D3.7 Evaluation report methanol retrofit inland chemical tanker

Synergetics | Synergies for Green Transformation of Inland and Coastal Shipping

GRANT AGREEMENT NO.	101096809
DURATION OF THE PROJECT	42 months
DELIVERABLE NUMBER	D3.7
DELIVERABLE LEADER	MARIN
STATUS	FINAL
SUBMISSION DATE	30-06-2026
AUTHOR	N. van Spronsen MARIN n.v.spronsen@marin.nl
CO-AUTHORS	R.-J. Zimmerman, MERC K. Hoyer, B. Friedhoff, DST T. Mühlheim, KMG

Co-Funded by the European Union. Views and opinions expressed are however those of the authors only and do not necessarily reflect those of the European Union or CINEA. Neither the European Union nor the granting authority can be held responsible for them.

Funded by the Horizon Europe Programme of the European Union under grant agreement No 101096809
Funded by the Horizon Europe guarantee of the United Kingdom, under project No 10068310
Funded by the Swiss State Secretariat for Education, Research and Innovation

| Table of Contents

Funded by the Horizon Europe Programme of the European Union under grant agreement No 101096809
Funded by the Horizon Europe guarantee of the United Kingdom, under project No 10068310
Funded by the Swiss State Secretariat for Education, Research and Innovation

List of Figures

List of Tables

Funded by the Horizon Europe Programme of the European Union under grant agreement No 101096809
Funded by the Horizon Europe guarantee of the United Kingdom, under project No 10068310
Funded by the Swiss State Secretariat for Education, Research and Innovation

Release Approval

1 | Release Approval

NAME	ROLE	REMARKS
P. Garcia Barrena	WP-Leader	30-06-2026
B. Friedhoff	Project Coordinator	30-06-2026

Funded by the Horizon Europe Programme of the European Union under grant agreement No 101096809
Funded by the Horizon Europe guarantee of the United Kingdom, under project No 10068310
Funded by the Swiss State Secretariat for Education, Research and Innovation

Executive Summary

Initially, the goal of this deliverable was to provide an overview of the evaluation and experience with methanol retrofit of an inland chemical tanker. Due to regulatory and market constraints for methanol ICE as well as remaining technical challenges with fuel availability, fuel quality and engine durability, the originally planned retrofit activities within the project duration were not feasible. For that reason, the tasks were limited to analytical, regulatory and evaluation work apart from physical deployment and operational experience. The revised tasks ensure the scope reflects what can be realistically delivered while maintaining the project's objectives and expected impacts.

Focusing on analytical and design activities keeps the scope realistic while ensuring that the work continues to generate the insights on energy demand, system configuration and operational constraints needed for SYNERGETICS' comparative assessment framework. In addition to the description and evaluation of this demonstrator described in this report, the Annexes includes the operational and SPEC analysis (technology selection) that was pending from deliverable D3.1 for this demonstrator.

Demonstrator 2 shows that technically and operationally viable decarbonisation pathways for inland chemical tankers are already within reach. The case of the *Stolt IJssel* demonstrates the willingness of vessel owners to invest in innovative retrofit solutions, provided that regulatory clarity and industrial readiness are aligned. The absence of a realised retrofit within the project period should therefore not be interpreted as a lack of ambition, but as evidence that regulatory uncertainty and market immaturity currently outweigh technical feasibility. This demonstrator makes these barriers tangible and highlights where targeted regulatory action can unlock private investment.

In addition to the case study for the Stolt Ijssel, a more general Chapter 8 covering the current situation of technical readiness, commercial readiness and regulatory readiness of methanol for internal combustion engines was included in this deliverable based on work provided by the SYNERGETICS consortium. These findings have been presented to several target groups like EUROMOT and Commission bodies to support the removal of the regulatory barrier related to the Regulation (EU) 2016/1628. Further information on methanol in internal combustion engines is published in the following SYNERGETICS reports:

D1.1 Relevant identified technical solutions

D2.2 Report on lessons from Past Pilots

D3.17 Evaluation report on application of methanol: compression ignited vs dual-fuel

D3.19 HSE Workshop

D4.2 Fact sheets of most promising retrofit measures (Fact sheet #1)

D4.6 Model for a standardised procedure for regulatory approval of greening retrofit solutions

D5.4 Handbook for Implementation of Greening Retrofit Solutions

All of these reports are publicly available via the SYNERGETICS website synergetics-project.eu. Fact sheet and D5.4 will be updated once the situation significantly changes. The regulatory framework will hopefully be changed in the coming years, amongst others, facilitated by a Dutch subsidy scheme for further development and field-testing of hydrogen and internal combustion engines in inland waterway. Additionally, experience gathered in maritime shipping may help to overcome barriers in IWT. The economic viability of methanol used as a fuel for internal combustion engines can be checked for applications in inland and coastal shipping based on the SYNERGETICS Decision Support Tool for vessel owners, also available via the SYNERGETICS website.

Funded by the Horizon Europe Programme of the European Union under grant agreement No 101096809
Funded by the Horizon Europe guarantee of the United Kingdom, under project No 10068310
Funded by the Swiss State Secretariat for Education, Research and Innovation

1. | Introduction

This report was intended to evaluate the applied methanol retrofit of the inland chemical tanker Stolt IJssel operated by Mercurius Shipping (MERC). This tanker was selected as demonstrator 2 (Demo 2) within the SYNERGETICS project. Unfortunately, the retrofit could not be implemented even though MERC successfully went through two HAZID workshops and applied for derogation recommendations with CESNI and ADN. The report will, therefore, explain the circumstances that hindered the implementation and describe the efforts that were made to gain information and knowledge for a theoretic retrofit despite all difficulties.

This report describes the concept, the challenges, and the lessons learned regarding Demo 2. Focusing on analytical and design activities while keeping the scope realistic and ensuring that the work continues generating insights on the energy demand, system configuration, and operational constraints needed for SYNERGETICS' comparative assessment framework.

2. | Description of the vessel and its operation

2.1 The vessel

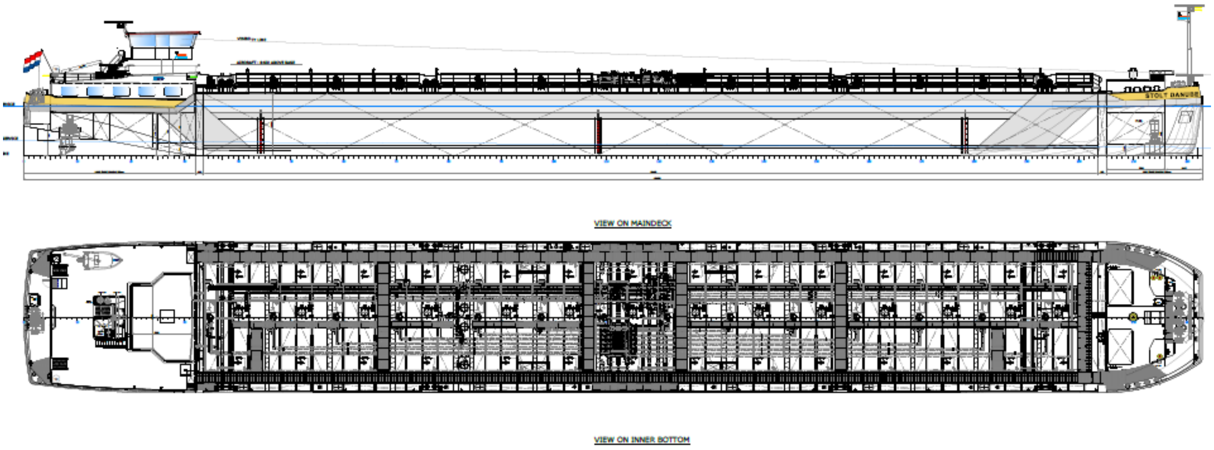
The Demo 2 reference vessel is the Stolt IJssel, owned by Mercurius Shipping Group and operated by Stolt-Nielsen Limited. The Stolt IJssel is a type C inland chemical tanker, which transports chemical cargo in liquid form between Amsterdam, Rotterdam, and Antwerp (ARA), and other smaller ports nearby. In Table 2 the main particulars of the vessel are presented.

Beside sailing in the ARA area, the vessel also operates along the Rhine, sailing up to Ludwigshafen near Mannheim in Germany. The main bunkering location is in Dordrecht. The propulsion system consists of three electric azimuth thrusters supplied by three gensets of about 550 kWe power each.

2 | Main particulars of the Stolt IJssel.

Main particular	value	unit
Length, over all	109.9	m
Beam, moulded	14.0	m
Draught, design	4.60	m
Tank Capacity (approx.)	5200	m^3
Number of cargo tanks	14	

Funded by the Horizon Europe Programme of the European Union under grant agreement No 101096809
Funded by the Horizon Europe guarantee of the United Kingdom, under project No 10068310
Funded by the Swiss State Secretariat for Education, Research and Innovation



1 | Side and top view of the Stolt Danube, sister ship of the Stolt IJssel.

2 | Chemical tanker Stolt IJssel from the Mercurius Fleet

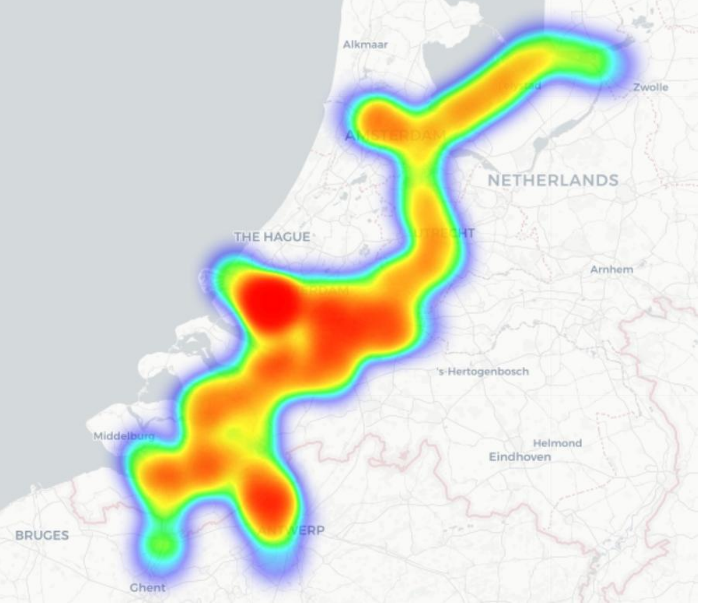
The ship is equipped with a double hull. The cargo area is divided into fourteen holds with a total capacity of about 5000 m³. Each cargo hold is equipped with heating coils to heat the cargo, and a deep well pump for unloading.

The vessel has a diesel-electric propulsion system, with the engine room located at the foreship, and propulsion is provided by means of three ducted thruster units. The stakeholders intend lowering the carbon footprint of the vessel by exploring different solutions that would use methanol as energy carrier, alone or combined with diesel.

Funded by the Horizon Europe Programme of the European Union under grant agreement No 101096809
Funded by the Horizon Europe guarantee of the United Kingdom, under project No 10068310
Funded by the Swiss State Secretariat for Education, Research and Innovation

2.2 Sailing routes

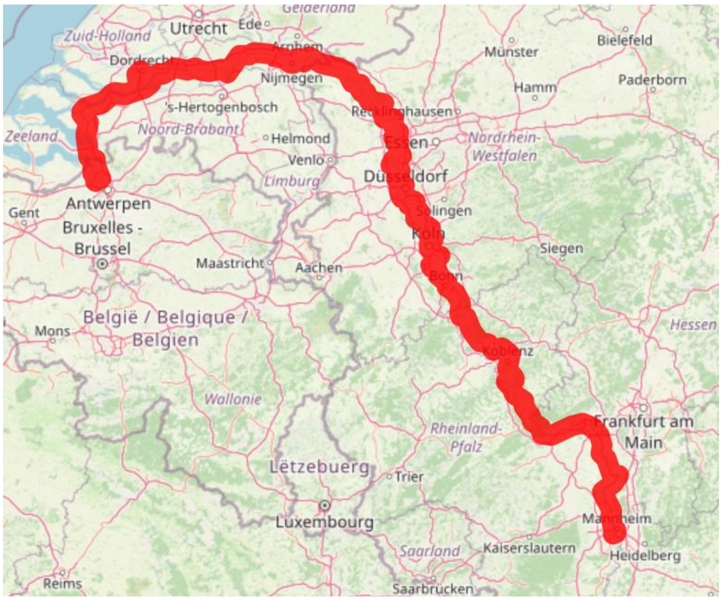
The vessel mainly operates between the cities of Antwerp, Rotterdam, and Amsterdam (ARA). This can be seen in the geospatial distribution presented in Figure 3. This representation was made using AIS data from the ship.



3 | Geospatial operational distribution of the Stolt IJssel

Further analysis has been conducted to find out the most energy demanding operation of the vessel. This resulted to be the mission of sailing up the Rhine to Ludwigshafen and back.

This operation starts at the bunkering location in Dordrecht, continues with the first trip to Antwerp followed by a second trip up to Ludwigshafen, near Mannheim in Germany. Then, the vessel sails back on the same route without bunkering in Ludwigshafen. The total mission extends over 1468 km. An overview of the route is presented in Figure 4.



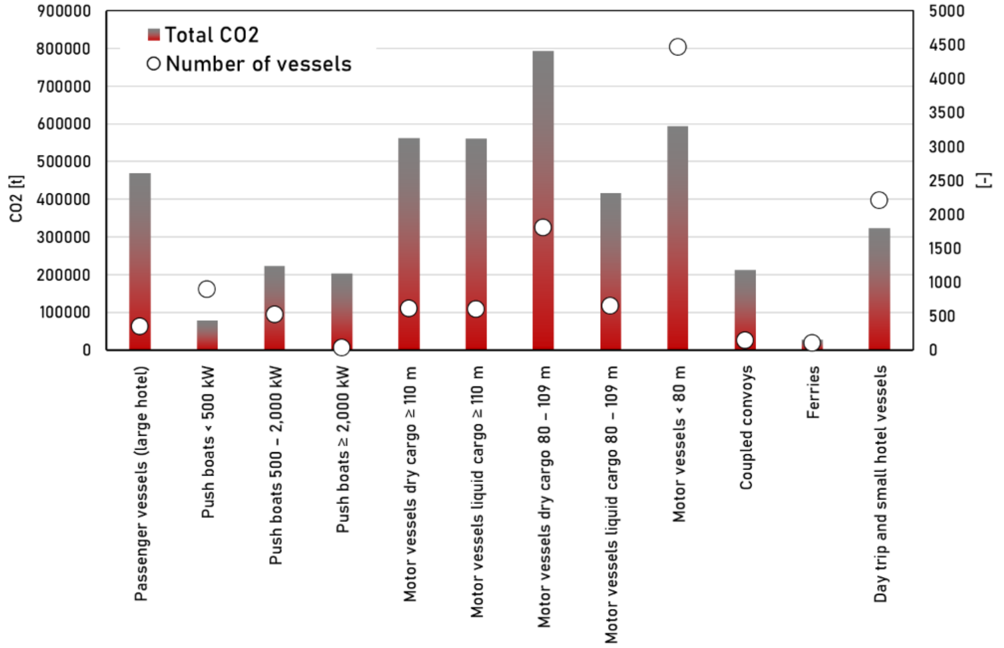
4 | Route of the Stolt IJssel

Funded by the Horizon Europe Programme of the European Union under grant agreement No 101096809
Funded by the Horizon Europe guarantee of the United Kingdom, under project No 10068310
Funded by the Swiss State Secretariat for Education, Research and Innovation

2.3 Impact

When selecting the ships which will serve as the Demonstrators in SYNERGETICS, one of the factors considered was the possible impact of the retrofit. To estimate the magnitude of the impact, several aspects are taken into account: the absolute CO_2, NO_x and PM emissions of the ships of a certain type (i.e. the ships within a certain fleet family), the relative CO_2, NO_x and PM emissions of the ships within a certain fleet family (i.e. the absolute CO_2, NO_x and PM emissions of a fleet family normalized by the number of ships within the family), the operational area of a ship, etc.

This vessel belongs to the fleet family which is among the five biggest CO_2-emitting, NO_x-emitting and PM-emitting fleet families in absolute terms (fleet family: "Motor vessels liquid cargo 80 - 109 m"). as shown partly in Figure 5.



5 | Absolute CO_2 emissions of the fleet families of the European inland fleet and number of vessels within the families in 2015 (similar ranking for NO_x and PM emissions)

The work conducted for this Demonstrator including the lessons learned will provide vessel owners, operators and policy-makers in this fleet segment guidance on how to approach a similar case.

Funded by the Horizon Europe Programme of the European Union under grant agreement No 101096809
Funded by the Horizon Europe guarantee of the United Kingdom, under project No 10068310
Funded by the Swiss State Secretariat for Education, Research and Innovation

3. | Analyses

The Stolt IJssel was selected for a methanol retrofit, however, a Power and Energy Concept (SPEC) analysis was performed to confirm methanol as best retrofit option and to evaluate other suitable retrofit options.

With the operational analysis the power and energy demand of the vessel are defined for the whole operation of the vessel. This is later used as input for the technology selection, the so-called Ship Propulsion, Power and Energy Concepts analysis. The SPEC analysis gives an indication of what could be the most suitable power and energy concepts form a technology, investment, and operational point of view. In addition, from this analysis an indication of the main parameters (weight and volume of power and energy systems, equivalent CO_2 emissions, etc.) of each concept is given, which allows to compare each concept and quickly evaluate its impact on the design of the ship. From this comparison the most suitable concepts can be selected for a further detailed study of their viability.

The purpose of this methodology allows an objective comparison of the different propulsion, power and energy concepts that could be used to reduce the CO_2 and harmful emissions for inland and coastal vessels and thereby contributes to the objectives of SYNERGETICS.

MARIN conducted an operational analysis and technology selection (SPEC analysis) of the Stolt IJssel as well as of the other demonstrators within the SYNERGETICS project. The results can be found in detail in deliverable D3.1[1] of SYNERGETICS. The definition of the terms used in the operational and SPEC analysis can be found in this deliverable as well.

A short summary of the operational and SPEC analysis carried out for this demonstrator is presented in section 3.1 and 3.2, respectively.

3.1 Operational analysis

During the operational analysis, the operation, user needs, and requirements were defined to determine the power profiles. The Operational Analysis was carried out using measured operational data of the reference ship provided by Shipping Technology, thanks to the concession of Stolt-Nielsen.

The data covered the operations of the vessel from the 27th of March 2023 to the 11th of March 2024, with a sample rate of one minute. The registered parameters were the GPS datetime and location, the GPS speed, the power of the bow thruster, the propulsion power, the generated power and the hotel & auxiliary power. Other parameters were derived from the registered data, such as the energy consumption. After a statistical analysis and filtering of the data, the latter has been used to obtain representative values to describe the most critical Bunker Independent Operation (BIO). A Bunker Independent Operation is a sequence of the operations the ship needs to carry out without intermediate bunkering. The energy required for the BIO defines the amount of energy carrier (fuel, batteries, etc.) that needs to be carried on board to complete all the operations within the BIO.

Based on the analysed data, the operational profile presented in Table 3 was developed. The 'Power Percentage' refers to a percentage of the maximum installed power, in this case called 'Max generated power', based on the installed power.

[1] https://www.synergetics-project.eu/wp-content/uploads/2025/05/SYNERGETICS_D3.1_SPEC-analyses-of-full-scale-and-model-scale-demonstrators_FINAL3.pdf

Funded by the Horizon Europe Programme of the European Union under grant agreement No 101096809
Funded by the Horizon Europe guarantee of the United Kingdom, under project No 10068310
Funded by the Swiss State Secretariat for Education, Research and Innovation

3 | Operational profile of the Stolt IJssel

Task	Power Percentage [% of max. power]	Time Percentage [% of BIO time]
Sailing upstream	70	30
Sailing downstream	50	30
Sailing (no current)	60	30
Waiting	10	10

3.2 SPEC analysis

The results from the operational analysis and the stakeholders' requirements were used as input for the next step of the analysis. The selection of the most suitable/feasible technology is performed using MARIN's Ship Power and Energy Concept tool, which, through a weighted multi criteria analysis, allows to assess what solutions (energy carrier + energy converter) are feasible within the reference ship and its operations and what is their impact on the design in terms of weight, volume, efficiency and costs. The stakeholders and users can influence the results of the analysis by weighting the different criteria based on what is more relevant for them.

For this demonstrator, the diesel-electric case has been used as a benchmark to compare the other solutions, as this is the propulsion system currently used on the Stolt IJssel. In Table 4 an overview of the total ranking can be seen. It should be noted that as the base of this demonstrator has a diesel-electric architecture. Therefore, the concepts included in the ranking as well as in the SPEC results are for ships with electric propulsion. For instance, the solution #16 is the benchmark case, and it refers to a diesel-electric solution. No conversion to a ICE-direct drivetrain is considered.

4 | Ranking overview of Demo 2.

Concept	Ranking		
	Overall	Technology & Investment	Operations
#16 = Diesel (EN590) CI ICE (hi-speed)	8.2	8.1	8.5
#4 = Diesel (POME, UCO) CI ICE	9	9	9
#8 = e-CH3OH (CO2 PTS)/Dsl 65/35%vol CI ICE	6.1	5.7	6.6
#9 = e-CH3OH (CO2 PTS)/Dsl 95/5%vol CI ICE	5.8	6	5.5
#19 = e-LNG (CO2 PTS) SI ICE	6.8	6.8	6.7
#21 = Battery-electric (renewable)	7.7	8.8	6.5
#36 = e-H2 300b ISO LT PEMFC	3.3	2.2	4.3

Funded by the Horizon Europe Programme of the European Union under grant agreement No 101096809
Funded by the Horizon Europe guarantee of the United Kingdom, under project No 10068310
Funded by the Swiss State Secretariat for Education, Research and Innovation

For the Stolt IJssel, operating as described in the operational analysis, the following conclusions summarise the findings of the SPEC analysis:

- The battery-electric and compressed hydrogen concepts (#21 and #36) have the best performance in terms of emissions. The electricity used to charge the batteries and to produce hydrogen is derived from renewable sources. However, these concepts require a very large volume and weight on board, making them less attractive for the Stolt IJssel. It has to be noted that for the battery concept, the term "uncontained" refers to the volumetric and gravimetric energy densities of the battery cells only, while the term "contained" refers to the volumetric and gravimetric energy densities of the whole battery system, including, for example, the support structure and the support systems of the battery such as BMS, cooling and ventilation.
- The methanol concepts offer a different range of emission reduction depending on the methanol share in the fuel blend. Concept #8 is considered to be the most conservative DF methanol concept in terms of volume share in the fuel blend for the future methanol Dual Fuel Internal Combustion Engines, while concept #9 refers to the most optimistic one. The reduction in CO_2 equivalent emissions is dependent on the methanol share in the blend, and it is due to the fact that methanol is produced by carbon capture at a point source (CO2 PTS) and therefore it has a negative CO_2 Well to Tank emissions value according to some GHG accounting methodologies.
- The bio-Diesel concept (#4) offers a substantial reduction in emissions. This is due to the negative CO2 Well to Tank emissions value according to the accounting method applied here, and it is very dependent on the pathway from source to production and transportation of the fuel.
- Concepts #16 and #4 have similar costs in terms of volume and weight, as they refer to the same technology and similar fuel types.
- The methanol concepts (#8 and #9) require a relatively small increase in volume and weight. This is mostly due to the lower energy density (volumetric and gravimetric) of methanol compared to Diesel.

Funded by the Horizon Europe Programme of the European Union under grant agreement No 101096809
Funded by the Horizon Europe guarantee of the United Kingdom, under project No 10068310
Funded by the Swiss State Secretariat for Education, Research and Innovation

4. | Design Concept

4.1 Methanol combustion in ICE for the main propulsion

The findings of the SPEC analysis conclude that the optimal retrofit solution for the Stolt IJssel will be the battery-electric and compressed hydrogen concept. This concept has the drawback of a very large volume and weight requirement on board, and therefore making it less attractive for the Stolt IJssel. The next best concept, dual fuel (DF) methanol ICE, has the stakeholder's preference due to a relatively small increase in volume and weight resulting in the same amount of cargo capacity.

Methanol can be utilized in internal combustion engines in different ways. Similar to methane (LNG), methanol has a high octane but a low cetane number. Due to the low cetane number, methanol will not easily ignite from pressure and heat which will prohibit it to work in a diesel engine where the fuel is compression ignited. Thus, methanol can be used in a dual fuel engine. The principle of a dual fuel engine is that diesel is injected as pilot fuel and ignites by the compression in the cylinder. Direct after the initial ignition the main fuel (methane or methanol) is injected. The amount of pilot fuel depends on the physical design and the control strategy of the fuel system. Further information on methanol combustion concepts are available in the following SYNERGETICS deliverables and not repeated here:

D1.1 Relevant identified technical solutions

D3.17 Evaluation report on application of methanol: compression ignited vs dual-fuel

D4.2 Fact sheets of most promising retrofit measures (Fact sheet #1)

All reports are publicly available via the SYNERGETICS website synergetics-project.eu.

4.2 Alternative

If methanol ICE is not an option, a bio-Diesel solution can be an alternative. The implementation of this solution does not necessitate any structural or system retrofit on the vessel.

Funded by the Horizon Europe Programme of the European Union under grant agreement No 101096809
Funded by the Horizon Europe guarantee of the United Kingdom, under project No 10068310
Funded by the Swiss State Secretariat for Education, Research and Innovation

5. | Challenges

As mentioned above, it was not possible to implement the retrofit on bord of the Stolt IJssel due to several major issues occurring during the project. The first issue is related to significant regulatory uncertainties. During the proposal phase of SYNERGETICS, where the demonstrators were selected, the availability of a methanol engine was announced for the following year. However, the engines were not able to comply with the requirements of Regulation (EU) 2016/1628 (NRMM Stage V). Due to forming and emission of formaldehyde during combustions, methanol is, up to now, not listed as reference fuel, for type approval of engines in this regulation. The inclusion of methanol in ES-TRIN 2025/1 as low-flashpoint fuel and the successful application of MERC for derogation recommendations via CESNI and ADN were not sufficient. While the pilot vessel of the H2020 project FASTWATER was allowed to retrofit a CCNR II engine to run on dual-fuel with methanol without fulfilling St. V emission limits, this was not an option for SYNERGETICS after the end of transition periods between CCNR II and St. V.

The common Selective Catalytic Reduction (SCR) exhaust gas aftertreatment system used for conventional fuel engines are not suitable for the combustion of methanol, since the SCR reaction is inhibited by residuals such as long-chain alkanes, alkenes and aromatic compounds. Especially the conversion of NO_x is limited depending on the engine configuration and combustion principle. Further, unburned methanol and formaldehyde can be found in the exhausted gas. Solutions for a suitable exhaust gas treatment have been published in 2025[2]. They must now be approved and established in collaboration with the engine manufacturers.

Nevertheless, due to the regulatory uncertainties and the challenges for the exhaust gas treatment, engine manufacturers have paused the development activities for engines suitable for inland navigation vessels.

During the SYNERGETICS project the concept of methanol ICE retrofitting for the Stolt IJssel has been extensively investigated. There were three main challenges that could not be resolved:

1. Significant regulatory uncertainty persists: methanol is not listed as a reference fuel under Regulation (EU) 2016/1628 (NRMM Stage V) for application in inland waterway transport.
2. Suitable engines are not expected in the relevant power range for use in inland shipping for the coming years and engine manufacturers have paused development activities for this segment (due to regulatory uncertainty).
3. Availability and cost of green methanol further inhibit deployment.

Due to the above mentioned external regulatory and market constraints for methanol ICE, the originally planned retrofit activities within the project duration are therefore considered not feasible. For that reason, the tasks were limited to analytical, regulatory and evaluation work. The revised tasks ensure the scope reflects what can be realistically delivered while maintaining the project's objectives and expected impacts; these analytical components are already fed into SYNERGETICS outputs.

This case shows that vessel owners willing to act as first movers in decarbonisation currently face a structural disadvantage, as investment risk is not balanced by regulatory flexibility or market incentives. Addressing this imbalance is crucial to accelerate the energy transition in inland shipping.

[2] https://www.springerprofessional.de/exhaust-gas-aftertreatment-for-methanol-dual-fuel-engines/50877472

Funded by the Horizon Europe Programme of the European Union under grant agreement No 101096809
Funded by the Horizon Europe guarantee of the United Kingdom, under project No 10068310
Funded by the Swiss State Secretariat for Education, Research and Innovation

6. | Lessons learned

The following points summarise the lessons learned from this demonstrator:

1. **Inform policy makers and other stakeholders:** The Stolt IJssel serves as an exemplary case of an inland vessel of a fleet family of Motor vessels for liquid cargo between 80 - 109 m in length. This is the fleet family of the five biggest CO_2-emitting, NO_x-emitting and PM-emitting fleet families in absolute terms. The outcome of this case is disseminated amongst policy makers and other stakeholders in the IWT sector, and has therefore a big impact on possibilities of emission reduction for the sector. This aligns with the objectives of SYNERGETICS, which aim to inform policy makers and other stakeholders by providing insights into updated Transition Pathways Task 5.2 and scenarios for policy makers Task 5.3.

2. **Provide clarity of regulatory procedures:** Clarity and streamlining of the regulatory procedures for greening retrofit solutions on board helps to define major bottlenecks that hinder the accelerated adoption of greening retrofit solutions. In the Demo of the Stolt IJssel, significant regulatory uncertainty persists: methanol is not listed as a reference fuel under Regulation (EU) 2016/1628 (NRMM Stage V) for application in inland waterway transport. Therefore, engine manufacturers have paused development activities for this segment. Clarity in these rules helps to deal with the assessment, developments, and acceptance procedures.

3. **Entrepreneurial willingness is not the limiting factor for decarbonisation in inland shipping:** A key lesson from this demonstrator is that entrepreneurial willingness within the inland shipping sector is not the limiting factor for decarbonisation. Instead, uncertainty in regulation and the lack of commercially available engine solutions create a bottleneck that discourages first movers. Future innovation programmes should explicitly recognise this risk and create frameworks in which pioneering vessel owners are enabled rather than exposed.

Funded by the Horizon Europe Programme of the European Union under grant agreement No 101096809
Funded by the Horizon Europe guarantee of the United Kingdom, under project No 10068310
Funded by the Swiss State Secretariat for Education, Research and Innovation

7. | Conclusions and recommendations

From the work carried out for this Demonstrator within SYNERGETICS, the following conclusions can be found:

- Based on the operational analysis and technology selection carried out for the Stolt IJssel, the battery-electric and compressed hydrogen concepts display the best performance in terms of emissions. However, these concepts require a very large volume and weight on board, making them less attractive for the Stolt IJssel. The bio-Diesel concept offers a substantial reduction in emissions due to the negative CO_2 Well to Tank emissions value, which is very dependent on the pathway from source to production and transportation of the fuel. The methanol-based dual fuel ICE concepts require a relatively small increase in volume and weight. This is mostly due to the lower energy density (volumetric and gravimetric) of methanol compared to Diesel.
- This Demo case has a high impact on the inland waterway transport due to the number of ships in its fleet family. Although the retrofit and full-scale operational testing will not be conducted during this project, valuable insights can still be gained from the operational and SPEC analysis. These findings will be used as input for the SYNERGETICS Decision Support Tool for Vessel Owners (Task 5.1) and the updated Transition Pathways (Task 5.2) and scenarios for policy makers (Task 5.3).
- The potential of a methanol retrofit has a drawback in regulatory uncertainty. It is recommended to address this uncertainty at policy makers and regulatory bodies so that solutions can be found in regulatory procedures. It is expected that engine manufacturers will follow-up in developing activities in the segment of IWT.
- Inform and convince a wide range of stakeholders in an early stage on a similar retrofit case is key to enable effective collaboration and to eliminate hurdles.
- Gain awareness of the business case for ship owners and operators.
- Clarity and streamlining of the regulatory procedures at an early sate of the process helps to eliminate hurdles in the design stage.
- To enable owner-led innovation, regulatory bodies should introduce transitional or pilot regimes that allow controlled deployment of alternative fuels such as methanol in inland shipping. Such regimes would provide the confidence required for engine manufacturers to resume development and for vessel owners to commit capital. Without these measures, the sector risks a deadlock in which all stakeholders await action from others.

Funded by the Horizon Europe Programme of the European Union under grant agreement No 101096809
Funded by the Horizon Europe guarantee of the United Kingdom, under project No 10068310
Funded by the Swiss State Secretariat for Education, Research and Innovation

8. | General state of play of methanol in ICE

(Green) methanol combines the advantages of a cleaner fuel alternative with the challenges of a toxic, low-flashpoint fuel, whose volumetric energy density is significantly lower than that of diesel or heavy fuel oil, resulting in substantially larger fuel tanks or shorter vessel range. It is unlikely to become a universal fuel choice across all shipping segments, but it is likely to remain a viable option for specific use cases, where its technical and operational constraints can be accommodated. Where the application allows to resolve the key constraints of ship integration, safety design, and fuel storage volume, methanol represents a credible fuel option for internal combustion engines in inland and coastal shipping.

The European regulatory framework for Methanol for inland and coastal shipping has significantly improved in the last few years. ES-TRIN 2025/1 contains dedicated methanol provisions for inland vessels, EN 18071:2025 provides a harmonized methanol bunkering standard for inland navigation, and MSC.1/Circ.1621 remains the main IMO safety reference for ships using methyl/ethyl alcohol as fuel. The remaining difficulty lies less in the absence of technical rules than in the need for project-specific approval, integration, training, and fuel sourcing.

For inland and smaller coastal vessels, methanol is most relevant where three conditions are met: the vessel can accommodate the fuel-volume penalty, a viable bunkering concept is available, and the owner can manage a more complex approval and safety-engineering pathway than for diesel. Recent scientific work and demonstrator projects show that methanol ICE is technically feasible in retrofit-oriented dual-fuel concepts and in compression-ignited concepts using pilot fuel or ignition improvers, but also confirm that formaldehyde control, low-load combustion stability, material compatibility, corrosion, and lubrication management remain key engineering topics.

8.1 Methanol Facts

Methanol has a number of key properties that make it a potentially promising marine fuel. It is liquid at ambient temperature and pressure and can, therefore, be stored in simple fuel tanks on board without insulation or overpressure. Methanol is sulphur-free, produces negligible soot and burns cleanly compared to conventional marine diesel fuel, which results in high local air-quality advantages compared to conventional marine fuels.

The three main disadvantages of methanol are following:

- Toxicity: Methanol is toxic to humans by inhalation, ingestion and skin absorption, so its use requires strict handling procedures and a trained crew.
- Low energy density: Methanol has a much lower volumetric energy density than diesel, which means vessels need significantly larger fuel tanks or must accept shorter range and reduced payload flexibility.
- Low flash point: Methanol is a low-flashpoint fuel which creates higher ignition risk and requires dedicated safety measures such as secondary barriers, ventilation and gas detection.

Methanol is also fully miscible in water and much less persistent in the environment than oil-based marine fuels after a spill. However, methanol releases can still create acute hazards because of flammable vapours, toxic exposure, and operational risks during cleanup and ventilation. The environmental profile is, therefore, better than oil from a persistence perspective, but not operationally trivial.

On the supply side, methanol can be produced from fossil and non-fossil pathways. Fossil methanol is still the dominant market product, while bio-methanol and e-methanol are increasingly important for decarbonization strategies. A major European milestone is the Kassø e-methanol facility in Denmark, inaugurated in May 2025, with a stated capacity of 42,000 tonnes per year. This confirms industrial progress, but renewable methanol remains constrained in both availability and cost compared with fossil methanol.

Funded by the Horizon Europe Programme of the European Union under grant agreement No 101096809
Funded by the Horizon Europe guarantee of the United Kingdom, under project No 10068310
Funded by the Swiss State Secretariat for Education, Research and Innovation

8.2 Fuel Standards and Specifications

Marine methanol now has a dedicated international product standard. ISO 6583:2024 defines general requirements and specifications for methanol from all production pathways at the custody-transfer point for use in marine diesel engines, fuel cells, and other marine applications and defines three different quality categories: MMA, MMB and MMC. This gives shipowners and fuel buyers a far more robust basis for marine procurement than relying solely on general chemical-market specifications.

In commercial market practice, the non-marine specific IMPCA reference specification for methanol remains highly relevant, because price reporting and methanol commodity trading still align strongly with IMPCA-conforming products. In project terms, that means methanol procurement should specify not only the fuel name, but also the applicable fuel grade, purity expectations, traceability basis, and any sustainability certification required for compliance or reporting. The importance of methanol fuel quality was also evidenced by the methanol-powered research vessel UTHÖRN[3].

8.3 Emissions and Environmental Performance

In the context of emissions to air, different aspects are discussed. On the one hand, a distinction is made between toxic and climate-impacting emissions. On the other hand, a distinction is made between local and global emissions. Examples of toxic emissions are nitrogen oxides, particulate matter, formaldehyde, etc., while climate-impacting emissions include CO2, methane, laughing gas, etc. Local emissions have effects on the immediate surroundings of the source, such as toxicity. The effects of global emissions are not limited locally; they can be climate-impacting substances, or substances damaging the ozone layer or sulphur emissions from the seagoing sector. While methanol, in general, burns cleaner compared to traditional ship fuels, discussions with DG GROW and JRC in the context of an NRMM amendment as well as recent publications show, that the formaldehyde emissions from methanol engines are a field that requires research. It is likely, that formaldehyde emissions can be controlled with appropriate exhaust gas aftertreatment. However, the risks associated with formaldehyde are not fully understood and, therefore, the basis for emission limits is missing. Formaldehyde forming results from incomplete combustion of a carbon-containing fuel. These emissions generally vary depending upon different variables, such as engine concept and operating point. A good overview of recent publications from this context can be found in the study "Methanol as marine fuel" by Öko-Institut e. V.[4].

SYNERGETICS partner ScandiNAOS also conducted tests on an engine-test dyno with Fourier Transform Infrared Spectroscopy (FTIR) applied for exhaust gas measurements. Usually, exhaust gas is measured with Flame Ionization Detection (FID) technology, which allows the quantification of unburned hydrocarbons (HC), but not the differentiation of the individual components. For St. V engines relevant for IWT, the total emission of HCs is limited to 0.19 g/kWh. However, treating formaldehyde as part of the HC emissions will probably not be accepted.

8.4 Regulations

For inland navigation, the key technical reference is ES-TRIN. The latest update, ES-TRIN 2025/1, in force since January 2026, introduced new rules on low-flashpoint fuels, in particular the storage and use of methanol. In practical terms, methanol is now clearly embedded in the applicable inland-vessel technical framework rather than being treated solely as an experimental special case.

For coastal and seagoing vessels, the principal international safety reference remains IMO MSC.1/Circ.1621, the interim guidelines for ships using methyl/ethyl alcohol as fuel. The guideline defines fuel as methyl/ethyl alcohol fuels suitable for safe operation on board and complying with an

[3] https://www.nordsee-zeitung.de/bremerhaven/beim-antrieb-des-neuen-awi-forschungsschiffes-uthoern-hakt-es-immer-noch-227175.html

[4] https://www.oeko.de/fileadmin/oekodoc/Methanol-as-a-marine-fuel.pdf

Funded by the Horizon Europe Programme of the European Union under grant agreement No 101096809
Funded by the Horizon Europe guarantee of the United Kingdom, under project No 10068310
Funded by the Swiss State Secretariat for Education, Research and Innovation

international standard, and it provides the functional framework for design, arrangements, operation, and safety.

The engine-approval route, however, remains complex under the current set of regulations. Under the NRMM/Stage V framework, methanol is not part of a simple diesel-like reference-fuel route. Commission Delegated Regulation (EU) 2017/654 nonetheless allows manufacturers to permit engines to run on additional market fuels beyond the standard fuels, provided the fuel is declared and compliance is demonstrated accordingly. CESNI's explanatory material also notes that field-testing provisions under Regulation (EU) 2016/1628, read together with Annex XI of 2017/654, can facilitate temporary testing of engines using fuels such as methanol on inland vessels. In practice, this means methanol ICE projects require a manufacturer-specific and project-specific approval strategy, which significantly increases the costs for current prototype projects.

8.5 Technical Concept

When methanol is used as fuel for an internal combustion engine, several design challenges are to be met. First, methanol is a low flashpoint fuel which means that the regulations for the use of low flash-point fuels on board vessels must also be complied with. In addition, the methanol flame is virtually invisible in daylight. This can pose a safety risk for the crew and special sensors would also have to be used for detection; for example, infrared cameras or temperature measurement would be suitable. One advantage of burning methanol is that the flame temperature is significantly lower than that of diesel and water can be used very well as an extinguishing agent. In contrast to diesel, methanol is significantly more corrosive, and the lubricating effect of alcohol is also significantly poorer than that of diesel. The metals and rubbers that encounter methanol must therefore be selected very carefully. This also applies to spare parts in later use. The following engine concepts are relevant for the use of methanol as fuel in marine applications. For the dual fuel concepts the baseline is to replace 50 % to 80 % (energy ratio) of diesel with methanol. The following engine concepts are relevant for the use of methanol as fuel in marine applications, with option 2 and 4 being compared in SYNERGETICS Deliverable 3.17:

1. Dual fuel high pressure direct injection (DF-HPDI) as 2-stroke and as 4-stroke
2. Dual fuel port injection (DF-PI)
3. Port injection spark ignited (SI)
4. Compression ignited, with ignition improver (CI)

8.6 Equipment for Methanol-Powered Vessels

Methanol tank and piping materials require careful selection because methanol can affect corrosion behaviour, elastomers, and lubrication. Stainless steel and suitable coatings are commonly used solutions. Additionally, to the general fuel tank regulations, ES-TRIN 2025/1 requires methanol fuel tanks to be designed to prevent electrostatic charges, a fixed piping system for safe gas freeing, a secondary barrier to prevent leakage as well as a greater minimum clearance distance in order to add an extra safety layer.

Fuel pumps, valves, filters, and other methanol components create hazardous zones that require secondary containment and leak detection. In practical terms, fuel preparation equipment is typically placed either in dedicated spaces or in enclosed cabinets that are separated from non-hazardous spaces and integrated into the vessel's overall ventilation and shutdown concept.

For inland vessels, ES-TRIN allows two main approaches for methanol-fuelled machinery spaces: gas-safe engine rooms and ventilated engine rooms. In a gas-safe engine room, a single failure in the methanol system must not lead to methanol leakage into the engine room, and methanol piping and equipment within the engine-room boundaries must be protected by a secondary barrier, either through double-wall piping or through ventilated ducts or enclosures.

In a ventilated engine room, ES-TRIN requires the ventilation system to ensure at least six air changes per hour, to be independent from other ventilation systems, and to handle and purge probable maximum

Funded by the Horizon Europe Programme of the European Union under grant agreement No 101096809
Funded by the Horizon Europe guarantee of the United Kingdom, under project No 10068310
Funded by the Swiss State Secretariat for Education, Research and Innovation

leakage. If methanol vapour concentration exceeds 250 ppm, an optical and acoustic alarm must be triggered. If concentration exceeds 40% of the lower explosion limit or ventilation fails, the methanol supply and methanol components in the affected engine room must be shut down automatically. ES-TRIN also requires at least two portable methanol detectors for ventilated-engine-room concepts.

8.7 Special Safety and Other Requirements

Methanol's low-flashpoint nature means that ship safety is built around containment, ventilation, detection, shutdown logic, training, and procedures. The flame can be difficult to see in daylight, so detection and emergency response concepts must be designed accordingly. Water can be effective in firefighting, but crew protection and area control remain critical because of vapour hazards and toxicity.

8.8 Bunkering

The bunkering of Methanol for inland navigation is regulated by EN 18071:2025 which covers transfer systems to and from inland navigation vessels and explicitly includes land-, truck-, and vessel/barge-based bunker scenarios. It addresses technical requirements for nozzles, connections, flanges, and fail-safe features as well as operational and risk-assessment requirements.

Operationally, North-West Europe has moved beyond isolated trials. The Port of Rotterdam reported 11,819 tonnes of bio-methanol bunkered in 2025, up from 3,946 tonnes in 2024. Port of Antwerp-Bruges completed a 4,300-tonne green methanol bunkering of Ane Maersk in 2024. Waltershofer Hafen in Hamburg has been approved for ship-to-ship methanol bunkering since 2025. Amsterdam completed its first 500-tonne ship-to-ship green methanol bunkering in 2025, reported via the European Sea Ports Organisation.

For inland and coastal projects, the most realistic conclusion is that methanol bunkering is now available in selected hubs, but not yet ubiquitous. Truck-to-ship remains a practical entry route for early or smaller-volume projects, while ship-to-ship and barge-based supply are becoming established in major North-West European ports.

8.9 Economics

Public price visibility is strongest for fossil methanol. Methanex's published European contract price for 1 April to 30 June 2026 is EUR 850/mt, posted on 31 March 2026. DNV's 2025 methanol shipping report notes that bio-methanol averaged around USD 2,500 per tonne MGOe in 2025, roughly three times the cost of marine gas oil, and identifies cost and availability as the main obstacles to wider uptake.

For project economics, this means that methanol cannot be discussed with a single generic price assumption. Fossil methanol has a clearer commodity pricing structure, while low-GHG methanol remains contract- and availability-driven. Retrofit and integration cost are even harder to generalize because they depend on engine concept, tank arrangement, safety design, approval route, and bunkering concept. A robust project assessment therefore needs vessel-specific cost modelling rather than a universal CAPEX benchmark.

8.10 Considerations for Deployment

The deployment of methanol in inland and coastal shipping depends on more than fuel availability. The key conditions are a vessel profile that can tolerate the tank-volume penalty, access to a feasible bunkering concept, a manageable approval pathway, crew and operator readiness for methanol-specific procedures, and access to a fuel source whose environmental profile matches the project's objectives. Methanol is therefore unlikely to become a universal fuel choice across all shipping segments, as vessel types, duty cycles, space constraints, infrastructure access, and fuel-supply conditions vary too widely for a single solution to fit every application. Instead, methanol is most attractive where these conditions align, such as for pilot boats, tugboats, ferries, workboats, and some inland cargo applications on repeat corridors. Its use is less straightforward where space is extremely constrained, port access is irregular, or a near-drop-in pathway is commercially preferred.

Funded by the Horizon Europe Programme of the European Union under grant agreement No 101096809
Funded by the Horizon Europe guarantee of the United Kingdom, under project No 10068310
Funded by the Swiss State Secretariat for Education, Research and Innovation