Deliverable 2.1:

Technical feasibility study

EPM3 – LNG STRADDLE CARRIERS

CORE LNGas hive

Core Network Corridors and Liquefied Natural Gas

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D 2.1. Technical feasibility Study

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More Information

Public CORE LNGas HIVE reports and additional information related with the project execution and results are available through CORE LNGas Hive public website at **www.corelngashive.eu**

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1. Introduction

As part of CORE LNGas Hive, a pilot activity is being developed in order to demonstrate the use of LNG as fuel for straddle carriers inside two terminals of Barcelona Seaport. LNG is the most promising fuel to reduce both oil dependency and emissions.

The activity started in January 2016 and will last until 2019. The main activities will be performed in 2016 and 2017, while the pilot follow up will continue until 2019.

The transformation of the machines in the terminals APMT and BEST will be studied. Thus, the following participants are involved in this project: APB, APMT, BEST, GNF, HAM, and IDIADA.

This document summarizes the main tests carried out on the APMT and BEST engines. These tests consisted of measuring vehicle speed, pollutant emissions and fuel consumption. Moreover, the engine and straddle carrier conversions are explained considering their technical feasibility. Also the LNG store and station capacity is specified in order to design the fuel supply system. In the final part, a new risk assessment is presented.

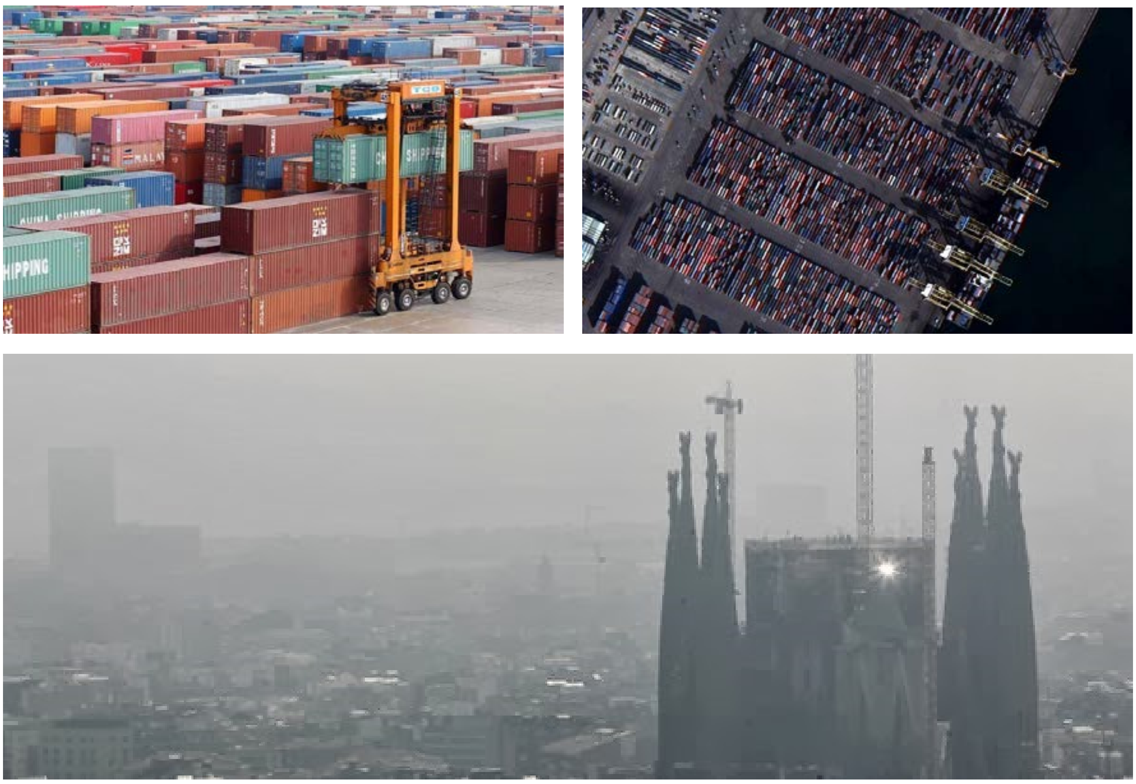


Figure 1. Left – straddle carrier; Right – Barcelona Seaport; Bottom – Smog in Barcelona city

2. APMT real-driving emissions test

APMT is one of the terminals of Barcelona Seaport and in it the engine Valmet 612 is tested. These carriers are equipped with a diesel engine to be replaced in the future by Gas Engines.

First of all, several tests have had to be performed in order to determine if straddle carrier engines running with LNG fuel are suitable to reach the targets of oil and pollutant emissions reduction.

Real-driving emissions test procedures uses the Portable Emissions Measurement System (PEMS from now on) to measure gaseous pollutant and particle number emission during a range of normal operating conditions. To run this sort of test, it is essential to prepare the vehicle or, in this case, the straddle carrier with the PEMS device. Likewise, a design of the route that usually follows the machine or adjusted to avoid any issues on the correct functionality of the terminal is necessary. The test route should be controlled to perform the same trajectories, distances and manoeuvres during the pilot phase with the engine converted.

Figure 2. APMT terminal.

The straddle carriers at APMT have 2 engines that operate theoretically in parallel and delivering each one of them exactly the same power. Given this condition, only one PEMS was installed. The exhaust emissions of one of the two engines were measured and the total emissions would be the result of multiplying by 2 times the obtained values.

2.1. Tests description

In order to perform a good comparison between diesel and natural gas emissions, a series of specific tests have been designed. The purpose is to define a specific and repeatable duty cycle, so that the emission outputs can be compared with both fuels. Regarding the tests performed, some assumptions were taken into account. These assumptions are explained below:

- Every test cycle was carried out in a specific zone designated by APMT in order not to interfere with the terminal's daily work and, in order to perform all the tests more safely.
- The whole test cycle was performed with the same load.
- The person who drove these machines was an expert driver of straddle carriers.

2.1.1 Testing Area

The test was carried out inside the APMT terminal, in the Port of Barcelona. It was agreed to mark a restricted area where a circuit would be set using cones and where a series of pre designed tests could be performed using a calibrated test container whose weight is 30 Tm.

In the following image the straddle carrier route can be seen:

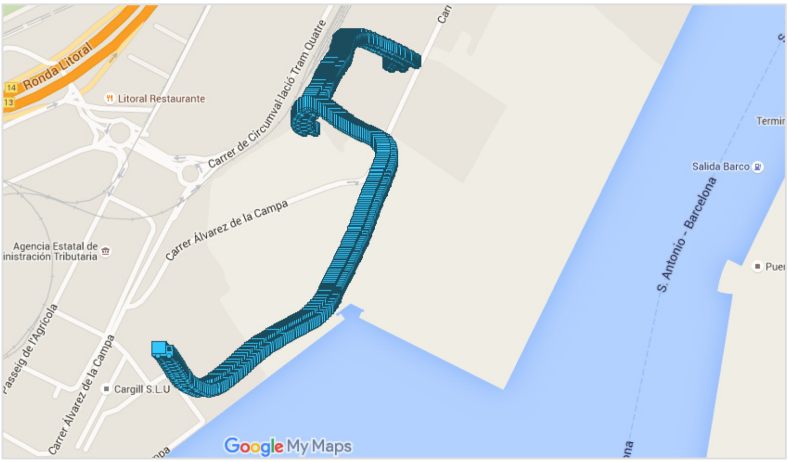


Figure 3. Straddle carrier route

Different zones divide the straddle carrier way. Apart from the way (marked in green), there are three red marked areas which are mentioned below from bottom to top:

- Test area
- Zone where the container is kept
- Zone where the straddle carrier is parked and instrumented.

The machine was instrumented next to the hangar area, just where it is usually parked overnight. Once the test has started, the straddle carrier must pick up the container and take it to the marked restricted area for testing. A series of pre-defined tests were performed in the testing area, and after finishing these tests, the operator brings the container back to the same place and parks the machine in the same parking slot.

Just to give an order of magnitude, the dimensions of the testing area were around 150x50 metres, whereas the distance from the hangar area to the testing area around 1000 m.

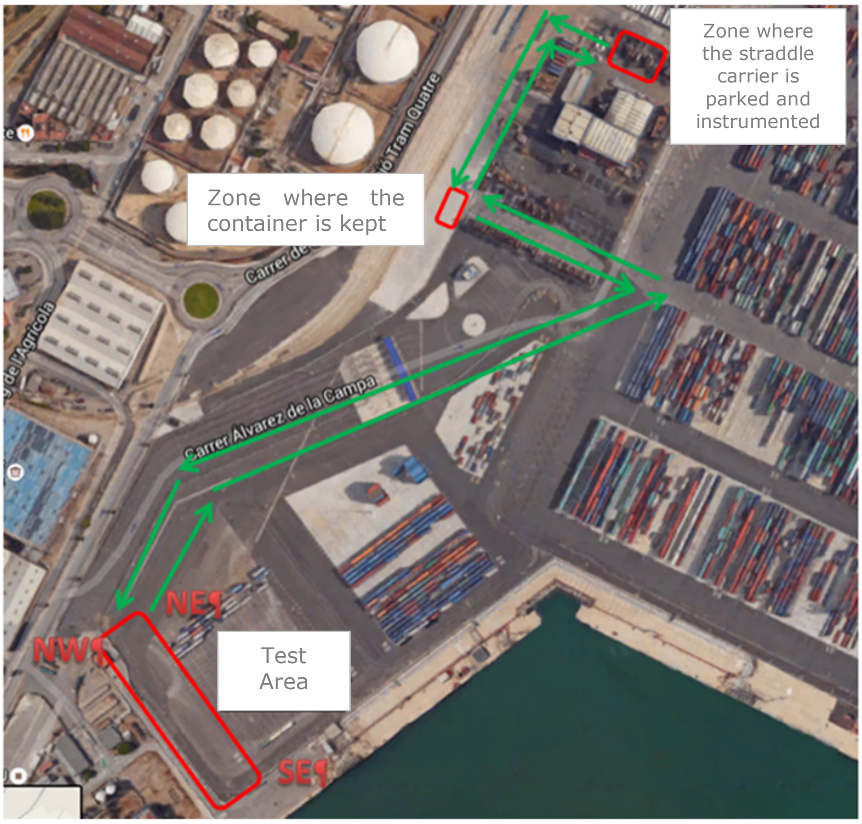


Figure 4. Satellite view of the testing area in APM Terminal

2.1.2 PEMS installation and measurement devices

PEMS is the device that measures emissions from combustion engines as the vehicle or the equipment is being used and allows real-world in-use testing. The equipment installed on the straddle carrier consists on:

- **Gas analyser modules:** There are two different ones: a general main module which measures CO, CO_2, NO and NO_x concentration and a specific THC analyser, which also requires a H-He gas supply in order to keep a flame on and a high temperature inside the device, which is required for the proper work of the system.
- **Communication module:** collects all the information signals and communicates with the computer.
- **Power Supply Module:** receives a 24V DC supply and delivers this power to the other modules.
- **Heated sampling line**, which brings a constant exhaust gas sample of 2.5 l/min into the measuring modules. As it name says, this pipe is isolated and

heated in order to keep the exhaust gas sample hot, conditions required by the Gas Analysis modules.

- **Exhaust gas flow meter**: Consists on an extension of the exhaust pipe, where two pressure and two temperature sensors are installed. This device is a pitot type sensor: the gas flow is calculated through measuring the pressure difference between the front and the rear side of an obstacle place in the middle of a gas stream.
- **Pitot-Box:** receives the signals of pressure and temperature from the exhaust gas sensors. Then, calculates the pressure drop and using the temperature input and the sensor calibration parameters is able to calculate the exhaust gas flow.
- **Gas Bottles:** three different gas bottles were used:
  - **Pure Air:** used before and after the test to calibrate the zero values of the measured pollutant concentrations.
  - **Span Gas:** an externally certified gas bottle, where the concentration of the different measured pollutants is known. This bottle is also used at the beginning and at the end of the test to calibrate the high extreme of the pollutant concentration.
  - **H-He:** used as fuel to keep the flame on (subsequently the temperature) inside the HC module.
- **GPS module:** measures Longitude, Latitude, Altitude and Vehicle Speed through Global Position Satellite system.
- **WS ("Weather Station") module:** measures ambient conditions.
- **Additional signal inputs:** In order to obtain additional information which would be helpful to analyse the data, some external sensors were installed and connected through a Racelogic "V-BOX" device.

Figure 5. PEMS installed on the top of the Straddle Carrier

Figure 6. Bundle of heated gas sampling, pressure and temperature lines tied to the railing

Figure 7. Vehicle tested, front side view

Figure 8. Air gas bottle installed laying down on the floor

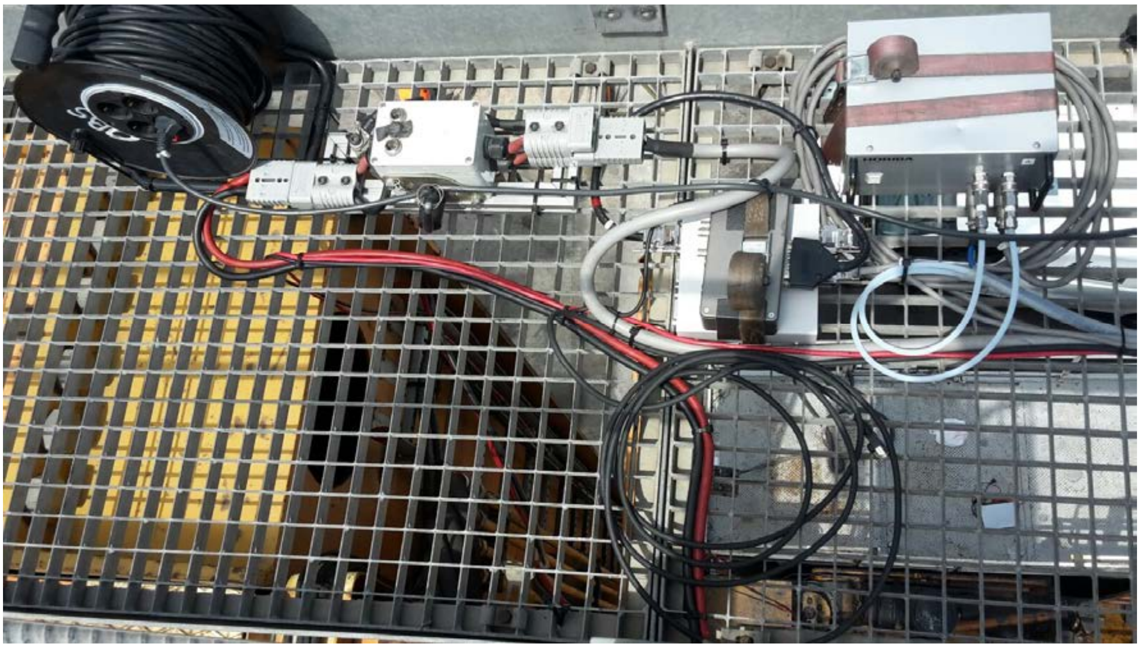


Figure 9. Pitot box and additional wiring

2.1.3 Tests sequence

To perform the test cycle, a test sequence of ten steps has been followed. In each one, vehicle speed is measured in addition to exhaust flow, which involves CO, THC and NO_x emissions. All steps are explained below.

- **Step 1 - "Unladen 01":** Engine Start and trip to the area where the test container was stored.
- **Step 2 - "Laden 01":** Lift up the container and carry it through the terminal to the reserved testing area.
- **Main tests:** to perform the pre-defined tests once the restricted testing area is reached.
    - **Step 3 - "Test 01a":** three and a half anti clockwise (driver´s cabin in the inner side of the turn) laps. Starting at the NW corner of the circuit and the container on the floor, full power elevation to the top, keep 5 seconds up, bring the container down to the minimum height where the machine is allowed to advance (around 1m over the floor), start the machine moving forward along the long side of the circuit (NW to SW corners), turn the SW and the SE corners and stop the straddle. Once the machine has stopped, wait for 5 seconds and lift the container up at full power. Once up, wait for 5 seconds, and bring the container back to the floor. Wait for 5 seconds and lift the container up to 1m and start again. Repeat this sequence after turning every 2 corners for 3 whole laps and a half (in order to finish at the same place as the beginning), in total 7 corners. The test ends when the container has been left again on the floor.
    - **Step 4 - "Test 01b":** manoeuvres to turn the straddle around repeat the same sequence in a clockwise way (driver´s cabin now in the outer side of the turn) in order to catch the different power shares between the two engines when turning. Start at the NE corner, and repeat the static lifts-up-down after turning on the SW, NE during three full laps and perform the last lift at the NE corner.
    - **Step 5 - "Test 02":** At the NE corner, repeat 10 full power lifts up and downs whilst the machine remains stationary. Maintain the container for 10 seconds up and keep it another 10 seconds on the floor.
    - **Step 6 - "Test 03a":** Starting at the NE corner and keeping the cabin in the inner side of the lap, repeat 5 non-stop complete turns to the circuit and finally finish at the NE corner. The purpose is to accelerate the machine and lift the container up at the same time. This was performed on the straight from NE to SE corners. At the end of the straight, without decelerating and whilst the container is at the highest position, turn both NE and SE corners. Once the SW-NW long side has been faced, then take the container down (always keeping full speed) and turn NW and NE corners with the container at the lowest position.
    - **Step 7 - "Test 03b":** Same as before, 5 complete laps this time performing anticlockwise turns (cabin outside). Lifts ups always on the NW to SW straight, SW & SE turns always container is up, SE to NE container is dropped down, NE and NW turns always container remains

at the lowest position. End at the NW corner and leave the container on the floor.

- **Step 8 - "Test 04":** 10 one way (no turning) full load lifts whilst full load longitudinal acceleration. When the container is at the highest point, container descent at full speed whilst longitudinal speed deceleration. Leave the container on the floor for ten seconds and repeat 10 times the sequence (go and return). As the engine power is divided into acceleration and lifting, it was necessary to use a longer straight than from come to cone. For this 4th exercise, the whole length of the delimited test area was used (from wall to wall)

- **Step 9 - "Laden 02":** Once the fourth test was finished, the container is carried through the terminal back to the point where it was initially picked up.
- **Step 10 - "Unladen 02":** Back to the parking area, without any load being carried.

The complete test was previously designed to last for around 2 hours of uninterrupted work. During the execution of the test, the number of turns and events was adapted in order to have in total these 2 hours of continuous data. The GPS tracks of the test sequence is shown below.

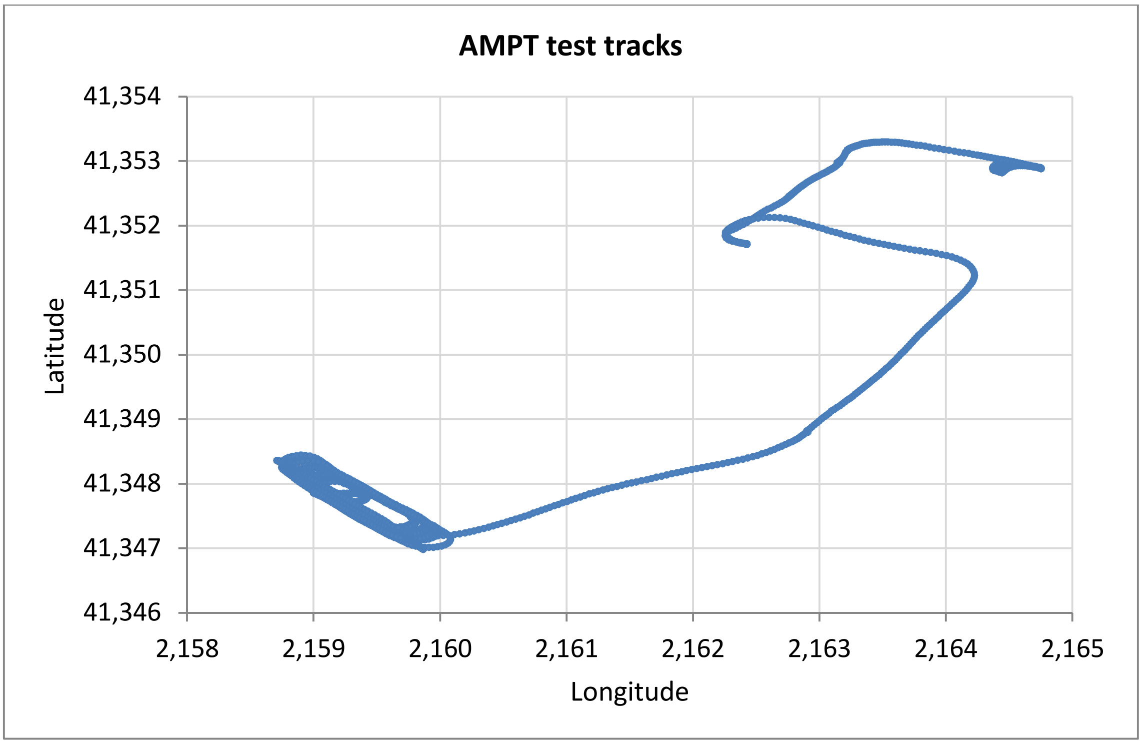


Figure 10. APMT test tracks

In any case, between the different steps as well as at the start of the test, several manoeuvres were produced to carry out the following operation. For this reason, in the presentation of the results these periods of time have been avoided and only the real period that lasted each test has been taken into account as detailed below:

	Start (s)	End (s)
Step 1	1150	1675
Step 2	1675	1850
Step 3	2000	2710
Step 4	3065	3780
Step 5	4150	4850
Step 6	5010	5420
Step 7	5630	6200
Step 8	6300	6950
Step 9	7070	7330
Step 10	7330	7440

Table 1: Step duration of APMT test

2.2. APMT tests results

The results of the different test sequence are presented below.

2.2.1 Step 1: Unladen 01

This step basically consists of the engine start up and movement to the area where the test container is located. The results of this step are shown below:

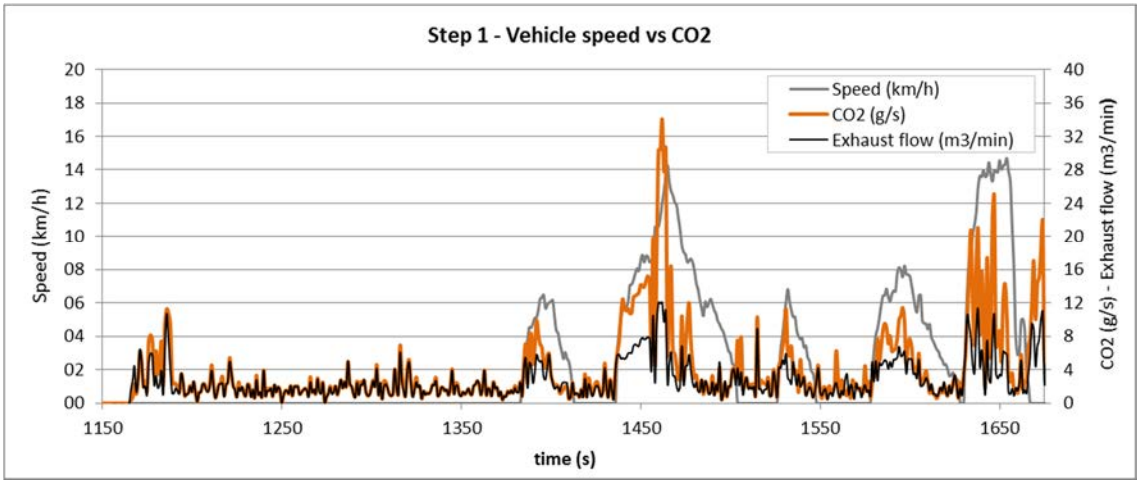


Figure 11. Unladen 01 vehicle speed, exhaust flow and CO2 emissions

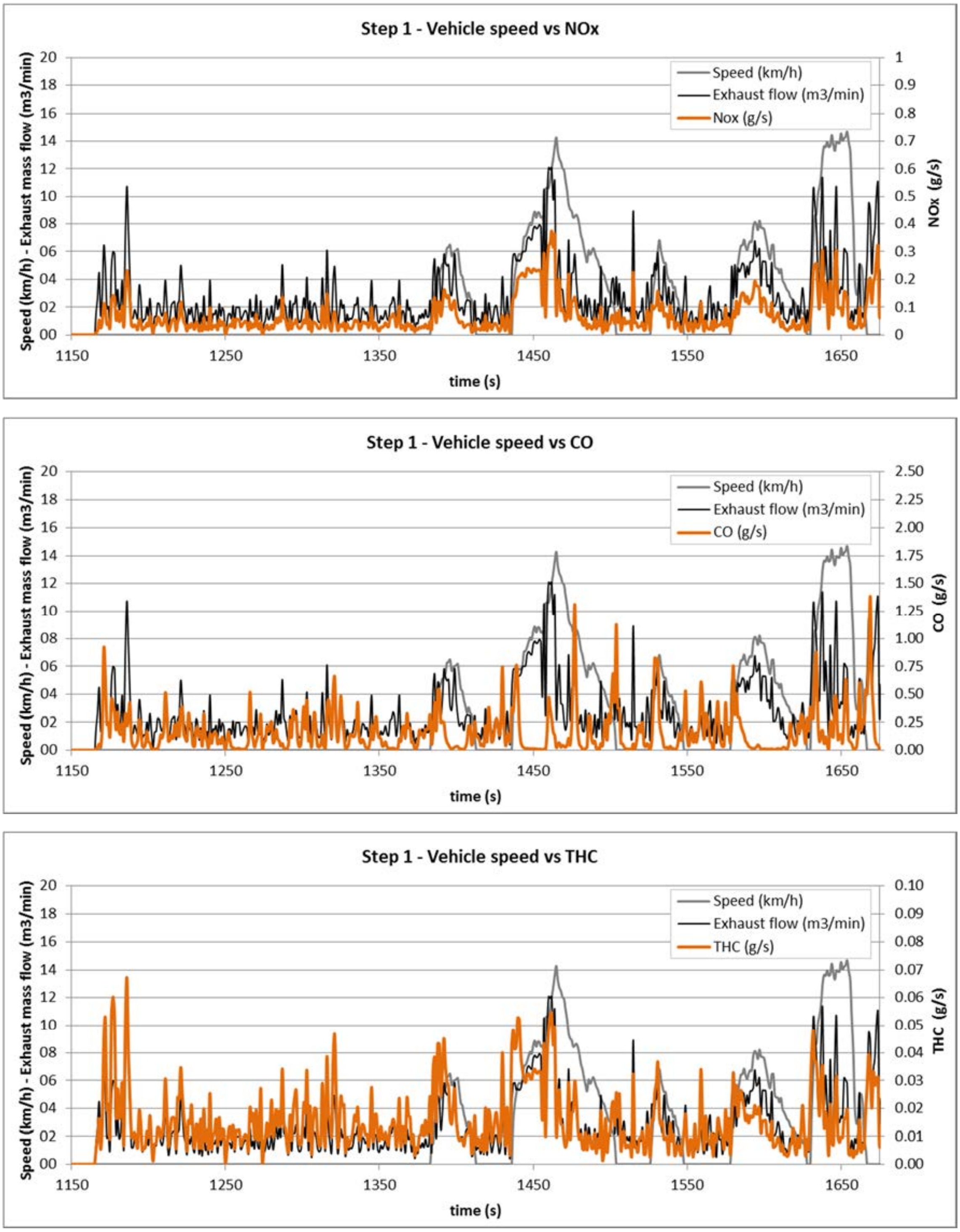


Figure 12. Unladen 01 pollutant emissions

STEP 1 AVERAGE PARAMETERS		
Exhaust flow	[m³/min]	2.74
Vehicle speed	[km/h]	2.5

Table 2: Unladen 01 average parameters

STEP 1 PARAMETERS		
CO2	[g]	2139.04
CO	[g]	84.94
THC	[g]	8.10
NOx	[g]	35.86
Fuel consumption	[Total cycle litres]	0.82
Average fuel consumption	[l/h]	5.58

Table 3: Unladen 01 pollutant emissions and fuel consumption

2.2.2 Step 2: Laden 01

Step 2 deals with collecting the container and taking it through the terminal to the reserved testing area.

As step 1, these are the results of step 2:

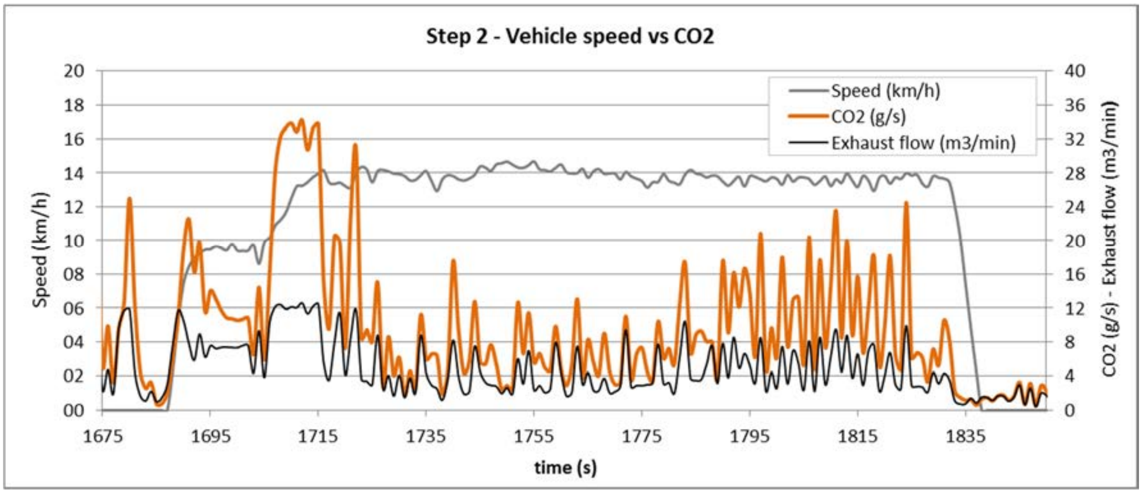


Figure 13. Laden 01 vehicle speed, exhaust flow and CO2 emissions

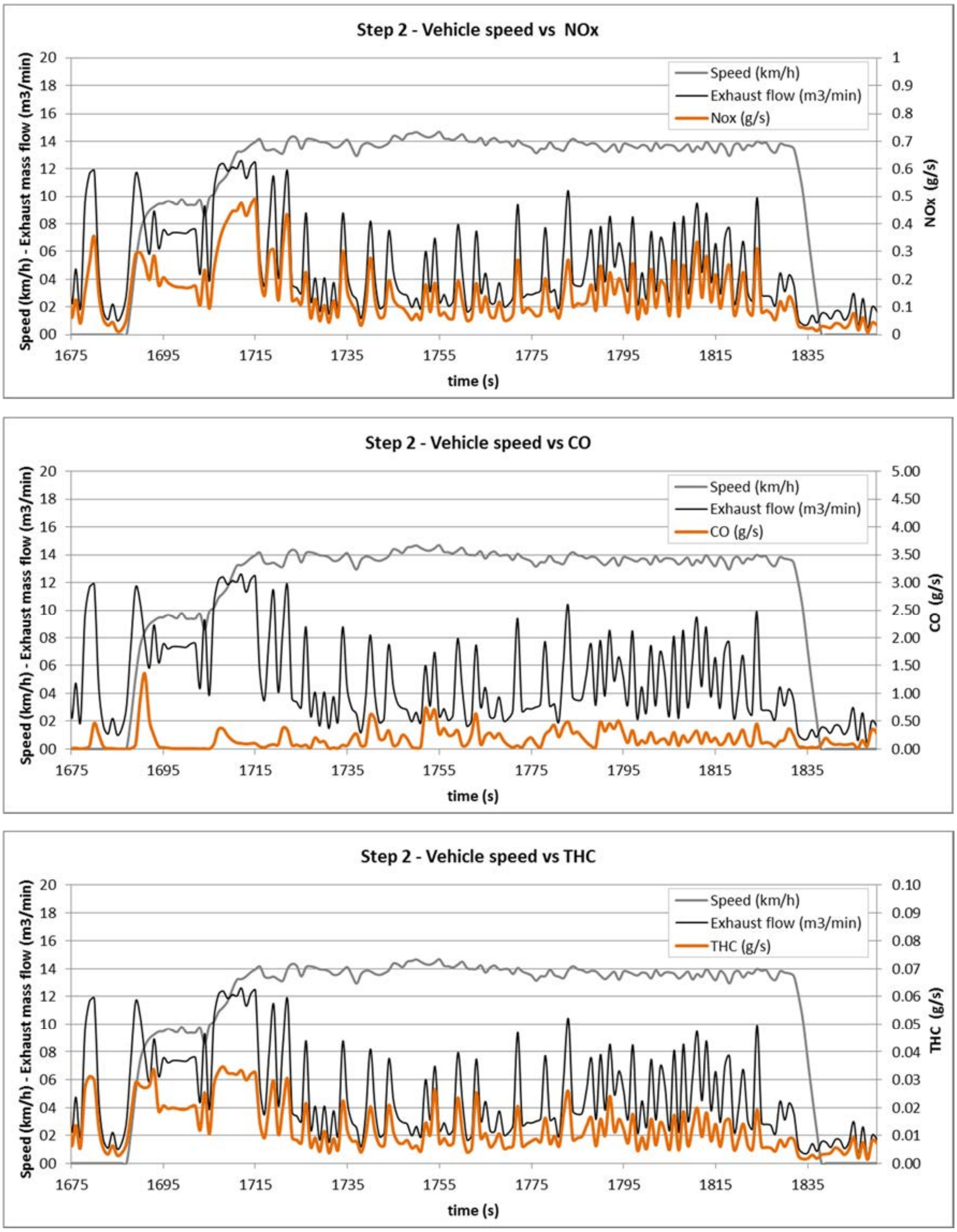


Figure 14. Laden 01 pollutant emissions

STEP 2 AVERAGE PARAMETERS		
Exhaust flow	[m^3/min]	4.93
Vehicle speed	[km/h]	11

Table 4: Laden 01 average parameters

STEP 2 PARAMETERS		
CO2	[g]	1731.88
CO	[g]	31.59
THC	[g]	2.22
NOx	[g]	25.58
Fuel consumption	[Total cycle litres]	0.66
Average fuel consumption	[l/h]	13.51

Table 5: Laden 01 pollutant emissions and fuel consumption

2.2.3 Step 3: Test 01a

This test demands three and a half anticlockwise laps (operator's cabin is on the inner side of the turn). The results are as follows:

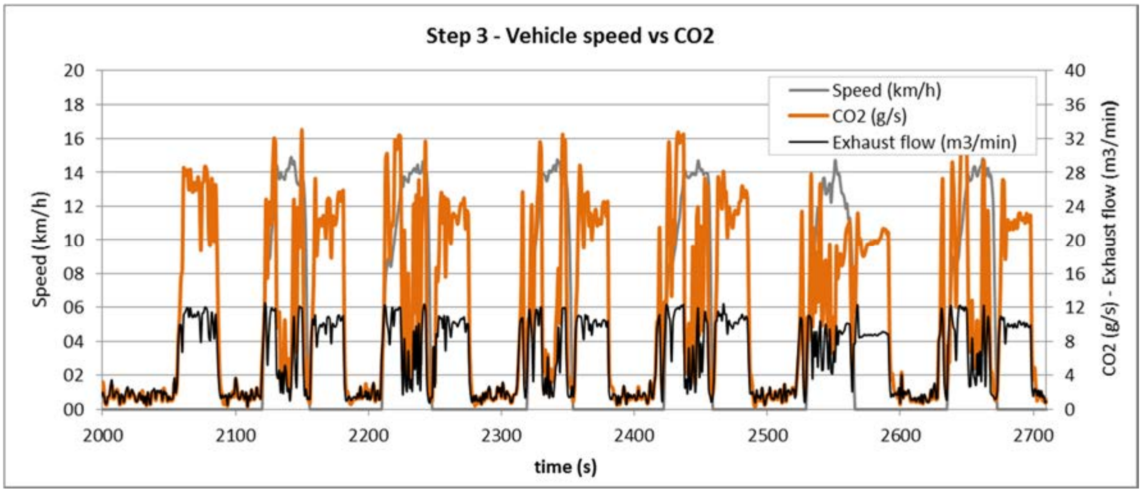


Figure 15. Test 01a vehicle speed and exhaust flow

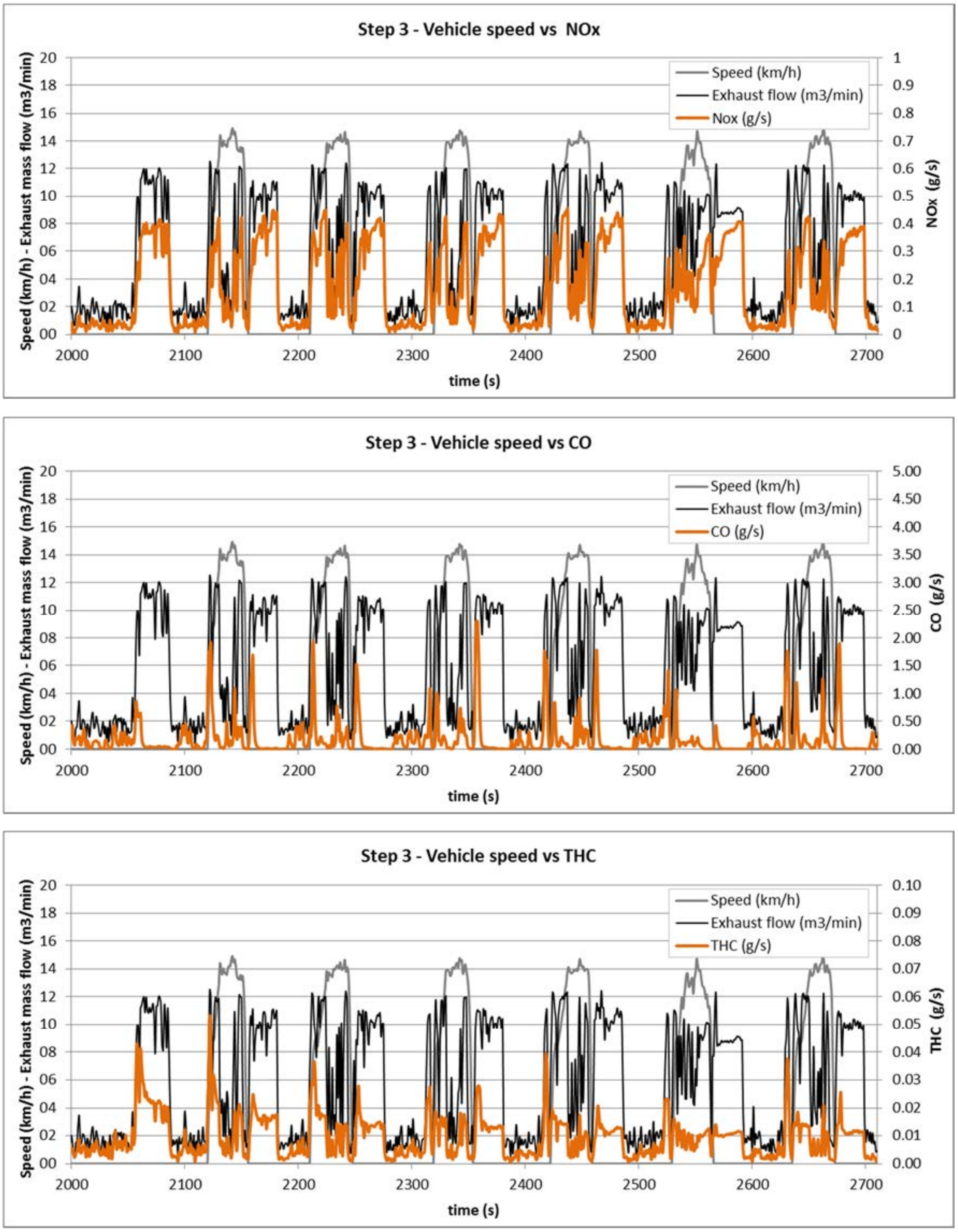


Figure 16. Test 01a pollutant emissions

STEP 3 AVERAGE PARAMETERS		
Exhaust flow	[m^3/min]	5.70
Vehicle speed	[km/h]	3.5

Table 6: Test 01a average parameters

STEP 3 PARAMETERS		
CO2	[g]	8207.41
CO	[g]	140.08
THC	[g]	6.77
NOx	[g]	123.01
Fuel consumption	[Total cycle litres]	3.13
Average fuel consumption	[l/h]	15.84

Table 7: Test 01a pollutant emissions and fuel consumption

2.2.4 Step 4: Test 01b

Unlike test 01a, this one is carried out by three and a half clockwise laps (operator's cabin on the outer side). These are the results:

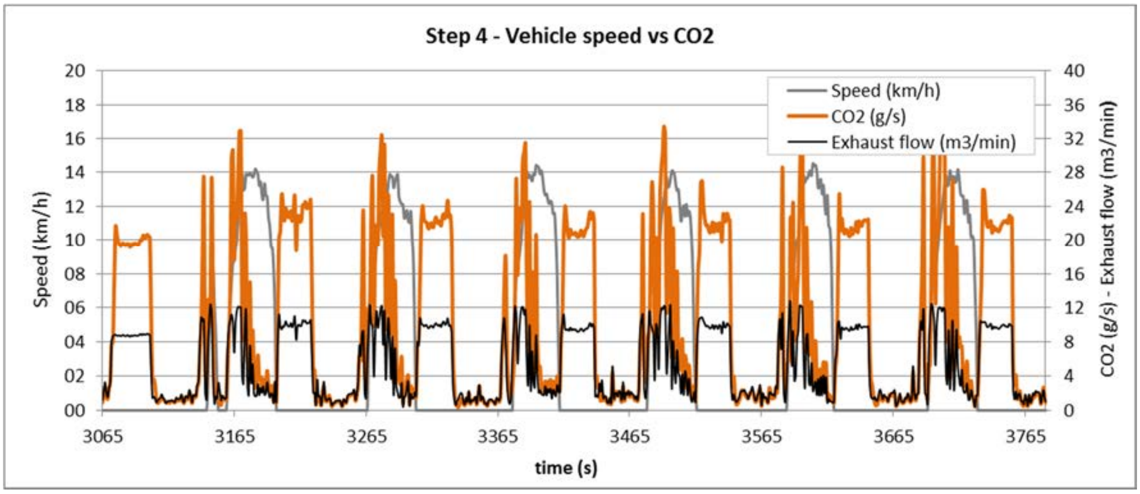


Figure 17. Test 01b vehicle speed and exhaust flow

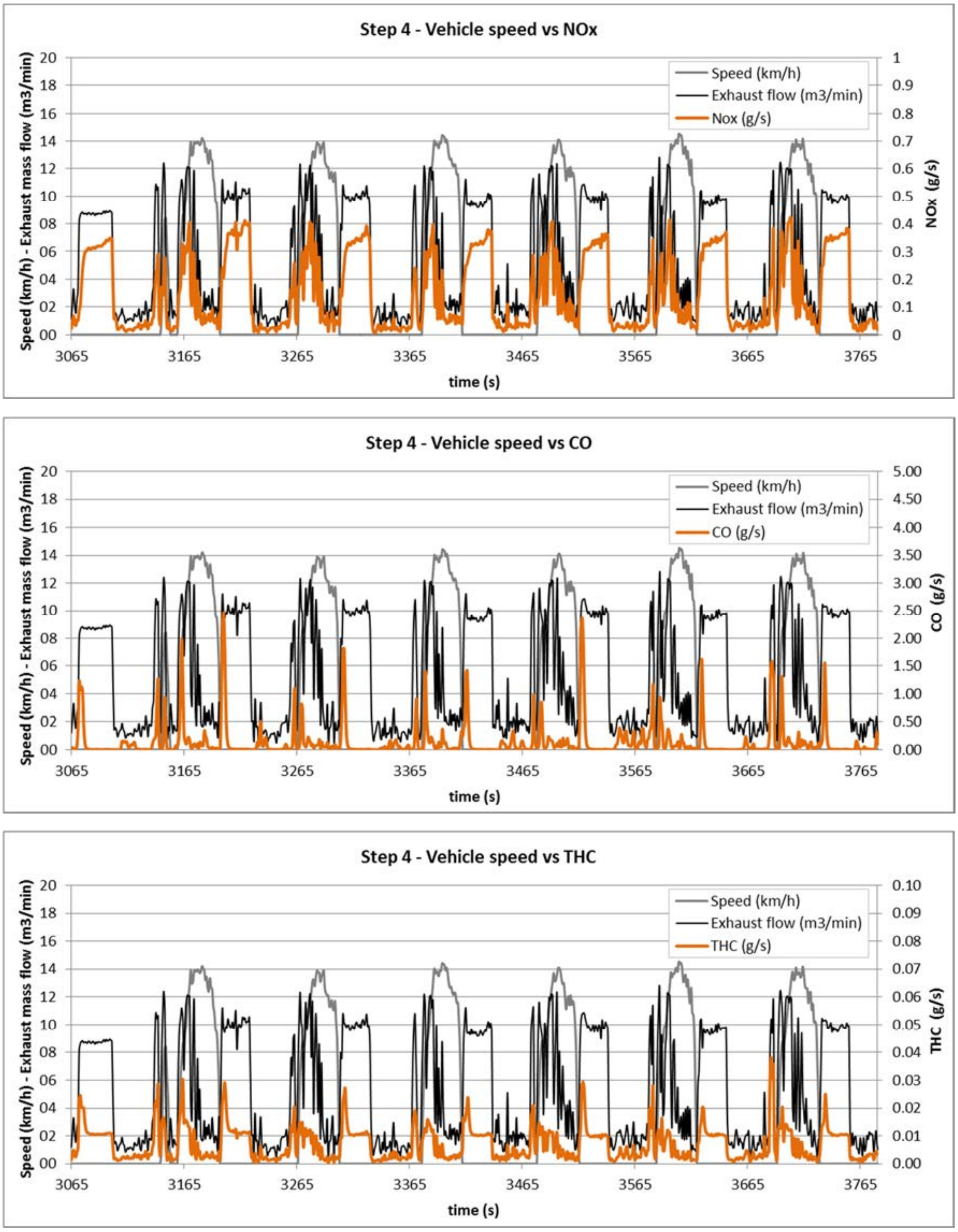


Figure 18. Test 01b pollutant emissions

STEP 4 AVERAGE PARAMETERS		
Exhaust flow	[m³/min]	5.28
Vehicle speed	[km/h]	3.4

Table 8: Test 01b average parameters

STEP 4 PARAMETERS		
CO2	[g]	7383.79
CO	[g]	108.92
THC	[g]	5.06
NOx	[g]	109.39
Fuel consumption	[Total cycle litres]	2.81
Average fuel consumption	[l/h]	14.15

Table 9: Test 01b pollutant emissions and fuel consumption

2.2.5 Step 5: Test 02

This test is different from the previous one. In this case the straddle carrier has to perform ten container liftings without moving the machine.

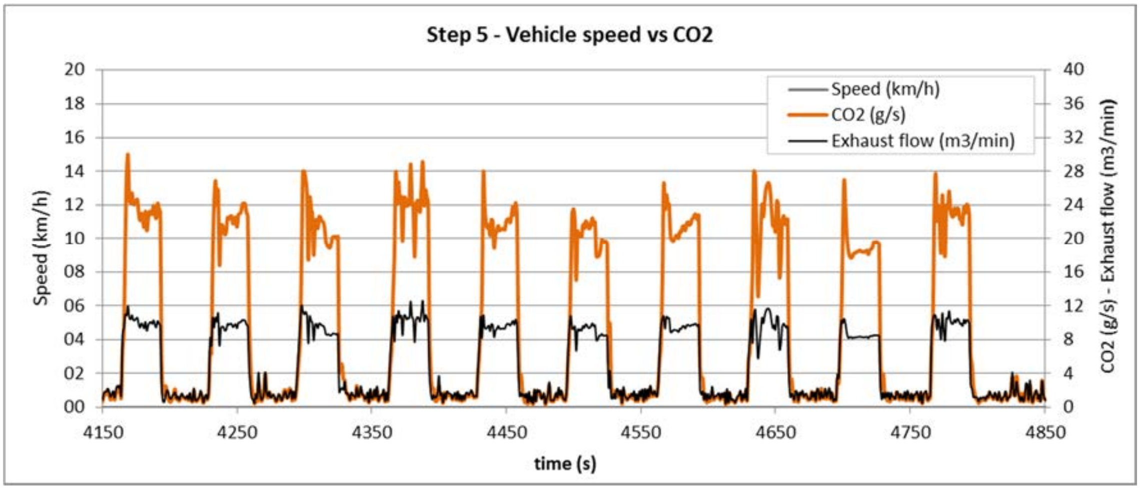


Figure 19. Test 02 vehicle speed and exhaust flow

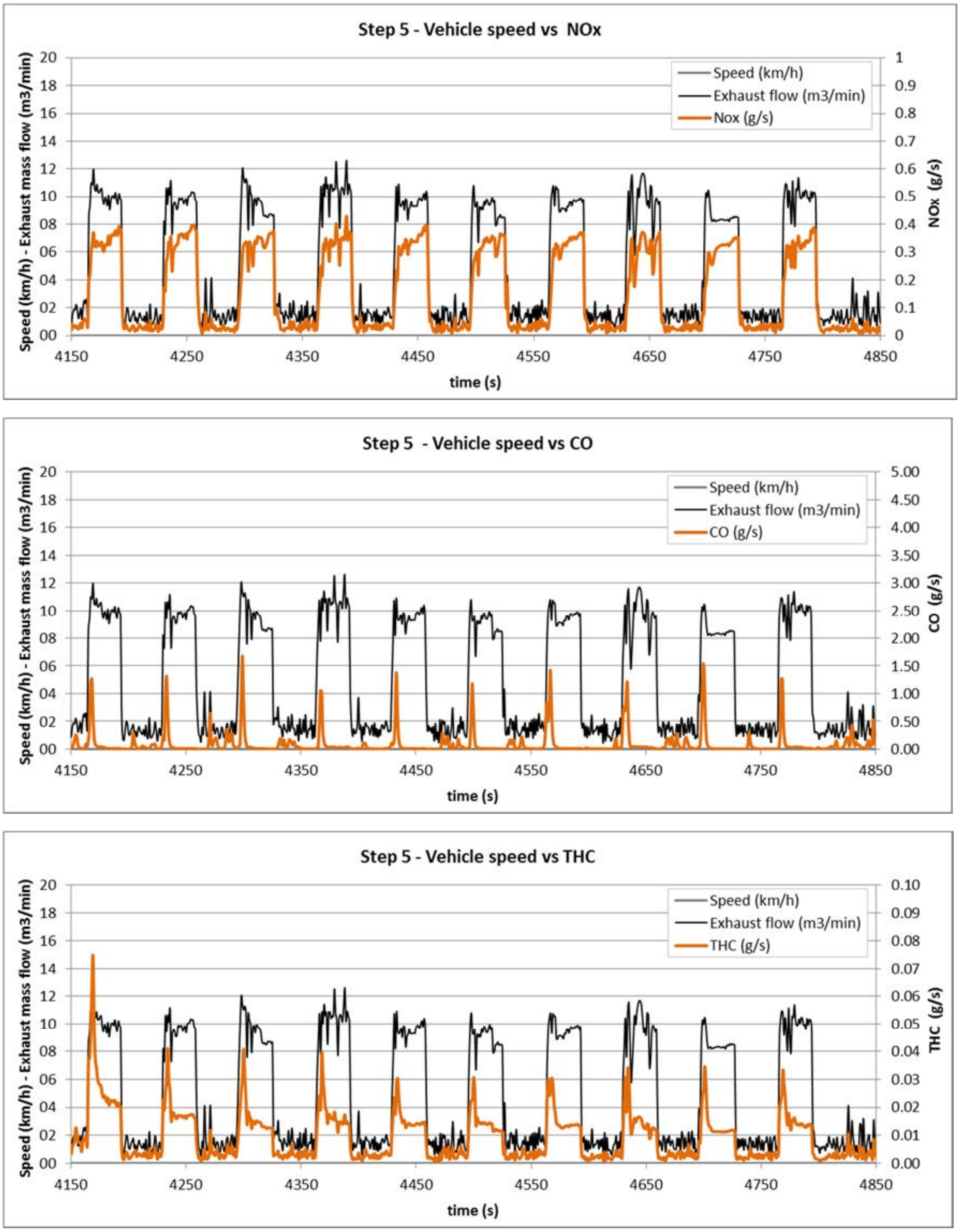


Figure 20. Test 02 pollutant emissions

STEP 5 AVERAGE PARAMETERS		
Exhaust flow	[m^3/min]	4.91
Vehicle speed	[km/h]	0.0

Table 10: Test 02 average parameters

STEP 5 PARAMETERS		
CO2	[g]	6811.27
CO	[g]	63.15
THC	[g]	6.53
NOx	[g]	107.50
Fuel consumption	[Total cycle litres]	2.60
Average fuel consumption	[l/h]	13.34

Table 11: Test 02 pollutant emissions and fuel consumption

2.2.6 Step 6: Test 03a

For this test, the straddle carrier has to carry out five clockwise laps in which the operator's cabin is on the inner side. The vehicle speed and exhaust flow results were as follows:

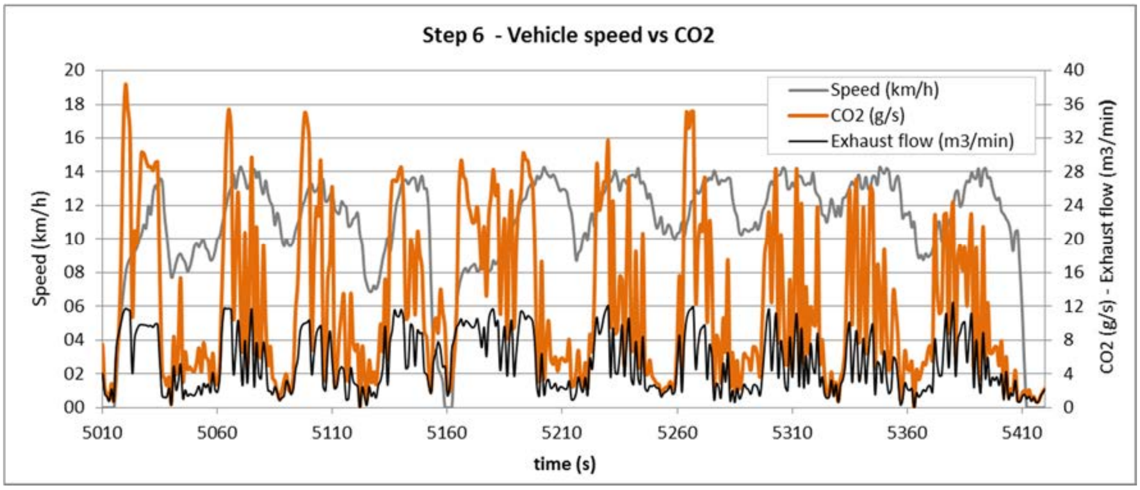


Figure 21. Test 03a vehicle speed and exhaust flow

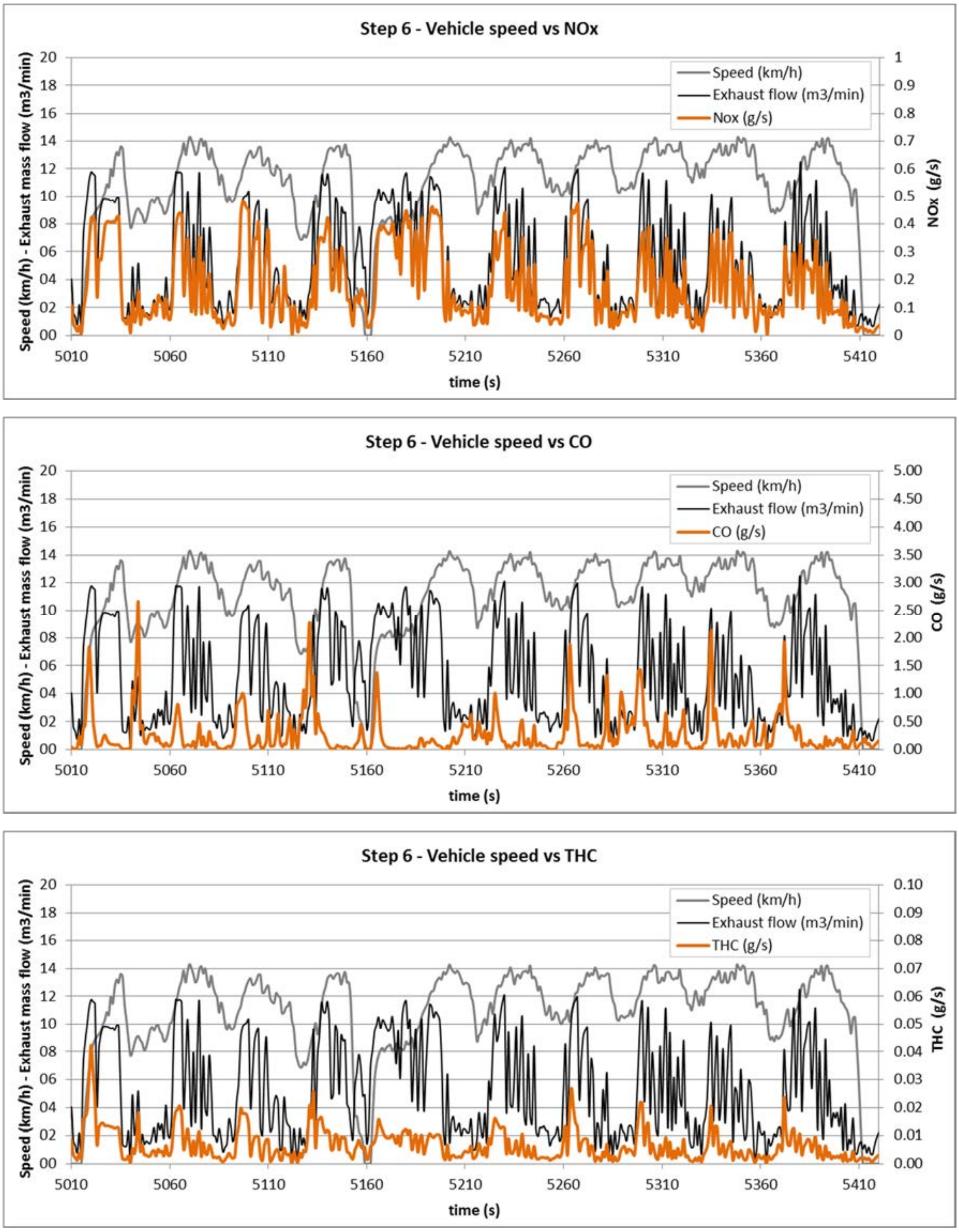


Figure 22. Test 03a pollutant emissions

STEP 6 AVERAGE PARAMETERS		
Exhaust flow	[m^3/min]	5.16
Vehicle speed	[km/h]	10.8

Table 12: Test 03a average parameters

STEP 6 PARAMETERS		
CO2	[g]	5019.05
CO	[g]	112.76
THC	[g]	2.70
NOx	[g]	72.38
Fuel consumption	[Total cycle litres]	1.91
Average fuel consumption	[l/h]	16.76

Table 13: Test 03a pollutant emissions and fuel consumption

2.2.7 Step 7: Test 03b

This test is almost the same as the previous one; nevertheless, in this case the main difference consists of five anticlockwise laps, the operator's cabin being on the outer side. The vehicle speed and exhaust flow results were as follows:

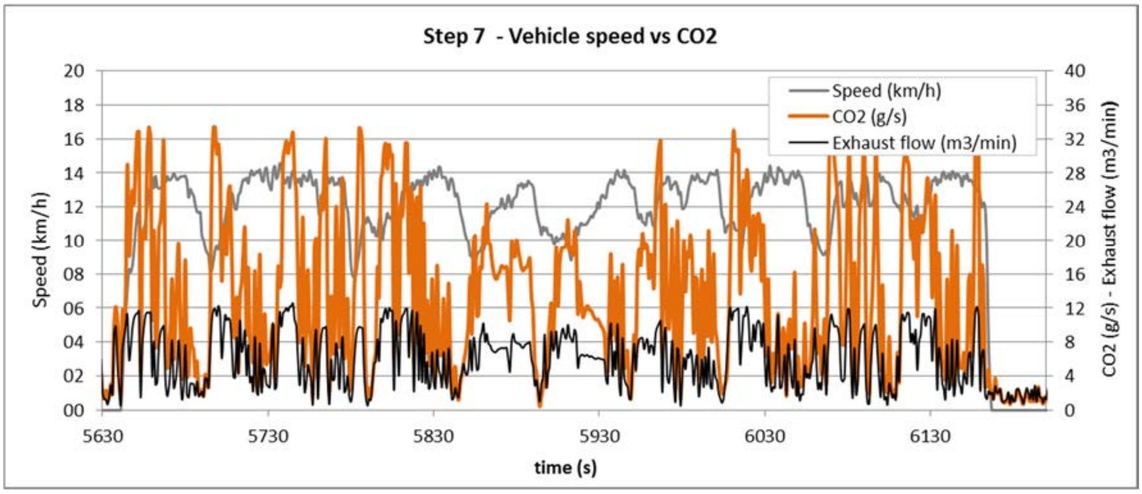


Figure 23. Test 03b vehicle speed and exhaust flow

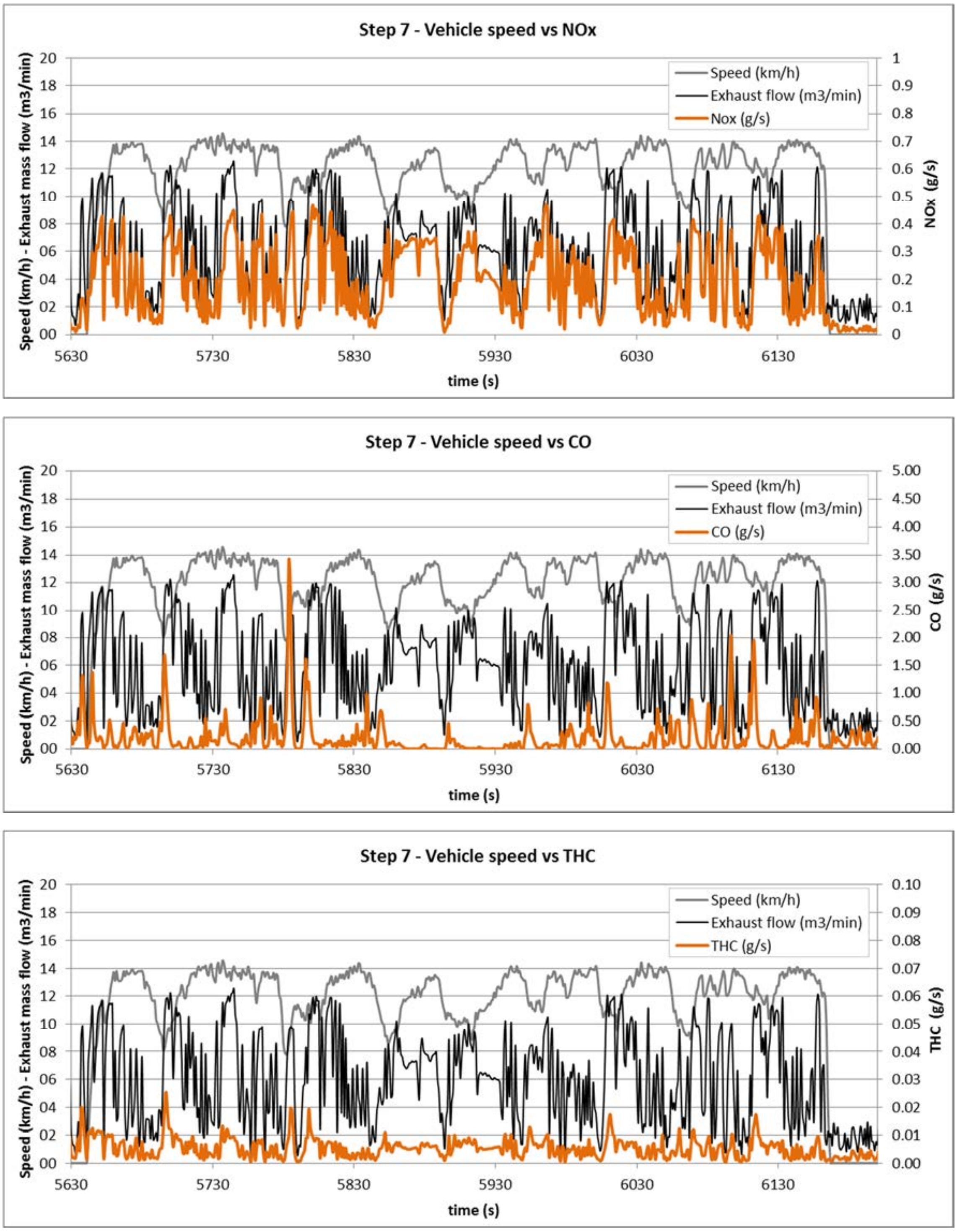


Figure 24.: Test 03b pollutant emissions

STEP 7 AVERAGE PARAMETERS		
Exhaust flow	[m^3/min]	5.96
Vehicle speed	[km/h]	11.2

Table 14: Test 03b average parameters

STEP 7 PARAMETERS		
CO2	[g]	7669.57
CO	[g]	125.37
THC	[g]	3.05
NOx	[g]	110.53
Fuel consumption	[Total cycle litres]	2.92
Average fuel consumption	[l/h]	18.43

Table 15: Test 03b pollutant emissions and fuel consumption

2.2.8 Step 8: Test 04

For this test the straddle carrier does ten back and forth, which means, lifting the load on the back and downloading it on the return. The results were as follows:

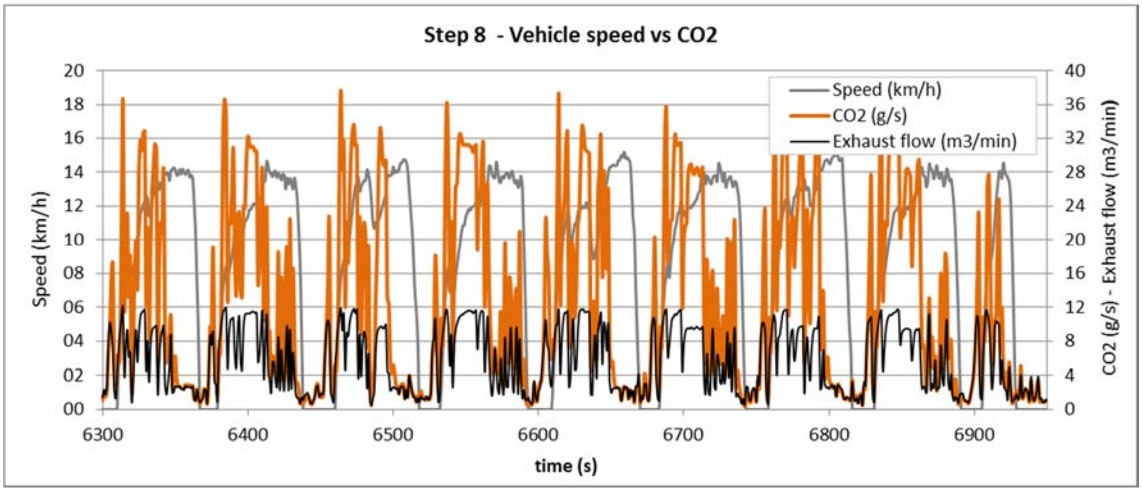


Figure 25. Test 04 vehicle speed and exhaust flow

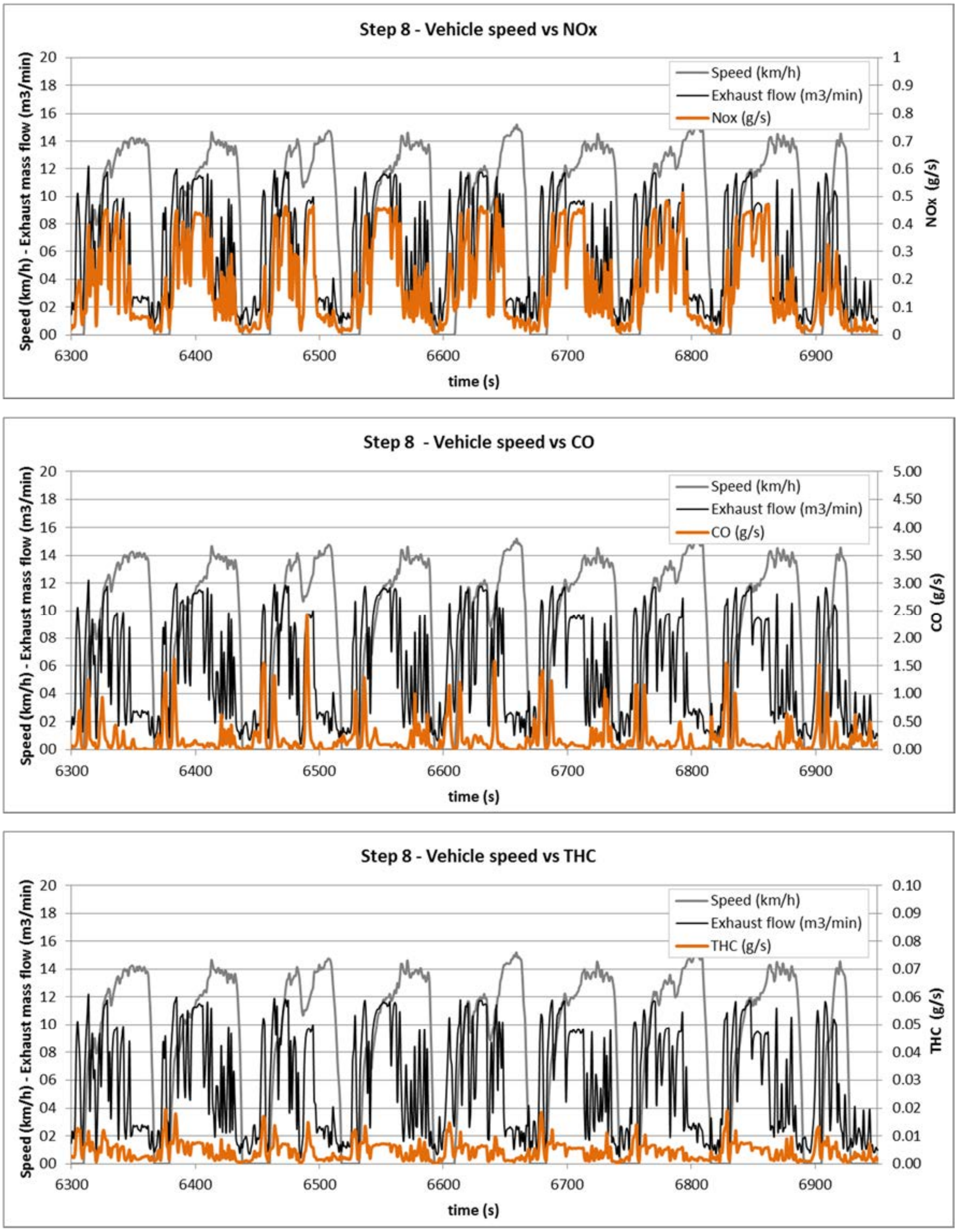


Figure 26. Test 04 pollutant emissions

STEP 8 AVERAGE PARAMETERS		
Exhaust flow	[m³/min]	5.68
Vehicle speed	[km/h]	8.6

Table 16: Test 04 average parameters

STEP 8 PARAMETERS		
CO2	[g]	8234.97
CO	[g]	135.68
THC	[g]	2.93
NOx	[g]	116.93
Fuel consumption	[Total cycle litres]	3.14
Average fuel consumption	[l/h]	17.36

Table 17: Test 04 pollutant emissions and fuel consumption

2.2.9 Step 9: Laden 02

This step is performed when the fourth test has finished. The container is carried through the terminal back to the storage zone, specifically to the point where it was collected in the beginning. As previous steps, the results are shown below:

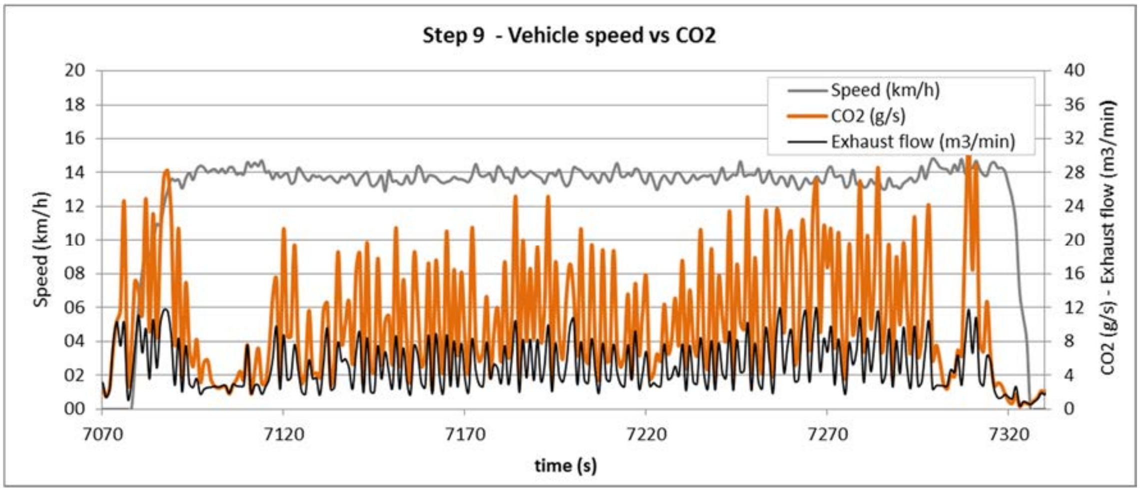


Figure 27. Laden 02 vehicle speed and exhaust flow

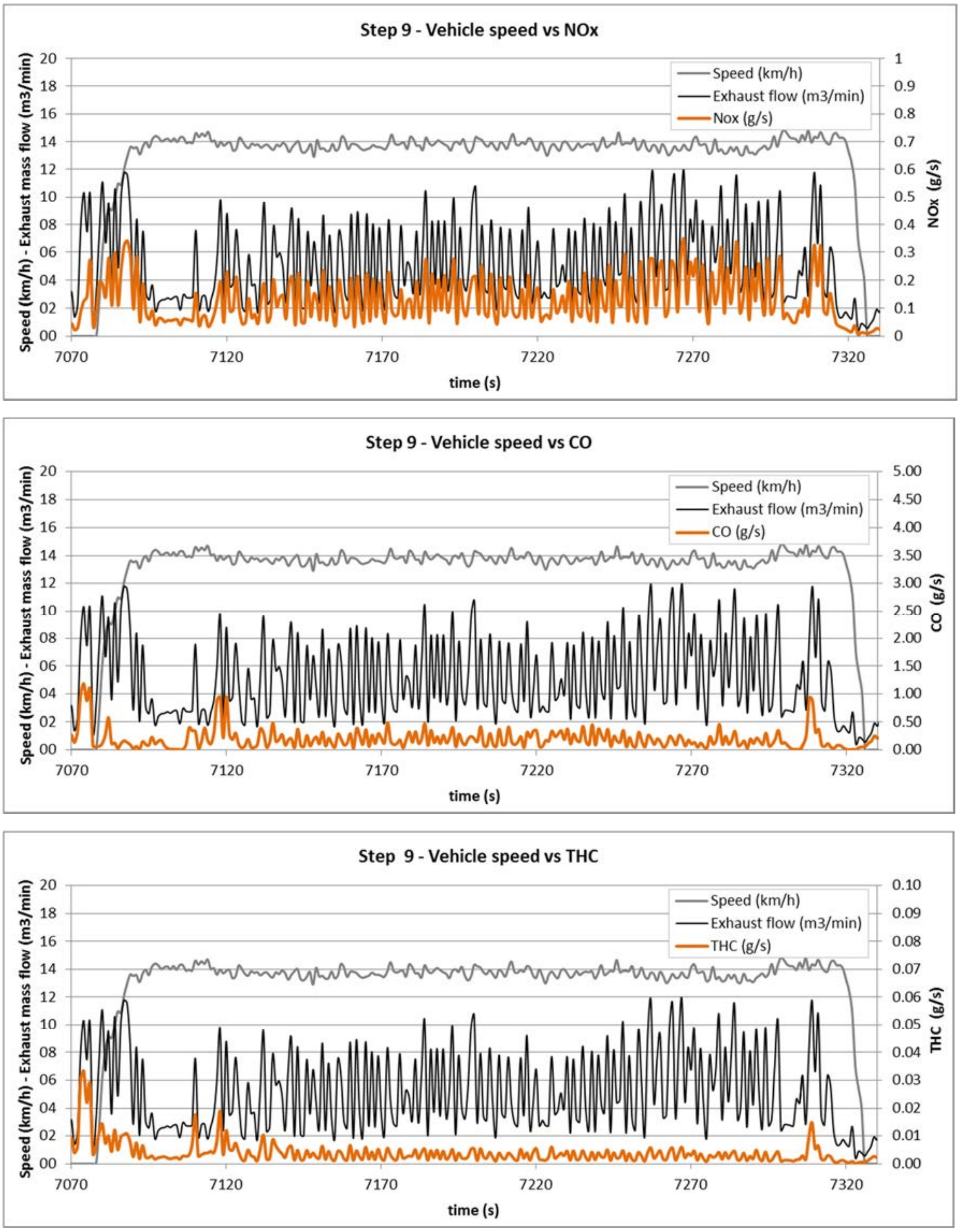


Figure 28. Laden 02 pollutant emissions

STEP 9 AVERAGE PARAMETERS		
Exhaust flow	[m^3/min]	5.11
Vehicle speed	[km/h]	12.8

Table 18: Laden 02 average parameters

STEP 9 PARAMETERS		
CO2	[g]	2750.55
CO	[g]	51.59
THC	[g]	1.02
NOx	[g]	33.38
Fuel consumption	[Total cycle litres]	1.05
Average fuel consumption	[l/h]	14.46

Table 19: Laden 02 pollutant emissions and fuel consumption

2.2.10 Step 10: Unladen 02

The final step consists of taking the straddle carried back to the parking area, without carrying any load. The results were as follows:

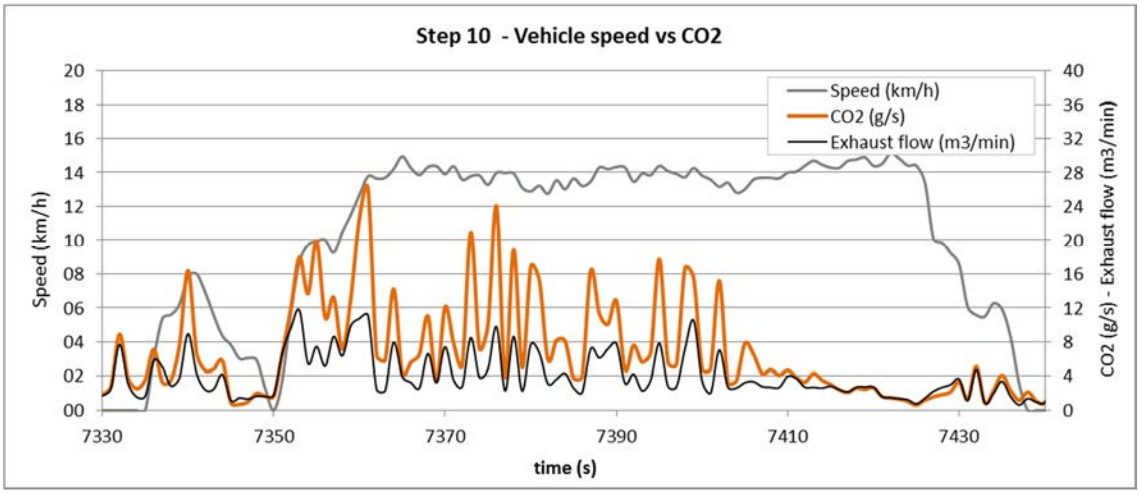


Figure 29. Unladen 02 vehicle speed and exhaust flow

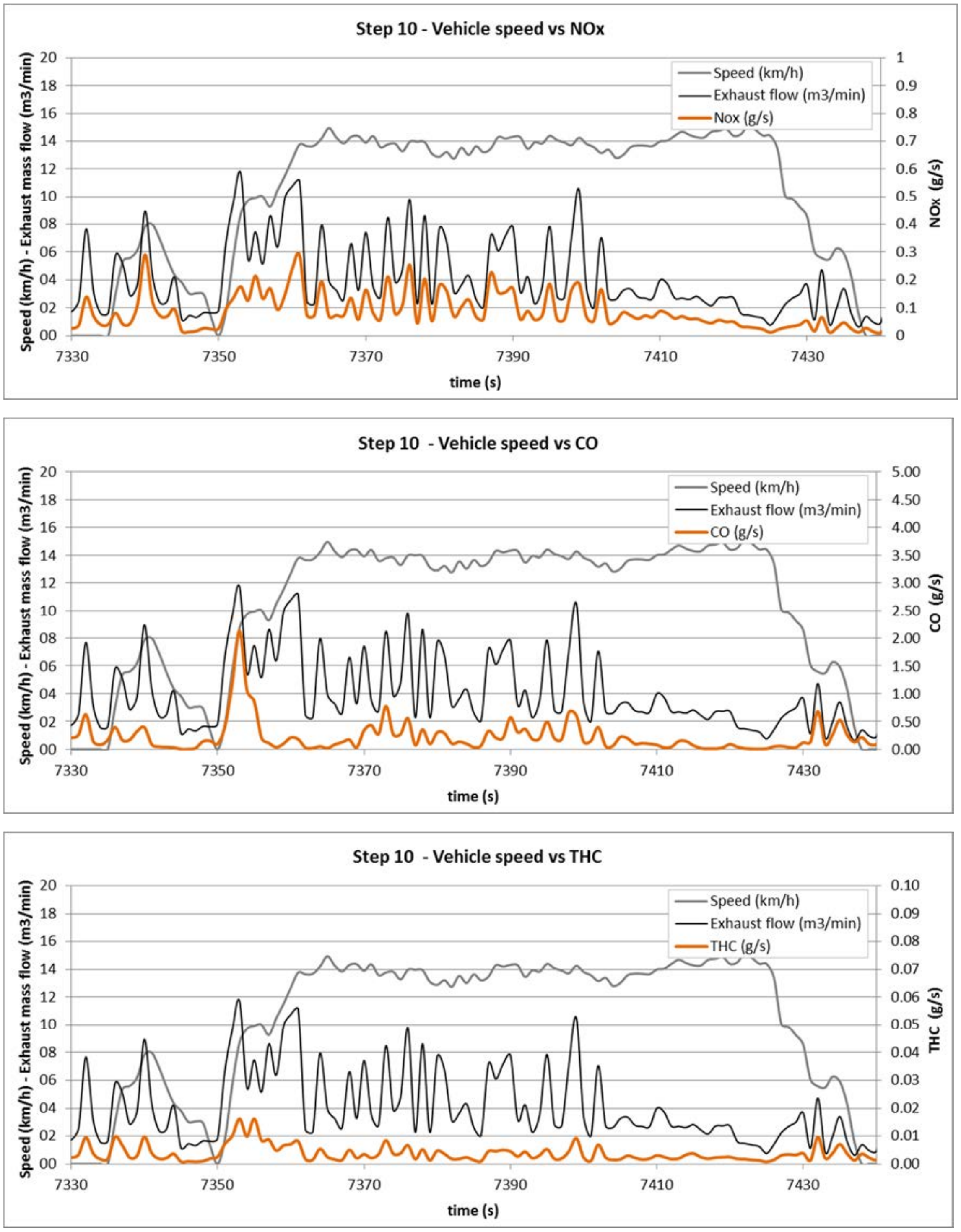


Figure 30. **Unladen 02 pollutant emissions**

STEP 10 AVERAGE PARAMETERS		
Exhaust flow	[m^3/min]	4.05
Vehicle speed	[km/h]	10.4

Table 20: Unladen 02 average parameters

STEP 10 PARAMETERS		
CO2	[g]	756.28
CO	[g]	24.74
THC	[g]	0.42
NOx	[g]	9.64
Fuel consumption	[Total cycle litres]	0.29
Average fuel consumption	[l/h]	3.53

Table 21: Unladen 02 pollutant emissions and fuel consumption

2.2.11 Reliance between vehicle speed and emissions

Once the complete test is performed and each step's results obtained, the dependency between the vehicle speed and pollutant emissions can be seen.

The charts below show the reliance between these variables in the whole cycle. For each comparison, the zone belonging to test 4 is taken in order to observe clearly this dependency. The first comparison deals with vehicle speed and CO2.

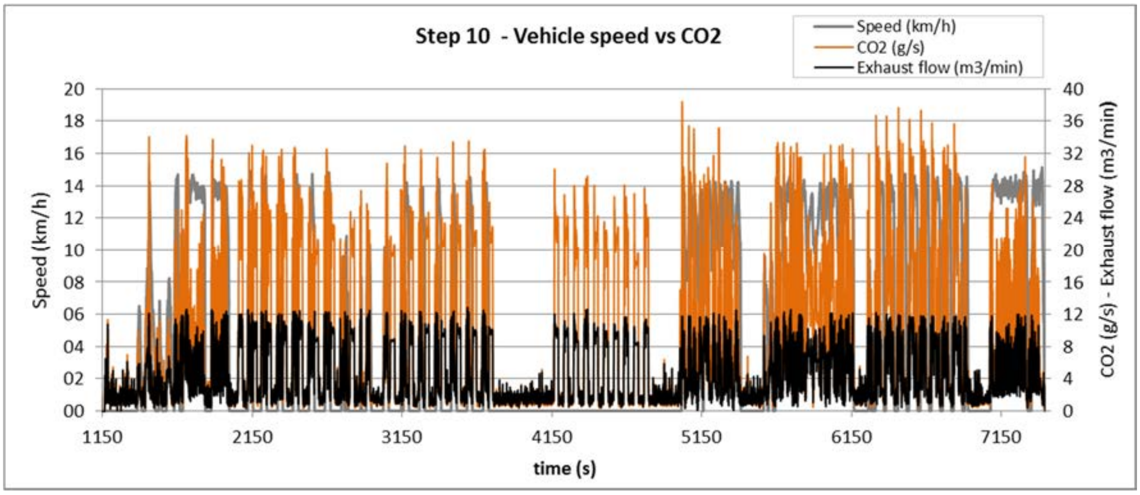


Figure 31. Vehicle speed vs CO2

The second comparison is between the engine speed and NO_x emissions:

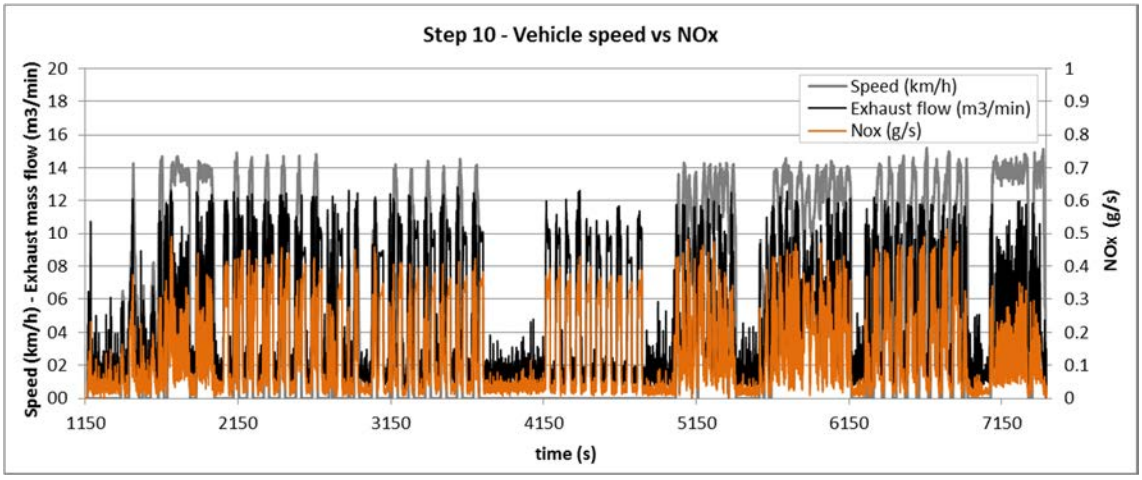


Figure 32. Vehicle speed vs NOx

The comparison between vehicle speed and THC pollutant is as follows:

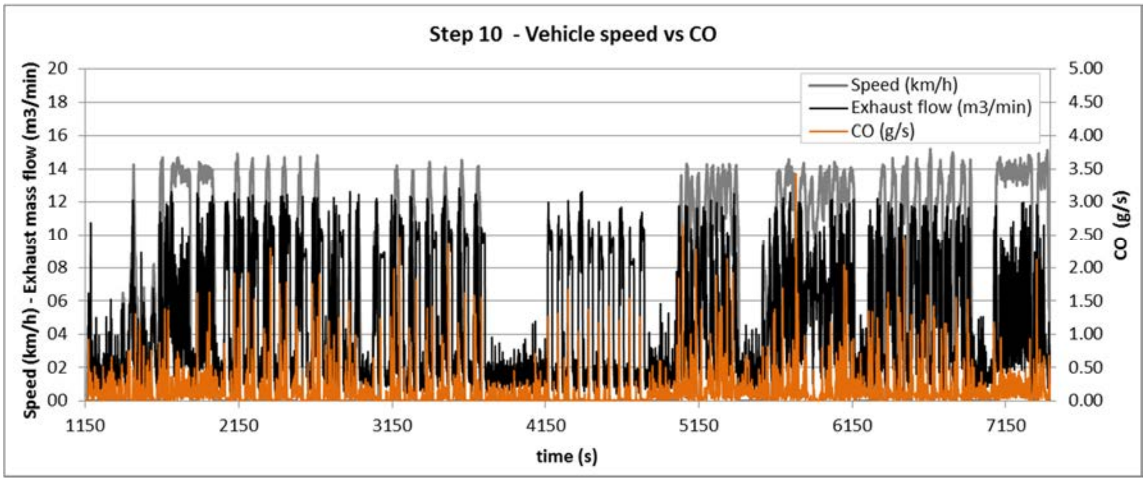


Figure 33. Vehicle speed vs THC

Vehicle speed and CO is the last comparison:

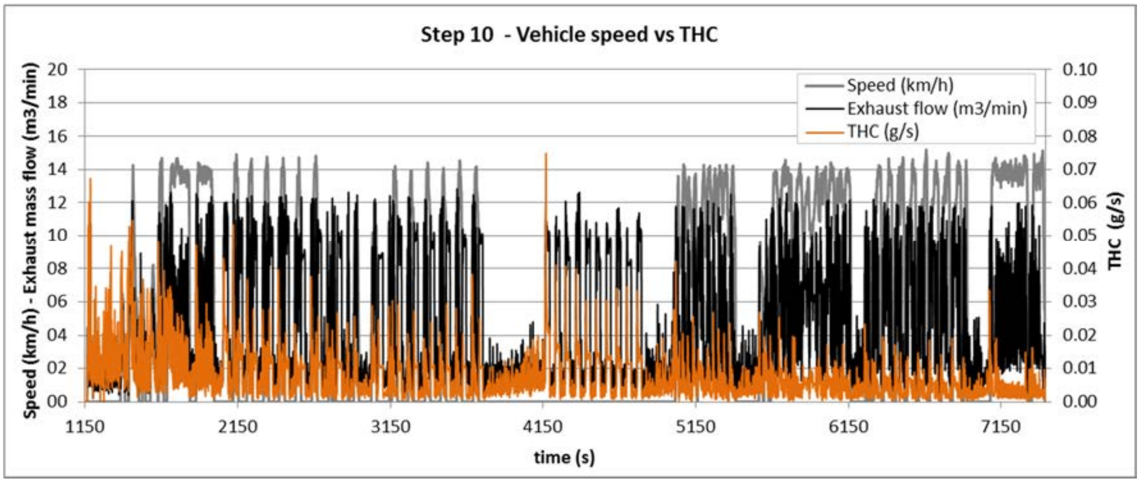


Figure 34. Vehicle speed vs CO

As can been seen in the previous charts and especially in the chart of each step, CO_2 and NO_x emissions are higher in the moments of high vehicle speed and in the instant where the vehicle has just slowed down.

In contrast, THC emissions are very low compared to CO_2 and NO_x emissions and remain almost constant, nevertheless, they increase at the same moments as the other pollutant emissions; whereas CO emissions are worse before and after vehicle speeding.

The following table shows the results of the four pollutant emissions in the TBC cycle:

	NO_x	CO	THC	CO_2
Total emissions cycle (g)	744.21	878.82	38.81	50703.89
Cycle time (h)	1.34	1.34	1.34	1.34
Emissions (g/s)	0.15	0.18	0.008	10.51
Distance (km)	8.16	8.16	8.16	8.16
Emissions (g/km)	91.20	107.70	4.75	6213.70
Emissions (g/km/Tn)	3.04	3.59	0.16	207.12

Table 22: APMT tests pollutant emissions

Moreover, it is important to perform a comparison of the energy consumption in order to make evident the fuel savings provided by a natural gas engine. Hence the diesel consumption results are defined in the following table.

	Total cycle litres	Litres/h
Fuel consumption	19.33	14.40*

Table 23: APMT tests fuel consumption. (*Only for 1 engine)

3. BEST real-driving emissions test

Like TBC terminal, several tests must be performed in the BEST terminal because it makes use of engines which have to be converted in order to run with LNG fuel.

The straddle carriers at BEST have one single SISU engine, 273 Kw/1500 Nm. The power of this engine is divided into three systems that operate in parallel:

- Wheels
- Container elevator
- Steering (requires a very small power compared to the others)

Each one of these systems works independently. The engine is powerful enough to supply the power that each system requires to work at maximum performance level. This means that no one of the three systems will suffer a performance reduction when working at the same time. The engine will deliver its maximum power when the three independent systems require their respective maximum power: full longitudinal acceleration, container elevation at max speed and quick turn of the vehicle.

The first two operations occur frequently, whilst the third one rarely occur while any of the other two are taking place. Nevertheless, the steering system requires a minimal amount of power compared to the other two.

Figure 35. BEST Straddle Carrier

3.1. Tests description

Initially, it was planned to develop the same real-driving emissions test as performed in the APMT terminal at BEST terminal, but it was not possible since the daily activities of the straddle carriers operators could not be interrupted, among other reasons. In order to get the emissions results in the normal operation course of the machine, two different tests were studied.

On the one hand, a real-life test was designed to follow part of the usual route of the Straddle Carrier according to the suggestions of the BEST employees. On the other hand, a new test was created by IDIADA and the technicians advices according to the terminal restrictions.

Both tests were performed using a calibrated test container whose weight is 25 Tm.

3.1.1 Testing Area

The machine was instrumented where it is usually parked overnight, next to the hangar area. The tests would always start and finish in this place so that the beginning and the end of the test would always be a displacement across the terminal without carrying any load. The tests performed at BEST terminal were as follows:

- Real-life
- Test cycle defined

Figure 36. Aerial view of the terminal

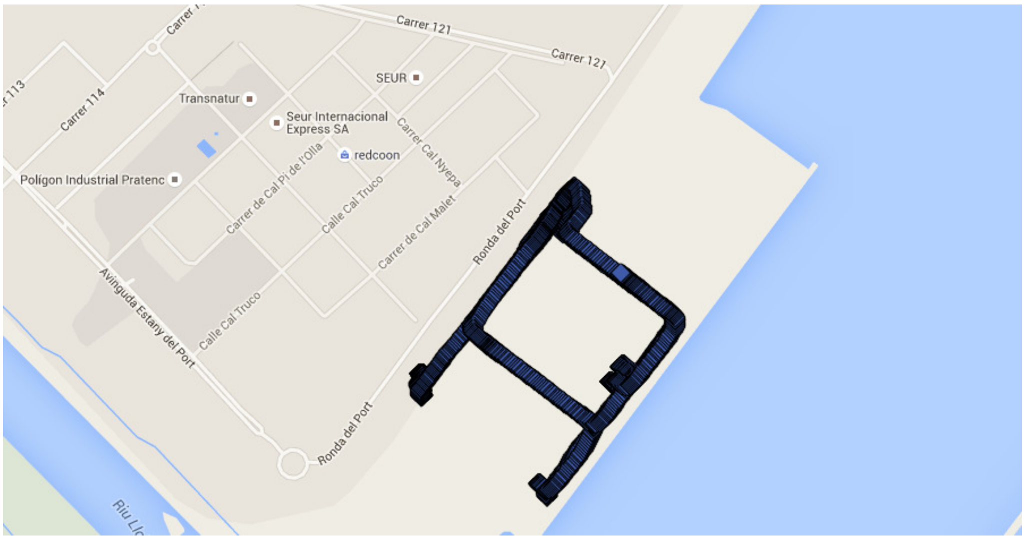


Figure 37. Real-life BEST test

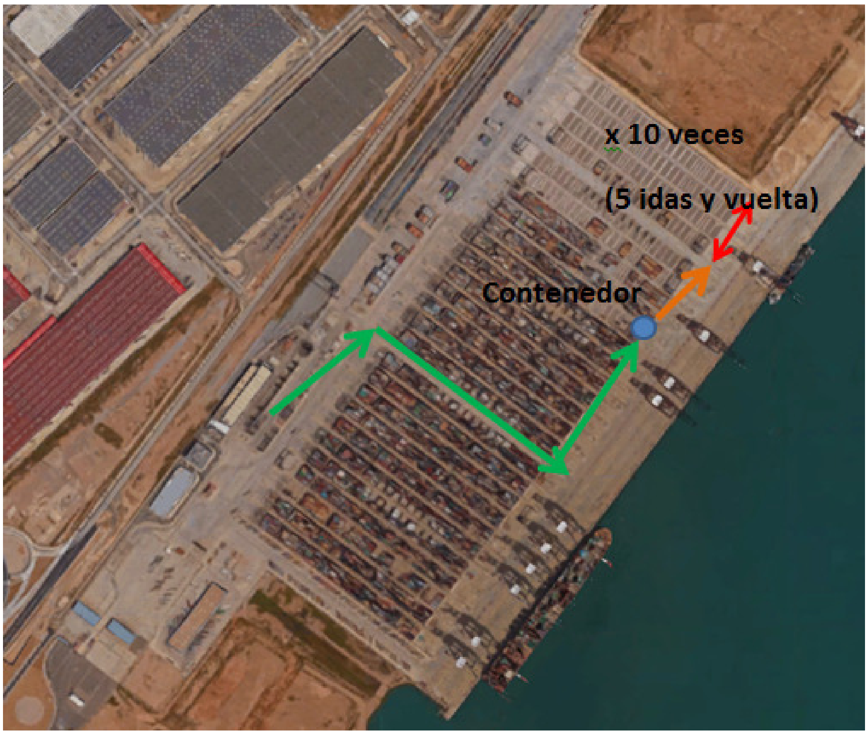


Figure 38. Test cycle defined

It is also important to remark that the following assumptions need to be taken into account:

- The test was performed during 1 day. Firstly in a real-life work, after that, with a test cycle defined.
- These two parts of the test make use of different registered loads in order to normalise the result according to the load.
- The test was performed on the daily work zone, not specific work.

- The person who drove these machines was an expert driver of straddle carriers.

The real GPS tracks that follow each test are represented in the following graphs based on latitude and longitude.

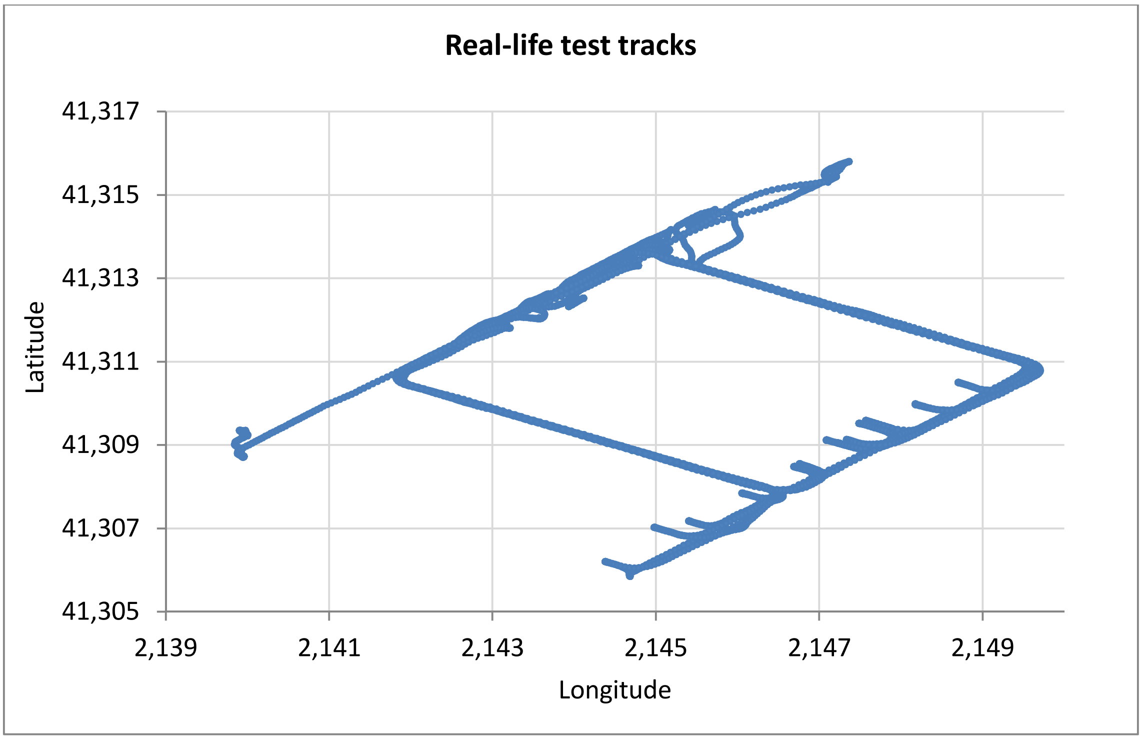


Figure 39. Real-life test tracks (BEST)

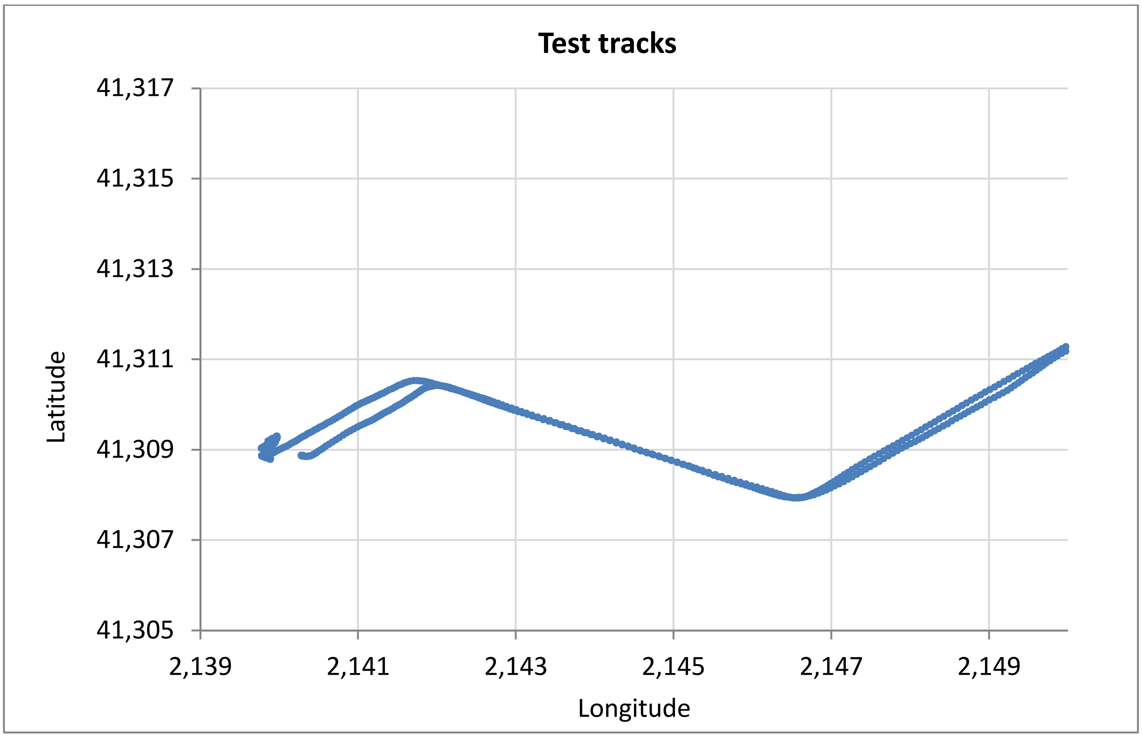


Figure 40. Test cycle defined tracks (BEST)

3.1.2 PEMS installation and measurement devices

For the tests of BEST terminal, the same devices as APMT tests are used, in other words, the PEMS device is needed to instrument. As described previously, PEMS installation consists on the following elements:

- Gas analyser modules
- Communication module
- Power supply module
- Heated sampling line
- Exhaust gas flow meter
- Pitot-box
- Gas bottles
- GPS module
- WS station
- Additional signal inputs

Figure 41. PEMS installed on the top of the Straddle Carrier

Figure 42. Bundle of heated gas sampling, pressure and temperature lines

Figure 43. PEMS modules installation

Figure 44. Straddle Carrier a few minutes before the execution of the test

3.2. Real-life tests

In this part, the results of real-life test are shown as a function of time. Firstly, like APMT tests, the vehicle speed, exhaust flow and CO2 emissions are shown below:

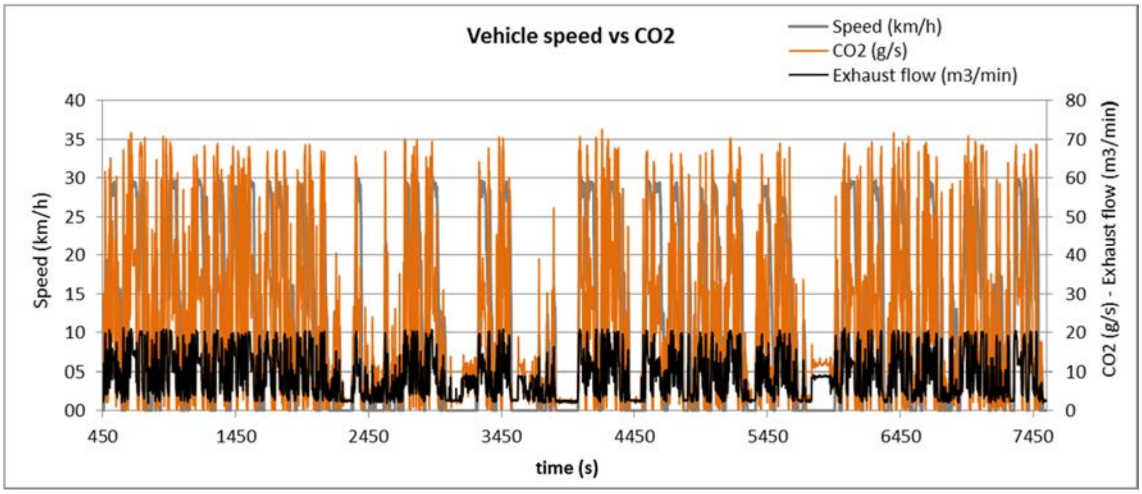


Figure 45. Real life speed and exhaust results

The previous chart is divided in parts in order to see more clearly these results:

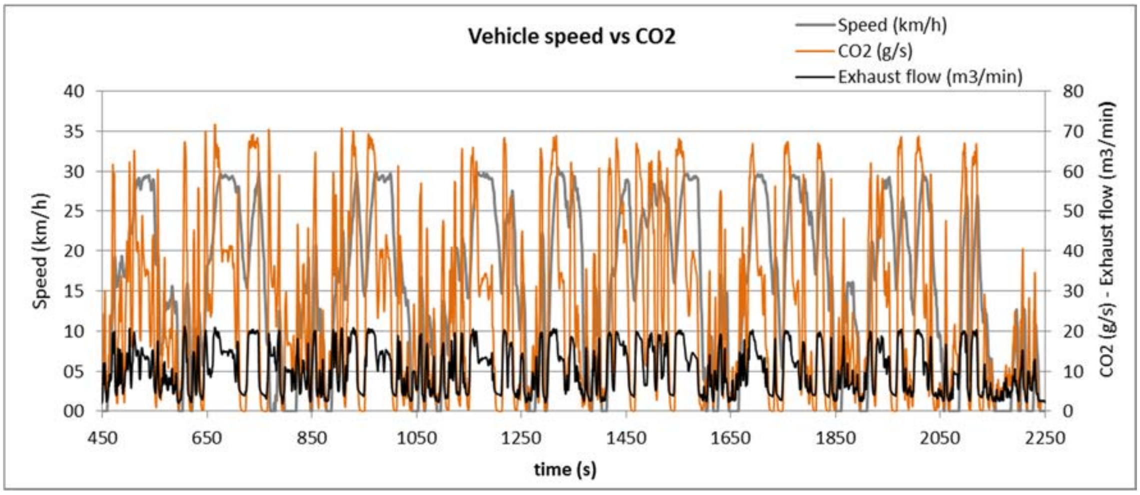


Figure 46. From 450 s to 2250 s

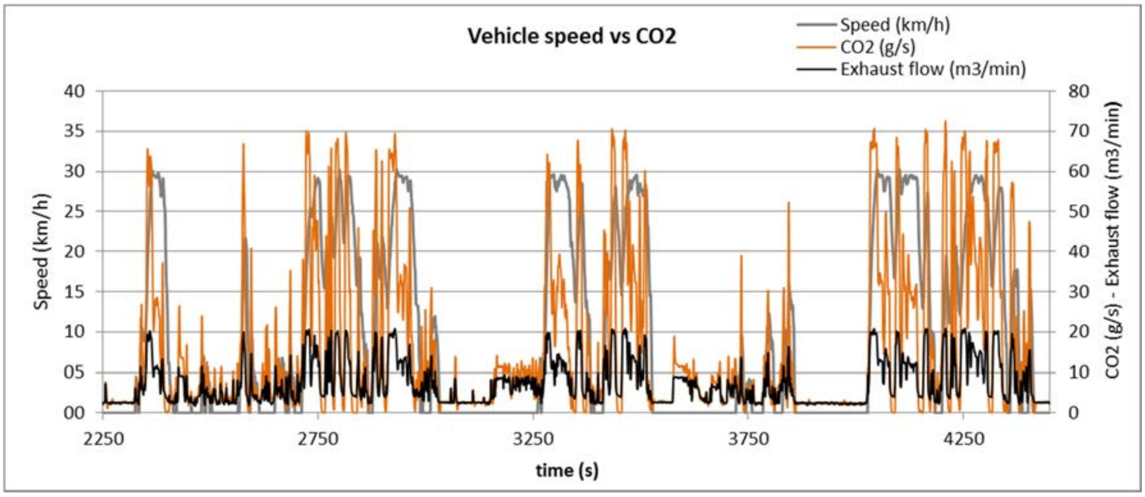


Figure 47. **From 2250 s to 4450 s**

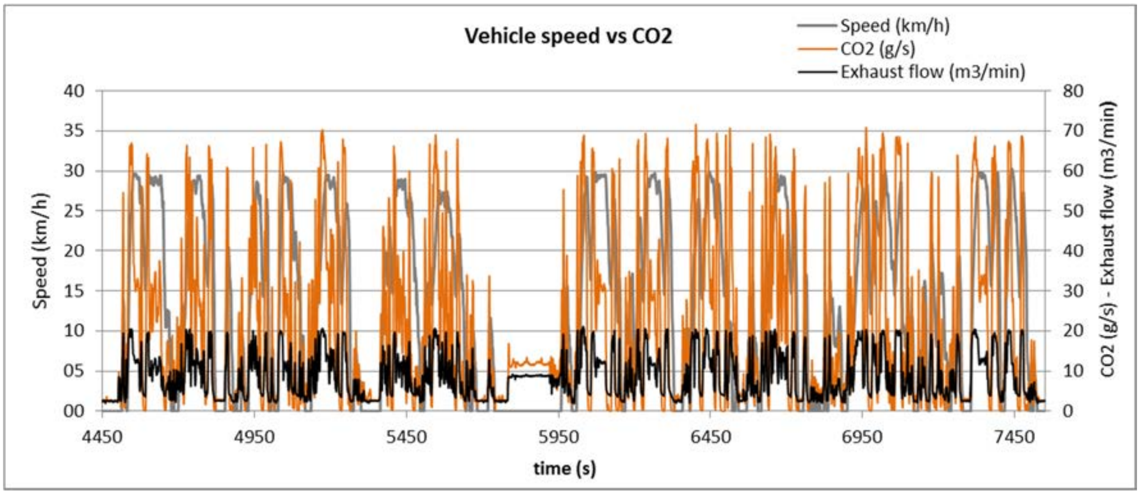


Figure 48. **From 4450 s to 7550 s**

Once the test results have been shown, it is time to show the results of the emissions in the whole cycle. The following charts show NO_x, THC and CO_2 emissions during the whole real life test.

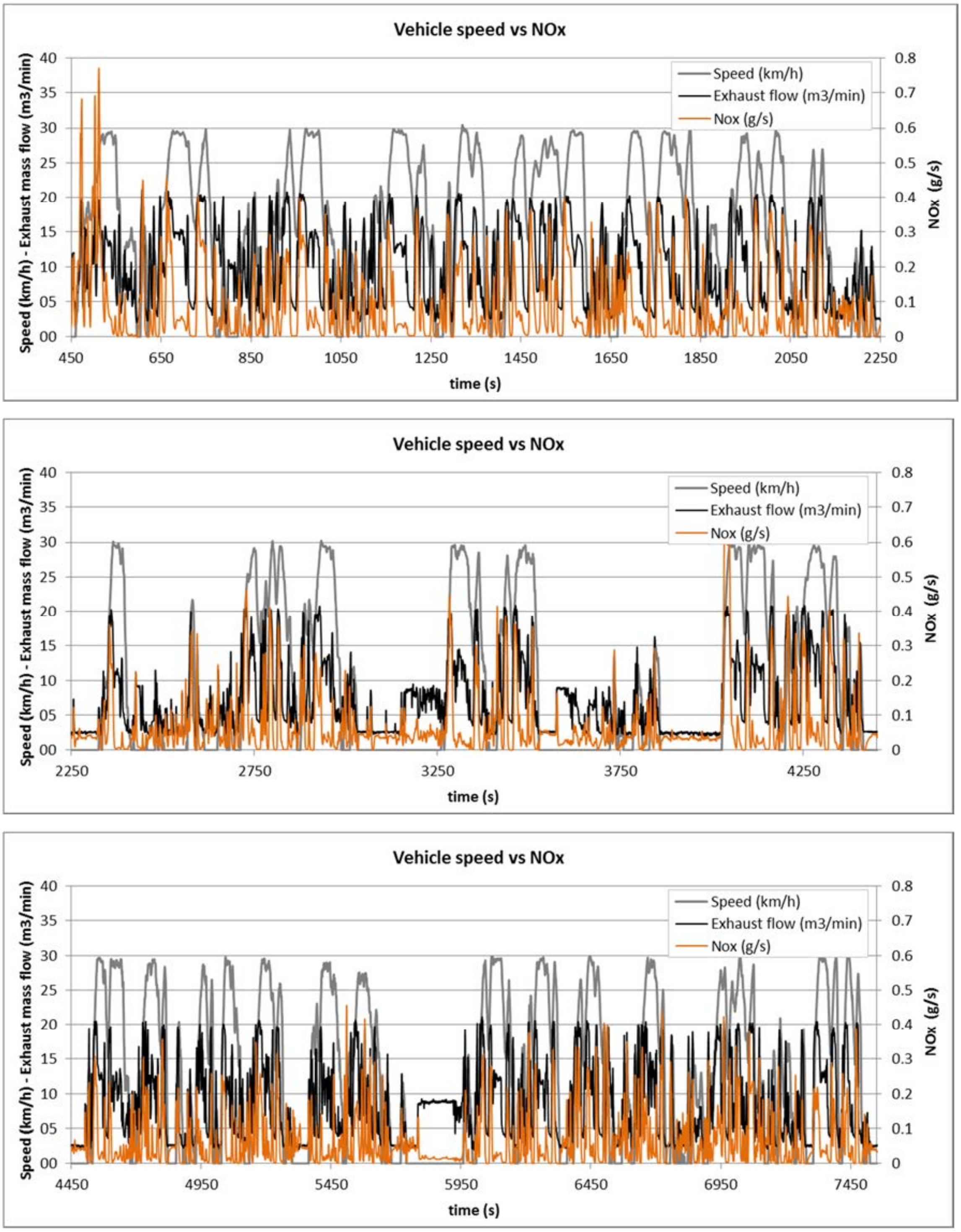


Figure 49. NOx emissions in real-life test

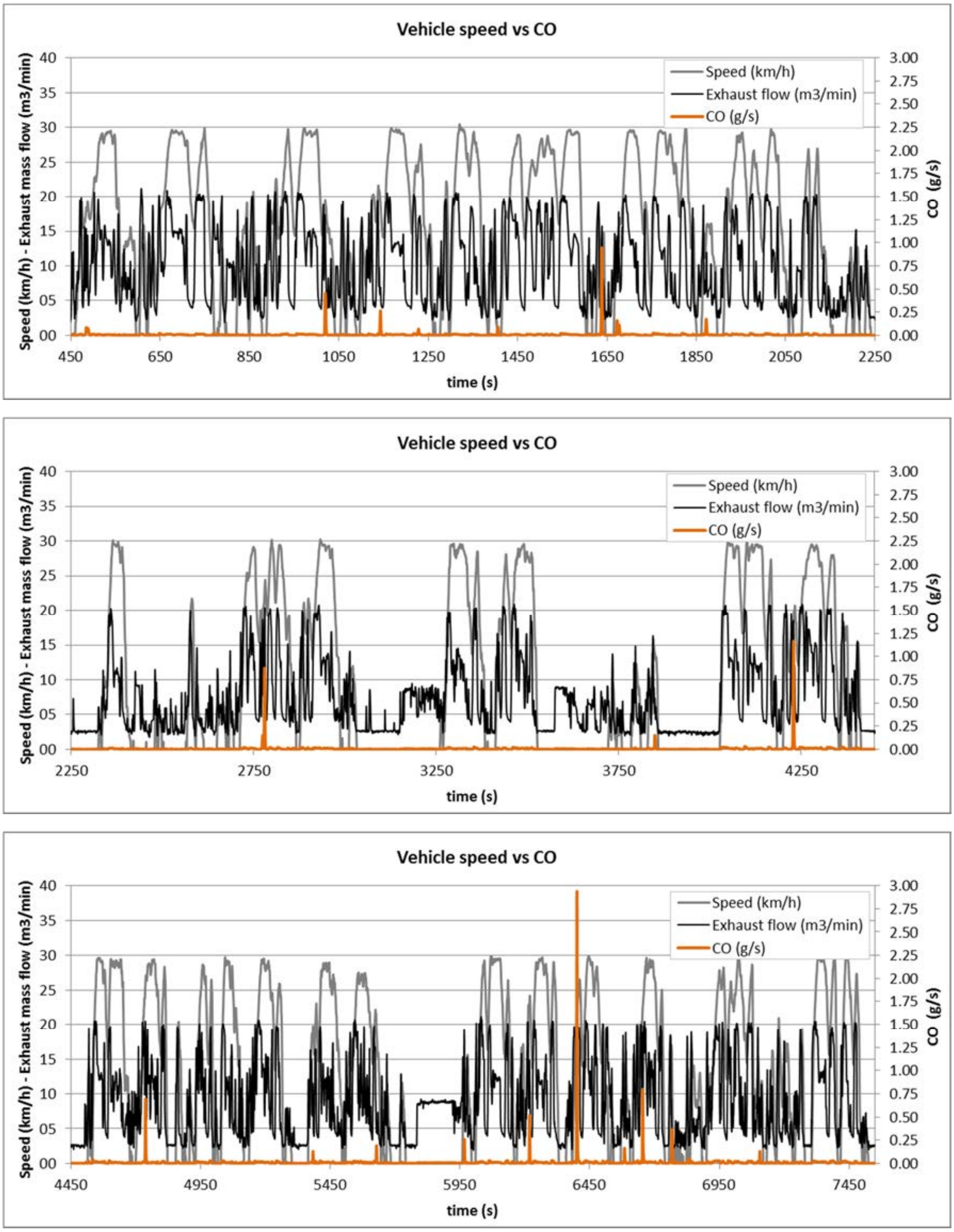


Figure 50. CO emissions in real-life test

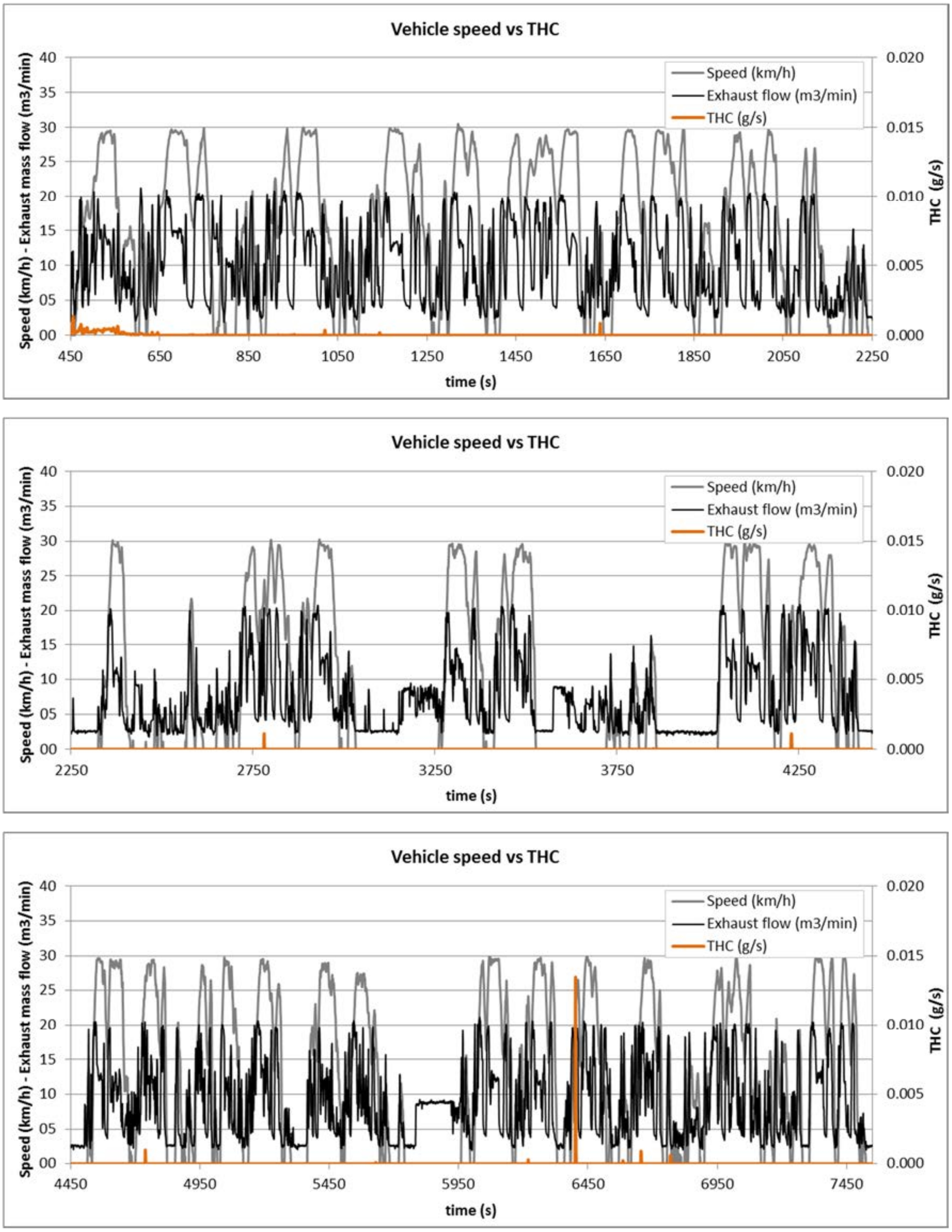


Figure 51. THC emissions in real-life test

And now, the following table deals with the summary of the emissions in addition to the fuel consumption:

	NO_x	CO	THC	CO_2
Total emissions cycle (g)	447.70	74.26	0.09	142,683.06
Cycle time (h)	1.97	1.97	1.97	1.97
Emissions (g/s)	0.063	0.0105	1.2E-05	20.09
Distance (km)	25.28	25.28	25.28	25.28
Emissions (g/km)	17.71	2.94	0.0034	5,643.02
Emissions (g/km/Tn)	0.71	0.12	0.00014	225.72

Table 24: Real-life cycle pollutant emissions summary table

	Total cycle litres	litres/h
Fuel consumption	54.40	27.58

Table 25: Real-life cycle fuel consumption

3.3. Test cycle defined

After a real-life cycle, a test cycle was created in order to compare these results with the engine conversion results, in other words, the test must be executed in accordance with the following defined sequence:

1. From the Hangars to the place where the 25 Tm container is stored, 5 -10 minutes of idle or displacement delivering low power.
2. Carry the container from the place where is kept to the testing area.
3. Execution of the pre-defined test. The sequence was:
    a. Container on the ground
    b. Full acceleration forwards and full power container elevation. Container and max speed (30 km/h) are reached at a very similar time.
    c. Maintain the max speed and container up during 2-3 seconds and brake. Stop the machine after two lamp posts (around 200 m).
    d. Leave the container on the ground, max speed. Wait 5 seconds
    e. Lift the container up at max speed. Hold up for 5 seconds.
    f. Container back to the ground. Wait 5 seconds.
4. Repeat the same 10 times (5 times each way).

This is the next test performed after carrying out the real-life ones. Vehicle speed and exhaust flow results are shown below:

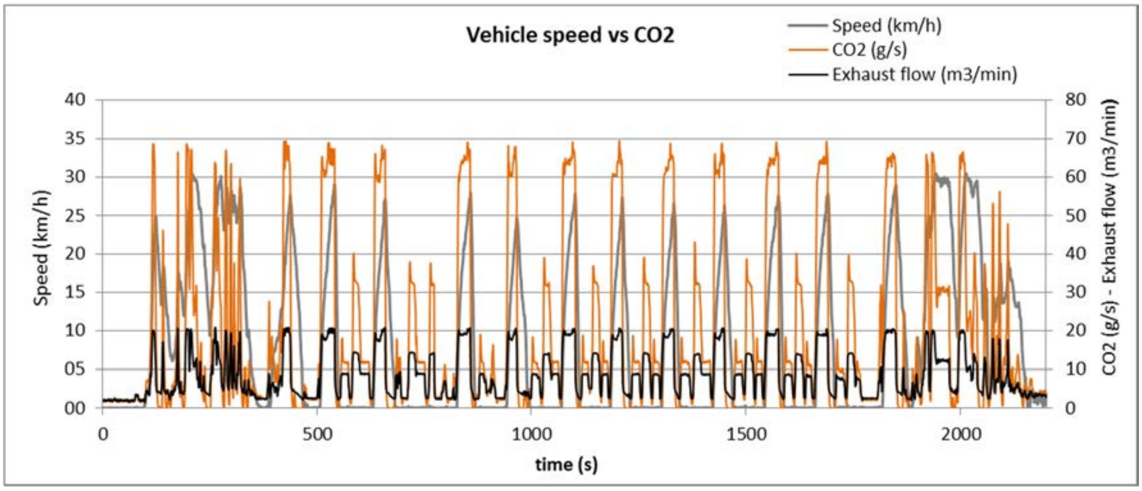


Figure 52. Test cycle defined speed, exhaust and CO2 emissions results

NO_x, CO, THC and CO_2 emissions are the next results to be shown:

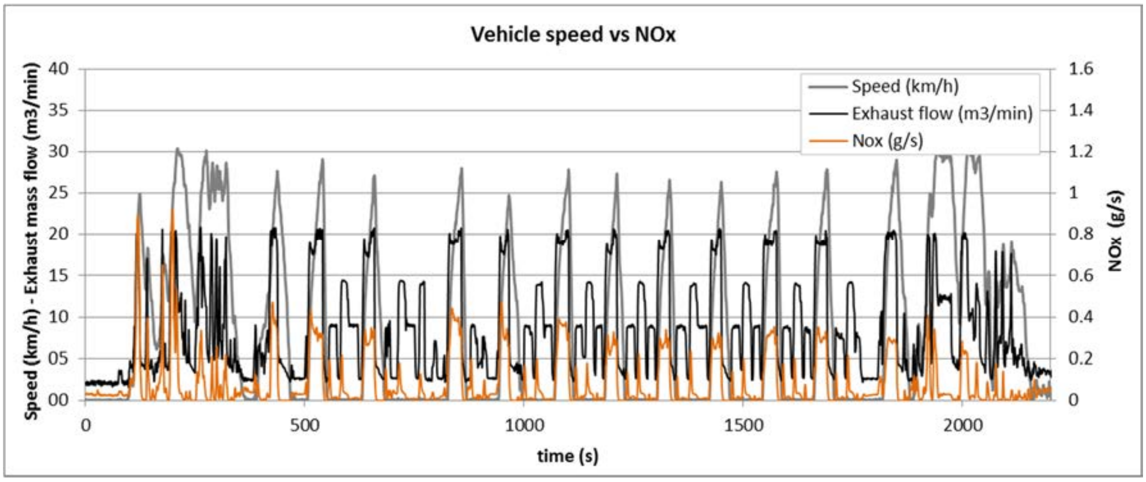


Figure 53. NOx emissions in test cycle defined

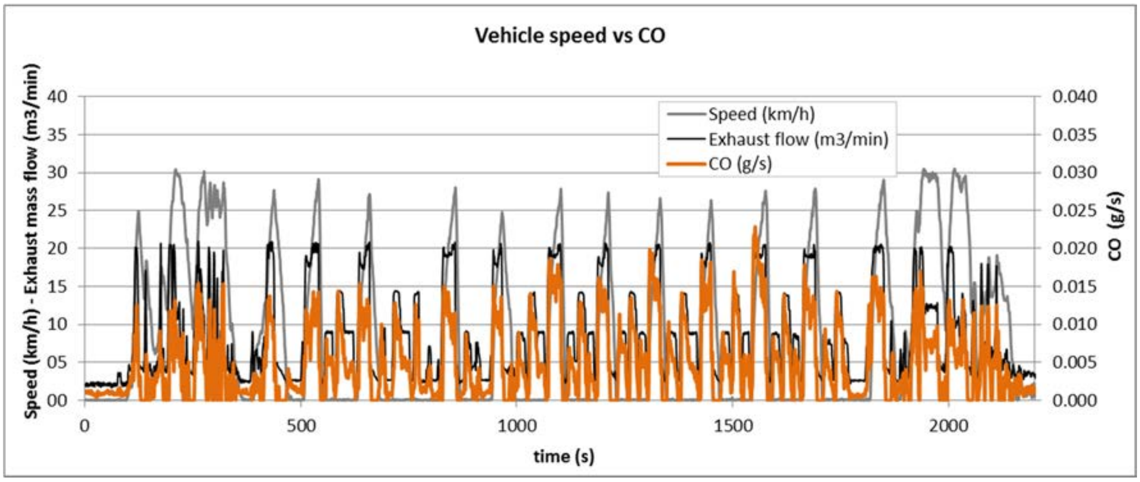


Figure 54. CO emissions in test cycle defined

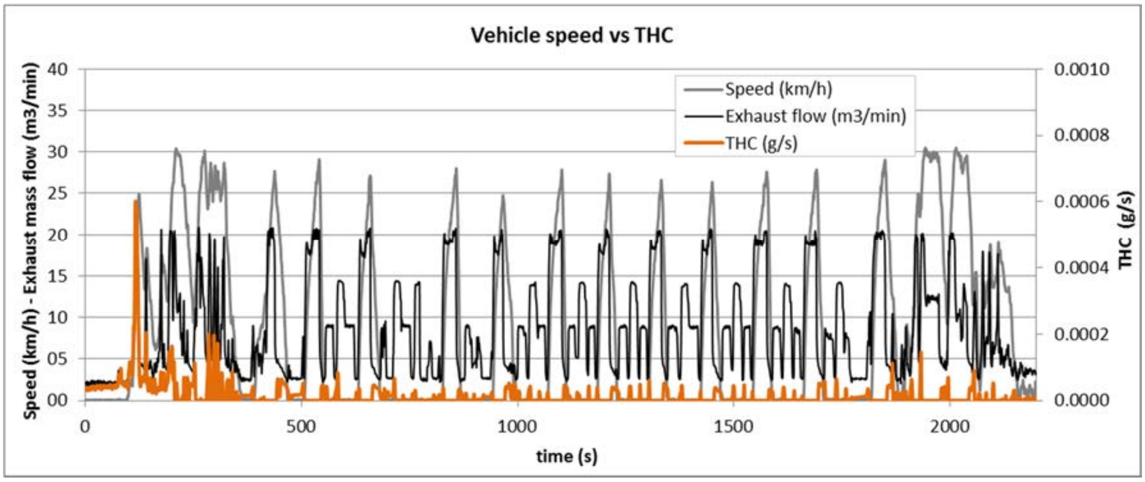


Figure 55. THC emissions in test cycle defined

As in the previous test, below the emissions summary as well as the fuel consumption in the whole cycle are shown:

	NO_x	CO	THC	CO_2
Total emissions cycle (g)	164.00	10.93	0.04	43,568.39
Cycle time (h)	0.61	0.61	0.61	0.61
Emissions (g/s)	0.075	0.0049	1.63E-05	19.80
Distance (km)	5.30	5.30	5.30	5.30
Emissions (g/km)	30.95	2.06	0.0068	8,223.67
Emissions (g/km/Tn)	1.24	0.08	0.00027	328.95

Table 26: Test cycle defined pollutant emissions summary table

	Total cycle litres	Litres/h
Fuel consumption	16.61	27.18

Table 27: Test cycle defined fuel consumption

4. Determination of engine performance and exhaust emissions in a test bench

In order to define the current status of the engines, both engines required to be subjected to a performance and exhaust emissions tests. This type of test is developed at IDIADA facilities, concretely in a test bench where the engine is fully instrumented and rehearsed. These tests will be useful in the future to view the capabilities of the converted engine and to compare the variation of exhaust gas emissions between the engine powered by diesel and by natural gas.

For this reason, the terminals had to send an engine from their Straddle Carrier to IDIADA to carry out the corresponding tests. The APMT terminal could submit and engine since it has some machines in disuse. On the contrary, the BEST terminal has all its machines in operation and was not able to leave the engine for about a month at IDIADA. Therefore, the performance and exhaust emissions test in a test bench was only performed for the APMT engine.

Figure 56. APMT engine views.

Full load tests were carried out in accordance with Regulation No 85[1] which defines the procedure for the representation of the power curve at full load as a function of the engine speed. During the full load test the smoke was also measured.

In addition, an engine mapping was performed to measure the exhaust emissions and complete the data. An engine mapping is a kind of test that determines the performance curve to see the behaviour of the engine when it is subjected to changes in speed, load and ignition timing among many other parameters.

[1] Regulation No85 of the Economic Commission for Europe of the United Nations (UN/ECE) – Uniform provisions concerning the approval of internal combustion engines or electric drive trains intended for the propulsion of motor vehicles of categories M and N with regard to the measurement of net power and maximum 30 minutes power of electric drive trains.

4.1. APMT engine performance test

The engine was installed on the test bench and mechanically verified. Then it was equipped with sensors whose functions are to measure flows, temperatures and pressures, and with equipment that calculates the exhaust emissions parameters and other factors that have some effect on the engine output. Moreover, the test bench has a dynamometer, an opacimeter to measure the smoke production and an exhaust gas analyser.

Parameter	Units
Air flow	kg/h
Intake air pressure (after air filter)	mbar
Intake air temperature (after air filter)	ºC
Tª air after high compressor	ºC
P air after high compressor	mbar
Exhaust pressure before turbine-1	mbar
Exhaust Tª before turbine-1	ºC
Exhaust Tª after turbine-1	ºC
Exhaust pressure (after turbine)	mbar
Lambda	--
NOx	ppm
NO	ppm
NO2	ppm
HC	ppm
CO	ppm
CO2	%
O2	%
Oil pressure	bar
Oil temperature	ºC
Fuel pressure before engine	bar
Fuel temperature before engine	ºC
Fuel pressure after engine	bar
Fuel temperature after engine	ºC
Inlet Engine Coolant Temperature	ºC
Outlet Engine Coolant Temperature	ºC
Engine Coolant Pressure	ºC
Engine coolant massflow	kg/h

Table 28: Engine parameters measured

The Valmet 612 engine with the characteristics of Table 29 was tested according to the test atmospheric conditions defined by the regulation.

Parameter	Description
Manufacturer	Valmet 612
Cycle	Four stroke
Cylinder number	6
Engine capacity	7.400 cm^3
Combustion system	Compression ignition
Fuel	Diesel

Table 29: Main parameters of APMT engine

The results of the power and torque curve at full load as a function of the engine speed are shown in the following graphs. As can be seen, the maximum net power is 102.5 kW at 1900 min^{-1} while the maximum net torque is 570 Nm at 1400 min^{-1}.

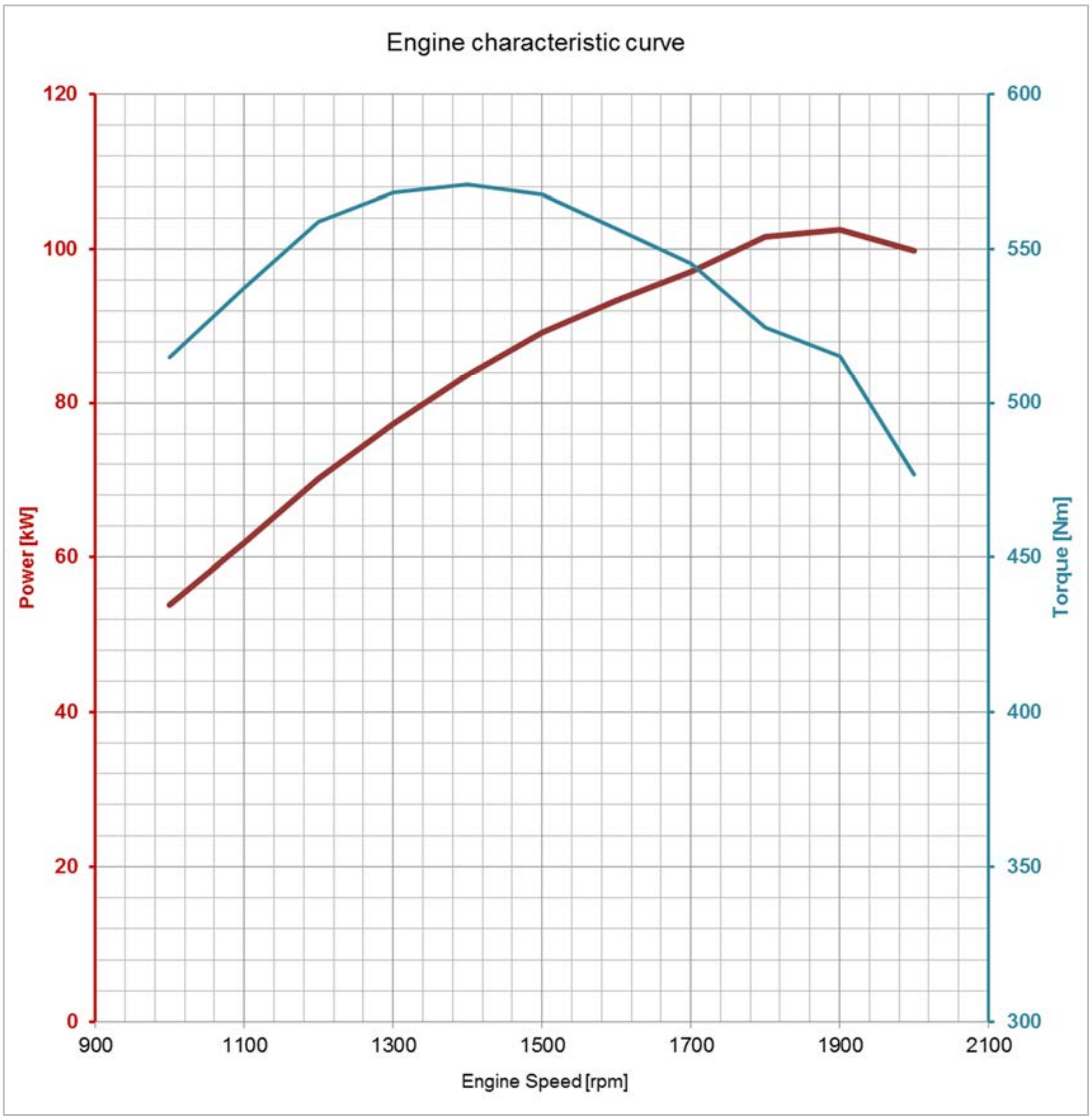


Figure 57. APMT engine characteristic curve

During the full load test, the smoke results at steady state speed were measured as shown in Table 30.

Speed rpm	**Opacity** 1/m
1000	1.916
1100	1.588
1200	1.449
1300	1.204
1400	1.011
1500	0.781
1600	0.665
1700	0.565
1800	0.485
1900	0.412
2000	0.386
1900	0.413
1800	0.481
1700	0.538
1600	0.665
1500	0.791
1400	1.004
1300	1.134
1200	1.371
1100	1.675
1000	2.012

Table 30: Opacity results of APMT engine

4.2. APMT engine mapping

The engine mapping was performed to measure the exhaust gas emissions at different speeds and loads taking advantage of the engine installation in the test bench. The results of this test will be taken into account after the engine conversion to compare its capabilities and develop an assessment of the pollutant emissions of both diesel and natural gas fuels.

SPEED rpm	Net power kW	Net torque Nm	Fuel consumption kg/h	NO_X ppm	CO ppm	THC ppm
1000	11.4	109.0	3.33	330.3	279.2	237.0
1000	22.5	215.1	5.33	424.5	156.2	219.4
1000	33.7	321.4	7.50	560.1	133.1	212.8
1000	45.2	431.8	10.04	669.7	279.8	210.9
1000	54.8	523.6	12.15	737.3	628.9	195.5
1000	54.9	524.3	12.23	994.4	1057.0	247.6
1200	13.7	108.7	4.00	260.7	183.0	202.5
1200	27.0	214.9	6.42	406.8	146.7	217.2
1200	40.5	322.6	8.89	539.7	108.8	198.1
1200	54.1	430.5	11.68	670.4	110.3	186.1
1200	67.1	534.2	14.68	746.1	262.9	158.6
1200	70.4	560.3	15.61	1029	582.4	193.5
1400	15.5	106.1	4.92	252.2	170.4	185.1
1400	31.2	212.5	7.61	385.5	143.6	193.0
1400	46.9	319.7	10.68	513.2	98.0	184.6
1400	62.6	427.2	13.69	626.9	85.4	173.7
1400	78.2	533.4	17.18	687.6	155.2	156.8
1400	83.9	572.4	18.63	706.1	219.7	138.8
1600	17.9	107.2	5.89	232.6	159.6	183.5
1600	35.7	213.2	9.04	349.7	129.2	182.2
1600	53.6	320.1	12.35	473.2	83.4	162.6
1600	71.6	427.2	15.91	584.8	72.3	153.0
1600	89.4	533.4	19.91	636.1	122.8	141.5
1600	93.8	559.8	21.01	643.8	152.3	131.4
1800	20.2	106.9	6.96	213.8	144.3	180.9
1800	40.2	213.2	10.64	322.6	113.3	169.9
1800	60.3	320.0	14.36	506.3	89.1	177.1
1800	80.5	427.2	18.52	704.4	107.6	183.0
1800	100.3	532.4	23.00	586.9	113.0	129.6
1800	100.9	535.4	23.17	584.9	123.4	119.9
2000	22.5	107.2	8.45	204.8	135.4	173.3
2000	44.7	213.2	12.52	401.0	155.9	205.4
2000	67.0	320.1	16.86	388.3	72.3	140.8
2000	89.6	427.9	21.67	466.9	78.4	125.1
2000	99.8	476.8	23.98	495.6	108.8	116.5

Table 31: Engine mapping results of APMT engine

4.2.1 Exhaust gas emissions

The engine mapping imposes several operating parameters of the engine for different working conditions. The exhaust emissions, fuel consumption and performance plots are used to be the cover letter of the machine.

The exhaust emissions and the fuel consumption value can be plotted by contour maps, where three-dimensional data can be graphed. Once the engine mapping has taken place, it is interesting to view the exhaust emissions in terms of speed and load. Brake Mean Effective Pressure (BMEP) is a parameter generally used to represent the torque behaviour in standardized terms and, therefore, is an indicator of the load applied to the engine.

Thus, nitrogen oxides (NO_x), carbon monoxides (CO) and total hydrocarbon (THC) emissions are displayed in the following contour maps based on engine speed and BMEP. As it can see, the engine produces less pollutant emissions at medium speeds and loads where it should work normally. In spite of this, it will be interesting to see how the pollutant emissions decrease with natural gas combustion with regard to the current combustion.

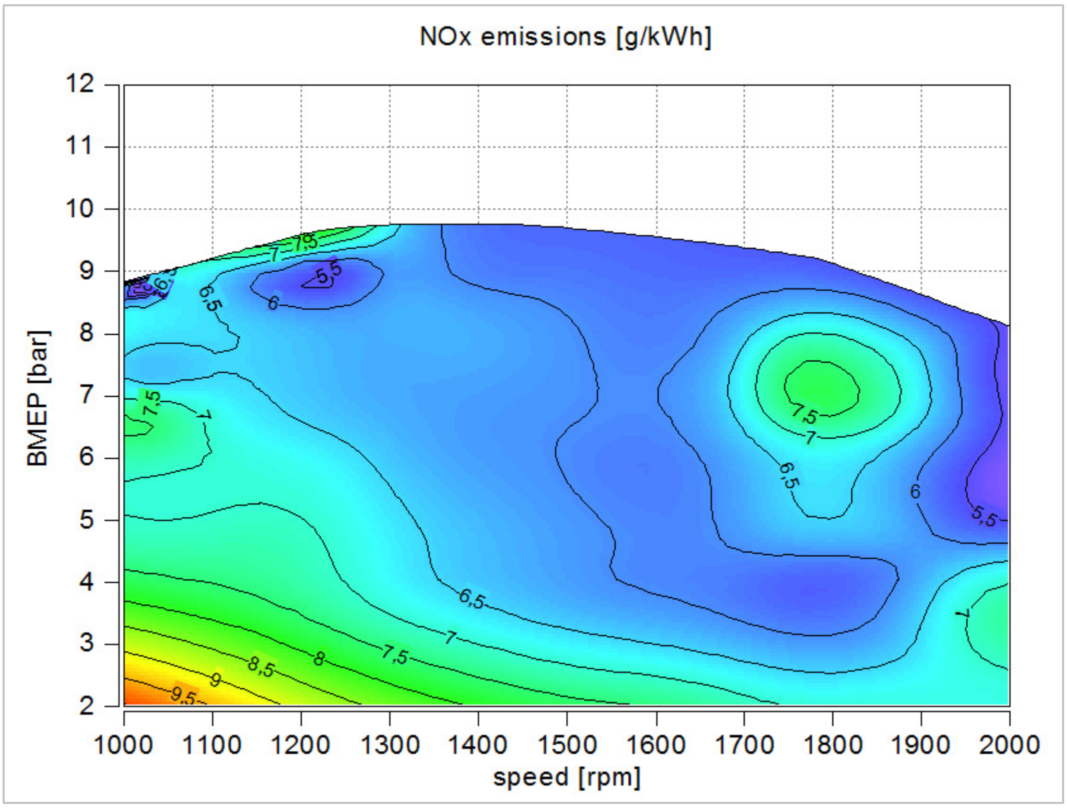


Figure 58. NO_x emissions of APMT engine

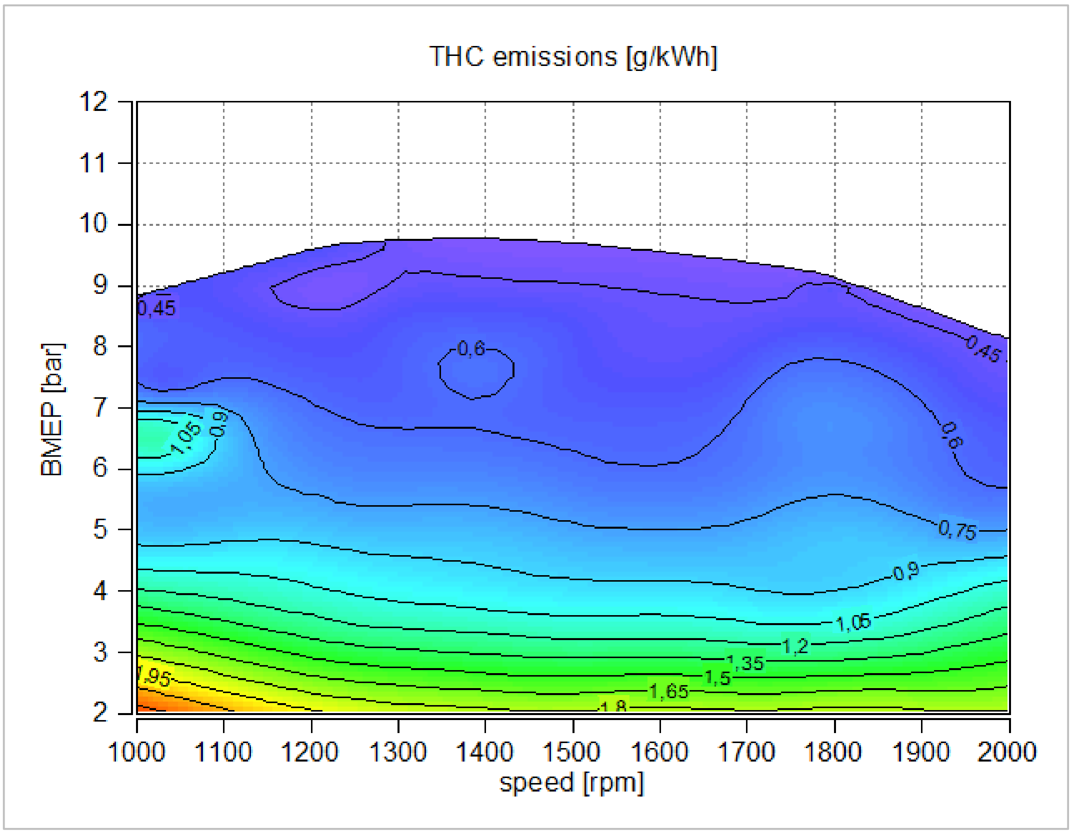


Figure 59. THC emissions of APMT engine

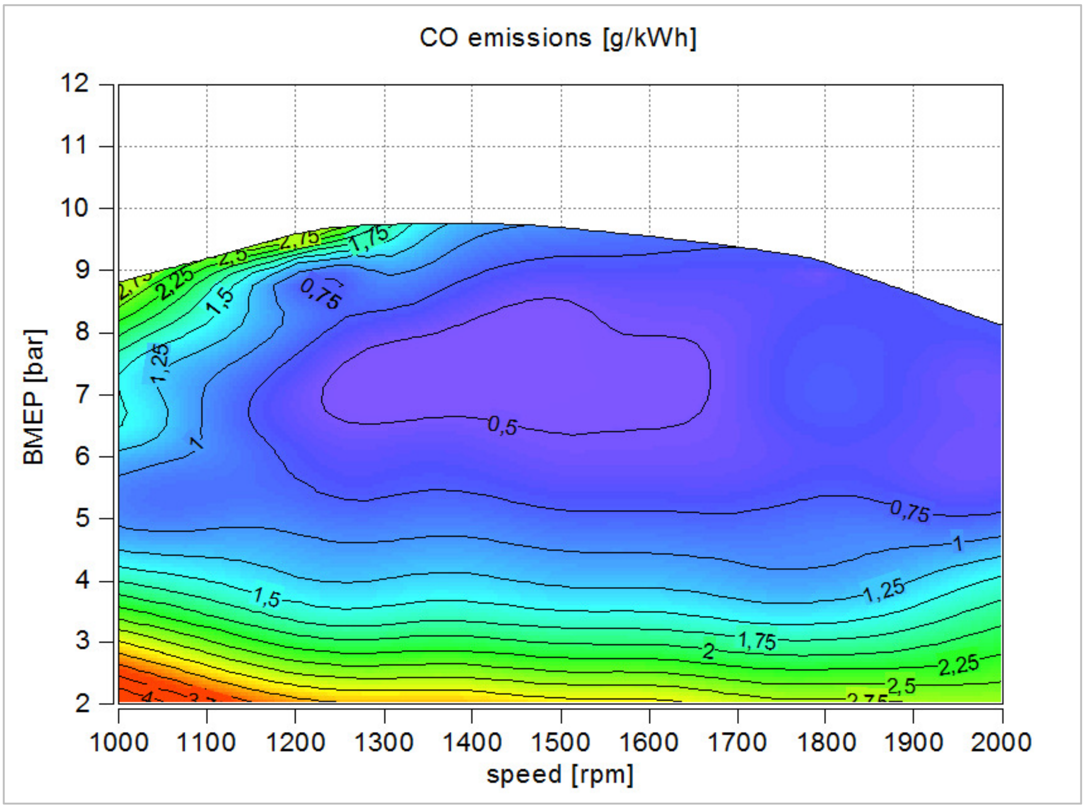


Figure 60. CO emissions of APMT engine

4.2.2 Fuel consumption

Relating the energy consumption, **¡Error! No se encuentra el origen de la referencia.** shows the specific diesel consumption of the engine, which indicates its efficiency to transform the fuel into mechanical energy, and it is expressed as the fuel consumed in terms of mass to obtain a characteristic power during a period of time (g/kWh).

The graph reveals that the engine presents an increase in fuel consumption at higher speeds while the best efficiency is achieved at high loads and medium speeds.

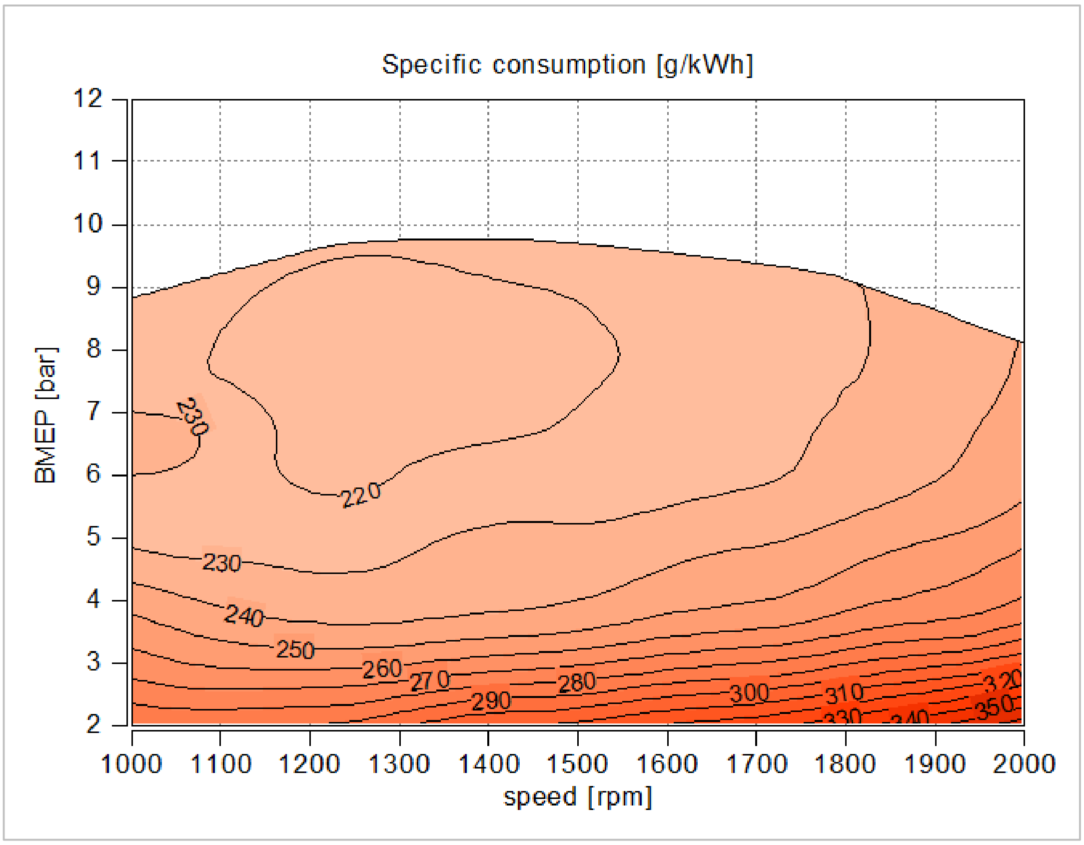


Figure 61. Fuel consumption of APMT engine

5. Engine & Straddle Carrier Conversion

This chapter explains the planned solutions to convert the straddle carrier and the original engines and obtain a natural gas and dual fuel combustion according to their needs and the availability of the machines.

5.1. Engine conversion

IDIADA identifies some possible different engines based on the baseline engines used in the straddle carriers.

Since there is not any regulation in place allowing NG for Non-Road applications yet, this new gas engine will follow the Directive 2012/46/EU[2] and equivalences from Regulation 49.06[3] and Regulation 595[4]. Since this project deals with the development of an engine conversion pilot and to view the exhaust emissions reductions of a natural gas, it is not necessary to subject the prototype to a homologation process. This means that the engine does not need to comply with the current emissions standards despite it will be designed and calibrated to achieve the highest reduction of pollutant emissions.

Moreover, as the engine is supplied and powered by natural gas, the new components will follow the regulation No 110[5] concerning the approval of those specific components of motor vehicles that use compressed natural gas or liquefied natural gas.

5.1.1 APMT engine conversion

From APMT side, this terminal makes use of two VALMET 612's with 134 kW each as baseline engines. It was decided to convert the diesel engine of the straddle carrier into a gas engine powered by natural gas. Hence the conversion of the Valmet 612

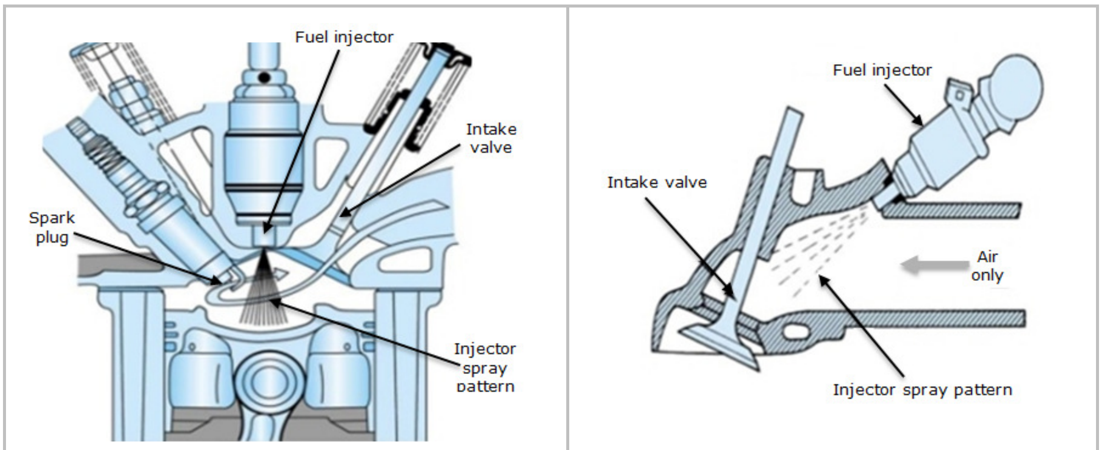
[2] Commission Directive 2012/46/EU of 6 December 2012, amending Directive 97/68/EC of the European Parliament and of the Council on the approximation of the laws of the Member States relating to measures against the emission of gaseous and particulate pollutants from internal combustion engines to be installed in non-road mobile machinery.
[3] Regulation No 49 of the Economic Commission for Europe of the United Nations (UN/ECE) — Uniform provisions concerning the measures to be taken against the emission of gaseous and particulate pollutants from compression-ignition engines and positive ignition engines for use in vehicles
[4] Regulation (EC) No 595/2009 of the European Parliament and of the Council of 18 June 2009 on type-approval of motor vehicles and engines with respect to emissions from heavy duty vehicles (Euro VI) and on access to vehicle repair and maintenance information and amending Regulation (EC) No 715/2007 and Directive 2007/46/EC and repealing Directives 80/1269/EEC, 2005/55/EC and 2005/78/EC.
[5] Regulation No 110 of the Economic Commission for Europe of the United Nations (UNECE) — Uniform provisions concerning the approval of: I.Specific components of motor vehicles using compressed natural gas (CNG) and/or liquefied natural gas (LNG) in their propulsion system; II.Vehicles with regard to the installation of specific components of an approved type for the use of compressed natural gas (CNG) and/or liquefied natural gas (LNG) in their propulsion system [2015/999].

engine will be based on the modification of some parts and the replacement or implementation of some new systems to work with natural gas.

There are a variety of approaches and technologies to convert a diesel engine into natural gas engine in accordance with its performance characteristics. These technologies range in cost and complexity, as well as in efficiency and emissions. Natural gas fuelling technologies follow those of gasoline powered engines as natural gas; in consequence this engine should operate in accordance with the Otto cycle.

Heavy-duty machines or vehicles work much like gasoline engines with a spark-ignited internal combustion engines. They used to be supplied with liquefied natural gas (LNG) to meet range requirements. This fuel is cooled and stored cryogenically in a liquid form and in a security part of the machine. In comparison with compressed natural gas (CNG), LNG presents a higher energy density which means that the tank is able to store more fuel on board.

Fuel can be injected into the intake manifold (port fuel injection or PFI) or into the combustion chamber (direct injection or DI). With the former technology, the fuel is combined with air in the intake manifold where the mixture has more time to form and is directed to the combustion chamber. About the latter option, natural gas is injected directly into the combustion chamber where the flow movement allows the correct mixture. For the difficulties that the implementation of a direct injection presents because hard transformation of the head is needed, in that project a fuel injection will be considered at the intake port.



Direct injection | Port injection

Figure 62. Schemes of direct and port injections

Then, the air-fuel mix is ignited by the spark of a spark plug following Otto cycle combustion. So the spark plug system must be studied including its characteristics and location in the engine.

Once the performance test of the APMT engine is completed and in order to study the dimensions, the components and, therefore, the modifications that will be implemented in the engine, it is necessary to carry out a three-dimensional data of the engine by a 3D scanner. The 3D scanner is a type of device that studies an object or environment to collect data about the external characteristics and, in particular, the dimensions, shapes and location of all engine systems.

Entire engine has been scanned as well as the different parts of it like the intake and exhaust manifold. As an example, 3D scanning allows engineers to draw the new intake manifold where natural gas injectors will be located and design it according to the baseline geometry taking into account the inlet holes.

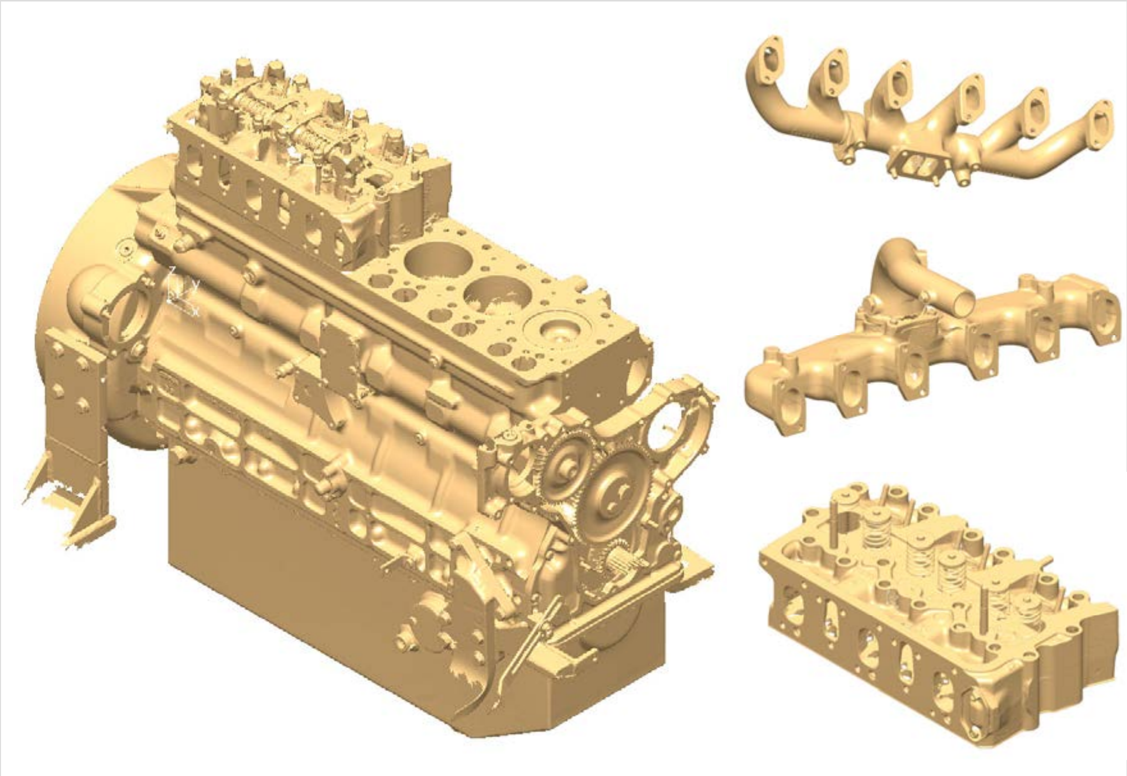


Figure 63. 3D scan of the different parts of the APMT engine

The combustion chamber will be modified by the mechanization of the piston and a part of the head, in order to reproduce accurately the gas combustion. At this point, a study of the shape of the piston bowl and the values of the compression ratio will be developed.

The gas combustion needs natural gas injectors, which will be located in a new design of intake manifold. To obtain the best mixing conditions, a Computational Fluid Dynamics (CFD) simulation is going to take part during the design process to determine the location of the injectors. Since the diesel injector will be removed, the spark plug could be located in the hollow of the diesel injector.

Moreover, new components – such as supports – and new systems will be analysed according to the engine status and, especially, to its age. For example, components that are not installed in an old engine should be taken into account as the Electronic Control Unit (ECU), electrical wiring and sensors. According to the engine operating conditions, it will be necessary to choose a throttle valve, a turbocharger, an intercooler and a catalyst. Most of these systems will be studied after the gas combustions environment.

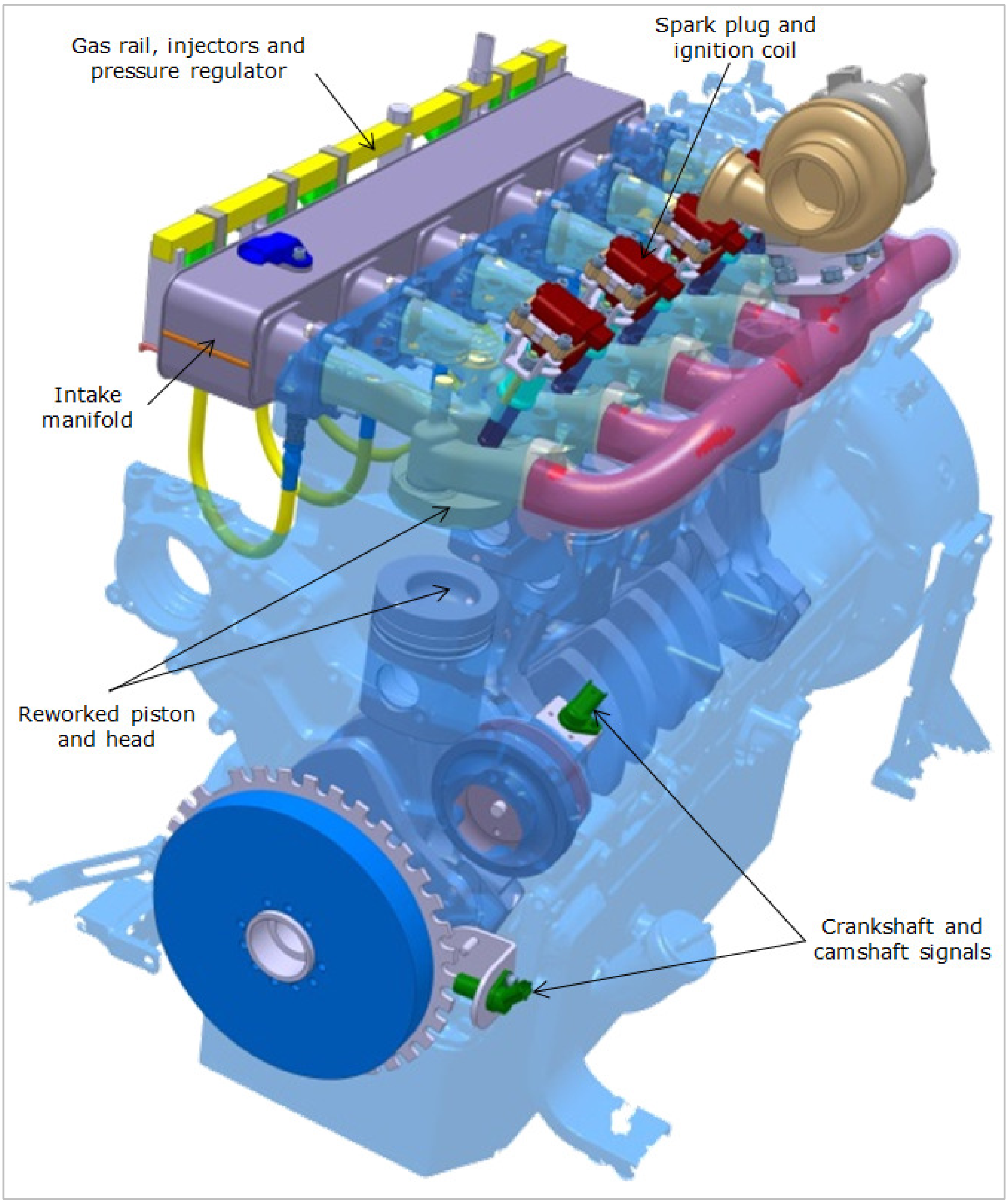


Figure 64. Planned modifications of the APMT engine

5.1.2 BEST engine conversion

From the BEST side, the terminal uses a SISU engine of 273 kW/1500 Nm. It was decided to convert the diesel engine of the BEST straddle carrier into a dual fuel engine, which means that the engine operates with diesel or with both diesel and natural gas. This type of engine allows to return to diesel combustion at any time and if the natural gas supply ends. But before developing the engine conversion, it is necessary to know the technical feasibility of the straddle carrier approved by the manufacturer.

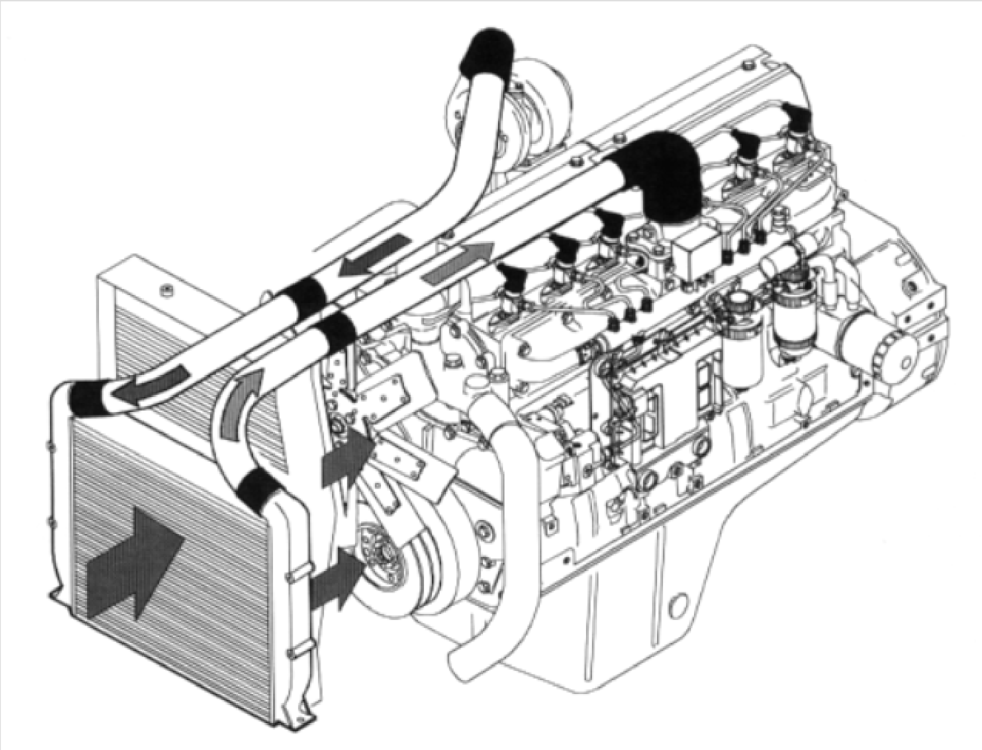


Figure 65. Scheme of the original engine SISU.

Dual fuel engine adopts a Diesel cycle combustion using diesel pilot injection like a spark plug and then the single combustion stroke continues by means of natural gas delivered into inlet duct of each cylinder.

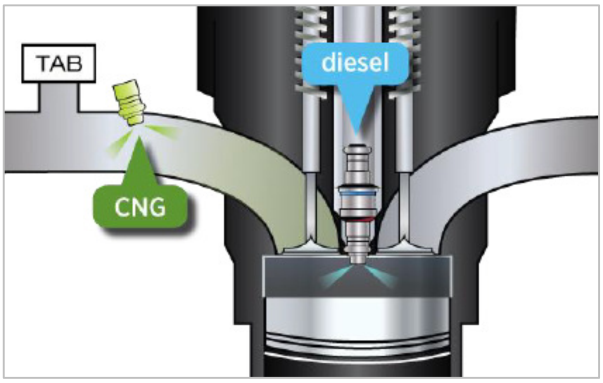


Figure 66. Scheme of the dual fuel injection

In dual fuel engines, natural gas is mixed with the inlet air in the combustion chamber either by direct mixing in the intake manifolds with air or by injection directly into the cylinder. The injection solution is to implement a gas port injection installed in the intake pipe, while pilot quantities of diesel are injected directly into the cylinder to ignite the gas as the baseline operation of the engine. Since dual fuel engine requires significant synchronization of the injection systems to optimize diesel substitution and, therefore, the combustion process, a standard engine control unit – an electronic control unit (ECU) – must be integrated with some new sensors.

Furthermore, additional exhaust after-treatment systems will be added in order to manage the exhaust emissions from the methane combustion.

Therefore, the conversion takes into account mechanical modifications to inject natural gas and control the exhaust emissions and, consequently, electronic modifications, whose function is to govern the natural gas system. The result of the conversion is that the engine will replace a percentage of the diesel without loss of performance.

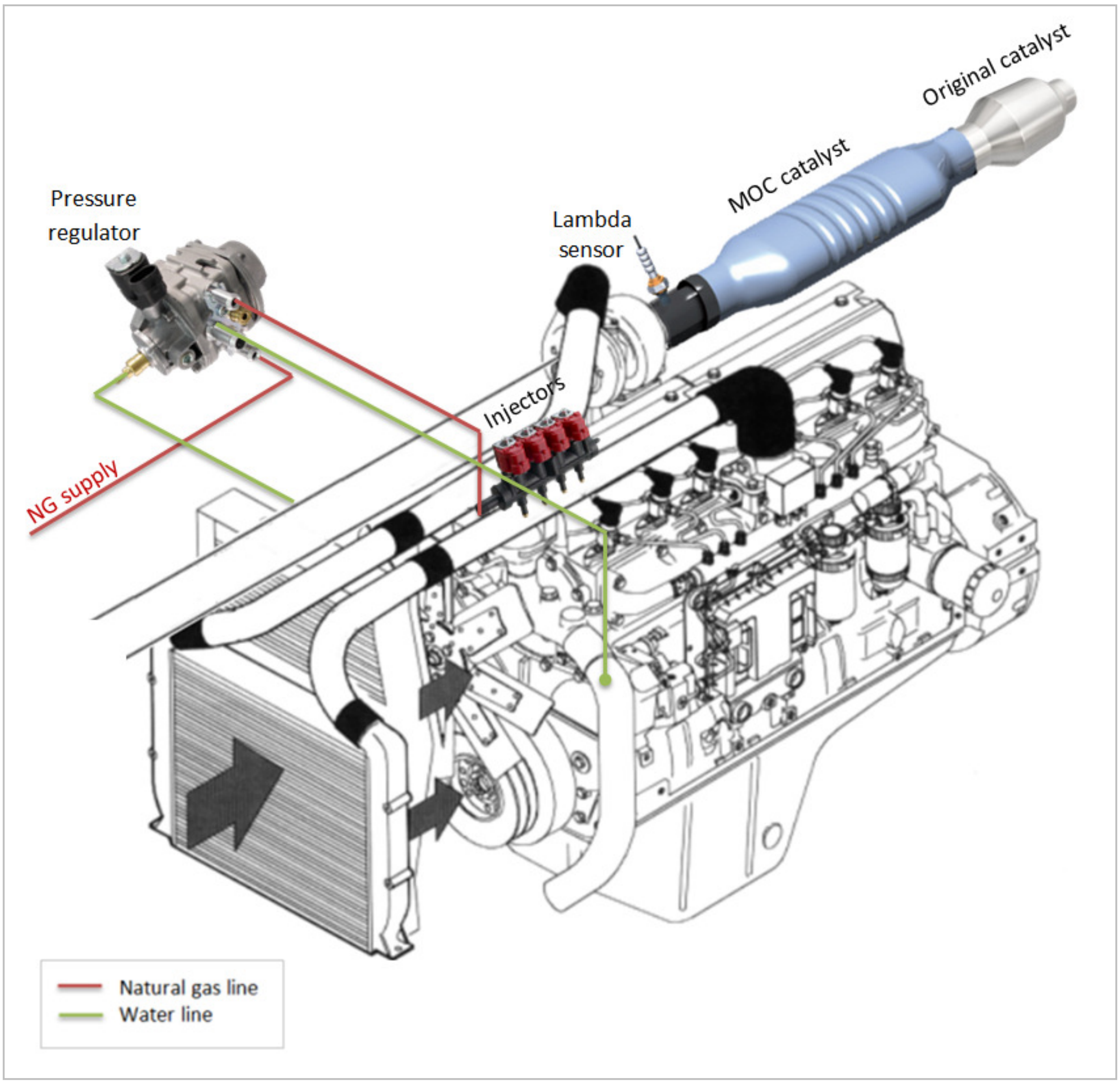


Figure 67. Modifications and new components installation in the BEST straddle carrier engine.

5.2. Straddle carrier conversion

Since the engine of the straddle carrier will be converted, the machine also involves some modifications, particularly in the fuel supply. The supply of natural gas requires a fuel tank and pipe network whose design should be studied in accordance with the straddle carrier dimensions.

5.2.1 BEST Straddle Carrier conversion

With regard to the BEST straddle carrier, a study of the main changes should be submitted to the manufacturer of the machine – KALMAR – in order to approve the technical feasibility of the straddle carriers considering the engine conversion and in particular all the new components installed.

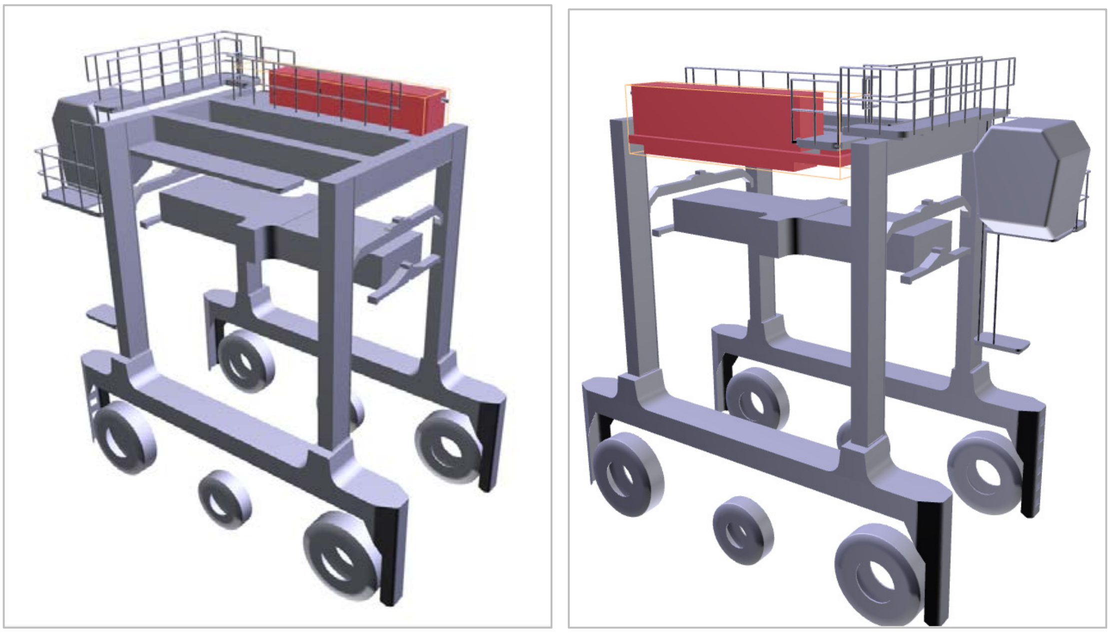


Figure 68. CAD geometry of the BEST straddle carrier

To this end, IDIADA performs a CAD geometry of the machine considering the most relevant parts. For its part, HAM studies the feasibility of installing the LNG system according to the straddle carrier dimensions. Under the usable space and the defined engine location, the LNG tank will be located as close as possible to the engine in order to avoid complex pipe lines. As it can see in the next figure,

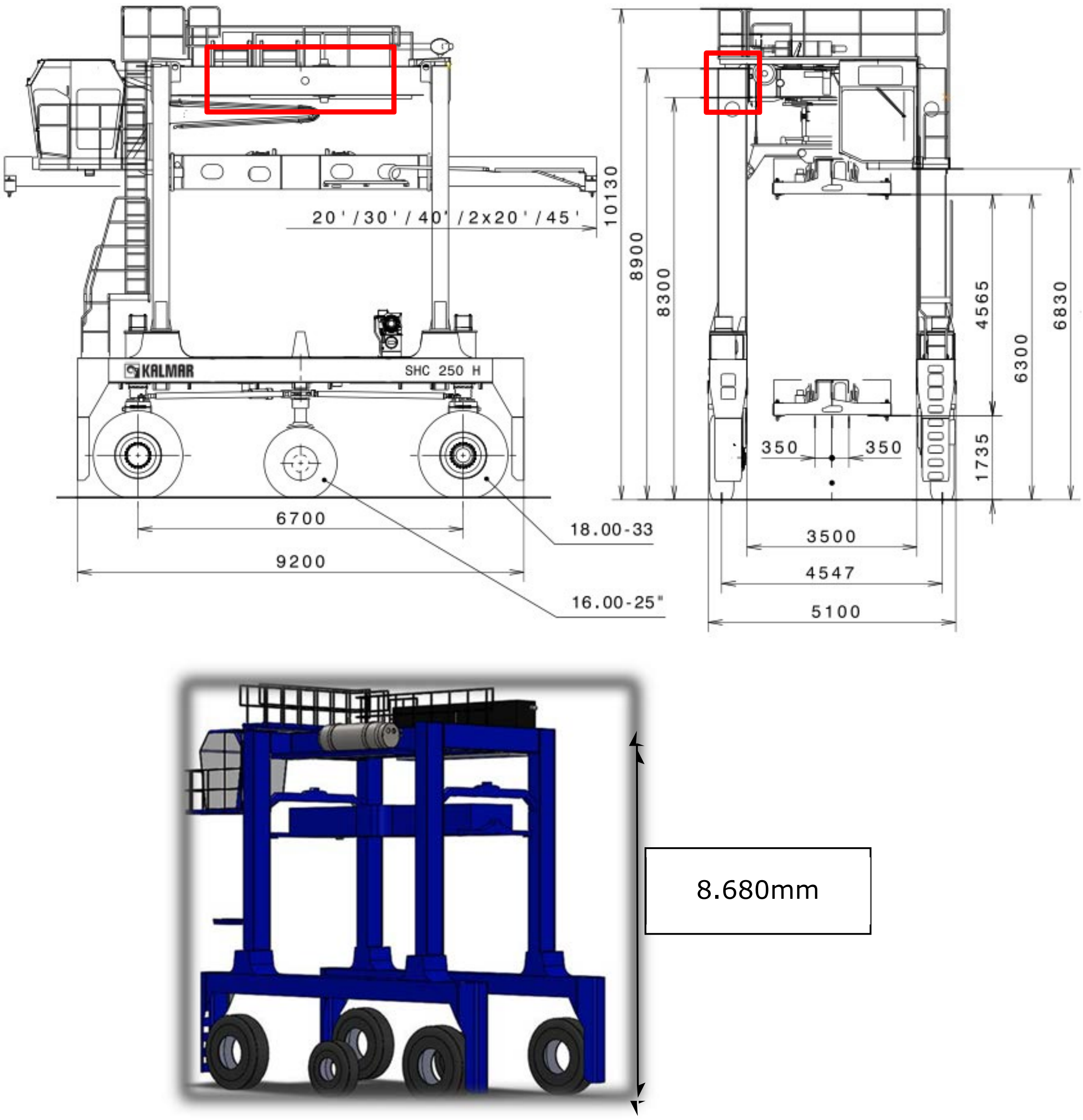


Figure 69. Location of the engine and the LNG system on the best straddle carrier

The subjection is located around the tank and welded on the structure of the Straddle Carrier. The maximum solicitation that this subjections will have to support is 5.713N.

In the internal face, is located a rubber to avoid the contact metal-metal.

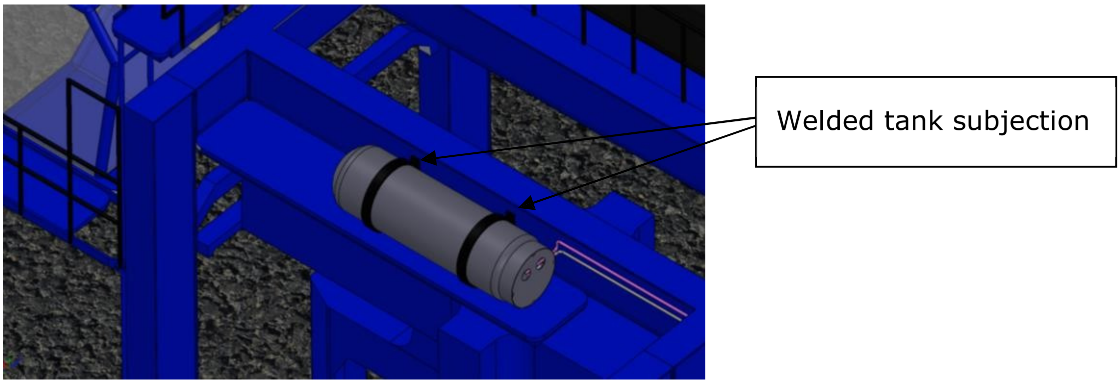


Figure 70. LNG Tank fixed

Figure 71. Straddle Carrier in Best Terminal

The pipe system will be located on the same way as hydraulic installed system, using clamps on the structure.

The pipe system is defined as;

- Filling pipe: From the tank to the filling zone.
- Cooling system: From the tank to an exchange system (cabi heating pipe).
- Consumption pipe: From tank to engine

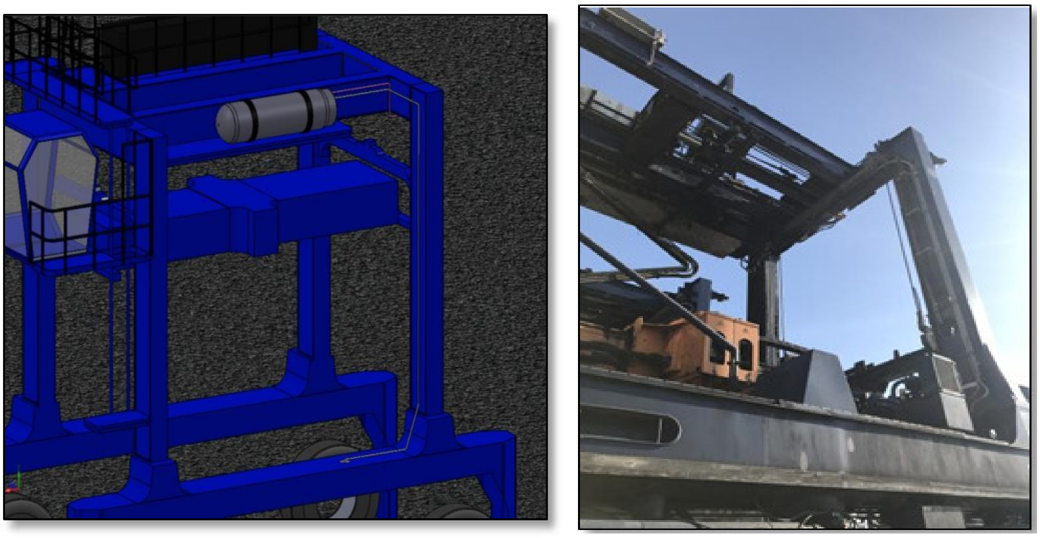


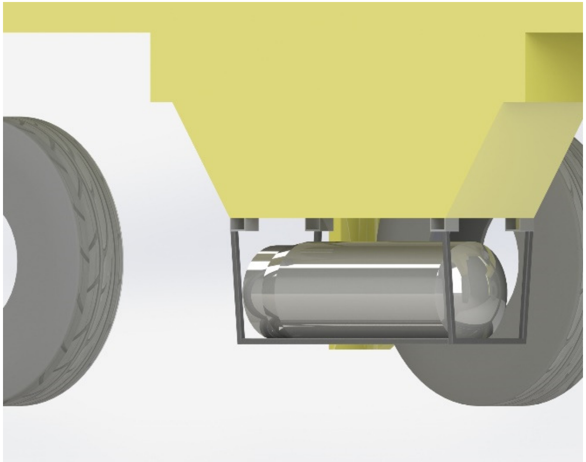
Figure 72. Pipe system

Figure 73. Filling zone

5.2.2 APMT Straddle Carrier conversion

The LNG storage on the APMT Straddle Carrier, will be located under the engine, between the heels. At the moment, on that location is installed a stairs for maintenance, that stairs will be modified in order to adjust the tank.

Figure 74. Straddle carrier stairs



The LNG storage tank will be located on a bench, protected and subjected.

The subjection will be part of the structure of the bench. Between faces of the subjection, will be located a rubber to avoid the contact face to face of the metal.

Figure 75. Bench

To give more protection to the LNG storage tank and to avoid the weather wear, a drawer will protect the kit.

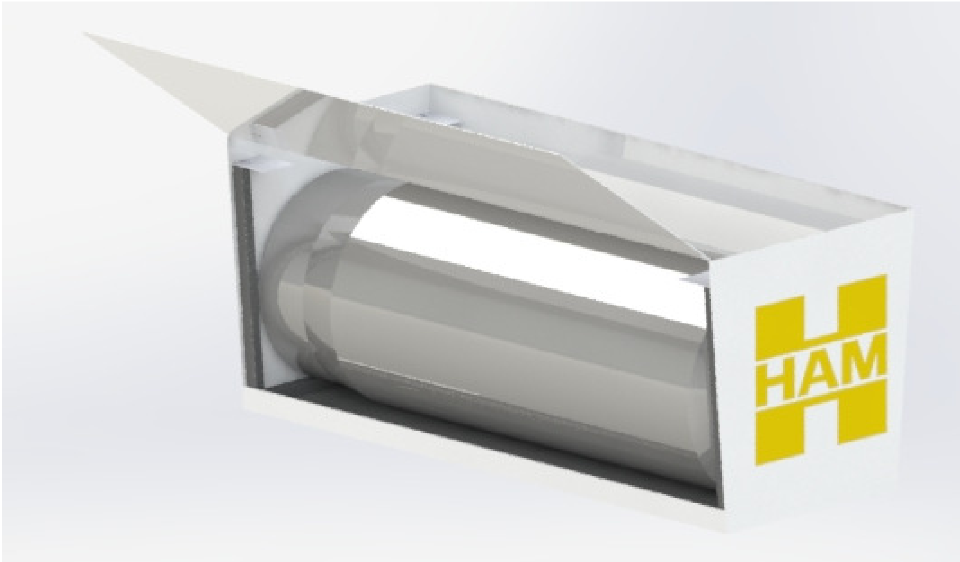


Figure 76. **Drawer**

Figure 77. **Closed drawer**

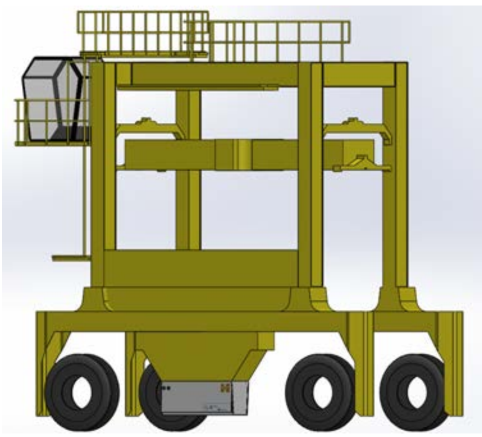


Figure 78. **Straddle Carrier**

Figure 79. Straddle carrier actually

5.2.3 LNG Supply

The LNG supply system of the straddle carrier will be created to feed the dual engine system designed, that implies that the initial fuel system is not going to be modified.

The LNG supply system is going to be located on the bottom of the Straddle Carrier, specifically on the opposite site of the engine.

Figure 80. LNG Dewar

PLUMBING STYLE	*SINGLE*
DESCRIPTION	HLNG158
DIM "A" (mm)	1917
DIM "B" (mm)	660
DIM "C" (mm)	1454
DIM "D" (mm)	162
LIQUID CAPACITY (L)	481
ESTIMATED TARE WT (Kg)	254
FULL ESTIMATED TARE (Kg)	470.5

Table 32:LNG Tank description

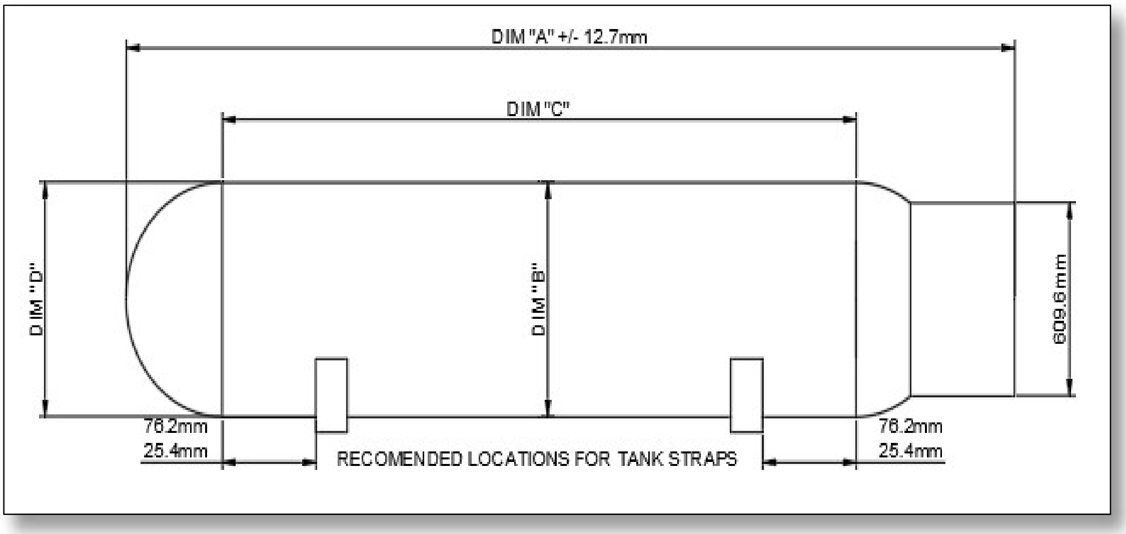


Figure 81. LNG: Tank dimentions

- LNG density: 450Kg/m^3 - LNG Capacity: 481 L = 0.481 m^3 - LNG Wg; WL = 450Kg/m^3 * 0.594m^3 = 216.5 Kg - Tare tank: 254Kg - Total Tare: 216.5Kg + 254Kg = **470.5Kg**

Table 33: LNG Storage specifications

Designed, constructed and tested to all applicable standards:

- US Specifications: SAE, J2343, NFPA, SE, CA Title13, TRRC.
- Available Specifications: R110, TPED, RDW, AS1210, PESO, GOST, KGA, KHK.
- System drop and fire tested per R110.
- Auto refrigeration system.
- 2nd Generation cryogenic super insulation.
- "Integrated" system vaporizer.

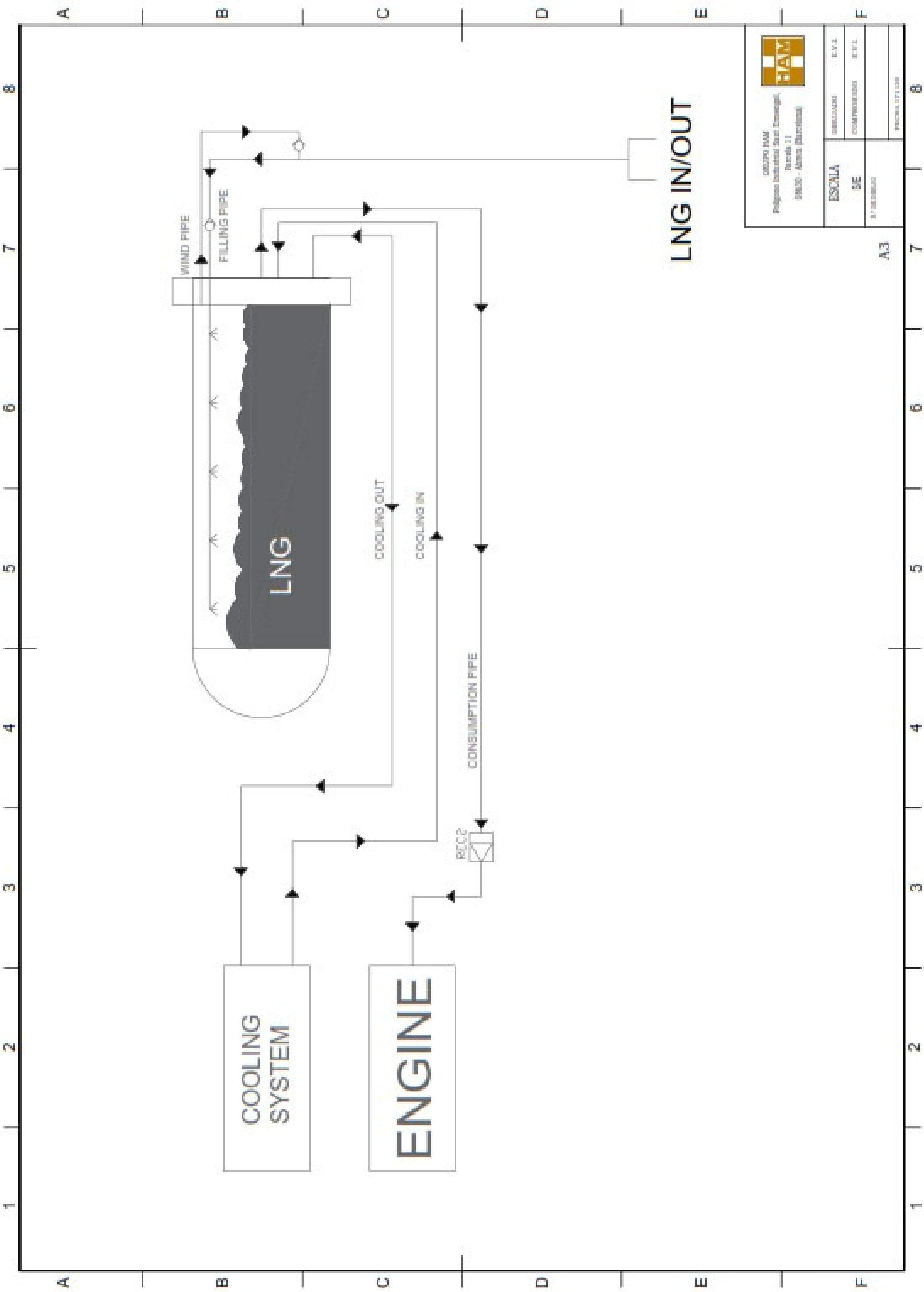


Figure 82. P&I Storage system

SYSTEM	DESCPRIPTION
FILLING PIPE	Pipe next to the structure from the point of fill and the entrance of the tank.
WIND PIPE	Pipe used to get down the internal presure of the tank. This pipe act just in case that it's necessary. (Automaticaly).
COOLING IN	System used to get up the temperature inside the tank. It's used to get more service pressure inside the tank.
COOLING OUT	Pipe to extract the cooling in system.
CONSUMPTION	Direct pipe to the engine.
REC2	Regulator before entry on the engine.
LNG IN/OUT	Filling and wind pipe.

Table 34: Pipe description

5.2.4 Regulation

In order to define a regulatory framework for the regulation of the modification, the Straddle Carrier is defined as a vehicle of the MAA category, Automotive Machines (according to the General Vehicle Regulations). Likewise, and within the same category, MAA is defined as, automotive machine to carry out agricultural, forestry and works and/or services of category 1 with a maximum construction speed ≤ 40 km / h.

Defined within the framework according to the General Vehicle Regulations, the regulations are.

5.2.4.1 Regulation Nº.110 R110

This regulation No. 110 applies to:

Specific components for vehicles of category M and N powered by CNG (compressed natural gas) and LNG (liquefied natural gas).

Vehicles of category M and N with respect to the installation of specific components powered by CNG (compressed natural gas) and LNG (liquefied natural gas).

Classification of the components according to;

- *Class 0.* Parts subjected to high pressures including tube and fittings containing CNG at a pressure higher than 3 MPa and up to 26 MPa.
- *Class 1.* Parts operating at medium pressure, containing CNG. Pressure between 450kPa and 3,000kPa (3Mpa).
- *Class 2.* Components of low pressure. CNG containers at pressures between 20Kpa and 450Kpa.
- *Class 3.* Parts as safety valves or elements protected by the same CNG containers at a pressure between 450kPa and 3,000kPa (3MPa).
- *Class 4.* Parts in contact with gas at a pressure below 20 kPa.
- *Class 5.* Parts in contact with the gas at a temperature below -40ºC.
- Class 6. Elements in contact with the gas at pressure higher than 26Mpa.

All components must be by the following Class definition diagram.

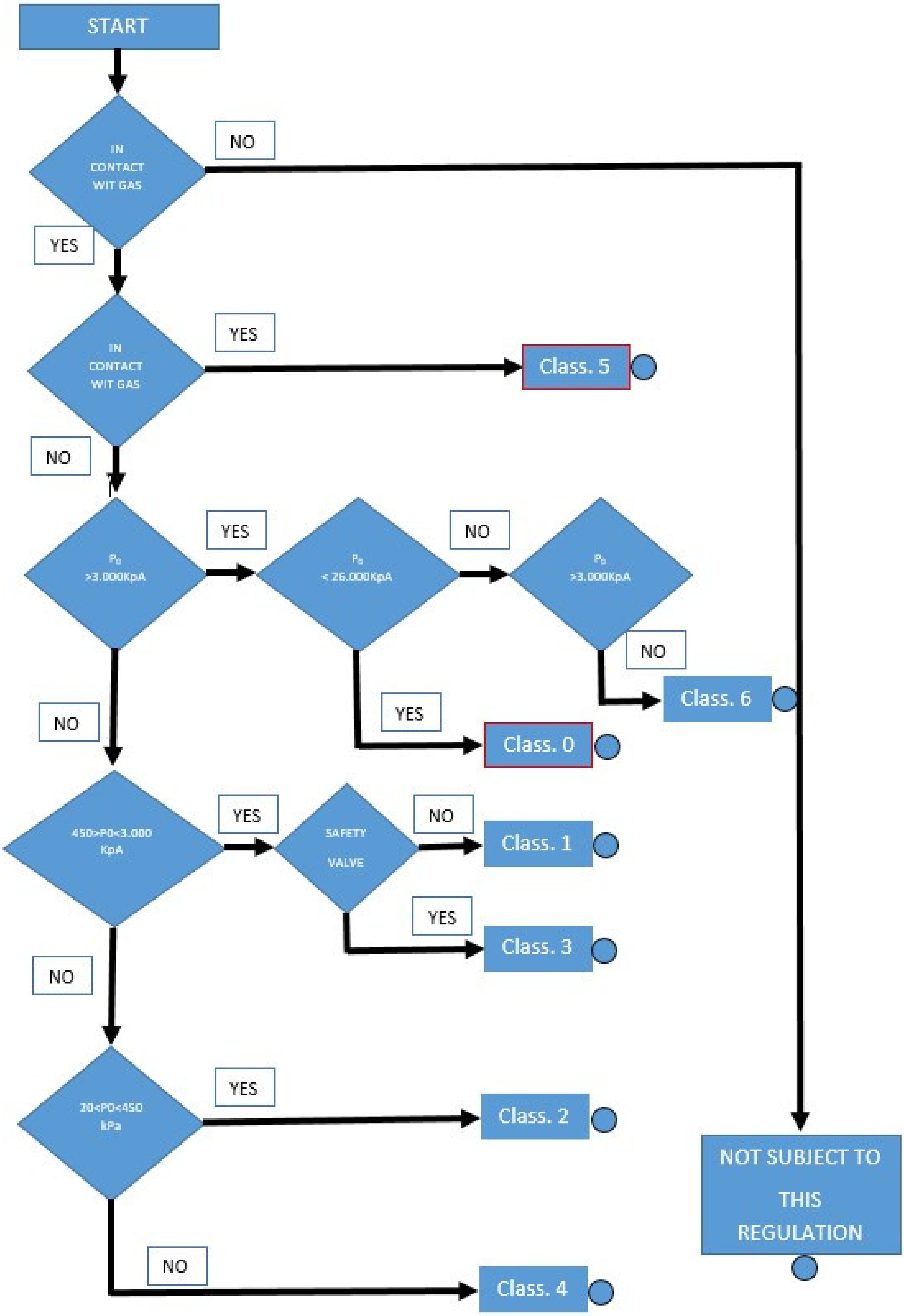


Figure 83. R110 Diagram

Specific testing according to component.

Specific and applicable test according to classes (excluding the LNG tank).

TEST	CL.0	CL.1	CL.2	CL.3	CL.4	CL.5	CL.6	ANEXO
SOBREPRESIÓN O FUERZAS	X	X	X	X	O	X	X	5A
FUGA EXTERNA	X	X	X	X	O	X	X	5B
FUGA INTERNA	A	A	A	A	O	A	A	5C
TEST DURABILIDAD	A	A	A	A	O	A	A	5L
COMPATIBILIDAD LNG	A	A	A	A	A	A	A	5D
RESISTENCIA CORROSION	X	X	X	X	X	A	X	5E
RESISTENCIA CALOR SECO	A	A	A	A	A	A	A	5F
ENVEGECIMIENTO	A	A	A	A	A	A	A	5G
TEST DESTRUCTIVO	X	O	O	O	O	A	X	5M
CICLO TEMPERATURA	A	A	A	A	O	A	A	5H
CICLO PRESION	X	O	O	O	O	A	X	5I
RESISTENCIA VIBRACIONES	A	A	A	A	O	A	A	5N
TEMPERATURAS DE OPERACION	X	X	X	X	X	X	X	5O
BAJA TEMPERATURA LNG	O	O	O	O	O	X	O	5P

Table 35 Application according to classes

Requirements for the installation

A) The LNG system of the vehicle must operate correctly and safely at operating pressure and operate according to the temperature at which it was designed.

B) All the components must be marked individually or jointly.

C) Necessary the use of appropriate materials for its function.

D) All components must be installed correctly for their function.

E) The LNG system must be pressurized in order to test the non-appearance of leaks. Process through a system that does not generate bubbles or equivalent for 3 minutes.

F) The system must be designed and assembled, avoiding possible danger points, collisions, etc.

G) Only specific components can be connected for proper operation.

H) The vehicle can have heating for the driver's compartment and / or the cargo area of the tank of the LNG system.

I) the heating system will be accepted if it complies with the technical requirements, adequate and with the appropriate safety measures without influencing the proper functioning of the LNG system.

J) The identification of "fed with LNG" in the vehicle would be necessary.

K) Vehicles of category M2 and M3 must have a level as marked in Annex 6.

L) The level must be installed in the front part in vehicles of category M2 or M3 and on the other hand, in the external part of the doors.

M) A level must be installed at the point of loading of the vehicle.

Own requirements of the installation, tank / tanks of LNG

The storage system must:

- The tank or tanks must be installed permanently.

- The installation does not allow the system to be metal-metal contact.

- When the vehicle is ready to move, the tanks should not be less than 200mm from the ground surface.

The tank or tanks must be installed and fixed to support the following accelerations.

- Vehicles M1 and N1:
  - 20g in the direction of travel.
  - 8g perpendicular to the line of travel.
- M2 and N2 vehicles:
  - 10g in the direction of travel.
  - 8g perpendicular to the line of travel.
- M3 and N3 vehicles:
  - 6.6g in the direction of travel.
  - 5g perpendicular to the line of travel.

5.2.4.2 Manual of reforms in vehicles. RD866/10 2014

Royal Decree 866/2010 regulates the processing of vehicle reforms. Its purpose is to unify criteria of Spanish legislation on the subject and that issued by the European Union. This Royal Decree maintains the coherence between the European regulation of homologation of vehicles and the national one on the reforms of the same ones; its application will allow to maintain the conditions of active and passive safety of the vehicles and their behaviour in regard to the protection of the environment. Likewise, it establishes the documentation that must be presented before the bodies of the competent Administration in the matter of technical inspection of vehicles, the transformation and the specific requisites required will be those contained in this Manual of Vehicle Reforms.

The Royal Decree 866/2010, in its article 3, defines the Manual of Vehicle Reforms in this way:

"Document prepared by the Ministry of Industry, Tourism and Commerce in collaboration with the competent bodies in the field of ITV of the Autonomous Communities, which establishes the descriptions of the typified reforms, their codification and the precise documentation for their processing."

STRUCTURE OF THE MANUAL

This manual divides the vehicles into four sections;

I. VEHICLES OF CATEGORIES M, N AND O.

II. VEHICLES OF CATEGORIES L, QUADS AND UTV.

III. AGRICULTURAL VEHICLES

IV. WORK VEHICLES AND / SERVICES

Definition of actions according to Royal Decree for modifications on the configuration of the drive unit of a vehicle.

"Modification of the location, replacement, adition or reduction of the number of fuel tanks".

MANUAL DE REFORMAS DE VEHÍCULOS
III.- VEHÍCULOS AGRICOLAS
Grupo Nº 2. Unidad Motriz
(2.7)

DESCRIPCIÓN: Modificaciones sobre la configuración de la unidad motriz del vehículo

2.7.- Modificación de la ubicación, sustitución, adición o reducción del número de depósitos de combustible

CAMPO DE APLICACIÓN

Categorías

T1	T2	T3	T4	T5.1	T5.2	MTC	MAA	MA2	MA3	TCA	RA	MAR
SI	SI	SI	SI	SI	SI	SI	SI	SI	SI	SI	NO	NO

ACTOS REGLAMENTARIOS

Sistema afectado	Referencia	Aplicable a												
		T1	T2	T3	T4	T5.1	T5.2	MTC	MAA	MA2	MA3	TCA	RA	MAR
Depósito de combustible	**74/151/CEE (III)**	(1)	(1)	(1)	(1)	(1)	(1)	-	-	-	-	-	x	x
Depósitos de combustible	**70/221/CEE(I)**	-	-	-	-	-	-	-	-	-	(1)	-	x	x
Masa máxima en carga	**74/151/CEE (I)**	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	-	(1)	x	x
Masas y dimensiones (resto vehículos)	**97/27/CE**	-	-	-	-	-	-	-	-	-	(1)	-	x	x
Equipos especiales para GLP	**Reglamento CEPE/ONU 67R**	-	-	-	-	-	-	-	-	-	(1)	-	x	x
Equipos especiales para GNC	**Reglamento CEPE/ONU 110R**	-	-	-	-	-	-	-	-	-	(1)	-	x	x
Sistemas especiales de adaptación al GLP o GNC	**Reglamento CEPE/ONU 115R**	-	-	-	-	-	-	-	-	-	(1)	-	x	x

Ver Apartado 4 del preámbulo.

MANUAL DE REFORMAS DE VEHÍCULOS III.- VEHÍCULOS AGRICOLAS **Grupo Nº 2. Unidad Motriz** **(2.7)**

DOCUMENTACIÓN NECESARIA				
Proyecto Técnico	**Certificación final de obra**	**Informe de Conformidad**	**Certificado del Taller**	**Documentación adicional**
NO	NO	SI	SI	NO

- **Informe de conformidad**
- **Certificado del Taller**

CONJUNTO FUNCIONAL
El titular del vehículo o la persona por él autorizada aportará: - Copia de la Resolución de la Autoridad de homologación. - Informe según Anexo II. - Certificado del taller según Anexo III.

INSPECCIÓN ESPECÍFICA. **PUNTOS A VERIFICAR SEGÚN MANUAL DE PROCEDIMIENTO DE INSPECCIÓN DE LAS ESTACIONES ITV (SECCIÓN III)**
Capítulo 9. - Motor y Transmisión

NORMALIZACIÓN DE LA ANOTACIÓN DE LA REFORMA EN LA TARJETA ITV
__/__/___ Modificación configuración depósitos combustible 1 x _____ litros en ______ + 1 x ______ litros en ______ + _____ … (Firma y sello) ITV Nº NNNN

Table 36 Inspections. Manual of vehicles reforms

6. Risk Assessment

RISK DESCRIPTION	RISK EVALUATION	ACTION PLAN (INCLUDING COUNTERMEASURES)	RESPONSIBLE	DUE DATE	STATUS
No refilling LNG station	R	To confirm with GNF the real chances of implementing a LNG station	GNF	As soon as possible	Pending
No agreement with APMT and BEST for LNG purchase because of NG vs Diesel price	R	To confirm real prices of LNG that can be expected during the pilot	APB, GNF, APMT, BEST	As soon as possible	Pending
Permits for LNG station inside the Port terminal	Y	APB to confirm terminals will have the rights to install LNG station	APB	As soon as possible	Pending
BEST straddle carrier conversion	Y	BEST cannot provide an engine for baseline testing in test bench	IDIADA	To be cancelled	Only "on-board" measurements possible

Table 37: Risk assessment in this project

7. Conclusions

Finally, a lot of tests were performed on both APMT engines and BEST engines at Barcelona Seaport. These tests consisted of different steps and each one was a test in which vehicle speed and pollutant emissions were measured.

Currently, IDIADA has a VALMET 612 engine (APMT) in its facilities where research about the engine conversion from Diesel running engine to NG running engine is being carried out. However, BEST engines are used daily so the feasibility study that IDIADA should perform is more difficult despite a first design of the engine is developed.

Taking into account the LNG features, the autonomy of the engines and an estimation of the capacity of LNG tanks have been calculated as well. A first study of its location has been carried out.

In conclusion, after considering the operation of the machine, the original design of the engine and the location of the natural gas fuel tank, it can be considered that the transformation of the APMT Straddle Carrier is feasible. Although a more exhaustive transformation design is needed, it will be developed in the coming months and will be presented in the following deliverables.

With regard to the BEST machine, it is complicated to define its technical feasibility due to its engine could not be tested at IDIADA test benches.

8. List of Acronyms and Abbreviations

APB	Autoridad Portuaria de Barcelona – Port de Barcelona
APMT	APM Terminals
BEST	Barcelona Europe South Terminal
BMEP	Brake Mean Effective Pressure
CFD	Computational Fluid Dynamics
CO	Carbon monoxide
CO_2	Carbon dioxide
ECU	Electronic Control Unit
GNF	Gas Natural Fenosa
HAM	HAM Criogénica
LNG	Liquefied Natural Gas
NG	Natural Gas
NO_x	Nitrogen oxides
PEMS	Portable Emissions Measurement Systems
THC	Total Hydrocarbon