The Maersk methanol vessels

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2021-11-10

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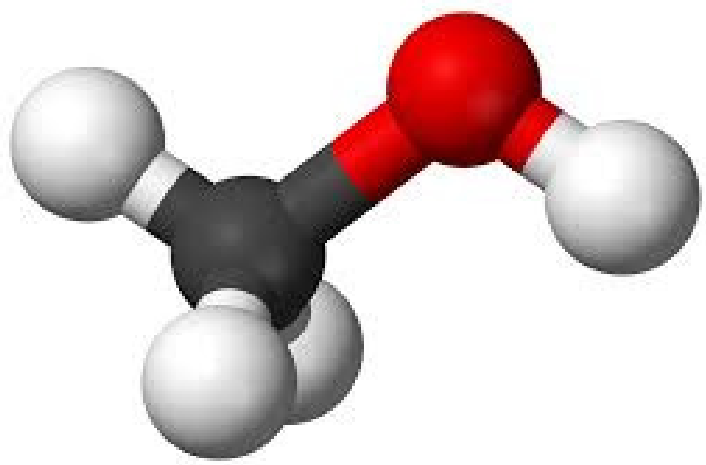
Agenda

- Why Methanol
- Principal system design
- Engine technology
- Vessel integration challenges
- Fuel Sourcing



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Maersk Methanol Vessel Orderbook

One 1 900 TEU Feeder
Delivery 2023

MAN G50 Engine
1 500 m3 Methanol

Eight 14 000+TEU Large vessels
Delivery from 2024

MAN G95 Engine
16 000 m3 Methanol

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WHY METHANOL

- **Can be produced "green" – either from electrolysis combined with carbon capture or from biomass**
- Not a greenhouse gas
- Liquid at room temperatures – comparatively easy to store
- Highly biodegradable – low risk of marine environment impact
- Available technology

ADDITIONAL TECHNICAL CHALLENGES

- Lower energy content than oil – 2.5 x volume for same energy
- Methanol is low flashpoint – IGF code/ IMO MSC Circ.1621 applies
- Methanol is toxic to humans

Methanol Human Toxicity

- Humans are exposed to Methanol all the time with a back-ground level of 0.5 mg/kg
- 1 liter of orange juice gives similar Methanol ingestion as 8 hrs of 40 ppm exposure
- Skin contact of hand in liquid methanol for 1 hour and 40 minutes will give a potential lethal exposure of 10 ml of Methanol

SAMPLE	METHANOL LEVEL
Fresh and Canned Fruit Juices (Orange and Grapefruit Juices)	1-640 mg/l (average of 140 mg/l)
Beer	6-27 mg/l
Wines	96-329 mg/l
Beans	1.5-7.9 mg/kg
Lentils	4.4 mg/kg
Carbonated Beverages	~56 mg/l
Human Body Background Level	0.5 mg/kg (0.73 mg/l in blood)

EXPOSURE/DOSE	ADDED BODY BURDEN OF METHANOL
Background body burden in humans	35 mg*
Skin contact of hand in liquid methanol, 2 min	170 mg
Inhalation, 40 ppm methanol for 8 hr	170 mg
Inhalation, 150 ppm for 15 min	42 mg**
Inhalation, ingestion of 12 oz (0.34 liter) of aspartame sweetened diet beverge	21 mg
Ingestion of 0.2 ml of methanol	170 mg
Ingestion, 0.7-3 oz (25-90 ml) of methanol	Lethal (~21000-70000 mg)

*Estimated from methanol body burden of 0.5 mg/kg body weight for a 70 kg person
**Assuming 100% absorption in lung (60%-85% more likely)

Readily bio-degradable and not very toxic to marine life

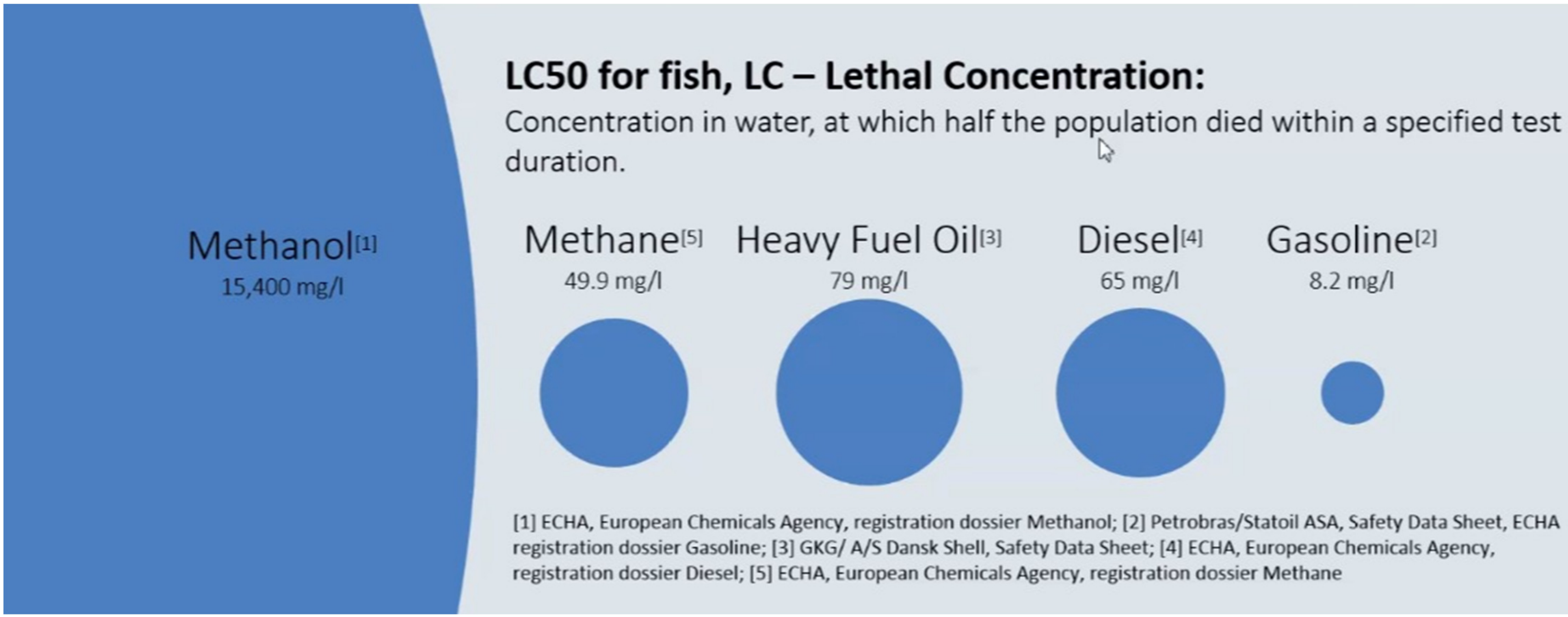

Figure by: Daniel Sahnen Meyer Werft

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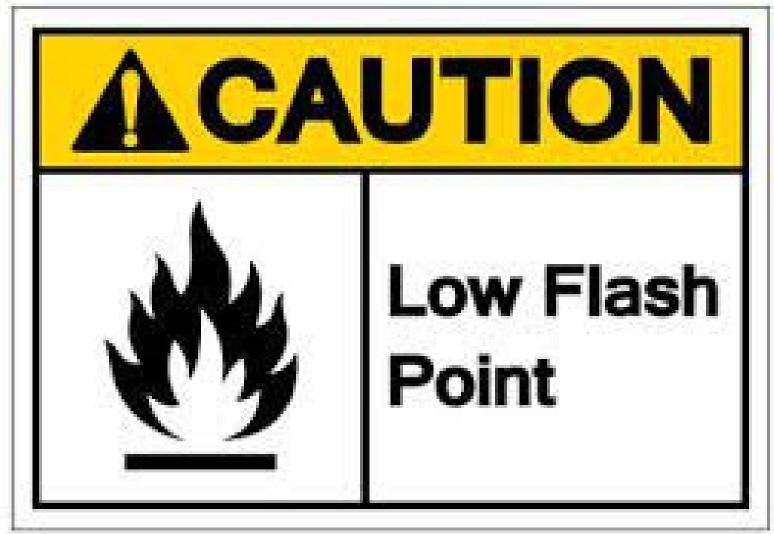
Methanol is a low flashpoint fuel

This means naturally evaporating methanol will form a flammable mixture with air at normally occurring ambient temperature and pressure

For methanol this is approximately the range 10 to 55 deg C corresponding to about 5-35% concentration (by volume)

Flammable means it will ignite if subjected to an ignition source (spark/flame)

Methanol will NOT self-ignite at these temperatures



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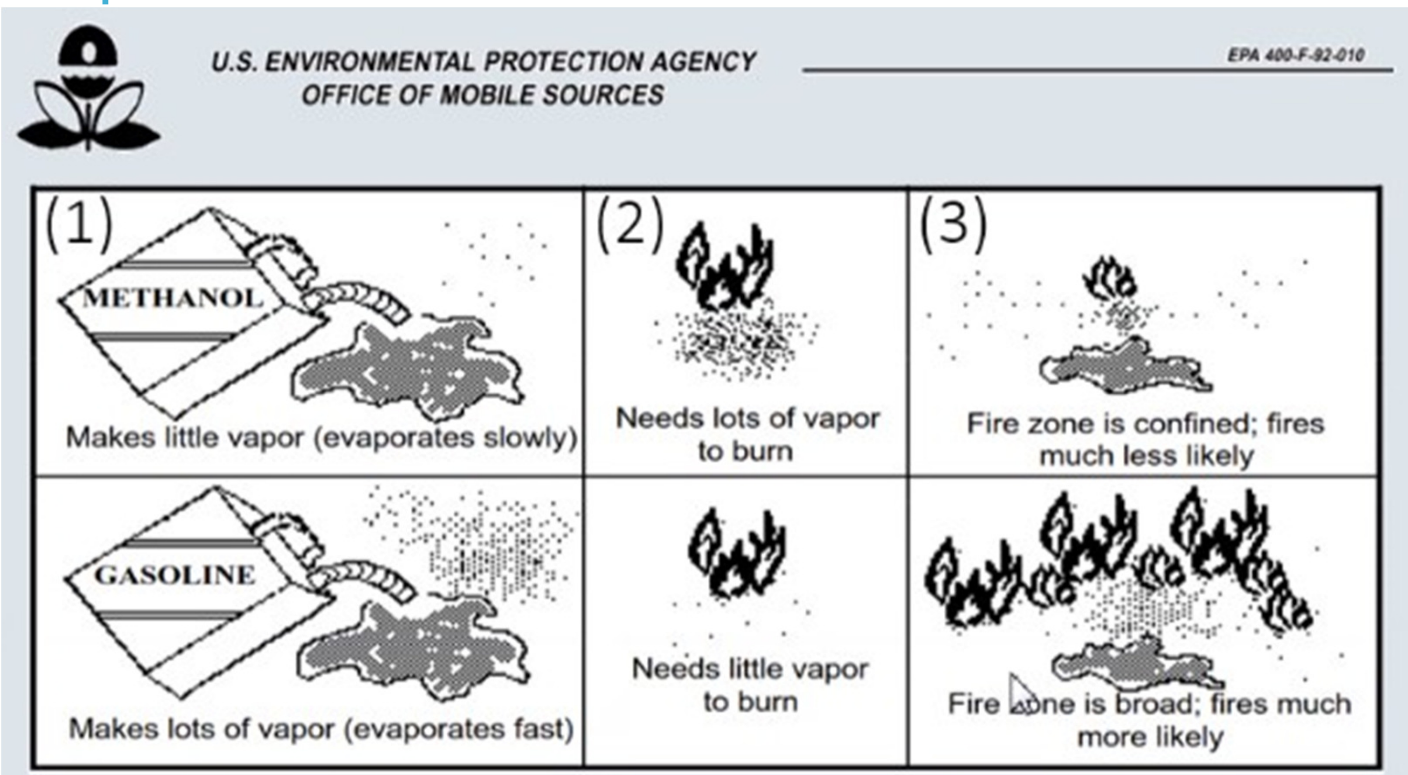
Methanol burns 75% slower with 1/8 the heat release compared to Gasoline



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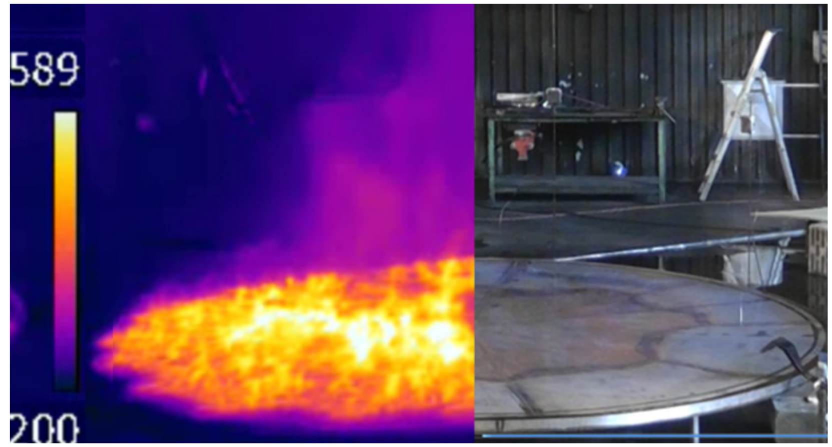
Regulations lean heavily on LNG experience

Focus on fire safety (low flash point)

Toxicity concern is indirectly covered through containment to prevent fire

Methanol fires are different than oil fires as methanol blends with water and may continue to burn in mixtures with 80% or more water.



Burning methanol-water solution may be nearly invisible

Fire mitigation principles

Pool fires

- Small inventory in piping
- Double wall piping in Engine Room
- Haz drain system in fuel prep space
- N2 purging of piping when not in use

Jet fires

- Small inventory in piping
- Double wall piping in Engine Room
- Aut. shutdown and purge

Explosion

- Inerting
- Dedicated vent syst. in haz spaces
- Safe venting on deck (High velocity)
- Haz area classification (Ex elec eqt)
- Gas detection

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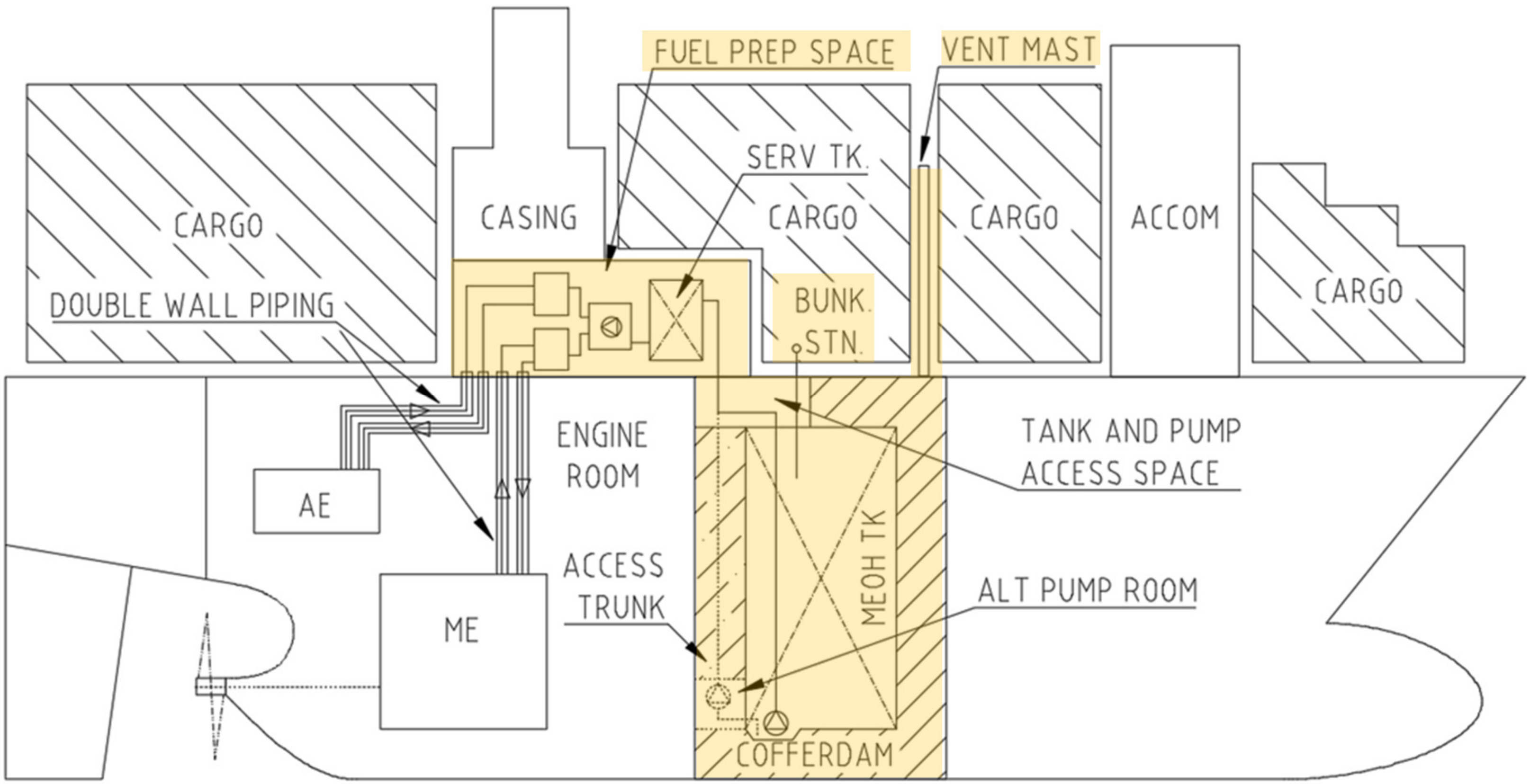
Principal system design

Methanol fuel system basic principle



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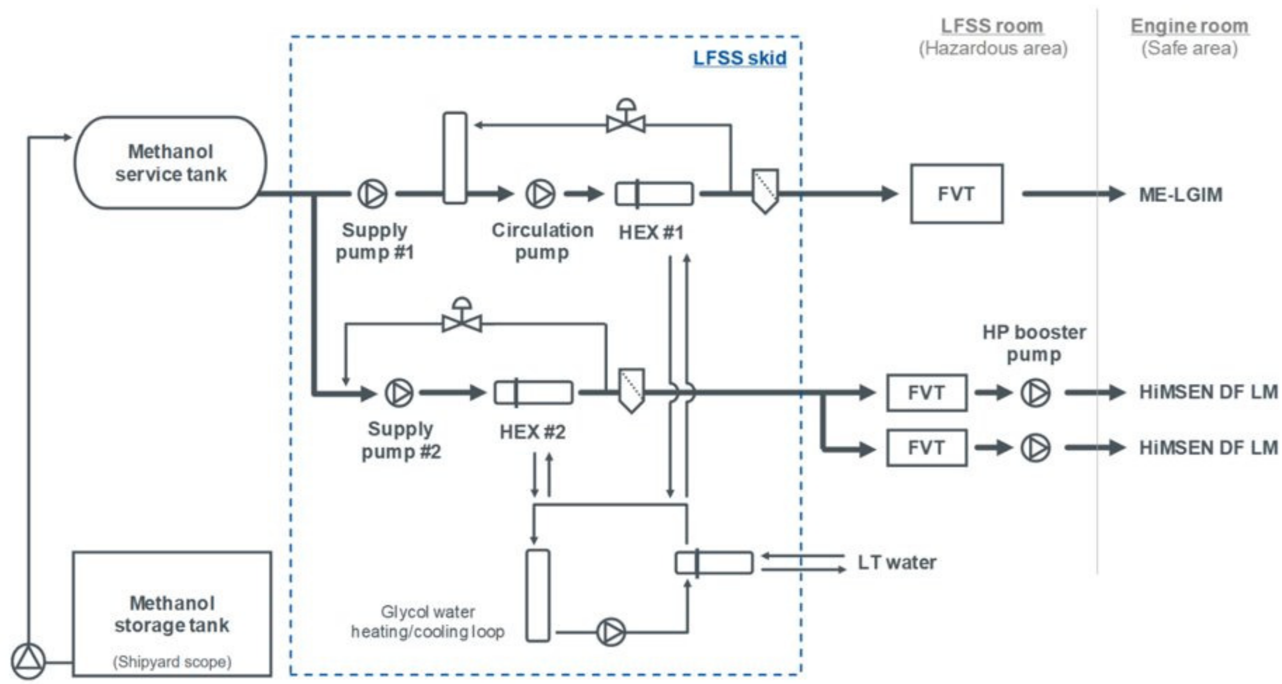
Methanol Fuel Supply system

- 10-13 bar Methanol fuel supply system based on centrifugal pumps for both Main engine and Auxiliary engines
- Each Auxiliary engine will have a separate high pressure piston pump bringing the Methanol to 300 bar
- All Fuel equipment is placed in Fuel Preparation Room on upper deck area with ventilated double wall piping to engines
- Systems are automatically Nitrogen purged when not in use or in case of a Methanol system failure or leak detection



Source: Hyundai Heavy Industries

Classification: Public

Engine Technology

Fuel Supply System

- Skid mounted
- So far delivered for Main Engine only on Methanol carriers. Solstice will be first vessel for both ME and AE
- Mainly SS316 materials and Atex design
- Interface to FVT's, Engines and CAMS for automatic start/stop and purging

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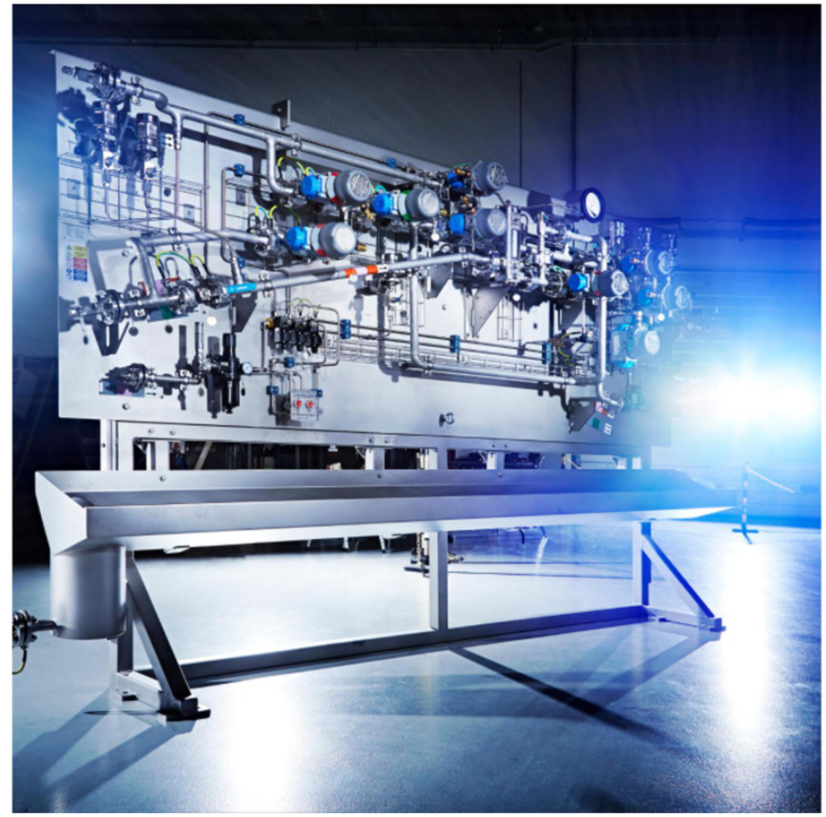
Fuel Valve Train

- For Main Engine supplied by Eltronic Fueltech from Hedensted, Denmark
- Controls Methanol supply to engines and secures Nitrogen purging of engine system after Methanol system stop
- Water connection for Water in Methanol Tier III system



Source: Eltronic-Fueltech

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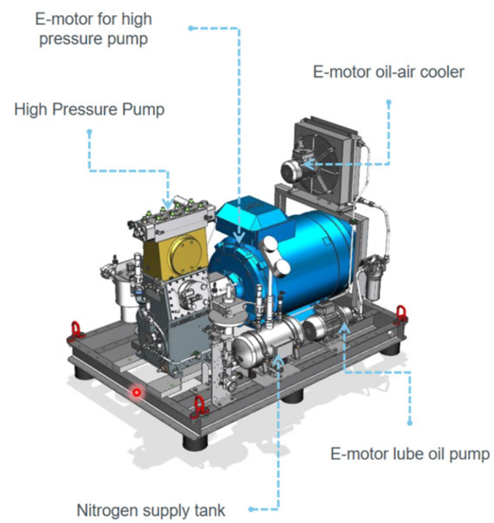
High Pressure Booster Pumps

- Hammelmann reciprocating pump used in water process industry
- Up to 4,000 bar pressure



Purpose
- To pressurize Methanol up to 300 bar

Technical data
- Type: Reciprocating
- Flow: 50 liter/min (according to engine load)

Main equipment on skid
- High pressure pump
- Electric motor for high pressure pump: 45 kW
- Electric motor for oil-air cooler: 1.8 kW
- Electric motor for lube oil pump: 0.44 kW
- Nitrogen supply tank: 15 liter
- Control & Safety valves

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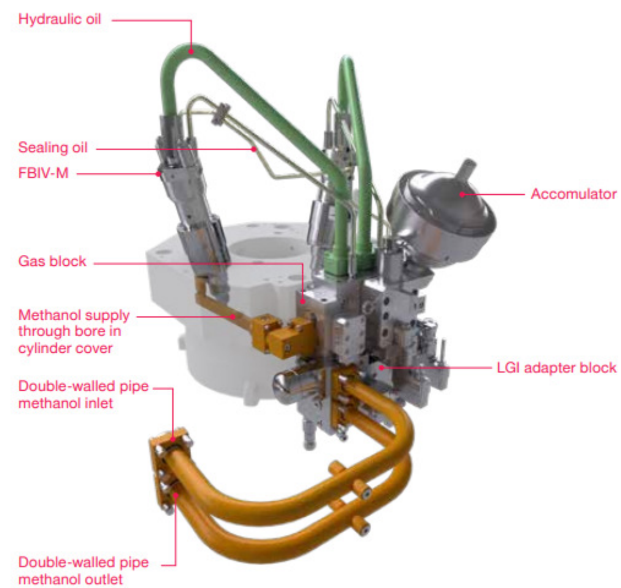
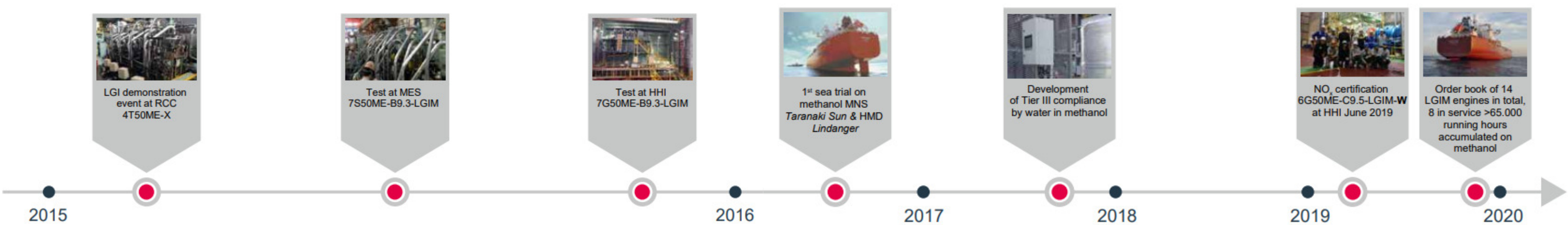
Methanol Main Engine development

- ME-LGIM on 50 bore engines since 2015
- G95ME-LGIM10.5 EGR-TC is currently being designed specifically for Equinox
- 8 cylinder engine similar as Hong Kong class de-rated to 45.5 MW





 Source: MAN-ES SE

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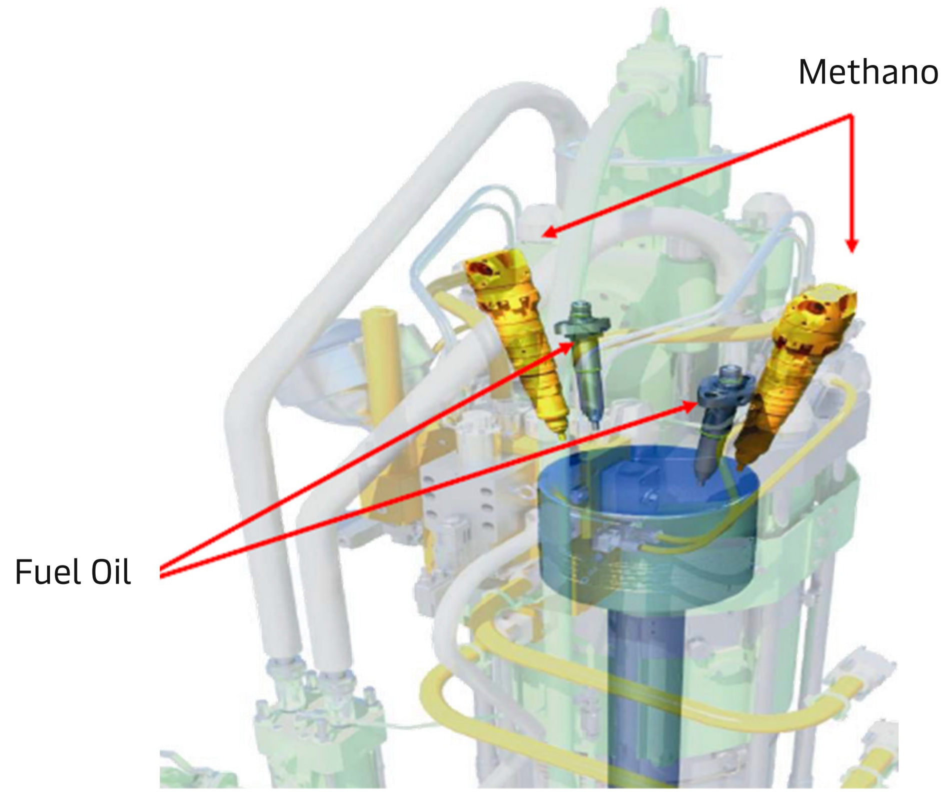
Classification: Public

Dual fuel engines

- The Maersk vessels are designed for full capability on both fuel oil and methanol.
- The dual fuel technology is based on a completely separate injection system for methanol
- Both fuel systems will be operating in parallel as methanol require a small pilot fuel burst to ignite in the diesel cycle
- For methanol operation Maersk intend to use biodiesel or similar for the pilot fuel
- As both fuel systems are pressurised it is possible to shift to pure fuel oil use “on the fly”



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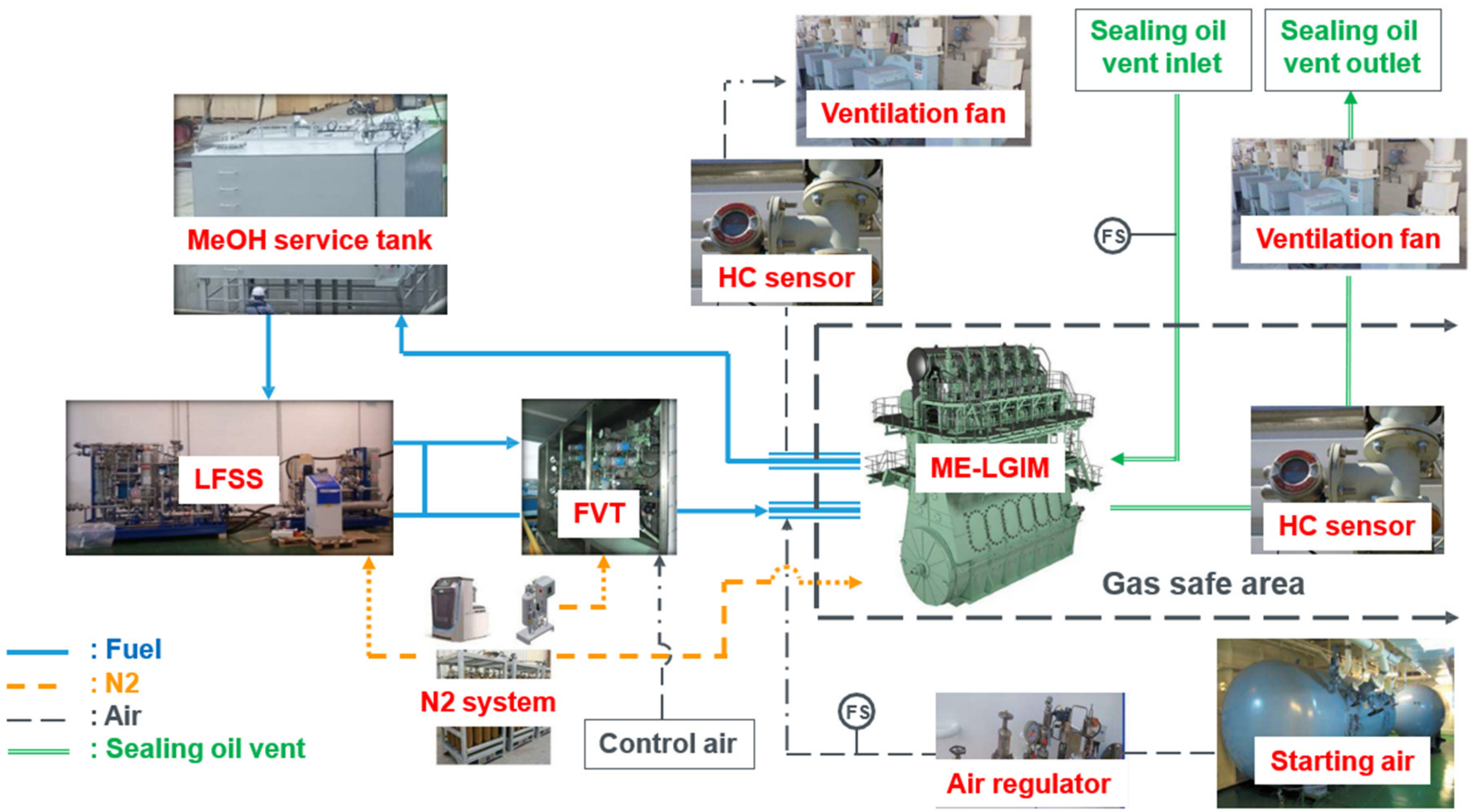
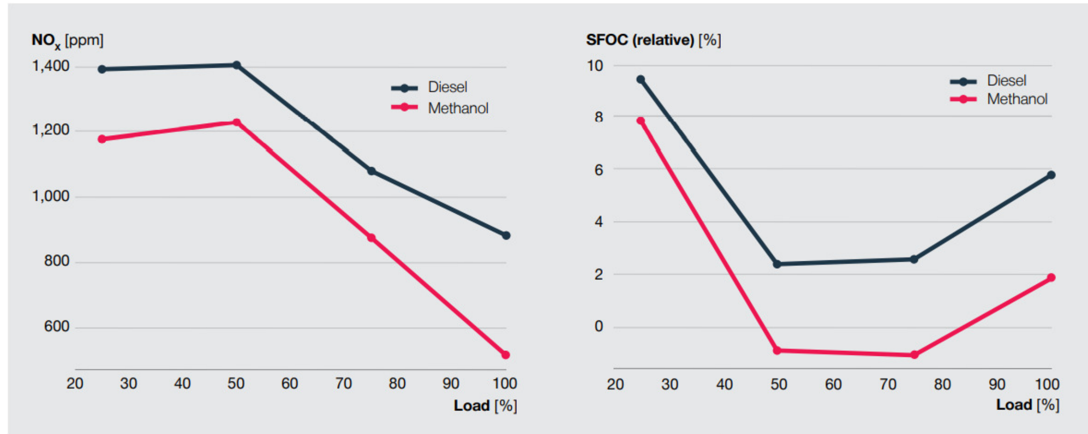
Auxiliary Systems of ME-LGIM



Properties, Emissions and Performance

- Methanol has no soot formation given there is no double bound carbon strings in the fuel
- Given the lower peak combusition temperatures of Methanol will give approximately 30% less NOx emissions



Energy storage type/chemical structure	Energy content, LHV [MJ/kg]	Energy density, [MJ/L]	Fuel tank size relative to MGO	Supply pressure [bar]	Flash-point [°C]	Vapour pressure at 20°C [bar]	Auto-ignition temperature [°C]	Emission reduction compared to HFO Tier II [%]			
								SO_x	NO_x	CO_2	PM
Ammonia (NH_3) (liquid, -33°C)	18.6	12.7(-33°C) / 10.6 (45°C)	2.8 (-33°C) / 3.4 (45°C)	80	132	0.13 / 0.13	630 / 470	100	Compliant with regulation	~90	~90
Methanol (CH_3OH) (65°C)	19.9	14.9	2.4	10	9	2.2-8.5		90–97	30–50	11	90
LPG (liquid, -42°C)	46.0	26.7	1.3*1	50	-104		410-580 (depending on the composition)	90–100	10–15	13–18	90
LNG (liquid, -162°C)	50.0	21.2	1.7*1	300				90–99	20–30	24	90
LEG (liquid, -89°C)	47.5	25.8	1.4*1	380				90–97	30–50	15	90
MGO	42.7	35.7	1.0	7–8							
Hydrogen (H_2) (liquid, - 253°C)	120.0	8.5	4.2		Not defined		500				

*1 assuming fully refrigerated media

Source: MAN-ES

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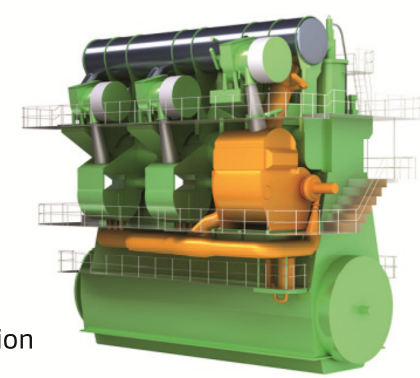
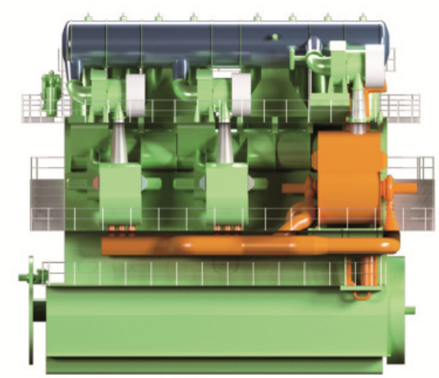
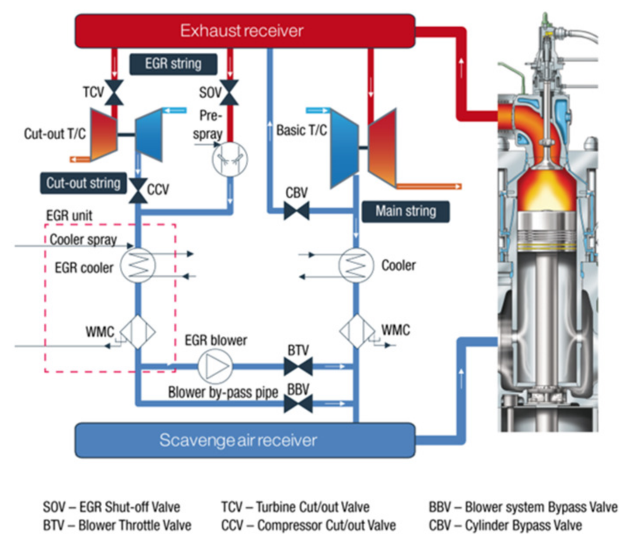
Tier III compliance Equinox

- Vessel will be Tier III compliant in US and North-Sea ECA's
- Main Engine
  - compliance using EGR-TC system by MAN-ES
  - In Tier II the engine will run in TC cut-out mode for lower fuel consumption
  - Mærsk participated in EGR development by vessel test of first version on Alexander Mærsk and first Tier III compliant EGR system on Maersk Cardiff in 2013
- Aux Engines
  - Compliance using LP-SCR using Urea as reactant







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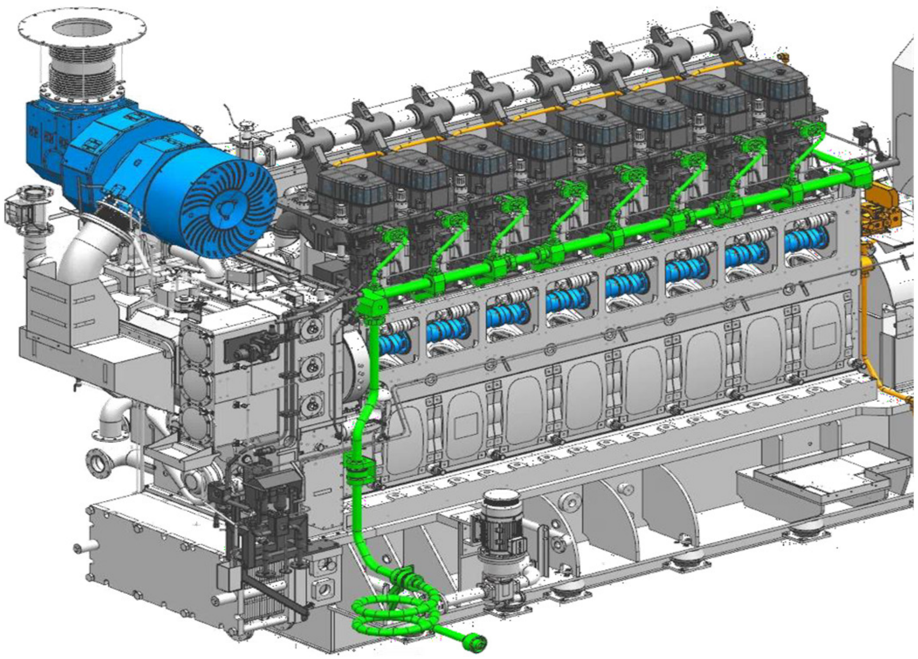
Auxiliary Engines on Methanol

- **Existing medium speed marine market:**
  - One conversion on Wärtsilä Z40S engines on Stena Germanica in 2015 (Vessel is built in 2000)
  - ABC engine in Belgium offers Methanol engines running on Otto-cycle (Based on development project on a tugboat in the port of Antwerp)

- **1.5-2 years from now:**
  - **Hyundai Himsen 32DF-LM** will be installed on both Feeder and 16,000 TEU Container vessels
  - Common rail Diesel-cycle injection (300 bar) using pilot fuel for ignition (Bio-diesel)
  - Major fuel injector design and manufacturing company is making the Methanol injector design together with Himsen



Source: HHI-EMD

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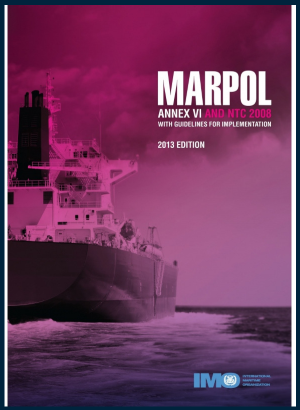
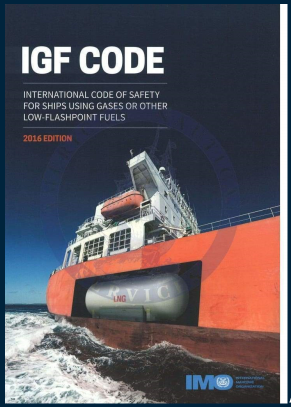
Vessel integration challenges

Regulatory regime

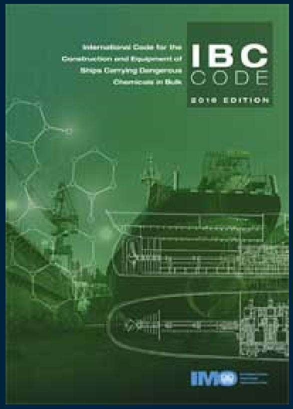


~~Reg 12A Fuel tank placement~~

LNG

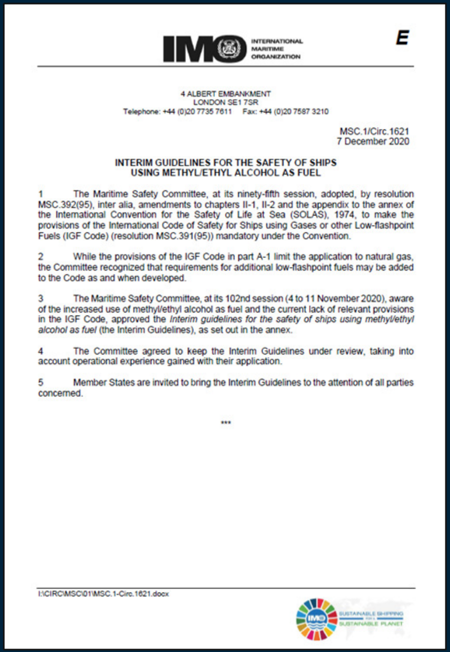


LNG as fuel



Methanol as cargo

MSC.1/Circ. 1621



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MSC.1/Circ.1621
7 December 2020

INTERIM GUIDELINES FOR THE SAFETY OF SHIPS USING METHYL/ETHYL ALCOHOL AS FUEL

1 The Maritime Safety Committee, at its ninety-fifth session, adopted, by resolution MSC.392(95), inter alia, amendments to chapters II-1, II-2 and the appendix to the annex of the International Convention for the Safety of Life at Sea (SOLAS), 1974, to make the provisions of the International Code of Safety for Ships using Gases or other Low-flashpoint Fuels (IGF Code) (resolution MSC.391(95)) mandatory under the Convention.

2 While the provisions of the IGF Code in part A-1 limit the application to natural gas, the Committee recognized that requirements for additional low-flashpoint fuels may be added to the Code as and when developed.

3 The Maritime Safety Committee, at its 102nd session (4 to 11 November 2020), aware of the increased use of methyl/ethyl alcohol as fuel and the current lack of relevant provisions in the IGF Code, approved the *Interim guidelines for the safety of ships using methyl/ethyl alcohol as fuel* (the Interim Guidelines), as set out in the annex.

4 The Committee agreed to keep the Interim Guidelines under review, taking into account operational experience gained with their application.

5 Member States are invited to bring the Interim Guidelines to the attention of all parties concerned.

***

Methanol as fuel
(Interim guidelines)

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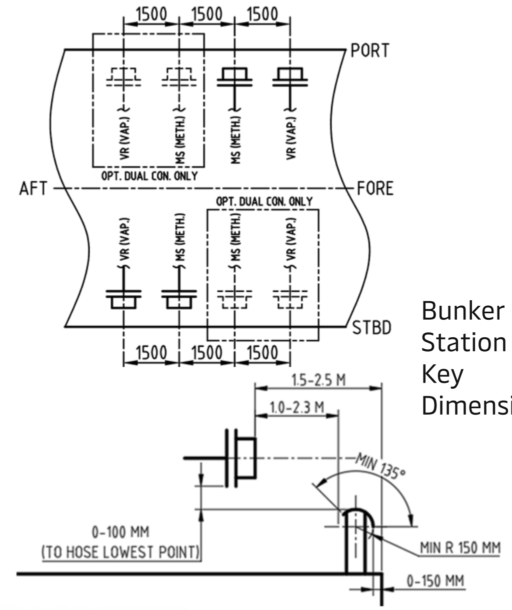
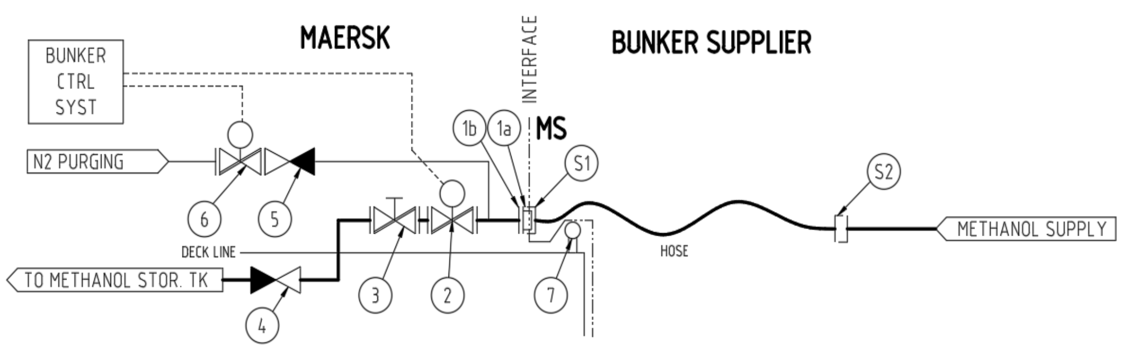
Bunkering methanol

Regulations stipulate	Methanol as cargo	Fuel oil bunkering
- Dry type quick connect/disconnect couplings (QCDC)	- Not used	- Not used
- Breakaway coupling	- Not used	- Not used
- Emergency Shut Down (ESD) link	- Standardized but not yet required	- Not used
- Remote operation during bunkering	- Yes	- No R.C. Valves
- Drain/purge of bunker lines not in use	- Not always	- No
Ports request		
- Vapour return	- Yes	- No



Bunker Station Key Dimensions

Maersk is developing a standard interface specification for bunkering and we are happy to share and cooperate on this to facilitate interoperability



Dry Quick Connect/ Disconnect (QCDC)
NATO STANAG 3756

Standard ESD connector
OCIMF Linked Ship/Shore Emergency Shutdown Systems for Oil and Chemical Transfers 1st Ed 2017

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Fuel tanks

Big methanol fuel storage space is needed in addition to fuel oil storage

Fuel tanks shall be surrounded by cofferdams – except below waterline toward shell

The fuel tanks need to be large and approaching cubic to optimise ratio of cofferdam to fuel tank.

Fuel tanks will be coated like chemical tanker and coating is only guaranteed by builder for smooth tank surfaces

Need for structural stiffening of shell makes it hard to arrange tanks adjacent to shell

Smooth tank insides mean structural stiffening in the cofferdams leading to ventilation challenges in cofferdams as well as access challenges in both tanks and cofferdams

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Fuel tank access

Very deep tanks mean long access ladders/stairs

Fuel tanks may be accessed very seldom (years)

State of the ladders will be unknown when opening tank

Ladder attachment points are know weak points for tank coating

Only limited part of tank is available for close up visual inspection from bottom

Remote operated vehicle (Drone) inspection is rapidly evolving

The ladder system is an obstacle for a drone

Maersk is seriously considering the need for human access in service and the need for permanent ladder systems

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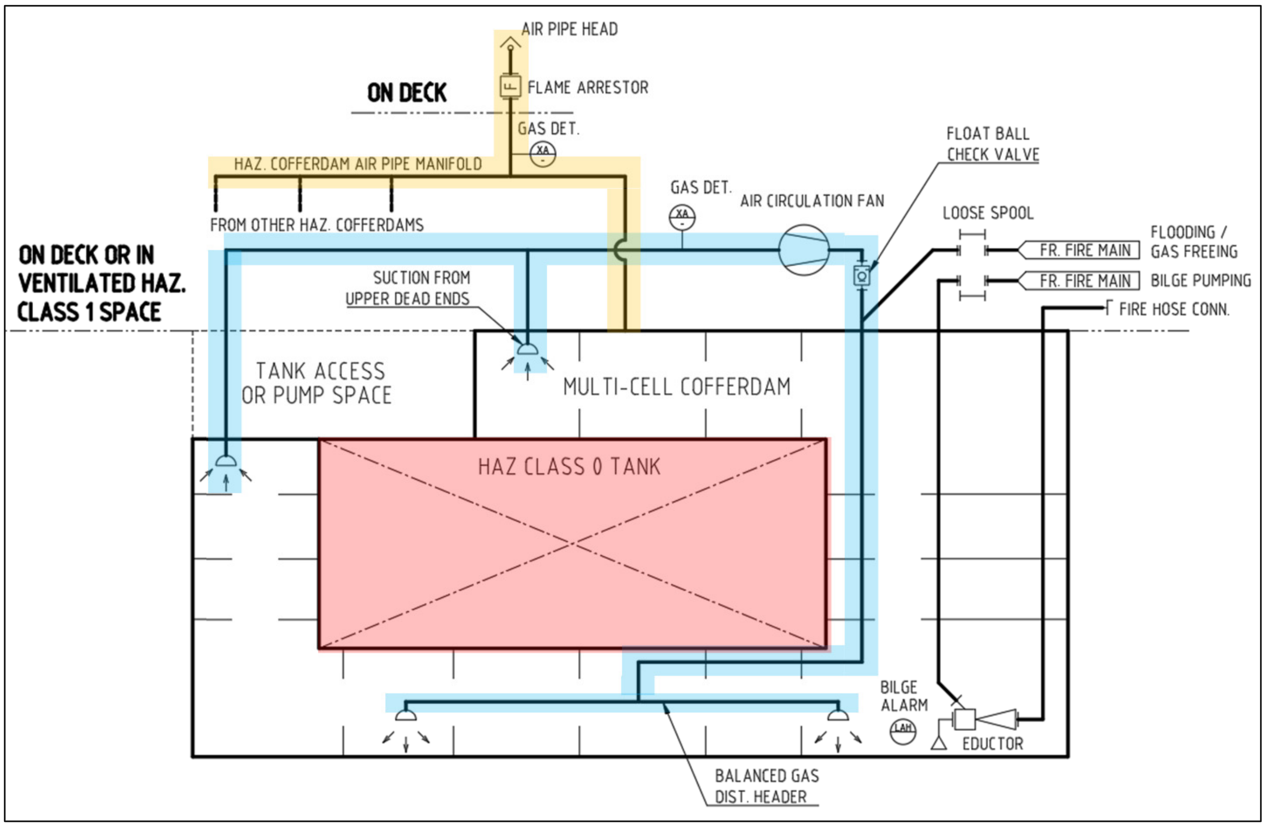
Cofferdam gas detection



Cofferdams will be large and compart-mentalized

Methanol vapour is near neutral buoyant in air

Access may be dangerous due to corrosion induced oxygen depletion

A small leak may go undetected a long time

Ventilation is undesirable due to moist air condensation causing spurious bilge alarm and corrosion

Effective gas detection is planned through a circulation system leaving the instrumentation easily accessible

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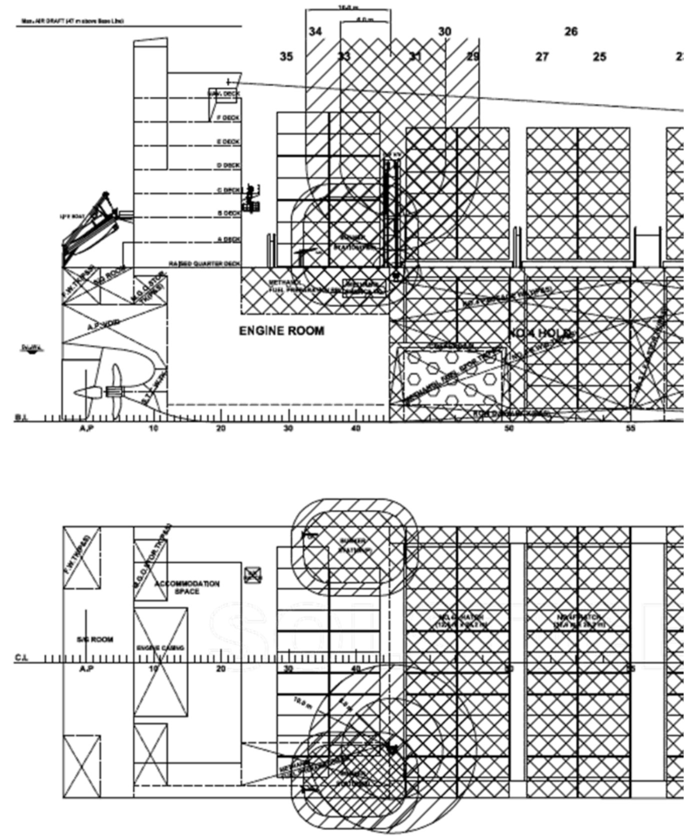
Tank venting and Hazardous ventilation systems

- Breathing system (PV-valves) for methanol tanks will release methanol/inert gas vapour
- Ventilation systems for cofferdams/fuel preparation spaces and pipe ducts may potentially release methanol vapour
- Bunker station connections may release methanol

All these generate independent hazardous zones on deck require:
- Access control for nonauthorized personnel
- Ex-proof equipment
- Limitations on cargo stowage and handling
- Separation to other openings and inlets

Finding an arrangement of vents and openings that minimizes impact on ship operation is challenging



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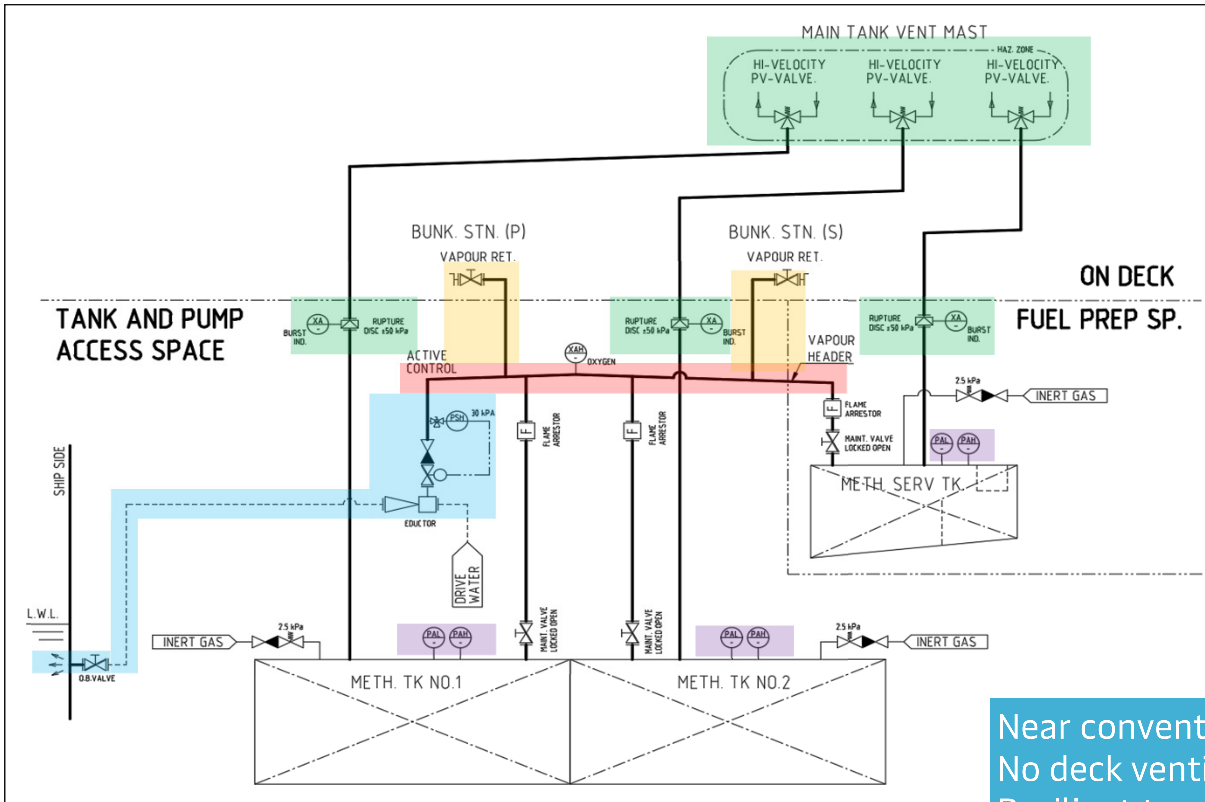
Tank pressure control (non-venting)



Vapour header for inert gas reuse
Limits need for nitrogen gas generation

Vapour return to shore
No venting during bunkering

Vapour seawater dilution underwater ejection
Controlled pressure relief to safe location

Shutdown on over/under pressure
Pump and bunker stop if pressure out of bounds

Vent mast with rupture disc protection
Last line of defence
No haz. atm. above deck - vent mast may be damaged
Rupture detection allow warning of imminent release

Near conventional design
No deck venting
Resilient to vent mast damage
No-release in port compliant

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Hazardous drain/bilge system

Systems are engineered to have minimal leaks and spills

Local leaks and system purge are collected and returned to the fuel system (combined service/drain tank)

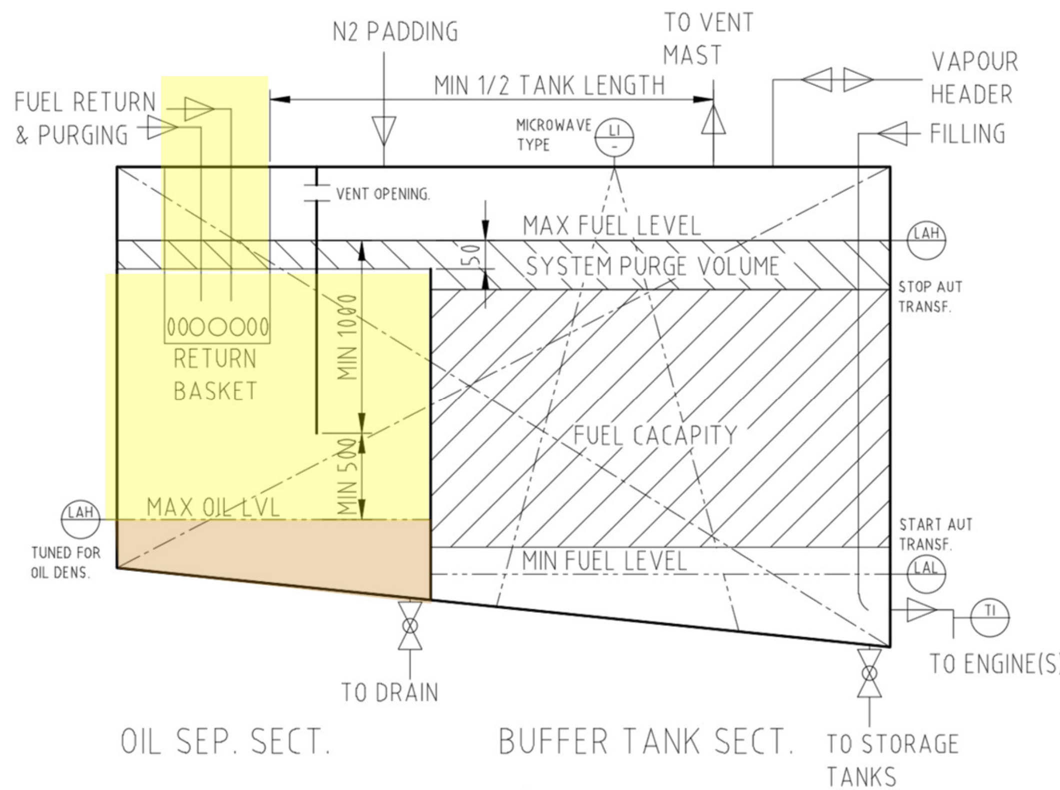
Remaining bilge "events" are very hard to predict, both medium and volume (not SW, as all above waterline)

Sizing of a bilge tank and system is an unknown – an overflowing bilge tank must be avoided

Pumping hazardous bilge with a pumping system that is very rarely used may be a hazard in itself

Maersk is considering if the hazardous spaces themselves can be the bilge holding space for major events

Once situation is stabilised the hazard level of room content can be assessed and managed



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Fuel sourcing

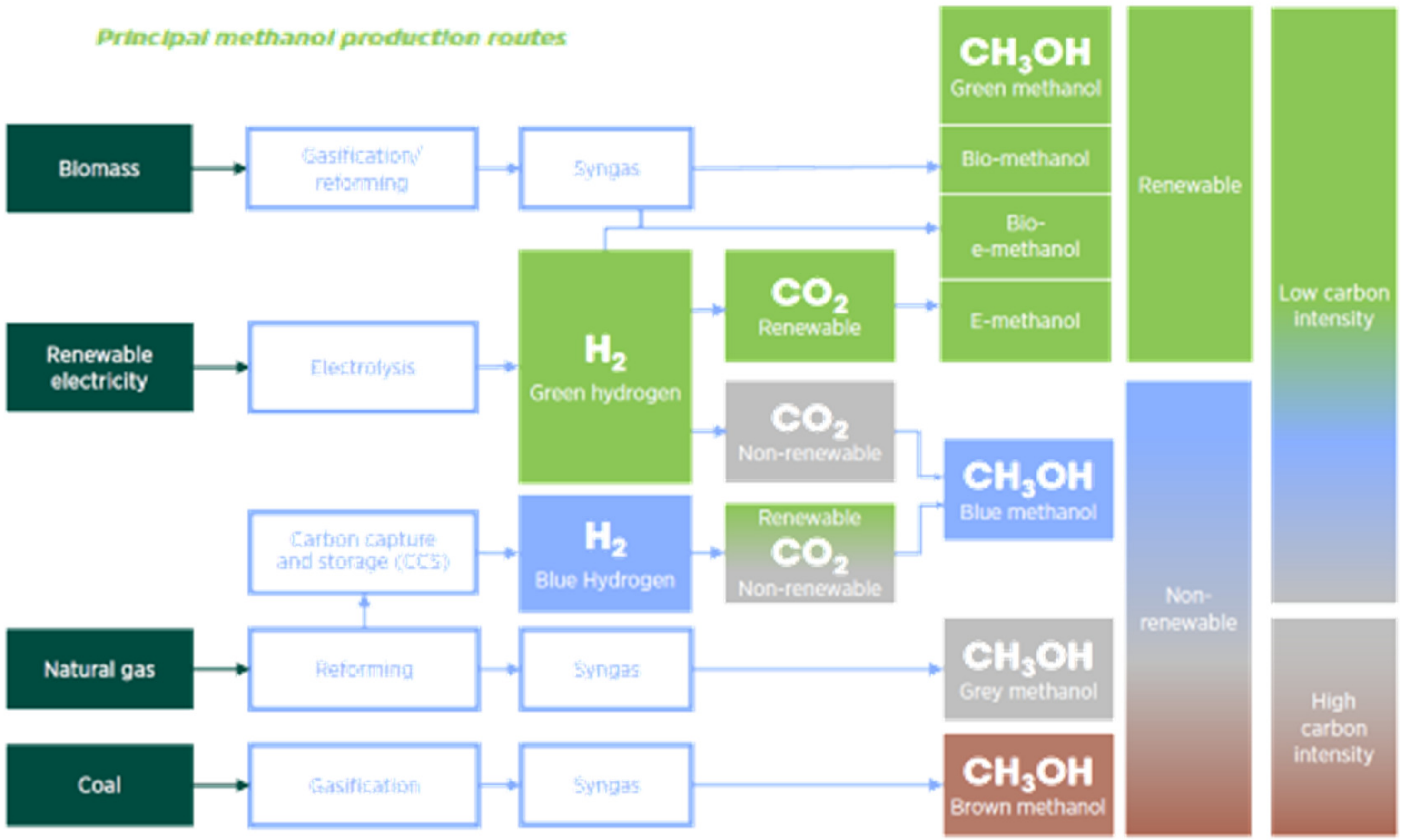
Manufacture

Almost all methanol today is made by reforming natural gas

but

There is good potential to scale up green manufacture of methanol

A limiting factor may soon be availability of biogenic CO2 for carbon based e-fuels



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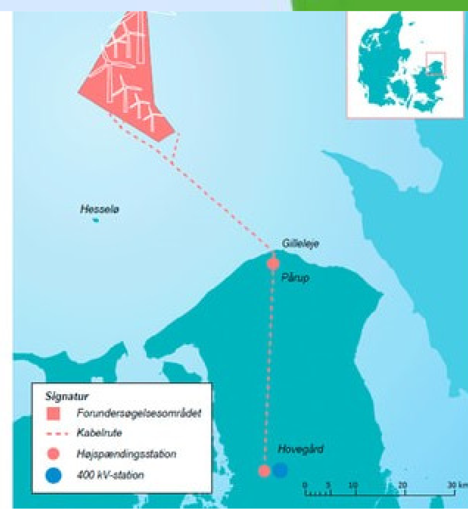
Fuel sourcing - What does it take

- To make 360,000 ton e-Methanol you need:
- 3,900 GWh* (up to 1,900 GWh available as some kind of waste heat potentially covering heating of 95,000 homes)
- 530,000 ton CO2*
- 1,100,000 ton Water*

- 49 x 15MW off-shore windturbines (735 MW)
- Largest planned wind-turbine farms in DK (Thor and Hesselø) are planned with 67 x 15 MW turbines, 1,000 MW (cover 11 vessels)
- Will make about 3% of Maersk fleet CO2 emissions renewable
- Abt. 40 GW of renewable power is needed to cover entire Maersk fleet
- Globally 2,799 GW renewable power is installed**
- In 2020 261 GW renewable power was installed with Asia as main contributor accounting for 64 % of installed capacity**

*) BASF and bse Engineering sign development agreement to transform CO2 and renewable electricity into methanol; power-to-methanol - Green Car Congress

**) Renewable Capacity Statistics 2021 (irena.org)



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The End

Supporting slides follow

Property	Methanol	LNG	Diesel	Gasoline
Density [kg/m³]	790	448	850	740
Heating value (volume-based) [MJ/l]	15,8	22,0	35,6	34,6
Heating value(mass-based) [MJ/kg]	20	49	42,8	46,7
Flash point [°C]	11	-188	52 - 96	-45
Self ignition temperature [°C]	455	540	250	280 - 460
Lower explosion limit [vol.-%]	5,5	4,6	0,5	1,4
Upper explosion limit [Vol.-%]	36	15	7,5	7,6
Heat release i. c. o. fire [kW/m²]	450	4000	1400	2500
Boiling point (@ 1 bar) [°C]	65	-162	170 - 350	25 - 190
Enthalpy of evaporation [kJ/kg]	1160	511,7	250	375
Vapour pressure (bei 20°C) [bar]	0,13	gaseous	0,004 (40°C)	0,25 - 0,45
Relative Vapour density (air=1)	1,1	0,55	6	3 - 4
Viscosity (@ 20°C) [cSt]	0,74	-	2,5 - 3,0	0,6
water solibility	100%	negligible	negligible	negligible

Figure by: Daniel Sahnen Meyer Werft

Relatively benign chemical properties

High ignition temperature

High LEL%

High evaporation enthalpy

Vapour density near air

It is NOT a room filling gas like LNG