The 2nd International Workshop on Liquefied Hydrogen Technology

Report

October, 2018

Japan Ship Technology Research Association

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1 Introduction

To realize a large-scale hydrogen-utilization society in the future, the establishment of efficient technologies on hydrogen production, delivery, storage and utilization are necessary, and liquefied hydrogen is expected to be one of the most important delivery and storage technologies.

To promote industry-academia cooperation on liquefied hydrogen technology and to accelerate R&D, the world-first "International Workshop on Liquefied Hydrogen Technology" was held in March 2015, resulting in the promotion of information exchange among researchers and engineers. Since then, Japan's efforts on realizing a large-scale hydrogen-utilization society have been accelerated, with the initiation of the liquefied hydrogen supply-chain demonstration and the announcement of national "Hydrogen Basic Strategy" at the end of 2017.

To support these efforts, "The 2nd International Workshop on Liquid Hydrogen Technology" was organized, providing key companies and researchers with an opportunity on comprehensive discussion and exchange of opinions on liquefied hydrogen technologies. The workshop became a forum for experts and stakeholders to share many latest knowledge and information on the technology.

The 2nd International Workshop on Liquefied Hydrogen Technology

Date, Time	October 24 (Wed), 2018 9：30～17：00
Venue	Hotel Crown Palaise Kobe
Organizer	Japan Ship Technology Research Association
Co- Organizer	Japan Science and Technology Agency

2 Program

Welcome address	
9:30 –9:45	Mr. Bunro Shiozawa Deputy Program Director, Energy Carriers, SIP (Cross-ministerial Strategic Innovation Promotion Program)
	Mr. Noriyoshi Okaguchi Vice-Mayor of Kobe City
Keynote（Introduction of projects and technical trends related to liquefied hydrogen in Japan and abroad）	
9:50 –10:15	"Hydrogen Scaling Up" Mr. Yasunori Kotani（Representative speaker: Mr. Aoi Miyake） Chief Engineer, Department 3, Technology Development Division 5 Honda R&D Co., Ltd. Automobile R&D Center（Hydrogen Council）
10:15 –10:40	"Introduction of Hydrogen Strategy and Activities of Relating Projects by NEDO" Mr. Katsumi Yokomoto Project Manager, Director, Fuel Cell and Hydrogen Technology Group, Advanced Battery and Hydrogen Technology Dept. NEDO
10:40 –11:05	"United States Liquefied H_2 Activities" Dr. Jay Keller President and CEO, Zero Carbon Energy Solutions, Inc. (Former Manager of Hydrogen Research Development, Sandia National Laboratories)
11:05 –11:30	"Trends & Activities towards a hydrogen oriented economy - European & Norwegian prospects and perspectives" Dr. Steffen Møller-Holst Vice President Marketing, SINTEF (Chairman Transport Pillar, FCHJU, Chairman, Norwegian Hydrogen Forum)
11:30 –11:55	"China's Progress in Application of Liquefied Hydrogen" Dr. Sifeng Yang（Representative speaker: Mr. Yaozhong Zhao） Deputy Director, Beijing Institute of Aerospace Testing Technology
Lunch Break（11:55-13:30）	
Session on R&D in the world（Current status of R&D on liquefied hydrogen technologies）	
13:30 –13:55	"H_2 Energy — At the heart of the energy transition" Mr. Jean-Claude Joyeux Director, Engineering & Projects, Hydrogen Energy Business Unit, Air Liquide
13:55 –14:20	"Realization of the Hydrogen Energy Society ~Iwatani Activities for Liquid Hydrogen~" Mr. Yasuhiro Nakajima Assistant General Manager, New Energy Technology & Development Technology & Engineering Division, Iwatani Corporation
14:20 –14:45	"Technologies for large-scale hydrogen liquefaction - Enabling H_2 mobility" Mr. Umberto Cardella Process Engineering, Linde Kryotechnik AG
Coffee Break（14:45-15:15）	
Session on marine transportation of liquefied hydrogen（Current status of marine transportation technologies of liquefied hydrogen and safety issues）	
15:15 —15:40	"International Liquefied Hydrogen Supply Chain" Dr. Motohiko Nishimura Chief Administrative Officer, Senior Manager, Technology Development Department CO_2-free Hydrogen Energy Supply-chain Technical Research Association (HySTRA)
15:40 –16:05	"International Liquefied Hydrogen Supply Chain" Mr. Noriaki Usui Director, Dangerous Goods Transport Office, Inspection and Measurement Division, Maritime Bureau, MLIT
16:05 –16:30	"Development of transfer arms for marine transportation of liquefied hydrogen" Mr. Akihiko Inomata Manager, Section1, Environmental System Research Department, Technical Institute Corporate Technology Division, Kawasaki Heavy Industries, Ltd.
16:30 –16:55	"Safety assessment of LH2 cargo handling operation" Dr. Noriyuki Aoyama Senior Consultant, Research & Consulting Group, Japan Marine Science Inc.
Closing address	
16:55 –17:00	Mr. Nobumitsu Kambayashi President Japan Ship Technology Research Association

Welcome address "SIP, Energy Carrier Program"
Bunro Shiozawa, Deputy Program Director, SIP

Welcome address "Hydrogen Smart City Kobe Initiative"
Noriyoshi Okaguchi, Vice-Mayor of Kobe City

General view of the meeting room

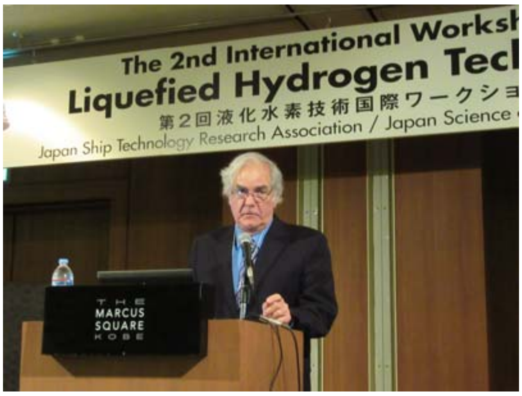
Speakers

Bunro Shiozawa
Deputy Program Director, Energy Carriers, SIP

Noriyoshi Okaguchi
Vice-Mayor of Kobe City

Aoi Miyake
Hydrogen Council/Honda R&D

Katsumi Yokomoto
NEDO



Jay Keller
Zero Carbon Energy Solutions, Inc.

Steffen Møller-Holst
SINTEF

Yaozhong Zhao
Beijing Institute of Aerospace Testing Technology

Jean-Claude Joyeux
Air Liquide

Yasuhiro Nakajima
Iwatani Corporation

Umberto Cardella
Linde Kryotechnik

Motohiko Nishimura
HySTRA

Noriaki Usui
Ministry of Land, Infrastructure, Transport and Tourism

Akihiko Inomata
Kawasaki Heavy Industries, Ltd.

Noriyuki Aoyama
Japan Marine Science Inc.

Nobumitsu Kambayashi
Japan Ship Technology Research Association

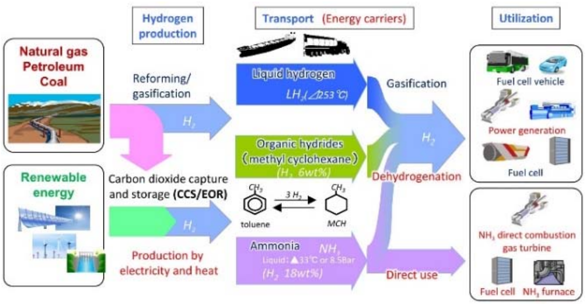
3 Welcome address

3-1 "SIP (Energy Carriers)"

Bunro Shiozawa,

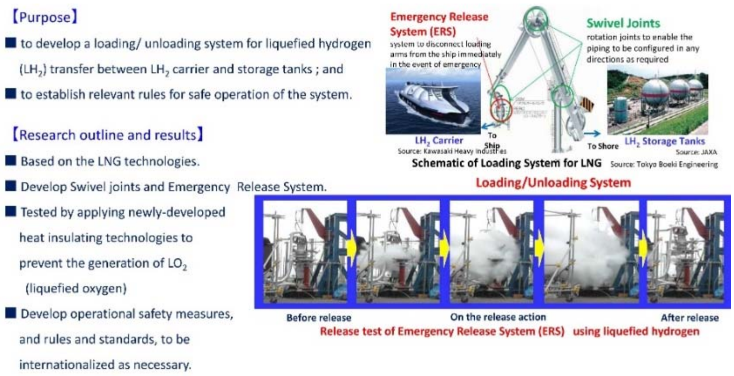
Deputy Program Director, Energy Carriers, SIP

- At the 21st Conference of the Parties (COP21) of the Framework Convention on Climate Change, Prime Minister Abe mentioned hydrogen production, storing and delivery as an important technology for a CO_2-free society. In addition, in December 2017, Japan announced the world's first 'Hydrogen Basic Strategy'. The visions of "Hydrogen Basic Strategy" were also mentioned in Japan's "Strategic Energy Plan", revised in July, 2018. The Energy Plan also mentioned hydrogen delivery, hydrogen power generation and industrial application of hydrogen.
- "Strategic Innovation Creation Program (SIP)" launched by "Integrated Science and Technology Innovation Conference" selected 10 key technologies, one of which is "energy carrier", covering all hydrogen supply chain developments. Its basic policy is to build a "CO_2 free hydrogen chain". In this CO_2-free hydrogen chain, hydrogen is produced either by the reformation of foreign fossil, fuels such as brown coal and natural gas, with using CCS (carbon dioxide capture and storage) technology, or by electrolysis using renewable energy. For the transportation to Japan, hydrogen carrier technologies of liquefied hydrogen (LH2), organic hydride, or ammonia will be applied. In the case of ammonia, direct combustion and ammonia fuel cell will be used for applications.



Vision of CO2 free hydrogen value chains

- One of energy carrier research themes is the development of loading arm for LH2. Based on technologies for liquefied natural gas (LNG) loading arm, LH2 loading arm is designed specifically for safe handling and operation with extremely-low-temperature LH2. The Japan Ship Technology Research Association is in charge of the development of international standard developments.



Development of Loading System for Liquefied Hydrogen and the Relevant Rules for Its Operation

3-2 “Hydrogen Smart City Kobe Initiative”
Noriyoshi Okaguchi,
Vice-Mayor of Kobe City

- Kobe City's CO_2 reduction target in 2030 is 34%, higher than the national target of 26% (compared to 2013). For that target, the City promotes three major policies for: (1) energy conservation, (2) renewable energy, and (3) innovative technologies related to energy conservation / renewables.
- Kobe City has promoted the concept Hydrogen Smart City". Kobe’s local companies have committed to hydrogen from the early stage, and the City has provided supports, including provision of demo sites, coordination of component suppliers, and outreach to improve social acceptance.
- At "Hydrogen Supply Chain Building Demonstration Project", hydrogen will be produced from Australian brown coal, and transported to northeast part of Kobe Airport Island. We are aiming to develop the world's first long-distance large-volume liquefied hydrogen transport and to construct liquefied hydrogen transfer system.
- "Hydrogen energy utilization system development demonstration project" aims to develop an energy system that supplies electricity and heat by gas turbine power generation to provide heat and alacrity to public facilities such as hospitals. In April 2018, we succeeded in supplying electricity and heat by driving with the world's first 100% hydrogen.
- At City’s “Hydrogen Cluster Study Group” hydrogen related industries are working on information exchange, and on prototype development. The City thinks environment and energy fields, including hydrogen, as one of the growth industries, providing support on prototyping and business.
- Hydrogen will contribute to build environmentally-friendly city, as well as to promote Kobe economy, to improve energy security, to expand business opportunities of local small and medium enterprises, and to create new jobs. I believe it will make a big contribution. I would like to pursue these efforts in Kobe City, to make the City the number one in the world.

4 Keynote

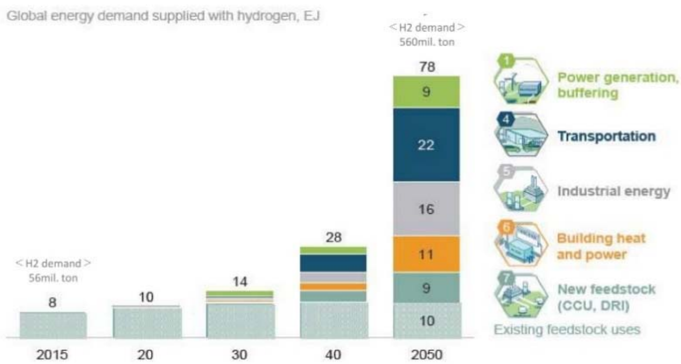
4-1 "Hydrogen Scaling Up"

Yasunori Kotani (Representative: Aoi Miyake)
Chief Engineer, Department 3, Technology Development Division 5
Honda R&D Co., Ltd. Automobile R&D Center (Hydrogen Council)

- The Hydrogen Council is an initiative aimed at reducing CO_2 by utilizing hydrogen, established at the World Economic Forum in January 2017 (Davos Conference). Thirteen companies (Japanese companies: Toyota, Honda, Kawasaki Heavy Industries) were founded members, and membership has also expanded with 33 steering members (Japanese participating companies: Iwatani Corporation, JXTG Energy), supporting members 20 companies (new participating Japanese companies: Toyota Tsusho, Marubeni, Mitsubishi Corporation, Mitsubishi Heavy Industries, Mitsui & Co., Sumitomo Mitsui Banking Corporation, Sumitomo Corporation).
- In November 2017, the Hydrogen Council announced the roadmap "Hydrogen, Scaling Up" on full-scale deployment of hydrogen. With the introduction of a large amount of hydrogen, by 2050 hydrogen utilization will be responsible for about 1/5 of the total energy consumption and can reduce CO_2 emissions by about 6 billion ton/year (compared to the current situation). The market size of hydrogen will be 2.5 trillion dollars, creating 30 million jobs.

Hydrogen Vision for 2050（Hydrogen, Scaling up）

- At present, hydrogen demand is about 8 EJ/year, but it expands to 78 EJ in 2050.



Hydrogen demand by 2050（Hydrogen, Scaling up）

- Contribution of hydrogen to CO_2 reduction in 2050 is 60 ton/year. The transport sector is the largest, 32 ton/year (1.7 billion ton/year for passenger cars and 800 million ton/year for trucks).
- In the transport sector, compared to ICE and BEV, FCEV has advantages over cruising distance and fuel supply time. Hydrogen technology has begun to spread in FCV and cogeneration, and in the transport sector it expands to large vehicles and vessels around 2030. Hydrogen power generation will start to spread after 2025, and hydrogen steel will start to spread after 2030.

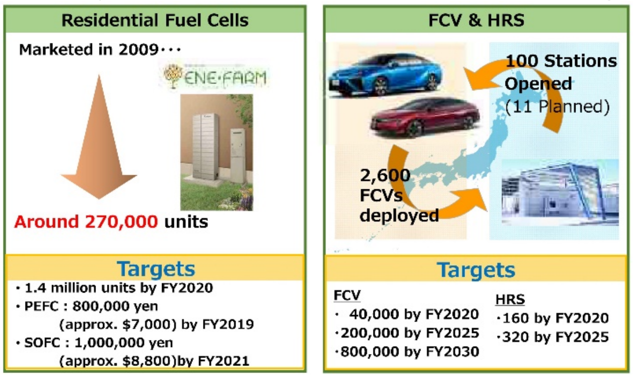
4-2 "Introduction of Hydrogen Strategy and Activities of Relating Projects by NEDO"

Katsumi Yokomoto

Project Manager, Director, Fuel Cell and Hydrogen Technology Group, Advanced Battery and Hydrogen Technology Dept.

New Energy and Industrial Technology Development Organization（NEDO）

- Yesterday (October 23rd), the world's first Hydrogen Energy Ministerial Meeting was held in Tokyo, a total of 31 countries/regions/international organizations discussed the utilization of hydrogen, and announced the Tokyo Statement.
- Japan's "Hydrogen Basic Strategy", announced in December 2017, shows the vision toward 2050. For hydrogen costs, Japan aims for \$3/kg in 2030 and \$2/kg in 2050.
- Hydrogen and Fuel Cell Strategy Roadmap, announced by the Ministry of Economy, Trade and Industry (METI), indicates that a dramatic expansion of hydrogen utilization in Phase 1, and full-scale introduction of hydrogen power generation and establishment of a large-scale hydrogen supply chain in Phase 2. In Phase 3, we are aiming to establish a CO_2-free hydrogen supply system. Today at Phase 1, and 270,000 stationary fuel cells are already in the market. The deployment target for 2020 is 1.4 million. Also today, 2,600 FCVs are on the road, with the target of 40,000 in 2020, 200,000 2025, and 800,000 in 2030. There are 111 hydrogen stations (of which 11 are in development), with the target of 160 in 2020, and 320 in 2025. Stationary SOFC has been commercialized, and two FC buses and 80 FC forklifts are deployed.



Deployment of Phase1 of Hydrogen and Fuel Cell Strategic Roadmap

- NEDO aims to develop innovative technologies on PEMFC (durability of 50,000 hours, non-platinum catalyst), SOFC (durability of 90,000 hours, generation efficiency of >60%). For hydrogen stations, NEDO started R&D to halve the cost in 2020. NEDO also supports hydrogen gas turbine development, hydrogen supply chain development.

Development of hydrogen gas turbine by NEDO

- NEDO implements a so-called Power-to-Gas project. Fukushima project aims to supply hydrogen to the Tokyo Olympics and Paralympic Games with a water electrolyzer of 10MW.

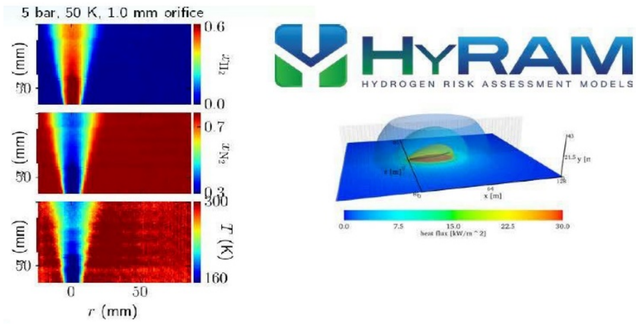
4-3 "United States Liquefied H2 Activities"

Jay Keller

President and CEO, Zero Carbon Energy Solutions, Inc.

(Former Manager of Hydrogen Research Development, Sandia National Laboratories)

- Liquefied hydrogen is a promising technology for large hydrogen stations, but there is a problem that the safety distance is 75 feet (23m). Based on scientific knowledge, the US Hydrogen Safety Panel, centering on Sandia National Laboratory (SNL), concludes that it can be reduced.
- SNL has developed HyRAM (Hydrogen Risk Assessment Model) as a tool for quantitative risk analysis based on scientific knowledge. It is utilized for making actual reference standards.



HyRAM (Sandia National Laboratories)

- The behavior of released liquefied hydrogen has high uncertainty and cannot be fully incorporated into the model. At DOE, the laboratory model (ColdPLUME) was developed in FY 2018, by using Raman spectroscopy on the behavior of gas plume (low temperature cloud) caused by liquefied hydrogen. In order to apply it to the demonstration field, the plume observation device assuming liquefied hydrogen release from a liquefied hydrogen delivery truck was developed by the National Renewable Energy Laboratory (NREL).
- Currently, the hydrogen storage task group of the National Fire Protection Association (NFPA) analyzes the behavior of liquefied hydrogen release in two scenarios: the release from a liquefied hydrogen delivery truck and the release from a pipe or an evaporator at a hydrogen station.
- As a result of this demonstration and analysis, HyRAM became able to simulate both compressed hydrogen and liquefied hydrogen. It also provides us with knowledge for optimal vent line design.

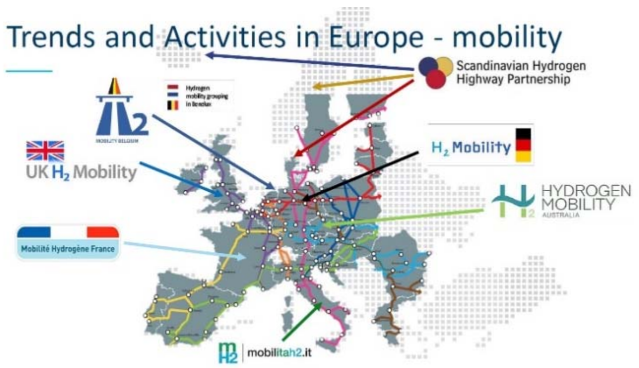
Plume monitor device at NREL

- In addition to SNL and NREL, Lawrence Livermore National Laboratory (LLNL), UK Institute for Occupational Safety and Health (HSL), Chart Industries (Low Temperature Tankmaker) cooperate with further analysis of behavior of liquefied hydrogen.

4-4 “Trends & Activities towards a hydrogen oriented economy —European & Norwegian prospects and perspectives”

Steffen Møller-Holst
Vice President Marketing, SINTEF
（Chairman Transport Pillar, FCHJU, Chairman, Norwegian Hydrogen Forum）

- The European Union has announced that it will reduce CO_2 emissions by 20% in 2020, by 40% in 2030 and by 80-95% in 2050. In September 2018, many European energy ministers gathered in Austria and signed an agreement to utilize hydrogen to reduce CO_2.
- The European Fuel Cell Hydrogen Joint Undertaking (FCH JU) is a public-private partnership, responsible for hydrogen and fuel cell R&D in Europe. FCH JU consists of an industry grouping “Hydrogen Europe”, a research institute grouping “Hydrogen Europe Research”, and European Commission.
- In Europe, several countries has partnerships for FCV and hydrogen station deployment. With the development of hydrogen applications, we expect large demand of hydrogen, so that the development of liquefied hydrogen supply chain is needed.



Partnership for FCV and hydrogen station around Europe

- Norway is an exporting country of energy; it exports renewable electricity, and also CO_2-free hydrogen in the future. The electric power surplus by wind power generation and hydro power generation is 15TWh/year, driving down the electricity cost as well as hydrogen production cost.
- Norway is producing hydrogen from hydroelectric power, solar power, wind power, natural gas reforming. Also by-product hydrogen is available.

Hydrogen production base in Norway

- In Norway, the transport sector accounts for 30% of the CO_2 emissions. To reduce emissions in this sector, FCV, FC bus, FC truck, FC train are expected. Furthermore, in Norway, development of ships (fishing boat, high speed boat, ferry, cruise ship etc.) using hydrogen is also expected.

4-5 China’s Progress in Application of Liquefied Hydrogen”

Sifeng Yang (Representative speaker: Yaozhong Zhao)
Deputy Director, Beijing Institute of Aerospace Testing Technology

- At the end of 2017, more than 1,000 FCVs (including FC buses) are deployed and about 1,300 will be added in China.
- Beijing Aerospace Testing Technology Institute (BIAT) is the largest research institute in China in liquefied hydrogen production and storage capacity. There are eight liquefied hydrogen facilities in China, four of which are in BIAT. The total production capacity of liquefied hydrogen in China is 80m^3/day or more.
- BIAT has developed a liquefied hydrogen transport trailer of 3.5-25m^3. The maximum liquefied hydrogen tank for transportation in China is over 300m^3. BIAT also owns vehicles capable of transporting liquefied hydrogen in the 40-100m^3 for long-distance transportation.

Liquid hydrogen transportation trailer of BIAT
and liquefied hydrogen transporting vehicle

- BIAT has also conducted R&D on liquefied hydrogen safety. BIAT also has the ability to test hydrogen related equipment under various conditions and has also developed a densitometer, liquid level gauge, thermometer for liquefied hydrogen. BIAT is also working on domestic standards on production, transport, storage, filling and use of liquefied hydrogen.
- BIAT is building China's first liquefied hydrogen filling station in Beijing. Hydrogen supply capacity is more than 1,500kg/day, with 35MPa refueling, 70MPa refueling and liquefied hydrogen refueling.
- BIAT is developing 500-1,000 L onboard liquefied hydrogen tank, particularly suitable for FC commercial vehicles, FC buses, and FC heavy-duty trucks.
- In the future, there is a large demand for hydrogen production, storage and supply in China. China's aerospace industry and BIAT expect to have global cooperation with all countries to contribute to "Hydrogen Energy China" and "Hydrogen Energy World".

Liquefied hydrogen facility at BIAT

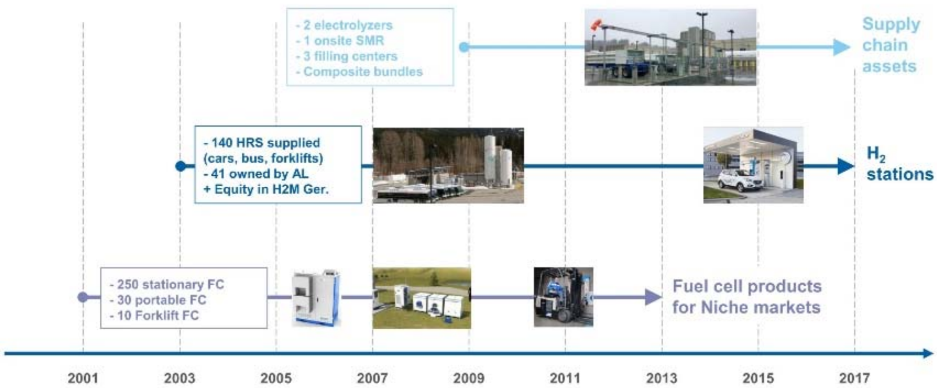
5 Session on R&D in the world
Current status of R&D on liquefied hydrogen technologies

5-1 “H_2 Energy ― At the heart of the energy transition”

Jean-Claude Joyeux

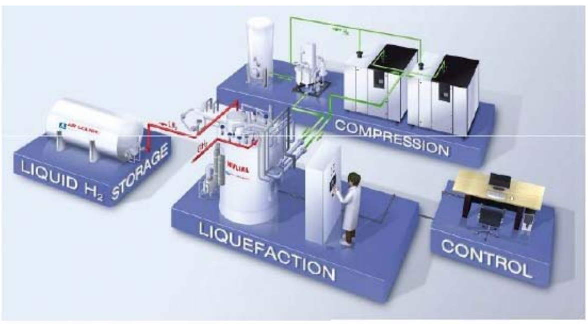
Director, Engineerign & Projects, Hydrogen Energy Business Unit, Air Liquide

- Air Liquide is a leader in industrial gas with total sales of 20 billion EUR, net income of 2 billion EUR, and employment of 65,000 worldwide. Air Liquide's hydrogen production volume is 14 billion m^3/year, and annual hydrogen sales is 2 billion EUR.
- Air Liquide has deployed nine FC forklift refueling facilities and over 100 hydrogen stations for FCV worldwide.



Achievement of Air Liquide's FC development and hydrogen station deployment

- For hydrogen demand of hydrogen mobility, FC bus is 20kg/day, FC truck is 100kg/day, FC train is 150kg/day, hydrogen ferry is 1ton/day and large cruise ship is 10ton/day. The hydrogen station for FCV is 100-200kg/day, and the hydrogen filling facilities for FC forklift is 100kg/day.
- In term of total cost of ownership (TCO) for liquefied hydrogen production, it is preferable to use a helium recycling type at 1-5ton/day, a mixed gas recycling type at 5-25ton/day, and a hydrogen recycling type at 25ton/day or more.
- The diagram below shows a liquefier system using Helium-Turbo-Brayton cycles, patented by Air Liquide. This system can scale up to 25ton/day. It is also highly efficient and can be designed compactly, so it can be used for re-liquefaction of boil-off gas.



	1 ton/day	1.3 ton/day	2.5 ton/day
	HYLIAL 600	HYLIAL 800	HYLIAL 1500
LH2 production (l/h)	600	800	1500
Expected Compressor Power (kW)	550	690	1260
Cold Box size (L x W x H) in m	8.1 x 4.8 x 5.5 (with gangway)	8.1 x 4.8 x 5.5 (with gangway)	9.0 x 4.5 x 5.5

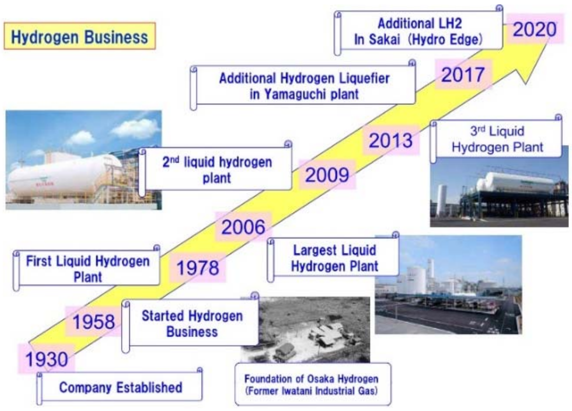
Liquefaction equipment using Air Liquide's Helium-Turbo-Brayton cycle

5-2 “Realization of the Hydrogen Energy Society ~Iwatani Activities for Liquid Hydrogen~”

Yasuhiro Nakajima

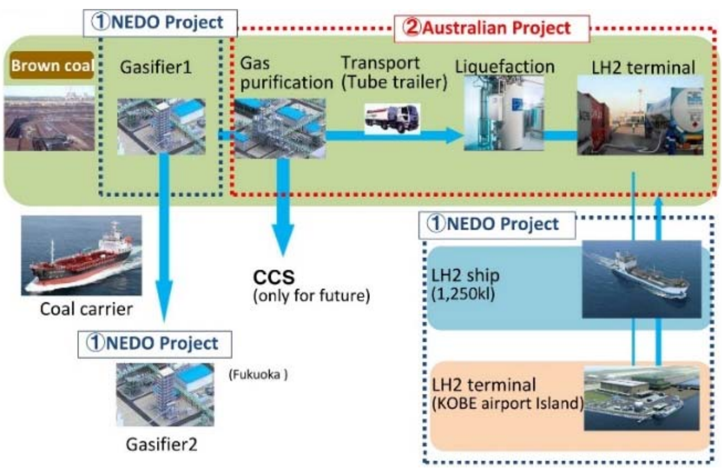
Assistant General Manager, New Energy Technology & Development, Technology & Engineering Division, Iwatani Corporation

- The current hydrogen market in Japan is 150m^3/year, and 99% is used in refineries and ammonia production plants. Iwatani has a 70% share of the hydrogen market.
- Iwatani was established in 1930, and it has started a hydrogen business in 1958.



Deployment of hydrogen business in Iwatani

- Iwatani Industry has three liquefied hydrogen plants in Japan, covering the whole of Japan. In liquefied hydrogen production capacity, Hydro Edge (Sakai City, Osaka Prefecture) has two line of 3,000L/h (expanded to 4 lines in 2020), Iwatani Gasso Chiba Factory (Ichihara City, Chiba Prefecture) has one line of 3,000L/h, and Yamaguchi Liquid Hydrogen (Shunan City, Yamaguchi Prefecture) has two lines of 3,000L/ h.
- Iwatani's hydrogen stations are currently 23 (6 are mobile stations). We are also participating in "Nippon Hydrogen Station Network Joint Company (JHyM)", established in February 2018, for the construction of a hydrogen station network.
- With Kawasaki Heavy Industries, Shell Japan and J-Power, Iwatani participates in demonstrate liquefied hydrogen supply chains from Australian lignite.

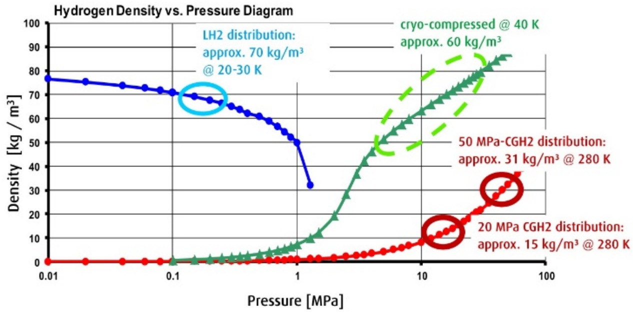


Demonstration of liquefied hydrogen supply chain using Australian lignite

5-3 "Technologies for large-scale hydrogen liquefaction — Enabling H2 mobility"

Umberto Cardella
Process Engineering, Linde Kryotechnik AG

- The Linde group's total sales are 17.1 billion EUR, with operating profit of 4.2 billion EUR and the number of employees of 57,600. Linde Kryotechnik is a department that deals with helium, hydrogen, neon, and other gases. We are developing liquefaction technologies, participating in national projects, and supplying gas to the aerospace industry.
- In the hydrogen density comparison in hydrogen storage, Liquefied hydrogen has the highest hydrogen density.

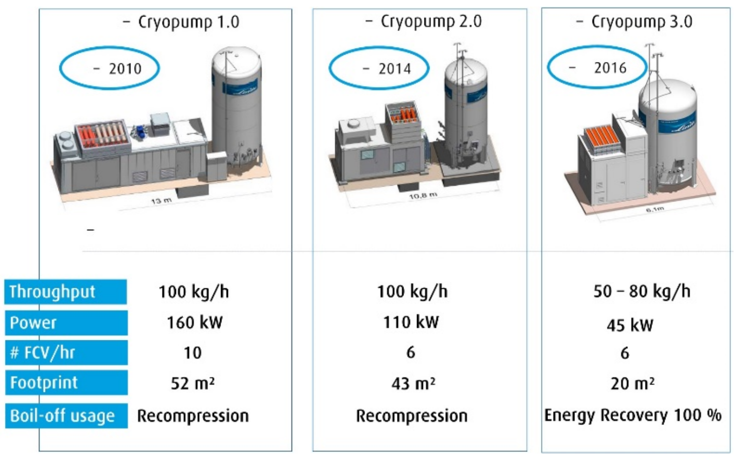


Comparison of hydrogen density in storage form of hydrogen

- Application of liquefied hydrogen is rocket fuel (plant capacity ~ 20ton/day), semiconductors (~ 5ton/day), and mobility (50ton/day). For hydrogen demand of mobility, it is assumed that FCV is 0.4kg/day, FC bus is 30kg/day, FC truck is 100kg/day, FC train is 250kg/day and hydrogen ship is 1-10ton/day.

Linde's Hydrogen Value Chain

- In comparison with hydrogen liquefaction technologies, we think that helium Brayton cycle is suitable for small scale demand (~ 3tons/day), hydrogen cloud cycle is suitable for medium and large scale demand (4 ~ 100tons/day).
- Linde is developing a liquefied hydrogen station using a cryopump. In 2010, the capacity was 100kg/h, with electric power consumption of 160kW and footprint of 52m^2. In 2016, the capacity was 50-80kg/h, with electric power consumption of 450kW and footprint of 20m^2.



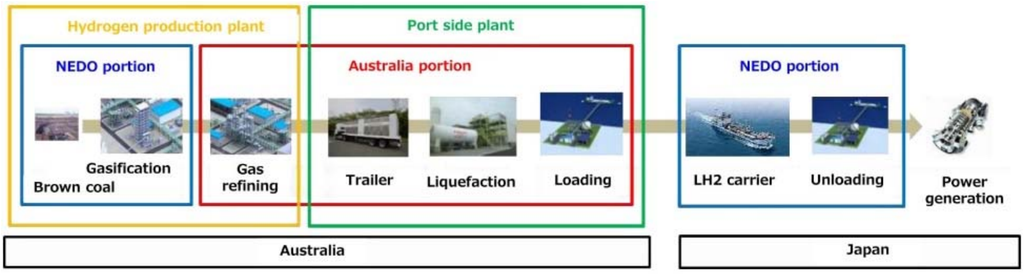
Linde's cryopump type liquefied hydrogen station

6 Session on marine transportation of liquefied hydrogen
Current status of marine transportation technologies of liquefied hydrogen and safety issues

6-1 "International Liquefied Hydrogen Supply Chain"

Motohiko Nishimura
Chief Administrative Officer, Senior Manager, Technology Development Department
CO2-free Hydrogen Energy Supply-chain Technical Research Association (HySTRA)

- At the pilot demonstration of the international supply chain of liquefied hydrogen, we aim to import liquefied hydrogen to Japan in 2020. NEDO portion consists of lignite gasification equipment in Australia, hydrogen transport ship, and hydrogen receiving facility. Australia potion consists of gas refining equipment and hydrogen liquefaction equipment. HySTRA is founded to implement NEDO potion, with the members of KHI, Iwatani Corporation, Shell Japan, and J-Power. The commercial supply chain will start in 2030.



Pilot demonstration composition of liquefied hydrogen's international supply chain

- LCA analysis also shows that lignite-derived hydrogen with CCS has low CO_2 emissions comparable to those of renewable energy hydrogen.
- The basic design of liquefied hydrogen transport ship was completed, and KHI starts construction in 2019. In 2016, the safety standards of liquefied hydrogen carrier ship, proposed to the International Maritime Organization (IMO), was adopted as a provisional standard.
- We are constructing a hydrogen receiving facility at Kobe Airport Island. The liquefied hydrogen storage tank is 2,500m^3, and it also has a BOG treatment facility.

Liquefied hydrogen receiving facility

- Obayashi Corporation, KHI, Kobe City, Kansai Electric Power, Iwatani Corporation and Osaka University participate in NEDO demonstration of hydrogen cogeneration system plant (1 MW). This plant was installed in Kobe Port Island in December 2017, and this is the world's first thermoelectric supply by 100% hydrogen gas turbine power generation.
- The hydrogen gas turbine, developed by KHI, can handle combustion gas from any composition of 100% natural gas up to 100% hydrogen. By steam spraying, we succeeded in reducing the NOx level below the regulation value. A dry process is under development.

6-2 "Development of IMO Requirements for the Safe Transport of Liquefied Hydrogen in Bulk"

Noriaki Usui

Director, Dangerous Goods Transport Office, Inspection and Measurement Division, Maritime Bureau, Ministry of Land, Infrastructure, Transport and Tourism (MLIT)

- The IGC code is an international regulation concerning the transportation of liquefied gas by a ship, which is stipulated by the International Maritime Organization (IMO). This IGC code is a mandatory code based on the International Convention for the Safety of Life at Sea (SOLAS).
- The Ministry of Land, Infrastructure, Transport and Tourism (MLIT) proposed the IMO to establish safety standards for transporting liquefied hydrogen, and was able to standardize it as a provisional standard in November 2016 (Liquid Hydrogen Carrier Ship Guidelines).
- According to the guideline, the minimum requirement for liquefied hydrogen is as follows.

Minimum requirements for liquefied hydrogen

A	Product name	Hydrogen
C	Ship type	2G（Non-toxic and inflammable gas）
D	Independent tank Type C（For steam specific gravity heavier than heavier cargo）	Not required
E	Control of vapour space within cargo tank	Not required
F	Vapor detection	Required
G	Gauging	Flammable and sealed type（C） Required
I	29 Special requirements (low temperature, hydrogen embrittlement, permeability, hydrogen fire, breadth of the flammability limit, high pressure, static electricity, prevention of dangerous purging, characteristics of hydrogen fires, low density and high diffusivity, caused by fire)	Not required

- Future plans for transporting liquefied hydrogen are as follows.

Future plans for liquefied hydrogen transport

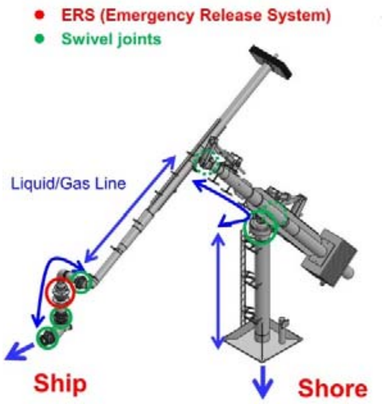
FY2020	Demonstration experiment by a pilot ship
FY20XX	Proposal to IMO to seek amendments to the IGC Code for the inclusion of liquefied hydrogen, based on the latest findings from the demonstration experiment?
FY20XX	Construction and operation of commercial vessels?

6-3 Development of transfer arms for marine transportation of liquefied hydrogen

Akihiko Inomata

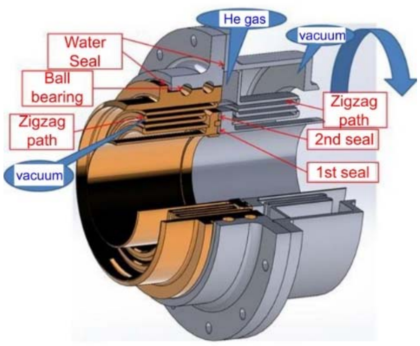
Manager, Section1, Environmental System Research Department, Technical Institute, Corporate Technology Division, Kawasaki Heavy Industries, Ltd.

- As part of the demonstration of liquefied hydrogen international supply chain, KHI and partners are developing loading arms for loading and unloading on liquefied hydrogen.
- The liquefied hydrogen loading arm is essentially the same as the LNG loading arm. However, while LNG is -162 °C, liquefied hydrogen temperature is as low as -253 °C, so that vacuum heat insulation is necessary.
- An important part of the loading arm is ERS (Emergency Removal System) and swivel joint (rotary joint) for the operation of liquefied hydrogen.



Loading arm for liquefied hydrogen under development at SIP

- For the ERS, a check valve was selected. The product test of the valve was conducted, based on ISO 16904 (transfer of liquefied natural gas), at Noshiro Rocket Test Site of the Japan Aerospace Exploration Agency (JAXA). Emergency breakaway time was within 1.3 seconds.
- Six swivel joints are installed at loading arms. It requires very high thermal insulation. The product test was also conducted at the same site. It is confirmed the safe operation of 400,000 rotations, without any leakage.



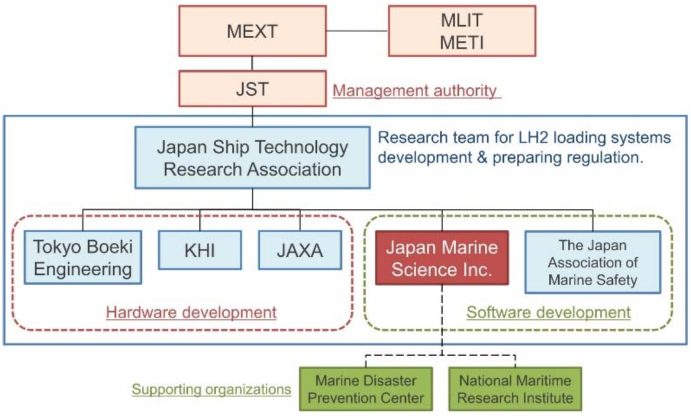
Structure of swivel joint

- The behavior of liquefied hydrogen at ESR activation was investigated using Phast (advection diffusion simulation software).

6-4 Safety assessment of LH_2 cargo handling operation

Noriyuki Aoyama
Senior Consultant, Research & Consulting Group, Japan Marine Science Inc.

- At the development of hydrogen loading arm in SIP program, Japan Marine Science and Japan Marine Accident Prevention Association are working on the software to develop national guidelines on liquefied hydrogen transport, transfer from berth, and risk assessment (HAZID).



SIP project framework

- Experiments on hydrogen flame (0.4MPa, pinhole: 0.2mm/1.5mm), it could easily extinguish with sodium bicarbonate. Water was not effective. As a countermeasure against hydrogen flame, after closing the valve, it is better to wait until the flame extinguishes naturally, but in the case of emergency, crewmembers may try to extinguish the flame.
- Differences in behaviors of liquefied hydrogen and LNG in the transport of cargo (in tank) are summarized, below.

Behavioral differences in transporting liquefied hydrogen and LNG cargo (in tank)

	LH2	LNG
Prepa-ration	✓ Connect liquid and return gas line ✓ Connect seal gas line for cargo compressor ✓ O_2 purge by GN_2 ✓ N_2 purge by GH_2 at ambient temp. ✓ Measure of tank level of LH_2 ✓ ESDS test ✓ Prepare seal gas for cargo compressor ✓ Line cool down ✓ Tank cool down	✓ Connect liquid and return gas line ✓ O_2 purge by GN_2 ✓ Measure of tank level of LH_2 ✓ ESDS test ✓ Prepare for cargo compressor ✓ Line cool down
LH_2 transfer	✓ Start loading operation ✓ Rate-up ✓ Full rate cargo transfer ✓ Rate-down ✓ Complete cargo transfer	✓ Start loading operation ✓ Rate-up ✓ High rate cargo transfer ✓ Rate-down ✓ Complete cargo transfer
Finish up	✓ Draining of LH_2 line ✓ H_2 purge by GH_2 at ambient temp. ✓ H_2 purge by GN_2 ✓ Measure of tank level of LH_2 ✓ Disconnect liquid and return gas line ✓ Disconnect seal gas line	✓ Draining of LH_2 line ✓ H_2 purge by GN_2 ✓ Measure of tank level of LH_2 ✓ Disconnect liquid and return gas line

- According to the Japanese Port Regulation Law, the inter-boat safety distance for cargos handling of inflammable dangerous goods is 30m, but with our simulation confirmed the safe distance for the release of high pressure hydrogen is below 30m.

7 Closing address

Nobumitsu Kambayashi
President, Japan Ship Technology Research Association

- I had been promoting commercialization of hydrogen technologies in private companies until two years ago. I also have been thinking that it was necessary to have more researchers in hydrogen technologies, especially researchers in the field of hydrogen energy technologies.
- With today's lectures, I felt hydrogen society coming soon. I would like to continue cooperating together globally toward our common goal of "realizing a hydrogen society".

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