AIChE 2019

[557 - Ammonia as a Fuel (Nov. 13 2019)]

Technical & Economic Feasibility Study for Commercial Ships with HFO, LNG, and NH3 as Fuel

HYUK KWON

Nov. 13, 2019

DSME
The First Mover of "Econology Ships"

2019 AIChE® ANNUAL MEETING
19AIChE Annual Meeting, Orlando, FL
Transforming the Future through Chemical Engineering
November 10-15, 2019
Hyatt Regency, Orlando

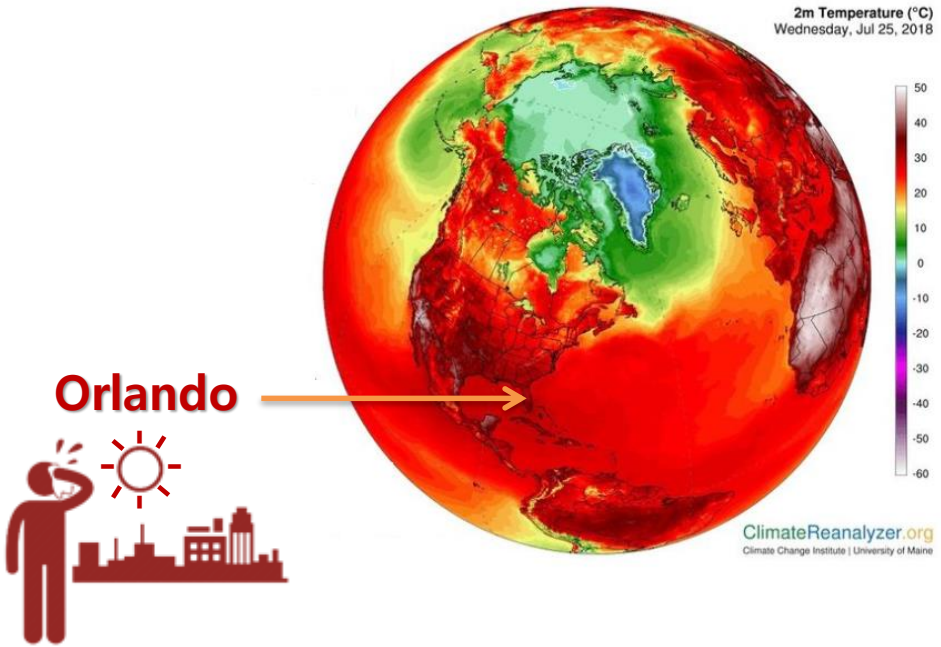
Contents

1. Background

1.1 Global Warming

[Mirror July 25, 2018]

Planet Fireball : “Global Warming”



Source - https://www.mirror.co.uk/

1.2 IMO, Initial Strategy on GHG Emission from Shipping

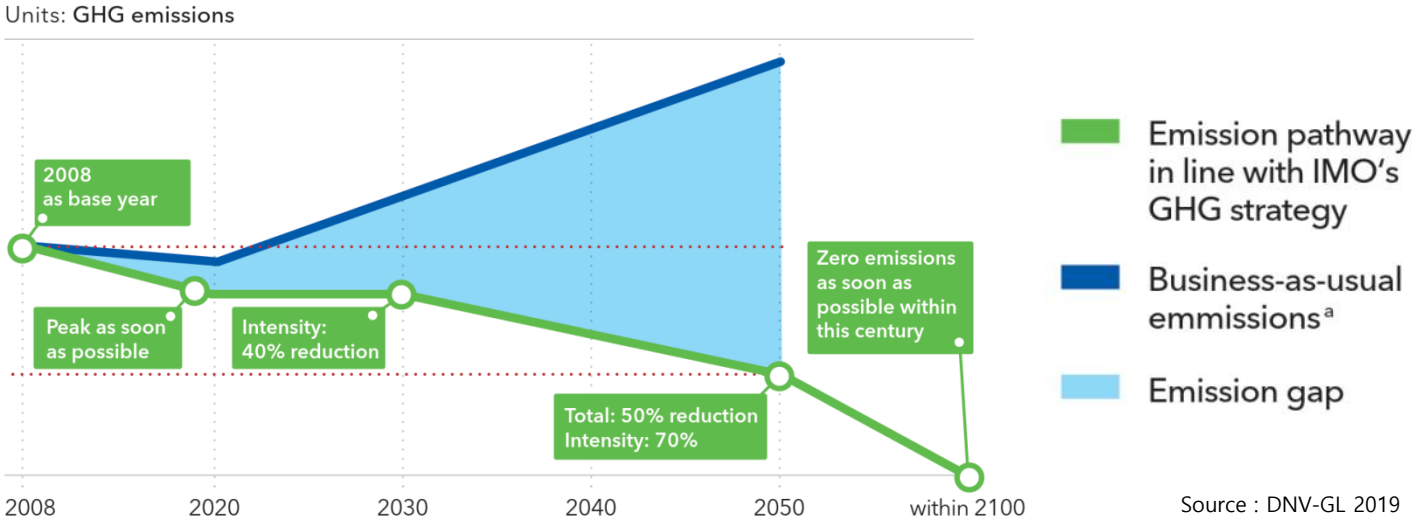
*GHG (Greenhouse Gas)

- **In April 2018, IMO announced an initial strategy on the reduction of GHG* emission from ships.**

  ⇒ The target is reducing the total GHG emission by at least 50% by 2050 compared to 2008.

[DSME] For reducing global warming as a ship builder, What should we do?

[IMO Strategy for Major Reductions in GHG Emissions from Shipping]



Source : DNV-GL 2019

2. Recent Trend on NH3 Fuel related to Ships

2.1 Maersk's News on CO2 Neutral Ship in 2030

① Dec. 5, 2018

WORLD MARITIME NEWS

Maersk Wants to Become Carbon Neutral by 2050

World's largest shipping company Maersk announced that it aims to become a carbon neutral company by 2050.

Posted on December 5, 2018 with tags decarbonization, Maersk.

② Dec. 13, 2018

SHIPPINGWATCH

Frontpage | Carriers | Suppliers | Services | Offshore | Ports | Danish

Bulk | Container | Tanker

Maersk will spend USD 2 billion on becoming CO2 neutral

BY RITZAU FINANS
Published 13.12.18 at 07:44

③ Feb.1, 2019

SHIPPINGWATCH

Frontpage | Carriers | Suppliers | Services | Offshore | Ports | Danish

Bulk | Container | Tanker

Maersk plans to launch its first CO2 neutral ship in 2030

BY SØREN PICO
Published 01.02.19 at 09:44

④ Oct. 24, 2019

MAERSK

Press releases

Alcohol, Biomethane and Ammonia are the best-positioned fuels to reach zero net emissions

24 October 2019

2.2 MAN ES's News on CO2 Neutral and NH3 Engines

① Feb. 11, 2019

SHIPPINGWATCH

MAN backs ambition for CO2 neutral ships by 2030

BY SØREN PICO
Published 11.02.19 at 14:46

② MAN ES's Presentations on NH3 Engine

Aug. 30, 2018 (@SMM 2018)

SMM

Propulsion of ships towards year 2050.
Using low carbon ammonia fuel

René Sejer Laursen
SMM 2018
30-08-2018

Oct. 30, 2018 (@NH3 Fuel Association)

NH3 FUEL ASSOCIATION

Ship Operation Using LPG and Ammonia As Fuel on MAN B&W Dual Fuel ME-LGIP Engines

René Sejer Laursen, MAN Diesel & Turbo, Denmark

Jun. 6, 2019 (@NH3 event 2019)

NH3 event 2019

Session: Using ammonia as a carbon free Marine fuel - René Sejer Laursen

③ Jan. 22, 2019

TradeWinds
The Global Shipping News Source
Tankers Dry Cargo Boxships Gas Offshore

Ammonia swings into frame as a potential future marine fuel

MAN Energy Solutions is pressing ahead with developing an engine as a new grouping seeks funding — but the industry will need to be convinced

- **Recently, MAN started NH3 engine development according to request of some ship owners**
- NH3 engine development : 2~3 years / Cost : € 5 M
- The first NH3 engine will be operated in early 2022

④ Feb. 12, 2019

MFAME

Fueled By Viswa Lab

MAN Energy Solutions To Launch Two-Stroke Ammonia Fuelled Engine

- Possible to burn NH3 fuel using ME-LGIP modification (~2.5 years)
- **NH3 engine project are participated with 3 unknown ship companies.**

By **Mfame Team** - February 12, 2019

3. DSME's Feasibility Study of NH3 as Ship Fuel

▣ Introduction of reports by major organizations related to ship GHG reduction

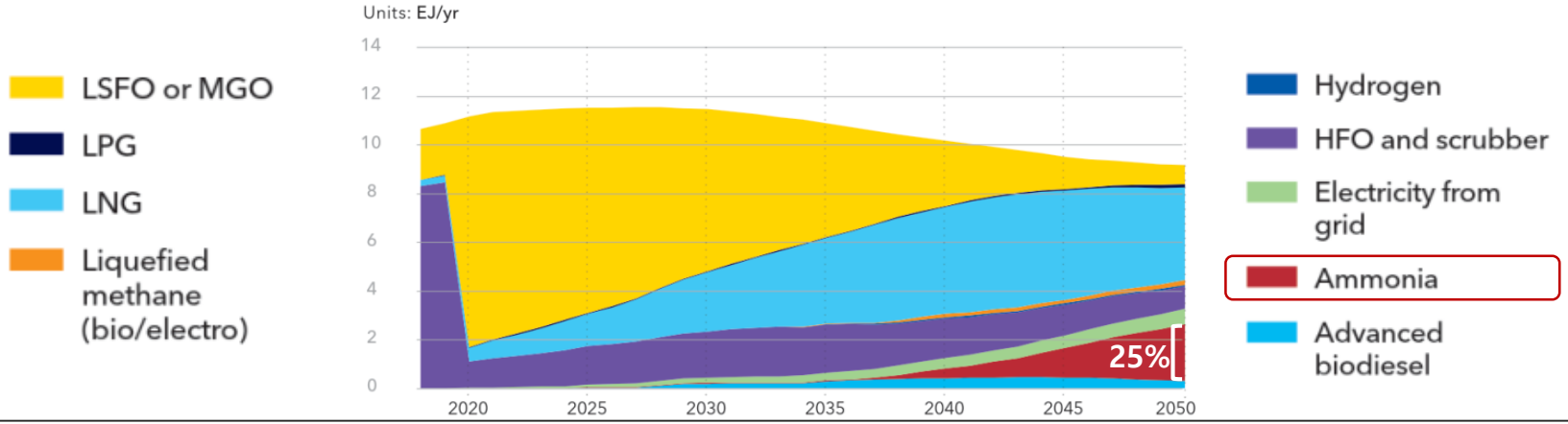
- IMO adopted initial strategy to reduce greenhouse gas emissions of ships

✓ **[ICS*]** "**NH3**", "Batteries", "Nuclear", and "H2" to achieve IMO's GHG reduction targets

✓ **[LR]** "**NH3**" = the most competitive fuel for Zero GHG Emissions on ships.

✓ **[DNV-GL]** "**NH3**" as a maritime fuel could take up **25%** of fuel market in 2050 (*LNG 41%, H2 1%)

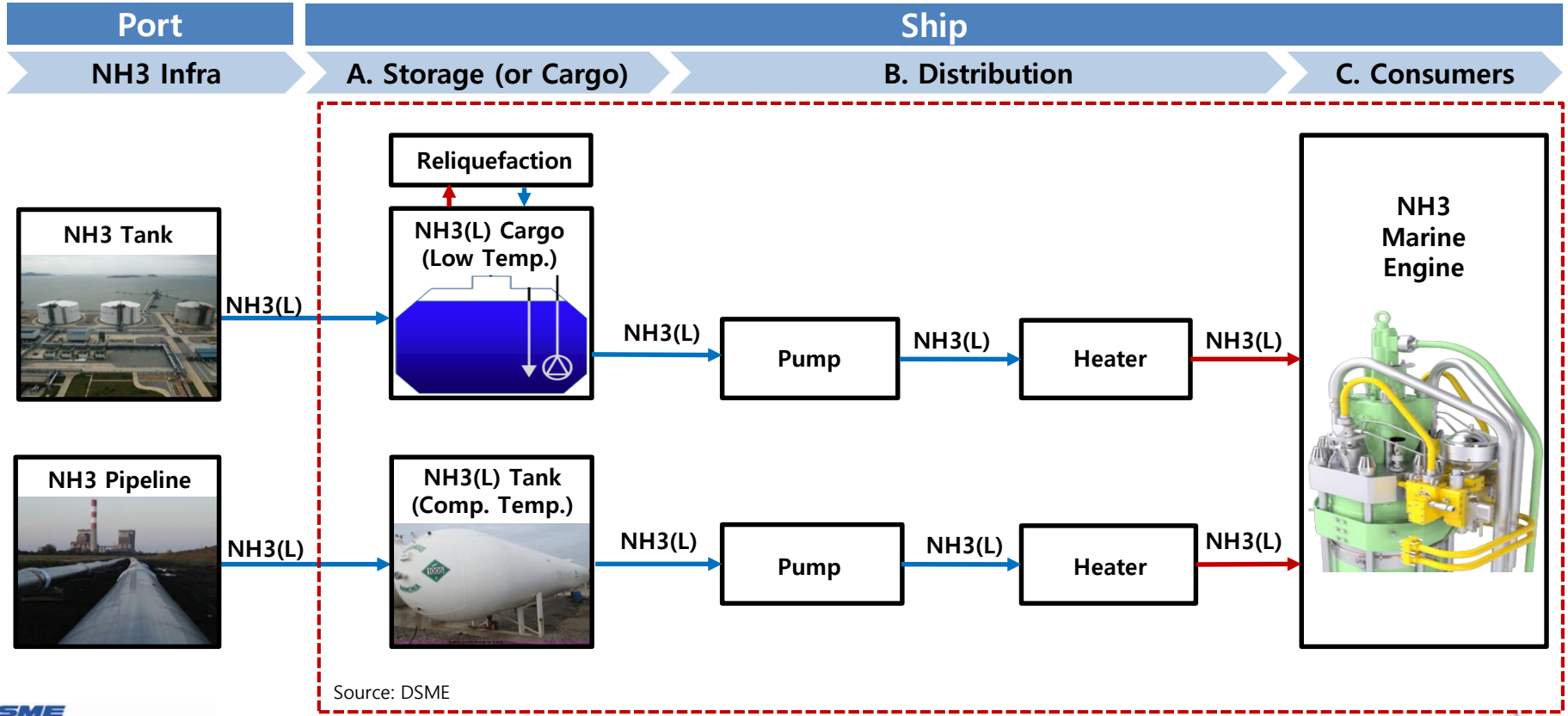
[DNV-GL, Maritime Energy Transition Outlook]



Source: DNV-GL 2019

3.2 Ship's Ammonia Fuel System Supply Chain

▣ NH3 Fuel Supply Chain Concept for Ships (ex) NH3 Carrier (w/NH3 Engine)



Source: DSME

3.3 Possibility to install NH3 Fuel System in Ships (1/9)

▣ Comparison Analysis of Potential Alternative Fuels for Ship GHG Reduction

Conditions for Potential Fuels	CH4	H2	NH3
① Carbon-free or Low-carbon Fuel			
② Available Engines for Ships			
③ Worldwide Infrastructure for Production And Distribution			
④ Transportable Ships for Alternative Fuel			
⑤ Competitive Fuel Prices			
⑥ Fuel Safety			
⑦ Rules & Code for Marine Transportation and Fuel Uses			
Total Analysis			

Evaluation Standard	○ Very Low	◔ Low	◐ Normal	◕ High	● Very High

3.3 Possibility to install NH3 Fuel System in Ships (2/9)

*EEDI (Energy Efficiency Design Index) **GWP (Global Warming Potential)

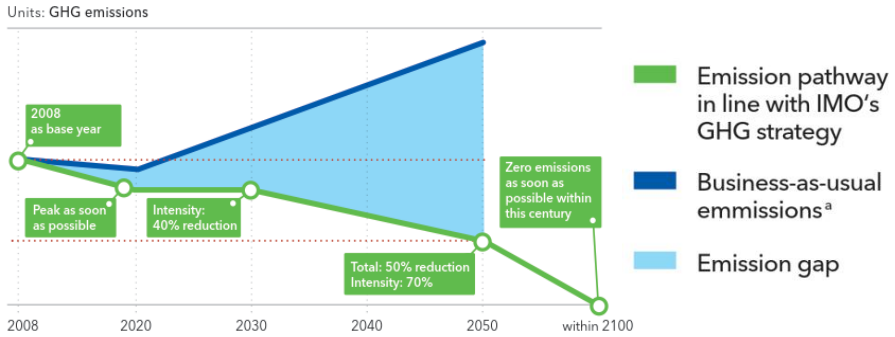
▣ Comparison Analysis of Potential Alternative Fuels for Ship GHG Reduction

Conditions for Potential Fuels	CH4	H2	NH3
① Carbon-free or Low-carbon Fuel	◐	●	●

- CH4 fuel has high competitiveness in terms of compliance for EEDI* regulation. (CO2 20~30% ⬇)
  However, when burning CH4, it generates unburned CH4. (GWP** – CH4(21) VS CO2(1))

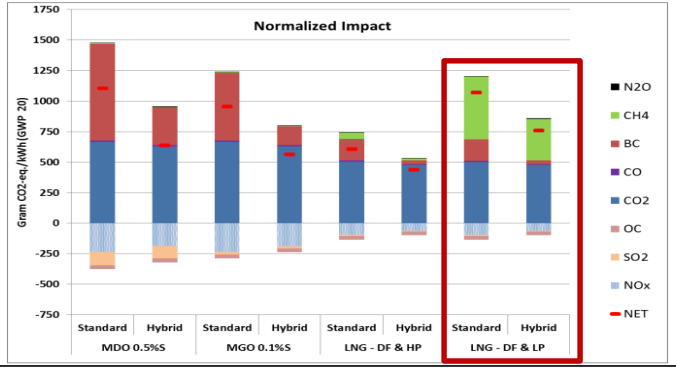
⇒ **In aspect of ship's GHG 50% reduction, the competitiveness of H2 and NH3 will be higher than CH4.**

[IMO Strategy for Reductions in GHG Emissions from Shipping]



Source: DNV-GL 2019

[Fuel & Engine VS Gram CO2-eq./kWh]



Source: Hydrogen the Next Maritime Fuel

3.3 Possibility to install NH3 Fuel System in Ships (3/9)

▣ Comparison Analysis of Potential Alternative Fuels for Ship GHG Reduction

Conditions for Potential Fuels	CH4	H2	NH3
② Available Engines for Ships	●	◕	◐

- CH4: Many engine manufacturers are supplying various CH4 engines for ships. (ex) ME-GI, X-DF, etc.
- H2 : Major ship engine makers have very low interest to make H2 engine for ships.
- **NH3: MAN ES announced the development plan of NH3 engines.**

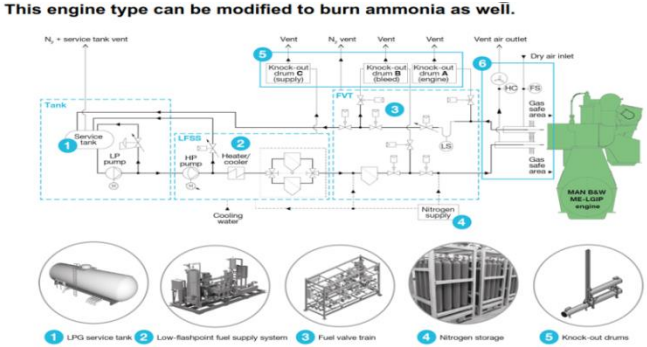
[Major CH4 Engines for Ships: ME-GI and X-DF]

ME-GI

X-DF

Source: MAN & WinGD

[MAN, NH3 Engine/System Concept using ME-LGIP]



Source: MAN 2018

3.3 Possibility to install NH3 Fuel System in Ships (4/9)

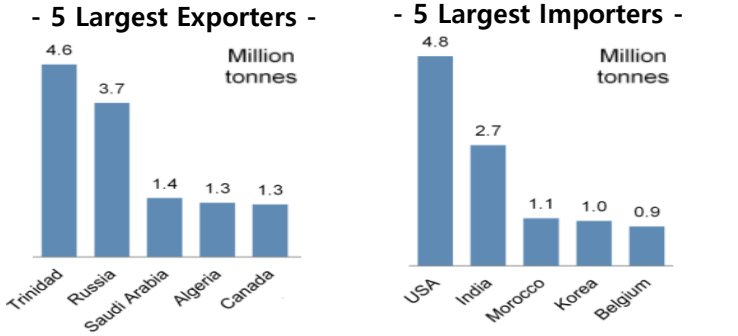
▣ Comparison Analysis of Potential Alternative Fuels for Ship GHG Reduction

Conditions for Potential Fuels	CH4	H2	NH3
③ Worldwide Infrastructure for Production and Distribution	◔	◔	◔

- NH3 Production(Worldwide) : 175 mil. ton (2016)
  : 10.5% of total NH3 is transporting on land and on sea.
- Global NH3 Import/Export : 18.5 mil. ton (2016)

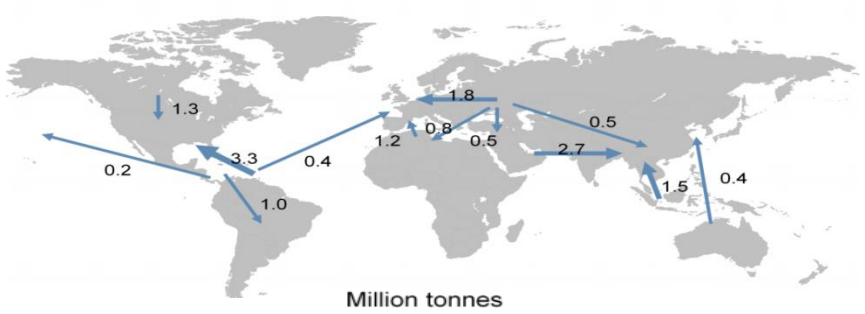
⇒ **NH3 is produced in many parts of the world, has a high marine cargo volume, and is easy to store and transport compared to other gas fuels. (*NH3 has more advantageous than H2.)**

[Global NH3 Trade (2016)]



Source: IFA

[Worldwide Main NH3 Flow (2016)]



Source: IFA 2016, 85% of Trade Shown

3.3 Possibility to install NH3 Fuel System in Ships (5/9)

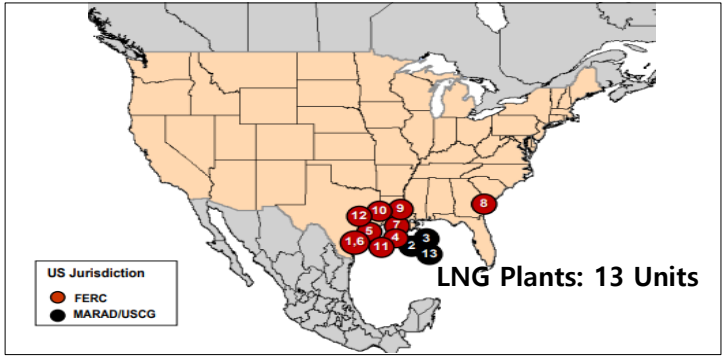
▣ Comparison Analysis of Potential Alternative Fuels for Ship GHG Reduction

Conditions for Potential Fuels	CH4	H2	NH3
③ Worldwide Infrastructure for Production and Distribution	◔	◔	◔

- Comparison of LNG VS NH3 Plants in North America
  - ✓ **LNG Plants (13 Units) VS NH3 Plants (66 Units)**
  - ✓ NH3 plants are distributed evenly across the coast and land.

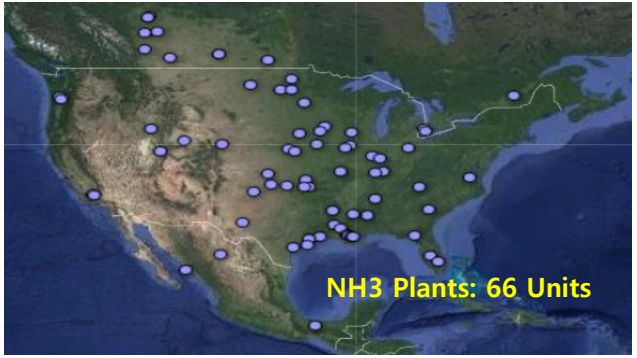
⇒ **NH3 can be more advantageous than LNG in terms of transporting and feeding to ships in US.**

[LNG Plants in North America (Jan. 2019)]



Source: www.ferc.gov

[NH3 Plants in North America(Nov. 2018)]



Source: Ammonia Energy

3.3 Possibility to install NH3 Fuel System in Ships (6/9)

▣ Comparison Analysis of Potential Alternative Fuels for Ship GHG Reduction

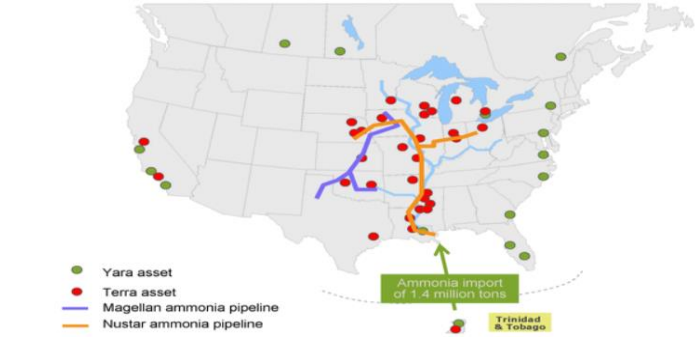
Conditions for Potential Fuels	CH4	H2	NH3
③ Worldwide Infrastructure for Production and Distribution	◔	◕	◔

- **NH3 pipeline in US (3,070 km, NH3 2.9 mil. ton/year)**

⇒ **Especially, some ships entering to GOM of US can have advantages when using NH3 infra for NH3 loading and unloading.**

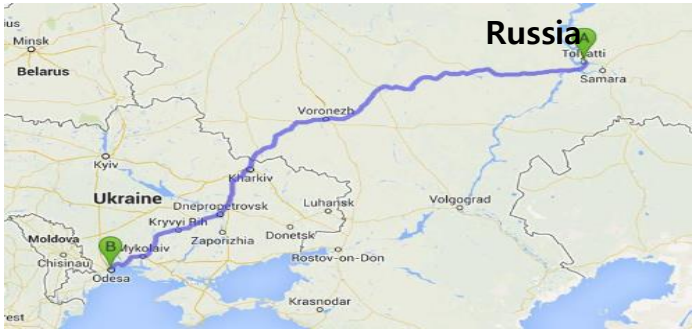
(*Russia-Ukraine NH3 Pipeline(2,400km, 3 mil. ton/year), Western Europe NH3 Pipeline (~70km))

[NH3 Pipelines in US]



Source: US EIA

[NH3 Pipelines from Russia to Ukraine]



Source: YARA

3.3 Possibility to install NH3 Fuel System in Ships (7/9)

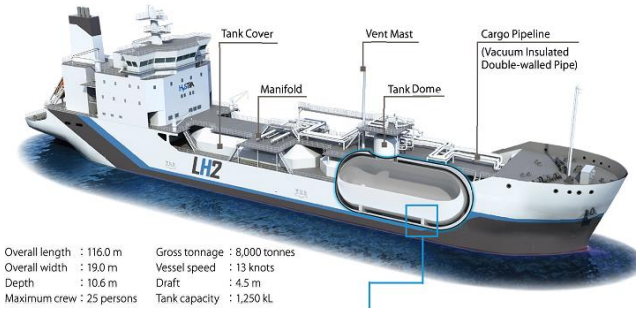
▣ Comparison Analysis of Potential Alternative Fuels for Ship GHG Reduction

Conditions for Potential Fuels	CH4	H2	NH3
④ Transportable Ships for Alternative Fuel	●	○	●

- CH4 Transportable Ships(Dec. 2018): 525 Units (LNG Carrier)
- H2 Transportable Ships(Oct. 2019): 0 Units (*Note: HySTRA's Pilot LH2 Carrier Project will be completed at 2020))
- **NH3 Transportable Ships(Jan. 2019): ~170 Units**

⇒ In aspect of transportable ships for alternative fuel, NH3 can have high advantages compared to hydrogen.

[HySTRA's 3D Image of Pilot LH2 Carrier]



Source: HySTRA

[Yara's LPG/NH3 Transportation Ships]

Source: YARA

3.3 Possibility to install NH3 Fuel System in Ships (8/9)

*LHV (Lower Heating Value)

▣ Comparison Analysis of Potential Alternative Fuels for Ship GHG Reduction

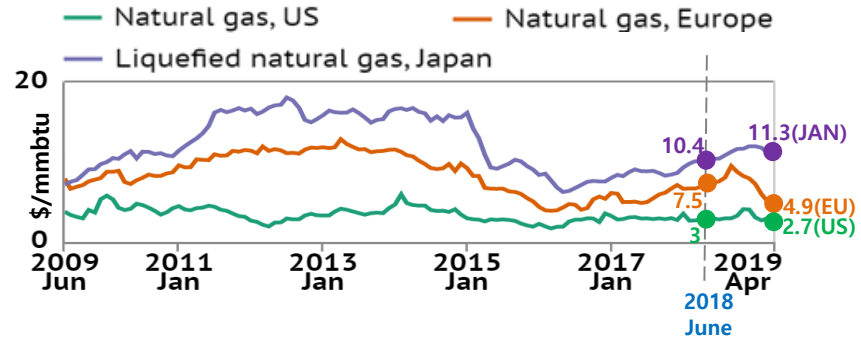
Conditions for Potential Fuels	CH4	H2	NH3
⑤ Competitive Fuel Prices	●	◔	◔

- NG Price (Apr. 2019) : $211.6/ton (@European Union)
- H2 Price (Apr. 2019) : $2,500/ton (@EU Air Liquids)
- **NH3 Price (Apr. 2019) : $298.8/ton (@Western EU)**

LHV* (GJ/Ton)

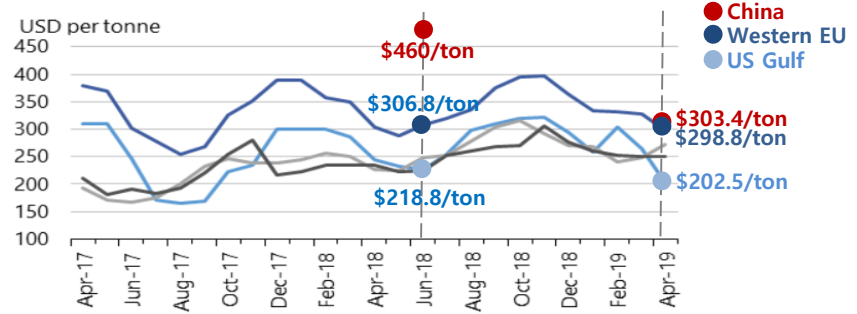
$4.5/GJ
$20.8/GJ
$16/GJ

[Natural Gas Price 2008~2019]



Source: World Bank 2019

[Ammonia Price (Spot) 2017~2019]



Source: AMIS Market Monitor

3.3 Possibility to install NH3 Fuel System in Ships (9/9)

▣ Summary of Potential Alternative Fuel Analysis for Ship's GHG Reduction

Conditions for Potential Fuels	CH4	H2	NH3
① Carbon-free or Low-carbon Fuel	◐	●	●
② Available Engines for Ships	●	◕	◑
③ Worldwide Production And Distribution Infrastructure	◔	◕	◔
④ Transportable Ships for Alternative Fuel	●	○	●
⑤ Competitive Fuel Prices	●	◕	◔
⑥ Fuel Safety	●	◕	◑
⑦ Rules & Code for Marine Transportation and Fuel Uses	●	◕	◑
Total Analysis	◔	◐	◐
Based on GHG 50% Reduction, Total Analysis	◐	◐	◔

Contents

4. Economic Case Study

- Case.1 Large Containership (23,270 TEU)
- Case.2 VLCC (300,000 m3)
- **Case.3 VLGC (w/NH3, 84,000 m3)**

4.3 Case.3 VLGC(w/NH3, 84,000 m3, 1/4)

▣ Target Ship: "NH3 Transportable VLGC"

1. Main information of "Economic Case Study of Ship Fuels"

1) Ship Fuels: HFO VS LSFO VS LNG VS NH3
2) Ship Type : VLGC(w/NH3, 84,000 m3)
3) Route : USA ↔ Asia
4) Cost Comparison Analysis
   A. CAPEX, OPEX, NH3 Sales Price
   B. Total Sales Price – Total Investment Cost
5) Economic Study Summary

4.3 Case.3 VLGC(w/NH3, 84,000 m3, 2/4)

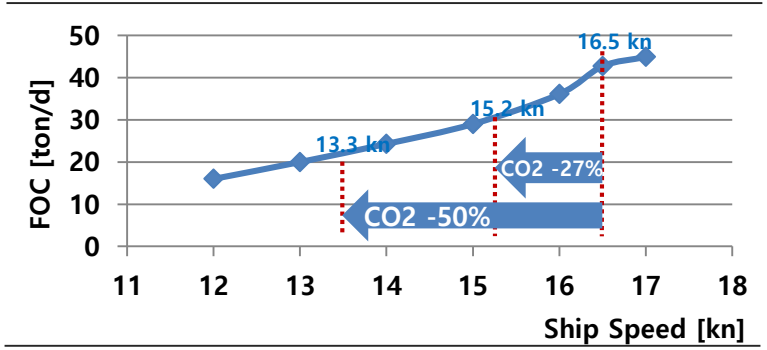
*FOC (Fuel Oil Consumption)

1) Ship Fuels: HFO vs LSFO vs LNG vs NH3

- **Target: Ship's CO2 50% Reduction using Speed Reduction and Fuel Change**
  - ✓ **HFO, LSFO :** Total CO2 50% = Speed Reduction (CO2 50%)
  - ✓ **LNG :** Total CO2 50% = Fuel Change(HFO ⇒ LNG, CO2 23%) + Speed Reduction (CO2 27%)
  - ✓ **NH3 :** Total CO2 50% = NH3(CO2-Free) 50% +LSFO 50% without Speed Reduction

⇒ **Ship Speed: HFO, LSFO(13.3 kn), LNG(15.2 kn), NH3(16.5 kn)**

[VLGC – FOC* VS Speed]



Source: DSME

[Main Conditions according to Fuel Selection]

Fuel	Engine	Region 1/2	Region 2/2	Storage Tank	
HFO	ME-C	HFO		HFO Tank	
LSFO	ME-C	LSFO		LSFO Tank	
LNG	MEGI	LNG		LNG Type B	
NH3	ME-LGIP (Modification)	NH3	LSFO	NH3(L) Tank	LSFO Tank

Source: DSME

4.3 Case.3 VLGC(w/NH3, 84,000 m3, 3/4)

*FSS (Fuel Supply System)
**Labor cost, Insurance, Maintenance and etc.

2) Cost Comparison Analysis

- **Summary of Main CAPEX & OPEX Results**

CAPEX

✓ Engine	: **ME-GI(LNG)**	> ME-LGIP(NH3)	> ME-C(LSFO)	= ME-C(HFO)
✓ Fuel Tank	: **LNG**	> NH3	> LSFO	= HFO
✓ FSS*	: **LNG**	> NH3	> LSFO	= HFO
✓ Scrubber	: **HFO**			

OPEX

✓ Fuel	: **LNG**	> NH3+LSFO	> LSFO	> HFO
✓ Scrubber OPEX	: **HFO**			
✓ Other OPEX**	: **LNG**	> NH3+LSFO	> HFO	= LSFO

- **Total CAPEX : LNG > NH3 > HFO > LSFO**
- **Total OPEX : LNG > LSFO > HFO > NH3/LSFO**
- **Total NH3 Sales Price : NH3 > LNG > LSFO = HFO**
- **Total NH3 Sales Price – Total Investment Cost : NH3 > LNG > HFO > LSFO**

4.3 Case.3 VLGC(w/NH3, 84,000 m3, 4/4)

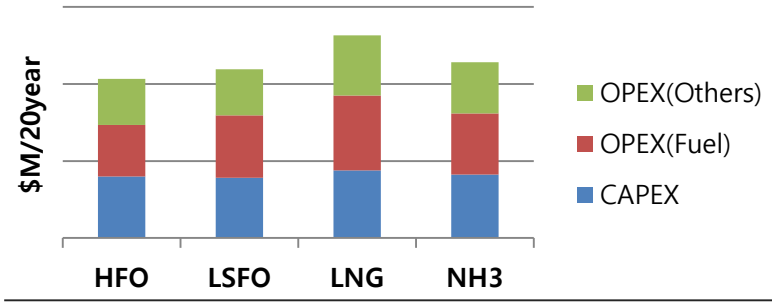
3) Economic Study Summary

- **In terms of NH3 carrier's GHG reduction(50% ⬇), NH3 fuel has the highest economic in this study.**
  - ✓ CAPEX & OPEX can be low if using NH3 cargo and existing systems of NH3 carriers
  - ✓ NH3 carriers with NH3 fuel can operate without ship speed reduction

4) Forecast

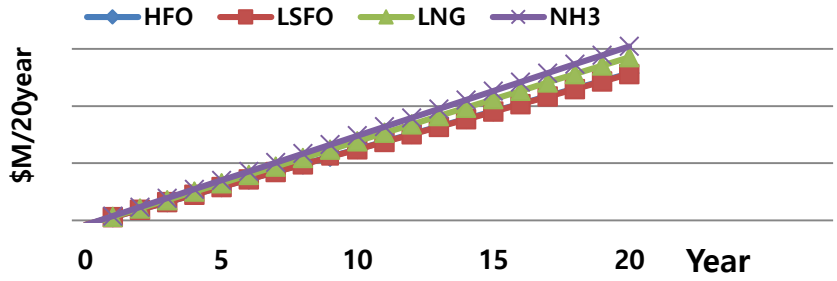
- **Short term** : We think first ammonia fuel system can be applied to ammonia carriers.
- **Medium/Long term** : If NH3 carriers(w/NH3 fuel) operate economically and environmentally, NH3 fuel/engines/systems will be also applied to other type ships.

[Lifetime(20Y), Total Investment Cost]



Source: DSME

[Gross Graph of △(Total NH3 Sales Price – Total Investment Cost)]



Source: DSME

5. DSME's Future Plan & Forecast

5.1 Future Plan

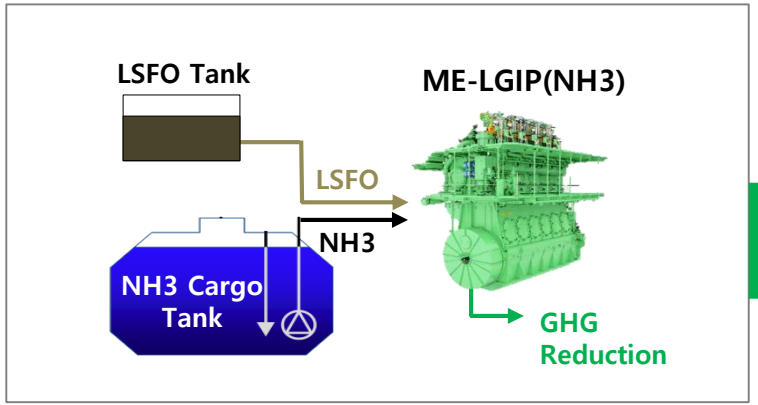
*FGSS (Fuel Gas Supply System)

[DSME's Future Plan]

① Doing Joint Research for "Feasibility and Design Concept Study of LPG/NH3 Carrier(w/NH3)"

② Making R&D projects with consortium for NH3 engine development and FGSS* pilot test

[NH3 Fuel Supply System for Ships]



Source: DSME

NH3 Fuel

[NH3 Carrier (w/NH3 Engine + FGSS)]

Source: YARA

5.2 Future Forecast

▣ What is the World's First NH3 Fuel Driven Ocean Going Ship?

LNG

World's first LNG driven ocean going ship
Owner: TOTE
Ship type: Container ship
Capacity: 3,100 Teu
Dual Fuel engine type: 8L70ME-C8.2-GI

First engine order: Year 2012

MeOH

World's first methanol driven ocean going ship
Owner: MOL
Ship type: Methanol carrier
Capacity: 50,000 dwt
Dual fuel engine type: 7S50ME-B9.3-LGIM

Year 2013

Ethane

World's first ethane driven ocean going ship
Owner: Hartmann Schifffahrt
Ship type: LEG Carrier
Capacity: 36,000 M^3
Dual Fuel engine type: 7G50ME-GIE

Year 2014

LPG

World's first LPG driven ocean going ship
Owner: Exmar
Ship type: VLGC
Capacity: 80,000 M^3
Dual Fuel engine type: 6G60ME-LGIP

Year 2018

NH3

World's first ammonia driven ocean going ship
Owner: Ammonia Transportation Ship Owner
Ship type: Ammonia Carrier
Capacity: 38,000 M^3 or 84,000 M^3
Dual Fuel engine type: ME-LGIP(NH3 Modification)

Year 202X
(by DSME)

Source: MAN ES + DSME

Thank You

DSME

The First Mover of
"Econology Ships"