Forschungsgesellschaft für Verbrennungskraftmaschinen und Thermodynamik mbH

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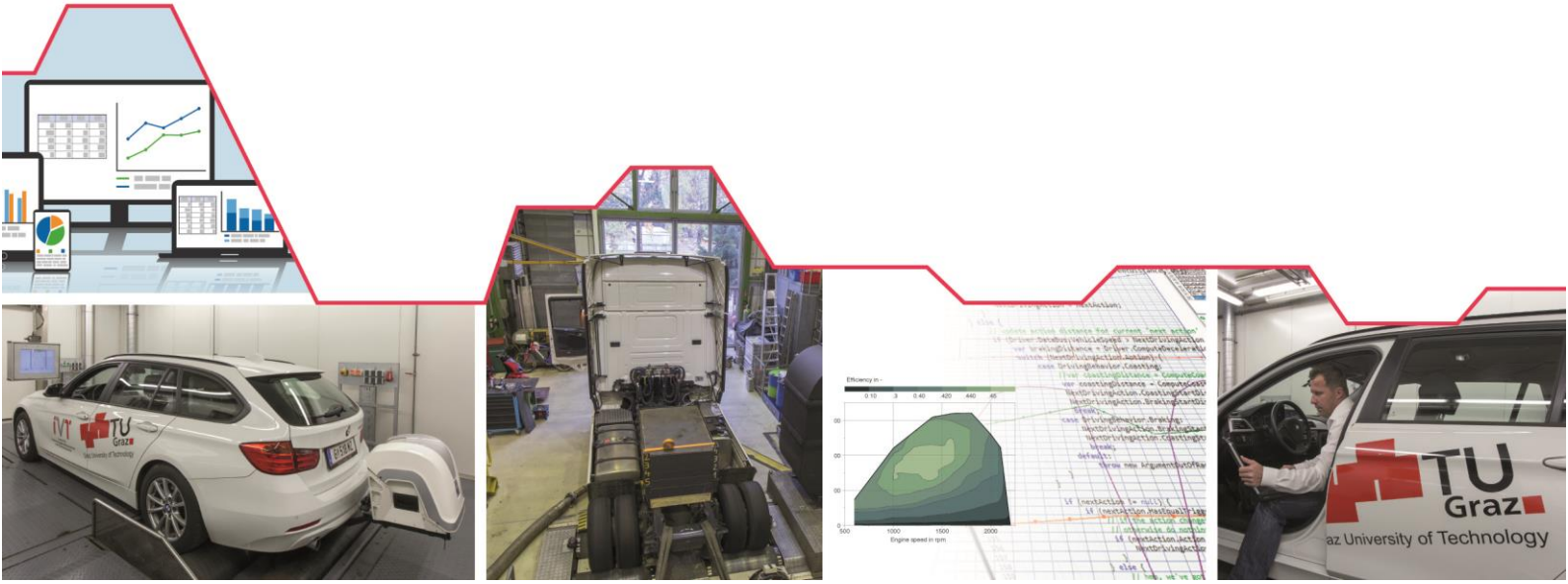
Emission performance of N3 HDVs based on chassis dyno tests

06.08.2021



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Datum 06.08.2021

Report No.: FVT-039/21/Wel EM-20/19/6932

Customer: Transport & Environment

Quote

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CONTENT

Abbreviations

AMT	Automated Manual Transmission
ASG	Analytik-Service AG
AVL	Anstalt für Verbrennungskraftmaschinen List
CAN	Controller Area Network
CPC	Condensation Particle Counter
DPF	Diesel Particle Filter
FTIR	Fourier-Transform Infrared Spectroscopy
FVT	Forschungsgesellschaft für Verbrennungskraftmaschinen und Thermodynamik mbH
HDV	Heavy Duty Vehicle
IAG	Industrie Automatisierungsgesellschaft mbH
ISC	In-service Conformity
LNG	Liquified Natural Gas
MIL	Malfunction Indicator Light
PEMS	Portable Emission Measurement System
SCR	Selective Catalytic Reduction
TUG	Graz University of Technology

1 Scope of the Work

FVT performed chassis dyno and on-road emission measurements on two N3 heavy-duty vehicles of emission standard Euro VI D. One vehicle was powered by LNG and one by Diesel. The test program comprised per vehicle two tests on the chassis dyno. FVT recorded standard exhaust gas components, exhaust mass flow and available CAN Bus signals. FVT measured additional non-regulated pollutants via FTIR on the chassis dyno only. In addition, FVT measured 23, 10 and 4 nm particles (50 % cut-off, 4 nm only on the chassis dyno) with a dilution system developed in the Horizon2020 project “Down-To-Ten” as ordered by the customer.

This report represents only the tests on the chassis dyno.

2 The Measurement Campaign

This section describes the measurement equipment, the selection of the test vehicles and the test program.

2.1 The Measurement Equipment

FVT installed the measurement equipment on the vehicles and recorded additionally available CAN Bus signals. FVT used the AVL MOVE as PEMS on the chassis dyno and measured the particles (23 nm, 10 nm and 4 nm) with CPCs and the Down-To-Ten dilution system. Additional non-regulated emission components have been recorded via FTIR from IAG on the chassis dyno. FVT provided the result files containing following signals in 1 Hz to the customer:

- Regulated and unregulated components: 13Butadiene, Acetaldehyde, Acetylene, Acrolein, Benzene, Butane, CH_4, CO, CO_2, COS, Cyclohexane, Ethane, Ethanol, Ethylene, Formaldehyde, Formic Acid, H_2SO_4, HC, HCN, HNCO, HNO_2, HNO_3, Isobutylene, Isopentane, Methanol, N_2O, NH_3, NO, NO_2, NO_x, Pentane, Propane, Propylene, SO_2
- Particle numbers > 23 nm (50% cut-off), > 10 nm and > 4 nm (only on the chassis dyno)
- Exhaust mass flow
- Available CAN Bus signal, vehicle specific.

A detailed description of the measurement systems can be found in the annex.

2.2 The Test Vehicles

FVT rented two N3 long haul trucks from independent hauliers. Both vehicles are form the make Iveco. Test vehicle°1, an Iveco Stralis, is powered by Diesel and test vehicle°2, an Iveco S-Way, is powered by LNG. The vehicle selection has been carried out in close coordination with the customer. Since both vehicles are long haul trucks from the same manufacturer, the vehicle technology is similar. Consequently, differences in the emission behaviour can be mainly related to the different engine technologies.

2.2.1 Test Vehicle°1

Test vehicle°1 is an Iveco Stralis from a freight company. Figure 1 shows the test vehicle. Table 1 gives an overview of the most important vehicle data.

Figure 1: Test vehicle°1, chassis dyno setup

Table 1: Test vehicle°1, vehicle data

Iveco Stralis MY 16	
Year of first registration	2019
Mileage [km]	216244
Rated engine power [kW]	353
Rated engine speed [rpm]	1900
Engine displacement [cm^3]	11120
Fuel	Diesel
Transmission system	12 gear AMT
Test mass on-road tests [kg]	27900

The customer received all available vehicle documents like registration document or certificate of conformity during the project work.

2.2.2 Test Vehicle°2

Test vehicle°2 is an Iveco S-Way LNG from a manufacturer independent rental company. Figure 2 show the test vehicle. Table 2 gives an overview of the most important vehicle data.

Figure 2: Test vehicle°2, chassis dyno setup

Table 2: Test vehicle°2, vehicle data

Iveco S-Way LNG	
Year of first registration	2021
Mileage [km]	7500
Rated engine power [kW]	338
Rated engine speed [rpm]	1900
Engine displacement [cm^3]	12900
Fuel	LNG
Transmission system	12 gear AMT
Test mass on-road tests [kg]	28000

FVT has already provided all documents like registration document or certificate of conformity to the customer.

2.3 The Test Program on the chassis dyno

The detailed test selection was determined with the customer. The following sections describe the test program in detail.

FVT performed two chassis dyno tests:

- The first test represents urban, rural and motorway driving based on a standard ISC test. The test was split in two single tests for better handling on the chassis dyno. One covers urban and rural driving and the other the motorway part.
  The first part was started as cold start and part 2, the motorway part, was pre-conditioned with 7 minutes driving on the motorway. It has to be mentioned that the motorway test is a follow up test, that means the vehicle and the emission control system were warm at the start of the preconditioning phase and consequently hot at the test start.
- The second test is based on the on-road Regional Delivery test (speed profile and road gradient) of the first test vehicle within to on-road part of this project. This test was also divided in two single tests that can be combined at the end. The first part covers the urban and rural part and the first minutes of motorway driving. The second part starts with the motorway part and continues with the following urban part until the end of the test.
  Part 1, the urban and rural part, is cold started and test part 2, the motorway part, is preconditioned with a 7 minutes motorway drive. This is again a follow up test means warm engine and emission control system at the start of the pre-condition phase and consequently hot after the 7 minutes motorway drive at the start of the test.

Figure 3 and Figure 4 show the speed traces for the two RDE tests of vehicle 2 on the chassis dyno.

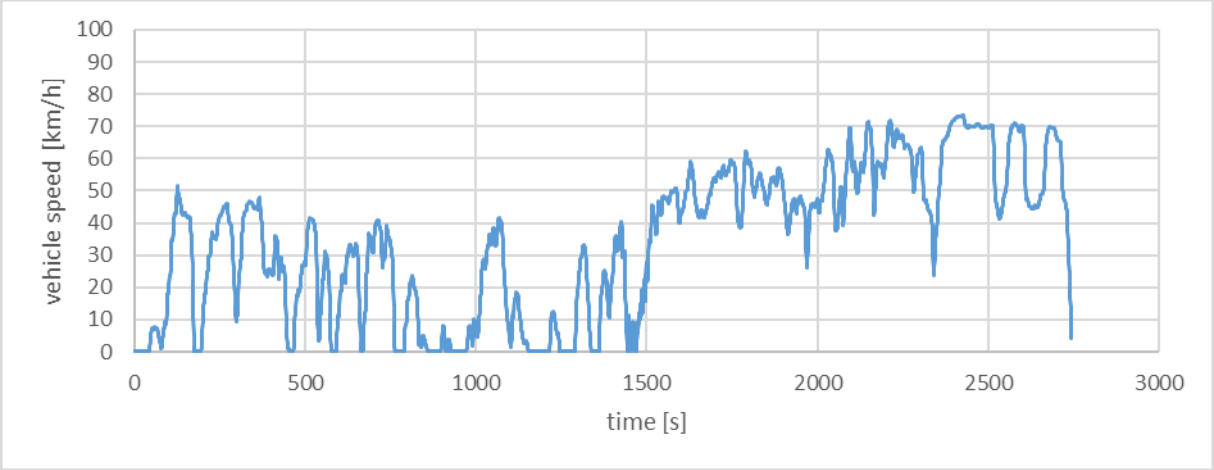

Figure 3: vehicle speed trace over time, RDE urban rural test of vehicle 2

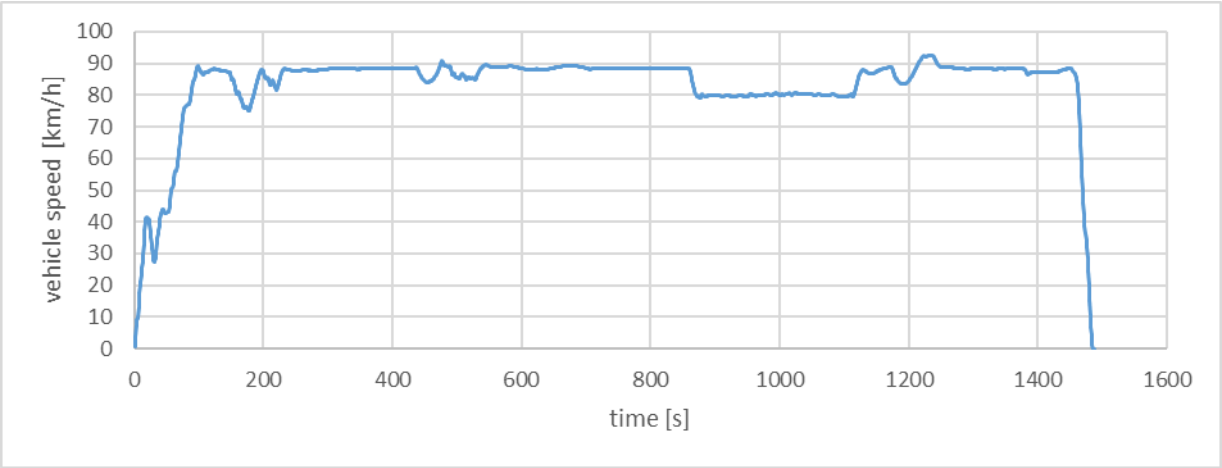

Figure 4: vehicle speed trace over time, RDE motorway test of vehicle 2

Figure 5 and Figure 6 illustrate the vehicle speed profile for the 2 regional delivery test parts of vehicle 2 on the chassis dyno.

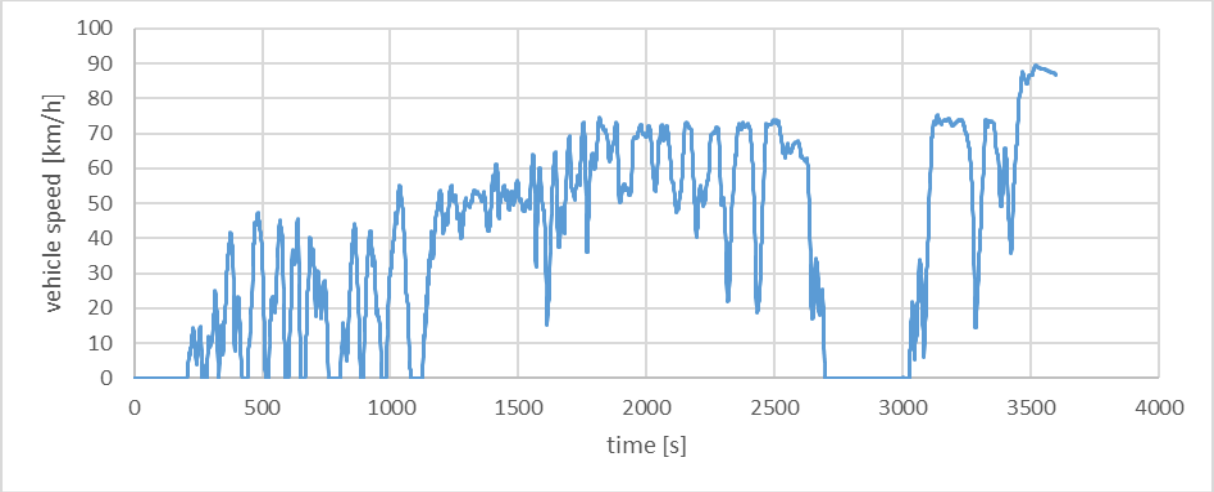

Figure 5: vehicle speed trace over time, RDE motorway test of vehicle 2

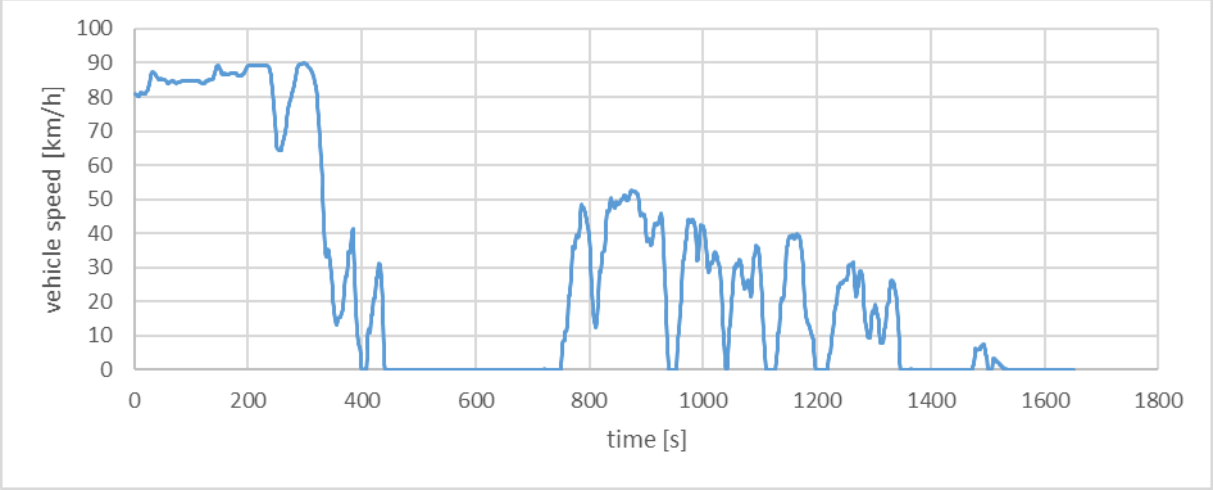

Figure 6: vehicle speed trace over time, RDE motorway test of vehicle 2

Road gradients for the regional delivery test have been calculated by use of the altitude derived from GIS based maps using the longitudinal and lateral GPS coordinates

measured by PEMS. This method reduces the uncertainty due to the GPS inaccuracies regarding the altitude.

Chassis dyno driving resistance parameters have been set according to an internal database that contains real-world parameters for different vehicle and tyre types. FVT used its experience in this topic due to the work for the development of VECTO. The driving resistance parameters have been set equal for both vehicles, because both vehicles are long haul trucks of the newest generation.

The total test mass on the chassis dyno was set also equal for both vehicles.

The auxiliary use during testing was set similar to the auxiliary use in on-road tests. That means auxiliaries like air conditioning or radio were switched on. Consequently, this was representative for real world driving.

3 The Test Results

This section gives an overview about the most important measurement results and boundary conditions.

FVT has already provided the detailed measurement results to the customer. The data provided contains second by second results of all recorded signals and in addition to that, overview files with average test results in g/km and g/kWh for the total test and for the different road categories or test phases.

The total test or phase result files contain some small negative values. These values can be interpreted as zero. In this case, the real values are smaller than the limit of detection of the different analysers and this leads to random noise around zero. The combination of this effect and a small analyser drift can lead to these negative results.

3.1 Test Results Vehicle°1

This section describes the test results of vehicle°1.

3.1.1 Chassis Dyno Test Results Vehicle°1

Following CAN Bus signals could be recorded for vehicle°1:

- Engine speed
- Engine fuel rate
- Current gear
- Actual gear ratio
- Actual engine percent torque
- Friction torque
- Engine coolant temperature
- Engine oil temperature
- Temperature upstream oxidation catalyst
- Differential pressure DPF
- Temperature upstream SCR
- Temperature downstream SCR
- Actual dosing quantity SCR fluid
- Tank level SCR fluid

FVT followed the test program already described in 2.3 and in Table 3 and Table 4. The shares of the different road categories are distance based.

The result files contain all test results split in phases (cold start and hot phase) and in addition the aggregated test results (test°1 +2 and test°3 + 4) split in road categories.

- For that reason, FVT has combined test°1 and 2 to one test which contains urban, rural and motorway driving after a cold start.
- FVT has done this aggregation also for test°3 and 4. The final test represents consequently the Regional Delivery test measured on the road, but a part of the motorway section is cut out of the test.

Table 3: Chassis dyno test overview, vehicle°1

Test nr.	Test	Duration [min]	Ambient temperature	Comment
1	RDE urban rural	45.7	21°C	-
2	RDE motorway	24.8	23°C	-
3	RDE Regional Delivery part 1	60.0	21°C	-
4	RDE Regional Delivery part 2	27.5	22°C	-

Table 4: Chassis dyno trip information

Test nr.	Distance [km]	Share of urban driving [%]	Share of rural driving [%]	Share of motorway driving [%]
1	26.8	34.3	65.7	0.0
2	34.6	0.0	0.0	100.0
3	39.9	15.8	74.8	9.4
4	24.1	20.6	0.0	79.3

The following tables give an overview on the start conditions of the different tests and some of the measured emission components via FTIR and CPC. The results are illustrated in distance based and brake specific form.

Table 5: Chassis dyno test results of gaseous emissions, distance based emissions, vehicle°1

Test nr.	Start conditions	CO2 [g/km]	CO [g/km]	THC [g/km]	NO [g/km]	NOx [g/km]	CH4 [g/km]
1	Cold start	1232.2	1.626	0.001	1.405	2.268	0.000
2	Hot start	947.0	0.002	0.000	0.522	0.647	0.000
3	Cold start	1180.4	2.339	0.001	1.099	1.528	0.000
4	Hot start	922.7	0.326	0.001	0.281	0.328	0.000

Table 6: Chassis dyno test results of unregulated and PN emissions, distance based emissions, vehicle°1

Test nr.	Start conditions	N2O [g/km]	NH3 [g/km]	PN4 [#/km]	PN10 [#/km]	PN23 [#/km]
1	Cold start	0.243	0.020	3.039E+11	2.083E+11	5.604E+10
2	Hot start	0.104	0.021	2.117E+11	1.503E+11	4.646E+10
3	Cold start	0.298	0.009	3.009E+11	1.997E+11	5.338E+10
4	Hot start	0.334	0.003	9.969E+10	7.227E+10	2.400E+10

Table 7: Chassis dyno test results of gaseous emissions, brake specific emissions, vehicle°1

Test nr.	Start conditions	CO2 [g/kWh]	CO [g/kWh]	THC [g/kWh]	NO [g/kWh]	NOx [g/kWh]	CH4 [g/kWh]
1	Cold start	757.5	1.000	0.001	0.864	1.395	0.000
2	Hot start	612.5	0.001	0.000	0.337	0.419	0.000
3	Cold start	693.8	1.375	0.001	0.646	0.898	0.000
4	Hot start	715.5	0.253	0.001	0.218	0.254	0.000

Table 8: Chassis dyno test results of unregulated and PN emissions, brake specific emissions, vehicle°1

Test nr.	Start condi-tions	N2O [g/kWh]	NH3 [g/kWh]	PN4 [#/kWh]	PN10 [#/kWh]	PN23 [#/kWh]
1	Cold start	0.149	0.013	1.868E+11	1.281E+11	3.445E+10
2	Hot start	0.067	0.014	1.369E+11	9.719E+10	3.005E+10
3	Cold start	0.175	0.005	1.769E+11	1.174E+11	3.138E+10
4	Hot start	0.259	0.002	7.729E+10	5.603E+10	1.861E+10

The chassis dyno tests 1 and 2 can be combined to one test, which contains urban, rural and motorway driving parts of an ISC test.

The same can be done with tests 3 and 4. These parts represent together sections of a regional delivery test.

The following tables show the results for the total tests and split in urban, rural and motorway driving parts.

Table 9: Chassis dyno test results of gaseous emissions, distance based emissions, combined tests, vehicle°1

Test nr.	Test part	CO2 [g/km]	CO [g/km]	THC [g/km]	NO [g/km]	NOx [g/km]	CH4 [g/km]
1+2	Total test	1071.4	0.711	0.000	0.907	1.355	0.000
3+4	Total test	1118.0	1.852	0.001	0.901	1.238	0.000
1+2	Urban	2104.0	3.805	0.008	3.590	6.026	0.000
3+4	Urban	2052.8	6.209	0.015	1.942	2.858	0.000
1+2	Rural	774.6	0.483	0.000	0.258	0.296	0.000
3+4	Rural	819.4	0.385	0.000	0.564	0.720	0.000
1+2	Motorway	947.0	0.002	0.000	0.522	0.647	0.000
3+4	motorway	702.0	0.081	0.000	0.447	0.515	0.000

Table 10: Chassis dyno test results of unregulated and PN emissions, distance based emissions, combined tests, vehicle°1

Test nr.	Test part	N2O [g/km]	NH3 [g/km]	PN4 [#/km]	PN10 [#/km]	PN23 [#/km]
1+2	Total test	0.165	0.021	2.52E+11	1.75E+11	5.06E+10
3+4	Total test	0.307	0.008	2.52E+11	1.69E+11	4.63E+10
1+2	Urban	0.365	0.003	3.13E+11	2.28E+11	6.56E+10
3+4	Urban	0.381	0.008	4.22E+11	2.88E+11	8.07E+10
1+2	Rural	0.179	0.030	2.99E+11	1.98E+11	5.10E+10
3+4	Rural	0.319	0.004	2.11E+11	1.36E+11	3.41E+10
1+2	Motorway	0.104	0.021	2.11E+11	1.50E+11	4.64E+10
3+4	motorway	0.194	0.014	1.47E+11	1.05E+11	3.36E+10

Table 11: Chassis dyno test results of gaseous emissions, brake specific emissions, combined tests, vehicle°1

Test nr.	Test part	CO2 [g/kWh]	CO [g/kWh]	THC [g/kWh]	NO [g/kWh]	NOx [g/kWh]	CH4 [g/kWh]
1+2	Total test	677.6	0.449	0.000	0.574	0.857	0.000
3+4	Total test	698.0	1.156	0.001	0.563	0.773	0.000
1+2	Urban	817.4	1.478	0.003	1.395	2.341	0.000
3+4	Urban	731.4	2.212	0.005	0.692	1.018	0.000
1+2	Rural	685.8	0.427	0.000	0.229	0.262	0.000
3+4	Rural	674.3	0.317	0.000	0.464	0.593	0.000
1+2	Motorway	612.5	0.001	0.000	0.337	0.419	0.000
3+4	motorway	656.8	0.076	0.000	0.418	0.482	0.000

Table 12: Chassis dyno test results of unregulated and PN emissions, brake specific emissions, combined tests, vehicle°1

Test nr.	Test part	N2O [g/kWh]	NH3 [g/kWh]	PN4 [#/kWh]	PN10 [#/kWh]	PN23 [#/kWh]
1+2	Total test	0.104	0.013	1.59E+11	1.11E+11	3.20E+10
3+4	Total test	0.192	0.005	1.57E+11	1.05E+11	2.89E+10
1+2	Urban	0.142	0.001	1.22E+11	8.84E+10	2.55E+10
3+4	Urban	0.136	0.003	1.50E+11	1.03E+11	2.87E+10
1+2	Rural	0.158	0.026	2.65E+11	1.75E+11	4.52E+10
3+4	Rural	0.262	0.003	1.74E+11	1.12E+11	2.81E+10
1+2	Motorway	0.067	0.014	1.37E+11	9.71E+10	3.00E+10
3+4	motorway	0.182	0.013	1.38E+11	9.85E+10	3.14E+10

A comparison of the average positive engine power of test°3 on the chassis dyno (67.66 kW) and the exactly same part of the on-road test°3 (67.68 kW, see report “Emission performance of N3 HDVs based on chassis dyno tests”), which is the base for the chassis dyno test, shows a good repeatability of on-road tests on the chassis dyno. Consequently, the chassis dyno tests represent real world driving, but the difference of the ambient temperatures on-road and on the chassis dyno limit the comparability of emission results for similar traffic situations. This is especially the case in the cold start phase.

3.1.2 Fuel Analysis Vehicle°1

FVT did a fuel analysis of the test fuel. For that reason, FVT took a sample out of the tank and sent that to the company ASG, which did the analysis of the fuel.

The calculation of the fuel consumption by use of the carbon balance is based on the values of the fuel analysis. The diesel fuel has a carbon mass content of 85.6 %, a calorific value of 42.515 MJ/kg and a density of 832.3 kg/m^3 (15°C, DIN EN ISC 12185:1977).

FVT forwarded the result file of ASG to the customer.

3.2 Test Results Vehicle°2

This section gives an overview on the test results of vehicle°2.

3.2.1 Chassis Dyno Test Results Vehicle°2

Following CAN Bus signals could be recorded for vehicle°2:

- Engine speed
- Engine fuel rate
- Engine gas mass flow rate
- Current gear

- Actual gear ratio
- Actual engine percent torque
- Friction torque
- Engine coolant temperature
- Engine oil temperature
- Engine exhaust gas temperature

In addition to that, FVT installed a lambda sensor.

FVT did the measurements described in section 2.3 and in Table 13. The distance based shares of the road categories are the same as for vehicle 1, because FVT measured vehicle 2 on exactly the same tests on the chassis dyno (see Table 4).

The result files are structured in the same way as for vehicle°1. They contain all test results split in phases (cold start and hot phase) and in addition split in road categories.

- FVT combined test°1 and 2 to a representative real world test, which includes urban, rural and motorway driving. This is the same test as test°1 + 2 of vehicle°1.
- For comparison reasons between vehicle°1 and vehicle°2, FVT and the customer agreed on repeating exactly the same tests 3 and 4 as for vehicle°1. This means that tests 3 and 4 are based on the speed profile of the Regional Delivery test of vehicle°1. As for vehicle°1, FVT combined tests 3 and 4 to one aggregated regional delivery test.

Since all chassis dyno tests are exactly the same as for vehicle°1, these tests allow a good comparison of the emission behaviour of vehicle°1 and 2. The on-road tests are not directly comparable in terms of emission's results due to the different weather conditions.

Table 13: Chassis dyno test overview, vehicle°2

Test nr.	Test	Duration [min]	Ambient temperature	Comment
1	RDE urban rural	45.7	21°C	-
2	RDE motorway	24.8	22°C	-
3	RDE Regional Delivery part 1	60.0	21°C	-
4	RDE Regional Delivery part 2	27.5	23°C	-

The following tables show the test results and the start conditions for the four chassis dyno tests. These results illustrate total test results in distance based and brake specific form.

Table 14: Chassis dyno test results of gaseous emissions, distance based emissions, vehicle°2

Test nr.	Start conditions	CO2 [g/km]	CO [g/km]	THC [g/km]	NO [g/km]	NOx [g/km]	CH4 [g/km]
1	Cold start	1036.669	3.321	0.330	0.681	0.728	0.248
2	Hot start	836.155	0.960	0.012	0.073	0.058	0.000
3	Cold start	1028.618	2.962	0.413	0.573	0.543	0.336
4	Hot start	888.722	1.353	0.013	0.361	0.355	0.006

Table 15: Chassis dyno test results of unregulated and PN emissions, distance based emissions, vehicle°2

Test nr.	Start conditions	N2O [g/km]	NH3 [g/km]	PN4 [#/km]	PN10 [#/km]	PN23 [#/km]
1	Cold start	0.015	0.076	3.71E+12	3.37E+11	9.78E+10
2	Hot start	0.000	0.015	5.95E+10	3.04E+10	4.30E+09
3	Cold start	0.020	0.072	3.61E+11	2.27E+11	1.06E+11
4	Hot start	0.000	0.035	1.32E+11	9.42E+10	4.81E+10

Table 16: Chassis dyno test results of gaseous emissions, brake specific emissions, vehicle°2

Test nr.	Start conditions	CO2 [g/kWh]	CO [g/kWh]	THC [g/kWh]	NO [g/kWh]	NOx [g/kWh]	CH4 [g/kWh]
1	Cold start	689.9	2.210	0.220	0.453	0.484	0.165
2	Hot start	546.6	0.628	0.008	0.048	0.038	0.000
3	Cold start	659.5	1.899	0.265	0.367	0.348	0.216
4	Hot start	719.5	1.095	0.011	0.292	0.288	0.004

Table 17: Chassis dyno test results of unregulated and PN emissions, brake specific emissions, vehicle°2

Test nr.	Start conditions	N2O [g/kWh]	NH3 [g/kWh]	PN4 [#/kWh]	PN10 [#/kWh]	PN23 [#/kWh]
1	Cold start	0.010	0.051	1.579E+11	1.037E+11	6.507E+10
2	Hot start	0.000	0.010	3.890E+10	1.986E+10	2.813E+09
3	Cold start	0.013	0.046	1.397E+11	8.780E+10	6.804E+10
4	Hot start	0.000	0.029	1.067E+11	7.626E+10	3.891E+10

The following tables show the combination of the single chassis dyno tests to representative tests with urban, rural and motorway parts. This was done in the same way as already explained for vehicle 1.

Table 18: Chassis dyno test results of gaseous emissions, distance based emissions, combined tests, vehicle°2

Test nr.	Test part	CO2 [g/km]	CO [g/km]	THC [g/km]	NO [g/km]	NOx [g/km]	CH4 [g/km]
1+2	Total test	923.0	1.983	0.150	0.337	0.348	0.106
3+4	Total test	994.0	2.564	0.314	0.520	0.496	0.255
1+2	Urban	1716.5	7.893	0.988	1.785	1.904	0.757
3+4	Urban	1818.2	6.841	1.208	1.367	1.353	1.000
1+2	Rural	703.7	1.082	0.008	0.141	0.152	0.000
3+4	Rural	763.2	1.288	0.014	0.279	0.242	0.003
1+2	Motorway	836.2	0.960	0.012	0.073	0.058	0.000
3+4	motorway	608.6	0.740	0.009	0.134	0.128	0.001

Table 19: Chassis dyno test results of unregulated and PN emissions, distance based emissions, combined tests, vehicle°2

Test nr.	Test part	N2O [g/km]	NH3 [g/km]	PN4 [#/km]	PN10 [#/km]	PN23 [#/km]
1+2	Total test	0.006	0.042	1.64E+12	1.63E+11	4.48E+10
3+4	Total test	0.015	0.063	3.04E+11	1.94E+11	9.18E+10
1+2	Urban	0.048	0.207	4.42E+12	5.76E+11	2.51E+11
3+4	Urban	0.061	0.167	7.44E+11	4.78E+11	2.31E+11
1+2	Rural	0.000	0.012	3.36E+12	2.20E+11	2.28E+10
3+4	Rural	0.000	0.033	2.02E+11	1.28E+11	5.89E+10
1+2	Motorway	0.000	0.015	5.95E+10	3.04E+10	4.30E+09
3+4	motorway	0.000	0.016	5.26E+10	3.13E+10	1.26E+10

Table 20: Chassis dyno test results of gaseous emissions, brake specific emissions, combined tests, vehicle°2

Test nr.	Test part	CO2 [g/kWh]	CO [g/kWh]	THC [g/kWh]	NO [g/kWh]	NOx [g/kWh]	CH4 [g/kWh]
1+2	Total test	608.1	1.306	0.099	0.222	0.229	0.070
3+4	Total test	671.9	1.733	0.213	0.352	0.335	0.172
1+2	Urban	764.9	3.517	0.440	0.795	0.849	0.337
3+4	Urban	713.4	2.684	0.474	0.536	0.531	0.392
1+2	Rural	617.6	0.949	0.007	0.124	0.133	0.000
3+4	Rural	664.8	1.122	0.012	0.243	0.211	0.003
1+2	Motorway	546.6	0.628	0.008	0.048	0.038	0.000
3+4	motorway	579.2	0.704	0.009	0.128	0.122	0.001

Table 21: Chassis dyno test results of unregulated and PN emissions, brake specific emissions, combined tests, vehicle°2

Test nr.	Test part	N2O [g/kWh]	NH3 [g/kWh]	PN4 [#/kWh]	PN10 [#/kWh]	PN23 [#/kWh]
1+2	Total test	0.004	0.027	1.08E+12	1.08E+11	2.95E+10
3+4	Total test	0.010	0.042	2.06E+11	1.31E+11	6.20E+10
1+2	Urban	0.021	0.092	1.97E+12	2.57E+11	1.12E+11
3+4	Urban	0.024	0.066	2.92E+11	1.87E+11	9.08E+10
1+2	Rural	0.000	0.010	2.95E+12	1.93E+11	2.00E+10
3+4	Rural	0.000	0.028	1.76E+11	1.11E+11	5.13E+10
1+2	Motorway	0.000	0.010	3.89E+10	1.99E+10	2.81E+09
3+4	motorway	0.000	0.015	5.01E+10	2.98E+10	1.20E+10

3.2.2 Fuel Analysis Vehicle°2

FVT contacted experts at TUG in the field of gas engines and discussed possibilities for taking a probe out of a LNG tank. Unfortunately, nobody could provide a solution. Due to safety reasons, FVT decided not to take a probe out of the LNG tank. However, FVT contacted the gas station where the vehicle tank was filled up before the tests and they could provide a data sheet for their LNG. Since no other data was available, FVT and the customer agreed on using this data[1].

The LNG has a density of 438.1 kg/m^3 at -160°C and an upper calorific value of 54.924 MJ/kg.

FVT has already provided this sheet to the customer.

[1] Of course, FVT will not include the costs for the second fuel analysis in the final invoice.

Annex

Measurement Systems

PEMS

The PEMS system used is an AVL MOVE. This system meets the requirements of the currently valid RDE legislation and enables CO_2, CO, NO_2, NO and THC to be recorded in real operation. CO_2 and CO are measured with your NDIR analyser, NO and NO_2 with a NDUV analyser and THC are measured with a FID. The exhaust gas mass flow is determined with an Exhaust Gas Mass Flow Meter (EFM). Data acquisition takes place with the system's own data logger. In addition to the emission data, all cycle-relevant data such as speed, temperature, air pressure, humidity, GPS position and ECU data are also recorded.

The analysers are calibrated prior to measurement by means of a so-called two-point calibration. This involves a routine consisting of purging the measuring lines, switching on the zero gas (synthetic air) and applying the respective final sample gas value for each analyser. A linear function of the analyser is assumed between zero and final value, which is checked by the manufacturer after reaching certain operating hours or in case of manual interventions in the system.

Technical data:

	Measurement range	Resolution
CO	0 … 15 Vol.-%	1 ppm
CO_2	0 … 20 Vol.-%	0.01 Vol.-%
NO	0 … 5000 ppm	0.1 ppm
NO_2	0 … 2500 ppm	0.1 ppm
THC	0 … 30000 ppmC1	0.1 ppmC1
CH_4	0 … 10000 ppmC1	0.1 ppmC1
O_2	0 … 25 Vol.-%	0.1 Vol.-%

Measuring device for the detection of particle number emissions

The complete measurement device consists of 3 CPC (Condensation Particle Counter) with 23, 10 and 4 nm cut-off points and a portable dilution system for the preparation of the extracted partial exhaust gas mass flow:

Technical data:

Airmodus A23 CPC	
Measured quantity	Particle number concentration in #/cm³
Concentration	0-100000 #/cm³

Particle size range	Dp50%=23nm
Logging rate	1 Hz
Operating temperatures	15°C-35°C
Aerosol sample flow	1 lpm

AVL CPC 10nm	
Measured quantity	Particle number concentration in #/cm³
Concentration	0-10000 #/cm³
Particle size range	Dp50%=10nm
Logging rate	2Hz
Operating temperatures	5°C-25°C
Aerosol sample flow	1 lpm

TSI 3775 4nm	
Measured quantity	Particle number concentration in #/cm³
Concentration	0-10^7 #/cm³
Particle size range	Dp50%=4nm
Logging rate	1 Hz
Operating temperatures	10°C-35°C
Aerosol sample flow	1,5 lpm

Portable Dilution System	
Dilution rate	1-8000
Exhaust sample flow	1 lpm
System efficiency	0.92 at 23nm 0.86 at 10nm 0.72 at 4nm

The measuring device provides the particle count in #/cm³ in the withdrawn partial exhaust gas mass flow. In order to be able to indicate the particle count in the total exhaust gas volume flow, this exhaust gas volume flow must be known. This total exhaust gas volume is measured by using of the exhaust flow meter of the AVL M.O.V.E. measuring system.

Additional equipment:

- Heated sampling line 4m

HDV chassis dyno

Manufacturer: Zöllner

Technical data:

- Max. pulling force: 27 kN
- Max. braking power: 360 kW
- Max. pulling power: 290 kW
- Max. speed: 120 km/h
- Possible vehicle mass: 3.5 t to 38 t
- Roller diameter: 0.5 m
- Max. axle load: 12 t
- Max. load test bed crane: 5 t

The entire mechanical test stand unit is constructed in the form of a steel frame structure in which the roller set, flywheel mass and electrical brake unit assemblies are housed. The test stand frame is supported on a steel frame integrated in the building and is connected to the building structure via vibration damping elements.

The test stand is designed as a double roller test stand and is thus suitable for vehicles with one driven axle. During calibration runs, the front and rear roller sets can be connected to each other with an electrically switchable clutch via a belt drive. In test operation, the rear roller set runs freely and tractive force is transmitted exclusively to the front roller set. The front roller set is connected to a flywheel mass via a toothed belt drive. The transmission ratio is 1:2.

A thyristor-controlled DC machine serves as a brake, which can be operated generatively (braking mode) and motor-driven (towing mode). The brake control is designed for transient driving operation.

The tractive force at the wheel contact point is determined by measuring the torque on the pendulum-mounted braking machine using a load cell. This works according to the strain gauge measuring principle.

The test stand can be equipped with a driving wind simulator. The air speed is then adapted to the respective simulated driving speed by infinitely variable speed control of the fan wheel. In this way, the same thermal conditions for engine cooling can be achieved as in actual driving operation.

Possible operation modes:

The test stand can be operated in stationary and transient mode, whereby both braking and towing operation are possible.

- Stationary operation (dynamometer):
  Control in this mode is either at constant tractive force or constant driving speed.

    - Constant tractive force: The drive torque on the rear wheels remains constant over the travel speed range.
    - Constant driving speed: The wheel speed on the driving axle remains constant. The tractive force is adjusted by the engine load.
- Transient mode (driving resistance simulation):
  In this operating mode, the test bench enables the simulation of driving resistance curves for commercial vehicles. The road and vehicle-specific factors are set on the test bench according to the driving resistance equation. The speed curve to be driven as a function of time is given to the driver via a screen using a driving control device.

<u>Emission measurement devices:</u>

- Full flow CVS system
- FTIR (IAG VERSA06) for regulated and additional unregulated exhaust gas components
- Instantaneous measurement data (max. 5 Hz)
- Particle number measurement and size distribution (on demand)