Prepared by	Approved by	Date	
Bengt Ramne, Ana Puljic, Oskar Thompson	Patrik Molander	2025-01-16	
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Introduction

The purpose of this document is to describe the results and conclusions from the CoMeBust-Me project.

The CoMeBust-Me project has been executed by the Swedish Maritime Administration, Chalmers University of Technology and ScandiNAOS AB between October 1st 2022 and December 31st 2024. The project has received funding from the Swedish FFI program, (Strategic Vehicle research and Innovation) as well as from the Swiss methanol producer PROMAN AG and the Methanol Institute, MI.

Executive summary

In the CoMeBust-Me project both industrial development and academic research has been performed. ScandiNAOS has developed a methanol-diesel dual-fuel concept from TRL 4 to TRL 7 while the academic research performed by Chalmers has had a more general objective to develop concepts for maximum replacement of fossil diesel with methanol while maintaining high engine efficiency and low emissions.

The technology developed in the project enables the conversion of existing and new diesel engines to methanol operation

In the project a Volvo 13L common rail laboratory engine has been used for the research and development of methanol combustion and two Volvo Penta D16 unit injector engines which were installed in a Swedish Pilot boat have been converted to dual-fuel methanol.

To make the Pilot boat suitable for methanol fuel a completely new methanol fuel system including a double walled fuel tank, pump, pressure regulators, filters and valves were installed. In addition, auxiliary systems such as ventilation and gas detection were added and fire suppression system updated.

The CoMeBust-Me project has generated a number of new projects where ScandiNAOS is providing engineering competence which can make dual-fuel conversion kits available for more engine brands than Volvo Penta within 18 – 24 months. This will in a very concrete way speed up the transition from diesel to methanol as an alternative fuel, since very few engine manufacturers have plans to develop their own solutions and make methanol engines available for the market before 2030.

A direct result of the CoMeBust-Me project is that the new ship that the well-known international environmental organization Greenpeace has ordered, will be equipped with the same type of dual-fuel Volvo Penta engines that have been installed in the Pilot boat in the CoMeBust-Me project.

For the new Greenpeace vessel ScandiNAOS will deliver 4 complete gensets which are powered by Volvo Penta engines converted to dual-fuel methanol operation. This is a break through project that is expected to generate much publicity and followers.

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1 Background

The use of fossil fuel for transport is a large contributor to the global emissions of greenhouse gases. Introduction of renewable alternative fuel is an important factor to reduce these emissions and to limit the global warming.

For some applications which do not to require large amounts of stored energy or where the energy storage is not subject to space and weight limitations, electrification can be an attractive and good alternative. However, for many applications which need large amount of stored energy and were available space and weight are limited, other alternatives are needed

Methanol has been identified as one of best alternatives to replace oil-based fossil fuel. Methanol is in liquid phase at ambient temperature and pressure which gives it much higher energy density compared to methane, hydrogen or batteries. It is an efficient fuel for internal combustion engines as well as for fuel cells. Methanol can be produced sustainably from various renewable energy sources. Bio methanol can be produced from any organic growing material. E-methanol can be produced from solar, hydro or wind power.

2 Project objectives

The CoMeBust-Me project was conceived on the realisation that methods are needed to enable the transition from fossil diesel to renewable methanol for existing diesel engines.

Objectives

The general objective of the project was to develop, install and verify technology that, in a cost-efficient way, enables the replacement of fossil fuels with methanol, for conventional diesel engines.

Specific objectives:

1. Identify the potential of the dual-fuel concept and how much of the diesel that can be replaced with methanol.
2. Develop a conversion kit and install on engines in an existing ship.
3. Do research for the next generation concept.

3 Work packages

The work was carried out in eight work packages (WP) as follows:

WP1	Project Management
WP2	Methanol dual-fuel research
WP3	Research for a novel dual methanol concept
WP4	Dual-fuel conversion of a Volvo Penta engines
WP5	Methanol conversion of ship - design
WP6	Methanol conversion of ship – shipyard work
WP7	Field test
WP8	Summary of result and dissemination

*Scandi***NAOS AB**
Adolf Edelsvärdsgata 11, 414 51 Göteborg, SWEDEN
Phone: +46 31 694361
e-mail:info@scandinaos.com

WP 1 Project Management

WP leader: ScandiNAOS

Deliverables

- Project plan including master schedule
- Progress Reports.
- Financial Reporting
- Final Report

WP 2 Methanol dual-fuel research

WP leader: Chalmers University of Technology

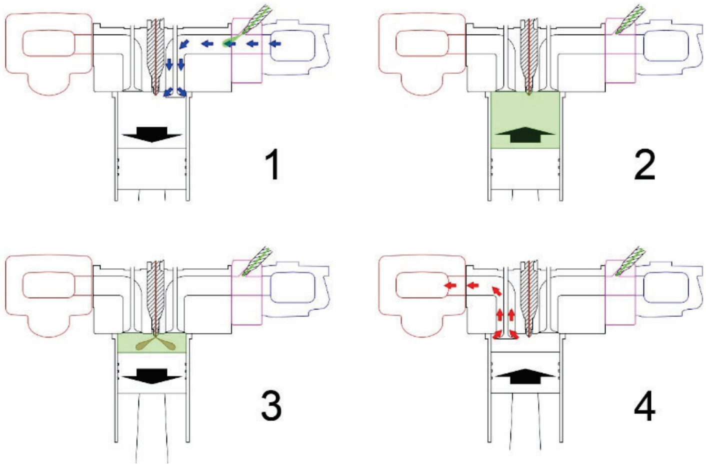
In WP2 a Volvo D13 common rail diesel engine was fitted with port fuel injectors and tested in the engine dyno of Chalmers. Methanol was added via port fuel injectors which were controlled by an additional dedicated methanol ECU. The dual-fuel operation was tested both with standard settings of the diesel ECU and with modifications to the diesel ECU where different diesel injection timing, pilot quantity, pilot separation, rail pressure and injection scenarios (single and double) were tested.

Dual-fuel port injection technology (DF)

All major marine engine suppliers have dual-fuel engines where methane gas (LNG) can replace a significant part of the HFO or MGO. Since the methane is in gas phase it is easier than for the liquid methanol to get a good mix with a uniform distribution. The methane is either introduced via a mixing unit arranged at considerable distance upstream the air inlet manifold or via one or several injectors at the intake manifold. The premixed methane-air mixture will enter each cylinder when its inlet valve is open.

In the case of a diesel methanol dual-fuel, DMDF engine, the upstream fuel mix is difficult to achieve. It is often a better option to inject the methanol into the air inlet manifold. Both single point and multi point injection can be considered. For a good performing engine, it is critical to get as similar fuel-air mixture both between all cylinders and between consecutive ignition cycles, as possible. For the best control of the flow of methanol into each cylinder, it is beneficial to place one injector per cylinder as close as possible to the inlet valve of each cylinder. This can be a challenging engineering task to find a good location without obstructing the air flow of the original air inlet manifold too much. In diesel only mode, the engine runs on the standard normal diesel cycle. When switched to methanol mode, the engine runs on a dual combustion cycle.

A diesel engine typically operates lean, i.e. there is an excess of air compared to fuel and the power is controlled by the fuel amount injected. In dual-fuel mode, where the methanol is pre-mixed with the air, there is a risk that the fuel mixture of the pre-mix becomes too lean i.e. below the flammability limit of methanol. For this reason, also in dual-fuel mode the engine will operate on diesel only when the engine is subject to very low power demand, where the mixture is very lean.



1 | The combustion principles of 4-stroke port injected engine with diesel pilot ignition

1. The piston moves down, methanol injects from the port into the inlet air
2. The piston moves up and compresses the air-methanol mixture, temperature and pressure are increased
3. Close to TDC, diesel is injected as pilot fuel and ignites the compressed methanol air mix in the cylinder. The piston is then pushed down by the expansion of the hot gases.
4. The exhaust gases are pushed out through the exhaust valve.

In WP2, a Volvo D13 common rail engine was modified for dual-fuel operation.

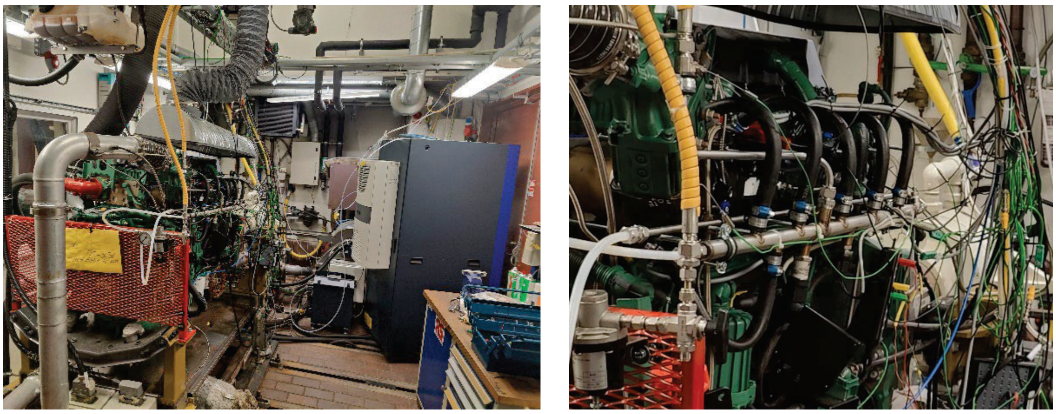
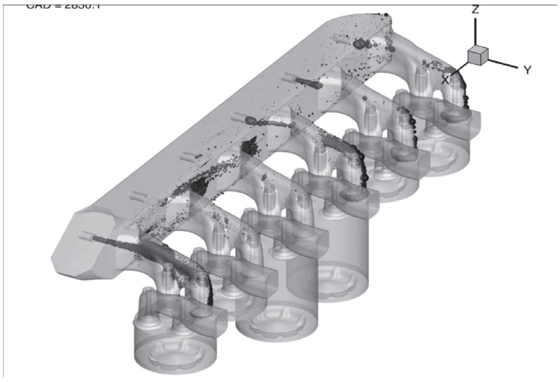


Figure 2, Volvo D13 in Chalmers engine dyno

Six injectors were installed on a modified inlet manifold to enable port-fuel injection (PFI) of methanol see Figure 2. An additional methanol ECU was connected to the injectors to control injection amount and timing.

The cylinder pressures were monitored for the cylinders and a significant disparity was observed when using PFI methanol. CFD simulations identified the issue as uneven methanol distribution among the cylinders. To address this, a redesigned inlet manifold was developed with injectors positioned closer to the cylinder intake ports see Figure 4. This new design significantly reduced cylinder-to-cylinder variations, though cylinder six still exhibited higher pressure and exhaust temperature. CFD results attributed this residual issue to methanol evaporation in the manifold and accumulation close to the last cylinder due the asymmetric air flow.



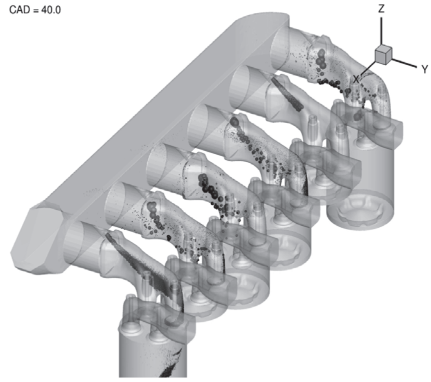


Figure 3, First location of port fuel injectors

Figure 4, Modified location of port fuel injectors

The second part of the WP focused on the dual-fuel operation. Engine performance in dual-fuel mode was studied at 10%, 25%, 50%, 75%, and 100% loads along a propeller curve. The dual-fuel performance was compared to the original diesel operation.

Initially, the settings of the standard diesel ECU were used and the amount and timing of methanol from the port fuel injectors controlled by the additional dedicated methanol ECU.

For the particular diesel ECU that was fitted on the Volvo D13 laboratory engine, it was possible to modify the injection timing, rail pressure, pilot quantity, pilot separation and fuel amount. This feature is not enabled for engines delivered for normal applications.

The possibility to modify the diesel injection characteristics enabled tests with various combustion strategies to be performed. Different diesel injection timing and injection scenarios (single and double injections)—were explored to optimize engine performance at each load point. Both stratified partial premixed combustion (PPC) and diesel-methanol compound combustion (DMCC) were tested. The methanol energy fraction (MEF), thermal brake efficiency (TBE) and NOx emissions were determined and reported for each load condition.

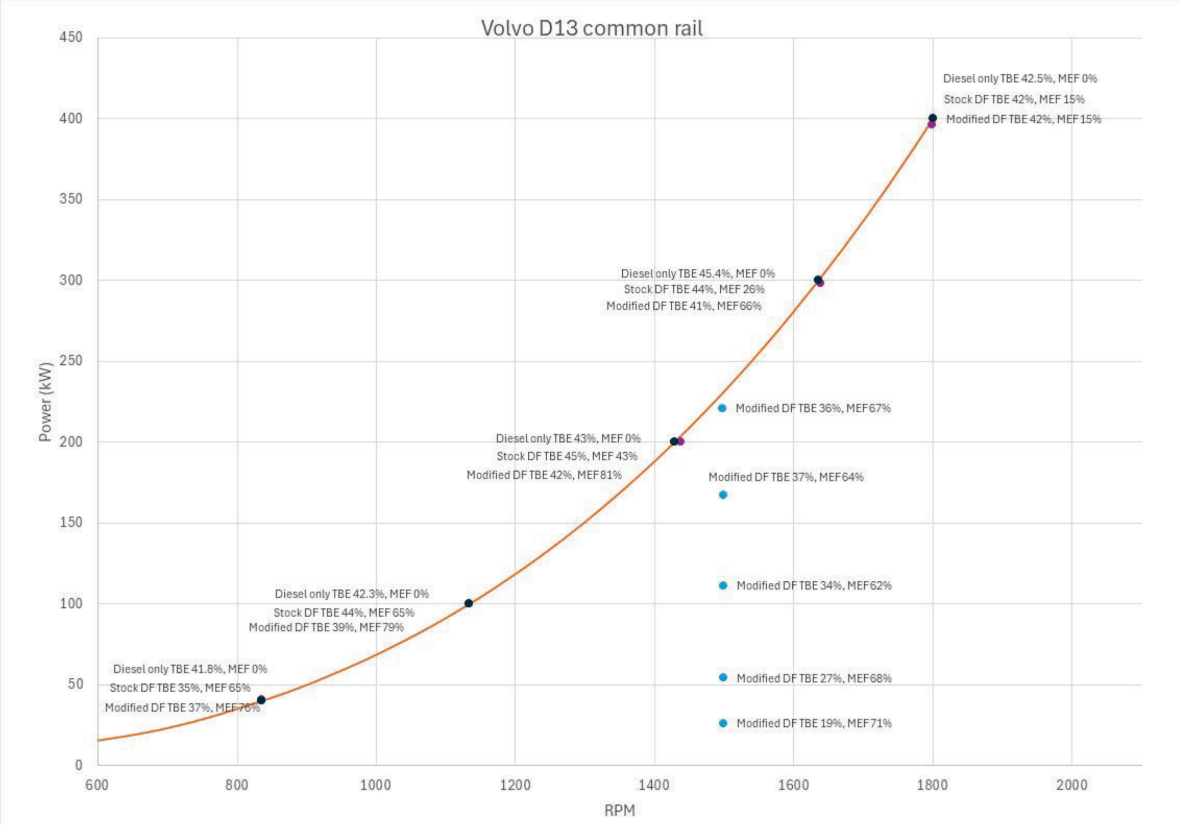


Figure 5, Engine efficiency and methanol energy fraction for various load point with both original (stock) diesel ECU settings and modified diesel ECU settings

Figure 5 shows results from the Volvo D13 engine before and after engine tuning for five operation points (10%, 25%, 50%, 75% 100%) on a propeller curve with exponent 3 as described by ISO 8178 for the E3 test cycle and for operation points at 1500 rpm for generator applications. These results show that for this engine, ECU tuning has a great impact on methanol performance and diesel replacement. The results also show that the greatest possibility of diesel replacement on this engine is in the low to midrange with a MEF measured at close to 80 % for 10%, 25% and 50% load. At higher load engine knock became a limiting factor thus lowering the potential amount of premixed methanol substantially and resulted in a much lower diesel replacement compared to low and medium load. The results and method of this work package are further detailed in the scientific publications.

Deliverables

Two Scientific publications have been prepared based on the research done in WP2

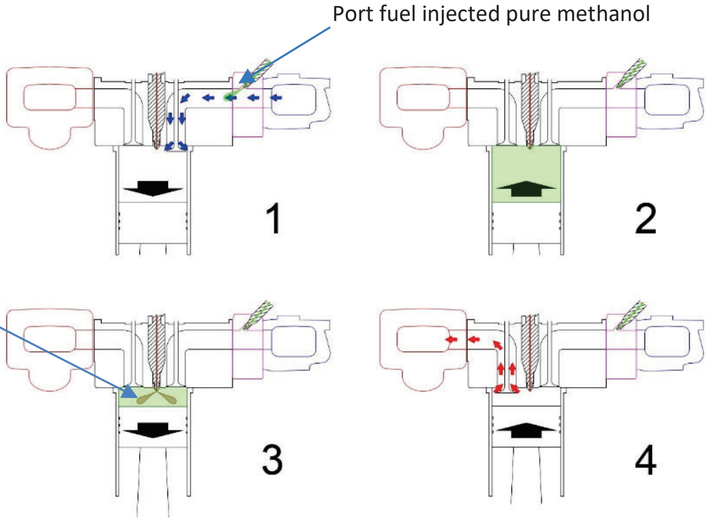
- **Effects of Port-Fuel Injected Methanol Distribution on Cylinder-to-Cylinder Variations in a Retrofitted Heavy-Duty Diesel-Methanol Dual-fuel Engine**
    - Seyed Morteza Mousavi, Srinibas Thripathy, Patrik Molander, Petter Dahlander
    - Department of Mechanics and Maritime Sciences, Chalmers University of Technology, Gothenburg SE-412 96, Sweden.
- **Detailed investigation of DMDF limits in a marine retrofit application by varying diesel injection parameters**
    - Oskar Thompson, Seyed Morteza Mousavi, Petter Dahlander
    - Department of Mechanics and Maritime Sciences, Chalmers University of Technology, Gothenburg SE-412 96, Sweden.

WP 3 Research for development of novel methanol combustion "Dual methanol"

WP leader: Chalmers University of Technology

WP3 focused on novel concepts to minimize or eliminate diesel usage and maximize the MEF. Initially, using a pre-chamber was proposed as a method to achieve 95% or higher MEF. However, after months of research and consultations with pre-chamber manufacturers and other research groups, this approach was deemed unsuitable due to the extensive modifications required to the cylinder head, high costs, and time constraints—making it impractical for retrofit applications within the project's scope.

Instead, an alternative approach using ignition enhancers and a dual-methanol system was proposed.



6 | The combustion principles of 4-stroke port injected engine with MD96 pilot ignition

1. The piston moves down, methanol injects from the port into the inlet air
2. The piston moves up and compresses the air-methanol mixture, temperature and pressure are increased
3. Close to TDC, methanol with ignition enhancer (MD96) instead of diesel fuel, is injected as pilot fuel and ignites the compressed methanol air mix in the cylinder. The piston is then pushed down by the expansion of the hot gases.
4. The exhaust gases are pushed out through the exhaust valve

In this method, pure methanol was used in the PFI system, while diesel was replaced with a methanol-ignition enhancer mixture (96% methanol and 4% Beraid 3555M, referred to as M96). Different amounts of ignition improver in the range of 3 to 6% was used in earlier works to reach stable combustion. We have tested the concept initially with 8% Beraid, and later switched to 4% Beraid, which still maintained a stable combustion even at the lowest loads. At lower loads, only direct injected M96 was used, while at higher loads, port fuel injected methanol supplemented the engine operation. This novel dual-methanol approach achieved up to 98% MEF. The performance and emissions of dual-methanol operation were evaluated at various loads along the propeller curve and at 1500 rpm for generator applications. While dual-methanol mode showed slightly lower efficiency and higher unburned CO and THC emissions, it significantly reduced NOx and soot emissions compared to conventional diesel combustion (CDC).

Deliverables

One Scientific publication have been prepared based on the research done in WP3

- **Retrofitting a heavy-duty marine diesel engine to run on methanol using Dual-Methanol method**
    - Seyed Morteza Mousavi, Oskar Thompson and Petter Dahlander
    - Department of Mechanics and Maritime Sciences, Chalmers University of Technology, Gothenburg SE-412 96, Sweden.

WP 4 Dual-fuel conversion of a Volvo Penta D16 for onboard application

WP leader: ScandiNAOS

In WP4 Volvo Penta D16 unit injector marine diesel engines were converted to dual-fuel operation. Both the D13 tested in WP2 and the D16, are 6 cylinder engines with similar arrangement with the one common cylinder head and the air inlet manifold on the side. Apart from the difference in volume, a significant difference is that the D13 is a common rail engine and the D16 is a unit injector engine. For the common rail engine the pressure can be varied and is independent of the crank angle. This means that fuel can be injected any time independent of the crank angle and also enables multiple injection for each combustion stroke. For a unit injector engine, a high pressure pump is integrated in each injector and actuated by the cam shaft. This means that it is only pressurized during a part of the combustion stroke limiting the fuel injection to a time window and to only one injection per combustion stroke at a pre-set pressure. The unit injector concept provides satisfactory performance for medium rated diesel engines but for higher rated engines with tougher emission requirements the common rail system provides better performance.

When converting a diesel engine to methanol there are certain factors that limits at what operation points methanol can be injected and what amount of methanol than can be injected.

1) Misfiring
   When port-injected methanol is introduced into the cylinder the high latent heat of vaporization together with the increase of fuel amount due to methanol's relatively low lower heating value (LHV) lead to a much colder environment in the cylinder before combustion compared to a diesel engine. This has the effect of in some cases drastically increasing the ignition delay between start of injection of diesel and start of combustion thus in some cases creating an unstable or incomplete combustion at low load.
2) Knocking
   At high load the risk of knocking, i.e. sections of the fuel pre-mixture spontaneously ignite away from the main propagating combustion event due to high pressures and temperatures in the cylinder, sets the limit of how much methanol that can be injected.
3) Cylinder peak pressure
   In a diesel engine the fuel is typically injected about 6 crank angle degrees before top dead centre. There is a certain ignition delay which will make the combustion start just after TDC. The burning fuel will release heat while the piston moves down generating a pressure distribution over time. When introducing additional fuel through the intake the effects in the cylinder of burning the extra port injected fuel occurs at the same time as the normal heat release of diesel. This can result in higher maximum cylinder pressures then the engine is designed for if timing is not adjusted accordingly.

With a standard ECU where the dual-fuel operation is limited to the original fuel injection map, the max MEF that could be reached was about 40% for the Volvo Penta 16L unit injector engine compared to about 50% for the Volvo 13L common rail engine using the standard diesel injection parameters.

If the OEM enables activation of a dedicated fuel map for the diesel during dual-fuel operation, the common rail engines provide much better potential to reach higher MEF by adjusting the diesel parameters for the different load point when the engine is operating in dual-fuel mode.

The engines in the Pilot boat 790 are two Volvo Penta D16 650hp (478 kW) unit injector diesel engines equipped with standard ECUs with no option to adjust the diesel fuel injection timing. The engines have now been fitted with dual-fuel conversion kits developed and manufactured by ScandiNAOS

The design of the conversion kit included risk analysis in cooperation with the Italian classification society RINA. Following deliverables were produced

Deliverables

- SNP21201-707-4 Ex-proof enclosure explosion test report
- SNP21201-790-1 Volvo dual-fuel engine, System block diagram
- SNP21201-790-3 Volvo dual-fuel engine, Cause and Effect matrix
- SNP21201-790-4 - Volvo dual-fuel engine, FMEA
- SNP21201-790-6 Test program
- SNP212101-601-5 Pressure sensor bracket
- SNP21201-601-4 Tank bracket aft
- SNP21201-601-3 Tank bracket forward
- SNP21201-601-2 Connection box bracket
- SNP21201-601-1 Exhaust temp adapter
- SNP21201-902 – Injector map
- VolvoD16-dyno-interface
- SND21201-901 NIRA methanol dual-fuel - technical description

Engine conversion

One Volvo Penta D16 unit injector engine was used for installation and tests of a prototype dual-fuel kit design to be suitable for onboard operation. Two additional similar dual-fuel kits were installed on the Volvo Penta D16 engines in the Swedish Pilot boat 790.

A principle illustration of the engine conversion can be seen in Figure 4. The parts added for methanol system are coloured in green.

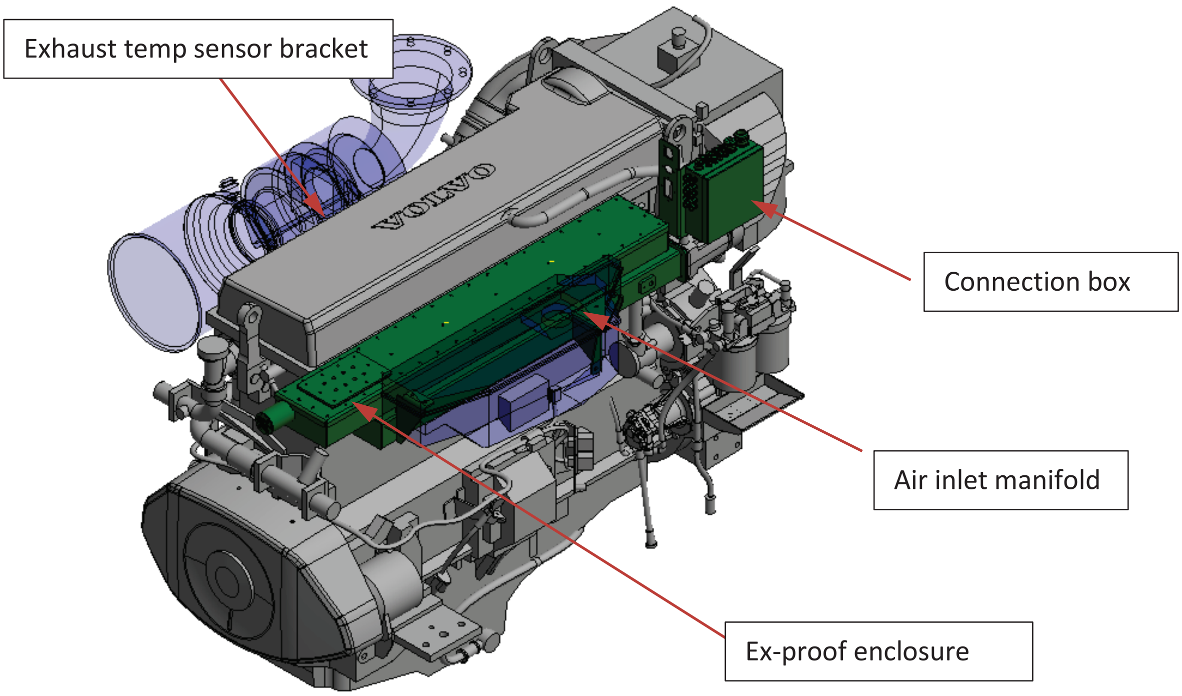


Figure 7 Overview of engine modification

Mechanical conversion

The original air inlet manifold was replaced with a new manifold that houses the methanol fuel rail and port fuel injectors. The new manifold was designed as an ex-proof enclosure.

Ex-proof enclosure

The concept of the explosion proof enclosure is inspired by IEC-60079-1 (explosion protection by flameproof enclosures “d”). The explosion proof enclosure can withstand the pressure and heat generated by an internal explosion and not transmit the ignition to external. By applying this concept, non-ex components can be used inside the enclosure.

To evaluate the concept of the ex-proof enclosure, explosion test were been done to identify maximum possible pressure. A number of tests were performed with different amount of methanol present in the manifold at different temperatures. Methanol volume of 5 ml, 35 ml, and 100 ml were injected into the manifold and heated up to temperature of 5 °C, 20 °C, 35 °C, 50 °C, and 65 °C before ignition.

The maximum pressure recorded from the test was 6.85 bar. There were no enclosure deformation or crack during the test. For ex-proof enclosure explosion test report, see SNP21201-707-4.

Once the maximum pressure was determined, an overpressure test was conducted at 1.5 times that pressure – approximately 10 bar. For ex-proof enclosure overpressure test report see SNP21201-707-5.

The dual-fuel engine control concept

The Engine Control unit (ECU) performs several functions: engine management, sensor integration, performance optimization and emission control.

The original ECU was kept, and an additional ECU for methanol control was added for each engine. The dual-fuel engine control concept requires communication between the original diesel ECU and the new methanol control ECU. To identify interconnections between two ECUs, engine control PLCs and ship safety system, a failure mode and effect analysis was conducted. The outcome of this analysis provided precise input of what sensor failure triggers which failure mode and the action when it happens. For example, if a sensor on injector 1 gives no signal, failure effect is that cylinder is unbalanced. This is detected by current measure and if it is too high or too low, alarm is triggered and sets a system response to go to diesel mode. For more details on FMEA analysis, see document SNP21201-790-4. In general, the control strategy is all abnormal conditions will lead the engines back to run on diesel only.

The development of the methanol control ECU was done as a collaboration between ScandiNAOS AB and NIRA. ScandiNAOS was providing input information, managed testing, analysed physical performance of engines, while NIRA developed the software. For more information on development workflow of ECU, see SND21201-901 document. Once these stages were done, a test on D13 at Chalmers was conducted. After the first test at Chalmers, dual-fuel functionality was implemented. This phase involved adding dual-fuel mode to the logic tree, identifying and implementing TSC1 (Torque/Speed control) diesel limiting conditions. For example, function of diesel limit dependency on engine RPM, safety features with provisions for emergency shutdowns, error handling, and knock detection must be implemented. The system is designed to be responsive to various operating conditions, automatically adjusting fuel mixtures and limits based on engine load, speed, and potential error states. It also includes data logging capabilities for diesel consumption, which can be used for further refinement of the dual-fuel operation. This phase of iterative development and adjusting of engine performance variables was a success due to cross-functional teamwork of two companies, effective communication and knowledge sharing. Once the ECU for VP D13 with dual-fuel functionality was developed, another test at Chalmers was conducted. Afterwards, minor adjustments were made for D16 followed by engine dyno tests on VP D16 at STT Emtec.

The Nira ECU holds a DNV type approval.

Sensor

The original VP engine is equipped with coolant temperature sensor, air inlet manifold air pressure sensor and an air inlet manifold air temperature sensor, that give input to diesel ECU.

In the ex-proof air inlet enclosure, methanol a fuel pressure and a temperature sensor are installed. Outside the enclosure, a crankshaft position sensor, a camshaft position sensor and an air inlet manifold pressure sensor are installed. These sensors communicate with the methanol ECU. For a more detailed look on sensor schematic communication between two ECUs and PLC, see document SNP21201-790-1.

Mapping of the dual-fuel control system

The earlier described limiting factors will decide how much of the diesel that can be replaced by methanol at different operation points and environmental conditions. To develop this map the engine is set-up in an engine dyno. Engine dyno tests are used in the development of engines for performance optimization. The engine dyno can be set to give specific torque resistance at specific engine speed.

For the pilot boat the engine will operate along a propeller curve.

The boat speed is approximately proportional to the engine speed and the engine power is proportional to the engine speed to the power of 2.5 – 3. ($P = k \times n^k$ where k is between 2.5 and 3). The nominal propeller curve will define a specific torque at a specific engine speed. The propeller curve will shift depending on the characteristics of the boat, the propeller and also environmental conditions such as wind and wave resistance. During acceleration the engine operation points will above the propeller curve and deceleration below.

When mapping the engine, a set of relevant points are chosen on and off the propeller curve, where the parameters such as injection timing and fuel amount is set for best operation. Parameters for any other operation point is calculated by interpolation.

The mapping of the dual-fuel system was performed at the engine dyno of STT Emtec in Sundsvall in October 2023. The engine was mapped for best operation. The resulting engine efficiency and methanol energy fraction is shown in Figure 8

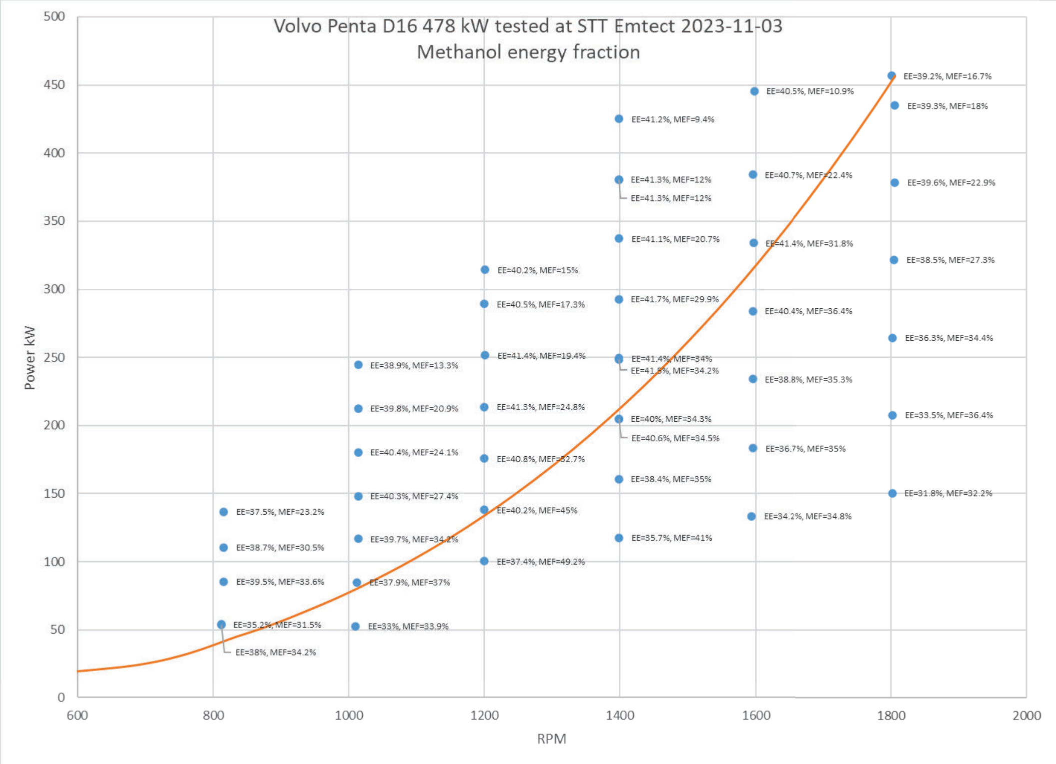


Figure 8, Engine efficiency and Methanol energy fraction vs Power

WP 5 Methanol conversion of ship – design

WP leader: ScandiNAOS

Deliverables

- SNP21201-100-1 General Arrangement
- SNP21201-780 System coordinate diagram
- SNP21201-790-2 Cause and effect matrix
- SNP21201-100-3 Component list
- SNP21201-105 Methanol tank dimensional drawing
- SNP21201-100-4 System description
- Pilot 790 - Rules Screening

Background

The conversion of the Swedish pilot boat "Pilot 790SE" was divided into two principle parts:

1) Adopting the boat with fuel and supporting systems.
   The design was executed in this WP5
2) Converting the two Volvo Penta diesel engines to dual-fuel methanol-diesel operation.
   The engine conversion work was done in WP 4

For the adoption of the boat following systems were added or modified

- Methanol fuel system including
  - Methanol tank and arrangement in tank room
  - Bunker station
  - Methanol supply system
- Ventilation system
- Drain system
- Fire protection
- Automation system
- Personal safety

All these systems are intertwined and work together to comply with requirements and safe methanol handling onboard. For more details, see system coordinate diagram SNP21201-780 document.

Methanol fuel system

Methanol tank

The methanol fuel tank is designed as "a tank in a tank". The inner tank is a conventional fuel tank, the outer tank is a second safety barrier. Both the inner tank and outer tank are made of stainless steel. For detailed dimensional drawing, see SNP21201-105.

The distance between inner and outer tank is about 50 mm apart from the aft upper section where a larger space between the tanks has been arranged. In this space supply pumps, fuel filters, pressure regulators, automatic fuel valves and fuel level sensors are located. The space is ventilated with an extraction ventilation system. A gas detector is installed to detect leakage in the outer tank. The space between tanks is consider as hazardous zone 1 and all components inside this should fulfil Ex-class requirements.

The inner tank is about 1200L capacity, a level indicator and a high-high level alarm are installed to monitor tank level and prevent over-filling during bunkering. The inner tank has a tank ventilation line that is equipped with a flame arrestor. The tank ventilation line ends at least 2 meters above deck, directed away from the cabin entrance and ends in a goose neck.

Bunker station

Originally there were two bunker stations for diesel located on the deck aft of the deck house. The SB bunker station was converted to bunker the new methanol tank.

The methanol bunker connection line has a drip-free coupling and is surrounded by a small coaming. The bunker line is single-walled above deck and is double-walled below deck.

Methanol supply system

There are two sets of methanol supply systems in the outer tank, one for each engine. The supply system includes a tank valve, a low-pressure pump, a filter, a master valve, and a pressure regulator. The tank valve and master valve are automatic valves that will shut down the methanol system by the control system. The pressure regulator is on the return line that keeps pressure in the supply system.

Methanol pipes outside of the tanks are double-walled and routed in the tank room through the engine room bulkhead into the engine room. The annular space of the double-walled pipes is open on the tank side, so any leakage from the inner pipe to the annular space will flow back to the outer tank and there be detected by the gas detector.

Manual shut off valve

Each system has manual valve with remote shut off from deck.

Tank room

The methanol tank is positioned between the original diesel tanks in the tank room. The space between tanks is narrow but care has been taken not to block the possibility of inspection of the diesel tanks.

Ventilation system

The ventilation of the inner tank arranged is routed through the deck and along the aft side of the deckhouse. It terminates with a flame arrestor above the deckhouse

The outer tank is arranged with extraction ventilation. An in-line extraction fan provides 30 air changes for the space between the inner and outer tank. The ventilation flow is monitored by a differential pressure sensor. A balancing damper is arranged to restrict the ventilation flow to avoid a potentially hazardous area around ventilation outlet. See SNP21201-707-2 for details.

The ventilation inlet and outlet are located aft of the wheelhouse, more than 2 meters above deck. Both supply and extraction line are arranged with a fire damper.

The outer tank ventilation piping is arranged with goose necks at the pipe ends directed away from cabin entrance.

Drain system

To collect leakage of methanol, a portable holding tank is placed in the rudder room. The holding tank has a capacity of 25L and is pre-filled with 80% water, which makes sure the mixture in the holding tank is not flammable. Leakages in the outer tank can be collected to the holding tank through a valve at the bottom of the outer tank.

Fire protection

Fire and gas detection system

To detect methanol leakage, methanol gas detectors are arranged in the engine room and outer tank. The system is designed to give alarm in 20% and 40% LEL (1,2% and 2,4% concentration in volume).

Heat fire detectors are arranged in the engine room and outer tank to detect methanol fire. All fire sensors and detectors to be connected to the existing fire system onboard.

Fire insulation

The engine room bulkhead between tank room and engine room is insulated with A60 insulation. The pipe and cable penetration are arranged accordingly.

Firefighting system

To suppress methanol fire onboard, dry portable chemical powder fire extinguishers suitable for methanol fire are arranged.

The existing fire suppression system (INERGEN) for the engine room is complemented with increased capacity.

The outer tank has a manual fire suppression system. A branch for manual fire extinguisher connection is arranged downstream of the fire damper on the ventilation supply line.

Automation system

The Pilot boat is equipped with a PLC for control and monitor methanol related system onboard, including sensors, pumps, valves, and signals from engine ECU. The PLC has one monitor control in the wheelhouse and one in the engine room.

UPS

In black-out situation, critical gas monitoring system to be powered by UPS. This covers PLC, HMI and gas detectors. The reason is to maintain leakage monitoring ability in black-out situation.

Over-filling protection

The level indicator in methanol inner tank gives a high alarm via PLC, which provides visual and audible alarm near bunker station.

The high-high level alarm in methanol inner tank is an independent alarm that hard-wired to shore. Once triggered, the pump on the shore side should automatically stop.

MeOH Stop and emergency stop

Original engine emergency stop should also stop the methanol system.
MeOH stop should stop only methanol systems and should not be confused with emergency stop button.

Personal safety

The emergency eye wash is prepared where methanol leakage could potentially occur: Inside the engine room, tank room and close to the onboard bunker station.

ScandiNAOS AB
Adolf Edelsvärdsgata 11, 414 51 Göteborg, SWEDEN
Phone: +46 31 694361
e-mail:info@scandinaos.com

Suitable Personal Protective Equipment (PPE), such as goggles, gloves, and portable methanol vapor detector in PPM level should be available onboard.

WP 6 Methanol conversion of ship – shipyard work

WP leader: SMA

The ship was converted at Simrishamns varv during 2nd half of 2024. The largest structural work was to fit the new double walled methanol tank into the existing tank room. The tank was very carefully designed to maximize the methanol volume in the limited space available. A temporary access hole had to be cut in the aft deck and bulkheads to get the tank into the position between the diesel tanks in the tank room.

Figure 9, methanol tank ventilation routed on the aft side of the deck house terminating above deck with a flame arrestor

Figure 10, SMA Pilot boat 790 at Simrishamns Shipyard when converted to methanol operation

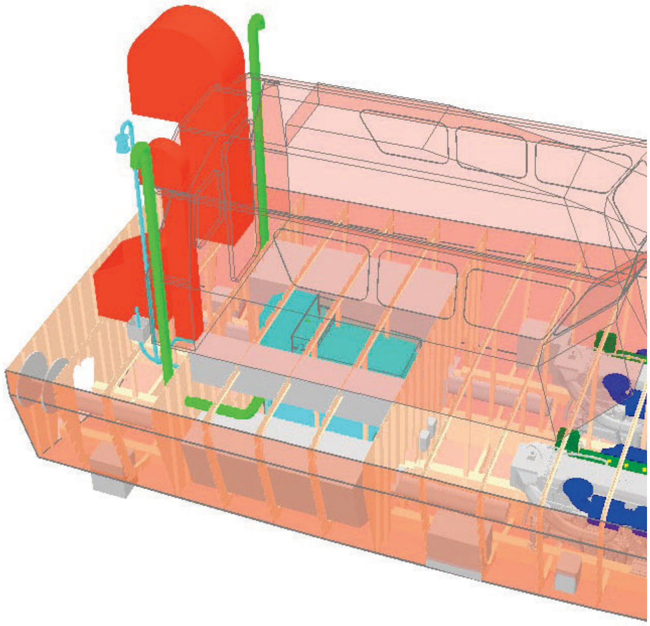


Figure 11, double skin methanol tank fitted in the tank room between the existing diesel tanks

The new methanol tank has a double skin with an enlarged space arranged at the aft upper part of the tank, between inner and outer surface, where pumps, valves pressure regulators and a gas detector has been fitted. Double walled pipes were routed from the fuel tank through the engine room bulkhead to the engines in the engine room. A bunker pipe was fitted between tank and the deck where the original diesel bunker station on the SB was converted to a methanol bunker station and fitted with a drip free coupling. Ventilation was routed both from the inner tank and from the intermediate space between tanks. The ventilation pipes were routed vertically along the aft side of the deck house and termites above the deck house top.

A monitoring system was installed to monitor the additional sensors from the methanol system and to control the fan, pumps and fuel valves.

WP 7 Field test

WP leader: ScandiNAOS

Due to delays in the project, the field tests have not been started at the official end of the project, however test will be performed during first quarter of 2025. Test to include

- Functionality tests
- Test of safety systems
- Engine performance test

The tests will be an important input for the next generation of dual-fuel kit that is being developed and will be delivered to the market in the 4th quarter of 2025

*Scandi***NAOS AB**
Adolf Edelsvärdsgata 11, 414 51 Göteborg, SWEDEN
Phone: +46 31 694361
e-mail:info@scandinaos.com

WP 8 Summary of result and dissemination

WP leader: ScandiNAOS

Results

In the CoMeBust-Me project both industrial development and academic research has been performed. ScandiNAOS has developed a methanol-diesel dual-fuel concept from TRL 4 to TRL 7 while the academic research performed by Chalmers has had a more general objective to develop concepts for maximum replacement of fossil diesel with methanol while maintaining high engine efficiency and low emissions.

The technology developed in the project enables the conversion of existing and new diesel engines to methanol operation.

In the project a Volvo 13L common rail laboratory engine was used for the research and development of methanol combustion. One Volvo Penta D16 unit injector engine was used for installation and tests of a prototype dual-fuel kit design for onboard operation. Two additional similar dual-fuel kits were installed on the Volvo Penta D16 engines in the Swedish Pilot boat 790. To make the Pilot boat suitable for methanol fuel a completely new methanol fuel system including a double walled fuel tank, pumps, pressure regulators, filters and valves were designed and installed. In addition, auxiliary systems such as ventilation and gas detection were added and fire suppression system updated.

The dyno test showed that, if a standard ECU is used, the maximum methanol replacement fraction, MEF that could be reached was about 40% for the Volvo Penta 16L unit injector engine and about 50% for the Volvo 13L common rail engine. When the mapping of the diesel ECU of the Volvo 13L common rail engine was adjusted, MEF up to 80% could be achieved for the best operation points. In dual-fuel mode the emissions of THC and CO were higher and the engine efficiency lower.

In addition to develop the methanol-diesel dual-fuel concept a novel concept was tested which was named dual-methanol. In this concept, pure methanol was used in the PFI system, while diesel was replaced with a methanol-ignition enhancer mixture (96% methanol and 4% Beraid 3555M, referred to as M96). At lower loads, only direct injected M96 was used, while at higher loads, port fuel injected methanol supplemented the engine operation. This dual-methanol concept achieved up to 98% MEF.

A direct result of the project is that the new ship that the well-known international environmental organization Greenpeace has ordered, will be equipped with the same type of dual-fuel Volvo Penta engines that have been developed in the CoMeBust-Me project.

ScandiNAOS will deliver 4 complete gensets to the newbuilding. The gensets will be powered by Volvo Penta engines converted to dual-fuel methanol operation. This is a breakthrough project that is expected to generate much publicity and following projects.

Dissemination

A press release was communicated at the start of the project.

The press release was distributed to the major Swedish newspapers as well as ship related magazines. Chalmers and the Methanol institute used their communication channels. The distribution was very successful. The analysis tool used by Chalmers showed that 45 000 000 potential readers/viewers/listeners might have been reached by the news.

Quantity is nothing without quality, but it was apparent that the message that we were going to convert Volvo Penta engines to methanol dual-fuel, also reached the relevant target groups. As a result of the press release, we were approached by engine producers, engine distributors, shipyards and ship operators who were interested in the dual-fuel kit development.

This has led to several new dual-fuel projects where ScandiNAOS is now providing engineering competence which will lead to that dual-fuel conversion kits will be available for several more engine brands within 18 – 24 months. There are very few OEMs that will have a methanol engine available for the market before 2030. The project has in a very actual way contributed to enable the transition from diesel to an alternative fuel that can be produced sustainably in large volumes and by that reducing the carbon footprint from shipping.

The project as generated three academic papers

1) Effects of port-fuel injected methanol distribution on cylinder-to-cylinder variations in a retrofitted heavy-duty diesel-methanol dual-fuel engine
2) Detailed investigation into DMDF limits in a marine retrofit application by varying diesel injection parameters
3) Retrofitting a heavy-duty marine diesel engine to run on methanol using Dual-Methanol method: to be submitted in January, to a SAE journal

A number of articles in the marine press has been published

1) **Manifold Times** - ScandiNAOS and partners to develop methanol conversion kits for diesel engines https://www.manifoldtimes.com/news/scandinaos-and-partners-to-develop-methanol-conversion-kits-for-diesel-engines/
2) **Lemsco** - Joint investment in methanol conversion kits for diesel engines paves the way for fossil free shipping https://www.lemsco.com/joint-investment-in-methanol-conversion-kits-for-diesel-engines-paves-the-way-for-fossil-free-shipping/
3) Port News - ScandiNAOS, Chalmers University and the Swedish Maritime Administration to develop Methanol conversion kits for diesel engines https://en.portnews.ru/news/343244/
4) **EIN Presswire** - Joint Investment in Methanol Conversion Kits for Diesel Engines Paves the Way for Fossil Free Shipping https://www.einpresswire.com/article/617613715/joint-investment-in-methanol-conversion-kits-for-diesel-engines-paves-the-way-for-fossil-free-shipping
5) **Ship and Bunker** - Swedish Group Seeks to Develop Methanol Propulsion Conversion Kit https://shipandbunker.com/news/world/795086-swedish-group-seeks-to-develop-methanol-propulsion-conversion-kit
6) **Baltic transport journal** - Methanol conversion kits for marine diesel engines https://baltictransportjournal.com/index.php?id=2716
7) Vessel performance information - ScandiNAOS AB joins with Chalmers University of Technology and the SMA to launch dual-fuel kits https://vesselperformance.info/2023/02/20/scandinoas-ab-joins-with-chalmers-university-of-technology-and-the-sma-to-launch-dual-fuel-kits/
8) **Offshore energy** - Swedish trio to develop methanol dual-fuel conversion kits for diesel engines https://www.offshore-energy.biz/swedish-trio-to-develop-methanol-dual-fuel-conversion-kits-for-diesel-engines/
9) **Marinemethanol.com** - Joint investment in methanol conversion kits for diesel engines paves the way for fossil free shipping https://www.marinemethanol.com/download/2023-02-16_CoMeBust-Me_Press_release.pdf

10) **Chalmers University of Technology**
https://research.chalmers.se/en/project/11043

*Scandi***NAOS AB**
Adolf Edelsvärdsgata 11, 414 51 Göteborg, SWEDEN
Phone: +46 31 694361
e-mail:info@scandinaos.com