Breakthrough LNG deployment in Inland Waterway Transport

Activity 2.3 Evaluation report pilot test Somtrans LNG

Wijnegem; Belgium

June 2020

Document history: version 3

Contributing authors: Alain Blanckaert/Somtrans

Co-financed by the European Union
Connecting Europe Facility

Disclaimer

The sole responsibility of this publication lies with the author. The European Union is not responsible for any use that may be made of the information contained therein.

Revision History

Revision	Date	Author	Organization	Description
V1	*22-06-2020*	*Alain Blanckaert*	*Somtrans*	*Processing draft document*
V2	*26-06-2020*	*Salih Karaarslan*	*EICB*	*Restructuring draft document*
V3	*29-06-2020*	*Alain Blanckaert*	*Somtrans*	*Final document*

Table of Contents

1 Introduction 5

2 7 parameter measurements 6

2.1 Parameter 1 running hours of DF engines 7

2.2 Parameter 2 engine speed 7

2.3 Parameter 3 load of DF engines 7

.... *8*

2.4 Parameter 4 LNG and diesel consumption of DF engines 10

2.5 Parameter 5 water depth, position and speed (GPS data) 10

2.6 Parameter 6 overall LNG and diesel bunkering 11

2.7 Parameter 7 gas ventilation events 13

3 E2/E3 test cycle data of test bed trials 14

4 On board emission measurement 14

5 Emission reduction 15

5.1 Reduction of NOx emission 15

5.2 Reduction of CO emission 16

5.3 Reduction of CxHy emission 17

5.4 Reduction of PM emission 18

6 Reduction of fuel consumption 19

7 Reduction of operational costs 19

Annex I - Engine load and gas consumption 22

Annex II – On board emission measurement report 28

1 Introduction

This document contains the pilot test setting measurement results of the inland tank barge Somtrans LNG of Somtralux. The pilot test is executed according to the pilot test settings as specified in activity 1.5 of the project. The measurements were carried out from 01/06/2019 until 31/12/2019. This report includes:

- 7 parameter measurements
    1. Running hours of engines
    2. Engine speed
    3. Load of engine
    4. LNG and diesel consumption
    5. Water depth, position, speed
    6. Overall LNG and diesel bunkering figures
    7. Gas ventilation events
- E3 test cycle by sea trials
- on board emission measurement

The evaluation of the obtained data can be divided into three main sections:

- Variance in emissions as result of the LNG technology
- Variance in fuel consumption as result of the LNG technology
- Variance in operational costs as result of the LNG technology

The variance concerns the comparison between the installed LNG technology and the base case referring to a conventional diesel installation. Furthermore, there will also be a comparison on the emissions between data obtained during test bed trials and data obtained during the pilot test in practice.

2 7 parameter measurements

The analysis for parameters 2, 3 and 5 was made during six trips in the pilot period. Not every trip was similar, because Somtrans LNG went to various load and discharge ports. Every trip the depth and speed were registered. The speed depends on different parameters, like dimension of waterways, water depth and intensity of other vessel traffic. Each trip contained the following actions:

- arrival at loading terminal
- loading
- sailing to discharge terminal
- discharging
- sailing to loading terminal

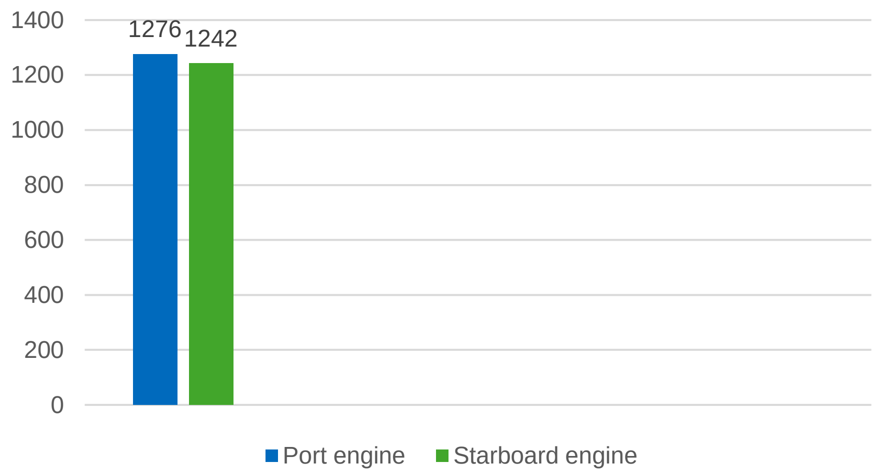
The six trips in the pilot period were made on the following dates:

- 16/06/2019 till 22/06/2019
- 09/07/2019 till 15/07/2019
- 03/10/2019 till 09/10/2019
- 26/10/2019 till 30/10/2019
- 11/11/2019 till 15/11/2019
- 03/12/2019 till 06/12/2019

2.1 Parameter 1 running hours of DF engines

The running hours of the two installed Dual Fuel (DF) propulsion engines on board of the Somtrans LNG are logged into the Wärtsilä database which provide the following results:

Figure 1: Total running hours DF engines on 31/12/2019



2.2 Parameter 2 engine speed

Both DF main engines are running on a variable rpm, which depends on a number of factors, like water depth, loaded draft and other vessels on the waterway. The DF engines almost never operate on full power.

2.3 Parameter 3 load of DF engines

During the pilot test, the load and rpm were logged by the WOIS (Wärtsilä Operator Interface System). Below is a diagram of every trip (sum of six) with data of the engine speed of each engine, in relation to the rpm. Every 4 seconds, the engine logs the speed, resulting in the total running hours (both in all and gas and diesel separately). Both main engines were counted together. Annex I provides more detailed figures on the engine load and the corresponding gas consumption.

Figure 2: Trip 1 16/06-22/06

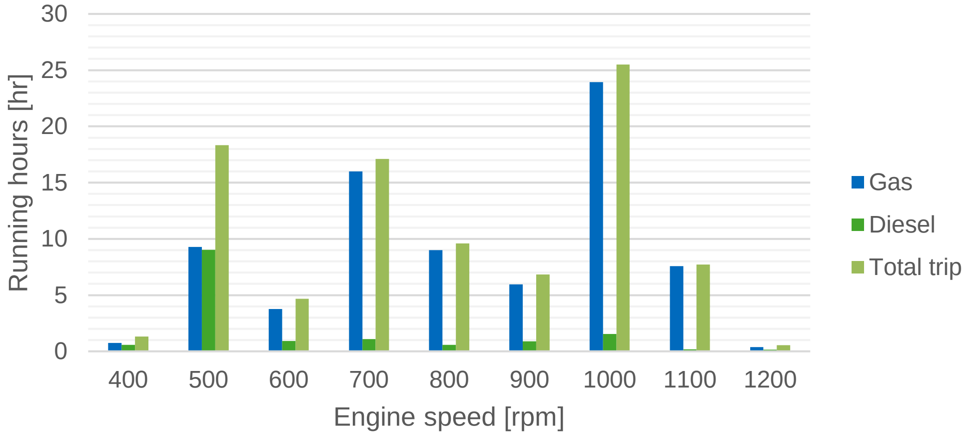


Figure 3: Trip 2 9/07-15/07

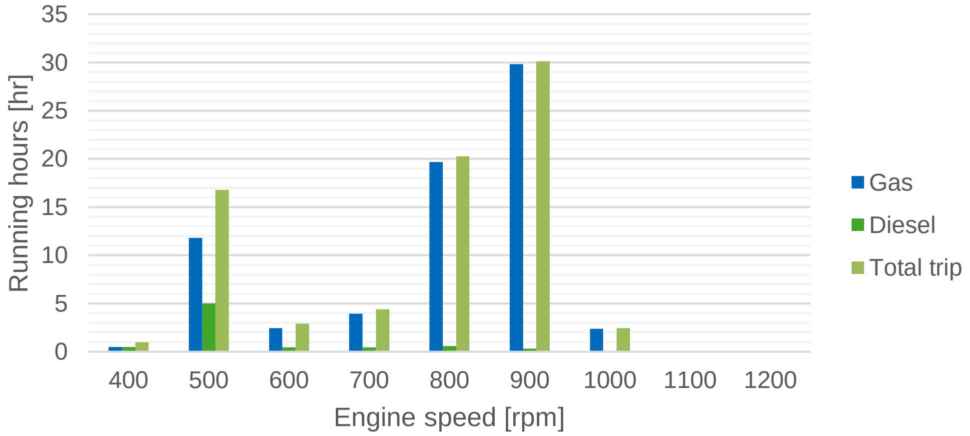


Figure 4: Trip 3 3/10-9/10

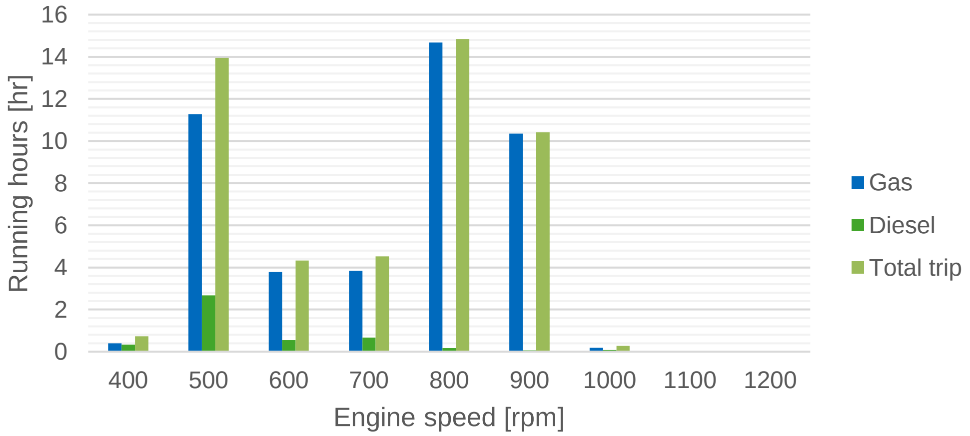


Figure 5: Trip 4 26/10-30/10

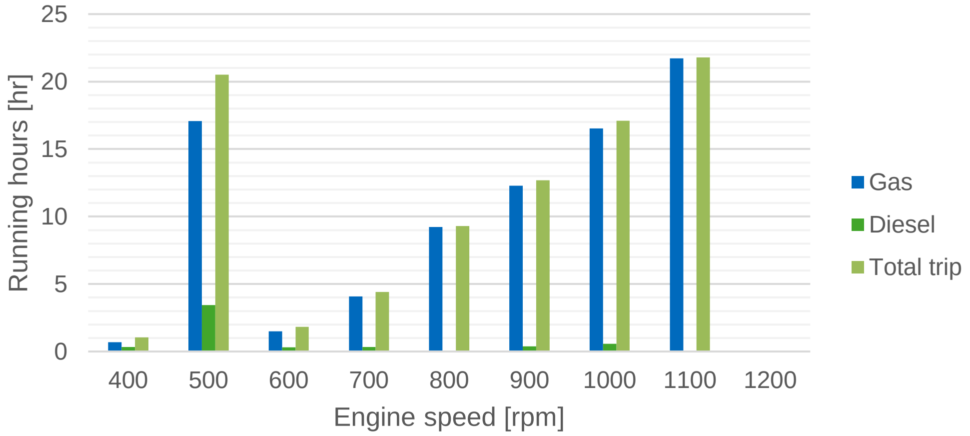


Figure 6: Trip 5 11/11-15/11

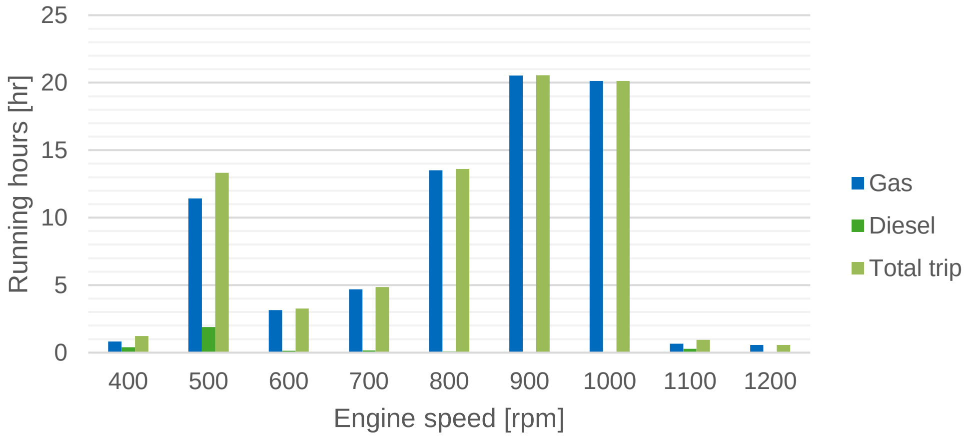
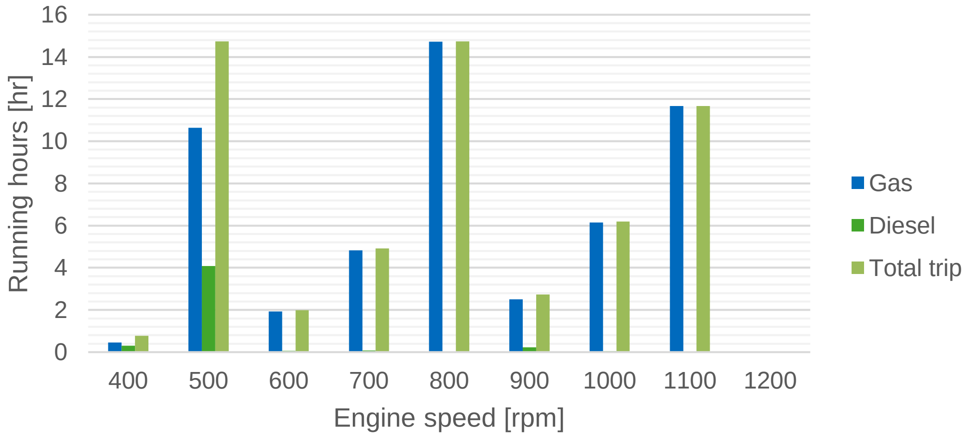


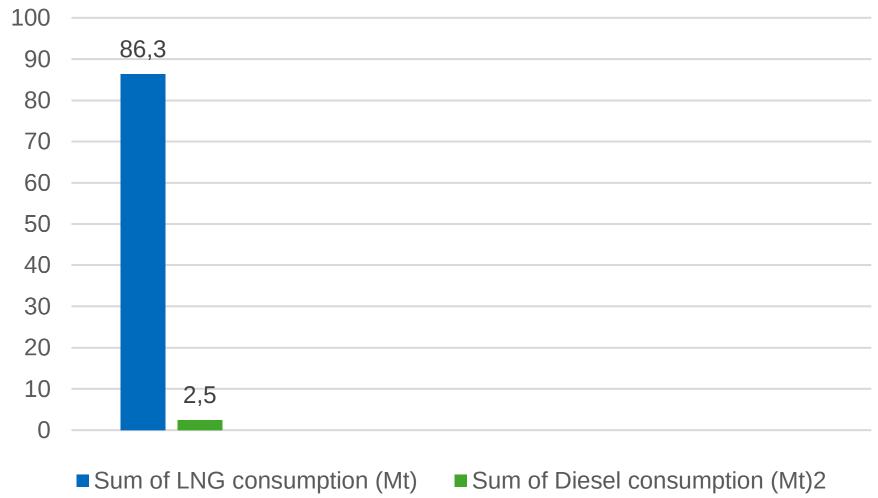
Figure 7: Trip 6 3/12-6/12



2.4 Parameter 4 LNG and diesel consumption of DF engines

The LNG fuel consumption was logged by the WOIS. The diesel consumption was logged manually. This resulted in the following fuel consumption records expressed in metric tonnes (Mt):

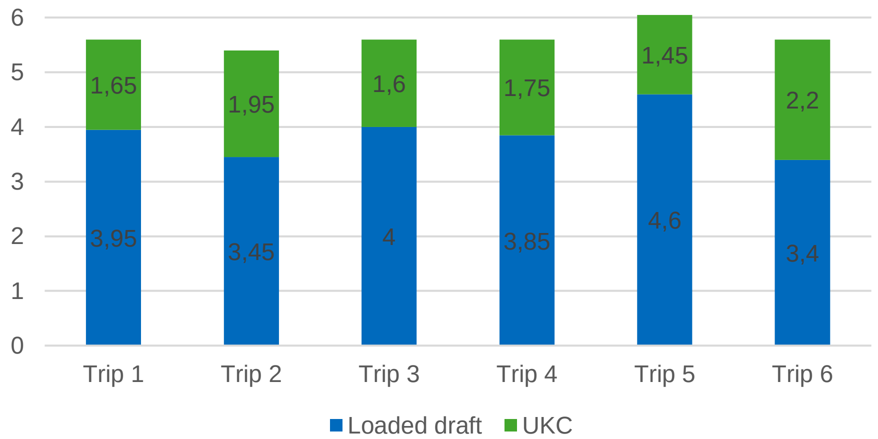
Figure 8: Fuel consumption 01/07/2019 till 31/12/2019



2.5 Parameter 5 water depth, position and speed (GPS data)

As mentioned before, six trips were made during the pilot period. Each trip, the captain noted the same depth under the barge, the “under keel clearance” (UKC). This data was gathered, by watching the depth sounder, which is installed in the wheelhouse. The captain was informed of the depth of the barge before the trip started. Together, the UKC and the draft of the barge form the water depth. Figure 9 provides a visual overview of the draft and UKC expressed in meters.

Figure 9: Loaded draft and UKC in meters

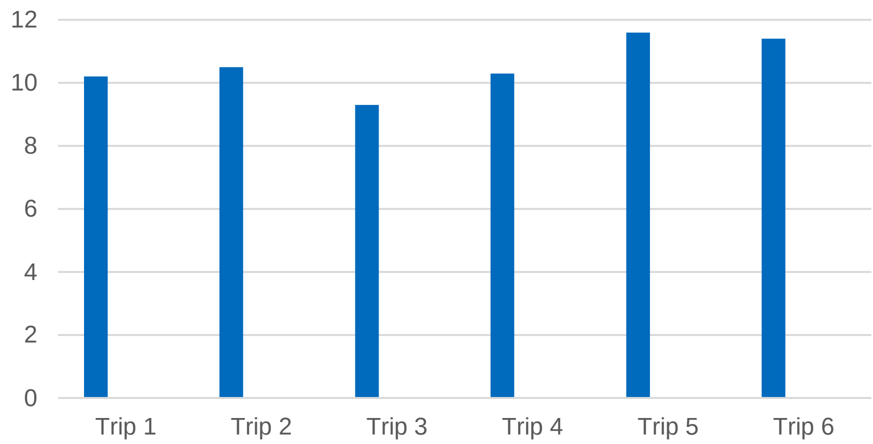


The captain logged the sailing speed manually by watching the GPS (installed in the wheelhouse). This was done during each trip. The data was collected during the following periods:

- 16/06/2019 till 22/06/2019
- 09/07/2019 till 15/07/2019
- 03/10/2019 till 09/10/2019
- 26/10/2019 till 30/10/2019
- 11/11/2019 till 15/11/2019
- 03/12/2019 till 06/12/2019

There was no possibility for the Somtrans LNG to sail at full speed during the whole trip due to, for example, limited available space on the waterways and the presence of other vessels. Figure 10 provides an overview of the average speed per trip.

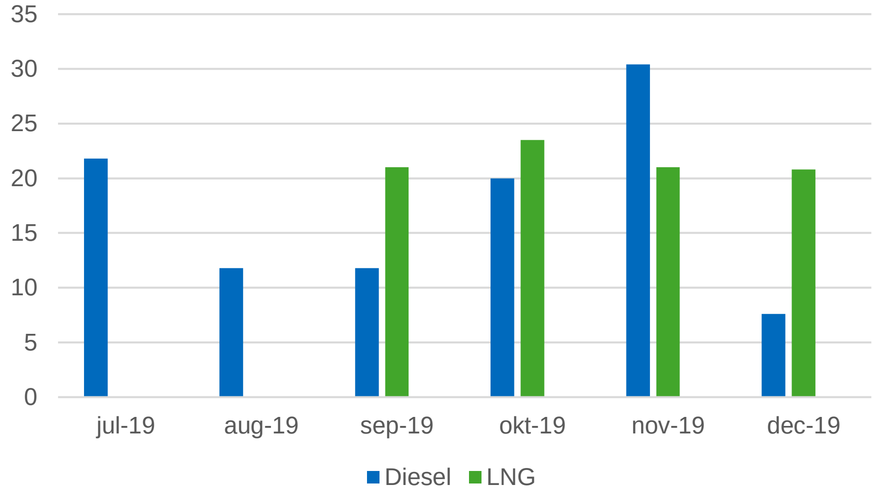
Figure 10: Average speed per trip in km/h



2.6 Parameter 6 overall LNG and diesel bunkering

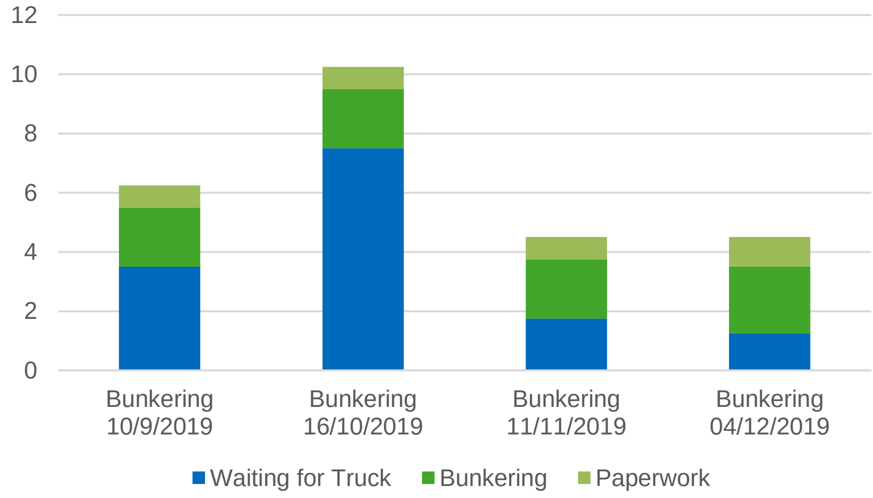
Diesel consumption is not just used for Wärtsilä's pilot fuel main propulsion engines, but mainly for the auxiliary generators: two for the bow thruster and for discharging. The other two auxiliary engines were installed to produce electricity for the barge. They are working one by one. Figure 11 provides an overview of the total bunkered amount diesel and LNG in tons, throughout the pilot period.

Figure 11: Total diesel and LNG bunkering in tons



Also the bunkering time for LNG has been registered, as bunkering operations for LNG are more cumbersome as compared to bunkering diesel, especially concerning the overall required time.

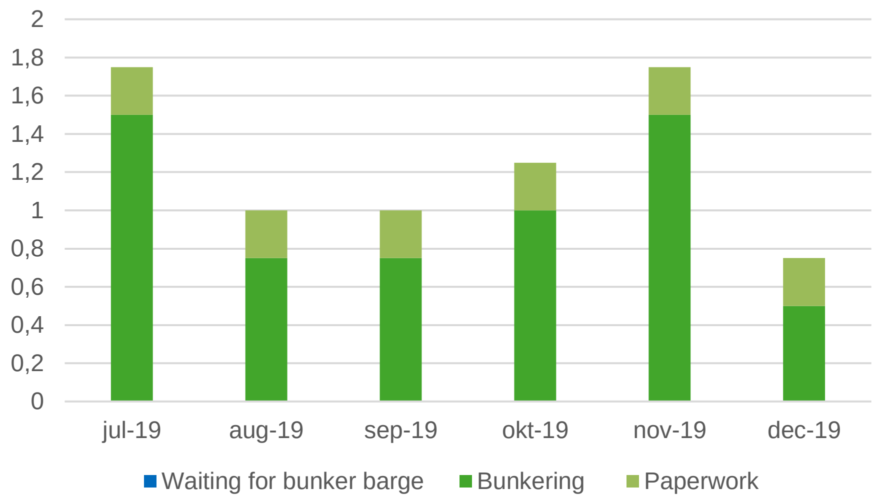
Figure 12: Total bunker time in hours



Looking at figure 12, it can be seen that bunker operations on 10/09/2019 and 16/10/2019 show a long waiting time specifically related to the arrival of the bunker truck. When the barge is loading or discharging, it is not always easy to make an exact estimate of the departure time and the bunkering duration. As compared to diesel, LNG bunker operations are not allowed on a jetty. They are conducted at special locations, designated by the authorities. So, the barge chooses a bunker location on her voyage, so as to avoid extra distance and sailing time.

As a comparison, figure 13 provides an overview on the total bunker time for diesel. The figure shows there is practically no waiting time for a diesel bunker barge to come alongside the Somtrans LNG, because there are many available bunker barges sailing in harbour areas, which are available 24/7 a day. For example, one can order diesel one hour in advance, where ordering LNG takes two to three days. So, there is a lot of flexibility for bunker operations during waiting time. The paperwork takes up less time as well, because the bunker checklist is 75% less extensive as compared to the LNG bunker checklist.

Figure 13: Total bunker time in hours for diesel



2.7 Parameter 7 gas ventilation events

During the pilot period, all gas alarms were monitored and no leakages where detected in the LNG installation. Last summer, there was one issue with increasing pressure in the LNG storage tank. During that time, it was very hot outside and the barge was sailing 30 minutes a day or less. These were very short trips in the Antwerp region. The lowest overpressure alarm was activated once. To avoid a boil off in the next few days, it was decided to sail for 2 hours in the Antwerp harbours. Afterwards, the pressure sank again and the problem was solved. Another solution to avoid overpressure, is to bunker LNG, causing the temperature in the LNG storage tank to decrease. This is only a solution when there’s enough space to load a complete truck.

During hot summer periods, when the barge isn’t sailing much, the crew has to monitor the pressure in the LNG storage tank frequently, to avoid a boil off.

3 E2/E3 test cycle data of test bed trials

The emissions of both DF main engines have been measured in test bed environments initiated by the OEM. These Factory Acceptance Test (FAT) values are taken into account for the analysis on the emission reduction, which is included in chapter 5 of this report. However, due to confidentiality, these values are not explicitly stated in this report.

4 On board emission measurement

The emissions of both DF main engines were measured on board of the Somtrans LNG in an E3 test cycle executed by SGS. The results of the measurement are included in this report and can be found in Annex II.

Both DF engines are approved according to CCR legislation for emission measuring. The stage is CCR2 which does not take LNG into account as a reference fuel. Hence, CCR2, as compared to NRMM Stage V, does not have a separate limit for unburned hydrocarbons for engines not running on 100% diesel fuel.

Table 1 provides an overview of the emissions of both main propulsion engines, according to the emission measurement on board of the vessel. The FAT values are not stated due to confidentiality, these values are taken into account though for the upcoming analysis. Furthermore, the CCR2 emission limits are added to provide a comparison.

Table 1: Overview emissions

Emmission measurement	Nox (g/kWh)	CO (g/kWh)	CxHy (HC) (g/kWh)	PM (g/kWh)
Port engine				
FAT			Confidential	
on board	1,5	2,6	8,6	0,1
CCR2	7,9	3,5	n/a	0,2
Starboard engine				
FAT			Confidential	
on board	1,6	2,4	7,4	0,1
CCR2	7,9	3,5	n/a	0,2

The emission measurement on board relive to the FAT values and shows in general no big deviations between FAT and on board measurement of NOx, CO and CxHy. PM values are less accurate however once measured on board of the vessel.

5 Emission reduction

Both main engines are certified by the CCNR2 standard. This is an emission standard applying to Inland Waterway Transport. LNG is not a reference fuel in the CCNR2 regulations, in contrast to the NRMM Stage V emission standard (European successor of CCNR2) which has entered in force in 2020[1] for power ranges >300kW and does take LNG into account as a reference fuel. However, apart from LNG engines, there are currently even no IWP diesel engines (>300kW) certified for NRMM Stage V. The industry is coping with difficulties to certify such engines.

The emission reduction analysis in this chapter takes four emission groups into account; NOx, CO, CxHy (HC) and PM. Emissions are calculated on a load of 100% of each main engine. The emission reduction is expressed as the reduction in emissions according to the on board measurement and FAT results, as compared to the CCNR2 emission limits. The FAT figures are not made explicit in gram/kWh due to confidentiality.

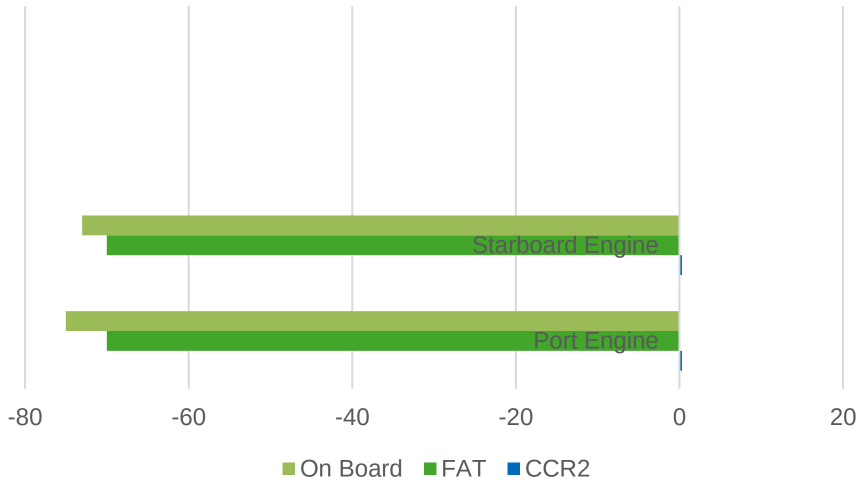
5.1 Reduction of NOx emission

NOx emissions were measured on board during the pilot period, resulting in the following stats. CCNR2 specifies the following calculation to determine the NOx emission of engines; 45* nominal engine speed (rpm)$^{-0.2}$ -3 g/kWh. For the applied engine (1.200rpm) the outcome will be 7,90 g/kWh.

The measured values on board are 1,5 gr/kWh for the port engine and 1,6 gr/kWh for the starboard engine. The reference point of the NOx emission in CCNR2 is 0% in the figure below. The figure shows a big reduction of NOx (in %) by the use of LNG fuelled engines.

[1] 2020 for engines with a power range of >300 kW and 2019 for engines with a power range of <300 kW. However, due to the Covid-19 crisis the European Commission has proposed to postpone the transition engine deadlines of the Stage V emission standards (https://dieselnet.com/news/2020/06eu.php).

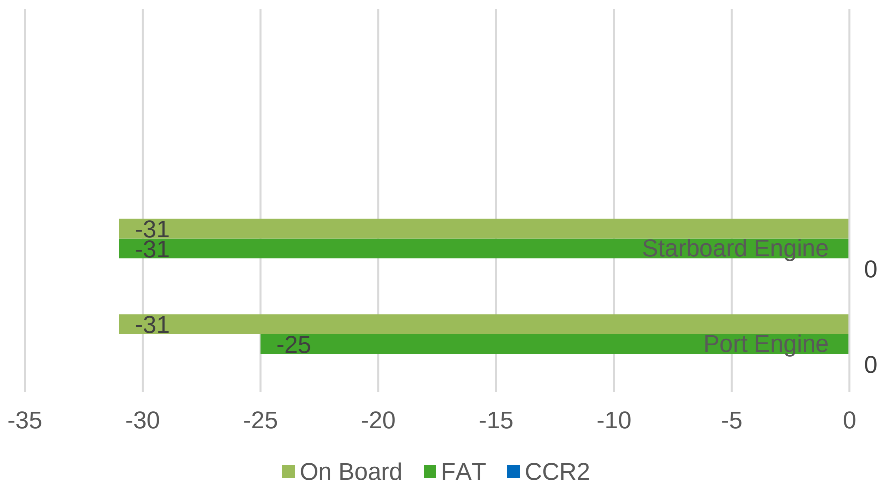
Figure 14: NOx emission reduction (%) compared to CCNR2



5.2 Reduction of CO emission

CO (carbon monoxide) is caused by unburned fuel in the engine. Measurements show a lower presence of CO when LNG is used. There's no big difference between FAT and on board measurement. The maximum standard of CCNR2 is 3,5 gr/kWh. The measured values at port engine is 2,6 gr/kWh and starboard engine is 2,4 gr/kWh. The reference point of the CO emission in CCNR2 is 0% in the figure below. The figure shows a big reduction of CO (in %) by the use of LNG fuelled engines.

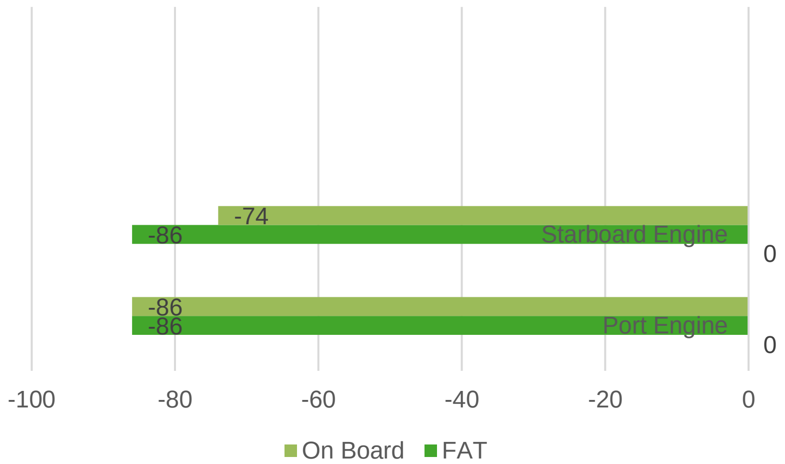
Figure 15: CO emission reduction (%) compared to CCNR2



5.3 Reduction of CxHy emission

CxHy (hydrocarbons) emissions are measured when gas engines are used and determinate unburned hydrocarbons. In contrast to NRMM Stage V, the CCNR2 standard does not specify CxHy limits for specifically gas engines since it does not take gas into account as a reference fuel. NRMM Stage V, however, specifies separate limits for fully and partially gaseous-fuelled engines as compared to engines running on other fuels, acknowledging the difficulty for gaseous-fuelled engines to limit CxHy emissions. Therefore, the limit for gaseous-fuelled engines, as specified in NRMM Stage V, will be taken into account for the sake of comparison in this report. A limit of 6,19 g/kWh will be assumed.[2] Figure 16 provides an overview of the CxHy reduction according to both the on board measurement and FAT values as compared to the Stage V limits.

Figure 16: CxHy emission reduction (%) compared to NRMM Stage V

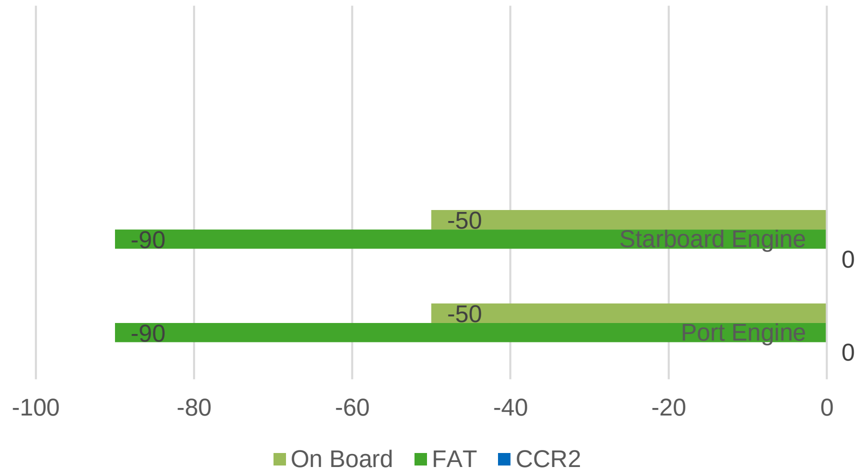


[2] The specific provisions on total hydrocarbon limits for fully and partially gaseous-fuelled engines can be found on p.55 of Regulation (EU) 2016/1628 (https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32016R1628&from=EN)

5.4 Reduction of PM emission

The amount of PM shows a big reduction (in %) in reference to CCNR2 standards thanks to LNG technology. The reference point of the PM emission in CCNR2 is 0% in the figure below.

Figure 17: PM emission reduction (%) compared to CCNR2



6 Reduction of fuel consumption

This chapter covers the saving of diesel fuel (EN 590) relative to LNG. The calculation below shows the total consumption of LNG and when both engines are operating in LNG DF modus. The calculation shows also the situation when both engines are running in 100% diesel modus.

At half engine load a comparable diesel engine consumes 150L/hr. At same engine output the DF engine in gas mode consumes 116kg/hr LNG and 4L/hr of pilot diesel. This is a reduction of (150-4) 146L when consuming 116kg LNG.

Both main engines used in the pilot period consumed 86,3 MT of LNG in total. Hence, 86.300/116*(150 - 4)= 108.619 litres of diesel fuel has been saved in the pilot period. Expressed in kilograms this is, 108.619*0,84= 91.240 KG of diesel fuel. In short:

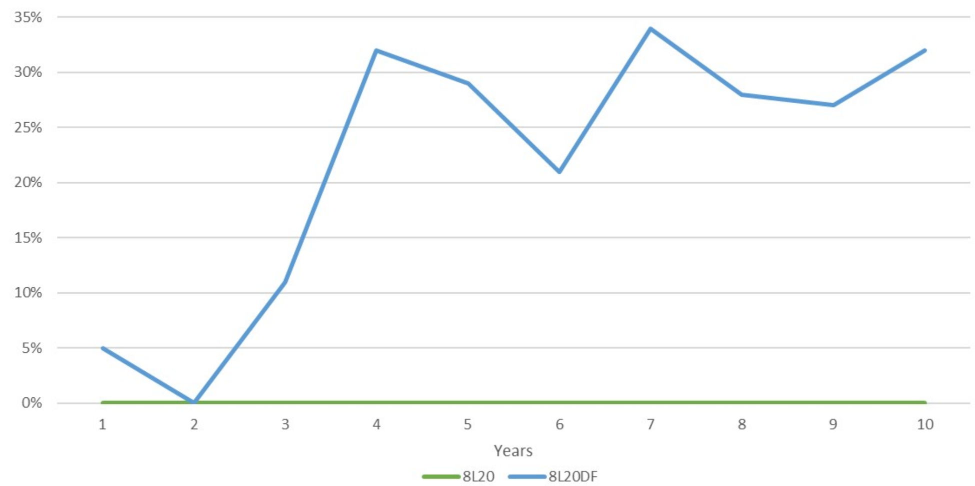
- Total consumed LNG: 86,3 MT
- Total saved Diesel: 91,2 MT

7 Reduction of operational costs

The application of LNG can result in reduced operational costs. During the pilot period fuel costs were lower as compared to the conventional situation in which diesel is the applied fuel. This is due to the relatively lower fuel price of LNG as compared to diesel. The reduced fuel costs in the pilot period were 20,820 EUR thanks to the use of LNG. This amount depends on the operating hours of the main engines and prices of diesel fuel and LNG, hence the result can be totally different, either more or less beneficial, in a different period.

Next to the advantage of LNG as compared to diesel in the field of fuel costs, there are the maintenance costs which are less in favour of LNG.

Figure 16: Yearly accumulative maintenance cost 8L20 engine vs 8L20DF engine



Note: 3000 running hours annually – Fuel: 8L20 (LFO) and 8L20DF (Gas)

Figure 16 shows the additional maintenance costs (in %) between a Wärtsilä 8L20 (running fully on diesel) and a Wärtsilä 8L20DF (dual fuel) during a period of ten years, with yearly running hours of 3,000. The maintenance costs are not every year the same due to differences in maintenance intervals and wear down of parts. So the yearly costs are fluctuating for the DF engine.

Furthermore, the LNG installation must be annually checked by the company which installed it. Afterwards, the classification society has to check the installation and certify it for one year. Both together cost about 3,000 EUR every year.

Bunkering LNG takes significantly more time as compared to bunkering diesel, especially when bunkering diesel is being done through a bunker boat. Figure 12 clearly shows that 'waiting', on average, contributed the most to the overall bunkering time.

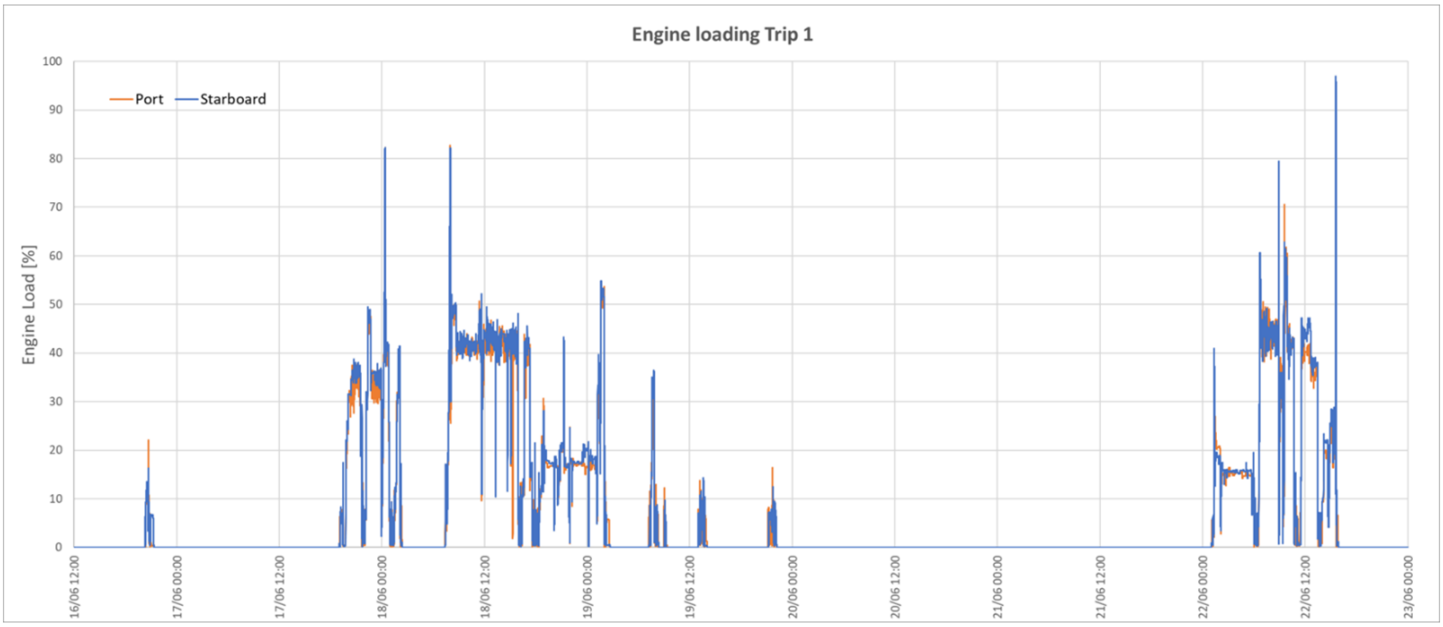
All these aspects are incorporated into table 2 and provide a short overview of the costs and benefits of using LNG throughout the pilot period. Not all aspects are taken into account, however, based on this brief overview it can be seen that the use of LNG, throughout the pilot period, resulted in a slight financial benefit as compared to using diesel as fuel.

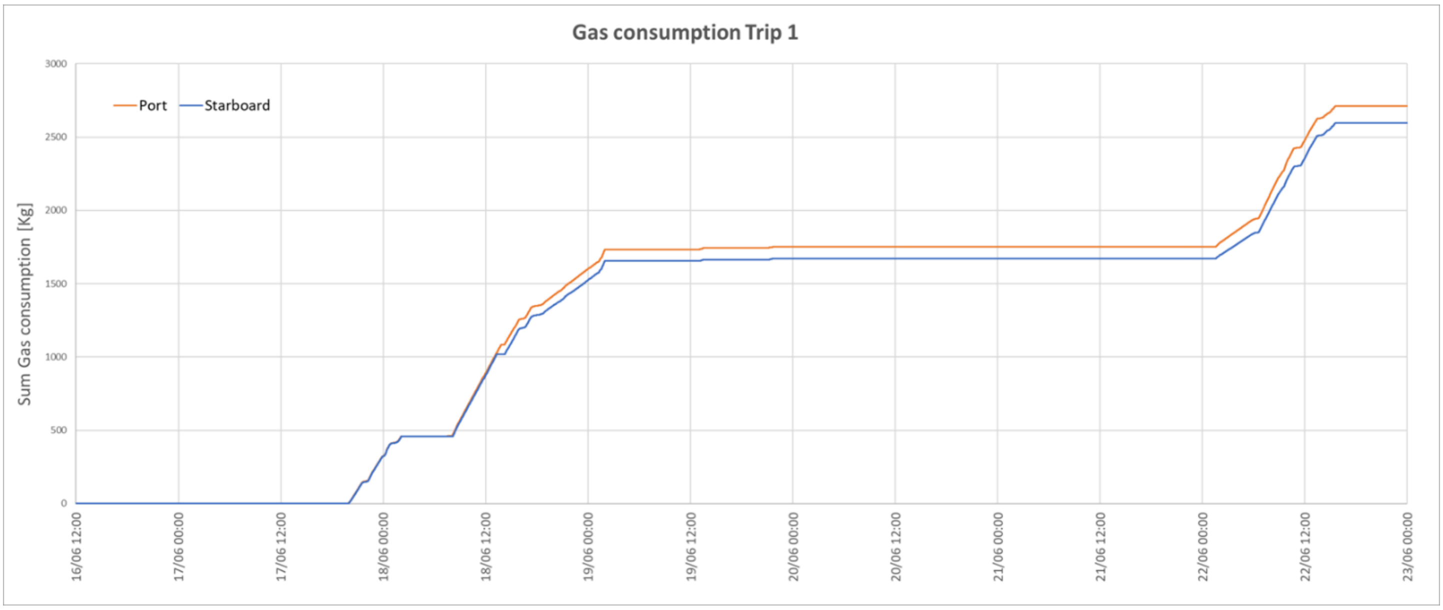
Table 2: short overview costs & benefits of the LNG installation on the Somtrans LNG during the pilot period

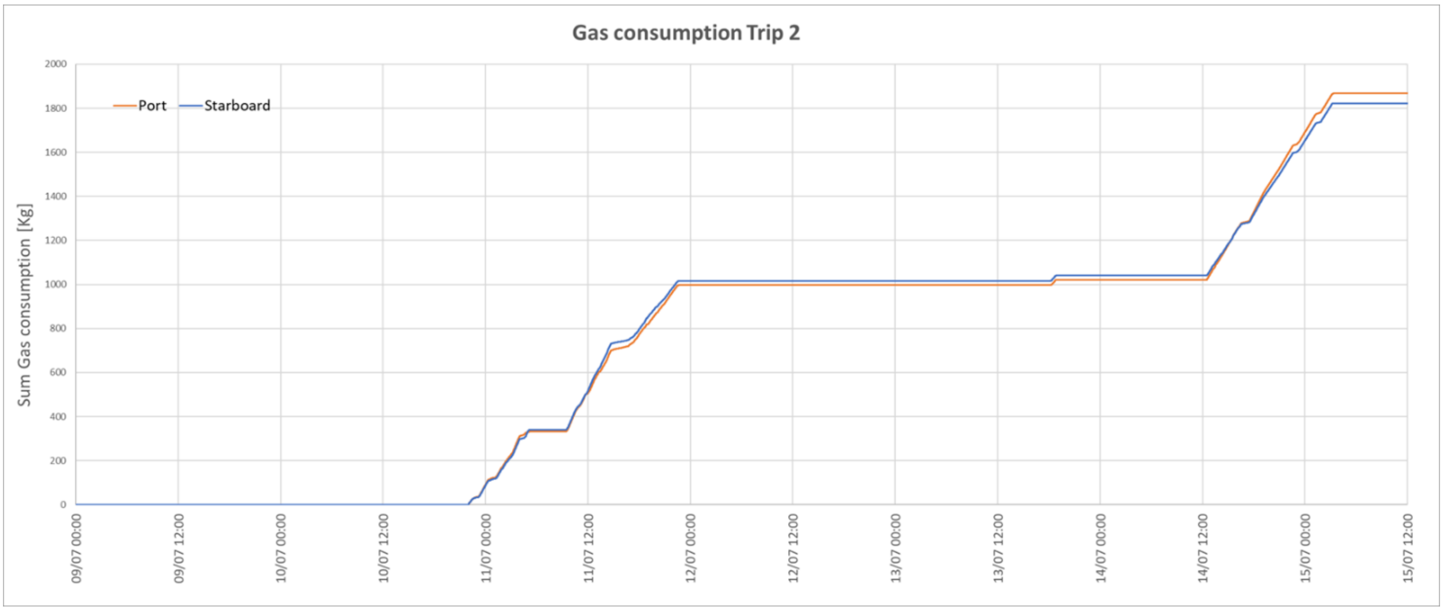
Dedicated costs & benefits LNG installation		**Operational Costs (€)**
Reduced fuel costs due to LNG	+	€ 20.820
Maintenance costs in pilot period	-	*€ 1.200*
Costs by classification company	-	*€ 750*

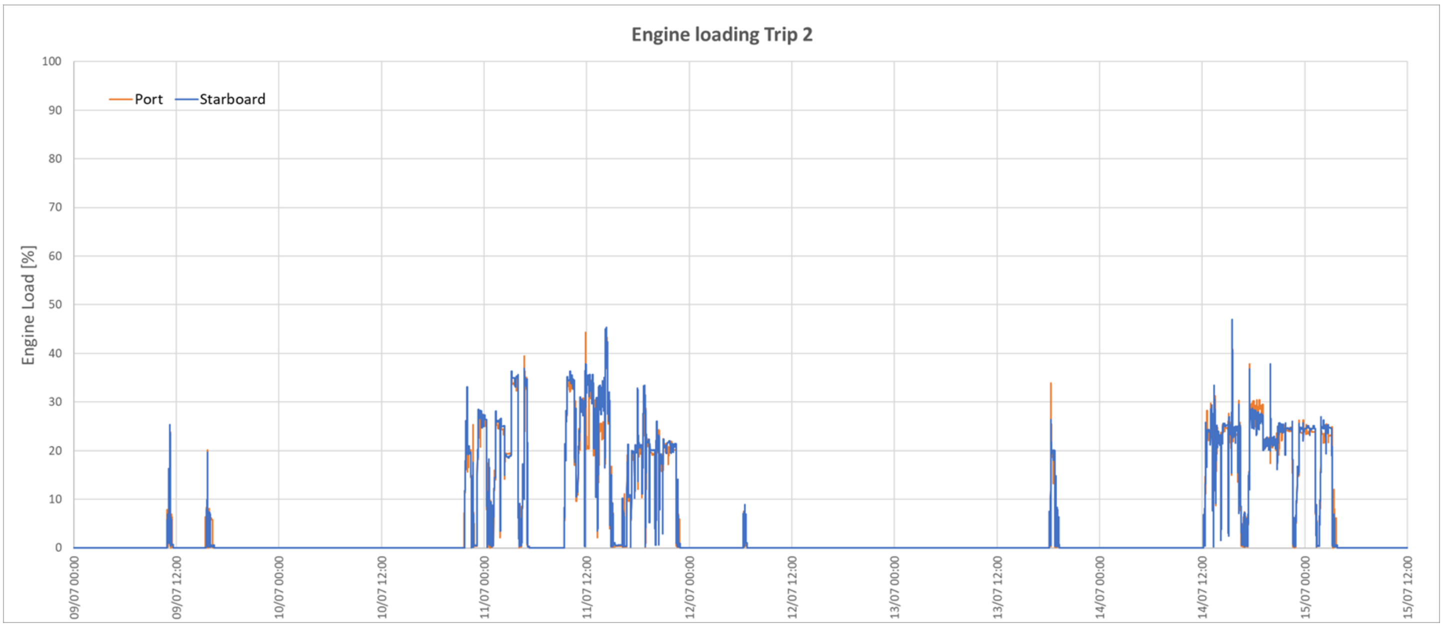
Costs of yearly check LNG installation	-	*€ 750*
Costs due wating time of maintenance	-	*€ 4.500*
Wating time to truck before bunkering	-	*€ 7.560*
Balance	**+**	**€ 6.060**

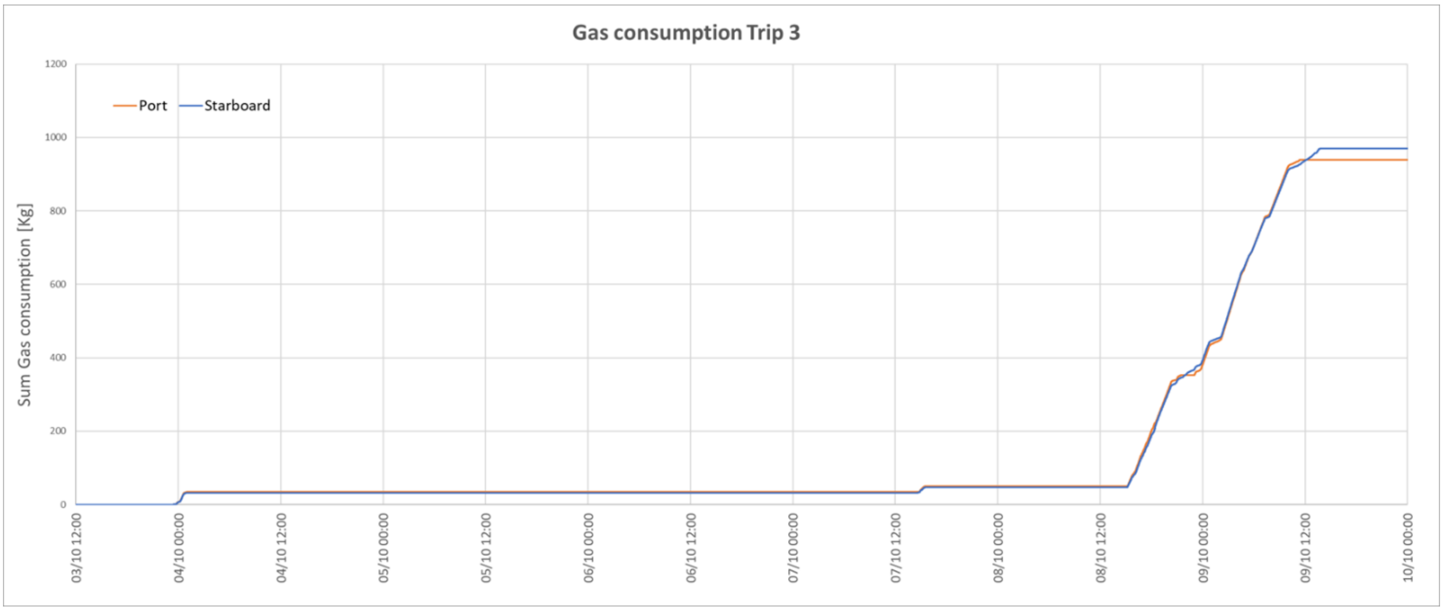
Annex I - Engine load and gas consumption

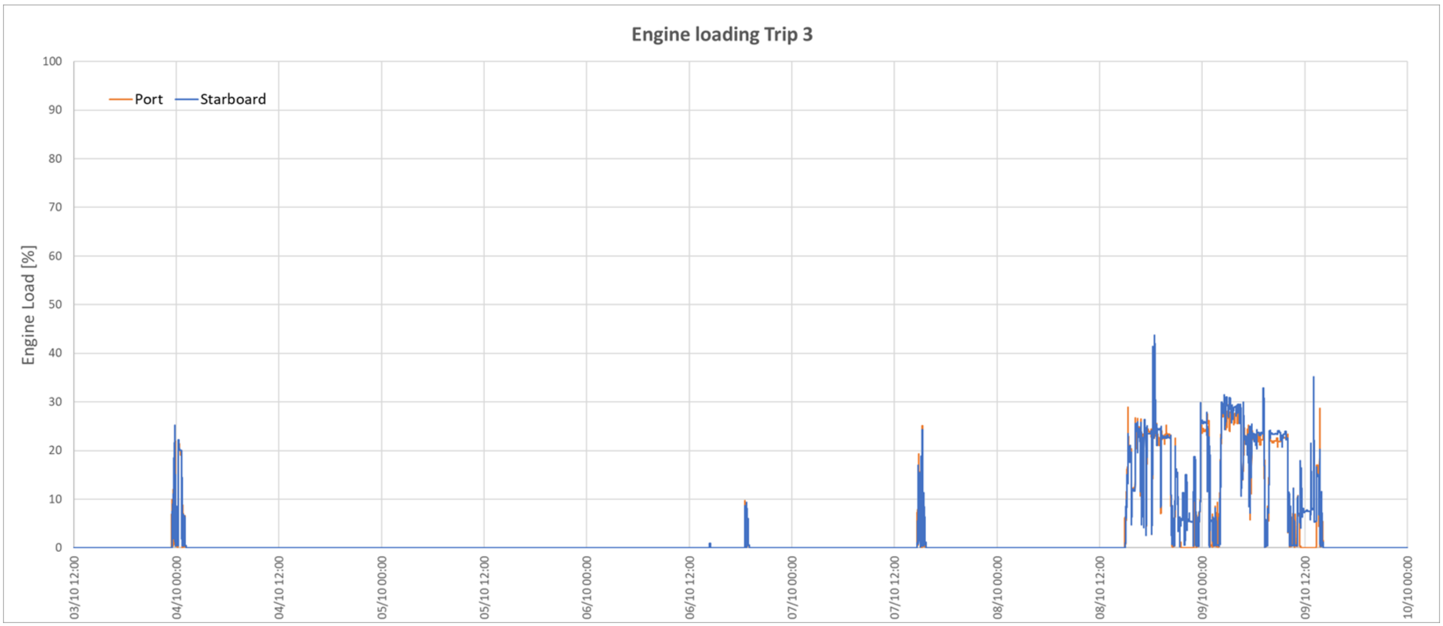


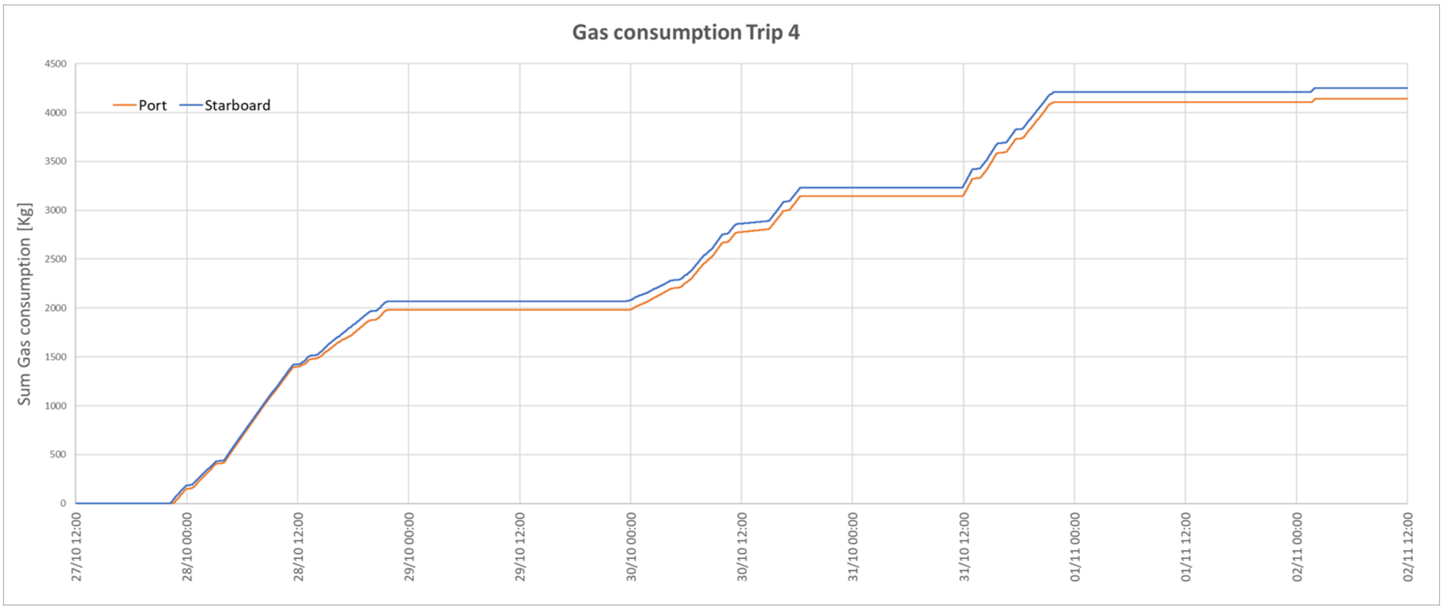


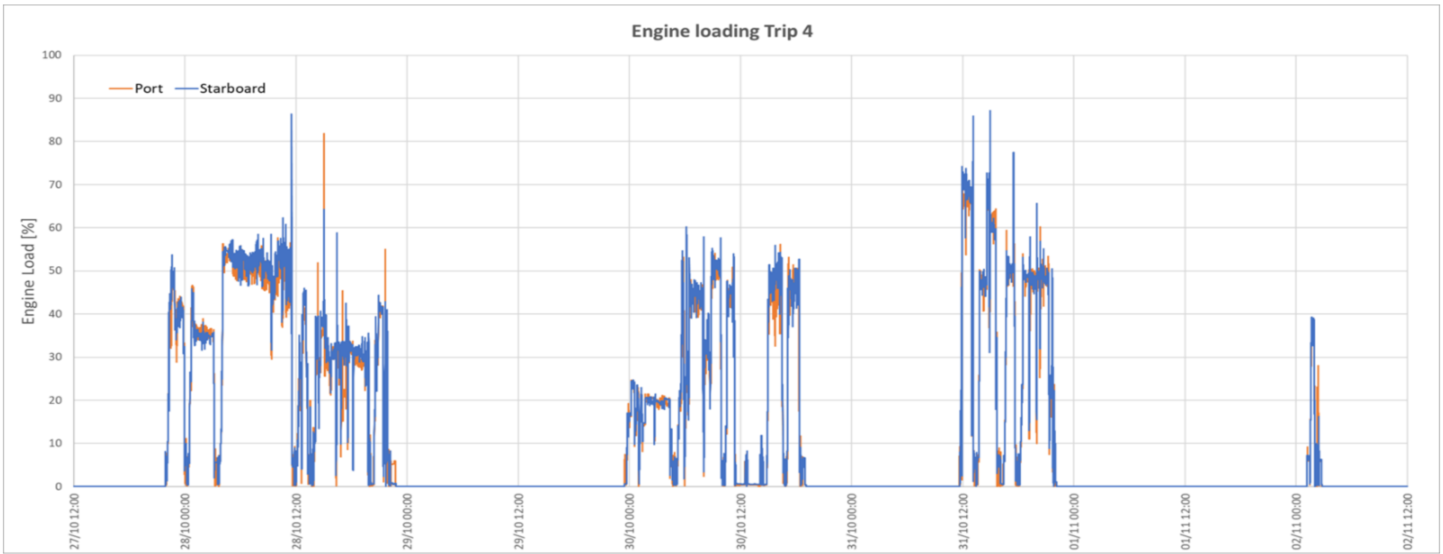

Gas consumption Trip 2
Port
Starboard
Sum Gas consumption [Kg]
2000
1800
1600
1400
1200
1000
800
600
400
200
0
09/07 00:00
09/07 12:00
10/07 00:00
10/07 12:00
11/07 00:00
11/07 12:00
12/07 00:00
12/07 12:00
13/07 00:00
13/07 12:00
14/07 00:00
14/07 12:00
15/07 00:00
15/07 12:00

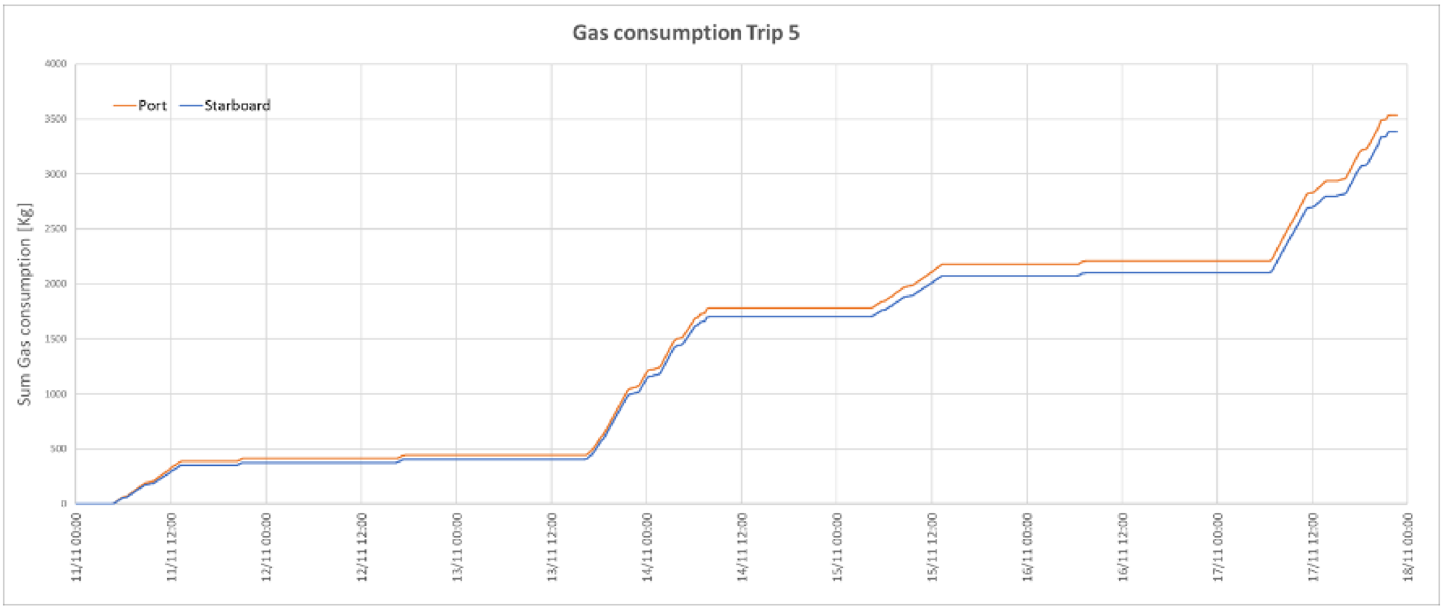

Engine loading Trip 2
Port
Starboard
Engine Load [%]
100
90
80
70
60
50
40
30
20
10
0
09/07 00:00
09/07 12:00
10/07 00:00
10/07 12:00
11/07 00:00
11/07 12:00
12/07 00:00
12/07 12:00
13/07 00:00
13/07 12:00
14/07 00:00
14/07 12:00
15/07 00:00
15/07 12:00


Gas consumption Trip 3
Port
Starboard
Sum Gas consumption [Kg]
1200
1000
800
600
400
200
0
03/10 12:00
04/10 00:00
04/10 12:00
05/10 00:00
05/10 12:00
06/10 00:00
06/10 12:00
07/10 00:00
07/10 12:00
08/10 00:00
08/10 12:00
09/10 00:00
09/10 12:00
10/10 00:00

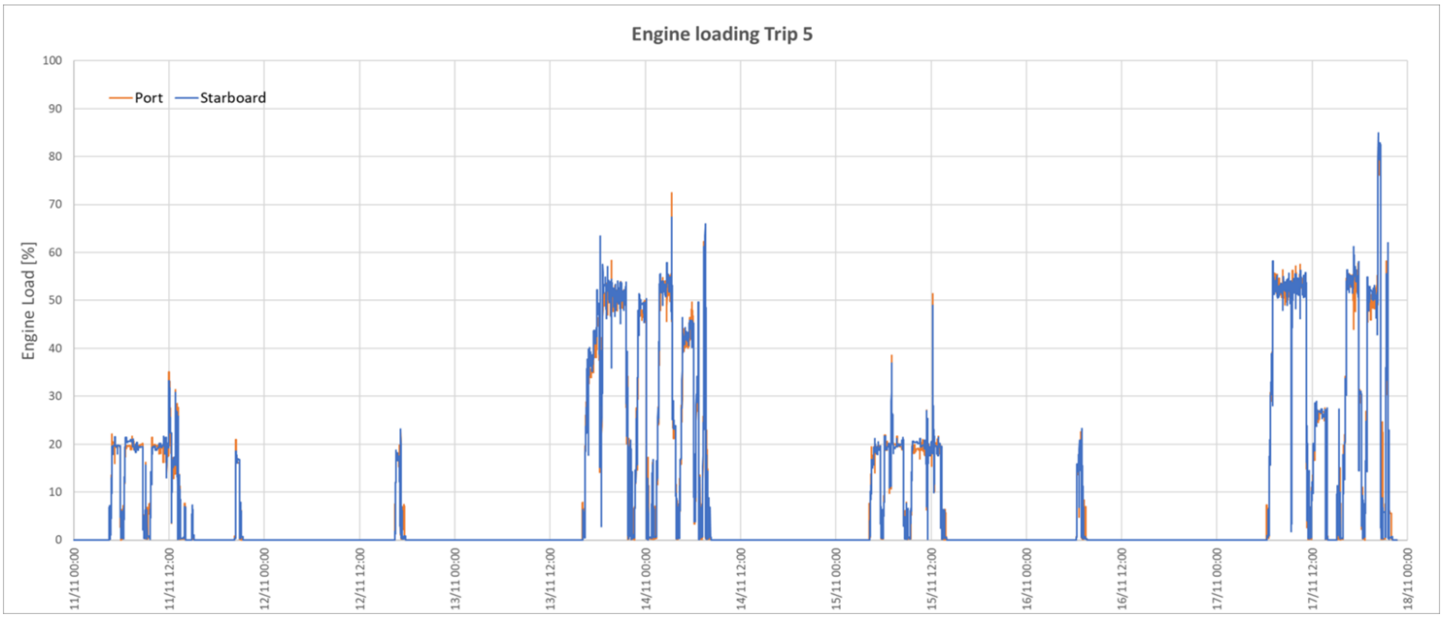

Engine loading Trip 3
Port
Starboard
Engine Load [%]
100
90
80
70
60
50
40
30
20
10
0
03/10 12:00
04/10 00:00
04/10 12:00
05/10 00:00
05/10 12:00
06/10 00:00
06/10 12:00
07/10 00:00
07/10 12:00
08/10 00:00
08/10 12:00
09/10 00:00
09/10 12:00
10/10 00:00


Gas consumption Trip 4
Sum Gas consumption [Kg]
Port
Starboard
4500
4000
3500
3000
2500
2000
1500
1000
500
0
27/10 12:00
28/10 00:00
28/10 12:00
29/10 00:00
29/10 12:00
30/10 00:00
30/10 12:00
31/10 00:00
31/10 12:00
01/11 00:00
01/11 12:00
02/11 00:00
02/11 12:00

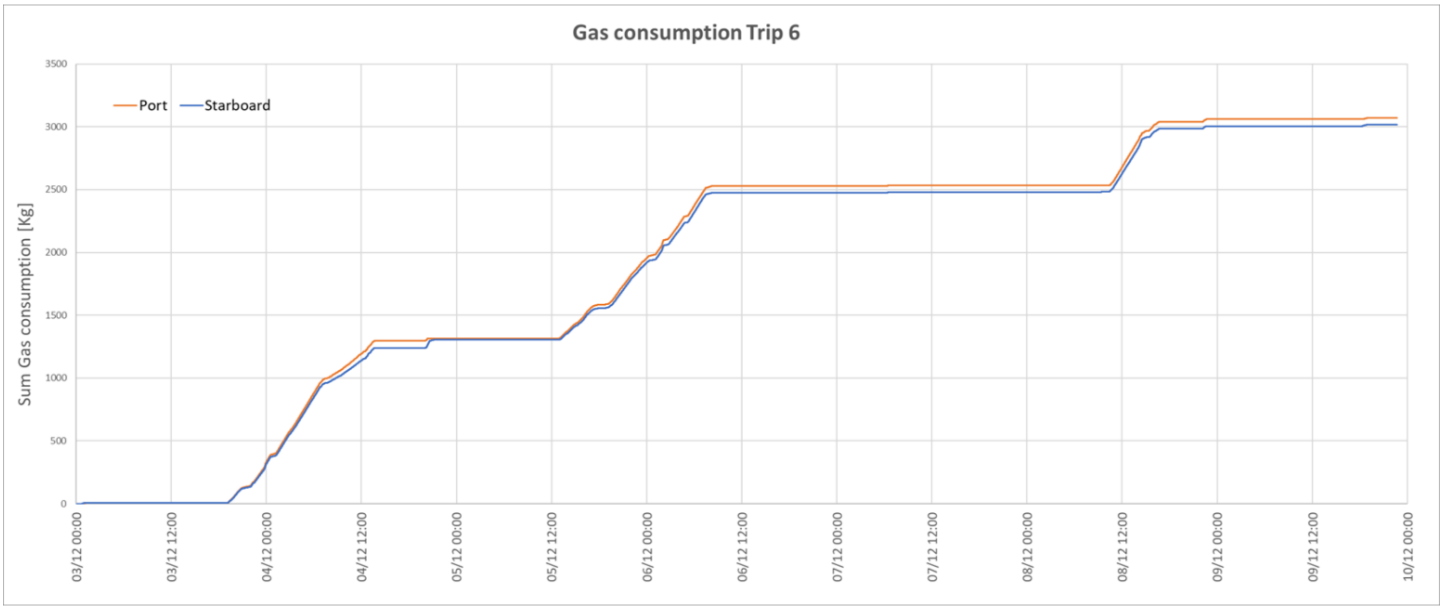

Engine loading Trip 4
Engine Load [%]
Port
Starboard
100
90
80
70
60
50
40
30
20
10
0
27/10 12:00
28/10 00:00
28/10 12:00
29/10 00:00
29/10 12:00
30/10 00:00
30/10 12:00
31/10 00:00
31/10 12:00
01/11 00:00
01/11 12:00
02/11 00:00
02/11 12:00



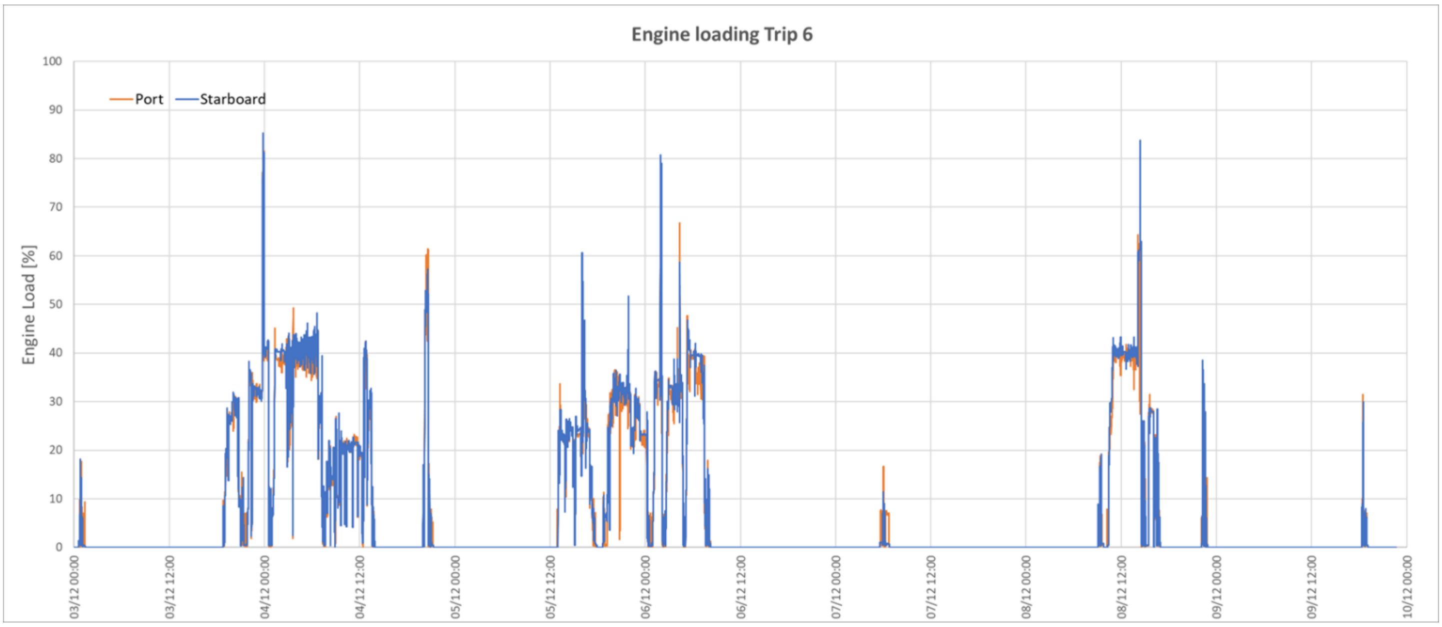
Gas consumption Trip 5
Port
Starboard
Sum Gas consumption [Kg]



Engine loading Trip 5
Port
Starboard
Engine Load [%]



Gas consumption Trip 6
Port
Starboard
Sum Gas consumption [Kg]
3500
3000
2500
2000
1500
1000
500
0
03/12 00:00
03/12 12:00
04/12 00:00
04/12 12:00
05/12 00:00
05/12 12:00
06/12 00:00
06/12 12:00
07/12 00:00
07/12 12:00
08/12 00:00
08/12 12:00
09/12 00:00
09/12 12:00
10/12 00:00



Engine loading Trip 6
Port
Starboard
Engine Load [%]
100
90
80
70
60
50
40
30
20
10
0
03/12 00:00
03/12 12:00
04/12 00:00
04/12 12:00
05/12 00:00
05/12 12:00
06/12 00:00
06/12 12:00
07/12 00:00
07/12 12:00
08/12 00:00
08/12 12:00
09/12 00:00
09/12 12:00
10/12 00:00

Annex II – On board emission measurement report

REPORT

EMISSION MEASUREMENTS

RESULTS OF THE MEASUREMENTS PERFORMED ON BOARD OF THE SOMTRANS LNG, DECEMBER 19, 2019

ON BEHALF OF:

SOMTRALUX S.A.

SGS

REPORT

EMISSION MEASUREMENTS

RESULTS OF THE MEASUREMENTS PERFORMED ON BOARD OF THE SOMTRANS LNG, DECEMBER 19, 2019

EZMO-2019-09-0007

15 JANUARI 2020

Laboratory

SGS NEDERLAND BV

Customer

Somtralux S.A.

Am Broch 2, L5450 Stadtbredimus Belgie

Mr. A. Blanckaert

Author	***Appoved by***
	
--	--
John van Middelkoop Senior measurement technician	Charlotte Wosten Technical Marager Air Monitoring

Version history		
Rev.	**Date**	**Changes**
0	January 15, 2020	
1		
2		
3		

Whenever a new version is made, the prior version is cancelled.

Project details

General information

Company name	Somtralux S.A.
Address	Am Broch 2
Postal code, city	L-5450 Stadtbredimus België
Contact	Mr. A. Blanckaert
Telephone number	+32 33 551 691
Email address	**tech@somtrans.be**
Client reference number	
SGS reference number	EZMO-2019-09-0007

Vessel data

Location	Somtrans LNG
Installation	WARTSILA W8L20DF PS and SB main engines

Measurement details

Kind of measurement	Emission measurements: O_2, CO_2, CO, NO_x and PM
Measurement period	December 19, 2019
Measuring staff	John van Middelkoop and Jaap Boot

Quality

For a list of the accredited activities (RvA L092) of the SGS Nederland BV Environment, Health and Safety Department in Arnhem, The Netherlands, we refer to the Dutch Accreditation Council RvA website (https://www.rva.nl/system/scopes/file_nls/000/000/076/original/L092-scn.pdf?1491490288).

Disclaimer

Terminology

°C	degrees Celsius
% by weight	percentage by weight
h	hours
ind	in normal condition dry (101.3 kPa, 273 K)
inm	in normal condition moist (101.3 kPa, 273 K)
K	Kelvin
kg	kilogrammes
kPa	kilo Pascal
m	metres
vppm	volume parts per million
mg/m_0^3	milligrammes per normal cubic metre
m^3	cubic metres
mg	milligrammes
vol%	volume percentage
g	grammes
GJ	gigajoules
m^3/h	flow under normal operating conditions
m_0^3/h	normalized flow (273 K, 1013 hPa, current % O_2 and dry flue gas)
m_0^3/h @ x vol% O_2	normalized flow (273 K, 1013 hPa at X vol% O_2 and dry flue gas)

Summary

SGS Nederland BV, Environment, Health and Safety carried out measurements on the Somtrans WARTSILA W8L20DF dual fuel main engines. The measurements were carried out on December 19, 2019.

The E3 test cycle is performed according to the international guidelines set out in International Marine Organization, IMO, MARPOL annex VI, for marine engine.

Purpose of the measurements

The purpose of the measurements was to determine the emissions in an E3 cycle.

Results of the emission measurments

A brief summary of the results is found in this section.

Table 1 Results measurements main engine PS

Item		Engine
Manufacturer		Wärtsilä
Type		W8L20DF
Serial Number		PAAE336536
Location		Somtrans LNG
Cycle		CCNR 2: Dual fuel: E3: 1480 kW @ 1200 rpm
Emissions		**Measured**
NOx relative emisson	(g/kWh)	***1.5***
CO relative emisson	(g/kWh)	***2.6***
CxHy as C relative emission	(g/kWh)	***8.6***
Particle mass relative emission	(g/kWh)	***0.1***

Table 2 Results measurements main engine SB

Item		Engine
Manufacturer		Wärtsilä
Type		W8L20DF
Serial Number		PAAE336537
Location		Somtrans LNG
Cycle		CCNR 2: Dual fuel: E3: 1480 kW @ 1200 rpm
Emissions		**Measured**
NOx relative emisson	(g/kWh)	***1.6***
CO relative emisson	(g/kWh)	***2.4***
CxHy as C relative emission	(g/kWh)	***7.4***
Particle mass relative emission	(g/kWh)	***0.1***

INDEX

1. INTRODUCTION 8

2. ENGINE DETAILS 9

3. DESCRIPTION OF MEASURING EQUIPMENT AND MEASUREMENT METHODS 10

3.1 MEASURING EQUIPMENT 10
3.2 MEASUREMENT METHODS 10
3.2.1 Gaseous flue gas components 10
3.2.2 Sampling dust 11
3.2.3 Determination of the flue gas temperature 11
3.3 MEASURING SURFACE EVALUATION 11

4. MEASUREMENT PROGRAMME AND DEVIATIONS FROM THE STANDARDS12

4.1 MEASUREMENT PROGRAMME AND PERIOD 12

5. CALCULATIONS 13

6. RESULTS 14

6.1 RESULTS OF THE MEASUREMENTS 14

7. DISCUSSION OF ERRORS 15

APPENDICES 16

LIST OF TABLES

Table 1 Results measurements main engine PS 5
Table 2 Results measurements main engine SB 5
Table 3 Engine data 9
Table 4 Measuring equipement SGS 10
Table 5 Measurement period, main engine PS 12
Table 6 Measurement period, main engine SB 12
Table 7 Results measurements main engine PS 14
Table 8 Results measurements main engine SB 14
Table 9 Measurement error 15

List of Appendices

Appendix 1: Measurement and calculation results
Appendix 2: Calibration results
Appendix 3: Calibration gasses
Appendix 4: LNG analyses

1. INTRODUCTION

SGS Nederland BV, Environment, Health and Safety carried out measurements on the Somtrans WARTSILA W8L20DF dual fuel main engines. The measurements were carried out on December 19, 2019.

The E3 test cycle is performed according the international guidelines set out in International Marine Organization, IMO, MARPOL annex VI, for marine engine.

PURPOSE OF THE MEASUREMENTS

The purpose of the measurements was to determine the emissions.

A short description of the engine is included in chapter 2. Chapter 3 describes the measuring equipment, measurement methods and the measuring surface. Chapter 4 describes the measurement programme. An overview of the calculations is presented in chapter 5. The results of the measurements are presented in chapter 6. The report concludes with a calculation of the degree of error for the measurements in chapter 7.

2. ENGINE DETAILS

The measurements are performed on board the vessel Somtrans LNG. In the table below the information on the main engine is given.

Table 3 Engine data

Component		Main Engine Port side	Main Engine Starboard
Supplier		WARTSILA	WARTSILA
Type		W8L20DF	W8L20DF
Serial number		PAAE336536	PAAE336537
Cylinders		8	8
Line / V		Line	Line
Charging		Turbo	Turbo
Intercooler		Yes	Yes
Rated power	kW	1480	1480
Rated speed	rpm	1200	1200

3. DESCRIPTION OF MEASURING EQUIPMENT AND MEASUREMENT METHODS

This chapter describes the measuring equipment and the measurement methods.

3.1 MEASURING EQUIPMENT

The following measuring equipment was used for the measurements.

Table 4 Measuring equipement SGS

Component	Analyser	Identification	Measurement principe	Standard
Fluegas temperature	Thermocouple K	15-015	Chromel-Alumel	ISO 8756
Oxygen	Horiba PG350	07-031	Paramagnetic	EN 14789
Carbon dioxide	Horiba PG350	07-031	Non-Dispersive IR	ISO 12039
Carbon monoxide	Horiba PG350	07-031	Non-Dispersive IR	EN 15058
Nitric oxide	Horiba PG350	07-031	Chemiluminescence	EN 14792
PM-total	Diluter after SCR	17-048	Isokinetic/Gravimetric	ISO 8178
Hydrocarbons	Ratfisch 53T	17-045	Flame ionisation detection	EN 12619

3.2 MEASUREMENT METHODS

The following paragraphs describe the measurement methods.

3.2.1 Gaseous flue gas components

The sampled flue gases were conducted through a temperature-controlled Teflon pipe (190 °C) to the flue gas cooler in which the moisture was removed from the flue gases by cooling them to around 3 °C. The dried and filtered flue gases were subsequently conducted to the measuring equipment.
Each component was regularly calibrated during a two-point calibration using nitrogen (reference gas) and certified calibration gases (span gas). The calibration included the analyser system, the data recording system and the computer. After calibration using reference or calibration gas, software corrected the analysers' signals to the calibration gas value.

After this adjustment, nitrogen was passed through the system again to check the functioning of the analyser. The calibrations did not include the sampling system. The sampling system was tested for leaks prior to the measurements and found to be without leaks.

3.2.2 Sampling dust

The particles are measured by means of a diluting system. A partial flue gas stream is approximately diluted 10 times. The flue gas/air mixture is let over quartz membrane filter.

3.2.3 Determination of the flue gas temperature

The flue gas temperature was determined using a controlled type K thermocouple and recording unit.

3.3 MEASURING SURFACE EVALUATION

WARTSILA main engines

The measuring surface is located in the 45 degrees vertical part of the chimney direct after the turbo at a height of approximately 2.5 meters above the deck in the engine room.

The diameter of the stack was about 0.4 metres. 2 measurement openings $^{1}/_{2}$" and 1 ½ " were available. The measuring surface was < 5 diameters after the last disturbance, and >5 diameters before the mouth / next disturbance.

The measuring surfaces does not meet the guidelines listed in the NEN-EN 15259.

4. MEASUREMENT PROGRAMME AND DEVIATIONS FROM THE STANDARDS

This chapter contains the measurement programme and the deviations from the measurement standards used.

4.1 MEASUREMENT PROGRAMME AND PERIOD

Table 5 Measurement period, main engine PS

Test		86%	72%	43%	15%
Date		19/12/19			
Start	(hh:mm)	12:54	12:08	12:22	12:38
End	(hh:mm)	13:04	12:18	12:32	12:48
Engine conditions					
P Load	(kW)	1273	1060	630	220
n_d Number of revolutions	(rpm)	1200	1098	930	640
q_{mf} Fuel consumption (oil)	(kg/h)	6.36	5.81	4.42	3.14
q_{mf} Fuel consumption (gas)	(Nm3/h)	297.10	231.10	137.34	46.22

Table 6 Measurement period, main engine SB

Test		86%	72%	41%	13%
Date		19/12/19			
Start	(hh:mm)	13:37	13:52	14:08	14:25
End	(hh:mm)	13:47	14:02	14:18	14:35
Engine conditions					
P Load	(kW)	1273	1060	610	190
n_d Number of revolutions	(rpm)	1201	1095	902	376
q_{mf} Fuel consumption (oil)	(kg/h)	6.36	5.81	4.42	3.14
q_{mf} Fuel consumption (gas)	(Nm3/h)	290.52	232.42	132.06	39.62

5. CALCULATIONS

The following calculations were carried out in order to be able to report the measurement results in the desired units and conditions:

Conversion of volume concentrations (vppm) to mass concentrations (mg/m_0^3):

$$C_{mass} = \rho \text{ x } C_{volume}$$

Conversion to standard (reference) oxygen concentrations:

$$C^{ref.O_2} = C^m \text{ x } \frac{(20.95 - a)}{(20.95 - O_2^m)}$$

Calculation of emissions in kg/h:

$$E = C \text{ x } Q_{fluegas} \text{ x } 3600 \text{ x } 10^{-6} \quad (kg/h)$$

Calculation of the relevant emission in g/GJ:

$$RE = C_{mass} \times \frac{V_{stoich}}{STW} \times \frac{20.94}{(20.94 - O_2^m)}$$

or:

$$RE = \frac{E}{Q_b \times STW \times 3600} = \frac{Q_{fluegas} \times C}{Q_b \times STW}$$

where:

a	=	standard oxygen percentage, depending on Engine type
C	=	component concentration
ρ	=	volume mass (kg/m_0^3)
H_2O	=	moisture concentration (vol%)
Q	=	flue gas flow in (m_0^3/h)
E	=	Emission (kg/h)
NHV	=	net heating value in MJ/m_0^3 or MJ/kg
V_{stoich}	=	stoichiometric dry flue gas volume in m_0^3 per m_0^3 or kg of fuel

For the purpose of calculating the q values, it is assumed that the gases concerned behave like ideal gases in flue gas, and have a molar volume of $22.41 m_0^3/kmol$.

Volume mass of flue gas components in kg/m_0^3

CO	- 1,250
NO_x as NO_2	- 2,053

For the calculation to g/kWh, the calculations as stated in Marpol are used.

6. RESULTS

This chapter contains a summary of the measurement results. The detailed measurement and calculation results are presented in Appendix 1.

6.1 RESULTS OF THE MEASUREMENTS

In the tables below the results of the measurements are summarized.

Table 7 Results measurements main engine PS

Item		Engine
Manufacturer		Wärtsilä
Type		W8L20DF
Serial Number		PAAE336536
Location		Somtrans LNG
Cycle		CCNR 2: Dual fuel: E3: 1480 kW @ 1200 rpm
Emissions		**Measured**
NOx relative emisson	(g/kWh)	***1.5***
CO relative emisson	(g/kWh)	***2.6***
CxHy as C relative emisson	(g/kWh)	***8.6***
Particle mass relative emission	(g/kWh)	***0.1***

Table 8 Results measurements main engine SB

Item		Engine
Manufacturer		Wärtsilä
Type		W8L20DF
Serial Number		PAAE336537
Location		Somtrans LNG
Cycle		CCNR 2: Dual fuel: E3: 1480 kW @ 1200 rpm
Emissions		**Measured**
NOx relative emisson	(g/kWh)	***1.6***
CO relative emisson	(g/kWh)	***2.4***
CxHy as C relative emisson	(g/kWh)	***7.4***
Particle mass relative emission	(g/kWh)	***0.1***

7. DISCUSSION OF ERRORS

The following measurement uncertainties have to be taken into account:

Table 9 Measurement error

	Sampling	Sample conditioning system	Analyser	Convertor effeciency	Reference gas	Total unc.
NO_x	2.0%	2.0%	7.4%	0.3%	2%	**8.1%**
O_2	2.0%	2.0%	4.1%	-	2%	**5.4%**
CO_2	2.0%	2.0%	4.3 %	-	2%	**5.5%**
CO	2.0%	2.0%	3.8 %	-	2%	**5.1%**
PM						**30%**
CxHy	2.0%	2.0%	7.4 %	-	2%	**8.1%**

APPENDICES

APPENDIX 1: MEASUREMENT AND CALCULATION RESULTS

Main engine PS

Engine					
Type		W8L20DF			
Number		PAAE336536			
Location		Somtrans LNG			
Oil					
Type		Liquid			
Identification code		EN-590			
Test		86%	72%	43%	15%
Date		19/12/19			
Start	(hh:mm)	12:54	12:08	12:22	12:38
End	(hh:mm)	13:04	12:18	12:32	12:48
Engine conditions					
P Load	(kW)	1273	1060	630	220
n_d Number of revolutions	(rpm)	1200	1098	930	640
q_{mf} Fuel consumption (oil)	(kg/h)	6.36	5.81	4.42	3.14
Fuel leakage	(kg/h)	0.00	0.00	0.00	0.00
q_{mf} Fuel consumption (gas)	(Nm3/h)	297.10	231.10	137.34	46.22
T_a Suction air temperature	(°C)	25	24	21	20
LT cooling water before engine	(°C)	87	87	86	85
p_c Charge air pressure	(bar)	2.88	2.21	1.18	0.14
T_{sc} Charge air temperature	(°C)	46	49	49	48
T_{sCRef} Charge air ref. temp.	(T seawater = 25 °C)	46	49	49	48
Ambient air					
Atmospheric pressure	(mbar)	1006	1007	1007	1006
Temperature	(°C)	22	23	19	20
Relative humidity	(%)	37	41	56	47
Results flue gas measurements					
T_{exh} Temperature	(°C)	343	357	381	395
O_2	(vol% dry flue gas)	11.7	12.0	12.9	11.6
CO_2	(vol% dry flue gas)	5.2	5.1	4.6	5.4
CO	(vppm dry flue gas)	540	404	330	450
C_xH_y as C_3H_8	(vppm wet flue gas)	1,230	960	750	890
NO_x	(vppm dry flue gas)	177	140	180	370
Particle measurement - PM					
Filternumber		1987	1984	1985	1986
Ambient pressure weighing after	(mbar)	10,212	10,212	10,212	10,212
Temperature weighing after	(°C)	20	20	20	20
Gross weight (uncorrected)	(g)	1.347	1.349	1.346	1.342
Gross weight (corrected)	(g)	1.35189	1.35380	1.35149	1.34697
Ambient pressure weighing before	(mbar)	1,012.000	10,212.000	10,212.000	10,212.000
Temperature weighing before	(°C)	20.000	20.000	20.000	20.000
Tare weight (uncorrected)	(g)	1.344	1.349	1.346	1.342
Tare weight (corrected)	(g)	1.34410	1.34720	1.34590	1.34210
Sampling volume	(m_0^3 dry flue gas)	0.41	0.39	0.40	0.41

Engine					
Type		W8L20DF			
Number		PAAE336536			
Location		Somtrans LNG			
Air data		86%	72%	43%	15%
Atmospheric pressure	(mbar)	1006.0	1006.5	1006.5	1006.3
Temperature	(°C)	22.0	23.3	19.3	19.7
Relative humidity	(%)	37.0	40.8	56.0	47.0
Absolute humidity	(vol%)	0.97	1.15	1.24	1.07
Absolute humidity (Ha)	(g/kg dry air)	6.07	7.25	7.80	6.70
Water saturation pressure at Rt	(mbar)	100	115	117	111
Absolute humidity Turbo (Hsc)	(g/kg dry air)	16	23	35	67
Fuel		Fuel = Liquid EN-590		Fuel = Gas high calorific NG	
Fuel type		Liquid		Gas	
Identification code		EN-590		high calorific NG	
Density at 15 °C		0.840		0.7573	(kg/m03)
Net caloric value		42.66	(MJ/kg)	37.62	(MJ/m03)
Carbon-content		86.00%	(% m/m)		
Hydrogen-content		13.00%	(% m/m)		
Nitrogen-content		0.10%	(% m/m)		
Sulphur-content		0.0060%	(% m/m)		
Calculated stoichiometric combustion data		Fuel = Liquid EN-590		Fuel = Gas high calorific NG	
Dry air demand		11.07	(m03/kg)	10.01	(m03/m03)
Dry flue gas flow		10.35	(m3/kg)	8.97	(m03/m03)
Wet flue gas flow		12.07	(m3/kg)	10.97	(m03/m03)
Fuel oil consumption	(kg/h)	6.36	5.81	4.42	3.14
Fuel gas consumption	(kg/h)	225.0	175.0	104.0	35.0
Calculated actual combustion data					
Air factor EAF		2.13	2.20	2.44	2.12
Dry flue gas flow	(m3/kg)	26.7	27.6	30.7	26.3
	(m3/h)	6187	4995	3326	1002
Wet flue gas flow	(m3/kg)	29.6	30.6	33.7	29.1
	(m3/h)	6852	5525	3650	1110
Water concentration	(vol% w et flue gas)	9.7	9.6	8.9	9.7
Calculated air intake flow					
Air intake	(kg/h)	195.6	184.7	155.6	95.8

Testconditions	86%	75%	50%	25%
Fa-factor (mechanically charged)	0.99	0.99	0.99	0.98
Fa-factor (turbo charged)	0.99	0.99	0.97	0.97
Applicable correction factors				
NOx correction				
KHDIES applicable	0.946	0.958	0.955	0.942
Particle correction				
Kp	1.066	1.048	1.040	1.056
Kfa	1.000	1.000	1.031	1.043
PTcorr	0.000			

Engine					
Type		W8L20DF			
Number		PAAE336536			
Location		Somtrans LNG			
Standard flue gas conditions					
Moisture	(vol %)	0.0			
Temperature	(°C)	0			
Pressure	(mbar)	1013			
Molar volume	(m^3/kmol)	22.40			
Oxygen concentration	(vol% dry flue gas)	15			
Test		86%	72%	43%	15%
Date		19/12/19			
Start	(hh:mm)	12:54	12:08	12:22	12:38
End	(hh:mm)	13:04	12:18	12:32	12:48
Results in flue gas at standard conditions					
CO	(vppm)	347	269	244	286
C_xH_y as C	(vppm)	2629	2118	1825	1882
NO_x	(vppm)	114	93.1	133	235
Flue gas flow	(m^3/h)	9618	7513	4500	1575
Relative emissions					
CO_2	(g/kWh)	501	470	475	482
CO	(g/kWh)	3.28	2.38	2.18	2.56
C_xH_y as C	(g/kWh)	10.64	8.04	6.98	7.22
NO_x	(g/kWh)	1.77	1.35	1.95	3.46
Weighed relative emissions (WRE)					
NOx	(g/h)	2249	1436	1230	762
NO_x **(Khdies corrected)**	(g/h)	2127	1375	1174	718
Load	(kW)	1273	1060	630	220
E3	factor	0.20	0.50	0.15	0.15
WRE per sample (Khdies corr.)	(g/kWh)	1.67	1.30	1.86	3.26
WRE NO_x	(g/kWh)	1.61			
WRE NO_x (Khdies corrected)	(g/kWh)	1.53			
CO	(g/h)	4176	2522	1372	564
Load	(kW)	1273	1060	630	220
E3	factor	0.20	0.50	0.15	0.15
WRE per sample CO	(g/kWh)	3.28	2.38	2.18	2.56
WRE CO	(g/kWh)	2.62			
C_xH_y as C	(g/h)	13544	8524	4399	1588
Load	(kW)	1273	1060	630	220
E3	factor	0.20	0.50	0.15	0.15
WRE per sample as C	(g/kWh)	10.64	8.04	6.98	7.22
WRE as C	(g/kWh)	8.63			
Particle measurement - PM					
Sample weight	(mg)	8	7	6	5
Particles	(mg/m_0^3 dry flue gas)	19	17	14	12
Particles (at standard conditions)	(mg/m_0^3 dry flue gas)	12	11	10	8
Particle	(g/kWh)	0.09	0.08	0.07	0.05
Particle corrected Kp, Kfa	(g/kWh)	0.10	0.08	0.08	0.06
Particle	(g/h)	117.57	83.77	46.23	12.03
Particle (Corrected; Kp en Kfa)	(g/h)	125.31	87.80	49.60	13.26
Load	(kW)	1273	1060	630	220
E3	factor	0.20	0.50	0.15	0.15
WRE PM	(g/kWh)	0.08			
WRE PM (corrected)	(g/kWh)	0.09			

Main engine SB

Engine					
Type		W8L20DF			
Number		PAAE336537			
Location		Somtrans LNG			
Oil					
Type		Liquid			
Identification code		EN-590			
Test		86%	72%	41%	13%
Date		19/12/19			
Start	(hh:mm)	13:37	13:52	14:08	14:25
End	(hh:mm)	13:47	14:02	14:18	14:35
Engine conditions					
P Load	(kW)	1273	1060	610	190
n_d Number of revolutions	(rpm)	1201	1095	902	376
q_{mf} Fuel consumption (oil)	(kg/h)	6.36	5.81	4.42	3.14
Fuel leakage	(kg/h)	0.00	0.00	0.00	0.00
q_{mf} Fuel consumption (gas)	(Nm3/h)	290.52	232.42	132.06	39.62
T_a Suction air temperature	(°C)	16	16	17	20
LT cooling w ater before engine	(°C)	86	86	86	85
p_c Charge air pressure	(bar)	2.90	2.20	1.12	0.14
T_{sc} Charge air temperature	(°C)	50	51	49	47
T_{sCRef} Charge air ref. temp.	(T seaw ater = 25 °C)	50	51	49	47
Ambient air					
Atmospheric pressure	(mbar)	1006	1005	1005	1005
Temperature	(°C)	24	26	27	28
Relative humidity	(%)	36	37	33	44
Results flue gas measurements					
T_{exh} Temperature	(°C)	326	348	370	392
O_2	(vol% dry flue gas)	11.8	12.0	13.0	11.5
CO_2	(vol% dry flue gas)	5.2	5.1	4.5	5.5
CO	(vppm dry flue gas)	522	353	304	460
C_xH_y as C_3H_8	(vppm w et flue gas)	1,190	760	600	880
NO_x	(vppm dry flue gas)	155	165	158	350
Particle measurement - PM					
Filternumber		1988	1989	1990	1991
Ambient pressure w eighing after	(mbar)	10,212	10,212	10,212	10,212
Temperature w eighing after	(°C)	20	20	20	20
Gross w eight (uncorrected)	(g)	1.326	1.352	1.354	1.336
Gross w eight (corrected)	(g)	1.33061	1.35671	1.35862	1.34105
Ambient pressure w eighing before	(mbar)	1,012.000	10,212.000	10,212.000	10,212.000
Temperature w eighing before	(°C)	20.000	20.000	20.000	20.000
Tare w eight (uncorrected)	(g)	1.324	1.352	1.354	1.336
Tare w eight (corrected)	(g)	1.32479	1.35110	1.35370	1.33400
Sampling volume	(m_0^3 dry flue gas)	0.46	0.43	0.43	0.46

Engine					
Type		W8L20DF			
Number		PAAE336537			
Location		Somtrans LNG			
Air data		86%	72%	41%	13%
Atmospheric pressure	(mbar)	1005.5	1005.0	1005.0	1005.0
Temperature	(°C)	24.4	25.7	27.0	27.7
Relative humidity	(%)	36.0	37.0	33.0	44.0
Absolute humidity	(vol%)	1.09	1.21	1.16	1.62
Absolute humidity (Ha)	(g/kg dry air)	6.84	7.61	7.33	10.22
Water saturation pressure at Rt	(mbar)	123	129	117	106
Absolute humidity Turbo (Hsc)	(g/kg dry air)	20	26	36	63
Fuel		Fuel = Liquid EN-590		Fuel = Gas high calorific NG	
Fuel type		Liquid		Gas	
Identification code		EN-590		high calorific NG	
Density at 15 °C		0.840		0.7573	(kg/m03)
Net caloric value		42.66	(MJ/kg)	37.62	(MJ/m03)
Carbon-content		86.00%	(% m/m)		
Hydrogen-content		13.00%	(% m/m)		
Nitrogen-content		0.10%	(% m/m)		
Sulphur-content		0.0090%	(% m/m)		
Calculated stoichiometric combustion data		Fuel = Liquid EN-590		Fuel = Gas high calorific NG	
Dry air demand		11.07	(m03/kg)	10.01	(m03/m03)
Dry flue gas flow		10.35	(m3/kg)	8.97	(m03/m03)
Wet flue gas flow		12.07	(m3/kg)	10.97	(m03/m03)
Fuel oil consumption	(kg/h)	6.36	5.81	4.42	3.14
Fuel gas consumption	(kg/h)	220.0	176.0	100.0	30.0
Calculated actual combustion data					
Air factor EAF		2.16	2.20	2.47	2.09
Dry flue gas flow	(m3/kg)	27.0	27.6	31.1	26.0
	(m3/h)	6119	5022	3243	860
Wet flue gas flow	(m3/kg)	29.9	30.6	34.0	28.9
	(m3/h)	6778	5559	3553	959
Water concentration	(vol% w et flue gas)	9.7	9.6	8.7	10.3
Calculated air intake flow					
Air intake	(kg/h)	197.8	184.7	157.4	95.2

Testconditions	86%	72%	41%	13%
Fa-factor (mechanically charged)	0.97	0.98	0.98	0.99
Fa-factor (turbo charged)	0.95	0.96	0.96	0.97
Applicable correction factors				
NOx correction				
KHDIES applicable	0.932	0.943	0.940	0.979
Particle correction				
Kp	1.054	1.043	1.047	1.007
Kfa	1.140	1.059	1.049	1.030
PTcorr	0.000			

Engine					
Type		W8L20DF			
Number		PAAE336537			
Location		Somtrans LNG			
Standard flue gas conditions					
Moisture	(vol %)	0.0			
Temperature	(°C)	0			
Pressure	(mbar)	1013			
Molar volume	(m^3/kmol)	22.40			
Oxygen concentration	(vol% dry flue gas)	15			
Test		86%	72%	41%	13%
Date		19/12/19			
Start	(hh:mm)	13:37	13:52	14:08	14:25
End	(hh:mm)	13:47	14:02	14:18	14:35
Results in flue gas at standard conditions					
CO	(vppm)	339	235	228	290
C_xH_y as C	(vppm)	2572	1678	1476	1852
NO_x	(vppm)	101	110	118	220
Flue gas flow	(m^3/h)	9410	7555	4333	1366
Relative emissions					
CO_2	(g/kWh)	490	473	473	486
CO	(g/kWh)	3.14	2.09	2.02	2.60
C_xH_y as C	(g/kWh)	10.19	6.41	5.62	7.14
NO_x	(g/kWh)	1.53	1.61	1.73	3.25
Weighed relative emissions (WRE)					
NOx	(g/h)	1948	1702	1052	618
NO_x **(Khdies corrected)**	(g/h)	1816	1604	990	606
Load	(kW)	1273	1060	610	190
E3	factor	0.20	0.50	0.15	0.15
WRE per sample (Khdies corr.)	(g/kWh)	1.43	1.51	1.62	3.19
WRE NO_x	(g/kWh)	1.65			
WRE NO_x (Khdies corrected)	(g/kWh)	1.55			
CO	(g/h)	3993	2216	1232	495
Load	(kW)	1273	1060	610	190
E3	factor	0.20	0.50	0.15	0.15
WRE per sample CO	(g/kWh)	3.14	2.09	2.02	2.60
WRE CO	(g/kWh)	2.39			
C_xH_y as C	(g/h)	12964	6789	3426	1356
Load	(kW)	1273	1060	610	190
E3	factor	0.20	0.50	0.15	0.15
WRE per sample as C	(g/kWh)	10.19	6.41	5.62	7.14
WRE as C	(g/kWh)	7.41			
Particle measurement - PM					
Sample weight	(mg)	6	6	5	7
Particles	(mg/m_0^3 dry flue gas)	13	13	11	15
Particles (at standard conditions)	(mg/m_0^3 dry flue gas)	8	9	8	10
Particle	(g/kWh)	0.06	0.06	0.06	0.07
Particle corrected Kp, Kfa	(g/kWh)	0.07	0.07	0.07	0.07
Particle	(g/h)	78.08	65.15	36.73	13.08
Particle (Corrected; Kp en Kfa)	(g/h)	93.84	71.94	40.35	13.57
Load	(kW)	1273	1060	610	190
E3	factor	0.20	0.50	0.15	0.15
WRE PM	(g/kWh)	0.06			
WRE PM (corrected)	(g/kWh)	0.07			

APPENDIX 2: CALIBRATION RESULTS

Projectnumber	EZMO-2019-09-0007
Projectlocation	Somtrans LNG
Date	19-Dec-19
Performer(s)	Jmi-Jbi

Tagnumber(s)	Horiba PG 250 SGS-07-031 FID Flatfisch 53T SGS-17-045						
		O_2 vol%	CO_2 vol%	CO vppm	NO_x vppm	SO_2 vppm	C3H8 vppm
Range analyser		25	20	1000	1000	100	1000
Spangasconcentration	20180791	20.95	18.19	910	899		915
Leaktest performed	Satisfies	Yes					
Calibration 1	**time Calibration**						
zero	11:30	0	0	0	0	0	0
span	11:34	20.95	18.19	910	899		915
Calibration 2	**time Calibration**						
zero before calibration	16:24	-0.01	0.05	1	0		1
span before calibration	16:29	20.77	18.05	902	902		905
deviation in % zero		0.0	0.3	0.1	0.0		0.1
deviation in % span		0.9	0.8	0.9	0.3		1.1

SGS

APPENDIX 3: CALIBRATION GASSES

Internal order number: 7080649
TA: 6200576797
Pos.-no.: 000010
PO number: 278541
Name:

MESSER

441582
SGS Nederland B.V.
T.a.v. afdeling Envi
Leemansweg 51
6827 BX ARNHEM
NIEDERLANDE

Zertifikatsauszug
Certificate Extract
Extrait de certificat

Accredited Mix

Komponenten Components Composants	Zusammensetzung / Composition / Composition Soll-Wert Rated value Valeur tolérée	Ist-Wert Actual value Valeur réelle	Unsicherheit (k=2 / 95% Konfidenz) Uncertainty (k=2 / 95% Confidence) Insécurité (k=2 / 95% Confidence)
Propan (C3H8)	917,93 MOL.PPM	915 MOL.PPM	+/-2% relativ
Kohlenmonoxid (CO)	899,12 MOL.PPM	910 MOL.PPM	+/-2% relativ
Kohlendioxid (CO2)	18,093 MOL. %	18.19 MOL. %	+/-2% relativ
Stickstoffmonoxid (NO)	899,54 MOL.PPM	899 MOL.PPM	+/-2% relativ
Schwefeldioxid (SO2)	920,92 MOL.PPM	930 MOL.PPM	+/-2% relativ
Stickstoff		Rest	

Bezugsbedingungen für Volumenanteile oder Massenkonzentrationen: 0°C, 1013 mbar / Reference conditions for volume fractions or mass concentrations: 0°C, 1013 mbar / Reference conditions for volume fractions or mass concentrations: 0°C, 1013 mbar

Methode / Method / Méthode:	**gravimetrisch / gravimetric / gravimétrique**
Analytik / Analysis / Analytique:	**Chem. Lum., NDIR, FID Chem. lu**

Volumen und Flaschen-Nr.: Volume and Cylinder Nr.: Volume et N° bouteille:	76296 10 Liter	**Min. Verwendungsdruck: Minimum utilisation pressure: Press. Util. Mini:**	5 bar
Chargen-Nr.: Batch no: N° de lot:	20180791	**Lagertemperatur: Storage / utilization temperature range: Température de stockage:**	-10°C bis/to/à 50°C
Ventilanschluss: Valve: Raccord de vanne:	M19x 1,5 If (DIN14)	**Herstelldatum: Date of Production: Date de fabrication:**	02.03.2018
Fülldruck (15° C): Filling Pressure (15° C): Pression (bar) (15° C):	150	**Ablaufdatum: Expiration date: Échéance:**	02.03.2020

Hersteller / Producer / Fabricant:
Messer Schweiz AG
Seonerstrasse 75
5600 LENZBURG
SCHWEIZ

Verantwortlich / Responsible / Responsable:
Reto Lehner

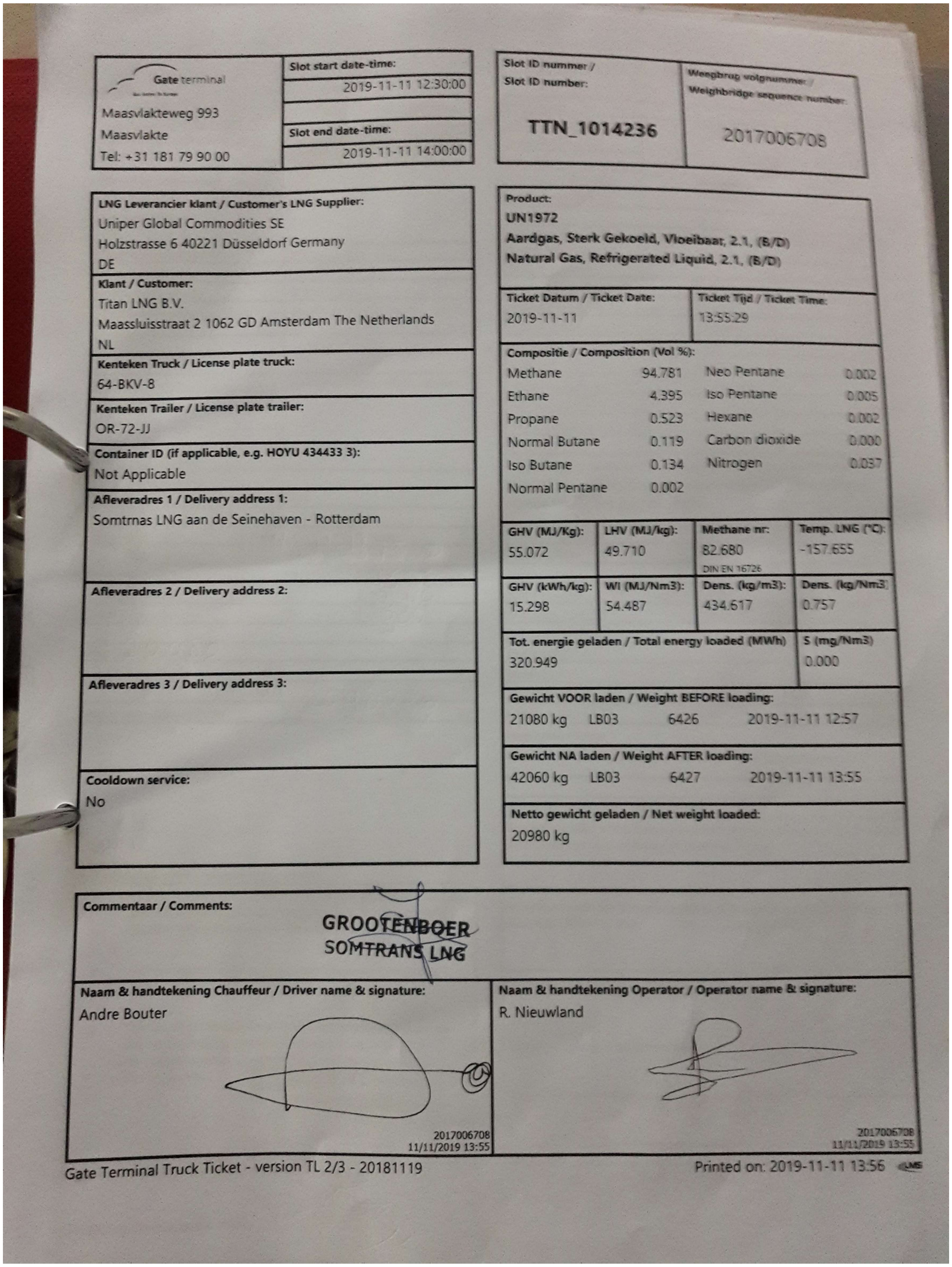
Ausstellungsdatum / Issued / Date d'émission:
05.03.2018

Es handelt sich um ein durch EDV erstelltes Zertifikat, das ohne Unterschrift gültig ist / This certificate is compiled by electronic software and is valid without signature / Il s'agit d'un certificat établi par EDV valide sans signature
Der Inhalt dieses Zertifikats darf nur in vollständiger Form veröffentlicht oder wiedergegeben werden / The content of this certificate shall not be reproduced except in full / Le contenu de ce certificat ne peut être publié ou transféré qu'en intégralité

Seite/Page/Page 1 - 1

SGS

APPENDIX 4: LNG ANALYSES



Gate terminal
Maasvlakteweg 993
Maasvlakte
Tel: +31 181 79 90 00

Slot start date-time: 2019-11-11 12:30:00
Slot end date-time: 2019-11-11 14:00:00

Slot ID nummer / Slot ID number: TTN_1014236
Weegbrug volgnummer / Weighbridge sequence number: 2017006708

LNG Leverancier klant / Customer's LNG Supplier:
Uniper Global Commodities SE
Holzstrasse 6 40221 Düsseldorf Germany
DE

Klant / Customer:
Titan LNG B.V.
Maassluisstraat 2 1062 GD Amsterdam The Netherlands
NL

Kenteken Truck / License plate truck:
64-BKV-8

Kenteken Trailer / License plate trailer:
OR-72-JJ

Container ID (if applicable, e.g. HOYU 434433 3):
Not Applicable

Afleveradres 1 / Delivery address 1:
Somtrnas LNG aan de Seinehaven - Rotterdam

Afleveradres 2 / Delivery address 2:

Afleveradres 3 / Delivery address 3:

Cooldown service:
No

Product:
UN1972
Aardgas, Sterk Gekoeld, Vloeibaar, 2.1, (B/D)
Natural Gas, Refrigerated Liquid, 2.1, (B/D)

Ticket Datum / Ticket Date: 2019-11-11
Ticket Tijd / Ticket Time: 13:55:29

Compositie / Composition (Vol %):

Methane	94.781	Neo Pentane	0.002
Ethane	4.395	Iso Pentane	0.005
Propane	0.523	Hexane	0.002
Normal Butane	0.119	Carbon dioxide	0.000
Iso Butane	0.134	Nitrogen	0.037
Normal Pentane	0.002		

GHV (MJ/Kg):	LHV (MJ/kg):	Methane nr:	Temp. LNG (°C):
55.072	49.710	82.680 DIN EN 16726	-157.655
GHV (kWh/kg):	**WI (MJ/Nm3):**	**Dens. (kg/m3):**	**Dens. (kg/Nm3)**
15.298	54.487	434.617	0.757

Tot. energie geladen / Total energy loaded (MWh): 320.949
S (mg/Nm3): 0.000

Gewicht VOOR laden / Weight BEFORE loading:
21080 kg LB03 6426 2019-11-11 12:57

Gewicht NA laden / Weight AFTER loading:
42060 kg LB03 6427 2019-11-11 13:55

Netto gewicht geladen / Net weight loaded:
20980 kg

Commentaar / Comments:
GROOTENBOER
SOMTRANS LNG

Naam & handtekening Chauffeur / Driver name & signature:
Andre Bouter
2017006708
11/11/2019 13:55

Naam & handtekening Operator / Operator name & signature:
R. Nieuwland
2017006708
11/11/2019 13:55

Gate Terminal Truck Ticket - version TL 2/3 - 20181119
Printed on: 2019-11-11 13:56