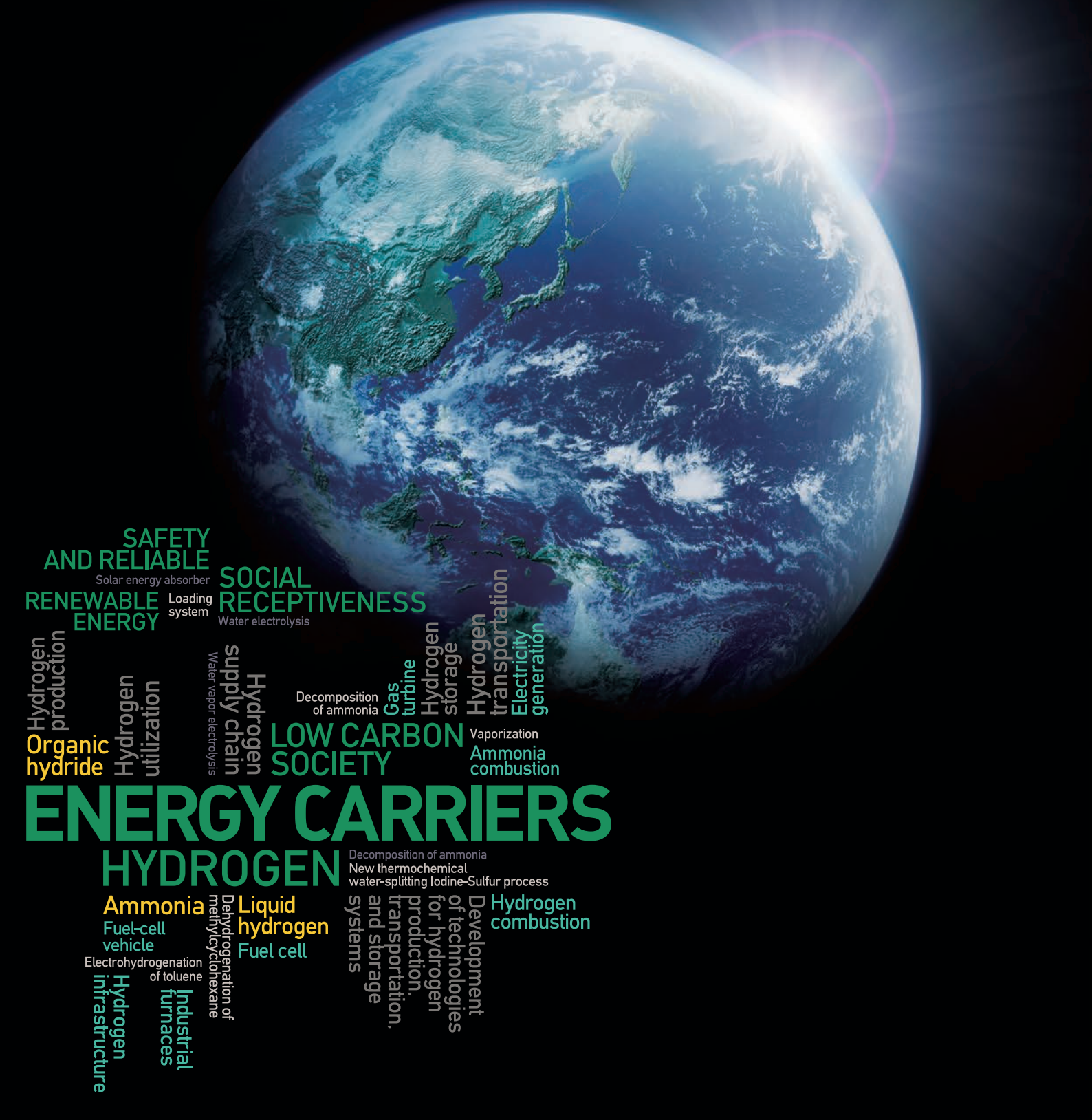
Cross-ministerial Strategic Innovation Promotion Program（SIP）

Energy Carriers



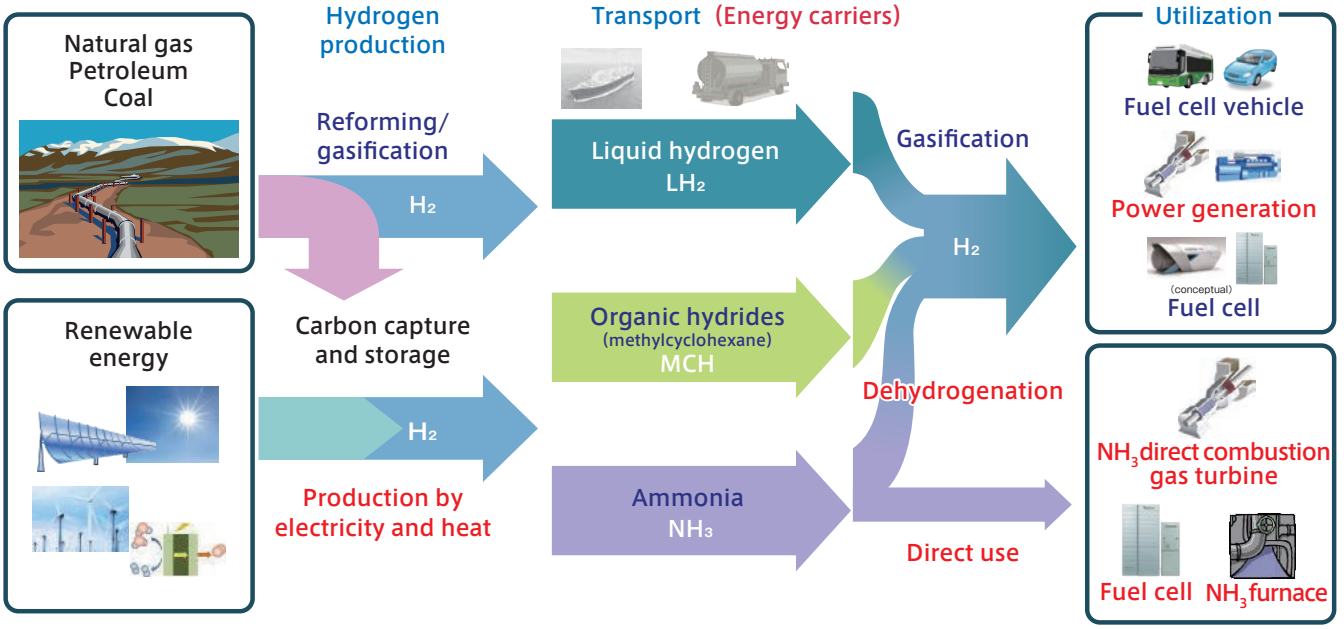
SIP Energy Carriers

Reducing CO_2 emission is a global issue. For Japan, a country poor in energy resources, it is necessary to construct a low-carbon society as well as to promote a stable energy supply through the diversification. We have large expectations for the role of hydrogen energy. However, towards the large-scale use of hydrogen, there remains a lot of issues to overcome technology barriers and high cost . Proceeding the research, development and demonstration of hydrogen technologies with industry-academia-government collaboration under the leadership of government will contribute significantly to solve energy and environment problems in Japan. And it will eventually bring Japan a world leader in hydrogen utilization and the related industries.

Under these circumstances, "Energy carriers", a technology development program toward the realization of hydrogen society has been launched as one of the 10 themes of the Cross-ministerial Strategic Innovation Promotion Program (SIP) spearheaded by the Council for Science, Technology and Innovation in 2014. "Energy carriers" is the method to efficiently store and transport hydrogen as liquid, while hydrogen, gaseous at normal state, is difficult to handle.

In this program, we aim to build CO_2 -free hydrogen value chain by focusing on the developments of technologies for CO_2 -free hydrogen production, conversion to energy carriers; liquid hydrogen, organic hydride and ammonia, and storage, transportation and utilization.

Strategy of Energy Carriers ～Development of CO_2 free hydrogen value chain～



- Hydrogen can be produced from various energy sources and can be utilized for electricity as well as fuel (Potential to reduce CO_2 emission significantly)
- Hydrogen has a difficulty in transportation, because it is low Btu gaseous form. It is essential to develop viable mass-transportation methods and related technologies (energy carrier) and make hydrogen to be affordable energy source.

Vision

Realize the world's first new type low carbon society utilizing hydrogen in Japan by 2030 and be a role model in the world.

2015-2020	2020-2030	2030-
● Commercialization of fuel cell vehicle, residential fuel cell cogeneration	● Expansion of fuel cell markets ● Introduction of hydrogen power generation	● Commercialization of large scale hydrogen power plant ● Introduction of carbon free hydrogen in large scale
● Developments of technologies related to carbon free hydrogen production, energy carrier and utilizations of hydrogen and carriers ● Demonstration of hydrogen society in 2020 Tokyo Olympics and Paralympics	● Demonstration of high efficient power generation using hydrogen and energy carrier from small scale up to large scale	● Japanese hydrogen relevant industries play an active role in the global market

Research & Development subjects

April 1, 2016

Hydrogen-related research subjects

1 High-Temperature Solar Thermal Energy Supply

2 Hydrogen Production Technology Using Solar Heat

8 Development of Cargo Loading/unloading System for Liquid Hydrogen and the Relevant Rules for Operation

9 Development of Hydrogen Engine Technology

Ammonia-related research subjects

Production

↓

Carrier transformation Transportation Storage

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Utilization

3 Development of Ammonia Synthesis Process from CO_2 Free Hydrogen

4 Basic Technology for Hydrogen Station Utilizing Ammonia

5 Ammonia Fuel Cell

6 Ammonia Direct Combustion

Organic hydrides -related research subjects

7 Development of Hydrogen Supplying Technology Based on Organic Hydride

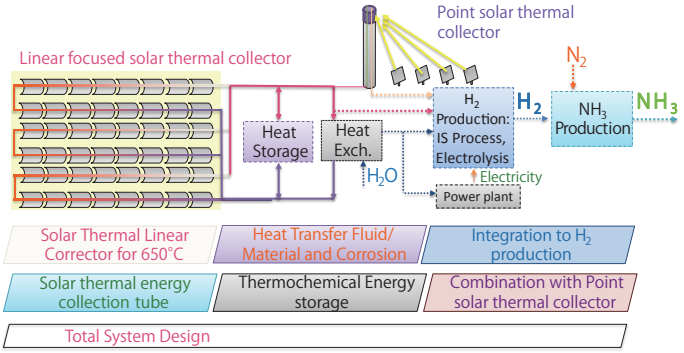
10 Safety Assessment of Energy Carrier

1 High-Temperature Solar Thermal Energy Supply System

Research Director Yukitaka Kato — Professor, Laboratory for Advanced Nuclear Energy, Tokyo Institute of Technology

Purpose Development of high-temperature (650°C) solar thermal energy supply system to produce H_2 efficiently by introduction of new solar thermal corrector, collecting tube, heat transfer media and thermal energy storage technologies

Research Outline The team is aiming that ammonia which has high volume hydrogen density is produced as an energy carrier by hydrogen produced from solar thermal energy supply system. High-temperature (650°C) solar thermal energy collection system with more than 70% of solar radiation and heat collection efficiency in which the temperature is higher than conventional solar thermal system is developed. Elemental technologies of solar corrector, heat transfer fluid, solar thermal energy correction tube, and thermal energy storage for 24 hour heat supply to H_2 production system are developed.



2 Hydrogen Production Technology Using Solar Heat

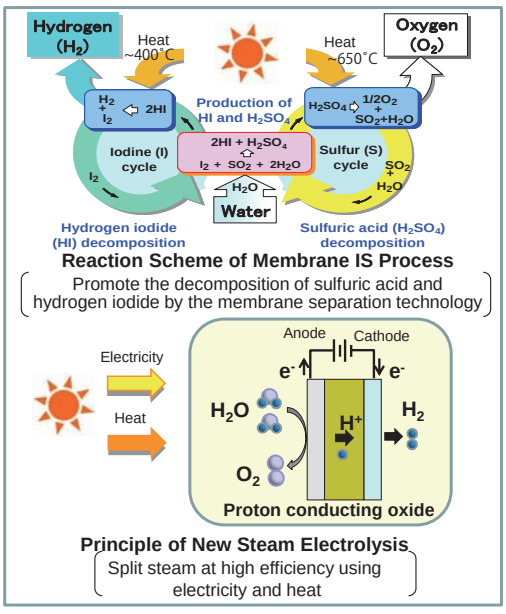
Research Director Nariaki Sakaba — Group Leader, HTGR Hydrogen & Heat Application Research Center, Japan Atomic Energy Agency

Purpose Development of highly efficient hydrogen production technologies by water splitting without CO_2 emission using solar heat at around 650°C

Research Outline Development of elemental technologies and demonstration of technical feasibility will be performed for the following two hydrogen production methods.

1) Membrane IS Process; hydrogen production by thermal water splitting using chemical reactions with iodine and sulfur, and membrane technologies

2) New steam electrolysis; hydrogen production by steam splitting with proton conducting oxide using electricity and heat



3 Development of Ammonia Synthesis Process from CO_2-Free Hydrogen

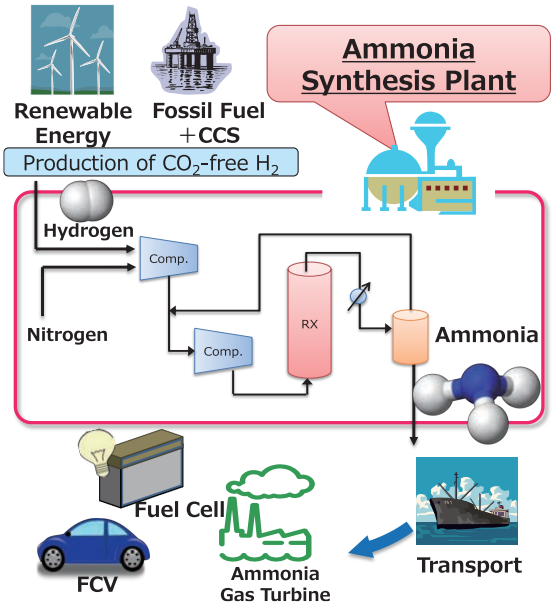
Research Director Yasushi Fujimura — General Manager, R&D Center, Technology Innovation Center, JGC Corporation

Purpose Development of high-efficiency ammonia synthesis process from CO_2-free hydrogen produced from renewable energy or fossil fuel

Research Outline Major R&D Item is as follows:

◆ Development of ammonia synthesis catalyst with high activity at low temperature

◆ The pilot plant will be constructed and operated in 2018 to confirm performance of the new catalyst and process.

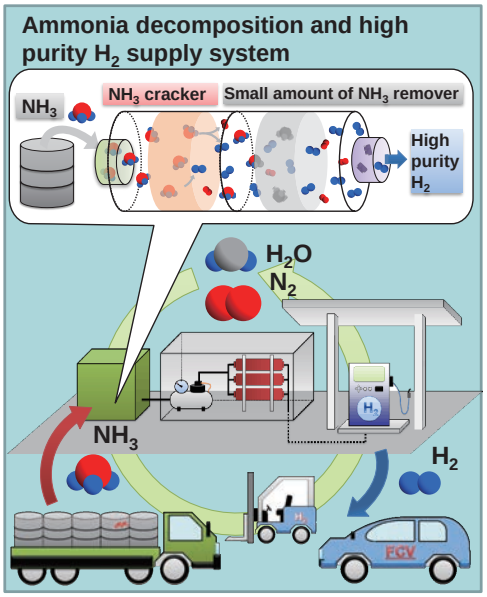


4 Basic Technology for Hydrogen Station Utilizing Ammonia

Research Director Yoshitsugu Kojima — Director, Institute for Advanced Materials Research, Hiroshima University

Purpose The purpose of this research is to develop ammonia decomposition and high purity H_2 supply system for hydrogen filling station.

Research Outline High purity H_2 supply system with low cost hydrogen transportation is a key issue to spread fuel cell vehicles (FCVs) and FC fork lifts. In this theme, we focused on ammonia as a hydrogen carrier because of high gravimetric and volumetric H_2 densities. We will develop a high purity H_2 supply system, which satisfies hydrogen fuel specifications for FCVs (ISO 14687-2) by NH_3 decomposition and separation technologies.



5 Ammonia Fuel Cell

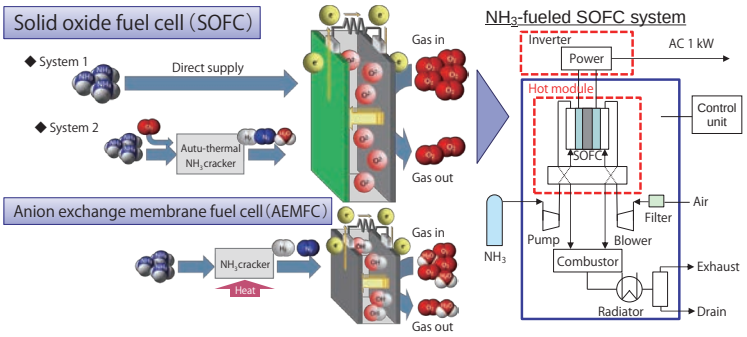
Research Director Koichi Eguchi — Professor, Graduate School of Engineering, Kyoto University

Purpose Development and demonstration of highly effective ammonia-fueled fuel cell systems

Research Outline ◆ Developing the direct ammonia-fueled SOFC systems and demonstrating 1 kW-scale power generation systems (main target)

◆ Investigating the combined systems as follows: (1) ammonia auto-thermal cracker and SOFC; (2) ammonia cracker and AEMFC (sub-target)

◆ Elucidating the compatibility of ammonia for the fuel cell systems and the degradation behavior of the ammonia-fueled fuel cells



6 Ammonia Direct Combustion

Research Director Hideaki Kobayashi — Professor, Institute of Fluid Science, Tohoku University

Purpose To develop ammonia direct combustion technology to utilize ammonia which is a hydrogen energy carrier as well as a CO_2-free fuel

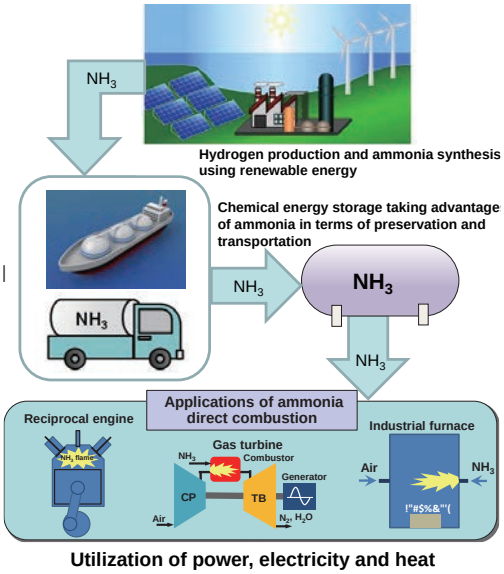
Research Outline Highly efficient utilization of ammonia combustion such as:

1) Gas turbine power generation using ammonia alone and ammonia/natural-gas mixed fuel

2) Application of ammonia reciprocal engines for transportations

3) Heat utilization in industrial furnaces using ammonia as a fuel

This project performs technology development and verification tests based on fundamental combustion research.



Utilization of power, electricity and heat

7 Development of Hydrogen Supplying Technology Based on Organic Hydride

Research Director Hideshi Iki — Principal Researcher, Central Technical Research Laboratory, JX Nippon Oil & Energy Corporation

Purpose To develop a practical hydrogen refueling station and hydrogen supplying system based on organic hydride technology

Research Outline The followings are focused to develop a modular dehydrogenation system for hydrogen refueling stations:

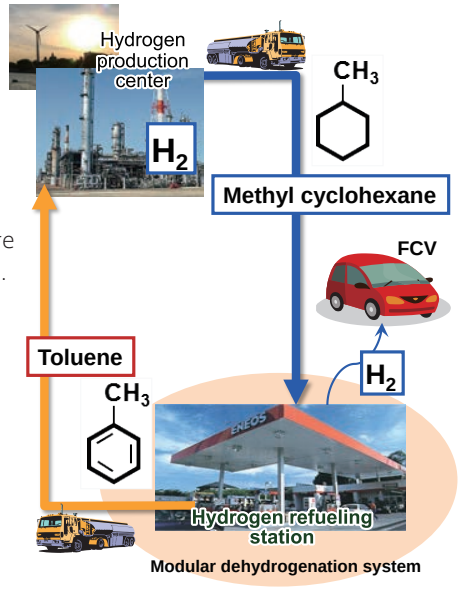
(1) Improving performance of the dehydrogenation catalyst

(2) Improving efficiency & reducing the size of modular dehydrogenation system

(3) Developing low-cost hydrogen purification system

(4) Conducting safety assessments

Technologies for efficient organic hydride production are also being developed. Further goal is to develop organic-hydride based hydrogen refueling stations and to promote widespread adoption of FCVs.



Modular dehydrogenation system

8 Development of Cargo Loading/unloading System for Liquid Hydrogen and the Relevant Rules for Operation

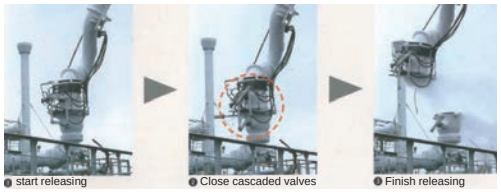
Research Director Tetsuya Senda — Deputy Managing Director, Japan Ship Technology Research Association

Purpose This research aims to develop a loading and unloading system for liquid hydrogen and to establish relevant rules for operation of the system.

Research Outline In the research, swivel joints and emergency release systems for liquid hydrogen are to be developed, based on the existing LNG handling technology, and a loading and unloading system for liquid hydrogen integrating the developed equipment will be constructed. Operational safety measures are also specified and rules and standards will be established for the safe operation of the world-first system. The rules and standards will be internationalized, as necessary.

LNG loading system

Swivel joint for LNG



Emergency release system for LNG

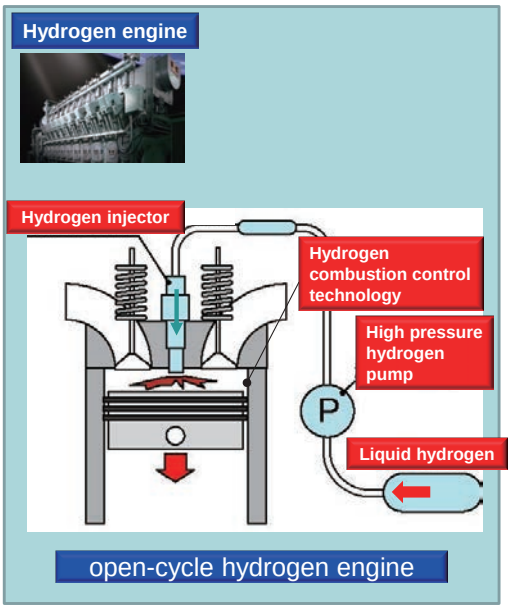
9 Development of Hydrogen Engine Technology

Research Director Masahide Kazari — Senior Manager, Technical Institute, Kawasaki Heavy Industries , Ltd.

Purpose We conduct the research for high efficiency and low-NOx-emission hydrogen engine realization.

Research Outline We conduct the following research items for high efficiency and low-NOx-emission open-cycle hydrogen engine which shall be used for power generation or ship propulsion.

- ◆ Hydrogen combustion control technology
- ◆ Low-NOx technology
- ◆ High pressure hydrogen injector
- ◆ High pressure hydrogen pump



Energy Carriers; their physico-chemical properties

	Pressurized Hydrogen (700MPa)	Liquid Hydrogen	Organic Hydride (Methyl Cyclohexane)	Ammonia
Molecular Weight	2.0	2.0	98.2	17.0
H_2 Content (wt%)	100	100	6.2	17.8
Volumetric H_2 Density ($kg\text{-}H_2/m^3$)	39.6	70.8	47.3	121
Boiling Point (℃)	—	-253	101	-33.4
H_2 Release Enthalpy Change ※ ($kJ/mol\text{-}H_2$)	—	0.90	67.5	30.6
Other Properties	● Widely used	● High purity ● Low energy to pressurize	● Existing oil infrastructures can be utilized.	● High H_2 density ● Direct use for combustion

※ H_2 release enthalpy change

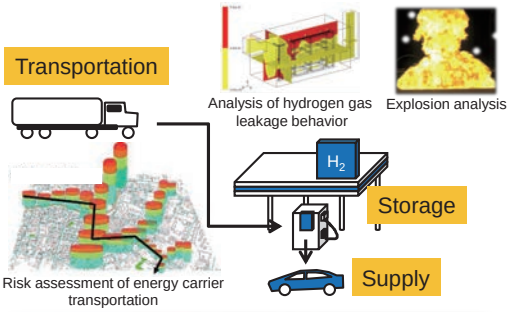
10 Safety Assessment of Eenergy Carrier

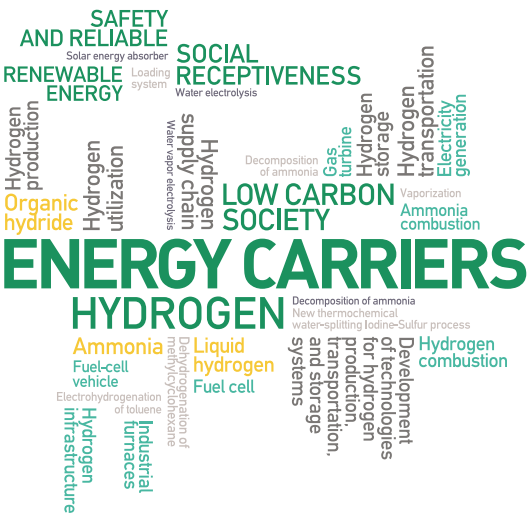
Research Director Atsumi Miyake — Professor, Center for Creation of Symbiosis Society with Risk, Yokohama National University

Purpose The purpose is to build the vital society in which hydrogen energy can be operated safely and sustainably within an acceptable cost in suitable area.

Research Outline Risk assessment and management of the following three supply chain in the transportation, storage, and supply processes are carried out not only from the perspective of the operators and manufacturers, but also from the perspective of the citizens.

1) Compressed hydrogen supply chain
2) Liquid hydrogen supply chain
3) Organic hydride supply chain





I would like to demonstrate the hydrogen technologies developed for production, transportation, storage and utilization as tangible results at the Tokyo 2020 Olympic and Paralympic Games.

It is not only a demonstration as a showcase but also aims to be a big first step toward hydrogen society in Japan.

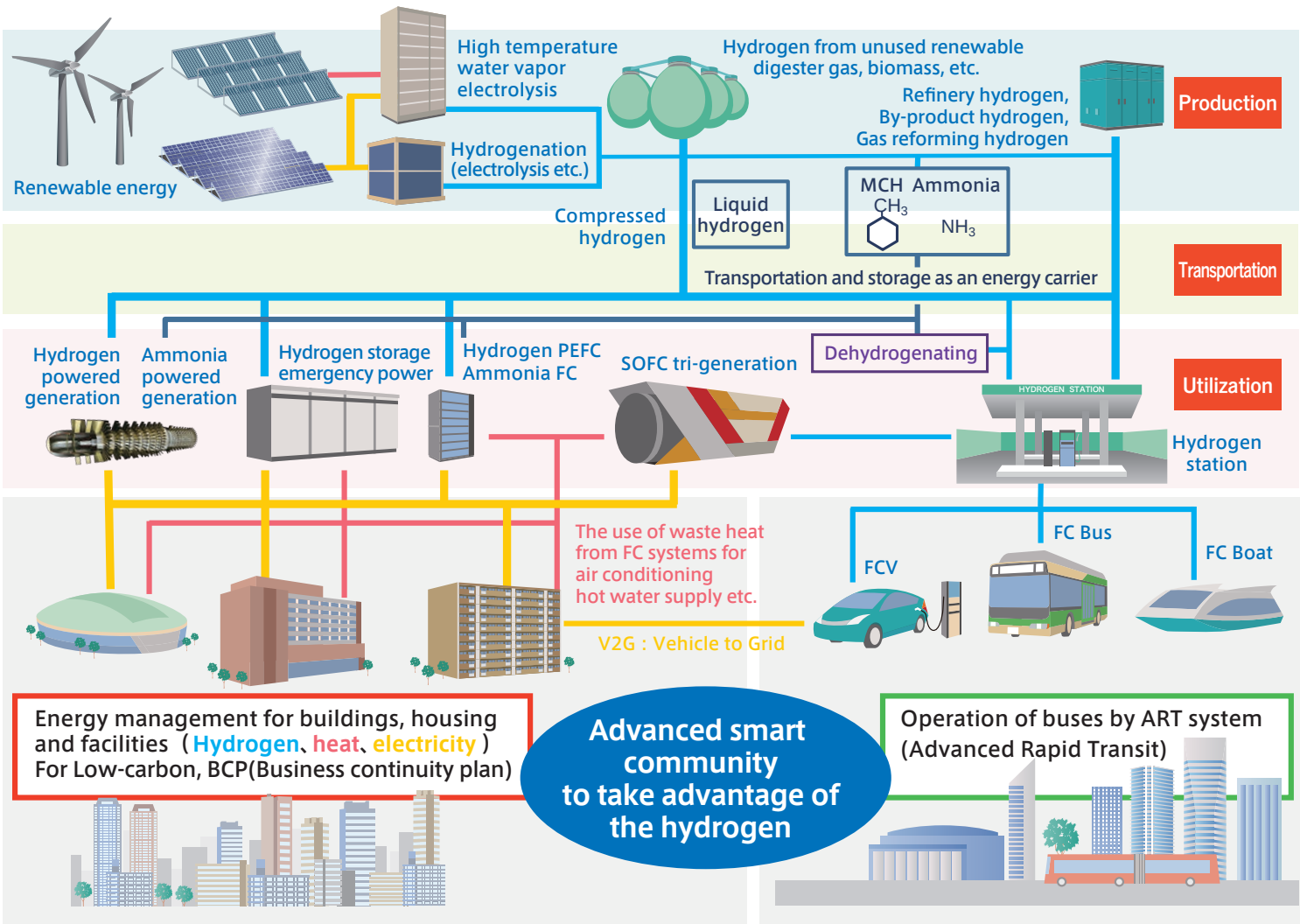
I have a confidence that hydrogen energy would contribute to the attractive urban development.

Program Director,
SIP Energy Carriers

Shigeru Muraki

Exective Adviser, Tokyo Gas Co.,Ltd

Basic Scheme of Hydrogen Society



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