AIChE 2019
Technical & Economic Feasibility Study for Commercial Ships with HFO, LNG, and NH3 as Fuel

HYUK KWON

Nov. 13, 2019
1. Background
2. Recent Trend on NH3 Fuel related to Ships
3. DSME’s Feasibility Study of NH3 as a Ship Fuel
4. Economic Case Study
5. DSME’s Future Plan & Forecast
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

• 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]

*GHG (Greenhouse Gas)
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

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

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

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 SOREN PICO
Published: 11.02.19 at 14:46

② MAN ES’s Presentations on NH3 Engine

Aug. 30, 2018 (@SMM 2018)

Oct. 30, 2018 (@NH3 Fuel Association)

Jun. 6, 2019 (@NH3 event 2019)

③ Jan. 22, 2019

**TradeWinds**

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.

**③** Jan. 22, 2019

- 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

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.
3. DSME’s Feasibility Study of NH3 as Ship Fuel
### 3.1 Ship's GHG Regulation and Strategy Trend

**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 ]

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![Graph showing the growth of various energy sources from 2020 to 2050. Units: EJ/yr.](graph.png)

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)

<table>
<thead>
<tr>
<th>Port</th>
<th>NH3 Infra</th>
<th>Ship</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Storage (or Cargo)</td>
<td>NH3 Infra</td>
<td>NH3(L) Cargo (Low Temp.)</td>
</tr>
<tr>
<td>B. Distribution</td>
<td></td>
<td>Pump</td>
</tr>
<tr>
<td>C. Consumers</td>
<td></td>
<td>Heater</td>
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Reliquification

Source: DSME
## Comparison Analysis of Potential Alternative Fuels for Ship GHG Reduction

<table>
<thead>
<tr>
<th>Conditions for Potential Fuels</th>
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<td>6. Fuel Safety</td>
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### Total Analysis

#### Evaluation Standard

- VERY LOW
- LOW
- NORMAL
- HIGH
- VERY HIGH
Conditions for Potential Fuels

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• 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 ]

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

Source: DNV-GL 2019

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**

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- 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 ]**

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

Source: MAN & WinGD

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**

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- 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)]

- **5 Largest Exporters**
  - Trinidad: 4.6
  - Russia: 3.7
  - Saudi Arabia: 1.4
  - Algeria: 1.3
  - Canada: 1.3

- **5 Largest Importers**
  - USA: 4.8
  - India: 2.7
  - Morocco: 1.1
  - Korea: 1.0
  - Belgium: 0.9

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

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- 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

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- 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 ]

[ NH3 Pipelines from Russia to Ukraine ]

Source: US EIA

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

*Comparison Analysis of Potential Alternative Fuels for Ship GHG Reduction*

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<td>●</td>
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</table>

- 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 ]

[ Yara’s LPG/NH3 Transportation Ships ]

Source: HySTRA

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

- Conditions for Potential Fuels
  - CH4
  - H2
  - NH3

- Competitive Fuel Prices
  - NH3 Price (Apr. 2019): $298.8/ton (@Western EU)

- LHV* (GJ/Ton)
  - CH4: $4.5/GJ
  - H2: $20.8/GJ
  - NH3: $16/GJ

- Natural Gas Price 2008~2019

- Ammonia Price (Spot) 2017~2019

Source:
- World Bank 2019
- AMIS Market Monitor
## Summary of Potential Alternative Fuel Analysis for Ship's GHG Reduction

### Conditions for Potential Fuels

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<td>●</td>
<td>●</td>
</tr>
<tr>
<td>⑦ Rules &amp; Code for Marine Transportation and Fuel Uses</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td><strong>Total Analysis</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Based on GHG 50% Reduction, Total Analysis</strong></td>
<td>●</td>
<td>○</td>
<td>●</td>
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</table>
4. Economic Case Study

- Case.1 Large Containership (23,270 TEU)
- Case.2 VLCC (300,000 m3)
- Case.3 VLG C (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
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)
### 2) Cost Comparison Analysis

#### Summary of Main CAPEX & OPEX Results

<table>
<thead>
<tr>
<th>Component</th>
<th>CAPEX</th>
<th>OPEX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engine</td>
<td>ME-GI(LNG) &gt; ME-LGIP(NH3) &gt; ME-C(LSFO) = ME-C(HFO)</td>
<td></td>
</tr>
<tr>
<td>Fuel Tank</td>
<td>LNG &gt; NH3 &gt; LSFO = HFO</td>
<td></td>
</tr>
<tr>
<td>FSS*</td>
<td>LNG &gt; NH3 &gt; LSFO = HFO</td>
<td></td>
</tr>
<tr>
<td>Scrubber</td>
<td>HFO</td>
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<td>Fuel</td>
<td>LNG &gt; NH3+LSFO &gt; LSFO &gt; HFO</td>
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<tr>
<td>Scrubber OPEX</td>
<td>HFO</td>
<td></td>
</tr>
<tr>
<td>Other OPEX**</td>
<td>LNG &gt; NH3+LSFO &gt; HFO = LSFO</td>
<td></td>
</tr>
</tbody>
</table>

- **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

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*FSS (Fuel Supply System)*
**Labor cost, Insurance, Maintenance and etc.*
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.
5. DSME’s Future Plan & Forecast
[ 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 ]

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

*FGSS (Fuel Gas Supply System)
5.2 Future Forecast

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

**NH3**
- **NH3 Carrier + NH3 Engine**
  - World’s first ammonia driven ocean going ship
  - Owner: Ammonia Transportation Ship Owner
  - Ship type: Ammonia Carrier
  - Capacity: 88,000 M³ or 84,000 M³
  - Dual Fuel engine type: ME-LGIP (NH3 Modification)

**LPG**
- **LPG Carrier + LPG Engine**
  - World’s first LPG driven ocean going ship
  - Owner: Exmar
  - Ship type: VLGC
  - Capacity: 80,000 M³
  - Dual Fuel engine type: 6G60ME-LGIP

**Ethane**
- **Ethane Carrier + Ethane Engine**
  - World’s first ethane driven ocean going ship
  - Owner: Hartmann Schifffahrt
  - Ship type: LEG Carrier
  - Capacity: 36,000 M³
  - Dual Fuel engine type: 7G50ME-G1E

**MeOH**
- **MeOH Carrier + MeOH Engine**
  - 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

**LNG**
- **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: LNG
- Year 2013: MeOH
- Year 2014: Ethane
- Year 2018: LPG
- Year 202X (by) NH3

Source: MAN ES + DSME
Thank You

The First Mover of “Econology Ships”