SIP "Energy Carriers" and Potential of Ammonia
- a door opener of a low carbon society -

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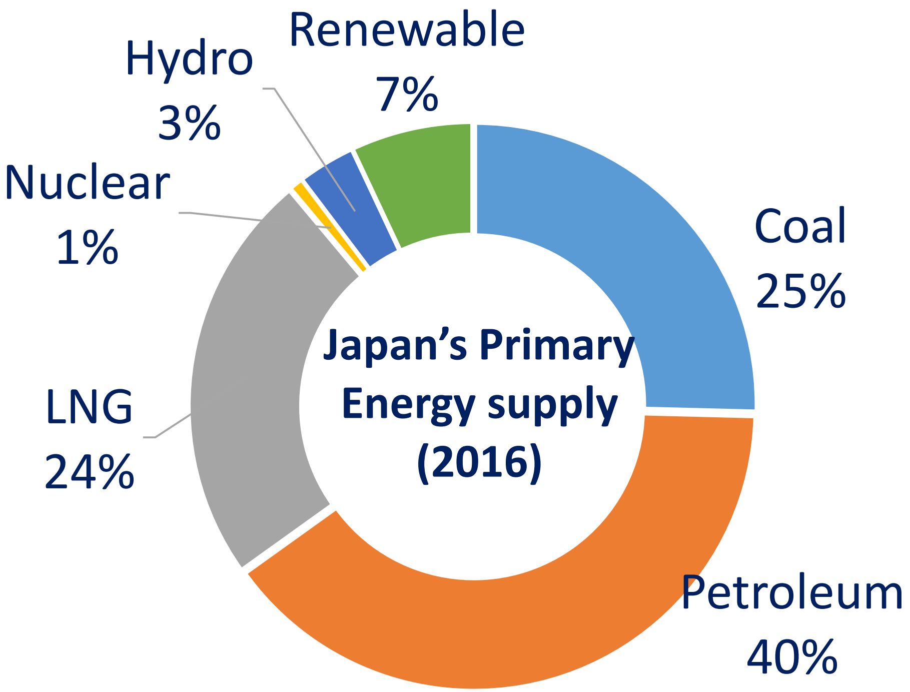
Cross-ministerial **S**trategic **I**nnovation **P**romotion **P**rogram

SIP "Energy Carriers"

Cabinet Office of Japanese government

Energy and environmental constraints of Japan

- Japan relies on her 90% primary energy supply on fossil energy source.
- To reduce GHG emission 80% by 2050 and to enhance energy security of Japan, we will have to greatly increase supply of renewable energy.



Primary energy	=	Fossil	+	Nuclear	+	Renewable
(Present)		89%		1%		10%
(2050)	Stay	↓80%		↓90-40%		↑ Need to substantially increase

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,"

"Strategic Plan for Hydrogen Utilization" (December 2017)

- Japan's first comprehensive plan on introduction and utilization of hydrogen energy, developed by the ministerial conference (chaired by Prime Minister) consisting of relevant ministers of the Japanese government.
- The following statement was made by the minister overseeing the Council of Science, Technology and Innovations (CSTI) at the conference:

  *"**Ammonia is a promising H_2 energy carrier**, and **direct use of ammonia** is one of the most feasible options for the construction of a low-carbon society. "*

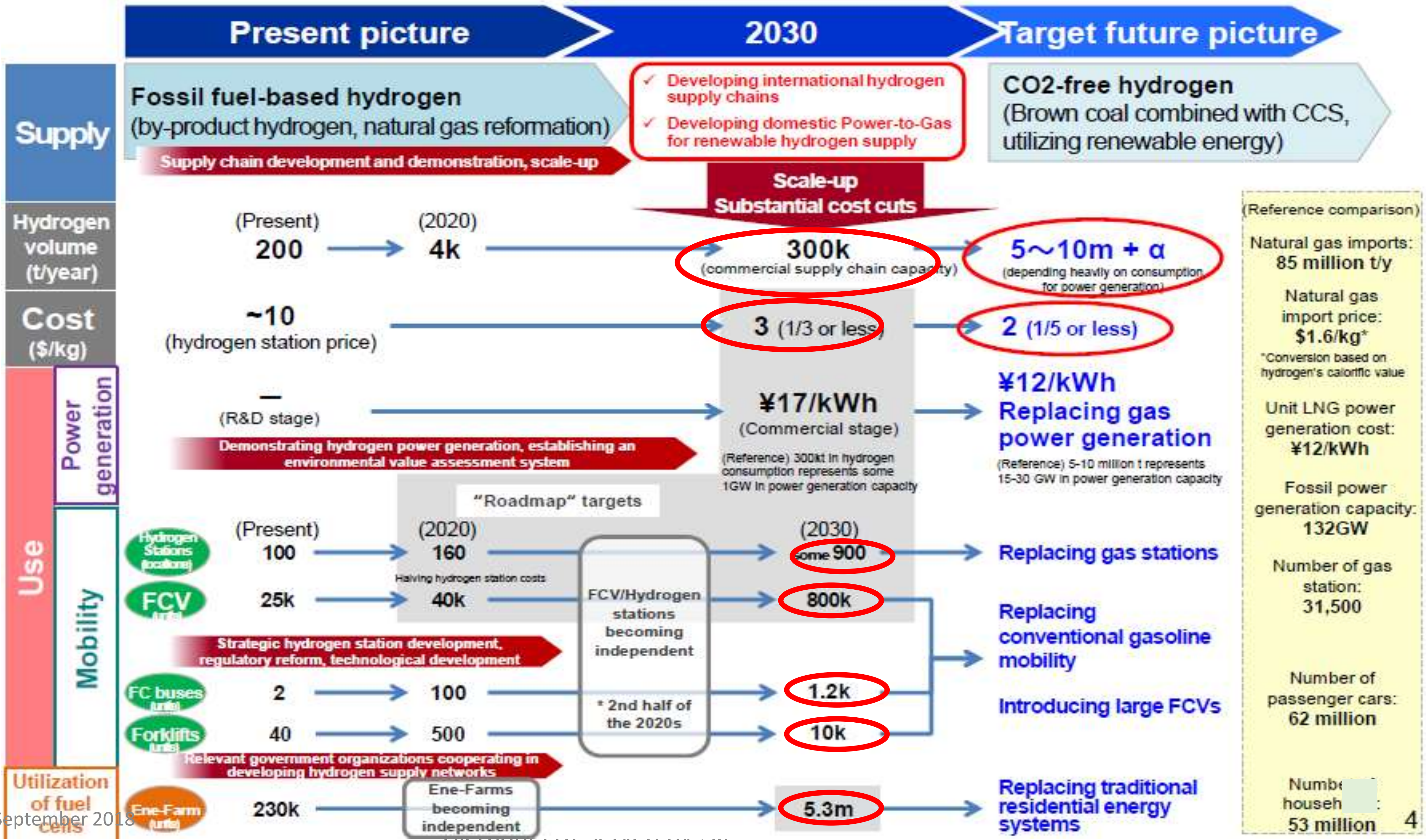
"National Basic Energy Plan" (May 2018)

- The Basic plan described as the following with regard to the Hydrogen energy:

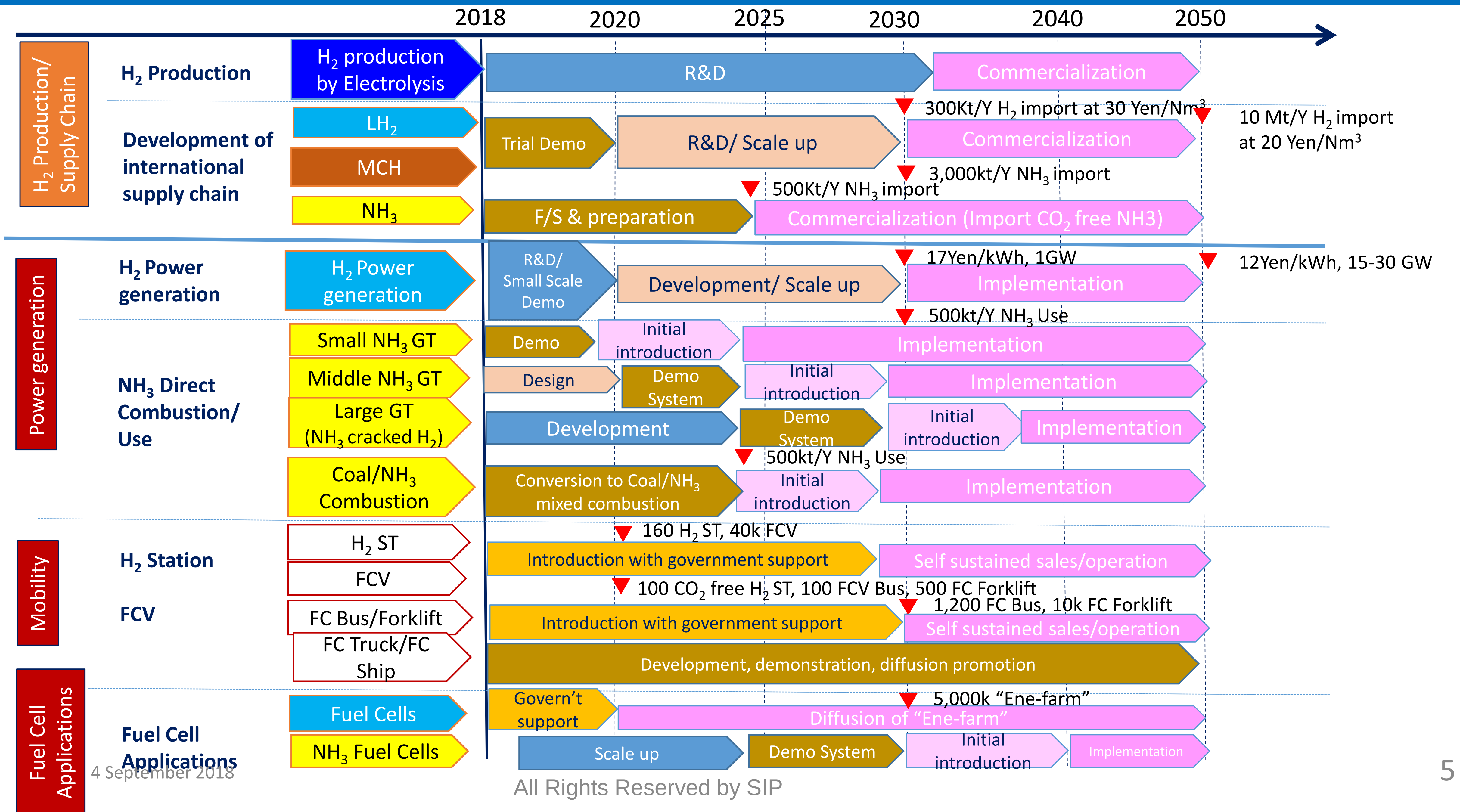
  "According to the "Strategic Plan for Hydrogen Utilization", further promote the use of hydrogen energy not only in transportation area but power generation and industry areas. "

Scenario for “Strategic Plan for Hydrogen Utilization”

METI



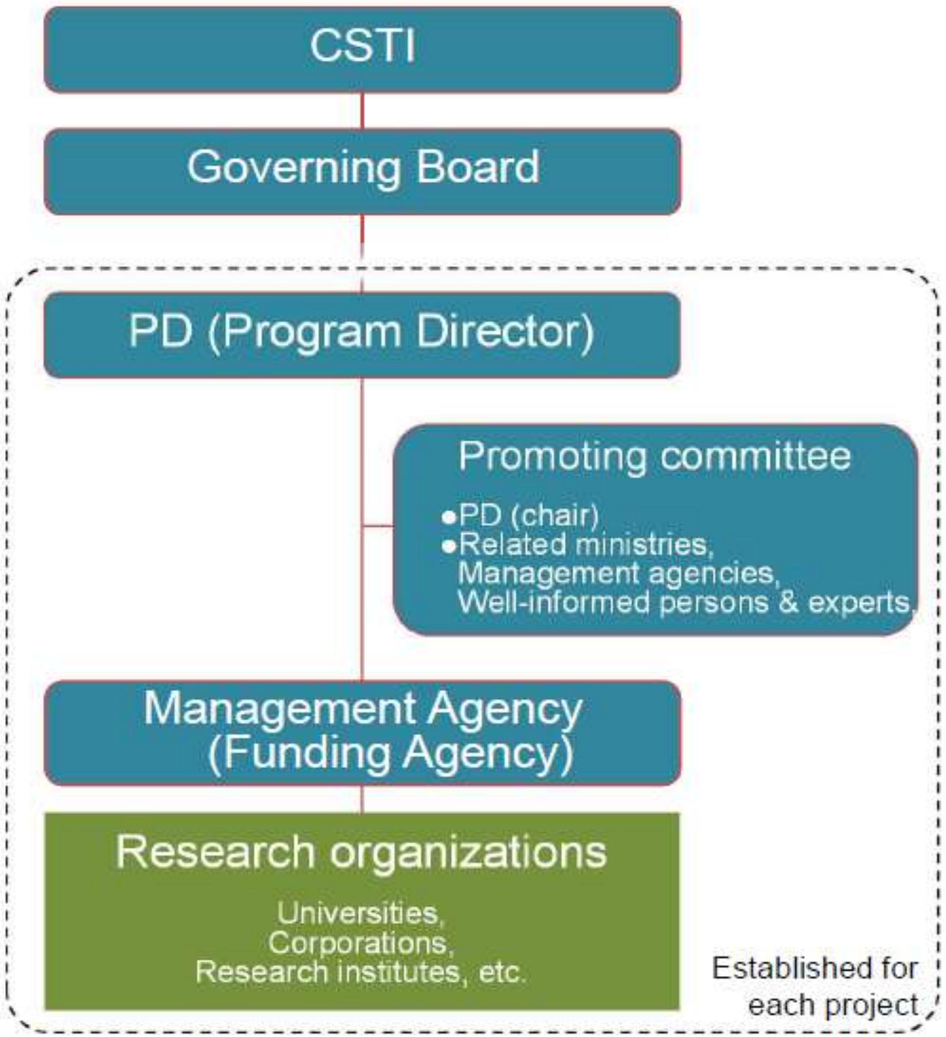
H_2/NH_3 related technology roadmap of the "Strategic Plan for Hydrogen Utilization" of 2017



SIP (Cross-Ministerial Strategic Innovation Promotion Program)
(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.
- **SIP "Energy Carriers"** was selected as one of the 11 themes of SIP in 2014 and have been allocated about 30 M$ every year.

< Governance structure >



PD: Mr. Muraki

Deputy PDs

Dr. Aika

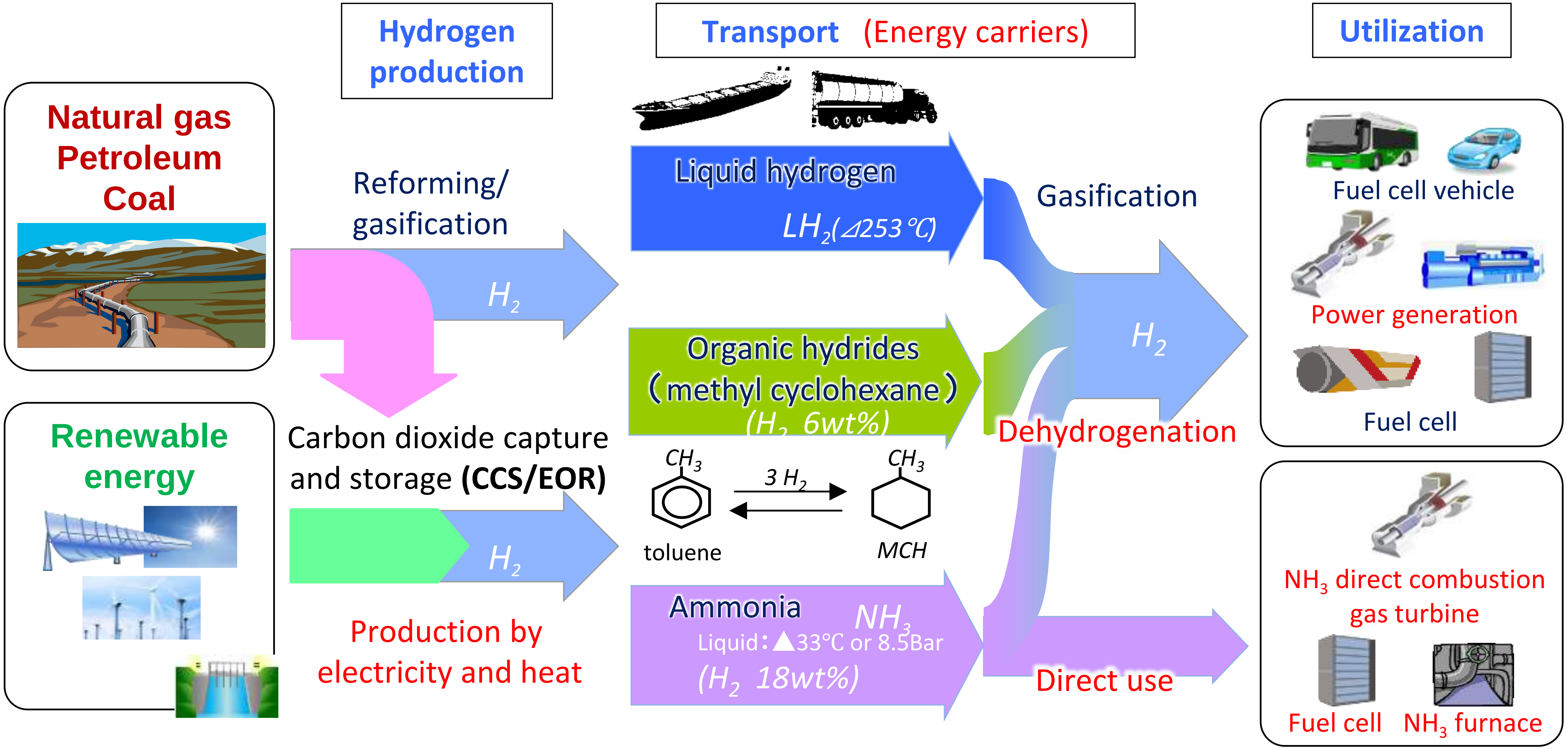
Mr. Shiozawa

CSTI: Council for Science, Technology and Innovation

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

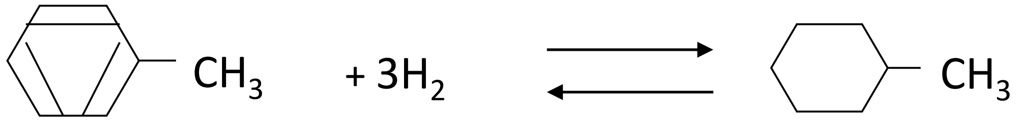
Envisaged CO_2 free hydrogen value chains



Energy Carriers; their physico-chemical properties

	H_2 content (Wt %)	Volumetric H_2 density ($kg\text{-}H_2/m^3$)	Boiling point (℃)	H_2 release enthalpy change* ($kJ/molH_2$)	Other properties
Liquefied Ammonia	17.8	121	-33.4	30.6	Acute toxicity, Corrosive
Methyl Cyclo-Hexane	6.16	47.3	101	67.5	Flammable, Irritative
Liquefied Hydrogen	100	70.8	-253	0.899	Very flammable, very combustible, explosive

MCH: Carry hydrogen using reversible chemical reaction between Toluene and Methyl Cyclohexane.



*H_2 release enthalpy change： Required energy to separate hydrogen other chemical substances.

NH_3 can be directly used as fuel
Recent Achievements (1/2)

Ammonia-fueled gas turbine power generation
(Press Release: on Sept. 17, 2015)

50kW NH3 fueled micro gas turbine

< NO_X 100ppm at burner outlet by Lab. combustion test

***Development of 2MW Gas Turbine** is almost completed*

Ammonia feed into a pulverized coal combustion power generation *(Press Released: on Jan. 10, 2017)*

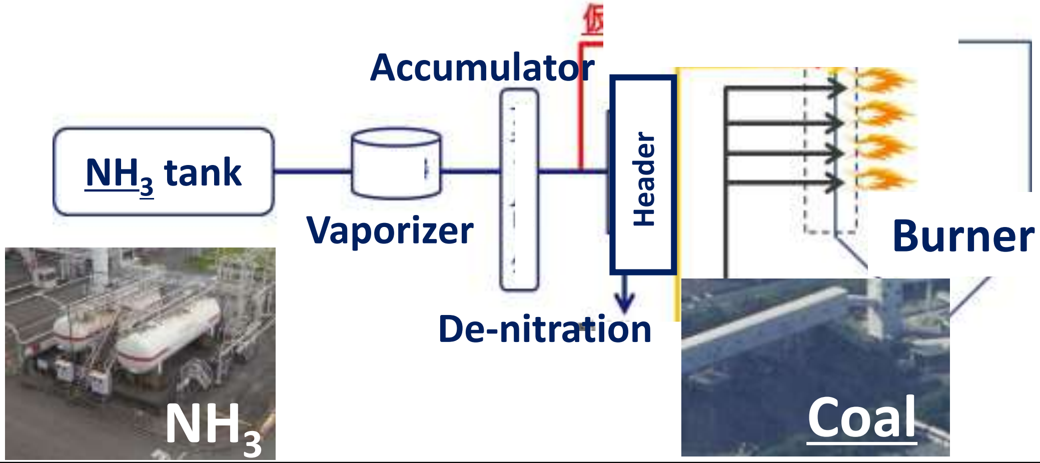
- 20% of coal (LHV) was replaced by ammonia.
- Complete combustion and no significant increase of NOx emission.

NH_3 / pulverized coal flame

Co-fired ammonia at the commercial coal power plant *(Press Release: on June 29 and Sept. 8, 2017)*

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

1MW-NH_3 feed/156MW-Coal
(Coal fired boileraand steam turbine)



NH_3 can be directly used as fuel
Recent Achievements (2/2)

Industrial furnaces
(Press Release: on Oct. 31, 2016)

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

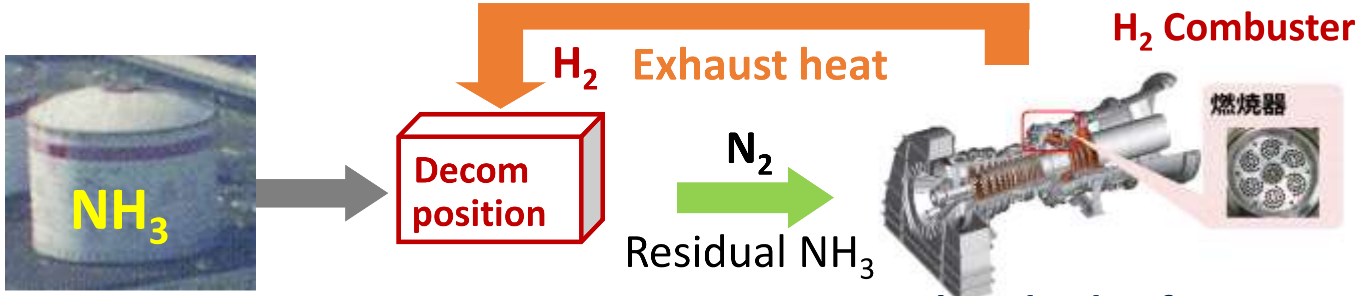
10kW model furnace

Direct ammonia-fueled solid oxide fuel cell (SOFC) *(Press Release: on Jul. 3, 2017)*

- Ammonia-fueled SOFC stack generated 1 kW of electrical power.
- The performance attained is equivalent to the hydrogen fueled SOFC.

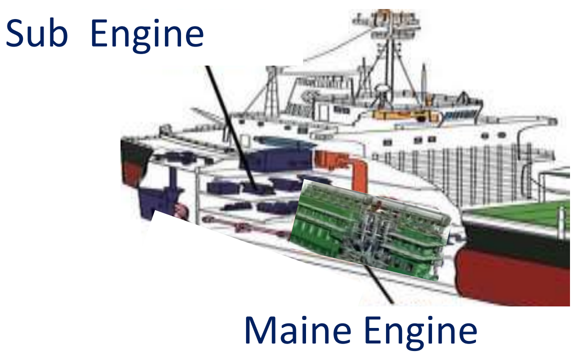
Fuel cell stack

Advanced combined cycle gas turbine

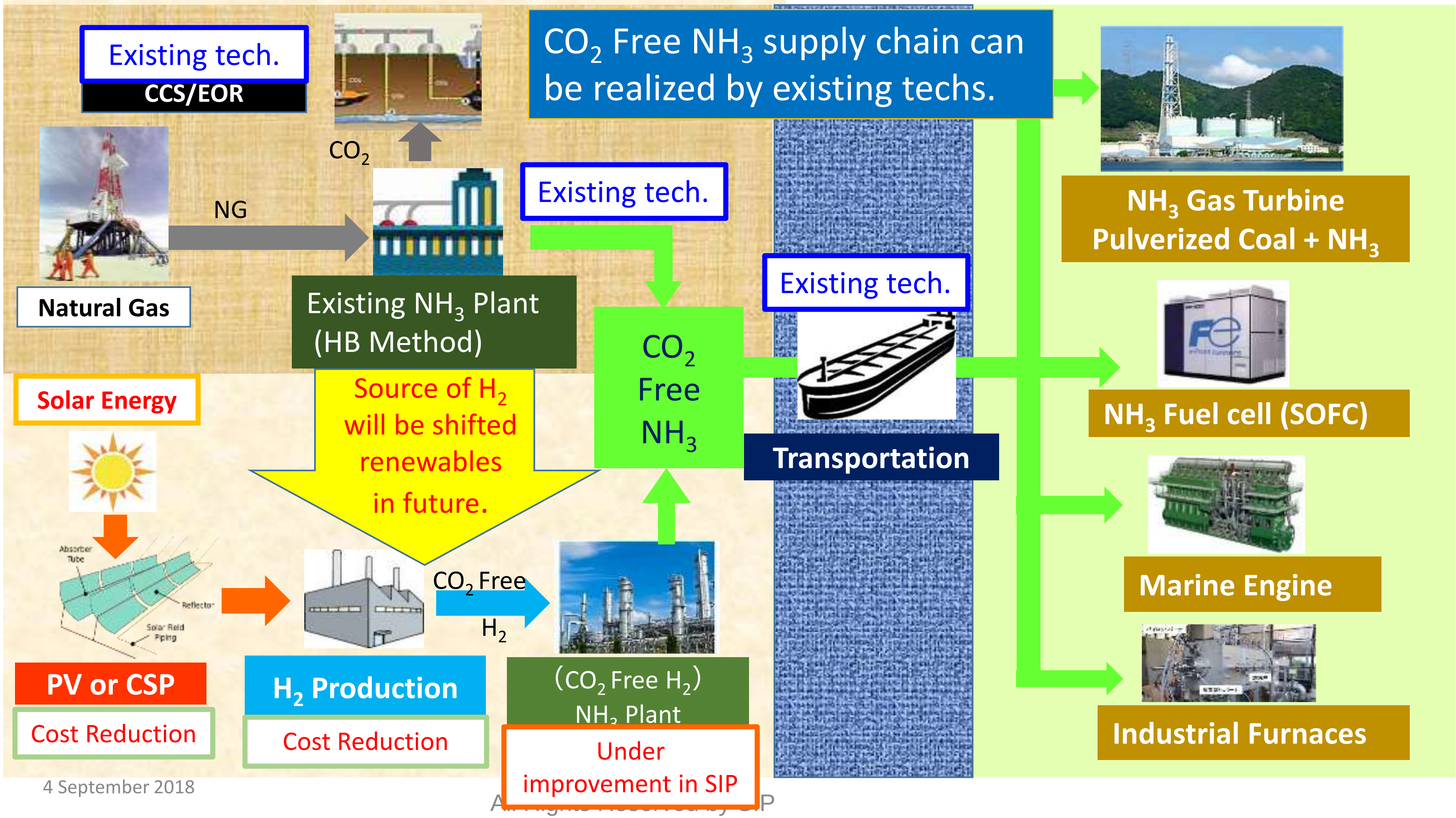


~hundreds of MWs Hydrogen gas turbine

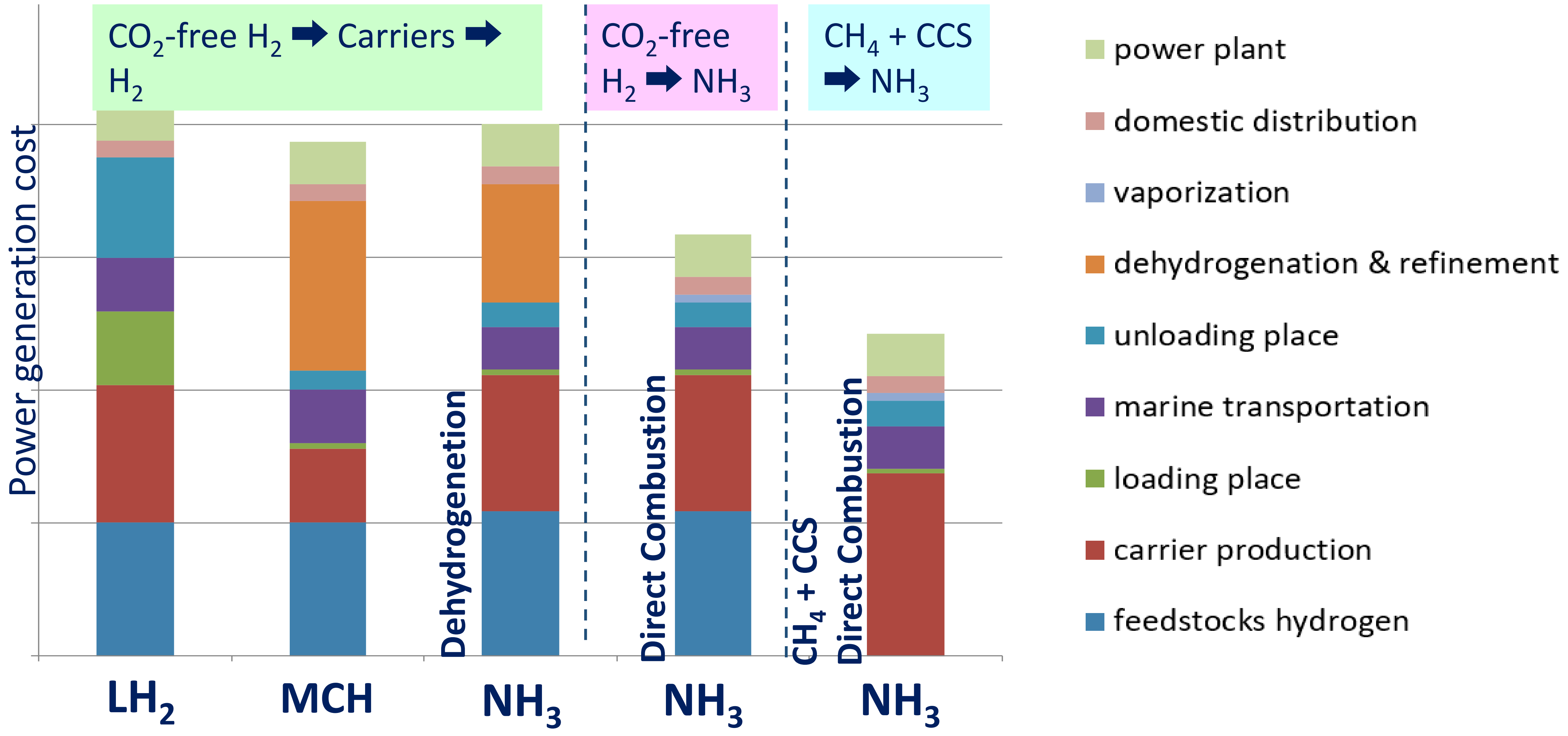
Marine Engine



Development of CO_2 free NH_3 value chain



Power generation cost comparison between 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 dehydrogenation. Thus it does not require input of energy in 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. But not known chronic toxicity (US EPA Study) and easy to detect.

(6) Energy equivalent cost of NH_3 is estimated to be **cheaper** than other CO_2 free 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 gas turbine or boiler (**cheaper CCS cost**).

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

Objective:
Aiming at commercialization of CO_2-free ammonia production and direct use technologies, development of road map towards the commercialization and promotion of collaboration between government and industry.

Studies to be conducted by the Consortium (examples):

(Production, transportation)

(1) Production of CO_2-free ammonia using CCS/EOR and renewable energy.
(2) Scale up of production plants and cargo ships.
(3) Supply capacity and supply chains.

(Use)

(1) Feasibility study and engineering of coal-ammonia mixed combustion power generation.
(2) Roadmap on ammonia combustion in small-medium-large scale gas turbines.
(3) Roadmap on ammonia fueled SOFC.
(4) Roadmap on ammonia utilization in industrial furnaces.

The Green Ammonia Consortium (present members)

Members

Mr. Muraki PD of SIP "Energy Carrier"
Mr. Shiozawa Deputy PD

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

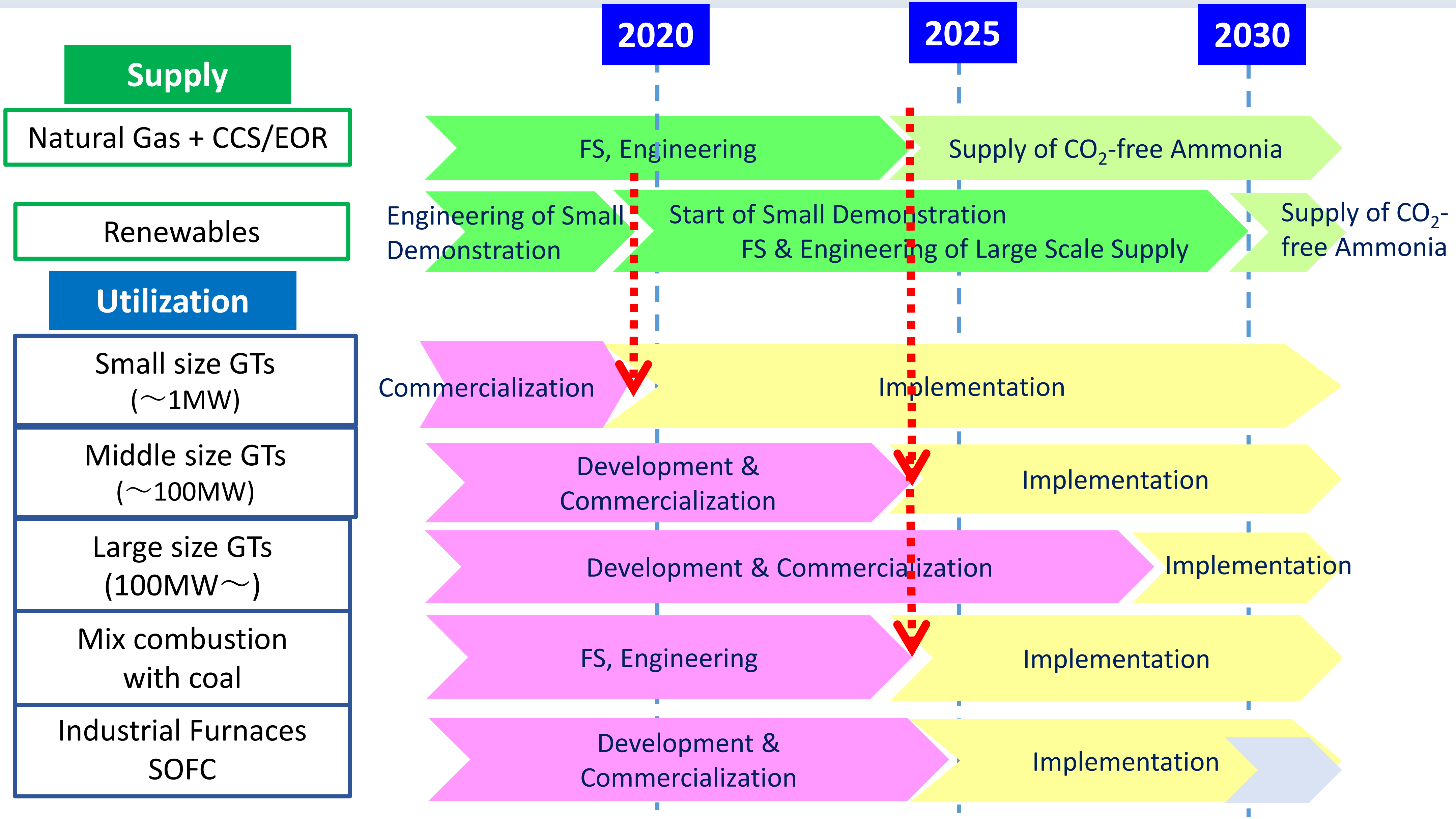
Supply and Trading
- Marubeni Corporation
- Mitsubishi Corporation Co.
- Mitsui & Co., LTD

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

Manufactures
- 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



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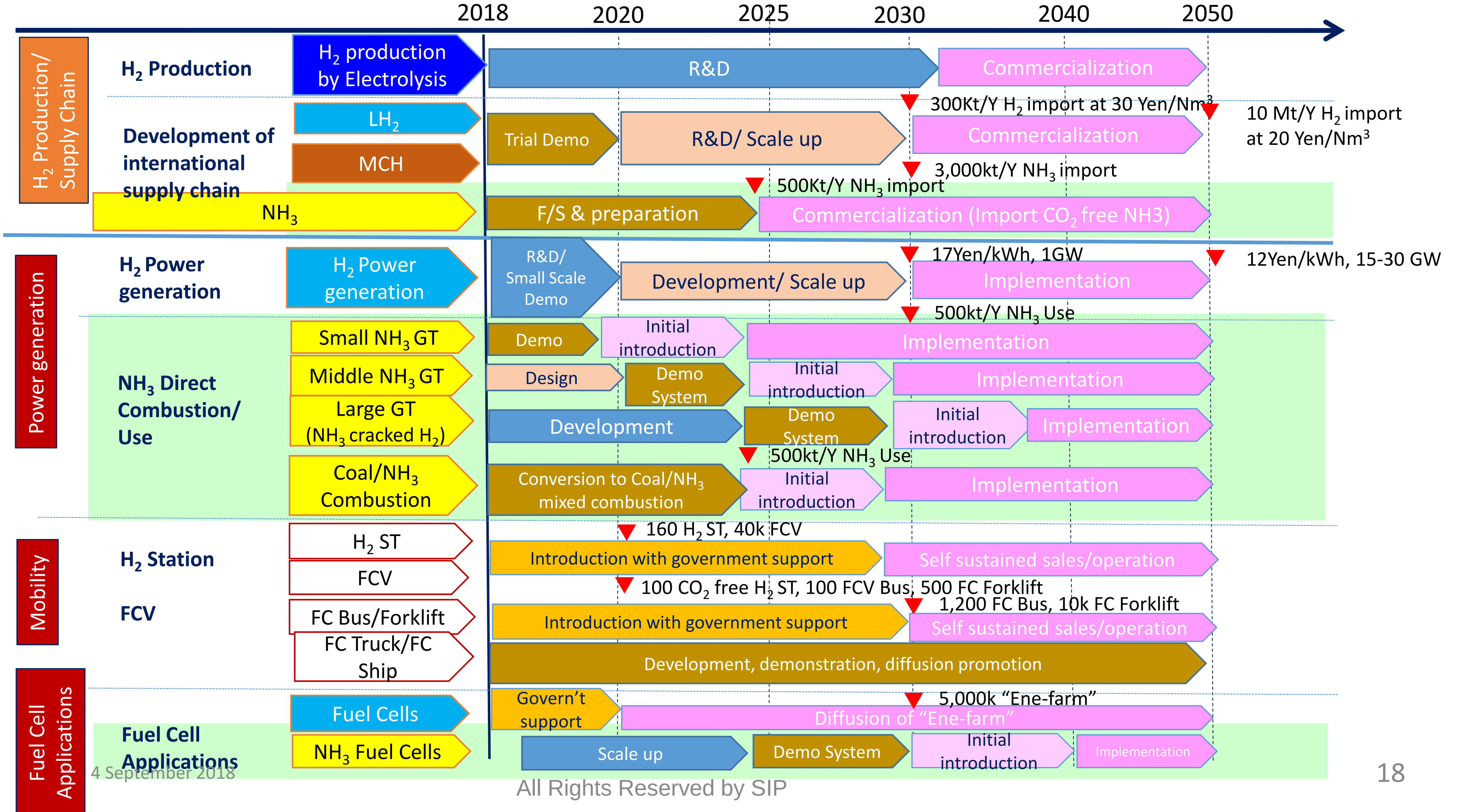

Thank you very much for your attention.

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