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Feasibility of Methanol as a Retrofit Fuel Solution for Ferries and Cruise Ships

Jyrki Salo

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Author: Jyrki Salo
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Supervisor(s): Thomas Finne, Tom Backlund

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Abstract

This thesis work aimed to determine the methanol feasibility as a retrofit solution to meet decarbonization demands targeting the four-stroke main engine powered vessels and more specifically, the ferry and cruise segment. Feasibility areas related to methanol retrofit are described and discussed. Feasibility areas are looked at from available literature point of view. Furthermore, continuously developing regulation impact on the general feasibility of methanol as an alternative fuel was discussed.

Feasibility areas are related to technical, commercial, safety and compliancy factors. Methanol properties as fuel is as well described and several types of methanol global availability are evaluated.

A questionnaire was used to evaluate customer´s and supplier's (Wärtsilä) standpoint on methanol retrofit. The questionnaire was identical for both supplier and customer representatives. The questionnaire questions covered the feasibility areas. Finally, the questions were analyzed by using the all the responses but also evaluated by using customer and supplier categorization. Also, professional groups were used to analyze the results.

Additionally, product values are described from the product and customer value perspective (PVP & CVP). The example value proposition is formulated into the methanol conversion. Co-creation of values related to the value proposition is as well discussed. A value system product model is explained and integrated into the example value proposition.

Language: English
Key Words: methanol, retrofit, feasibility

OPINNÄYTETYÖ

Tekijä: Jyrki Salo

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Ohjaaja(t): Thomas Finne, Tom Backlund

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Tiivistelmä

Tämä Thesis-työ käsittelee methanolin soveltuvuutta olemassa olevien nelitahtimoottoreiden polttoaineeksi matkustaja- ja risteilyaluksissa. Painopisteenä tässä työssä on CO_2 päästöjen vähennyspotentiaalin arviointi metanolipolttoainetta käyttäen. Soveltuvuutta käsitellään jälkiasennettavan metanolikonversion näkökulmasta. Konversion soveltuvuutta peilataan myös saatavilla olevaan kirjallisuuteen ja tieteellisiin artikkeleihin. Metanolipolttoaine konversioon liittyven säädösten kuvaus ja nykyinen tila ovat myös tämän työn aihealueena.

Käsitellyt metanolin soveltuvuusalueet liittyvät tekniikkaan ja kaupallisuuteen sekä turvallisuuteen ja sääntöjenmukaisuuteen. Metanolin polttoaineominaisuudet sekä eri metanolilaatujen saatavuus on arvioitu globaalisti.

Kyselylomaketta on käytetty asiakaskunnan ja toimittajan näkökulmien arvoimiseen metanolin soveltuvuudesta jälkiasennukseen. Kysymyslomakkeiden kysymykset kattavat metanolikonversion eri soveltuvuusalueet. Kyselyn tulokset ovat analysoitu käyttäen kaikkia saatuja vastauksia sekä kategorisoimalla asiakkaan ja toimittajan henkilöstön vastaukset. Tämän lisäksi vastauksia on analysoitu käyttäen ammattiryhmittäistä jakoa.

Tuoteen arvoja käsitellään käyttäen tuote- ja asiakasarvolupausnäkökulmia. Thesis sisältää esimerkin arvolupauksesta metanolikonversiolle. Arvojen yhteiskehittäminen on käsitelty toimittajan osalta yhdistettynä arvolupaukseen. Arvosysteemituotemalli on myös selitetty ja yhdistetty esimerkkinä toimivaan arvolupaukseen.

Kieli: English
Avainsanat: metanoli, jälkiasennus, soveltuvuus

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Appendix 1: Research interview questionnaire

Abbreviations

ABS	American Bureau of Shipping
ATEX	Atmosphere Explosible
CH_3OH	Methanol
CII	Carbon intensity indicator
CO_2	Carbon dioxide
CR	Common rail
CVP	Customer value proposition
DNV-GL	Det Norske Veritas- Germanischer Lloyd
DF	Dual fuel
EEDI	Energy Efficiency Design Index
EEXI	Energy Efficiency Existing Ship Index
EIAPP	Engine International Air Pollution Prevention
GD	Gas-Diesel
GHG	Greenhouse gas
GT	Gross tonnage
HFO	Heavy fuel oil
IGF Code	International Code of Safety for Ships using Gases or other Low-flashpoint Fuels
IMO TIER	IMO emission standard for NOx
IMPCA	International methanol producers and consumers association
IMO	International Maritime Organization
IRENA	International Renewable Energy Agency
LCA	Life cycle analysis
LFO	Light fuel oil
LHV	Lower heating value
LNG	Liquefied natural gas

MEPC	Marine Environmental Protection Committee
NH_3	Ammonia
NO_x	Nitrogen oxide
NPV	Net present value
OPEX	operating expenses
PVP	Product value proposition
ROI	Return of investment
Ro-pax	Roll on/Roll off passenger
SG	Spark-Gas
SO_x	Sulphur oxide
TtW	Tank to Wake
VSPM	Value System Product Model
WtW	Well to Wake

1 Introduction

Methanol has been raised as a potential future fuel while the maritime industry has been searching for ways to meet the demands of the industry's de-carbonization goals and upcoming legislation. Wärtsilä has installed a number of four strokes engines in ferries and cruise ships that serve as a target installation base for methanol fuel conversion projects. Green fuels like methanol have a lot of commercial and technical factors which are not noticeably clear to different stakeholders, when considering the feasibility of projects. The customers in this thesis are considered parties which operate Wärtsilä large bore engines in their ferry or cruise vessels.

The decision for retrofitting a vessel with methanol technology is big decision and therefore the feasibility needs to be evaluated from different angles. In this thesis, the main feasibility areas are analyzed and explained in a way that in specific case evaluation thesis work can used as a check list to evaluate the feasibility of project

Methanol retrofit is also a research and development project for suppliers of technology which needs a feasibility understanding from the supplier, so the retrofit fulfills the commercial and strategical goal of investment. Wärtsilä is developing multiple alternative fuel technologies simultaneously and prioritizing the development according to the inputs received from customers. This thesis is also looking at the related emission regulations and elaborating those as a feasibility factor.

The feasibility is evaluated also by using a uniform interview questionnaire for customer and supplier persons. The questionary results are analyzed, and the main findings are presented. The results are as well mirrored against the general available information related to different feasibility areas.

1.1 Research question

What are the customer and supplier standpoint differences concerning methanol feasibility as a retrofit fuel for cruise and ferries powered by Wärtsilä four stroke engines?

1.2 Research questions definitions

Customer segments typically have multiple names for example, names for ferries can include passenger ships, ferries, or bigger Ro-Pax vessels. Large bore four stroke engines are engines where the piston diameter is bigger than 320 mm. A large bore four stroke engines as and definition it limits the target installation base for bigger vessels which means that yacht and smaller vessels are not included. Typically, vessels that are typically focused on have a length of more than 120 meters and passenger capacity over 150. Wärtsilä large bore diesel engines are in this thesis, considered as following product reference types with available cylinder configurations: W46F, W46, W38 and Sulzer Z40, Z40S.

2 Introduction of feasibility factors of methanol retrofitting

To connect the questionary results to the defined feasibility factors author has done categorization.

2.1 Feasibility factor types

There are several factors which a researcher can evaluate when looking at the whole methanol retrofit project for a vessel. In this thesis, factors are general, technical, safety and commercial factors; however, a strong link between factors exists. The feasibility factors evaluated are categorized below:

- General feasibility factors
- Environmental factors
- Technical factors
    - Engine technology and needed technology
    - Vessel integration and modification needs
- Safety factors
    - Personal safety
    - Operational safety
    - Safety related rules and regulations
- Commercial factors

- Cost of conversion
- Cost of carbon emissions
- Cost of operation and life cycle status of vessel
- Technology development cost

Emissions and economic factors are presented in (DNV-GL, 2016) Use of Methanol as Fuel Methanol as marine fuel: Environmental benefits, technology readiness, and economic feasibility International Maritime Organization (IMO). It is good to know that the DNV-GL report was done before Energy Efficiency Existing Ship Index (EEXI) and Carbon intensity indicator (CII) related discussion has taken place in the marine industry in general.

3 Engine related technical factors

The technical core of the methanol modification of a vessel is concerns engines which are provide the propulsion and other power needed in the vessel. When modification is looked at from the whole vessel perspective, there are lot of systems which are needed for the delivery of methanol to the engines and for bunkering purposes.

3.1 Engine technology

Retrofitting methanol technology to the existing engine is a substantial change especially to the fuel injection technology, engine controls, safety, and automation side. Technology is developing continuously, and innovative solutions are introduced. A retrofit solution has a bit different demand than a new build solution when it comes to the used engine technologies. In normal cases, the starting point is the heavy fuel (HFO) oil or light fuel (LFO) operated engine. This thesis is focuses only on four-stroke engines. The base engine is gives a starting point for technical and commercial feasibility of solution. The existing engine technology that is available and is also assessed for methanol operation is called Gas-Diesel technology. The Gas-Diesel (GD) process has so-called pilot and main fuel injection systems. The purpose of pilot fuel is to deliver small amount of fuel to the combustion chamber where it starts the combustion. After that, the main fuel is injected into the combustion chamber. Usually, the pilot fuel in this process is LFO. GD engines have usually been used in power plant solutions where the gas quality is variates and contains impurities which can lead to as issue in dual fuel (DF), or sark ignited gas engines (SG) as example, oil field related gas installations.

Developments are also made to develop the lighter methanol feeding system which is called port fuel injection. The fundamental difference in this system is that it works with the Otto Cycle when it comes to the methanol injection. This arrangement is having limitations which comes to the fuel share mixtures and usage of methanol at high and low load area. This system can be cheaper to build since it can be based on the existing diesel fuel injection system and lower pressures. To increase the load range and fuel share options, a separate pilot or CR (Common rail) system is needed for ignition fuel.

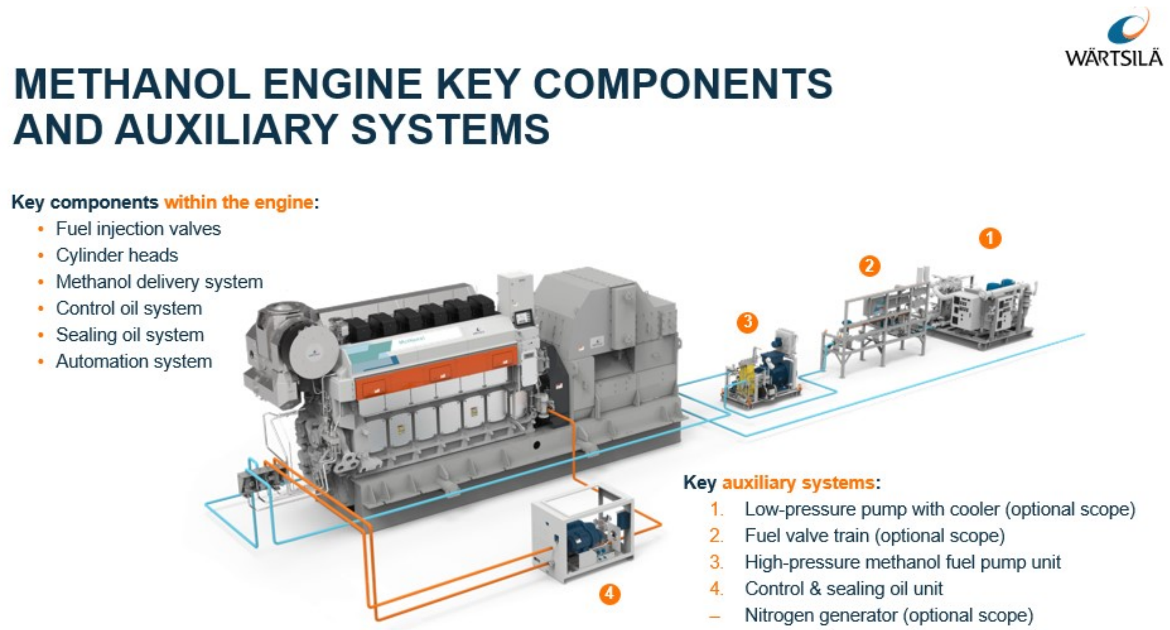

Figure 1 Methanol high-pressure system overview (Wärtsilä, 2023)

3.2 Injection system modifications

GD technology is a proven solution and currently industrialized four stroke solutions are based on this technology. In injections system, the change from the tradition four stroke focuses on to the delivery of methanol as a main fuel to the cylinder. Fuel is delivered through a fuel injector valve which is serves two purposes; it delivers the main fuel and pilot fuel to the combustion chamber.

Pilot fuel is delivered by using normal fuel injection pump pressure and the main fuel (methanol) is pressurized by using a high-pressure methanol pump that is located outside of the engine. Pilot fuel injection timing is determined by the shape and position of normal fuel pump helix plunger. The main fuel is injected through the same injector but using so- called common rail system. The main fuel timing control is done electro-hydraulically using a defined injection map.

A GD based methanol engine injector typically has control and sealing oil arrangement to secure the injector safe operation and to enable electro-hydraulic functionality.

3.3 Cylinder head

Due to changes in injector specification, the target engine cylinder head design needs to be evaluated and if needed a new cylinder head design should be introduced. A cylinder head as an engine component is demanding to design and manufacture, and impact on the total cost of conversion is high. In the best cases the existing cylinder head and methanol injector can be designed so that the existing design can be used just by introducing machining to the existing design for needed methanol components. In the worst cases a completely new cylinder head needs to be designed and validated for methanol usage.

3.4 Engine automation

When methanol common rail injection is introduced to the traditional four-stroke large bore medium speed engine, it will bring new demands to the automation system. The control system needs to have the capacity to determine the correct injection timing and duration in a changing operating situation. This means that the normal traditional speed load control system is no longer enough, and new processor-based automation system is needed to control the engine operation. (Wärtsilä, 2023)

Automation upgrade is also a cost driver for conversion but quite often needed for conversion projects related to the older engines. When looking at this feasibility factor one can note that on the automation side the design time to obsolescence is shorter than in other engine components, due to the automation component´s general lifetime in the market.

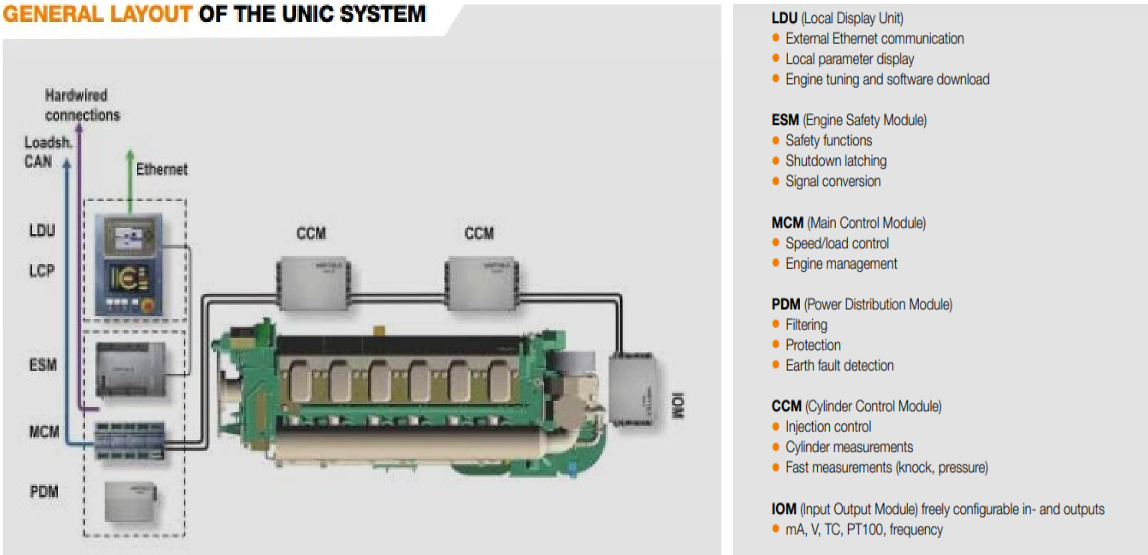

Figure 2. engine automation system (Wärtsilä, 2023)

Figure 2 is an illustrating of modern engine automation. Practically, methanol injection needs cylinder specific timing control. This control needs so-called cylinder control modules. Furthermore, engine speed control takes place in the main control module. It is obvious that engine automation upgrade is an integral part of methanol conversion.

3.5 Methanol high pressure piping, nitrogen generator, sealing oil and control oil pumps and piping

Figure 3 displays the methanol system basic principle for the high-pressure methanol system. Systems are normally divided into the different spaces. Methanol auxiliaries are normally installed into the nominated space where needed protections can be made. Engine room pipes and arrangements are made with double wall pipes. Double wall pipe is protected by nitrogen inertia gas.

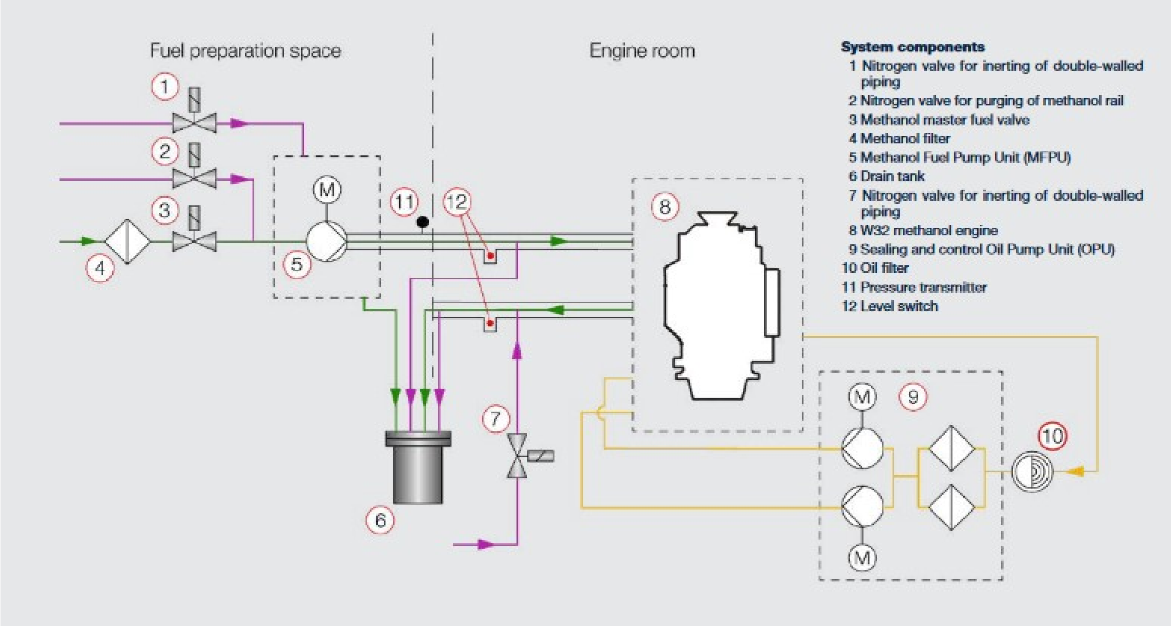

Figure 3. Methanol fuel system layout (Wärtsilä, 2023)

3.5.1 Methanol piping and protection

Due to the high pressure and other dangerous properties of methanol, high pressure piping needs special attention. What is to be noted is that making this type of piping for an existing vessel is even more challenging since certain design options are not possible. Classification societies have created a basic ruling concerning this type of piping and the focus is naturally on safety. Naturally, the nitrogen protection is needed in the high-pressure part of the piping.

3.5.2 Nitrogen generator

Nitrogen protection in methanol conversion needs nitrogen generator to deliver inert gas pressure to the protected areas of pipes and tanks.

3.5.3 Sealing oil arrangement

In GD based methanol engine, the Methanol side of the injector needs isolation from other parts of the injector, and it is done by using pressurized sealing oil delivered to the injector. Sealing oil pressure can be delivered from the separate pump unit. Technically, it is possible also to integrate an engine driven pump for this purpose with needed accessories. What can be used is determined by conversion possibilities of the engine in question and the practical space available for the pump at the engine free end. The chosen technical solution has a price impact and it is a factor of economic feasibility evaluation.

3.5.4 Control oil arrangement

Control oil arrangements are needed to enable the electro-hydraulic function of common rail side of the injector. These functions are related to the starting, duration and stopping of the injection.

The system layout from the Sulzer ZA40S Main engines converted by Wärtsilä is shown below in Figure 4. (Methanol Institute, 2023)

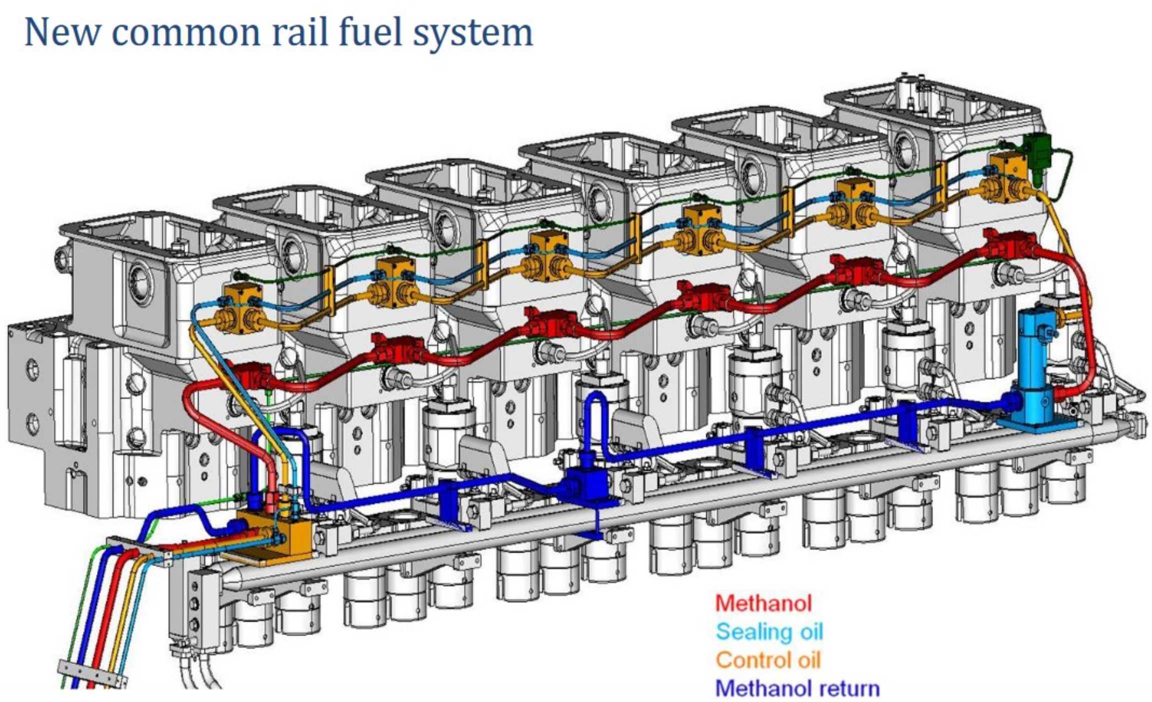

Figure 4. Methanol related common rail fuel system with sealing, Control and return lines on Sulzer ZA40S main engine.

3.6 Methanol running modes and limitations

A methanol engine running with a GD principle always uses diesel for the pilot or main fuel injections. The GD principle also enables a full back-up with diesel in case of malfunctions on the methanol side of the system. A back-up mode is same as a normal diesel operation and diesel mode terminology can be used as well. Between the diesel mode and methanol mode are also a mode which is called fuel sharing. In this mode the share between diesel and methanol variates in fuel share modes, the diesel consumption is naturally increased.

3.7 Summary of technical factors

Technical changes affect the fuel injections system and automation. Methanol conversion increases the need of safety upgrades for engine and high-pressure systems. Engine operation modes are also introduced, and the engine will operate according to GD process after modification when methanol fuel is used.

4 Vessel modifications and auxiliaries

Methanol conversion generates modification needs for auxiliary devices in vessel and as well to the bunkering arrangements and fuel storage. A common factor for these modifications from retrofit perspective is to find suitable space to accommodate the new devices and structural changes. When these factors are evaluated, there is tradeoff between vessel usability and the cost of actual conversion. For example, when looking at the space for the High-pressure methanol pump, we end up evaluating the distance from engine and determining the ATEX protection needs related to the actual space. Depending on the chosen space, the vessel usability could also be affected. On the other hand, due to the double wall piping from pump to the engine, increased distance is a significant cost driver.

4.1 Methanol Bunkering and bunkering station

Methanol bunkering can happen from one ship to another or from a truck to the vessel. In rare cases, methanol bunkering can also happen from a land-based tank to the ship. All these arrangements need to have safe design so that safety and environmental risks are eliminated. Table 1 gives an overview on the related safeguards.

Table 1. Methanol bunkering and related safeguards

Hazard	Examples of Safeguards
Flammability	• Elimination of ignition sources in zones near bunkering hoses and equipment (no smoking, no cell phones, etc.) • Use of Ex classed equipment such as bunker pump, gas detectors, etc. • Vapour detection • Bunker connections should be in open areas such as on deck • Anti-static measures such as grounding and bonding (ensuring there is no potential difference between the supplier and the receiver, and that cannot be developed during flow through a hose or pipe) Elimination or minimisation of leakage or spill through: • Use of drip-free couplings • Use of breakaway couplings • High level alarm • Automatic shutdown of pump when "high high" level is reached in the receiving tank • Emergency shut down equipment
Toxicity	• Personal protective equipment (PPE) fit for the task • Portable gas detector for monitoring exposure • Spill/leakage minimisation measures as above
Corrosivity	• Use of materials compatible with methanol • Spill trays in areas near pipe/hose connections • Use of drip-free couplings to prevent release

(Ellis J, 2021)

Bunkering arrangement related costs are part of a commercial feasibility evaluation.

4.2 Methanol tanks onboard

Methanol has lower energy content than traditional fuels. In practice this means that if the same operation autonomy level needs to be kept, additional tanks need to be made on-board. These tanks can be made from existing fuel tanks or converting ballast tanks, like in Stena Germanica vessel case, which can be seen figure 5.

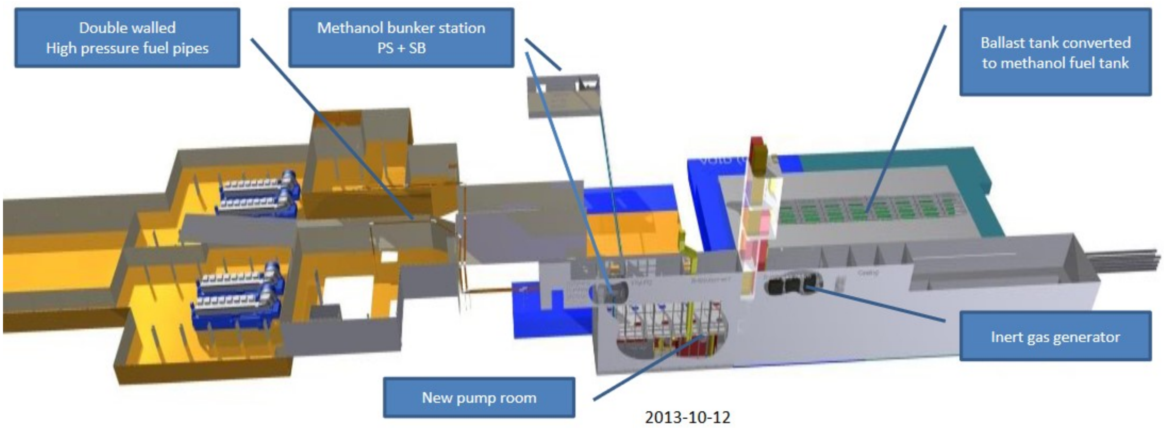

Figure 5. Stena Germanica general Methanol arrangement. (Methanol Institute, 2023)

Generally, the low flashpoint rules are valid on the methanol conversion. Furthermore, DNV has introduced a basic safety concept related to the methanol system, what is good to be followed, when tank arrangement is designed.

Related, four elements of safety for methanol-fueled vessel are described in Figure 6 (DNV, 2022).

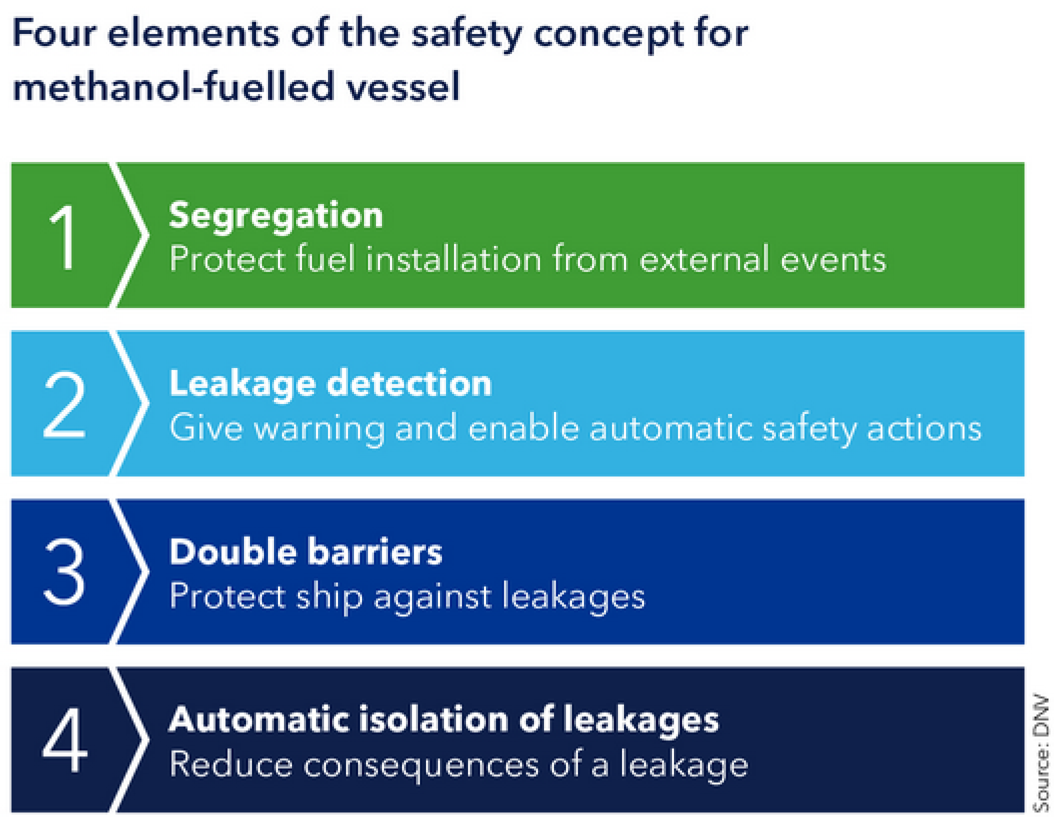

Figure 6. Safety elements for methanol fueled vessels. (DNV, 2022)

Challenges on safety and related design solution are in practice faced when idea is to use cofferdams, venting spaces, double walled pipes, and automatic leakage detections systems.

4.3 Methanol high pressure pump

Regarding the engines based on GD technology; the methanol needs to be pressurized to the high pressure ~600 bar. This is made by an external electric driven high-pressure pump. This pump can also be engine driven. A key demand from an electrical methanol pump, apart from the needed pressure level, is the capability to be leakage free. This capability is vital for the safe methanol operation.

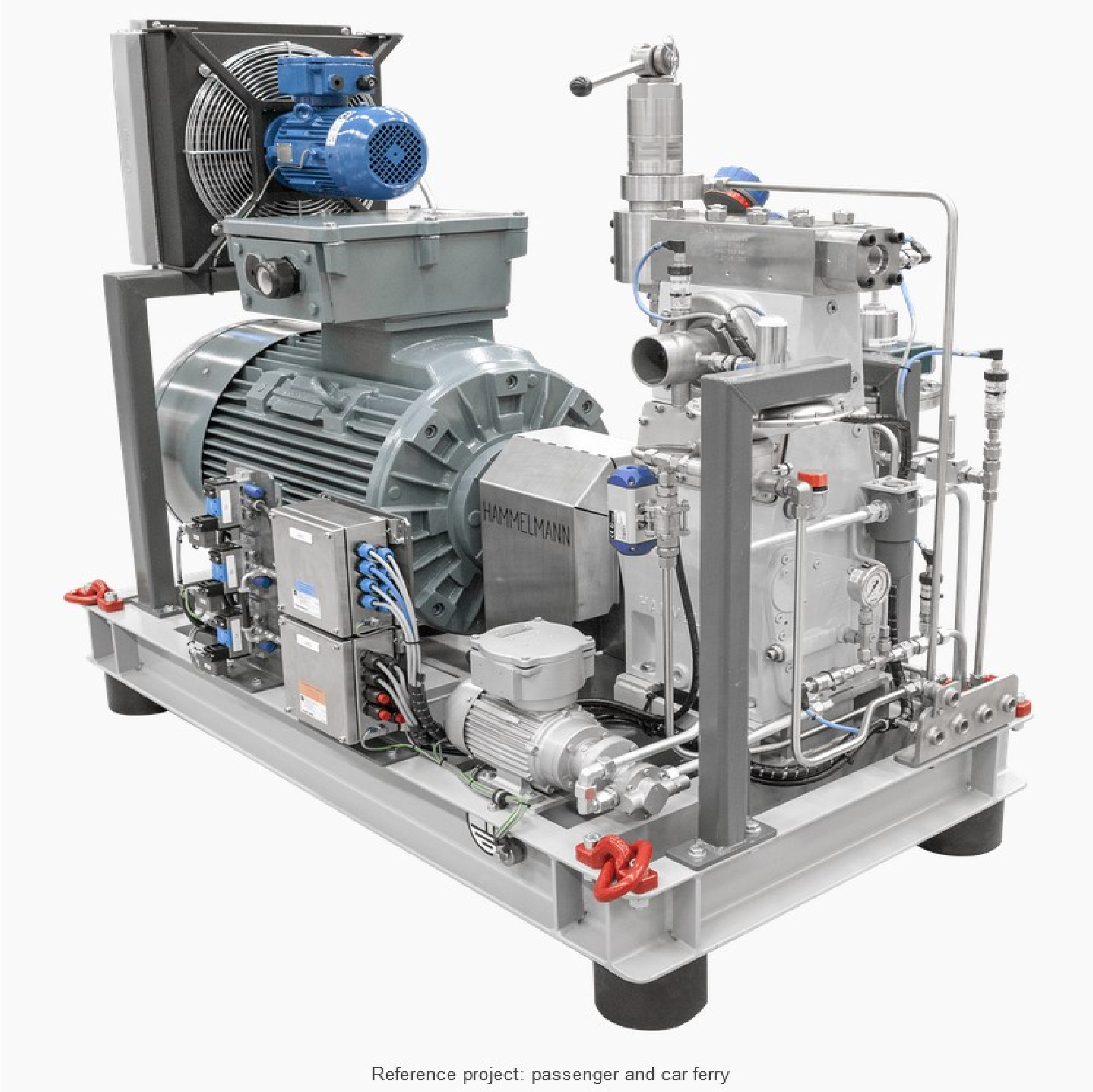

Figure 7. Hammelmann methanol pump (Hammelmann, 2023)

5 Technical rules for safe methanol operation

Methanol is a chemical that is very widely produced, and from a chemical point of view it is well known and the safety rules for the handling of methanol are well developed. Methanol has a material safety data sheet like any other commercial chemicals. What is new is that it has been introduced as fuel for marine engines and not anymore only a one of the chemicals what is transported by tankers.

Classification societies have established technical rules for the vessels which are either new builds or converted to the methanol operation. These rules cover the safety aspect to be taken into consideration in methanol operation. Typically, these concern the tank and piping arrangements with needed protection like nitrogen gas protection. Rules are also for detecting the methanol leaks in the engine room environment and for automatic safety needs. These rules are naturally one cost driver in methanol conversion and can contribute certain space arrangement challenges especially when a retrofit project is in question.

Methanol as fuel is classified as a low flash point fuel and the IMO´s International Code of Safety for Ship Using Gases or Other Low-flashpoint Fuels (IGF Code) gives rules which need to be followed on the new builds and conversions. (IMO, 2022)

5.1 Personal safety

Methanol also brings a new demand for the personal protection of the engine room crew. The material safety data sheet forms a base for needed protection equipment. Maintenance activities where direct exposure to the methanol needs to be well-planned and the flammability of the methanol needs to be taken in to account. Recommended personal protection and safety arrangements are as following table 2.

Table 2. Methanol personal protection and safety arrangements

Face area	Goggles and face shields
Hands	Nitrile or butyl gloves/ Anti-static rubber gloves
Body	Chemical resistant coveralls
Respiration	Fresh breathing air arrangements
Fire safety	Fire extinguishers (Multiple)
First aid	Industrial first aid kits
First aid	Water showers eye stations
First aid	Fresh water for washing and drinking purposes

(Methanol Institute, 2023)

6 Methanol handling, properties, and emissions

Methanol properties brings challenges to the personal protection and the operation in the engine room. Methanol nature as a chemical need to be taken account in everyday activities and especially in emergency situations like fire or when person exposures to the direct methanol contact. Methanol is a new fuel in maritime environment and therefore special training for the operating personality is good to include for the retrofit project scope.

6.1 Methanol handling

ABS Sustainability report from 2021 address well the technical and safety factors related to the Methanol usage onboard the Vessels) (ABS, 2023). ABS report describes the methanol properties and evaluates the methanol as an easier fuel to manage than liquefied natural gas (LNG), ammonia (NH_3) and hydrogen fuels which are other low emission fuel alternatives.

One crucial factor with methanol is the biodegradability. This is important especially with the possible leakages to the air or water.

Methanol (CH_3OH) is colorless, low flashpoint and corrosive liquid. Methanol is toxic. Person’s exposure to the massive quantities of methanol can face blindness, coma and even death if person ingests massive quantities of methanol. When methanol is having a skin contact it can cause irritation burns, inflammations, and cracking. In the normal maintenance and operation activities onboard the demand of extra safety on personal protection is existing. Personal safety requirements are included to the chapter 5.1.

Methanol is heavier than air. In practice this means that when having methanol leakages on-board those accommodates to the lowest points of the space. Special venting arrangement in this kind of situation is needed.

When methanol is burning it has colorless flame which gives challenges to the firefighting.

6.2 Methanol technical properties

Energy content is always an economical and technical factor when looking the retrofit feasibility in general. Energy content affects to the tank capacity which is always a challenge in marine designs. Methanol energy content 19,700 kJ/kg means in practice capacity what is 2,5 more times bigger than with traditional liquid fuels. Tank capacity can be less if the vessel has limited autonomy operation time, although this generates higher bunkering frequency. For the fuel tank arrangement, the non-pressurized tanks are clearly beneficial. Normal fuel tanks are structurally suitable for methanol.

Methanol is quite simple alcohol what comes to its chemical structure. Methanol is used widely in different kind of industry. Methanol is available globally. Main properties can be listed as following table 3.

Table 3. Wärtsilä methanol properties

Properties	Value	Remarks
Dissolving with water	Yes	
Corrosive	Yes	
Flash point	11°C	Diesel flash point 60°C
Energy content	$LHV_{Methanol}$ 19,9 MJ/kg	Diesel LHV_{diesel} 42,7 MJ/kg
Density	792 kg/m^3	Diesel 890kg/m^3
Weight compared to air (gas mode)	Heavier	
Toxicity	Toxic	
Explosiveness	Explosive	
Flame color	Invisible	

Wärtsilä, 2022

International methanol producers and consumers association (IMPCA) updates regularly so-called methanol reference conditions with the specified test methods, these shows in table 4.

Table 4. IMPCA Methanol reference specification

IMPCA REFERENCE SPECIFICATIONS

	TEST	UNIT	METHOD	LIMITS
1	Appearance		IMPCA 003	Clear and free from suspended matter
2	Purity on dry basis	% W/W	IMPCA 001	Min 99.85
3	Acetone	mg/kg	IMPCA 001	Max 30
4	Ethanol	mg/kg	IMPCA 001	Max 50
5	Colour	Pt-Co	ASTM D 1209 ASTM D 5386	Max 5
6	Water	% W/W	ASTM E 1064	Max 0.100
7	Distillation Range at 760 mm Hg	°C	ASTM D 1078	Max 1.0
8	Specific Gravity 20°C/20°C		ASTM D 4052	0.7910-0.7930
9	Potassium Permanganate Time test at 15°C	minutes	ASTM D 1363	Min 60
10	Chloride as Cl- Note 3, page 3	mg/kg	IMPCA 002	Max 0.5
11	Sulfur Note 1, page 3	mg/kg	ASTM D 3961 ASTM D 5453	Max 0.5
12	Water miscibility		ASTM D 1722	Pass test
13	Carbonizables	Pt-Co	ASTM E 346	Max 30
14	Acidity as Acetic Acid	mg/kg	ASTM D 1613	Max 30
15	Iron in solution	mg/kg	ASTM E 394	Max 0.10
16	Non Volatile Matter	mg/1000ml	ASTM D 1353	Max 8
17	TMA Note 2, page 3		optional (see notes for recommended methods)	
18	Aromatics Note 2, page 3		optional (see notes for recommended methods)	

(International Methanol Producer and Consumers Association, 2023)

6.3 Methanol and emissions

6.3.1 CO_2 emissions

Currently the biggest focus on engine related emissions is on CO_2 emissions. Methanol retrofit can give remarkable reduction to the CO_2 emission up to 75% level. This is possible if the methanol in use is green methanol and emissions are evaluated by well to wake principle. CO_2 reduction is lower if other methanol qualities and calculation principles are used. (DNV-GL, 2016). Methanol carbon content has impact to the total carbon emissions. Carbon content is normally well under control in methanol production process

6.3.2 NO_x emissions

Engine NOx emission forms during the combustion. Different engines have a bit different combustion characteristics and therefore general reduction number is difficult to give. Wärtsilä gives emission reduction percentage -50% compared to the diesel. NOx emission limits are based on keel laying date and called as IMO TIER I, II and III limits. In any modification affecting to the engine NOx specification, new engine EIAPP certificate needs to revise by amendment or issuing a new certificate by approved parent engine test.

6.3.3 SO_x emissions

Level of SOx emitted by engine is highly fuel dependent and fuel sulphury level is determining factor. When comparing to diesel engine which is running at optimum load in corresponding methanol operation, the SOx emission is reduced up to- 90%. In Methanol engine SOx emission are formed during the pilot (diesel) injection phase.

6.4 Summary of methanol handling, properties, and emissions

Methanol is toxic and easily flammable gas which forms a base of demands related also to the retrofit project technical demands. Toxic nature of methanol is introducing the new standard for the safety in engine room operations. Energy content is also property which will affect especially to the vessel tank capacity and therefore also to the general arrangement of the vessel.

With methanol conversion all the main emission can be lowered. Lowered emissions are key benefit of the methanol conversion and forms an important value for the investment decisions.

7 Commercial factors

All feasibility factors are at least partially also commercial ones. Major investment is conversion itself and related investments to other operational needs. In the operational face the costs are related to the actual fuel cost and availability. Rules and regulations related to the Methanol are major cost driver during the conversion and operation.

7.1 Vessel modification cost

It is not easy task to evaluate the total conversion cost. There are numerous factors which are affecting to the cost level, for example vessel size, type, engine type, tank arrangement, engine control, level of needed autonomous operation, bunkering arrangements, and targeted emission reduction. There is so far quite limited information about the methanol realized conversion projects cost. Stena Germanica methanol conversion made by Wärtsilä to the Sulzer Z40 main engines is indicating total cost of 22M€. 13M€ of the conversion is related directly to the methanol conversion onboard (Metanol institute, 2022). Onshore side is including the cost related to the methanol infrastructure and bunkering arrangements. This project can be considered as a pilot and therefore the future project is expected to be 30-40 % cheaper. Installation and project specific demands are anyhow heavily affecting to each project actual budget. Engine conversion cost is less than 50 % of total conversion cost. The conversion investment feasibility from the customer side needs to be evaluated based on project total cost. Vessel type impacts as well to the conversion general feasibility. Current methanol fleet tells that so far, the most potential ship types are container ships and tankers. Figure 8 eight includes DNV data where two-stroke vessel are also counted in.

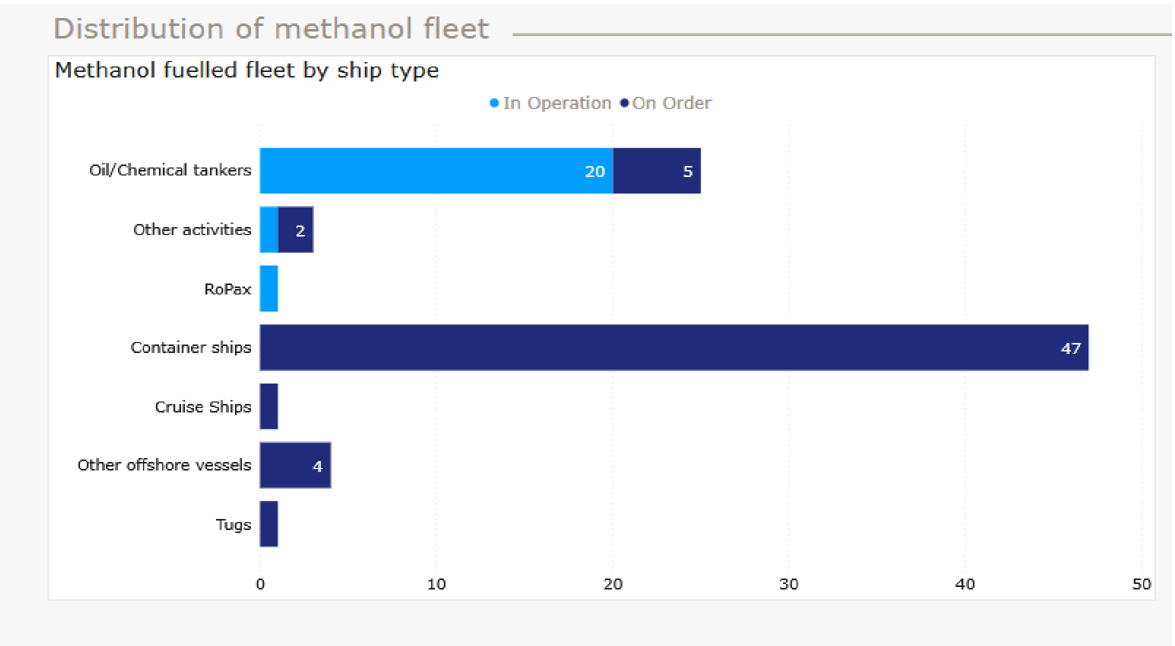

Figure 8. Methanol vessel in operation and under construction (DNV, 2022)

7.2 Related CO_2 emission legislation and business impact

In chapter 6 the main emissions behavior with methanol is described. Emission legislation evolves continuously. Strong effort for de-carbonization introduces more stricter rules and limits. Limits are emission specific but commonly targets to reduce the amount of GHG produced by shipping. CO_2 emissions are controlled by introducing the three types of rules for shipping EEDI, EEXI and CII indicator. Validity and limit developments are illustrated in Figure 9.

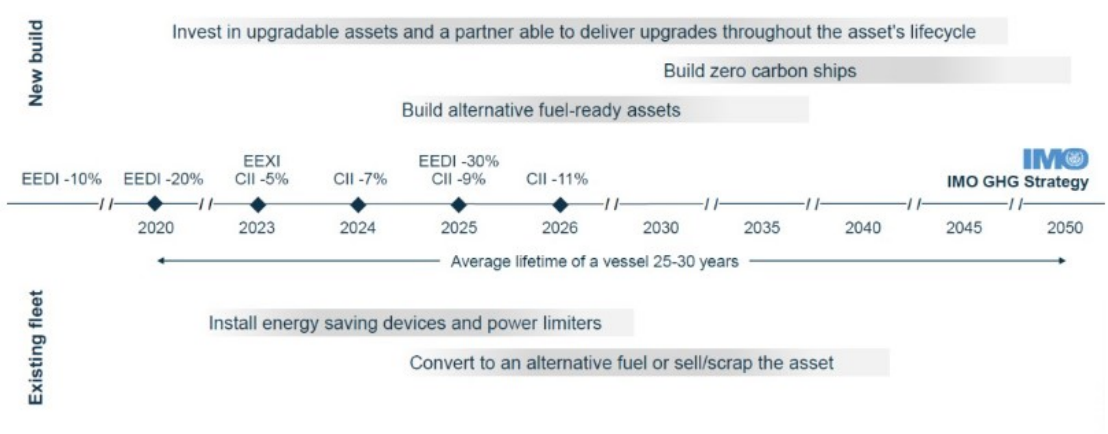

Figure 9. Marine CO_2 related rules new build and existing vessels (Wärtsilä, 2023)

Lot of indication is also that CO_2 related emission trade is coming force also in the maritime side for example in European union area. This naturally favors owners with low CO_2 footprint on their fleet.

7.2.1 EEXI

Energy Efficiency Existing Ship Index (EEXI) is the ruling what is valid for existing vessels. Every vessel needs to define their EEXI before the year 2023. Rule is defined in IMOs Marine Environmental Protection Committee (MEPC). Each vessel type has their own calculation formulas which are takes account multiple design features of the vessels. As a basic principle the EEXI is measuring the vessel CO_2 emission per transport work

7.2.2 EEDI

Energy Efficiency Design Index (EEDI) is similar than EEXI, but the main difference is that it is for the new vessels. EEDI ruling has been valid already from the 2013. EEDI limits are getting stricter on every five-year period.

7.2.3 CII

Carbon intensity Indicator (CII) is based on yearly audits. Ship needs to follow ship energy efficiency management plan (SEEMP) what is targeting to vessel energy consumption reduction. Based on yearly audit the vessels will receive CII rating from A to E. CII limits are getting stricter by every year what means in practice that vessel owners and operators needs to implement continuously new energy saving methods to keep their rating high enough. Figure 10 shows basic principle of CII rating system. In case of received the worst category E on rating, vessel operation is not anymore allowed if improvements are not done in time.

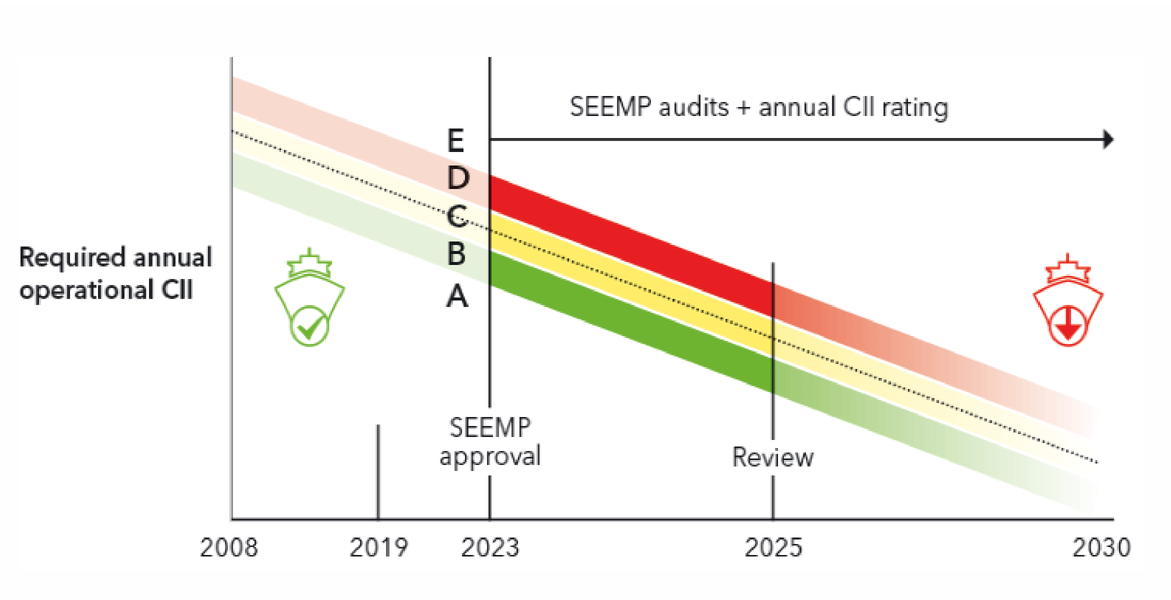

Figure 10. CII principle (DNV, 2023)

7.2.4 Methanol conversion and CII indicator reduction

Methanol has enormous potential to reduce CO_2 emissions and therefore it can give good option to meet the CII targets for existing vessels. The green methanol has biggest potential for CO_2 reduction when well to wake emissions are calculated. Green, grey, black, and blue methanol can be mixed with each other to reduce the carbon emissions. Rules and calculation models need to follow the well to wake (WtW) principle and currently there is not clear agreement on that side.

7.3 Available methanol types

Methanol is available from various sources and processes. Methanol types are categorized by the source of methanol which can be coal, gas, biomass, and hydrogen. Methanol's are also categorized based on the source of energy and level of CO_2 capture in the manufacturing process.

7.3.1 Black Methanol

Black methanol refers to the methanol production from coal when CO_2 capture technologies are not used. This represents about the half of world methanol production

7.3.2 Grey methanol

Grey methanol is outcome of the process where methanol is produced from natural gas and process do not involve any kind of CO2 capture technologies. Globally grey methanol share of the production is around 40-45 % of the production.

7.3.3 Blue methanol

Blue methanol is produced from solid feed stock or natural gas and process is includes CO_2 capture technologies

7.3.4 Green methanol

Green methanol is produced from the biomass or e-methanol produced from the green hydrogen, CO2 is captured, and renewable energy is used in production.

7.4 Methanol price

Methanol price is dependent about the quality and production process behind it. Naturally, to aim for the maximum carbon reduction, the methanol needs to have low WtW carbon footprint. Especially what comes to biofuels also the feeds stock price plays significant role.

Innovation report of renewable methanol (IRENA, 2022) gives a price range of renewable methanol production cost, Figure 11.

Figure 3. Current and future production costs of bio- and e-methanol

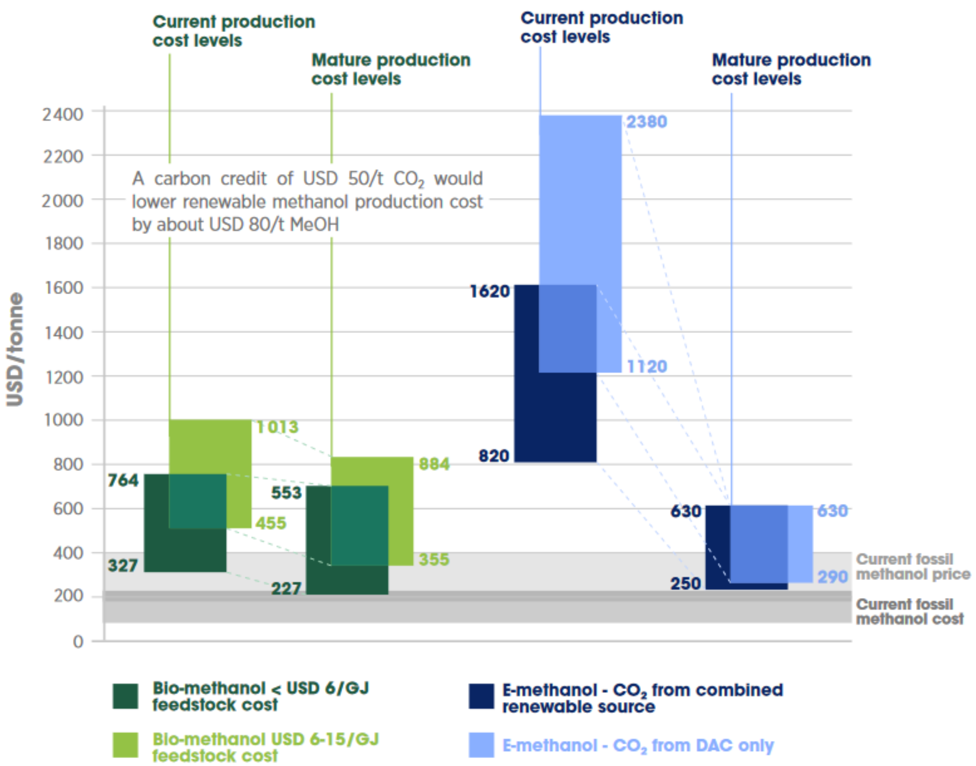

Figure 11 Renewable methanol production cost (IRENA, 2022)

Fossil methanol is globally well available. Geographical variation in methanol prices exists. Methanex publish contractual prices monthly, Table 5. (Methanex, 2023)

Table 5. Methanex methanol price history from year 2022

Methanex Monthly Average Regional Posted Contract Price History

	Methanex Non-Discounted Reference Price (MNDRP)		Methanex European Posted Contract Price (MEPCP)	Methanex Asian Posted Contract Price (APCP)	Methanex China Posted Contract Price (CPCP)
Date	$/gal	$/MT	€/MT	$/MT	$/MT
May.22	$1,92	$639	€ 570	$520	$470
Jun.22	$1,85	$615	€ 570	$480	$430
Jul.22	$1,82	$605	€ 555	$450	$410
Aug.22	$1,79	$595	€ 555	$420	$375
Sep.22	$1,76	$585	€ 555	$410	$375
Oct.22	$1,76	$585	€ 510	$410	$395
Nov.22	$1,76	$585	€ 510	$410	$395
Dec.22	$1,73	$575	€ 510	$410	$395
Jan.23	$1,73	$575	€ 478	$410	$370

(Methanex, 2023)

7.4.1 Off-sea time during the modification

Time at yard for the vessel modification highly depends about the retrofit design, location of tank, location of the high-pressure pumps and number of the engines to be converted. Typically, the time on yard is tried to minimize and certain part of work is done during the voyage. This kind of works are for example, smaller installation works, and engine modification works. Naturally, works done during the operation needs to be done according to the safety rules. Bigger steel works like tank modifications are always done at yard.

7.5 Vessel usability after and during the modification

Changing the fuel to the methanol from traditional fuels increases the need of tank capacity. If there is no space to accommodate fuel tanks other way than to convert the existing fuel tanks to the methanol, this will mean reduced operation range. Methanol has lower energy content per m^3. Bunker arrangements in practice and bunkering times can be considered as factors which affects to the vessel usability. Ferry and cruise ships very seldom considers reduction of their passenger capacity or cargo lanes as an option. Therefore, in retrofit projects other compromising solutions are needed, like modification of ballast tanks.

7.6 Methanol availability globally

DNV updates a map (Figure 14) related to the global availability of methanol. Map contains existing, decided and projects under construction, which comes to the methanol global infrastructure. (DNV, 2022)

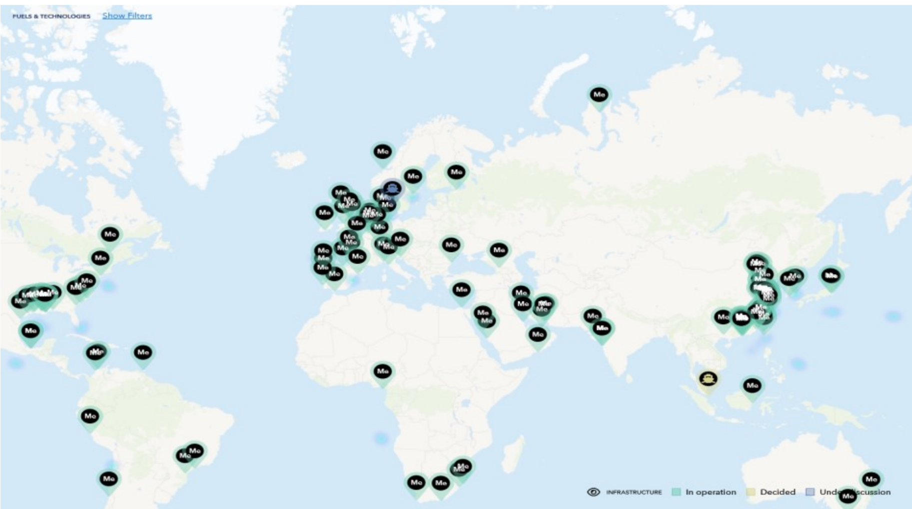

Figure 14. Methanol global availability (DNV, 2022)

Methanol is one of the most traded chemicals in the world. When methanol availability is analyzed is good to note that methanol terminals and methanol availability in the ports are different and highly geographical. Methanol can be easily transported by trucks unlike other new fuels. In truck transportation it is anyhow good to take energy value into the count. This means that number of needed methanol's trucks for bunkering is about 2,3 times more than in similar HFO/LFO bunkering. This can be an issue in time wise since the bunkering time is extended.

7.7 Summary of commercial factors

Commercial performance of methanol conversion needs to serve the remaining lifetime of the vessel. Investment needs to give return of investment in decent time. Conversion cost and methanol price are direct variables which are easy to calculate, but not necessarily easy to forecast. There are also indirect variables like emission wise performance and changes for the vessel usability. Additionally, factors which are time limited to the conversion moment, like off-hire time. Availability of green methanol can turn also to the commercial factor when the emission related out of compliancy time is penalized in the future.

8 Sustainability

Different methanol types which were described earlier are affecting to the methanol sustainability. Fossil fuel based like goal and LNG based methanol is having bigger environmental footprint than renewable based or methanol produced by green energy.

Whenever marine fuel sustainability is evaluated, focus has traditionally limited to the chosen fuel onboard and its environmental impact, this is nowadays described as a Tank to Wake (TtW) approach. Also, the related legislation still uses this same approach which in practice is not always guiding the fuel choice to the most sustainable alternative. In today's world the focus has changed to evaluate the complete value chains related to the made choices. This means, that the fuels are evaluated more with well to wake principle.

8.1.1 Tank to wake vs. well to wake

Once in (TtW), the vessels considered as an object what is evaluated, in Well to Wake (WtW) the whole value chain is under focus. Idea of TtW is simple to look how vessel is using energy and producing emission on its operation. WtW principle is looking emissions of the fuel production and usage. Energy side is monitored through whole fuel pathway. This view is including much more stakeholders and in away have more holistic view when we are looking the global emission impact of one specific vessel in operation.

8.1.2 Well to tank

To evaluate different fuels and methanol impact it is beneficial also to introduce the Well to Tank (WtT) definition. This is focusing to the early part of fuel supply chain and fuel production, source, energy density and needed logistical arrangement from WtT. Fuel journey to the tank is also called as a fuel pathway.

8.1.3 Sustainability with carbon intensity

Emission result of the any fuel is highly affected by evaluation principle used from the overall emission impact point of view. WtW emission is giving more complete picture about the fuel pathways, Figure 12.

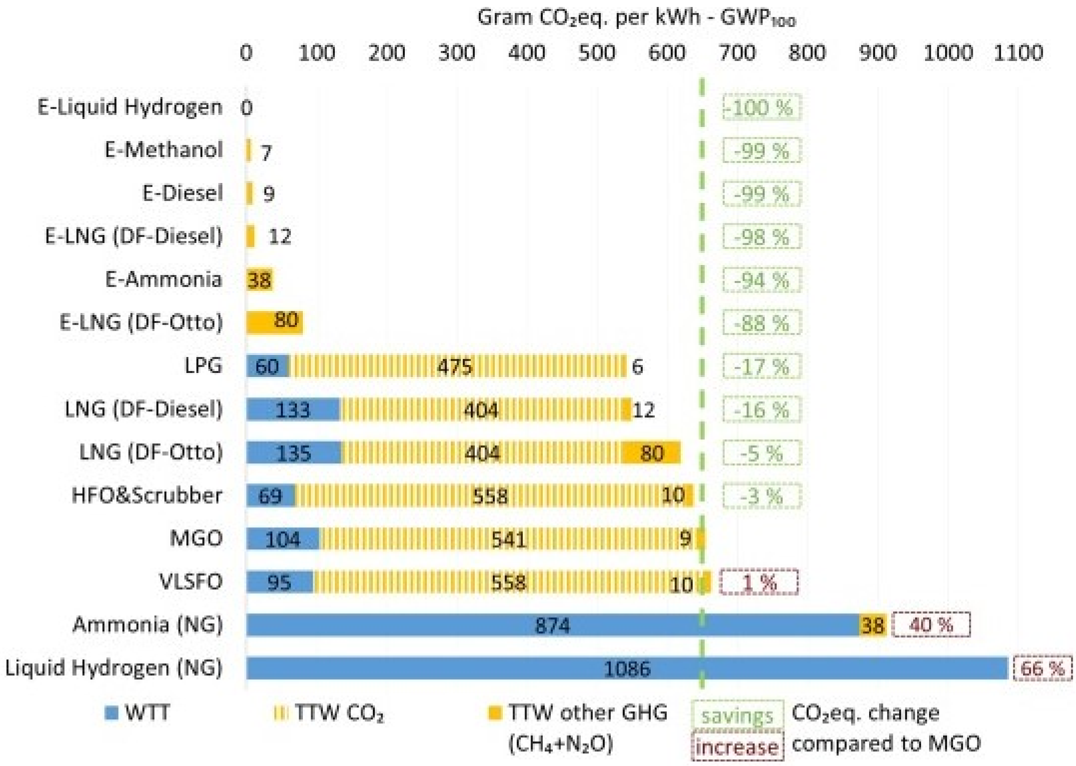

Figure 12. Well-to-Wake emissions in gram CO2eq per kWh (GWP100) (Elizabeth Lindstad, 2021 (103075,ISSN 1361-9209))

IMO is currently reviewing their rules in renewable fuels TtW emission calculation. TtW approach makes the evaluation simpler but on the other hand it does not give the whole answer to the question, how sustainable one fuel type is from the global emission and GHG point of view? Therefore, IMO has already ordered some studies on how to establish a method and how the WtW principle can be used in the future as a base for emission comparison of different fuels, like in the report ordered by IMO is taking up. (Ricardo 2021) Energy intensity of fuel chain against the power needed for vessel propeller indicates the energy performance of chosen fuel, this is illustrated in the Figure 13. The energy demand for the green fuels is significantly higher than traditional fossil fuels for example e-methanol this ratio is 6 to 1.

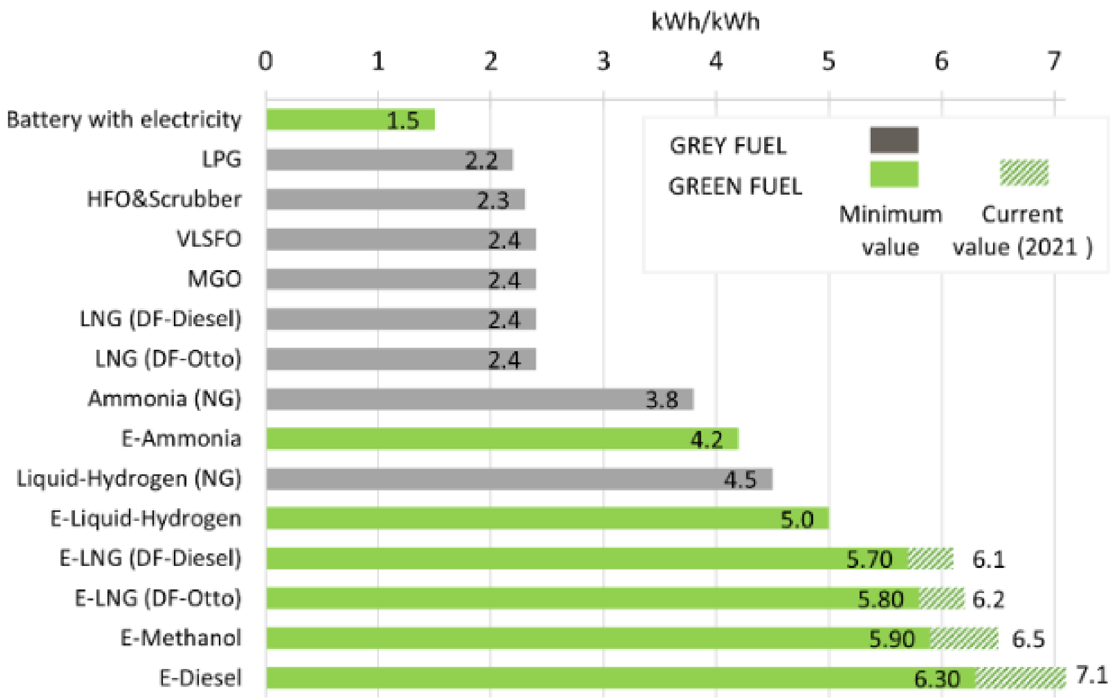

Figure 13. WTW - energy required as a function of fuel per kWh delivered at the propeller

(Elizabeth Lindstad, 2021 (103075,ISSN 1361-9209))

Work around this topic is continuing. WtW GHG standard will be discussed in IMO´s working group meeting 20 to 24 March 2023 and the week before MEPC 80 meeting in July 2023 (DNV, 2022). In this meeting the life cycle analysis (LCA) of renewable fuel will be taken up as an important agenda point.

9 Background of PVP and CVP theory

Product Value Proposition (PVP) and Customer value Propositions (CVP) are commonly used method to analyze how well the designed product or combination of product serves and fulfills the customer actual needs and expectations. CVP has a bit wider focus compared to the PVP and is analyzes the whole customer experience while the PVP is focusing more to the individual product. The CVP has been defined by (Payne; Frow;& Eggert, 2017) in the following way.

"A customer value proposition (CVP) is a strategic tool facilitating communication of an organization´s ability to share resources and offer a superior value package to targeted customers"

Literature is including definitions to the PVP, but mostly it is considered as a list of benefits what customer is receiving by buying the product or service.

9.1 PVP and CVP in Wärtsilä methanol conversion

Methanol conversion can be considered as a project what is including multiple sub-products. Methanol conversion can be looked from the PVP and CVP angle. Common for these both approaches are to be able to answer the following main questions:

- For whom the product or whole business is targeted?
- Against what is the product or business competing?
- What are the customers' requirements (benefits and expectations)?
- How is the product or service answering to the customers' requirements?

Wärtsilä uses model where the product needs to answer to the following question. Usage and creation of product values are anyhow under continuous development and recently the process is going more towards value co-creation of values what is described in Chapter 9.2.8.

9.1.1 Who in value proposition?

In this part of the proposition the customer side stakeholders are identified. In methanol conversion we can identify the target customer categories, business users, technical and economical buyers.

In this thesis we are focusing on the marine customer group and having focus only on the ferry and cruise segment with the main engines as described earlier.

Business users are professionals which will use the product or service to bring more value to their operation and business. In the marine side we can name chief engineers to represent the actual operators and maintenance crew on board, typically in daily involvement with the product during its lifetime. Higher level of business users are then managers like technical superintendents and fleet managers who carries the overall responsibilities about the operations.

Technical Buyers are usually the persons which have overall technical responsibility in the shipping companies' typical titles in shipping companies are for example, technical manager or director. This group has focus on the initial purchasing phase to and comparison of alternative technical solutions.

Economic buyer usually calculates the NPV and ROI values out from the business case in shipping company side and usually evaluates how well the values presented by supplier are in line with their values. Typically purchasing is led by financial officers and other economical managers in shipping company.

9.1.2 Against what in value proposition?

In this part of value proposition, the competition is analyzed. The target is to identify the related opportunities and reveal what kind of threats the new product or business introduction will bring with it. The competition is traditionally divided in to the external and internal competition. External competitors are other companies which are having product and services which are bringing similar values to the customer and can be considered as an alternative. Generally, in case of introducing a modern technology, it is possible that a straight competition is not existing in the market, but usually it starts to develop immediately after the new product launch. Internal competitors are similar product or solution in company's product portfolio which can give same or partial customer value. Using Wärtsilä as an example the ammonia retrofit development could be considered as an internally competing product.

9.1.3 What are customer requirements?

In today's world the marine technology development is focusing strongly to environmental values what can be introduced with the new products and solutions.

According the PVP theory customer have their business specific demands which are practically reviewed by evaluating how well the product values are answering following type of questions:

Functional needs: what are the needs while using the product or solutions?

Usability needs: How easy is the of usage of product or solution

Performance and efficiency need: what are the needs regarding for example the environmental or financial performance?

Regulatory and standard needs; what are the demands from the law and other regulations?

Economical needs: what are business needs that makes product feasible?

Effort and Risk: what are the risk and efforts related to purchase of the product or service?

9.1.4 How to answer the customer requirements?

In this part of the PVP explains how the issues stated in "what" part can be fulfilled. When value proposition is successful it gives easily answers to the questions. If the questions in "what" part are difficult to answer it is good to review the product values and consider if something has not identified or some development needs exist, which would help fulfill customer demands. Typically, excellent value proposition has good relationship and logic between what and how part in PVP.

9.1.5 Values and value co-creation from supplier perspective

PVP or CVP includes multiple values and different level of interactions. One way to illustrate these is to use so called Value System Product Model (VSPM), Figure 15. This model does not only include the product features but also explains the values of the business ecosystem and benefits created to the end-user and buyer (Haines-Group, 2023).

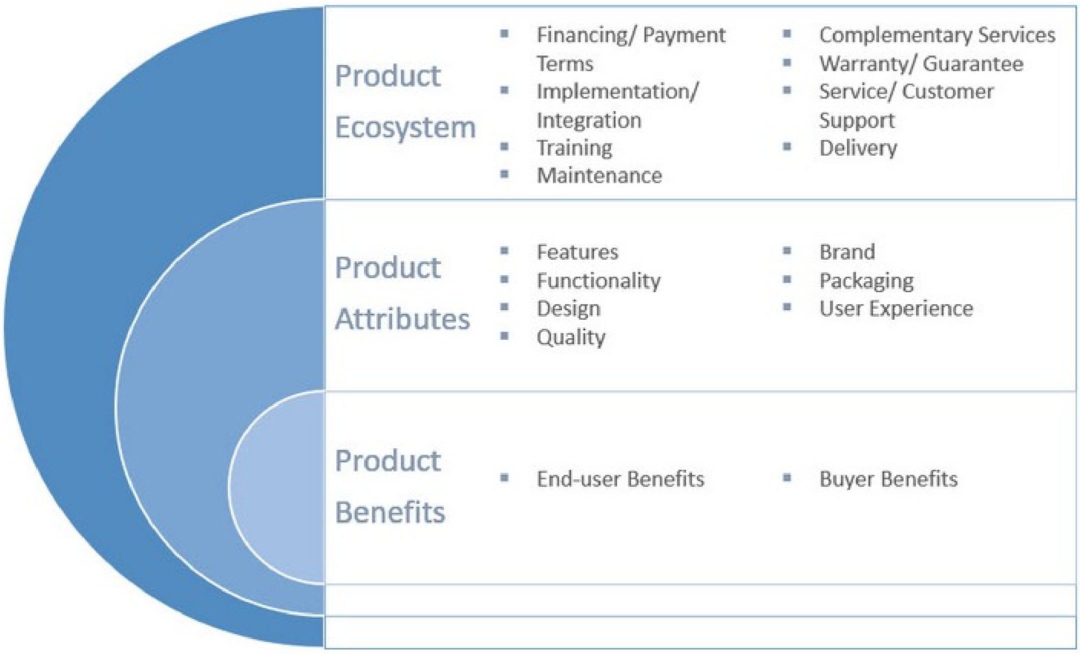

Figure 15. Value System Product Model. (Haines-Group, 2023)

Methanol conversion is offering which has multidimensional relations not only between customer and supplier but also between customer customers (end user), local and global level societies. This leads automatically to the situation where values cannot only be mapped by product features way. Wärtsilä in methanol conversion acts as a technology provider and is one of the suppliers in the whole project. It is evident that level of co-operation is huge on this type of project and therefore already in the value creation phase lot of co-creation between different stake holders takes place.

9.1.6 Supplier value creation process

This thesis handles value co-creation process mainly from suppliers' perspective. First, we need to understand how the customer creates values (Payne, Storbacka; & Frow, 2008). Figure 16 shows the conceptual framework for value co-creation.

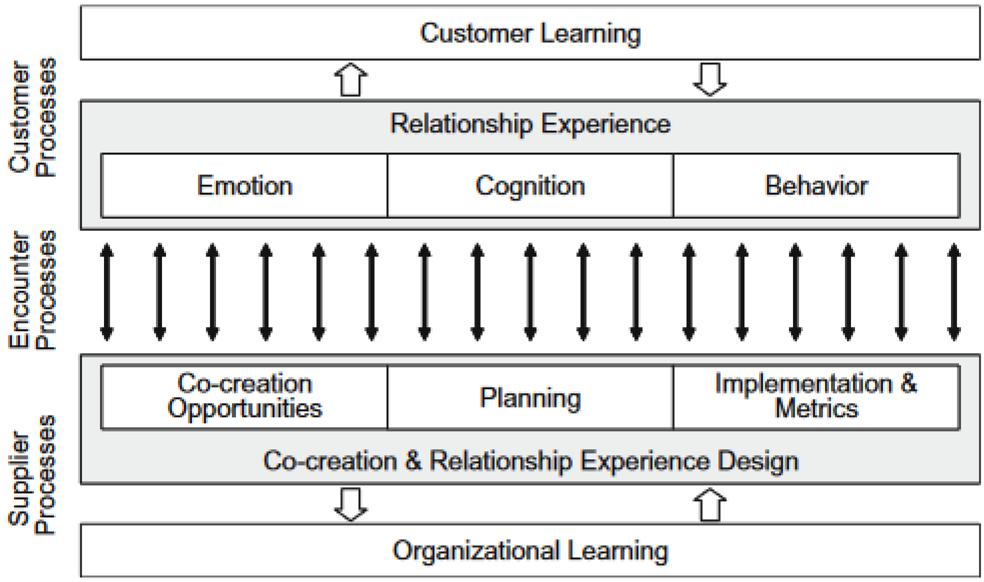

Figure 16. Conceptual framework for value co-creation (Payne et al., 2008)

Supplier co-creation opportunities can take in place in product meeting reviews and other discussion. In deepest way for example in methanol conversion this happens during the pilot installation delivery and operation where lot of interaction with customer takes place and customer values are more deeply understood. Co-creation opportunities comes also with legislation changes, new technical innovations and from the changes in customer business environment.

In practice the co-creation approach is meaning substantial changes to the product development traditional model where something is first developed and then marketed. Basically, this all needs to turn to the model where listening, agile adaptation, co-operation, and co-creation is actively used. (Payne et al., 2008).

In co-creation model the customer centricity is in focus. Challenging part is to monitor what increased integration with customer produces and turn that to the business opportunities. The needed metrics for monitoring needs to be developed and fine-tuned continuously in the changing environment.

Methanol conversion gives Wärtsilä also exceptionally good opportunity to understand how internal organization needs to be changed to serve new business. Naturally, during the project there is lot of possibilities to increase the customer knowledge and understanding. Anyhow critical issue from the supplier success perspective is how the information is turned to competition advantage for the future business.

9.1.7 Marketing and PVP and CVP

One of the greatest inputs of value proposition is for marketing. This is also valid in B2B environment. Successful sales need a solid marketing material what explains the product values and can answer to the customer questions, even those ones which are not yet asked. Well-made PVP or CVP gives all the ingredients to the successful sales and marketing material creation.

9.1.8 Example of methanol retrofit value proposition, supplier position and value co-creation

Figure 17 illustrates the traditional PVP/CVP values and answers to the questions what and how? Simultaneously, relationship of values, risks and value co-creation in the product ecosystem is illustrated. In the same figure, major product co-creation opportunities channels are visualized. Additionally, value system product model integrates to the values and shows the interfaces of the values. Product value proposition not often includes the risk assessment, but since risks are essential parameter on this magnitude project evaluation model, main risks are included.

Working Product ecosystem generates benefits throughout the supply chain. These benefits are greater than identified threads. Successful value proposition gives the expected values "what" to the customer and gives them competitive advantages in their own business landscape. Figure 17 illustrates this as a product benefit. Customer and their customers also form base for market driven value co-creation.

Supplier meets the customer expected values by product attributes which can deliver the needed outcome. This answers to the question "how" in product value proposition.

Product values are formed by all the stakeholders, including the official organizations e.g., International Maritime Organization (IMO), financial institutes and parties, which forms other norms to the industry.

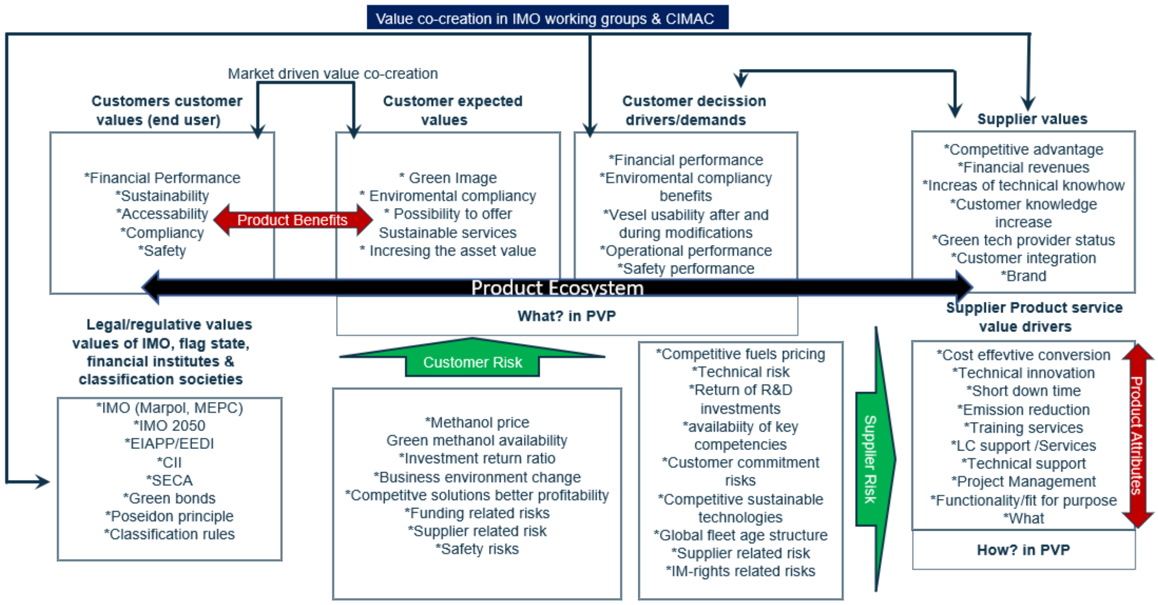

Figure 17. Methanol retrofit product values, risk, value co-creation and value model (Salo, 2023)

10 Empirical part

In this chapter of the thesis, the questionnaire results are analyzed. The correlation level between the supplier and customer standpoints are evaluated. Also, the different professional groups standpoint differences are described.

The results from the questionary were divided into categories of the main feasibility factors.

10.1 Research methods

Author uses in this thesis quantitative Likert scale method. Questionnaire questions are formulated by using a 5-scale method. This method is originally developed by psychologist Rensis Likert. Ajit Kumar Roy in his book describes the method in following way "A Likert scale is a psychological measurement device that is used to gauge attitudes, values, and opinions. It functions by having a person complete a questionnaire that requires them to indicate the extent to which they agree or disagree with a series of statements (Roy, 2020, p. 1)". Likert method is effective way to get overall result about the people's opinion and engagement to the topic. Author finds this good method for this thesis since purpose is to reveal general opinion of target group to the general feasibility factors. Totally 676 questionnaires were send to Wärtsilä customers and internal persons. Total response rate is 8,3%.

10.2 Interview questions and feasibility factors

The questions for the main factors are described in the following sections or under the following subheadings.

10.2.1 General factors

- In general, how feasible do you consider methanol to be as a green retrofit fuel solution for existing vessels?
- What are the two biggest challenges with retrofitting a vessel for running on methanol?
- What are the two biggest challenges with retrofitting a vessel for running on methanol?

10.2.2 Environmental factors

- Methanol and water mixing lowers NOx emissions significantly, but the freshwater tank capacity requirement on board for water mixing is 25% of the methanol tank capacity. This requirement is?
- Do you agree that methanol retrofit technology should only enable a maximum of 20% methanol usage and aim at light technical changes, improving only the CII index (not aim at complete carbon neutrality)?

10.2.3 Technical factors

- The best technology for methanol retrofitting is the traditional diesel process as base, combined with high pressure methanol injection?

- In the future, vessels need to comply with CII (Carbon Intensity Indicator) regulations. Does Converting to methanol meets these future regulatory demands?

10.2.4 Safety factors

- Methanol is toxic and has a low flash point. How challenging do you consider this to be from a safety point of view?

10.2.5 Commercial factors

- In your opinion, will methanol availability in the future be good enough to serve the needs of vessel retrofits? Please answer separately for each Methanol sub quality type.

- From an investment point of view, the maximum vessel age where a methanol retrofit project would still be feasible to execute is (choose the closest maximum age).

- Methanol is a liquid fuel that can be stored in pressureless tanks (converted HFO-tanks or modified ballast tanks). How big of a benefit is this in vessels after retrofit from a usability point of view compared to the pressurized tanks on board?

Questions have multiple connection points to different feasibility areas. The main feasibility areas for questions are illustrated in the below Table 4.

Table 4. Questionary questions and feasibility areas

• In General, how feasible you consider Methanol to be as a green retrofit fuel solution for existing vessels?	G
• What are the two biggest challenges with retrofitting a vessel for running on methanol?	G
• Mixings of methanol and water lowers NOx emissions significantly, but the freshwater tank capacity requirement on board for water mixing is 25% of the methanol tank capacity. This requirement is?	E C
• Do you agree that methanol retrofit technology should only enable a maximum of 20% methanol usage and aim at light technical changes, improving only the CII index (not aim at complete carbon neutrality)?	E C
• The best technology for methanol retrofitting is the traditional diesel process as base, combined with high pressure methanol injection?	T
• In the future, vessels need to comply with CII (Carbon Intensity Indicator) regulations. Converting to methanol meets these future regulatory demands?	E C
• Methanol is toxic and has a low flash point. How challenging do you consider this to be from a safety point of view?	S
• In your opinion, will methanol availability in the future be good enough to serve the needs of vessel retrofits? Please answer separately for each Methanol sub quality type?	C E

• From an investment point of view, the maximum vessel age where a methanol retrofit project would still be feasible to execute is? (Please, choose the closest maximum age)	C
• Methanol is a liquid fuel that can be stored in pressureless tanks (converted HFO-tanks or modified ballast tanks). How big of a benefit is this in vessels after retrofit from a usability point of view compared to the pressurized tanks on board?	C S

10.3 Professional roles

A Total of fifty-six responses were received from the questions and twenty-two of these came from the customers and thirty-six from supplier's employees. The professional distribution of roles is reported in Figures 18 an19.

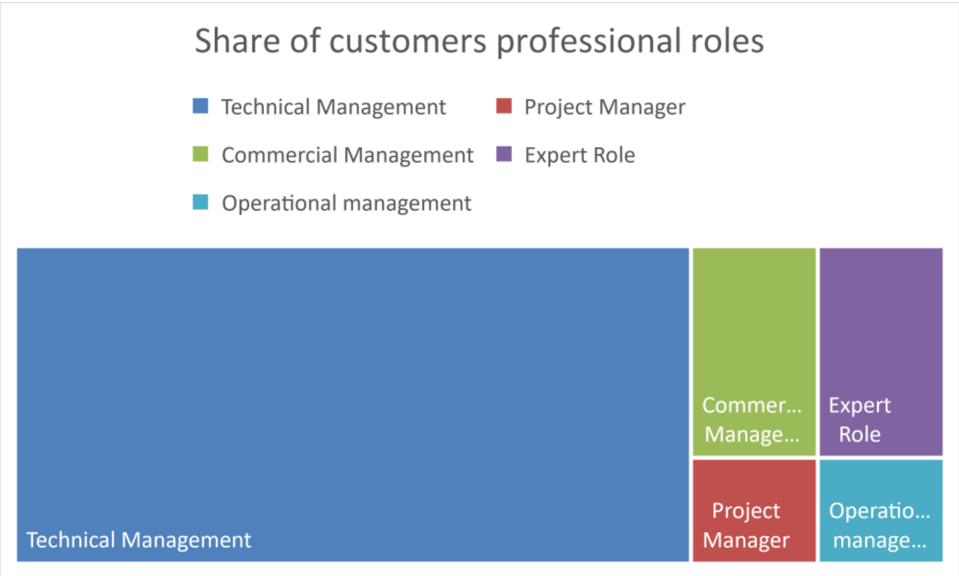

Figure 18. Share of customers professional roles

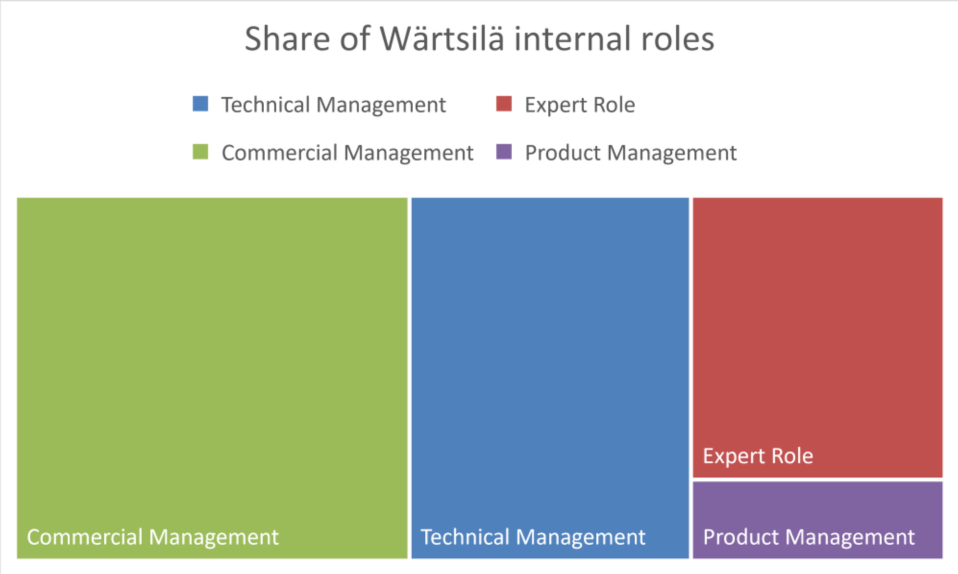

Figure 19 Share of supplier's professional roles

10.4 General feasibility overview

The median answer for the methanol retrofit feasibility is somewhat feasible. Among the supplier´s answers where retrofit is considered very feasible receives more weight than the customer side. In general, the results show that the methanol retrofit is considered as a feasible solution, Figure 20.

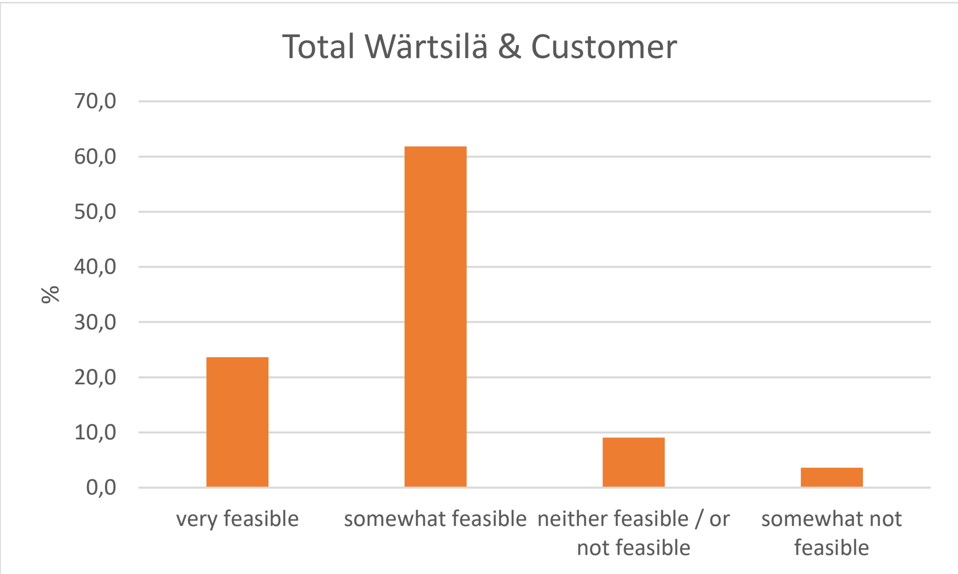

Figure 20. Methanol retrofit general feasibility

When feasibility is evaluated by asking about the possible challenges related to the methanol retrofit solution and naming two the most significant ones, the results are showing that the price of conversion and methanol availability in the future are considered the most challenging factors, picture twenty-one. Results are similar both on the supplier and the customer side. Methanol price is commonly seen as a challenge according to approximately 20% of the received answers. Differences among identified challenges come from the competencies related to the methanol operation and the methanol safety related properties.

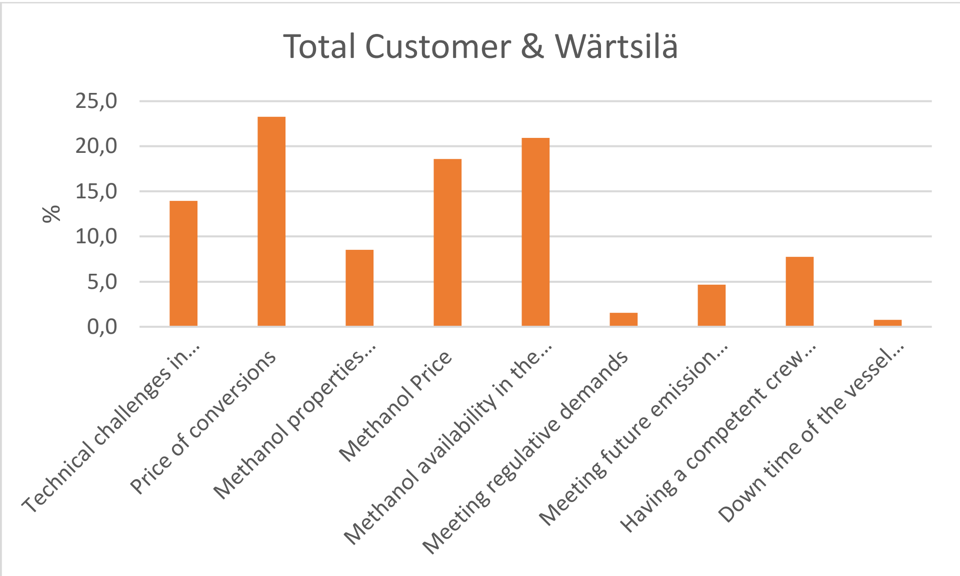

Figure21. Methanol conversion challenges

When the focus is on the methanol retrofit possibility from different professional groups perspective it can be noted that commercial, project and product management professionals see the price of the conversion as the biggest challenge. Technical, expert, and operational professionals are concerned that the availability of the methanol will be another significant challenge. Both professional groups also have concerns about the methanol price, Figure 22.

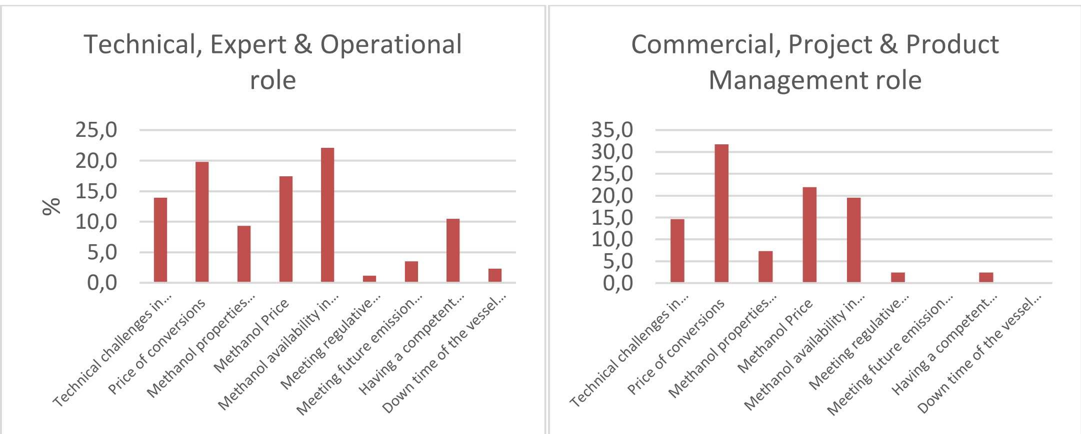

Figure 22. Professional group identified challenges on methanol retrofit

10.5 Environmental feasibility overview

10.5.1 Green methanol availability

Methanol type is a dominating factor in how emissions are expected to be reduced with methanol retrofit. Results shows that availability of green methanol is considered ´available´. None of the methanol types are considered as a fully available and what is to be noted is that answers do not correlate with the global production of different methanol types, Figure 23.

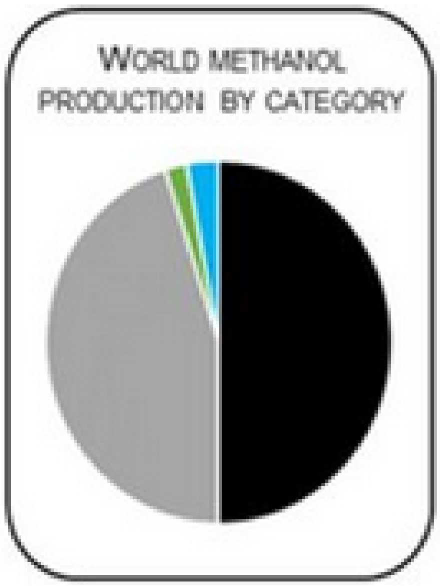

Figure 23. Black, grey, blue, and green methanol production globally (Lake Charles Methanol, 2023)

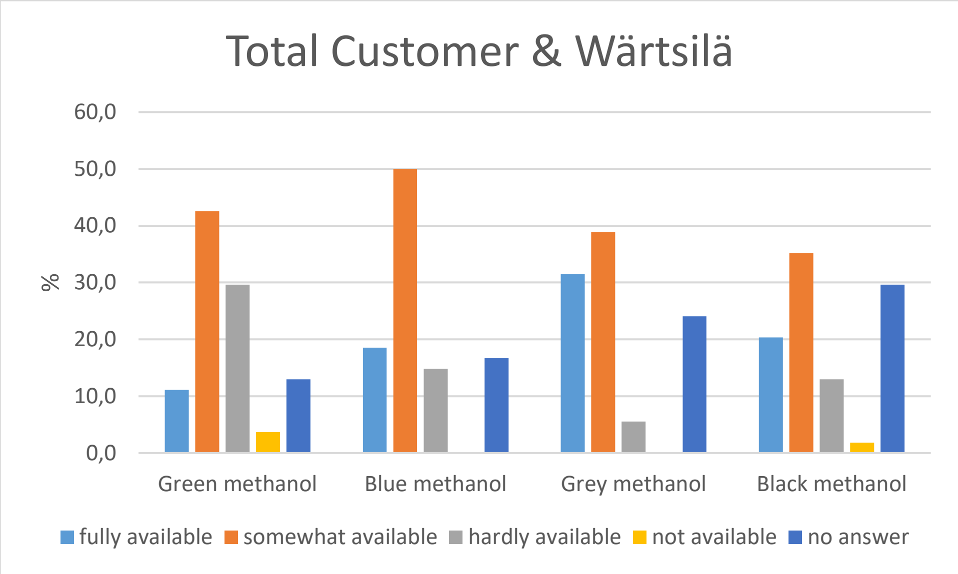

Figure 24. Results concerning availability of different methanol types

When responses concerning the different methanol types of availability is looked at, it can be noted that in both groups the number of ´no answer´ responses are high, Figure 24. Lower results on the availability of high-volume methanol types indicates that knowledge about the methanol availability has not yet been developed. The outlook on the availability on geographical variations is high and at the local level the situation can variate significantly.

10.5.2 NO_x emission reduction by methanol conversion

Methanol is mixes well with the water. In combustion of the fuel, the amount of NO_x formation is related to the combustion temperature. Adding water to the methanol lowers the NO_x emission but also significantly increases freshwater tank capacity need.

The questionary answers regarding the feasibility of water mixing with methanol indicates that this technology is found mainly somewhat feasible, Figure 25.

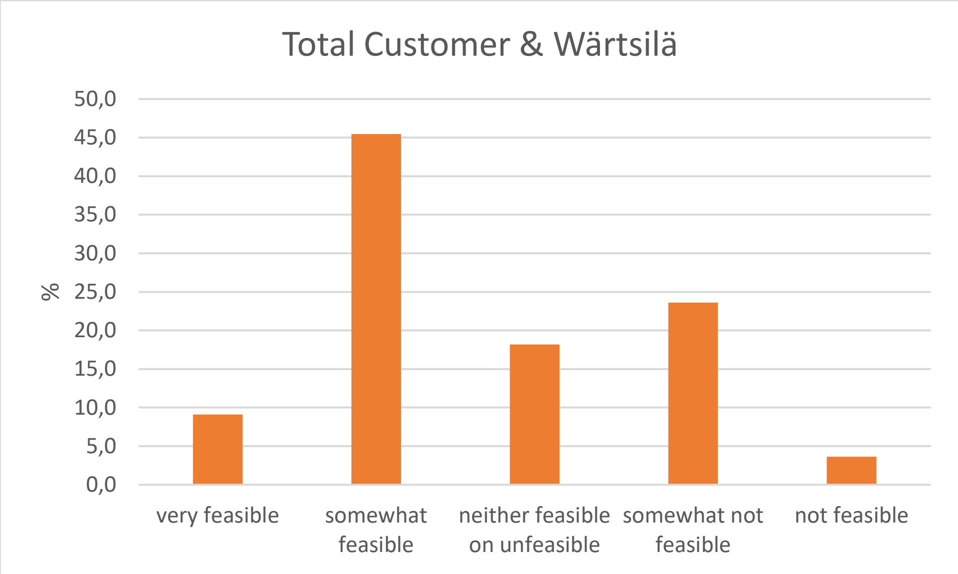

Figure 25. Feasibility of NOx reduction by water mixing

10.5.3 Partial methanol conversions

One of the questions in the questionary asked for the respondent´s opinion on the feasibility of only partial methanol conversion of the engines. Answers shows a more negative approach to that solution. Overall customers and commercial persons see it slightly more feasible than technical and supplier's personnel in general, Figure 26. Partial retrofit specific question was pointed out to the feasibility of CII compliancy with methanol retrofitting.

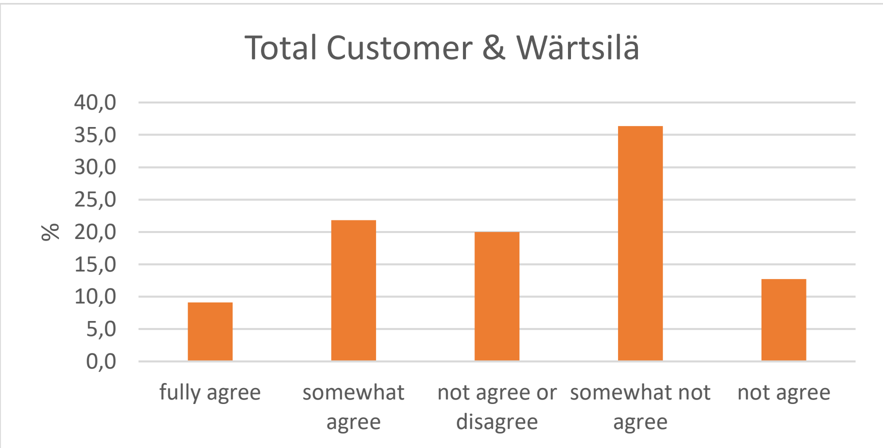

Figure 26. Partial methanol conversion feasibility questionary results

10.5.4 Methanol retrofit and CII

Methanol retrofit positive impact on the total carbon emissions is seen as somewhat feasible solution, Figure 27. In this question, there are no significant differences either with between supplier and customer groups or between commercial and technical personnel groups.

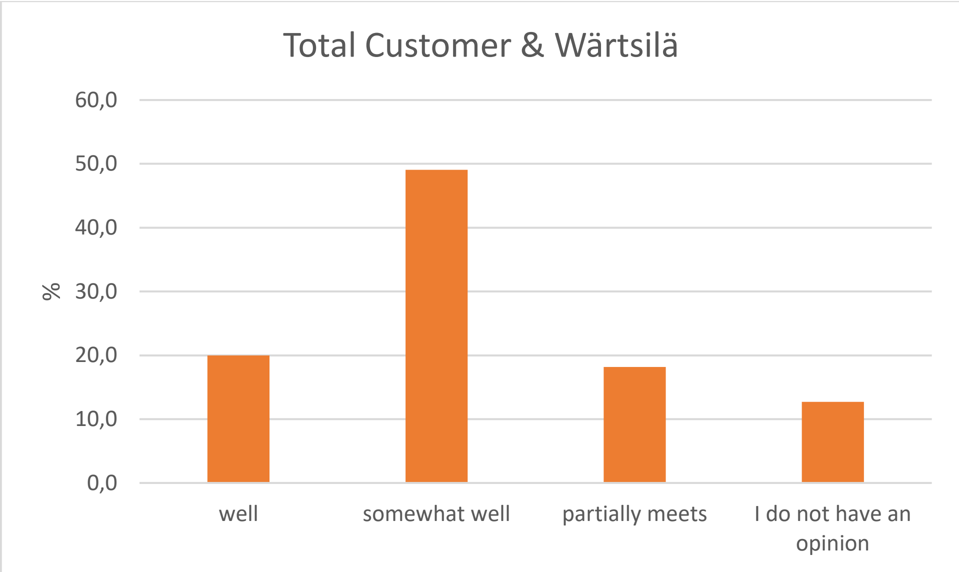

Figure 27. Methanol retrofit as method to lower CII indicator value

10.6 Technical feasibility overview

There is still quite a limited amount of experience regarding the different technical approaches related to the methanol conversion. Existing four-stroke installations uses high pressure methanol injection combined with the diesel injection. The question dealing with this method feasibility of the methanol conversion shows that on the customer side there is a weaker commitment to this statement than on the supplier side, Figure 28.

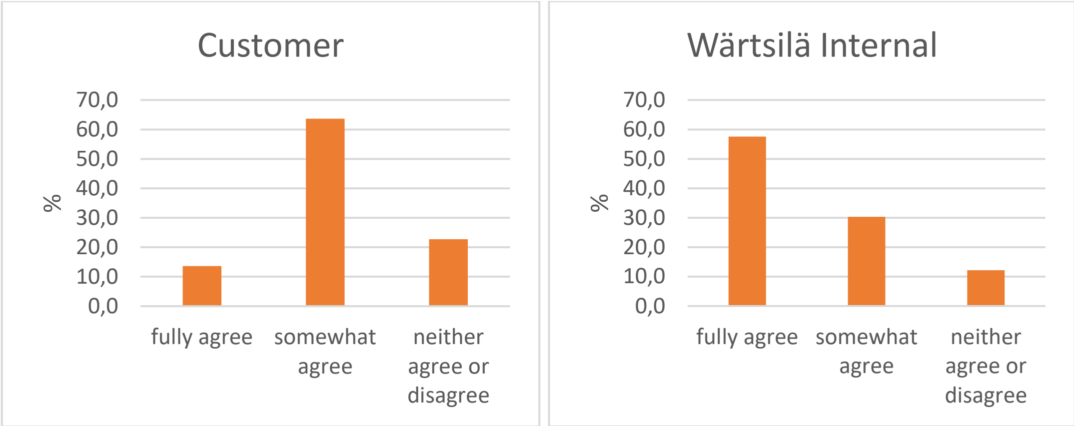

Figure 28. Customer and supplier responses to the high-pressure methanol injection technology question.

When the same question is analyzed by using professional groups, we can see that this technology is better accepted by technical and operational persons than by commercial and project related persons, Figure 29.

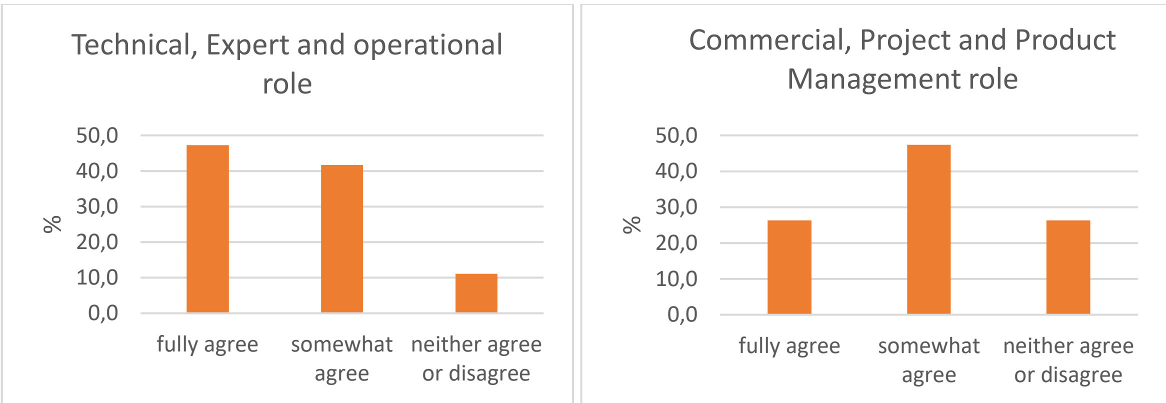

Figure 29. Professional groups responses to the high-pressure methanol injection technology question.

10.7 Safety feasibility factors

In the questionary, the safety topics were asked with one direct question which concerned methanol toxicity and low flash point: The respondents were asked how challenging these properties are considered. The results show that the safety challenges are somewhat challenging, Figure 30.

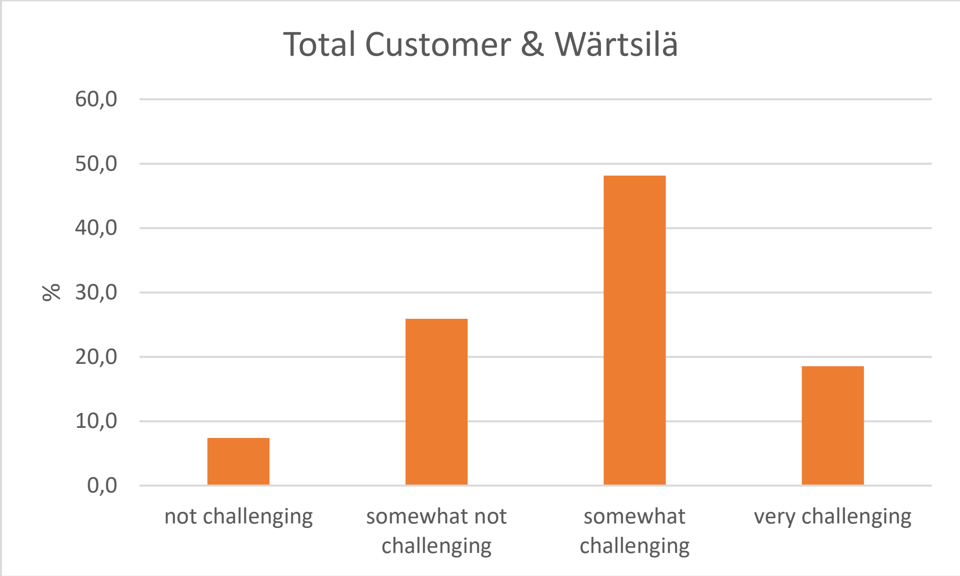

Figure 30. Methanol toxicity and low flashpoint as a safety challenge, all answers

In the safety question, we can see differences when the customer and supplier answers are analyzed. The customer considers the safety issues slightly more challenging than the supplier side. Also, percentages of answers where the safety issues are considered very challenging are higher on the customer answers, Figure 31.

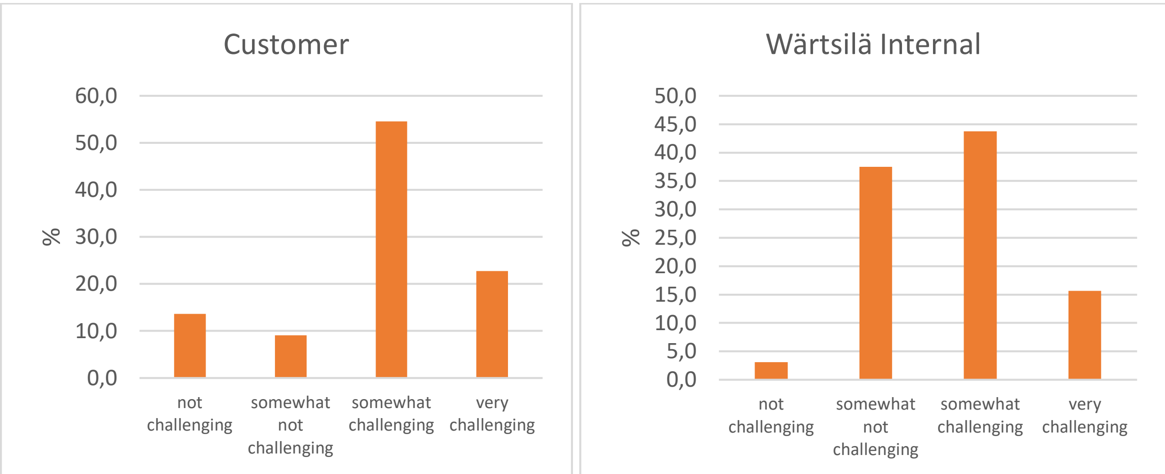

Figure 31. Methanol toxicity and low flashpoint as a safety challenge by customer and supplier

Methanol safety related properties are named in 8,5 % of all answers regarding two main challenges in methanol retrofit, Figure 32. This can also indicate a lack of knowledge about the needs of methanol operation in practice.

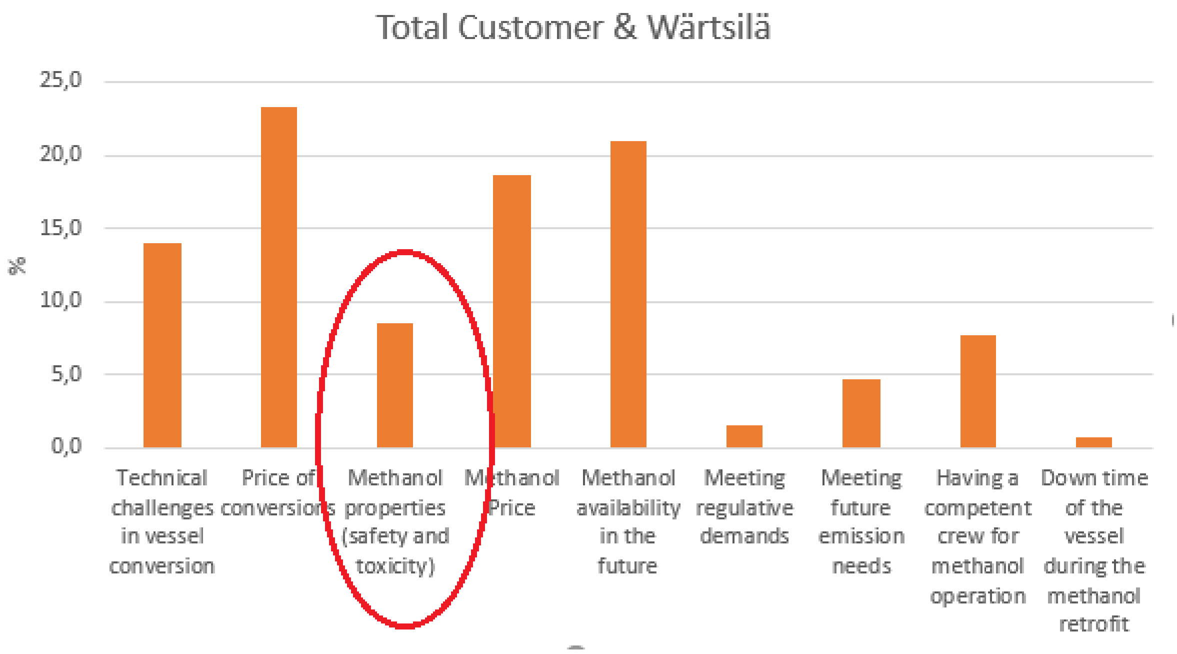

Figure 32. Methanol properties as a safety challenge

10.8 Commercial feasibility overview

10.8.1 Investment evaluation

From the customer perspective, the Methanol retrofit is an investment which needs to fulfill the strategical demands and give an expected revenue like any investment. With renewable fuel, the image of green operation is coming increasingly important and can also be a commercial factor; for example, cargo contractions might have a demands towards carbon neutrality.

Nevertheless, still when business cases are evaluated the price is the dominant factor and base for calculations such as return of investment (ROI). Cost drivers for methanol retrofit are the total cost of vessel conversion and related infrastructure investments in the portion that vessel owner or operator needs to cover. Methanol and back-up fuel price is important cost driver during the vessel´s life cycle.

10.8.2 Availability

One factor related to the fuel is fuel availability. Availability is a risk related factor which can turn easily to commercial factor. When the design fuel is not available, it can lead to a situation where a vessel is not operated efficiently with back up fuel. This potential situation operation can lead to emission penalties since the needed CO_2 emission level cannot be reached. Before looking at the availability related questionary results, it is good to give a realistic picture of methanol production and level of fuel consumption in the maritime sector. Figure 33 provides consumption figures before the pandemic. The total fuel consumption of the fuels is over two hundred million tons yearly.

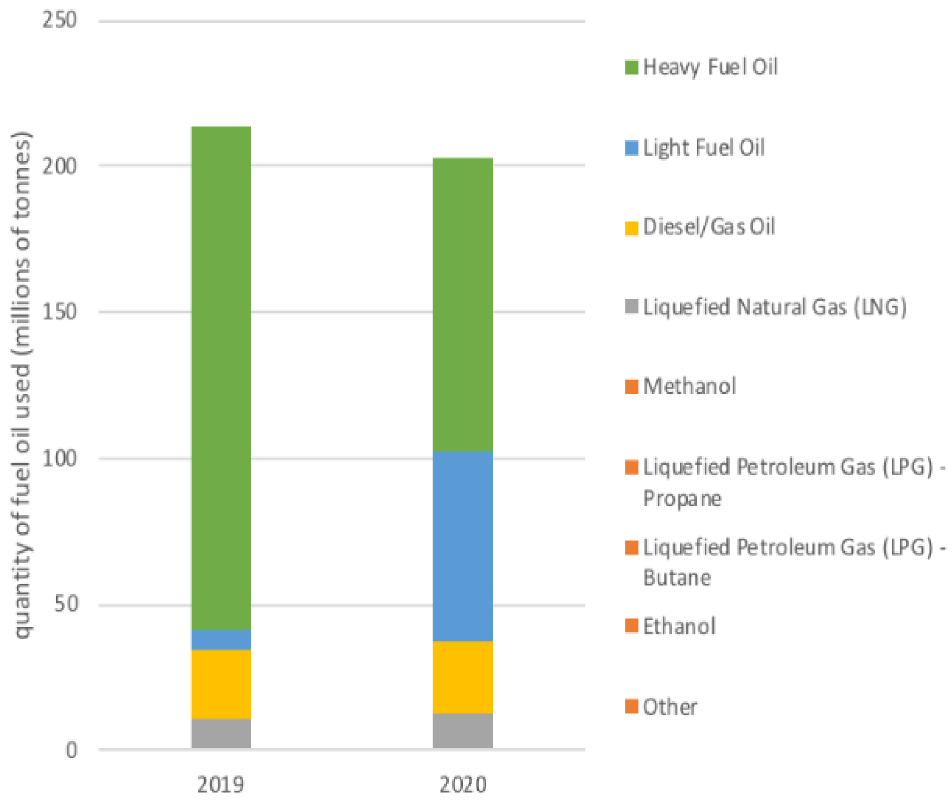

Figure 33. Aggregated annual amount of each type of fuel oil consumed by all ships of 5,000 GT and above (IMO, 2021).

The Methanol Institute is forecasts a rapid grow in renewable methanol production, but as a reference, the 2023 methanol production level is around 0,7 million tons yearly Figure 34.

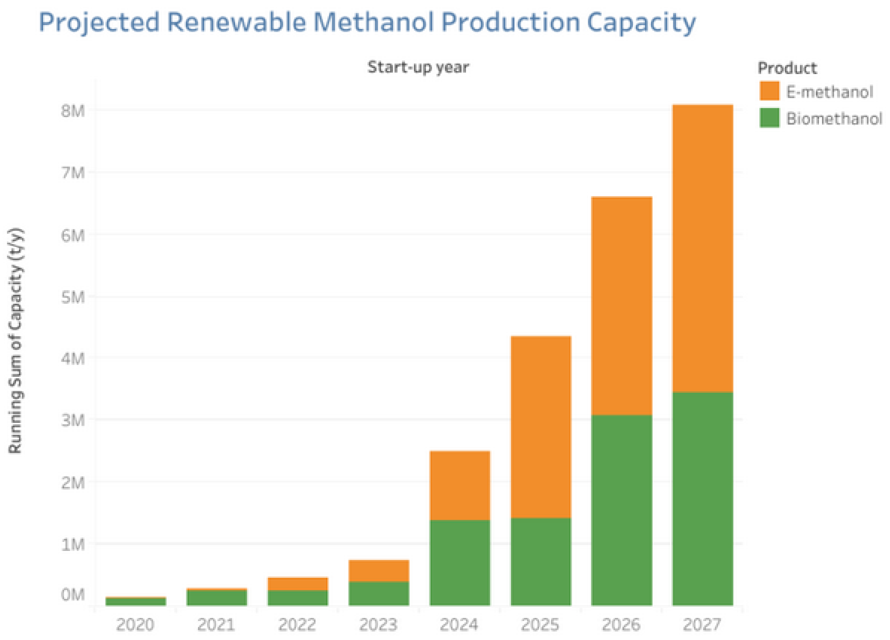

Figure 34. Methanol institute renewable database of current/announced projects

(Methanol Institute, 2022)

In the questionnaire, the respondents were asked to evaluate the availability of different methanol types.

The results shows that respondents consider the environmental methanol alternatives availability higher than other methanol types, Figure 35. These results do not follow the global production statistics, Figure 23.

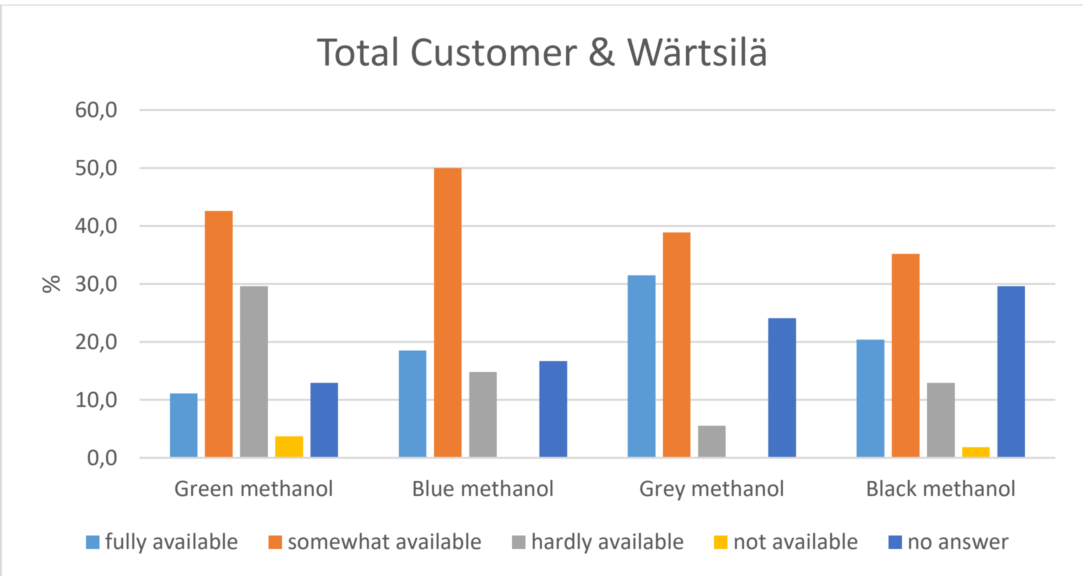

Figure 35. Results of methanol availability to meet retrofit demands by fuel category

10.8.3 Price of methanol retrofit conversion

In the questionnaire, the price of conversion is identified as the biggest challenge when all responses are selected, Figure 36. When focus is on the answers by professional groups the price of conversion is remaining inside the top two challenges, Figure 37.

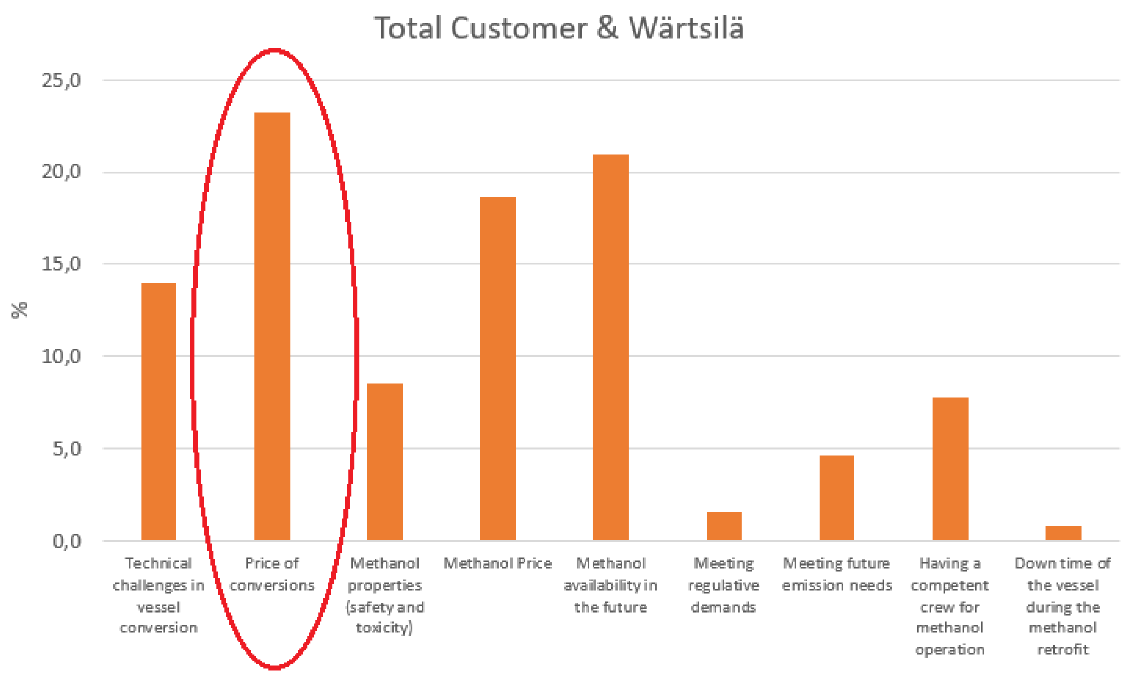

Figure 36. Price of conversion compared to other identified challenges, all responses

Figure 37. Price of conversion challenge evaluation by professional groups

10.8.4 Methanol price

Among the identified challenges, the future methanol price is identified as an important challenge, Figure 38.

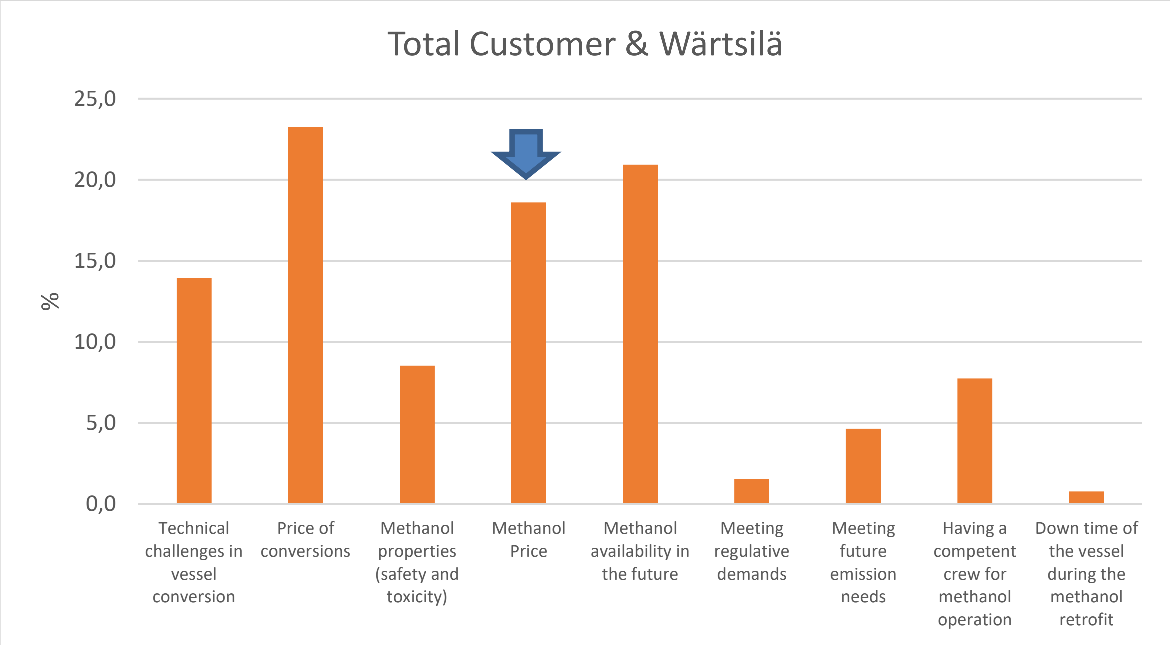

Figure 38. Methanol price challenge, all answers

Traditionally the cost of fuel is a crucial factor in all marine operations (Karvonen, 2006). Figure 39 shows the share of the fuel cost in relation to another cost in different type of vessel.

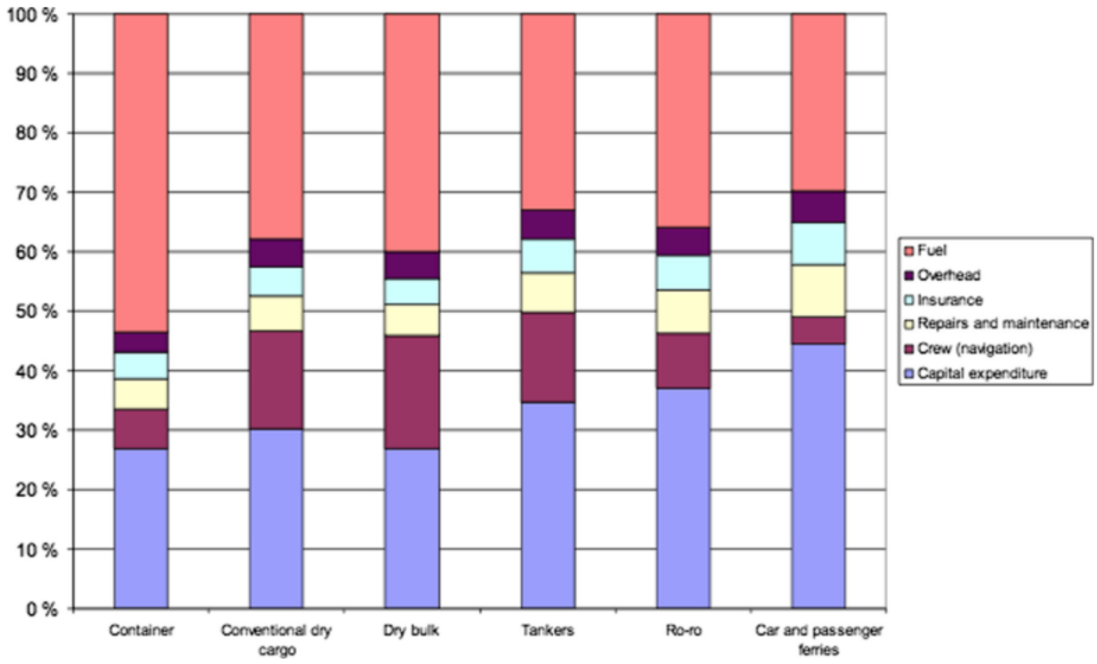

Figure 39 Vessel opex cost distribution with different vessel types (Karvonen, 2006)

11 Summary

This thesis is describing the various aspects of methanol retrofit feasibility on the ferry and cruise ships. To gain deeper insight into the different stakeholders´ standpoints, interview and questionnaire was used. The main points when evaluating the feasibility are related to commercial, technical and safety related factors. The methanol conversion price and methanol fuel price and environmental qualities availability are the factors that are the most significant ones.

Methanol conversion affects to the engine fuel injection system and related auxiliaries. Technical feasibility evaluation includes the review of safety and regulation related aspects which can be meaningful in a project feasibility evaluation. Technical challenges can be divided into the engine related and the auxiliary system related ones like methanol high pressure units and bunkering arrangement onboard and onshore.

Methanol qualities related to the safety and availability related to the different methanol sub-qualities are important to understand since new skills and demands occur also in operation when the fuels are taken into use.

With renewable fuels, the rules and legislation are not fully in place. There are continued discussions inside the maritime community about the correctness of current rules and how equally different vessel and fuel types are taken in account in the rules. Well to tank instead of the currently used well to wake definition is an important future topic to highlight the real emission level of different fuel pathways.

From the business perspective, the methanol conversion is an offering which includes multiple factors. To introduce the values correctly and efficiently, the interconnection between values and related stakeholders needs to be fully understood. An example value proposition is introduced in this thesis with related interconnections.

12 Conclusion

The green transition is the dominant topic in today's maritime world. Emission reduction is the main driver for any development related to the industry. Decarbonization is a part of every company´s strategy as number one target. This is naturally all in line with the fight against global warming. This thesis looks at one option in the large field of alternatives that today's ship owner and operator face when they are trying to improve their vessel operation environmental sustainability which is measured by example, EEXI, EEDI, CII indexes.

While the decarbonization goal is truly clear and needed, there is still a need to take care of the business profitability. Investment for the green technology is very remarkable and especially when thinking of older installation, the lifecycle and remaining lifetime are crucial decision factors.

Methanol has raised as one of the most potential solutions for retrofit fuel conversion. Methanol can bring benefits which are related to conversion work itself such a pressureless tanks and moderate conversion to the engine itself. Methanol as a fuel has also positive properties like its capability to mix with the water. There are naturally also challenges which comes with methanol toxicity and the low flashpoint, but the same challenges are also valid for other renewable alternatives like ammonia and hydrogen.

The International Maritime Organization has a huge task to form a regulation framework around methanol and other renewable fuels and ensure that those are fair and environmentally sustainable. A most crucial factor is the lifecycle analysis (LCA) of different fuels. This will be quite the dominant factor when evaluating how fast the renewable fuels are introduced in maritime world.

It will take time for the level of knowledge of methanol as a marine fuel to increase this will happen when this option is evaluated vessel by vessel.

Methanol conversion technology is developed in the engine maker’s side. Investment into research and development are expected to grow when the customers show more interest in methanol. Customers are monitoring the methanol availability in the market and awaiting the availability of green methanol in the world to increase. Green methanol can be a convenient answer for the maritime decarbonization challenge and work inside the industry to meet this challenge continues Methanol conversion is a wide topic and there are lot of challenges to study the topic under different feasibility areas in deeper way.

Overall, we can say that methanol retrofit conversion has a good potential to be one of the solutions for green shipping.

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Appendix 1

Research interview questionnaire

Methanol retrofit questionnaire

Section 1 ...

1. Are you answering this questionnaire as a *

- ◯ Wärtsilä Customer
- ◯ Wärtsilä Employee

2. Your role in your organization is?, choose the most suitable one *

- ◯ Commercial Management
- ◯ Operational Management
- ◯ Technical Management
- ◯ Expert Role
- ◯ Other

3. In General, how feasible do you consider Methanol to be as a green retrofit fuel solution for existing vessels?

- ◯ very feasible
- ◯ somewhat feasible
- ◯ neither feasible / or not feasible
- ◯ somewhat not feasible
- ◯ not feasible

4. The best technology for methanol retrofitting is the traditional diesel process as base, combined with high pressure methanol injection.

- ◯ fully agree
- ◯ somewhat agree
- ◯ neither agree or disagree
- ◯ somewhat disagree,
- ◯ disagree

5. In your opinion, will methanol availability in the future be good in enough to serve the needs of vessel retrofits? Please answer separately for each Methanol sub quality type.

1. Green methanol (process; biomass feedstock with renewable energy and electrolysis to methanol)
2. Blue methanol (process; solid feedstock & natural gas to methanol, CO2 capture)
3. Grey methanol (process; natural gas to methanol, no CO2 capture)
4. Black methanol (process; coal to methanol, no CO2 capture)

- ☐ **1. Green methanol** fully available
- ☐ **1. Green methanol** somewhat available
- ☐ **1. Green methanol** no answer
- ☐ **1. Green methanol** hardly available
- ☐ **1. Green methanol** not available
- ☐ **2. Blue methanol** fully available
- ☐ **2. Blue methanol** somewhat available
- ☐ **2. Blue methanol** no answer
- ☐ **2. Blue methanol** hardly available
- ☐ **2. Blue methanol** not available
- ☐ **3. Grey methanol** fully available
- ☐ **3. Grey methanol** somewhat available
- ☐ **3. Grey methanol** no answer
- ☐ **3. Grey methanol** hardly available
- ☐ **3. Grey methanol** not available
- ☐ **4. Black methanol** fully available
- ☐ **4. Black methanol** somewhat available
- ☐ **4. Black methanol** no answer
- ☐ **4. Black methanol** hardly available
- ☐ **4. Black methanol** not available

6. From an investment point of view, the maximum vessel age where a methanol retrofit project would still be feasible to execute is (choose the closest maximum age)

- ○ 5 years
- ○ 10 years
- ○ 15 years
- ○ 20 years
- ○ 30 years

7. In the future, vessels need to comply with CII (Carbon Intensity Indicator) regulations. Converting to methanol meets these future regulatory demands

- ○ well
- ○ somewhat well
- ○ I do not have an opinion
- ○ partially meets
- ○ does not meet

8. Methanol and water mixing lowers NOx emissions significantly, but the freshwater tank capacity requirement on board for water mixing is 25% of the methanol tank capacity. This requirement is

- ○ very feasible
- ○ somewhat feasible
- ○ neither feasible on unfeasible
- ○ somewhat not feasible
- ○ not feasible

9. Do you agree that methanol retrofit technology should only enable a maximum of 20% methanol usage and aim at light technical changes, improving only the CII index (not aiming at complete carbon neutrality)?

- ◯ fully agree
- ◯ somewhat agree
- ◯ not agree or disagree
- ◯ somewhat not agree
- ◯ not agree

10. Methanol is a liquid fuel that can be stored in pressure less tanks (converted HFO-tanks or modified ballast tanks). How big a benefit is this in vessels after retrofit usability point of view compared to the pressurized tanks on board?

- ◯ greatly beneficial
- ◯ somewhat beneficial
- ◯ I do not know
- ◯ somewhat not beneficial,
- ◯ not beneficial

11. Methanol is toxic and has a low flash point. How challenging do you consider this to be from a safety point of view?

- ◯ very challenging
- ◯ somewhat challenging
- ◯ no answer
- ◯ somewhat not challenging
- ◯ not challenging

12. What are the two biggest challenges with retrofitting a vessel for running on methanol?

- ☐ Price of conversion
- ☐ Meeting future emission needs
- ☐ Meeting regulative demands
- ☐ Having a competent crew for methanol operation
- ☐ Methanol availability in the future
- ☐ Methanol price
- ☐ Methanol properties (safety and toxicity)
- ☐ Technical challenges in vessel conversion
- ☐ Down time of the vessel during the methanol retrofit