CO_2 Free Ammonia
as CO_2 Free Fuel and Hydrogen Carrier
- Achievements of SIP “Energy Carriers” -

24 June, 2019

Bunro SHIOZAWA
(The former) Deputy Program Director
SIP “Energy Carriers”

Contents

1. Hydrogen Energy Policy of Japan and SIP "Energy Carriers"

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,"

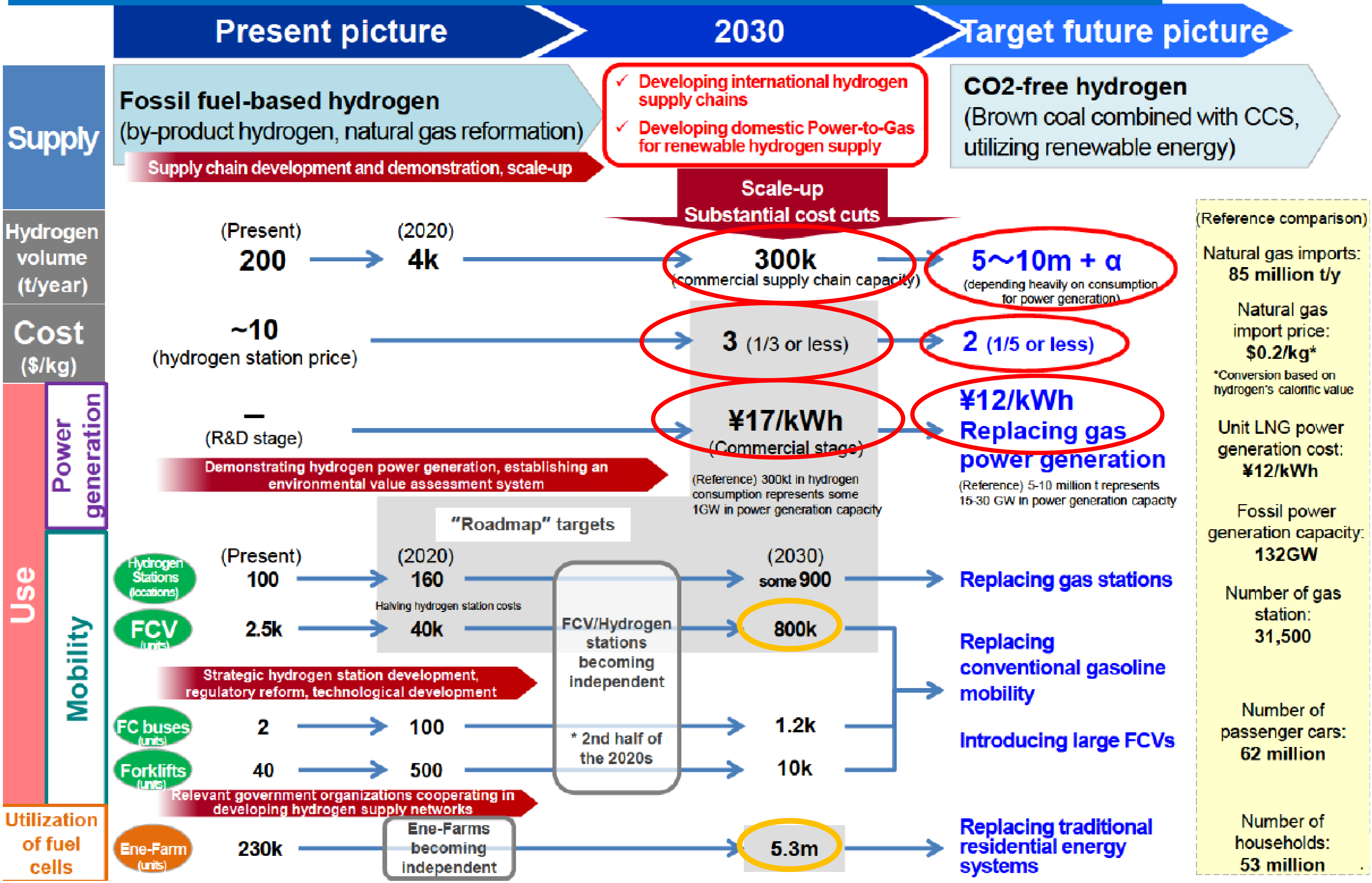
- **Council for Science, Technology and Innovation(CSTI)**
  Hydrogen is one of key areas of CSTI strategies.
  SIP program was launched 2014 (5 years program).
  SIP "Energy carriers" was one of 11 themes of SIP and continued 2014 – 18 fy.

SIP "Energy Carriers"

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

Scenario of Basic Hydrogen Strategy

METI



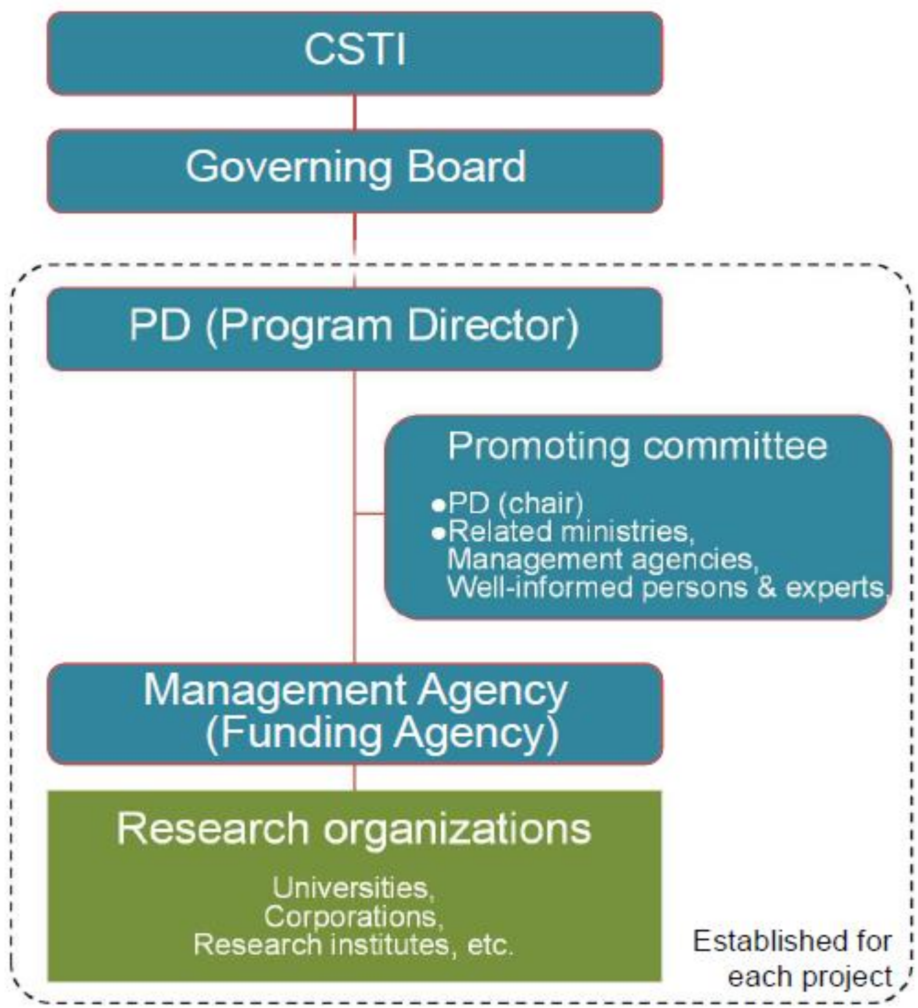
SIP (Cross-Ministerial **S**trategic **I**nnovation **P**romotion **P**rogram)
(CSTI of Cabinet Office)

- SIP is created by CSTI to realize innovation through promoting R&D overarching basic to applied research and to commercialization by cross-ministerial cooperation.
- CSTI appoints Program Directors (PDs) for each project and allocates the budget.
- CSTI identifies innovation themes to be covered by SIP and each theme continues for 5 years.
- **"Energy Carriers"** was selected as one of the 11 themes of SIP in 2014 and have been allocated about 30 M$ every year.

PD: Mr. Muraki

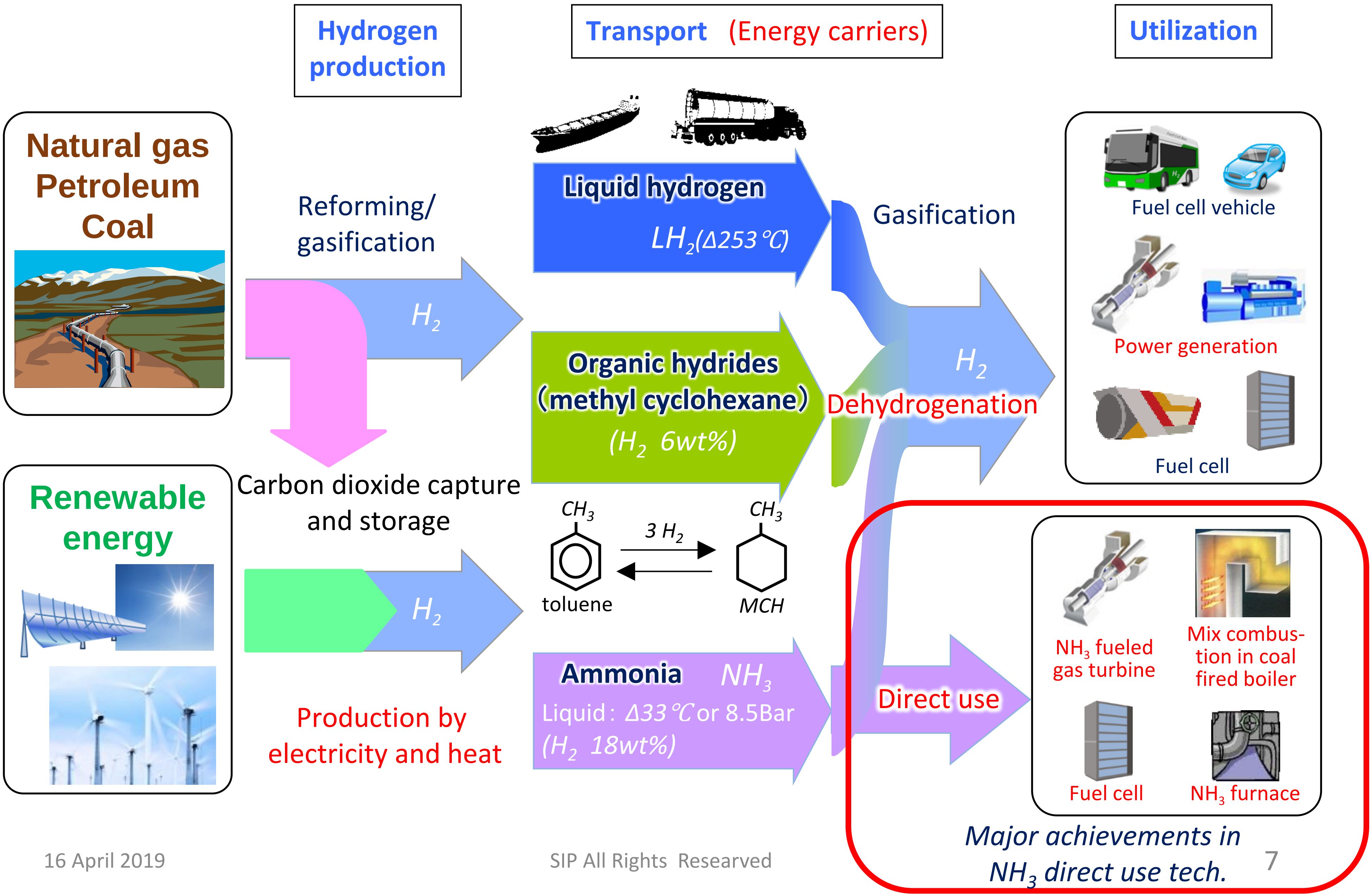
Deputy PDs

Dr. Aika Mr. Shiozawa



CSTI: Council for Science, Technology and Innovation

Scheme of CO_2 Free Hydrogen Value Chains



2. Major achievements of SIP “Energy Carriers”

- NH_3 direct use technologies -

Achievements ①

NH_3 fueled Gas Turbine

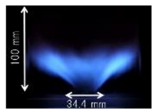
① Small and medium size gas turbines (GT)

- Developed 50kW and 300kW 100% NH_3 fueled GT

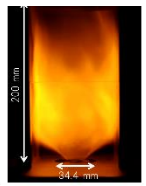
【Tohoku University / AIST / Toyota Energy Solutions】

50kW (100% NH_3) Micro Gas Turbine

CH_4 flame



NH_3 flame

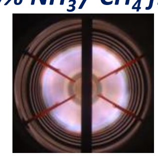


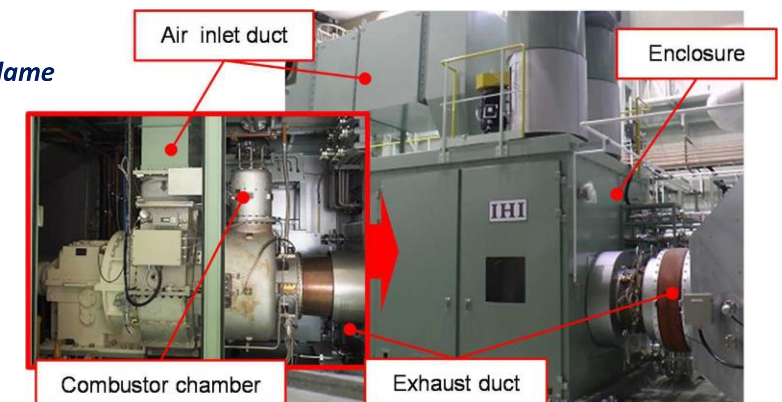
- 41.8 kW and 295 kW power generation was achieved by 100% ammonia fueled micro gas turbines (50kW and 300 kW rating respectively) with less than 15 ppm NOx emission using a standard SCR device.

- Developed 2MW 20% NH_3 co-firing GT 【 IHI Corporation】

- 2MW 20% NH_3 co-firing (with CH_4) gas turbine for power generation was developed.

20% NH_3 / CH_4 flame





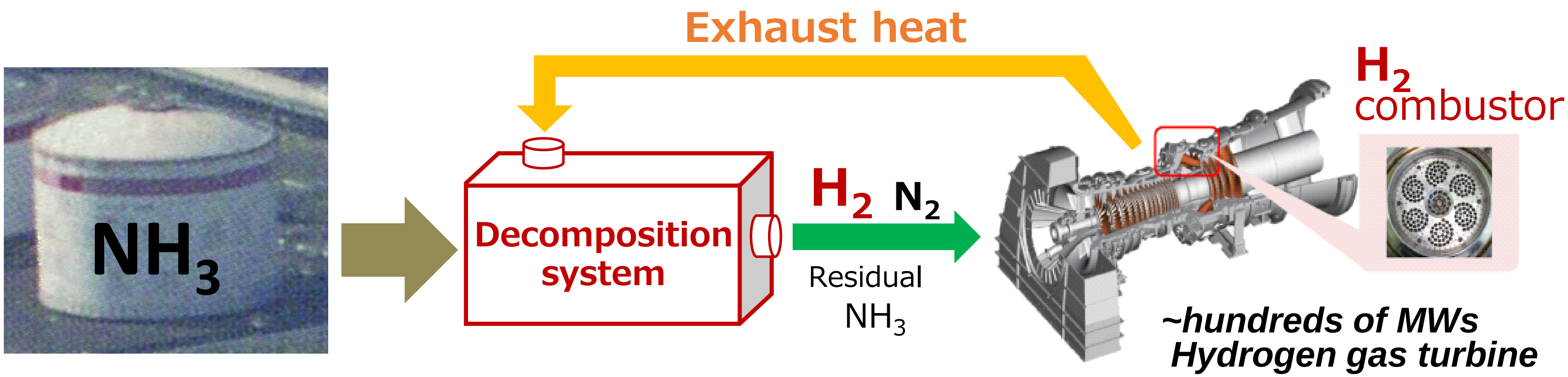
2MW (20% NH_3 / CH_4) Gas Turbine

Achievements ②

NH_3 fueled Gas Turbine

② Advanced combined cycle gas turbine (Several hundred MW class)

【 Mitsubishi Heavy Industries Engineering / Mitsubishi Hitachi Power Systems】



- Verified technical feasibility of this GTCC system; i.e.: to generate H_2 by cracking NH_3 inside the system using exhaust heat of GT without losing total power generation efficiency of the GTCC system.
- Basic concept of this system is to use NH_3 as H_2 carrier.
- This R&D will continue after SIP “Energy Carriers” finished.

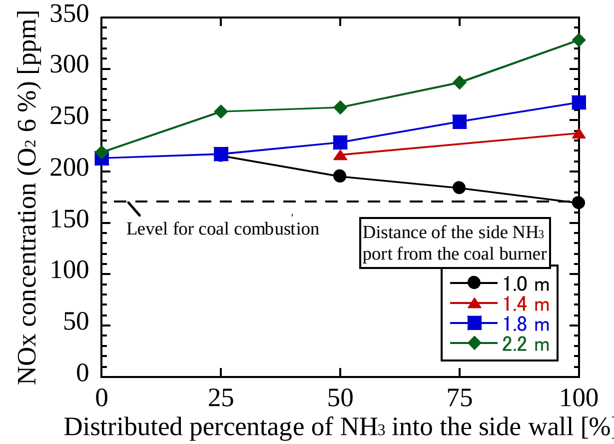
Achievements ③

NH_3-Coal mixed combustion

① Single-burner combustion test 【Central Research Institute of Electric Power Industry】

- It was found that by adjusting inlet point of NH_3 in pulverized coal combustion furnace, emission level of NO_X in 20% NH_3 mixed combustion can be controlled at the same level of 100% pulverized coal combustion.

NH_3 / pulverized Coal flame



② Co-fired ammonia at the commercial coal power plant 【The Chugoku Electric Power Co. Inc.】

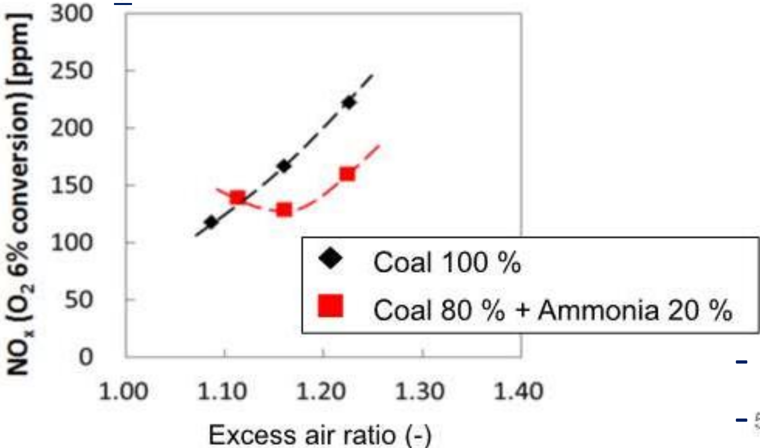
- Succeeded in stable and safe operation using NH_3-Coal mixed fuel: (1MW-NH_3 feed/156MW-Coal).
- Not observed Increase of NO_X and NH_3 concentration in exhaust gas.
- Succeeded in stable power generation during the demonstration test.

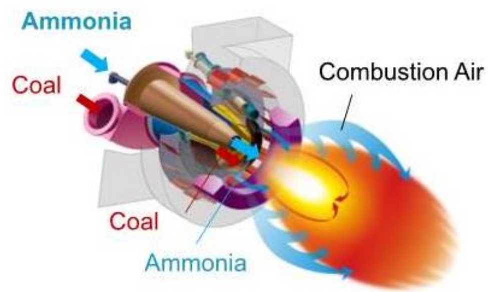
- It was evaluated that application of this NH_3 co-firing technology will enable reducing CO_2 emission from coal power generation utilizing existing facilities including existing denitration equipment, and thus will be cost efficient.

Mizushima power plant NO.2 Unit (156MW)

NH_3-Coal mixed combustion

③ NH_3-Coal mixed combustion demonstration test (10MW) 【IHI】





IHI Aioi Plant

The large scale combustion test facility

- NH_3 was completely combusted.
- NOx ＜200 [ppm]

- IHI announced that "the company successfully proved NH_3-Coal co-firing technology as the technology which enables to contain NO_X emission in the same level as that from ordinary coal power generation facility with minor modification of facility," while greatly reducing CO_2 emission.

④ Detailed F/S on introduction of NH_3 to existing coal power generation facility

【Chubu Electric Power, Tohoku Electric Power, Kansai Electric Power】

- Conducted technical as well as economic F/S on introduction of NH_3 as fuel into actual existing coal power generation plant sites.

Achievements⑤

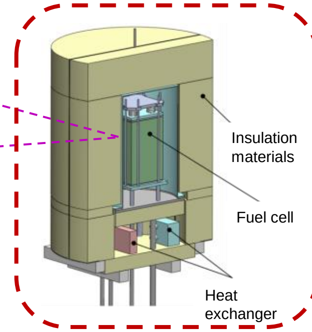
NH_3 fueled SOFC

NH_3-fueled solid oxide fuel cell (SOFC)

【Kyoto University / Noritake Co., Limited / IHI Corporation】

- Developed 100% NH_3-fueled 1kW SOFC system (direct supply of NH_3).
- Achieved almost the same power generation efficiency as that of H_2 fueled

Fuel cell stack
(Photo:courtesy of Noritake)



Hot test module

SOFC system

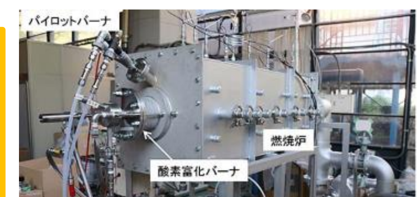
NH_3 fueled industrial furnace

【Osaka University, Taiyo Nippon Sanso, Nippon Steel Nissin】

① Model industrial furnace (100kW)

- Using NH_3 (30%) - CH_4 mixed fuel, achieved equivalent heating efficiency (55%) with that of 100% CH_4 fueled industrial furnace, while containing NO_x emission less than 150ppm.

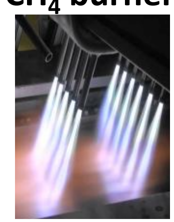
100kW Model Furnace



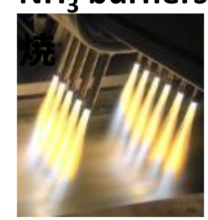
② Application of NH_3 mixed combustion burner for a degreasing furnace in steel plate manufacturing

- Using NH_3 (30%) - CH_4 mixed fuel, achieved to produce equivalent or even better quality of steel plate products than those processed by 100% CH_4 fueled degreasing furnace, in addition to 30% reduction of CO_2 emission.

CH_4 burners



NH_3 burners混焼



Achievements⑥

NH_3 synthesis process from CO_2 free hydrogen

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

- Developed a new catalyst and process to use renewable H_2 as raw material. This newly developed production process can operate under moderate temperature and pressure, and under the condition where input of renewable H_2 may fluctuate.
- Constructed a demonstration plant (20kg-NH_3/day) at Fukushima Renewable Energy Institute (FREA).
- This completed a model CO_2 free energy value chain (production of CO_2 free NH_3 ⇒ power generation by NH_3 fueled gas turbine (See "Achievements ① above) also located at FREA.

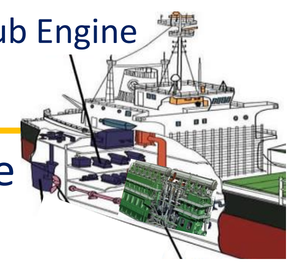
Pilot plant of a new NH_3 production process using renewable H_2 as raw material.

Newly developed catalyst.

NH_3 fueled marine engine

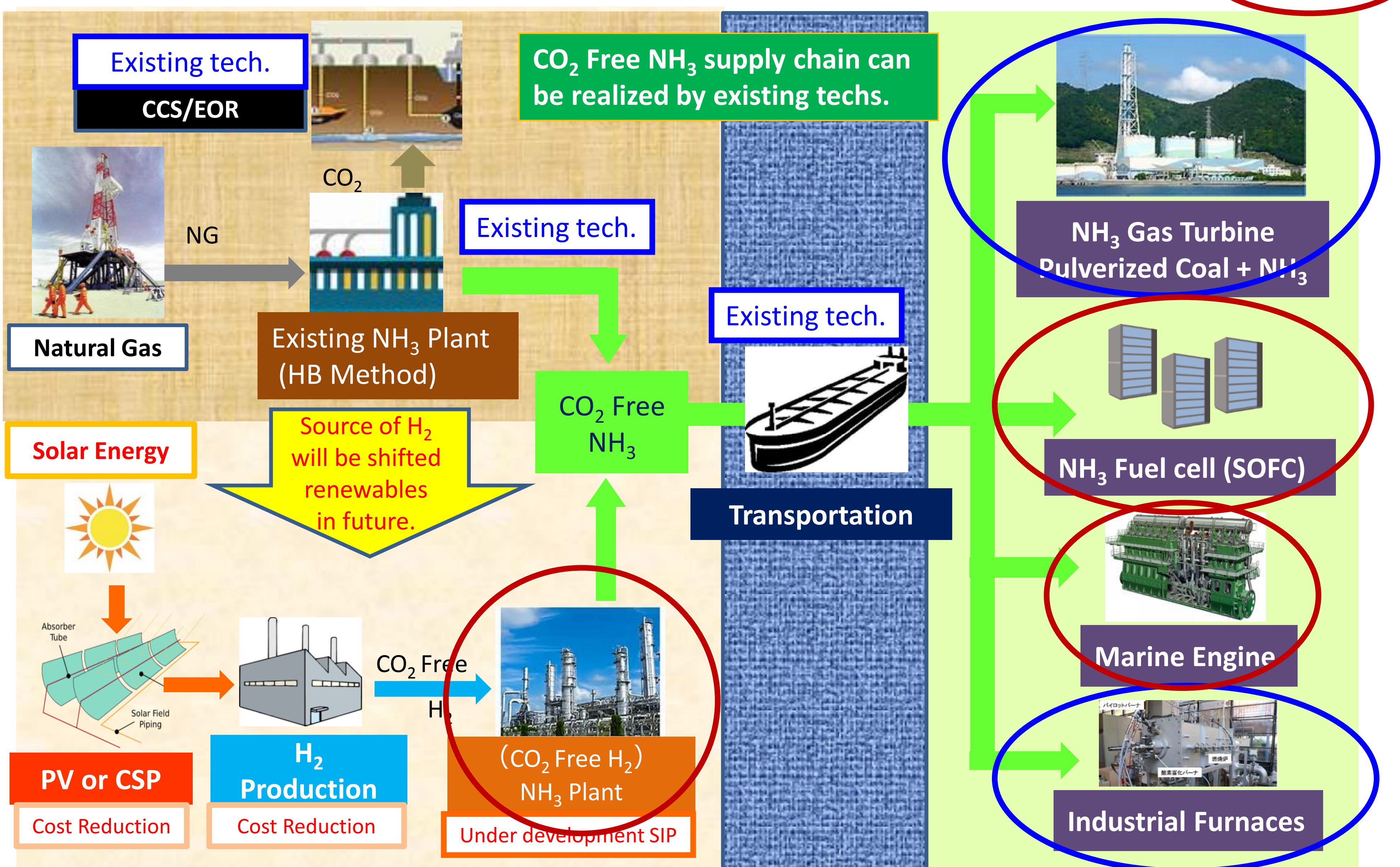
【JFE Engineering, National Institute of Maritime, Port and Aviation technology】

- Required technological challenges in order to use NH3 as fuel for marine engine were identified.



Status of CO_2 free Ammonia Value Chain

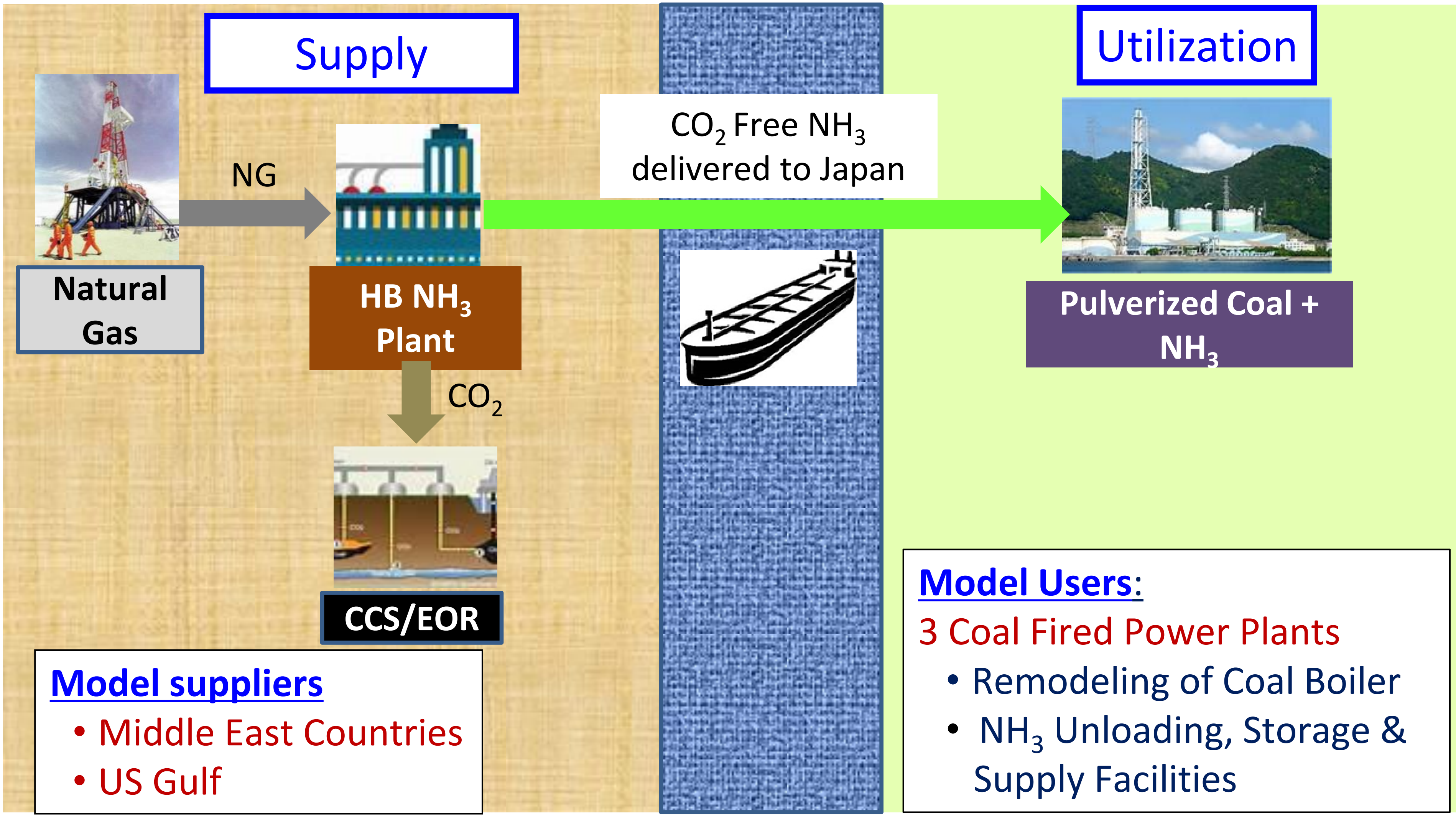
Developed
Additional work required



A feasibility study on CO_2 free NH_3 supply chain

(entitled “A Feasibility Study on the Supply Chain of CO_2-Free Ammonia with CCS and EOR”)

Conducted by IEEJ with having input from an engineering company, two trading companies and three power generation companies possessing coal fired power generation facilities.



Findings of the IEEJ Study

(entitled "A Feasibility Study on the Supply Chain of CO_2-Free Ammonia with CCS and EOR")

- 350 \$/ton after delivery to the sites ⇒ 3.5 Mton 2030, 5 Mton 2035

1. According to the analysis using a model developed by IEEJ, import of CO_2 free NH_3 for Coal/NH_3 mixed combustion in coal fired power generation facilities in Japan will amount to 3.5 million tons in 2030 and 5 million tons in 2035, if the price of the CO_2 free NH_3 is 350 \$/ton-NH_3 after delivery to the power generation sites.

- 350 \$/ton of CO_2 free NH_3 can be feasible

2. Such price level of 350 \$/ton-NH_3 would be acceptable level to both suppliers and users according to the analysis, since:
   (a) suppliers can secure 10% EIRR with this price; and
   (b) users can sustainably operate the facility using it as CO_2 free fuel to overcome the CO_2 emission constraints.

The price of "350 \$/ton -NH_3" already almost clears the H_2 cost target

Cost targets mentioned in "Strategic Plan for Hydrogen Utilization"

Target year	H_2 (\$/kg-H_2)
2030	3
Near future	2

⇒

Equivalent NH_3 price in terms of energy contents

NH_3 (\$/ton-NH_3)
480
320

"The Future of Hydrogen," very recent IEA Report

Transmission and distribution of hydrogen as ammonia is likely the cheapest mechanism for import to Japan from Australia

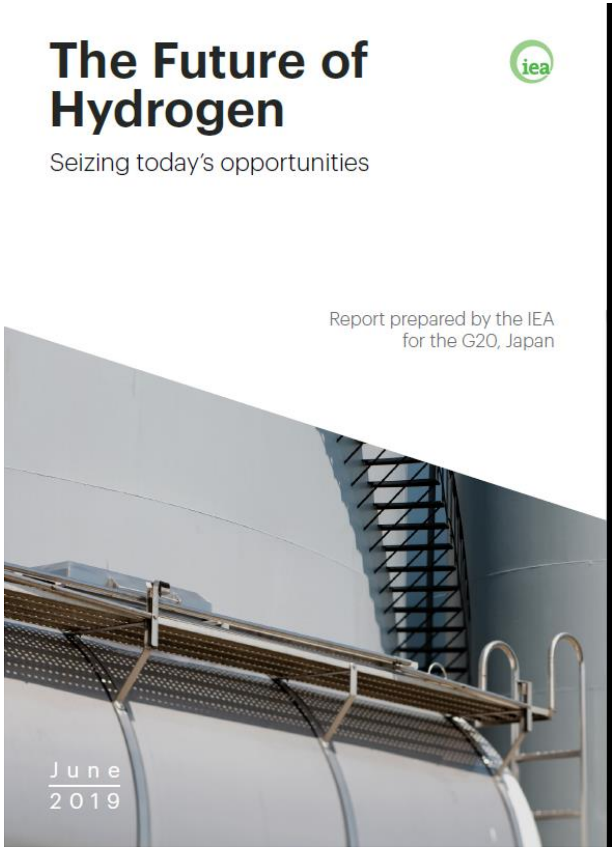
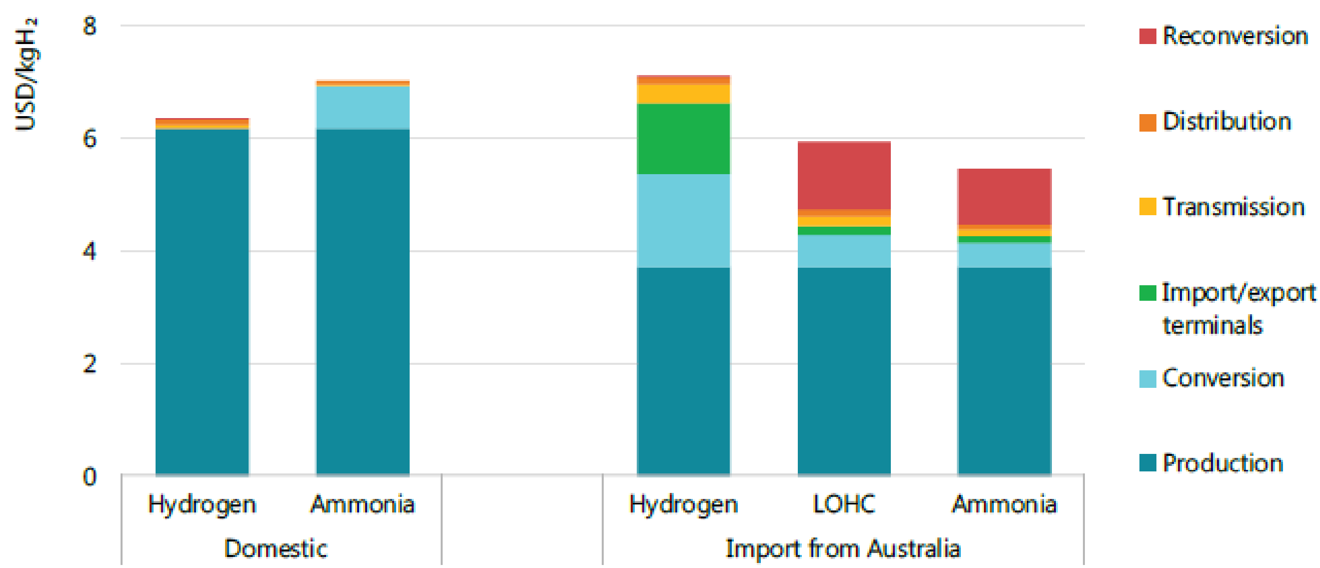


Figure 30. Cost of delivering hydrogen or ammonia produced via electrolysis from Australia to an industrial customer in Japan in 2030



Notes: Assumes distribution of 100 tpd in a pipeline to an end-use site 50 km from the receiving terminal. Storage costs are included in the cost of import and export terminals. More information on the assumptions is available at www.iea.org/hydrogen2019.

Source: IEA analysis based on IAE (2019), "Economical Evaluation and Characteristic Analyses for Energy Carrier Systems" and Reuß (2017), "Seasonal storage and alternative carriers: A flexible hydrogen supply chain model". All rights reserved.

The cost of transport from Australia to Japan could represent between 30% and 45% of the full cost of hydrogen; yet imports of electrolytic hydrogen could still be cheaper than domestic production.

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 dehydrogenation.
(Does not require energy for dehydrogenation.)

(4) NH_3 does not emit CO_2 in combustion. By R&D in SIP "Energy Carriers," it was found emission of NO_X in NH_3 combustion can be contained.

(5) NH_3 has acute toxicity and strong smell and needs handling with care. But not known chronic toxicity and easy to detect.

(6) Energy equivalent cost of NH_3 is **cheaper** than other energy carriers.

(7) NH_3 has already widely being used as de-nitration agent in power generation plant sites.

(8) CCS cost from NH_3 production plant is cheaper than that from exhaustion gas from turbine or boiler (**cheaper CCS cost**).

3. The way forward

The Green Ammonia Consortium

Dec. 2018

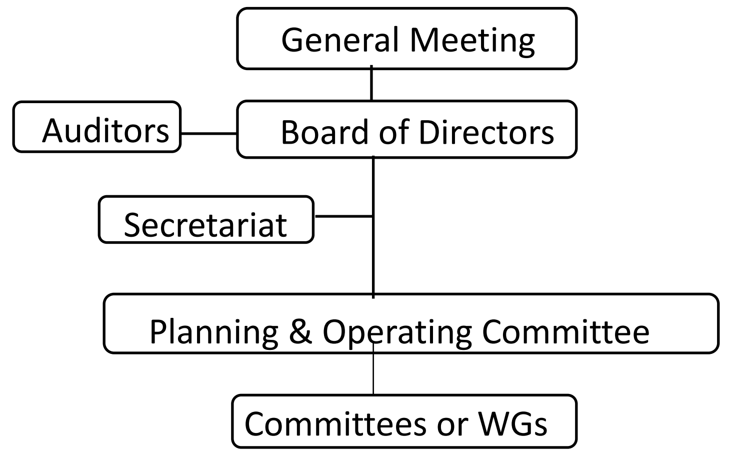
Objectives

Development of a commercial CO2 free ammonia value chain toward low carbon society.

Main activities

(a) Promotion of collaborations between industry, government and academia.
(b) Commercialization of NH3 utilization technologies and supply chain.
(c) Studies on Feasibilities, Environmental Impact and Standard & Regulation
(d) Strategy & Policy making
(e) International collaborations

Organization of GAC



to be established as necessary

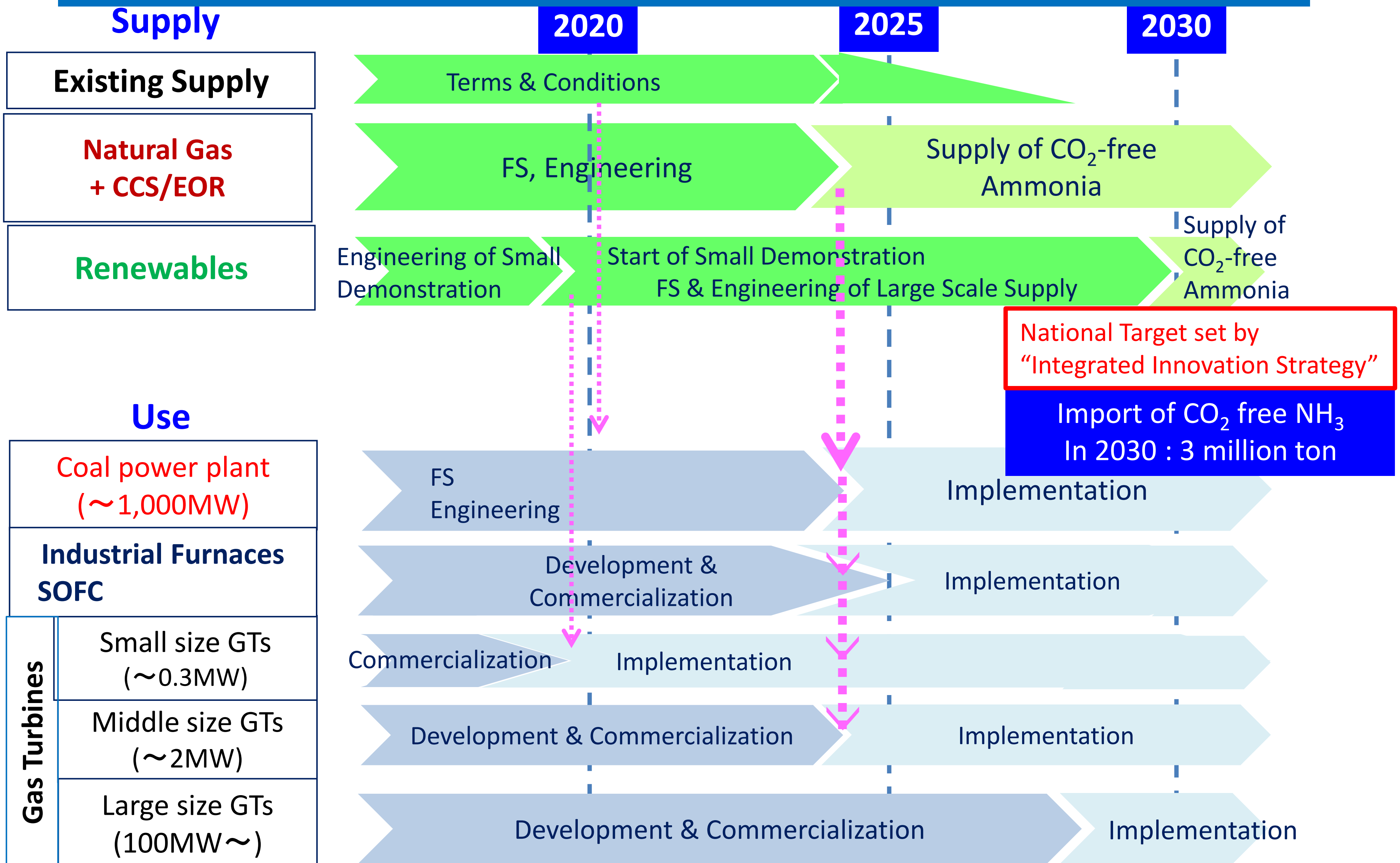
The Green Ammonia Consortium was originally established in July 2017. At that time, membership of the original consortium was only open for the entities which participated in SIP "Energy Carriers."

After SIP "Energy Carriers" ends in March 2019, a new "The Green Ammonia Consortium" will be established as an independent General Incorporated Association to be registered under the Japanese Law and its membership will be open for global entities which are interested in participating and are ready to contributing to the objectives of the new "The Green Ammonia Consortium."

GAC Mmbers
(As of June 6, 2019)

	CHEMICALS/MATERIALS	Toyota Central R&D Labs.
	Ube Industries	JGC Corpotration
ENERGY	Showa Denko K.K	Mitsui E&S
Kansai Electric Power	JNC	Mitsubishi Heavy Industries
(Kyushu Electric Power)	Sumitomo Chemical	Mitsubishi Hitachi Power Systems
(JERA*)	Toray	
The Chugoku Electric Power	JGC Catalysts and Chemicals	**FOREIGN COMPANIES**
Electric Power Development	Nippon Shokubai	Equinor ASA
Tohoku Electric Power	Mitsubishi Gas Chemical	KBR
Hokuriku Electric Power	Mitsubishi Material	The Hydrogen Utility
Osaka Gas		Woodside Energy
Tokyo Gas	**CIVIL ENGINEERING**	Yara International
Toho Gas	Hazama Ando Corporation	
JXTG Energy	Obayashi Corporation	**RESEARCH INSTITUTE**
Aramco Asia Japan	(Kajima Corporation)	The Institute of Energy Economics, Japan
Shell Japan	(Shimizu Corporation)	National Institute of Maritime, Port and Aviation Technology
TRADING	(Takenaka Corporation)	Japan Coal Energy Center
Suzuyo	**MACINERY & ENGINEERING**	Central Research Institute of Electric Power Industry
Sumitomo Corporation	IHI	CISRO (Australia)
Marubeni Corporation	JFE Engineering	**PUBLIC ORGANIZATION**
Mitsui & Co.	Chiyoda Corporation	Akita Prefecture Industrial Technology Center
Mitsubishi Corporation	Chugai Ro Corporation	City of Mihihama
LOGISTICS	thyssenkrupp Uhde Chlorine Engineers	City of Yokkaichi
Iino Kaiun Kaisha	Tokyo Electric Power Services	Austrade Tokyo Office
Uyeno Transtech	Toyo Engineering	State of the South Australia
Mitsui O.S.K.Lines	Toyota Energy Solutions	Norwaygien Embassy in Tokyo
Nippon Yusen Kaisha	Toyota Industries	

Roadmap of CO_2 free NH_3 supply chain
- Developed by members of GAC -



Thank you for your attention.

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SIP Cross-ministerial Strategic Innovation Promotion Program