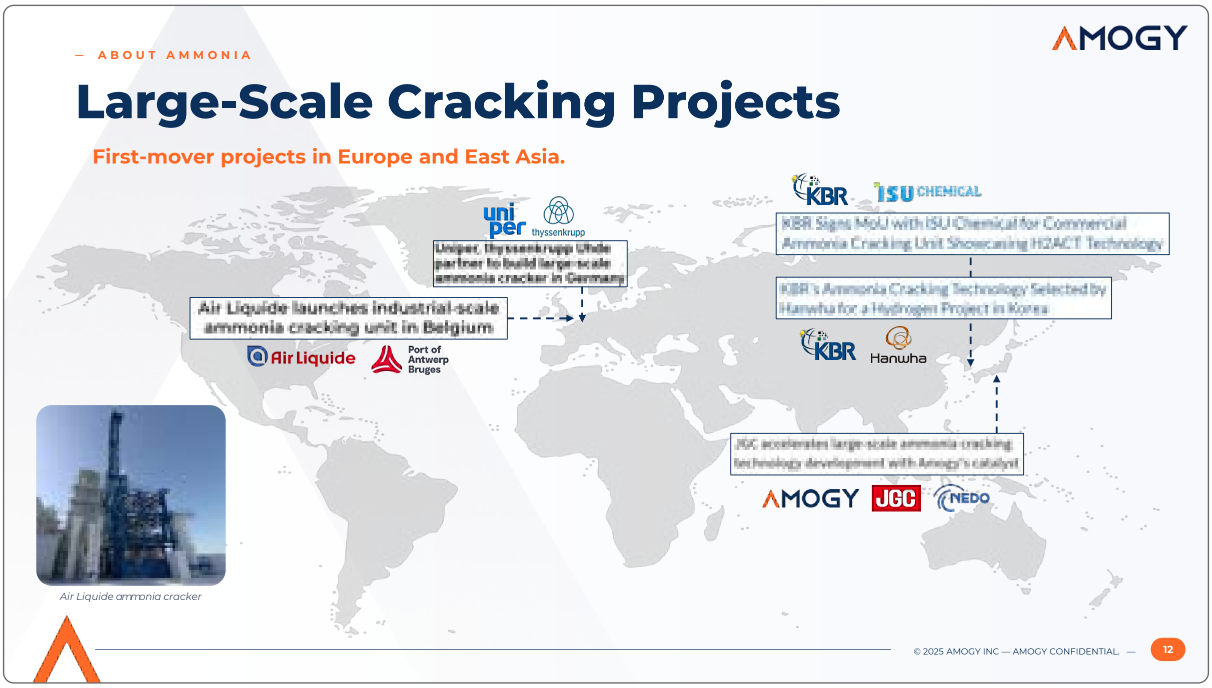
ABOUT AMMONIA
AMOGY
Large-Scale Cracking Projects
First-mover projects in Europe and East Asia.
uniper
thyssenkrupp
Uniper, thyssenkrupp Uhde partner to build large-scale ammonia cracker in Germany
Air Liquide launches industrial-scale ammonia cracking unit in Belgium
Air Liquide
Port of Antwerp Bruges
KBR
ISU CHEMICAL
KBR Signs MoU with ISU Chemical for Commercial Ammonia Cracking Unit Showcasing H2ACT Technology
KBR's Ammonia Cracking Technology Selected by Hanwha for a Hydrogen Project in Korea
KBR
Hanwha
JGC accelerates large-scale ammonia cracking technology development with Amogy's catalyst
AMOGY
JGC
NEDO
Air Liquide ammonia cracker
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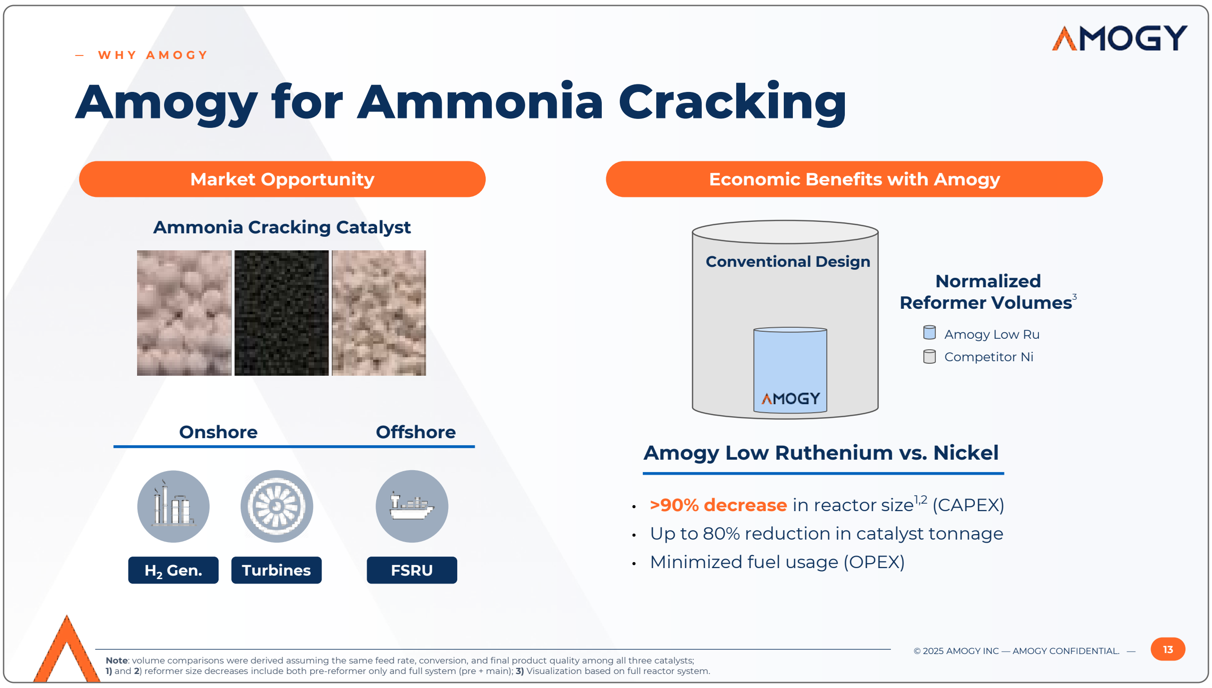
AMOGY
— WHY AMOGY
Amogy for Ammonia Cracking
Market Opportunity
Ammonia Cracking Catalyst
Onshore
Offshore
H2 Gen.
Turbines
FSRU
Economic Benefits with Amogy
Conventional Design
AMOGY
Normalized Reformer Volumes3
Amogy Low Ru
Competitor Ni
Amogy Low Ruthenium vs. Nickel
>90% decrease in reactor size1,2 (CAPEX)
Up to 80% reduction in catalyst tonnage
Minimized fuel usage (OPEX)
Note: volume comparisons were derived assuming the same feed rate, conversion, and final product quality among all three catalysts;
1) and 2) reformer size decreases include both pre-reformer only and full system (pre + main); 3) Visualization based on full reactor system.
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AMOGY
AMOGY.
Ammonia-to-Power Technology


ABOUT AMOGY
Company Profile
100+ Employees
Headquarters: Brooklyn, NY
Founded: Nov. 2020
Other Locations: Houston, TX, South Korea
Funding to date: $317M
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AMOGY
— ABOUT AMOGY
Company Footprint
Geoje, Korea
SHI Facility – MFG (2026)
Houston, TX
Product Dev, MFG
Brooklyn, NY
Amogy HQ, R&D Lab
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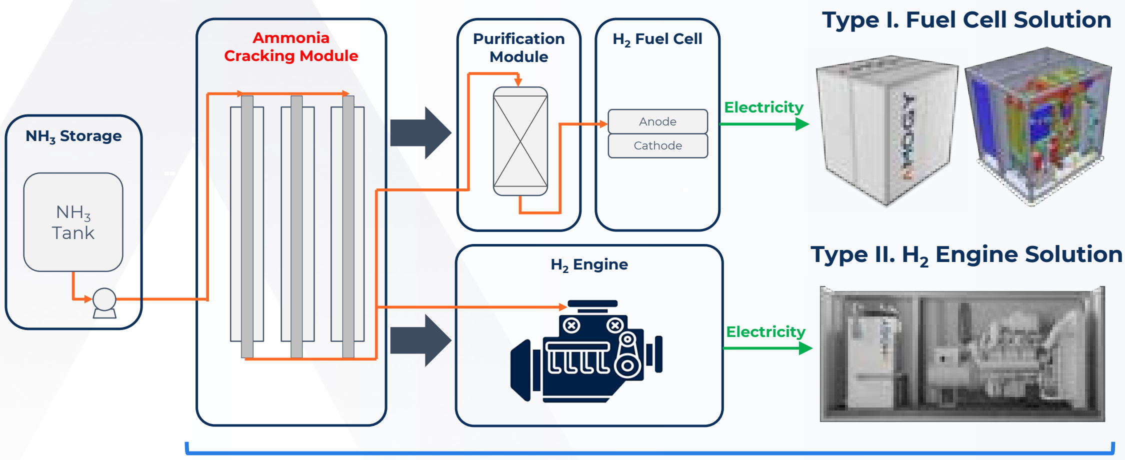
Our Investors

- **Funding raised to date: $317M**
- Seed: $3M | Mar 2021
- Series A: $20M | Nov 2021
- Bridge (uncapped note): $46M | Jun 2022
- Series B: $150M | Mar 2023
- Bridge (convertible note): $56M | Dec 2024
- Series B-2: $42M | Oct 2025

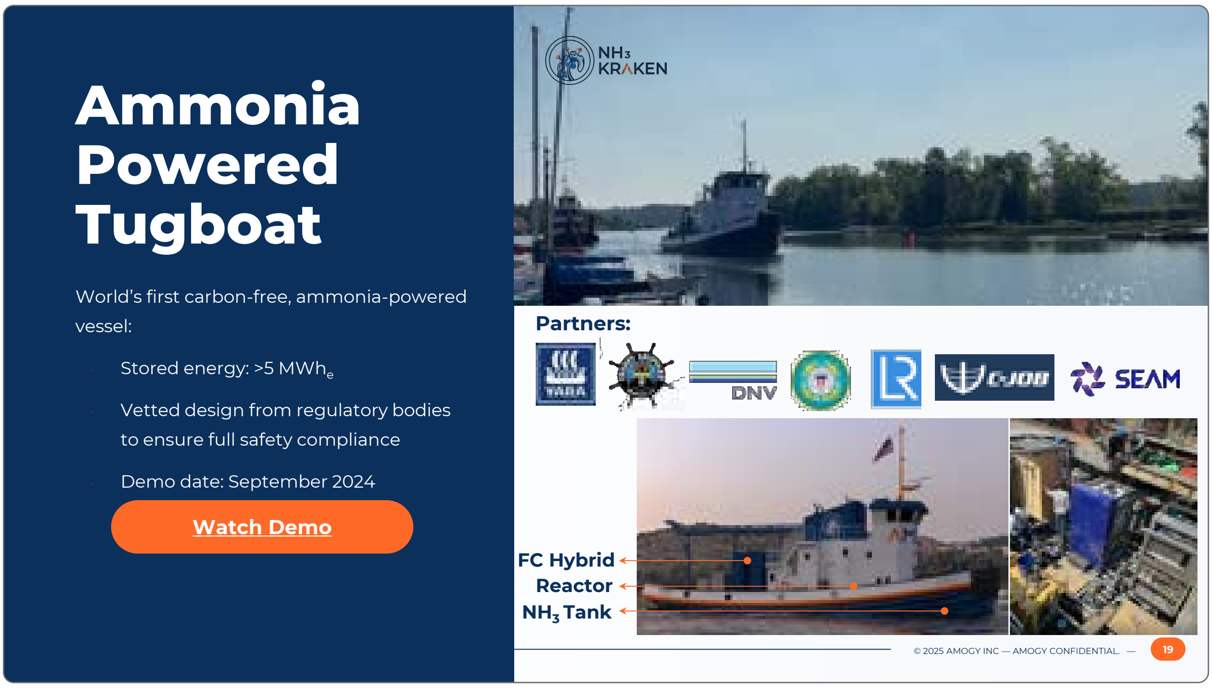
AMOGY

— ABOUT AMOGY

Amogy's Technology



Amogy's Ammonia-to-Power Systems


Ammonia Powered Tugboat
World's first carbon-free, ammonia-powered vessel:
Stored energy: >5 MWh$_e$
Vetted design from regulatory bodies to ensure full safety compliance
Demo date: September 2024
Watch Demo
NH3 KRAKEN
Partners:
DNV
SEAM
FC Hybrid
Reactor
NH$_3$ Tank
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OUR TECHNOLOGY
Amogy Milestones
AMOGY
Drone
2021
Tractor
2022
Class 8 Truck
2023
Tugboat
2024
Houston Facility
2025
2026+
Ammonia-to-power commercial deployments
Power Generation
Maritime
Hydrogen Carrier
$3M | Seed
(Feb. '21)
$20M | Series A
(Oct. '21)
$46M | Bridge
(Jun. '22)
$150M | Series B
(Mar. '23)
$56M | Bridge
(Dec. '24)
$42M | Series B-2
(Oct. '25)
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OUR TECHNOLOGY
AMOGY
Markets & Products
Ammonia-to-Power Solutions
Fuel Cell (P1)
Engine (P2)
Catalyst (P3)
Maritime Shipping
Distributed Power
Industrial Cracking
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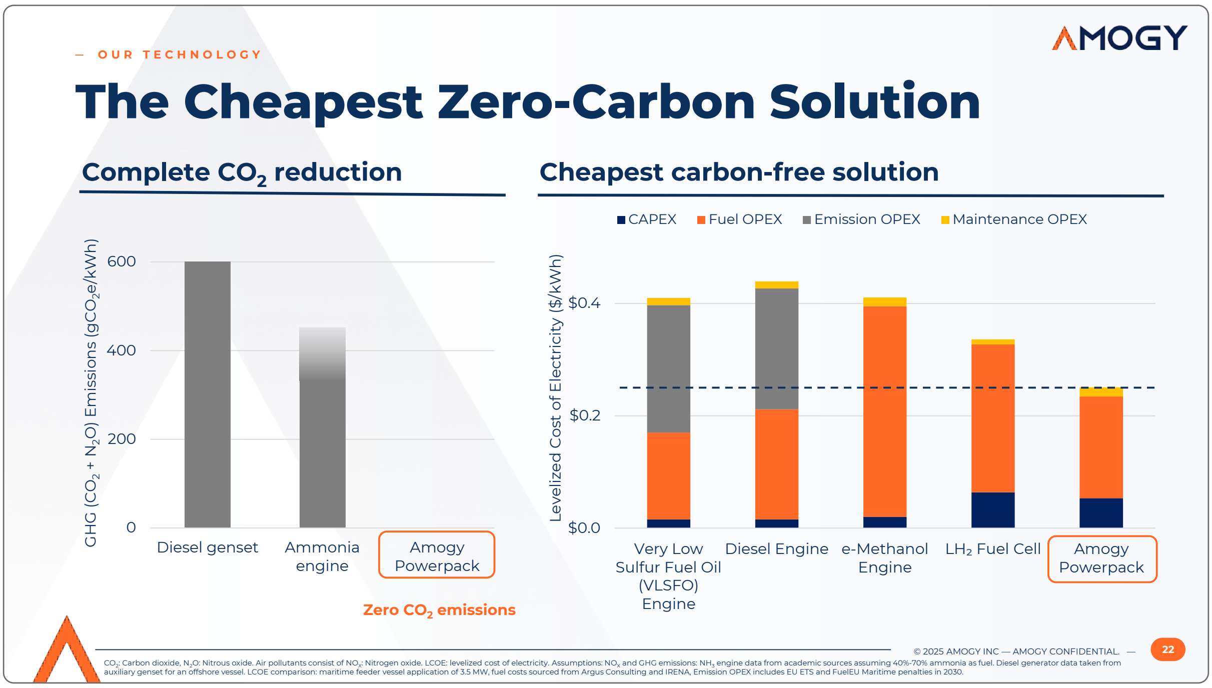
OUR TECHNOLOGY
AMOGY
The Cheapest Zero-Carbon Solution
Complete CO_2 reduction
GHG (CO_2 + N_2O) Emissions (gCO_2e/kWh)
600
400
200
0
Diesel genset
Ammonia engine
Amogy Powerpack
Zero CO_2 emissions
Cheapest carbon-free solution
CAPEX
Fuel OPEX
Emission OPEX
Maintenance OPEX
Levelized Cost of Electricity ($/kWh)
$0.4
$0.2
$0.0
Very Low Sulfur Fuel Oil (VLSFO) Engine
Diesel Engine
e-Methanol Engine
LH_2 Fuel Cell
Amogy Powerpack
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CO_2: Carbon dioxide, N_2O: Nitrous oxide. Air pollutants consist of NO_x: Nitrogen oxide. LCOE: levelized cost of electricity. Assumptions: NO_x and GHG emissions: NH_3 engine data from academic sources assuming 40%-70% ammonia as fuel. Diesel generator data taken from auxiliary genset for an offshore vessel. LCOE comparison: maritime feeder vessel application of 3.5 MW, fuel costs sourced from Argus Consulting and IRENA, Emission OPEX includes EU ETS and FuelEU Maritime penalties in 2030.


— OUR APPLICATIONS
Applications
Maritime Power
Stationary Power
Cracking Catalyst
Samsung Heavy Industries Is Advancing Ships Powered By Ammonia
SAMSUNG HEAVY INDUSTRIES
GS E&C, Amogy, and HD Hyundai Infracore Partner with South Korean City Pohang-si to Advance Ammonia-Based Distributed Clean Power Generation
GS
HD HYUNDAI INFRACORE
Amogy Accelerates Commercialization of Ammonia Cracking Catalyst in Partnership with JGC
JGC
NEDO
Success Through Partnerships
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— FOAK PROJECTS
Distributed Power in Pohang
GS건설이 포항에 짓는 특별한 발전소…탄소는 '0', 경쟁력은 '∞'
포항시, 분산에너지 활성화 협약…"무탄소 에너지 공급"
Sponsor
GS E&C
AMOGY
EPC
Project
System Providers
Fuel Supply
LOTTE FINE CHEMICAL
HD HYUNDAI INFRACORE
Project Overview
Amogy's 1st stationary power deployment under Korea's DEA
Scope: 1 MW pilot in late 2026-2027. SPC with GS is being established to own the project
Path to scale: scaling to 40 MW in 2028+
1 MW
2026–27
10-40 MW
2028
Energy Materials Co. (GS E&C Subsidiary)
Pohang Int'l Container Terminal
Distributed Energy Area (Youngilman Industrial Complex)
SITE
Secondary Battery Industrial Complex
Clean Hydrogen Terminal
FOAK: first-of-a-kind
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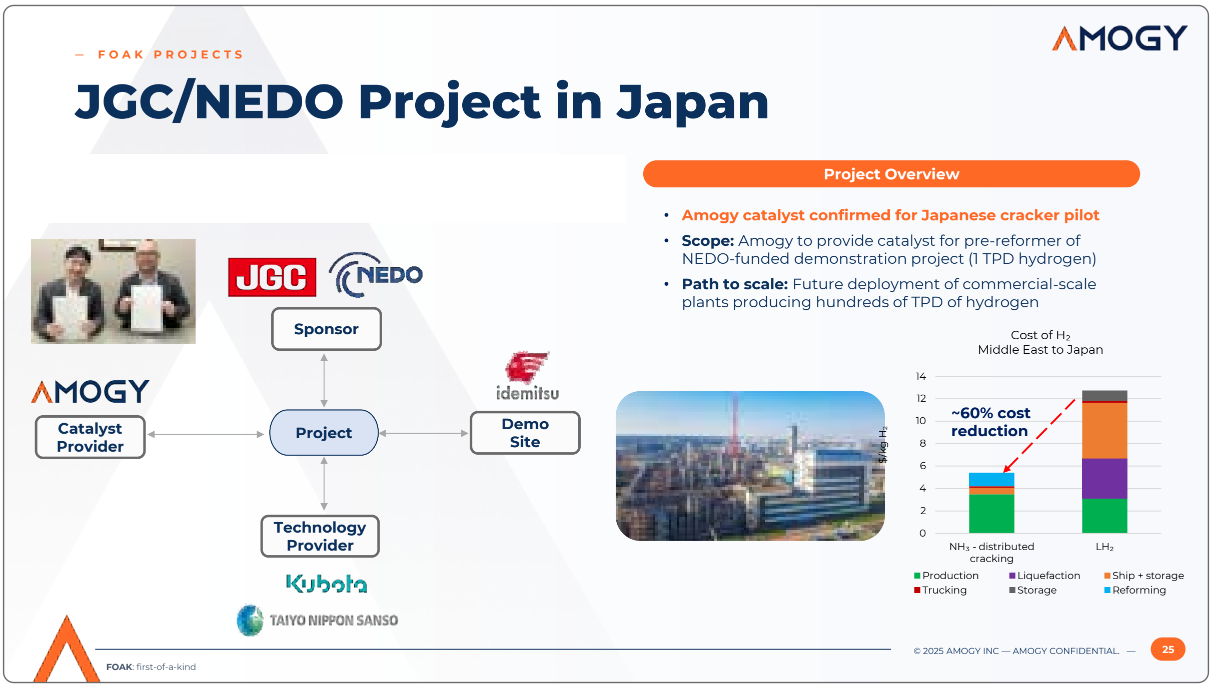
– FOAK PROJECTS
JGC/NEDO Project in Japan
AMOGY
Project Overview
• Amogy catalyst confirmed for Japanese cracker pilot
• Scope: Amogy to provide catalyst for pre-reformer of NEDO-funded demonstration project (1 TPD hydrogen)
• Path to scale: Future deployment of commercial-scale plants producing hundreds of TPD of hydrogen
JGC
NEDO
Sponsor
AMOGY
Catalyst Provider
Project
idemitsu
Demo Site
Technology Provider
Kubota
TAIYO NIPPON SANSO
Cost of H₂
Middle East to Japan
~60% cost reduction
$/kg H₂
14
12
10
8
6
4
2
0
NH₃ - distributed cracking
LH₂
Production
Liquefaction
Ship + storage
Trucking
Storage
Reforming
FOAK: first-of-a-kind
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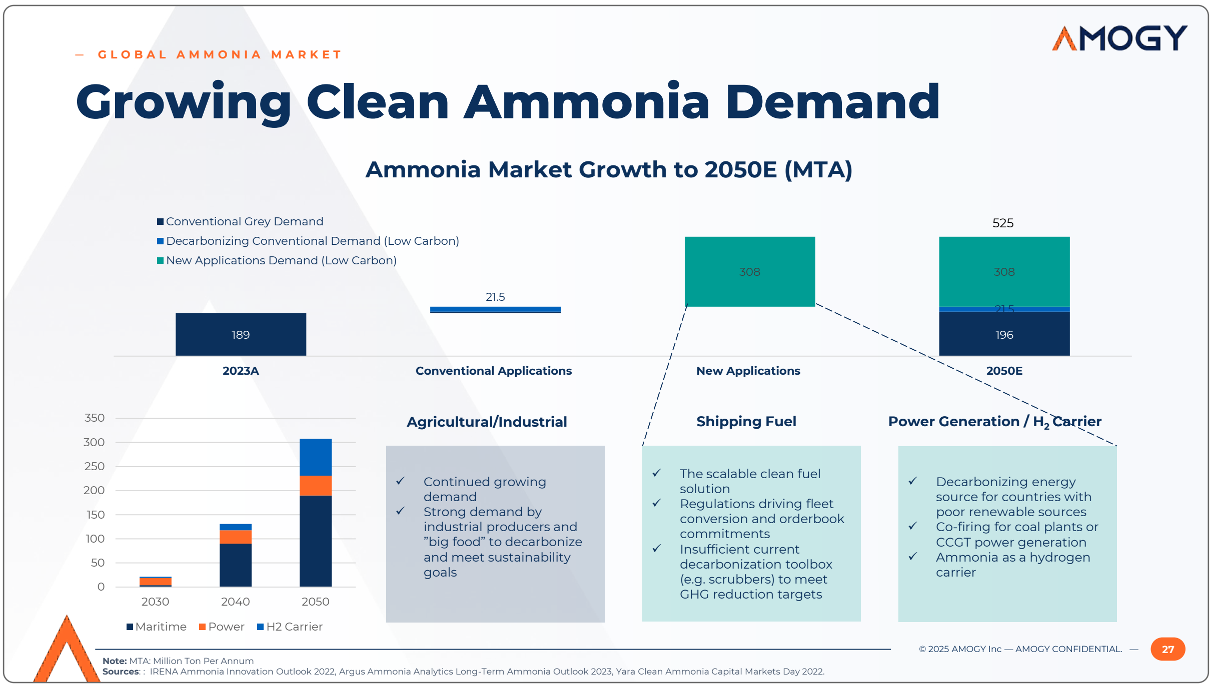
AMOGY
Ammonia Market Outlook


GLOBAL AMMONIA MARKET
AMOGY
Growing Clean Ammonia Demand
Ammonia Market Growth to 2050E (MTA)
Conventional Grey Demand
Decarbonizing Conventional Demand (Low Carbon)
New Applications Demand (Low Carbon)
189
21.5
308
525
308
21.5
196
2023A
Conventional Applications
New Applications
2050E
350
300
250
200
150
100
50
0
2030
2040
2050
Maritime
Power
H2 Carrier
Agricultural/Industrial
Continued growing demand
Strong demand by industrial producers and "big food" to decarbonize and meet sustainability goals
Shipping Fuel
The scalable clean fuel solution
Regulations driving fleet conversion and orderbook commitments
Insufficient current decarbonization toolbox (e.g. scrubbers) to meet GHG reduction targets
Power Generation / H2 Carrier
Decarbonizing energy source for countries with poor renewable sources
Co-firing for coal plants or CCGT power generation
Ammonia as a hydrogen carrier
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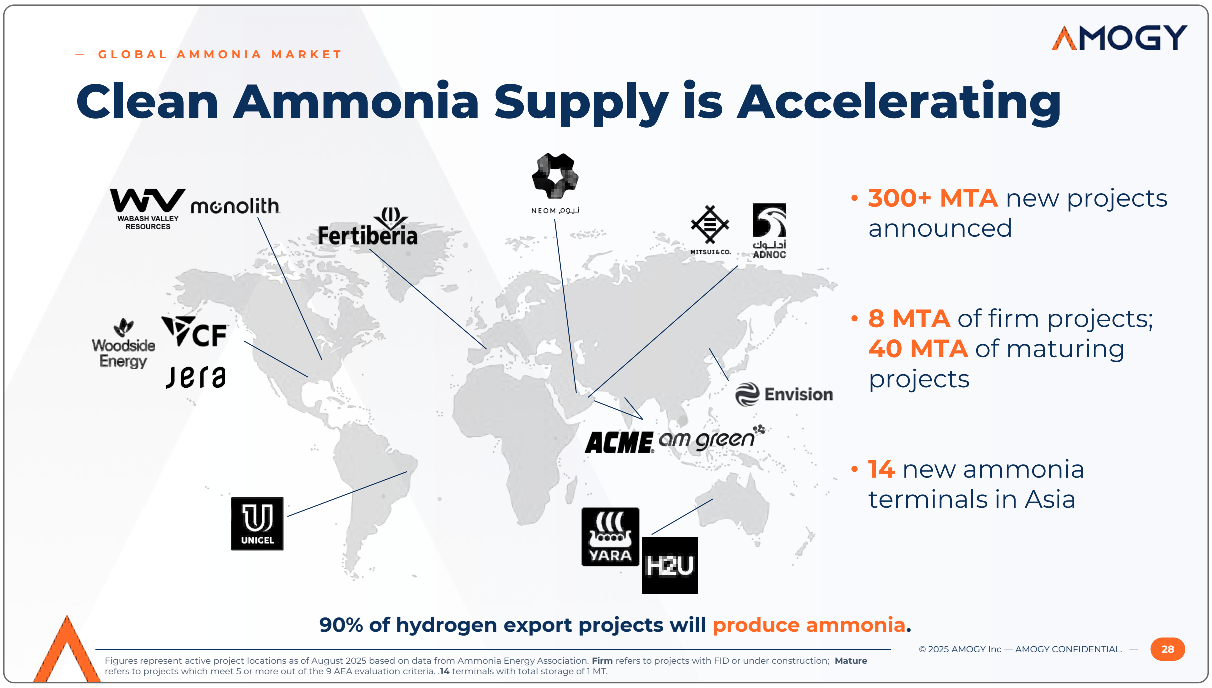
Note: MTA: Million Ton Per Annum
Sources: : IRENA Ammonia Innovation Outlook 2022, Argus Ammonia Analytics Long-Term Ammonia Outlook 2023, Yara Clean Ammonia Capital Markets Day 2022.


GLOBAL AMMONIA MARKET
AMOGY
Clean Ammonia Supply is Accelerating
WABASH VALLEY RESOURCES
monolith
Fertiberia
NEOM
MITSUI&CO.
ADNOC
Woodside Energy
CF
JERA
Envision
ACME
am green
UNIGEL
YARA
H2U
300+ MTA new projects announced
8 MTA of firm projects; 40 MTA of maturing projects
14 new ammonia terminals in Asia
90% of hydrogen export projects will produce ammonia.
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Figures represent active project locations as of August 2025 based on data from Ammonia Energy Association. Firm refers to projects with FID or under construction; Mature refers to projects which meet 5 or more out of the 9 AEA evaluation criteria. 14 terminals with total storage of 1 MT.

AMOGY

— GLOBAL AMMONIA MARKET

Zoom In: China & India

Rapid Supply Infrastructure Buildout

- **40+ MTA** projects announced
- **5+ MTA** reached FID (40% of global total)
- Entirely green ammonia
- Projects co-located with solar PV
- Inner Mongolia (China) and Gujarat (India)

Commercial Detail

- Pricing of **$500-600/t from China** and **$600-700/t from India**
  - ~**50% cost reduction** vs N. America
- Available for exports for power gen in East Asia

Source: Ammonia Energy Association. Figures represent active project locations as of August 2025.

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AMOGY

— GLOBAL AMMONIA MARKET

Demand Drivers of Clean Ammonia

Governing Body	National Policy
South Korea (flag)	CHPS – subsidized 15 yr contracts for power gen from clean NH_3/H_2 (7% of all power by 2035) DEA – incentivizes distributed power <40 MW. Path for Korean companies to become utilities
Japan (flag)	Roadmap for ammonia as a fuel: 2030 (3 MTA); 2050 (30 MTA); Power sector decarbonization target of 60% by 2035.
Singapore (flag)	National H_2 strategy; 50% of power from hydrogen / ammonia by 2050; Green Data Centre Roadmap (300 MW of capacity for green power). Increased focus in Q4 '25
Taiwan (flag)	Net-zero electricity by 2050; 12% of power gen from hydrogen / ammonia; Renewable Portfolio Standard for large power users[1]
EU (flag)	CBAM: requires exports into the EU to pay a GHG tax on embedded emissions; RED III: 42% of industrial energy in EU must be renewable
IMO (flag)	IMO GHG Framework: introduces emissions limits for ocean-going vessels and institutes a tax on GHG emissions for non-compliance

CHPS – Clean Hydrogen Production Standard, which subsidizes ammonia for power generation (2% of South Korean power in 2030, 7% in 2036). **DEA –** Distributed Energy Act, promotes the use of distributed power generation for grid stability. 1 – requires a minimum of 10% of power to come from renewable sources. **CBAM:** Carbon border adjustment mechanism; RED III: renewable energy directive

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AMOGY

— GLOBAL AMMONIA MARKET

Ammonia Demand Drivers

Strong regulatory demand drivers can enable exponential growth.

Market	Customers	End Use	Regulatory Drivers	Clean NH_3 Type	Timing / Profile
Asian Power	• Power asset operators • Data centers • Behind-the-meter	• Coal replacement • Power gen decarb • FTO – grid access issues	• Japan CfD • Korea CHPS, DEA • Voluntary corporate	**Green** & **Blue**	2026 2030 2035 2050
Shipping Fuel	• Vessel owners & operators • Shipyards	• Shipping fuel decarb	• IMO • FuelEU Maritime • Voluntary corporate	**Green** & **Blue**	2026 2030 2035 2050
Fertilizer	• Fertilizer producers	• Agriculture focused on low-carbon	• RED III for industry • CBAM • Voluntary corp.	**Blue** (EU), **Green** (Asia)	2026 2030 2035 2050
EU Cracking	• NH_3 crackers and refineries	• Refinery decarb to avoid penalties • Heat & power	• RED III for transport • CBAM • Voluntary corp.	**Green**	2026 2030 2035 2050

Source: Yara Clean Ammonia.

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Thank You

Seonghoon Woo

Chairman, CEO & Co-Founder

amogy.co

shwoo@amogy.co

Global Technology and Policy Trends for the Expansion of Clean Ammonia 3

Development of Ammonia Fuel System for Marine Applications

HoKi Lee
Vice President, Samsung Heavy Industries

Education

Ph. D. Mechanical Engineering, Washington State University, USA (2008)
M. Sc. Mechanical Engineering, Washington State University, USA (2005)
B. Sc. Mechanical Engineering, Washington State University, USA (2003)

Professional Career

2022 - Head of Green Energy Technology Center, Samsung Heavy Industries
2009 - 2022 Principal Research Engineer, Samsung Heavy Industries
2008 - 2009 Instructor, Washington State University

Research Interest

LNG handling and fuel supply systems
Reducing carbon emissions from ships
Alternative fuel technologies
Nuclear energy utilization
Greenhouse gas reduction technologies.

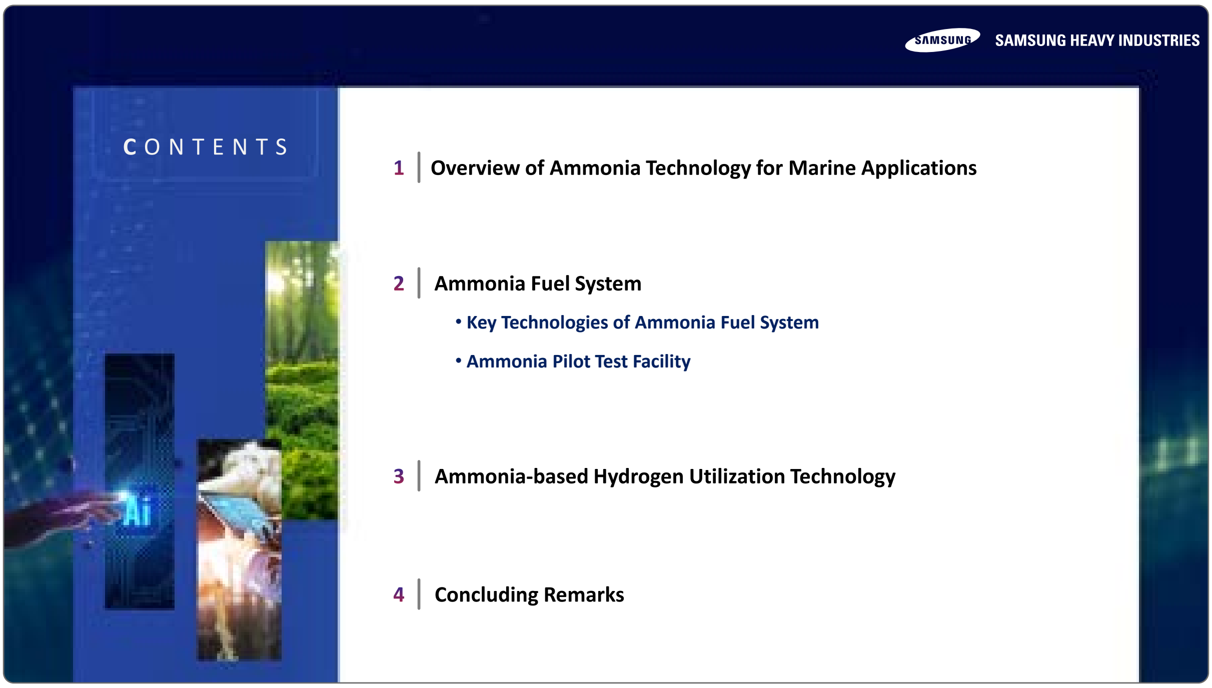
Speech Summary

IMO's GHG regulations spotlight ammonia as a vital green marine fuel. Samsung Heavy Industries developed an ammonia fuel system for propulsion ships, showcasing its design, function, and safety approach. This system significantly mitigates environmental impact, facilitating its widespread adoption in the shipping industry.

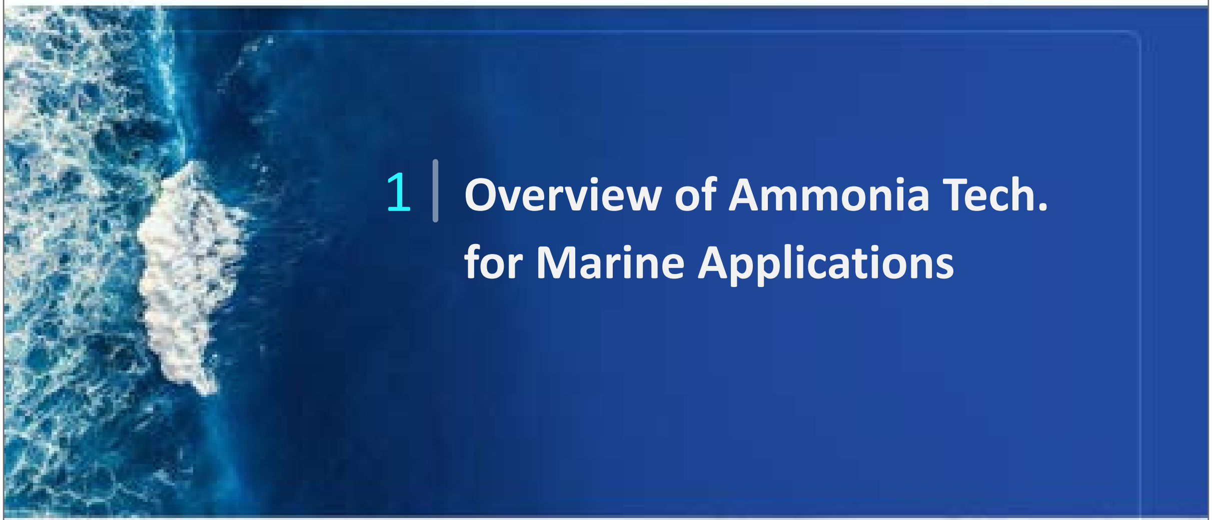
Company Introduction

Since its foundation in 1974, Samsung Heavy Industries has successfully delivered ships and offshore facilities to global shipping firms and oil companies. Samsung Heavy Industries has attained industry leading competitiveness by striving to realize advanced technology, production efficiency, and high value-added shipbuilding. Samsung Heavy Industries continues to bolster its position by pioneering new markets.


SAMSUNG HEAVY INDUSTRIES
Development of Ammonia Fuel System
for Marine Applications
HOKI LEE (Vice President)
Green Energy Technology Center / Samsung Heavy Industries
December 2025


SAMSUNG HEAVY INDUSTRIES
CONTENTS
1 Overview of Ammonia Technology for Marine Applications
2 Ammonia Fuel System
• Key Technologies of Ammonia Fuel System
• Ammonia Pilot Test Facility
3 Ammonia-based Hydrogen Utilization Technology
4 Concluding Remarks

SAMSUNG HEAVY INDUSTRIES



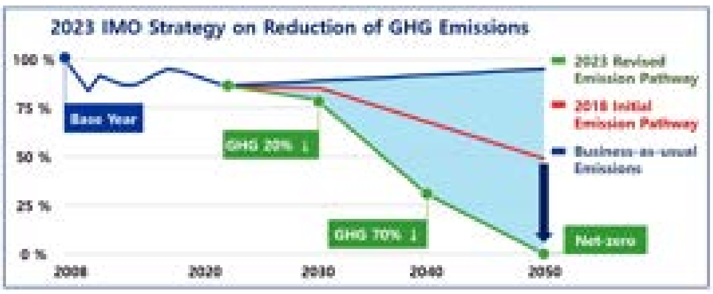
1 | Overview of Ammonia Tech. for Marine Applications

Environmental Regulations for Shipping

SAMSUNG HEAVY INDUSTRIES

Continuous Strengthening of Environmental Regulations for Net-zero in International Shipping

- **[IMO] Revised GHG strategy : Net-zero GHG emissions by 2050**
  * Greenhouse Gas
- **[IMO] EEDI/EEXI and CII regulations → Net-zero Framework (Pricing mechanism for GHG emissions)**
  * EEDI: Energy Efficiency Design Index, EEXI : Energy Efficiency eXisting ship Index, CII : Carbon Intensity Indicator
- **[EU] FuelEU Maritime regulation and EU-ETS (Emission Trading System)**



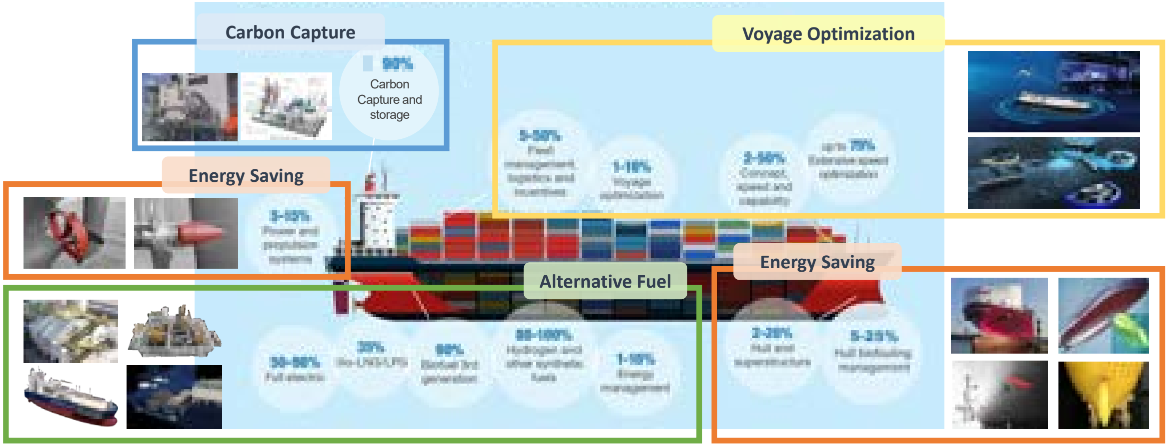
* Source: IMO, DNV, LR

Technical Solutions for GHG Reduction

SAMSUNG HEAVY INDUSTRIES

A Wide Variety of Solutions and their GHG Reduction Potential

- **Achieving net-zero through transition to eco-friendly alternative fuels**



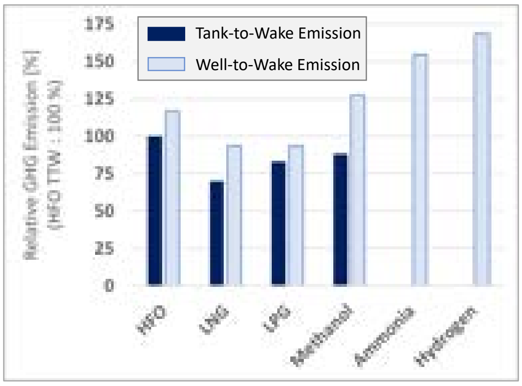
* Source: IMO

Outlook for Alternative Marine Fuels

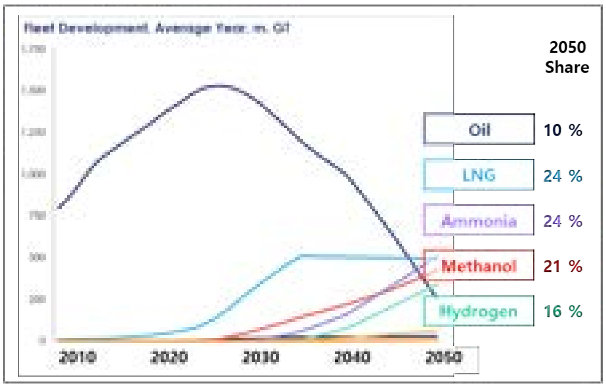
SAMSUNG HEAVY INDUSTRIES

Transition to Zero-carbon Fuels Driven by Technology and Market Conditions

- **[Short Term] Low-carbon fuels (LNG, LPG) & carbon capture technology**
- **[Long Term] Zero-carbon fuels (ammonia, hydrogen) & carbon-neutral fuels (e-fuels)**



GHG Emission of Alternative Marine Fuels



* Source : Clarksons Research ('23)

Outlook of Marine Fuels

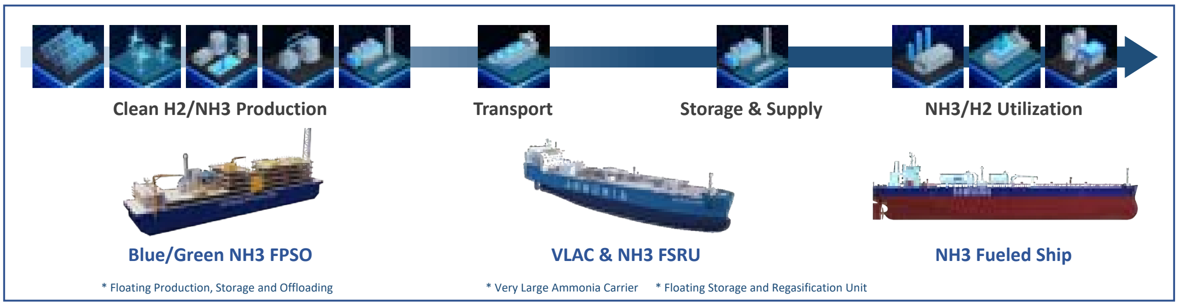
Ammonia for Marine Applications

SAMSUNG HEAVY INDUSTRIES

Ammonia : Representative Zero-carbon Solution Available before Commercialization of Hydrogen

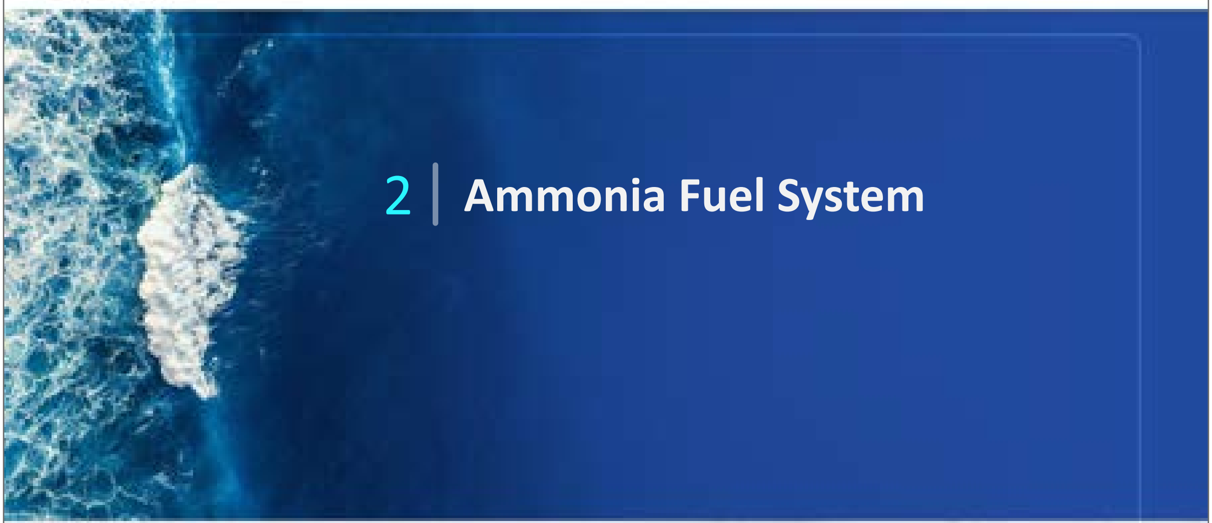
- **Reduction of CO_2 emission by 90 % compared to heavy fuel oil**
- **Growing demand for ammonia as power generation and marine fuels and hydrogen carrier**
- **Needs for safety system and emission management technology due to toxicity**

SHI's Technology Development for Entire Ammonia Value Chain



- 7/21 -

SAMSUNG HEAVY INDUSTRIES



2 | Ammonia Fuel System

- 8/21 -

Development Roadmap

SAMSUNG HEAVY INDUSTRIES

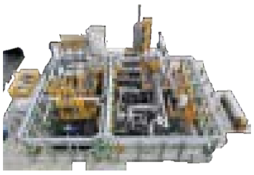
Advancement and Commercialization of Key Technologies for Ammonia Fueled Ship

- R&D in response to ammonia DF engine development status and market demand
  * Dual Fuel
- Development of key technologies → Commercialization of VLAC → Commercialization of ammonia fueled ships
  * Very Large Ammonia Carrier

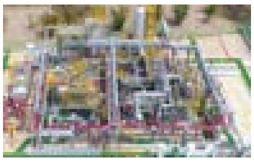
Development Roadmap for Ammonia Fuel System

'23 | '24 | '25 | '26

System Design
- Process development
- Basic & detail design



Pilot Test
- Facility construction
- System verification



System Optimization
- Design for commercialization
- System improvement

Commercialization
- VLAC
- Ammonia fueled ship

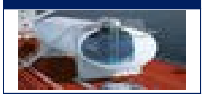
- 9/21 -

Key Technologies of Ammonia Fuel System

SAMSUNG HEAVY INDUSTRIES

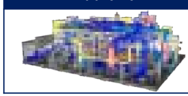
Core Systems and Specifications for A-max COT

Ammonia Fuel Tank



- Material : Low temp. carbon steel
- Capacity : 3500 m³
- Design : 4 barg, -50 ºC
- BOR : 0.05 %/day
  * Boil-off Rate

Fuel Supply System



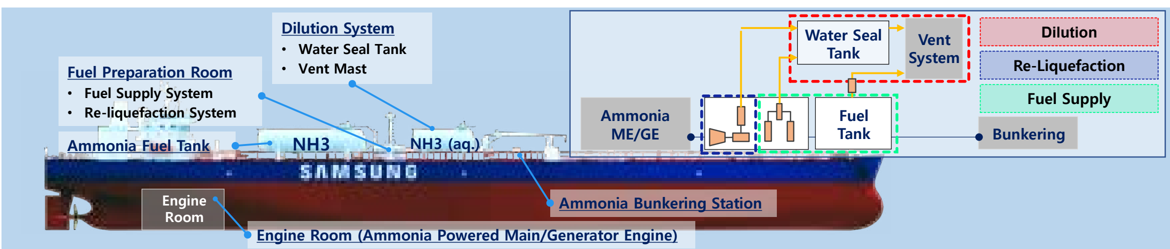
- Fuel supply to engines
- Capacity : 4.5 ton/h
- Pressure & temp. control
- Fuel circulation/recovery

Re-liquefaction System

- Re-liquefaction of BOG
  * Boil-off Gas
- Capacity : 150 kg/h
- Prevention of stress corrosion cracking

Dilution System

- Absorption of ammonia into water
- Treatment of effluent
- Reduction of ammonia concentration



- 10/21 -

Key Technologies of Ammonia Fuel System

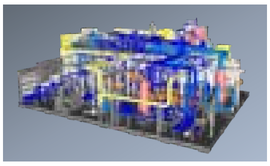
SAMSUNG HEAVY INDUSTRIES

Fuel Supply System - Basic and Detail Design for Various Ship Specifications

- Development of design package (PFD, H&MB, P&ID, sizing, etc.) for A-max, VLCC, Containership and VLAC
  * Process Flow Diagram, Heat and Material Balance, Piping and Instrumentation Diagram * Very Large Crude Oil Carrier * Very Large Ammonia Carrier
- Design improvement by pilot tests and third party verification

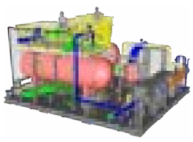
Ammonia Treatment System

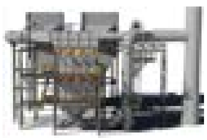
- Development of treatment system for safe handling and less emission of ammonia
- Pilot tests and performance verification of treatment systems based on dilution, adsorption and combustion methods


[Fuel Supply System for A-max]


[Fuel Supply System for VLAC]

Fuel Supply System


[Dilution System]


[Adsorption Recovery System]


[Combustion System]

Ammonia Treatment System

- 11/21 -

Key Technologies of Ammonia Fuel System

SAMSUNG HEAVY INDUSTRIES

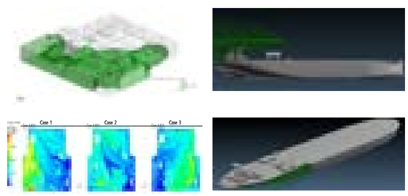
Control System - 'Push and Go' System for Single-Command Operation

- Automated control system considering optimal operating conditions
- Single-command start-up and automatic LFSS control responding to engine signals
  * Low-flashpoint Fuel Supply System

Safety Study

- CFD simulation on dispersion and ventilation for risk assessment (fuel preparation room, vent mast, bunker station)
  * Computational Fluid Dynamics
- HAZID/HAZOP and design optimization of ventilation system, vent mast and gas detection equipment
  * Hazard Identification / Hazard and Operability

'Push and Go' Control System



Safety Study

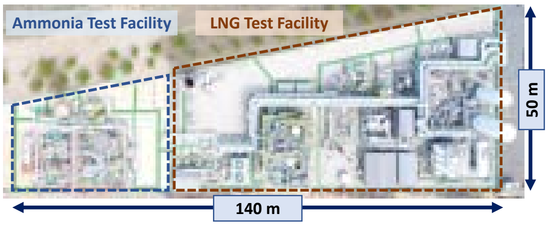
- 12/21 -

Ammonia Pilot Test Facility - Introduction

SAMSUNG HEAVY INDUSTRIES

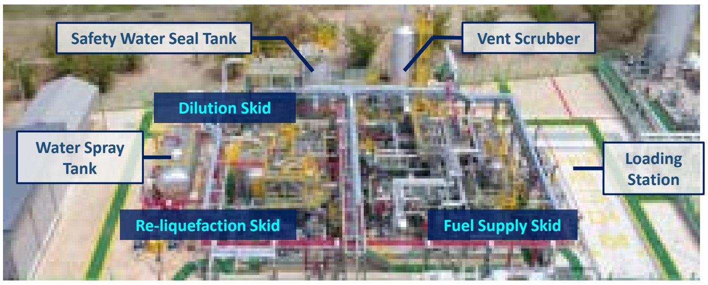
Purpose of Test Facility

- **Verification** of system performance and safety
- **Optimization** of system design and control logic
- **Expansion into Green Energy Test Hub**
  (LNG + ammonia + hydrogen)



Facility Overview

- Location : SHI Geoje shipyard
- Area : 1,260 m³
- Main system
  - Fuel supply skid
  - Re-liquefaction skid
  - Dilution skid



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Ammonia Pilot Test Facility - Test Results

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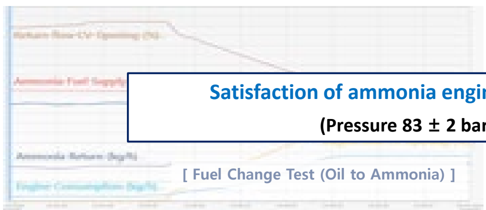
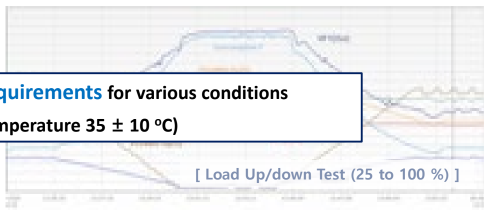
Verification of System Performance → Certifications from Classification Societies (LR, KR)

* Statement of Fact (SoF) * Lloyd's Register, Korean Register

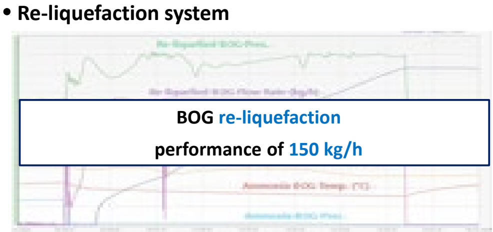
- **Fuel supply system**





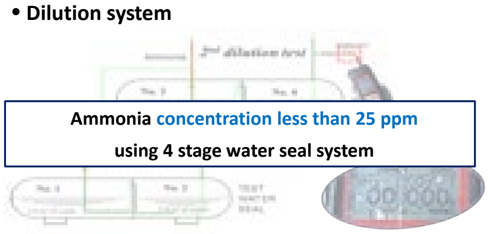
Satisfaction of ammonia engine requirements for various conditions
(Pressure 83 ± 2 barg, Temperature 35 ± 10 °C)

- **Re-liquefaction system**



BOG **re-liquefaction**
performance of **150 kg/h**

- **Dilution system**



Ammonia **concentration less than 25 ppm**
using 4 stage water seal system

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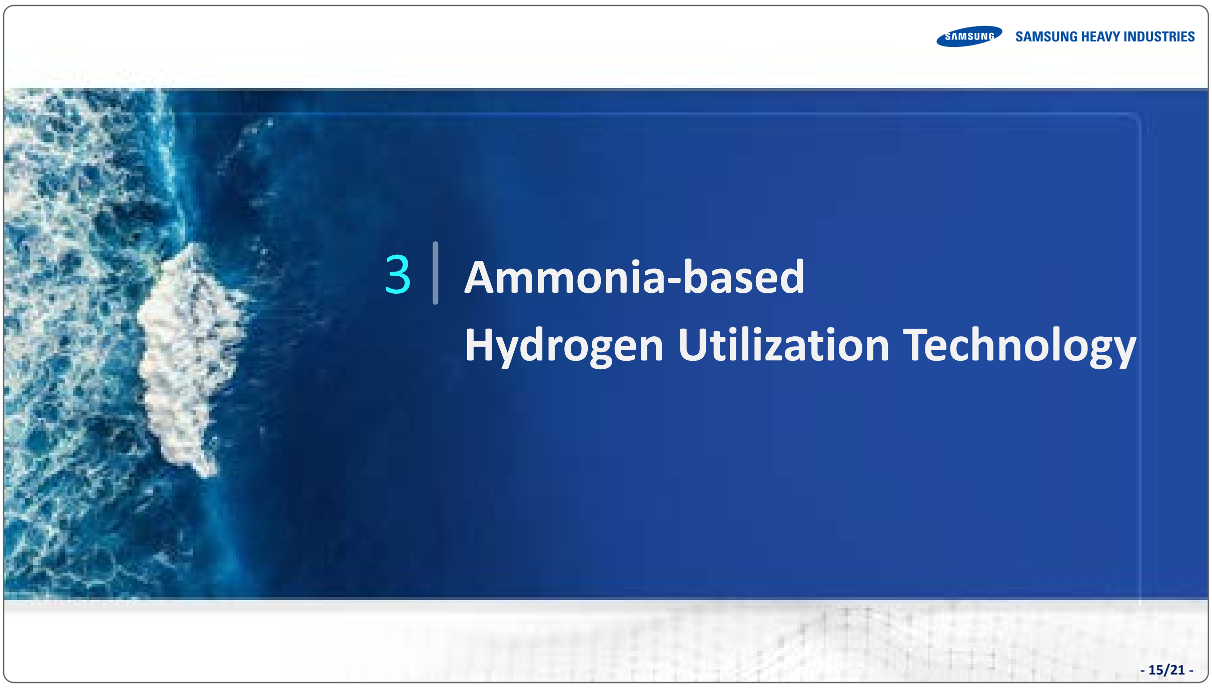
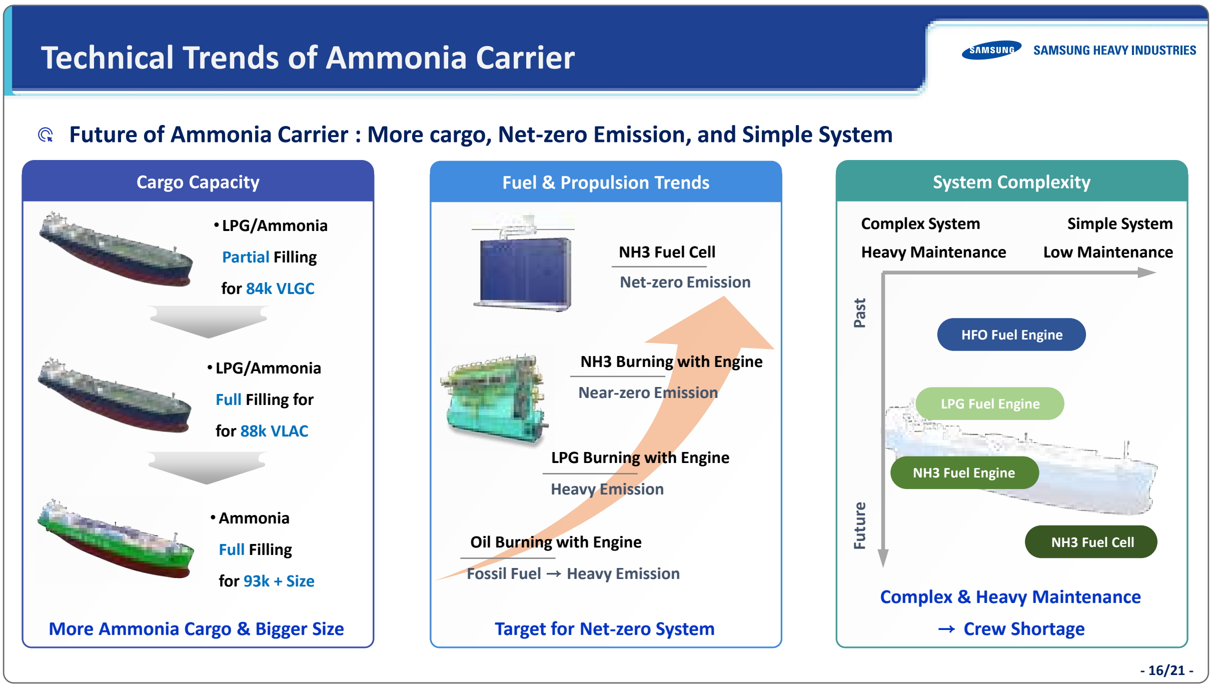

SAMSUNG SAMSUNG HEAVY INDUSTRIES
3 | Ammonia-based
Hydrogen Utilization Technology
- 15/21 -


Technical Trends of Ammonia Carrier
SAMSUNG SAMSUNG HEAVY INDUSTRIES
Future of Ammonia Carrier : More cargo, Net-zero Emission, and Simple System
Cargo Capacity
• LPG/Ammonia
Partial Filling
for 84k VLGC
• LPG/Ammonia
Full Filling for
for 88k VLAC
• Ammonia
Full Filling
for 93k + Size
More Ammonia Cargo & Bigger Size
Fuel & Propulsion Trends
NH3 Fuel Cell
Net-zero Emission
NH3 Burning with Engine
Near-zero Emission
LPG Burning with Engine
Heavy Emission
Oil Burning with Engine
Fossil Fuel → Heavy Emission
Target for Net-zero System
System Complexity
Complex System
Heavy Maintenance
Simple System
Low Maintenance
Past
Future
HFO Fuel Engine
LPG Fuel Engine
NH3 Fuel Engine
NH3 Fuel Cell
Complex & Heavy Maintenance
→ Crew Shortage
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Fuel Cell Powered Ammonia Carrier

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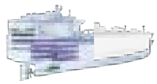
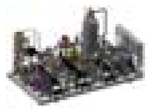
Key Technologies of Fuel Cell Powered VLAC

Optimum Arrangement for F/C System

- Totally changed for fuel cell system
  - FC room / Motor room / SWBD room
  - Other machinery areas



Fuel Gas Supply System



- NH3 fuel gas supply system
- Waste heat utilization
- Segregated fuel gas supply room

Ammonia Cargo Tank

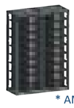
- Type A cargo tank for ammonia cargo

Fuel Cell & Elec. Propulsion System

- AMOGY powerpack system
- Redundancy concept for single fuel
- Dual electric motor with reduction gear

Electrical Essential System

- AMP & BRU and battery system for operation mode
- Optimized elec. grid system (DC to DC / DC to AC mixing)



* AMP : Alternative Maritime Power
* BRU : Breaking Resistor Units

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Technology Development for Ammonia Powerpack

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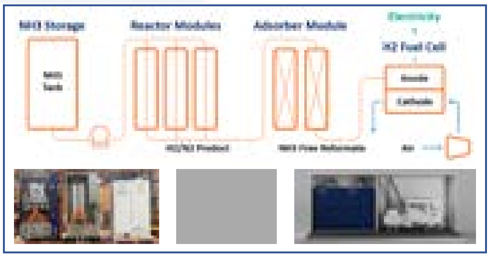
Strategic Collaboration with AMOGY

- AMOGY : U.S. company developing compact and high-efficiency ammonia cracking technology
- Collaboration to develop next generation ammonia-based power generation system for ships



Detailed Development Plans

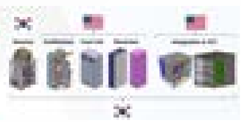
FAT Facility

- Expansion of pilot test facility for FAT
- Conducting FAT for ammonia-based power generation system

* FAT : Factory Acceptance Test

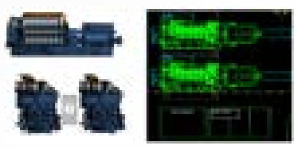
Manufacturing

- Cooperation on mass production and optimization of AMOGY cracking module
- Management of equipment, process and supply chain



Next Generation Product

- System scale-up for large ships and onshore power generation
- Optimization of reformer container and BOP



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4 | Concluding Remarks

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SHI Vision & Future Plans

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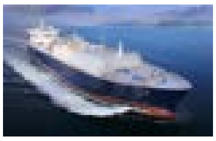
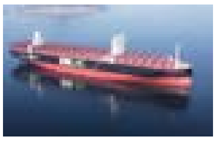
A Leading Provider of Green Energy Solutions for a Net-zero Future

- Timely preparation of ammonia fuel technologies, from engines to fuel cells
- Driving eco-friendly shipbuilding and offshore industries with technological innovation and strategic cooperation

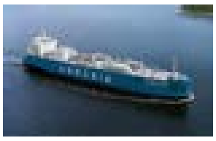
2020 — 2030 — 2050



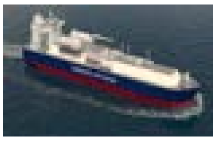
✓ Advanced LNG Technology (LNG Carrier & DF)



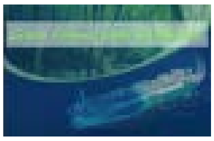
✓ Expansion of LNG DF
✓ Methanol & LPG
✓ WHRS + ORC



✓ Ammonia
✓ LNG DF + OCCS
✓ Fuel Cell



✓ Hydrogen
✓ Nuclear Power



✓ Net-zero GHG Emission

* WHRS : Waste Heat Recovery System
* ORC : Organic Rankine Cycle
* OCCS : Onboard Carbon Capture and Storage System

- 20/21 -


Innovative R&D for the Sustainable Voyage to a Net-zero Future
AMMONIA
SAMSUNG
Thank You

Global Technology and Policy Trends for the Expansion of Clean Ammonia 4

Progress and Outlook of the Green Ammonia Project by Hive Energy

Colin Loubser
CEO, Hive Energy Africa

Colin has more than 25 years of experience in researching, founding and setting up new business enterprises in deregulating, emerging and nascent industries. These include Renewable Energy (Wind & Solar PV), Telecommunications, Payment Systems, Carbon Credits, Biocarbon production, Green Ammonia and Green Hydrogen

2015 – Current: Hive Energy: Africa Initiate, establish and lead the Hive Hydrogen Green Ammonia Project in Coega and new Renewable Energy Projects in Mozambique and South Africa.

PROGRESS AND OUTLOOK OF THE COEGA GREEN AMMONIA PROJECT BY HIVE HYDROGEN

HIVE HYDROGEN

WORLD HYDROGEN EXPO 2025


Artist's impression - to scale - impression of the Coega Green Ammonia Plant

COEGA GREEN AMMONIA PROJECT - HIGHLIGHTS

HIVE

~$5.3bn *Project Capex*	**~1 million tons** *Annual Green Ammonia Produced/year*	**3,309 MW** *Renewable Energy Capacity*	**Q4 2029** *COD*

- **World leading**, fit for purpose, modern embedded infrastructure built in 2009.
- Port with **18m Draft**, 3.4km Breakwater for year round operation of 250m Berth
  - Suitable for Very Large Ammonia Carriers.
- Available **Skilled Labour, Electrical Grid built, modern road and rail fully operational**

WORLD HYDROGEN EXPO 2025


STRATEGIC INTEGRATED PROJECT – DECEMBER 2022
HIVE
The Minister of Electricity and Energy Congratulates the Hive Hydrogen Team


JAPAN - MEMORANDUM OF COOPERATION DECEMBER 2023
HIVE
伊藤忠商事株式会社とHIVE HYDROGEN SAとの協業覚書署名祝賀会 - 2023年12月8日
CELEBRATING THE OCCASION OF THE SIGNING OF THE MEMORANDUM OF COOPERATION BETWEEN ITOCHU AND HIVE HYDROGEN SA – 8 DECEMBER 2023

OFFICIALLY S.AFRICA'S LIGHTHOUSE GREEN HYDROGEN PROJECT

12 June 2025: The Honourable Cyril Ramaphosa President of South Africa, congratulating the Chairman of Hive Hydrogen - Thulani Gcabashe and the Head of New Ventures for Climate Fund Managers - Sebastiaan Surie on the signing of the final development stage $20m / R360m Development Funding Agreement for Hive Hydrogen to take the Coega Green Ammonia project to Final Investment Decision.

COEGA GREEN AMMONIA IS EU FLAGSHIP PROJECT FOR GLOBAL GATEWAY

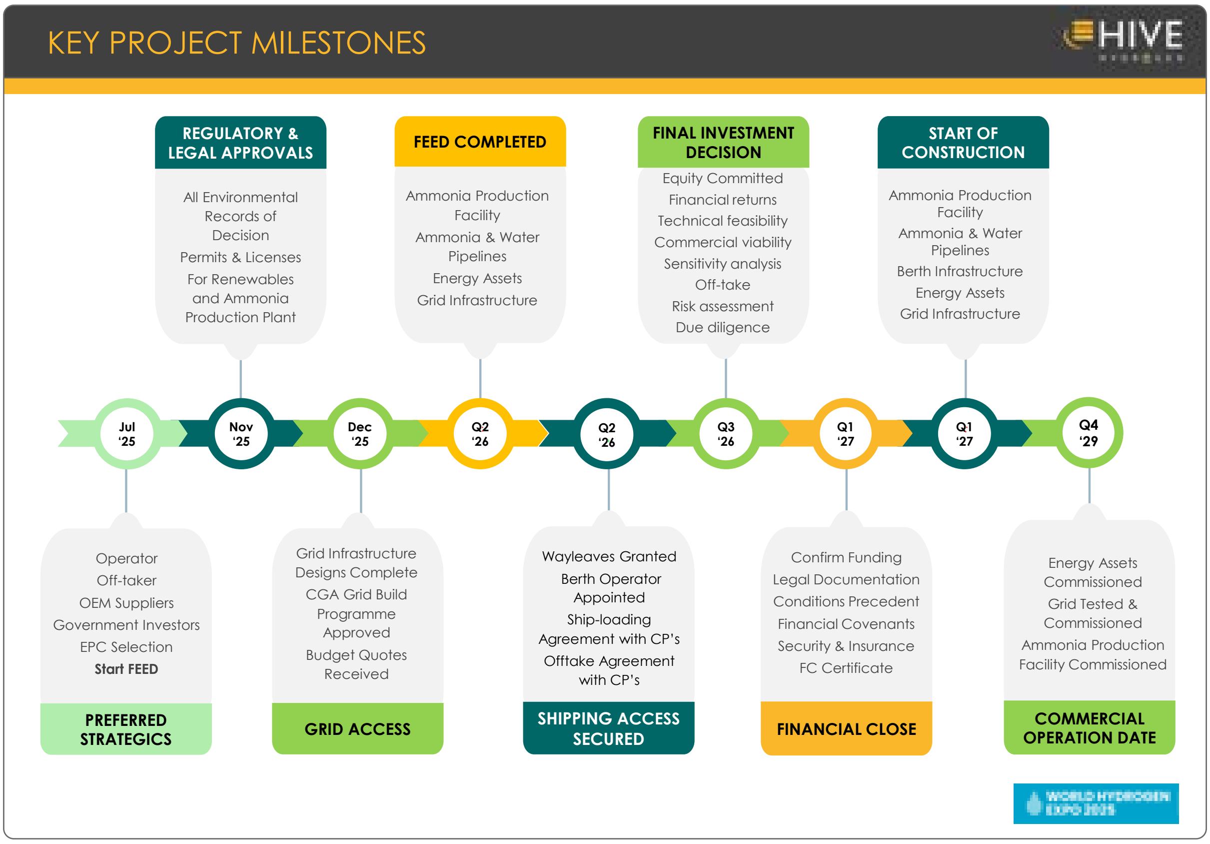
A PARTNERSHIP WITH KOREA IN 2026 WILL COMPLETE THE PICTURE

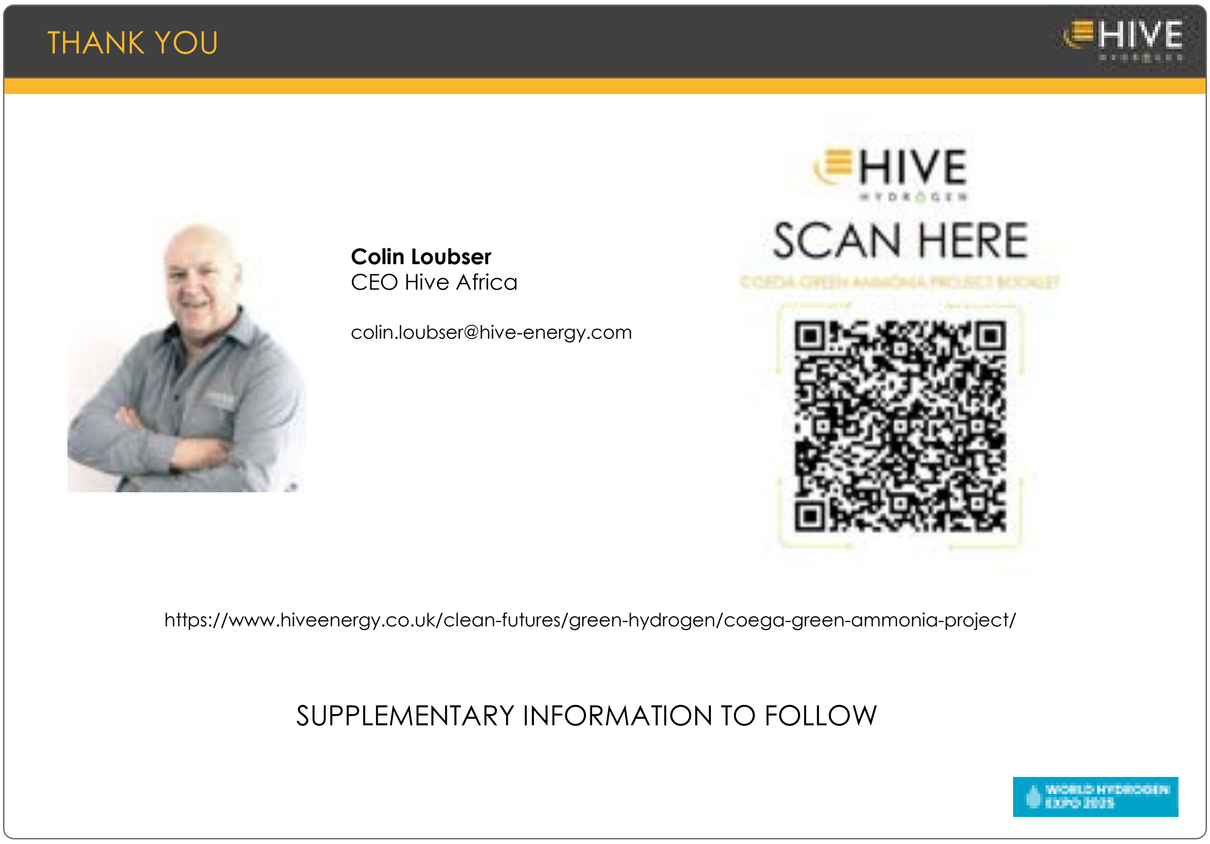
Hive Hydrogen has been building strong relationships with S. Korea and are actively looking for Green Ammonia off-takers, equity investors, Engineering, solar panel manufacturers and development partners from South Korea

President Lee Jae-myung at the G20 summit in November 2025 met with South African President Cyril Ramaphosa, the chair of the summit.

MAJOR PROGRESS IN PAST 12 MONTHS

DEVEX FUNDING	• **$20m** (FEED & BFS) Development Funding terms agreed with Climate Fund Managers - 12 June 2025 • **$5m** Pre-FID funding - board approved - Development Bank of SA (08 May 2025)
3 309MW RENEWABLEs INVESTMENT OPPORTUNITY	• Funders/Investors have a **unique opportunity to invest** in Ready to build Wind and Solar Assets. The liberalized Electricity Regulations and S. African Government Support for Green Hydrogen makes it **one of worlds best locations** to invest in INVEST IN HIVE ENERGY
NEW ENABLING LEGISLATION ENACTED	The Electricity Regulation Amendment Act 38 of 2024, effective January 1, 2025, to **modernize** South Africa's electricity sector established a new Transmission System Operator (01 July 2024) , to oversee the national grid, promote competition, and renewable energy. The Act also introduced the **open market** platform for electricity trading.
GRID ACCESS ON TRACK	• **Full Ministerial support** ensuring requirements are in plan for government and NTC • Bi-lateral confirmations given to S. Korea, Japan, EU, Malaysia, Germany and others
MORE EFFICIENT ELECTROLYSER	• **Game changing Solid Oxide Electrolyser Cells** with 20-30% better efficiency vs Alkaline launched 30 October 2025
LESS RENEWABLES LOWER AMMONIA PRICE	• **FOB Price < $650/ton** when SOEC is utilized as higher efficiency requires lower Capex on renewables v Alkaline (2,777MW v 3,309MW) and consequent lower wheeling costs reduce OPEX as a result too
EPC RFP (FEED) PROCESS COMPLETE	• RFI Stage completed with 17 EPC's shortlisted • **FEED RFP** responses receive and selection process underway


KEY PROJECT MILESTONES
HIVE
REGULATORY & LEGAL APPROVALS
All Environmental Records of Decision
Permits & Licenses
For Renewables and Ammonia Production Plant
FEED COMPLETED
Ammonia Production Facility
Ammonia & Water Pipelines
Energy Assets
Grid Infrastructure
FINAL INVESTMENT DECISION
Equity Committed
Financial returns
Technical feasibility
Commercial viability
Sensitivity analysis
Off-take
Risk assessment
Due diligence
START OF CONSTRUCTION
Ammonia Production Facility
Ammonia & Water Pipelines
Berth Infrastructure
Energy Assets
Grid Infrastructure
Jul '25
Nov '25
Dec '25
Q2 '26
Q2 '26
Q3 '26
Q1 '27
Q1 '27
Q4 '29
Operator
Off-taker
OEM Suppliers
Government Investors
EPC Selection
Start FEED
PREFERRED STRATEGICS
Grid Infrastructure Designs Complete
CGA Grid Build Programme Approved
Budget Quotes Received
GRID ACCESS
Wayleaves Granted
Berth Operator Appointed
Ship-loading Agreement with CP's
Offtake Agreement with CP's
SHIPPING ACCESS SECURED
Confirm Funding
Legal Documentation
Conditions Precedent
Financial Covenants
Security & Insurance
FC Certificate
FINANCIAL CLOSE
Energy Assets Commissioned
Grid Tested & Commissioned
Ammonia Production Facility Commissioned
COMMERCIAL OPERATION DATE


THANK YOU
HIVE
Colin Loubser
CEO Hive Africa
colin.loubser@hive-energy.com
HIVE
SCAN HERE
https://www.hiveenergy.co.uk/clean-futures/green-hydrogen/coega-green-ammonia-project/
SUPPLEMENTARY INFORMATION TO FOLLOW

6th WORLD HYDROGEN EXPO 2025 Conference

Global Technology and Policy Trends for the Expansion of Clean Ammonia 5

Investment Strategy for Green Ammonia Infrastructure in Korea

KwangJun Kim

Senior Executive Director, Saman Corporation

Education

1988 Bachelor of Science in Chemical Engineering, Inha University
2014 Completion of the Chief Energy Officer Course, Korea Energy Economics Institute

Professional Career

2024 ∽ Senior Executive Director of SAMAN Corporation
2018 ∽ 2024 Managing Director of Byuksan Corporation
2004 ∽ 2017 New Business Group Manager of POSCO
1996 ∽ 2004 Section Chief of POSCOE&C
1989 ∽ 1996 Assistant Manager of Hyundai Engineering
1987 ∽ 1989 Process Operation Engineer of KUMHO Petrochemical Corporation

Research Interest

2011 ∽ 2023 Gas Wholesale Business Division Member of the Gas Technology Standards Committee
2014 ∽ 2016 Executive Committee Member, LNG Equipment Technology (ISO/TC67/WG10)
2011 ∽ 2014 Director of the Synthetic Natural Gas Technology Research Project

Speech Summary

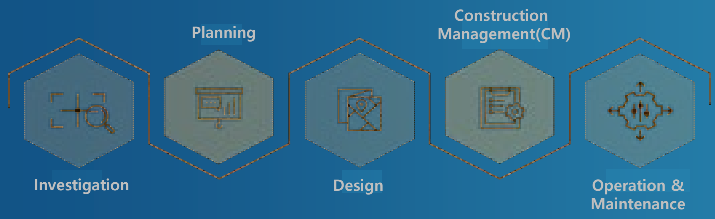
At the present time, interest in green hydrogen and ammonia is growing globally to address climate change. In Korea, the CHPS market is scheduled to begin operations in 2024, and various companies are participating through various clean hydrogen power generation methods. However, at present, infrastructure for unloading, storing, and supplying clean ammonia imported from overseas is a key requirement.
This article will introduce the legal standards and capacity calculations for this ammonia infrastructure.

Company Introduction

SAMAN is a No. 1 multidisciplinary engineering firm in Korea.
SAMAN's excellence has been proven by many major domestic and international Construction and development projects.
Under the management philosophy of "With Technology let's make Human & Nature come together.", we have more than 1,600 professional technical personnel, including over 360 specialized technicians and Ph.Ds with the best technical skills.

Investment Strategy for Green Ammonia Infrastructure in Korea

2025.12.05



Kim Kwangjun (김광준)
Senior Executive Director
kjkim2@samaneng.com

Saman is taking the lead with its mission to create environment-friendly social infrastructure that facilitates harmony between human and nature.

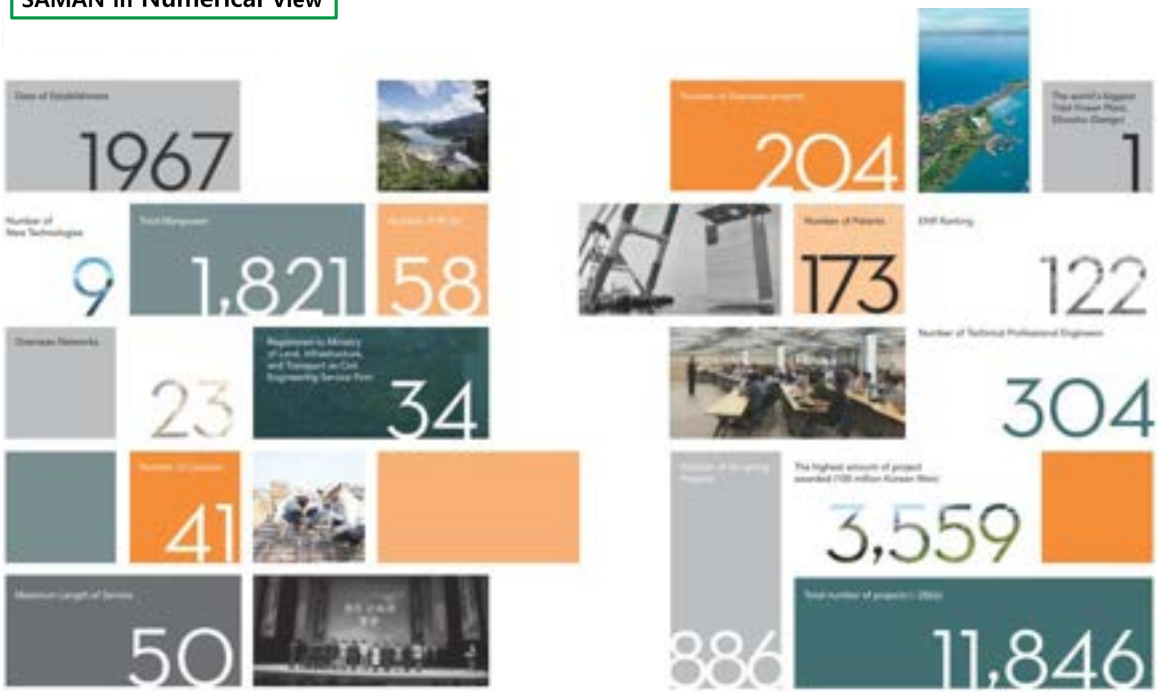
saman Saman Corp.

CONTENTS

saman Saman Corp. 2

1. Saman Corporation

SAMAN in Numerical View



1. Saman Corporation

【 LNG Terminal 】

- **Project** Dangjin Terminal Storage Tanks #5–7(Engineering Services)
- **Client** Korea Gas Corporation(KOGAS)
- **Location** Seokmun National Industrial Park, Dangjin-si
- **Schedule** Feb. 2023 – Feb. 2030
- **Facilities** Three 270,000kl storage tanks(above ground), Utilities and Facilities
- **Scope of Work** LNG storage tanks, including tank structures and surrounding piping(Engineering services)

- **Project** Dangjin LNG Terminal (Phase 1) (Engineering and Construction Management Services)
- **Client** Korea Gas Corporation(KOGAS)
- **Location** Seokmun National Industrial Park, Dangjin-si
- **Schedule** Jul. 2020 – Jul. 2027
- **Facilities** 1,560 t/h vaporization sending-out facilities, loading/unloading facilities, LNG bunkering facilities, Buildings, utilities and facilities
- **Scope of Work** Design and engineering of a production terminal handling 1,560 t/h of LNG(Engineering services)

1. Saman Corporation

【 Green Ammonia Infra. 】

- **Project** Samcheonpo Green Ammonia Infra pre-feasibility study (Engineering Services)
- **Client** Korea South-East Power Corporation(KOEN)
- **Location** Gyeingsangnam-do Geseong-gun Hai-myeon Deoho-ri
- **Schedule** May. 2025 – Nov. 2025
- **Facilities** Two 50,000ton storage tanks(aboveground), 200 t/h vaporization sending-out facilities, unloading facilities, Buildings, utilities
- **Scope of Work** Ammonia storage tanks and Infra Facilities including boiler renovation (Engineering services)

- **Project** Boryeong Green Ammonia Infra Basic Design (Engineering Services)
- **Client** Korea Midland Power Corporation(KOMIPO)
- **Location** Chungcheongnam-do Boryeong-si Ocheon-myeon
- **Schedule** Nov. 2025 – Oct. 2026
- **Facilities** Two 40,000ton storage tanks(aboveground), 200 t/h vaporization sending-out facilities, unloading facilities, Buildings, utilities
- **Scope of Work** Ammonia storage tanks and Infra Facilities including dock renovation (Engineering services)

saman Saman Corp. 5

1. Saman Corporation

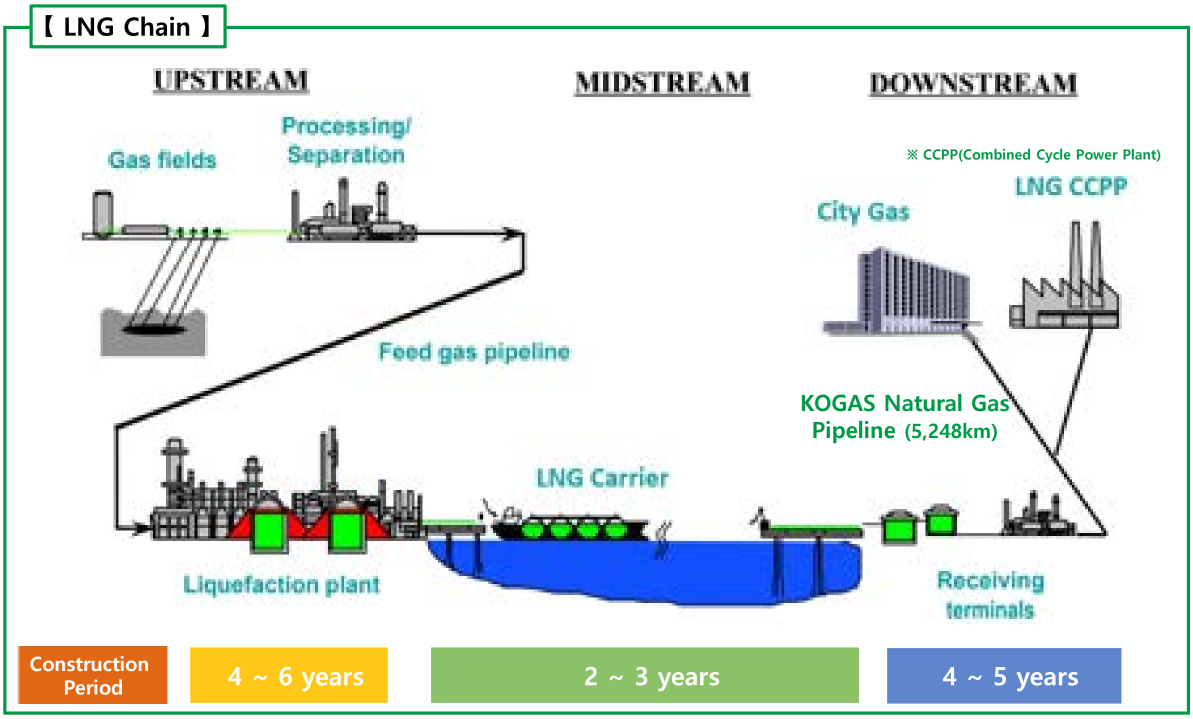
【 Green Hydrogen 】

- **Project** Chungju Dam Hydropower-Based Green Hydrogen Infrastructure Pilot Project(Engineering Services)
- **Client** Korea Water Resources Corporation(K-water)
- **Location** Dream Park Industrial Complex, Chungju-si
- **Schedule** Sep. 2024 – Dec. 2025
- **Power Source** Chungju Dam Unit 2 Hydropower
- **Production** 1.5 MW PEM Electrolyzer
- **Scope of Work** 1.5 MW green hydrogen production facility(Engineering)

- **Project** Seongnam(Water Treatment Plant) Green Hydrogen Infrastructure Project(Engineering Services)
- **Client** Korea Water Resources Corporation(K-water)
- **Location** Seongnam Water Treatment Plant, Seongnam-si
- **Schedule** May 2024 – Sep. 2024
- **Power Source** Small hydropower generation at the water treatment plant
- **Production** 0.6 MW ALK Electrolyzer
- **Scope of Work** Supply facilities for a mobile hydrogen refueling station(Engineering)

saman Saman Corp. 6

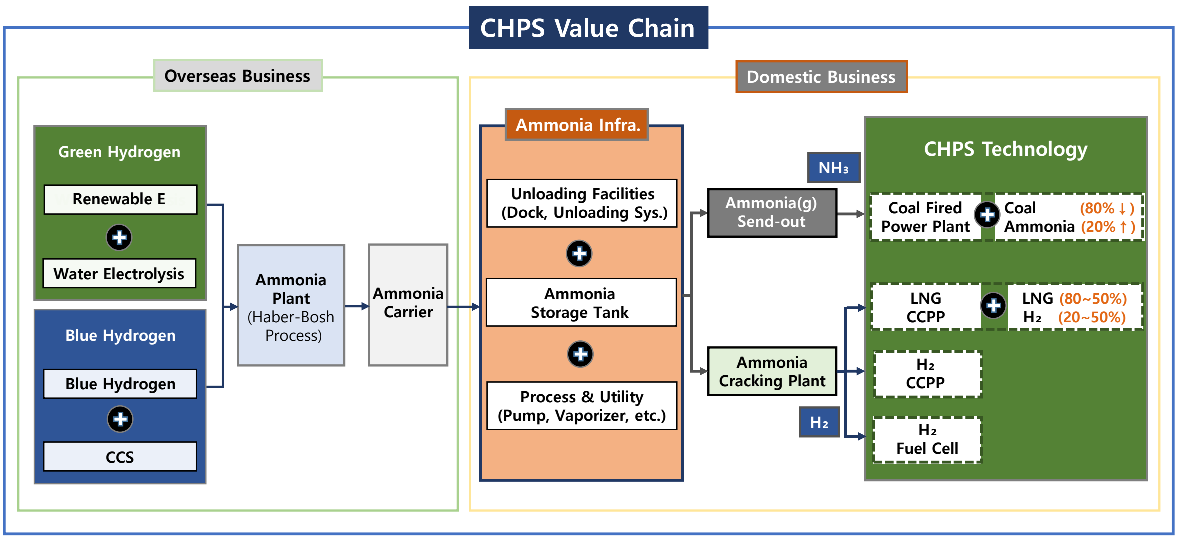
2. Clean Hydrogen Portfolio Standard(CHPS)



saman 7

2. Clean Hydrogen Portfolio Standard(CHPS)

CHPS can be participated by various clean power plants, but ammonia infrastructure, which is the unloading, storage, and supply facilities for clean ammonia imported from overseas, is an essential facility.



※ CCPP (Combined Cycle Power Plant)

saman 8

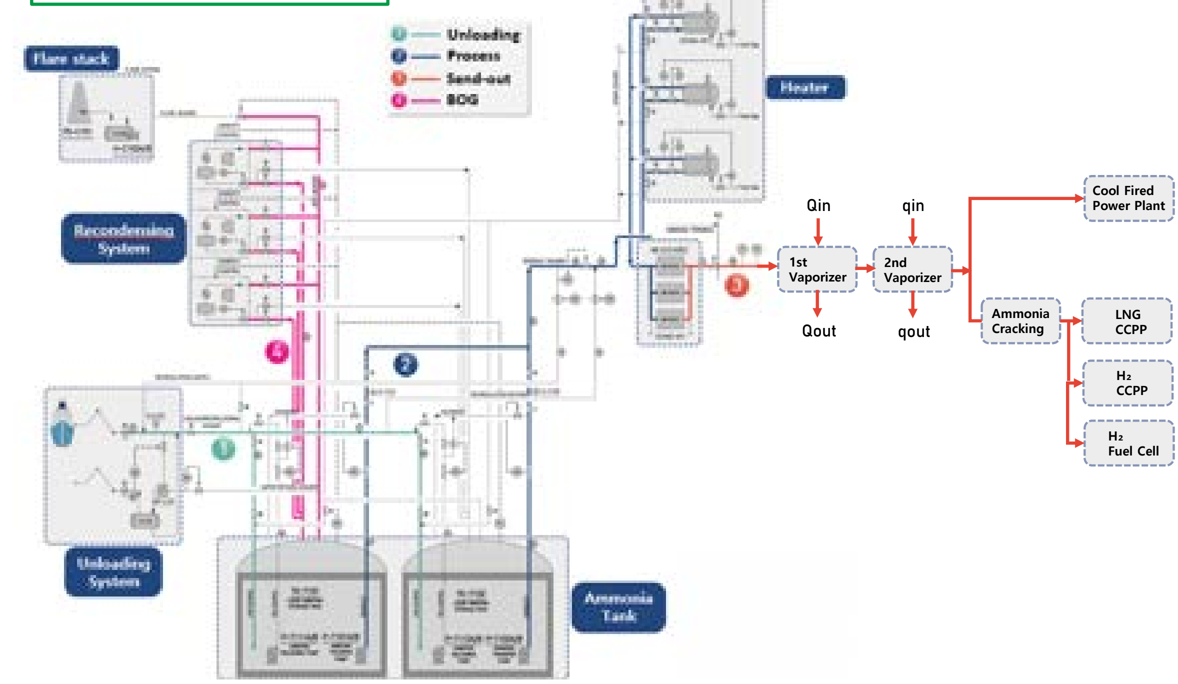
3. Korean Hydrogen Lows

(Green or Blue) Ammonia → Applicable Lows

	Hydrogen Economy Promotion and Hydrogen Safety Management ACT (Hydrogen ACT, 수소법)	High Pressure Gas Safety Control ACT (High Press. Gas ACT, 고압가스법)	※ Urban Gas Business ACT (도시가스사업법)	Hydrogen and Hydrogen Compounds Business Bill (Hydrogen Business Bill, 수소사업법)
Bill	-	-	-	2025.01.17 (???)
New Enactment	2020.02.04	1973.02.07	1978.12.05	???
Enforcement Decree Act	2021.02.05	1973.08.16	1979.02.08	???
Enforcement Regulations Act	2021.02.05	1973.10.22	1984.08.28	???
Key Takeaways	- The purpose is to establish a foundation for promoting the transition to a hydrogen economy in which hydrogen is used as a primary energy source, to systematically and efficiently foster the hydrogen industry, and to establish necessary matters for the safety management of hydrogen products and hydrogen-using facilities, thereby promoting the development of the national economy and contributing to ensuring the safety of the people.	- Licensing standards for the manufacture, storage, and distribution of high-pressure gas, as well as manufacturers of containers and equipment. - Standards for appointing a security manager at high-pressure gas facilities. - Standards for final inspections upon completion of high-pressure gas facility installation. - Standards for the service life of high-pressure gas containers to ensure their safety. - Technical standards for preventing accidents caused by high-pressure gas.	- Establishing the scope of the gas business. - Gas retail business licensing standards. - Government approval requirements for gas rates and gas supply. - Standards for appointing safety managers for gas business operators. - Inspection standards for gas appliance manufacturers.	- The Hydrogen Business Bill sets out the licensing requirements for entry by various stakeholders into the hydrogen business. - Business operators providing pipelines or terminal are required to: provide shared access to their infrastructure for other business entities and obtain approval from the Ministry of Trade, Industry, and Energy (MOTIE) for pipeline/terminal facility usage fees and other terms and conditions of use; - Under the Bill certain hydrogen business entities must submit a five-year hydrogen (compound) supply plan annually. Based on these plans, the Government forecasts hydrogen (compound) supply and demand and imposes stockpiling obligation on designated hydrogen (compound) stockpile entities.
(Green or Blue) Ammonia	Hydrogen Compounds (수소화합물)	Ammonia	-	Hydrogen Compounds (수소화합물)

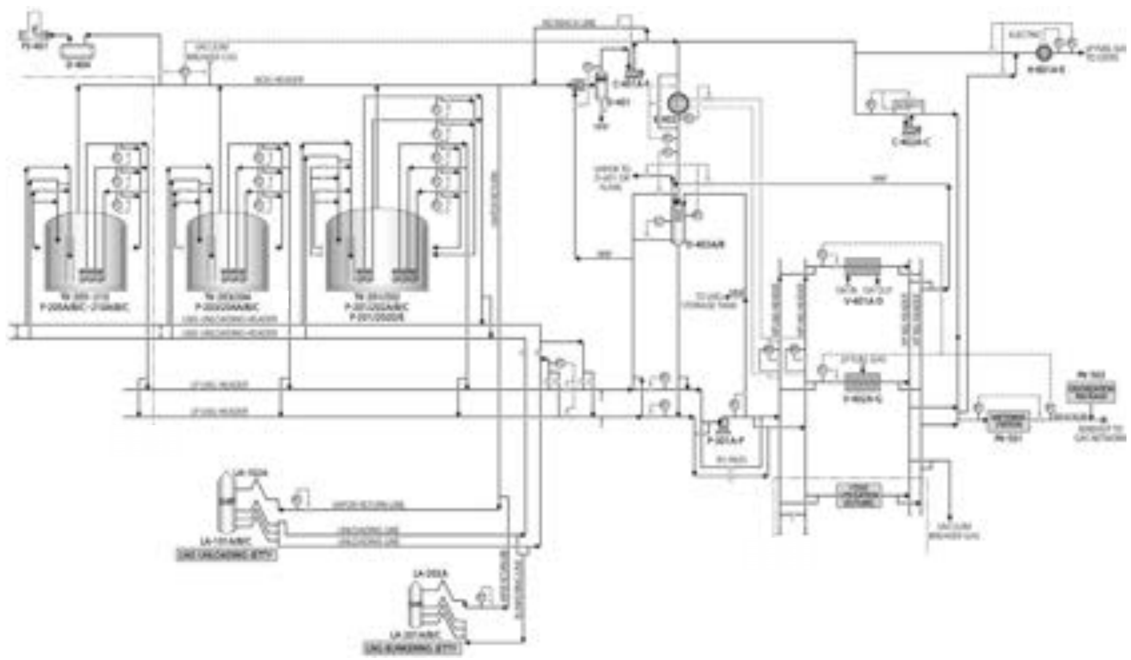
4. Process Flow

【 Typical Ammonia Infra. 】



4. Process Flow

【 Typical LNG Terminal 】



5. Ammonia Import & Send-out Conditions

Import

General	▷ Phase : Liquefied Ammonia ▷ Temp. : -33℃ ▷ Press. : Cargo Pump Press.
Composition(wt%)	
Gray Ammonia	【Domestic(LOTTE, Namhae)】 ▷ NH_3(99.5~), H_2O(~0.5), Oil(5~10ppm)
	【Overseas(PETRONAS, OCI)】 ▷ NH_3(99.5~), H_2O(0.1~0.5), Oil(10ppm)
Green & Blue Ammonia	【Green - Yara Pilbara PJT(Austrialia)】 ▷ NH_3(~99.5), H_2O(0.2~0.5), Oil(10ppm)
	【Green - NEON PJT(SaudI Arabia)】 ▷ NH_3(99.5~99.9), H_2O(0.1~0.5)
	【Blue - Mesaieed PJT(Qatar)】 ▷ NH_3(99.5~99.9), H_2O(0.1~0.5)

Ammonia Infra.

NH_3 → / H_2 →

Send-out

Coal Fired Power Plant	▷ Phase : Gaseous Ammonia ▷ Temp. : 40~50℃ ▷ Press. : 3~5barg ▷ Comp. : Same as Import
LNG CCPP H_2 CCPP H_2 Fuel Cell	▷ Phase : Gaseous Ammonia ▷ Temp. : TBC ▷ Press. : TBC ▷ Comp. : Same as Import

5. Ammonia Import & Send-out Conditions

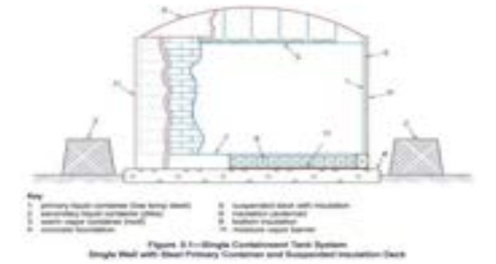
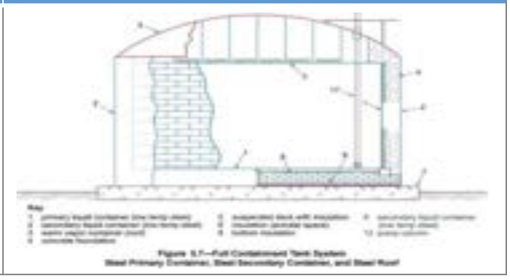
【 Typical LNG Compositions 】

Component	Algeria	Abu-Dhabi	Australia	Malaysia	Indonesia	Brunei	Indonesia	Alaska	Algeria
Nitrogen	0.278%	0.106%	0.014%	0.320%	0.030%	0.000%	0.090%		1.400%
CH_4	91.397%	87.074%	87.822%	91.151%	89.180%	89.400%	90.600%	99.800%	89.800%
C_2H_6	7.874%	11.410%	8.304%	4.284%	8.380%	6.300%	6.000%	0.100%	6.000%
C_3H_8	0.443%	1.271%	2.982%	2.873%	1.670%	2.800%	2.480%		2.200%
$i\text{-}C_4H_{10}$	0.004%	0.062%	0.400%	0.701%	0.240%				0.300%
$n\text{-}C_4H_{10}$	0.004%	0.079%	0.475%	0.661%	0.271%	1.500%	0.820%		0.300%
$i\text{-}C_5H_{12}$	0.000%	0.001%	0.000%	0.010%	0.020%	0.000%			0.000%
$n\text{-}C_5H_{12}$	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.010%		0.000%
Total	100.000%	100.003%	99.997%	100.000%	99.991%	99.800%	100.000%	99.900%	100.000%
HHV Gas, Btu/SCF	1,078.4	1,123.0	1,142.9	1,118.5	1,117.1	1,021.0	1,110.8	1,010.8	1,088.1
Wobbe Index	1,393.0	1,419.4	1,431.0	1,414.0	1,417.0	1,423.8	1,411.3	1,358.2	1,383.2
GPM C2+	2.25	3.44	3.32	2.37	2.92	2.86	2.54	0.03	2.40

Component	Oman	Trinidad	Qatar	Confidential	Confidential	Indonesia	Confidential	Confidential	Confidential
Nitrogen	0.000%	0.000%	0.190%	0.050%	0.430%	1.002%	0.099%	0.015%	0.307%
CH_4	87.664%	92.260%	89.870%	92.070%	84.550%	96.379%	91.425%	92.629%	91.021%
C_2H_6	9.716%	6.394%	6.650%	6.890%	10.930%	2.004%	7.418%	6.888%	7.534%
C_3H_8	2.037%	0.909%	2.300%	0.970%	3.210%	0.451%	0.872%	0.348%	0.949%
$i\text{-}C_4H_{10}$	0.286%	0.214%	0.410%	0.000%	0.470%	0.069%	0.075%	0.022%	0.081%
$n\text{-}C_4H_{10}$	0.297%	0.223%	0.570%	0.000%	0.380%	0.090%	0.088%	0.033%	0.081%
$i\text{-}C_5H_{12}$	0.000%	0.000%	0.010%	0.020%	0.020%	0.003%	0.012%	0.022%	0.014%
$n\text{-}C_5H_{12}$	0.000%	0.000%	0.000%	0.000%	0.000%	0.001%	0.012%	0.042%	0.012%
Total	100.000%	100.000%	100.000%	100.000%	99.990%	100.000%	100.000%	100.000%	100.000%
HHV Gas, Btu/SCF	1,127.6	1,082.1	1,115.6	1,077.4	1,156.7	1,025.4	1,082.9	1,070.6	1,082.8
Wobbe Index	1,421.5	1,396.9	1,412.6	1,363.6	1,432.1	1,353.1	1,396.2	1,390.5	1,393.6
GPM C2+	3.34	2.10	2.72	2.11	4.08	0.71	2.26	1.97	2.33

6. Ammonia Storage Capacity

【 Storage Tank Type (LNG & Ammonia) 】

	Single Containment	Full Containment
API 625		

【 Storage Capacity 】

▣ LNG Terminal Case (Urban Gas Business Act)

LNG Storage Capa. ⊖ Ship Capa. ⊕ Seasonal Variation ⊕ Emergency Stockpile ⊖ Ship Adjust Quantity

☞ Storage Capacity : 30 days (Urban Gas Business, Direct Importer, Natural Gas Shipping Business, etc.)
☞ Emergency Stockpile : 9 days (Urban Gas Business only)

▣ Ammonia Infra. (Hydrogen Business Act not Enacted)

☞ Coal Fired Power Plant Case : Coal(15~30 Days), Ammonia(?)
☞ LNG CCPP, H_2 CCPP, H_2 Fuel Cell : Ammonia(?), H_2(?)

7. System Configuration of Ammonia Process

Major Equipment		Design Basis	Equipment Capacity		
			Unit Capa.	Q'TY	Configuration
Unloading	Unloading Arm	Depending on the ship max. unloading rate	2,000 m^3/hr	2	50% x 2 = 100%
	Jetty Drain Drum		10~20 m^3/hr	1	100% x 1 = 100%
	Vapor Return Arm	Reloading case	4,000 m^3/hr	1	100% x 1 = 100%
Storage	Storage Tank	Depending on the Hydrogen Business Act	30000~50000 ton	2	50% x 2 = 100%
Send-out	Pump	Depending on the ammonia demand	100t/hr	2/tank	100% x 2 = 200%/tank
	1st Vaporizer		100t/hr	3	50% x 3 = 150%
	2nd Vaporizer		100t/hr	3	50% x 3 = 150%
	Gas Heater		100t/hr	3	50% x 3 = 150%
Reliquefaction	BOG Reliquefaction	BOG rate when unloading	3.5t/hr	3	50% x 3 = 150%
Flare	Flare Stack	Emergency Analysis	100t/hr	1	100% x 1 = 100%
Utility	N2, Air, Water, etc.	-	-	-	-

saman Saman Corp. 15

Global Technology and Policy Trends for the Expansion of Clean Ammonia 6

Ammonia Adsorbents as Key Enabling Technologies for a Clean Ammonia Society

KwangBok Yi
Professor, Chungnam National University

Education

2000-2004, Ph.D., Chemical Engineering, Louisiana State University, Baton Rouge, USA
1998-2000, M.S., Chemical Engineering, Chungnam National University, Daejeon, Korea
1990-1997, B.S., Chemical Engineering, Chungnam National University, Daejeon, Korea

Professional Career

2010-Present, Professor, Chemical Engineering Education, Chungnam National University, Daejeon, Korea
2006-2010, Senior Researcher, Korea Institute of Energy Research, Daejeon, Korea
2004-2006, Postdoctoral fellow, Institutt For Energiteknikk, Norway

Research Interest

Ammonia adsorbent for ammonia cracking process and maritime ammonia fuel
CO adsorbent for energy conversion and production
CO2 adsorbent for direct air capture
NOx conversion to NH3 and enrichment process

Speech Summary

This talk presents an integrated pathway for clean hydrogen from ammonia. Introduces high-efficiency cracking, advanced adsorbent-based NH_3 removal, and scalable purification. Especially, it highlight material innovations enabling <0.1 ppm NH_3 H_2 production for industrial deployment.

Company Introduction

Chungnam National University: a leading national research university in Daejeon, Korea

2025 Hydrogen Deep Dive

Ammonia Adsorbents as Key Enabling Technologies for a Clean Ammonia Society

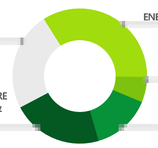
Chungnam National University
Kwang Bok Yi

2025. 12. 5.

Eergy Trends

Accelerated Global Warming

GREENHOUSE GAS EMISSIONS



Energy·Mobility(49%)
↓
Industry (24%)
↓
Agriculture/Forestry (22%)

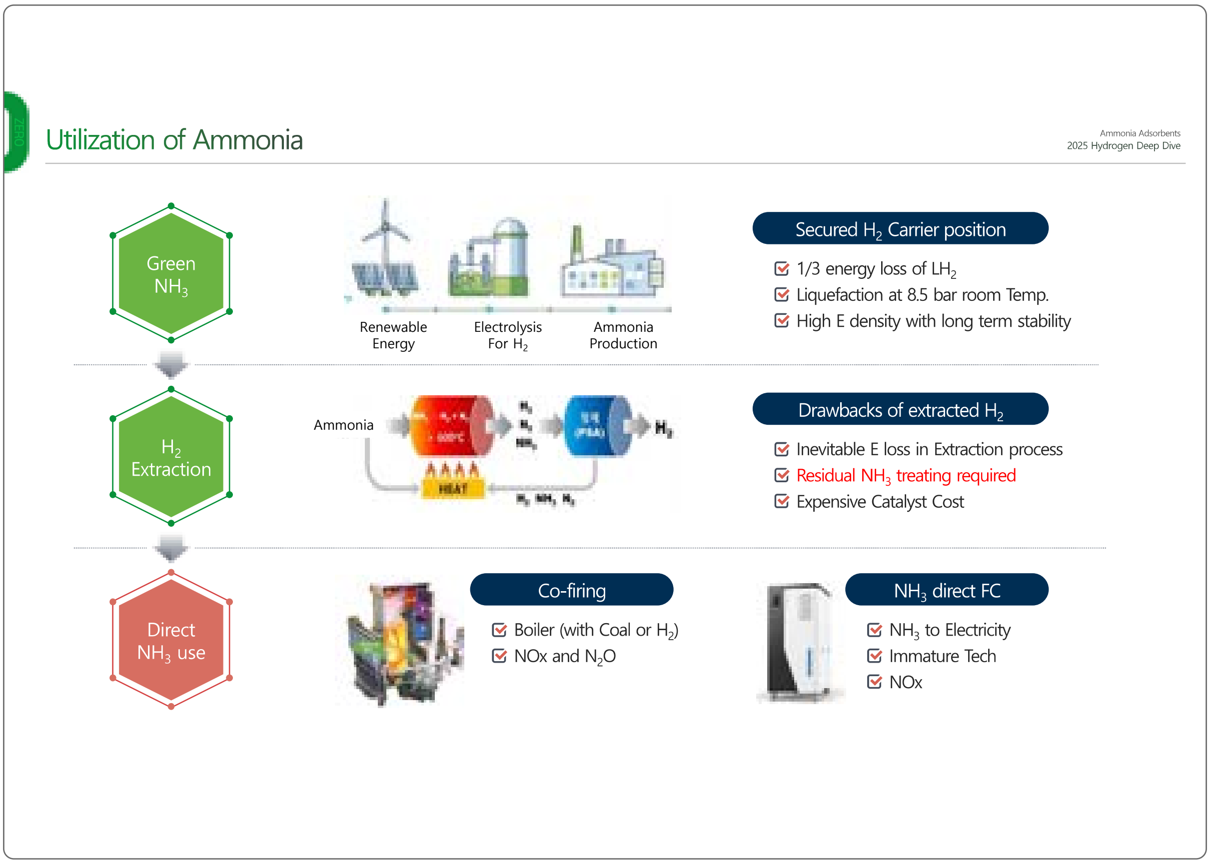
Carbon Neutrality Policy

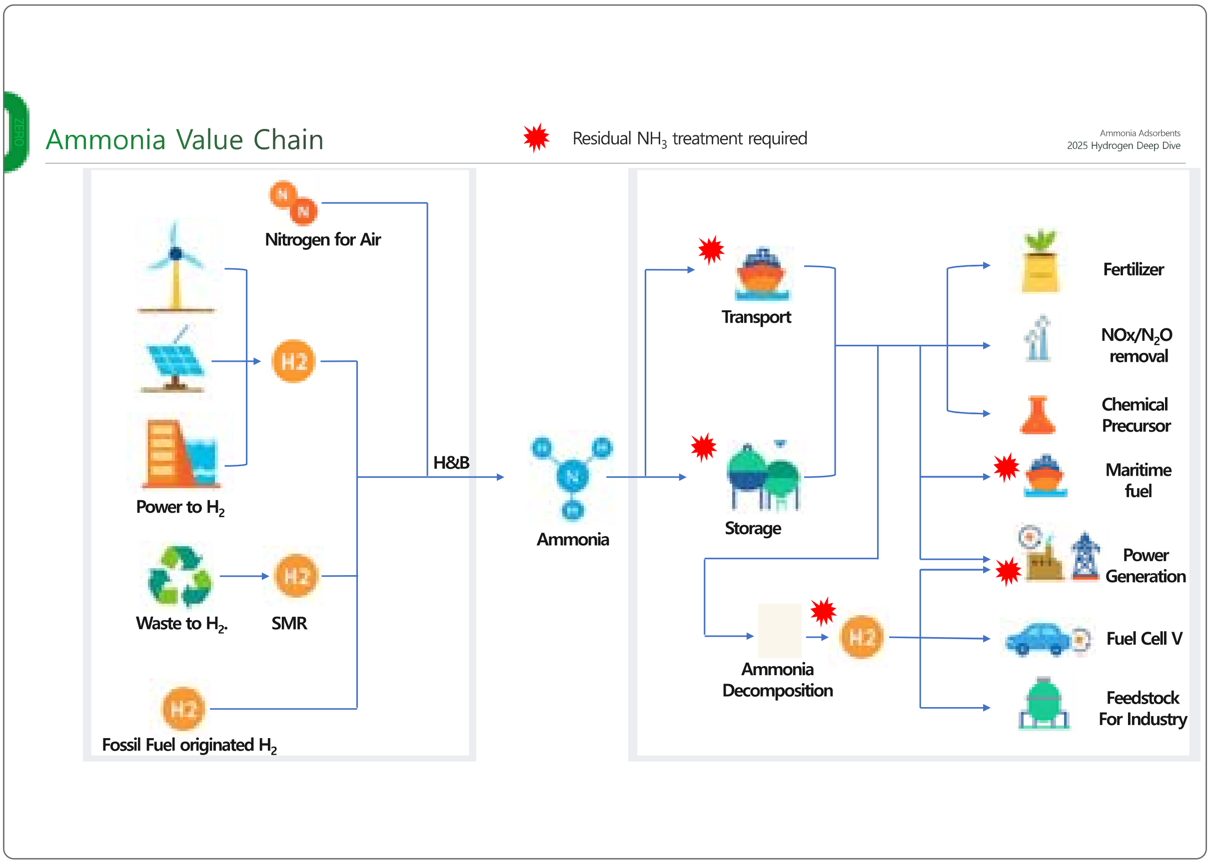
- GB, France, New Zealand (2019, Legislation)
- Sweden (2017, Legislation)
- EU (2020, LEDS)
- Canada (2019, Presidential Statement)
- Korea, Japan (2020, Presidential Statement)

Energy Paradigm Shift

CO_2 Net-Zero Emissions

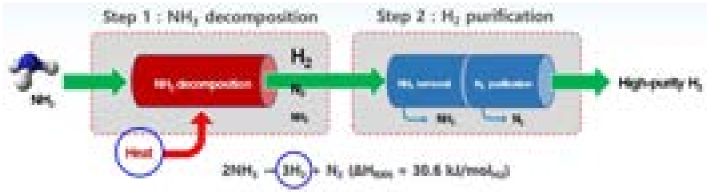
Limits of CCUS techs
↓
Obstacles to Hydrogen Society
↓
Carbon free ammonia based Energy·Mobility re-organization


Utilization of Ammonia
Ammonia Adsorbents
2025 Hydrogen Deep Dive
Green NH3
Renewable Energy
Electrolysis For H2
Ammonia Production
Secured H2 Carrier position
1/3 energy loss of LH2
Liquefaction at 8.5 bar room Temp.
High E density with long term stability
H2 Extraction
Ammonia
HEAT
H2
Drawbacks of extracted H2
Inevitable E loss in Extraction process
Residual NH3 treating required
Expensive Catalyst Cost
Direct NH3 use
Co-firing
Boiler (with Coal or H2)
NOx and N2O
NH3 direct FC
NH3 to Electricity
Immature Tech
NOx


Ammonia Value Chain
Residual NH3 treatment required
Ammonia Adsorbents
2025 Hydrogen Deep Dive
Nitrogen for Air
H2
Power to H2
Waste to H2
SMR
Fossil Fuel originated H2
H&B
Ammonia
Transport
Storage
Ammonia Decomposition
Fertilizer
NOx/N2O removal
Chemical Precursor
Maritime fuel
Power Generation
Fuel Cell V
Feedstock For Industry

Where in needs of NH_3 treatment (On-shore industry)

Ammonia Adsorbents
2025 Hydrogen Deep Dive



Ammonia based hydrogen production process

- ☑ Catalysts development
- ☑ System configuration
- ☑ Ammonia scavenging technology

R&D Activities (Korea)

- ☑ KIST
- ☑ KRICT
- ☑ Wonik Materials
- ☑ Doosan Enerbility
- ☑ Panasia
- ☑ POSCO

R&D Activities (Multinational)

- ☑ Syzygy
- ☑ Starfire
- ☑ H2site
- ☑ Amogy
- ☑ Topsoe
- ☑ Thyssenkrupp Uhde

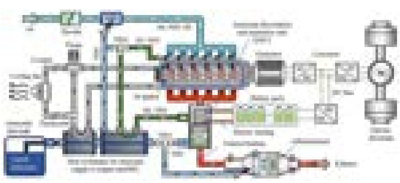
600 ~ 3000 ppm of NH3 in exit stream of decomposition reactor

Where in needs of NH_3 treatment (Maritime use)

Ammonia Adsorbents
2025 Hydrogen Deep Dive

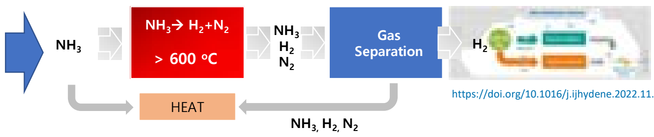
Source:

Ammonia Powered Engine (NH_3 catch system)



https://doi.org/10.1016/j.etran.2023.100288

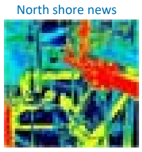
Hydrogen extracted from Ammonia for Fuel cell (Down stream protection)



https://doi.org/10.1016/j.ijhydene.2022.11.157

Ammonia leak in vessels (Safety issue)

North shore news



BS-shipmanagement.com

https://www.reddit.com/r/CatastrophicFailure/

Currently available NH_3 removal techs and trends

Wet Acid Scrubbers

- Types: Spray tower, Packed bed
- High NH_3 removal efficiency, ammonium salt production
- ppm ~ % level NH_3 slip after cracking
- Small scale only, waste water, not suitable for ultra pure H_2

Dry Adsorption / Solid Acid

- Solid **acid-functionalized** adsorbents and NH_3 traps
- Critical for **ultra-high-purity H_2** (PEMFC)
- No moisture/ion contamination
- Not suitable for continuous process (No regeneration)

Ammonia Slip Catalysts (ACS)

- Converts residual NH_3 to N_2 at low temp
- Used in SCR systems with cracking + combustion units
- Only available when SCR already exist
- Complicated and large facilities

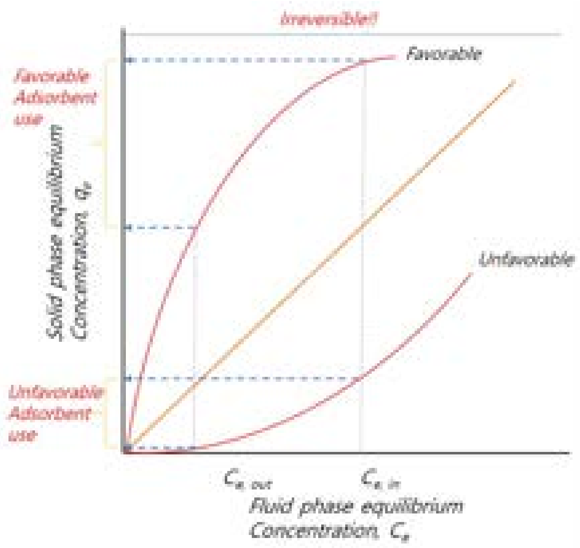
Not sufficient for high purity H_2 production!
(~ 99% max. removal)

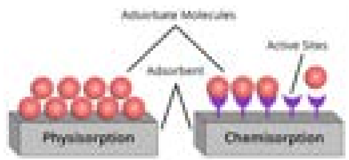
- Scrubing + recovery of NH_3
- Integrated Cracking-Combustion-SCR
- Hybrid Systems for Small Scale Application

Other miscellaneous techs

Reverse Osmosis (Liquid treatment)
Precipitation(Liquid, Fertilizer)
Biological treatment
Photocatalysis

Ammonia adsorbents (Basic concept)



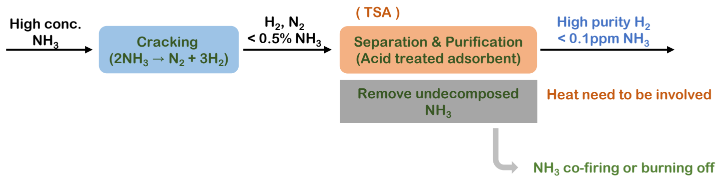


Isotherm characteristics deciding factors

- Surface acidity
- Surface interaction with adsorbate
- Pore shape and size distribution
- Specific surface area

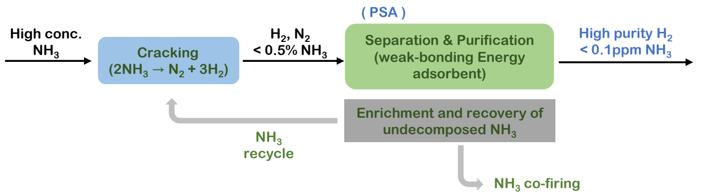
PSA or TSA

Ammonia Adsorbents
2025 Hydrogen Deep Dive



TSA

- ☑ Intermittent operation
- ☑ Utilize heat for regeneration
- ☑ Suitable for safety maintenance (ex. Maritime)
- ☑ Variety of applicable adsorbents



PSA

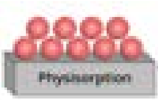
- ☑ Continuous operation
- ☑ Utilize pressure for regeneration
- ☑ Suitable for industrial use (Energy production)
- ☑ Limited adsorbents

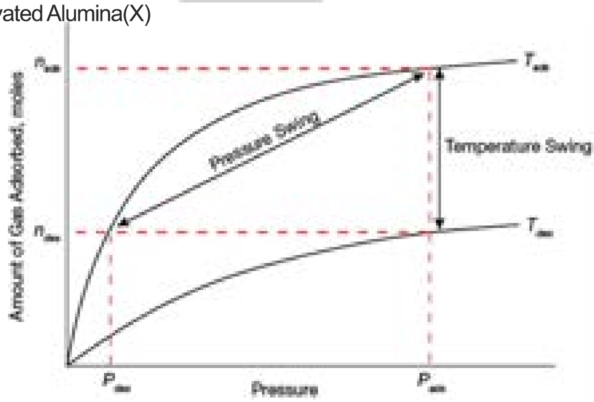
- Ammonia is not suitable for PSA process due to the its strong basic properties. → Controlling degree of interaction?
- If so, PSA can be applied for NH_3 removal and enrichment

Selection of adsorbents

Ammonia Adsorbents
2025 Hydrogen Deep Dive

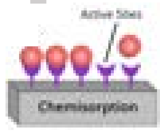
Acidic solid (X)   Zeolite (Δ)
Activated carbon(X)
MOF (Δ)
Silica(X)
Activated Alumina(X)





Controlling surface interaction

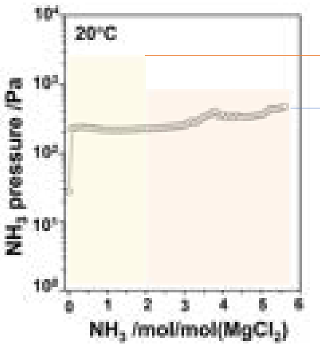
- ☑ Modifying surface functional group
- ☑ Utilizing amine complex formation



Acidic solid (O) – 13X
MOF (?)
Activated Alumina (Δ)

Metal halide vs. NH_3 (Amine Complex Formation for PSA)

P-C isotherm for $MgCl_2$-NH_3 system



1~5mol/mol, 2000~4000ppm
(1/3000 of P_{NH3})

NH$_3$ Fuel Conference 2016
September 18-21, 2016, Los Angeles, CA
(9:05-9:30, September 20, 2016)
Yoshitsugu Kojima
Hiroshima University
Institute for Advanced Materials Research

Amine coordination reaction

$$MgCl_2(s) + NH_3(g) \rightleftharpoons Mg(NH_3)Cl_2(s)$$
$$Mg(NH_3)Cl_2(s) + NH_{3(g)} \rightleftharpoons Mg(NH_3)_2Cl_2(s)$$
$$Mg(NH_3)_2Cl_2(s) + 4NH_{3(g)} \rightleftharpoons Mg(NH_3)_6Cl_2(s)$$

Stepwise and discrete intercalation

Mechanism

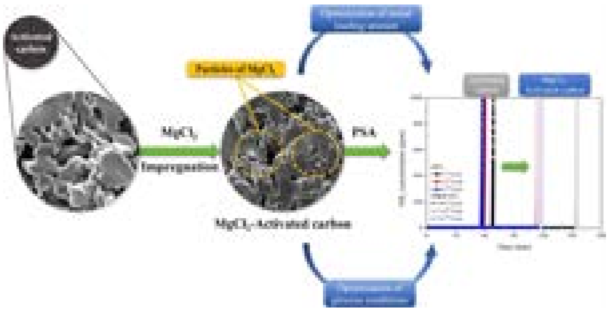
- ☑ P ↑ → μ(NH_3) ↑
- ☑ Void/interlayer expansion -> X- coordination ↓
- ☑ M-(NH_3)x coordination formation
- ☑ ΔHr ~-55 kJ/molNH_3 (physisorption region)

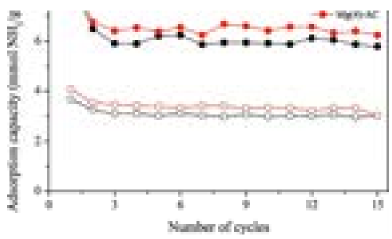
Metal and halide anion can be chosen accordingly based on their electronegativity and its gap.

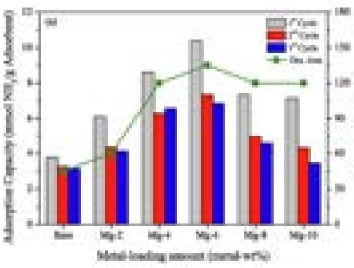
Drawback! → low penetration due to its dense structure.

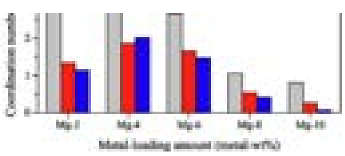
Coating of Metal halides on porous material ?

PSA operation with M-X/AC









< 1 ppm of NH_3 in effluent stream

< 0.1 ppm of NH_3 with guard bed

M.W. Hong et. Al., J. Ind. Eng. Chem, 2023

Metalsilicate for TSA application

Metal Oxide as NH_3 ads.

- ☑ High selectivity
- ☑ Rapid mass transfer
- ☑ Thermal/Chemical stability
- ☑ NH_3 active surface defects
- ☑ Oxygen vacancies for N attraction

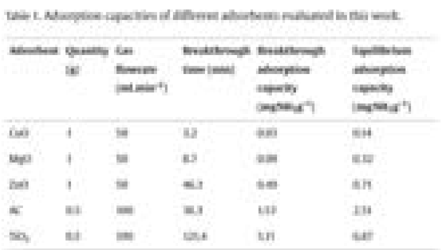


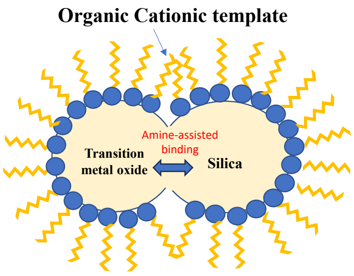
Table 1. Adsorption capacities of different adsorbents evaluated in this work.

Adsorbent	Quantity (g)	Gas flowrate (mL min⁻¹)	Breakthrough time (min)	Breakthrough adsorption capacity (mgNH₃ g⁻¹)	Equilibrium adsorption capacity (mgNH₃ g⁻¹)
CaO	1	50	1.2	0.03	0.14
MgO	1	50	8.7	0.09	0.32
ZnO	1	50	46.2	0.49	0.71
AC	0.1	100	30.3	1.17	2.14
SiO_2	0.1	100	125.4	5.11	6.07

E. Rezaei et. Al., J. Env. Chem. Eng., 2017

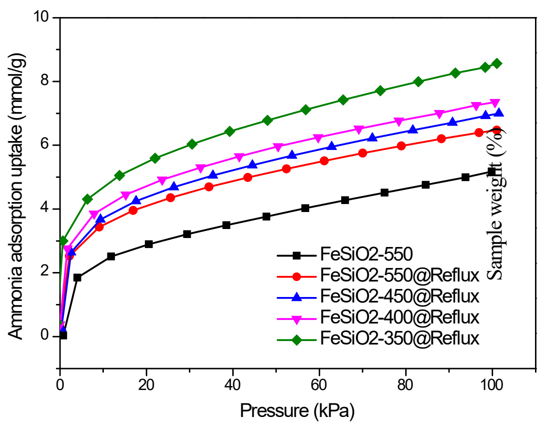
Improving Surface Properties Strategies

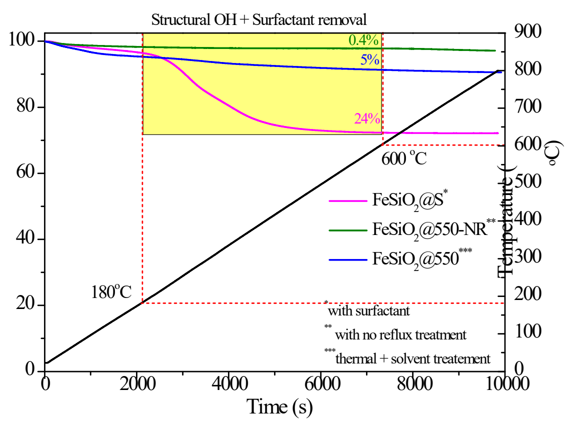
- ☑ Surface area → by applying porous materials
- ☑ Particle size and shapes → by organic templates
- ☑ Surface acidity → Transitional metal hybrid with silica



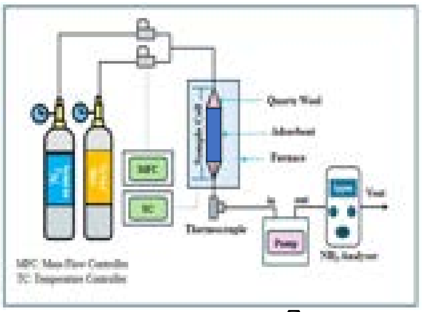
Strategy: Highly porous metal embedded silica with Oxygen vacancy holding surface

Effect of reflux on surface modifaction

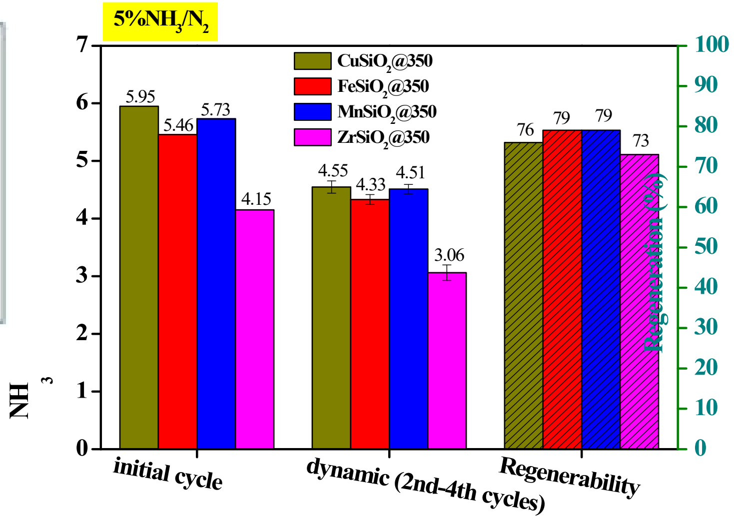




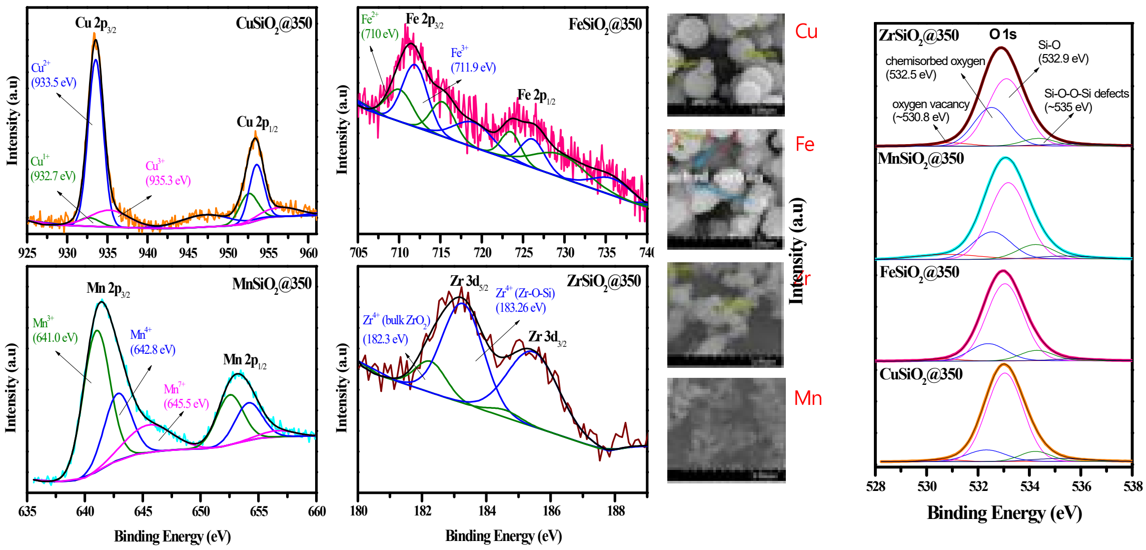
Adsorption capacity of metal silicate in TSA condition



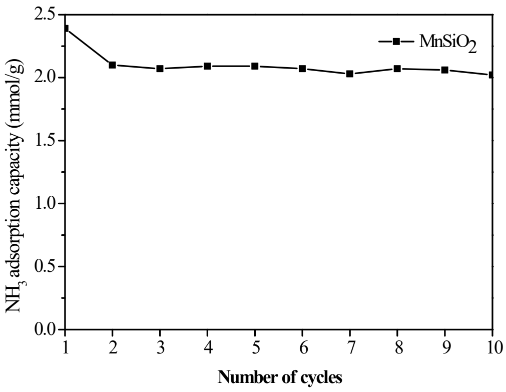
Breakthrough Conditions			
Adsorption		Desorption	
T	P	T (°C)	P
25°C	0 barg	80 (Water bath)	0 barg

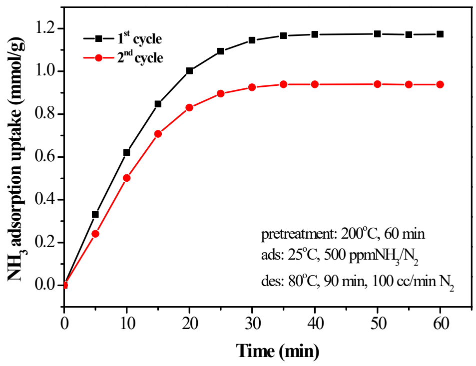


Oxygen vacancies vs. particle size



Low Conc. NH_3 adsorption stability of $MnSiO_2$





Dynamic adsorption (exclusive of 1st cycle) was stable at 96%
Average adsorption capacity of 2.07 mmol/g

Dynamic Adsorption efficiency can be stable at 1-1.2 mmol/g for 500 ppm NH3 adsorption

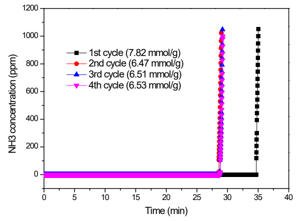
Mass production of NH_3 adsorbents

Ammonia Adsorbents
2025 Hydrogen Deep Dive

Factors for optimization of mass production process

- What kind of binder do we choose?
- What would be the binder content?
- Calcination Temperature?
- Dough making sequence?
- More additive?
- Additive doping sequence?

Every steps need to be checked if we sacrifice too much adsorption capacity



Thank you for your attention.

WORLD HYDROGEN 6th EXPO 2025 Conference

Panel Discussion

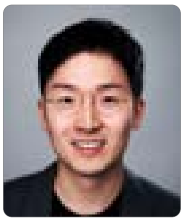
Technological and Economic Challenges for Clean Ammonia Utilization

Moderator

KwangBok Yi
Professor, Chungnam National University

Panelists

Alexander Oliver Bower
Global Head of Marketing & Sales,
Gentari Hydrogen Sdn Bhd



SeongHoon Woo
CEO, Amogy

HoKi Lee
Vice President, Samsung Heavy Industries

Colin Loubser
CEO, Hive Energy Africa

KwangJun Kim
Senior Executive Director, Saman Corporation

Hydrogen Deep Dive V：

Hydrogen：Future to TECH

Breakthroughs in Hydrogen Production Techniques

Breakthroughs in Hydrogen Production Techniques 1

From Waste to Value: CCUS & Sustainable Hydrogen Pathways for Industrial Decarbonization

Marat Mayan
Founder & CEO, Airovation Technologies

Education
- 2002 B.A., Business Administration & Human Resource Management, Ben-Gurion University
- 2011 M.A., Government & Counter-Terrorism, Reichman University – Lauder School of Government
- Graduate Studies in Political Science & Security Studies, Hebrew University of Jerusalem
- Senior Command & Leadership Training, in collaboration with Israeli Defense Forces

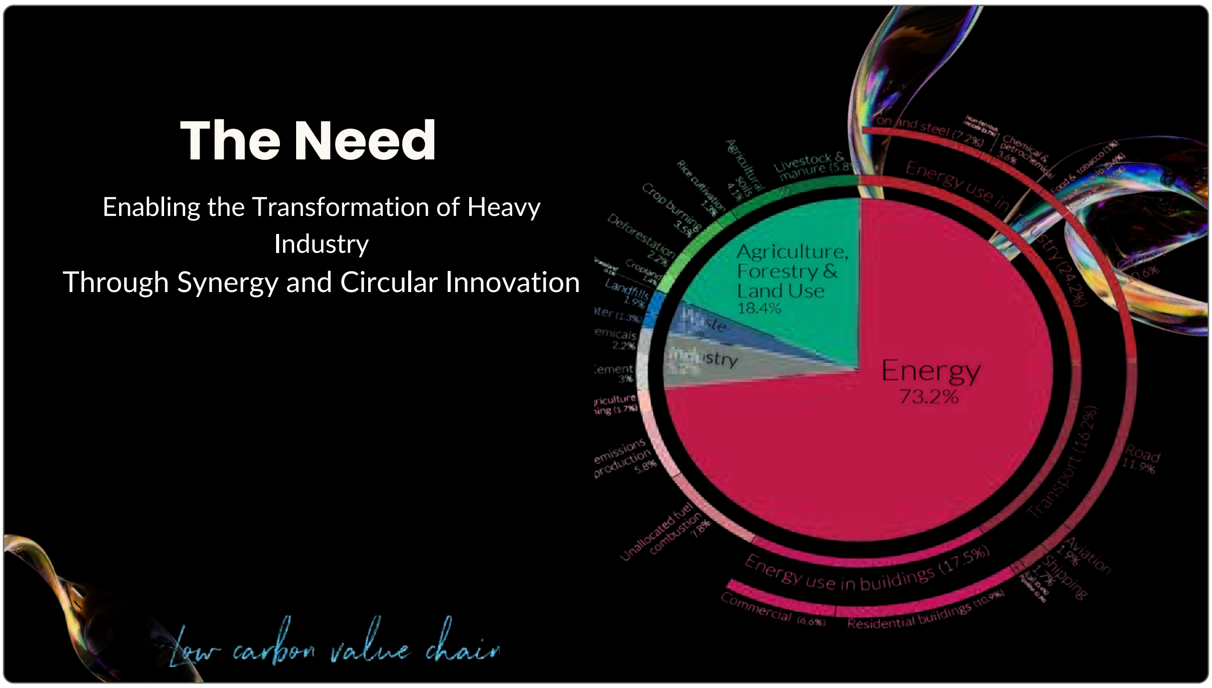
Professional Career
- 2017–Present: Founder & CEO, Airovation Technologies & Airosphera – Leading disruptive CCUS & hydrogen innovation; partnerships across Israel, Japan, Korea, India, Saudi Arabia, Europe.
- Multiple grants from Israel Innovation Authority; Winner, Beijing Cleantech Competition (2021); Winner, ASPER Prize (2025).
- 2013–2016: Founder & CEO, Salamandra-Zone – Fire evacuation technologies for high-rise buildings.
- 1987–2013: Lieutenant Colonel, Israel Ministry of Defense & IDF – Established Israel's first CBRN battalion; directed counter-terrorism and engineering units.

Research Interest
- CCUS and hydrogen innovation
- Circular economy & cross-sector industrial synergies
- Industrial decarbonization pathways & hydrogen economy strategies
- Climate tech scale-up & commercialization

Speech Summary
Airovation's award-winning CCUS platform transforms CO_2, Phosphogypsum, and industrial gypsum into profitable low-carbon products and affordable green hydrogen. By enabling powerful cross-sector synergies, it delivers both economic feasibility and environmental impact, supporting industries from fertilizers to cement and SAF.

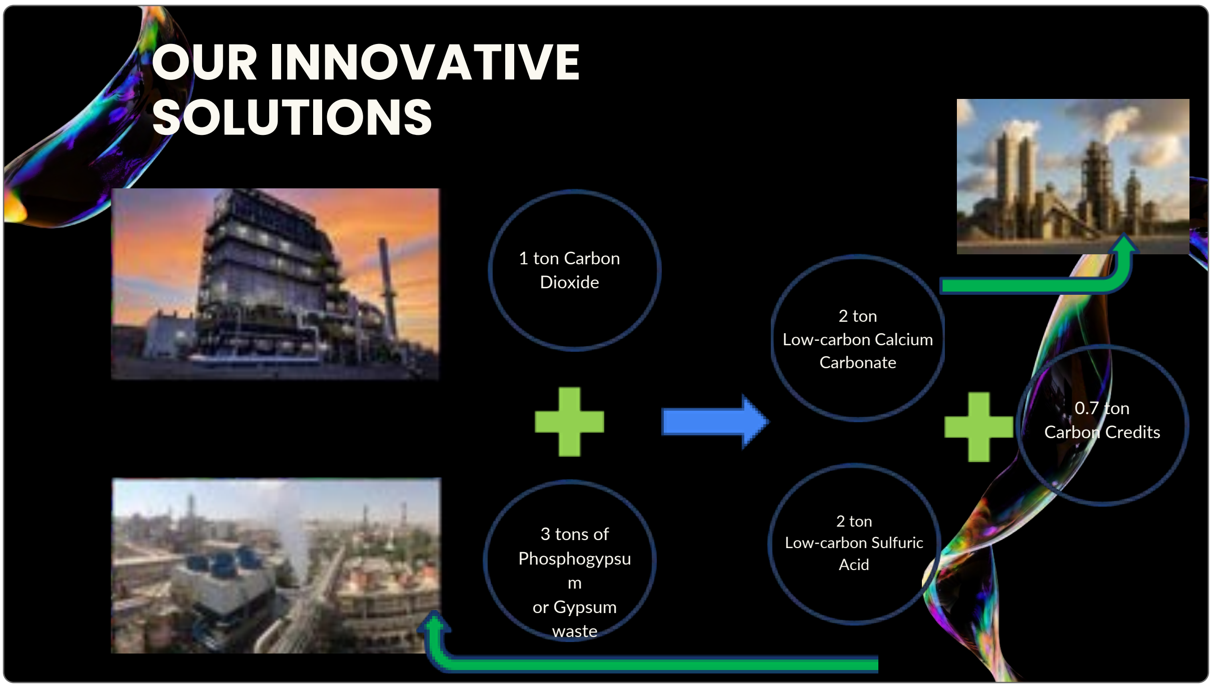
Company Introduction
Airovation Technologies is a global climate-tech innovator transforming CO_2 and industrial waste into valuable low-carbon products. Supported by the Israel Innovation Authority and international partners, Airovation drives decarbonization in fertilizer, metals, cement, and hydrogen sectors.
Brief Introduction of Company (≤100 characters):
Airovation: Award-winning CCUS & hydrogen solutions turning CO_2 and waste into low-carbon value.

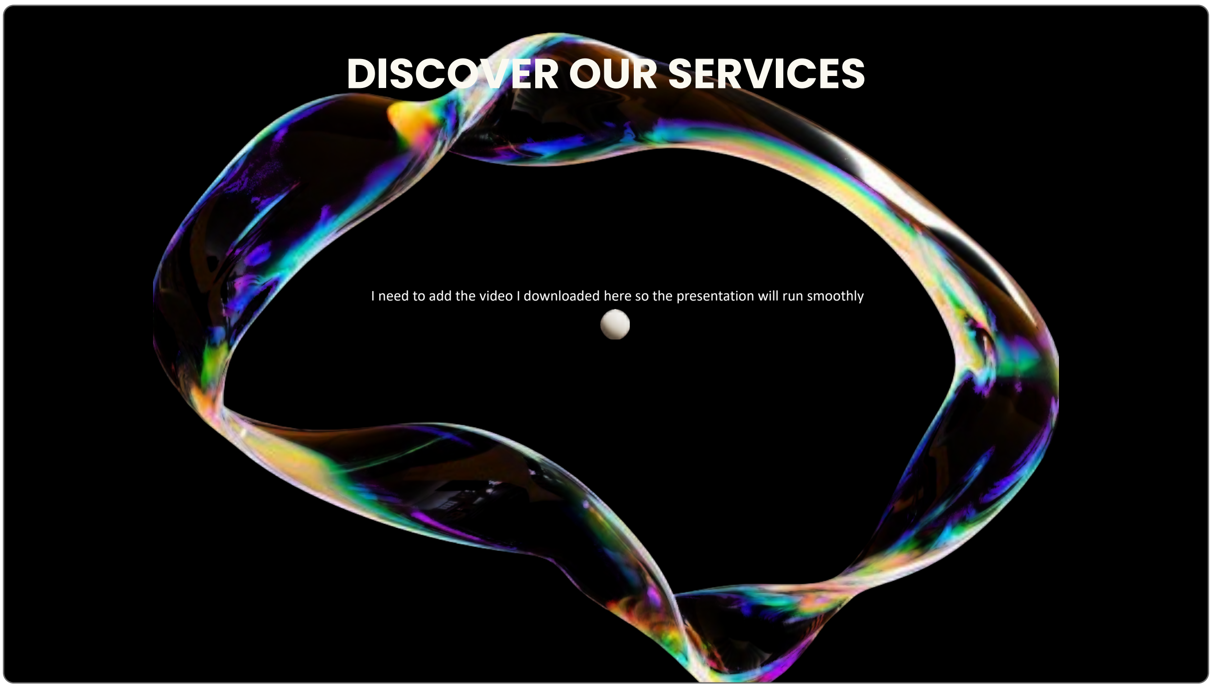

Low carbon value chain
airovation technologies
Presenting - Marat Maayan
www.airovation-tech.com
marat@airovation-tech.com
3 Horeg St Modi'in Israel


The Need
Enabling the Transformation of Heavy Industry
Through Synergy and Circular Innovation
Agriculture, Forestry & Land Use
18.4%
Energy
73.2%
Energy use in buildings (17.5%)
Transport (16.2%)
Road
11.9%
Low carbon value chain

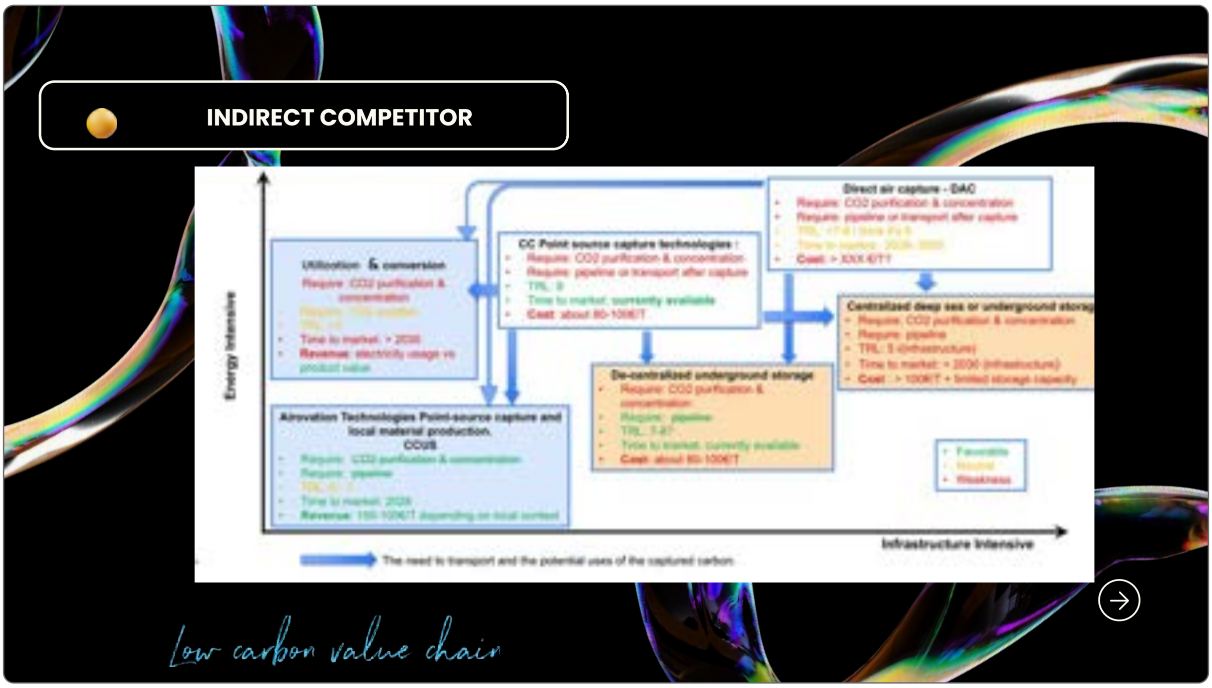

INTRODUCTION
Airovation enables low-carbon, cost-competitive hydrogen production through a breakthrough CO_2-mineralization process, creating the conditions for rapid industrial adoption and scalable market demand of Hydrogen .
Low carbon value chain

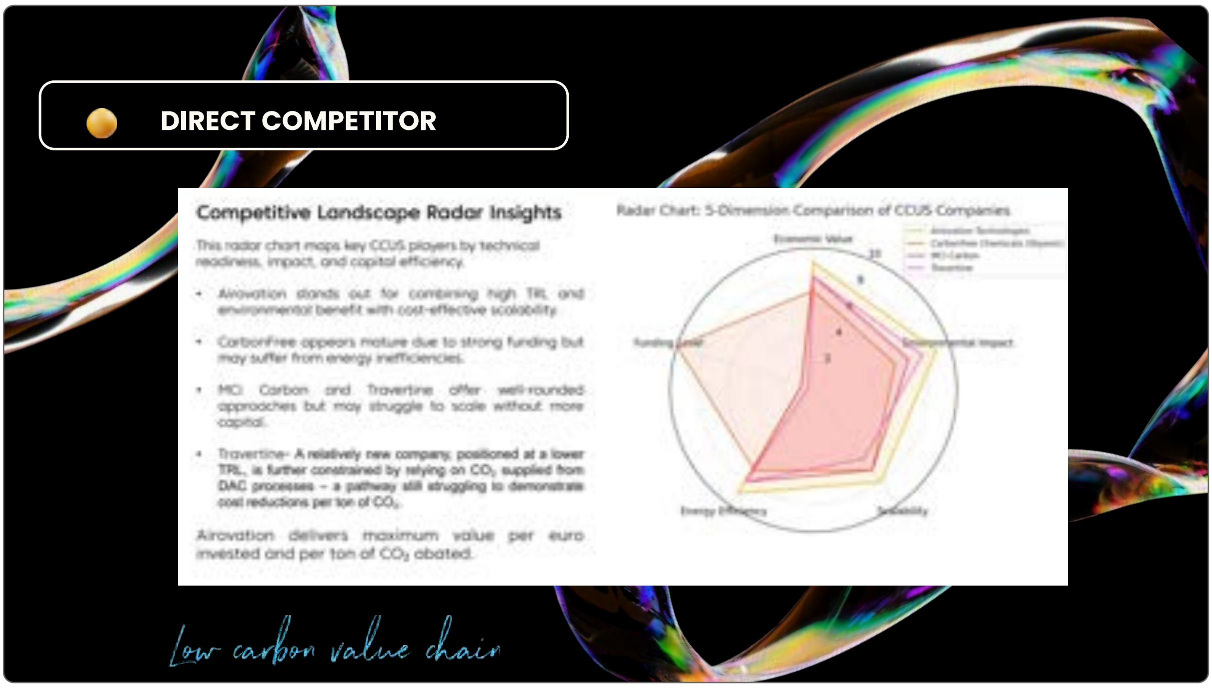

Grey Hydrogen
Global Annual CO_2 By-Product Emissions
1.2 B Tons
PROBLEM STATEMENT
Green hydrogen remains priced at levels that significantly limit broad commercial adoption. Despite its environmental benefits, the high production and infrastructure costs continue to slow market uptake across most industrial sectors.
Low carbon value chain


OUR INNOVATIVE SOLUTIONS
1 ton Carbon Dioxide
3 tons of Phosphogypsum or Gypsum waste
2 ton Low-carbon Calcium Carbonate
2 ton Low-carbon Sulfuric Acid
0.7 ton Carbon Credits

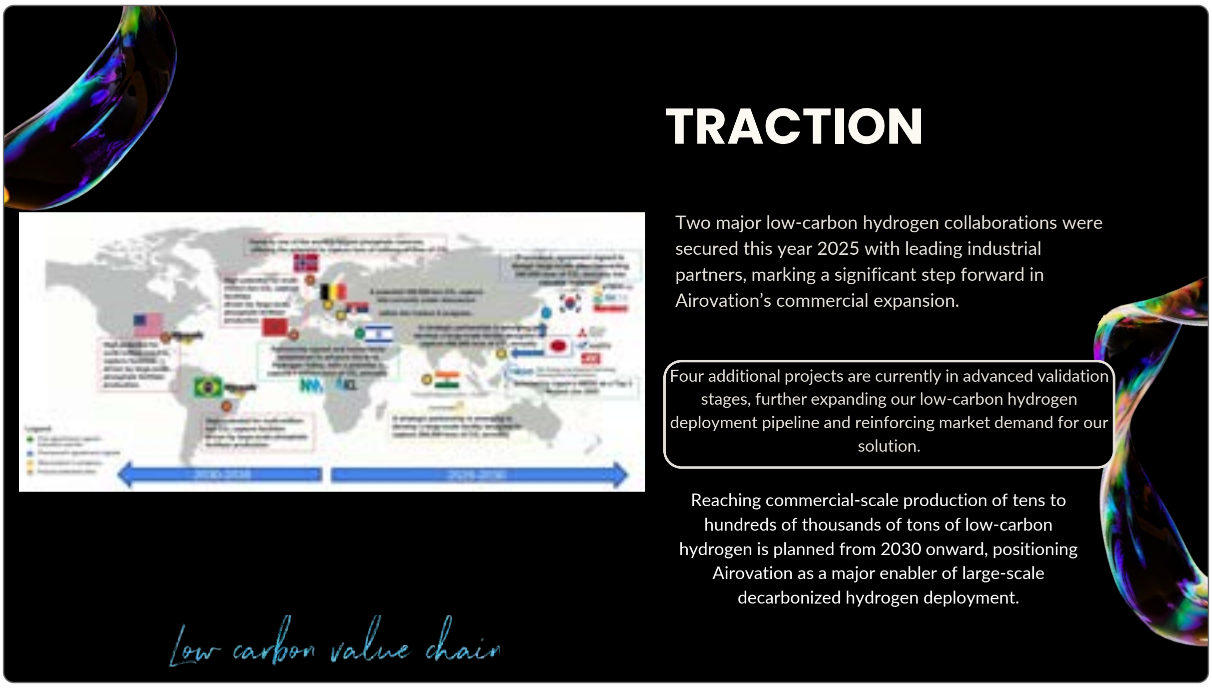

DISCOVER OUR SERVICES
I need to add the video I downloaded here so the presentation will run smoothly


SIZE OF MARKET
Understanding the market potential is essential for Airovation. Across our target geographies, hard-to-abate industriesת, including fertilizer, steel, chemicals, energy, and waste management, represent a multi-billion-dollar opportunity for large-scale CCUS and low-carbon material solutions. Within these sectors, we estimate that over 30% of facilities face immediate regulatory and economic pressure to decarbonize, translating into thousands of potential industrial sites suitable for our CO_2-mineralization technology. Capturing even 5% of this addressable market positions Airovation for significant commercial scale, supporting a clear and strategic pathway for growth.
Serviceable Obtainable Market: 150 M$
Serviceable Addressable Market: 45Bn $
Total Addressable Market: 135Bn $
low carbon value chain


INDIRECT COMPETITOR
Direct air capture - DAC
CC Point source capture technologies
Utilization & conversion
Centralized deep sea or underground storag
De-centralized underground storage
Airovation Technologies Point-source capture and local material production. CCUS
Energy Intensive
Infrastructure Intensive
low carbon value chain


DIRECT COMPETITOR
Competitive Landscape Radar Insights
This radar chart maps key CCUS players by technical readiness, impact, and capital efficiency.
• Airovation stands out for combining high TRL and environmental benefit with cost-effective scalability.
• CarbonFree appears mature due to strong funding but may suffer from energy inefficiencies.
• MCi Carbon and Travertine offer well-rounded approaches but may struggle to scale without more capital.
• Travertine- A relatively new company, positioned at a lower TRL, is further constrained by relying on CO2 supplied from DAC processes – a pathway still struggling to demonstrate cost reductions per ton of CO2.
Airovation delivers maximum value per euro invested and per ton of CO2 abated.
Radar Chart: 5-Dimension Comparison of CCUS Companies
Economic Value
Environmental Impact
Scalability
Energy Efficiency
Funding Level
Low carbon value chain


KEY COMPETITIVE ADVANTAGES
2027-2030
ICL
airovation technologies
Fertilizer Plant
3 mt/y Phosphogypsum
Low Carbon Sulfuric Acid
Phospho-gypsum
CCUS
CO2
SMR
100kt/y H2 = 1Mt/y CO2
Low Carbon Hydrogen
H2
Blue Hydrogen
100 kt/y H2
$400M
2 M/T/Y Low Carbon sulfuric acid $140M
2.1 M/T/Y Low Carbon Calcium carbonate $60M
Total $600M
Low carbon value chain


TRACTION
Two major low-carbon hydrogen collaborations were secured this year 2025 with leading industrial partners, marking a significant step forward in Airovation's commercial expansion.
Four additional projects are currently in advanced validation stages, further expanding our low-carbon hydrogen deployment pipeline and reinforcing market demand for our solution.
Reaching commercial-scale production of tens to hundreds of thousands of tons of low-carbon hydrogen is planned from 2030 onward, positioning Airovation as a major enabler of large-scale decarbonized hydrogen deployment.
Low carbon value chain


Low carbon value chain
THANK YOU
for your time and attention
Presented by Marat Maayan
www.airovation-tech.com
marat@airovation-tech.com
3 Horeg St. Modi'in Israel

Breakthroughs in Hydrogen Production Techniques 2

Project Helios - Cement Production Decarbonisation through Green Hydrogen

Robert Saunders
Managing Director, Elecseed

Education
Bachelor of Engineering (Hons) – Energy Engineering 1992-1996
London South Bank University (United Kingdom)
Circular Economy and Sustainability Strategies 2022
University of Cambridge

Professional Career
Managing Director (2022 – present)
Elecseed Pty Ltd (Australia)
Director (2025 – present)
Elecseed Lab (Korea)
Board Member – Australian Korean Chamber of Commerce, AustCham, (2025 – present)
(Korea)
WSP Calibre (2017 – 2022)
General Manager Renewables
(Australia)
BG Group (2016 - 2017)
General Manager Building Services and Renewables
(Australia)
WSP Opus (2012 - 2015)
National Building Sector Leader
(Australia)
Ashburner Francis (2008 – 2011)
Chief Operating Officer
(Australia)
Saunders Specialised Services Ltd
Managing Director
(United Kingdom)

Research Interest
Green Hydrogen Production and Wastewater treatment enabling the delivery of the UN sustainable development goals – 2020
Bi-Facial Photovoltaics and the Albedo Effect Research Project – Queensland University of Technology, Australia, 2023

Speech Summary
300 Word Version
Due to Korea's physical nature and climate, its ability to produce green hydrogen is limited within its own shores. Korea has therefore turned its attention in seeking to invest internationally in the production of Green Hydrogen with friendly nations who do have the natural resources and skills available, such as Australia.
Cement manufacturing accounts for 8 % of global carbon emissions a year, mostly through the heating of limestone to create the main ingredient, called clinker. Australia consumes about 12 million tonnes of cementitious products annually, with around half of this imported.
Project Helios is located in South Australia in partnership with the Korean Government and local partners and aims to produce green cement through the use of the redundant fly ash from a coal fired power station. This involves drying the flyash via large scale ovens which traditionally would occur via fossil fuels like Natural Gas/ However, in the case of Project Helios, the drying process uses Green Hydrogen produced via Korean Electrolysis technology and investment adjacent to the facility.
This decarbonised cement will be used locally in construction, roads and mining and could create a new export industry for South Australia to nations such as Korea.
The project is supported by the South Australian Government who are signatories to a Statement of Cooperation signed in 2023 between Elecseed, Korea Hydro Nuclear Power and Hallett Group and aims to reduce Australia's total carbon dioxide emissions by 1% annually through the generation and use of green hydrogen.
The speech will focus on the journey so far and how Australia and Korea have collaborated on this globally intriguing project, the use of Korean technology and project programme.

300 Character Version
Cement accounts for 8 % of global carbon emissions a year, through a heating process. Project Helios is in partnership with the Korean Government and produces green cement through the use of redundant fly ash from a coal fired power station. The flyash moisture is removed by drying with Green Hydrogen using Korean Technology.

Company Introduction
Elecseed is a progressive Renewable Energy Developer and Consultancy providing innovation, technical eminence, funding, and multifaceted solutions to deal with the paradigm shift in how we generate, manage, and consume energy.
With offices in Seoul Korea and Brisbane and Adelaide in Australia, Elecseed identifies and leads specific market needs, not only to propel our drive to a greener future but also satisfy the immediate economic needs and demands. We have experience across the Asia Pacific in bringing the right partners to develop solutions across renewables including Photovoltaics, Wind, Hydrogen and Battery Storage technology, leveraging off strategic financial and engineering expertise.

Presenting today / 발표자

Robert Saunders | 로버트 손더스

B.Eng (Hons) Energy Engineering
London South Bank University
United Kingdom

Managing Director Elecseed | 일렉시드 호주법인장

Brisbane Australia
robert.saunders@elecseed.io

Presentation Index

- Elecseed
- Climate Change
- Supply and Demand
- Elecseed Masterplan
- Project Helios
- Scale up and Export

elecseed

Welcome to Elecseed

We are living in a significant time as nations and companies decarbonise their assets to meet aligned global targets and provide for a cleaner future.

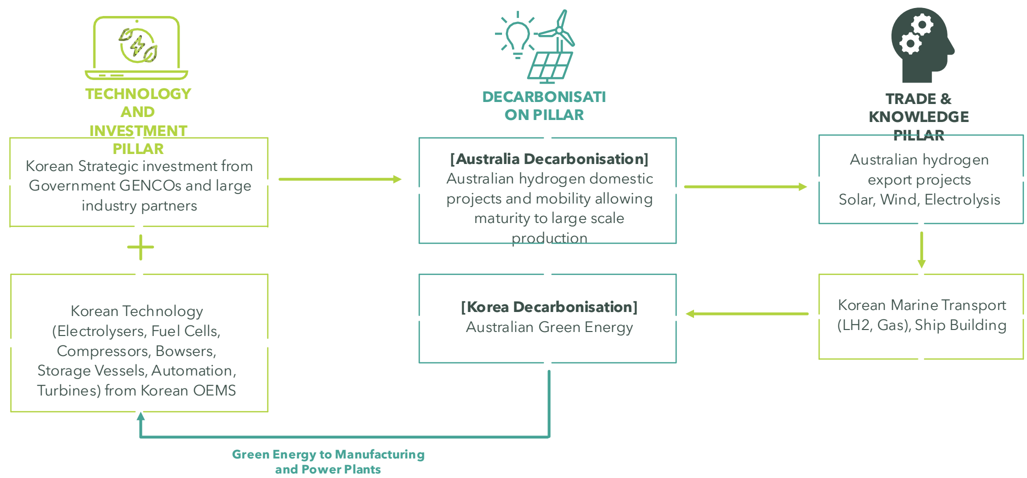
Elecseed is a progressive Renewable Energy Developer and Consultancy providing innovation, technical eminence, funding, and multifaceted solutions to deal with the paradigm shift in how we generate, manage, and consume energy.

With offices in Seoul Korea and Brisbane Australia, Elecseed identifies and leads specific market needs, not only to propel our drive to a greener future but also satisfy the immediate economic needs and demands.

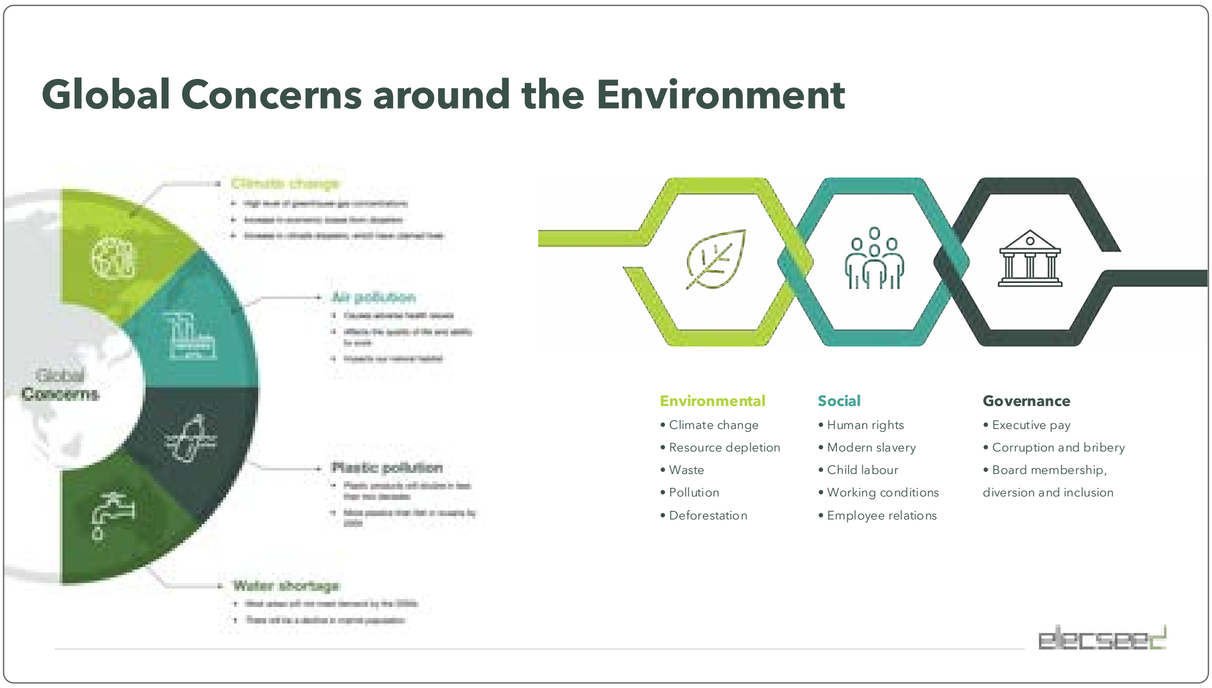
We have experience across the Asia Pacific in bringing the right partners to develop solutions across renewables including Photovoltaics, Wind, Hydrogen and Battery Storage technology, leveraging off strategic financial and engineering expertise.

Join us in our tenacious journey to a more sustainable and responsible world, driving the future of renewable energy solutions.

The “Closed Loop” between our nations – A Unique Mutual Opportunity




Climate Change
Let's Remind Ourselves
elecseed


Global Concerns around the Environment
Climate change
Air pollution
Plastic pollution
Water shortage
Global Concerns
Environmental
• Climate change
• Resource depletion
• Waste
• Pollution
• Deforestation
Social
• Human rights
• Modern slavery
• Child labour
• Working conditions
• Employee relations
Governance
• Executive pay
• Corruption and bribery
• Board membership, diversion and inclusion
elecseed

You cannot ignore the Science

Greenhouse gas increase: Atmospheric concentrations of major greenhouse gases like carbon dioxide and methane are at their highest levels in at least two million years, largely due to human activities.

Observed warming: Global temperatures and sea surface temperatures have clearly risen since the 1800s. This warming is happening faster than at any point in recorded history.

Rising sea levels: Global mean sea levels are continuing to rise at an accelerating rate.

Ocean acidification: Oceans are becoming more acidic as they absorb excess carbon dioxide, which poses risks to marine life.

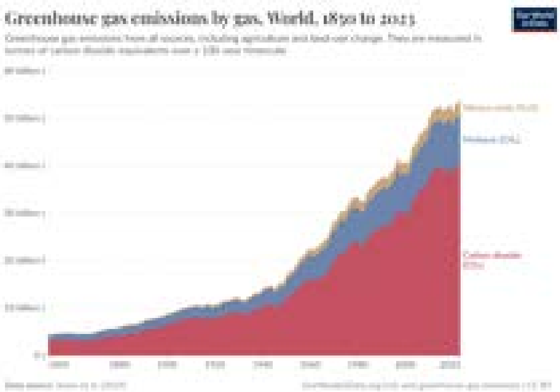
Extreme weather: The frequency and intensity of some extreme weather events are increasing. This includes more extreme heat events on land and in oceans, longer fire seasons, and decreased snow cover in alpine regions.

Glacial Melting: Melting glaciers are a significant consequence of human-caused climate change, primarily due to rising temperatures from greenhouse gas emissions

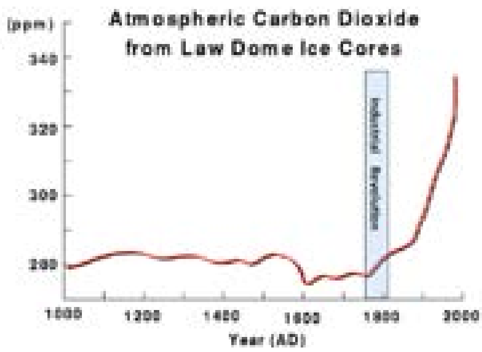
"Climate Change is destroying our path to sustainability. Ours is a World of looming challenges and increasingly limited resources. Sustainable development offers the best chance to adjust out course"

Bank Ki-moon
8th Secretary-General of the United Nations from 2007 to 2016

Climate Change and the Industrial Revolution



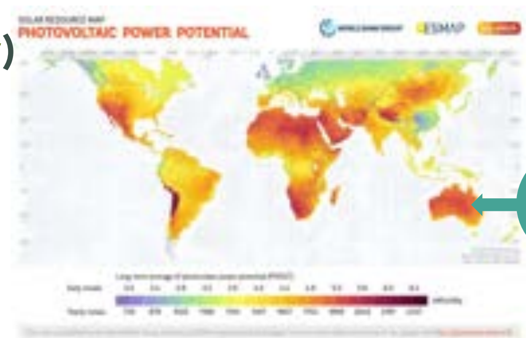
Human attribution: Human activities are responsible for virtually all the global heating over the last 200 years, with the burning of fossil fuels being the largest contributor.



Concentration of Carbon Dioxide from trapped air measurements for the DE08 ice core near the summit of Law Dome, Antarctica. (Data measured by CSIRO Division of Atmospheric Research from ice cores supplied by Australian Antarctic Division)

Australia – (The Supply)

- Global Demand for Green Hydrogen expected to increase rapidly as nations decarbonise.
- The Transformation to Hydrogen cannot occur without a stable green energy market and supply
- In the Southern Hemisphere, in particular Australia, that will be primarily through photovoltaics (solar)
- Australia with its land space, existing skills in the gas sector, port infrastructure and sunshine, is well placed to be a "**Food Bowl**" for Green Hydrogen production.
- Abundance of Critical Minerals



One of the Highest Irradiance in the World

Lots of land space

elecseed

Australia – A Green Energy "Super-Power"

Six Forms of Renewable Energy are easily supported in Australia

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The Republic of Korea – (The Demand)

- Enviable Manufacturing Capabilities
- Increasing Energy Requirements
- Globally Leading Technology
- Worldwide Investment Appetite

Source : International Energy Agency (IEA)

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The Republic of Korea – Green Hydrogen and Ammonia Demand

□ **Source : The 11th Basic Plan for Electricity Supply and Demand (Draft)**

Classification	Year of 2030	Year of 2038
Power Generation (Proportion)	15.5TWh(2.4%)	38.5TWh(2.4%)
Hydrogen and Ammonia Demand (Quantity Converted to Ammonia)	6,650 Thousand. tons	16,520 Thousand. tons

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Negativity

- CQH2 - Queensland
- Trafigura – South Australia
- Origin Energy Hunter Valley
- AGL Torrens Island Hydrogen Hub
- Woodside
- Gibson Island

Developers dump Gladstone's Central Queensland Hydrogen Project CQH2

By Jasmine Hines | ABC Capricornia | Hydrogen Fuel

Mon 30 Jun

Energy giant Origin retreats from flagship green hydrogen project as hopes for fuel fade

By energy reporter Daniel Mercer

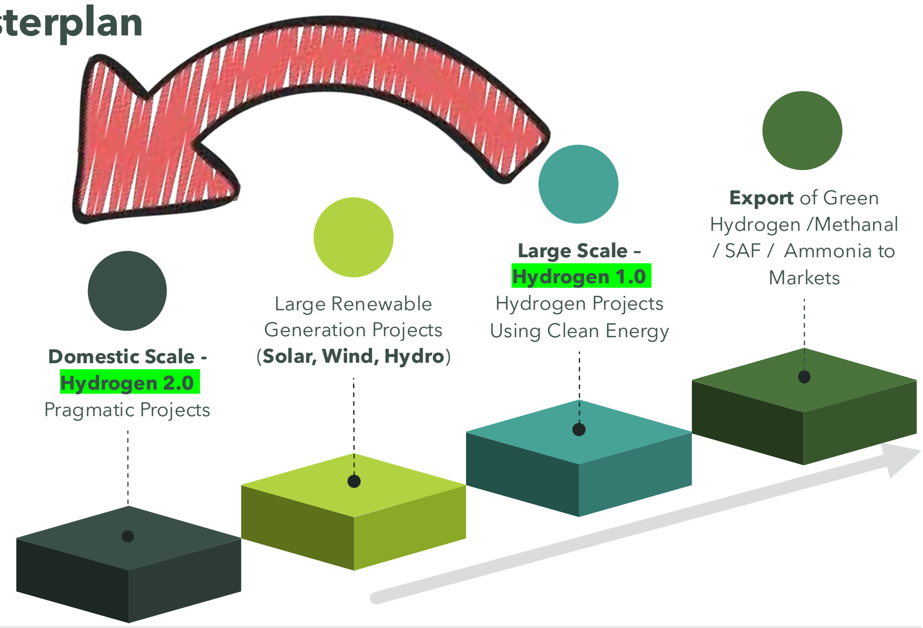
Energy Industry

Thu 3 Oct

Several Large Scale Failed Projects – All Export Focused

elecseed

Masterplan



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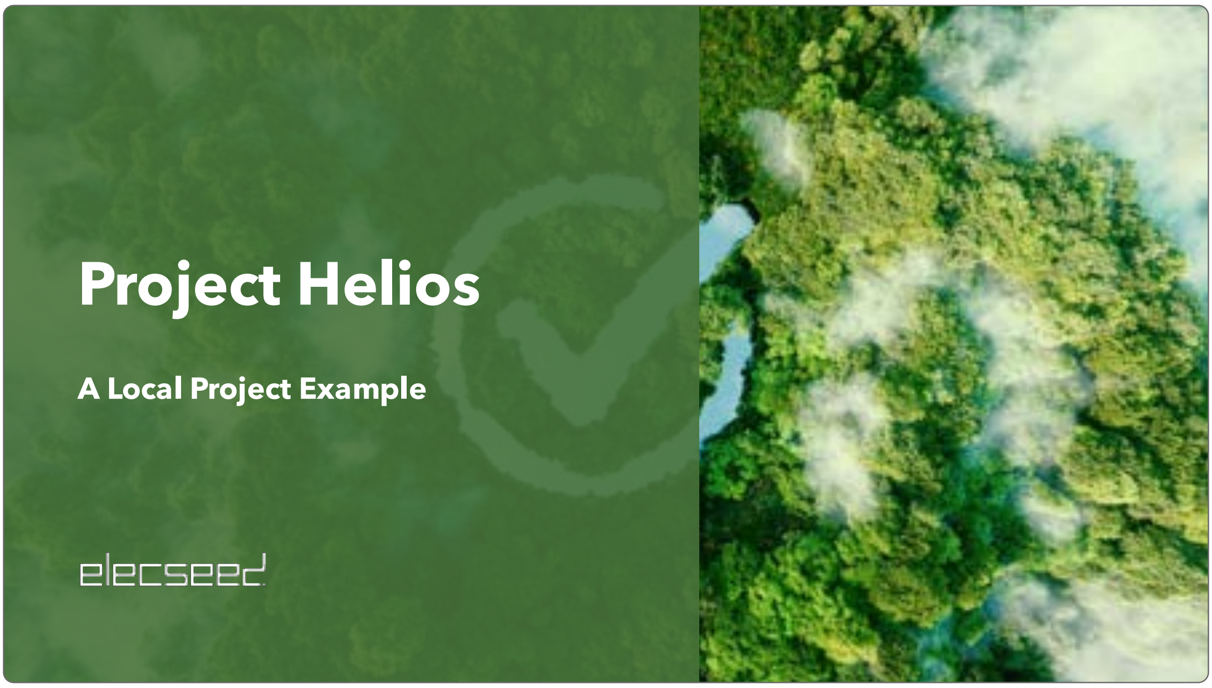

Project Helios - Korea & Australia Collaboration

Elecseed
Developer & Investor (Australian-Korean Business)

Hallett Group
Hydrogen Off-Taker (Australian Business)

Korea Hydro & Nuclear Power
Strategic Investor (Korean Government GENCO)

South Australia Government
Permitting, Support, Grant (Australian State Government)

- Cement Drying Process
- Green Hydrogen made on site
- Korean Technology and Strategic Investment
- Global First

Project Helios – A Cement Industry Project

- **In 2021**, world-wide emissions from making cement produced about **2.9 Billion metric tonnes of CO2**. For perspective, if the cement industry was a country, it would be **the fourth largest national emitter in the world**, behind China, the US and India (Source : CSIRO)
- Global Demand for concrete and cement is predicted to grow **12 to 23 %** above todays levels by 2050 (Source : Scientific America) – although in Korea has declined in 2025 due to a construction recession
- **Coal Fired Power Stations are being closed** around the World and **leaving layers of flyash**, used as a **feedstock for supplementary cementitious materials (SCM)**
- **Australia currently consumes around 12 million tons per annum** of cement with around half of this imported in the form of finished (powdered) cement or cement clinker.
- The Helios project will use existing and proven technology to manufacture supplementary cementitious materials (SCMs) that can **replace greater than 50% of traditional high CO_2 emitting** clinker-based cement.

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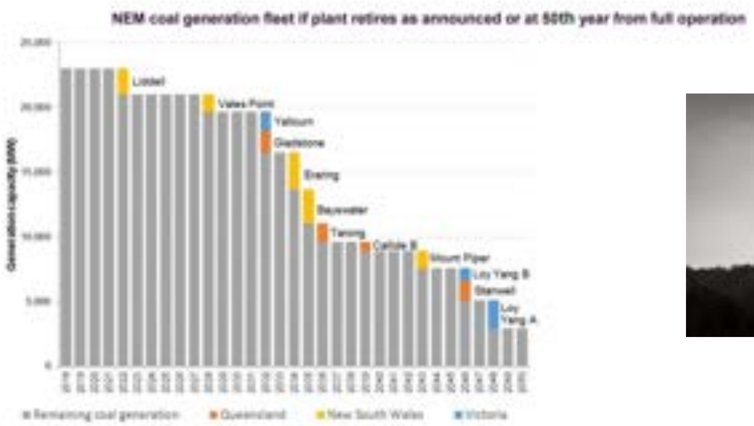
Australian Coal Fired Power Station Closure - Flyash



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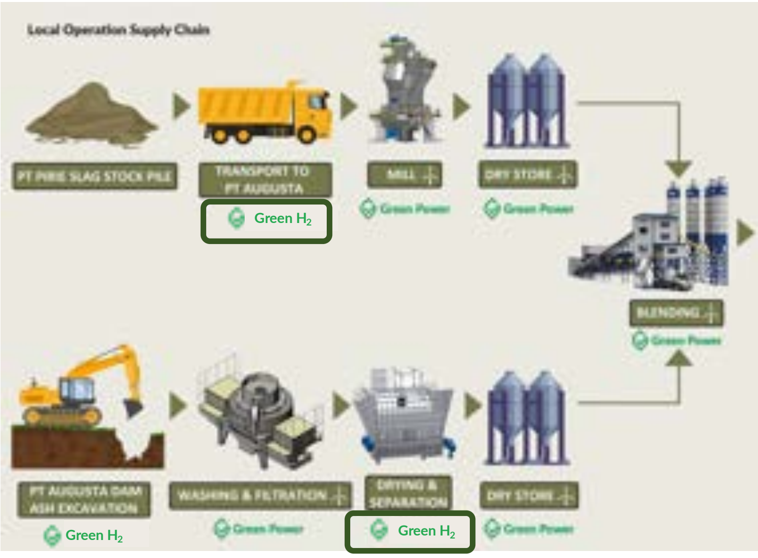
Project Helios Site – 40 Years Supply of Flyash

Circular Economy

Approximately 22 to 5% Moisture through a Drying Process

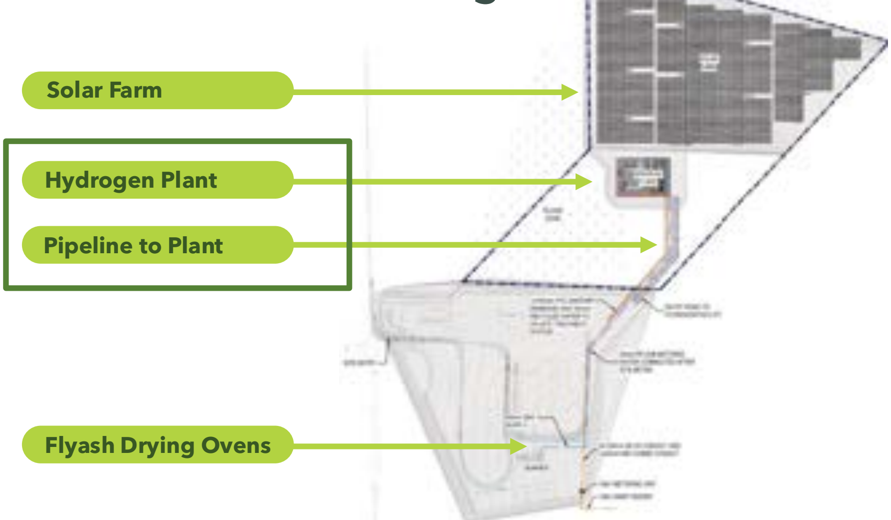
Overall Project Flow



Rail

H_2 &/or Electric Truck

Project Helios – General Arrangement



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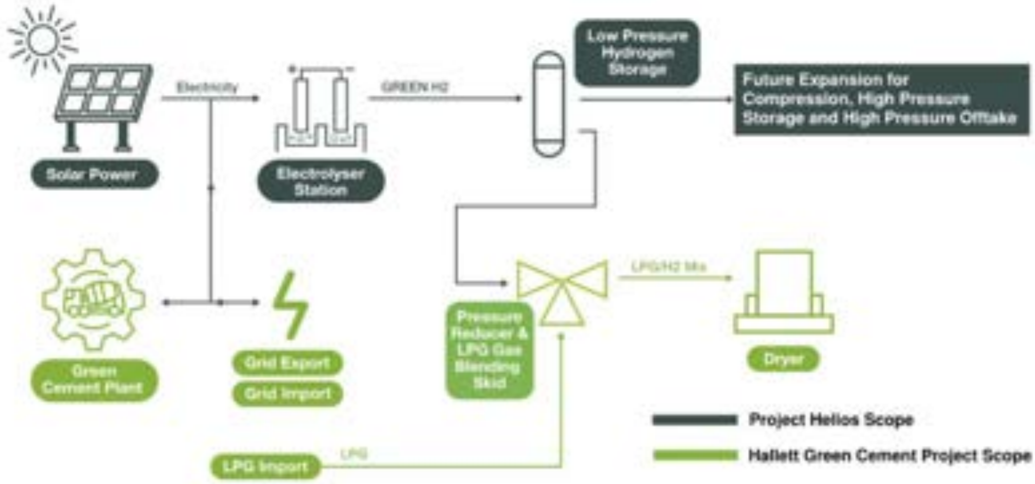
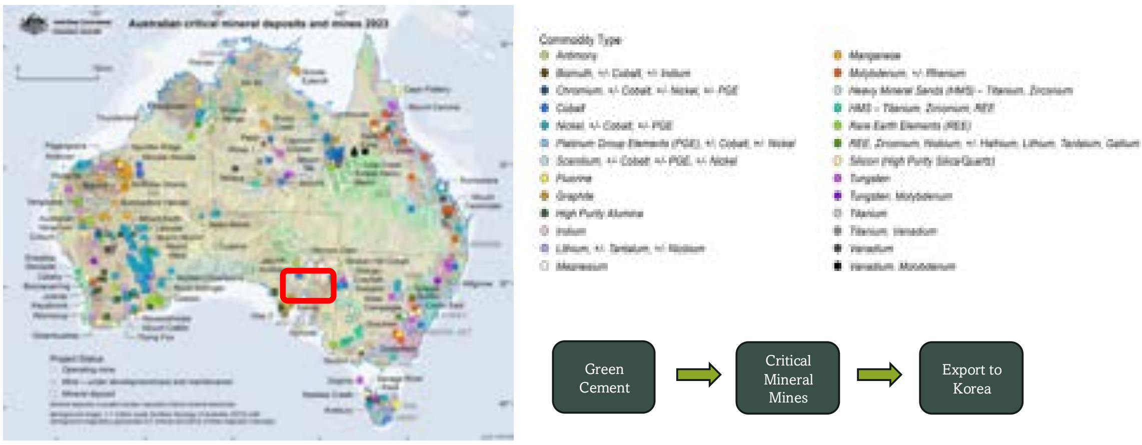
Blend – then scale up

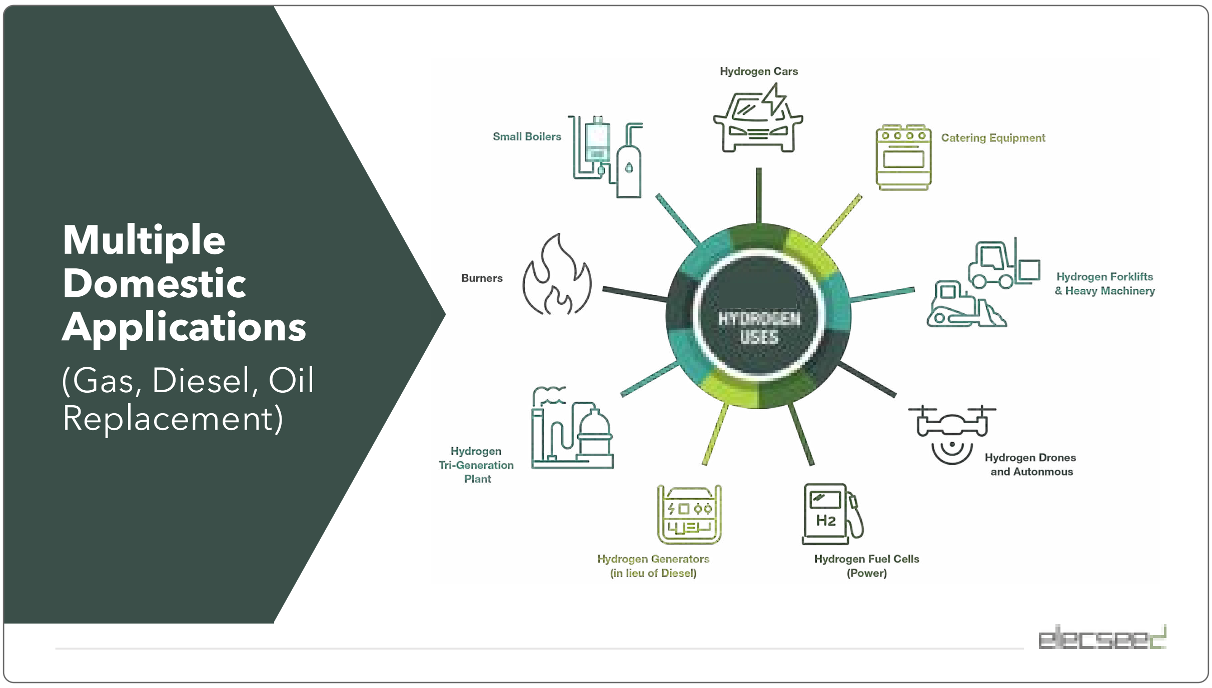


elecseed

South Australia – a Critical Minerals Super Hub

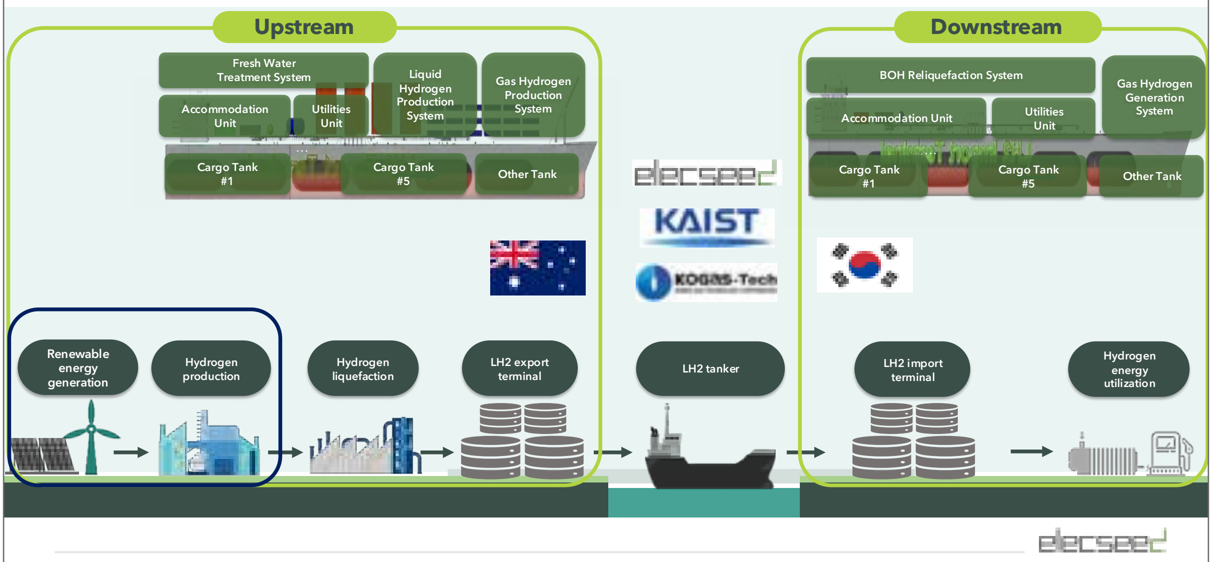


elecseed

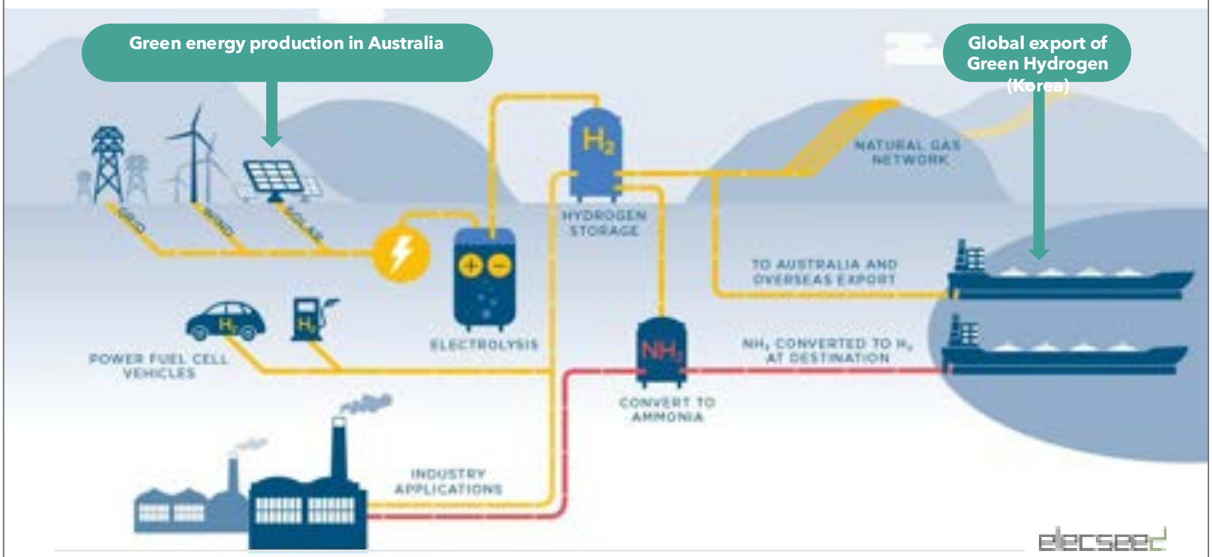

Multiple Domestic Applications
(Gas, Diesel, Oil Replacement)
HYDROGEN USES
Hydrogen Cars
Small Boilers
Catering Equipment
Burners
Hydrogen Forklifts & Heavy Machinery
Hydrogen Tri-Generation Plant
Hydrogen Drones and Autonmous
Hydrogen Generators (in lieu of Diesel)
Hydrogen Fuel Cells (Power)
H2
elecseed


Scale up and Export
elecseed

Logistics - KETEP National Study (에너지기술평가원 지원과제)



Green Hydrogen – Export, The Big Picture



Adjacent to Deep Sea Port Location

elecseed

elecseed

Thank you
감사합니다

Driving future energy

Catalyzed heat exchanger for fuel processing

Amin Mehdipoor
Business Development Manager, Catator AB

Education
2011-2008, M.S., Innovative & Sustainable Chemical Engineering, Chalmers University of Technology, Gothenburg, Sweden
2007-2002, B.S., Chemical Engineering, Amin Kabir University of Technology, Tehran, Iran

Professional Career
2025 – now, Business Development Manager, Catator AB, Sweden
2025-2021, Technical Sales Manager, Grolman Group, Sweden
2021-2020, Business Development Manager, Iris.ai
2020-2018, Algol Chemicals, Sweden
2018-2015, Johnson Matthey, Sweden
2015-2014, Nordic Sugar, Denmark
2014-2013, Encubator AB, Sweden
2008-2006, Tam Irankhodro, Iran

Speech Summary
Showcasing Catator's advanced catalyzed heat exchanger for efficient catalytic fuel processing, and our catalytic burner series for off gas combustion—delivering compact and robust hydrogen solutions for next-gen energy systems

Company Introduction
Catator develops advanced catalytic solutions for efficient, clean hydrogen energy systems.

Content

2

Catator

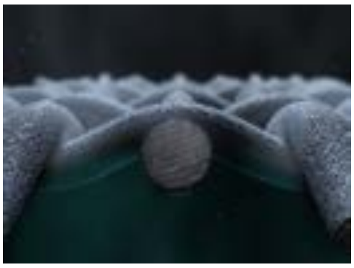
Catator in brief

World-leading contract development partner for commercialization of hydrogen

- Based in Lund, Sweden and at the forefront of hydrogen-related catalysis for three decades.
- Based on the CataLite Coating technology and innovative designs for reactors, reformers, and burners, we deliver catalyzed hardware to industry leaders.
- We deliver solutions for Electrolyzer & Fuel Cell Manufacturers, Syngas & E-fuel production, and Fuel Reforming & Processing.

3

Integrated Catalyzed Hardware



CataLite® Coatings

Structured catalysis

Patented multi-stage technology enabling the application of catalysts to virtually any metal surface, ensuring strong adhesion of a highly porous and active catalytic layer, enhancing heat and mass transfer and enabling smaller catalyst volumes and reactor sizes.

Contract Development Services

Unmatched application expertise

More than 30 years of in-house application experience, design expertise and track record as a development partner to leading hydrogen technology pioneers.

Hardware

Integrated solutions

From design, construction, prototyping, and manufacturing, we serve as an integral part of the customers' supply chain to deliver ground-breaking Reactors, Reformers, Burners, and Fuel Processing Systems.

4

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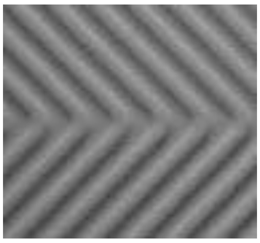
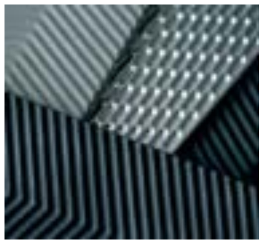
Technology platforms



CataLite® Synreactors
Reactor cells reimagined
Compact reactors for decentralized, small-scale production of e-fuel.

CataLite® Reformers
Thermally integrated fuel reforming
Efficient reformers for conversion of e-fuels to hydrogen or other reformates.

CataLite® Burners
Compact combustion. Zero emissions.
Catalytic burners for combustion in P2X and X2P applications.



CataLite® Systems
Efficient e-fuel processing systems
Complete systems for processing of e-fuels and their off-gases.

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Content

6

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CataLite® Coatings

Unprecedented levels of performance and design freedom

The CataLite® technology enables a highly adhesive, nano-porous, and structured Catalytic layer that can directly integrated with advanced reactors, reformers and burners.

Benefits

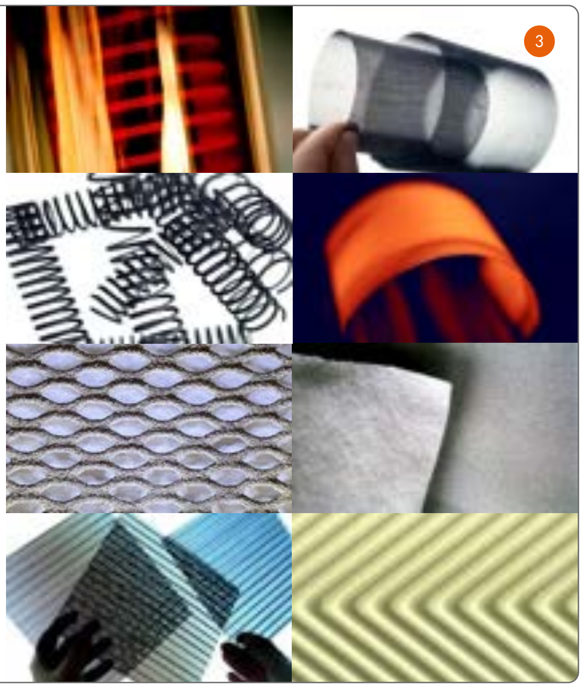
Reduced reactor size. Up to 80% size reduction compared to conventional catalysts due to higher mass and transfer capacity

Enhanced efficiency. Reduced thermal losses due to compact reactor geometry and integrated process solutions

Long-lasting performance. Unmatched thermo-mechanical durability and heat conductivity, extending system lifespan and ensuring uniform conversion

Limitless scalability and design freedom. Ability to dimension to any capacity requirement. Higher performance through tailoring of geometrical structure for each application.

7



Coating Stability

Thermal Cycling CataLite® Plates

Catalyst specification

Plate material: AISI 310

Catalyst comp.: Stabilized Platina on γ-Al_2O_3

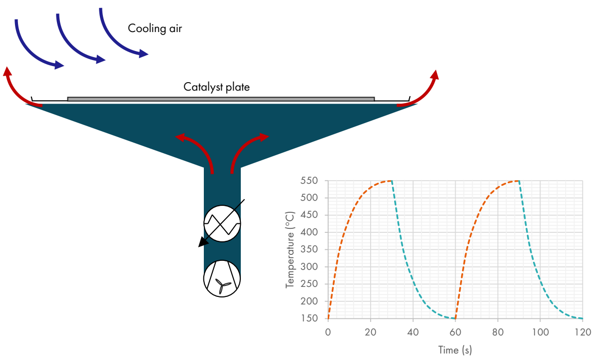
Test method

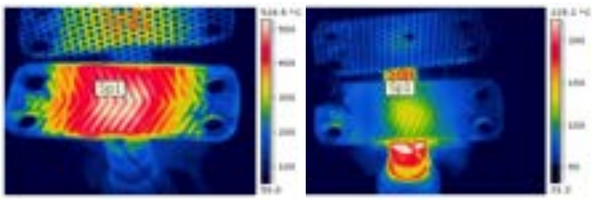
Continuous temperature cycling between 150 and 550°C

Conditions: 1020 cycles of 60 s each

Conclusions

Catalyst coating highly stable, weight loss of catalyst < 1 wt%





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Coating Stability

Wire mesh vs metal monolith substrate

Catalyst specification

Mesh material:	High temperature ferritic stainless steel EN 1.4767
Wire diameter:	0.5 mm
Mesh opening:	1.3 mm
Catalyst comp.:	Stabilized Platina on γ-Al_2O_3

Test method

Catalyst heated in oven at 1000°C for 24 h followed by ultrasonic treatment of catalyst in room temperature.

Conclusions

Commercial automotive metal monolith catalyst shows approx. 6 times higher weight loss than the wire mesh CataLite® catalyst

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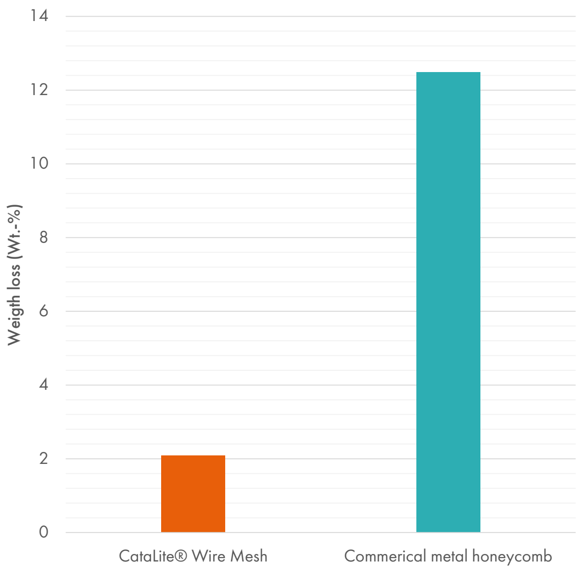

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Catalyst Performance

Case example Natural Gas combustion: Long-term performance at elevated temperatures

Catalyst specification

Mesh material:	High temperature ferritic stainless steel EN 1.4767
Catalyst comp.:	Stabilized Platina on CeO_2/γ-Al_2O_3

Test method

Combustion of natural gas over a CataLite® burner for 10,000 h

Estimated operating temperature between 800-1000°C

Conclusions

Very stable emission levels over the entire test period. Expected life above 20,000 h on stream.

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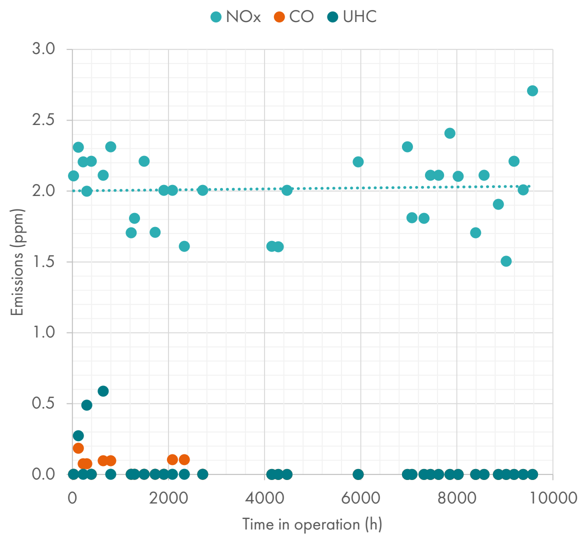

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Content

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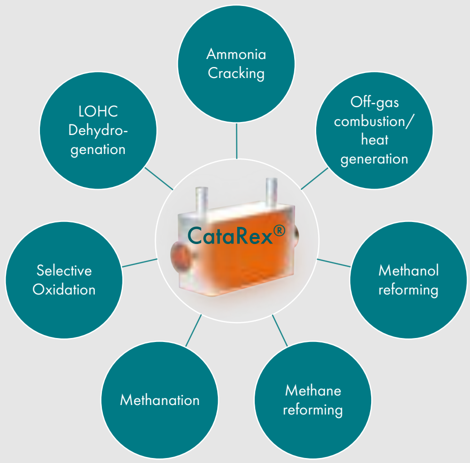
CataRex® Reactor technology

For production and reforming of electro-fuels

- Catalyzed Heat Exchange Reactor
- Integrates catalytic reactions and heat exchange to produce heat, synthesize, or reform e-fuels.
- Shell-and-tube or shell-and-plate heat exchangers with CataLite® coating on one or both sides of the tubes or plates
- CataRex® allows for the integration and close thermal coupling of exothermal and endothermal reaction into a single system, enabling process intensification and space savings.



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CataLite® Reformers

Case Example: CataRex Ammonia Cracker

- Ammonia Fuel Processing Unit with integrated Thermal Processing to produce hydrogen for an SOFC
- Based on the CataRex® technology

Shell-and-plate or tubular design

Shell-and-plate design

- Very compact solution optimal for low pressure operation i.e. a few bars
- Extremely high heat transfer capacity
- Pressure drop control on both sides through dimension of gap between plates

Tubular design

- Very robust solution optimal for operation at elevated pressures
- Tube in tube principle - combustion in the centre tube and reforming over coated mesh-type of catalysts placed in the outer tube

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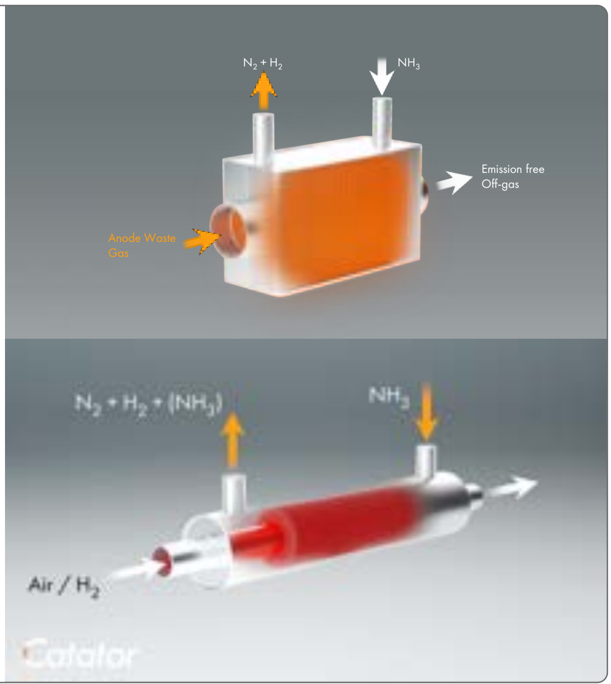

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CataLite® Burners

Case Example: Off-gas Burner for Electrolyzer

- **Hydrogen Production:** H2 emissions during upstart and transient conditions
- **Syngas production:** CO emissions during upstart and transient conditions

Case Example: Anode Off-gas Burner for Fuel Cells

- Catalytic combustion of Anode off-gas

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catator.com

WORLD HYDROGEN 6th EXPO 2025 Conference

Breakthroughs in Hydrogen Production Techniques 4

Precision hydrogen flow measurement in SOFC and SOEC applications

Peter Brouwer

Market Developer Renewable Energy,
Bronkhorst High-Tech B.V.

Education

1997 - 2000, M.S., Electrical and Electronic Engineering, Twente University, Enschede, The Netherlands
1994 – 1997, B.S., Electrical and Electronic Engineering, Hanzehogeschool, Groningen, The Netherlands

Professional Career

2025-Present, Head of Product Management and Market Development, Bronkhorst High-Tech B.V., The Netherlands
2023-2025, Market Developer Renewable Energy, Bronkhorst High-Tech B.V., The Netherlands
2023-Present, Board Member NWBA (Dutch Hydrogen and Fuel Cell Association), The Netherlands
2014-2023, Manager Education and Research, HAN University of Applied Sciences, School OF Engineering & Automotive, Arnhem, The Netherlands
2001-2014, Senior Engineer and Team Leader R&D, Bronkhorst High-Tech B.V, The Netherlands

Research Interest

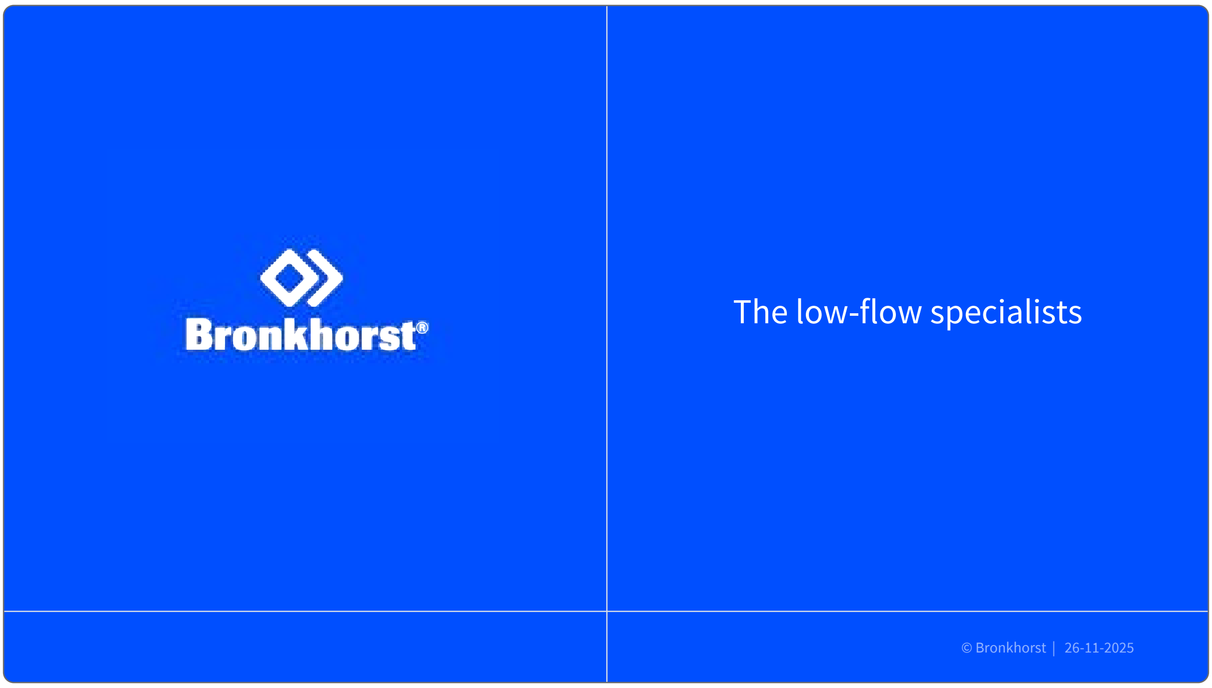
Neutral-color Transparent Solar Cells for Smart Window
Optically Enhanced Flexible Crystalline Silicon Solar Cells
Hybrid Energy Conversion and Storage Devices
Joule-heating based Solar Steam for Water Purification and Desalination

Speech Summary

Solid Oxide FC/EC technology is very promising for stationary hydrogen application, mainly because of its high efficiency compared to PEM or alkaline technology. It is no surprise that there is increasing focus on this technology.
However, high temperatures, water vapor and sensitive system components makes hydrogen flow measurement and control challenging in these systems. Bronkhorst offers flow measurement solutions with advanced functionality, specifically designed to adapt to these demanding applications. Additionally, our flow meters can be calibrated in a circulation rig with hydrogen, eliminating the need for surrogate gas and ensuring the lowest measurement uncertainties.
We invite you to join our presentation to learn more about these innovative solutions and how they can benefit your applications. Don't miss this opportunity to gain valuable insights and ask any questions you may have.

Company Introduction

We are the low-flow specialists.
We offer the most extensive range of low-flow (mass) flow meters and controllers on the market. From standard models to tailor-made solutions, our instruments are designed to meet the demands of laboratories, machinery, industrial applications, and even hazardous environments—ensuring precision and reliability in every process.


Bronkhorst®
The low-flow specialists
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Precision hydrogen flow measurement
in SOFC and SOEC applications
Peter Brouwer| Seoul | 5 December, 2025
Bronkhorst®

Introduction

Product and Market Development Manager

Peter Brouwer

"Shaping the future means delivering the right solutions for tomorrow's market;
driven by innovation, guided by sustainability."

Innovative low-flow specialist

- Bronkhorst is a PIONEER
  … in the field of innovative, micro- to low-flow gas and liquid metering instruments. We are setting new standards, not following others.
- Bronkhorst is a CREATOR
  … developing and manufacturing the most extensive range of low flow instruments. Not available doesn't mean impossible. Put us to the test!
- Bronkhorst is committed to COLLABORATION
  … in designing and producing innovative, customized configurations. Our skilled engineers go above and beyond to assist our customers around the world.


Extensive expertise in many markets
Analytical
Automotive
Bioprocessing & bioreactors
Food & beverage
Medical, health & personal care
(Petro)chemical, metal & glass
Focus Market
Renewable energy
Semiconductor
Surface treatment
Water treatment
6
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Place your subtitle here
Our worldwide presence
40+
years experience in Mass Flow & Pressure
800+
employees corporatewide
24H
round-the-clock technical support
1 mln+
instruments in the field
7
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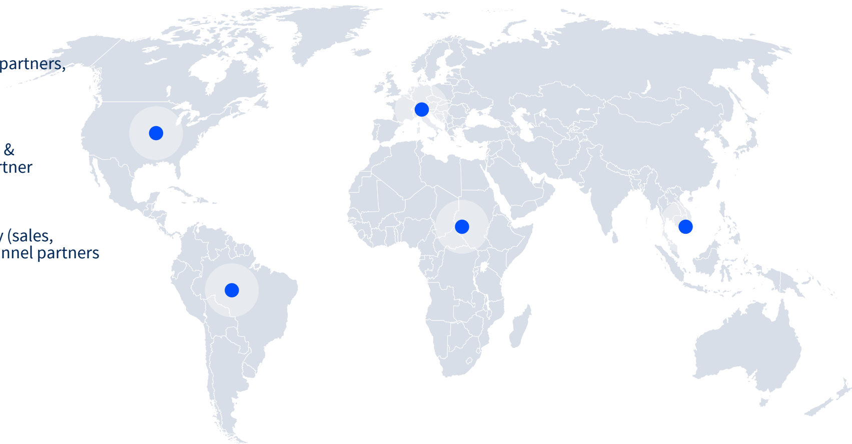
Worldwide sales & support

- **Europe**
  5 subsidiaries, 17 channel partners, 4 production locations
- **North America**
  1 subsidiary (sales, service & production), 1 channel partner
- **Asia & Oceania**
  6 subsidiaries, 1 subsidiary (sales, service, production), 8 channel partners
- **South America**
  2 channel partners
- **Africa & Middle East**
  2 channel partners



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Introduction into

Solid Oxide technology

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Solid Oxide is…

A technology…

- In development
- To build
  - Electrolyser cells (SOEC)
  - Fuel cells (SOFC)
- Has a solid oxide electrolyte
  - Activated at high temperatures (700+ °C)
  - Transporting O^{2-} ions

Core products - Ceres Power Holdings plc

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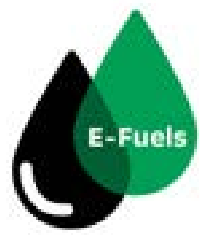
Advantages of Solid Oxide technology

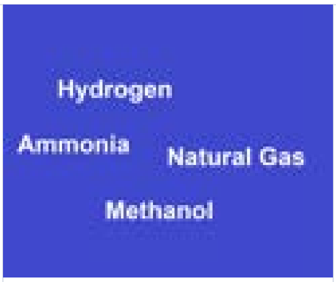
High Efficiency

Up to 85% efficient (when reusing heat)



Simultanious CO_2 electrolysis

Syn gas production for e-fuel synthesis



Fuel Flexibility

A Solid Oxide Fuel Cell can be operated with many fuels, not only hydrogen

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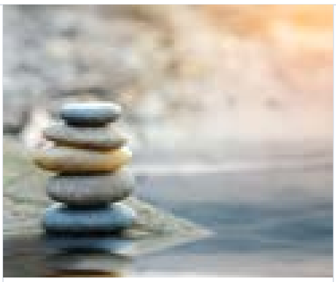
Research topics on solid oxide technology

Thermal management

Temperature gradients
Thermo-mechanical stress
Dynamic strategies



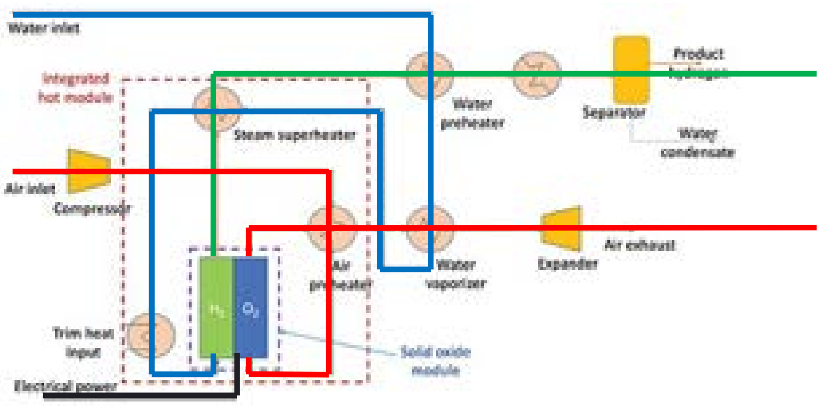
Stability

Material degradation
New materials
Integration techniques

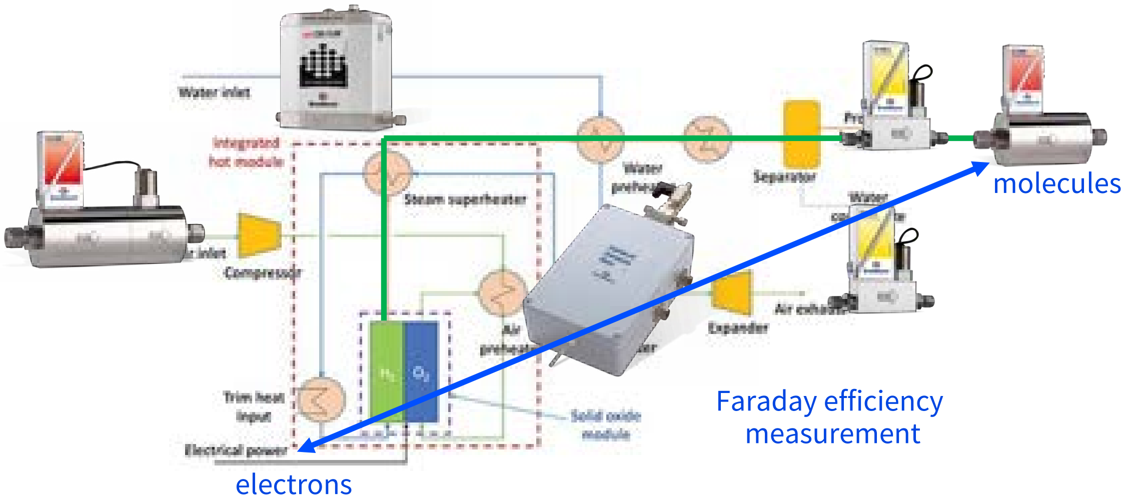
Faraday Efficiency

Percentage of electrons used for chemical reaction
Measure for leakages and side reactions

Typical Balance of Plant for SOEC



Instrumentation for research on SOEC



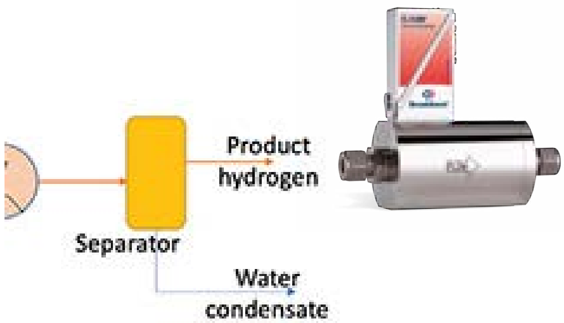
Hydrogen flow measurement

Requirements

- High accuracy
  - For Faraday efficiency

Challenges

- High temperature
- Temperature gradients
- Humidity, 'wet hydrogen'



Measurement tips

Starting points

1. Choose an accurate flow meter
2. Prevent temperature gradients
3. Dry the gas as much as possible

Subsequent steps

1. Calibrate instrument
2. Convert for mixture with water vapor
3. Create stable environment

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Our solutions

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Real gas calibration

- Bronkhorst offers hydrogen real gas calibration as option
  - for new products
  - (re)calibration
- Range 1 ml_n/min up to 200 m^3_n/h H_2
- Closed loop gas recirculation system
- Best possible accuracy!

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Real time gas conversion

- FLUIDAT® on board available in
  - EL-FLOW Prestige
  - FLEXI-FLOW Compact
- Mixtures can be created in the instrument, e.g. H_2 and H_2O
  - Ratio can be modified in real time for variable gas mixtures!
- Relative humidity sensor can be used as input for gas mixture modification

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Product Announcements

EX-Flow X200

- The next generation of intrinsically safe gas flow meters and controllers designed for hazardous environments
- The new EX-FLOW design makes the integration into your system simpler and cost-effective
- Compact, for IECEx Gb and ATEX zone 1 applications
- Direct hookup to safety barriers, no need for expensive cables or control units
- Scheduled for release in 2026

IN-FLOW upgrade

- High flow and high accuracy are main specifications for electrolysers / fuel cell test equipment
- New electronics and sensor design enables faster response and higher accuracy
- FLUIDAT on board for easy reconfiguration
- Integrated Mass Flow Controller up to 1000 m3n/h
- Scheduled for release in 2026

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Conclusions

- We are the low flow specialists
- Our focus is on energy transition
- Solid Oxide technology is very promising
- Development requires accurate instrumentation, but flow measurement is challenging
- We offer solutions
  - Real gas calibration
  - Real time conversion of changing mixtures
- We develop new instruments for demanding hydrogen applications

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Thank you for your attention!

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Republic of Korea

Bronkhorst®

Meet us in Hall: B5 Stand: 5F70

Breakthroughs in Hydrogen Production Techniques 5

Accelerating clean hydrogen solutions with High-efficiency heat exchangers

MyoungSoo Shin
Professional of Sales Manager,Alfa Laval

Education
2024-2010, bachelor's degree, Naval Architecture & Ocean Engineering, Inha University, Seoul, Korea

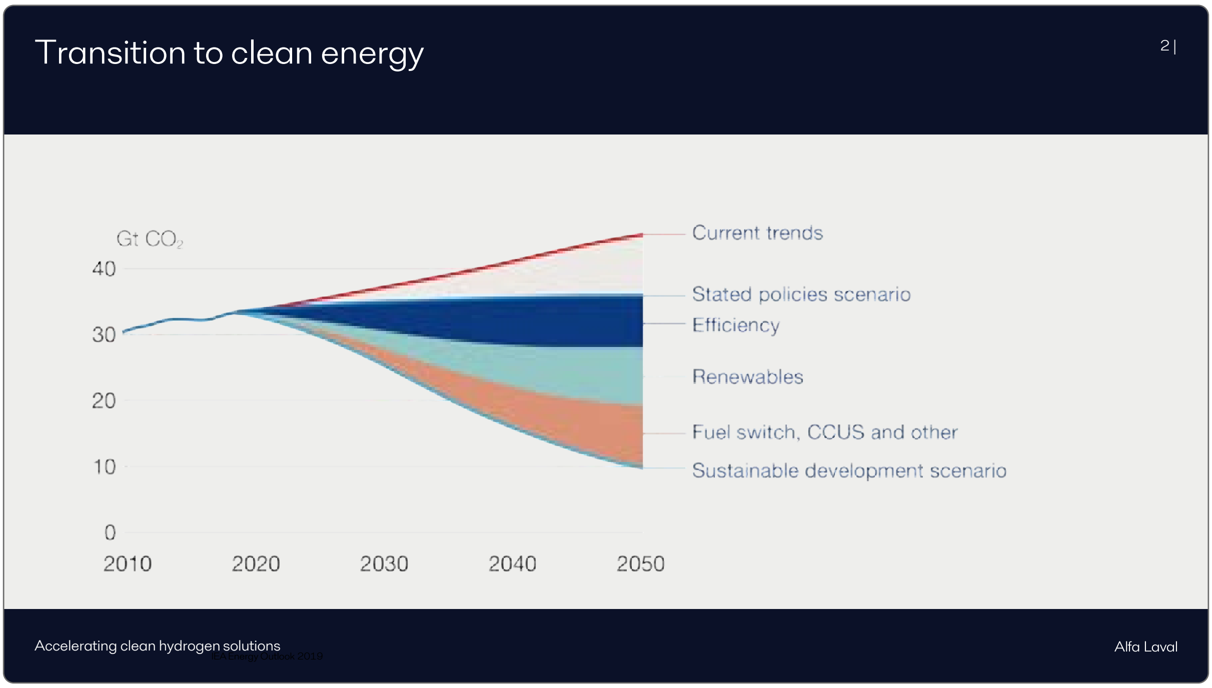
Professional Career
2010-2014, Assistant manager, Offshore structural design team, STX Offshore & Shipbuilding
2015-2018, Assistant manager, Sales team, Jone Crane Korea
2018-present, Professional, ENERGY Div.-BU WHE&GPP, Alfa Laval Korea

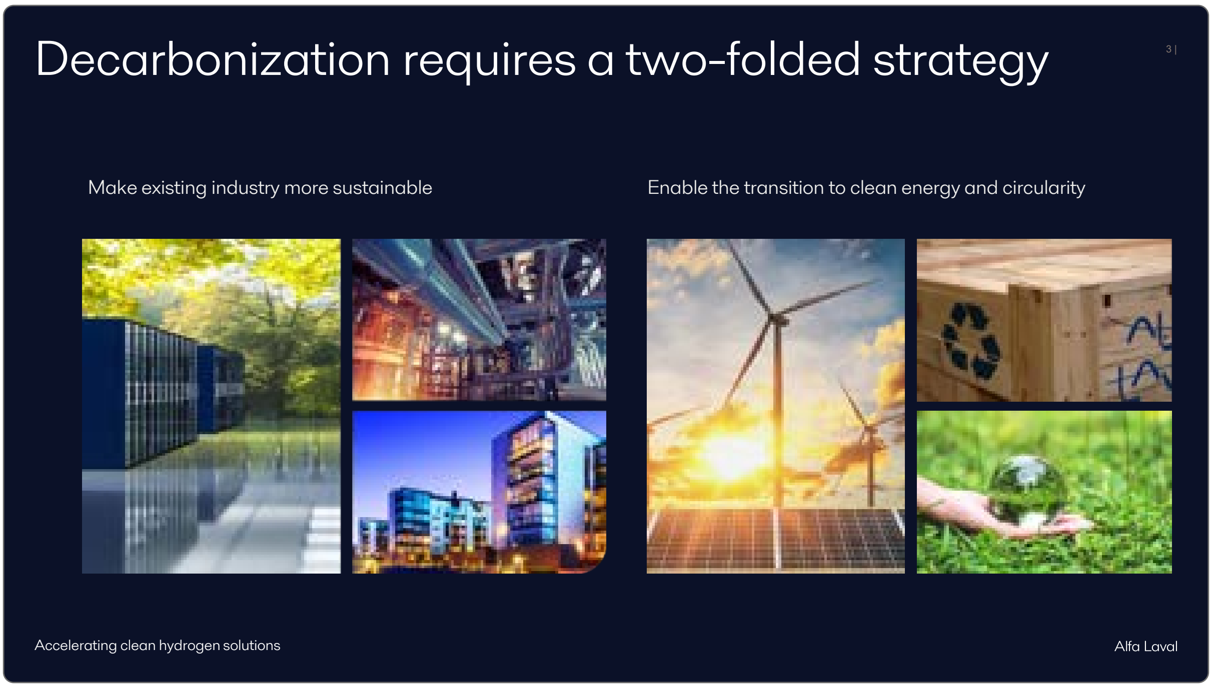
Research Interest
AFC, PAFC, FEMFC system R&D
International Standard for Fuel cell
Catalysts and MEA research
Physical mobility for hydrogen fuel cell system

Speech Summary
Alfa Laval's hydrogen leadership accelerates the clean hydrogen economy. By focusing on energy efficiency, system optimization, and scalable technologies, Alfa Laval aims to reduce production costs and support global projects like flagship, NEOM and HOPE. Their advanced heat transfer solutions support a key role in enabling sustainable hydrogen applications across industries.

Company Introduction
Alfa Laval is a global clean energy solutions company that pursues energy efficiency and sustainability based on heat exchange, fluid handling, and separation technologies.


Accelerating clean hydrogen solutions
Classified by Alfa Laval as: Business
Alfa Laval


Transition to clean energy
2 |
Gt CO₂
40
30
20
10
0
2010
2020
2030
2040
2050
Current trends
Stated policies scenario
Efficiency
Renewables
Fuel switch, CCUS and other
Sustainable development scenario
Accelerating clean hydrogen solutions
Alfa Laval


Decarbonization requires a two-folded strategy
3 |
Make existing industry more sustainable
Enable the transition to clean energy and circularity
Accelerating clean hydrogen solutions
Alfa Laval


4
Sustainability focus areas in Alfa Laval
with customers
Clean energy
Energy efficiency
Circular economy
SUSTAINABLE PARTNERSHIP
Accelerating clean hydrogen solutions
Alfa Laval


Alfa Lavals offering in Clean energy
5
Energy Hunter
Hydrogen
Carbon capture utilization and storage
Energy storage
Data center
District Energy
Renewable fuels and chemicals
Accelerating clean hydrogen solutions
Alfa Laval


Accelerating decarbonization through energy efficiency
6
Alfa Laval as a part of the Energy Efficiency Movement
Energy Efficiency Movement
An open-door initiative bringing stakeholders together to raise awareness and accelerate actions to increase global energy efficiency – our 'first fuel' to a decarbonized future. We just need to make it happen, together!
Join us and be part of the solution!
www.alfalaval.com/energyefficiencymovement
Energy savings
Resource savings
Emission savings
READ MORE >


Watt's it worth?
Energy savings
50 GW
Emission reduction
25 MT
10 million
households
Paris
Accelerating clean hydrogen solutions
Alfa Laval


Accelerating clean hydrogen solutions
8
Alfa Laval as supporting member of the Hydrogen Council
Hydrogen Council
Alfa Laval, together with the about 140 other members share a united vision and long-term ambition: for hydrogen to foster the clean energy transition for a better, more resilient future.
With Alfa Laval's proprietary technologies and heat transfer expertise in combination with our global manufacturing capabilities, we enable the acceleration of a hydrogen economy through energy efficient and scalable solutions.
Hydrogen Council
Energy savings
Resource savings
Emission savings
READ MORE >

Accelerating clean hydrogen solutions

9

Alfa Laval as supporting member of the most important Hydrogen and energy efficiency organizations

Decarbonization drives the clean hydrogen market

10

More than 90 countries with **Net-Zero targets**

Key enablers for the energy transition:

- Massive electrification
- Clean molecules
- Energy efficiency

Over 50 countries have introduced **hydrogen strategies**

Upp to 20% of global energy from hydrogen 2050

Accelerating clean hydrogen solutions

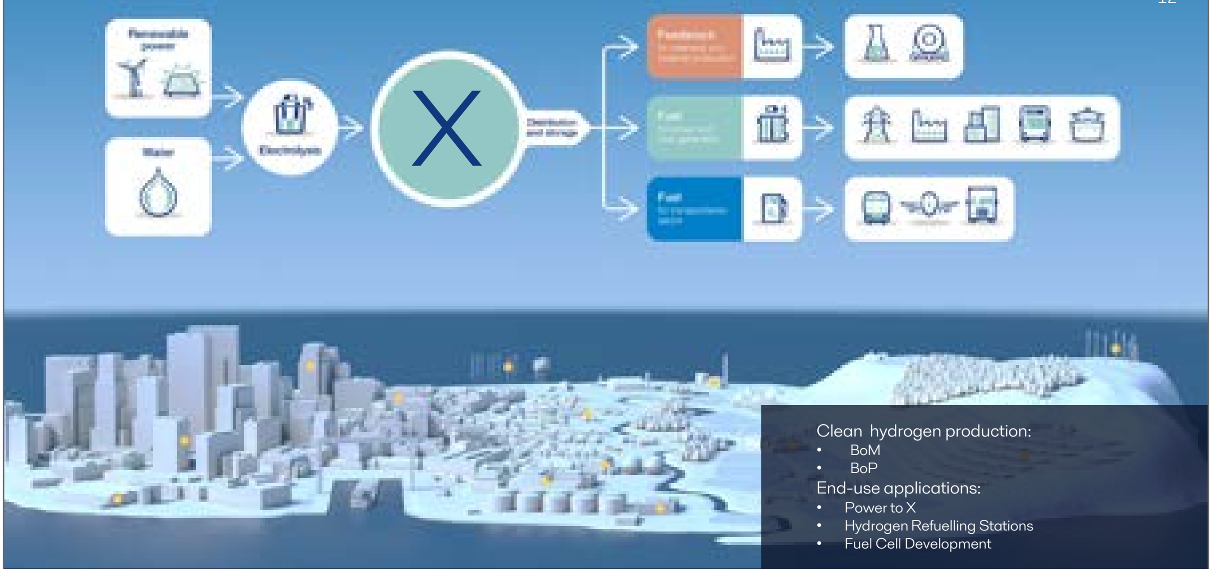
Alfa Laval

Clean hydrogen – a future energy carrier

- Hydrogen demand continues to grow as it holds huge potential for **enabling the energy transition** – in particular for the hard-to-abate sectors
- Renewable hydrogen is a **zero-emission solution** for industrial processes, power or heat generation and as fuel in the transportation sector
- Alfa Laval **offers a wide portfolio** of heat transfer technologies for compact, efficient and scalable clean hydrogen production, distribution, storage and end-use applications.

Accelerating clean hydrogen solutions

12



Accelerating clean hydrogen solutions

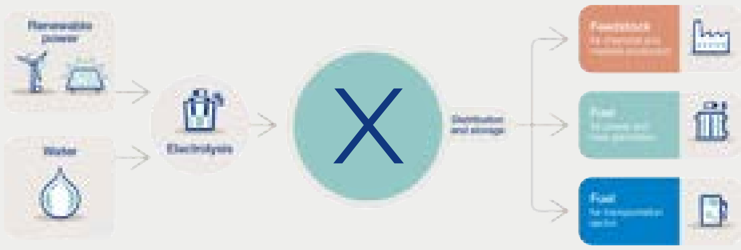
Alfa Laval

Heat transfer optimization across the value chain

13

Renewable hydrogen production:
- Electrolyser cooling
- Process water desalination
- Post-treatment cooling
- Plant cooling
- Waste heat recovery

End-use applications:
- Hydrogen refuelling stations
- Fuel cell development
- Industrial use, power-to-X
- Waste heat recovery

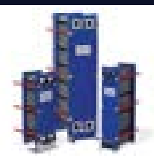


Accelerating clean hydrogen solutions | Alfa Laval

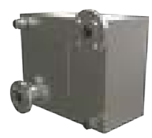
Innovative heat transfer technologies

14

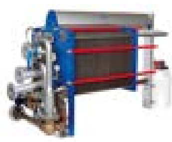
combining outstanding performance with remarkable compactness



Alfa Laval gasketed plate-and-frame heat exchangers



Alfa Laval printed circuit heat exchangers

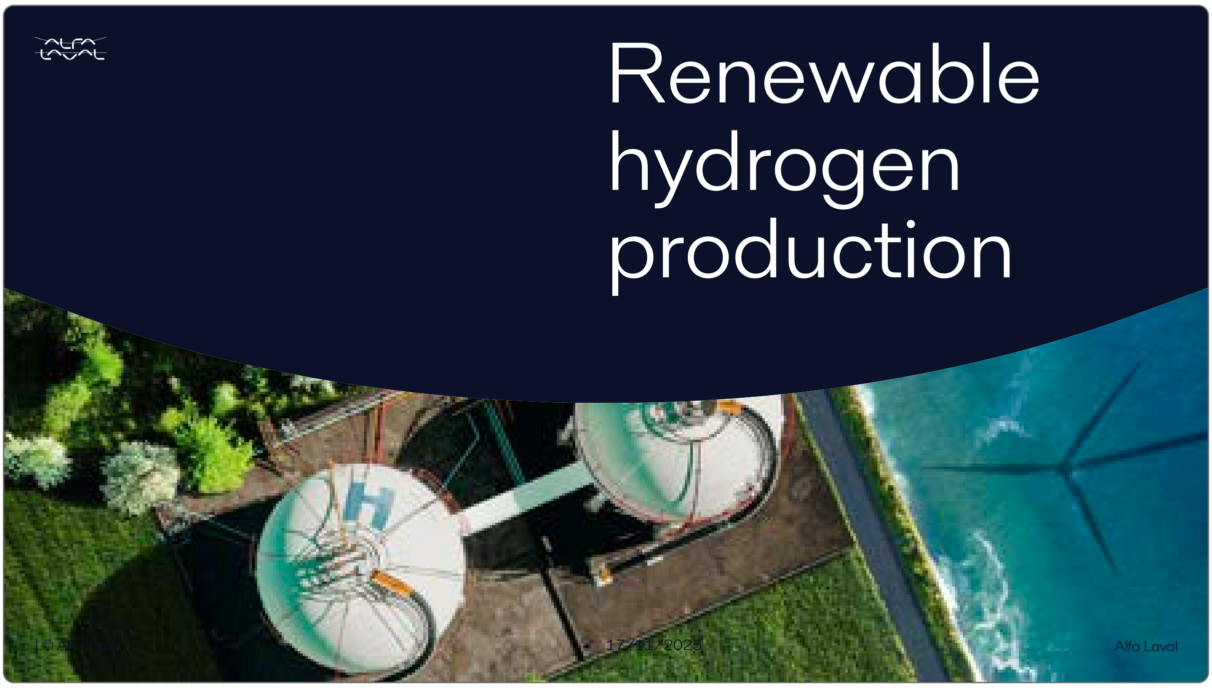


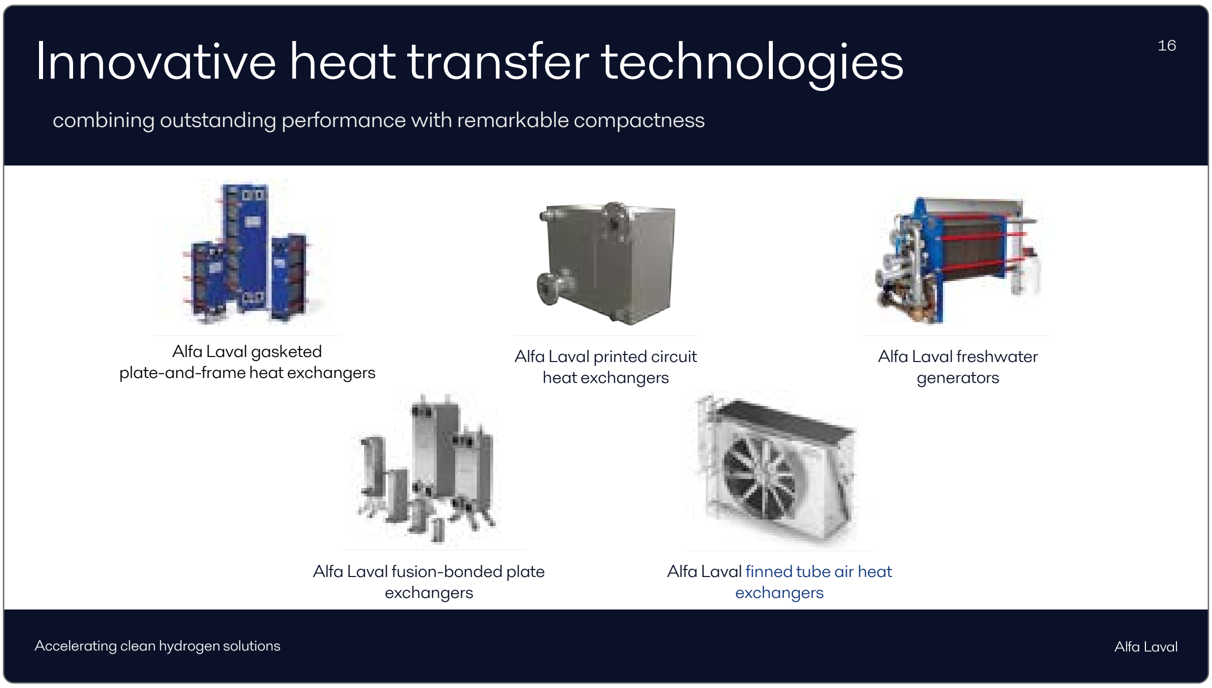
Alfa Laval freshwater generators

Alfa Laval fusion-bonded plate exchangers

Alfa Laval finned tube air heat exchangers

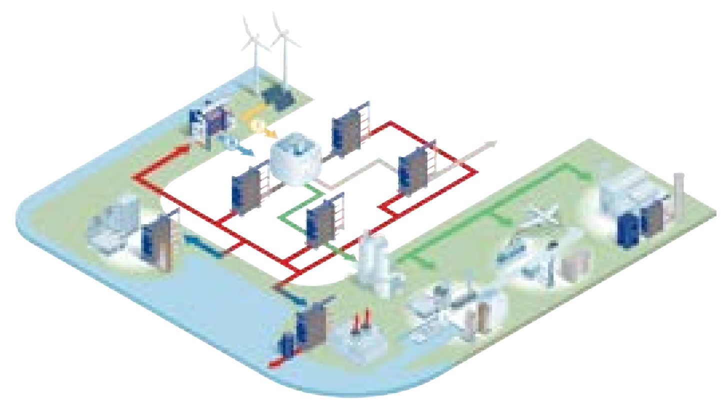
Accelerating clean hydrogen solutions | Alfa Laval


Renewable hydrogen production
Alfa Laval


Innovative heat transfer technologies
16
combining outstanding performance with remarkable compactness
Alfa Laval gasketed plate-and-frame heat exchangers
Alfa Laval printed circuit heat exchangers
Alfa Laval freshwater generators
Alfa Laval fusion-bonded plate exchangers
Alfa Laval finned tube air heat exchangers
Accelerating clean hydrogen solutions
Alfa Laval

Heat transfer technology across the value chain

17



Heat transfer needs:

1. Electrolyte cooling
2. Gas cooling
3. Process water desalination
4. Post-treatment cooling
5. Overall plant cooling
6. Waste heat recovery
7. End-use applications

Accelerating clean hydrogen solutions

Alfa Laval

Heat transfer technology connected the stack

Alfa Laval plate heat exchangers for electrolyser cooling

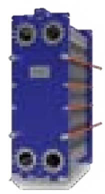
✓ Maximizing electrolyser performance
✓ Optimizing equipment lifetime
✓ Securing oxygen-safe operation

Alfa Laval portfolio

Innovative heat transfer technology

Wide range from small to large

Material expertise



Alfa Laval gasketed plate-and-frame heat exchangers

Alfa Laval fusion-bonded plate exchangers

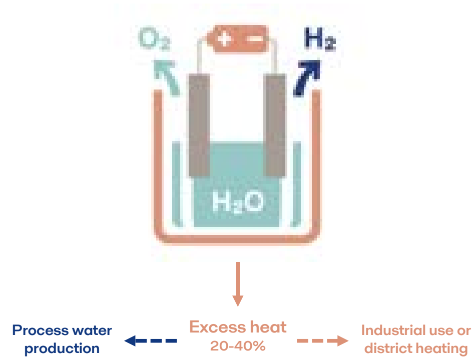
Accelerating clean hydrogen solutions

Renewable hydrogen production insights

Alkaline and PEM technologies

Electrolysis generate **20-40% excess heat**. Optimized temperature control is crucial for maximizing process efficiency and equipment lifetime

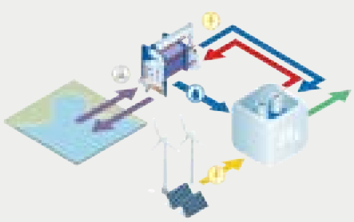
Every 10 MW electrolyser capacity needs around **50-60 m³/day of clean water**. Process water desalination crucial to maximize electrolyser performance



Process water generation for electrolysis

Thermal desalination with Alfa Laval freshwater generator

Desalination with conventional reverse osmosis

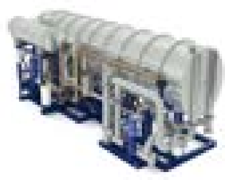


Combining cooling and water generation with
- ✓ Smallest footprint
- ✓ Minimized chemicals
- ✓ Minimized electricity consumption
- ✓ Low maintenance needs

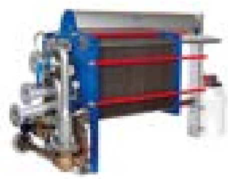
Accelerating desalination performance

- **Alfa Laval fresh water generators** for process water desalination
  - ✓ Enabling a smaller footprint
  - ✓ Reducing chemicals
  - ✓ Reducing electricity consumption
- **Alfa Laval portfolio**
  - Innovative heat transfer technology
  - Offshore and onshore applications
  - Wide range: capacity 2.0 - 7000 m^3/day
  - Material expertise, titanium plates
  - High quality freshwater, <<2ppm TDS

Accelerating clean hydrogen solutions



Alfa Laval MEP



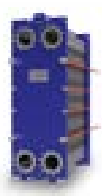
Alfa Laval AQUA

Renewable hydrogen as a beacon of hope

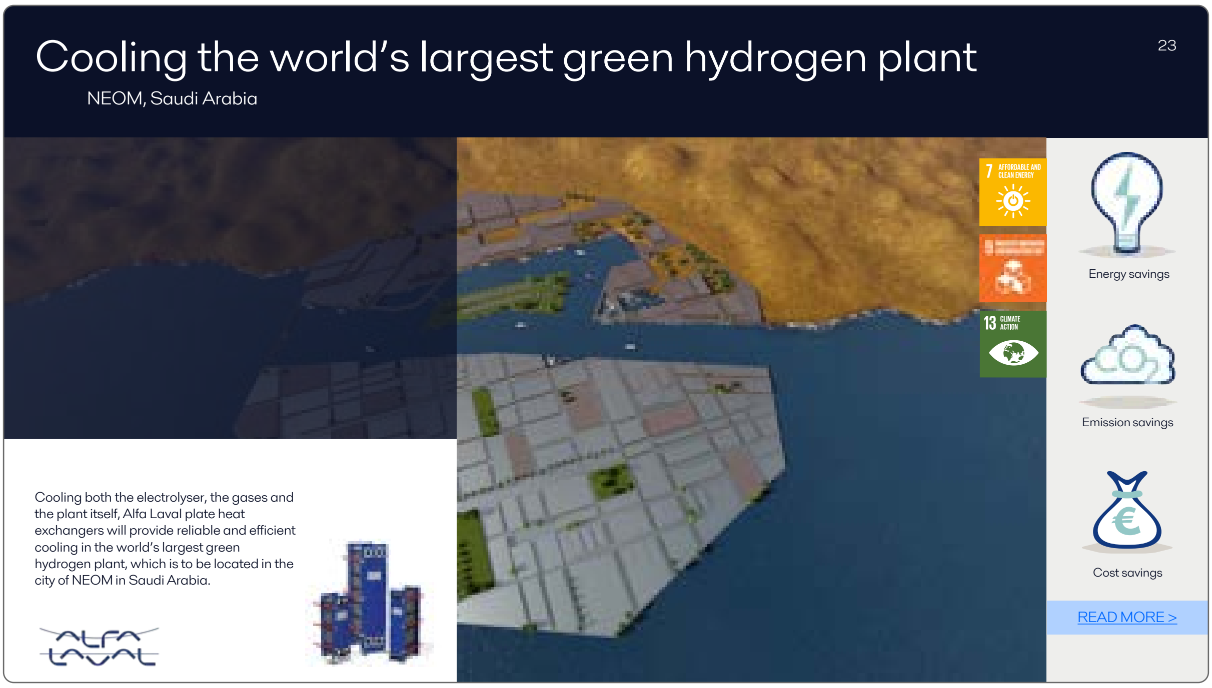
22

Thyssenkrupp, Germany

A pioneering electrolysis pilot reduces CO_2 emissions in both steelmaking and chemical production. Heat exchangers from Alfa Laval cool the hydrogen, oxygen and catholyte as well as condense the moisture.



READ MORE >


Cooling the world's largest green hydrogen plant
23
NEOM, Saudi Arabia
Cooling both the electrolyser, the gases and the plant itself, Alfa Laval plate heat exchangers will provide reliable and efficient cooling in the world's largest green hydrogen plant, which is to be located in the city of NEOM in Saudi Arabia.
Energy savings
Emission savings
Cost savings
READ MORE >


Power-to-X

Power-to-X

- Power-to-X (P2X) is a key component in decarbonizing the chemical, marine and aviation industries by converting electricity into gaseous or liquid fuels or chemicals
- "X" refers to: clean ammonia, e-methanol, methane, renewable hydrogen and syngas
- Power-to-X can enable more sustainable industry, transportation and energy storage while utilising existing infrastructure, as well as provide an important energy storage solution.
- Alfa Laval's efficient heat exchangers have a proven record of securing highly cost-effective production from the chemical industry

Accelerating clean hydrogen solutions

Alfa Laval's Power-to-X offering

26

E-methanol

- Combining renewable hydrogen with a CO_2 source opens up the path to e-methanol
- Apart from being used as fuel and energy storage, e- methanol is also instrumental for decarbonizing the chemical industry
- Alfa Laval supports smaller scale markets with the same high quality of solutions and services as for mega-sized plants
- Our compact technologies are suitable for a wide range of applications; steam generation, reactor interchangers, distillation section exchangers including reboilers and condensers, as well utility cooling and heating

Clean ammonia

- Ammonia is well established as a cornerstone of the fertilizer industry, but it also plays a significant role in refrigeration systems
- Clean ammonia is creating new possibilities for areas like fuel and energy storage
- Alfa Laval has a long track record of supporting the ammonia industry
- Our process heat transfer are suitable for a wide range of applications in green ammonia: waste heat boilers, steam drums and ammonia condensers, as well as utility cooling and heating to maximize energy efficiency

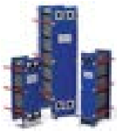
Accelerating clean hydrogen solutions

Alfa Laval

Alfa Laval's Power-to-X offering

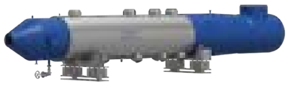
27

combining outstanding performance with remarkable efficiency

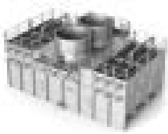


Alfa Laval gasketed plate-and-frame heat exchangers

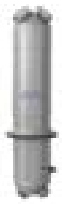
Alfa Laval Compabloc



Alfa Laval Olmi process gas boiler



Alfa Laval Wet Surface Air Coolers (WSAC)



Alfa Laval Packinox

Accelerating clean hydrogen solutions

Alfa Laval

Heat transfer technology clean Ammonia production

28

Heat transfer needs:

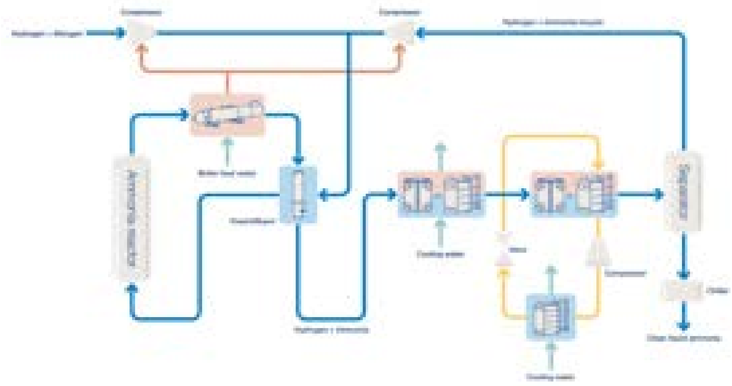
- Steam generator for compressors
- Feed/effluent
- Ammonia condensers
- Overall plant cooling
- Waste heat recovery

Alfa Laval portfolio Hydrogen

Alfa Laval

Clean Ammonia production

29



Heat transfer needs:
1. Steam generator for compressors
2. Feed/effluent
3. Ammonia condensers
4. Overall plant cooling
5. Waste heat recovery

Accelerating clean hydrogen solutions

Alfa Laval

Heat transfer technology e-methanol production

30

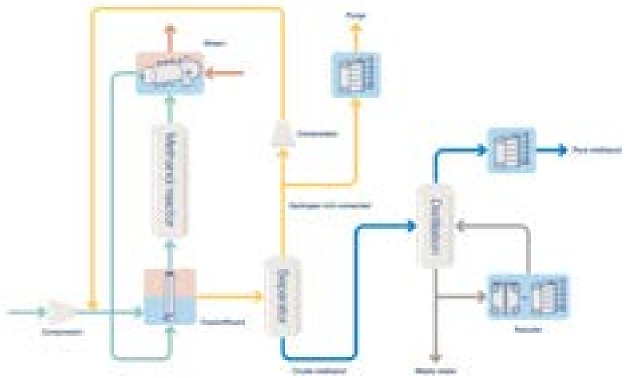
Heat transfer needs:
Steam generator for compressors
Feed/effluent coolers
Purge coolers
Reboilers & condensers
Overall plant cooling
Waste heat recovery

Alfa Laval portfolio Hydrogen

Alfa Laval

e Methanol production

31



Heat transfer needs:

1. Steam generator for compressors
2. Feed/effluent coolers
3. Purge coolers
4. Reboilers & condensers
5. Overall plant cooling
6. Waste heat recovery

Accelerating clean hydrogen solutions

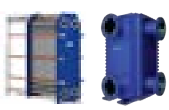
Alfa Laval

e methanol as fuel to reduce carbon emissions

32

- Alfa Laval as investor and partner to Liquid Wind, Sweden

Liquid Wind aims to develop commercial-scale e-Methanol facilities through a partnership consortium. Alfa Laval is their heating & cooling partner, bringing expertise in heat balance and energy optimization of the complete system.



Liquid Wind ALFA LAVAL carbon clean SIEMENS energy TOPSOE

Energy savings

Emission savings

Cost savings

READ MORE >

Hydrogen refuelling Stations

Hydrogen refuelling insights

Hydrogen a fuel for decarbonizing the transportation sector.

For **road transportation**, hydrogen fuel cell vehicles will complement where battery solutions face limitations:
-Heavier load
-Longer distances
-Crucial refuelling times

High demands on both time and space **efficient refuelling stations**.

Alfa Laval's pre-cooling offering

- **Alfa Laval printed circuit heat exchangers** for precooling in hydrogen refuelling serving any vehicle
  - ✓ Enabling back-to-back refuelling
  - ✓ Ensuring lowest possible customer waiting times
  - ✓ Reducing footprint with 85%
- **Alfa Laval portfolio**
  - Reliable and proven technology
  - Wide range; H35 and H70 standards
  - Design pressure up to 1,250 bar (18,125 psi)
  - Operating temperatures down to -70°C (-94°F)

Accelerating clean hydrogen solutions

Alfa Laval HyBloc™

Product range

36

The HyBloc™ range comprises different models, offering solutions for all capacity needs.

HyBloc – for gas hydrogen / liquid coolant applications
Extended standard range includes model 3,6 | 5 | 7,5 | 18

HyBloc C – for gas hydrogen / CO2 coolant applications
Extended standard range includes C 3,6 | C 5 | C 7,5

Liquid hydrogen special PCHE

We help you select the ideal model according to your cooling fluid, capacity requirements and further aspects to maximize performance.

Alfa Laval

Fuel Cells

Fuel cells

38

- The transformation of the world's energy systems is going to entail a wide range of solutions
- Fuel cells are going to be a fundamental part of our clean energy transition
- Fuel cells will be used for everything from distributed power to power generation for the every-growing data center sector
- Alfa Laval offers thermal transfer technologies ensuring strong fatigue resistances under the high temperatures and thermal stress for all types of fuel cell technologies (PEM, SOFC etc.)

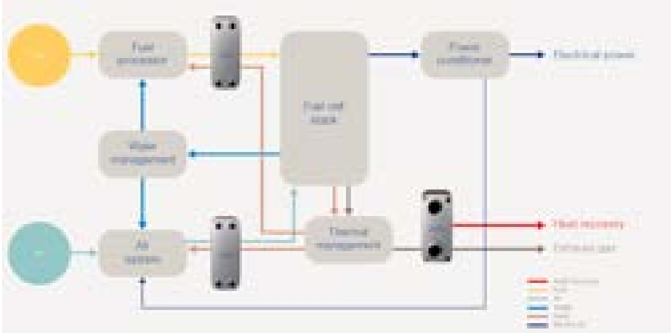
Accelerating clean hydrogen solutions

Alfa Laval

Fuel cells

39

- Heat transfer solutions for all types of fuel cells technologies
  - Fusion-bonded heat exchangers that can handle temperatures above 600°C
  - Gas-to-liquid heat exchangers for uneven flow requirements
  - Innovations in higher gas-to-gas temperatures



Accelerating clean hydrogen solutions

Alfa Laval

Alfa Laval's fuel cells offering

combining outstanding performance with remarkable efficiency

40

Alfa Laval brazed plate heat exchangers

Alfa Laval fusion-bonded plate heat exchangers

Alfa Laval gas-to-liquid plate heat exchangers

Accelerating clean hydrogen solutions

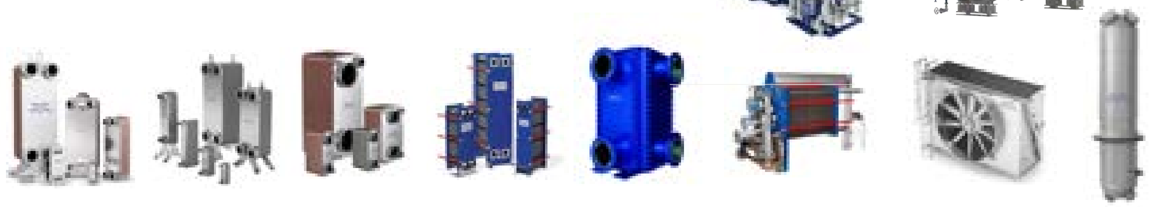
Alfa Laval

The right solution every time

41

Performance Simplified

Alfa Laval – Only supplier offering a complete range.
Expertise in all technologies.
Alfa Laval will help you save time in equipment selection as we will help your project teams select the right technology for every position.



Accelerating clean hydrogen solutions

Alfa Laval

Breakthroughs in Hydrogen Production Techniques 6

Scaling Economic Industrial Decarbonization: How Utility Global H2Gen® Technology is delivering Decarbonization without Compromise for the Hard-to-Abate Sectors

Vladimir Novak
Chief Commercial Officer, Utility Global, Inc.

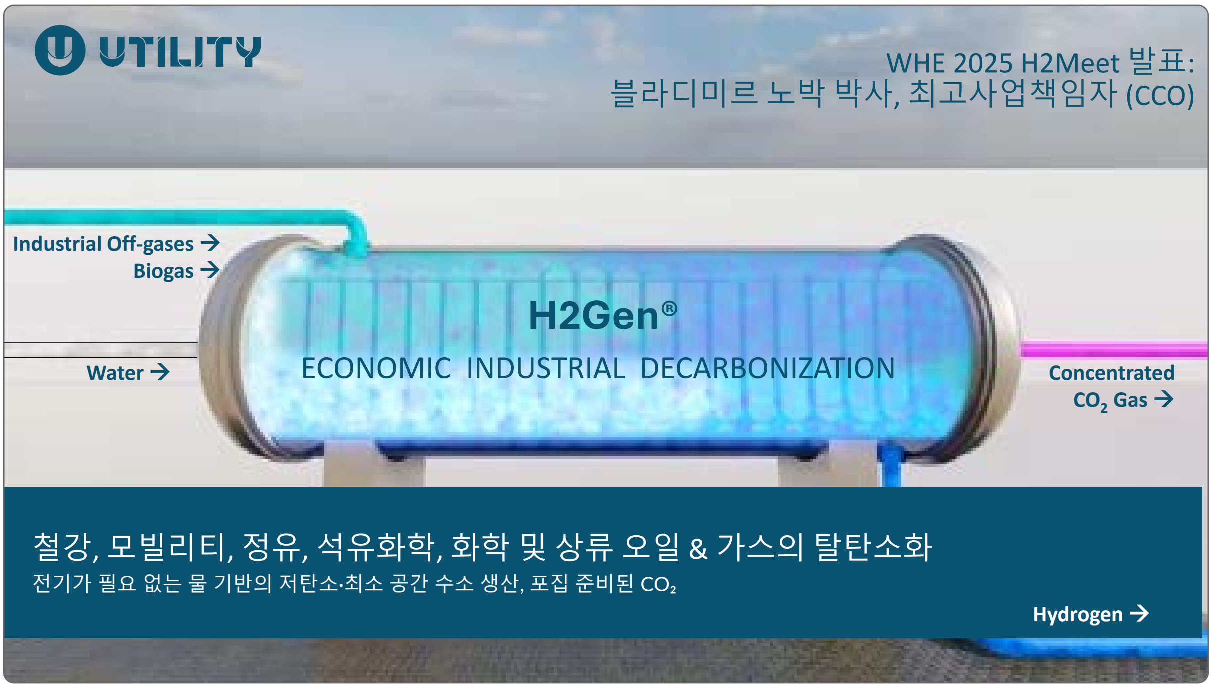
Education
2009 – 2011, Executive MBA (Magna cum Laude), Rice University – Jesse H. Jones Graduate School of Business, Houston/USA
2002 – 2006, Doctor of Philosophy (Ph.D.), Mechanical Engineering – Fusion Energy (Magna Cum Laude), Georgia Institute of Technology, Georgia/USA
2000 – 2002, Master of Science, Mechanical Engineering (Summa cum Laude), Georgia Institute of Technology, Georgia/USA
1993 – 1998, Bachelor of Science, Mechanical Engineering, Univerzitet u Beogradu, Belgrade/ Serbia

Professional Career
2024 – Present, Chief Commercial Officer, Utility Global, Houston/USA
2023 – 2024, Co-Chief Executive Officer, CT-Coating, Seattle/USA
2022 - 2023, Chief Commercial Officer, USNC, Seattle/USA
2008 – 2022, Director, Strategic Partnerships (2019 – 2022), Adviser to the President (2017 – 2019), Commercial Business Manager (2015 – 2017), Group Leader – Chevron Technology Ventures(2010 – 2015), Chevron, San Francisco, Houston/USA
2006 – 2008, Lead Energy Systems Engineer, GE, USA
2000 – 2006, Research Engineer – Fusion Energy, U.S. Naval Research Laboratory, USA
1991 – 2000, Tennis Professional, ATP Tour

Research Interest
Ph.D. focus: Fusion Energy, Thermal Sciences, Thermodynamics, Heat Transfer, Fluid Mechanics, Experimental R&D, Numerical 3D modelling

Speech Summary
- Utility Global is leading the charge to effectively decarbonize hard-to-abate sectors such as steel, mobility, refinery/chemical, and upstream oil & gas
- With a world-class team of industry leaders and advisors, and the support of some of the most significant investors in industrial decarbonization, Utility is successfully commercializing and scaling its technology globally
- Steel Focus: Arcelor Mittal, Brazil
- Biogas/H2 Mobility Focus: Maas Energy, USA
- Korea Focus: Frontier Korea (Certification & Demonstration), Utility Korea subsidiary, Seongnam, Korea
- The H2Gen® reactor is a revolutionary, versatile, easily scalable technology that harnesses the energy in industrial off-gases and biogases to produce pure hydrogen from water, and concentrated carbon dioxide streams without electricity
- H2Gen® sits at the intersection of gas processing and electrolysis without the complexity and cost
- Korea, the perfect market for H2Gen®: Strategy implemented into action, Korea is a global force in the maritime, refinery, chemical, steel sectors and a world leader in hydrogen ecosystems for biogas, mobility, power generation, hydrogen derivative fuels.
- Strategic Partnerships, the key to our success: Utility has built and continues to build powerful partnerships with significant companies and investors for the greatest decarbonization impact.
- Join us on our journey to decarbonize the world

Company Introduction
Utility delivers practical solutions that drive economic industrial decarbonization across industries such as steel, mobility, refining, chemicals, and upstream oil & gas. The company's breakthrough H2Gen® technology harnesses energy from industrial off-gases and biogases to produce application-specific high-purity, low-to-negative carbon intensity hydrogen on-site from water, without electricity, using its proprietary electrochemical process. H2Gen® also produces a high-concentration carbon dioxide stream, which can eliminate or reduce the cost of carbon capture. H2Gen® systems are modular, scalable, and operationally flexible, integrating seamlessly into existing hard-to-abate industrial assets with a record small footprint, enabling practical, economic decarbonization.


UTILITY
WHE 2025 H2Meet 발표:
블라디미르 노박 박사, 최고사업책임자 (CCO)
Industrial Off-gases →
Biogas →
Water →
H2Gen®
ECONOMIC INDUSTRIAL DECARBONIZATION
Concentrated CO_2 Gas →
철강, 모빌리티, 정유, 석유화학, 화학 및 상류 오일 & 가스의 탈탄소화
전기가 필요 없는 물 기반의 저탄소·최소 공간 수소 생산, 포집 준비된 CO_2
Hydrogen →


경제적 산업 탈탄소화스케일업 및 첫 번째 프로젝트 영상
UTILITY
Economic Industrial Decarbonization
https://media.utilityglobal.com/videos/economic-industrial-decarbonization
UTILITY

Utility
소유주, 프로젝트 및 회사 존재감

H2Meet 2024

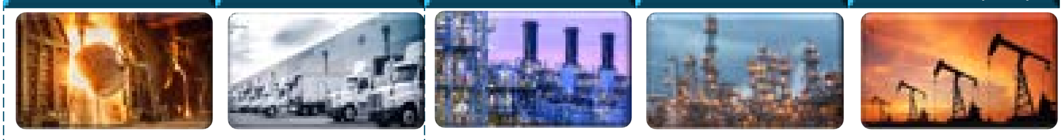
유틸리티 순위: 59

소유주

Ara Built to Decarbonize.™
aramco
ArcelorMittal
SAMSUNG
ONTARIO POWER GENERATION
SAINT-GOBAIN

UTILITY

유틸리티는 전 세계 배출량의 20% 이상을 탈탄소화할 수 있음
시장 초점: 전략적 난감(감축이 어려운) 산업



	주요 시장		미래 성장		
	철강	운송수단	석유화학, 화학	정유공장	오일 & 가스(상류)
총 배출 비율	7% 석탄 & 가스 원료 기반 배출	5% 매립지, 폐수, 농업에서 발생하는 바이오가스	4% 원료 기반 배출	3% 원료 기반 배출	3% 석유 생산 중 연소되는(플레어링 되는) 가스
시장 규모	$225 Billion[1]	$870 Billion[2]	$200 Billion[3]	$100 Billion[3]	$15 Billion[3]

시장을 대표하는 기업들의 예

철강	운송수단	석유화학, 화학	정유공장	오일 & 가스(상류)
ArcelorMittal, STELCO, TATA STEEL, thyssenkrupp, JFE, CLIFFS, posco	REPUBLIC SERVICES, TOYOTA, HYUNDAI, WM, CAL BIO GAS	LYB, OXY, Chevron Phillips, DUPONT, Celanese	aramco, TOTAL, eni, ExxonMobil, Marathon, ConocoPhillips	aramco, bp, Shell, Chevron, ExxonMobil, TOTAL

UTILITY

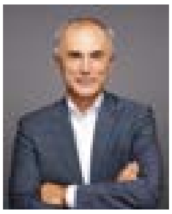
1) 2050년 시장 규모는 "IEA Steel Roadmap" 보고서를 기반으로 함
2) 2050년 시장 규모는 McKinsey & Company, Global Energy Perspective 2023: Hydrogen Outlook 기반
3) 2035년 시장 규모는 McKinsey & Company, Global Energy Perspective 2023: Hydrogen Outlook 기반

세계적 수준의 산업 자문단

- Dr. Henrik Adam (유틸리티 이사회 자문 – 철강)

- Tata Steel Netherlands Holding BV 회장
- Tata Steel UK 회장
- Tata Steel Europe CEO
- ThyssenKrupp Electrical Steel CEO
- 현 EUROFER(유럽철강협회) 회장
- 현 독일 철강연구소 VDEh 회장
- 기계공학 박사(자동차 기술 분야)

- Eric Duchesne (유틸리티 이사회 자문 – 정유/석유화학)



- TotalEnergies 자본 프로젝트 실행 & 운영 총괄, 다운스트림 CTO
- 정유·석유화학·재생에너지 분야 35년 경력
- 전 세계 수십억 달러 규모 프로젝트에서 2,000명의 엔지니어를 이끌음
- 정유 및 석유화학 자산 탈탄소화 집중
- 혁신적 변혁 기술의 산업화를 이끈 검증된 실적
- 장비 공급업체, EPC, 투자자들과의 강력한 네트워크 보유

- Tetsuya Shioda (수석 자문 & 일본 대표 – 철강)

- 일본제철(Nippon Steel Corporation)에서 40년 이상 근무
- 일본 및 세계적으로 잘 알려진 철강 산업 전문가
- NSC 탈탄소화 리더(HBI, 수소, 바이오 탄소, CCUS 등)
- 경영진 대상 상업·기술 자문으로 신뢰받는 전문가
- 전략적 의사결정팀 멤버: US Steel, ArcelorMittal/Nippon Steel India, Usiminas DD 및 운영 계획
- 전 일본제철(NSC) 유틸리티 글로벌 챔피언: 철강 탈탄소화에서 H2Gen® 우위 공식 이사회 승인 주도

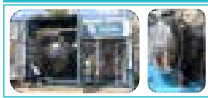
- 곧 발표 예정 – 바이오가스

UTILITY

5

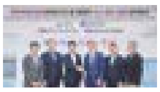
H2Gen® 글로벌 상용화 가속화

2025년 11월 – 휴스턴에서 Frontier H2Gen 플랜트 가동



- 다양한 고객 공급가스 조성을 테스트하기 위한 상업용 플랫폼
- 상업 배치 이전의 향후 기술 발전을 위한 가속 상용 수준 테스트베드

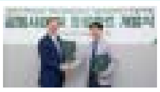
2025년 10월 – 한국 인증 및 데모 플랜트



성남시 Seongnam City

- 성남시 하수처리장 바이오가스를 활용하는 Utility H2Gen® 프로젝트 발표
- 데모에서는 연료전지 등급 수소가 판매·배송·사용되며 수소 모빌리티에 활용됨, H2Gen® 리액터는 KGS 기준을 통과할 예정

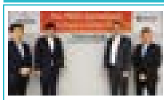
2025년 6월 – 청정 수소 프로젝트 공동 보도자료 발표



kunhwa

- 건화 E&C는 한국의 선도적인 엔지니어링 및 컨설팅 회사
- 초기 협력은 H2Gen®을 중·대형 모빌리티용 지역 바이오가스-수소 허브에 배치하는 데 중점

2025년 4월 – 바이오가스 → 수소 Pre-FEED 연구 보도자료 발표



Hanwha

- 한국 개발사 및 EPC인 한화 E&C 인프라사업부와 협력
- 2030년까지 총 3억 달러 이상 규모의 20개 설치 잠재력,프로젝트 자본 투자 기회는 약 1억 달러 이상

2025년 하반기 – 프로젝트 계약 발표

ArcelorMittal

- 약 2.5 TPD 수소 프로젝트Pre-FEED 엔지니어링 설계 시작을 위한 계약 체결7월 29일 보도자료 발표
- 브라질 프로젝트는 투자자 권리 계약에 따라 향후 글로벌 대형 프로젝트로 확대될 예정

MAAS

- 약 3.5 TPD 수소 프로젝트 – 미국 캘리포니아 Maas Energy후속 프로젝트가 파이프라인에 있으며 10월 7일 보도자료 발표
- 글로벌 오프테이커들과 3건의 초기 오프테이크 계약 체결 → 초기 프로젝트 용량을 초과하는 수요 확보

임박한 프로젝트 계약들

글로벌 선도 철강회사	구두 승인 완료:1 TPD H2Gen® 상업용 데모 프로젝트 (FEL 범위 및 예산 확정)~62 TPD 대규모 수소 프로젝트
글로벌 선도 철강회사	첫 번째 프로젝트에 대한 구두 승인 확보:목표 규모 약 14 TPD 수소

강력하고 성장하는 상업팀

약 55명의 총 직원60% 엔지니어 / 과학자

- 최근 영입을 통해 경영 및 상업팀을 지속 강화:
  - Dr. Henrik Adam, 철강 산업 이사회 자문
  - Eric Duchesne, 정유·석유화학·화학 자문

UTILITY

6


한국 시장 진입: 바이오가스 기반 수소 모빌리티 프로젝트
한국은 H2Gen®에 완벽한 시장임을 입증함
한국의 수소 & 탈탄소화 시장 동인
수소 모빌리티 분야 선도국45,000대 이상의 차량 / 200개 이상의 수소충전소(HRS)
파트너십을 위한 세계적 혁신 기업 보유
수소 발전 분야 선도국연료전지 / 혼소(Co-firing)
UTILITY
H2Gen®
글로벌 철강 분야 핵심 플레이어
글로벌 해운·해양 분야 선도국
세계 5위 정유·석유화학 시장
CO_2
야심찬 탈탄소화 목표
수소·바이오가스·탈탄소화를 위한 강력한 정부 정책 및 인센티브
즉시 개발 조치가 가능한 13개의 진행 중인 프로젝트
서울
대구
부산
프로젝트 지도 키(Key)
>1.5 TPD 수소 프로젝트
데모 및 인증 프로젝트 부지성남 데모 및 인증 프로젝트 개발 중
공동 프로젝트 개발사
GH
UTILITY
kunhwa
- 바이오가스/바이오매스 자산을 보유하고 있고,
- 기존 또는 신규 수소 수요가 있는 지자체들과 중요하고 빠르게 진행되는 협업
- 한국 최초 모빌리티 프로젝트를 포함한 혁신적 배치 사례
- 중공업 탈탄소화 협업 개시
UTILITY
7


첫 번째 프로젝트 (캐나다)
모듈형, 확장 가능, 공장 제작, 소형 설치 면적(40피트 길이 ISO 컨테이너)
UTILITY

휴스턴 “Frontier” 시설

고객 방문이 가능한 확장형 H2Gen 시설

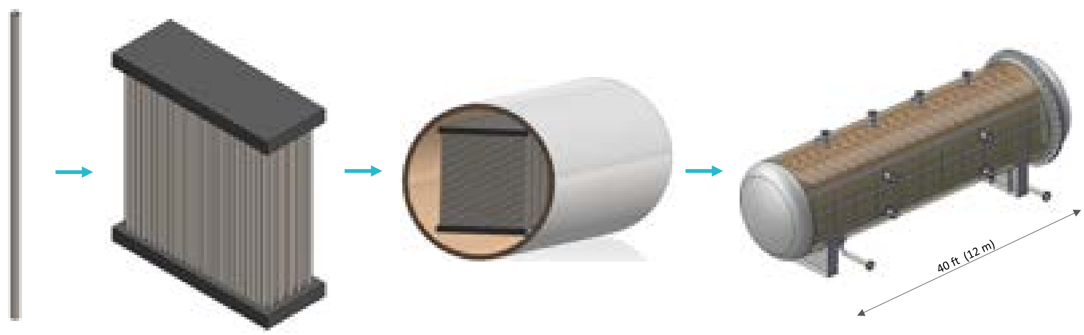
목적: Frontier 시설은 고객을 위한 H2Gen® 기술 쇼케이스 캠퍼스로, 두 가지 주요 목적을 수행함:

1) 신규 시장 진입을 지속하는 과정에서 다양한 고객 공급가스 조성을 테스트할 수 있는 상업용 플랫폼
2) 상업 배치 이전에 계획된 및 향후 기술·제조 발전을 위한 가속 상업 수준 테스트베드

규모: Frontier의 리액터는 유틸리티의 다중 톤급 수소 생산 상업 시스템의 축소 버전으로, 2028년 초 COD 예정. 하루 최대 50 kg의 순수 수소를 생산하며, 다양한 원료(feedstock)를 시뮬레이션해여러 시장 적용 분야에서 고객 사업장의 실제 운영 조건을 재현할 수 있음.

주요 구성 요소: H2Gen 시스템 및 시설은 2028년 가동·시운전 예정이며 현재 FEED 중인상업용 전체 규모 시스템과 동일한 구성 요소를 포함함 — 리액터, 셀 팩, 제어 장치, BOP, 안전 시스템 등.또한 쇼케이스 캠퍼스에는 셀 및 셀 팩 제조 공정도 포함됨.

H2Gen® 리액터 디자인



Single Cell (단일 셀, 튜브)

Cell Pack(셀 팩)

셀 팩은 압력용기 (예: ISO 컨테이너)에 삽입됨

H2Gen 리액터 (기본적으로 길이 40피트)

리액터 용량은 가스 내 전기화학적 에너지에 따라 달라짐(예: 바이오가스는 희석된 고로가스 대비 더 높은 에너지 함량을 가짐)

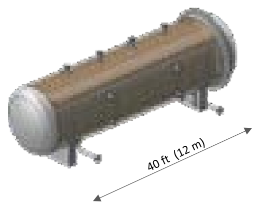
UTILITY

플랜트 규모 확장 (Plant Size Scale Up)

표준화된 공장 제작 리액터로 모든 규모의 적용처 제공

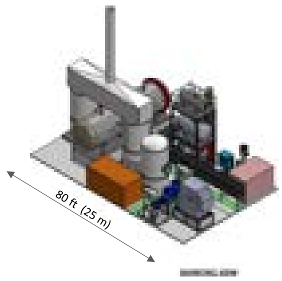
표준화된 리액터

- 공장 제조
- 높은 생산성, 낮은 비용, 짧은 제조 시간에 최적화



단일 리액터 플랜트

- 2–5 TPD 수소 범위를 위한 대부분 표준화된 플랜트
- 바이오가스 → 모빌리티 적용에 가장 가능성이 높음



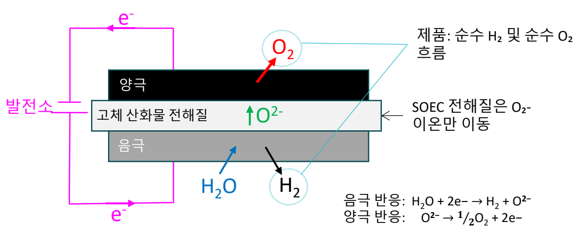
대형 적용을 위한 플랜트

- 10–500 TPD 수소
- 대규모 플랜트 용량을 위해 표준 리액터들을 연결
- 작은 설치 면적, 경쟁력 있는 비용

UTILITY

기술 기본 원리: 전기 없이 물에서 수소 생산

기존 전기분해

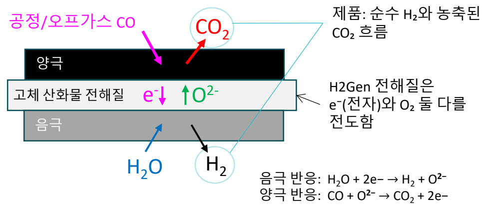


SOEC

Solid Oxide Electrolysis Cell

- 전기를 사용하여 H_2O에서 H_2 생산
- **새로운 전력 인프라 필요**
  - **높은 비용**
  - **제한된 규모**
  - **빠른 성능 저하**
  - **큰 설치 면적**

UTILITY 독자 기술



H2Gen®

전기 없이 물(H_2O)에서 수소 생산

- 가스 내 전기화학적 에너지를 이용한 H_2O → 수소 생산
- **기존 산업 자산과 통합됨**
  - **저비용**
  - **낮거나 음(負)의 탄소 집약도**
  - **전기 필요 없음**
  - **작은 설치 면적**

UTILITY

바이오가스 → 모빌리티 비교: H2Gen® vs. 스팀 메탄 개질(SMR)

더 낮은 수소 비용 및 제로 탄소 집약도

전환 과정	CI 점수 (kg CO_2e / kg H_2)	주요 요약 사항
SMR (스팀 메탄 개질) 바이오가스 공급원 → 표준 전처리 → RNG로 업그레이드 (CH_4를 CO_2에서 분리) $ (*H2Gen에는 고가의 업그레이드 장비가 필요하지 않음*) → SMR 수소 생산 (*SMR은 RNG를 H_2로 전환*) → H_2를 CO_2 & N_2에서 분리 $ (*H2Gen에는 고가의 후처리가 필요하지 않음*) → 순수 수소	6.9	**SMR** ▪ 고메탄 함량 가스만 전환할 수 있으므로 RNG 플랜트가 필요함 ▪ RNG 플랜트는 공정에 복잡성과 비용이 증가하는 추가 단계를 더함 ▪ RNG로 업그레이드 시 필요한 전력 및 관련 배출로 인해 CI가 증가함 ▪ 공정 가스 혼합물에서 H_2를 분리해야 하므로 비용이 증가함 ▪ 메탄 누출 때문에 RNG+SMR 경로는 PTC 요건을 충족하지 못함
독자 기술 H2Gen® 바이오가스 공급원 → 표준 전처리 → (*H2Gen은 업그레이드가 필요하지 않음*) → H2Gen 수소 생산 (*H2Gen은 바이오가스를 한 단계로 H_2로 전환*) → (*H2Gen은 고가의 분리 공정 없이 고순도 수소를 생산함*) → 순수 수소	~0[1]	UTILITY **H2Gen®** ▪ H2Gen은 인센티브를 극대화함 ▪ 운영적으로 단순하며, H2Gen에 필요한 표준 전처리 단계 ▪ H2Gen의 작은 설치 면적은 기존 인프라에 영향을 주지 않으며, SMR 설치 면적의 약 1/3 ▪ 복잡성 감소와 소형화로 인해 큰 비용 절감 ▪ SMR 대비 감소된 자본 비용(capex)

H2Gen은 SMR보다 훨씬 단순하고, 비용이 낮으며, 배출량도 적은 옵션을 제공함

UTILITY

1) 분석은 매립지 가스를 기준으로 수행됨.축산(낙농) 바이오가스의 경우 탄소 집약도(CI) 점수는 매우 음(負)값임.

가장 어려운 산업 부문의 경제적 탈탄소화

가스 투입물
- 공정 가스
- 오프가스
- 바이오가스

H_2O

농축된 CO_2 흐름
- ✓ 농축 CO_2 흐름(30%–95%)
- ✓ CCUS를 위한 포집 지점을 통합함

고순도 수소 사용 산업
- 이동수단
- 철강
- 화학
- 청정 액체 연료(SAF, 메탄올 등)

고객에게 제공되는 가치(Value Add)
- 기존 인프라와 공정을 탈탄소화
- 저가치 오프가스를 사용하여 물에서 청정 수소 생산
- 소형 설치 면적과 높은 운영 유연성을 가진 경제적 현장 수소 생산

투자자에게 제공되는 가치
- 동일한 H2Gen 시스템으로 여러 산업의 탈탄소화 수요를 해결
- 높은 프로젝트 확실성 – 수소 생산에 전력이 필요 없고, 새로운 전력 인프라나 인허가도 불필요
- 소규모부터 대규모 생산 능력까지 경쟁력 보유

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주요 자본 프로젝트 및 기술 상용화 경험을 갖춘 기업가적 문화
제조, 프로젝트 수행, 다양한 공학 분야, 세라믹, 전기화학, 다중 물리 시뮬레이션 분야 전문성
UTILITY


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WORLD HYDROGEN 6th EXPO 2025 Conference

Exploring New Hydrogen Storage and Distribution Solutions

Materials challenges in the Hydrogen Economy

Jens Eichler
Hydrogen Technology and Business Architect, 3M

Education

1995-2000 studied Materials Science at Technical University Darmstadt, Germany
2001-2003 PhD in Materials Science at Technical University Darmstadt, Germany in collaboration with Bosch
2004 Post- Doc at Indian Institute of Science, Bangalore, India

Professional Career

2005-2007 Senior Specialist for non-oxide ceramic materials at ESK, Kempten, Germany
2007-2013 Director Research and Development at ESK, Kempten, Germany
2011-2014 Lecturer at University of Applied Sciences, Kempten, Germany
2014-2024 Senior Scientist in the Corporate Research Materials Lab at 3M, Neuss, Germany
Since 2025 3M Hydrogen Technology and Business Architect at 3M Ventures, Neuss, Germany

Research Interest

Previous: Ceramics and Ceramics Processing
Functionally particle filled polymers for thermal management and interactions with electromagnetic waves
Additive Manufacturing
Current: Adhesives and Sealants for the assembly of electrolyzer and fuel cell
Adhesives for the assembly of liquid hydrogen tanks and system components
Materials science challenges in the hydrogen economy – materials for extreme conditions

Speech Summary

The Hydrogen Economy along the full value chain provides materials science challenges that can potentially be solved applying 3M's 49 technology platforms. Based on the customer need profile examples will be given how product optimization can solve these challenges.
In the case of storage and distribution one of the key challenges is assembly and insulation of liquid hydrogen tanks. To improve insulation performance of large storage tanks glass bubbles have proven to be an effective insulator combined with improved operational performance.
Epoxy adhesives provide low hydrogen permeability and superior performance at 20 Kelvin to allow assembly of components into a liquid hydrogen tank.
For compressed hydrogen tanks improved matrix resin can optimize the weight and/or hydrogen volume of the tank and adhesives assist in the assembly of the tank.
All these examples show how solving specific materials science challenges can offer potential to improve hydrogen system component performance relevant to the industry.

Company Introduction

3M was founded in 1902 in Minnesota, USA, and today is considered one of the most innovative companies worldwide. With 63,000 employees, the multi-technology company has a presence in many countries around the globe. The foundation of its innovative strength is the diverse use of 49 proprietary technology platforms. Today, the portfolio includes a wide range of products for almost every area of life. 3M can proudly look back on more than 132,000 patents over the course of its corporate history. The company has research and development facilities in 29 countries worldwide.


3M Science. Applied to Life.™
Materials Challenges
in the Hydrogen Economy
Dr. Jens Eichler, Hydrogen Technology & Business Architect
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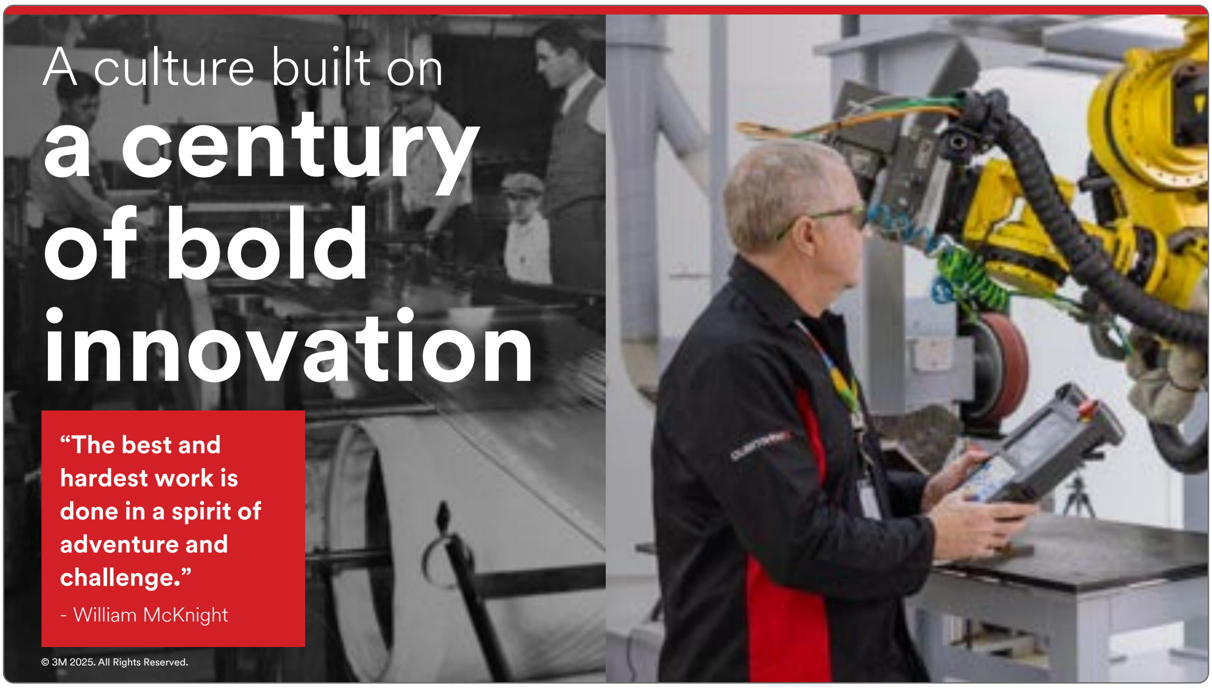
A culture built on
a century
of bold
innovation
"The best and hardest work is done in a spirit of adventure and challenge."
- William McKnight
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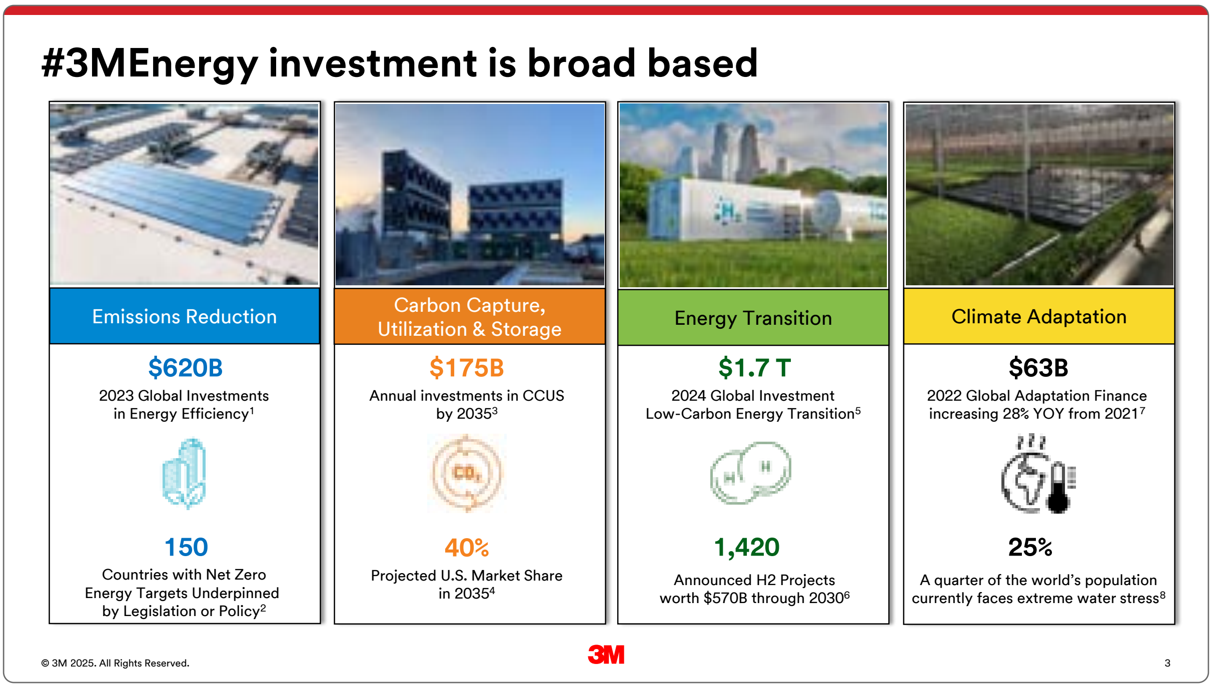
#3MEnergy investment is broad based
Emissions Reduction
$620B
2023 Global Investments in Energy Efficiency1
150
Countries with Net Zero Energy Targets Underpinned by Legislation or Policy2
Carbon Capture, Utilization & Storage
$175B
Annual investments in CCUS by 20353
CO2
40%
Projected U.S. Market Share in 20354
Energy Transition
$1.7 T
2024 Global Investment Low-Carbon Energy Transition5
H H
1,420
Announced H2 Projects worth $570B through 20306
Climate Adaptation
$63B
2022 Global Adaptation Finance increasing 28% YOY from 20217
25%
A quarter of the world's population currently faces extreme water stress8
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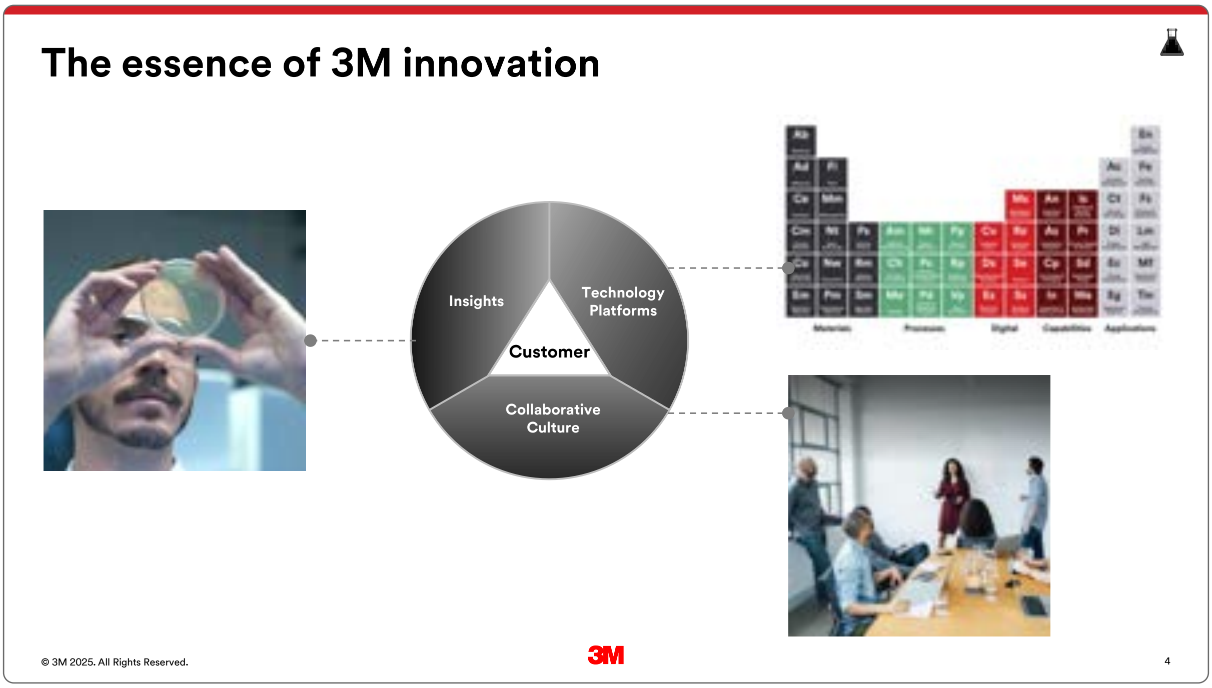
3


The essence of 3M innovation
Insights
Technology Platforms
Customer
Collaborative Culture
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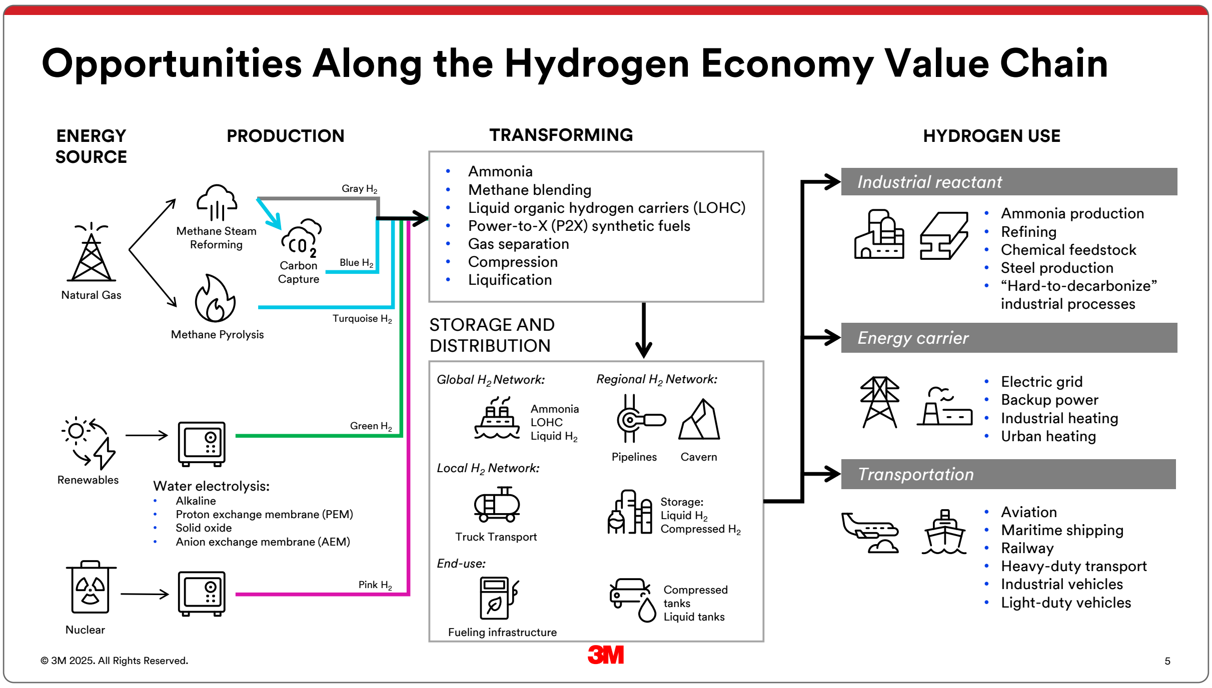
4


Opportunities Along the Hydrogen Economy Value Chain
ENERGY SOURCE
PRODUCTION
TRANSFORMING
HYDROGEN USE
Natural Gas
Methane Steam Reforming
Carbon Capture
Methane Pyrolysis
Gray H2
Blue H2
Turquoise H2
Renewables
Water electrolysis:
Alkaline
Proton exchange membrane (PEM)
Solid oxide
Anion exchange membrane (AEM)
Green H2
Nuclear
Pink H2
Ammonia
Methane blending
Liquid organic hydrogen carriers (LOHC)
Power-to-X (P2X) synthetic fuels
Gas separation
Compression
Liquification
STORAGE AND DISTRIBUTION
Global H2 Network:
Ammonia
LOHC
Liquid H2
Regional H2 Network:
Pipelines
Cavern
Local H2 Network:
Truck Transport
Storage:
Liquid H2
Compressed H2
End-use:
Fueling infrastructure
Compressed tanks
Liquid tanks
Industrial reactant
Ammonia production
Refining
Chemical feedstock
Steel production
"Hard-to-decarbonize" industrial processes
Energy carrier
Electric grid
Backup power
Industrial heating
Urban heating
Transportation
Aviation
Maritime shipping
Railway
Heavy-duty transport
Industrial vehicles
Light-duty vehicles
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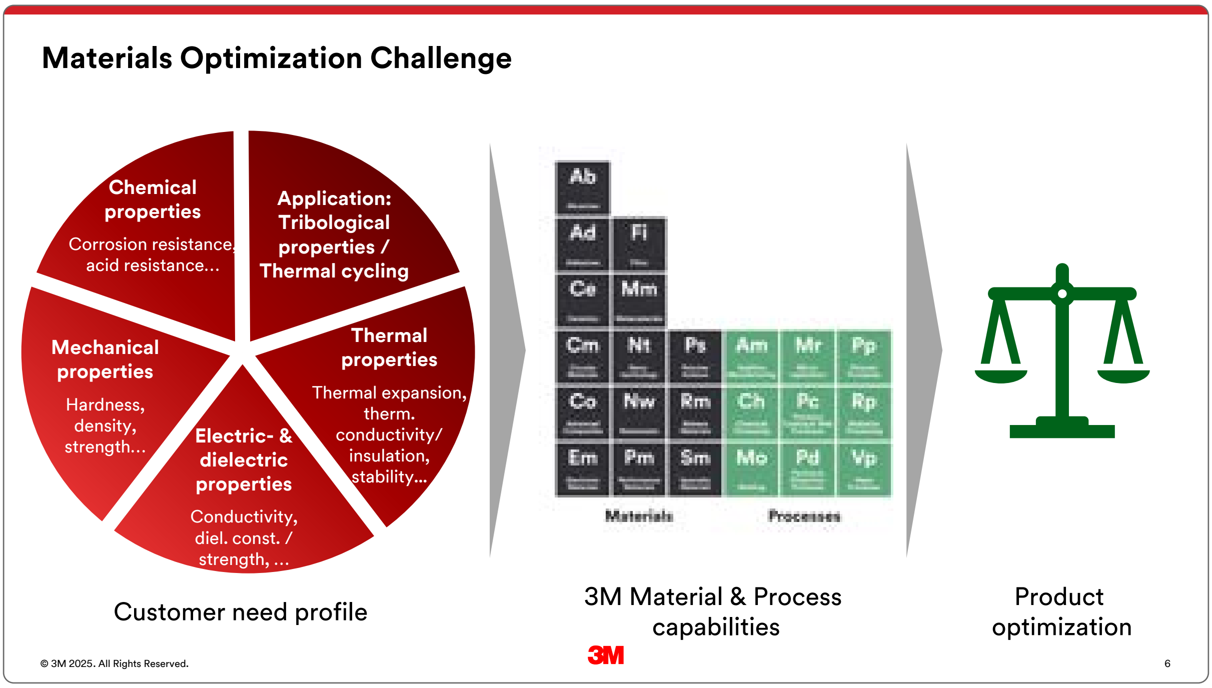
5


Materials Optimization Challenge
Chemical properties
Corrosion resistance, acid resistance...
Application: Tribological properties / Thermal cycling
Mechanical properties
Hardness, density, strength...
Thermal properties
Thermal expansion, therm. conductivity/ insulation, stability...
Electric- & dielectric properties
Conductivity, diel. const. / strength, ...
Customer need profile
Ab
Ad
Fi
Ce
Mm
Cm
Nt
Ps
Am
Mr
Pp
Co
Nw
Rm
Ch
Pc
Rp
Em
Pm
Sm
Mo
Pd
Vp
Materials
Processes
3M Material & Process capabilities
Product optimization
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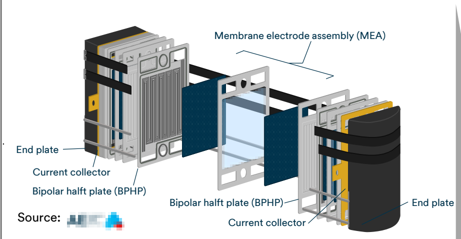
6

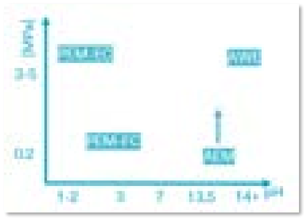
Adhesives for assembly of Electrolyzer and Fuel Cell



Customer need profile:
- Easy assembly at large scale
- Lifetime stability
- Enabling design
- End of life disassembly

1. Automated Assembly	▪Product form & specification ▪Application process
2. Hydrogen Readiness	▪Hydrogen specific characteristics ▪Permeability, poisoning, blistering
3. Application Requirements	▪Performance & lifetime customer specifications

3M Material & Process capabilities



Product optimization

3M

Evaluating 3M Material Platforms for H2

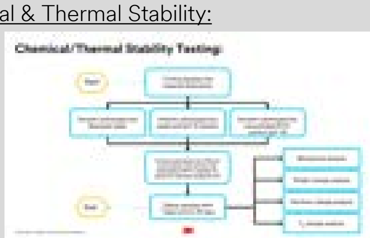
Low Hydrogen Permeability:

1. Epoxy
2. Polyurethanes
3. Acrylates
4. Silicones

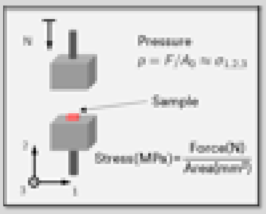
Catalyst Poisoning by Leachables or Volatiles:

Leachables and Volatiles → Analyze organic and ionic content → Evaluate effect on electro-chemical cell

Chemical & Thermal Stability:



Creep Stability using Accelerated Methods:



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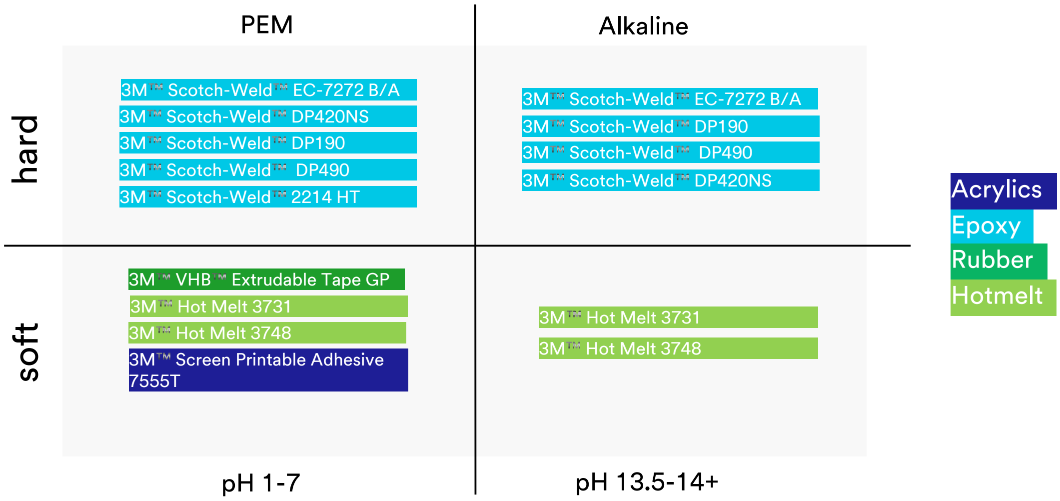
3M Solutions



 3M 9

Collaboration for Innovation: SupplHyInno Rhineland Cluster & HyInnoAEM Project

 3M 10

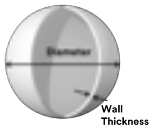
Glass bubbles as effective and stable insulation for Hydrogen Storage Tanks Leveraging a lightweight filler common in polymers

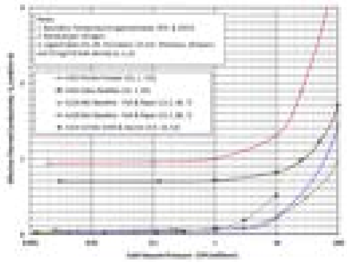
Customer need profile:

- Thermal Insulation:
  - blocking IR-radiation
  - reduced boil-off
- No thermal cycle damage
- Long term stability / package stability
- Easy / fast fill of in-between wall space

3M Material & Process capabilities

3M™ Glass Bubbles K1 for Cryogenic Insulations





Product optimization

Note: The information we are furnishing you is based on tests performed by a third-party at their facility and may be based on a limited sample size. Your results may vary due to differences in test types, conditions, systems, and facilities. See www. https://ntrs.nasa.gov/citations/20180006604 for more information.

3M

Adhesives for assembly of Liquid Hydrogen Storage Tanks

Customer need profile:

- Easy assembly of large components
- Adhesives for carbon fiber composites
- Adhesive performance from room temperature to -253°C
- Low hydrogen permeation

Low Hydrogen Permeability:

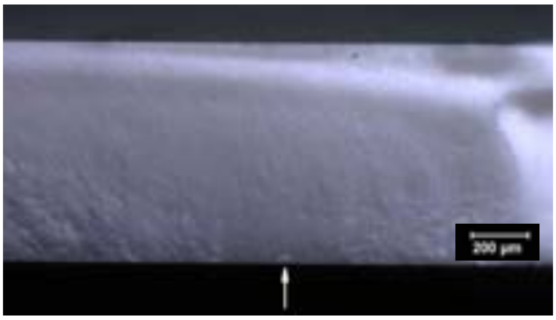
1. Epoxy
2. Polyurethanes
3. Acrylates
4. Silicones

3M Material & Process capabilities

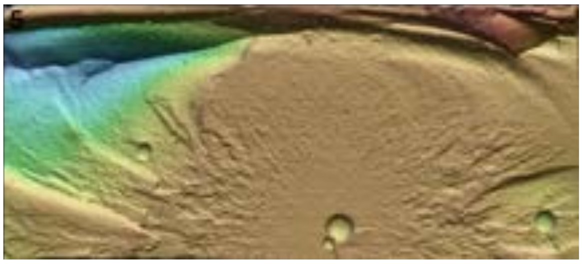
Product optimization

3M

Fracture Mechanics: Ceramics vs. Polymers @-253°C



Source: G. Quinn; J. Eichler; et al., J. Am. Ceram. Soc., 87 [3] 513–16 (2004)



Source: 3M internal testing of 2216 under Liquid Nitrogen in 4-point-bending

3M

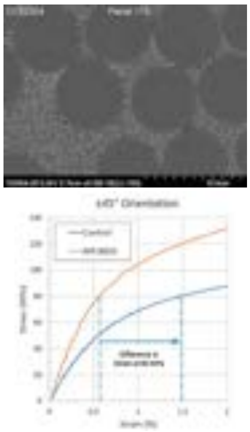
Matrix Resin for High Pressure Hydrogen Storage Tanks

Source: IKV at RWTH Aachen University

Customer need profile:

- Fast and easy processing of fibers and matrix resin
- Burst pressure 2x use pressure:
  - Fiber winding
  - Matrix resin
- Low cost – low fiber use
- Low hydrogen permeation

Status: 3M experimental material

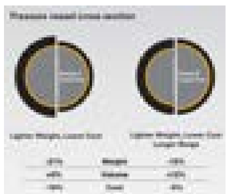


Source: J. Nelson et al., Jet Composites Magazine, N133 p.139-147 (2020)

3M Material & Process capabilities

Source: IKV at RWTH Aachen University

Potential impact of 3M Matrix Resin use on Tank Design:



Product optimization

3M

Additional 3M Solutions for the Hydrogen Economy

3M Pipeline Infrastructure Products
3M™ Scotchkoat™
for protection & flow efficiency

3M™ Silicon Nitride &
Silicon Carbide
Gas Seal Face

3M™ Silicon Carbide for
Chemical Pumps in the
Balance of Plant

3M™ Nextel ceramic fibers
providing strength and
stiffness up to 1000°C

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Contact: Jeichler@mmm.com

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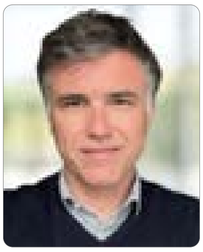
Exploring New Hydrogen Storage and Distribution Solutions 2

Large-scale liquid hydrogen technologies enabling intercontinental hydrogen transportation: Techno-readiness & economic assessment



Sébastien Lichtle
Director of LH2 Product Line,Air Liquide E&C

Education
Engineer's degree, Industrial Processes and Materials at INP Phelma
Grenoble (France)
1998 - 2001

Professional Career
As Director of the Liquid Hydrogen Product Line at Air Liquide Engineering & Construction, Sébastien leads a multidisciplinary team dedicated to delivering best-in-class technical solutions to customers both within the Air Liquide group and across the broader industry. His core responsibilities include managing the complete product and technology portfolio while spearheading the development of new, market-driven products.
Sébastien brings over 25 years of experience in Engineering and Cryogenic Technologies for the energy sector. His career has progressed through a variety of key roles, including
Principal Process Engineer, Manager of engineering for large-scale LNG and Natural Gas plants, and Director of Technology for LNG. A recognized expert in his field, he holds several patents for his innovations.

Research Interest
Technologies for Treatment and Liquefaction of gases, especially, Hydrogen, Helium and Natural Gas.

Speech Summary
Large-scale hydrogen liquefaction (XL LH2) is crucial for intercontinental transport. Current technologies are ready-for-offer up to 150tpd, significantly reducing TCO. Scaling to 300tpd is on track and promises TCO reductions exceeding 60%. Integration with reforming is ready, but integration with intermittent electrolysis requires developing flexible cryogenic operations.

Company Introduction
Air Liquide is a world leader in gases, technologies and services for industry and healthcare. Present in 60 countries with approximately 66,500 employees, the Group serves more than 4 million customers and patients.

Exploring New Hydrogen Storage and Distribution Solutions 3

BEYOND THE BOND, ADHESIVE SOLUTION FOR HYDROGEN APPLICATION

Hyunseob Shim
Lead Application Engineer, Henkel Korea

Education
2008~2014 Bachelor of Chemical Engineering, Soongsil Univ, Seoul, Korea

Professional Career
2009, Harvard Project for Asian and International Relationship Participant, Boston, USA
2009~2011, Soongsil International Ambassador, Soongsil Univ, Seoul, Korea
2012, New Generation Seminar, US Embassy, Seoul, Korea
2013, Internship, Henkel hotmelt adhesive R&D Center, Cheonan, Korea
2014~2019, Application Engineer of Industrial Assembly / General Manufacturing adhesive in Henkel Korea Innovation Center, Seoul, Korea
2022~Present, Lead Application Engineer of General Manufacturing / MRO adhesive in Henkel Korea, Innovation Center, Seoul, Korea

Research Interest
1. Fluid application management by Adhesive
2. Design initiative and automation solution by adhesive (Instant bonding, Light cure adhesive, 2 component silicone)
3. Pipe sealing and repair by adhesive (No need to replace new component, but by adhesive only)
4. Protective coating solution by adhesive (Chemical resistance coating, Better reliability)
5. Cost saving and value proposition by adhesive to MRO industry (Power plant, Oil and gas, Steel, Mining)
6. Chemical resistance coating solution by adhesive
7. Light weight and Design innovation by adhesive (Vehicle, Appliance, Motor)

Speech Summary
1. Customer pain point at hydrogen application – high pressure sealing & leakage
   - Compressor, Fitting, C&T sealing, Connector etc
   - Proven data for reliability at various fluid applications and industry by Adhesive
2. Traditional solution (Mechanical assembly) vs. Adhesive solution
   - Theoretical principle
   - Design guideline
3. Value point (Performance, Reliability) Adhesive vs. Mechanical parts
4. Global Case History by adhesive solution (Fluid, Hydrogen)

Company Introduction
Henkel Adhesive Technologies is world's No.1 producer in adhesives, sealants and functional coatings for industrial customers as well as consumers and craftsmen. Henkel's LOCTITE Hydrogen Ready Solutions effectively tackle the challenges in hydrogen industries. Built on over 70 years of Henkel's expertise in industrial sealants, our solutions are driven by a commitment to enhance industrial reliability and sustainability. We have been rigorously tested to ensure safety and reliability and meeting the stringent performance requirements of KIWA GASTEC QA AR 214 for admixtures up to and including 100% hydrogen gas.

LOCTITE

HYDROGEN SEALING SOLUTIONS

05.DEC,2025
LEAD APPLICATION ENGINEER
LUCAS SHIM

BEYOND THE BOND

HYDROGEN ECONOMY CRITICAL SUCCESS FACTORS

SAFETY & ENVIRONMENT	COMPATIBILITY	EFFICIENCY
Leakage	Testing	System efficiency
Pressure hazards	Materials compatibility	Durability
Hydrogen embrittlement	Approvals	Automation

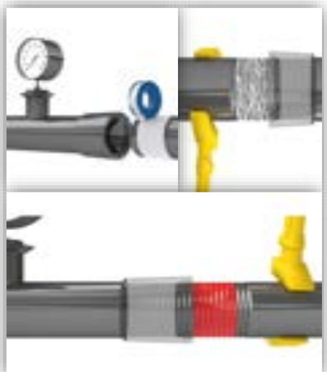
LOCTITE **BEYOND** THE BOND

CONVENTIONAL METHOD

LOCTITE

BEYOND THE BOND

CONVENTIONAL METHOD, WHY FAILED?



LOCTITE

BEYOND THE BOND

THREAD SEALING

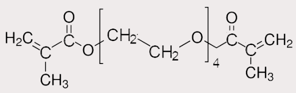
Traditional Solutions

Mechanical Seal | EPDM seal | Cone & Thread

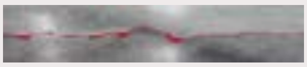
- Most H_2 pipework made of stainless and connections are typically welded or use flanged pipe connections
- Tube connections are typically assembled with costly cone & thread fittings and PTFE tape
- Certain components (like H_2 sensors) can't be welded and require threaded connections where H_2 leak prevention can be compromised:
  - Mechanical seals require tight tolerances and minor defects lead to leaks
  - EPDM seals can lose sealing properties over time
  - PTFE Tape can shred and leak
  - Cone & Threads are costly and susceptible to loosening

LOCTITE Solution

Value Proposition

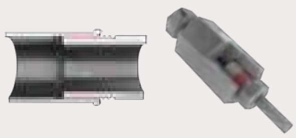


- Anaerobic sealants based on dimethacrylate esters are chemically compatible with hydrogen



- Anaerobics fill all the air spaces between the threads, resulting in an effective and reliable leak-proof, vibration-resistant seal
- Solution tested and approved both at customers and at external lab

Design Guidelines

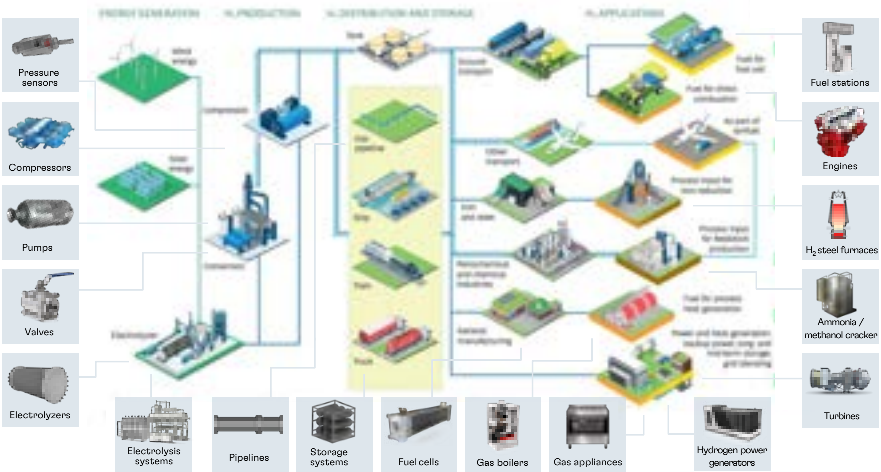


NPT (tapered threads)

- NPT connections are recommended
- When tightened, threaded connections enable metal to metal and eliminating leak pathways
- This design limits H_2 contact with the adhesive thus eliminating the contamination risk

LOCTITE BEYOND THE BOND

HYDROGEN ECOSYSTEM AND TARGET DEVICES



LOCTITE® BEYOND THE BOND

CERTIFICATION WITH KIWA

Kiwa is a Dutch **certification body** that provides testing, inspection, certification, consulting and training services in various markets.

Certified according to KIWA GASTEC QA AR 214 for use on metallic threaded joints in pressure class 8 hydrogen gas systems:

- LOCTITE 55
- LOCTITE 567
- LOCTITE 577
- LOCTITE 638

certifications available in select countries

LOCTITE® BEYOND THE BOND

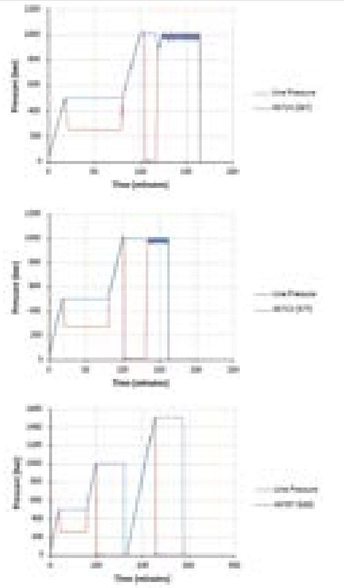
HENKEL TEST RESULTS

High Pressure

- LOCTITE 567, LOCTITE 577 and LOCTITE 638 have been tested in this testing setup.
- Tests confirmed the ability of our products to effectively seal threaded connections at very high operating pressures.
- Typically, maximum operating pressures in the most demanding "real-life" applications don't exceed **700 bar**
- We therefore also have the ability to **provide a safety coefficient for the most extreme applications.**

Product	500 bar (7,252 psi)	1000 bar (14,504 psi)	1500 bar (21,756 psi)
LOCTITE 567	60 mins	17 mins*	-
LOCTITE 577	60 mins	[illegible] mins*	-
LOCTITE 638	60 mins	60 mins	60 mins

*Pressure variation observed at time indicated, test discontinued

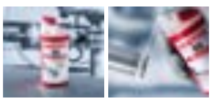


LOCTITE

BEYOND THE BOND

HYDROGEN READY THREAD SEALANTS

LOCTITE 55

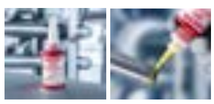


White, non-curing **thread sealing cord** provides immediate full pressure sealing. Allows reliable re-adjustments without leakage. **Ideal for BSPT and NPT pipe threads.**

LOCTITE 567

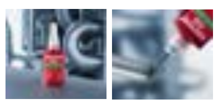
White, high viscosity **anaerobic curing paste** thread sealant. Provides instant low-pressure seal. Seals and locks metal threaded pipes and fittings. Allows for easy disassembly. **Ideal for NPT pipe threads**

LOCTITE 577



Yellow, high viscosity **anaerobic curing paste** thread sealant. Provides instant low-pressure seal. Seals and locks metal threaded pipes and fittings. Allows for easy disassembly. **Ideal for BSPT and NPT pipe threads.**

LOCTITE 638



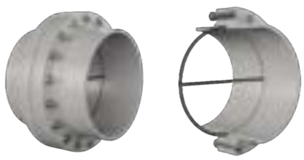
Green, medium viscosity **anaerobic curing adhesive** with high shear strength. Typically used to retain bearings on shafts, but also ideal for thread sealing and locking applications in **high pressure and/or extreme environments.** Ideal for BSPT and NPT pipe threads.

LOCTITE

BEYOND THE BOND

FLANGE SEALING

Traditional Solutions

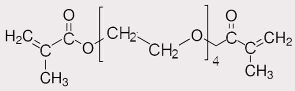


Pre-cut gasket

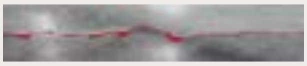
- Most H_2 pipework made of stainless, connections are typically welded or use flanged pipe connections. In addition many H_2 compressors and valves utilize performed gaskets on flanged connections.
- Preformed seals are costly, require tight tolerances and small defects cause leakage.
- Preformed seals / gaskets lose their sealing properties over time and may not fully conform to surface roughness, creating possible leak paths

LOCTITE Solution

Value Proposition

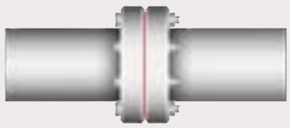


- Anaerobic sealants based on dimethacrylate esters are chemically compatible with hydrogen



- Anaerobics fill all the air spaces between the threads, resulting in an effective and reliable leak-proof seal
- Solution tested and approved both at customers and at external lab

Design Guidelines



- Flanges normally are flat, raised. Need to apply the product correctly to ensure the seal
- When tightened, the flanges allow for metal-to-metal contact, eliminating leak paths and increasing the stiffness and strength of the connection.
- This design limits H_2 contact with the adhesive thus eliminating the contamination risk

LOCTITE

BEYOND THE BOND

FLANGE SEALING TEST PROCESS

LOCTITE 510, LOCTITE 518, LOCTITE 574

The LOCTITE Hydrogen Ready Flange Sealants were evaluated by an independent third-party laboratory to assess their performance in hydrogen environments. Tests were performed on 304 stainless steel raised flanges, where the sealed assemblies were pressurized with 100% hydrogen gas and closely monitored for pressure drops under two sequential conditions, varying in pressure and temperature.

Product	Step 1			Step 2		
	Pressure	Temperature	Duration	Pressure	Temperature	Duration
LOCTITE 510	41 bar	Ambient	18 hrs.	20 bar	80°C	6 hrs.
LOCTITE 518	41 bar	Ambient	18 hrs.	20 bar	80°C	6 hrs.
LOCTITE 574	41 bar	Ambient	18 hrs.	20 bar	80°C	6 hrs.

LOCTITE

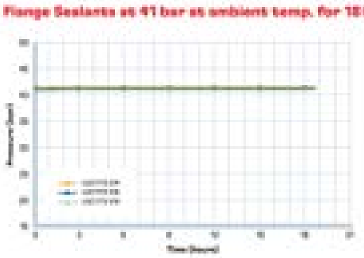
BEYOND THE BOND

FLANGE SEALING TEST RESULTS

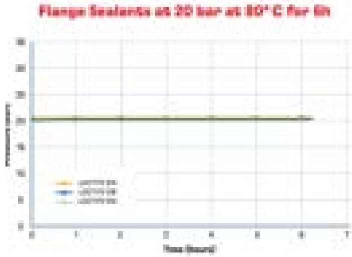
LOCTITE 510, LOCTITE 518, LOCTITE 574

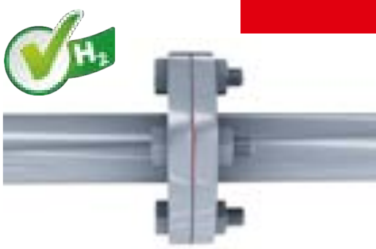
Throughout the testing period, no pressure drops were observed, confirming the LOCTITE Hydrogen Ready Flange Sealants provide consistent, reliable, and leak-free sealing performance against hydrogen under demanding conditions.

Flange Sealants at 41 bar at ambient temp. for 18 h



Flange Sealants at 20 bar at 80° C for 6h





LOCTITE

BEYOND THE BOND

HYDROGEN READY FLANGE SEALANTS

LOCTITE 510

LOCTITE® 510 is a **pink** high viscosity anaerobic curing flange sealant for close fitting, rigid metal flanges. **Ideal for steel, stainless steel & cast iron surfaces.** Fills gaps up to 0.25 mm. Provides instant low-pressure seal. Resists temperatures up to **400°F (204°C).**

LOCTITE 518

LOCTITE® 518 is a **red gel**, semi-flexible anaerobic curing flange sealant for close fitting, rigid metal flanges. **Ideal for steel, stainless steel & aluminum surfaces.** Fills gaps up to 0.25 mm. Provides instant low-pressure seal. Resists temperatures up to **300°F (150°C).**

LOCTITE 574

LOCTITE® 574 is an **orange** high viscosity anaerobic curing flange sealant for close fitting, rigid metal flanges. **Ideal for steel, stainless steel & cast iron surfaces.** Fills gaps up to 0.25 mm. Provides instant low-pressure seal. Resists temperatures up to **300°F (150°C).**

LOCTITE — BEYOND THE BOND

CUSTOMER APPLICATION CASE HISTORY

THREAD SEALING HYDROGEN AT HIGH PRESSURE

(Spain)

- Compressor
- Thread Sealing H_2 @ 1000 bar
- SS (AISI 316) ¼" and ½" NPT
- Reliability, no leak issue
- Loctite 638

THREAD SEALING OF VARIOUS FITTINGS

(UK)

- Burners and heaters
- Thread Sealing of pipe fittings of heating equip. utilizing H_2
- Be DVGW EN751-1 certified
- Loctite 577

THREAD SEALING AT HIGH TEMPERATURES

(Portugal)

- Hydrogen purifier device
- Thread Sealing to withstand 250°C and 40 bar pressure hydrogen gas
- Loctite 278 and Loctite 565

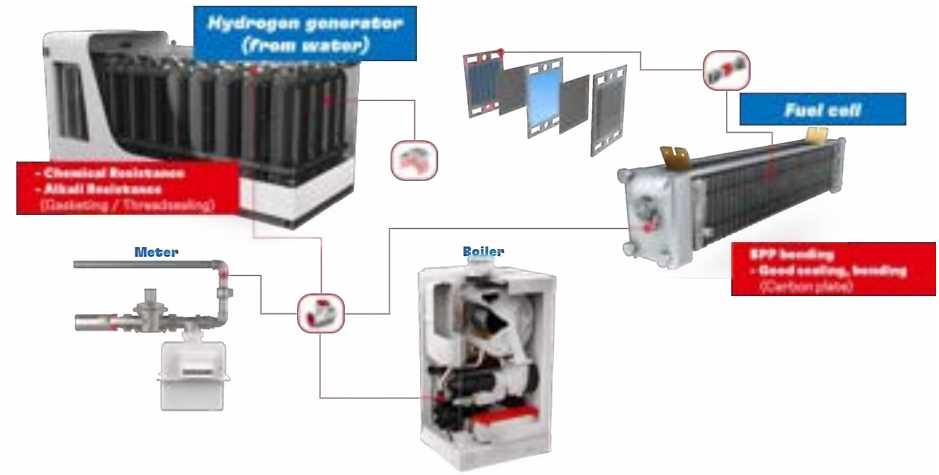
HIGH PRESSURE THREAD SEALING

(Portugal)

- Hydrogen refuel stations
- Connection between H_2 bottles, compressor and refuel system (700 bar)
- Loctite 565 + tape

LOCTITE — BEYOND THE BOND

ELECTRORYSER, FUEL CELL



LOCTITE. BEYOND THE BOND

THANK YOU

LOCTITE. BEYOND THE BOND

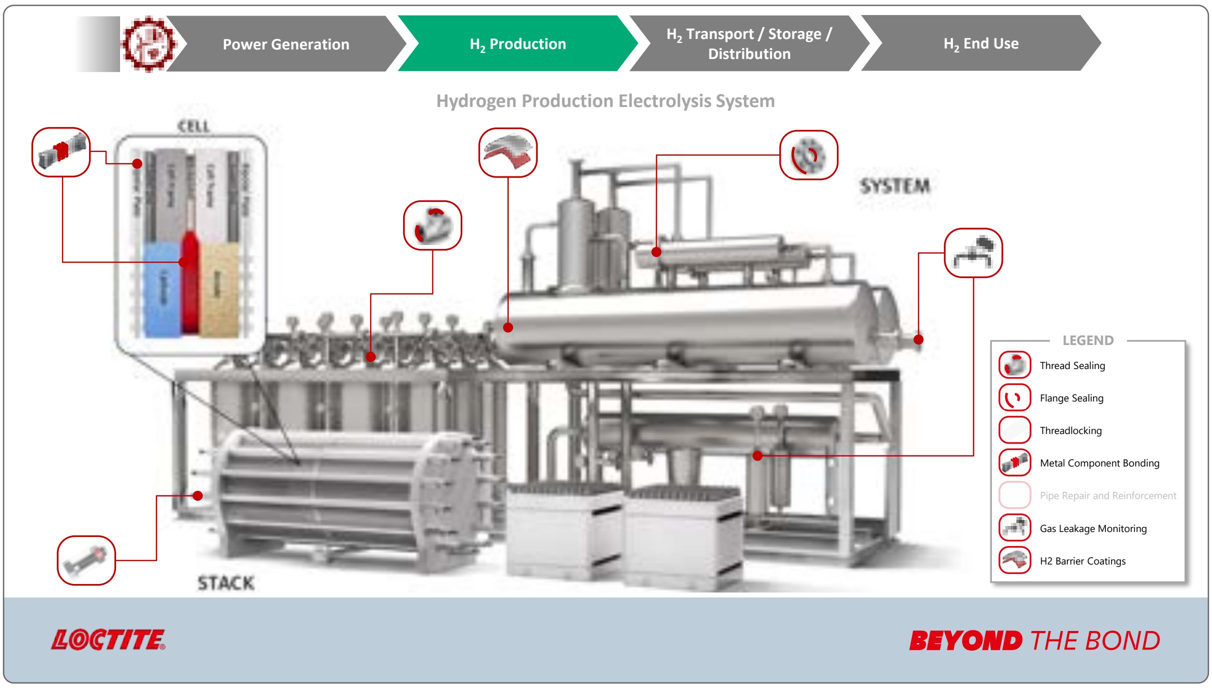
ADHESIVES, SEALANTS, COATINGS & MONITORING H_2 OPPORTUNITIES

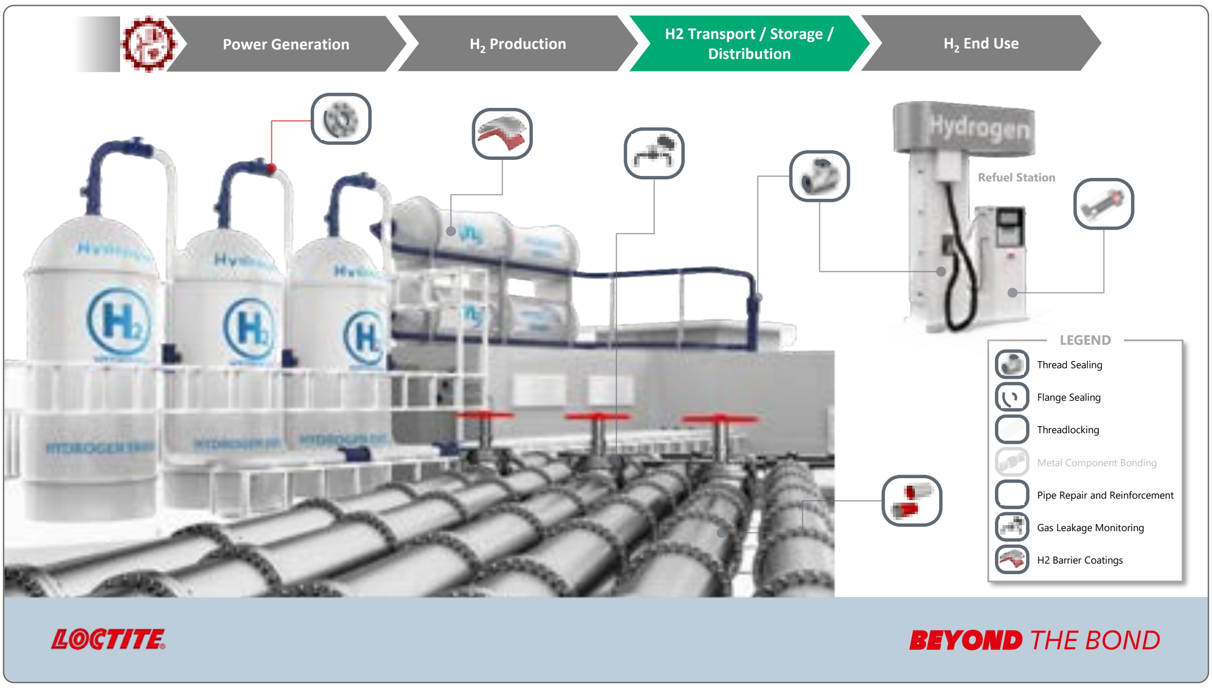
● Available
○ Under Development

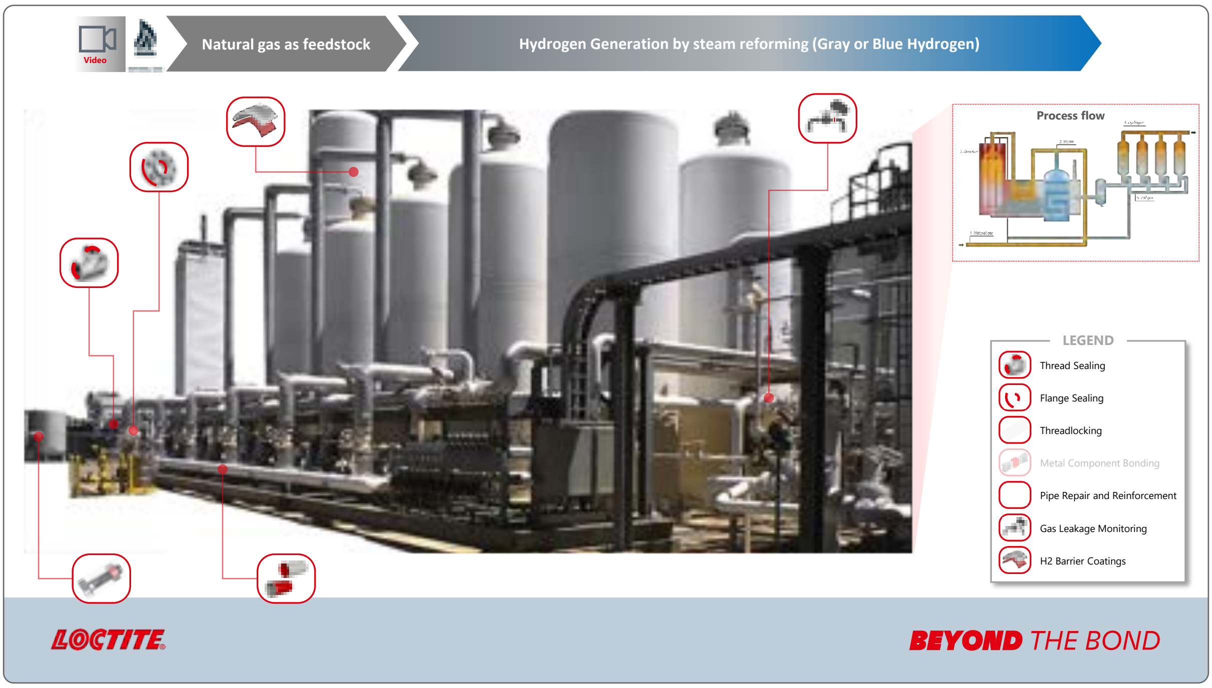
Applications \ Target Device	H_2 Production: Electrolyzers	H_2 Production: Electrolysis Systems	H_2 Transport / Transmission / Storage / Distribution: Valves	Compressors	Pumps	Pressure Sensors	New H2 Pipelines	Current CH4 Pipelines	Storage Systems	Fuel Stations	H_2 End Use: Fuel Cells	Gas Boilers	Gas Appliances	Engines	Power Generators	Turbines	Ammonia Crackers	Steel Furnaces	Mobility Drive Trains
Thread Sealing	●	●	●	●	●	●			●	●	●	●	●	●	●	●	●		●
Flange Sealing	●	●	●	●	●		●	●	●	●	●			●	●	●	●	●	●
Threadlocking	●	●	●	●	●				●	●	●	●	●	●	●	●	●	●	●
Component Bonding & Sealing	○										○								
Pipe Protection*							○	○											
Gas Leakage Monitoring		●	●						●	●					●	●	●	●	
H_2 Barrier Coatings	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○

Pipe Protection - Internal Lining, External Protection, External Pipe Repair*

LOCTITE — BEYOND THE BOND




Power Generation
H2 Production
H2 Transport / Storage / Distribution
H2 End Use
Hydrogen
Refuel Station
LEGEND
Thread Sealing
Flange Sealing
Threadlocking
Metal Component Bonding
Pipe Repair and Reinforcement
Gas Leakage Monitoring
H2 Barrier Coatings
LOCTITE
BEYOND THE BOND


Video
Natural gas as feedstock
Hydrogen Generation by steam reforming (Gray or Blue Hydrogen)
Process flow
LEGEND
Thread Sealing
Flange Sealing
Threadlocking
Metal Component Bonding
Pipe Repair and Reinforcement
Gas Leakage Monitoring
H2 Barrier Coatings
LOCTITE
BEYOND THE BOND

Exploring New Hydrogen Storage and Distribution Solutions 4

Case Study & Research for Hydrogen Refueling Station Performance Test Apparatus

Moonbeom Heo
Team Leader, TÜV SÜD KOREA

Education
2009-2011, Master's degree, Chung-ang University, Korea
1999-2008, Bachelor's degree, Chung-ang University, Korea

Professional Career
10/2020 - Present, TUV SUD KOREA Ltd., Team Leader
11/2020 – 10/2020, Hyundai Motor Company, Senior Manager
01/2012 – 11/2020, Hyosung Heavy Industries, Manager

Research Interest
Technical feasibility analysis of hydrogen facilities
Hydrogen charging system design
Rotating body (High Voltage Motor) Inspection/Certification
Wind turbine component, assembly QA / QC

Speech Summary
Although hydrogen refueling stations are expanding, systematic performance verification remains insufficient. Some early stations fail SAE J2601 and metering uncertainty fuels consumer distrust. This study compares global cases, highlighting the need for simplified methods, accurate metering, and standardized procedures to enhance reliability and global alignment.

Company Introduction
TÜV SÜD is a global leader in safety and certification with 26,000+ employees and 600 hydrogen experts in 20+ countries. The company provides end-to-end hydrogen services across the value chain, from green production and storage to mobility, infrastructure, and international standardization

Case Study & Research for Hydrogen Refueling Station Performance Test Apparatus

2025 World Hydrogen Expo (H2 MEET)

Mun-Beom, Heo / Team Leader TÜV SÜD KOREA

**Add value.
Inspire trust.**

CONTENTS

TÜV SÜD at a glance

15,000+
technical experts

150+
years of safety, security & sustainability

1,000+
locations worldwide

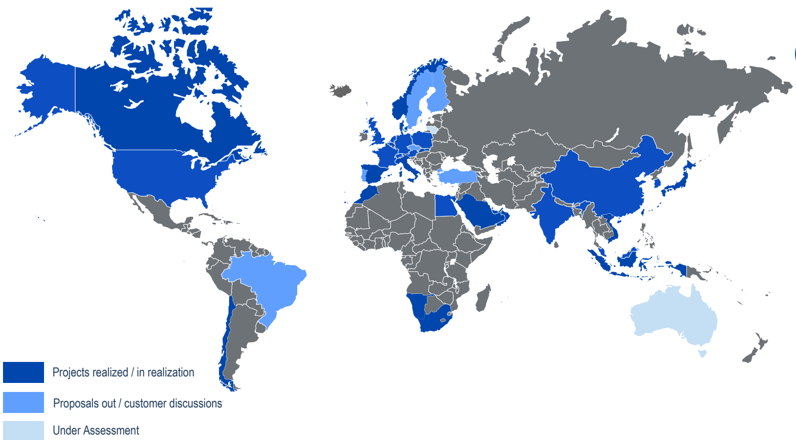
26,000+
TÜV SÜD employees

€2.9
billion in annual revenue

100 %
independent & impartial

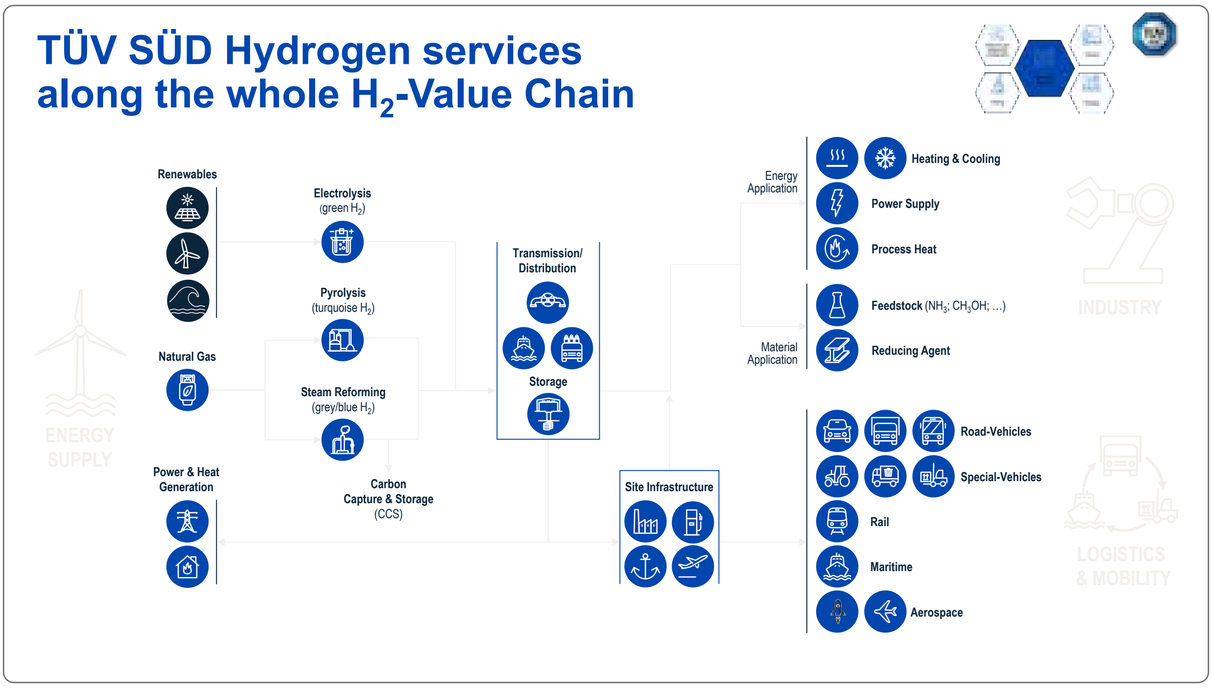
600+ Hydrogen Experts
Global Footprint in 20+ countries
Pioneers in H2 safety & Green Hydrogen Certification (2011, CertifHy, CMS70)

The TÜV SÜD Hydrogen story – Using our international expert network to help companies safely access the hydrogen market

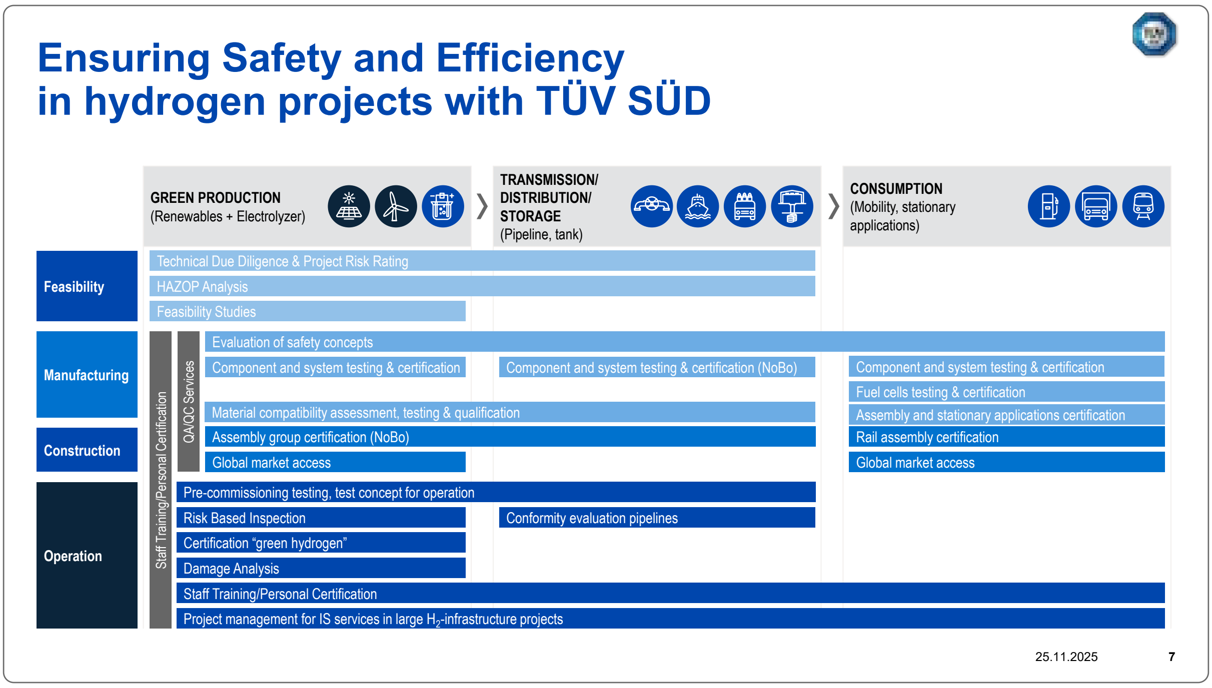


- **~ 600 experts** with relevant hydrogen know-how and strongly growing
- **Hydrogen activities in >20 countries** from strategy until operation
- **New services** based on market needs (e.g. green/low carbon H2, H2-ready)
- **Active memberships** in e.g. Hydrogen Council, Hydrogen Europe and Dii
- **Investor projects**: TDD, Trainings, market and fund evaluation

Hydrogen capabilities along the value chain 25.11.2025 4


TÜV SÜD Hydrogen services along the whole H2-Value Chain
Renewables
Electrolysis (green H2)
Pyrolysis (turquoise H2)
Natural Gas
Steam Reforming (grey/blue H2)
Carbon Capture & Storage (CCS)
Power & Heat Generation
ENERGY SUPPLY
Transmission/ Distribution
Storage
Site Infrastructure
Energy Application
Heating & Cooling
Power Supply
Process Heat
Material Application
Feedstock (NH3; CH3OH; ...)
Reducing Agent
INDUSTRY
Road-Vehicles
Special-Vehicles
Rail
Maritime
Aerospace
LOGISTICS & MOBILITY


TÜV SÜD Hydrogen services along the whole H2-Value Chain
Production
Transmission
Storage & Site infrastructure
End Use: Industry and mobility
• Electrolyzer solutions: from design to operation
• Plant Safety Solutions for hydrogen production (blue, turquoise, pink)
• Carbon Capture & Storage
• European Hydrogen Backbone: 50+ projects in the largest pipeline H2 infrastructure in Europe
• Hydrogen readiness for materials and components in critical infrastructures
• H2 strategy and Ecosystem development
• Design review
• Manufacturers & supply chain assessment
• Feasibility assessment
• Construction supervision
• Hydrogen Handling and storage in complex infrastructures
• Salt caverns and site storage
• Hydrogen refuelling stations
• Integrated hydrogen systems for aviation infrastructure
• Gaseous and cryogenic H2 tanks
• Safe applications of Hydrogen in hard-to-abate industry (steel, cement, glass, etc…)
• H2 ready for thermal power plants
• Hydrogen use in railway (storage, safety concepts)
• Hydrogen storage systems in passenger cars, light and heavy duty vehicles
• Fuel cells
• Aerospace


Ensuring Safety and Efficiency
in hydrogen projects with TÜV SÜD
GREEN PRODUCTION
(Renewables + Electrolyzer)
TRANSMISSION/
DISTRIBUTION/
STORAGE
(Pipeline, tank)
CONSUMPTION
(Mobility, stationary
applications)
Feasibility
Manufacturing
Construction
Operation
Staff Training/Personal Certification
QA/QC Services
Technical Due Diligence & Project Risk Rating
HAZOP Analysis
Feasibility Studies
Evaluation of safety concepts
Component and system testing & certification
Component and system testing & certification (NoBo)
Component and system testing & certification
Fuel cells testing & certification
Material compatibility assessment, testing & qualification
Assembly and stationary applications certification
Assembly group certification (NoBo)
Rail assembly certification
Global market access
Global market access
Pre-commissioning testing, test concept for operation
Risk Based Inspection
Conformity evaluation pipelines
Certification "green hydrogen"
Damage Analysis
Staff Training/Personal Certification
Project management for IS services in large H_2-infrastructure projects
25.11.2025
7


TUV SUD Consulting Service
Global hydrogen business and technical support
Overseas Maket
Energy, Infra, Industry Trend and Policy, Regulation Analysis
Policy / Regulation
Relevant Laws and Regulatory, Permits, Licensing Procedures
Competitor & Player
Global and local Competitor / Player, Benchmarking, JV Possibility
Code / Gap Analysis
Korea Import/Export Support and KGS Code Gap Study/Analysis
Technial Feasibility
Investigate applicable technologies and infrastructure environments
Economic Analysis
CAPEX/OPEX Estimation and IRR, NPV, B/C Analysis, etc
Risk Analysis
Identify and respond to Political/Financial/Operational risks
Hydrogen Import
Carbon emissions Verification of overseas hydrogen Import
H_2

CONTENTS

HRSTA (Hydrogen Refueling Station Test Apparatus)

HRSTA ?

A vehicle simulation test apparatus for verifying the performance and safety of hydrogen refueling stations

HRSTA Key Function

- Fuelling Protocol(SAE J2601) Compliance Test
- Evaluation of HRS system safety and metering accuracy

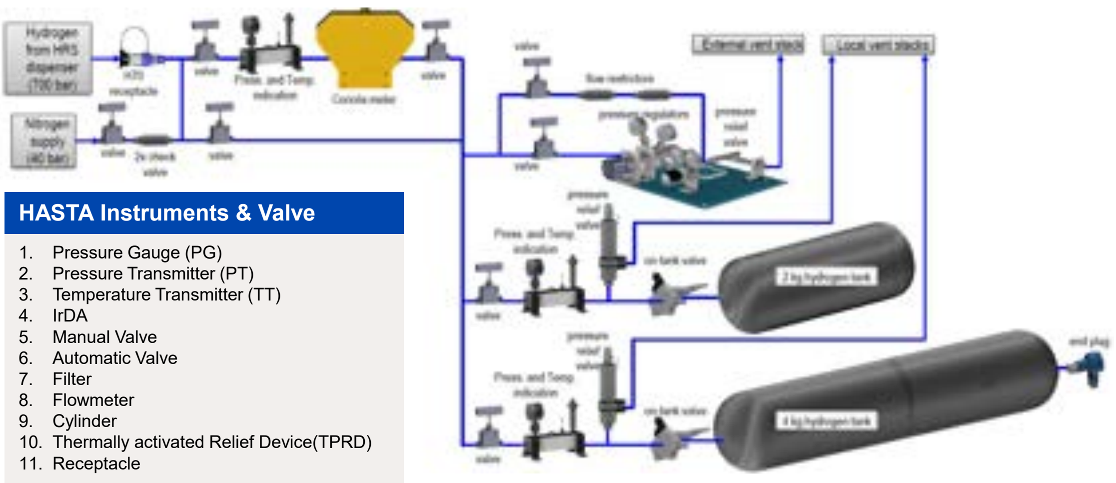
Status & Backgound

- Performance variations occur across HRS
  : Differences in system design and construction methods lead to varying performance
- Lack of international compliance and absence of domestic standards
  : Some early stations do not meet international fueling protocol requirements
- Measurement errors occur
- Growing consumer distrust and concerns regarding gas metering accuracy
- Diverse fueling conditions
  : Increasingly complex conditions due to various mobility applications

Need & Importance

- **Evaluation Criteria** : Unified performance evaluation is needed.
- **Safety Assurance** : Standardize and verify station performance.
- **Consumer Trust** : Accurate metering reduces concerns.
- **Environment Adaptation** : Tools for diverse mobility required.
- **Global Competitiveness** : Ensure compatibility with international standards.

HRSTA System Configuration



HASTA Instruments & Valve

1. Pressure Gauge (PG)
2. Pressure Transmitter (PT)
3. Temperature Transmitter (TT)
4. IrDA
5. Manual Valve
6. Automatic Valve
7. Filter
8. Flowmeter
9. Cylinder
10. Thermally activated Relief Device(TPRD)
11. Receptacle

* Reference : TUV SUD (NEL) HRS light duty FTS

CONTENTS

Relevant Standards & Codes

Domestic(Korea)

Enforcement Rule of the High-Pressure Gas Safety Control Act

KGS Code FP217

International

ISO 19880-1

SAE J2601

Domestic(Korea) Standards & Codes

Enforcement Rule of the High-Pressure Gas Safety Control Act [Effective Date : May 19, 2025]

Article 2 (Definitions of Terms)

The term **"Charging Safety Performance Evaluation Apparatus"** refers to equipment used to conduct safety performance tests and evaluations of hydrogen refueling protocols for hydrogen vehicles. Such protocols regulate the hydrogen refueling process according to the permissible temperature and pressure within the vessel so that hydrogen can be charged safely.

Article 3 (Methods of Confirmation, etc.)

Notwithstanding paragraph (1), a hydrogen refueling facility for which a technical review by the KGS is in progress as of the effective date of this Notice, or which has undergone such technical review prior to the effective date, may have its charging safety performance confirmed by substituting the results of another hydrogen refueling facility equipped with charging equipment and charging logic of the same specification.

* Reference : Enforcement Rule of the High-Pressure Gas Safety Control Act

Domestic(Korea) Standards & Codes

Special Provisions on the Operation of Safety Performance and Measurement Performance Evaluation Apparatus for Hydrogen Vehicle Refueling Stations [Effective Date : July 13, 2023]

Article 4 (Special Provisions on Standards)

An evaluation apparatus that satisfies all of the following standards may be used to charge hydrogen at hydrogen vehicle refueling stations.

Safety Valve

GAS / Flame Detector

Pressure Gauge

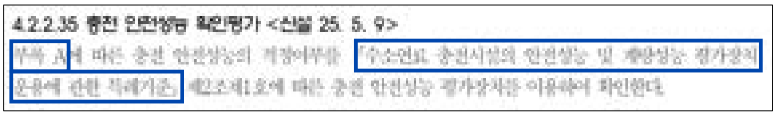
Explosion Proof(KCs)

Vent Stack

* Reference : Enforcement Rule of the High-Pressure Gas Safety Control Act

Domestic(Korea) Standards & Codes

KGS FP 217 - Standards for Facilities, Technology, and Inspection of Storage-type Hydrogen Fueling


4.2.2.35 충전 안전성능 확인평가 <신설 25. 5. 9>

4.2.2.35 Verification and Evaluation of Charging Safety Performance [Newly Established on May 9, 2025]

The appropriateness of charging safety performance, in accordance with Appendix A, shall be verified using a charging safety performance evaluation apparatus as prescribed in Article 2, subparagraph 1 of the *Special Provisions on the Operation of Safety Performance and Measurement Performance Evaluation Apparatus for Hydrogen Vehicle Refueling Stations*.

* Reference : KGS Code FP 217

International Standards & Codes

ISO 19880-1 : Gaseous hydrogen – Fueling Station, Part 1 : General requirements

Clause 12 (HRS Inspection and Performance Test Procedures)

12.1 General
As part of commissioning prior to opening the station for use by the public,
the hydrogen fuelling station shall be inspected and tested as detailed in 12.2 to 12.6
to ensure compliance with the requirements of this document.
If specific factory acceptance tests are not conducted, or not acceptable,
these tests shall be performed as part of the site acceptance testing (SAT).
The commissioning of the hydrogen fuelling station is not complete
until all inspection and test results demonstrate compliance with requirements as defined above.

12.5 Fuelling safety and performance testing
The fuelling test shall be performed using a hydrogen station test apparatus (HSTA) or equivalent equipment that can simulate a vehicle. The HSTA shall be capable of testing according to the fuelling protocol in use (e.g., SAE J2601).

Annex J (Basic Design and Guideline of HRSTA)

The communications system may also be designed to send faulty temperature or pressure signals to determine if the dispensing system will adapt and perform safe fill in the event of faults in the communications signal from the vehicle (HSTA).
— Hydrogen storage systems that have at a minimum rated capacity of between 4 kg to 7 kg hydrogen at 70 MPa and 15 °C.
— Ideally, the pressure drop should be within 17 MPa to 19 MPa to be representative of the worst-case conditions being encountered in vehicles currently.

* Reference : ISO 19880-1:2020

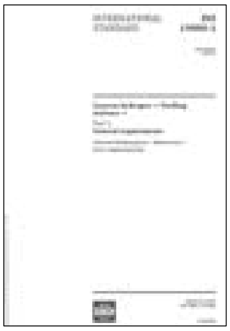
Domestic vs. International Standard

For HRSTA Components & Function

* Reference
1) Enforcement Rule of the High-Pressure Gas Safety Control Act
2) ISO 19880-1:2020

Enforcement Regulations of the High Pressure Gas Safety Management Act

VS



ISO 19880-1

HRSTA Components / Function	Domestic	International
Storage Tank	O	O
Receptacle	O	O
Valves (Manual, PRV, etc.)	O	O
TPRD (Thermally activated pressure relief device)	X	O
Pressure Gauge/Sensor	O	O
Temperature Gauge/Sensor	X	O
Vent Stack	O	O
H2 Gas Detector	O	O
H2 Flame Detector	O	X
Filter	X	O
IrDA System (SAE J2799)	X	O
Pressure Drop	X	O
Certificate	O	X

Domestic standards focus on “Safety,”
while international standards cover both “Safety” & **“Performance.”**

Domestic vs. International Standard

For HRSTA Test Contents

* Reference
1) KGS FP 217

KGS Code FP 217

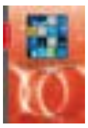
Test Division	Description
Termination of fuelling	Fuelling shall terminate within **5 seconds** after receiving an abort signal.
Communication → Non-communication	During fuelling, the system shall **switch to non-communication mode within 0.5 s** and shall not return to communication mode.
Data error	In case of **abnormal communication**, fuelling shall stop or switch to non-communication mode. - CRC frame errors and data loss beyond SAE J2799 allowance shall be monitored.
Measurement of hydrogen vehicle capacity	**Hydrogen vehicle capacity shall be measurable.** If the measured value and the calcul-ated value are inconsistent, fuelling shall be stopped within 5 seconds.
CHSS temperature	Fuelling shall stop when CHSS temperature goes out of the range **−40 to 85 ℃.**
CHSS pressure	Fuelling shall stop when CHSS pressure goes out of range. This includes cases where the **initial pressure is below 0.5 MPa**, when the initial pressure is set higher than the service pressure, or when the pressure **exceeds 87.5 MPa.**
SOC	Fuelling shall stop if **SOC exceeds 100%.**
Fuel mass (general)	**Before fuelling,** the amount of hydrogen shall be more than **200 g/s**, and the fuelling rate **during operation** shall be more than **60 g/s.**
Fuelling table	**Target pressure and APRR** shall be correctly set and verified.
Non-communication fuelling	In non-communication mode, hydrogen vehicle capacity shall be measurable, or **manual capacity setting shall be available** if measurement is difficult.

These are also same as ISO 19880-1

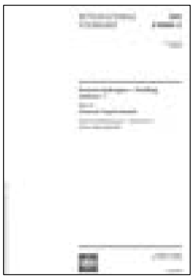
Domestic vs. International Standard

For HRSTA Test Contents (KGS FP 217 vs ISO 19880-1)

* Reference
1) Enforcement Rule of the High-Pressure Gas Safety Control Act
2) ISO 19880-1:2020



VS



ISO 19880-1

Test item	Description
Measurement of hydrogen vehicle capacity	It shall be verified that the tank volume estimated by the apparatus is within ±15% of the actual value.
Pre-cooling capacity	Verify cooling capacity is sufficient, e.g., during back-to-back fuelling.
High APRR fuelling	Simulate high fuelling rate by lowering ambient temperature or overriding APRR. Check max APRR and mass flow peak. Repeat ≥ 2 times with vessel temperature monitoring.
Low APRR fuelling	Simulate low fuelling rate by raising ambient temperature or overriding APRR. Check min APRR and mass flow control at high pressure. Repeat ≥2 times.
Top-off fuelling	At low initial pressure (~3 MPa), verify target pressure, APRR, and temperature control during final fuelling stage.

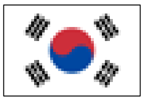
→ It is also necessary to refer to the specific evaluation items specified in ISO 19880-1.

CONTENTS

Case Study and Status of HRSTA

* Reference
1) Monthly Hydrogen Economy: "Hy-PAS," a performance evaluation device that enhances the safety of hydrogen charging infrastructure.

Country
: South Korea



Divsision	Description
Equipment	Hy-PAS(Hydrogen station – Performance Assessment System) (2022)
Development	KGS(Korea Gas Safety Corporation) → Developed with reference to Hy-StEP and CSA-HDTA
Features	• Test for SAE J2601 Protocol & HRS Safety • Capable of testing up to 20kg • MFC wass applied at the Vent Stack • All electrical instruments complaint with KCs Explosion Proof
Application	It planned for phased utilization after institutionalization in May 2025

Reference picture

Case Study and Status of HRSTA

Country
: Taiwan

Division	Description
Equipment	HRSTA (Hydrogen Refueling Station Test Apparatus) (2023)
Developer	ITRI (Industrial Technology Research Institute, Taiwan)
Features	• Equipped with 35 MPa receivers for both truck and passenger vehicle applications • Safety evaluation for pressure, explosion, and thermal hazards completed by TÜV SÜD UK
Application	Currently under use : Performance evaluation in progress at Taiwan's first HRS with TÜV SÜD participation

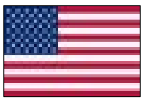
Reference picture

It is recommended that a safety evaluation (Risk assessment, FMEA, etc) be performed on any HSTA prior to use.

Case Study and Status of HRSTA

* Reference
1) Powertech
2) HyStEP

Country
: USA



Division	Description
Equipment	HyStEP (Hydrogen Station Equipment Performance) (2015)
Developer	Led by the U.S. DOE (Department of Energy) : Developed and manufactured by Powertech Labs. Later upgraded in Canada as the CSA-HDTA model (2017).
Features	• Designed and operated in accordance with DOE safety requirements. • In use since the early implementation of fuelling protocols. • Mounted on a mobile trailer, capable of visiting multiple stations to verify protocol performance and supply conditions.
Application	In active use : Verified 22 hydrogen refueling stations through the California Air Resources Board(CARB).

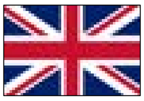
Reference picture

It is recommended that a safety evaluation (Risk assessment, FMEA, etc) be performed on any HSTA prior to use.

Case Study and Status of HRSTA

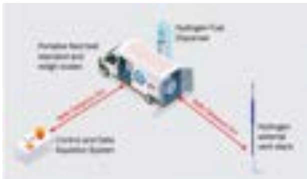
* Reference
1) TÜV SÜD NEL

Country
: UK



Division	Description
Equipment	NEL LD HFTS (Light Duty Hydrogen Field Test Standard) (2021)
Developer	MetroHyVe government project (Metrology for Hydrogen Vehicles) : TÜV SÜD NEL (National Engineering Laboratory, UK). → Heavy-Duty version under development.
Features	• Safety assessment conducted by TÜV SÜD NEL in accordance with UK safety regula tions (PSSR, DSEAR, etc.) • Focus Accuracy verification of hydrogen refuelling for passenger car HRSs • Capable of verifying SAE J2601 fuelling protocol (4–6 kg range) • Complies with OIML R139 (International Fuel Measurement Standard)
Application	Actively used in Europe : Serving as a reference infrastructure standard for hydrogen measurement.

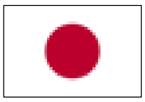
Reference picture



Case Study and Status of HRSTA

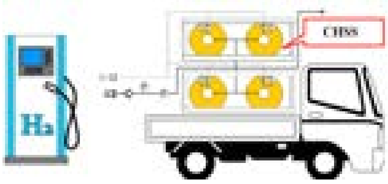
* Reference
1) HySUT

Country
: JAPAN



Division	Description
Equipment	HySUT Test Truck
Developer	HySUT (Hydrogen Supply/Utilization Technology Association) : the standardization of the hydrogen industry and the establishment of institutional frameworks in Japan
Features	• Designed and manufactured in accordance with HySUT-G 0004/0003 standard • Validates hydrogen refueling station performance through JPEC-S 0003 protocol tests • Verifies dispenser metering accuracy through gravimetric and metering-based calibrat ion • Capable of visiting multiple stations to verify
Application	Extensively used in Japan, with more than 60 successful deployments

Reference picture



HySUT Test Truck

Test Apparatus

CONTENTS

Conclusion and Insight

Institutionalization and Action Plan

Korea institutionalized HRSTA only in May 2025 despite many HRS already in place. Clear action plans are required for existing stations, making HRSTA more critical. Currently only one HRSTA is owned by KGS, so simplification of equipment and government support are essential for wider adoption.

Industry Awareness Improvement

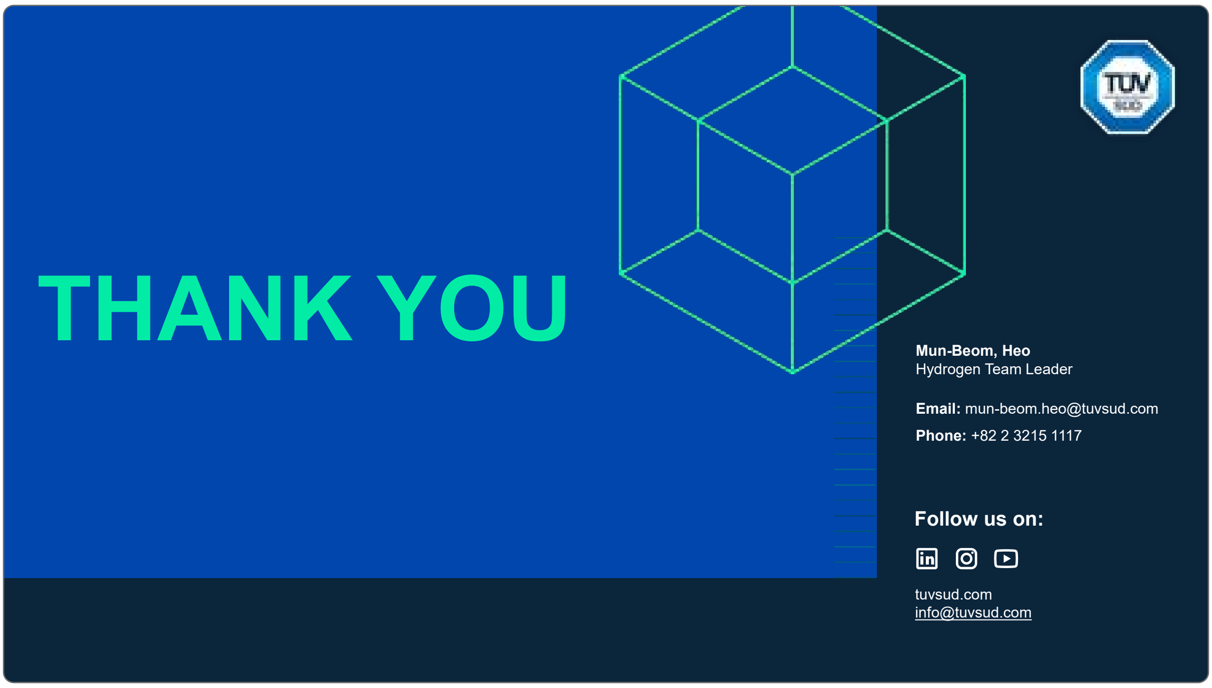
Industry stakeholders must improve awareness: beyond safety (KGS Code), performance assurance should be proven through third-party evaluation or self-declaration, with reference to international standards such as ISO.

Consumer Trust Enhancement

Accurate metering via HRSTA is vital to resolve consumer distrust and enhance public acceptance of hydrogen refueling

Leadership in International Standards

Future performance evaluation criteria should cover diverse mobility applications, sequential and simultaneous fuelling, enabling Korea to lead and contribute to international standards.


THANK YOU
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Follow us on:
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info@tuvsud.com

Exploring New Hydrogen Storage and Distribution Solutions 5

“Industrializing Hydrogen Storage for Global Mobility” How OPmobility is enabling the next generation of zero-emission transport

Chanjoo Park
Asia Managing Director, Opmobility

Exploring New Hydrogen Storage and Distribution Solutions 6

TBD

Mikaa Blugeon-Mered

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