NANYANG TECHNOLOGICAL UNIVERSITY SINGAPORE

An Overview of Alternative Sources of Maritime Energy

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About the report…..

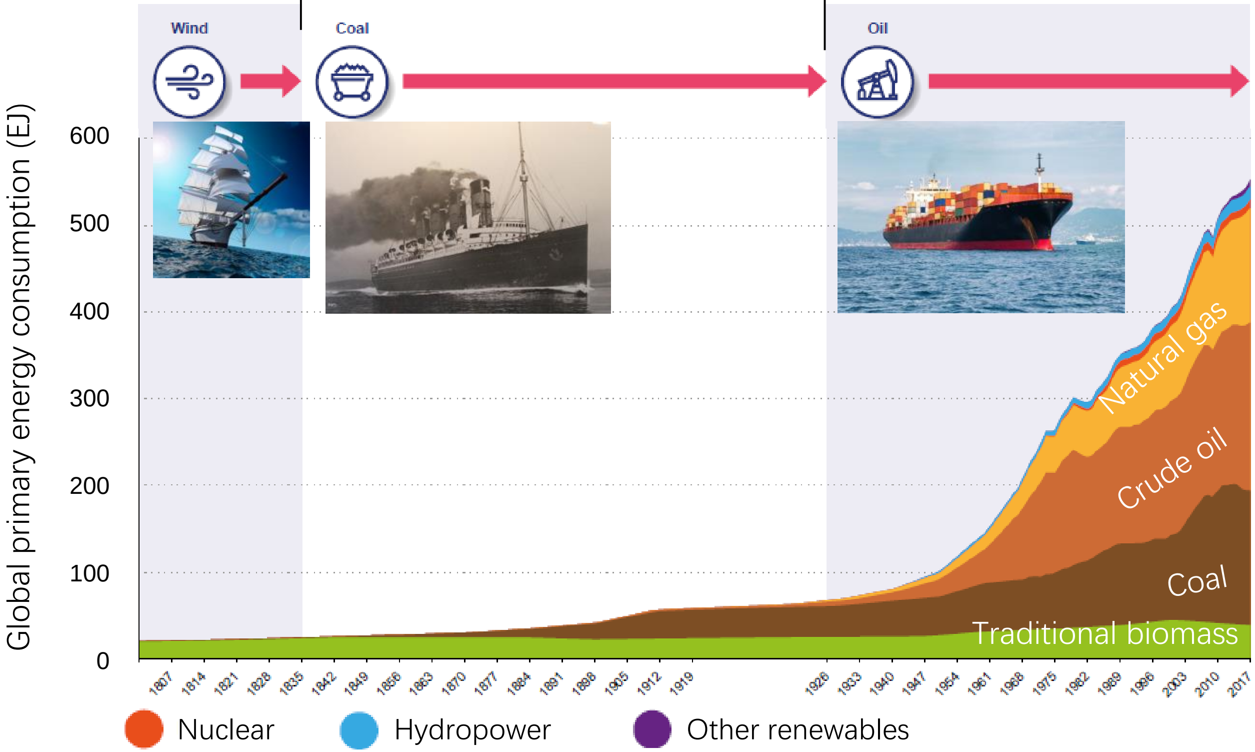
- Global Energy Transition and Shipping Sector
- Potential Alternative Fuels for Shipping Industry
- Characteristics of Alternative Fuels – Comparisons
- GHG Emissions by Alternative Fuels
- Cost of Technologies and Alternative Fuels
- Potential Pathway of Alternative Fuel Adoption – 2030 and 2050
- Adequacy of Alternative Fuel for Shipping Sector in 2050
- Will Alternative Fuels be Ready for Shipping Sector to Meet GHG Target in 2050?

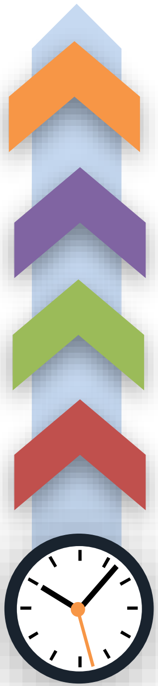
Energy transition.. from the past to present

Energy source for shipping sector:

"Sail" to "steam power" after huge success in rail transport

"Steam propulsion" to "internal combustion engine" due to operational simplicity, robustness and fuel economy of diesel engines





Full-energy transition

Reduction in cost

Prototyping by end-user

Emergence of new technologies

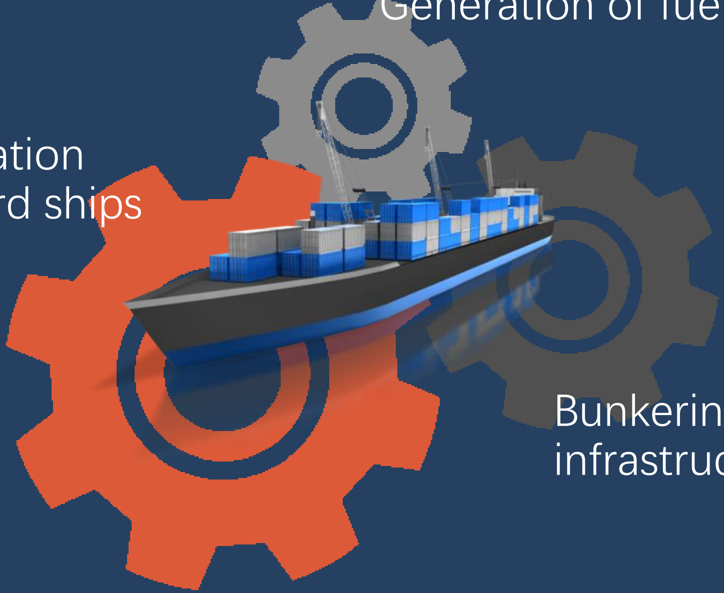
What are the RIGHT choices for the future?

Global trend

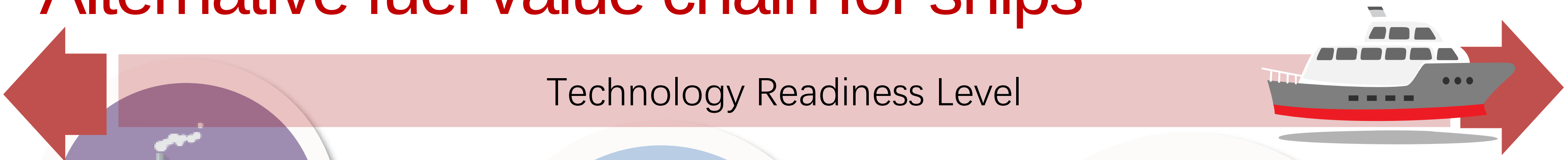
Generation of fuels

Application onboard ships

Bunkering infrastructure



Alternative fuel value chain for ships

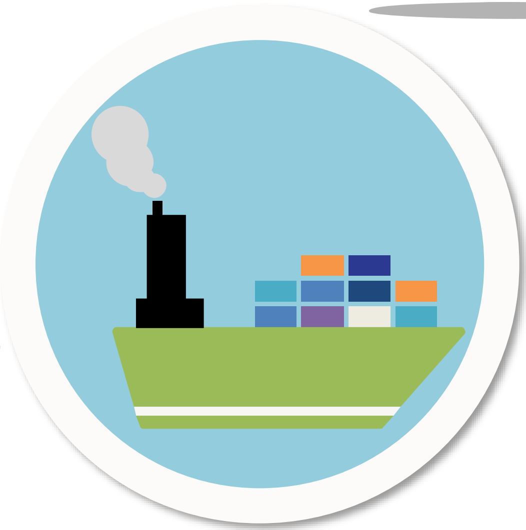


Generation of fuels

Feedstock & production technologies, current supply and demand, competing use by other sector, surplus for shipping sector

Transportation

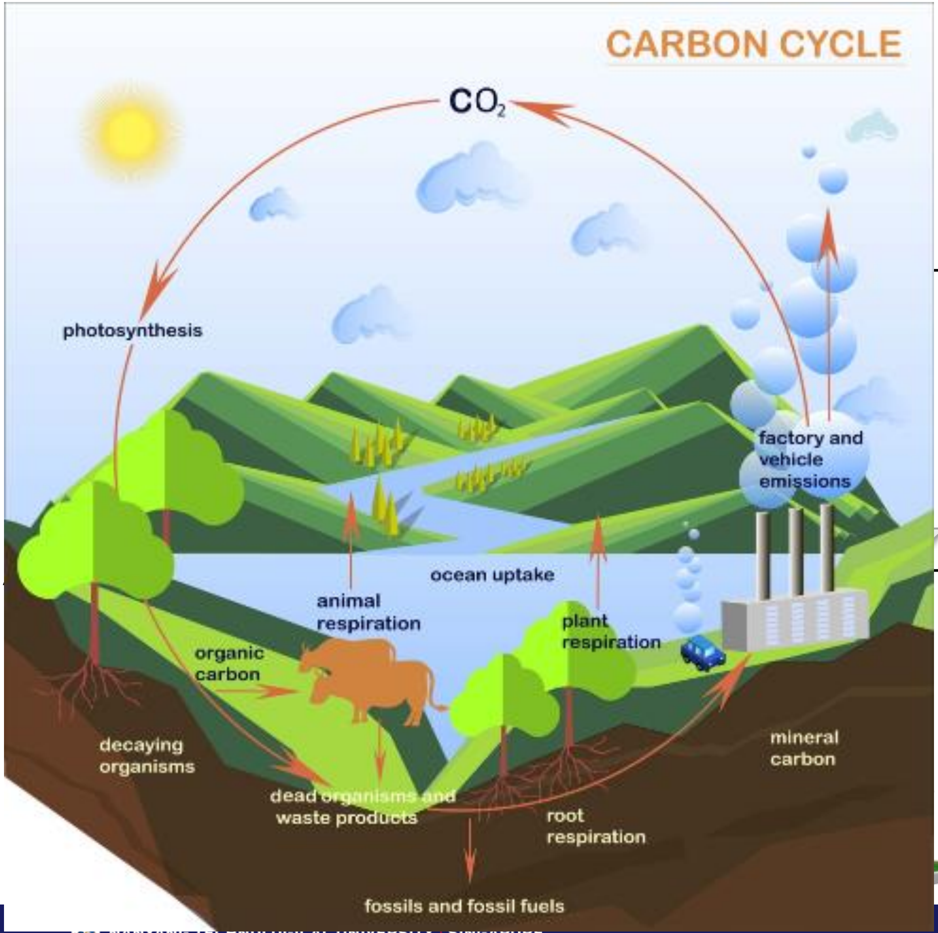
Properties of fuels, form of the fuel to be transported, bunkering infrastructure requirement and safety



Onboard application

Energy converts, fuel storage, ease of operation, technical and safety issues, manpower, cost and emissions (onboard and LCA)

Many types of alternative fuels… How can we categorise them?



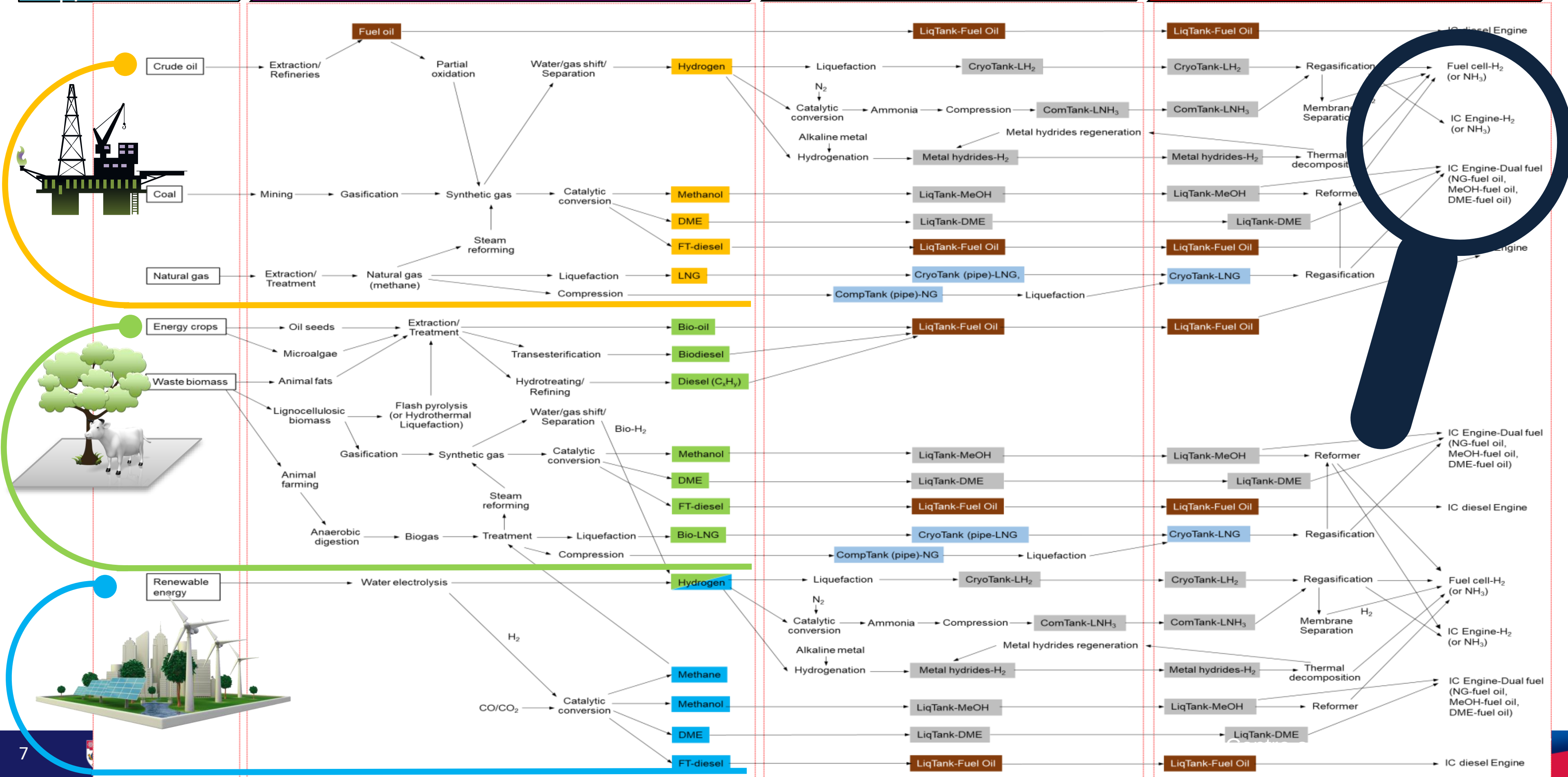
Fossil-based alternative fuels — Containing less carbons

Biomass-based alternative fuels — Containing biogenic carbons

Renewable (non-bio) energy — Such as electricity and hydrogen from wind and solar energy

Value chain, technologies involved and technology readiness

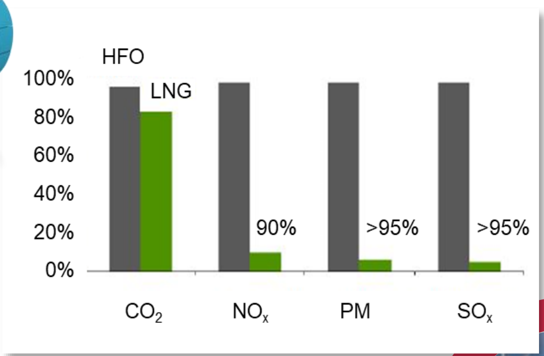
Primary source | Production | Transportation | Application onboard



LNG and bio-LNG

Dual-fuel engine, fuel gas supply system and storage on board vessels (TRL 9)

Natural gas reserves ~180 trillion m^3 (R/P ratio 60-80 year)



Requirement of a global network of infrastructure for its application worldwide

LNG

Bio-LNG

Produced from organic waste and wastewater via landfill degradation or anaerobic digestion

Able to leverage on LNG infrastructure

Used as a drop-in fuel with LNG

Presence as bioenergy providing further emission reduction

Potential for bio-methane production worldwide ~1,000 million m^3

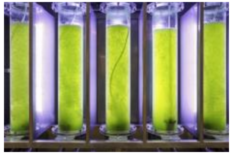
Requirement of sufficient production of bio-methane and value chain development to support its application



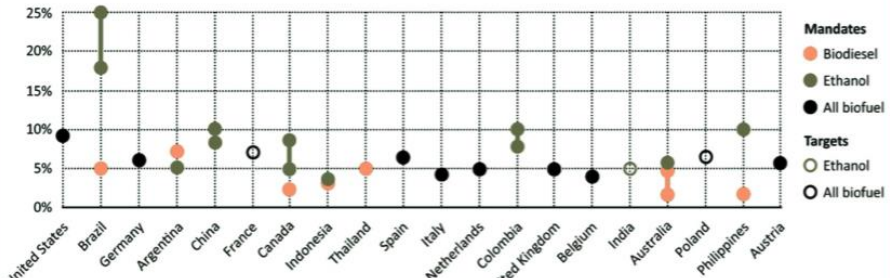

Biodiesel






Biodiesel blend as drop-in fuel



Source: Souza and others, 2015

Blending mandates and targets for biodiesel for automotive use

It is compatible with marine distillate and applicable with existing ships/ existing bunkering infrastructure (TRL 9).

Able to support industry only partially due to its insufficient supply. The utilisation of biodiesel blends can be considered.

Country/ region	Blend target	Year
World	1%	2016
USA	5%	2018
EU	3%-4%	2020
Australia	50%	2050
Germany	10%	2025
Netherlands	1%	2015
Israel	20%	2025
Indonesia	2%	2016
Nordic countries	3%-4%	2020

Source: Yilmaz and Atmanli (2017)

Blending targets for biofuels for aviation

Requirement of fuel specification standardisation (properties of biodiesel produced from different sources are different).

Methanol and bio-methanol

CO_2
from power plant

Requirement of dual-fuel engine or engine modification/ bunkering infrastructure (TRL 9).

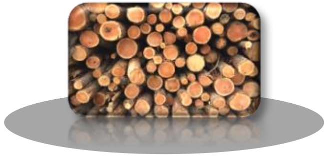
Presence as current commodity / existing distribution infrastructure

Landfill gas
(bio-methane)

Overall environmental performance on emission reduction

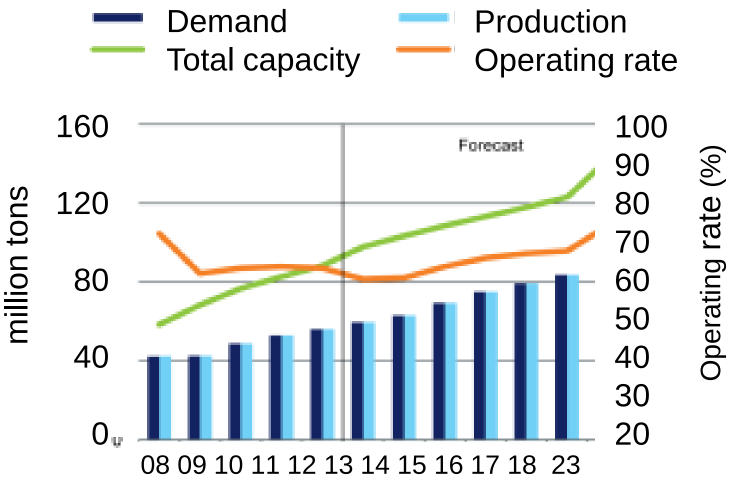
Able to support industry partially (~7-8% of energy demand).

Low energy density (15.8 MJ/L)



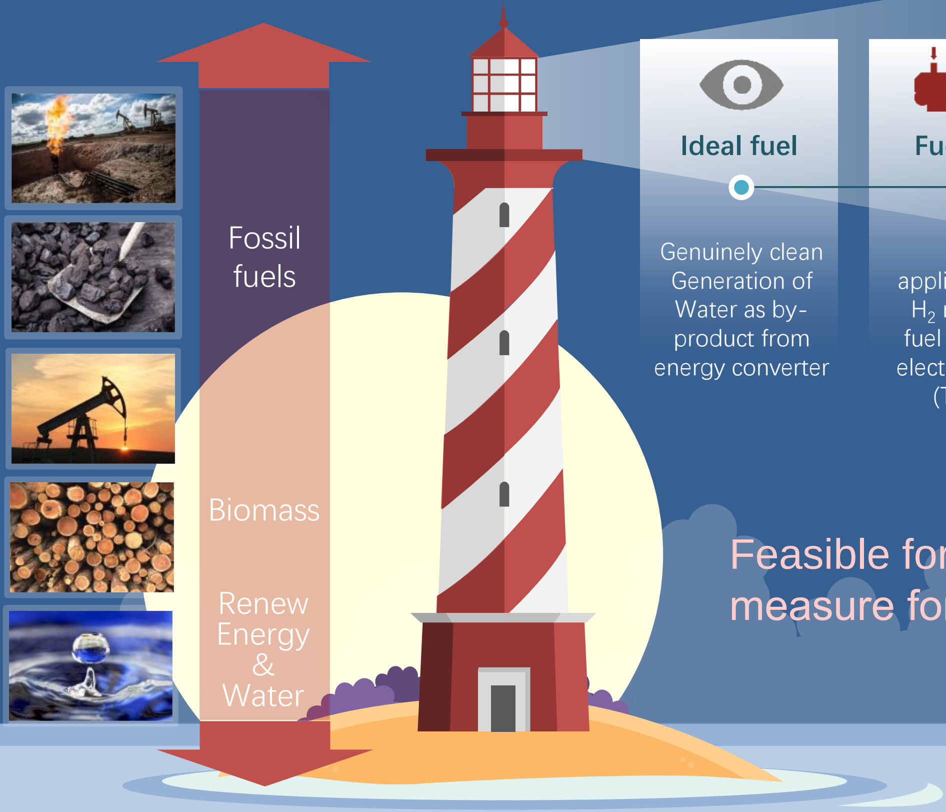
Biomass
Wooden biomass, energy crops

Fossil fuels
Oil, natural gas and coal



Source: Adopted from IGP Energy (2014),Methanol data.

How about “hydrogen”?



Ideal fuel
Genuinely clean Generation of Water as by-product from energy converter

Fuel Cell
The application of H_2 requires fuel cell with electric motor (TRL6).

H_2 Carrier
H_2 can be stored in several forms. (still low energy density compared to other fuels)

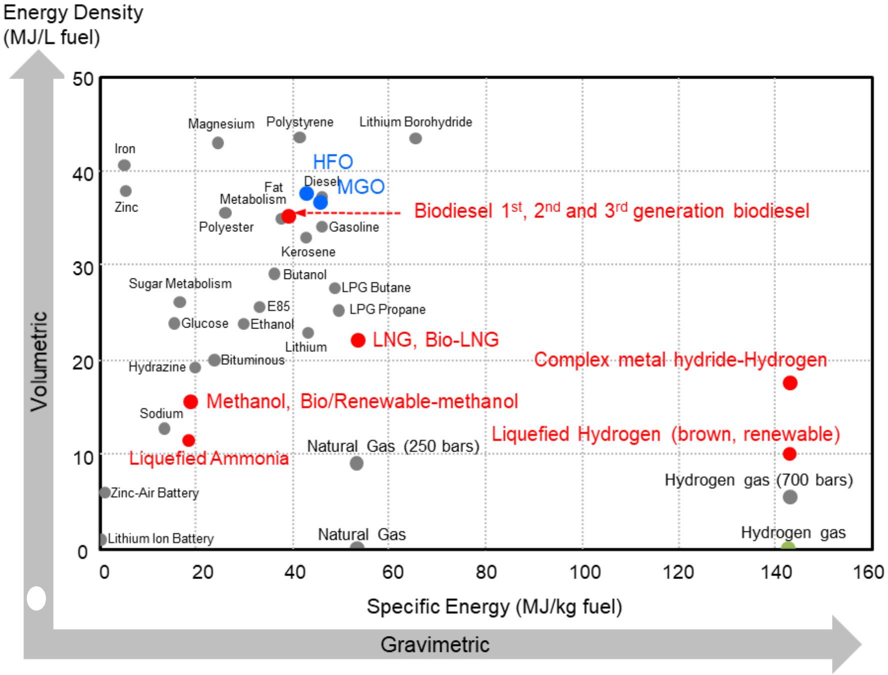
Safety
Lightest and smallest element
Wide flammability range
Invisible flame during the daylight hours

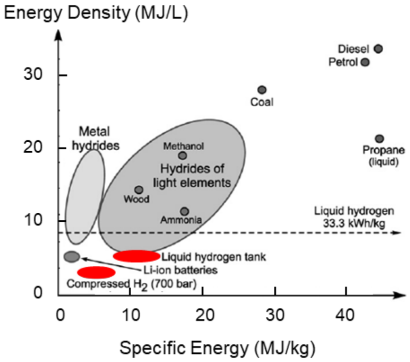
Worldwide
Establishment of H_2 production
Establishment of the value chain and a global network of infrastructure for its application worldwide

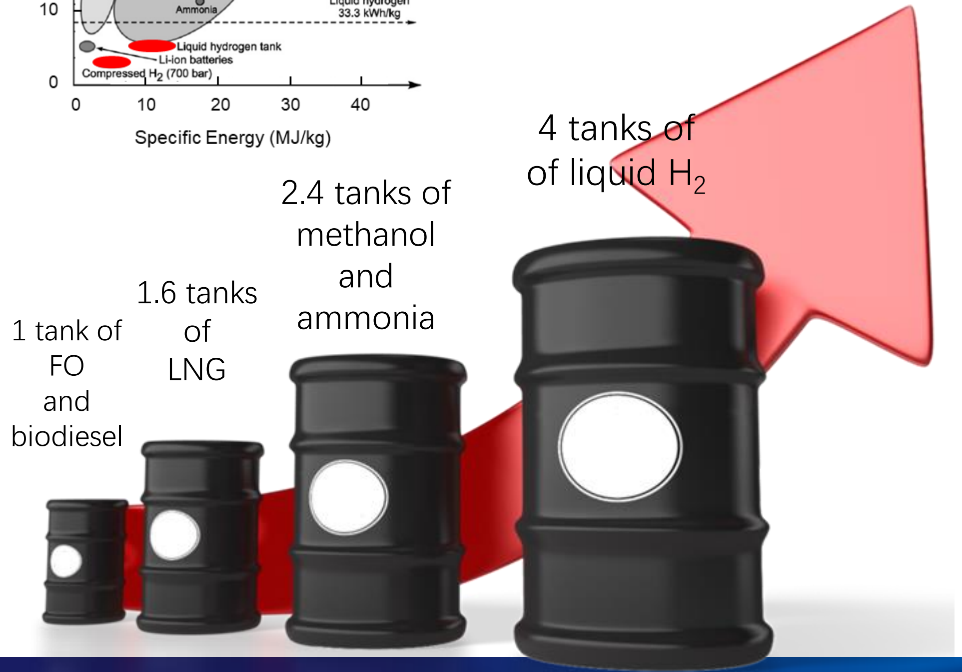
Feasible for the whole industry to adopt as a major measure for “zero emission”.

Energy content… any changes to the current practice?

Energy content -> Tank Size, Range

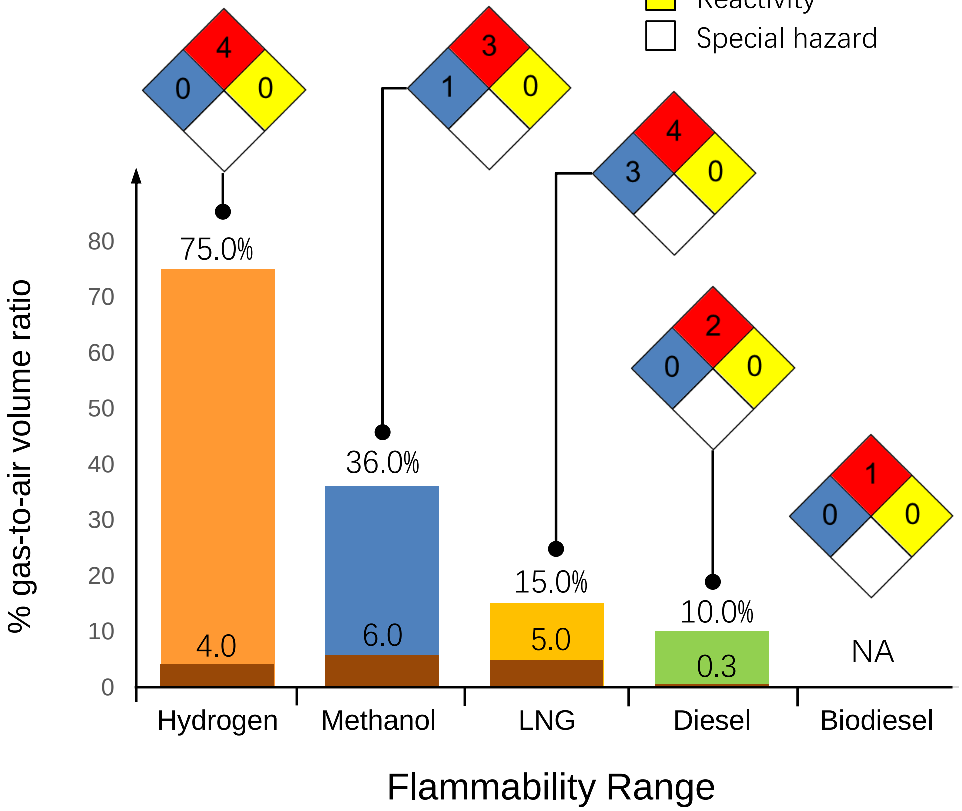


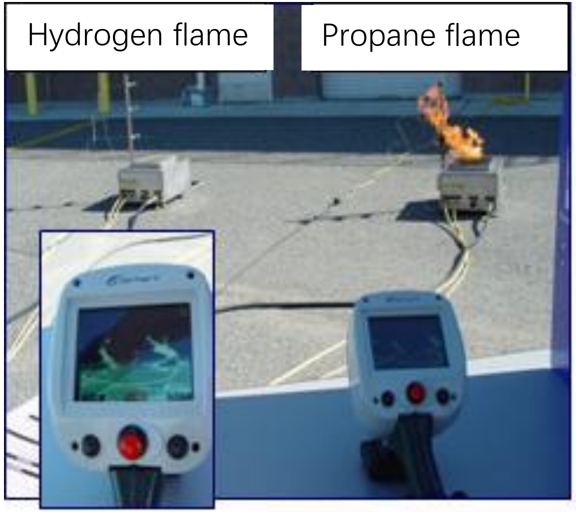




Safety…

Fire hazard (flashpoint)
Health hazard
Reactivity
Special hazard



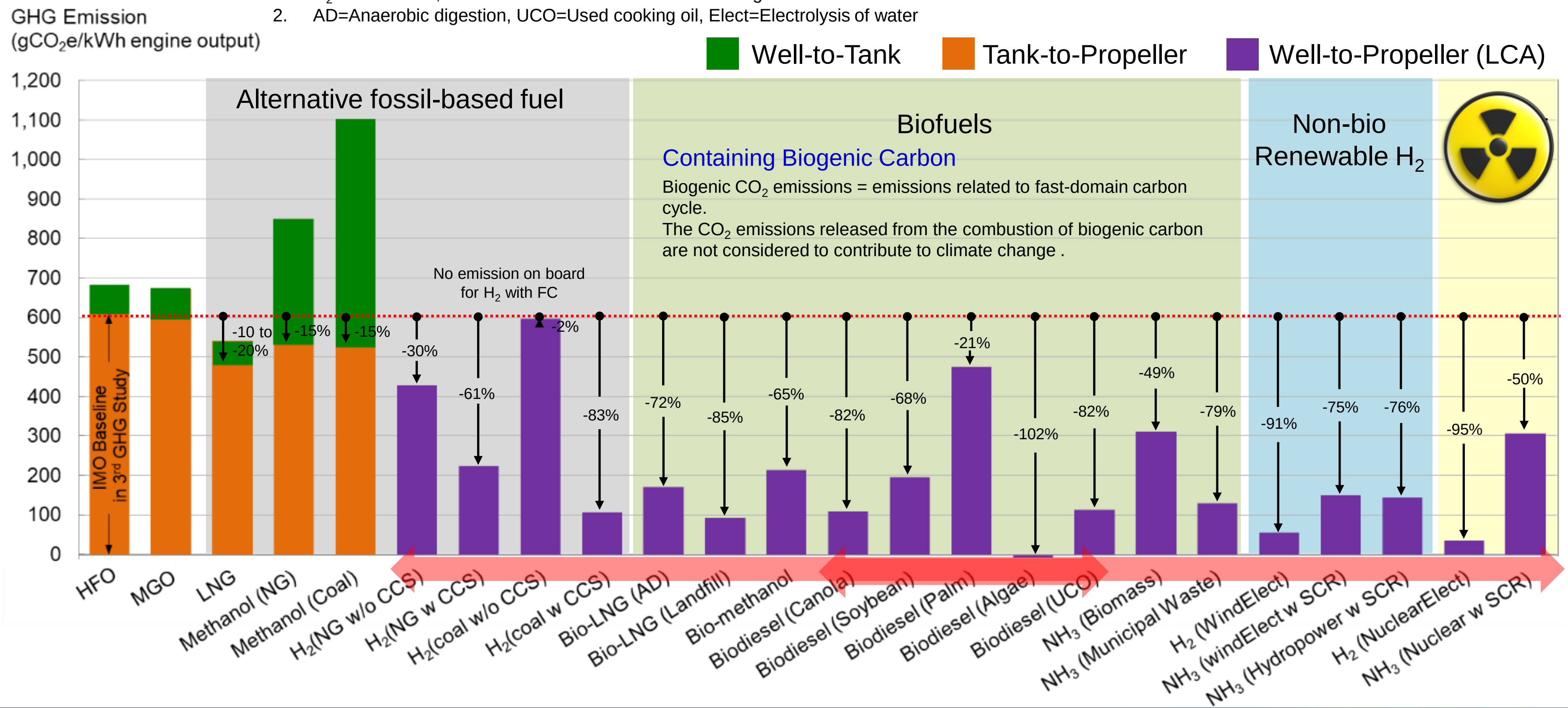


Hydrogen and Propane Flames in Daylight

Source: Hydrogen Tool (2017), Hydrogen Compared with Other Fuels, https://h2tools.org/bestpractices/hydrogen-compared-other-fuels, accessed in July 2018.

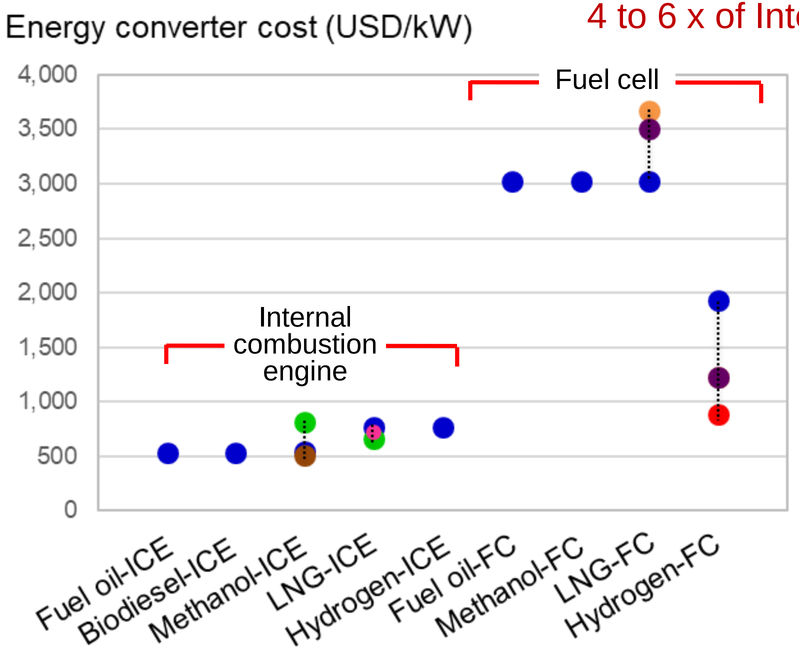
GHG Emission….

Note:
1. H_2 with fuel cell, other fuels with internal combustion engines
2. AD=Anaerobic digestion, UCO=Used cooking oil, Elect=Electrolysis of water

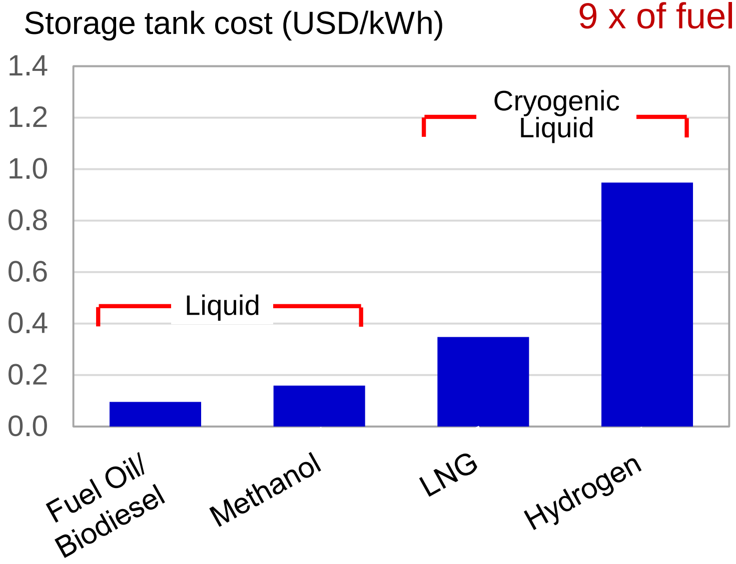


Cost of energy converter and shipboard storage

4 to 6 x of Internal Combustion Engine



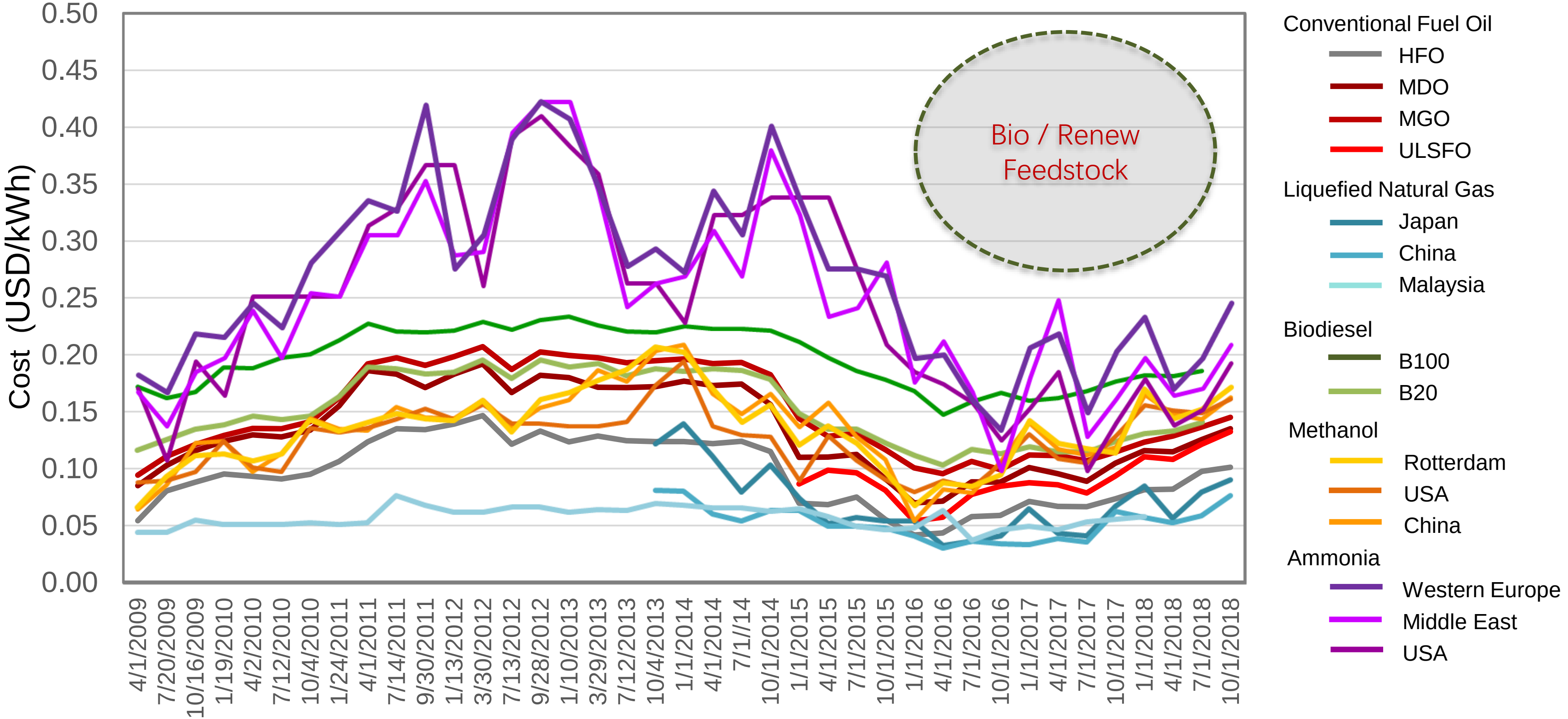
9 x of fuel oil



(Source: ● Horvath, *et al.*, 2018; ● Dolan and Andersson, 2016; ● Ellis and Tanneberger, 2015; ● Wärtsilä, 2018; ● Wei, *et al.*, 2017; ● Schoots, *et al.*, 2010)

Cost of fuels

Fuel cost (USD/kWh) = Cost of fuel (USD/tonne) x SFOC (g/kWh)



Source: Historical price of fuels obtained from www.afdc.energy.gov/data/, and Methanex Monthly Average Regional Posted Contract Price History

Potential scenarios

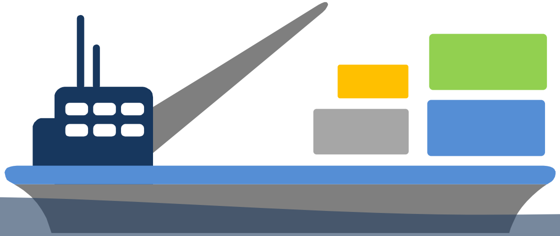
- Conventional fuels
- LNG
- Hydrogen (renewable)
- Biofuels (biodiesel, bio-LNG, bio-methanol)

Note: Based on RCP 2.6 SSP 4 (~1,500 million tonnes in 2050), T&O (reduction of ~200 million tonnes), 2050's target:<450 million tonnes

SCENARIO 1
No specific dominance:
The moderate evolution of technologies

In 2030: Conventional fuels (LSFO and distillates) and LNG (fossil)
In 2050: Conventional fuels (LSFO and distillates), LNG (fossil-based), biodiesel and H_2

The adoption of alternative fuels will result in 543 million tonnes CO_2 emission in 2050.



SCENARIO 2 Biofuel dominance:
Strong evolution of biofuel technologies

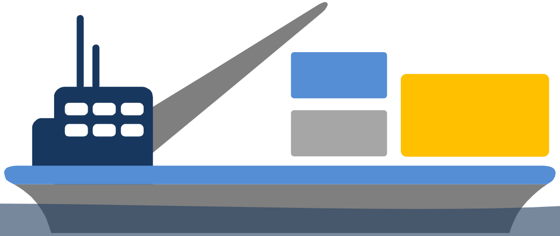
In 2030: Conventional fuels (LSFO and distillates), LNG (fossil and bio (70%:30%) and biodiesel
In 2050: Conventional fuels (LSFO and distillates), LNG (fossil and bio (50%:50%) and biodiesel

The adoption of alternative fuels will result in 503 million tonnes CO_2 emission in 2050.

SCENARIO 3 Hydrogen dominance:
Strong evolution of hydrogen technologies

In 2030: Conventional fuels (LSFO and distillates) and LNG (fossil)
In 2050: Conventional fuels (LSFO and distillates), LNG (fossil) and hydrogen

The adoption of alternative fuels will result in 390 million tonnes CO_2 emission in 2050.



Sufficient supply in 2050?

Yes — Yes, if a significant expansion of production capacity is realised. — Yes, but require R&D. — No — *million tonnes

TYPE		Conventional	Fossil-based		Biomass-based				Non-bio renewable
		LSFO/MGO	LNG	Methanol	Bio-LNG	Bio-methanol	Biodiesel 1st & 2nd gen	Biodiesel 3rd gen	Renewable Hydrogen
Production/ Technical potential globally for all industries (million tonnes/year)		4,671	3,195	Refer to Crude oil and natural gas	900	>900	Vegetable oil ~180 million tonnes, mainly for food (<20% for biodiesel production).	Technical potential ~ 3,780 million tonnes of biodiesel	Able to produce >1,260 million tonnes H_2)
Pathway 1	Demand*	57	92	-	-	-	162		11
	Adequacy	Meeting 50.6 years of global demand	Meeting 52.6 years of global demand	-	-	-	Not sufficient based on vegetable oil production	~5% of technical potential	~1% of technical potential
Pathway 2	Demand*	55	68	-	68	-	147		-
	Adequacy	Same as Pathway 1	Same as Pathway 1	-	~1% of technical potential	-	Not sufficient based on vegetable oil production	<5% of technical potential	-
Pathway 3	Demand*	55	42	-	-	-	-	-	80
	Adequacy	Same as Pathway 1	Same as Pathway 1	-	-	-	-	-	<7% of technical potential

For international shipping……

Now

Fuel oil
LNG

LNG (fossil):
Dominant alternative fuels due to its adequacy (supply) to support entire shipping industry, but unable to meet 2050's GHG target

Biodiesel (1st and 2nd gen):
Able to support partially due to its supply, drop-in fuel with diesel

Methanol (fossil):
Mainly used as a clean fuel and on-board GHG emission reduction

2030

Bio-LNG:
Able to use as a drop-in fuel with LNG facilitating the industry to meet 2050's GHG target

Biodiesel (3rd gen):
There is a need for R&D for 3rd gen biodiesel towards sustainability

Bio-methanol:
Onboard and LCA emission reduction

2050…

Hydrogen and its carriers:
Ideal towards sustainability, Due to the technology maturity, there is a requirement in R&D in its carrier and fuel cell for marine application and establishment of renewable hydrogen supply chain and bunkering infrastructure. Timeline depends on the selection of hydrogen carrier.

Special thanks to…..

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