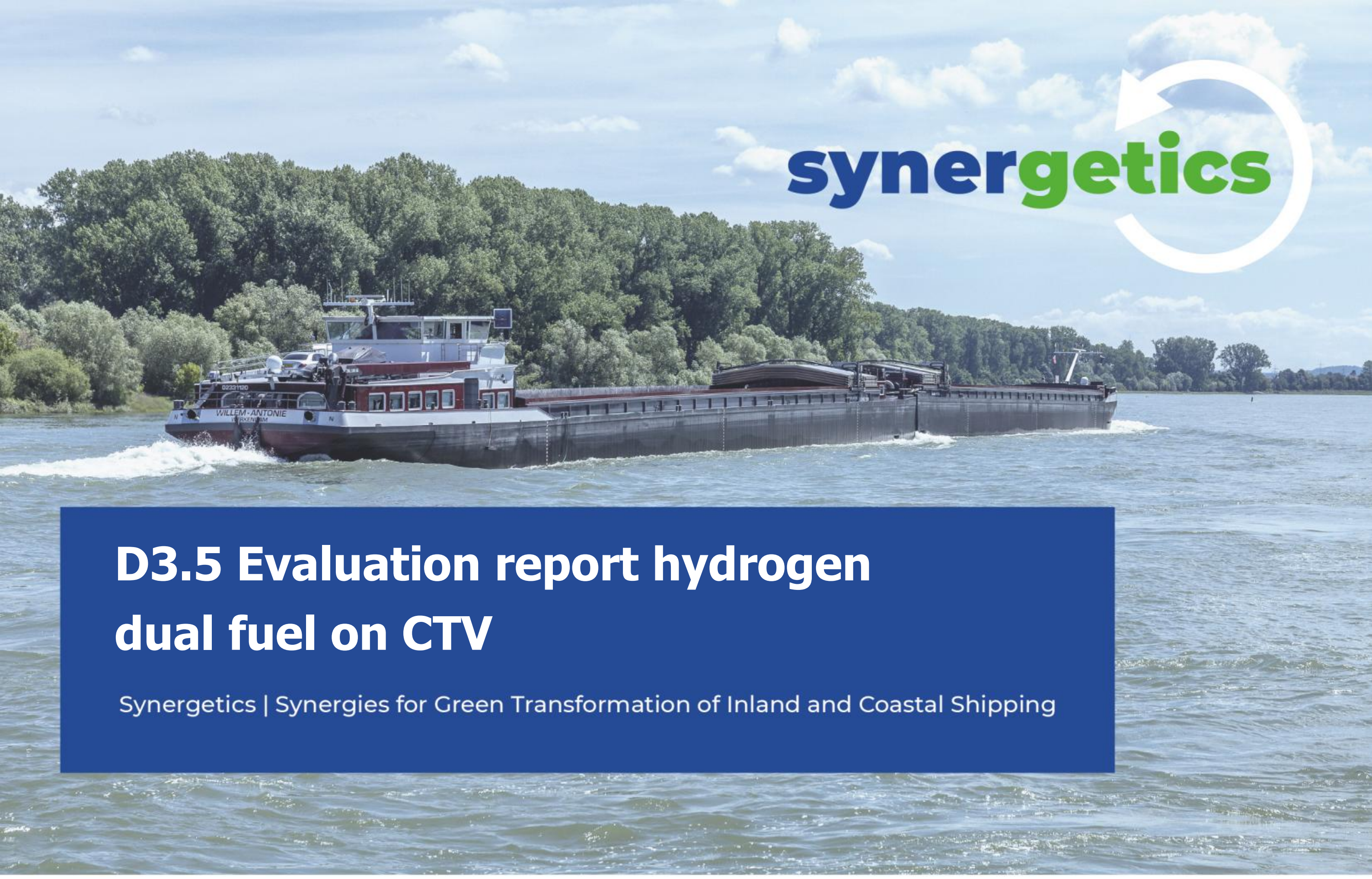

D3.5 Evaluation report hydrogen dual fuel on CTV

Synergetics | Synergies for Green Transformation of Inland and Coastal Shipping

GRANT AGREEMENT NO.	101096809
DURATION OF THE PROJECT	42 months
DELIVERABLE NUMBER	D3.5
DISSEMINATION LEVEL	SEN - Sensitive
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Release Approval

Table 1-1: Release Approval

Name	Role	REMARKS
A. Grasman	Reviewer 1	23-06-2025
B. Friedhoff	Reviewer 2	25-06-2025
P. Garcia	WP-Leader	17-07-2025
B. Friedhoff	Coordinator	28-07-2025

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Executive Summary

This deliverable describes the retrofitting of a Crew Transfer Vessel (CTV) from pure diesel propulsion to a dual-fuel hydrogen engine. It addresses the structural, engine-related, and organisational changes and adjustments involved. The economic aspects are also analysed.

The CTV Hydrocat 48 was extended to accommodate the 300 bar hydrogen cylinders on deck. It can be refuelled from a 500 barg hydrogen tank trailer in about an hour, although a shore side installation with compressors is also possible.

The installed MAN LE448 engines were retrofitted to dual fuel operation and were able to reduce up to 80 % in CO2 emissions, but could only do this in a limited operating range. On average 30 % CO2 emission reduction was achieved. The dual-fuel option provides a back-up system such that the vessel can always fall back on diesel when hydrogen is too expensive or not available. It also reduces the impact as refuelling can be required on a daily basis. When this does not fit the schedule diesel can be an alternative as the vessel still has the same range as before in diesel-mode. Maintenance aspects were considered to be quite minimal (3 monthly check up needed).

The CAPEX of the retrofit was 25 % of the vessel newbuilt value, which was considered acceptable. The real challenge is in the OPEX, as the fuel cost is currently very high. Increased availability of green hydrogen is paramount.

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 D3.1 for this demonstrator.

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1. Introduction

This report provides an overview of the crew transfer vessel Hydrocat 48, owned by CMB TECH, selected as demonstrator 1 (Demo 1) within the SYNERGETICS project. Initially, the hydrogen powered tug boat Hydrotug 1 was selected as Demo 1. However, due to circumstances external to the project, it was not possible to use the Hydrotug 1 as demonstrator.

As the goal of Demo 1 is the demonstration of the utilisation of hydrogen in internal combustion engines in inland and coastal vessels, the scope was amended so that a retrofit of diesel engines into dual fuel hydrogen-diesel became the demonstrator. For such, Volvo Penta D8 MG engines (used for gensets) and Volvo Penta D8 MH (used for direct propulsion) were retrofitted into dual fuel engines, using both hydrogen and diesel. These engines have a power range between 330 and 440 kW approximately, which makes them suitable for most inland and coastal ships.

However, the vessel Hydrocat 48 is not fitted with Volvo Penta engines, but with MAN engines, that were also retrofitted from single fuel diesel engines to dual-fuel to serves as demonstrator for the application of hydrogen in internal combustion engines in inland and costal ships.

This report addresses the main aspects considered in its design and construction, as well as an evaluation of the powering and emission performance. Technical challenges encountered during the project are addressed in this report, including the lessons learned.

In addition to the work mentioned above, at the end of this deliverable the operational and SPEC analysis of this demonstrator is presented.

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2. Description of the vessel

The Hydrocat 48 is a catamaran Crew Transfer Vessel (CTV) owned by Windcat Workboats, which is a subsidiary of CMB.TECH. The vessel operates mainly in the North Sea, transferring crew between shore and offshore wind parks located at the East of England. In Table 2-1 the main particulars of the vessel are presented and a photo of the ship is displayed in Figure 2-1. The vessel is powered by two MAN D2862 LE428 engines which were modified to run either on diesel or on a combination of diesel and hydrogen (dual fuel).

Furthermore, the Hydrocat 48 is equipped with the Windcats' Windgrip® system. For crew transfer, a girth wraps around the boat landing and increases the bollard push on the turbine. This enables a safe transfer even with higher swells. TTo create substantial weight reduction, a lightweight carbon composite superstructure, the CarbonCube, has been installed. This carbon composite passenger accommodation is equipped with integrated vibration dampers, effectively reducing noise levels by over 10 decibels (dBa) and therefore increases comfort for both passengers and crew.

The Hydrocat 48 is part of the Windcat MK3,5 series and since the launching of the Hydrocat, 48 more vessels have been built and prepared for hydrogen operations.

Table 2-1: Main particulars of the Hydrocat 48.

Ship type	**Crew transfer vessel**	
Classification	Lloyd's ✠ 100A1 SSC, HSC, Catamaran, Wind Farm Service Vessel	
Propulsion type	Direct	
Engine type	2 x MAN D2862 Dual-fuel (hydrogen – diesel)	
Length over all	25.00	m
Beam, moulded	7.30	m
Operational draught	1.90	m
Service speed	26	kn
Max. speed	28	kn
Engine power	2 x 749	kW
Propeller type	Controllable Pitch Propeller (CPP)	

Figure 2-1: Photo of the Hydrocat 48.

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3. Objectives of the engine retrofit

Various studies of alternative fuel sources, in order to decarbonize CTV emissions, have been performed by Windcat Workboards to select the best alternative fuel. From these studies, the use of hydrogen in internal combustion engines has been selected as the most promising carbon free fuel for this application.

Implementing dual fuel hydrogen technology offers some advantages in the transition phase towards 100% hydrogen fuelled systems:

- **Cost effective power system**, the increase in Capex (Capital Expenditure) compared to a traditional ICE (Internal Combustion Engine) is low and very low compared to hydrogen fuel cell technology. The hydrogen storage remains expensive;
- **Reliable**, combustion engines are robust, reliable and have a long operational track record;
- **Maintainable**, additional maintenance on the hydrogen injection system is very low;
- **Back-up**: dual fuel engines offer the added advantage of full traditional fuel back-up in case hydrogen is not available or too expensive. This is a very important added benefit for industrial and marine operators;
- **Safety & training**, crew & managers can gradually gain experience and confidence by doing;

By mixing hydrogen into the air intake system of the engine, less diesel is required to deliver the requested power output.

In the hydrogen combustion reaction, hydrogen and oxygen act as reactants, producing water as product. This reaction is exothermic, which means that releases energy. This energy is used to heat the air inside the cylinders, which expands generating work and consequently power. The hydrogen combustion reaction can be expressed as follows:

$$2H_2(g) + O_2(g) \rightarrow 2H_2O(l) + \text{energy}$$

From equation above it can be seen that CO_2 is not generated as product in the reaction, offering a direct reduction in CO_2 emissions. Since the fuel blend of the dual fuel engines still contains diesel, the tank to wake CO_2 emissions are not completely eliminated, but are however reduced significantly. NO_X levels are kept under control by optimal combustion strategy and TIER III compliance exhaust after-treatment systems.

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4. Design and implementation of the dual fuel technology on board

This chapter describes the main aspects considered in the design and implementation of the hydrogen system and the dual fuel engines on the CTV.

It should be mentioned that, as no specific regulations were in place for a seagoing vessel using hydrogen as a fuel, the IGF Code [1] was the main guidance in the process of approval. As the IGF Code is expressly written as guidance for LNG systems and ships that use low flashpoint fuels, various design concepts have been based on the alternative design route as described in SOLAS regulations II-1/55 [2].

4.1 Hydrogen storage

On board compressed hydrogen stored at a maximum pressure of 350 barg is used. Compressed hydrogen typically is stored in pressure vessels or gas cylinders. Multiple types are widely available on the market (Type I, II, III, IV, V), each with their own advantages and disadvantages. The types of cylinders used for this project are type III cylinders, this type features a thin and lightweight aluminium liner, fully overwrapped with carbon composite.

The choice for this type of cylinders is to be found in the handshake between the ratio “cylinder weight per kilogram hydrogen stored”, refuelling speed and cost. Nine cylinders are packed together in a so called stillage and 3 of such stillages are kept as stationary fuel tanks on board. Technical specifications are given below:

Table 4-1: Technical specifications of hydrogen storage system.

Dimension	Unit	Value
Total volume	L	8694
Storage pressure	barg	350
Total mass	kg	212
Useable mass	kg	197
Stillage composition	-	9 x 322L cylinders
Number of stillages	-	3
Cylinder specification		
Volume	l	322
Cylinder weight	kg	141.6 ± 7
Gas capacity	kg	19.1
Operating temperature	°C	-40 to +85
Operating pressure	barg	350
Cylinder approval	-	TPED / EC79

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The calorific value of hydrogen is 120 MJ/kg, which is approximately three times higher than diesel fuel. The 197 kg of usable hydrogen thus results in the equivalent of 591 kg or 687 litres of diesel. The capacity has been based on several factors:

- Standardized supply chain of compressed hydrogen which is available (350 barg & 700 barg);
- Cost of pressure vessels and hydrogen. The higher the pressure, the higher the fuel cost;
- Lengthening of the vessel with two frames which showed minimum impact in hull resistance;
- Weight of the storage system to have minimum influence on this high speed & low weight vessel;
- Sufficient capacity to deliver dual fuel energy for at least one full day of operation.

The storage tanks have been installed behind the wheelhouse and are "open to air", promoting sufficient natural ventilation to evacuate and dilute the gas in case of a leakage. This is observed in Figure 4-1.

Figure 4-1 Storage tanks positioned aft of the wheelhouse (blue containers)

4.2 Fuel supply system

The hydrogen fuel piping, fittings, sensors, and valves have been selected carefully and are of the highest quality available in the gas industry. Correct pressure ratings, pressure relief systems, remotely operated isolation valves, double block and bleed valves, sensor monitoring data and gas detection systems provide the necessary mitigations for safe handling and operation.

The pressure of the gas is brought down in two steps, providing a stable input pressure towards the dual fuel engine. Pipes installed in the exterior are single walled, inside the engine room the pipes are double walled. Connections are foreseen to inert the systems piping with nitrogen; however, this will only be done prior to intrusive maintenance on the system.

4.3 Bunkering of hydrogen

Hydrocat 48 can be bunkered in the following ways and it is up to the charterer to select a gas supplier and define the bunkering concept:

- Bottle balancing from high pressure fixed shore based hydrogen storage or tube trailer to the vessels storage system. This is basically using the pressure difference to fill the vessels tank;
- Using a shore based storage system with a booster or compressor. This concept is very similar to using a pump when transferring a liquid.

When CMB.TECH is asked to manage the refuelling, a 500 barg tube trailers is used for bottle balancing as shown in Figure 4-2.

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As bunkering high pressurized hydrogen gas requires precautionary measures, a dedicated safety zone is assigned for the bunker operation. Further, the bunker management plan is followed, a toolbox meeting is held and the specific bunker checklist will be followed to ensure all required steps are met for safe bunkering operation. A toolbox meeting is a short informational session between the involved members in the bunker operation. We shortly repeat each members function and responsibilities and finalize and sign the safety checklist.

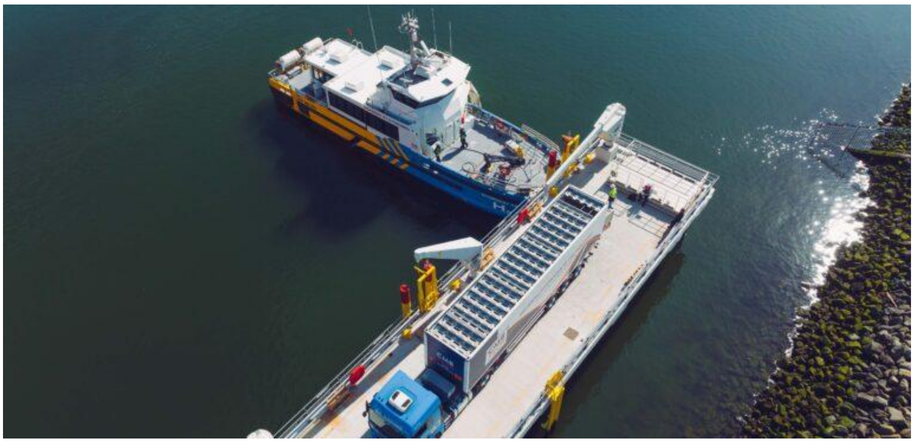

Figure 4-2 Bunkering operation

Figure 4-3 shows on the left the evolution of the hydrogen pressure on the Hydrocat 48 over time, bunkering with the 500 barg tube trailer. The bunkering process takes 45 minutes plus 15 minutes for preparation and administration.

The right side graph shows the impact on temperature of the hydrogen gas in the stillages, it is to be noted that temperature increases whilst gas is expanding (Joule-Thomson effect) and this effect is high with high gas flow rates, thus in the beginning of the gas transfer. The gas is often cooled to keep the temperature close to 50 °C to avoid damage to the storage medium or overpressure in the tanks.

The steps which are visible in both graphs show the switching of the high pressure banks in the hydrogen refuelling trailer.

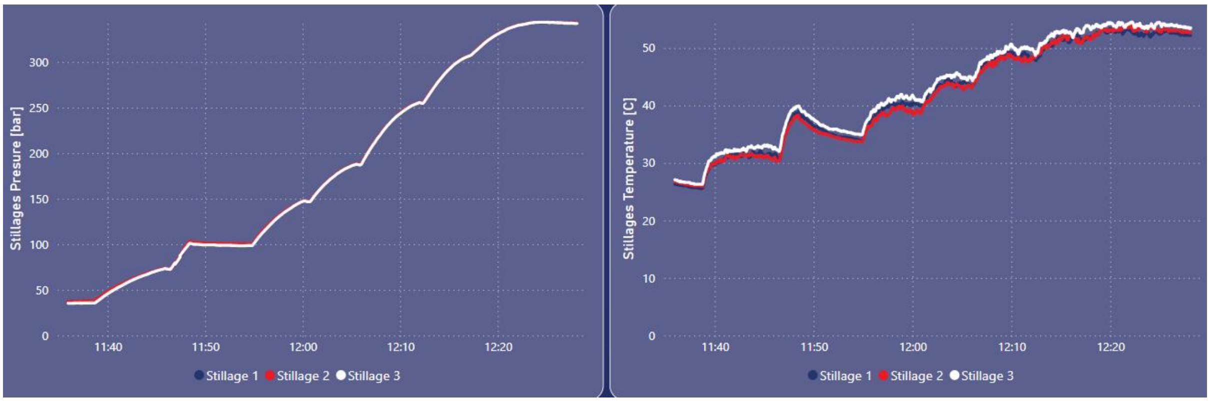

Figure 4-3 Hydrogen pressure and temperature during bunkering

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4.4 Modification of main engines

The base engine was modified by the addition of the hydrogen injection system which includes the following components:

- H_2 Enclosure:
    - H_2 fuel rail
    - H_2 manifold
    - Flow control device (i.e., Injector)
- H_2 double walled flexible line
- H_2 double walled transport tube
- H_2 injection ring
- Mounting brackets
- Shortened charge air tubes

Hydrogen is injected upstream of the charge air cooler directly into the airstream via a novel injection ring system. The pre-mixed H_2/air mixture enters the combustion chamber of which is ignited by a diesel pilot.

Since the engine operates at high speeds, it generates high-frequency vibrations. To optimize the mounting system for the hydrogen enclosure (brackets), multiple rounds of finite element analysis were conducted during the design process. A picture of the MAN hydrogen engine is given in Figure 4-4.

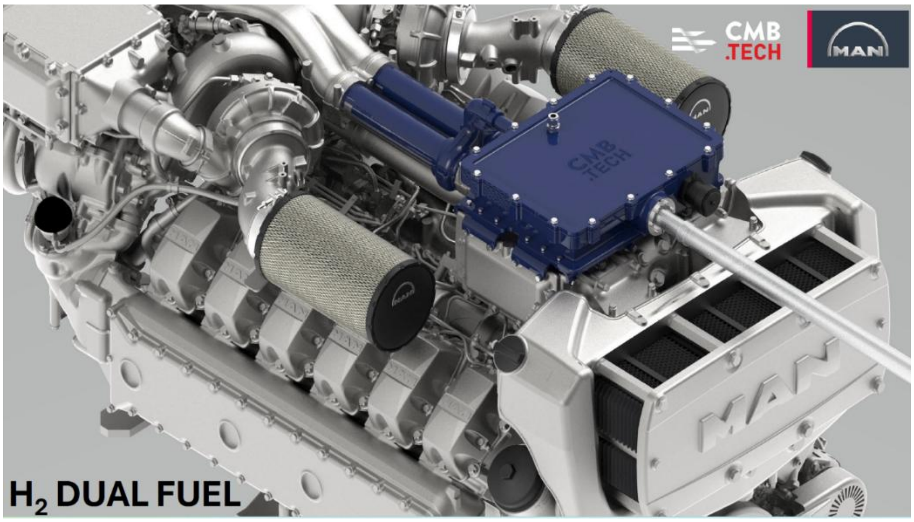

Figure 4-4 MAN CMB.TECH Dual Fuel hydrogen engine. Blue components represent the additional hydrogen fuel connection manifold.

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4.5 Influence on the design of the ship

The main modifications to the vessel design are:

- lengthening of the vessel with two frames to accommodate the hydrogen stillages;
- modifications where required to accommodate MAN engines, as this series of vessels used to be built with MTU engines;
- raising the wheelhouse with 700 mm to keep good lines of sight towards the aft ship;

The hydrogen stillages are located behind the wheelhouse, on the centre of gravity of the vessel, where they have least influence on stability and seakeeping behaviour.

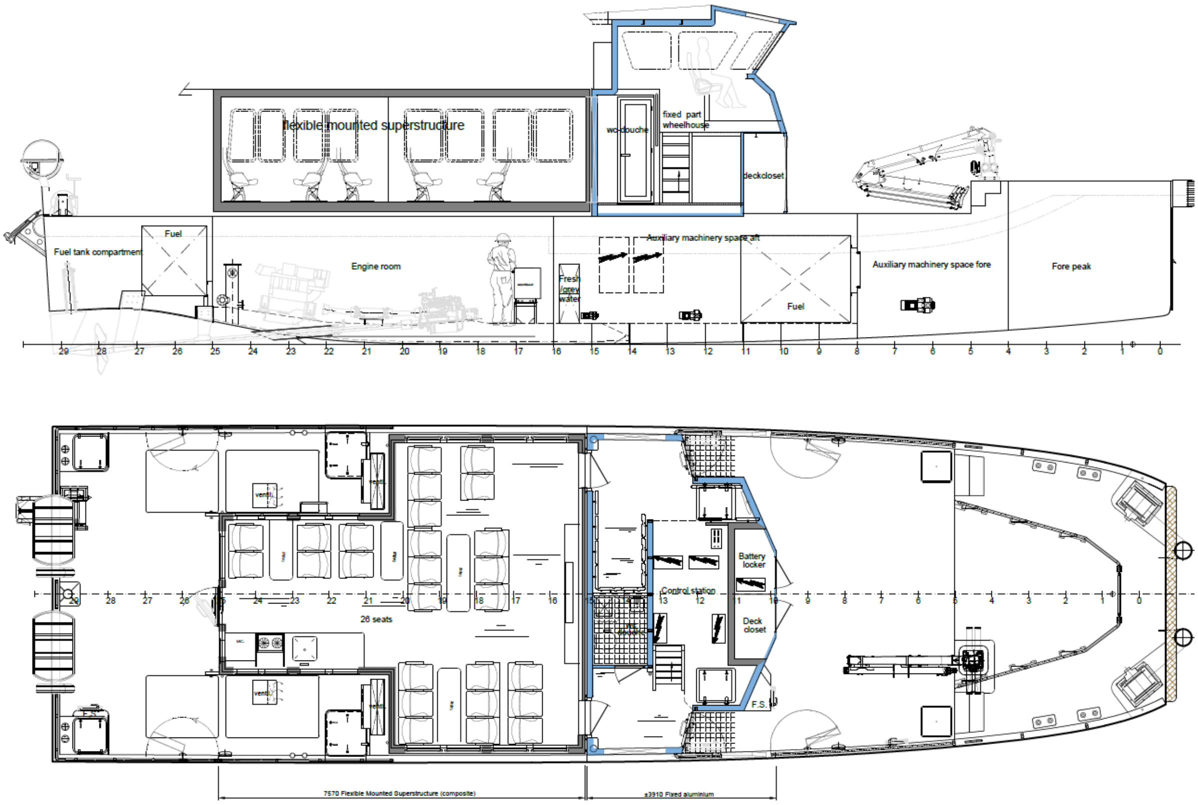

Figure 4-5: General arrangement mk3,5 series without hydrogen

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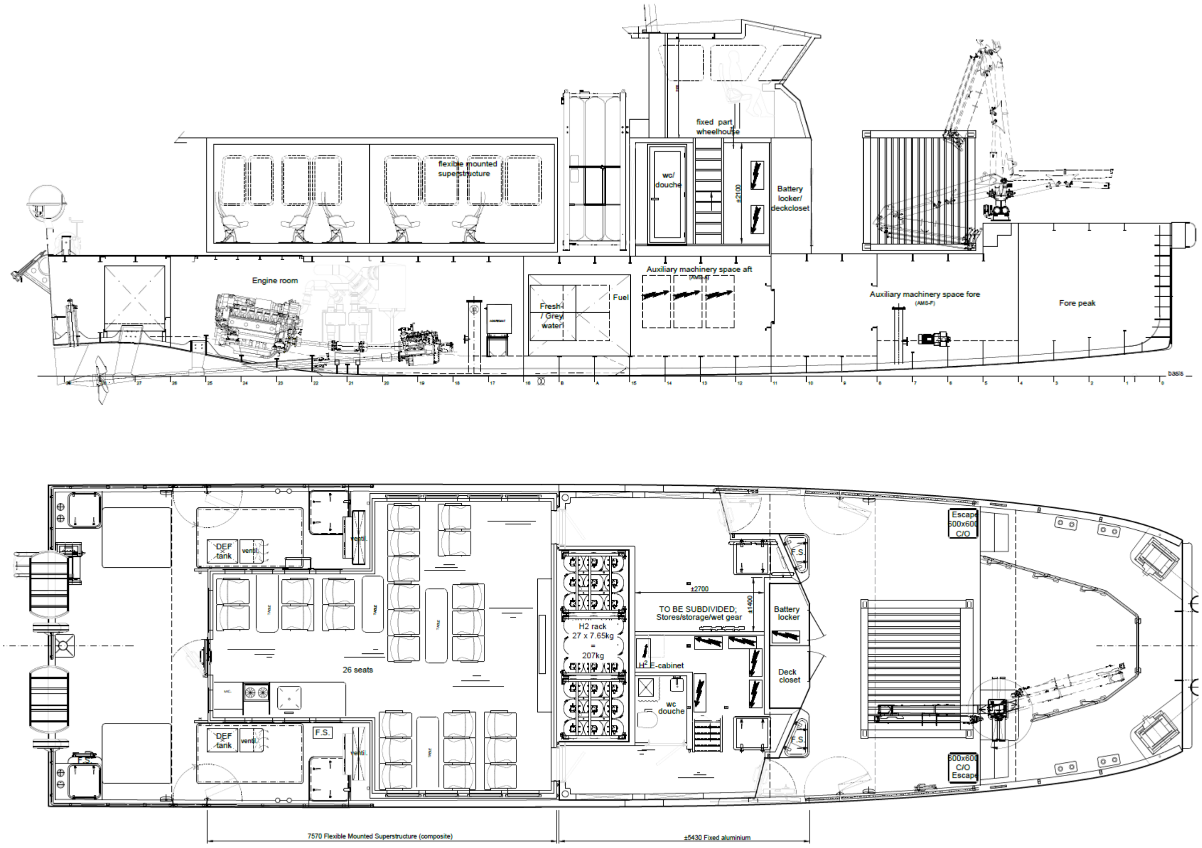

Figure 4-6: General arrangement mk 3,5 series with hydrogen.

As these types of vessels are built to be as light in weight as possible, the added weight for the hydrogen system was crucial. The total added weight for the hydrogen stillages, piping, valves, sensors, and detection systems is around 5 tonnes. The deck area has been kept similar in square meters to have no influence on operations. Further, a bunker manifold has been integrated SB fw deck at the foreship on the starboard side, and the vent mast has been integrated into the vessel's mast.

4.6 Influence on the operation of the vessel

The main influence on the operation of the vessel is related to hydrogen bunkering. The hydrogen storage is limited and thus requires regular refuelling. The frequency could be daily, depending on the usage of hydrogen and operational profile. The hydrogen bunkering takes approximately 45 minutes + 15 minutes of preparations/administration when using a 500 barg tube trailer.

Further, regarding the operations, the economic speed is slightly reduced as the overall efficiency of the vessel is lightly affected by the additional weight. Transit time to the offshore windmill parks is therefore longer as on a diesel vessel.

Training for the crew has minor impact on the operations. There has been agreed both with class and the flag state that we train the crew with two specific courses:

- Advanced firefighting for tankers;
- specific hydrogen training developed by CMB.TECH and reviewed and approved by class and flag;

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Approval for bunkering of hydrogen comes with the required administrative work for permits, bunker management plan, discussions with ports & authorities and others.

4.7 Influence on the operation of the vessel

When looking at the financial picture, an increase of 25 % additional CAPEX of the whole ship compared to the diesel variant, is a realistic number. This includes lengthening of the vessel, hydrogen storage, fuel supply system, engine injection system, gas detection, alarm & control switchboards.

This 25 % can be split up further into 80 % directly related to hydrogen system and 20 % for vessel modifications. Of the 80 % hydrogen system, 75 % goes directly to the hydrogen storage system the remaining 25 % covers all the other hardware.

The OPEX (Operational Expenditure) increase could be split up in training, maintenance, operational downtime (due to bunkering) and hydrogen fuel cost.

Given the current prices of green hydrogen, being between 15 and 20 €/kg, increased with the logistic cost of around 5 €/kg, the hydrogen fuel cost has by distance the largest impact on OPEX. A small saving in OPEX can be obtained through lower need for Adblue (see chapter 5).

Scaling up green hydrogen production would help decreasing the pure fuel cost. The logistic cost today is driven by the occupation of a tube trailer, to bring 200 kg of hydrogen to the vessel. Hydrogen refuelling infrastructure in ports could drastically reduce this logistic cost.

Maintenance is limited to a three-monthly examination of the system. The special survey (every 5 years) requires a more in depth investigation on the hydrogen system integrity (for example pressure cylinders examination). All together these OPEX figures are on the low side. Training also has a small impact on the OPEX figures.

Operational downtime could have a slightly larger impact if the hydrogen bunkering would occur on daily basis, however it is hard to give numbers or estimates as this is a point of negotiation in the charter party.

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5. Engine performance and emissions

The performance and emissions of the MAN LE448 dual fuel engine are given in Figure 5-1 to Figure 5-5. Here, it can be observed that:

- Hydrocarbons (THC), carbon monoxide (CO) and nitrogen oxides (NO_X) were reduced in dual fuel mode;
- CO_2 reductions tie-up with diesel (carbon) fuel substitutions
- A saving of up to 50 % on AdBlue usage was found, as the exhaust after treatment system had less 'work' due to the lower NO_X emission.

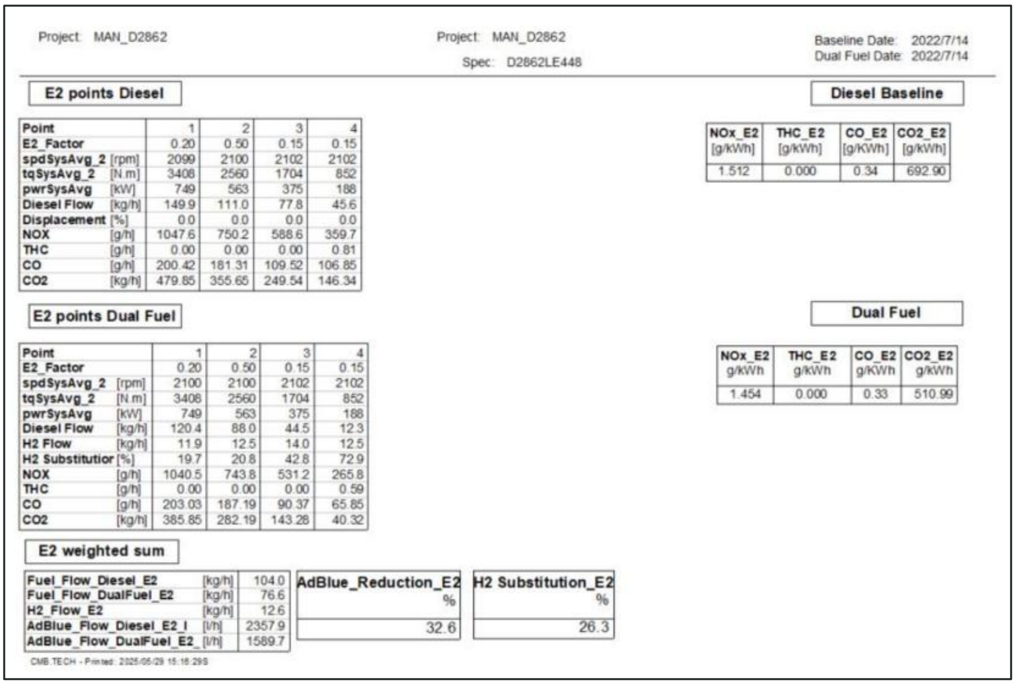
The engines were tested against the IMO E2 and E3 cycle as required by the IMO NO_X Technical Code [3]. These two test cycles have weighing factors that dictate in which condition the engines are to be tested. These typically do not represent the actual operating conditions (especially not in the case of a CTV), but are required for official compliance documents.

5.1 E2 emission verification measurements

The E2 cycle is a constant speed cycle. Because a Controllable Pitch Propeller is used the engine can run at constant speed and give variable power output. The emission results are given in Figure 4-2, and based on this cycle the CO_2 emission reduction is 35 %. The other reductions are smaller.

Table 5-1 E2 Test Cycle (source: IMO NOx Technical Code)

Test Cycle type E2	Speed	100%	100%	100%	100%
	Power	100%	75%	50%	25%
	Weighting factor	0.2	0.5	0.15	0.15



Project: MAN_D2862

Project: MAN_D2862
Spec: D2862LE448

Baseline Date: 2022/7/14
Dual Fuel Date: 2022/7/14

E2 points Diesel

Point		1	2	3	4
E2_Factor		0.20	0.50	0.15	0.15
spdSysAvg_2	[rpm]	2099	2100	2102	2102
tqSysAvg_2	[N.m]	3408	2560	1704	852
pwrSysAvg	[kW]	749	563	375	188
Diesel Flow	[kg/h]	149.9	111.0	77.8	45.6
Displacement	[%]	0.0	0.0	0.0	0.0
NOX	[g/h]	1047.6	750.2	588.6	359.7
THC	[g/h]	0.00	0.00	0.00	0.81
CO	[g/h]	200.42	181.31	109.52	106.85
CO2	[kg/h]	479.85	355.65	249.54	146.34

Diesel Baseline

NOx_E2 [g/kWh]	THC_E2 [g/kWh]	CO_E2 [g/KWh]	CO2_E2 [g/kWh]
1.512	0.000	0.34	692.90

E2 points Dual Fuel

Point		1	2	3	4
E2_Factor		0.20	0.50	0.15	0.15
spdSysAvg_2	[rpm]	2100	2100	2102	2102
tqSysAvg_2	[N.m]	3408	2560	1704	852
pwrSysAvg	[kW]	749	563	375	188
Diesel Flow	[kg/h]	120.4	88.0	44.5	12.3
H2 Flow	[kg/h]	11.9	12.5	14.0	12.5
H2 Substitutior	[%]	19.7	20.8	42.8	72.9
NOX	[g/h]	1040.5	743.8	531.2	265.8
THC	[g/h]	0.00	0.00	0.00	0.59
CO	[g/h]	203.03	187.19	90.37	65.85
CO2	[kg/h]	385.85	282.19	143.28	40.32

Dual Fuel

NOx_E2 g/kWh	THC_E2 g/kWh	CO_E2 g/KWh	CO2_E2 g/kWh
1.454	0.000	0.33	510.99

E2 weighted sum

Fuel_Flow_Diesel_E2	[kg/h]	104.0
Fuel_Flow_DualFuel_E2	[kg/h]	76.6
H2_Flow_E2	[kg/h]	12.6
AdBlue_Flow_Diesel_E2_I	[l/h]	2357.9
AdBlue_Flow_DualFuel_E2_	[l/h]	1589.7

AdBlue_Reduction_E2 %	H2 Substitution_E2 %
32.6	26.3

CMB.TECH - Printed: 2025/05/29 15:16:29S

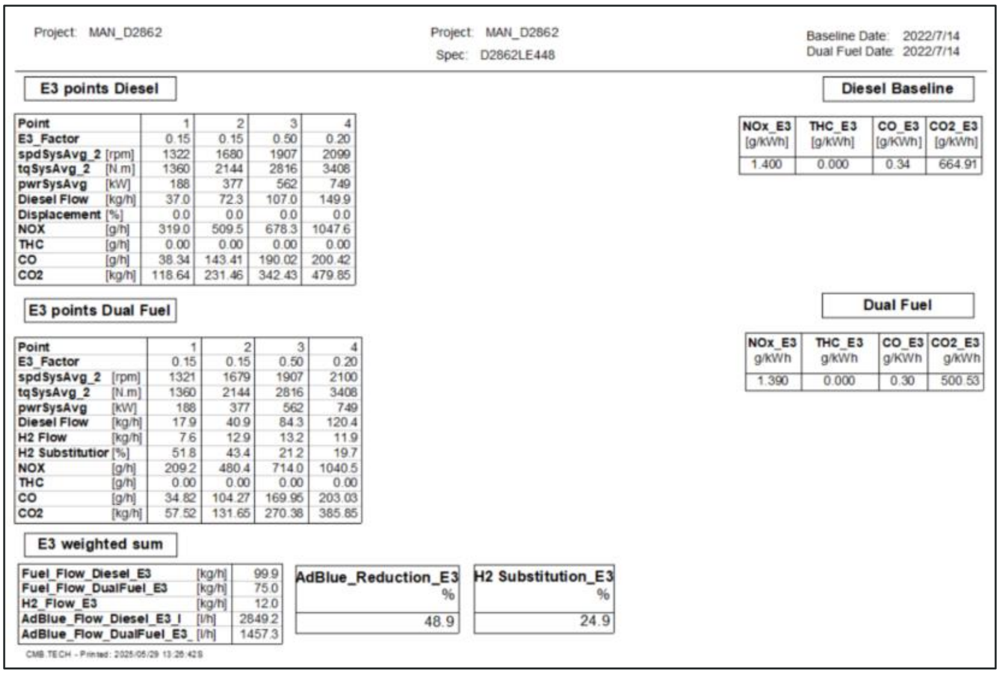
Figure 5-1 E2 emission verification

5.2 E3 emission verification measurements

The E3 cycle is a typical ship cycle where the engine speed and power increase following the propeller-law. The emission results are given in Figure 5-2, and based on this cycle the CO_2 emission reduction is 25 %. The other reductions are smaller.

Table 5-2 IMO E3 Test Cycle (source: IMO NOx Technical Code [3])

Test cycle type E3	**Speed**	**100%**	**91%**	**80%**	**63%**
	Power	100%	75%	50%	25%
	Weighting factor	0.2	0.5	0.15	0.15



Project: MAN_D2862

Project: MAN_D2862
Spec: D2862LE448

Baseline Date: 2022/7/14
Dual Fuel Date: 2022/7/14

E3 points Diesel

Point		1	2	3	4
E3_Factor		0.15	0.15	0.50	0.20
spdSysAvg_2	[rpm]	1322	1680	1907	2099
tqSysAvg_2	[N.m]	1360	2144	2816	3408
pwrSysAvg	[kW]	188	377	562	749
Diesel Flow	[kg/h]	37.0	72.3	107.0	149.9
Displacement	[%]	0.0	0.0	0.0	0.0
NOX	[g/h]	319.0	509.5	678.3	1047.6
THC	[g/h]	0.00	0.00	0.00	0.00
CO	[g/h]	38.34	143.41	190.02	200.42
CO2	[kg/h]	118.64	231.46	342.43	479.85

Diesel Baseline

NOx_E3 [g/kWh]	THC_E3 [g/kWh]	CO_E3 [g/KWh]	CO2_E3 [g/kWh]
1.400	0.000	0.34	664.91

E3 points Dual Fuel

Point		1	2	3	4
E3_Factor		0.15	0.15	0.50	0.20
spdSysAvg_2	[rpm]	1321	1679	1907	2100
tqSysAvg_2	[N.m]	1360	2144	2816	3408
pwrSysAvg	[kW]	188	377	562	749
Diesel Flow	[kg/h]	17.9	40.9	84.3	120.4
H2 Flow	[kg/h]	7.6	12.9	13.2	11.9
H2 Substitutior	[%]	51.8	43.4	21.2	19.7
NOX	[g/h]	209.2	480.4	714.0	1040.5
THC	[g/h]	0.00	0.00	0.00	0.00
CO	[g/h]	34.82	104.27	169.95	203.03
CO2	[kg/h]	57.52	131.65	270.38	385.85

Dual Fuel

NOx_E3 g/kWh	THC_E3 g/kWh	CO_E3 g/KWh	CO2_E3 g/kWh
1.390	0.000	0.30	500.53

E3 weighted sum

Fuel_Flow_Diesel_E3	[kg/h]	99.9
Fuel_Flow_DualFuel_E3	[kg/h]	75.0
H2_Flow_E3	[kg/h]	12.0
AdBlue_Flow_Diesel_E3_I	[l/h]	2849.2
AdBlue_Flow_DualFuel_E3_	[l/h]	1457.3

AdBlue_Reduction_E3 %
48.9

H2 Substitution_E3 %
24.9

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Figure 5-2 E3 emission verification

5.3 Power vs RPM diesel replacement

The diesel replacement curve (Figure 5-3 and Figure 5-4) show that a high share of hydrogen (80 %) can only be obtained in a limited working area. On average the replacement is in the order of 20-30 %, which is why in the previous section an CO_2 reduction of this order was obtained. This is typically seen with engines that are retrofitted to dual-fuel. When developing new engines, other fuel intake options are possible which can enlarge the hydrogen uptake.

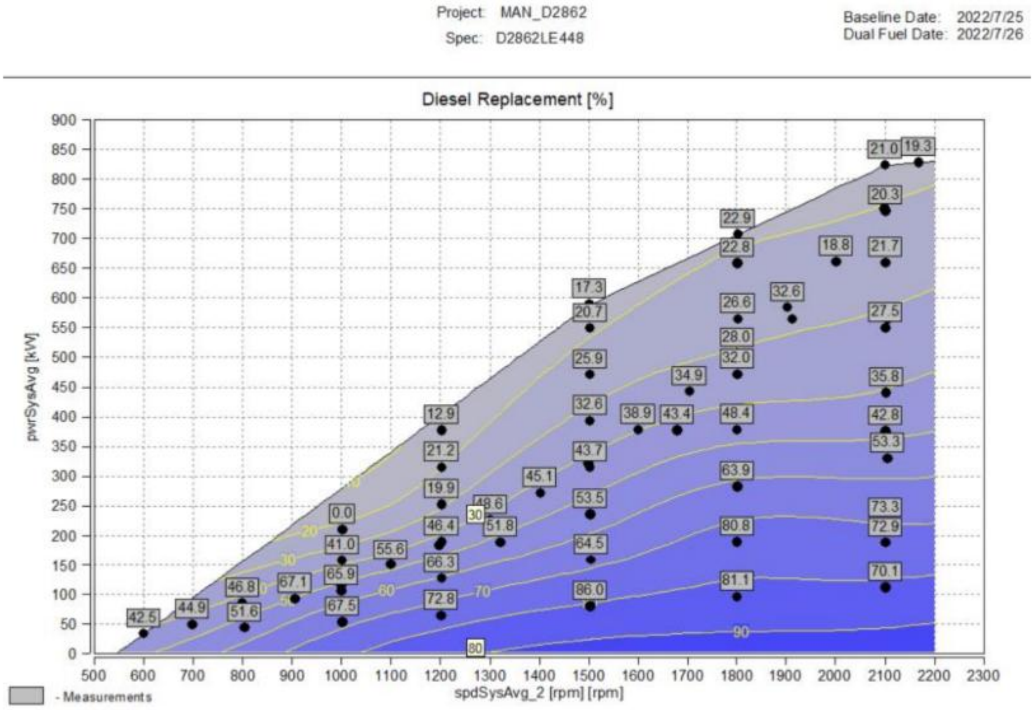

Figure 5-3 Diesel replacement % based on power and RPM

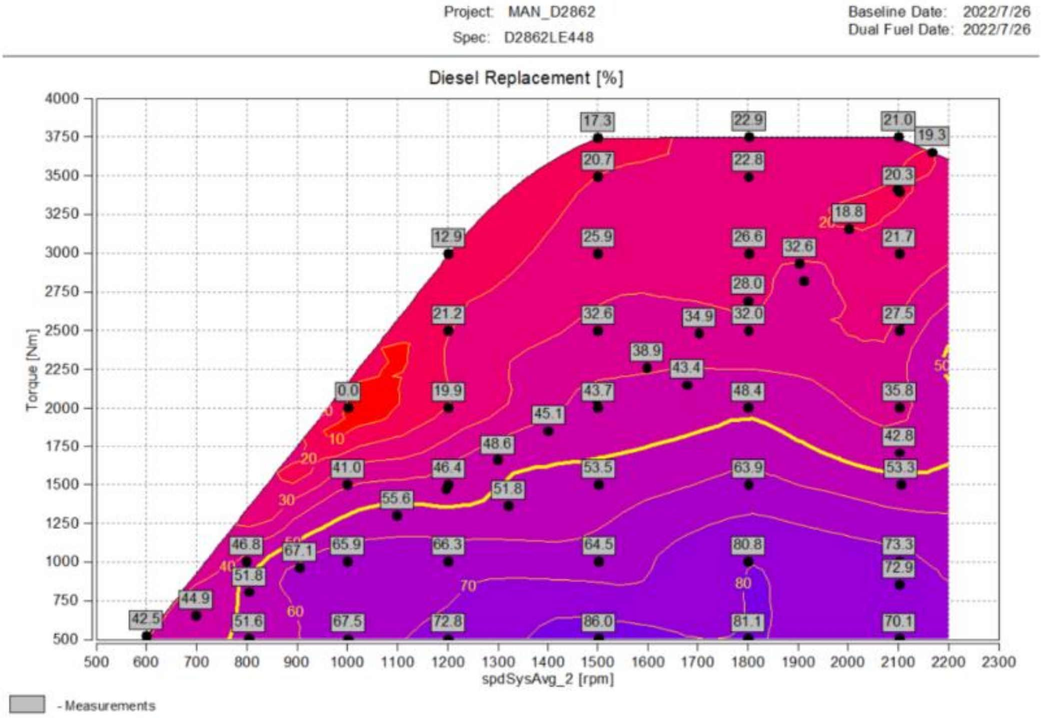

Figure 5-4 Diesel replacement % based on torque and RPM

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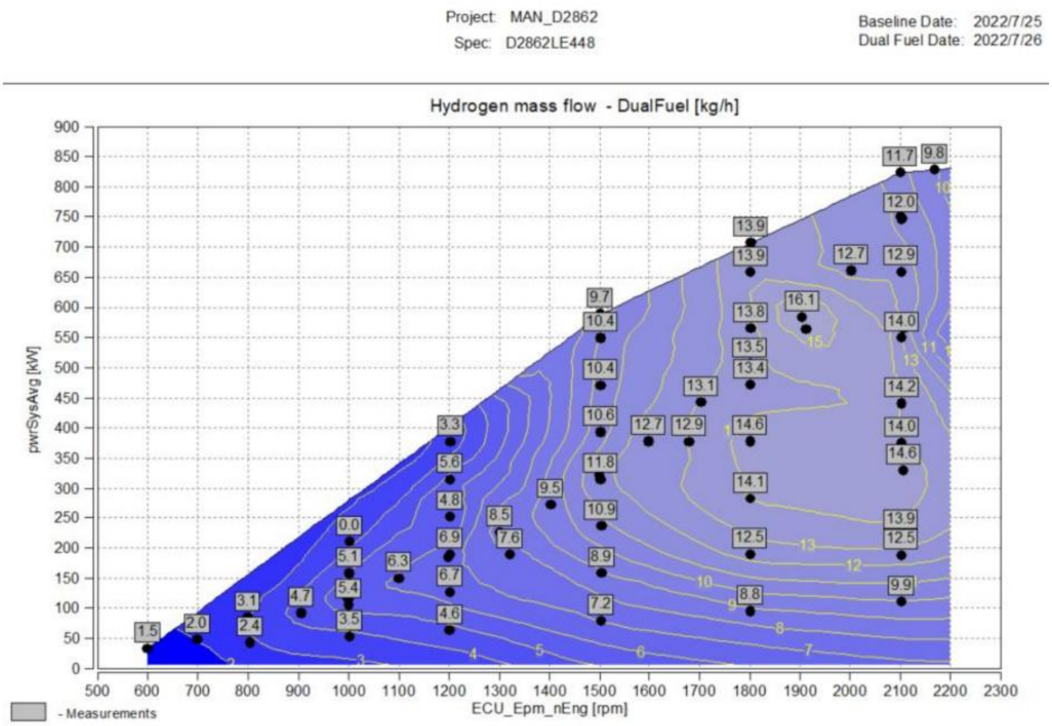

Figure 5-5 Hydrogen mass-flow based on power and RPM

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6. Vessel performance

A typical day of operation for a CTV can be seen as follows:

Crew is arriving on the vessel and offshore windfarm engineers are being pick-up on in the harbour. CTV leaves the harbour and speeds up to the windfarm where engineers are brought to different windmills. During the period engineers are busy, the CTV uses the Windgrab system to connect itself to a windmill in order to minimize propulsion and fuel consumption. Later, engineers are being picked up, speeding back to port.

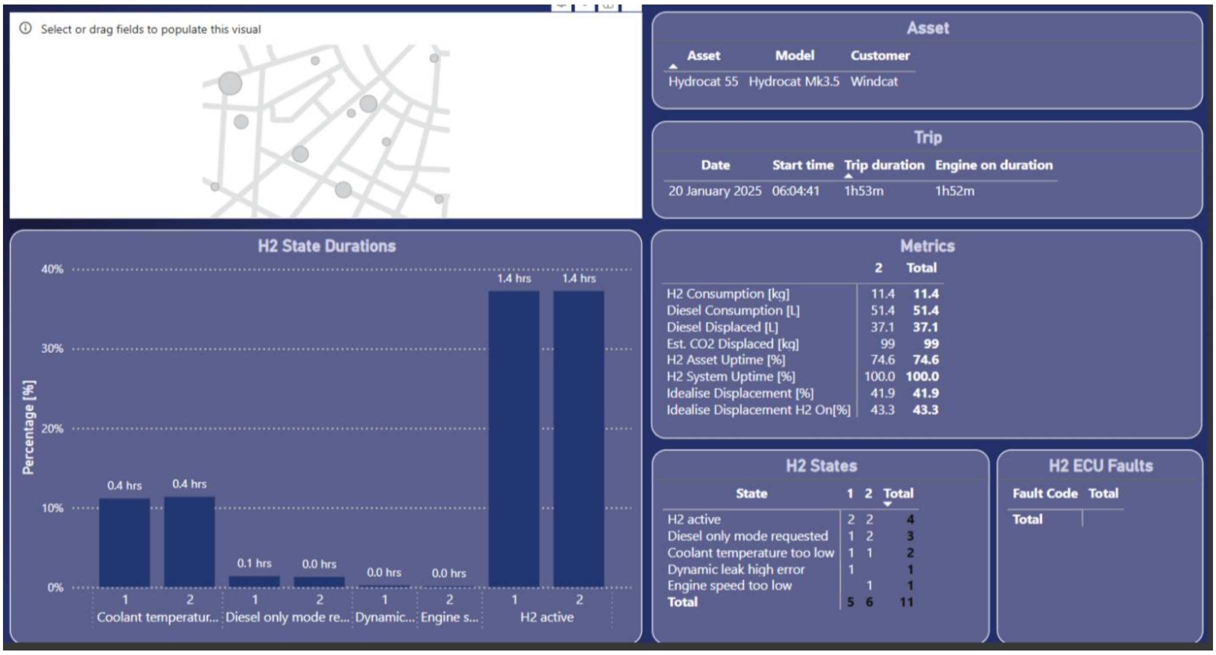
Over this typical day of operation, the CO_2 emissions are reduced by 30 % compared to a sister vessel. The CO_2 reduction is in direct relation with the diesel fuel consumption decrease. Consumption numbers are based on accurate monitoring of main engine fuel meters and hydrogen flow meters.

The fine particles (PM) were not measured, but it could be assumed they would also be lowered by 30 %.

The NO_X levels remain unchanged as the vessel is equipped with an exhaust aftertreatment system complying with IMO Tier III.

Furthermore, the operational speed has slightly decreased due to the additional weight. Another effect of the weight is the vessel is less comfortable in heavy sea states, although it has to be mentioned that in days of very bad weather these vessels are not sailing out.

The transition in modes from "diesel" to "dual fuel" operation are seamless, without any power or rpm fluctuation, creating a very reliable feeling with the crew. Figure 6-1shows a dashboard from the remote monitoring system which captures data from the vessels.



Asset

Asset	Model	Customer
Hydrocat 55	Hydrocat Mk3.5	Windcat

Trip

Date	Start time	Trip duration	Engine on duration
20 January 2025	06:04:41	1h53m	1h52m

Metrics

	2	Total
H2 Consumption [kg]	11.4	**11.4**
Diesel Consumption [L]	51.4	**51.4**
Diesel Displaced [L]	37.1	**37.1**
Est. CO2 Displaced [kq]	99	**99**
H2 Asset Uptime [%]	74.6	**74.6**
H2 System Uptime [%]	100.0	**100.0**
Idealise Displacement [%]	41.9	**41.9**
Idealise Displacement H2 On[%]	43.3	**43.3**

H2 States

State	1	2	Total
H2 active	2	2	4
Diesel only mode requested	1	2	3
Coolant temperature too low	1	1	2
Dynamic leak high error	1		1
Engine speed too low		1	1
Total	5	6	11

H2 ECU Faults

Fault Code	Total
Total	

Figure 6-1: Dashboard from the remote monitoring system which captures data from the vessels

6.1 Challenges

The availability of hydrogen hardware such as gas cylinders, regulators, valves, and sensors which are developed for marine environments and carry approval from class were non existing when the project began.

It required intensive discussions and a pragmatic approach both from designers and classification to overcome these challenges.

It could also be seen that hydrogen regulators are very sensitive for contamination, which can make the system unreliable.

By updating software and remote monitoring over the years, CMB.TECH has been able to improve the overall reliability of the hydrogen fuel system.

7. Conclusions

The Hydrocat main engines were successfully retrofitted to dual-fuel hydrogen operation. The ship did require an extension to accommodate the hydrogen storage. The vessel can be refuelled in an hour, which may need to happen daily when it is often running in dual-fuel mode.

A 30 % reduction on CO_2 was obtained, though 80 % was proven to be possible in limited operating conditions. Air pollutant emissions were also reduced, but the exhaust after treatment system was still needed in order to comply with NO_X regulations in diesel-only mode.

Regulations are required in order to create designs which can develop further into standardized products. The IMO is aiming to finalize the hydrogen rules in the CCC11[1] in September 2025 for seagoing vessels. Although we are cautious as prescriptive rules tend to be conservative, creating overkill which affects CAPEX.

CMB.TECH notices an evolution in availability of hydrogen specific hardware which is helping to get the CAPEX down.

To decrease the high OPEX, hydrogen refuelling infrastructure and upscaling of hydrogen production is key.

Dual fuel technology provides the advantage of reliability of the vessel, which is unrelated to the reliability of the hydrogen system. This gives a certain amount of comfort to owners and operators.

The additional maintenance and the exposure for the crew to intervene on the hydrogen system are low.

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[1] 11th session of the Sub-Committee on Carriage of Cargoes and Containers

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8. Bibliography

[1] International Maritime Organization, Code of safety for ships using gases or other low-flashpoint fuels (IGF Code), 2016.

[2] International Maritime Organization, International Convention for the Safety of Life at Sea (SOLAS), 1974.

[3] International Maritime Organization, Technical Code on Control of Emission of Nitrous Oxides from Marine Diesel Engines (NOx Technical Code), 2008.

Annex 1: Operational and SPEC analysis of Demo 1

Following Amendment No. AMD-101096809-5 of SYNERGETICS project, the Hydrocat 48, a catamaran crew transfer vessel (CTV) owned by CMB.TECH was stablished as Demonstrator 1.

At the time of writing Deliverable D3.1, the Amendment was still under discussion, therefore it was not yet decided whether the Hydrocat 48 would be part of the project or not. After the Amendment was approved, the Hydrocat 48 was included in SYNERGETICS as Demonstrator 1. Since deliverable D3.1 did not contain the operational and SPEC analysis for this demonstrator, it has been included in this deliverable.

Introduction of Demo 1

As already described in Chapter 2, the reference vessel for Demo 1 is The Hydrocat 48 is a catamaran Crew Transfer Vessel (CTV) owned by Windcat Workboats, which is a subsidiary of CMB.TECH. The vessel operates mainly in the North Sea, transferring crew between land and offshore wind parks located at the East of England. Table 8-1 repeats Table 2-1 for clarity.

Table 8-1: Main particulars of the Hydrocat 48.

Ship type	**Crew transfer vessel**	
Classification	Lloyd's ✠ 100A1 SSC, HSC, Catamaran, Wind Farm Service Vessel	
Propulsion type	Direct	
Engine type	2 x MAN D2862 Dual-fuel (hydrogen – diesel)	
Length over all	25.00	m
Beam, moulded	7.30	m
Operational draught	1.90	m
Service speed	26	kn
Max. speed	28	kn
Engine power	2x 749	kW
Propeller type	CPP	

Operational profile

The following profile was defined to describe a typical operation of the Hydrocat when transferring crew between land and offshore:

- 12 hours per day at sea;
- 2 hours running 100 % MCR, (which corresponds to a shaft power of approximately 1450 kW);
- 1.5 hours running 22 kn;
- The remainder time idle running and slow sailing

Table 8-2 and Figure 8-1 provide an overview of the operational profile for Demo 1.

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Table 8-2: Demo 1, operational tasks

Tasks	**Speed [kn]**	**P_{Prop} [kW]**	**P_{Aux} [kW]**	**Duration [hrs]**	**% time on total**
Economic cruising	22	572	10.5	1.5	13%
Max speed	28	1450	10.5	2	17%
Slow sailing	7	18	10.5	8.5	71%

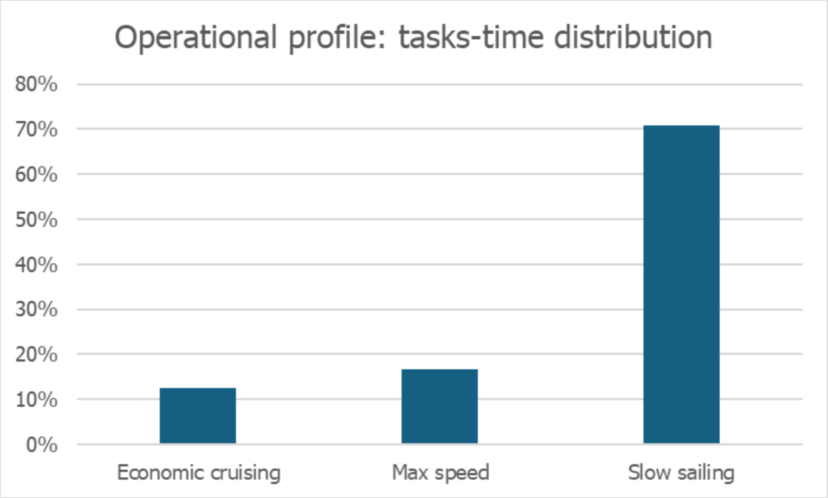

Figure 8-1: Demo 1, tasks time distribution

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SPEC analysis of Demo 1

Preselection and ranking

The result from the operational analysis has been used as inputs for the next step of the analysis. An overview of the inputs used in the preselection can be seen in Table 8-3. The selection of the most suitable/feasible technology is performed using the Ship Power and Energy Concept (SPEC) 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 are their impacts on the design, in terms of weight, volume, efficiency and costs. The stakeholders and users can influence the results of the analysis by weighing the different criteria based on what is more relevant for them. In annex 2 the full output of the ranking of this demonstrator is presented.

Table 8-3: Preselection input of Demo 1

Parameter	**Value**	
Max Effective Power *[kW]*	1460.5	
Endurance *[d]*	0.5	
Estimated downtime *[%]*	0	
Expected lifespan *[yr]*	25	
Average power delivered *[kW]*	691	
Minimum TRL	7	
CO_2 price/ton emission *[EUR/t]*	73	
Zero emission only?	Yes	No X
Minimum SRL	3	

For this demonstrator, no preference was given by the stakeholders, therefore the criteria have been weighted equally, as it can be seen in Table 8-4 and Table 8-5.

Table 8-4: Demo 1, "Technology & Investment" criteria. Weight factors.

Ranking - Technology & Investment	
Criteria	*Weight [%]*
Contained energy density volume	8.3
Contained energy density weight	8.3
CapEx energy carrier	8.3
TRL energy carrier	8.3
SRL energy carrier	8.3
Specific volume on board power systems	8.3
Specific weight on board power systems	8.3
CapEx on board power systems	8.3
Chain efficiency systems	8.3
TRL on board power systems	8.3
Harmful exhaust emission	8.3
Green House Gas emission	8.3

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Table 8-5: Demo 1, "Operations" criteria. Weight factors.

Ranking - Operations	
Criteria	*Weight [%]*
Contained energy density volume	16.7
Contained energy density weight	16.7
OPEX energy carrier	16.7
Chain efficiency systems	16.7
Harmful exhaust emission	16.7
Green House Gas emission	16.7

For this demonstrator, the dieses case has been used as a benchmark to compare the other solutions. In Table 8-6 an overview of the total ranking can be seen. It should be noted that as the base concept of this demonstrator was a vessel with diesel-electric architecture, the concepts included in the raking as well as in the SPEC results are for ships with electric propulsion. For instance, solution #16 is the benchmark case, and it refers to a diesel-electric solution.

Table 8-6: Ranking overview of Demo 1.

System	**Overall**	**Technology & Invest-ment**	**Operations**
#16 = Diesel (EN590) CI ICE (hi-speed)	8.3	8.3	8.4
#4 = Diesel (POME, UCO) CI ICE	9	9	9
#8 = e-CH3OH (CO2 PTS)/Dsl 65/35%vol CI ICE	6.5	6.4	6.6
#9 = e-CH3OH (CO2 PTS)/Dsl 95/5%vol CI ICE	6.1	6.7	5.5
#19 = e-LNG (CO2 PTS) SI ICE	6.9	7.2	6.7
#21 = Battery-electric (renewable)	6.6	6.9	6.2
#36 = e-H2 300b ISO LT PEMFC	3.1	2.1	4
#47 = H2 300b/Dsl 96/4%vol CI ICE	2.3	3.7	1

The calculation of the winning technology is done by ranking each criterion from 1 to 9 (worst to best). Linear scaling is applied for the intermediate values. This may not be representative when outliers exist in the dataset (like Battery-electric). Extreme values will get a very low or high score, whilst they are sometimes still in an acceptable range, but there is no threshold value that defines what is acceptable and what is not. By adjusting the weighing factors some (in)significance can be given to scales that are off.

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Overview of the SPEC results

The results of the SPEC analysis are presented in Annex 2. In Figure 8-2, Figure 8-3, and Figure 8-4 a comparison in weight, volume and CO2 emissions of some concepts is shown. It should be noted that in the solution with batteries, the term “fuel” used in SPEC refers to the weight and volume of batteries, as for a battery electric PPE system these are the energy carriers instead of fuel.

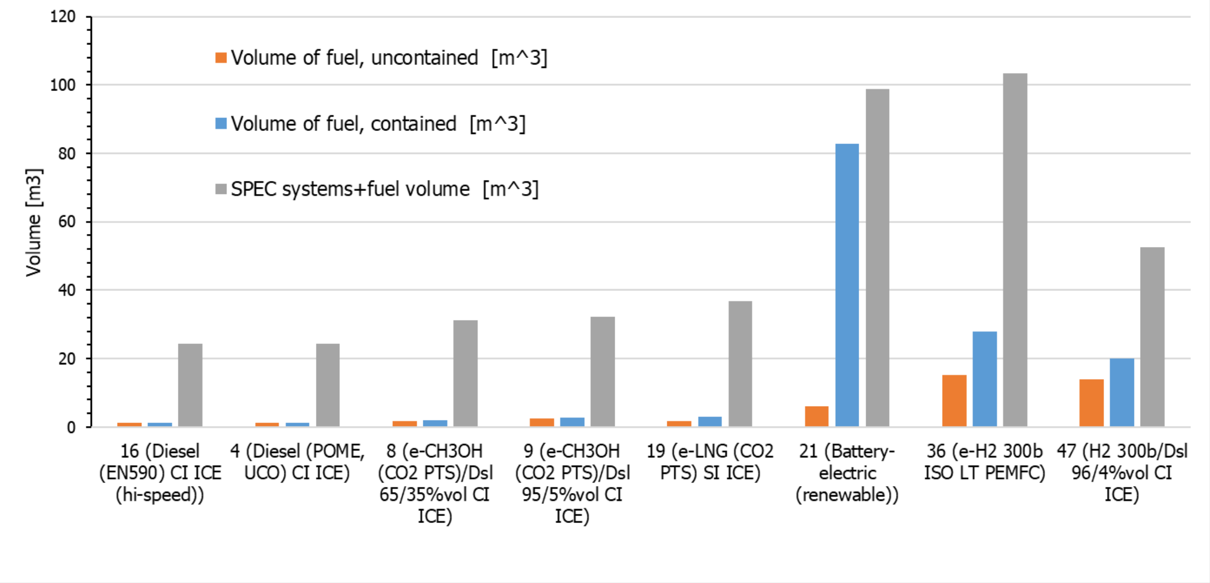

Figure 8-2: Overview of the fuel and systems volume for each concept resulting from the SPEC analysis of Demo 1.

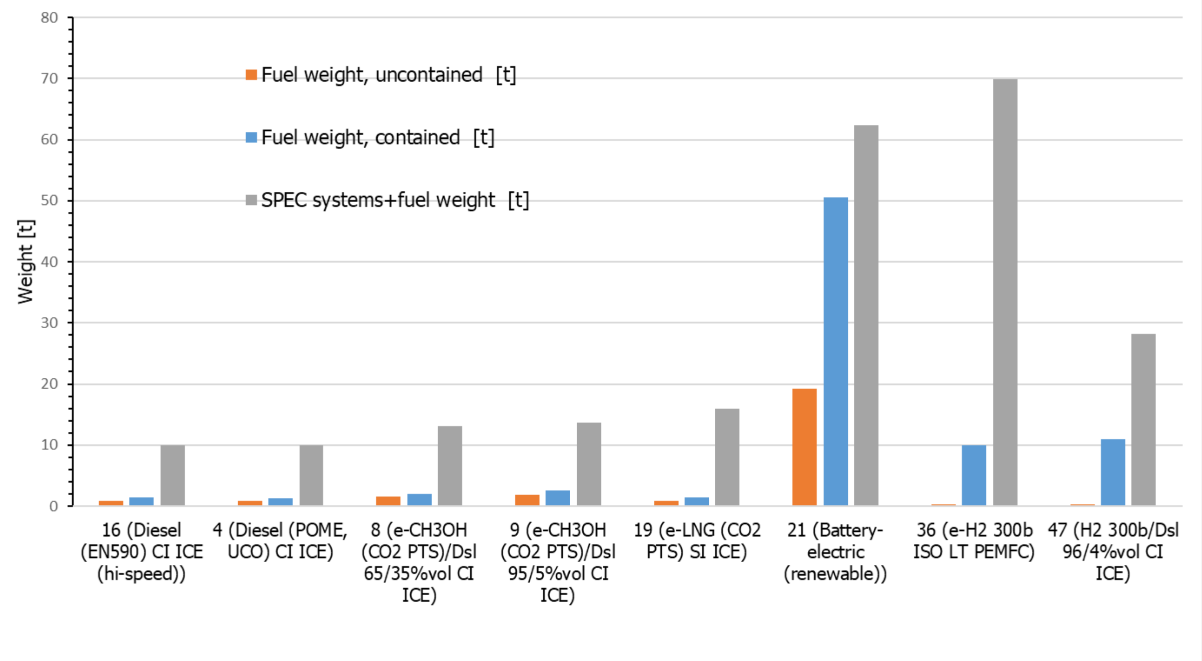

Figure 8-3: Overview of the fuel and systems weight for each concept resulting from the SPEC analysis of Demo 1.

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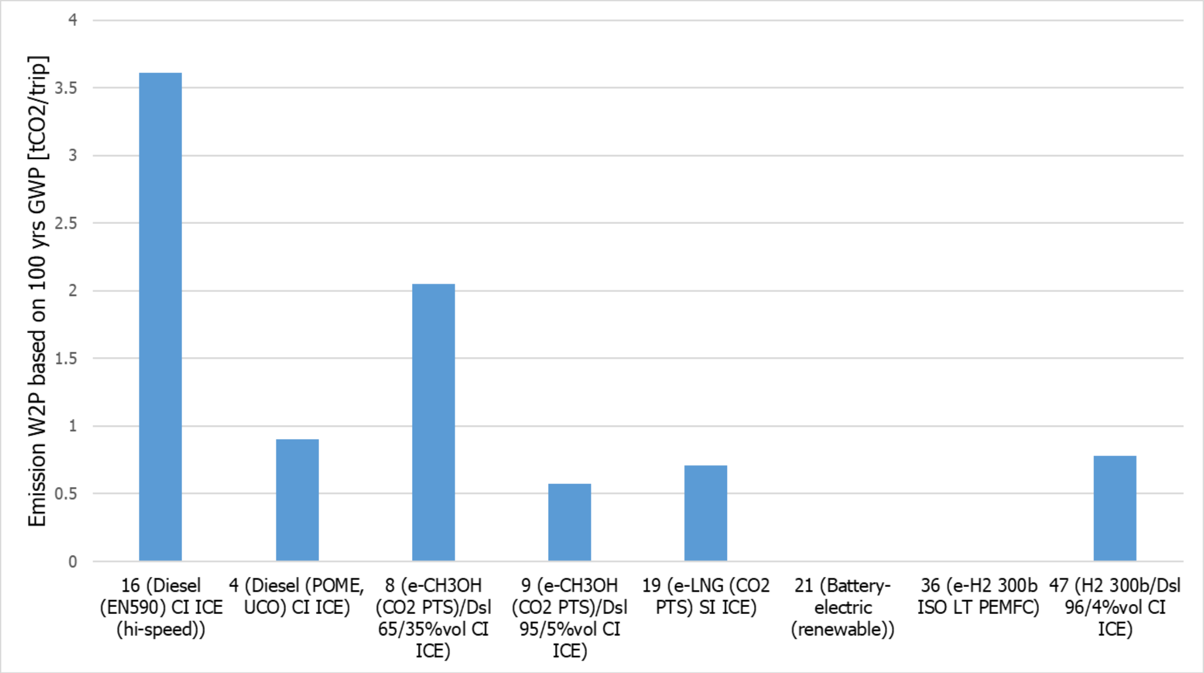

Figure 8-4: Overview of the CO2 equivalent emissions (well to propulsion) per trip for each concept resulting from the SPEC analysis of Demo 1.

In Figure 8-4, only the CO2 emissions from the production, transportation, and use of the fuel are considered, while those from the creation of the supporting infrastructure, such as the construction of wind or solar farms and engine manufacturing, are excluded.

Conclusions of the SPEC analysis

For the Hydrocat 48, 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 a renewable source. However, these concepts require a very large volume and weight on board, making them less attractive for this Demo. 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 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 CO2 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 CO2 Well to Tank emissions value. 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.

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- The bio-Diesel concept (#4) offers a substantial reduction in emissions. This is due to the negative CO2 Well to Tank emissions value, 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 DF hydrogen solution (#47) shows intermediate results in terms of volume and weight compared to the other options. The containment system for the 300-bar hydrogen storage significantly impacts the total weight and volume of this solution. This DF hydrogen option offers emission reductions comparable to those of renewable methanol and LNG.

Annex 2: Complete results of the SPEC analysis

Overview of concepts considered in the SPEC analysis

(TRL ≥ 7 and SRL ≥ 3)

Concept	Description
#4 = Diesel (POME, UCO) CI ICE	Diesel (HVO from UCO, POME) ICE CI 4-stroke high speed (diesel)
#5 = Diesel (20% UCO) CI ICE	Diesel (20% FAME UCO) ICE CI 4-stroke high speed (diesel)
#6 = Diesel (50% UCO/rapeseed) CI ICE	Diesel (20% FAME UCO, 30% HVO rapeseed) ICE CI 4-stroke high speed (diesel)
#8 = e-CH3OH (CO2 PTS)/Dsl 65/35%vol CI ICE	e-CH3OH 65%vol + Diesel 35%vol ICE CH3OH 4-stroke high speed
#9 = e-CH3OH (CO2 PTS)/Dsl 95/5%vol CI ICE	e-CH3OH 95%vol + Diesel 5%vol ICE CH3OH 4-stroke high speed
#10 = e-CH3OH (CO2 PTS) SI ICE	e-CH3OH (renewable electricity + flue gas CO2) ICE CH3OH 4-stroke high speed
#12 = CNG SI ICE	CNG ICE NG SI 4-stroke medium speed
#16 = Diesel (EN590) CI ICE (hi-speed)	Diesel (EN590) ICE CI 4-stroke high speed (diesel)
#19 = e-LNG (CO2 PTS) SI ICE	e-LNG (renewables + flue gas CO2) ICE NG SI 4-stroke high speed
#21 = Battery-electric (renewable)	Electricity (renewable) stored in Li-NMC battery None
#22 = LNG SI ICE	LNG ICE NG SI 4-stroke medium speed
#29 = CH3OH (glycerin) SI ICE	CH3OH (glycerin) ICE CH3OH 4-stroke high speed
#30 = Diesel (palm oil) CI ICE	Diesel (HVO from palm oil) ICE CI 4-stroke high speed (diesel)
#31 = Diesel (soybean oil) CI ICE	Diesel (HVO from soybean oil) ICE CI 4-stroke high speed (diesel)
#35 = e-CH3OH (CO2 DAC) SI ICE	e-CH3OH (Renewable electricity + DAC CO2) ICE CH3OH 4-stroke high speed
#36 = e-H2 300b ISO LT PEMFC	e-CompH2 300 bar in ISO container (Renewable) LT PEMFC
#37 = CH3OH SI ICE	CH3OH (Natural gas) ICE CH3OH 4-stroke high speed
#38 = H2 300b intg. LT PEMFC	CompH2 300 bar (natural gas) LT PEMFC
#40 = Diesel (MGO) CI ICE	Diesel (MGO) ICE CI 4-stroke high speed (diesel)
#41 = LNG DF ICE CI	LNG ICE NG CI/SI 4-stroke medium speed
#44 = e-H2 300b intg. LT PEMFC	e-CompH2 300 bar integrated tanks (Renewable) LT PEMFC
#47 = H2 300b/Dsl 96/4%vol CI ICE	CompH2 300 bar (natural gas) ICE CI DF H2 4-stroke high speed
#48 = Battery-electric (fossil)	Electricity (fossil) stored in Li-NMC battery
#51 = GTL (natural gas) CI ICE	GTL (natural gas) ICE CI 4-stroke high speed (diesel)
#52 = Diesel (EN590) CI ICE (hi-speed) Direct	Diesel (EN590) ICE CI 4-stroke high speed (diesel)

Note: Concepts preceded by 'e-' indicate the resource is obtained using electricity from renewable sources.

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SPEC technology & investment ranking of Demo 1

System	Technology & Investment	Cont. energy density on volume, scaled	Cont. energy density on weight, scaled	CAPEX based on energy, scaled	TRL for energy carrier	SRL	Specific volume of power systems, scaled	Specific weight of power systems, scaled	CAPEX based on power, scaled	Generic efficiency, scaled	TRL
#16 = Diesel (EN590) CI ICE (hi-speed)	8.3	8.7	8.6	9	9	5	8.1	9	8.7	4.7	9
#4 = Diesel (POME, UCO) CI ICE	9	8.4	9	9	9	5	8.1	9	8.7	4.7	9
#5 = Diesel (20% UCO) CI ICE	8.4	9	8.5	9	9	5	8.1	9	8.7	4.7	9
#6 = Diesel (50% UCO/rapeseed) CI ICE	8.6	8.4	9	9	9	5	8.1	9	8.7	4.7	9
#8 = e-CH3OH (CO2 PTS)/Dsl 65/35%vol CI ICE	6.4	5.8	6.1	9	7	5	7.2	8.6	7.2	4.7	7
#9 = e-CH3OH (CO2 PTS)/Dsl 95/5%vol CI ICE	6.7	4.4	4.9	9	7	7	7.2	8.6	7.2	4.7	7
#10 = e-CH3OH (CO2 PTS) SI ICE	7.8	4.1	4.7	9	7	8	8.8	9	7.9	4.8	7
#12 = CNG SI ICE	5.8	2.9	2.1	8.9	8	5	6.6	7.3	9	5.6	8
#19 = e-LNG (CO2 PTS) SI ICE	7.2	4	8.3	9	7	4	6.6	8	9	4.7	7
#21 = Battery-electric (renewable)	6.9	1	1	1	9	6	9	8.5	7.2	9	9
#22 = LNG SI ICE	6.4	4	8.3	9	8	4	4.2	6.2	8.8	5.6	8
#29 = CH3OH (glycerin) SI ICE	6.7	4.1	4.7	9	7	4	8.8	9	7.9	4.8	7
#30 = Diesel (palm oil) CI ICE	7.1	8.4	9	9	9	3	8.1	9	8.7	4.7	9
#31 = Diesel (soybean oil) CI ICE	7.4	8.4	9	9	9	3	8.1	9	8.7	4.7	9
#35 = e-CH3OH (CO2 DAC) SI ICE	7.9	4.1	4.7	9	7	8	8.8	9	7.9	4.8	7
#36 = e-H2 300b ISO LT PEMFC	2.1	1.3	1.9	8.9	7	4	1	1	1	4.8	7
#37 = CH3OH SI ICE	6	4.1	4.7	9	7	4	8.8	9	7.9	4.8	7
#38 = H2 300b intg. LT PEMFC	1	1.4	1.8	8.8	7	4	1	1	1	4.8	7
#40 = Diesel (MGO) CI ICE	8.3	8.9	8.7	9	9	5	8.1	9	8.7	4.7	9
#41 = LNG DF ICE CI	5.8	4	8.3	9	8	4	3.2	5.9	8.1	5.5	8
#44 = e-H2 300b intg. LT PEMFC	2.3	1.4	2.7	8.9	7	4	1	1	1	4.8	7
#47 = H2 300b/Dsl 96/4%vol CI ICE	3.7	1.4	1.8	8.8	7	4	6.8	7.6	7.1	5	7
#48 = Battery-electric (fossil)	6.2	1	1	1	9	6	9	8.5	7.2	9	9
#51 = GTL (natural gas) CI ICE	8.1	8.2	9	9	9	5	8.1	9	8.7	4.7	9

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SPEC operations ranking of Demo 1

Concept	Operations	Cont. energy density on volume, scaled	Cont. energy density on weight, scaled	Operational expenditure, scaled	Generic efficiency, scaled	Harmful emissions, scaled	W2P CO2 emission, scaled
#16 = Diesel (EN590) CI ICE (hi-speed)	8.4	8.7	8.6	8.5	4.7	1	4.3
#4 = Diesel (POME, UCO) CI ICE	9	8.4	9	6	4.7	1	7.8
#5 = Diesel (20% UCO) CI ICE	7.8	9	8.5	6.6	4.7	1	5.1
#6 = Diesel (50% UCO/rapeseed) CI ICE	8.2	8.4	9	6.8	4.7	1	5.8
#8 = e-CH3OH (CO2 PTS)/Dsl 65/35%vol CI ICE	6.6	5.8	6.1	7.3	4.7	2.6	6.3
#9 = e-CH3OH (CO2 PTS)/Dsl 95/5%vol CI ICE	5.5	4.4	4.9	6.1	4.7	2.6	8.3
#10 = e-CH3OH (CO2 PTS) SI ICE	6.3	4.1	4.7	5.8	4.8	4.2	8.6
#12 = CNG SI ICE	4	2.9	2.1	7.8	5.6	4.2	5.6
#19 = e-LNG (CO2 PTS) SI ICE	6.7	4	8.3	3.6	4.7	4.2	8.1
#21 = Battery-electric (renewable)	6.2	1	1	3	9	9	9
#22 = LNG SI ICE	9	4	8.3	9	5.6	4.2	5.8
#29 = CH3OH (glycerin) SI ICE	6.4	4.1	4.7	7.4	4.8	4.2	7.1
#30 = Diesel (palm oil) CI ICE	4.5	8.4	9	5	4.7	1	1
#31 = Diesel (soybean oil) CI ICE	5.3	8.4	9	5.2	4.7	1	2.1
#35 = e-CH3OH (CO2 DAC) SI ICE	3.7	4.1	4.7	1	4.8	4.2	8.9
#36 = e-H2 300b ISO LT PEMFC	4	1.3	1.9	2.2	4.8	9	9
#37 = CH3OH SI ICE	4.6	4.1	4.7	7.6	4.8	4.2	3.9
#38 = H2 300b intg. LT PEMFC	4.3	1.4	1.8	8	4.8	9	3.8
#40 = Diesel (MGO) CI ICE	8.5	8.9	8.7	8.5	4.7	1	4.3
#41 = LNG DF ICE CI	8.5	4	8.3	8.9	5.5	4.2	5.2
#44 = e-H2 300b intg. LT PEMFC	4.5	1.4	2.7	2.2	4.8	9	9
#47 = H2 300b/Dsl 96/4%vol CI ICE	1	1.4	1.8	8	5	2.6	4.2
#48 = Battery-electric (fossil)	6.6	1	1	7.4	9	9	5.4
#51 = GTL (natural gas) CI ICE	7.5	8.2	9	8	4.7	1	3.6

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SPEC output of Demo 1

Concept [ID]	16 (Diesel (EN590) CI ICE (highspeed))	4 (Diesel (POME, UCO) CI ICE)	8 (e-CH3OH (CO2 PTS)/Dsl 65/35%vol CI ICE)	9 (e-CH3OH (CO2 PTS)/Dsl 95/5%vol CI ICE)	19 (e-LNG (CO2 PTS) SI ICE)	21 (Battery-elec-tric (renewable))	36 (e-H2 300b ISO L PEMFC)
Endurance [d]	0.5	0.5	0.5	0.5	0.5	0.5	0.5
DownTime [%]	0	0	0	0	0	0	0
LifeSpan [yr]	25	25	25	25	25	25	25
CO_2 price/ton emission [EUR/t]	73	73	73	73	73	73	73
Average power percentage [%]	23.39	23.39	23.39	23.39	23.39	23.39	23.39
Max. effective power [kW]	1,461	1,461	1,461	1,461	1,461	1,461	1,461
Average power [kW]	342	342	342	342	342	342	342
Fuel weight, contained [t]	1.4	1.3	2	2.6	1.4	50.6	10
Fuel weight, uncontained [t]	0.9	0.9	1.5	1.9	0.8	19.2	0.3
Volume of fuel, contained [m^3]	1.2	1.3	2	2.7	3	82.8	28
Volume of fuel, uncontained [m^3]	1.1	1.2	1.8	2.4	1.8	6.1	15.3
SPEC systems weight [t]	8.6	8.6	11.1	11.1	14.5	11.7	59.9
SPEC systems volume [m^3]	23.1	23.1	29.3	29.3	33.7	16.1	75.5
SPEC systems+fuel weight [t]	10	9.9	13.1	13.7	15.9	62.3	69.9
SPEC systems+fuel volume [m^3]	24.3	24.4	31.3	32.1	36.7	98.9	103.5
Cost SPEC systems [MEUR]	1.168	1.168	1.919	1.919	1.015	1.899	4.928
Cost SPEC storage of energy carrier [MEUR]	0.001	0.001	0.002	0.002	0.01	3.921	0.143
Cost SPEC systems+storage [MEUR]	1.17	1.17	1.921	1.921	1.025	5.82	5.072
Generic efficiency [-]	0.37	0.37	0.37	0.37	0.37	0.81	0.38
Required consumable energy/trip [kWh]	11,143	11,143	11,113	11,113	11,023	5,063	10,877
Total cost of ownership [MEUR]	14.116	26.771	20.9	27.049	38.139	24.302	48.696
Emission based on 100 yrs GWP, W2P/trip [t]	3.61	0.9	2.05	0.57	0.71	0	0
Emission based on 20 yrs GWP, W2P/trip [t]	3.61	0.9	2.05	0.57	1.47	0	0
Lifetime emission based on 100 yrs GWP [t]	65,892	16,348	37,453	10,405	12,964	0	0
TRL [ID]	9	9	7	7	7	9	7
SRL [ID]	5	5	5	7	4	6	4

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