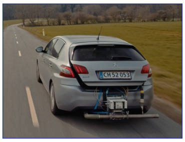
Annex 55-1




A Report from the Advanced Motor Fuels Technology Collaboration Programme

Real Driving Emissions and Fuel Consumption

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Argonne National Laboratory, United States

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IEA-AMF
Technology Collaboration Programme on
Advanced Motor Fuels

Technology Collaboration Programme
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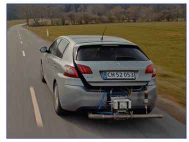

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Summary / Abstract

AMF TCP annex 55 on Real Driving Emissions and Fuel Consumption was created to answer the key question on how vehicle fuel economy, efficiency and emissions in real world driving compare to certification test results. The scope of the annex included the influence of various parameters including vehicle type and powertrain, environmental conditions, driving style and route as well as an overall assessment of benefits and challenges of real world driving testing compared to dynamometer testing.

The methodology determined suitable for answering the key question was assessment of real driving emissions (RDE) performance compared to dynamometer vehicle testing with RDE vehicle performance investigated over typical regional driving conditions such as city, highway, arterial, free-speed, and congested routes.

RDE CO_2 emissions for diesel vehicles agree well (<3%) with worldwide harmonized light vehicles test cycle (WLTC) data while larger gaps exist with the older NEDC cycle. Up to 11% between RDE and WLTC were observed for gasoline vehicles. The on road measured CO_2 emission rates from close to 50 North American vehicles were mostly above the fleet wide compliance levels. This translated to fuel consumption from real-world testing being on average, 22% higher than the observed fuel consumption from tests on a chassis. A bigger variation also exists for light commercial vehicles (LCV). Ethanol (E85) and compressed natural gas (CNG) vehicles showed similar deviations between WLTC and RDE results as gasoline vehicles while overall CO_2 levels of CNG vehicles were lower than comparable gasoline counterparts. The legacy diesel vehicles (before 2018) that were tested had no compliance challenges for PN, CO, but showed significant NOx emission issues and fuel economy were worse than advertised. While Euro 6d vehicles (Model Year 2018 on) have acceptable NOx levels, increased RDE NOx emissions levels were observed for Euro 6b vehicles with significant variations based on emissions control technology choices. Gasoline vehicles without dedicated particulate filter (GPF, Gasoline Particulate Filter) showed

larger PN level increases from new European driving cycle (NEDC) to WLTC while WLTC emissions levels were similar to RDE results. Ethanol (E85) vehicles showed a reduction in PN emissions compared to gasoline while relative NOx emissions trends were inconclusive. General emissions spikes with Plug-In Hybrid Electric Vehicles (PHEV) for cold starts were observed; however, the spikes had no significant impact on overall test cycle results.

Measurements of diesel vehicles at 0, 5 and 20°C showed scattered results with no clear trends. Highway driving of diesel vehicles showed little sensitivity to temperature; urban driving resulted in higher NOx emissions at lower temperatures. Low ambient temperature testing assures that after treatment systems are also effective at harsh ambient conditions.

Consistency between test cycle and real world driving can be achieved with test cycles that reflect real driving behavior. RDE testing further helps ensure compliance of vehicles with emissions targets across the entire operating range. Development and application of miniaturized portable emissions measurement systems (Mini-PEMS) could provide opportunities for larger-scale testing and support technical inspections.

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Content

Introduction

The levels of air pollutants from internal combustion engine (ICE)-powered vehicles that are being sold in the marketplace today are much lower than those from earlier vehicle generations. This change is largely the result of technology forcing regulations to control the exhaust emission rates of various air pollutants such as hydrocarbons, carbon monoxide, oxides of nitrogen (NOx), particle mass (PM), and particle number (PN). Over time, changes to those regulations have reflected the extraordinary advances in fuels, engines, and emission control technologies that have been produced by automotive researchers/manufacturers over the past decades. There is evidence to suggest that the performance of vehicles may not be fully captured in compliance or type approval tests, even though they are conducted with varying driving cycles and in environmentally controlled laboratories. This became particularly visible in the wakes of Diesel-gate which led to accelerated introduction of RDE methods in Europe and elsewhere.

Objectives

This project aims to develop an emission rate and fuel consumption inventory of vehicles driven on-road in varying countries in typical seasonal corresponding climates, using vehicles fueled with advanced, renewable, and conventional fuel. Vehicle performance is investigated over typical regional driving conditions such as city, highway, arterial, free-speed (German), and congested routes. In short, the objective of this project is to explore real driving emissions (RDE) and real-world performance of vehicles operating under a range of worldwide driving conditions.

Description of activities

Annex 55 formal text was finalized in the summer of 2017 with an anticipated end date of April 2019 and defined the following work packages:

- Work package 1: Annex management
- Work package 2: Literature review and world regulation review
- Work package 3: Fuel and technology effects on real-world driving emissions and efficiency
- Work package 4: Comparison of on-road testing to laboratory testing
- Work package 5: Assessment of weather conditions on real-world driving emissions and efficiency
- Work package 6: Evaluation of different emissions measurement techniques

During a planning conference call of annex participants held in August 2018, a timeline for completing Annex 55 activities was developed, along with a uniform report outline for Annex 55 member contributions. Based on this timeline, the Annex 55 end date was extended from April 2019 to November 2019 with a timeline shown in Figure 1.

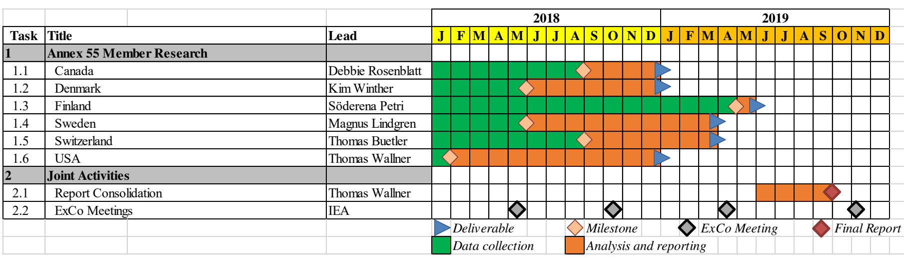


Figure 1: IEA Annex 55 timeline

Regular conference calls were held with technical updates from the member countries, the sequence of technical updates was as follows:

- August 23rd 2018: Technical Update conference call
- September 27, 2018: Mike Duoba of Argonne National Laboratory summarizing United States project status and results
- November 20, 2018: Kim Winther of Teknologisk Institut summarizing project status and results from Denmark
- January 30, 2019: Debbie Rosenblatt of Environment and Climate

Change Canada summarizing project status and results from Canada

- February 22, 2019: Magnus Lindgren of the Swedish Transport Administration summarizing project status and results from Sweden
- March 29, 2019: Thomas Bütler of the Swiss Federal Laboratories for Materials Science and Technology summarizing project status and results from Switzerland
- April 26, 2019: Söderena Petri of VTT Technical Research Centre of Finland LTD summarizing project status and results from Finland

Physical AMF pre-meetings held at the Meeting of the Executive Committee in Delhi in October 2018 and Stockholm in May 2019 was used to develop and agree on general conclusions and findings for the annex.

Literature and world regulation review

RDE is a new and additional vehicle test at type approval and throughout its vehicle normal life which can be conducted with market fuels. Certain types of pollutants are checked on public roads in real life conditions using PEMS. The trip must include 3 portions: urban; rural and motorway in that order. Some payload may be added up to 90% of the allowed mass of passengers plus pay-mass of the vehicle. The emissions produced during the RDE trip are recorded every second and computed by specific evaluation methods. The results of the RDE emissions for the entire and the urban part alone have to remain below 'Not to Exceed' emissions limits.[1]

The purpose of the RDE test in Europe is to verify worldwide harmonized light vehicles test procedure (WLTP) results under varying ambient conditions and to hinder the use of defeat devices which can detect a test environment (as exposed in the Diesel-gate scandal).

The test can be performed in temperatures from 0 to 30°C with up to 90% of the vehicles maximum permissible total weight. The test may be cold start or hot start and may include altitudes up to 700m. All auxiliary systems such as A/C may be used freely during the test. The cycle shall be 90 minutes long and the distance shall be evenly distributed between urban, rural and highway driving (with some tolerances). For each segment a certain average speed interval shall be reached. Urban driving must include a certain amount of stop-time. Highway driving shall be dynamic, which limits the use of cruise control.

The normality of the driving shall be verified be means of CO2 mass flow across the speed range, Relative Positive Acceleration (RPA) and velocity- acceleration (v*a) which shall basically ensure that the load profile resembles WLTC. Until recently further two normalisation methods (EMROAD and CLEAR) were used, but it seems they are now being discarded. RDE in Europe is used both for type approval and for in-use conformity control (market surveillance).

China 6 (CN6b) includes a RDE test based on Euro 6 RDE pack2 with conformity factors of CF=2.1 both for NOx and PN. RDE emissions test conformity will be applicable to all vehicles from July 2023. Until July 2023, RDE tests results are monitored and reported. Until July 2022, CF are subject to evaluation and verification. The cold start period is recorded but excluded from RDE data evaluation. A further extended condition is added for altitude comprised between 1300 m and 2400 m with an emission corrective factor of 1/1.8. Only MAW data evaluation method is to be used.[1]

The latest Automotive Industry Standard (AIS) 137 draft for adoption of Bharat Stage (BS) VI includes a proposed RDE protocol for India. Bharat Stage VI emission standards will apply to light- and heavy-duty vehicles, as well as two- and three-wheeled vehicles. As proposed, the BS VI standards will go into effect for all vehicles in these categories manufactured on or after April 1, 2020. The draft BS VI proposal specifies mass emission standards, type approval requirements, and on-board diagnostic (OBD) system and durability levels for each vehicle category and sub-classes therein. The RDE protocol is one component of that regulatory proposal.[2]

In the United States, certification includes chassis dynamometer fuel economy and emissions testing using urban and highway driving schedules. Over the years additional tests with higher load drive schedules and hot and cold laboraotry temperatures have been added to better encompass driving styles and climates. The United States Environmental Protection Agency (EPA) has been experimenting with portable emissions measurement systems (PEMS) equipment since the late 2000s. EPA states, "The intended uses of PEMS include data collection for the purpose of populating emissions factor databases, and on-vehicle compliance testing to ensure that in-use vehicles are emitting pollutants as expected." [3] There have been no known annoucements by EPA to use g RDE as a certification requirement.

Methodology

In Canada, a fleet of nominally 50 light duty vehicles covering model years 2010-2017 with gasoline or diesel engines was tested in the laboratory (FTP, HWFET, and US06), and on-road, using their respective fuels. A 5-mode on road driving cycle was designed in-house at the Emissions Research and Measurement Section (ERMS) of Environment and Climate Change Canada. The route chosen enabled a mix of driving on arterial and highway roads at different speeds and congestion conditions. It should be noted that this on road driving cycle is not the same as the RDE cycle used in EU regulations[4]. The ERMS has also developed a EURO VI-compliant test route, which is now the current test route for in-use light-duty vehicle tests. However, the data for the fleet of 50 in this report is based on the ERMS 5-mode cycle. Figure 2 illustrates the driving route and Table 1 provides the details of each test mode.

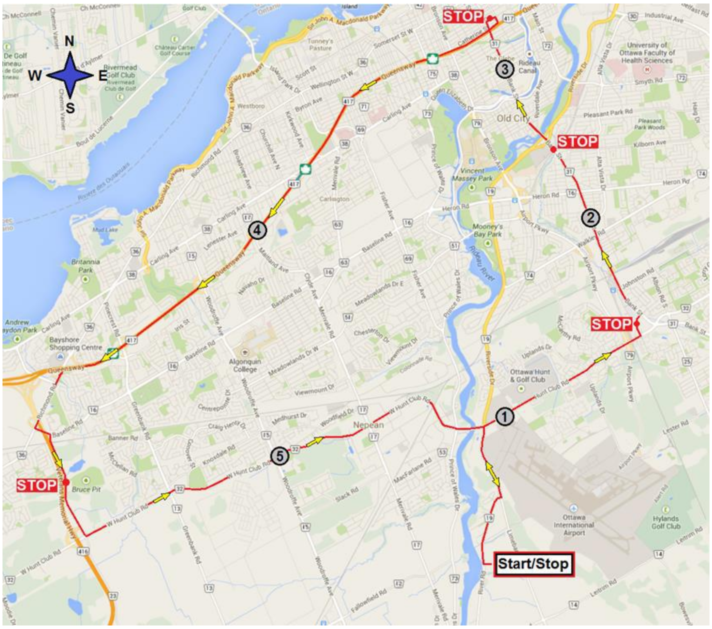


Figure 2: Canadian 5-mode On road driving route

Table 1: Characteristics of the Canadian 5 mode on road driving cycle

Mode	Average Speed (kph)	Max Speed (kph)	Idle Time (%)	Distance (km)	Time (min)
1	30.3	82.6	29%	6.6	13.45
2	31.9	70.6	24%	4.9	9.48
3	23.1	56.5	26%	2.6	6.73
4	63.3	109.3	10%	15.4	14.60
5	41.9	90.4	25%	13.1	18.91

The mode weighted emission rate for the complete test is reported as:

$$etest = 0.55(d1*e1 + d2*e2 + d3*e3 + d5*e5) + 0.45(d4*e4)$$

where *di* is the distance for mode *i* and *ei* is the average mass emission rate measured over mode *i*, 55% and 45% representing the share of real world driving postulated in the respective modes.

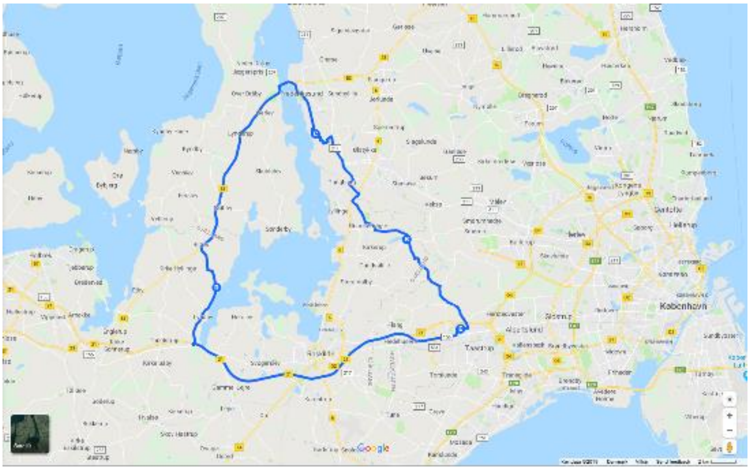
Three replicates were completed for each fuel-vehicle-driving cycle combination in laboratory tests, while four replicates are available for most of the 5-mode on road tests.

In addition, two vehicles were tested both with laboratory test cycles and on-road driving to assess the impact of advanced fuels:[1]

- A 2015 model year GMC Sierra flex-fueled vehicle (FFV) with a 6.0L V8 engine, tested with E0 (Tier 2) and E85 fuels in laboratory tests (FTP, HWY and US06), and with E10 and E85 fuels during on road tests using a 5-mode driving cycle.
- A 2016 model year Chevrolet Impala dual fuel vehicle (DFV) with a 3.6L engine tested with E0 (Tier 2) and CNG in laboratory tests (FTP, HWY and US06) and on road tests using a 5-mode driving cycle.

Denmark completed testing of four Euro 6b class diesel vehicles and one Euro 5b gasoline car in cold weather conditions on an 85-km real driving emission route (Figure 3).

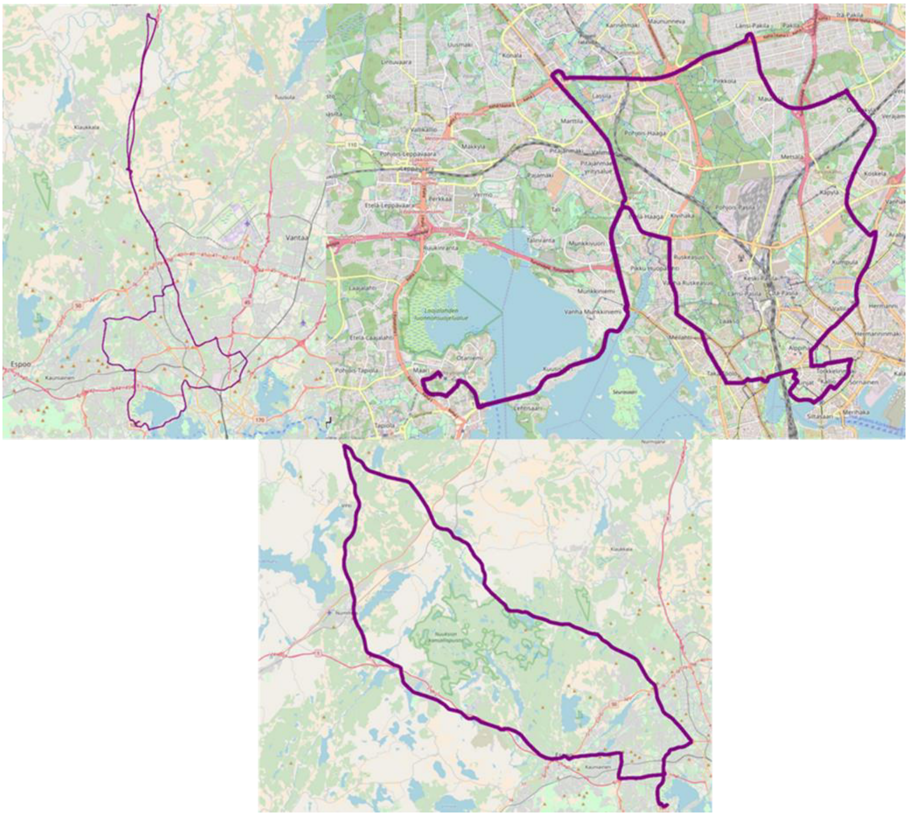
1 This testing was conducted with support from Natural Resources Canada - Program of Energy Research and Development and Transport Canada - ecoTECHNOLOGY for Vehicles Program



	Distance [km]	Time [hh:mm]	Average [km/h]	Max [km/h]
Urban	32.9	00:59	33.2	60
Rural	32.0	00:25	74.1	90
Motorway	19.8	00:10	110.5	116
Full RDE	84.7	01:36	52.5	116

Figure 3: Cold weather RDE cycle, Denmark-Copenhagen area

Finland has executed one testing campaign on chassis dynamometer for four Euro 6 diesel vehicles and two on-road PEMS measurement campaigns. Figure 4 shows the on-road routes in Finland including characteristics of the various segments. Each vehicle uunderwent on-road measurement campaign during summer and winter conditions. One vehicle (Car C) was tested twice on the chassis dynamometer; First with original ECU software and afterwards with updated ECU software for lower NO_x emissions. The update was done by the OEM as a part of their public campaign.



Route	Distance km	Urban %	Rural %	Highway %
Euro 6 RDE	~ 85	~ 42	~ 31	~ 27
VTT City	~ 40	~ 90	~ 10	
VTT Highway	~ 104	~ 17	~ 53	~ 30

Figure 4: Finnish on-road routes and characteristics.

Sweden has tested almost 200 vehicles evenly divided between diesel and gasoline (including 5 ethanol flex fuel) over several different test cycles such as PEMS, WLTC, ERMES and NEDC. All 200 vehicles have not been tested in all of the cycles, for example PEMS have been tested on almost 60 vehicles. Two different PEMS-routes have been used, One in Essen and one in Gothenburg., see Figure 5. Both routes fulfil the requirements given in Regulation (EC) no. 692/2008 as regards emissions from light passenger and commercial vehicles. Both routes are about 90 km and takes between 90-120 minutes to drive.

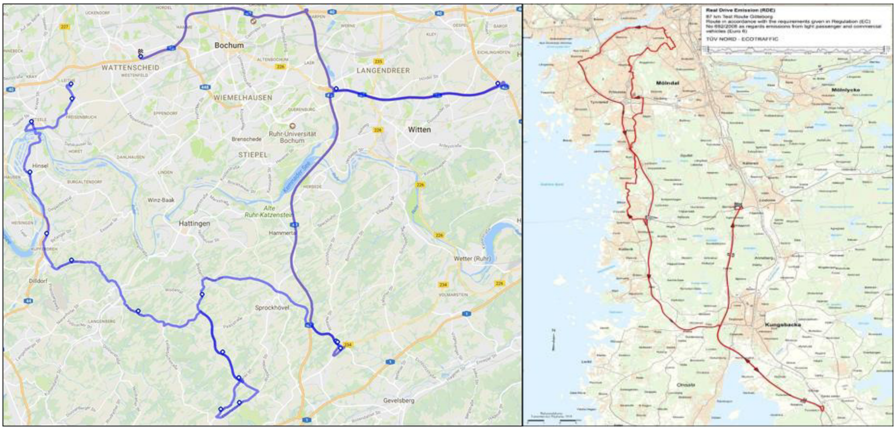
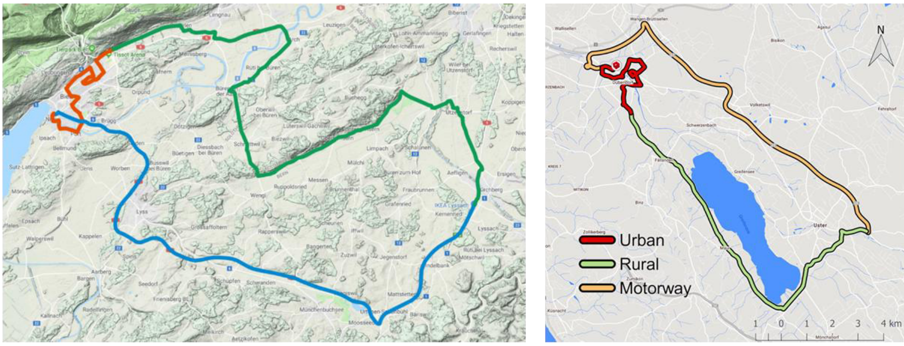


Figure 5: Swedish RDE routes in Essen/Germany (left) and Gothenburg/Sweden (right)

In Switzerland, the Swiss laboratory for exhaust emission control and IC-engines of the Bern University of Applied Sciences (AFHB) performed several on-road (RDE) and chassis dynamometer (WLTC) measurements with two flex-fuel gasoline/ethanol vehicles (FFV E0/E85) and 1 Hybrid electric vehicle (HEV). Figure 6 shows the used RDE route (compliant with the EU-regulation) including characteristics of the various segments.

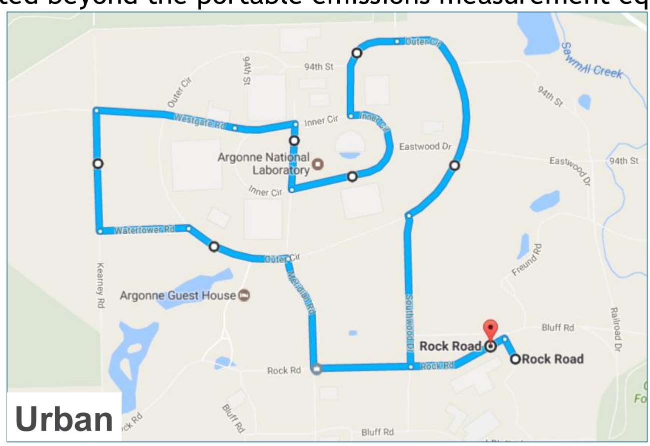
The vehicles tested by the Automotive Powertrain Technologies laboratory (APTL) at Empa, have been measured on chassis dyno in a climate chamber and have performed RDE measurements on a route in the area of Zürich. The route is used for research purposes and is not compliant with ER-regulation, but fulfills most of the criteria.



Route	Distance [km]	Urban Share [%]	Rural Share [%]	Motorway Share [%]	Duration [min]	Av. Speed [km/h]
AFHB06	96	34.5	35.5	30	101	57
Empa Std	38	35.7	34.2	30	41	55

Figure 6: Swiss RDE routes from AFHB (left, AFHB06) and APTL (Empa Std) and corresponding route characteristics

The US tested a gasoline vehicle as well as a plug-in hybrid vehicle on three specific routes (urban, arterial, and highway) on roads in the Chicago metropolitan area (Figure 7). The vehicles were extensively instrumented beyond the portable emissions measurement equipment.



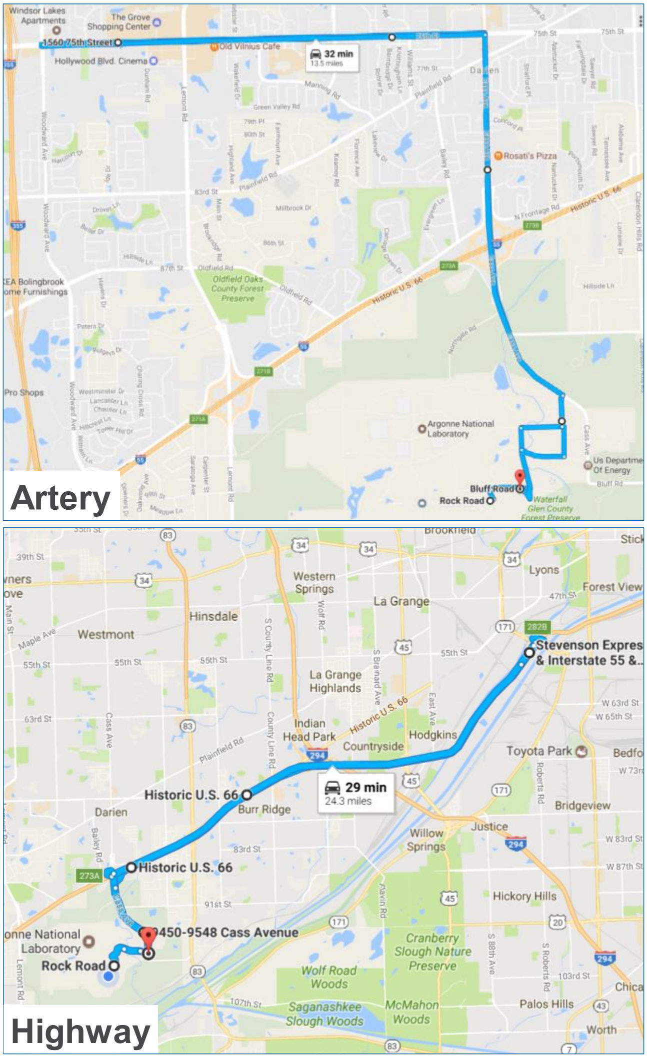


Figure 7: RDE routes developed by Argonne National Laboratory

Results

Fuel Consumption

Canada compared the fuel consumption from the 5 mode on road driving cycle, based on the calculation above to the fuel consumption of the FTP and HWY tests based on the ratio of 0.55 city driving and 0.45 highway driving. It should be noted that the on road 5 mode route was not developed to mimic the laboratory cycles but was developed to represent real world driving. However, it was found that fuel consumption from the 5 mode real-world testing was, on average, 22% higher than the observed fuel consumption from tests on a chassis dynamometer. The variation among the vehicles is shown in *Figure 8* where the ratio of the on road fuel economy to laboratory fuel economy is indicated by the solid line at 122%, the dashed lines representing ± 1 standard deviation.

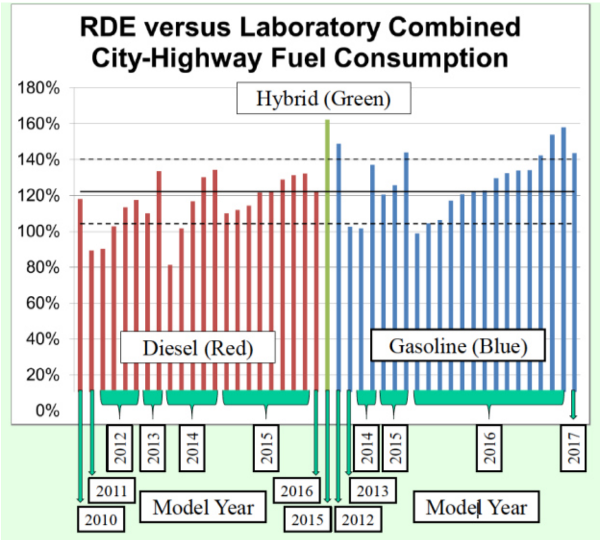


Figure 8: On road driving vs Laboratory City-Highway Fuel Consumption (MY2010-17)[5]

(**Note**: *RDE is used generically here and does not refer to the EU RDE cycle. The data in the figure are based on the 5-mode ERMS cycle*)

Figure 9 shows the on road CO_2 emissions, in grams per mile, compared with the fleet wide CO_2 compliance levels for passenger cars and Light trucks which are available from 2012 onwards. The measured values of CO_2 emission rates showed much less variation between tests (3-4 replicates) compared to the emissions of CO and NO_x emission rates as described in the following section. The average values for individual vehicles were mostly above the fleet wide compliance levels. However, this cannot be taken as a particularly indicative comparison as the compliance levels are for the passenger car and light truck fleets of individual manufacturers, and the few vehicles from a particular manufacturer's fleet are not necessarily representative. Again, it should also be noted that the ERMS on road 5 mode route was not developed to mimic the laboratory cycles but was developed to represent real world driving.

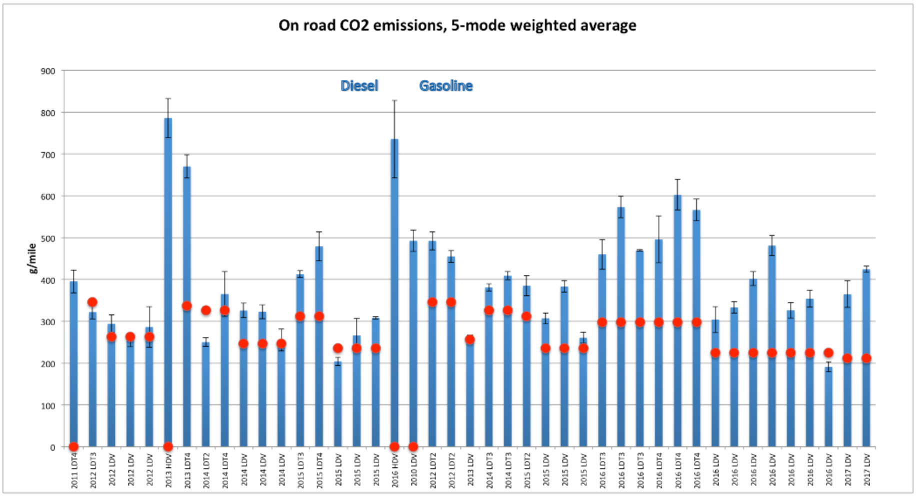


Figure 9: On road CO_2 emissions from LDV fleet (Canada)

(Red dots represent fleet average CO_2 standards for Passenger cars and Light trucks and do not apply to HDV (2013 and 2016), 2010 LDV and 2011 LDT4.)

Denmark found that none of the vehicles delivered the fuel economy advertised or declared by the manufacturer when tested in real life. Diesel vehicles, however, delivered significantly better fuel economy and lower CO2-emission than gasoline.

Sweden concluded that of the vehicles tested in the NEDC (type I) cycle, 94% had a higher recorded CO2 value compared with the declared values, despite using the same settings on the vehicle dynamometer. The average difference was almost 7%. Emissions of CO2 during real driving was even higher than declared values. The difference between WLTP and PEMS in real driving condition was only 3% for diesel vehicles and 11% for gasoline vehicles (Figure 10).

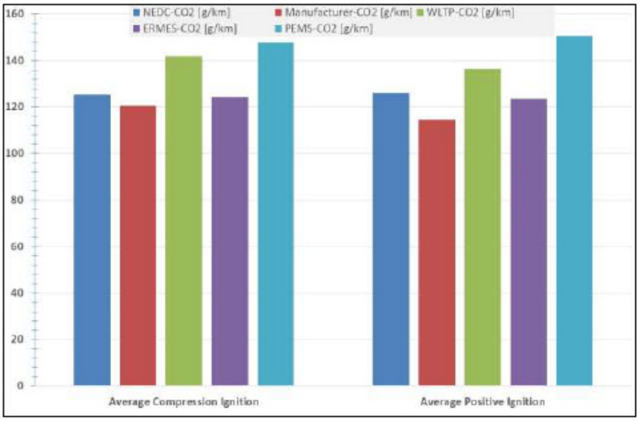


Figure 10: Average CO_2 emission in g/km for cars with compression ignition and positive ignition engines

Finland found that in on-road testing some vehicles had CO_2 value close to the declared values whereas others had more difference. The deviation between the declared and on the Euro 6 RDE route measured value changed between 1 % and 41 % depending of the vehicle and time of testing. As an average for four vehicles, the CO_2 emissions exceeded the declared value by around 17 % (Figure 11).

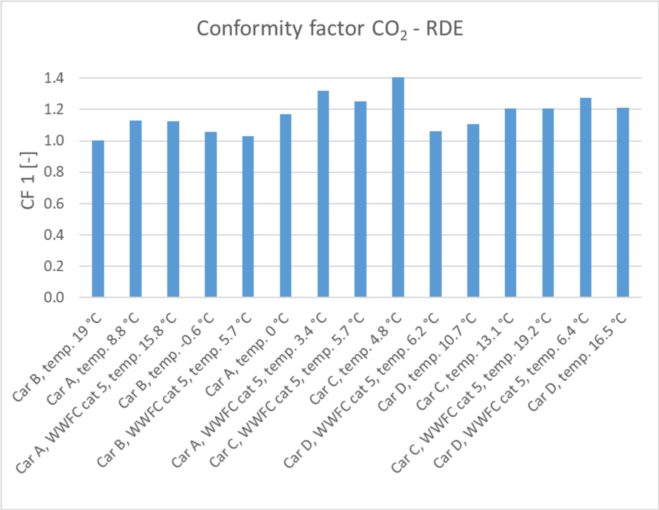


Figure 11: Conformity factor of CO_2 emissions on RDE-route

Switzerland conducted measurements on various powertrain technologies. The tested electric hybrid vehicle (HEV) has low fuel consumption and these values are only slightly influenced by the initial state of the vehicle (cold/warm start, SOC - state of charge of the HEV-battery) and by the different drive modes (Normal, Power, Economy).

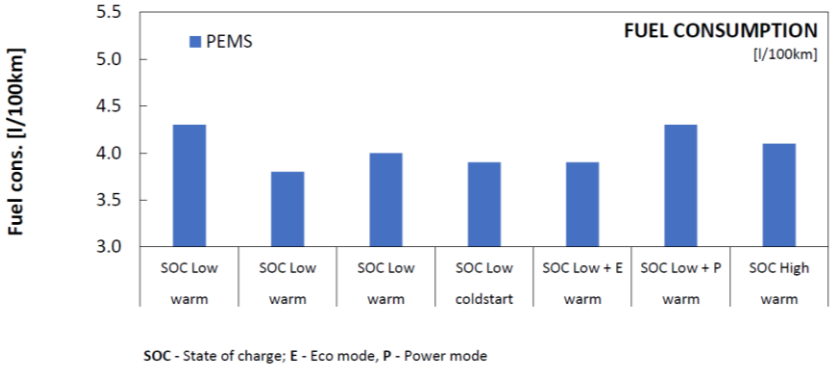


Figure 12: Fuel consumption of the tested HEV during real driving measurements (source: AFHB Swiss report B525 figure 5, EV part.)

The fuel consumption of the two flex fuel vehicles (FFV) measured with both type of fuels E0 & E85 on a chassis dynamometer (WLTC, cold start) with both sets of instruments (BAGS & PEMS) and under real driving condition (PEMS) are shown Figure 13.

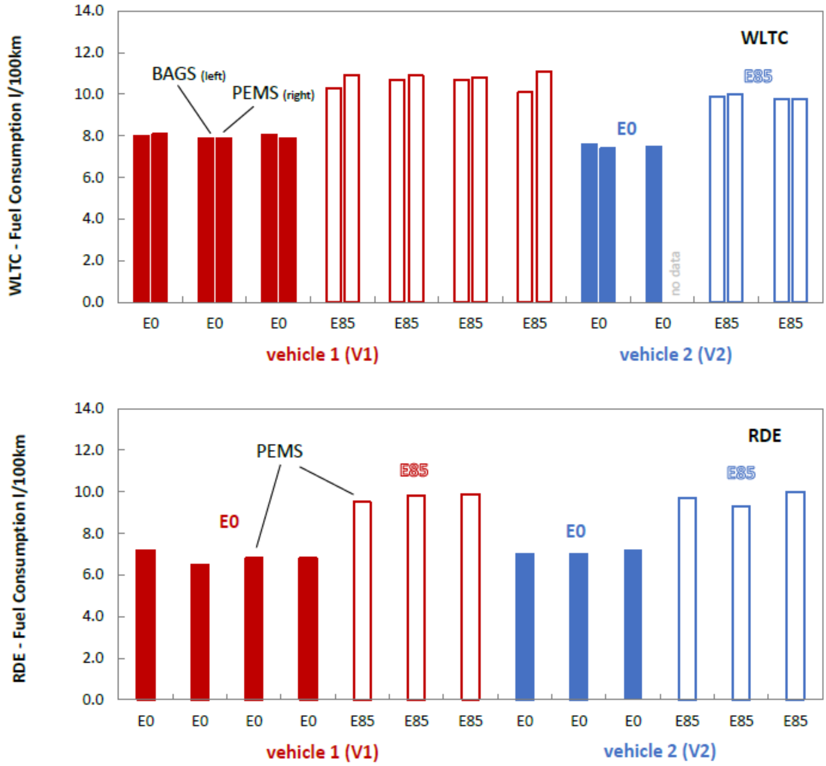


Figure 13: Fuel consumption measured on chassis dyno and during RDE with both vehicle and fuel type. (Source: AFHB Swiss report B525 figure 8, FFV part.)

It can be remarked, that the volumetric fuel consumption with E85 is generally higher, due to the lower heat value of this fuel. The results obtained with BAGS (CVS) and with PEMS on chassis dynamometer correlate well with each other. There is a stronger dispersion of the results from the RDE-circuit, than from chassis dynamometer.

The median CO_2 emissions of six LCV (light commercial vehicles, Euro 6b, N1-III) show only minor differences comparing the NEDC, WLTC and RDE operation. On the chassis dyno the vehicle weights have been set according to the WLTP procedure (+28% payload). For the "RDE low" measurement, the weight was adjusted according to WLTP specifications whereas for the "RDE high" measurements, the vehicles have been loaded with 90% of the maximum permissible payload). The median WLTC and RDE low results only differ by 1%, whereas the RDE high results are 14% higher than the RDE low values.

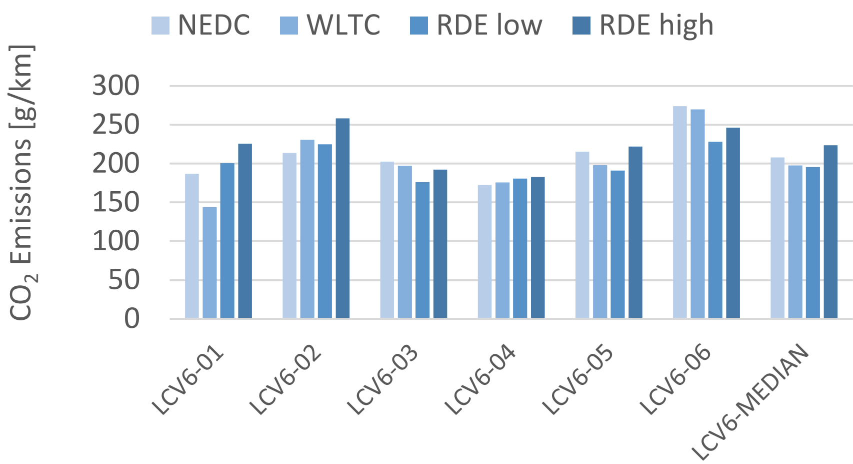


Figure 14: Comparison of CO_2 emissions of six LCV on the chassis dyno and in real world operation with different payloads (Route: Empa Std)

Emissions

Greater variability in Canadian test results was noted during the on-road emissions testing compared to the chassis dynamometer testing. The measured values of CO_2 emission rates showed much less variation between tests (3-4 replicates) compared to CO, NO_x and THC measured values. Graphical display of emissions of CO and NOx from the on road testing compared to FTP certification limits are provided in Figure 15 and Figure 16.

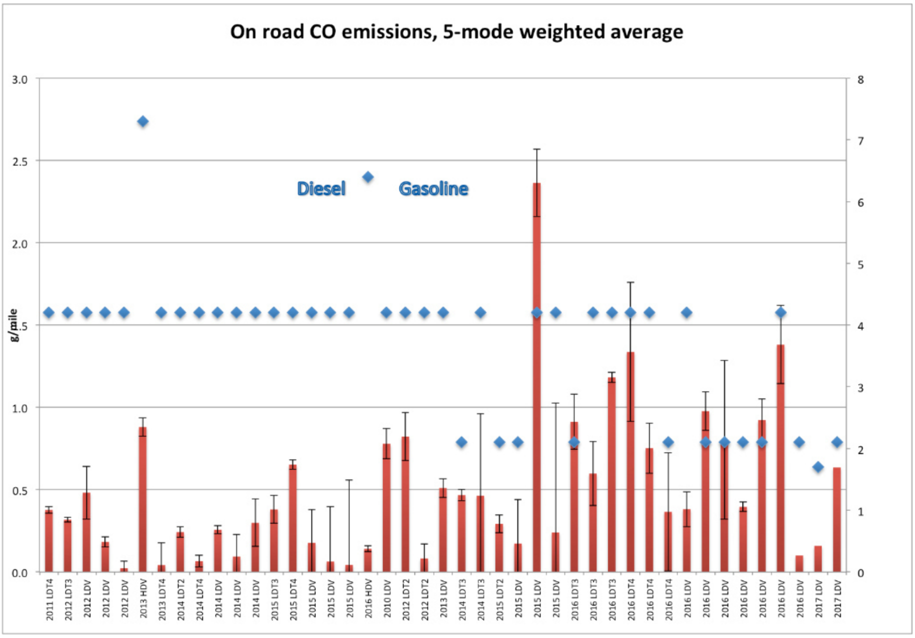


Figure 15: On road CO emissions from LDV fleet – Canada

(On road CO emission rates are represented by the red columns; the blue diamonds represent the FTP certification limits for the respective vehicles and should be read quantitatively from the right axis.)

While there is significant variability in Figure 15, among the tests (3-4 replicates) comparison shows that none of the CO emission rates measured on road exceeded the respective FTP limit, and most of the fleet had on road CO emission rates well below 50% of the FTP limits.

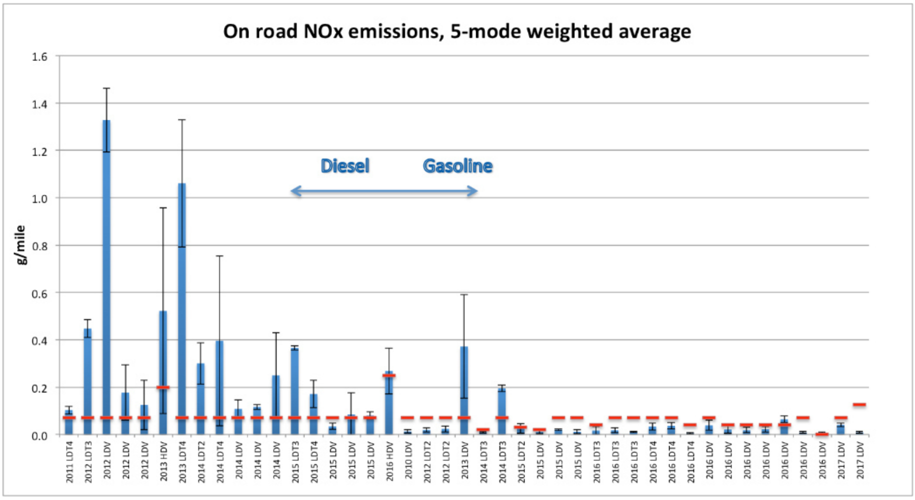


Figure 16: On road NO_x emissions from LDV fleet - Canada

Figure 16 highlights the difficulty for the diesel fleet to meet the FTP limits during on road driving (NOx emission rates, blue columns, compared with the FTP emission limits, red lines for respective vehicles). Although there is higher variability among the tests for NOx measurements than for CO, CO_2 and THC, most of the diesel fleet (along with three vehicles from the gasoline fleet) are clearly above the FTP limits. As the actual FTP NOx emission rates for individual vehicles are available in most cases, it is possible to directly compare these two measured values.

Figure 17 shows most of the tested vehicles are within a narrow range inside the 0.07 g/mile FTP NO_x emission limit while the on road emissions cover a higher range, exceeding the FTP limit going as high as 1.4-7.5 times their FTP emissions. The outlier with the high on road emissions is 19 times above the limit. While it can be expected that on road driving presents some challenges that the FTP might not, clearly there are differences in the ability of the tested vehicles to meet these challenges.

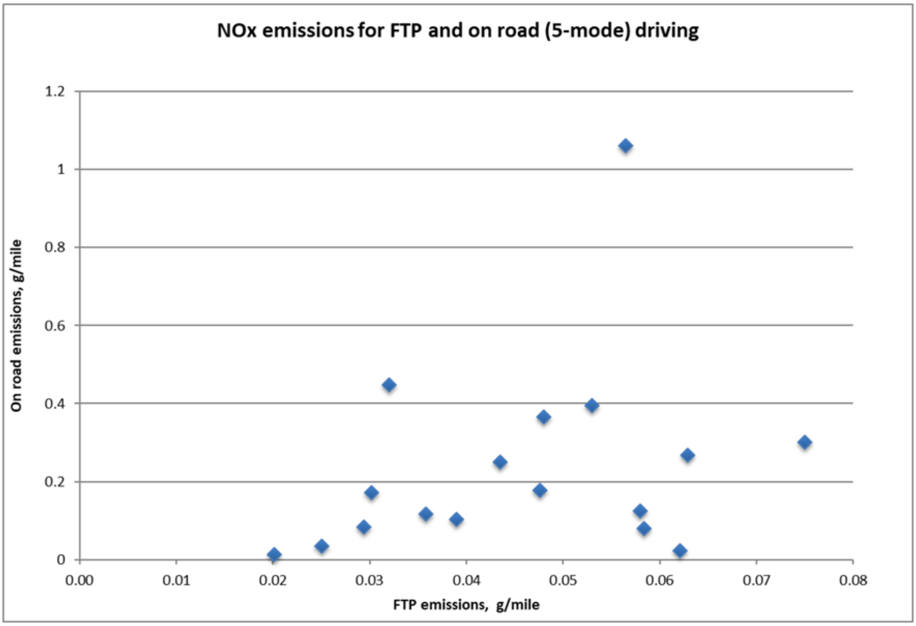


Figure 17: On road vs FTP NO_x emissions for diesel LDVs -Canada

The results from Denmark showed a wide range of NOx emissions between the different test cars in real-world driving with NOx Conformity Factors reaching as high as 18 for EURO 6b diesel vehicles Gasoline NOx was much lower than any diesel tested. Particulate filters, however, worked well on all the diesels, bringing PN even below the non-filtered gasoline engine level.

Sweden reported that the emissions on NOx from the diesel vehicles was on average 6.6 times higher than the certified value. These data include results from Euro 5 vehicles. Also some gasoline vehicles with direct injections showed high NOx emissions during real world driving (Figure 18).

Finland reported wide variation in NOx emissions was observed between the NEDC and WLTC driving cycles on chassis dynamometer and on-road between the vehicles (Figure 19 and Figure 20). During the project the ECU of Car C, which was equipped with an SCR system, was updated with new software as part of the OEM public campaign to reduce the NOx emissions in real-driving conditions. In Figure 19, Car C measurements WLTC cold and hot 3 as well as NEDC cold and hot 2 were performed with updated software. The update reduced NOx emissions to a much lower level.

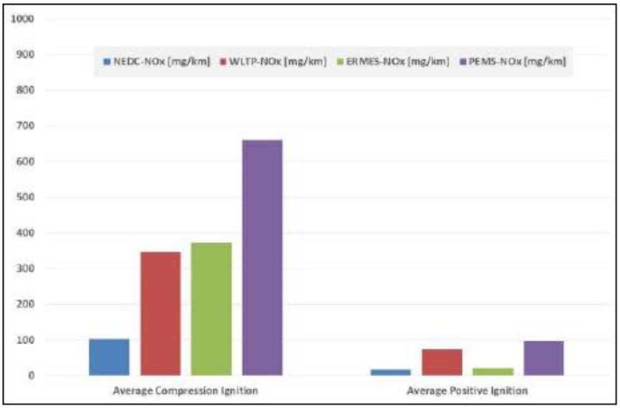


Figure 18: Average NOx-emission in g/km for cars with compression ignition and positive ignition engines

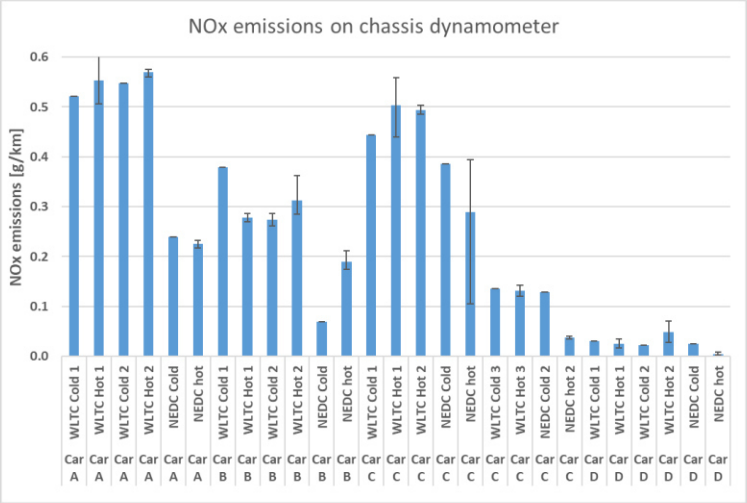


Figure 19: NO_x emissions on chassis dynamometer (Car C WLTC cold and hot 3 as well as NEDC cold and hot 2 with updated ECU software)

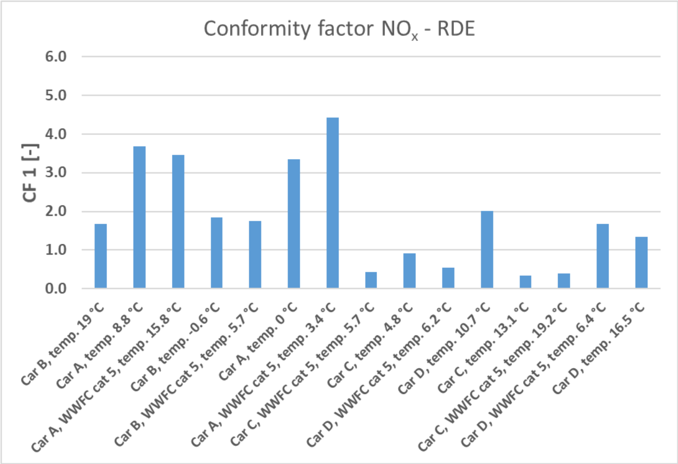


Figure 20: Conformity factor of NO_x emissions on RDE route

Also in Switzerland, the variations of the NOx emissions were high. The six LCV (light commercial vehicles, Euro 6b, N1-III) show the highest NOx emissions in the hot started CADC cycle. The RDE testing with the different weight settings show smaller variations but mostly exceeded the RDE limits for Europe.

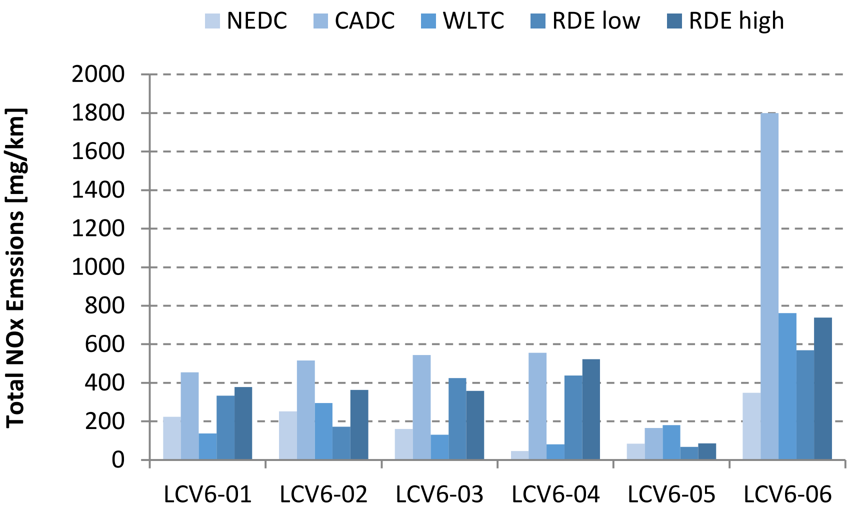


Figure 21: Comparison of NOx emissions of six LCV on the chassis dyno and in real world operation with different payloads (Route: Empa Std)

Emissions of particles was low from all diesel vehicles as those vehicles are equipped with DPF. However, gasoline vehicles and especially those with direct injection showed rather high emissions of particles (over 100 times more compared to the lowest diesel vehicle). None of the tested gasoline vehicles were equipped with a filter. A shift from diesel to gasoline might result in lower emissions of NOx but higher emissions of particles and CO2. On average, the difference in CO2 emissions between similar sized diesel and gasoline vehicles was 20%. A tested natural gas vehicle showed particle number emissions, which are comparable to the emissions of a diesel vehicle equipped with a filter.

The differences among the vehicle technologies decrease when taking into account particles >10nm, in particular emissions of the gasoline vehicles are 50 times more than those of the Diesel DOC/DPF.

The cold start testing in Switzerland showed that NOx Emissions of Diesel engines can increase significantly if the chassis dyno tests are conducted at low ambient temperature conditions (-7degC). SCR Systems first need to heat up to be fully functional. The tested LCV vehicles (Euro6b) showed no SCR activity at low temperature at all.

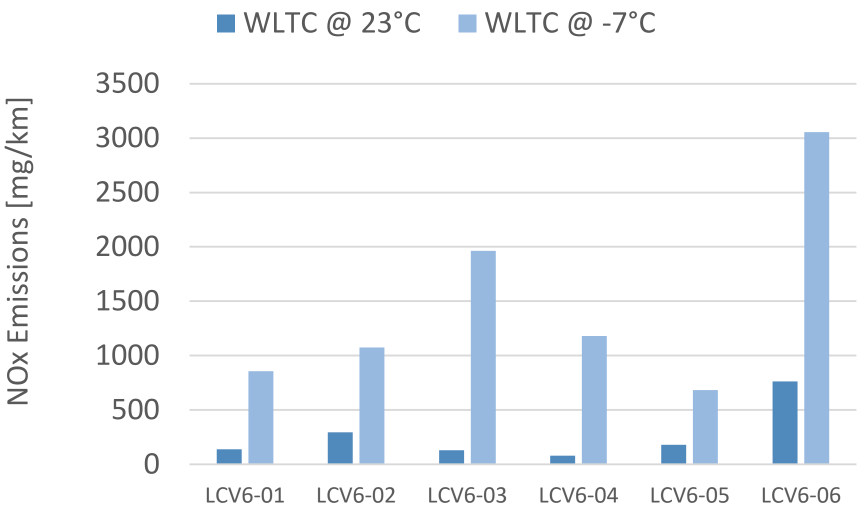


Figure 22: Comparison of NOx emissions of a six Euro6b LCV at different ambient temperatures.

Fuel impact

Canada tested two vehicles to assess the impacts of fuels on emissions from vehicles: one FFV tested with E0/ E10 and E85 and one DPV tested with E0 and CNG. The use of both E85 and CNG resulted in a decrease of CO_2 emissions both with chassis dynamometer testing and using the on road 5 mode driving cycle. Figure 23 and Figure 24 display CO_2 emissions in grams per mile for each advanced fuel. The CNG vehicle showed approximately 25% reduction in CO_2 compared to gasoline and the E85 showed approximately 5% decrease in tailpipe emissions. In a Well-To-Wheel perspective, sustainable produced biofuels could result in a significant CO_2 reduction compared with fossil fuels.

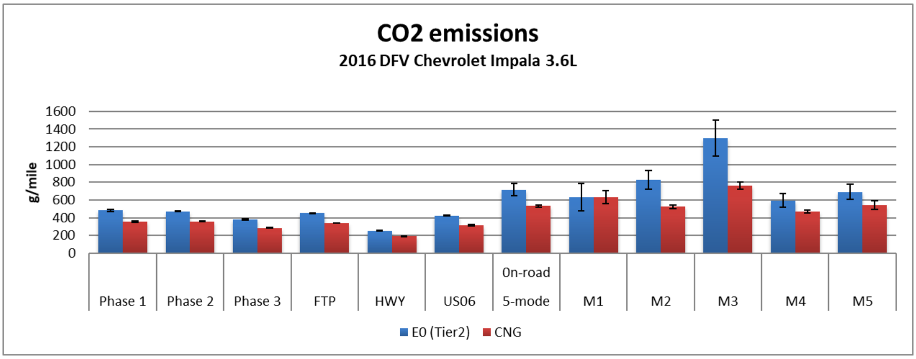


Figure 23: CO_2 Emissions, g/mile, from a DPF using CNG and E0 Fuel

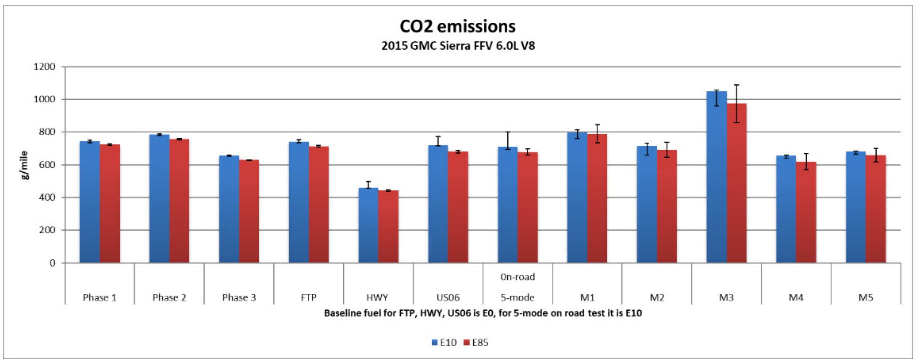


Figure 24: CO_2 Emissions, g/mile from a FFV using E85 and E0/E10 fuel

For these two test vehicles there was a lot of variability in the on-road NOx emission rates. As discussed, many factors may influence the emission testing on road, such as traffic patterns and weather conditions. Emission rates from these vehicles may be found in the appendix.

The THC emissions from the DFV showed variability in the on road testing. During the FTP tests, THC was increased with the use of CNG fuel, and although not statistically significant, there appears to be an increase in THC in the on road tests with CNG. For the chassis dynamometer tests, CH_4 was measured and NMHC calculated as displayed in Figure 26 indicating the majority of THC with the CNG fuel was CH_4. As well, for the FTP test, emissions of BTEX (benzene, toluene, ethylbenzene, xylene) were analyzed and indicated a clear reduction with the use of CNG compared to E0 gasoline fuel as illustrated in Figure 25.

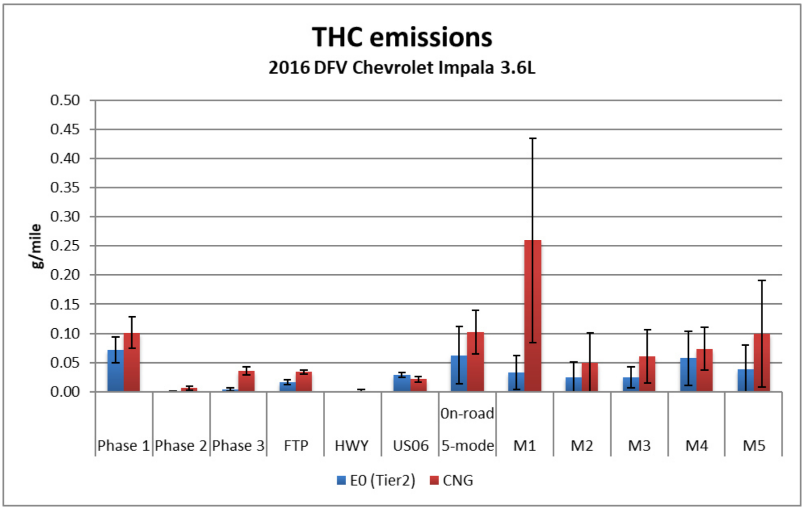


Figure 25: THC Emissions, g/mile, from a DFV using CNG and E0 Fuel

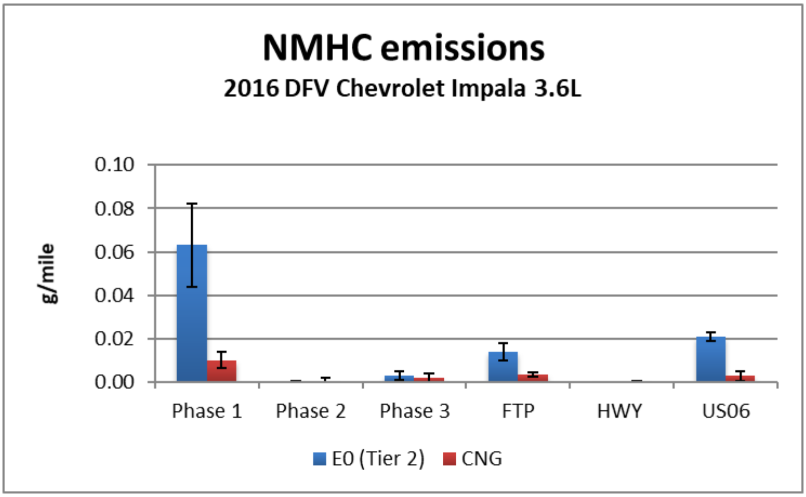


Figure 26: NMHC Emissions, g/mile, from a DFV using CNG and E0 Fuel

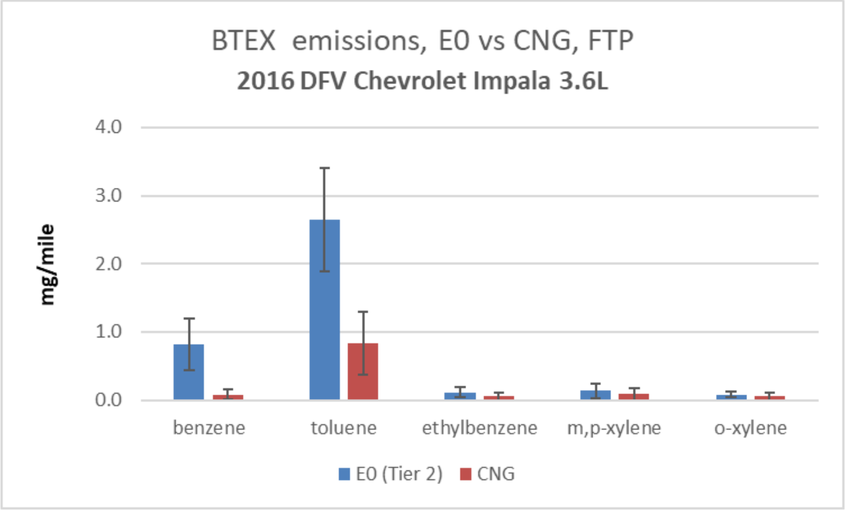


Figure 27: BTEX Emissions, mg/mile, from a DFV using CNG and E0 Fuel

The FFV showed very low emissions of THC, Figure 28, with all of the hot start tests both in the laboratory and on road. Both the cold start phase of the FTP and Mode 1, cold start, of the 5 mode on-road driving cycle showed emissions of THC, along with to lesser extent the hot start phase of the FTP, indicating the effectiveness of the emission control systems once at optimum operating temperature. As with DFV, for the FTP tests, emissions rates of BTEX were analyzed, Figure 29, and were decreased with the use of E85 compare to gasoline due to the lower aromatic content of E85.

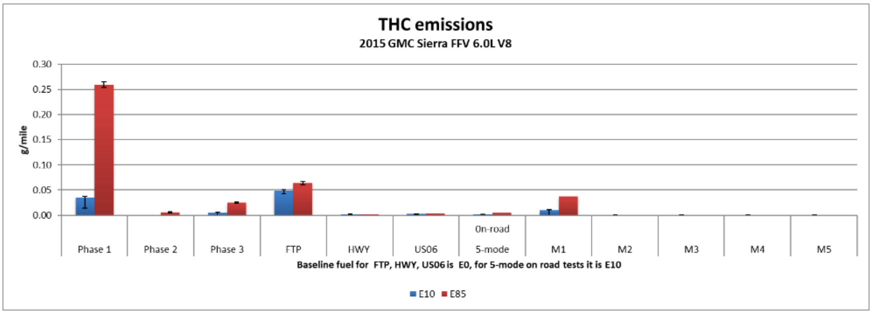


Figure 28: THC Emissions, g/mile, from a FFV using E85 and E0/E10 Fuel

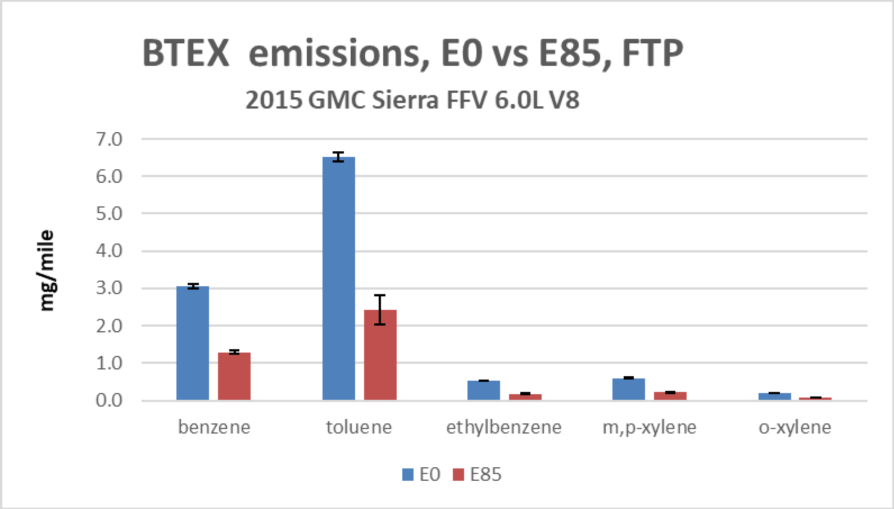
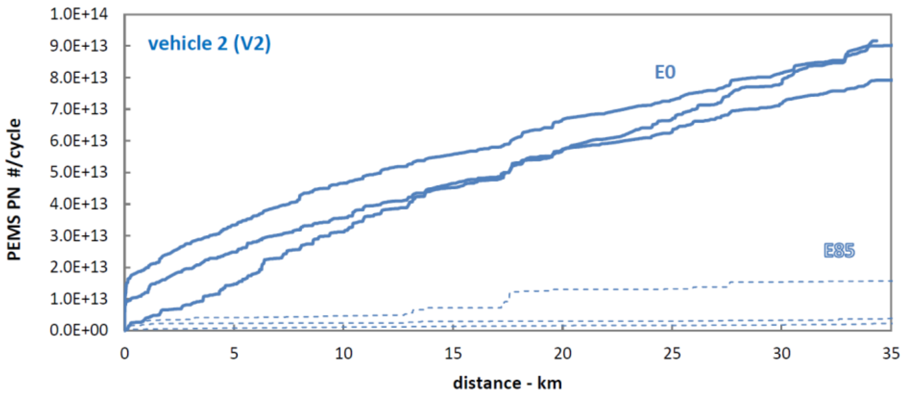


Figure 29: BTEX Emissions, mg/mile, from a FFV using E85 and E0/E10 Fuel

The Swiss FFV measurements show that the use of E85 instead of E0 fuel leads to a reduction of NOx and PN-emissions for both investigated vehicles and in all driving conditions.



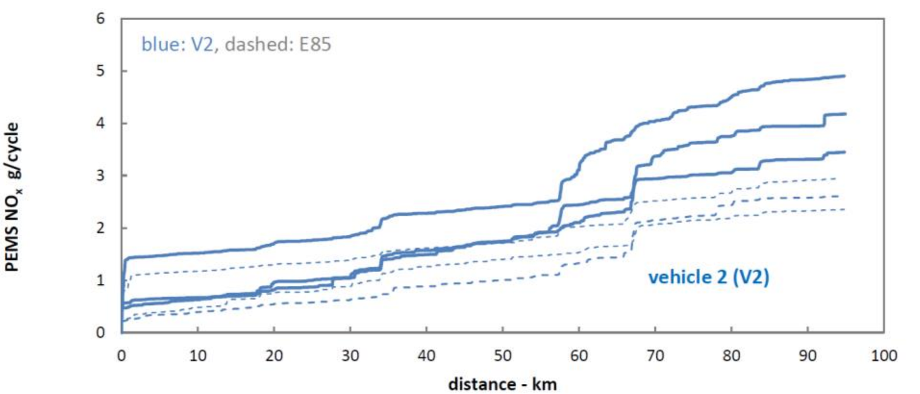


Figure 30: Cumulative NOx and PN-Emission during RDE-measurements with 2 types of fuels (flex-fuel vehicle 2, Euro 5) (source: AFHB Swiss report B525 figure 5-1 & 7-1, FFV part.)

CNG vehicles showed similar deviations between WLTC and RDE results as gasoline vehicles while overall CO2 levels of CNG vehicles were lower than comparable gasoline counterparts. In a Swiss measurement campaign, a comparison of two identical (weight, power, transmission type) cars, one equipped with a CNG engine, one with a gasoline engine, have been compared on the chassis dyno (same dyno setting for NEDC and WLTC) and during RDE testing. Overall, the CNG vehicle emitted 21 – 25% less CO_2 compared to the gasoline version.

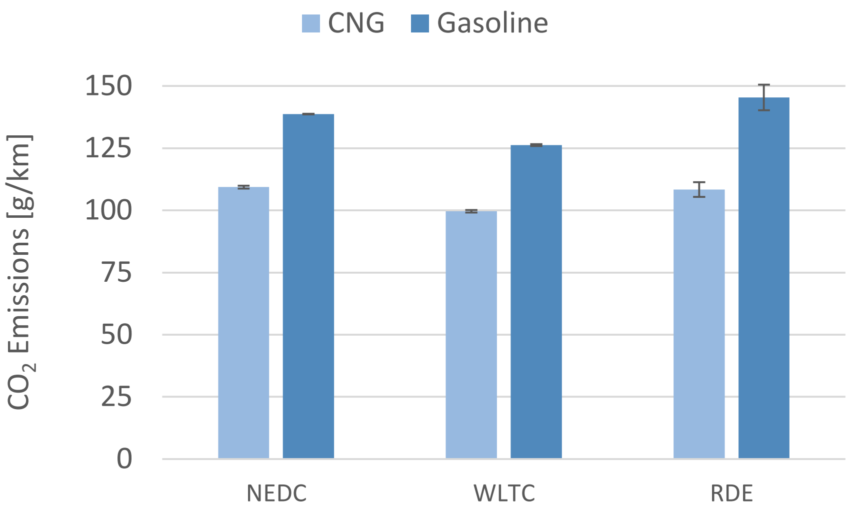


Figure 31: Comparison of CO_2 emissions of a CNG and a gasoline vehicle with comparable powertrain specifications (RDE route: Empa Std)

Finland did not find difference in emissions on on-road measurements between the EN590 and WWFC (Worldwide Fuel Charter) category 5 diesel fuels. Diesel fueled cars are still somewhat ahead of gasoline in terms of real world CO2-emission. Around 7% benefit to the diesel seems to be the consensus figure.

(Plug-In) Hybrid Vehicles

The Swiss HEV tested vehicle shows low emissions and fuel consumption. In real world driving condition, the IC-engine of the HEV works between 39% and 59% of the total cycle time.

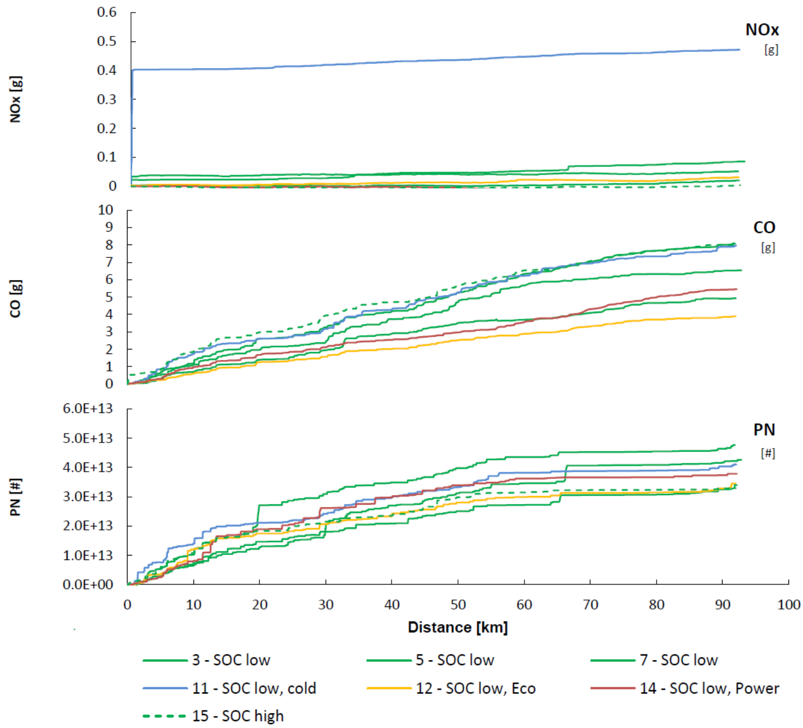


Figure 32: Cumulative NOx, CO and PN-Emission during RDE-measurements with HEV (Euro 5) with different SOC state and driving mode (source: AFHB Swiss report B525 figure 6, HEV part.)

U.S. test results indicate that for the plug-in hybrid vehicle, small amounts of emissions came from the engine through short operations during the charge depleting phase. Overall, emissions are still very low in both charge-depleting mode and charge-sustaining mode (Figure 33).

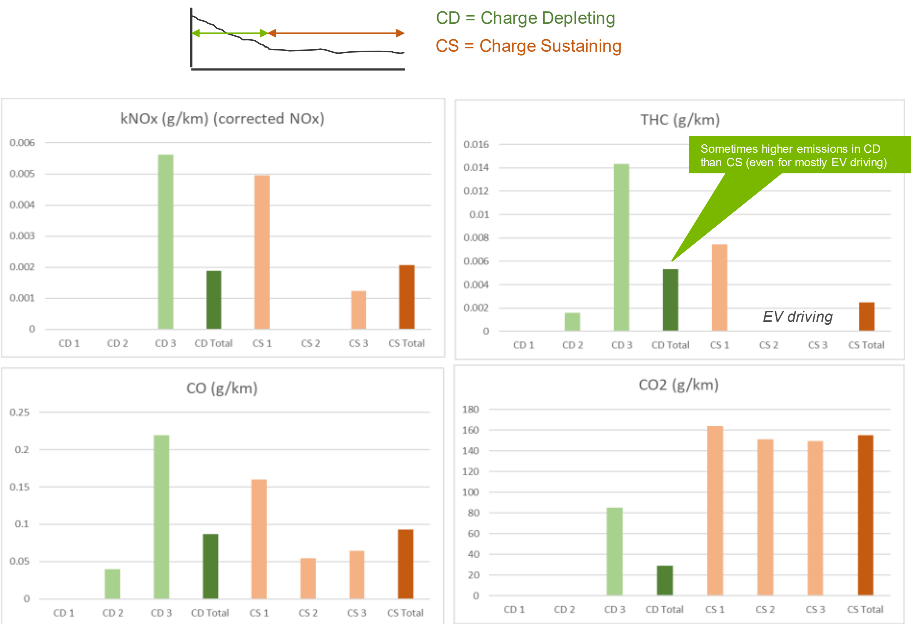


Figure 33: PHEV emissions profiles for charge depleting and charge sustaining operation highlighting influence of engine starts

Methodology assessment

On the basis of specific drive metrics developed by the United States research, (such as positive kinetic energy and accelerations) the dynamometer testing was more repeatable in energy intensity than the on-road testing. Emissions and driving aggressiveness in the real world were generally higher (30%-100%) than laboratory certification testing.

With the European RDE-methodology the energy intensity of RDE does resemble WLTC. However, it is not the objective of RDE to achieve maximum repeatability or likeness to WLTC but rather to ensure the robustness of the emission control in all reasonable operating conditions.

Applicability and potential impact

Fuel consumption and emission performance should be evaluated in a test procedure that is as close to real world operation as possible to be representative. The use of RDE (and PEMS?) could seriously counteracts the use of defeat devices. Following this recommendations, significant fuel consumption and air quality improvements should be possible. It is important to learn from past actions and leapfrog to the latest procedures.

Conclusions

The results contributed by the annex partners support the conclusion that it is important to have a test cycle that reflects real driving behavior which the new WLTC accomplishes. The test cycle has to be developed to represent real driving conditions for certification data (fuel consumption, CO_2 emissions and exhaust gas emissions) to agree well with normal use. Real driving testing further helps ensure compliance of vehicles with emissions targets across the entire operating range. Engines with compression ignition (diesel) showed better agreement of RDE fuel consumption and CO_2 results compared to certification data than spark ignited engines (gasoline, compressed natural gas/CNG and ethanol/E85). Low ambient temperature testing assures that aftertreatment systems are also effective at harsh ambient conditions. Highway driving of diesel vehicles showed little sensitivity to temperature; urban driving resulted in higher NO_x emissions at lower temperatures. Real driving methods can help assess the real-world impact of new fuels, e.g. alcohol fuels and paraffins, in different climate regions where cold-starting etc. could be an issue. It is not the objective of RDE to achieve maximum repeatability or likeness to WLTP but rather to ensure the robustness of the emission control in all reasonable operating conditions. RDE seriously counteracts the use of defeat devices.

Outlook

Development and deployment of miniaturized PEMS (Mini-PEMS) show potential as they would allow for larger-scale testing both in terms of

number of vehicles as well as length of PEMS deployment which could possibly even employed to assist with technical inspections.
RDE methods can help assess the real-world impact of new fuels, e.g. alcohol fuels and paraffins, in different climate regions where cold-starting etc. could be an issue.

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RDE Act 4 and WLTP 2 - Commission Regulation (EU) 2018/1832

WLTP – Commission Regulation (EU) 2017/1151 - Consolidated version of 1 January 2019 (contains amendments made by Regulations 2017/1154, 2017/1347 and 2018/1832)

RDE Act 3 – Commission Regulation (EU) 2017/1154

RDE Act 2 – Commission Regulation (EU) 2016/646 amending Regulation (EC) No 692/2008 as regards emissions from light passenger and commercial vehicles (Euro 6)

RDE Act 1 – Commission Regulation (EU) 2016/427 amending Regulation (EC) No 692/2008 as regards emissions from light passenger and commercial vehicles (Euro 6)

Disclaimer

Abbreviations

AMF	Advanced Motor Fuels
BTEX	benzene, toluene, ethylbenzene, xylene
CF	conformity factors
CNG	compressed natural gas
DFV	dual fuel vehicle
ERMS	Emissions Research and Measurement Section
FFV	flex-fueled vehicle
FTP	Federal Test Procedure
GPF	gasoline particulate filter
HEV	hybrid electric vehicle
HWFET	Highway Fuel Economy Test Cycle
ICE	Internal combustion engine
IEA	International Energy Agency
LCV	light commercial vehicle
OBD	on-board diagnostic
PEMS	portable emissions measurement system
PM	particle mass
PN	particle number
RDE	real driving emissions
US06	US06 Supplemental Federal Test Procedure
WLTC	worldwide harmonized light vehicles test cycle
WLTP	worldwide harmonized light vehicles test procedure
WWFC	Worldwide Fuel Charter