Development of Technologies to Utilize Green Ammonia in Energy Market

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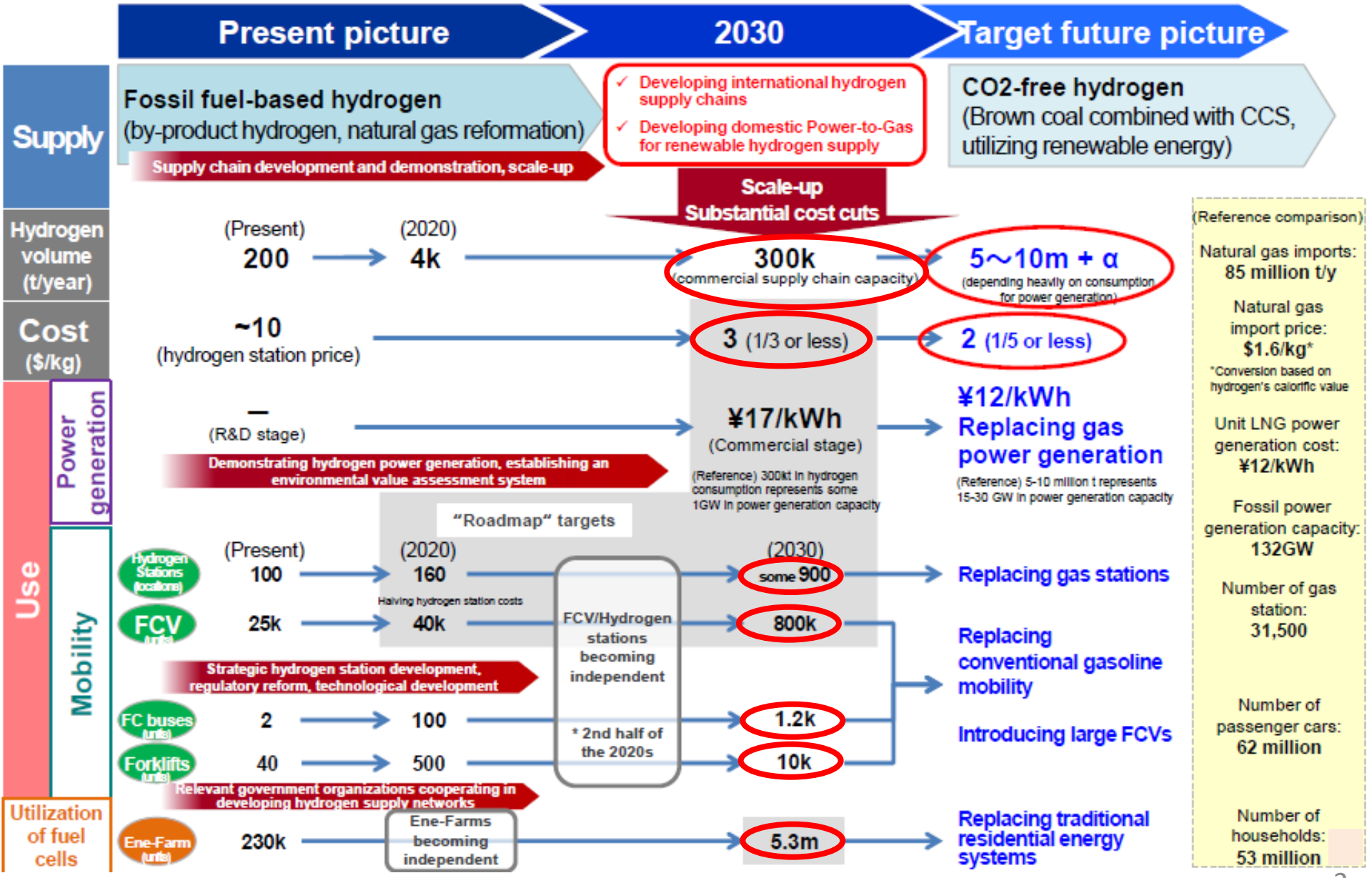
Policies and Actions toward a Low Carbon Society

- Speech by Prime Minister Abe at COP21
  "The key to acting against climate change without sacrificing economic growth is the development of innovative technologies. To illustrate, there are technologies to produce, store and transport hydrogen towards realizing CO_2–free societies,"

- Council for Science, Technology and Innovation(CSTI)
  Hydrogen is one of key areas of CSTI strategies.
  SIP program was launched 2014 (5 years program).
  Hydrogen energy carrier is one of 11 themes of SIP.

- Strategic Plan for Hydrogen Utilization (December 26, 2017)
  (Cabinet Meeting chaired by Prime Minster)
  Scenario for Basic Hydrogen Strategy
  (Direct use of ammonia is one of the most feasible options for the low-carbon society.)

Scenario for Basic Hydrogen Strategy



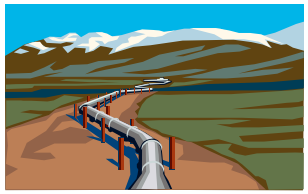
11 Themes of SIP

Priority policy issues	Themes	Objective
Energy	Innovative Combustion Technology	Improving fuel efficiency of automobile engines
	Next-Generation Power Electronics	Integrating new semiconductor materials into highly efficient power electronics system
	Structural Materials for Innovation (SM⁴I)	Developing ultra-strong and –light materials such as magnesium-, titanium-alloys and carbon fibers
	Energy Carriers	**Promoting R&D to contribute to the efficient and cost-effective technologies for utilizing hydrogen**
	Next-Generation Technology for Ocean Resources Exploration	Establishing technologies for efficiently exploring submarine hydrothermal polymetallic ore
Next-generation infrastructures	Automated Driving System	Developing new transportation system including technologies for avoidance accidents and alleviating congestion
	Infrastructure Maintenance, Renovation and Management	Developing low-cost operation & maintenance system and long life materials for infrastructures
	Enhancement of Societal Resiliency against Natural Disasters	Developing technologies for observation, forecast and prediction of natural disasters
	Cyber-Security for Critical Infrastructures	Development of technologies that monitor, analyze, and defend control and communication system as well as confirm integrity and authenticity of system components to protect critical infrastructures against cyber threats.
Local resources	Technologies for Creating Next-Generation Agriculture, Forestry and Fisheries	Realizing evolutionary high-yield and high-profit models by utilization of advanced IT etc
	Innovative Design/Manufacturing Technologies	Establishing new styles of innovations arising from regions using new technologies such as Additive Manufacturing

Scheme of CO_2 Free Hydrogen Value Chains

Hydrogen production | **Transport** (Energy carriers) | **Utilization**

Natural gas
Petroleum
Coal

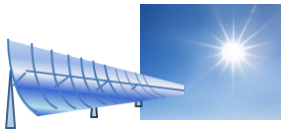


Reforming/
gasification

H_2

Carbon dioxide capture
and storage

Renewable
energy

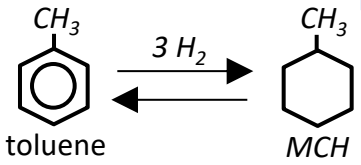


H_2

Production by
electricity and heat

Liquid hydrogen
LH_2(Δ253℃)

Organic hydrides
(methyl cyclohexane)
(H_2 6wt%)



Ammonia NH_3
Liquid : Δ33℃ or 8.5Bar
(H_2 18wt%)

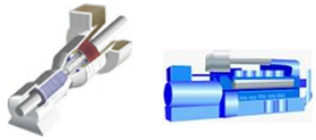
Gasification

H_2

Dehydrogenation

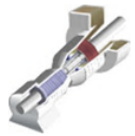
Direct use

Fuel cell vehicle



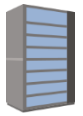
Power generation

Fuel cell



NH_3 fueled
gas turbine

Mix combus-
tion in coal
fired boiler



Fuel cell

NH_3 furnace

≪Ammonia direct use≫

【Power generation sector】
Gas turbine, Coal fired boiler, Fuel Cell

【Industrial sector】
Industrial furnace

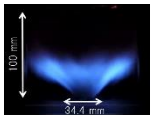
【Transportation sector】
Marine Engine

Key Achievements

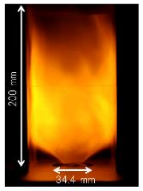
Ammonia-fueled gas turbine power generation

☆ Tohoku University / AIST / Toyota Energy Solutions / IHI Corporation

50kW (100% NH_3) Micro Gas Turbine



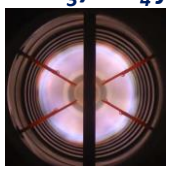
CH_4 flame



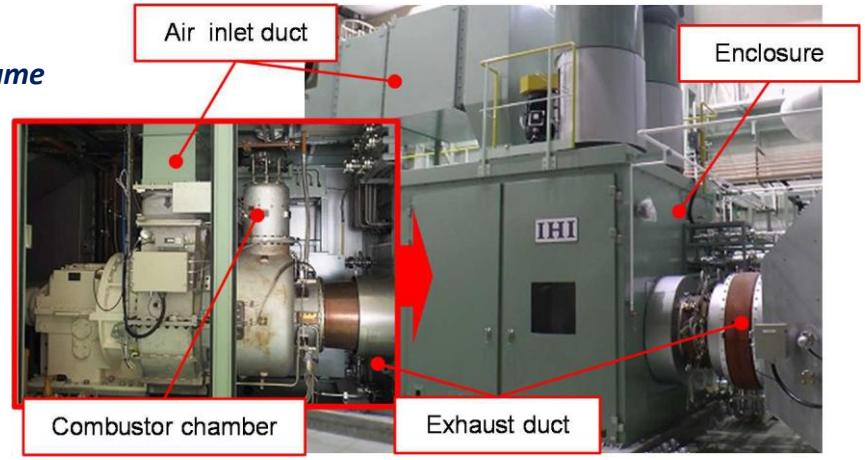
NH_3 flame

- 41.8 kW power generation was achieved by using 100% ammonia fueled micro gas turbine with less than 10 ppm NOx emission using an ordinary SCR device.

20% NH_3 / CH_4 flame



- Stable flame and low NOx emission were achieved by 2MW class gas turbine under the condition of co-fired 20% ammonia with city gas (methane).

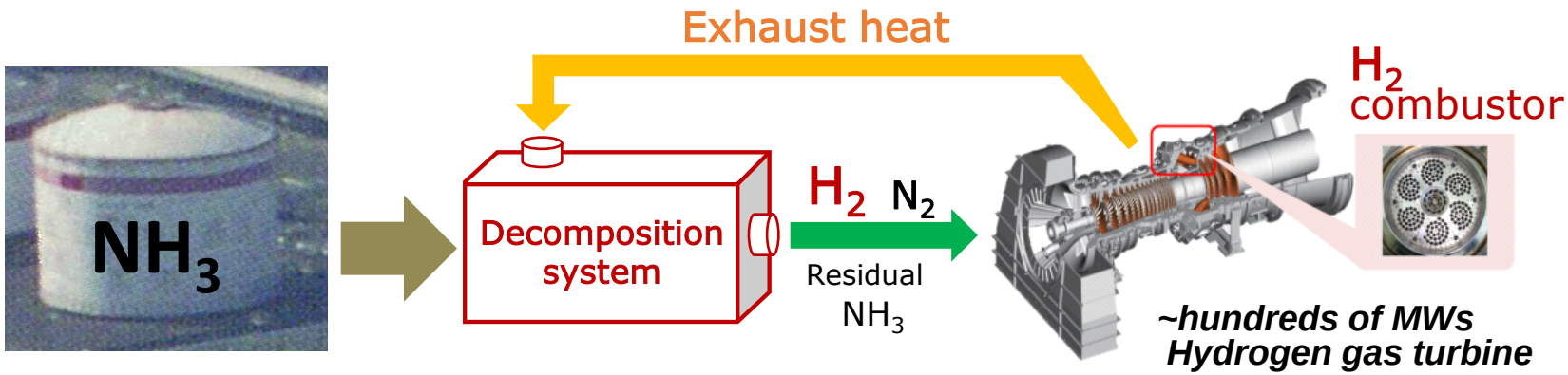


2MW (20% NH_3 / CH_4) Gas Turbine

Key Achievements

Advanced combined cycle gas turbine

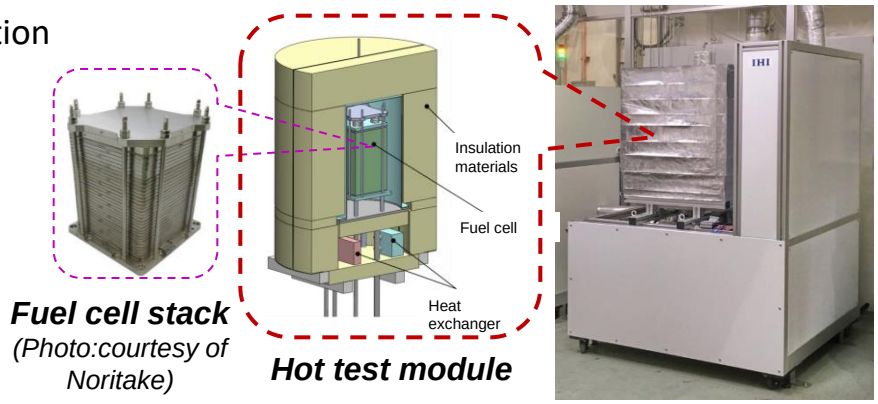
☆ Mitsubishi Heavy Industries Engineering / Mitsubishi Hitachi Power Systems



Direct ammonia-fueled solid oxide fuel cell (SOFC)

☆ Kyoto University / Noritake Co., Limited / IHI Corporation

- Development of 100% ammonia-fueled SOFC stack (direct supply of ammonia) and generated 1 kW of electrical power.
- The performance attained is equivalent to the hydrogen fueled SOFC.



Fuel cell stack
(Photo:courtesy of Noritake)

Hot test module

SOFC system

Key Achievements

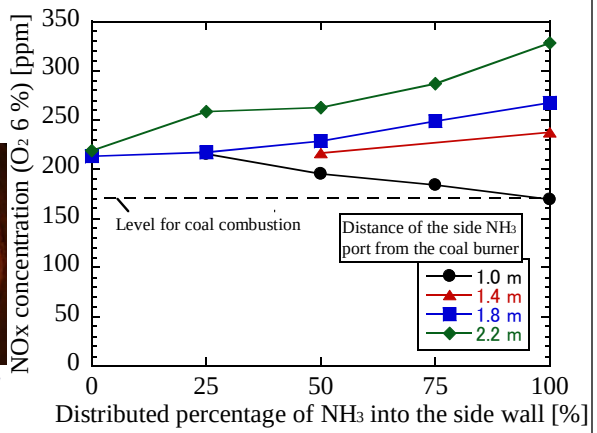
~Mix combustion of NH_3 in coal fired boilers~

The single-burner combustion test furnace

☆ Central Research Institute of Electric Power Industry

Coal consumption	100 kg/hr [760 kW : in put]
Max. feeding rate of NH_3	30 kg/hr [20% : LHV base]

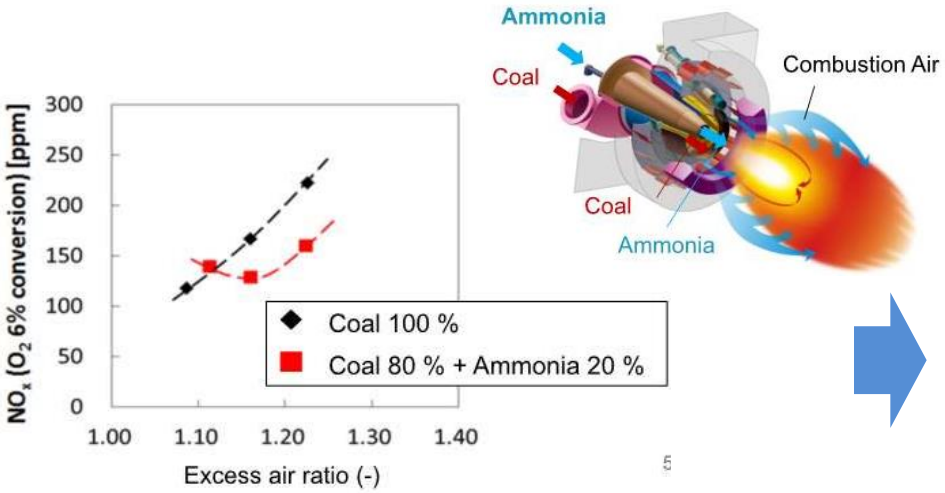
NH_3/ pulverized coal flame



Coal firing test furnace

☆ IHI Corporation

Coal consumption	1.6 ton/hr [10 MW : in put]
Max. feeding rate of NH_3	400 kg/hr [20% : LHV base]



- Ammonia was safely combusted.
- NOx is under 200 [ppm].
- There is no ammonia slip in the exhaust gas.

Key Achievements

~Mix combustion of NH_3 in coal fired boilers~

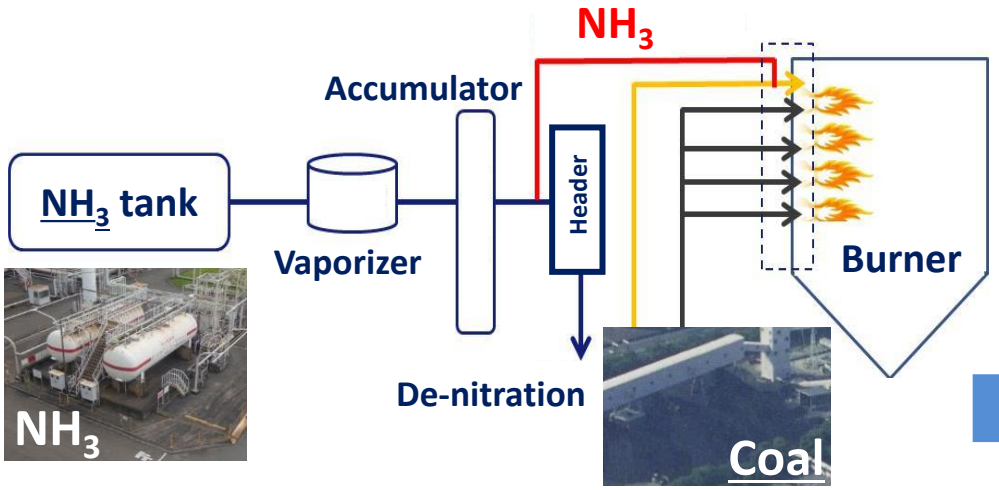
Co-fired ammonia at the commercial coal power plant

☆ The Chugoku Electric Power

Coal consumption	50 ton/hr [120 MW : out put]
Max. feeding rate of NH_3	450 kg/hr [1% : LHV base]

1MW-NH_3 feed / 120MW-Electricity
(Coal fired boiler and steam turbine)

The Chugoku Electric Power Co., INC. Mizushima Power Station



- Ammonia was safely combusted.
- There is no ammonia slip and no increase of NOx in the exhaust gas.
- The electricity was supplied steadily during the demonstration.

Co-fired ammonia at the commercial coal power plant

The video of the demonstration can be seen from the following URL

SIP Energy Carriers - The coal power generation by co-firing ammonia

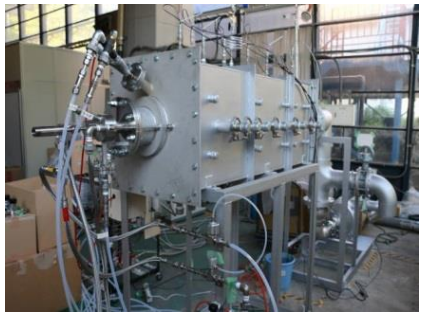
https://www.youtube.com/watch?v=ldU-qMvWFDk

Key Achievements

Industrial furnaces

☆ Osaka University / Taiyo Nippon Sanso

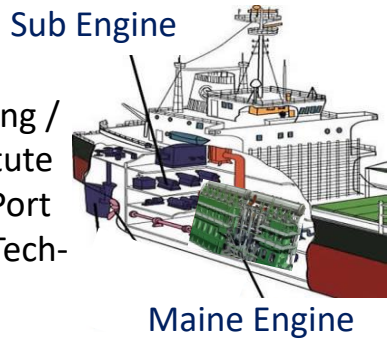
- Successfully controlled NOx generation below the environmental standard.
- Developed oxygen enriched combustion and staged combustion.



10kW model furnace

Marine Engine

☆ JFE Engineering / National Institute of Maritime, Port and Aviation Tech-nology



Development of ammonia synthesis process from CO_2 free hydrogen

☆ JGC Corporation / AIST / National Institute of Technology, Numazu College / JGC Catalysts and Chemicals Ltd

- Developed new catalysts and processes utilizing hydrogen derived from renewable energy.
- Constructed a demonstration plant at Fukushima Renewable Energy Institute (20kg-NH_3/day).

New catalyst for producing ammonia

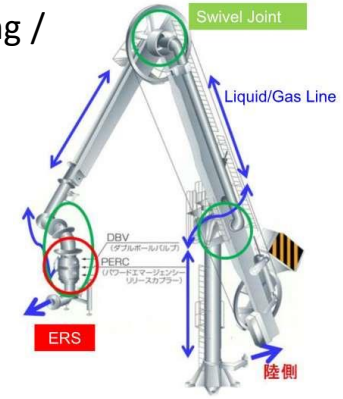
Ammonia Synthesis Demonstration Plant

Key Achievements

Loading system for Liquid Hydrogen

☆ JSTRA / Tokyo Boeki Engineering / Kawasaki Heavy Industries

- Loading arm for LH2 is basically same composition as that for LNG.
- The swivel joint and Emergency release system (ERS) for LH2 is developed.

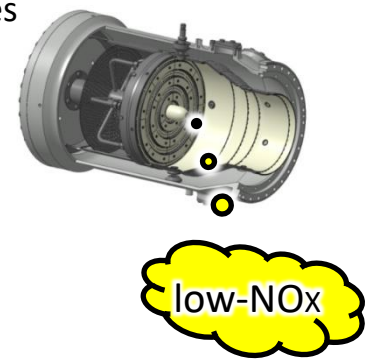


LNG Loading system

Hydrogen-fueled gas turbine

☆ Kawasaki Heavy Industries

- Developed 100% hydrogen-fueled Dry Low Emission (DLE) combustion technology that achieved low-NOx combustion without using water and steam.



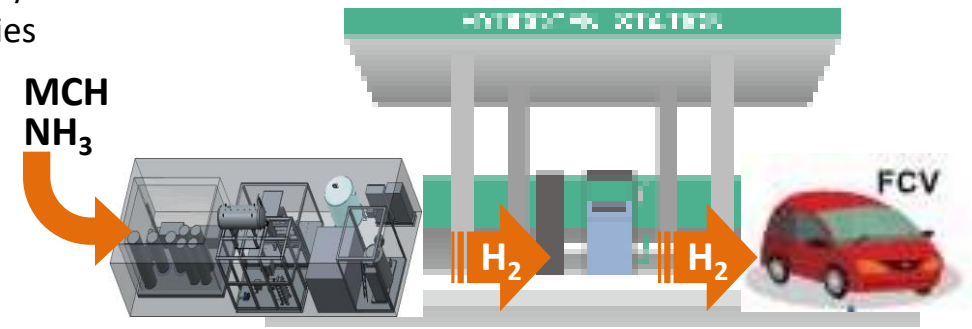
DLE Combustor

JSTRA : Japan Ship Technology Research Association

Development of Hydrogen supplying Technology based on MCH/Ammonia

☆ **MCH:** JXTG / Tokyo Institute of Technology / Waseda University / AIST / NOK
Ammonia: Hiroshima University / Showa Denko / Taiyo Nippon Sanso / Toyota Industries

- Developed the high performance catalyst and purification system.
- Improving efficiency and reducing the size of modular dehydrogenation system (MCH).



Dehydrogenation System ***Hydrogen Refueling Station***

Feasibility Studies

Supply

Natural Gas

NG

HB NH_3 Plant

CO_2

CCS/EOR

Middle East Countries
US Gulf

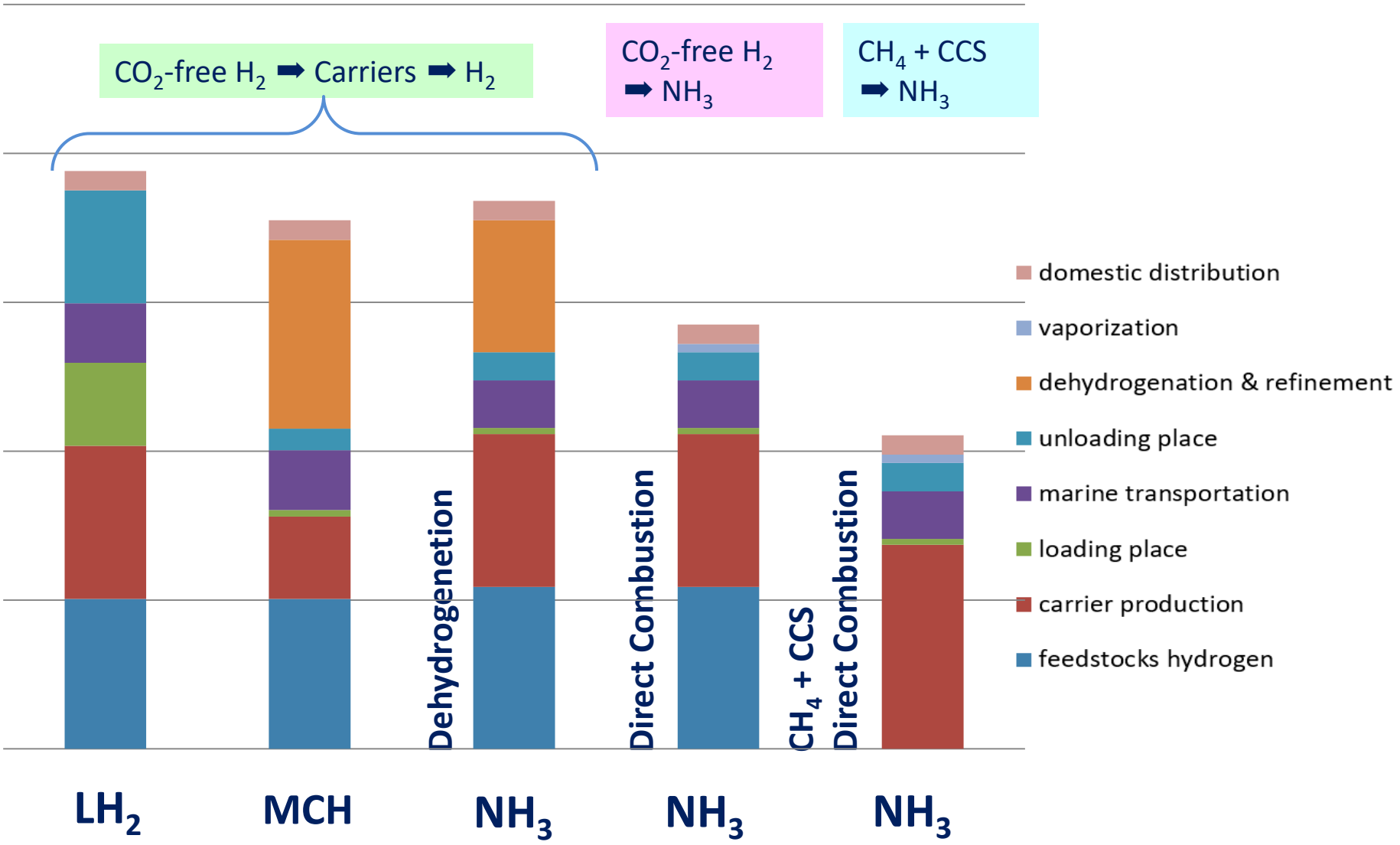
CO_2 Free NH_3 delivered to Japan

Utilization

Pulverized Coal + NH_3

3 Coal Fired Power Plants
- Remodeling of Coal Boiler
- NH_3 Unloading, Storage & Supply Facilities

Cost Comparison (per hydrogen unit) of Energy Carriers



NH_3 as H_2 Energy Carrier

(1) NH_3's volumetric hydrogen content is significantly larger than that of other energy carriers (high H_2 content) ⇒ relatively compact infra.;

(2) Transportation and storage technologies for NH_3 are already existing. Annually more than 18 M tons of NH_3 is being traded internationally.

(3) NH_3 can be directly used as fuel without CO_2 emissions, and NO_X emissions in NH_3 combustion can be controlled.

(4) NH_3 has acute toxicity with strong smell and easy to detect but not chronic toxicity (US EPA Study), and safety measures are common practice.

(5) CCS from NH_3 production plant is a feasible option, and energy equivalent cost of NH_3 is estimated to be the most feasible option.

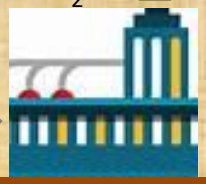
Development of CO_2 free Ammonia Value Chain

Existing tech.

CCS/EOR

CO_2

NG



Existing tech.

Natural Gas

Existing NH_3 Plant (HB Method)

CO_2 Free NH_3 supply chain can be realized by existing techs.

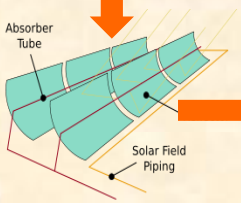
Existing tech.

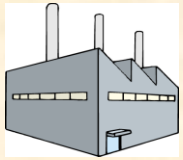
Transportation

CO_2 Free NH_3

Source of H_2 will be shifted renewables in future.

Solar Energy





CO_2 Free H_2

PV or CSP

Cost Reduction

H_2 Production

Cost Reduction

(CO_2 Free H_2) NH_3 Plant

Under development SIP

NH_3 Gas Turbine Pulverized Coal + NH_3

NH_3 Fuel cell (SOFC)

Marine Engine

Industrial Furnaces

The Green Ammonia Consortium *(Established in July, 2017)*

Currently under SIP (Limited to SIP participants)
April 2019: Independent & Open Organization for Global Industry

Objective:

- Promotion of collaborations between industry, government and academia
- Commercialization of CO_2 free NH_3 value chain
- Strategy & Policy making
- International collaboration

Current Members

Electricity Gas
- Chubu Electric Power
- Electric Power Development (J Power)
- Hokkaido Electric Power
- The Chugoku Electric Power
- The Kansai Electric Power
- Tohoku Electric Power
- Osaka Gas

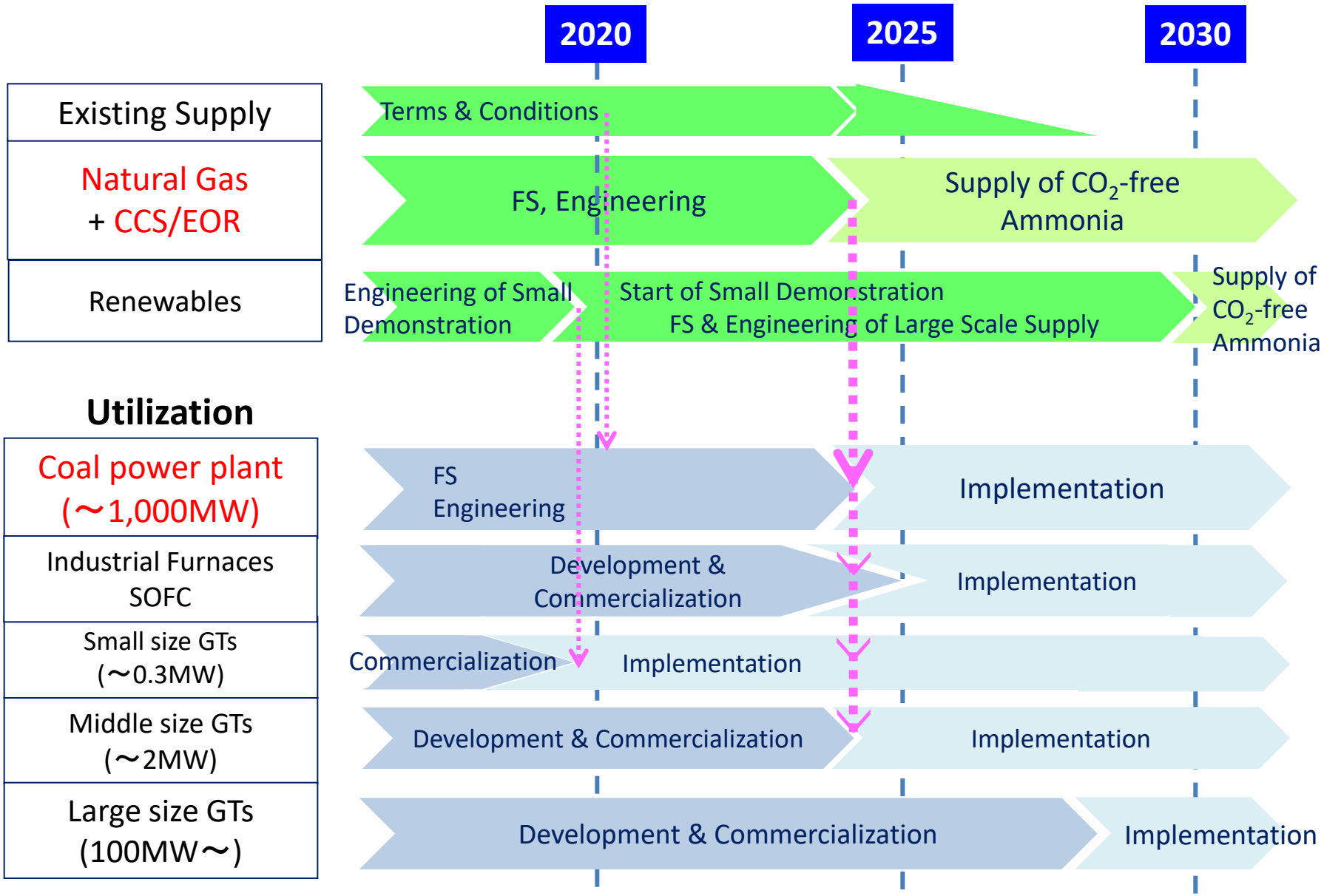
Supply and Trading
- Marubeni Corporation
- Mitsubishi Corporation Co.
- Mitsui & Co., LTD

Chemicals
- JGC Catalysts and Chemicals Ltd.
- Nippon Shokubai
- Noritake Co., Limited
- Taiyo Nippon Sanso
- Ube Industries

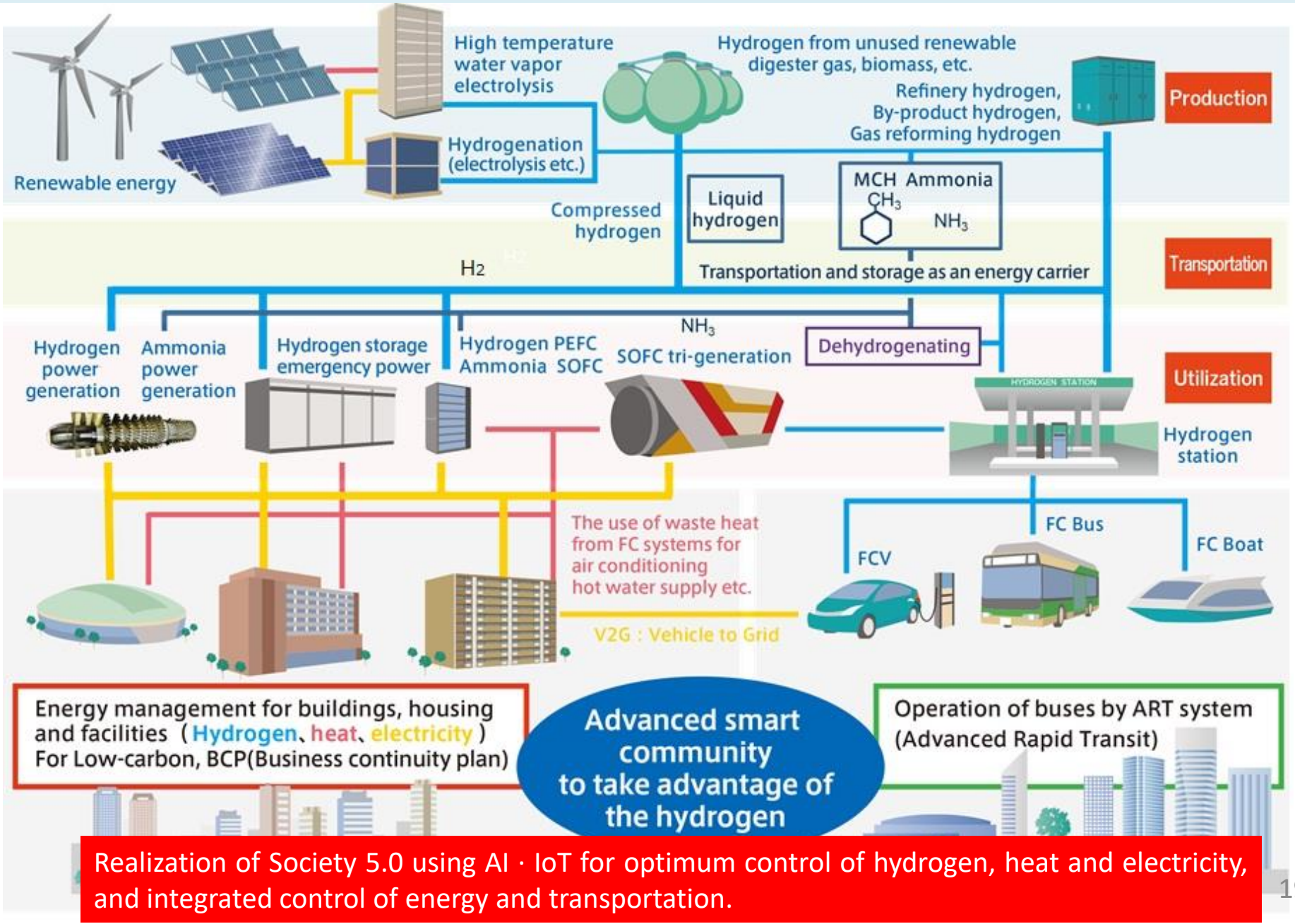
Manu factures
- IHI Corporation
- JFE Engineering
- JGC Corporation
- Mitsubishi Heavy Industries
- Mitsubishi Hitachi Power Systems
- Toyota Central R&D Labs.
- Toyota Energy Solutions
- Toyota Industries Corporation
- Toyota Motor Corporation

Research Institutes
- Central Research Institute of Electric Power Industry
- Japan Coal Energy Center
- National Institute of Applied Industrial Science and Technology
- National Institute of Maritime, Port and Aviation Technology

Roadmap of Ammonia Supply Chain



Demonstration of Hydrogen Society



Realization of Society 5.0 using AI · IoT for optimum control of hydrogen, heat and electricity, and integrated control of energy and transportation.

Thank you for your attention.