NANYANG TECHNOLOGICAL UNIVERSITY SINGAPORE

Methanol as a Marine Fuel – Availability and Pre-trial Considerations

Presented by **Dr Liu Ming**

Research Lead

Maritime Energy & Sustainable Development Centre of Excellence

11 Nov 2020

Introduction

Introduction

Objective

- Study the potential of renewable methanol as a future marine fuel.
- Understand the pre-requisite of methanol fuelled application for sea trial.

Methodology

- High level analysis from methanol production to its application.
- Relates energy and mass flow of renewable feedstock to methanol production.
- Review of existing technologies and guidelines.
- Case studies and profiling to project the potentials with local marine community.

Methanol Fuel in General

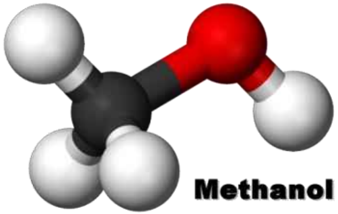
Properties and Emission

Comparison of fuel emission factors between methanol and other fuels

Fuel	Energy Convertor TRL[1]	Calorific Value[2]	SFOC	Operational Fuel Emission Factor (g/kWh)					
		MJ/kg	g/kWh	CO_2	CH_4	N_2O	SO_x	NO_x	PM
LSHFO	9	40.5	179	541	0.01	0.027	3.23	15.8	0.72
MDO	9	42.6	170	524	0.01	0.026	0.32	14.8	0.16
LNG	9	48.6	150	412	3	0.016	0.003	1.17	0.027
LH2	3 ~ 4	120	57	0	0	0	0	0	0
Methanol	8 ~ 9	20	381	522	0	0	0	3.05	0
Ammonia	6	18.9	381[3]	0	0	N.A.	0	N.A.	0
SVO soy	7~8	37.5	195		0.0064	0.013	0.37	17.1	0.19
Biodiesel soy	9	37.8	187		0.0061	0.013	0.36	17.9	0.18
HVO	9	44.1[3]	164[4]						

[1] Technology Readiness Level; [2] Lower heating value; [3] Calculated value [4] Calculated from lower heating value.

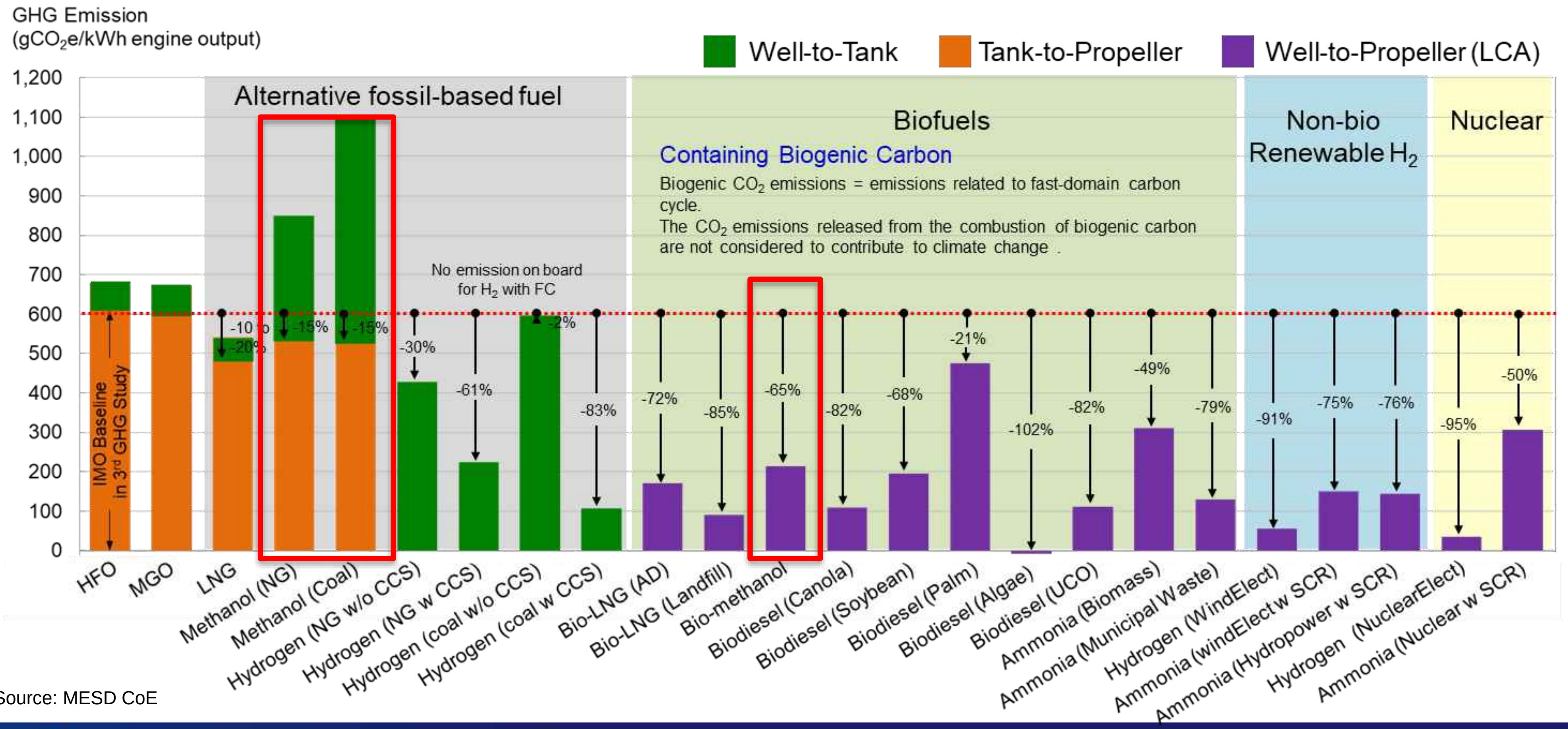
- ✓ The simplest form of alcohol
- ✓ Liquid state at ambient temperature and pressure
- ✓ Acceptable energy density
- ✓ Clean combustion
  - SOx free and low NOx, low PM combustion
  - No global warming potential due to fuel slip
  - Formaldehyde emission worth concerning under certain engine types
- ✓ Fully degradable in air and water



LCA GHG Emissions of Alternative Fuels

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

Two-stroke Engine



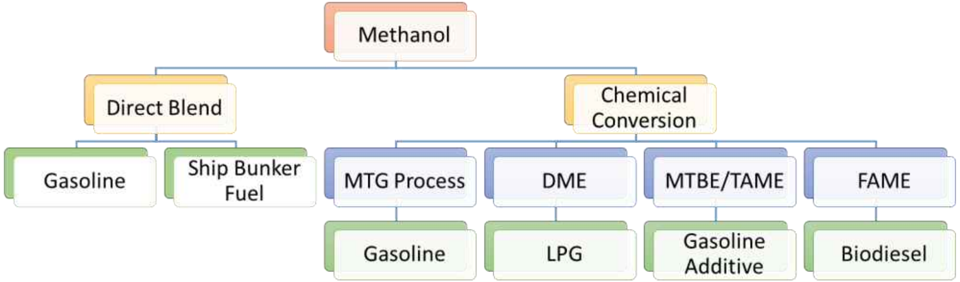
Source: MESD CoE

Development of Methanol as a Marine Fuel

Other completed, ongoing and upcoming methanol projects

Project/vessel name	Company	Vessel Type	Engine Type	Engine Power (kW)	Gross Tonnage	Remarks
Pilot 729 SE	ScandiNAOS	Pilot boat	SI, high speed (CNG convert) (CI convert)	313	20	Retrofit
Jupiter		Road ferry	SI, high speed	1324	737	Retrofit
Leanship	Volvo Penta		High-speed dual fuel on methanol			Retrofit
Methaship	Caterpillar, MAN etc.	Cruise Ropax Ferry	Medium speed			
Green Marine Methanol	A consortium of 22 companies	Total 9 ships including new build and retrofit		1,000 ~ 12,000	300 ~23,000 (DWT)	Methanol is from carbon neutral sources
The HyMethShip			Hydrogen ICE with methanol converter and CCS			Claims 97% CO_2 reduction

- ✓ Chemical tanker carries and consumes methanol as both cargo and fuel
- ✓ Methanol engine technology covers both compression ignition (CI) and spark ignition (SI)
- ✓ There are methanol fuelled harbour craft in trial and development



- ✓ Besides the direct use of methanol as fuel, other energy conversion routes are being explored.

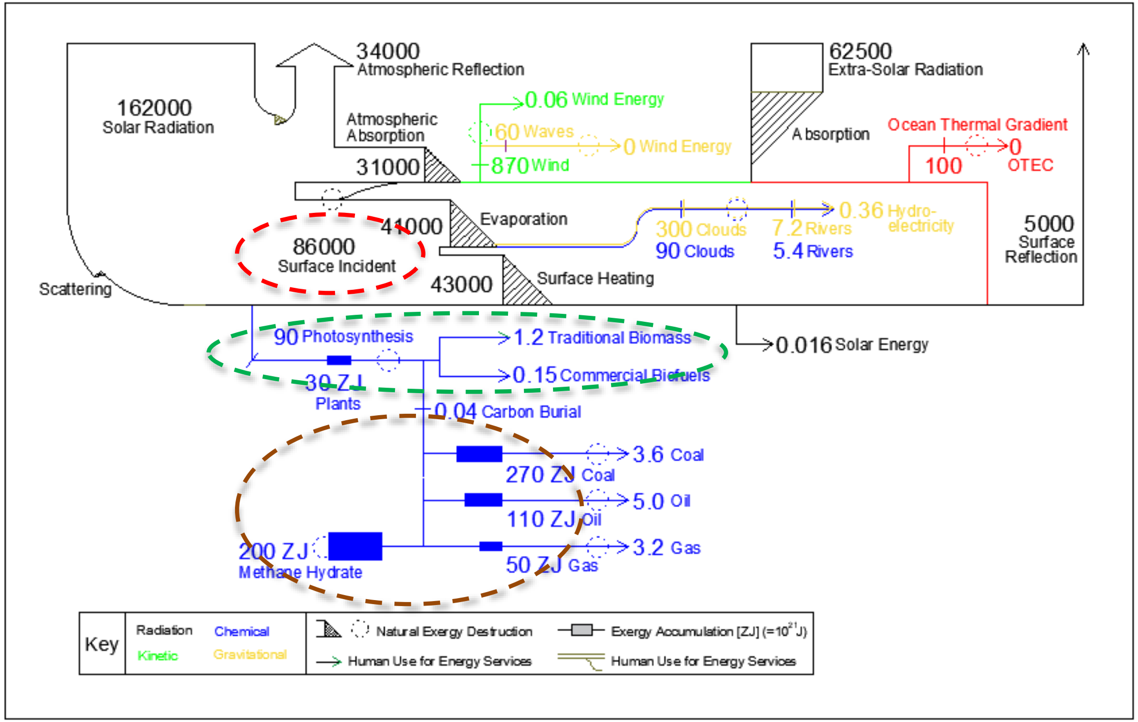
Methanol Fueled Marine Vessels

Methanol powered ocean-going ships

Vessel Name	Company	Vessel Type	Ignition Type	Engine Power (kW)	DWT (tonne)	Remarks
Mari Couva	NYK	Oil/Chemical Tanker	CI, slow speed, 2 stroke	7,180	49,000	New Build
Mari Kokako	IINO Kaiun Kaisha & Mitsui	Oil / Chemical Tanker	CI, slow speed, 2 stroke	7,180	49,000	New Build
Lindanger	Waterfront Shipping	Oil / Chemical Tanker	CI, slow speed, 2 stroke	10,320	49,999	New Build
Leikanger	Waterfront Shipping	Oil / Chemical Tanker	CI, slow speed, 2 stroke	10,320	49,999	New Build
Mari Jone	Marinvest	Oil / Chemical Tanker	CI, slow speed, 2 stroke	7,580	49,999	New Build
Mari Boyle	Marinvest	Oil / Chemical Tanker	CI, slow speed, 2 stroke	7,580	49,999	New Build
Taranaki Sun	MOL	Oil / Chemical Tanker	CI, slow speed, 2 stroke	8,470	49,994	New Build
Manchac Sun	MOL	Oil / Chemical Tanker	CI, slow speed, 2 stroke	8,470	49,994	New Build
Cajun Sun	MOL	Oil / Chemical Tanker	CI, slow speed, 2 stroke	8,470	49,994	New Build
N.A.	Proman Stena Bulk	N.A.	Dual fuel (12,500 ton/y, fuel consumption)	N.A.	49,900	New Build
N.A.	Proman Stena Bulk	N.A.	Dual fuel (12,500 ton/y, fuel consumption)	N.A.	49,900	New Build
Stena Germanica	Stena Lines	RO-Pax	CI, 4 stroke, medium speed	23,000	10,670	Retrofit

Methanol Availability

Global Theoretical Feedstock for Methanol Production



Global exergy flux, reservoirs and destruction (All units in TW if not specified)

Source: W. Hermann, "Quantifying global exergy resources", Energy, 31(12), 2006, p. 1690

The global energy demand was 19 TW year in 2018

In comparison, the total shipping needed 0.332 TW year

Fossil, solar energy and biomass feedstock provide enormous potential forms of energy including methanol

Solar

Biomas
s

Fossil

Other Biomass-to-Fuel Options

Energy yields

Methanol	Biogas	Ethanol	Palm oil
129 ~ 438 GJ/ha.a	268 ~ 364 GJ/ha.a	114 ~ 221 GJ/ha.a	~ 166 GJ/ha.a

Methanol

Catalytical reaction

Miscanthus

Biogas

Fermentation

Maize

Ethanol

Fermentation

Sugar cane

Palm oil

Extraction

Oil palm

- ✓ Biomethanol route has the potential to be the top producer in terms of energy yield per unit area of land
- ✓ The pursuit of feasible energy crops plays the key role to enable biomethanol as a mainstream fuel in future
- ✓ By 2035, there will be enough land globally to feed 9 billion people and to produce more biomass for energy and material use (*source: World Bioenergy Association*)

Renewable Methanol Production | Technoeconomic Studies

Production cost of bio and renewable methanol (desktop studies)

Feedstock	Conversion process	Capacity (tonnes/day)	Cost year	Bio & renewable methanol production cost ($/GJ)	Fossil methanol price ($/GJ)
Forest residue	SilvaGas process	2000	2008	14.48	16.7 ~ 41.8 ($333~832/ton)
Forest residue	RENUGAS process	2000	2008	22.67	16.7 ~ 41.8
Maize residue	Gasification	18.8~3792	2008	21.6~29.5	16.7 ~ 41.8
Pine wood	Gasification	2400	2012	~ 20	22.1~24.2 ($439~482)
Wood	Gasification and water electrolysis	890	2010	18.7	16.7~23.1 ($333~459/ton)
CO_2 and hydrogen	CO_2 capture from power plant hydrogenated with H_2 from water electrolyser	890	2010	33.8	16.7~23.1
Animal manure	Biogas upgrading and water electrolysis	2.85	2010	34.52	16.7~23.1
Animal manure	Biogas upgrading and water electrolysis	59.3	2010	21.03	16.7~23.1
Animal manure	Biogas upgrading and water electrolysis	37.1	2010	22.74	16.7~23.1
Wood	Gasification and water electrolysis (20% wind penetration)	1053	2010	19.6	16.7~23.1
Wood	Gasification and water electrolysis (50% wind penetration)	1053	2025	23.0	n.a.

Investment cost of facilities for (bio-) and renewable methanol vs fossil methanol

Company	Feedstock	Invest-ment Cost (million USD)	Capacity (kt/y)	Capital Cost (USD/t/y)	Source
Chemrec	Black liquor	440	100	4,400	Chemrec 2008
Värmsland Methanol	Wood	540	100	5,400	Värmsland Methanol, 2011
CRI	Flue gas CO_2	15	1.6	9,500	CRI 2011
N.A.	Natural gas	650 ~ 1,300	1,000	650 ~ 1,300	Bromberg & Cheng, 2010

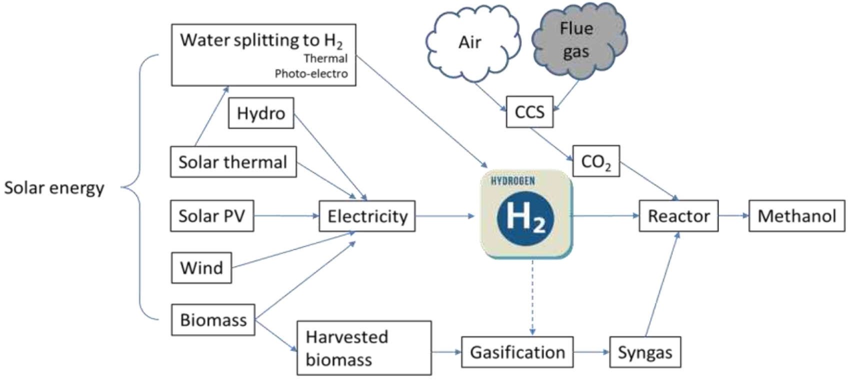
In general, bio and renewable methanol is more expensive than fossil-based methanol

The investment cost of facility of bio and renewable methanol is approx. 5 to 10 times higher than fossil methanol

Cost reduction of bio and renewable methanol is expected with economy of scales

Renewable Methanol Production | Future Outlook

Renewable methanol production pathways



- ✓ The unlimited future supply of renewable methanol relies on the successful carbon capture technology and green hydrogen production
- ✓ Wind energy is attractive due to the highest energy yield per unit of land area
- ✓ In tropical area, biomass route deserves consideration because the region is rich in lignocellulose and forest residual feedstock.

Bio and renewable methanol production projects and facilities globally

Location	Company or Project	Year	Capacity	Feedstock
USA	Smithfield BioEnergy	2003 ~ 2008	7,000 gallons/day (21 t/day)	Swine manure
Iceland	Carbon Recycling International[1]	2011	4,000 t/y	Flue gas CO_2 and H_2 from water electrolysis
Niederaussem, Germany	MefCO_2	2014	1 t/day	Flue gas CO_2
Sweden	BioDME	2008	4 t/day DME	Black liquor
Canada	Enerkem	2016	38 million litre/y (30,096 t/y)	municipal waste (100,000 ton/a, dry)
Canada	Alberta Pacific	2011	N.A.	wood
Sweden	Chemrec Piteå	2011 ~ 2016	70 MW MeOH output from 100 MW biomass[2]	black liquor
Sweden	Varmlands Methanol AB	late 2015	300 t/day (or 90,000 t/year)	Forest residual

Guidelines for Marine Methanol

IGF and Carriage of Cargoes and Containers (CCC)

Summary of codes for methanol used as marine fuel

Codes	Timeline	Objective & Descriptions	Remarks
IGF	Jan 2017	International standard for ships other than vessel covered by the IGC Code, operating with gas or low-flashpoint liquids as fuel.	Focusing initially on liquefied natural gas (LNG)
CCC 6	Sept 2019	✓ Timely updating of the International Maritime Solid Bulk Cargoes Code (IMSBC Code) and the International Maritime Dangerous Goods (IMDG) Code. ✓ Update and review of other Codes including the IGF Code and the IGC Code.	Finalized draft interim guidelines for the safety of ships using methyl/ethyl alcohol as fuel, for submission to the Maritime Safety Committee (MSC) for approval.
CCC 5	Sept 2018		The sub-committee agreed, in principle, to draft interim guidelines for the safety of ships using methyl/ethyl alcohol as fuel.
CCC 4	Sept 2017		IMSBC Code amendment developed and IMDG Code amendments finalized.
CCC 3	Sept 2016		The IGF Code Correspondence Group was tasked with further developing draft technical provisions.
CCC 2	Sept 2015		Draft text of technical provisions for the safety of ship using methyl/ethyl alcohol as fuel, for further consideration by a correspondence group.
CCC 1	Sept 2014		Draft international code of safety for ships using Gases or other Low flashpoint Fuels (IGF Code) agreed.
CCS	Dec 2017	Provide technical standards for methyl/ethyl alcohol fuel, fuel cells and biodiesel fuel application on ships for emission control.	Apply to steel ships of not less than 20m in length and using methyl/ethyl.

Observations on IGF and CCCs

- The purpose is to ensure the operation is safe and environmental sound onboard.
- Provide mandatory, good practices, advisories, etc on safe handling of methanol related machinery, storage and propulsion system.
- Alcohol fuel (methyl - , ethyl -) specific codes are based heavily on the existing IGF code, where a higher standard on cryogenic fuel can be overkill for methanol.
- The full development of the methanol operational codes still awaits further operating experience from the marine industry.
  - Overall codes are mainly descriptive
  - Common sense is applied extensively
  - Further development needed

Latest update

- ❑ IMO interim guidelines on methanol - Nov 2020
- ❑ Bunkering Technical Reference (LR & MI) –Jul 2020

Case Study and Pre-trial Considerations

Green Pilot, Stena Germanica, and Possible Adoption in Singapore

Green Pilot

Stena Germanica

<u>Green Pilot</u>
- ✓ Inland water vessel with modified SI and CI engines to burn methanol
- ✓ Fuel injection system modified and ECU remapped for methanol
- ✓ Combustion improver added to achieve reliable ignition

<u>Stena Germanica</u>
- ✓ Modified 4 x 6000 kW compression ignited dual fuel CI engine
- ✓ Modified high pressure fuel system
- ✓ Enlarged fuel storage from ballast water tanks
- ✓ Truck to ship methanol bunkering
- ✓ Methanol supplied from biomass or natural gas origin

<u>Adoption by Singapore harbour craft</u>
- ✓ Refer to the main report on future energy options of Singapore harbour craft.
- ✓ In the short term, it is challenging for green methanol* to act as a mainstream alternative fuel due to availability and compatible engines.
- ✓ For mid- to long-term perspectives, green and blue methanol** adoption will grow with advanced technology.
- ✓ SB prefixed chemical tankers or bunker tankers have the convenience to use their cargo (i.e. methanol) as fuel.

*Green methanol: methanol produced from renewable energy and biomass

** Blue methanol: methanol produced from CCU

Pre-sea trial Considerations

Marine Engine

Types of engines used by Singapore harbour craft

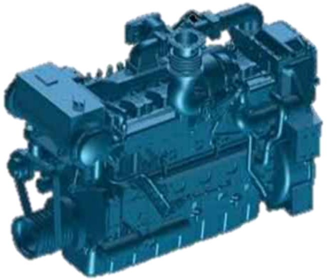
Vessel Type	Engine Types	
	Main Engine	Auxiliary Engine
SP (<12 pax)	CI, High-Speed Engine	CI, High-Speed Engine
SP (>12 pax)	CI, High-Speed Engine	
SC	CI, High-Speed Engine	
SB	CI, Medium-Speed Engine or CI, High-Speed Engine	
ST	CI, Medium-Speed Engine or CI, High-Speed Engine	
SR	CI, High-Speed Engine	

CI: Compression Ignition

For Singapore harbour craft

Conversion technology

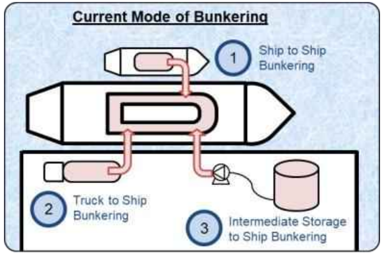
- Types of craft
- Full specification
- Space requirement (fuel tank, fuel system, risk assessment)
- Types of engines
- Type of ignition (CI, SI or swap)
- Cold start consideration
- Types of fuel (neat, additive, dual fuel?)
- Decision on engine retrofitting



Source: Weichai

Bunkering

- Bunkering facility
- Operating mode
- Standard and guidelines



Preparation for sea trial

- Sea trial checklist
- Clearance from port authority
- Control and monitoring Test
- Endurance and speed Test

Conclusion

- Methanol has the potential to become a mainstream marine fuel in the future when an absolute reduction of greenhouse gas emission is becoming mandatory.
- Southeast Asia, rich in biomass feedstock, needs to consider dedicated energy crops, forestry residuals and waste streams as the potential feedstock for green methanol production.
- From the future perspective, direct carbon capture from flue gas or air, combined with green hydrogen generation will be the ultimate source of renewable methanol.
- Methanol adoption is likely to start with chemical tankers that carry methanol as both cargo and fuel. As an interim option, fossil methanol will be adopted earlier, and at meantime prepare the marine industry for future uptake of renewable methanol fuel.

Thank you

Contact MESD:
D-MESD@ntu.edu.sg

For more information, please visit MESD website http://coe.ntu.edu.sg/MESD_CoE