

Possible sources and associated costs in the near and long term for H₂ used in Japan

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Views and opinions in this material are those of the authors and do not represent the organizational views of the Institute of Applied Energy.



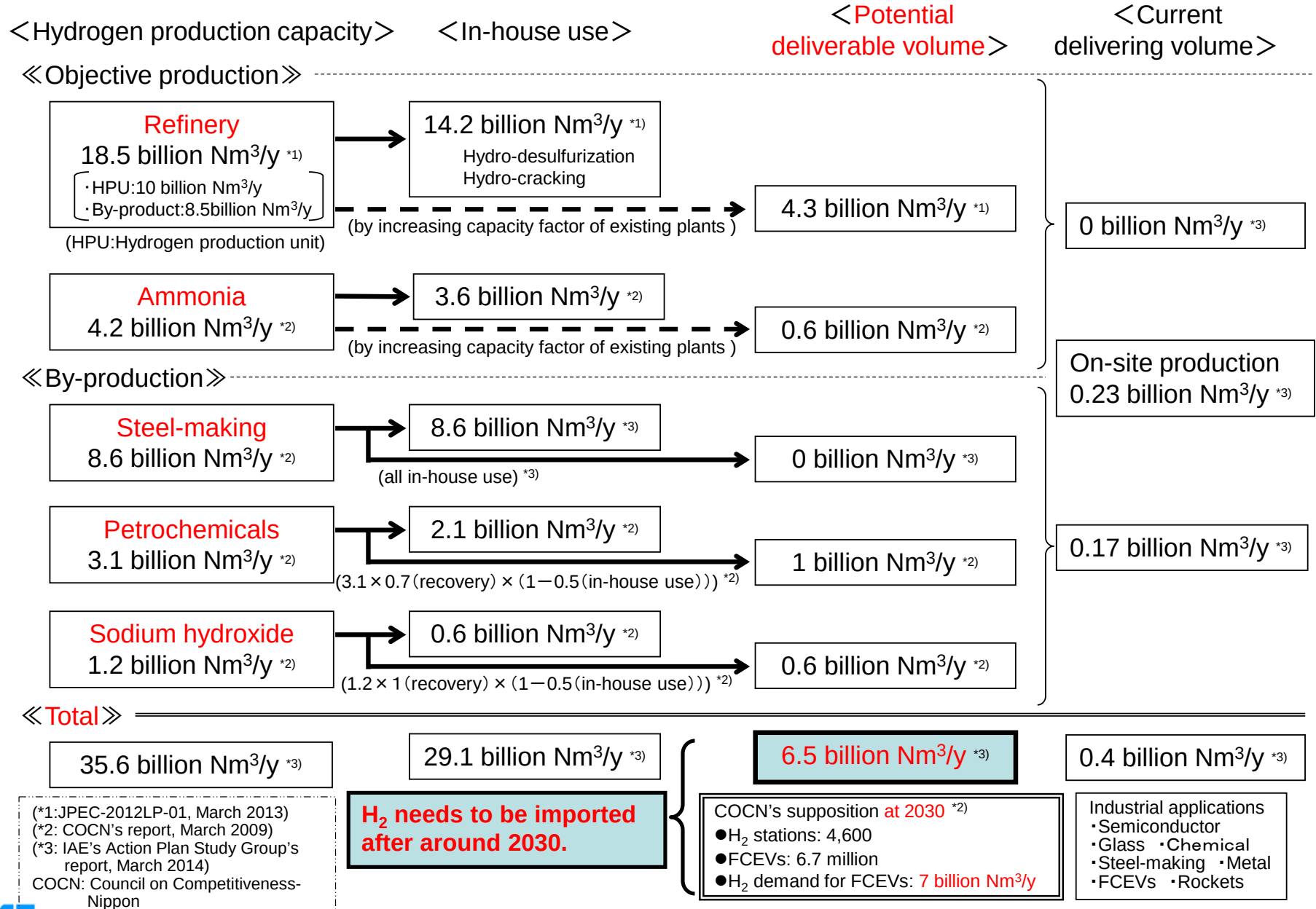
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1-1. Current hydrogen deliverable volume in Japan



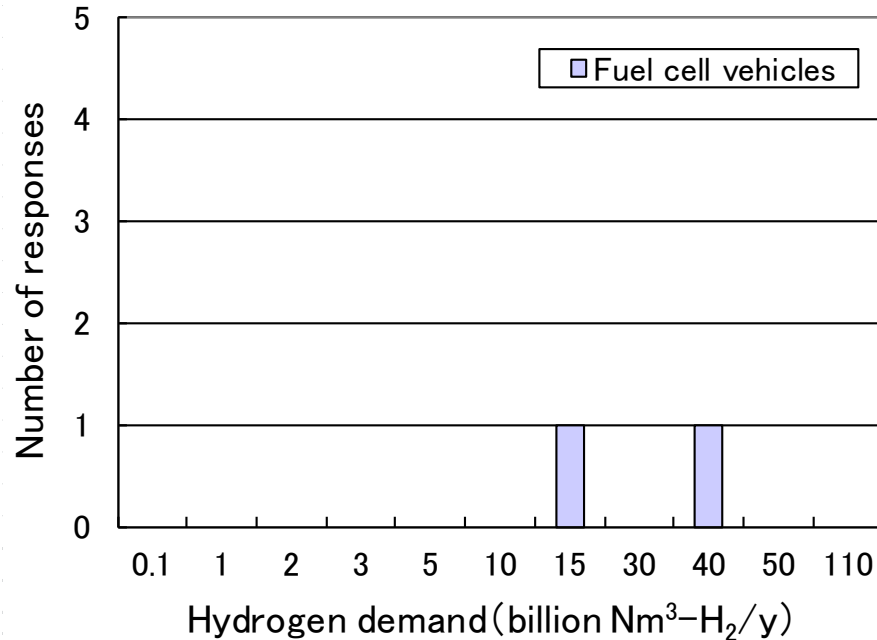
1-2. Current hydrogen costs in Japan

Hydrogen production source or technology		Hydrogen production cost (yen/Nm ³ -H ₂)	References and cost estimation basis
By-product H ₂	Sodium hydroxide	20	various literatures and documents, but details unknown
	Steel-making	24~32	previously estimated cost = 12~20 yen/Nm ³ energy cost up since then = 12 yen/Nm ³ updated cost = 24~32 yen/Nm ³
	Petrochemicals	20	various literatures and documents, but details unknown
Objective product H ₂ (existing plants)	Refinery	23~37	previously estimated cost = 10~24 yen/Nm ³ energy cost up since then = 13 yen/Nm ³ updated cost = 23~37 yen/Nm ³
Objective product H ₂ (new plants to be installed)	Ammonia	N.A.	
	Fossil fuel reforming	31~58 (* running cost only)	no inclusion of reformer equipment cost reformer efficiency = 70% town gas for industry and commercial = 1.7 yen/MJ No.1 fuel oil = 1.4 yen/MJ LPG = 2.9 yen/MJ naphtha = 1.8 yen/MJ electricity for PSA = 0.33 kWh/Nm ³ -H ₂ grid electricity cost averaged in 2012 = 16.5 yen/kWh
	Electrolysis	84 (grid electricity) 76~136 wind power~photovoltaic (* running cost only)	no inclusion of electrolyser cost electrolysis efficiency = 70% grid electricity cost averaged in 2012 = 16.5 yen/kWh wind power = 300,000 yen/kW ⇒ 14.9 yen/kWh photovoltaic ≥ 10kW = 290,000 yen/kW ⇒ 23.6 yen/kWh photovoltaic < 10kW = 385,000 yen/kW ⇒ 26.8 yen/kWh no inclusion of electricity transmission because of on-site (power generation site) electrolysis

(* Calculations are not necessarily based on the same assumptions)

The descriptions are all IAE's translation of the document dated April 14th 2014 by Fuel Policy Planning Office of METI.

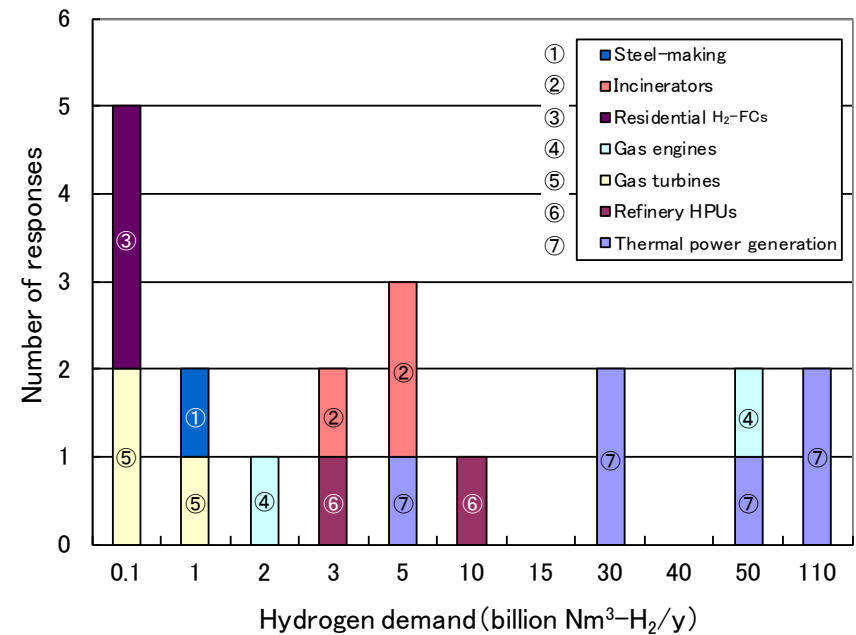
2-1. Hydrogen demand in 2050 (interview with stakeholders)



CO₂-free hydrogen demand for fuel cell vehicles in 2050



about 40 billion Nm³/year at best



CO₂-free hydrogen demand for end-use applications other than fuel cell vehicles in 2050



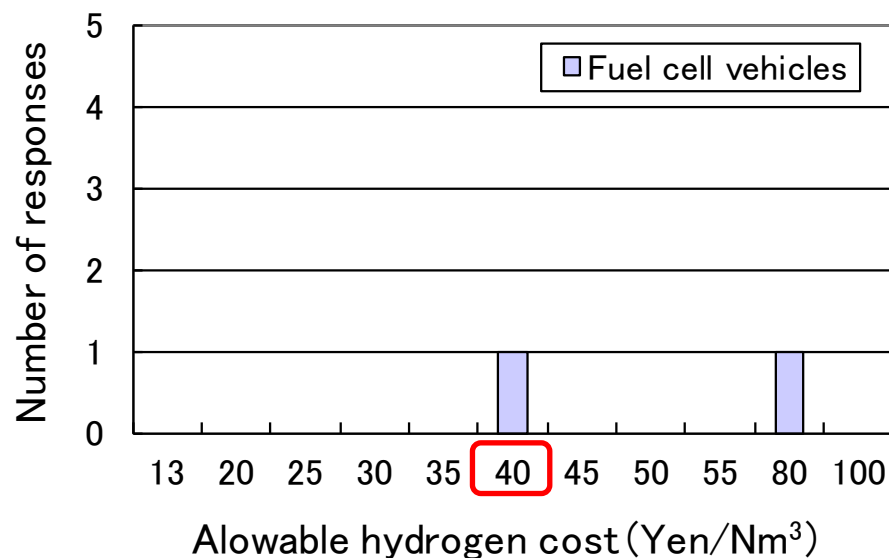
about 180 billion Nm³/year at best



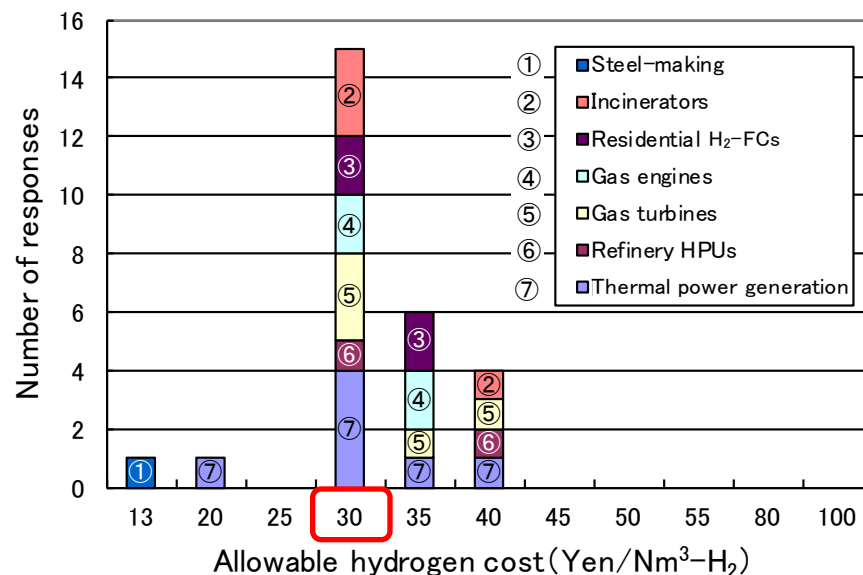
about 220 billion Nm³/year at best in total at 2050

(Note: All answers were obtained as experts' personal opinions.)

2-2. Allowable hydrogen costs in 2050 (interview with stakeholders)



Allowable CO₂-free hydrogen cost
for fuel cell vehicles in 2050



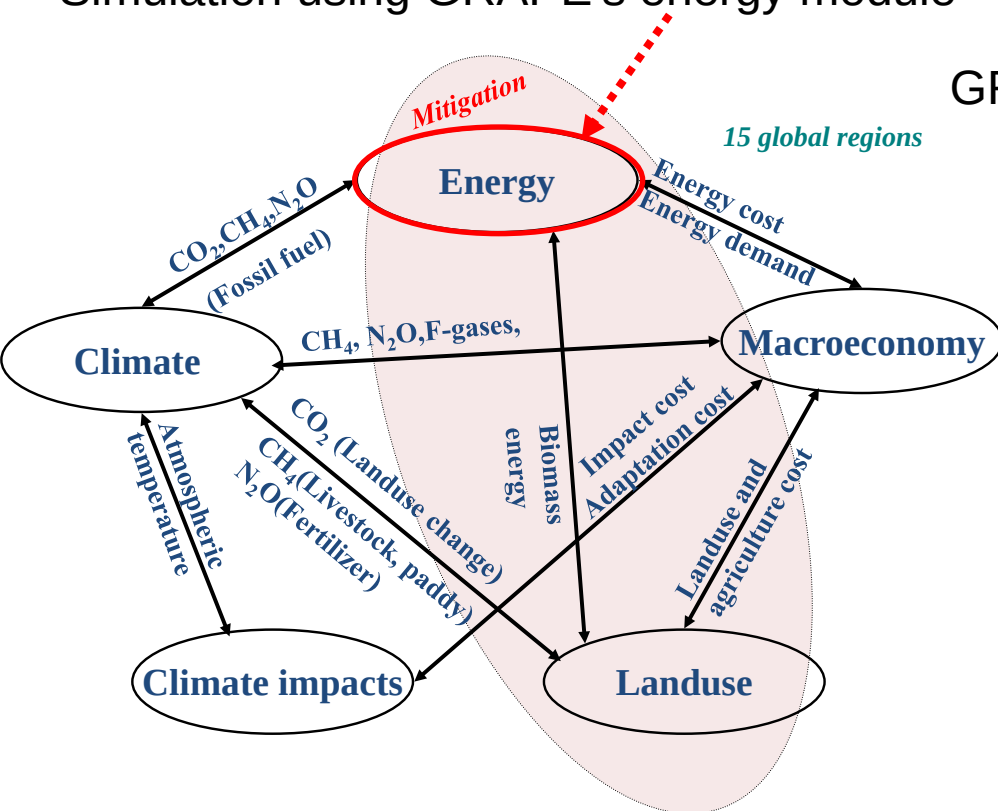
Allowable CO₂-free hydrogen cost
for end-use applications other than
fuel cell vehicles in 2050

(Note: All answers were obtained as experts' personal opinions.)

3. Energy system model analysis

1) Simulation framework of the **GRAPE model**

Simulation using GRAPE's energy module



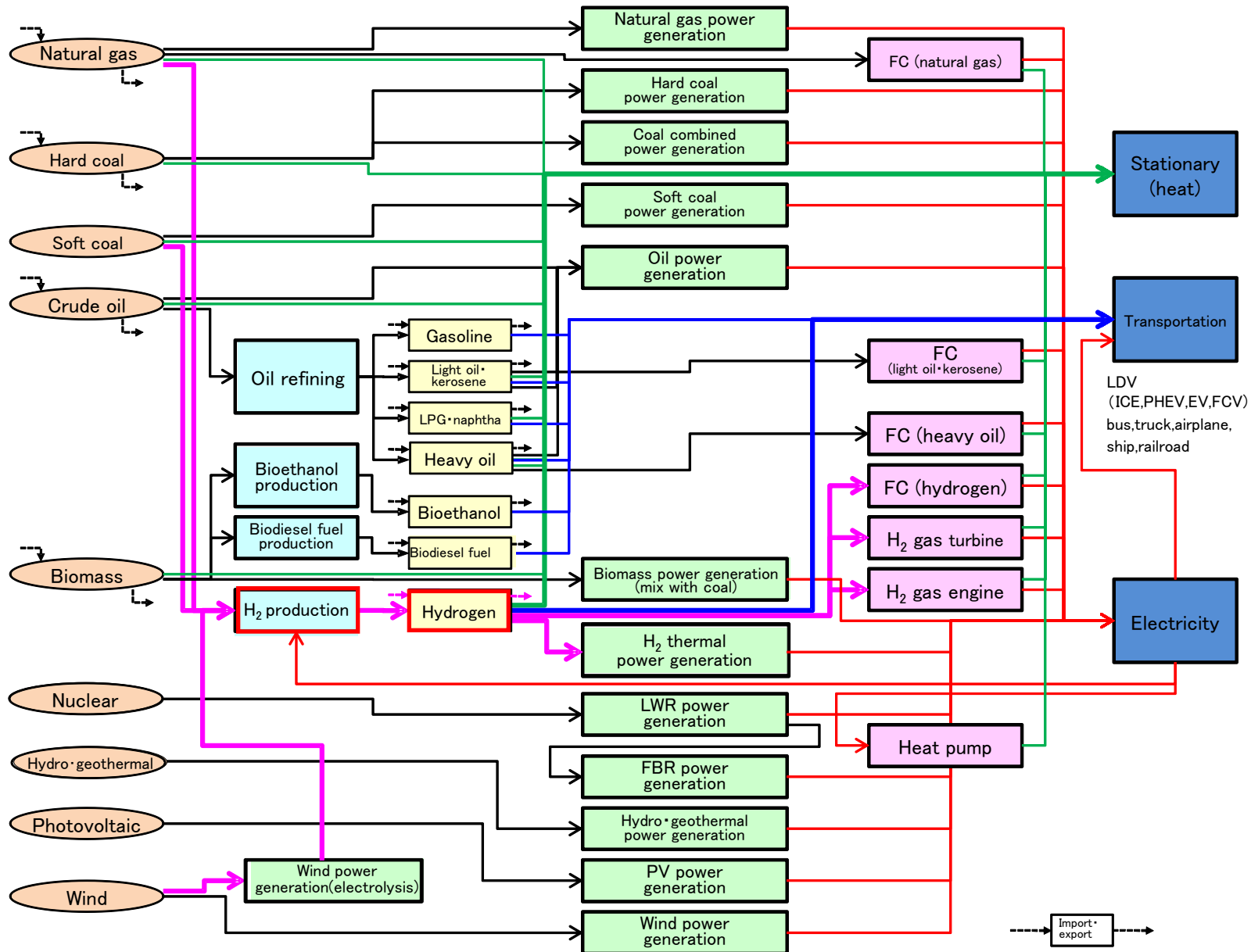
GRAPE: an integrated assessment model for long-term analyses of energy, economy, climate change, land-use, and environmental impacts.

GRAPE stands for Global Relationship Assessment to Protect the Environment

Achievements:

Referred in the Third, Fourth and Fifth Assessment Report and the Fourth Assessment Report of IPCC (Intergovernmental Panel on Climate Change), and various international model comparison projects.

2) Schematic diagram of energy flow



3) Assumptions

<Nuclear power plants in Japan>

- Phasing out after the operation of 40 years
- No new installations or no replacement

<CO₂ emissions in Japan>

- 15% reduction from 1990 levels by 2020
- 80% reduction from 1990 levels by 2050

<H₂ cost>

- About 50 yen/Nm³ at CIF (cost, insurance and freight).

(Note : Hydrogen manufacturers' latest feasibility studies show that
CIF 30 yen/Nm³ or less is possible at commercialization phase.)

<Case studies>

- With domestic CCS (Carbon Capture and Storage available in Japan)
- Without domestic CCS (not available in Japan)

4) Simulation results (an example)

(1) Contribution of hydrogen to zero-emission power source ratios

	Calculation results (%)						
	Japanese government's previous target	With domestic CCS			Without domestic CCS		
	@2030	@2030	@2035	@2040	@2030	@2035	@2040
● Fossil with CCS	-	12.3	22.8	27.2	0	0	0
Renewables	ca.20	32.9	40.8	45.3	28.2	36.2	40.6
Nuclear	ca.50	19.4	13.2	7.0	19.4	13.2	7.0
● Hydrogen	-	1.6	2.7	8.4	2.8	10.3	22.7
● Total	ca.70	66.2	79.5	87.9	50.4	59.7	70.3

- Japanese government's previous target
70% by 2030
 - "With domestic CCS" case
22.8% share of fossil with CCS makes contribution to clear the target in 2035.
 - "Without domestic CCS" case
22.7% share of hydrogen makes contribution to clear the target in 2040.
- 
- CO₂-free hydrogen is a potential option in Japan.

5) Case studies

(1) Hydrogen demand in 2050

<Calculating conditions>

《CO₂ emissions in Japan》

- 5% reduction from 1990 levels in 2020
- 80% reduction from 1990 levels in 2050

《H₂ CIF cost》

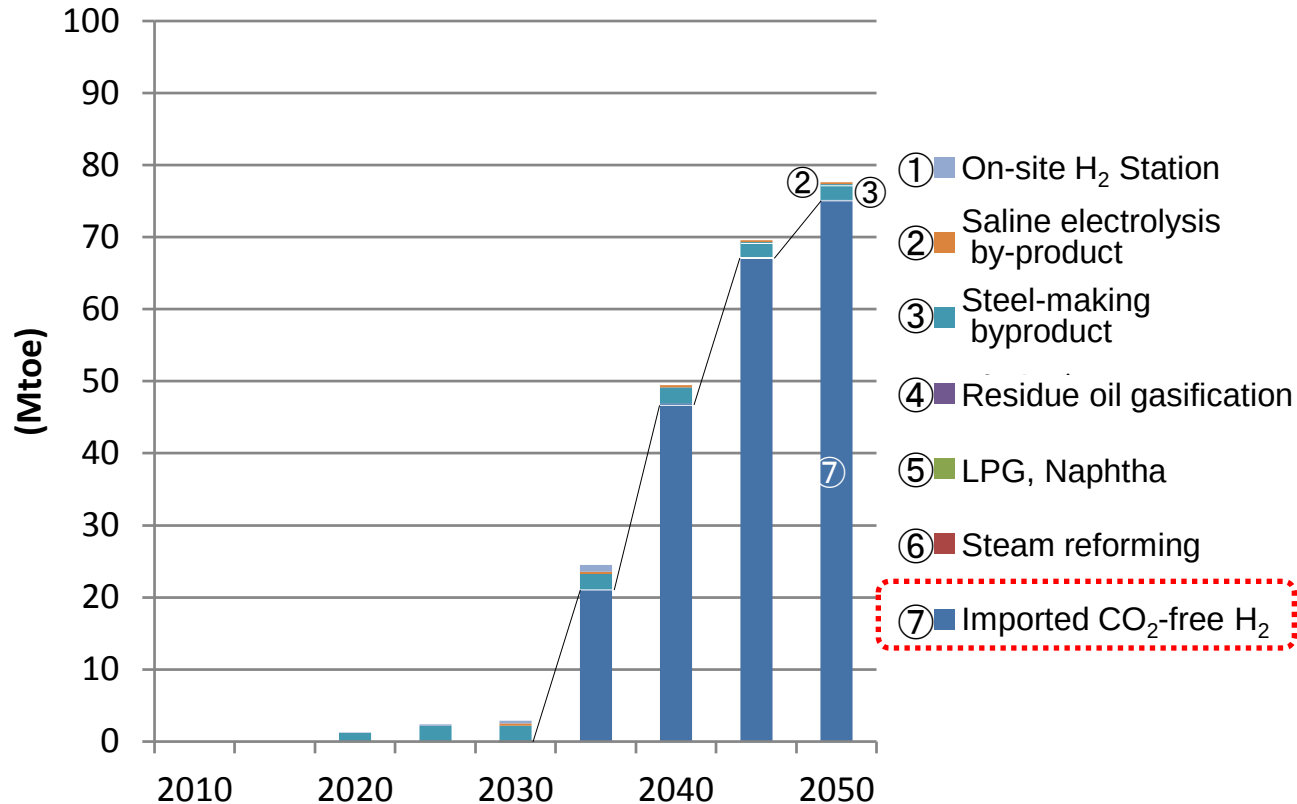
- About 40 yen/Nm³ at 2020
- About 30 yen/Nm³ at 2050

		Annual hydrogen demand @2050			
		With domestic CCS		Without domestic CCS	
Imported CO ₂ -free H ₂ CIF cost	Yen40/Nm ³ @2020	Case ①		Case ②	
	~	Elec. power gene. 116 billion Nm ³		Elec. power gene. 169 billion Nm ³	
	Yen30/Nm ³	Stationary	86 "	Stationary	78 "
	@2050	Transportation	81 "	Transportation	86 "
		Total	283 "	Total	333 "

The order of total hydrogen demand is the same as that from stakeholder interview.

(2) Hydrogen supply constitution in 2050

(with domestic CCS available case)



(1 Mtoe = about 3.9 billion Nm³-H₂)

Imported CO₂-free hydrogen shares almost all portion of supply under the condition of **CIF 30 yen/Nm³-H₂** in 2050

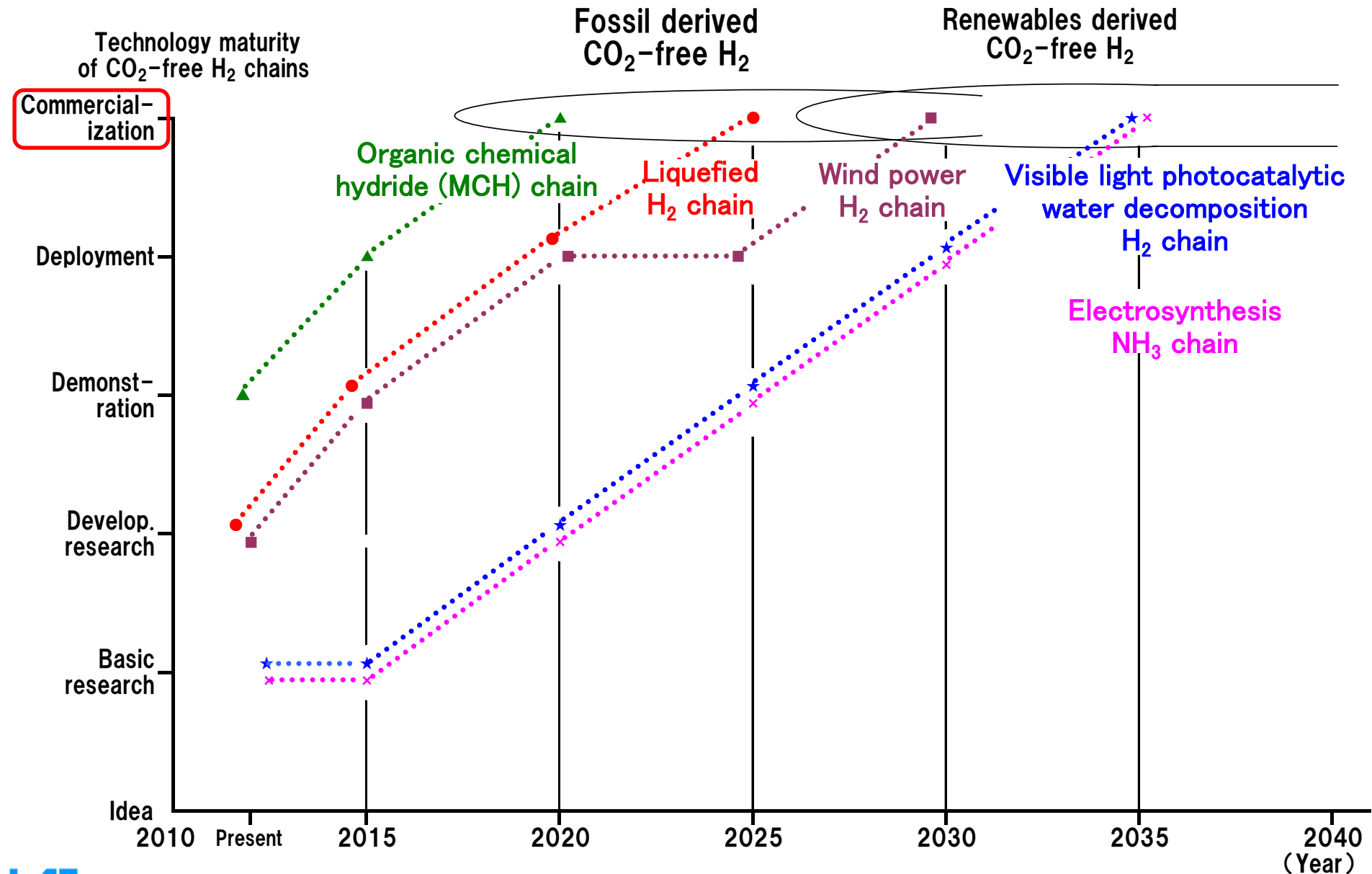
4. CO₂-free hydrogen chains

(1) List of typical global chains

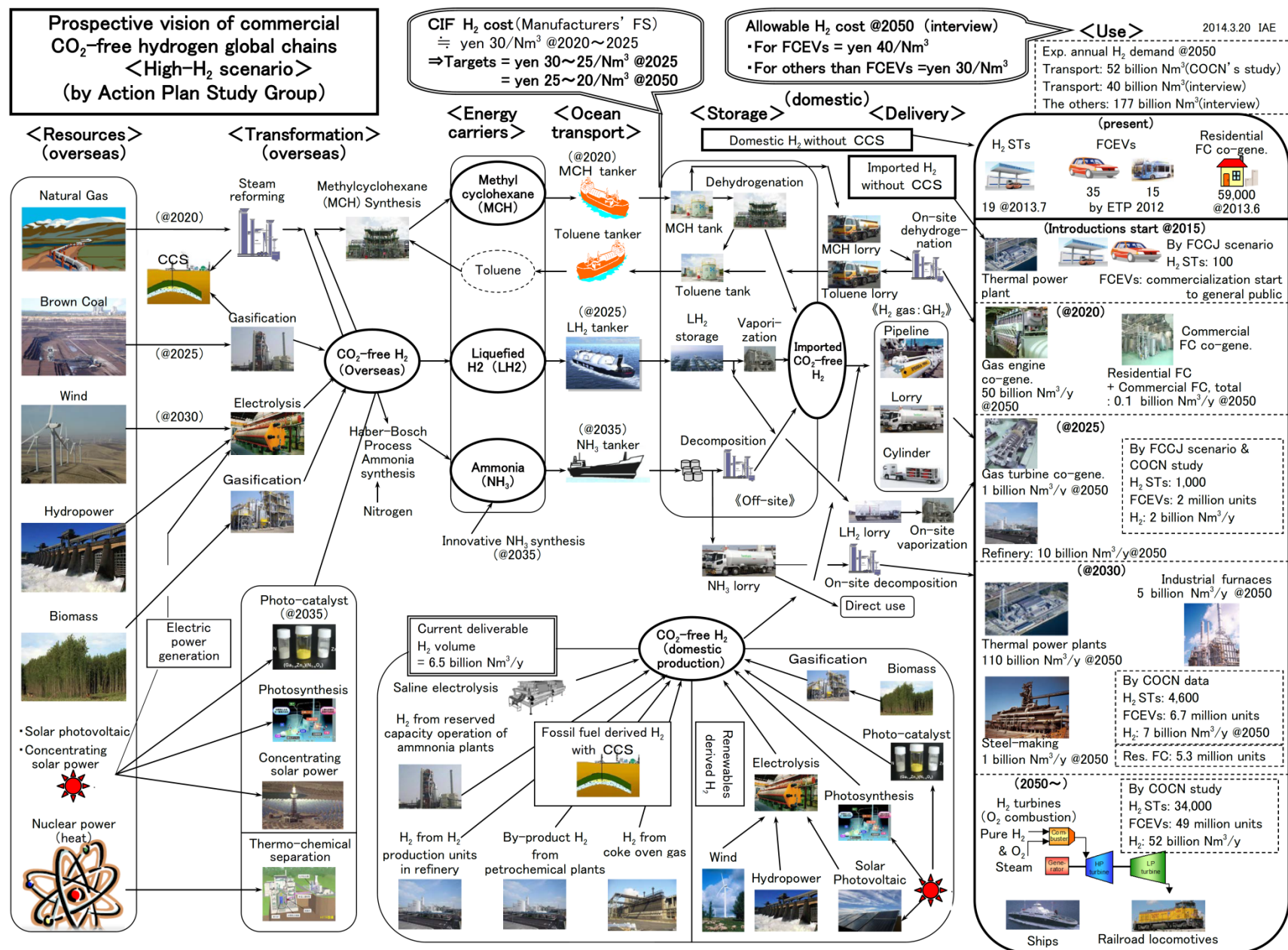
Chains	Overseas		Ocean transportation	Domestic	End-users
	Resources	Processes and hydrogen carriers		Processes	
1-1	Petroleum		Petroleum	Refining·CCS·H ₂ (via LPG·naptha, via heavy oil)	H ₂ stations/FCVs
2-1	Coal		Coal	Refining·CCS·H ₂	Household fuel cells
• 2-2		CCS·H ₂ ·Liq.	Liq. H ₂	Vaporization	
2-3		CCS·H ₂ ·MCH	MCH	Dehydrogenation	Business fuel cells
2-4		CCS·NH ₃	NH ₃	Decomposition	
3-1	Natural gas	CCS·LNG	LNG	Vaporization·CCS·H ₂	Gas turbine CHPs
3-2		CCS·H ₂ ·Liq.	Liq. H ₂	Vaporization	
• 3-3		CCS·H ₂ ·MCH	MCH	Dehydrogenation	Gas engine CHPs
3-4		CCS·NH ₃	NH ₃	Decomposition	
4-1	RE	Power gen·electrolysis·Liq.	Liq. H ₂	Vaporization	H ₂ power gen. plants
4-2	(power generation)	Power gen·electrolysis·MCH	MCH	Dehydrogenation	(air combustion)
4-3	·wind ·solar heat ·photovoltaic ·hydraulic·etc	Power gen·photoelec. syn NH ₃	NH ₃	Decomposition	
5-1	Photovoltaic (direct utilization)	Visible light photocatalytic H ₂ ·Liq.	Liq. H ₂	Vaporization	H ₂ power gen. plants
5-2		Visible light photocatalytic H ₂ ·MCH	MCH	Dehydrogenation	(O ₂ combustion)
5-3		Visible light photocatalytic H ₂ ·NH ₃	NH ₃	Decomposition	

Note: Toluene + H₂ ⇌ Methylcyclohexane (MCH)

(2) Estimation of technology maturity of CO₂-free hydrogen chains



5. Prospective vision of commercial CO₂-free hydrogen chains



6. Future issues

(just for discussion)

1) To achieve allowable (end-users' acceptable) H₂ cost range under the collaboration of all stakeholders.

- Industries' cost-down steps
 - To specify potential H₂ end-uses with large-scale in particular
 - To define supply chains and commercialization time
 - To do section-wise cost analysis of supply chains
(which section has large cost impact?)
 - To set up cost-down targets of each section
(including government financial support, if needed)
 - To decide action plan to achieve targeted cost-down

6. Future issues (continued)

- Government's strong leadership and financial support
 - Preceded infrastructure preparation in particular
 - Technology development and demonstration stage
 - RD&D financing, capital cost support for large-scale demonstration
 - Niche markets stage: high cost gap
 - Stable, technology-specific incentives
 - e.g. Feed-in tariffs, tax credits, loan guarantees
 - Strong support for capital cost and operation cost
 - Outreach activities
- Academia
 - Basic research and development
 - Human resources development

6. Future issues (continued)

2) To draft scenarios leading to commercialization of potential H₂ chains (Action Plan Study Group's plan in FY2014)

- potential H₂ end-uses with large-scale in particular
 - Which comes first?
 - What is the trigger?
 - Thermal power plants?
 - Hydro-desulfurization in refinery?
 - H₂-based steel-making?
 - Industrial H₂ co-generations (gas turbines, gas engines)?
- Domestic H₂ delivery
 - In consideration of end-uses, supply sources, volume, distance, etc.
- Domestic H₂ production
- Overseas H₂ production

**Thank you very much
for your attention !**

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