

KOREAN REGISTER

탄소중립을 위한 해운산업의 전망

문건필
대체연료기술연구팀

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5. 요약



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서론

1. GHG regulations
2. Life cycle analysis

3. Decarbonization scenario
4. Fuel properties

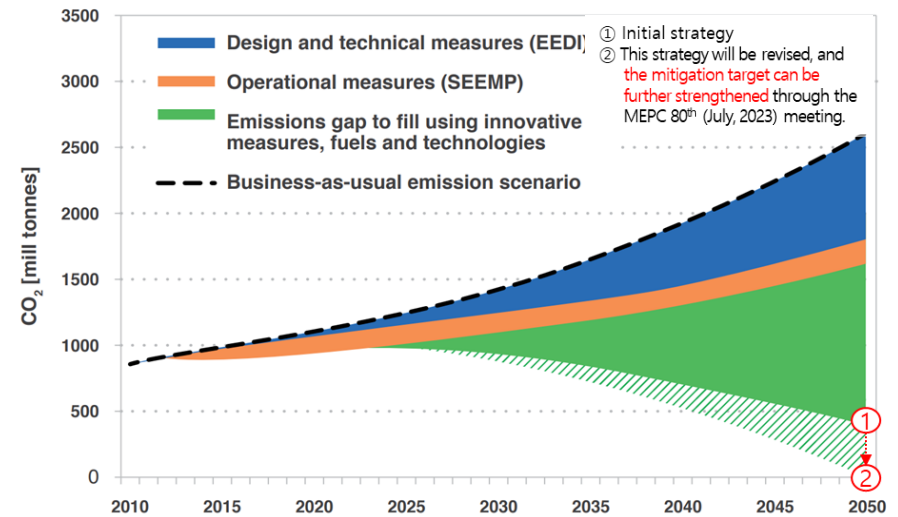
강화되는 GHG 규제 대응, 대체연료 및 혁신 기술 개발 필요성

VISION ▶▶ Decarbonization

Phase GHG emissions of ships out ASAP in this century

TARGET ▶▶

- Carbon Intensity to decline**
- Further Phases of EEDI for New Ships
- Carbon Intensity to decline**
- (tCO₂/ton·mile) 40% by 2030 and 70% by 2050 compared to 2008
- GHG emissions to peak and decline**
- **Peak** GHG emissions as soon as possible
- (Total annual emissions) 50% by 2050 compared to 2008

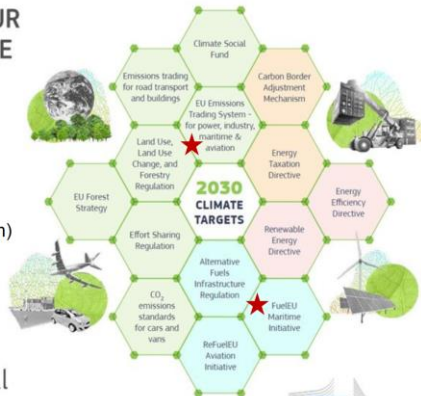


Source : IMO action to reduce greenhouse gas emissions from international shipping

EUROPEAN GREEN DEAL

REACHING OUR 2030 CLIMATE TARGETS

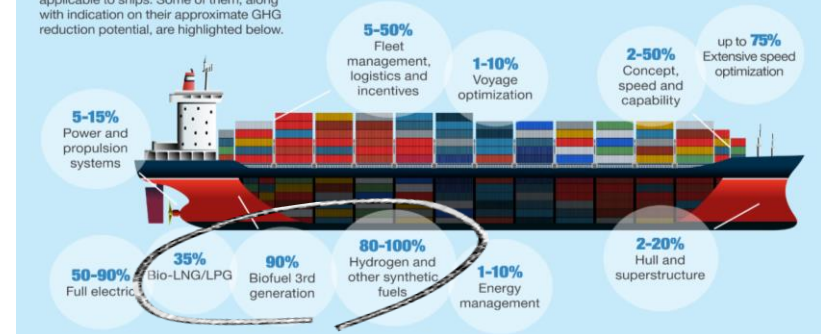
- EU 2030 Climate Target
40% → 55% (1990 baseline)
- Maritime sector
 - EU ETS (emission trading system)
 - FuelEU Maritime



#EUGreenDeal

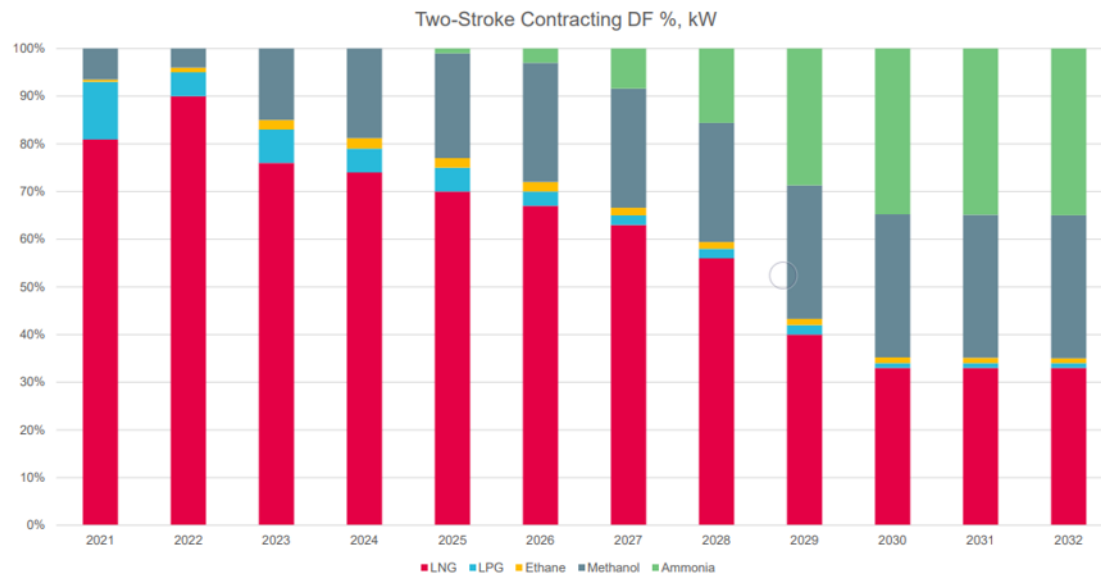
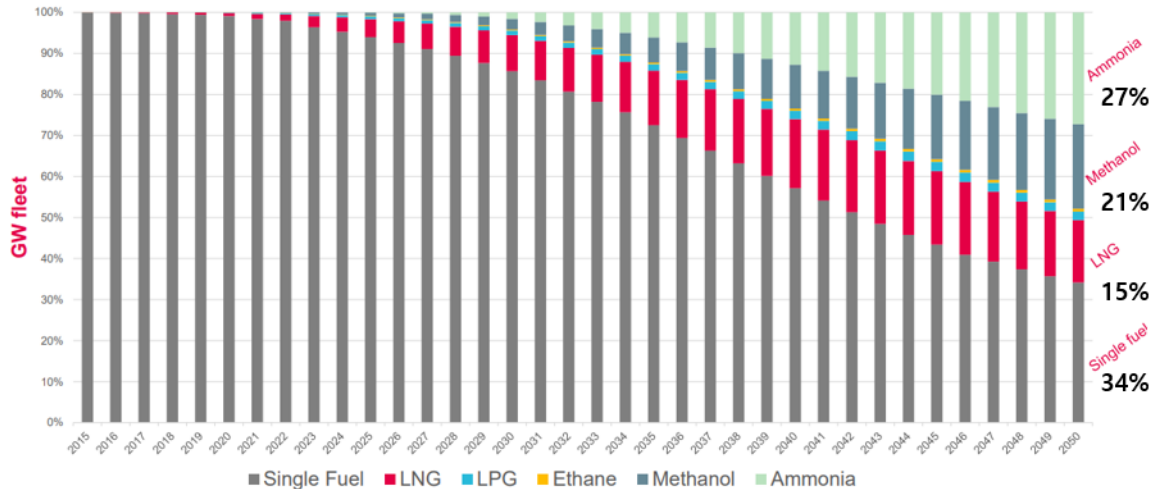
A wide variety of design, operational and economic solutions

Achieving the goals of the Initial IMO GHG Strategy will require a mix of technical, operational and innovative solutions applicable to ships. Some of them, along with indication on their approximate GHG reduction potential, are highlighted below.



Source: IMO action to reduce greenhouse gas emissions from international shipping, IMO

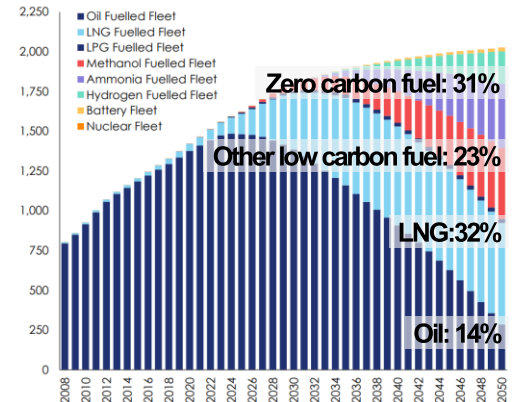
다양한 탈탄소 시나리오



Source: MAN B&W Ammonia engine, Motorship PFF conference, Nov. 2022

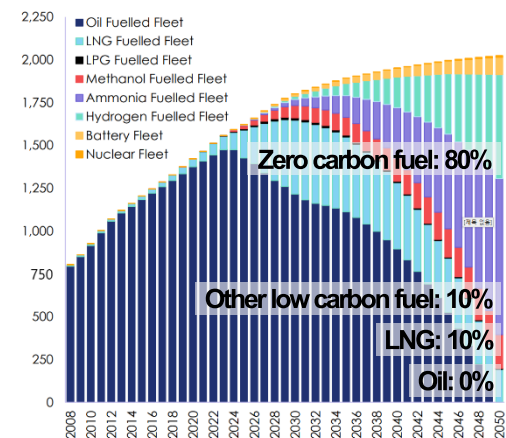
* IMO의 초기전략 기준, 미래선대 예상

Fleet Development, Average Year, m. GT



* 2050 해운의 넷제로를 위한 선대 예상

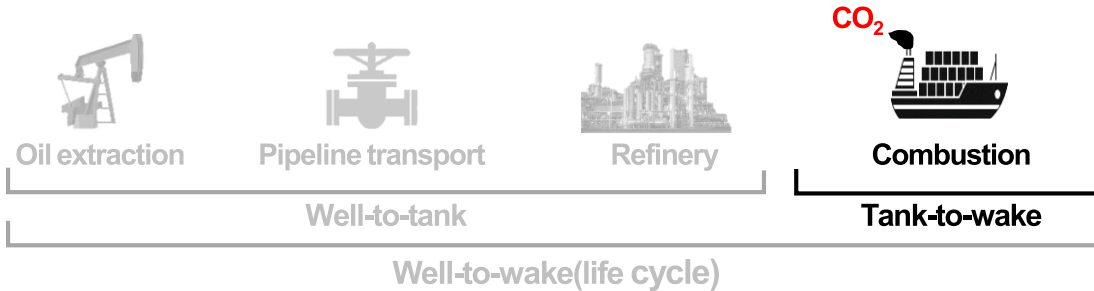
Fleet Development, Average Year, m. GT



Source: Clarksons Research, Fuelling Transition: Tracking the Economic Impact of Emission Reductions & Fuel Changes, Mar. 2023

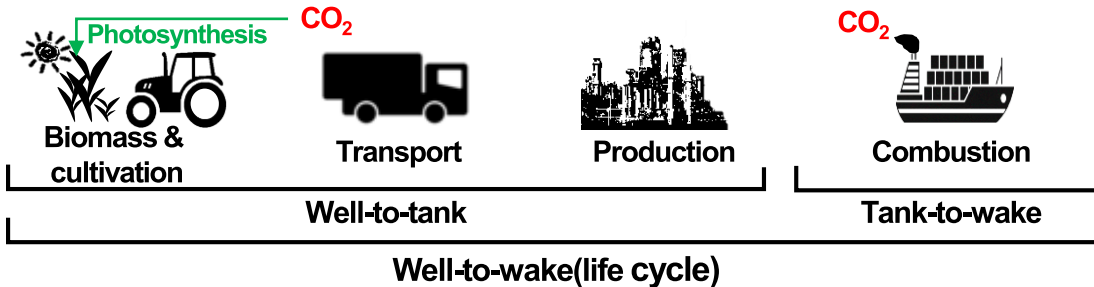
전주기 관점(LCA)에서의 GHG 규제

☑ 전통적인 선박 연료



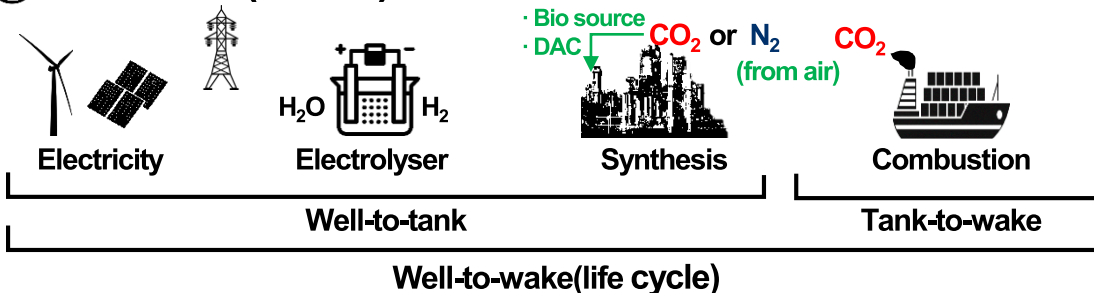
Tank to wake
CO₂ emissions

☑ 바이오연료



VS.

☑ 합성연료(e-fuel)

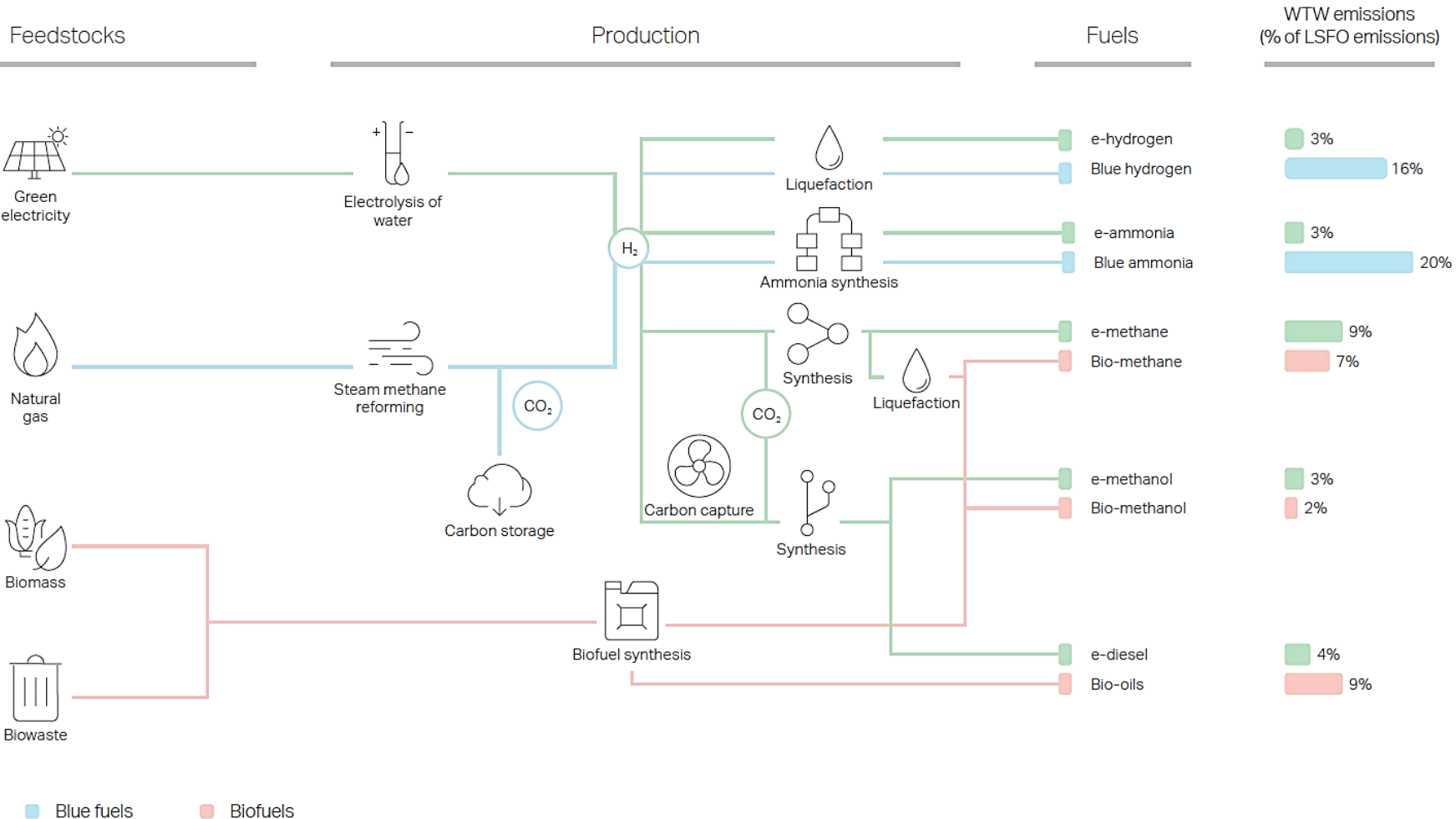


Well to Wake(or propeller)
GHG emissions

* 그린 수소는 다양한 대체연료를 생산하기 위해 필수적인 중간 생성물

청정 연료 제조

☑ 전통적인 선박 연료

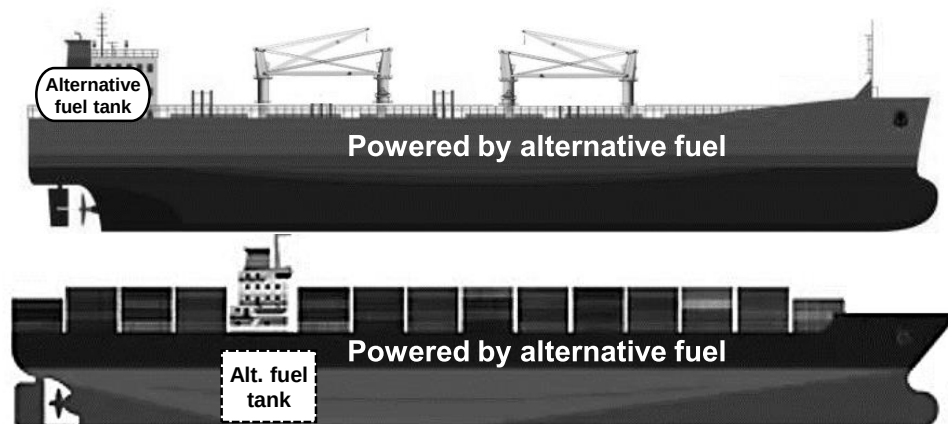
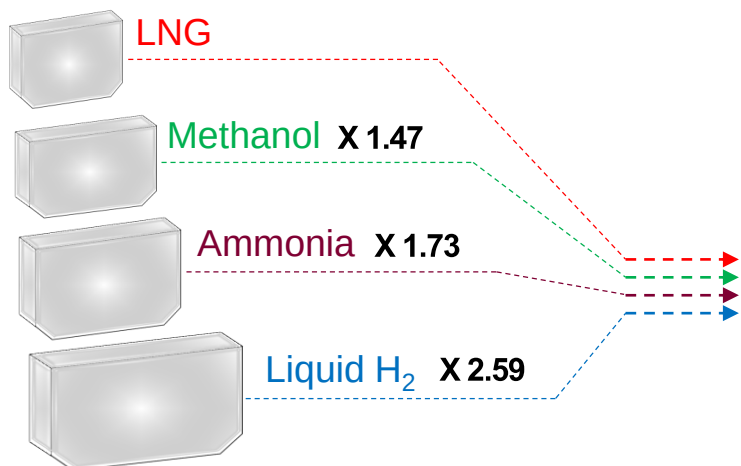


대체연료 물성

Energy storage type	Supply energy	Energy density	Required tank volume	Supply pressure	Injection pressure	Emission reduction compared to HFO Tier II			
	MJ/kg	MJ/L	m ³ *1	bar	bar	%	%	%	%
HFO	40.5	35	1,000	7-8	950	SO _x	NO _x	CO ₂	PM
Liquefied natural gas (LNG -162°C)	50	22	1,590	300 methane	300 methane	90-99	20-30	24	90
				380 ethane	380 ethane	90-97	30-50	15	90
LPG (including Propane / Butane)	42	26	1,346	50	600-700	90-100	10-15	13-18	90
Methanol	19.9	15	2,333	10	500	90-95	30-50	5	90
Ethanol	26	21	1,750	10	500				
Ammonia* (liquid -33°C)	18.6	12.7	2,755	70	600-700	90-95	Tier	95	90
Hydrogen (liquid -253°C)	120	8.5	4,117						

Source: MAN energy solutions, Engineering the future two-stroke green-ammonia engine, 2019

대체연료에 적용에 따른 연료 탱크 용량 비교(LNG 연료 탱크 기준)



* 가정: 동일한 거리 운항 조건

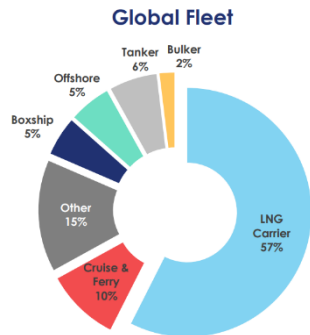


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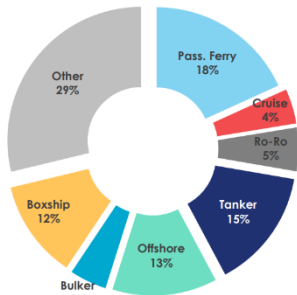
대체연료: 저탄소 연료

- | | |
|--------------|---------|
| 1. LNG | 4. LPG |
| 2. Methanol | 5. OCCS |
| 3. Biodiesel | |

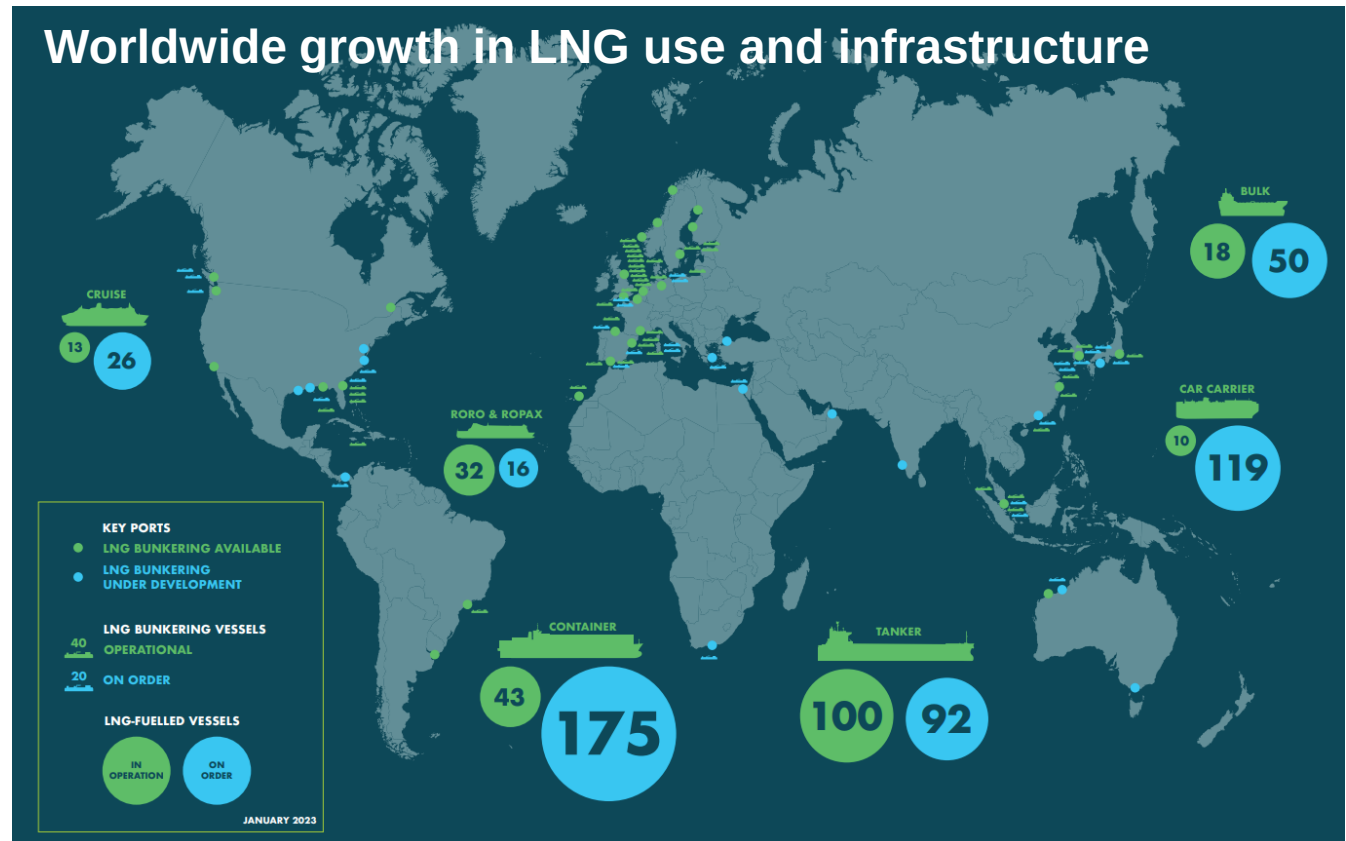
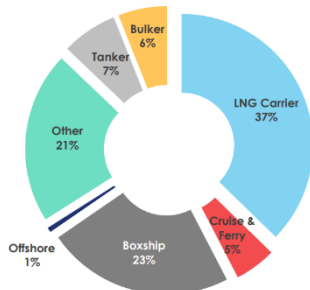
LNG 추진 선대 현황 및 bunkering 항구



**Global Fleet
(excluding LNG carriers)**



Global Orderbook

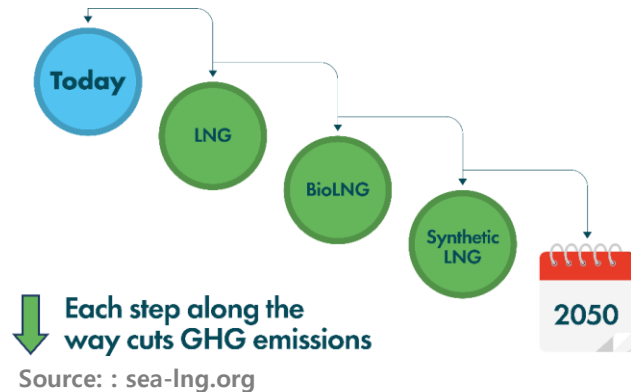


Left image source: Clarksons Research, Fuelling Transition: Tracking the Economic Impact of Emission Reductions & Fuel Changes, Mar. 2023

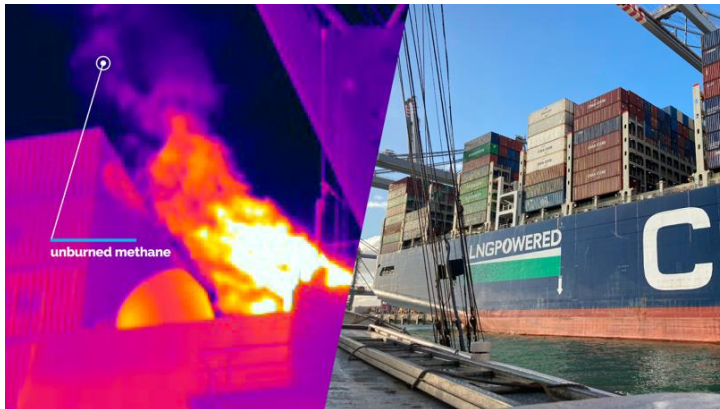
Right image source: SEA-LNG, LNG-Delivering decarbonisation, 2023

과도기적 연료로서 LNG?

- ☑ TTW CO₂ 배출 규제
→ WTW GHG 배출 규제



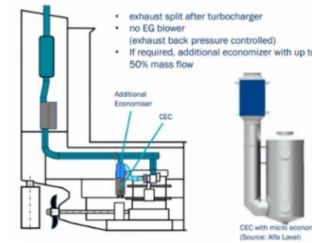
- ☑ 메탄슬립 (CH₄ GWP: X 29.8, over 100 yrs.)



Source : - Transport & Environment, Methane escaping from 'green' gas-powered ships, Apr. 13, 2022

- ☑ 메탄슬립 저감기술(2 행정, 저압 이중연료 엔진)

iCER Technology
Positioned adjacent to the engine



- ☑ 메탄슬립 저감기술(4 행정 발전기 엔진)

- 엔진 내부 형상 최적화 (~50%)
- 후처리시스템(~70%)
- 연소실 직접 분사 (~90%)

Source: MAN energy solutions, Managing methane slip



* LNG-수소 혼소 엔진

- 혼합비 : 25 %
- CO₂ 저감률 : 30%
- 메탄슬립 저감효과

Source: press release, Riviera, October 26, 2022, HHI-EMD tests new LNG-Hydrogen engine,

Synthetic(E)/bio LNG

☑ 액상 바이오가스(Liquified biogas) – ESL shipping



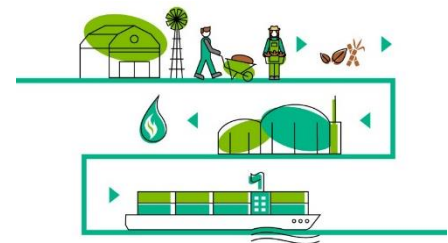
- 100% 재생 액화 바이오가스 적용 (June, 2020) (produced by Gasum 社)
- LBG : 폐자원에서부터 생산한 LNG와 호환가능한 가스 연료
- ESL 社는 전통적인 선박 연료 대비, GHG 배출량을 85%까지 저감 가능성 보고

☑ 바이오메탄(12,000 tonnes¹ 의 바이오메탄² 생산 지원) – CMA CGM

- 2021년 5월부터 화주가 원할 시, 바이오메탄 연료 사용 가능 (전주기적 관점에서 최소 67% CO₂ 저감)

¹ 2척의 LNG 추진 컨테이너선(1,400 teu)이 네덜란드 로테르담과 러시아 상트페테르부르크를 1년내 정기적으로 왕복할 수 있는 연료량

² 화석연료 기반이 아닌 신재생 청정 가스



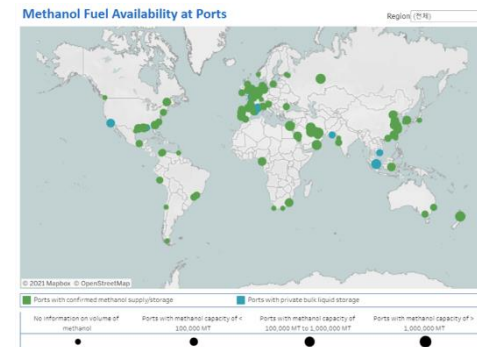
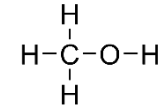
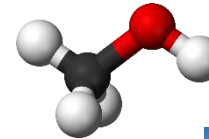
☑ 합성 LNG(Synthetic NG)- MAN Energy solutions



- 화석연료 기반 LNG와 신재생에너지 기반 합성 LNG 각 20 tons 혼합
- 화석연료 기반 LNG 대비, 56 tons의 이산화탄소 절감 효과 예상

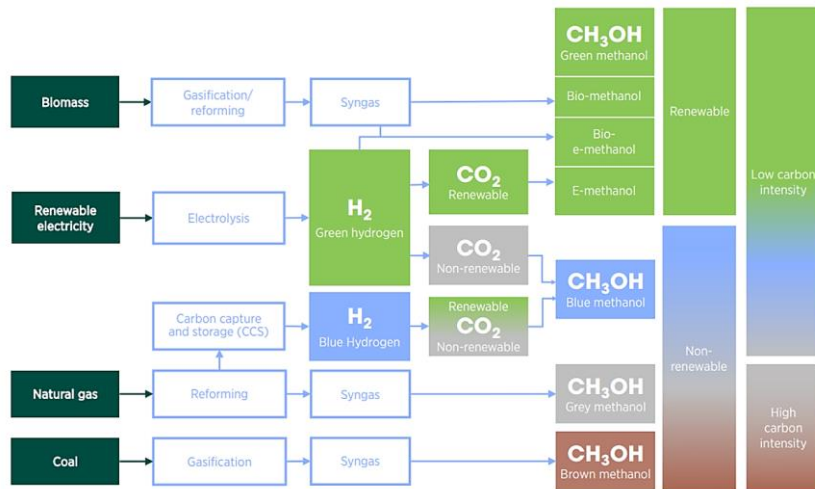
선박 연료로서 메탄올

- ☑ 메탄올 화학식: CH_3OH (the simplest alcohol)
- ☑ 세계적으로 이미 활용되고 있는 대체연료 (120,000 시간 이상의 엔진 운전 시간 보유)
- ☑ 배출물 저감 특성(SO_x , NO_x , PM, CO_2)
- ☑ 극저온 저장 및 운용 설비 불필요 (LPG: -42°C , LNG: -162°C , NH_3 : -33°C)
- ☑ 메탄올 연료 공급 압력: 13 bar
- ☑ 메탄올 벙커링 인프라: 이미 122개 터미널 운용 중
- ☑ 전주기적 관점에서 GHG 규제 발효 시, 그린 메탄올(바이오메탄올 또는 합성 메탄올)을 해운에 활용하기 위해 대량 생산 필요
- ☑ 메탄올 사용에 대한 안전성 관점 해결사항: 독성, 부식, 화재 등



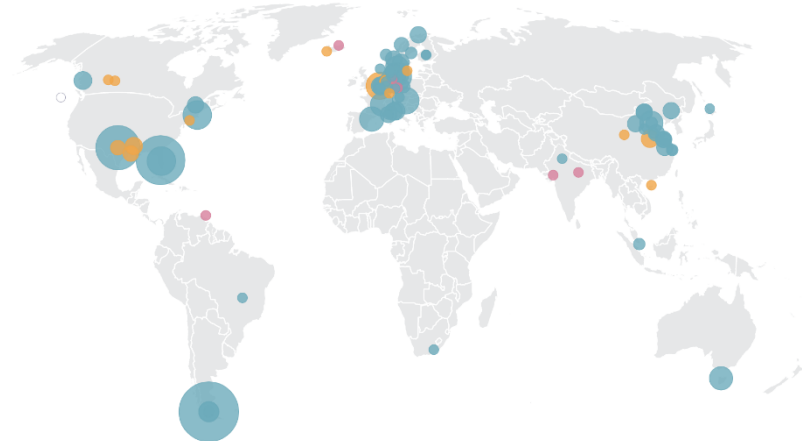
Source: Eelco Dekker, Methanol plotting a course to low carbon pathways, Motorship conference 2019

메탄올 생산 방법 및 그린 메탄올 생산 계획



Source: www.methanol.org

Sized by mt/year ● Existing ● Upcoming ● To be confirmed



Source: Methanol Institute, S&P Global commodity insights, 2023

A.P. Moller – Maersk accelerate s fleet decarbonization with 12 large ocean – going vessels to operate on green methanol from 2024 (9 strategic green methanol partnerships in 2022)



HMM places order for 9 methanol-fueled container (9,000 teu) ships will be delivering in 2025



바이오디젤 분류 및 특성

Classification of Biofuels

1st Generation Biofuels

- Also called conventional biofuels. It includes sugar, starch, or vegetable oil

2nd Generation Biofuels

- known as advanced biofuels and can be manufactured from different types of biomass. The biomass contains lignocellulosic material like wood, straw and waste plastic

3rd Generation Biofuels

- Extract from algae mostly marine algae

- ☑ 화석연료 기반 현존선, 규제대응 선호 연료
- ☑ 엔진 변경 없이, 사용할 수 있는 'drop-in fuel'
- ☑ 탄소 중립 연료(단, 원료에 따라 상이)
- ☑ 제한된 원료에 따른 생산량의 한계성
- ☑ 다른 산업군과의 확보 경쟁
- ☑ 벙커링 인프라, 가격



Soybean



Corn



Sugarcane



Sugar beet



Cassava



Palm oil



Certain fungi



Switchgrass



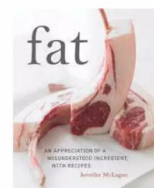
Jatropha



Camelina



Algae



Animal fat



Agricultural wastes

바이오텔의 해상실증 예시

☑ Maersk

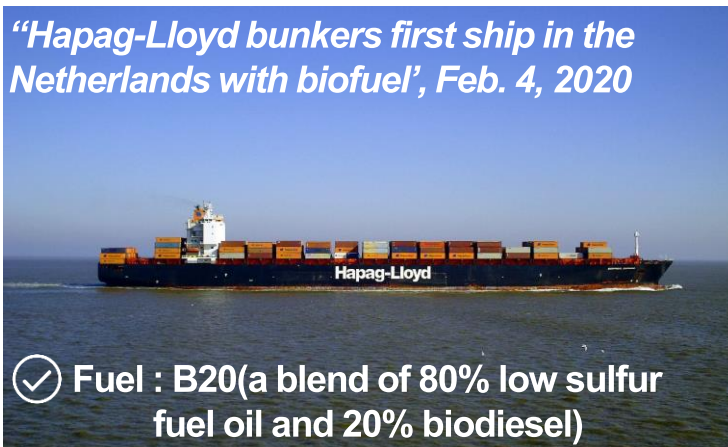
"Maersk Triple E class ship of 18,000 TEU sailed 25,000 nm from Rotterdam to Shanghai" Oct. 29, 2019



☑ Fuel : B20 test

☑ Hapag-Lloyd

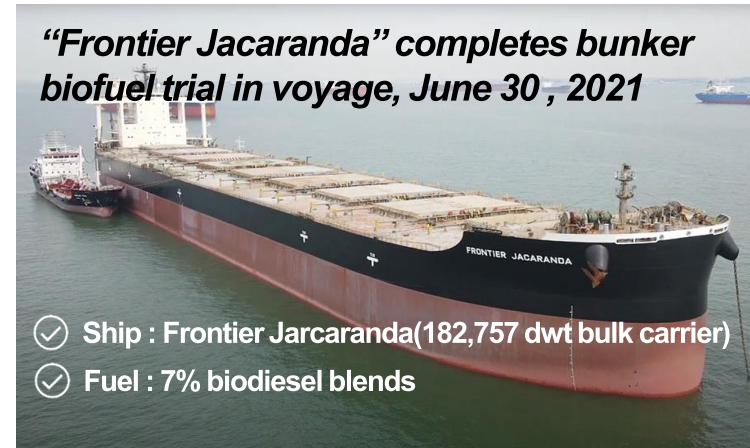
"Hapag-Lloyd bunkers first ship in the Netherlands with biofuel", Feb. 4, 2020



☑ Fuel : B20(a blend of 80% low sulfur fuel oil and 20% biodiesel)

☑ NYK Line

"Frontier Jacaranda" completes bunker biofuel trial in voyage, June 30, 2021



☑ Ship : Frontier Jacaranda(182,757 dwt bulk carrier)

☑ Fuel : 7% biodiesel blends

☑ Eagle bulk

"Eagle Bulk Shipping completes fossil-free voyage on marine biofuel", Dec. 8, 2021



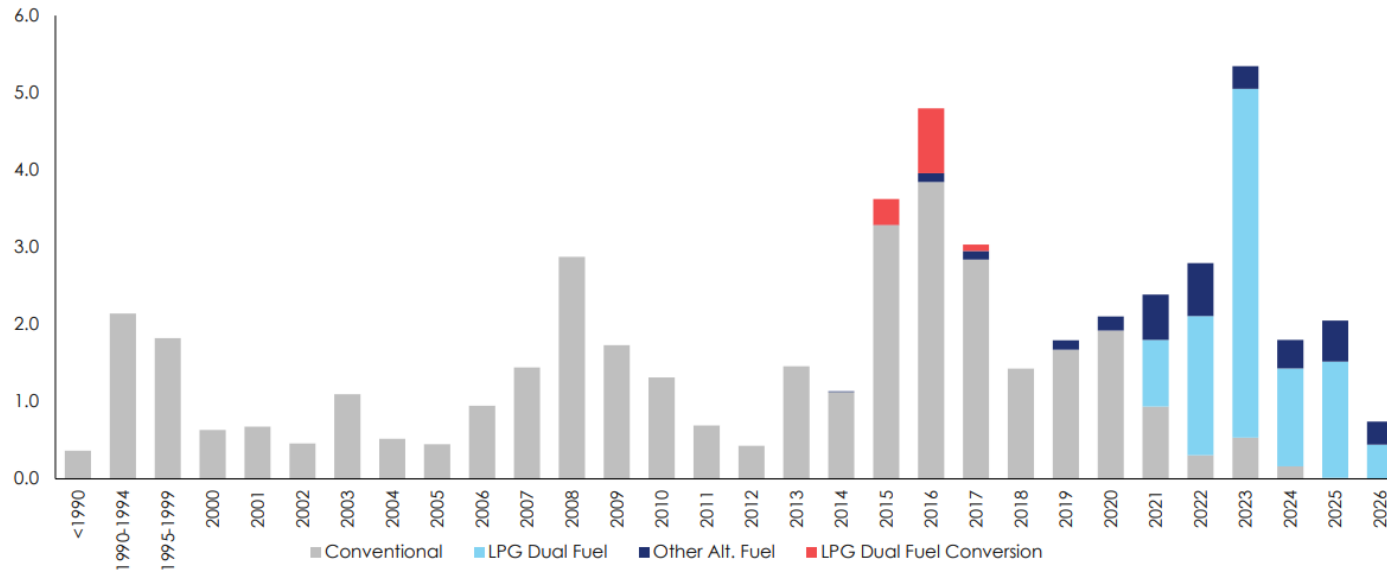
☑ Ship : Sydney Eagle(63,529 dwt bulk carrier)

☑ Fuel : Biodiesel blends

Photo: www.vesselfinder.com

LPG 추진선 현황(only to LPG carrier)

LPG Carrier Fleet Age Profile, Million cu.m.



Source: Clarksons Research, Fuelling Transition: Tracking the Economic Impact of Emission Reductions & Fuel Changes, Mar. 2023

LPG, VLS IFO

Engine Designe MAN B. & W.

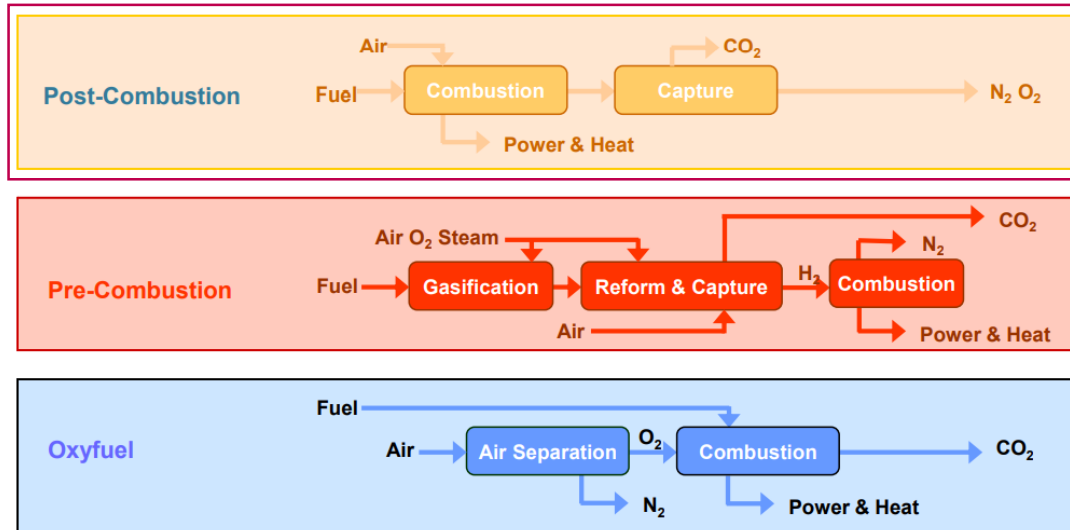
Contract	Built	Name	Type	mDWT	GT	Status	Technology	Model				
02/2023	2026	N/B Hyundai HI (Ulsan)	LPG	58,000		On Order	Diesel	6G40ME-C10.5-LGP				
03/2023	2026	N/B Hyundai HI (Ulsan)	LPG	60,000		On Order	Diesel	6G40ME-C10.5-LGP				
03/2023	2026	N/B Hyundai HI (Ulsan)	LPG	60,000		On Order	Diesel	6G40ME-C10.5-LGP				
02/2023	2026	N/B Hyundai HI (Ulsan)	LPG	58,000		On Order	Diesel	6G40ME-C10.5-LGP				
01/2023	2026	N/B Hyundai HI (Ulsan) Ulsan 3426	LPG	60,000		On Order	Diesel	6G40ME-C10.5-LGP				
02/2023	2026	N/B Hyundai Samha HI	LPG	58,000		On Order	Diesel	6G40ME-C10.5-LGP				
03/2023	2026	N/B Kawasaki HI Sakai	LPG	56,000		On Order	Diesel	750ME-C10.5-LGP				
01/2023	2026	N/B Kawasaki HI Sakai	LPG	56,000		On Order	Diesel	750ME-C10.5-LGP				
02/2023	2026	N/B Kawasaki HI Sakai	LPG	56,000		On Order	Diesel	750ME-C10.5-LGP				
09/2022	2025	N/B Hyundai HI (Ulsan) Ulsan 3404	LPG	60,000		On Order	Diesel	6G40ME-C10.5-LGP				
		Contract	Built	Name	Type	mDWT	GT	Status	Technology	Model	Refit	
01/2023	2025	N/B Hyundai	04/2014	2017	BW Mindoro	LPG	54,647	48,542	In Service	Diesel	6G40ME-C9.5-LGP	04/2022
12/2022	2025	N/B Hyundai	02/2014	2016	BW Bulder	LPG	54,446	47,384	In Service	Diesel	6G40ME-C9.5-LGP	05/2021
12/2022	2025	N/B Hyundai	02/2014	2016	BW Breeze	LPG	54,446	47,965	In Service	Diesel	6G40ME-C9.5-LGP	08/2021
11/2022	2025	N/B Hyundai	02/2014	2016	BW Freya	LPG	54,446	47,384	In Service	Diesel	6G40ME-C9.5-LGP	11/2021
12/2022	2025	N/B Hyundai	02/2014	2016	BW Fria	LPG	54,446	47,384	In Service	Diesel	6G40ME-C9.5-LGP	11/2021
03/2023	2025	N/B Hyundai	04/2014	2016	BW Maellan	LPG	54,647	48,542	In Service	Diesel	6G40ME-C9.5-LGP	03/2022
03/2023	2025	N/B Hyundai	04/2014	2016	BW Malacca	LPG	54,647	48,542	In Service	Diesel	6G40ME-C9.5-LGP	04/2022
03/2023	2025	N/B Hyundai	09/2014	2016	BW Nord	LPG	54,446	47,384	In Service	Diesel	6G40ME-C9.5-LGP	07/2021
08/2022	2025	N/B Hyundai	02/2014	2016	BW Tucana	LPG	54,561	47,342	In Service	Diesel	6G40ME-C9.5-LGP	10/2021
02/2023	2025	N/B Hyundai	09/2014	2016	BW Var	LPG	54,446	47,965	In Service	Diesel	6G40ME-C9.5-LGP	05/2021
02/2023	2025	N/B Hyundai	02/2014	2016	BW Volans	LPG	54,561	47,342	In Service	Diesel	6G40ME-C9.5-LGP	06/2021

Uptake currently limited to LPG carriers!

Vessel FACTS:
BW Gemini, 84,000 cbm VLGC, Owner BW LPG
Main Engine 6G60ME-C9.2 - 12,400 KW,
• built in 2015 to be fueled with HFO
• converted in 2020 to be fueled with LPG
• first LPG fueled vessel in the world
• 14 sister vessels will also be converted to LPG

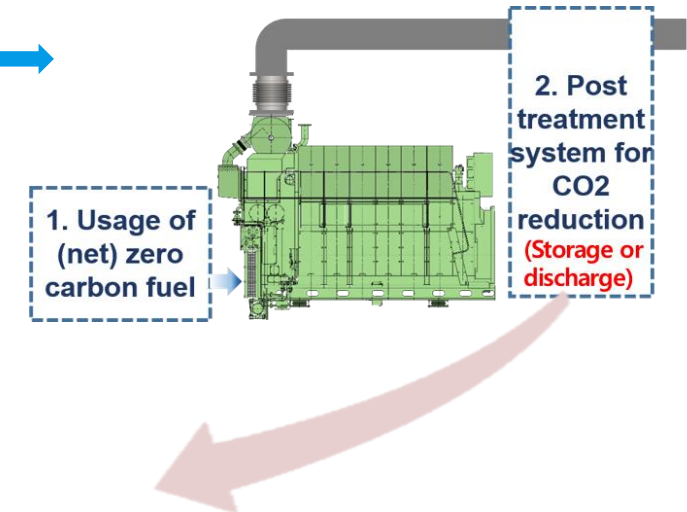
Compared to OIL - LPG provide significant emission reductions:
• SOx by 99%
• CO2 by 15%
• NOx by 10%
• PM by 90%

저탄소 연료 추진선 + 선박이산화탄소 포집시스템

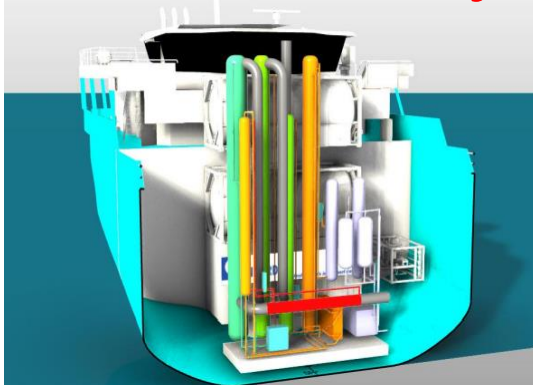


Source: TNO, CO₂ capture(on the SLEPNIR), 2020

* 선박용 내연기관에서 이산화탄소 저감방법

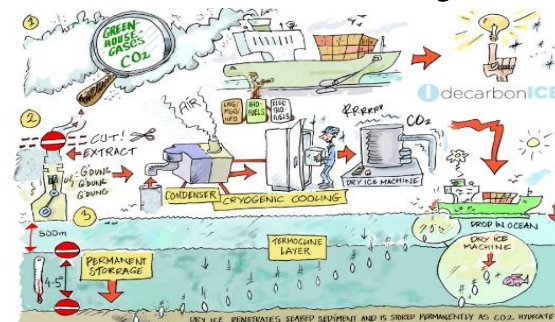


2.1 선박용 이산화탄소 포집장치(e.g.)



Source: www.conoship.com

2.2 포집 이산화탄소 바다 배출(e.g.)



Source: Jan Boyesen(MARLOG), How ship-based CCS supports the transition to future fuels?, Carbon Capture & Storage webinar week, Aug.18, 2021.

컨테이너선 OCCS 적용 실증 추진 (국내선사, 조선소, 기자재업체, 선급)



Source: KOREAIT Times, May 1, 2023



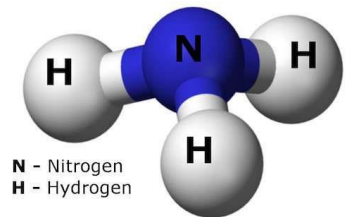
3

대체연료: 무탄소 연료

1. Ammonia
2. Hydrogen

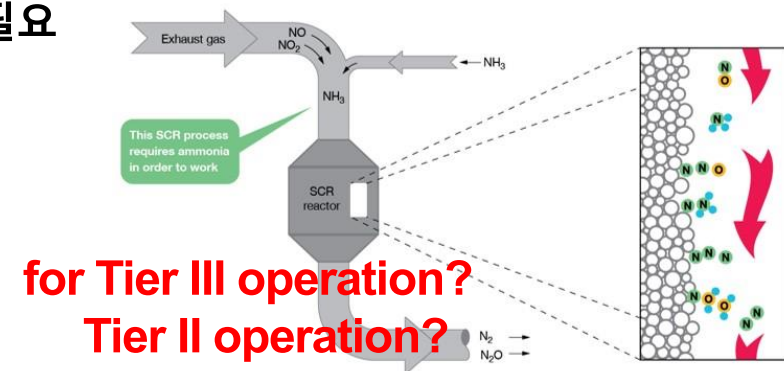
암모니아 특성

- ☑ 연료 내 탄소 불포함 → CO₂ 배출 없이 청정 연소 가능
- ☑ 액상 보관 가능(-33°C or 20°C, 8.5 bar) → LNG 대비 초극저온 설비 불필요
- ☑ 세계적으로 이미 대량 생산 및 운송 중(비료 활용 등)
- ☑ 수소 보다 가연한계가 좁아 안전함
- ☑ 일반 선박 연료보다 2-3배의 연료 탱크 필요 → 화물 손실
- ☑ 안전 문제(강 독성) 해결 및 재질 선정(강 부식성) 주의 필요
- ☑ 연료공급장치 및 배기가스 중 암모니아 대기 배출 최소화
- ☑ 과도한 질소산화물 배출 예상 (연료 내 질소, 높은 자기착화온도 등 기인)
→ 대용량의 질소산화물 저감장치 필수 적용 필요



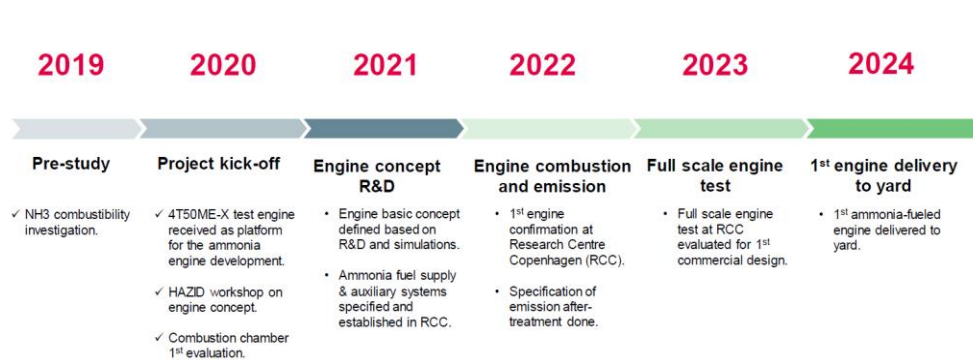
Energy storage type	Supply energy (MJ/kg)	Energy density (MJ/L)	Required tank volume (m ³)
HFO	40.5	35	1,000
Ammonia(liquid -33°C)	18.6	12.7	2,755
Hydrogen(liquid -253°C)	120	8.5	4,117

2	3	4	5	6	7	8	9
WtT			TW				
Pathway name	LCV [MJ/g]	CO _{2eq} WtT [gCO _{2eq} /MJ]	Energy Converter Class	C _f CO ₂ [gCO ₂ /gFuel]	C _f CH ₄ [gCH ₄ /gFuel]	C _f N ₂ O [gN ₂ O/gFuel]	C _{slip} As % of the mass of the fuel used by the engine
NH ₃ (natural gas)	0,0186	121	No engine	0	0	TBM	-
e-NH ₃	0,0186	0	No engine	0	N/A	TBM	N/A

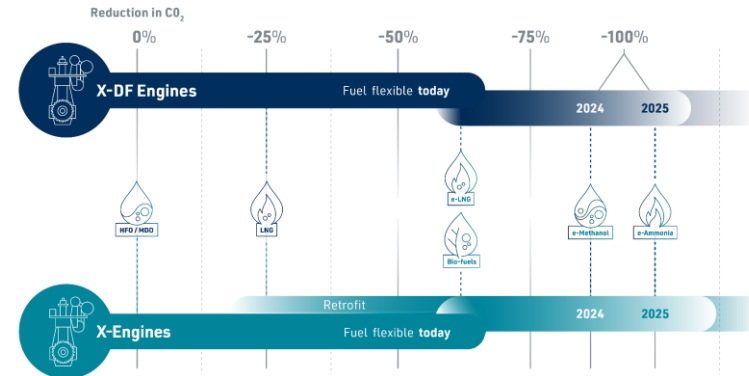


암모니아 엔진 개발 현황

☑ 해외 원천기술사 중심, 암모니아 연료 주 추진(저속 2행정) 엔진 개발 계획



Source: Peter H. Kirkeby, MAN ES engines for alternative fuels, Motorship PFF conference, Nov. 2021

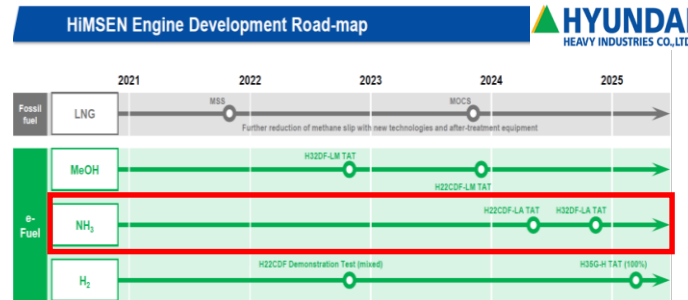


Source: www.wingd.com

☑ 국내외 암모니아 연료 발전기(중속 4행정) 엔진 개발 계획



Supported by:
Federal Ministry for Economic Affairs and Energy
on the basis of a decision by the German Bundestag
MAN Energy Solutions



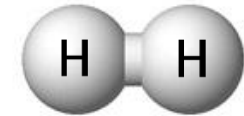
NH₃ DF Engine Development & On-board Verification (~2024)

* AmmoniaMot project
(~Dec. 2023)

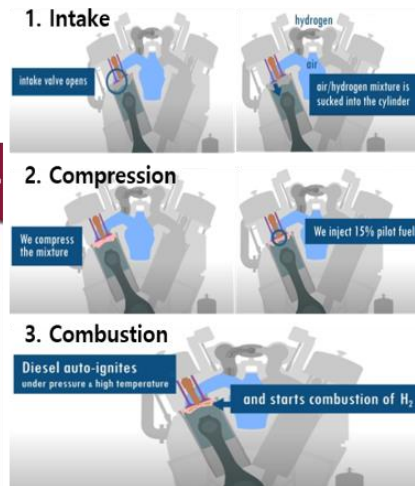
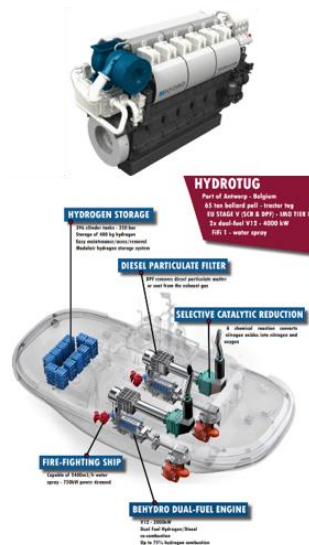
* Indicative: 2020
concept readiness: 2023

수소 특성 및 추진시스템

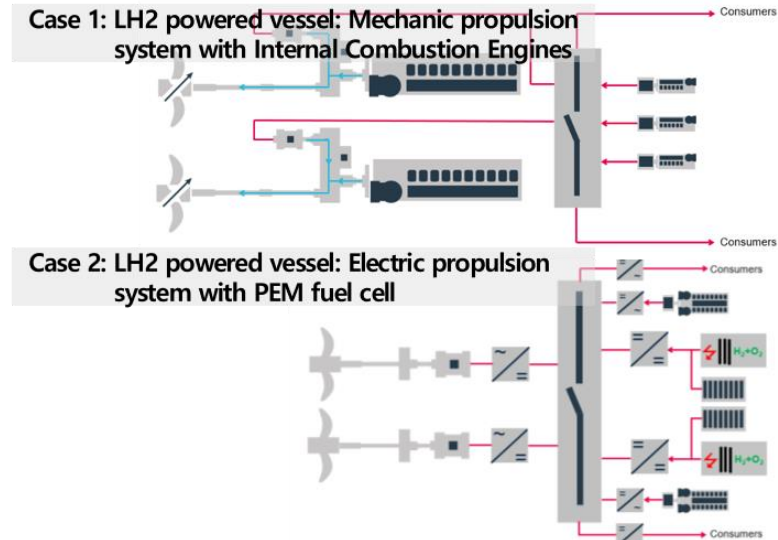
- ☑ 무색, 무취의 비독성 가스
- ☑ 수소의 끓는점이 매우 낮음(-253 °C)
→ 액상으로 저장 및 운송하기 위한 초 극저온 설비 설치 필요
- ☑ 넓은 가연한계 및 빠른 연소 속도
→ 고 난이도의 연소 제어 기술 필요
- ☑ 수소 연료 사용을 위한 벙커링 인프라 부재



Fuel type	Supply energy (MJ/kg)	Energy density (MJ/L)	Required tank volume (m³)
HFO	40.5	35	1,000
Ammonia(liquid, -33 °C)	18.6	12.7	2,755
Hydrogen(liquid, -253 °C)	120	8.5	4,117



Source: www.behydro.be, Mar. 2022



Source: Alexander Feindt, H2 in shipping-Fuel, technologies and ferry use case, Motorship PFF conference, Nov. 2021



5

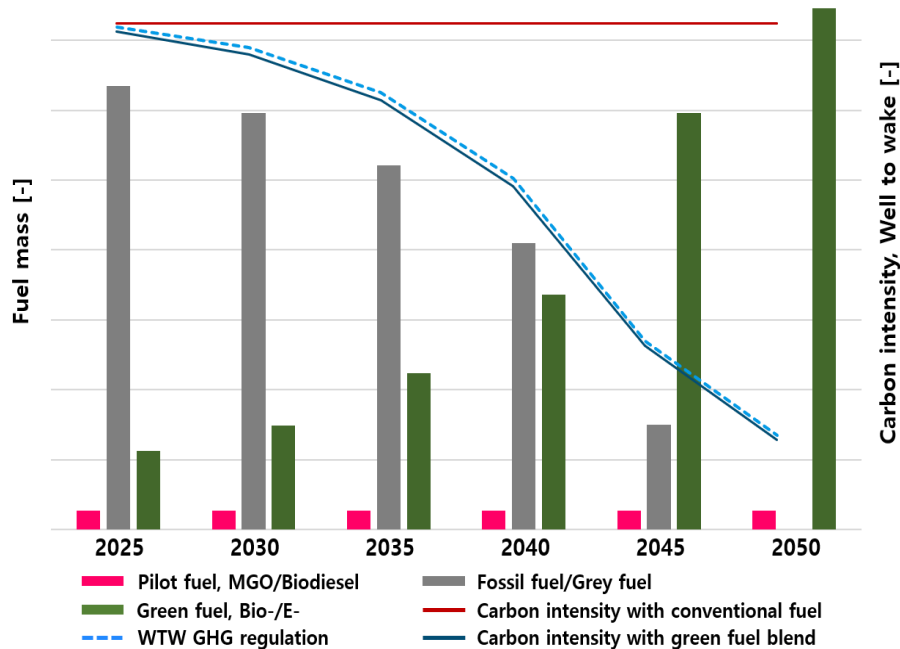
요약

5. Summary (Toward Carbon Neutral Shipping)

☑ 단일연료 추진선

- 감속 운항, 정시 도착, 운항 최적화,
- 2세대 이상의 바이오디젤 또는 E-diesel 등의 혼합률 증가
- 에너지 절감장치 장착, Onboard-CCS 적용 검토(입자상물질 제거 전처리 장치 필요)
- 이중연료(대체연료) 추진선으로 대체

☑ 대체연료 추진선(보유 또는 발주 예정)



Source: : Modified from 'Fuel mix and carbon intensity over time', Claes Tretow, Methanol DF operation – an owners experience, Motorship PFF conference, Nov. 2022

Option: LNG & Methanol

- (LNG 연료 限) 메탄슬립 규제 대응 기술 적용 고려
- (Fossil based low carbon fuel 사용 限) CO₂ 저감 한계 고려, OCCS의 적용 고려
- (drop-in fuel 적용) 그린 연료(E-/Bio-) 공급자(또는 파트너) 확보 후, 혼합률 증가 또는 대체 필요
- (무탄소 연료 사용 의무 限) 암모니아 등의 무탄소 연료 추진선으로 대체

Option: Ammonia

- 그린 암모니아(E-) 국내외 공급자 확보 필요
- 암모니아 엔진 규정 및 개발 동향 주시 필요
- 선원 대상, 암모니아 사용에 관한 사전 안전교육 필요

해운의 탈탄소화 ↔ 육상 파급 효과

- 그린 연료 생산
- 그린 연료의 벙커링

Port of Melbourne to establish green methanol bunkering hub

April 26, 2023

By Rakin Rahman



Port of Gothenburg aims to become bunkering hub for renewable methanol

PORTS & LOGISTICS

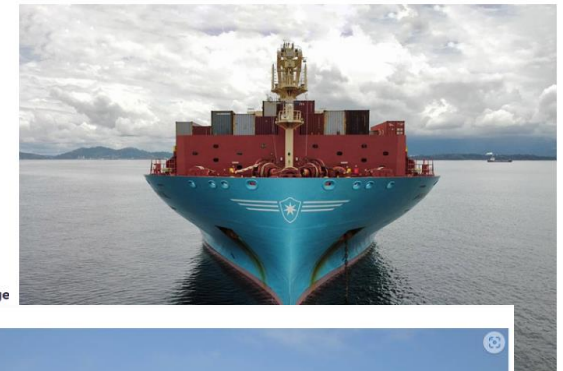
April 26, 2022, by Naida Hakirevic Previjak

Swedish Gothenburg Port Authority has published [general methanol operating regulations](#) for ship-to-ship bunkering and is making arrange to set up a value chain with the ambition to become the pri hub for renewable methanol in Northern Europe.



Green methanol bunkering project to trial in Singapore in 2023

October 5, 2022



LNG Bellina carried out the first LNG bunkering of an LNG-powered PCTC at the Port of Singapore in March (source: MOL)

Port of Singapore gears up for multi-fuel future of 2030

17 Mar 2023 by John Snyder



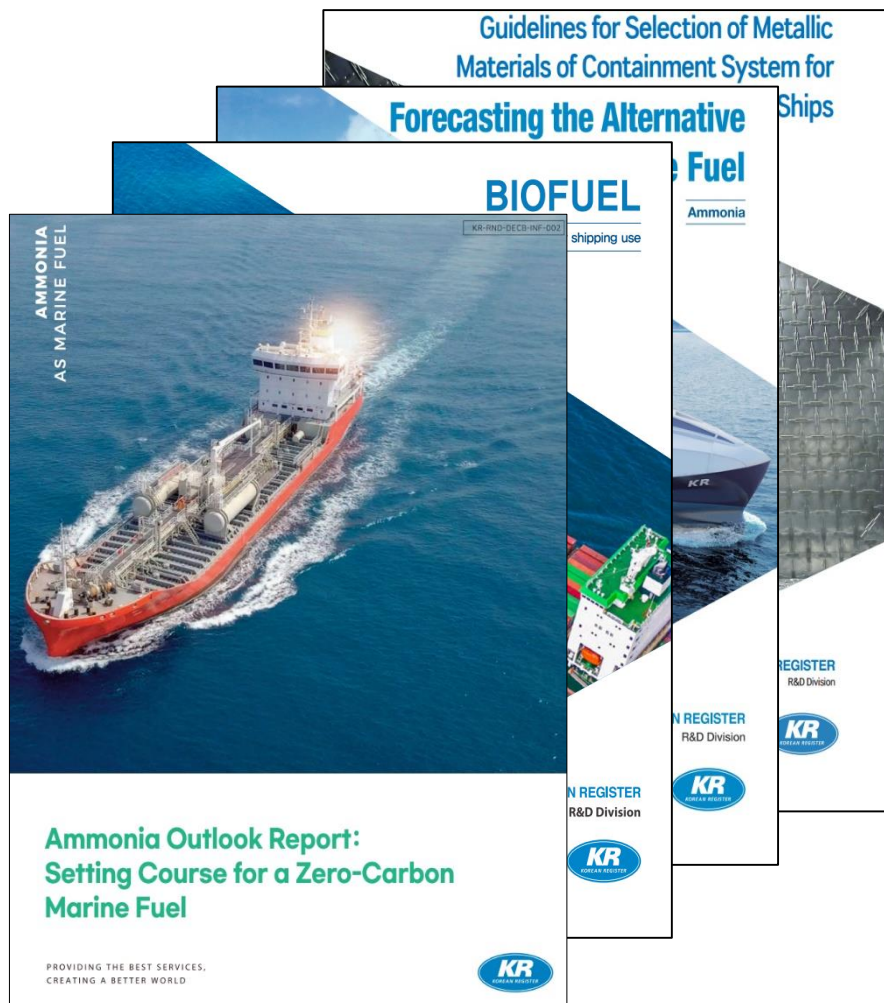
Maersk said the MoU with SING could evolve from vessel-to-vessel bunkering into a more holistic methanol supply chain (source: Maersk)

Maersk inks green methanol fuel MoU with Shanghai port

28 Mar 2023 by Jamey Bergman

Memorandum of understanding (MoU) will see the two parties work to implement ship-to-ship methanol bunkering operations

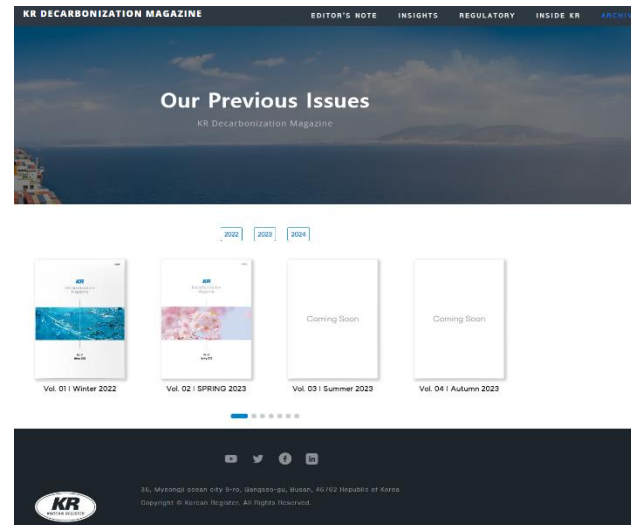




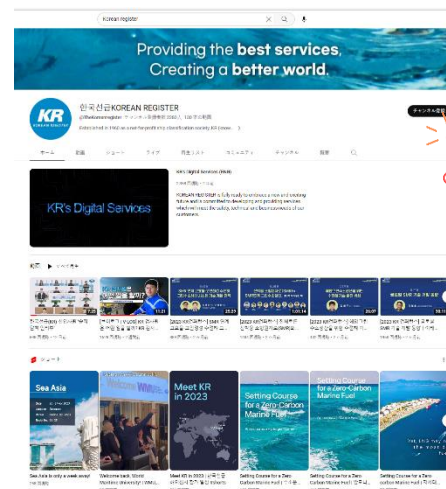
Technical document to be published

- Methanol Outlook Report (Sept. 2023)
- KR decarbonization guide (Oct. 2023)

⋮



<https://kr-decarbonization.co.kr>



<https://www.youtube.com/@TheKoreanregister>



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