Fuel ammonia supply cost analysis (Interim report)

September 2022

Fuel ammonia supply chain public-private task force

* This analysis was made based on the business environment from December 2021 to March 2022 and does not reflect the recent rise of resource and commodity prices.

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Overview of Analysis

Study objective, scope of analysis, and methodology

(Study objective)

- This study conducts a quantitative economic analysis of the fuel ammonia business to develop reliable fuel ammonia (NH_3) supply chain based on the discussions with industry officials and experts.

(Methodology and subject of analysis)

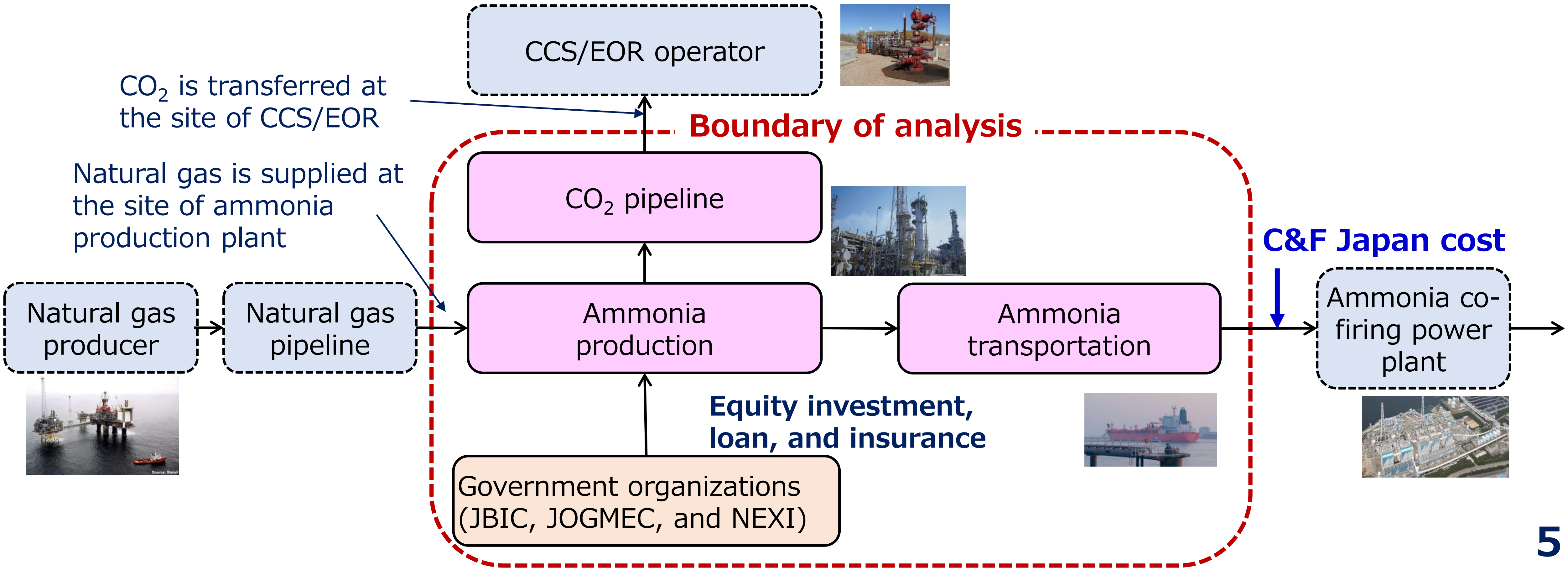
- The study develops a common standard economic model for four regions that will be a major fuel ammonia supplier for Japan.
- The study provides a standard case as the reference scenario and conducts sensitivity analysis.
- The study aims to form a consensus among the Task Force member companies and experts regarding the conditions at supplying countries (natural gas price, EPC costs, incentive systems, etc.), process technology, financing conditions, and evaluation methodology of investment.

(Assumptions of analysis)

- The study extracts objective conditions to realize i) 20% ammonia co-firing at coal-fired power plant, ii) three million tons of ammonia supply to Japan, and iii) targeted supply cost at high $10's per Nm^3-H_2 as of 2030. The study particularly assumes that an independent ammonia market as energy product will be formed separately from the existing ammonia market as chemical feedstock. The study also assumes a financially viable business condition with a certain level of internal rate of return (IRR) to obtain sufficient loans and investments.

Scope of analyzed supply chain

- The study calculates cost of supply of blue ammonia produced from natural gas and transported to Japan (the scope of analysis is bounded with red dotted line below).
  - Natural gas production and CCS/EOR segments are not included. Natural gas feedstock is supplied by pipeline from natural gas producer. Captured CO_2 is transferred to CCS/EOR operator at the site of storage (or at another particular point of transfer).



Calculation of C&F Japan Cost

C&F Japan Cost = FOB price (delivered price at the production site) + Transportation cost

FOB (free on board) price with proper EIRR (Equity Internal Rate of Return) is calculated based on the following steps:

1. NCF (Net cash flow) = Cash revenues (FOB price x production volume) – Cash expenses (OPEX + tax + loan repayment + interest)
2. NPV (Net present value) = $\sum_{n=1}^{N}\{NCF_n/(1+r)^{n-1}\}$ where N is project year, n is time period, and r is discount rate.
3. Specific level of "r" to equalize NPV and the present value of equity investment is defined as EIRR.
4. Required EIRR of is set at 9%, and FOB price is determined at the level to realize EIRR at 9%.
5. C&F (Cost and freight) is calculated by adding transportation cost to the obtained FOB price.

Assumptions of reference scenario (1/3)

- Four geographical regions (Middle East-1, Middle East-2, North America, and Oceania) are set as future ammonia supply sources for Japan
- **Feedstock of ammonia is assumed as natural gas.**

Standard model	Middle East-1	North America	Oceania	Middle East-2
Project years	**20**			
Ammonia production (t/d)	**3,000 (Approx. one million tons per year)**			
Natural gas price (US$/mmbtu)＊ **Refer to p13**	**2.5**	**3.0**	**4.0**	**3.5**
(for sensitivity analysis) (US$/mmbtu)	2.0, 3.0, 3.5	2.5, 3.5, 4.0	3.5, 4.5, 5.0	3.0, 4.0, 4.5
Fuel efficiency (Gcal/NH3-t)＊ **Refer to p14**	**9.0 (including energy consumption for CO2 dehydration and pressurization process)**			
CO2 capturing ratio ＊**Refer to p14**	**70% of the total CO2 emissions**			
(for sensitivity analysis)	60%			
Storage location of CO2	**Onshore CCS (depleted gas field)**	**Onshore CCS (depleted gas field)**	**Offshore CCS (depleted gas field)**	**Offshore EOR**
Point of CO2 transfer	**CO2 storage site**	**Connection point to CO2 pipeline network**	**Connection point to offshore CO2 pipeline**	**EOR site** (on condition that the storage ratio of CO2 is equivalent to CCS and the proper rules for storage are provided)
CO2 transfer cost ($/CO2-t)	**20**	**30**	**40**	**-10**

Assumptions of reference scenario (2/3)

Standard model	Middle East-1	North America	Oceania	Middle East-2
Transportation cost (fuel oil) ($/NH3-t)＊Refer top17	**42**	**72**	**31**	**42**
(for sensitivity analysis)	Ammonia fuel			
Nautical miles to Japan (Laden and Ballast)	**13,300**	**18,700**	**9,400**	**13,300**
Capital investment (US$ million) ＊ Refer to p15	**1,160**	**1,290**	**1,290**	**1,160**
	Local Factor (LF)=0.9	**LF=1.0**	**LF=1.0**	**LF=0.9**
	The above figures include the following expenditures: 1) Connection infrastructure to the CO2 transfer point (CO2 pipeline, pressurization, drier etc.) 2) Ammonia loading facility (Ammonia pipeline, storage tank for loading, etc.)			
EIRR(%)＊Refer to p17	**9%**			
(for sensitivity analysis)	8% and 10%			
Depreciation period	**15 years**			
(for sensitivity analysis)	20 years			
Interest rate (%)＊Refer to p19	**3.0**			
Debt /Equity Ratio	**70/30**			
Corporate tax (%)	**20**	**20**	**30**	**20**
Incentive system	**None**	**None** (45Q as sensitivity analysis)	**None**	**None**

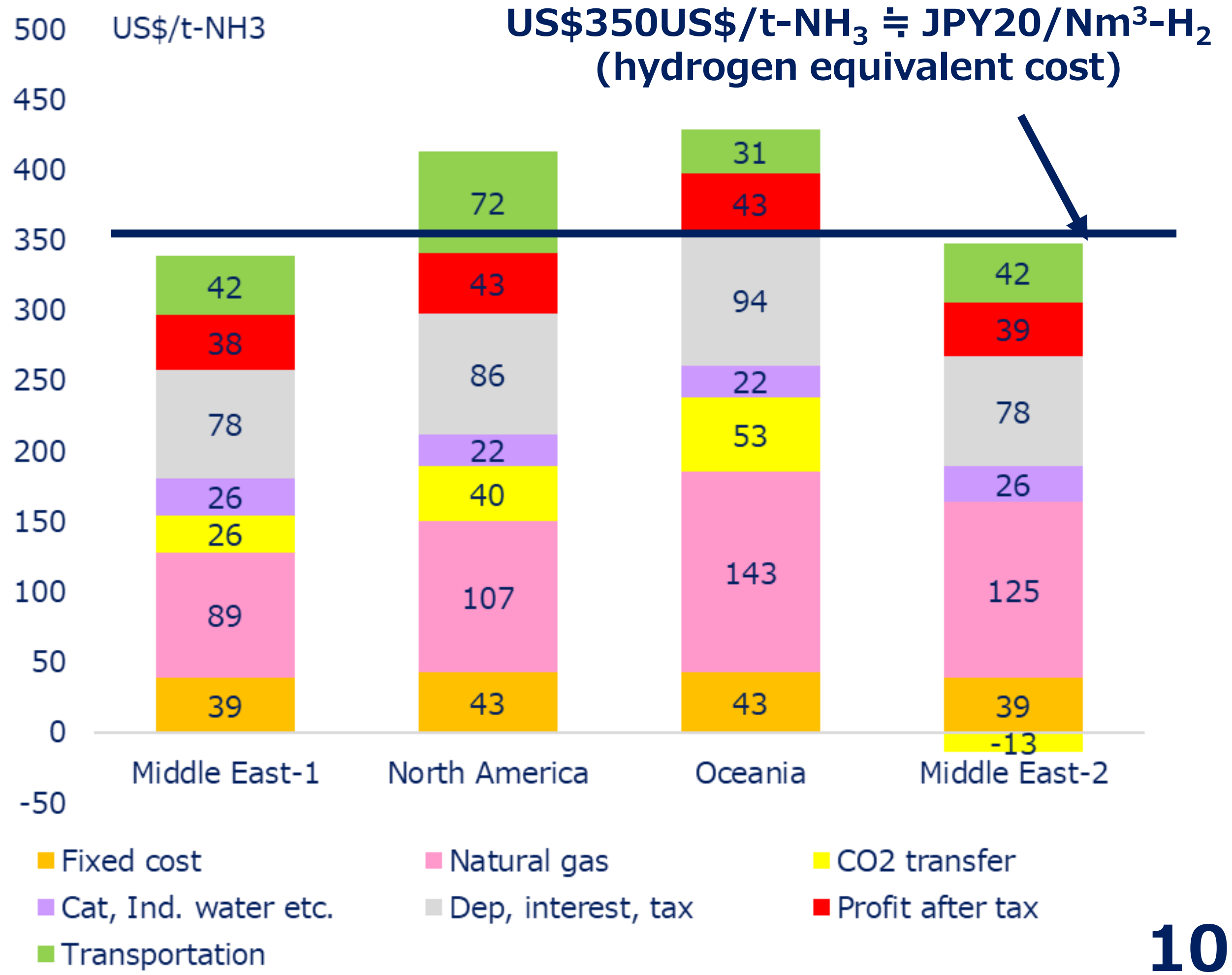
Assumptions of reference scenario (3/3)

Standard model	Middle East-1	North America	Oceania	Middle East-2
Personnel expenses (US$ million)	**3.7**	**5.9**	**5.9**	**3.7**
Managers	6 persons*US$120,000	6 persons*US$150,000	6 persons*US$150,000	6 persons*US$120,000
Panel Operators	22 persons*US$60,000	22 persons*US$100,000	22 persons*US$100,000	22 persons*US$60,000
Field Operators	28 persons*US$60,000	28 persons*US$100,000	28 persons*US$100,000	28 persons*US$60,000
Operation and Maintenance (O&M)	**CAPEX*1.5%/year**			
Insurance	**CAPEX*0.5%/year**			
General and administrative expenses (G&A)	**Personnel expenses*80% + O&M*20%**			
Catalysts (US$ million)	**6.1**			
Industiral water (US$ million)	**12.9**	**6.4**	**6.4**	**12.9**

C&F Japan cost of reference scenario

- C&F Japan cost of Middle East-1 case is **$339/t**, North American case is **$413/t**, Oceania case is **$429/t**, and Middle East-2 case is **$335/t**.
- C&F Japan cost of Middle East cases is around **JPY19/Nm^3-H_2**.

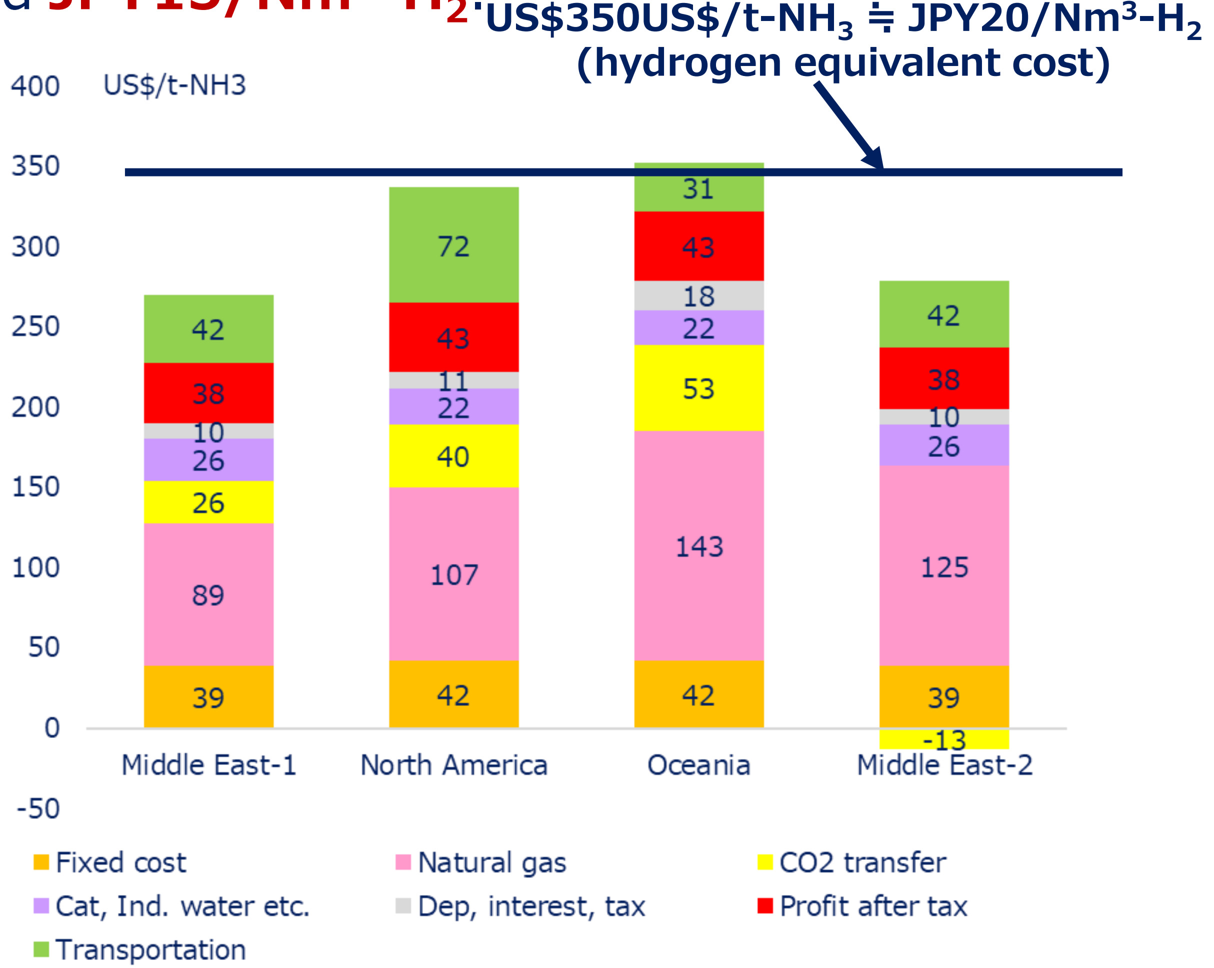
(US$/t-NH3)	Middle East-1	North America	Oceania	Middle East-2
Fixed cost	38.8	42.8	42.8	38.8
Personnel expenses	3.8	6.0	6.0	3.8
O&M	18.5	18.5	18.5	18.5
G&A, Insuance etc.	16.5	18.3	18.3	16.5
Variable cost	141.6	169.0	217.9	137.5
Natural gas	89.3	107.2	142.9	125.0
CO2 transfer	26.5	39.7	53.0	-13.2
Other	25.8	22.1	22.1	25.8
Depreciation/interest	68.0	75.6	75.6	68.0
Depreciation	58.2	64.7	64.7	58.2
Interest	9.8	10.9	10.9	9.8
Corporate tax	9.7	10.8	18.5	9.7
Profit after tax	38.5	42.8	42.7	38.5
Export price (FOB)	296.5	341.0	397.5	292.5
Transportation	42.0	72.0	31.0	42.0
C&F Japan cost	338.5	413.0	428.5	334.5



(Reference) C&F Japan cost from 21st year of the project

- C&F Japan cost of Middle East-1 case is **US$270/t**, North American case is **US$337/t**, Oceania case is **US$352/t**, and Middle East-2 case is **US$266/t**.
- C&F Japan cost of Middle East cases is around **JPY15/Nm³-H_2**.

(US$/t-NH3)	Middle East-1	North America	Oceania	Middle East-2
Fixed cost	38.5	42.4	42.4	38.5
Personnel expenses	3.7	5.9	5.9	3.7
O&M	18.5	18.5	18.5	18.5
G&A, Insurance etc.	16.3	18.1	18.1	16.3
Variable cost	141.6	169.0	217.9	137.5
Natural gas	89.3	107.2	142.9	125.0
CO2 transfer	26.5	39.7	53.0	-13.2
Other	25.8	22.1	22.1	25.8
Depreciation/interest	0.0	0.0	0.0	0.0
Depreciation	0.0	0.0	0.0	0.0
Interest	0.0	0.0	0.0	0.0
Corporate tax	9.6	10.7	18.3	9.6
Profit after tax	38.5	42.8	42.7	38.5
Export price (FOB)	228.2	265.0	321.4	224.2
Transportation	42.0	72.0	31.0	42.0
C&F Japan cost	270.2	337.0	352.4	266.2

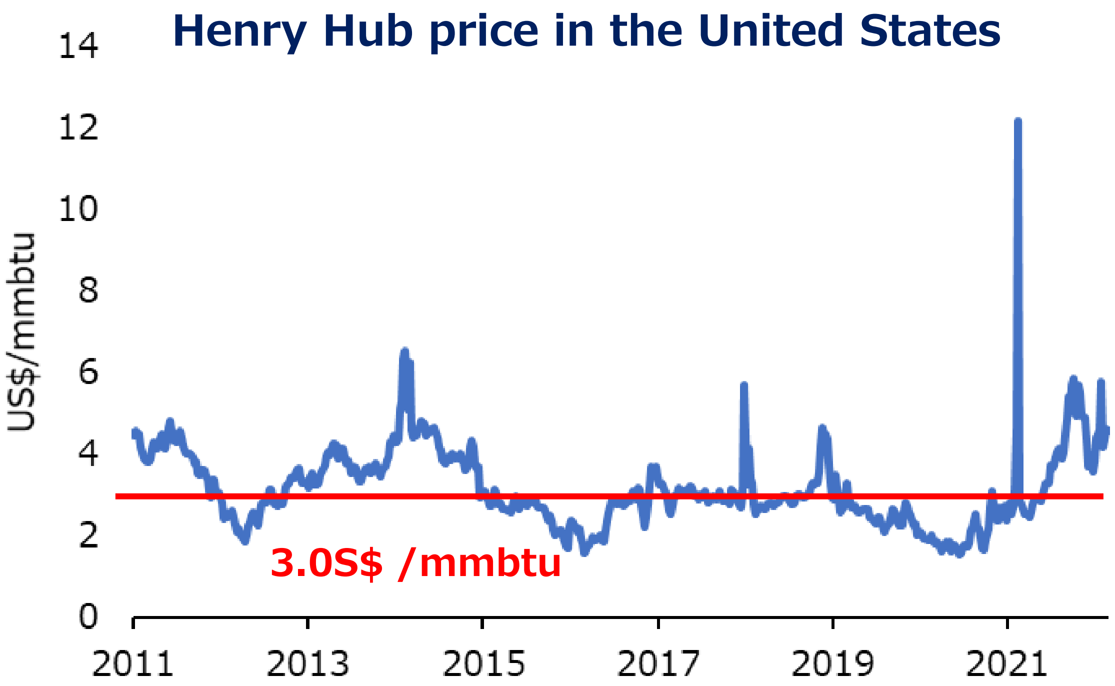


*Profit after tax (20-year average) and its corresponding corporate tax are added to the cash out flow amount after the period of depreciation. O&M expenses may increase after 21st year due to wearing.

Major assumptions

Natural gas prices

- Natural gas prices are set based on the U.S. Henry Hub price and each supplier's regional characteristics and pricing strategy.



Source: US Energy Information Administration

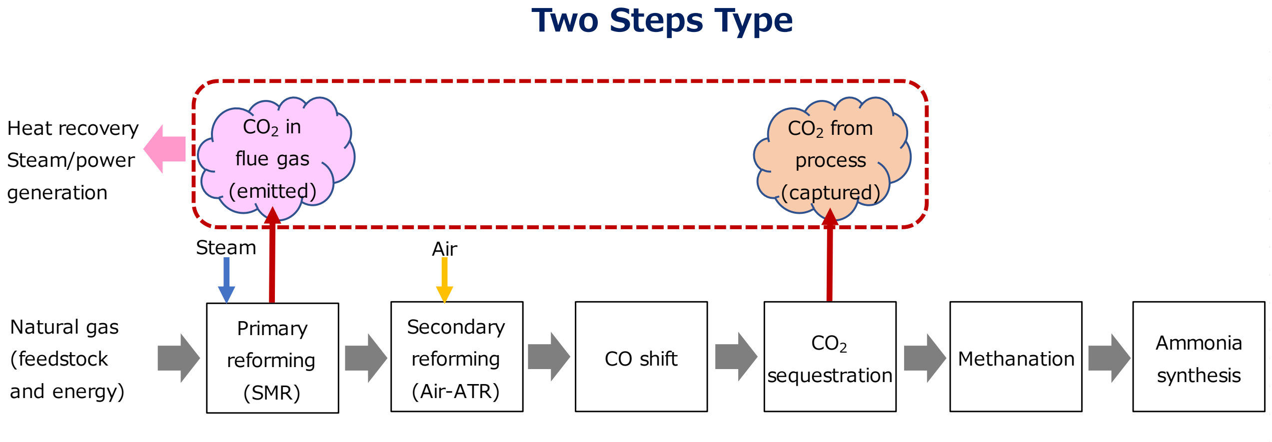
- **North America**
  - Refer to the historical average from 2011 to 2021 ⇒ **$3.0/mmbtu**
- **Middle East-1**
  - Assume the price is set by referring to its competitors in the United States and Oceania. The price is assumed to be set at 20% lower than Henry Hub price. ⇒ **$2.5/mmbtu**
- **Oceania**
  - Higher price than Henry Hub because its major gas supply source is offshore field ⇒ **$4.0/mmbtu**
- **Middle East-2**
  - Refer to the recent 25-year long-term contract by national oil company ⇒ **$3.5/mmbtu**

Note: The above estimates are also based on interviews to industrial experts.

Synthesis gas production process and CO_2 capturing ratio

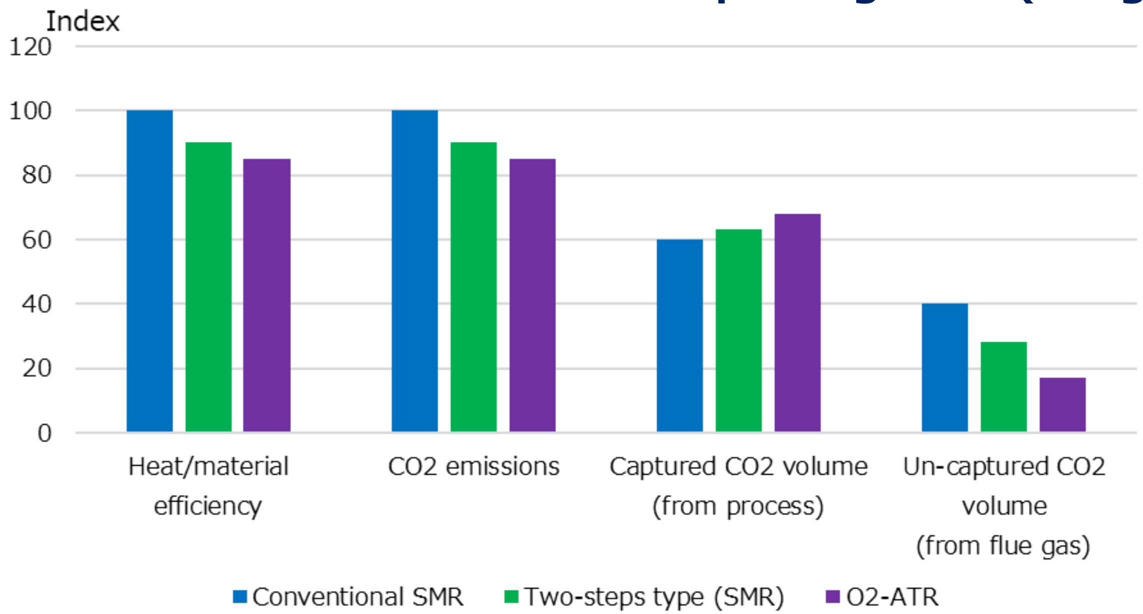
- This study (as of March 2022) assumes **the second-generation process** as the best available technology, and **the CO_2 capturing ratio in the entire process is assumed to be at 70%**.
  - The mainstream process is expected to evolve in the 2020s from the first generation (conventional SMR) to the second generation (Two Steps Type: SMR/Air-ATR) and to O_2-ATR, which will realize both cost reduction and capturing ratio improvement.

Concept of the second-generation process



- Evolution of production process reduces the fuel input to the primary reformation process and thus reduces CO_2 emissions.

Process evolution and CO2 capturing ratio (image)



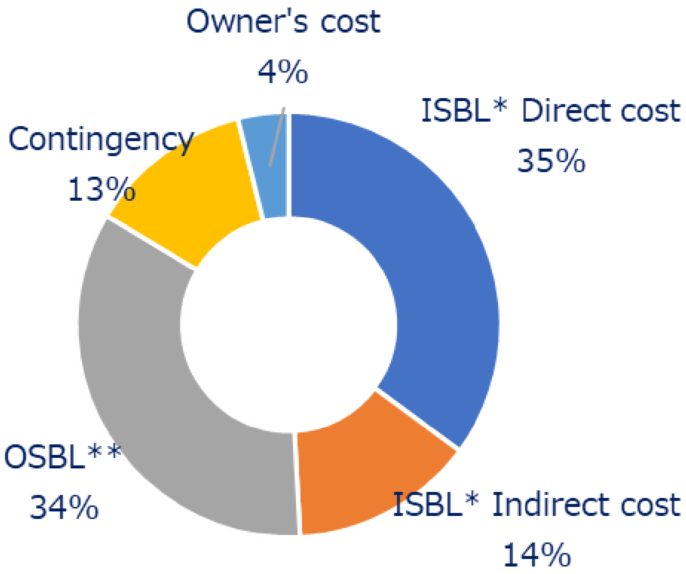
- Relative CO_2 emissions from the synthesis gas production process increases in more advanced processes, and the capturing ratio improves thanks to its higher CO_2 density.
- CAPEX increase is expected to be moderate (around 2 to 3%) and the entire economics can offset the CAPEX increase.

Source: Institute of Energy Economics, Japan (IEEJ) based on the interviews to industrial experts

CAPEX

- CAPEX is estimated by adding required costs for production plant construction, contingency allowance, and owner's cost (required cost before the project implementation) with assumption of cost reduction effects toward 2030.
- **CAPEX amount of Middle East (US$1,160 million) is based on the IEEJ's study in 2018**.
- Items and their shares in the CAPEX amount for Middle East are shown as below.

Shares of items of CAPEX
(Rough estimate for Middle East case)



*ISBL=Inside Battery Limit. Sections that are directly related to ammonia production; **OSBL=Outside Battery Limit. Sections that are indirectly related to ammonia production.
Note) The above figure is a rough estimate including cost reduction effects and thus the exact amount needs more detailed evaluation.

Methodologies of CAPEX assumption

- **Identification of licence and production capacity of ammonia production plant**
  i. Determination of material balance
  ii. Determination of heat balance
  ↓
- **Determination of major facilities and their capacities**
  ↓
- **Calculation of Direct cost of ISBL (See the right table)**
  ↓
- **Estimates of other cost items**

ISBL Direct cost	Summation of the following costs: - Reformer - Shift conversion - Air separation Unit - CO_2 removal - Nitrogen wash - Synthesis loop & refrigeration (Summed amount also includes the costs for reactor, reactor, tower-type reactor, heat exchanger, pump, compressor, pressure vessel, and labor to install those facilities.)
ISBL Indirect cost	40% of ISBL Direct cost
OSBL	50% of ISBL Direct and Indirect costs

Note) Land acquisition and development costs are not included.

Transportation cost

- Transportation cost to Japan is estimated at **$42/t-$NH_3$ (from Middle East), $72/t-$NH_3$ (from North America), and $31/t-$NH_3$(from Oceania).**
  - Assumed vessel size is Very Large Gas Carrier (VLGC) and assumed vessel fuel is fuel oil (FO).

Supplying region	**Middle East**	**North America**	**Oceania**
Transportation cost (US$/t-$NH_3$)	**42**	**72**	**31**
Fixed cost	23	34	17
Variable cost	19	38	14
Assumptions			
Vessel size	VLGC (84,000 m^3 ≒ 55,000 mt-NH_3)		
Vessel price	US$ 88 million		
Port charge at loading port	US$ 50,000		
Port charge at discharging port	US$ 60,000		
Panama Canal Toll (laden and ballast)	–	US$ 700,000	–
Averaged vessel speed	16.5 knots		
Fuel consumption during navigation	48 mt-FO/day		
Fuel consumption during port call	10 mt-FO/day		
Fuel oil price	US$ 530/mt-FO		
Distance (laden and ballast)	13,300 nautical miles	18,700 nautical miles	9,400 nautical miles

Remarks : Single port loading and single port discharging are assumed.

Financing conditions

- **EIRR**
  - **9% is assumed as reference scenario** assuming that the maximum financial assistance is obtained from governmental organizations.

- **Interests rate**
  - **3% is assumed as reference scenario** assuming that the maximum financial assistance is obtained from governmental organizations.

- **Dividend to equity investors**
  - **All cash flow after the repayment and interest is assumed to be distributed to equity investors.**

- **Terminal value of assets**
  - **The value of the project's asset is assumed to be zero** at the end of the project's period (after 20 years).

Sensitivity analysis

Sensitivity analysis

- **Natural gas cost** and **transportation cost** are the two major variables that bring greater effects to the level of C&F Japan cost.
  - **1% increase (decrease) EIRR increases (decreases) the cost by \$5/t-NH_3.**
  - **\$0.5/mmbtu increase (decrease) of natural gas price increases (decreases) the cost by \$18/t-NH_3.**
  - **10% decrease of CO2 capturing ratio decreases the cost by \$4-\$8/t-NH_3** (although the cost increases in Middle East-2 cases that assumes EOR).
  - **Fuel switching from fuel oil to ammonia** for transportation vessel **increases the cost by \$9.7-\$20.9/t-NH_3.**
  - **Tax benefits of 45Q decreases the cost from North America by \$7/t-NH_3.***
  - **Extension of depreciation period from 15 years to 20 years decreases the cost by \$5-\$7/t-NH_3.**

***45Q taxation rule in the United States**
- Tax benefits of \$50/t-CO_2 at the maximum for CO_2 sequestration by CCS
- Applied from the first to the twelfth year of the project
- Tax benefit is applied until the annual corporate tax becomes zero. The residual amount cannot be carried over to the next year.

Summary of sensitivity analysis

	Middle East-1	North America	Oceania	Middle East-2
Reference (REF)	**338.5**	**413.0**	**428.5**	**334.5**
1. EIRR				
EIRR=8% (REF-1%)	333.5	407.5	423.0	334.5
diff. from REF	*-5.0*	*-5.5*	*-5.5*	*0.0*
EIRR=10% (REF+1%)	343.5	418.5	434.0	339.5
	5.0	*5.5*	*5.5*	*5.0*
2. Natural gas price				
REF -\$0.5/mmbtu	320.5	395.0	410.5	316.5
	-18.0	*-18.0*	*-18.0*	*-18.0*
REF +\$0.5/mmbtu	356.5	431.0	446.0	352.5
	18.0	*18.0*	*17.5*	*18.0*
REF +\$1.0/mmbtu	374.5	448.5	464.0	370.5
	36.0	*35.5*	*35.5*	*36.0*
3. CO2 capturing ratio				
60% capture	335.0	407.5	421.0	336.5
(from 70%)	*-3.5*	*-5.5*	*-7.5*	*2.0*
4. Transportation cost				
Ammonia fueled vessel	348.2	433.9	439.9	344.2
	9.7	*20.9*	*11.4*	*9.7*
5. Incentive system				
45Q rule applied	-	406.0	-	-
(only in the United States)		*-7.0*		
6. Depreciation period				
20 years	333.0	407.0	421.5	329.0
(from 15 years)	*-5.5*	*-6.0*	*-7.0*	*-5.5*
			Cost increase	Cost decrease

Sensitivity analysis (ammonia fueled vessel)

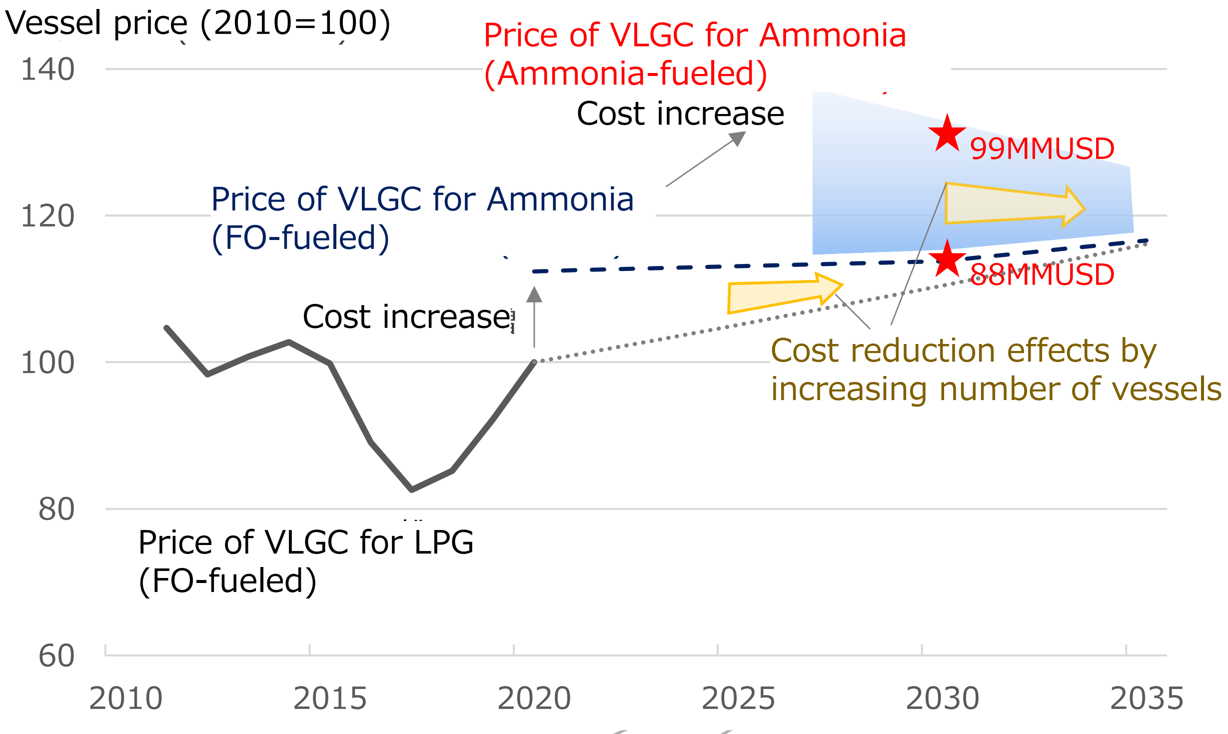
- Transportation cost to Japan by ammonia fueled vessel is estimated at **\$52/t-NH_3 (from Middle East), \$93/t-NH_3 (from North America), and \$42/t-NH_3(from Oceania).**
  - Ammonia price refer to FOB price at each supplying region.
  - Cost increase is due to higher vessel price and fuel expenses

Supplying region	**Middle East**	**North America**	**Oceania**
Transportation cost			
Reference (fuel oil-fueled vessel)(\$/t-NH_3)	42	72	31
Ammonia fueled vessel (\$/t-NH_3)	52	93	42
Difference	**+10**	**+21**	**+11**
Assumptions			
Vessel size	VLGC (84,000 m^3 ≒ 55,000 mt-NH_3)		
Vessel price	US\$ 99 million		
Port charge at loading port	US\$ 50,000		
Port charge at discharging port	US\$ 60,000		
Panama Canal Toll (laden and ballast)	–	US\$ 700,000	–
Averaged vessel speed	16.5 knots		
Fuel consumption during navigation	108 t-NH_3/day		
Fuel consumption during port call	23 t-NH_3/day		
Fuel oil price	US\$ 333.5/t-NH_3	US\$ 407/t-NH_3	US\$ 422/t-NH_3
Distance (laden and ballast)	13,300 nautical miles	18,700 nautical miles	9,400 nautical miles

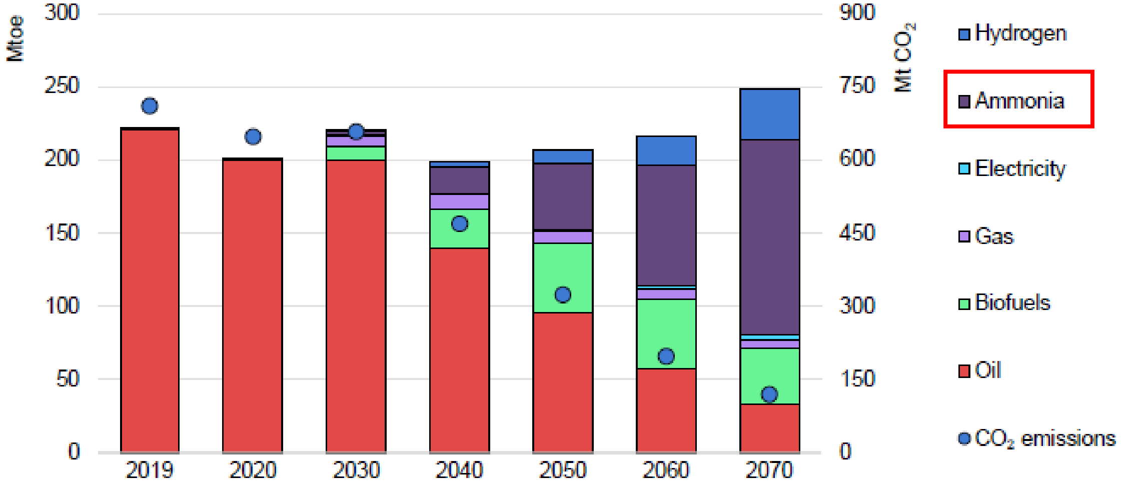
Remarks: Consumption of ammonia is calculated based on Lower Heating Value (LHV). Fuel oil is used as pilot fuel with 5% co-firing.

(Reference) Assumption for ammonia fueled vessel

- Price of ammonia fueled vessel is assumed to keep declining as the number of the vessel will increase.
  - The amount of vessel price increase is estimated based on the interviews to industrial experts.



Ammonia fueled vessel is expected to increase after 2030.



Outlook of energy consumption in the international maritime transportation in SDS scenario

Source: IEA, Energy Technology Perspective 2020

2024: Delivery of ammonia fueled tugboat (NYK Line / Green Innovation Fund)

2026: Delivery of ammonia fueled ammonia carrier (NYK Line / Green Innovation Fund)

Around 2026: MAN will start operation of ammonia-engine vessel.