Annex 43

A Report from the IEA Alternative Motor Fuels Technology Collaboration Programme

Performance Evaluation of Passenger Car, Fuel and Powerplant Options

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ADVANCED MOTOR FUELS
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Key Messages from AMF Research

Annex 43 — October 2016

Performance Evaluation of Passenger Car, Fuel and Powerplant Options

Operating Agent: VTT Technical Research of Finland Ltd
Partners: USA, Sweden, China, Canada, Japan

Main Conclusions

In the overall synthesis, **the electric drive proved to be the best option.** It was still better than any fossil fuel internal combustion engine (ICE) option, even when the electricity was assumed to contain the EU28 average carbon footprint. **The best ICE engine option was a compression ignition (CI) engine using a fully renewable HVO-type of fuel**, followed by a spark-ignition (SI) engine on biomethane, as a close contender. The **lowest combined score was attributed to SI/gasoline and SI/LPG.** Fuels with **high amounts of renewable contents help to reduce well-to-wheel (WTW) CO_2 emissions**, in a meaningful way. Furthermore, **use of more sophisticated fuels is still well justified, as they help to reduce tailpipe emissions**. However, this study was limited to Euro 5, whereas **use of the more stringent Euro 6 level technology may change this claim**, at least to some extent. Thus, **re-assessment is highly advisable, in the future**.

Background

Major de-carbonizing is needed in road transport, but there is no single solution that can solve the challenge. Instead, multiple technologies must be considered to find the best alternatives for each set of boundary conditions. Moreover, the importance of energy efficiency is increasing. Renewable and carbon-free energy can be introduced with biofuels or via electricity from renewable sources. Passenger cars constitute the majority of on-road vehicles, and for those, several new viable fuel and powerplant options are available, such as SI engines that employ high concentration ethanol fuel or biomethane. Furthermore, new biobased synthetic (parafinnic) diesel fuels have come to the market. Additionally, the number of electric-only cars being offered is steadily rising, with almost every OEM having at least one model in their product portfolio. Since the number of individual vehicle types, makes, and models is very large, the evaluation of future options is quite challenging. The goal of this research project was to deliver first-hand primary data for this type of assessment, envisioning that it could improve the opportunities of making appropriate choices amongst the several available options. Furthermore, as the number of available options is increasing for both powertrain technology and fuels, unbiased data, sanctioned by the IEA, on the performance (energy use and emissions) of new technologies was needed for decision makers, at all levels.

Research Protocol

The data in this assessment was either the result of tests specific to this study (CHN, SWE, CDN, FIN), or came from other suitable pre-existing available data (USA, JPN). Therefore, the used test protocols and duty-cycles were not 100 % harmonized, as most of the tests were made using the European type approval procedure (NEDC), with some data having been acquired using other types of approval cycles (US, Japan). Additionally, the Artemis cycles were labelled as being “more representative” of driving.

The fuel options included gasoline, without ethanol (or methanol) as low blends (E5, E10, M15), high concentration ethanol (E85) and compressed methane (CNG/CBG). For CI engines, regular mineral oil-only diesel fuel was used, without any biocomponent, or as a low blend of the conventional biodiesel FAME (B7), or similar vegetable oil. Furthermore, a paraffinic, fully synthetic and renewable diesel fuel (HVO) completed the fuel matrix. Most of the tests were run at +23 °C, with some additional ones at +5 and -7 °C. Altogether, 27 different cars representing eight platforms were involved. First, an evaluation of the end-use performance (TTW) was done, and then the data was combined with the WTT data from the JRC test fuel study (2014) to provide information on the complete fuel cycle (WTW). Fig. 1 depicts the results.

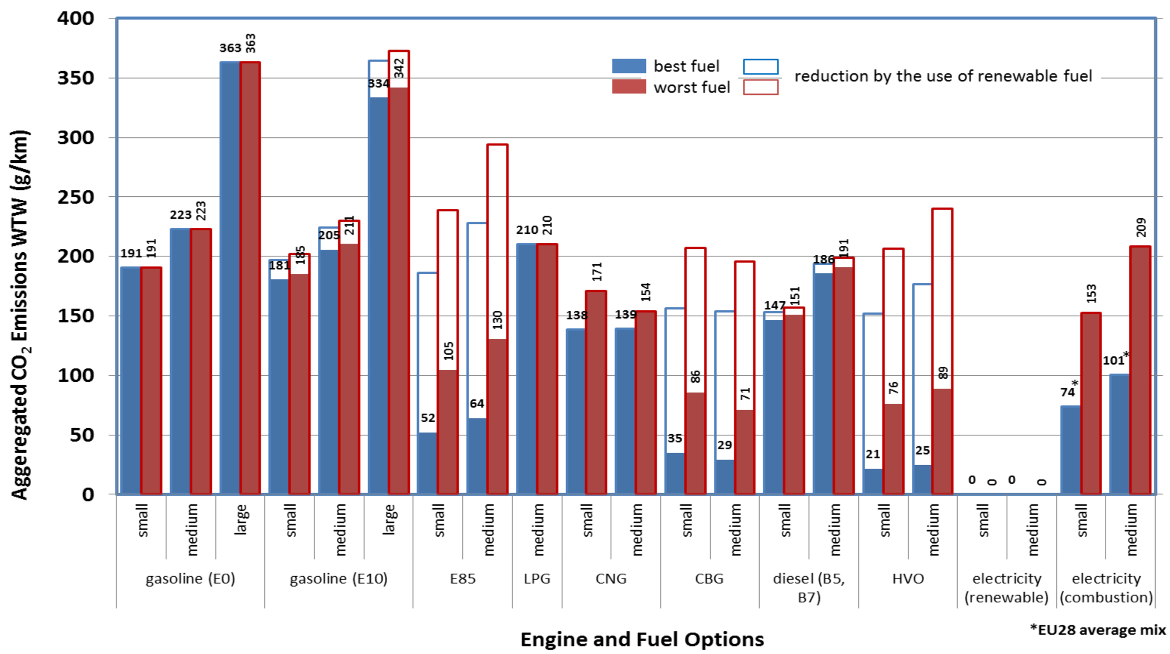
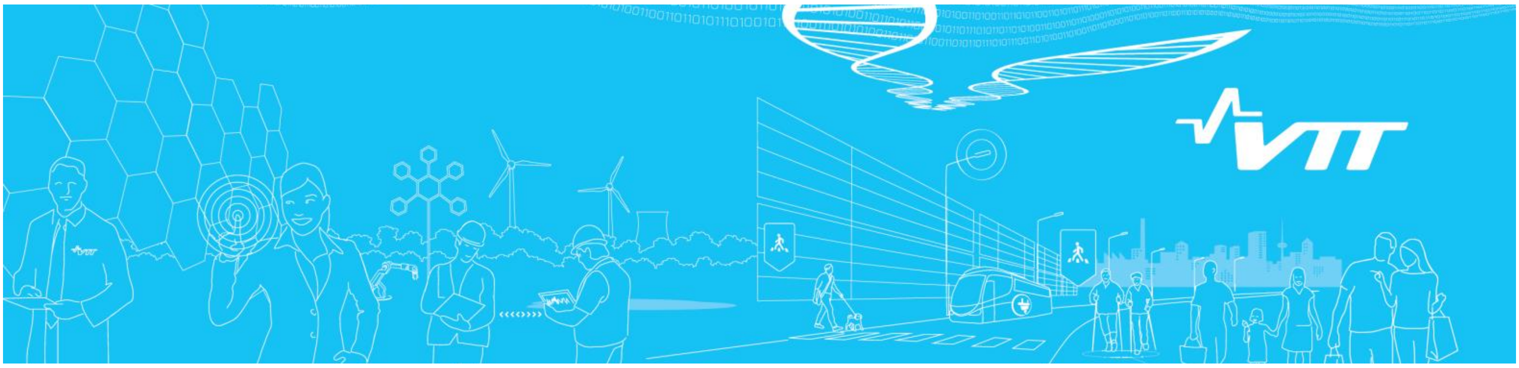


Fig.1: Aggregated well-to-wheels (WTW) CO_2 for the "best" and "worst" fuel pathways.

In the overall analysis and in trying to look at all of the options from as many standpoints and perspectives as possible, a scoring scheme was developed in the synthesis phase, based on five dimensions: 1) energy efficiency (25 %), 2) well-to-wheel (WTW) CO_2 emissions (25 %), 3) (harmful) local exhaust emissions (composite of five) (25 %), 4) sensitivity to cold ambient temperatures (15 %) and 5) driving range with one fill-up of fuel/energy (10 %). The % figure is the weighting of each dimension.

Key Findings

A high WTW CO_2 emissions rate is the major flaw of present-day motor fuels based only on mineral oil. However, with the right kind of fuel, ICE remains as a viable option. For example, an SI engine with a simple and robust three-way catalyst, meets even the most stringent emission regulations and allows the use of renewable energy via biomethane, with low harmful emissions and good low temperature response. With CI engines, better efficiency is at hand, but at the offset the control of NOx emissions is much more complicated. Furthermore, paraffinic, fully synthetic renewable diesel fuels, known as HVO, allow for very high amounts of renewable contents in the fuel, accompanied by positive effects on exhaust emissions. The high efficiency of the electric powertrain ascertains that the WTW CO_2 emissions rate remains low, even if the electricity used is not 100 % renewable; however, with current state-of-the-art batteries, the range is short and costs are high.



RESEARCH REPORT

VTT-R-00892-16

Performance Evaluation of Passenger Car, Fuel and Powerplant Options

Author Juhani Laurikko

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Summary

Passenger cars are a major vehicle class among road-going vehicles. Globally, 60 % of transport energy is used by cars. Because the number of individual vehicle types, makes and models is very large, the evaluation of future options is also quite challenging. This project report describes a research action that was taken to deliver first-hand primary data for this kind of evaluations, and greatly improve possibilities to make right-kind of choices among available options.

The core of the comparison/evaluation consisted of benchmarking a set of passenger cars of such make & model that offer multiple choices for powerplant, i.e. petrol, flex-fuel (E85), diesel, CNG/LPG and perhaps also hybrid and full-electric variations. This way the effect of vehicle can be "nullified". The test matrix included also some modulation of duty-cycle and ambient temperature in order to give more application and environment-specific data.

The results are presented first as per each national study, and then in a synthesis, comprising almost all submitted data. In the synthesis the options were broken down by type of combustion (SI or CI), and fuel. Further subdivisions were made per engine size and duty-cycle used.

The synthesis showed that despite the efficient exhaust emissions control required by the present-day stringent legislation, there are still definite differences among the options. The most important disparities were probably related to NOx and PM emissions, where high NOx was associated with CI engines, and high PM with SI engines of GDI type. It was also noted that use of more sophisticated fuels attributed to lower emissions and better overall efficiency.

In the overall synthesis the electric drive proved to be the best option, followed by CI engine using fully renewable HVO-type of fuel, with SI engine on CBG as a close contender. The lowest combined score was attributed to SI with gasoline or LPG.

Confidentiality	Public

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Preface

Major de-carbonizing actions need to take place in the road transport sector. There is no single solution that could solve the de-carbonization challenge. Multiple technologies must be considered in order to find the alternatives that are best suited for each given set of boundary conditions. Moreover, the importance of energy efficiency is increasing. Engine downsizing, switching to diesel fuel, and opting for hybridization contribute to fuel efficiency. Renewable energy can be introduced, either through biofuels or through electricity from renewable sources.

Passenger cars are a major class of on-road vehicles. Since the number of individual vehicle types, makes, and models is very large, the evaluation of future options is quite challenging. The goal of this research project is to deliver first-hand primary data for this type of evaluation, which could improve the possibilities for making appropriate choices among the many available options. The available technology options are increasing for both powertrain and fuel alternatives. Therefore, unbiased data sanctioned by the IEA on the performance (energy use and emissions) of new technologies is needed for decision makers at all levels.

Participants

Policy-Related Participants:

Finnish Transport Agency (FI), New Energy and Industrial Technology Development Organization NEDO (JPN), Organization for the Promotion of Low Emission Vehicles LEVO (JPN), Swedish Energy Agency, Swedish Road Administration Agency (SE), Tekes - The Finnish Funding Agency for Innovation (FI).

Industry Participants:

European Batteries (FI), Gasum (FI), Neste Oil (FI, Nikki Co. Ltd. (JPN), St1 (FI).

Academia and Test Laboratory Participants:

Argonne National Laboratory (US), AVL MTC Motortestcenter AB (SE), Beijing Institute of Technology (CHN), China Automotive Technology and Research Centre (CHN), Environment and Climate Change Canada (CDN) supported by Transport Canda's ecoTECHNOLOGY for Vehicles (eTV) Program and Natural Resources Canada's Program of Energy Research and Development (PERD) Advanced Fuels and Technologies for Emissions Reduction (AFTER 8), NTSEL - National Traffic Safety and Environment Laboratory (JPN), VTT Technical Research Centre of Finland (FI).

The author wants to express his gratitude to all Participants for their effort on the completion of this work. Further thanks are due to Magnus Lindgren (Swedish Transport Administration) and Jukka Nuottimäki (Neste, Finland) for their review and comments on the final report.

Espoo April 29, 2015

the Editor

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1. Introduction

Road transport needs major de-carbonising actions. However, there is no single solution that could solve this challenge. Therefore, we need to entertain multiple technologies in order to find the best-suited alternatives for each given set of boundary conditions.

Passenger cars are a major vehicle class among road-going vehicles. Globally, 60 % of transport energy is used by cars. Because the number of individual vehicle types, makes and models is very large, the evaluation of future options is also quite challenging. This project report describes a research action that was taken to deliver first-hand primary data for this kind of evaluations, and greatly improve possibilities to make right-kind of choices among available options.

The core of the comparison/evaluation consisted of benchmarking a set of passenger cars of such make & model that offer multiple choices for powerplant, i.e. petrol, flex-fuel (E85), diesel, CNG/LPG and perhaps also hybrid of EV variations. An example of this is VW Passat that offers all above-mentioned options for propulsion. Other similar examples can be found, too. The test matrix included also some modulation of duty-cycle and ambient temperature in order to give more application environment-specific data.

Making this kind of back-to-back comparison could “neutralise” the vehicle itself from the equation, thus highlighting the role of the propulsion system. Combined to the results of the downstream fuel-cycle research conducted at VTT in 2008/2009 (with the contribution from IEA-AMF), the output of this project can be enlarged to a comprehensive, full fuel-cycle evaluation.

This project can be also seen as a continuum to IEA Bus Project, and it opened up excellent possibilities for VTT to carry on with its world-class work in characterising real-use emissions and energy use of vehicles and fuel options. The results of past projects involving heavy-duty vehicles have enjoyed good international visibility.

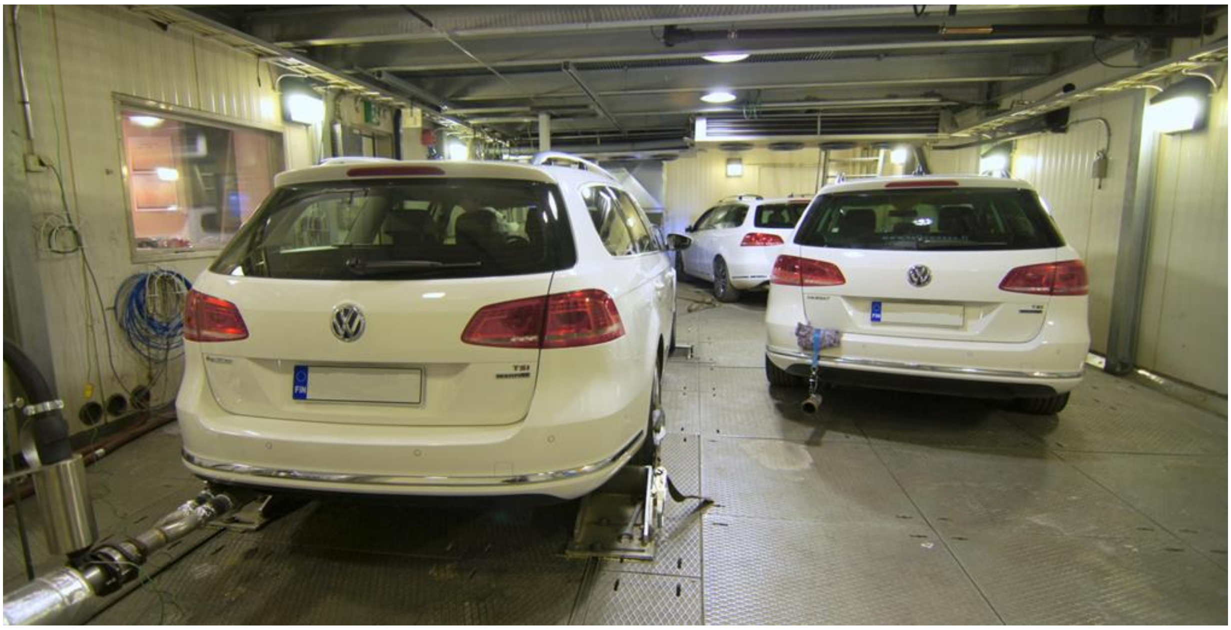

Figure 1. Test cars representing three different powerplant/fuel options in the test cell at VTT.

2. Purpose and Objectives

The core of this study consisted of benchmarking a set of makes and models of passenger cars that offer multiple options for powerplants and fuels. The project also demonstrated the differences in efficiency that arose from engine type and size, by testing engines of different power output offered to the same vehicle platform.

The test matrix allowed for modulation of the duty cycle and ambient temperature in order to obtain more application and environment-specific data. To make the assessment as realistic as possible, the evaluation was based on a set of different operating conditions and duty cycles. This varying of conditions is important, since previous experience has shown that cars tend to be optimized to type-approval conditions and common driving cycles.

The primary objective of the project was to produce comparable information about different powerplant options for fuel or energy efficiency and tailpipe emissions. By using selected vehicle platforms and basically performing “internal” comparisons between powerplant options, the vehicles themselves can be “nullified”. This approach emphasized the differences between alternative engine technologies, rather than the differences between car makes and models.

Furthermore, the new tank-to-wheels (TTW) data allows full fuel cycle (WTW) performance to be calculated by combining well-to-tank data for various fuels generated in the Annex 37.

3. Limitations

The most important limitation of the study at hand is related to the fact that the methodology was not fully consistent across all sub-studies. In principle the consistency of the measurement methodology regarding sampling and determining the pollutant concentrations is fine, but discrepancies are mostly related to driving patterns, as the North-Americans have mostly been using U.S. driving cycles, the Japanese study relates to Japanese cycles, and the rest of the studies (China, Sweden, Finland) refer to the European NEDC cycle. However, the Canadian study also gives a few cases related to the European cycle. Furthermore, both the Swedish and Finnish sub-studies also refer to Artemis cycles (CADC).

Another non-harmonised parameter was ambient temperature, which bears some relevance at least to results of cold-started tests. All sub-studies report most of their data as in "normal" ambient, but this value varies between +21 and +25 °C. In addition the Canadian, Swedish and Finnish studies present results from tests at -7 °C. Furthermore, the Finnish study contains results for most of the cases also at +5 °C, and the Canadians have reported one vehicle configuration tested at -18 °C.

In addition, fuel type and quality varies. Essentially there were cars for diesel, gasoline and gaseous fuels, but the diesels included qualities with mineral oil only, some were blends with biodiesel (FAME-type), but also fully paraffinic qualities (HVO) were used in some studies. Gasolines ranged from no ethanol to 5% and 10% blends, as well as M15 (15% of methanol) and high concentration E85 fuel with 85% of ethanol. Furthermore, the gaseous fuels were either LPG (Japan) or CNG (Canada and Finland).

For the before-mentioned reasons, eventually only part of the study results remains truly cross-comparable, even if the perceived amount of data is quite substantial.

Table 1. outlays the complete test matrix of the study, including number for vehicles, platforms, fuel types, duty-cycles and ambient temperatures.

Table 1: Complete test matrix of the study, including number for vehicles/platforms, fuel types, duty-cycles and ambient temperatures.

	vehicles		Fuel									Driving cycles														Temp.			
Participant	#platforms	# total	Diesel	LPG	CNG	E85**	E0	E10	BioG	M15	BEV	NEDC cold	ARTEMIS Urban cold	ARTEMIS Urban hot	ARTEMIS Road cold	ARTEMIS Motorway hot	ARTEMIS CADC cold	US.FTP UDDS cold	US.FTP UDDS hot	US. Highway hot	US.06 hot	JPN10/15 hot	JPN11 cold	JC.08 cold	JC.08 hot	+25	+23	+5	-7
USA	2	4					x											x	x	x	x						x		
CHN	2	6			x		x	x		x		x														x			
JPN	1	2		x			x															x	x	x	x		x		
SWE	1	3	x			x					x	x	x	x	x		x										x		x
FIN	1	7	x			x		x	x		x	x	x		x	x											x	x	x
CDN	1	4	x*		X	x	x	x				x						x		x	x			x			x		x

* includes biodiesels (B20, B100)

** in tests at -7°C the fuel was E75 (as in type approval testing)

4. Methods: Experimental work

4.1 Summary

Canada, China, Finland and Sweden have conducted first-hand experimental work for this Annex. Experimental work has been carried out in laboratory environment using chassis dynamometer and emission measurement equipment. The test vehicles have represented passenger car types typical to each participating country. The test matrix has also included various test fuels and drive cycles.

Finland and Sweden concluded their tests in 2012 and have submitted their results. China concluded measurements in 2013 and submitted a preliminary sub-report, which was going to be supplemented. However, due to changes in personnel, this was no longer possible. Also Canada finished their tests and submitted a pre-release of their data in May 2014, and last remaining data was received in June 2015. Furthermore, during the final reporting period, Canada submitted additional data on a FFV version of the trucks tested, and the data was assimilated in the report.

In addition, as agreed U.S. submitted suitable data from measurements at the Advanced Powertrain Research Facility of ANL (Argonne National Laboratory). They were part of the on-going powertrain technology evaluation programme funded by DOE Vehicle Technologies Program. Similarly, Japan submitted data from tests sponsored by NEDO at NTSEL (National Traffic Safety and Environment Laboratory) with one vehicle platform powered by an engine running either with gasoline or LPG.

Table 2 summarizes the dimensions of the activities of the participants in terms of number of different cars (or powerplant options on a single vehicle platform), duty cycles, fuels and ambient temperatures used in the measurements.

Table 2: Summary of the activities of participants

Participant	#Platforms	#Cars	#Cycles	#Fuels	#Temp
Japan	1	2	4	2	1
Canada	1	4	5*	8	3*
China	2	7	1	4	1
Sweden	1	3	5	2+EV	2
Finland	1	7	4	6+EV	3*
USA	2	4	10*	1	1

* not for all vehicles

As mentioned already earlier, the experimental test methodology was not fully consistent across all sub-studies. In principle, the sampling and analysis of the pollutant concentrations were according to present standards (but of different origin; EU, Japan or U.S.), allowing their direct comparison *per se*. However, largest inconsistencies were attributed to driving patterns, as the North-Americans are mostly using U.S. spec driving cycles, the Japanese study related only to Japanese duty-cycles, and the rest of the studies (China, Sweden, and Finland) referred to the European NEDC cycle. However, the Canadian study also gave a few cases related to the European cycle.

In addition, both the Swedish and Finnish sub-studies also refer to Common Artemis cycles (CADC), a set of real-world cycles developed in a European research project (Assessment and Reliability of Transport Emission Models and Inventory Systems) that run between 2000 and 2003.

The Common Artemis Driving Cycles (CADC) is chassis dynamometer procedures based on statistical analysis of a large database of European real world driving patterns. The cycles include three driving schedules: Urban, Rural road and Motorway. The Motorway cycle has two variants with maximum speeds of 130 and 150 km/h. See Appendix 1 for main characteristics and illustrations of these duty-cycles.

Another non-harmonised parameter was ambient temperature, which bears some relevance at least to results of cold-started tests. All sub-studies report most of their data as in “normal” ambient, but this value varied between +21 and +25 °C. In addition the Canadian, Swedish and Finnish studies contained data from tests at -7 °C. Furthermore, the Finnish study contains results for most of the cases also at +5 °C, and the Canadians have tested one car at -18 °C.

In addition, fuel type and quality were also varied. Essentially there were cars for diesel, gasoline and gaseous fuels, but the diesels included qualities with mineral oil only, some are blends with biodiesel (FAME-type), but also fully paraffinic qualities were used in one study (Finland). Gasolines ranged from no ethanol to 5 and 10% blends (E5, E10), as well as M15 (15% of methanol) and high concentration E85 fuel (E75 used for cold-ambient cold-start tests). Furthermore, the gaseous fuels were either LPG (Japan) or CNG (Canada and Finland).

4.2 Experimental work - Japan

4.2.1 Vehicles and fuels/powerplants

The following table 3 presents some data of the vehicles tested in Japan.

Table 3: Vehicles tested in Japan

Manufacturer and Make	Nissan Bluebird Sylphy (G11)	Nissan Bluebird Sylphy (G11)
Model Year	n/a (in production ’05 – 12´)	n/a
Curb Weight (kg)	appr. 1200	n/a
GVWR (kg)	n/a	n/a
Payload (kg)	n/a	n/a
Fuel	Gasoline	LPG*
Engine	2.0 L (MR20DE) I-4	2.0 L (MR20DE) I-4*
Horsepower (hp / kW @ rpm):	136/101 @ 5200	n/a
Torque (lb-ft / Nm @ rpm):	- / 200 @ 4400	n/a
Compression Ratio	10.0:1	n/a
Emission Standard	Japan	Japan
Emission Control System	n/a	n/a
Transmission	n/a	n/a
Test Conditions		
Starting Odometer (km)	n/a	n/a
Test Weight (kg)	n/a	n/a
RLHP @ 50 mph (RLkW @ 80 kmh)	n/a	n/a

*Nikki Co. Ltd., converted a normal gasoline vehicle to liquid-injection LPG vehicle.

NB: data in red is not supplied by NTSEL, but added by VTT from various public sources.

Figure 2 is a photograph of a similar vehicle that was tested in Japan, and Figure 3 is the fuel tank of the LPG-converted vehicle. According to the non-original data source, the vehicle platform appears to be a compact sedan (C-segment, length 4610 mm).

Figure 2: Nissan Bluebird Sylphy (G11-model).

Figure 3: LPG-tank of a converted Nissan Bluebird Sylphy (G11-model).

4.2.1.1 Test programme: duty-cycles, fuels and ambient conditions

The following table 4 presents combinations of vehicle, fuel, duty-cycle and ambient temperature for tests performed in Japan.

Table 4: combinations of vehicle, fuel, duty-cycle and ambient temperature for tests performed in Japan.

Vehicle	Fuel	Test Cycle			
		11 mode, cold	10.15 mode, hot	JC08, cold	JC08, hot
Nissan Bluebird Sylphy	Gasoline	√	√	√	√
Nissan Bluebird Sylphy Li-LPG	LPG	√	√	√	√

All testing is conducted in ambient temperature of +23°C.

4.2.2 Test set-up and equipment

No data was supplied of the sampling and analysis of the tests performed in Japan. However, it is safe to assume that both the methodology and apparatus conformed to present Japanese specifications for type approval testing. The tests were performed at National Traffic Safety and Environment Laboratory (NTSEL), performing all kinds of type approval testing for cars and other vehicles. Figure 4 is from a test cell related to these tests.

Figure 4: Exhaust emissions test cell at National Traffic Safety and Environment Laboratory (NTSEL), Japan.

4.2.3 Fuel information

Table 5 presents some information of the fuels used in the tests in Japan.

Table 5: Information of the fuels used in the tests in Japan.

Analysis	petrol		LPG
Carbon Fuel Fraction (%-wt)	87.0		n/a
Hydrogen Fuel Fraction (%-wt)	n/a		n/a
Net Heating Value (MJ/kg)	42.340		43.830
Research Octane Number	90		100
Density (kg/m^3 @ 15^{o}C)	0.7481		0.562
Vapour pressure (MPa)	0.0595		0.570
Distillation properties (°C)		Composition, mol-%	
T10	52.5	C_2H_6, C_2H_4	0.2
T50	92.0	C_3H_8	25.0
T90	141.5	n-C_4H_{10}	51.7
		i-C_4H_{10}	22.6
		C_6 & heavier	0.5

4.3 Experimental work - Canada

4.3.1 Vehicles and fuels/powerplants

The following table 6 presents some data of the four vehicles tested in Canada.

Table 6: Vehicles tested in Canada

Manufacturer and Make	**GMC Sierra 1500 Hybrid**	**GMC Sierra 2500 HD**	**GMC Sierra 2500 FFV**	**GMC Sierra 2500 Bi-Fuel**
Model Year	2013	2012	2015	2013
GVWR (kg)	3221 (7100 lb)	4537 (10000 lb)	4310 (9500 lb)	4310 (9500 lb)
Payload (kg)	667 (1470 lb)	603 (2923 lb)	1497 (3300 lb)	1270 (2799 lb)
Curb Weight (kg)	2554 (5630 lb)	3934 (8670 lb)	2813 (6200 lb)	3040 (6700 lb)
Fuel	Gasoline	Diesel or B20	Gasoline to E85	CNG/Gasoline
Engine	Hybrid Vortec 6.0L V8	Duramax 6.6L V8	Vortec 6.0L V8	Vortec 6.0L V8
Horsepower (hp/kW @ rpm):	332/244 @ 5100	397/296 @ 3000	360 @ 5400	301/225 @ 5000
Torque (lb-ft / Nm @ rpm):	367/498 @ 4100	765/1037 @ 1600	380 @ 4200	333/452 @ 4200
Compression Ratio	9.6:1	16.0:1	9.6:1	9.6:1
Emission Standard	EPA Tier2 LDT	EPA HDV 1	HDV HD85-10 40 CFR1-37.104	EPA MDVP/ Tier 2
Emission Control System	TWC/HO2S/SFI	Cooled EGR/ DPF/SCR	SFI/H02S/TWC/OB DII	TWC/HO2S/SFI
Transmission	Continuously Variable	6-Speed Automatic Allison 1000 Series	6-Speed Automatic HydraMatic 6L90	6-Speed Automatic HydraMatic 6L90
Battery	NiMH	--	--	--
Battery Capacity (Ah)	70	--	--	--
System Voltage (V)	300	--	--	--
Motor Power (kW @ rpm)	60kW	--	--	--
Test Conditions				
Starting Odometer (km)	3462	4881	3512	3503
Test Weight (kg)	2948 (6500 lb)	4318 (9500 lb)	3402 (7500 lb)	3402 (7500 lb)
RLHP @ 50 mph (RLkW @ 80 kmh)	18 (13)	40 (30)	25 (19)	25 (19)

Please note differences in test weight and road load.

Figures 5, 6 and 7 show photographs of the actual test vehicles during the test session at Environment Canada's facility at Air Quality Laboratories, located at 335, River Road, Ottawa. (see: http://www.ec.gc.ca/air-sc-r/default.asp?lang=En&n=98E7CB7E-1)

Figure 5: 2013 GMC Sierra 1500 Hybrid.

Figure 6: 2013 GMC Sierra 2500 HD and 2013 GMC Sierra 2500 Bi-Fuel.

Figure 7: 2013 GMC Sierra 2500 FFV.

4.3.2 Test programme: duty-cycles, fuels and ambient conditions

The following table 7 presents combinations of vehicle, fuel, duty-cycle and ambient temperature for tests performed in Canada.

Table 7: Combinations of vehicle, fuel, duty-cycle and ambient temperature for tests performed in Canada.

Vehicle		Test Cycle							
		FTP			HWFCT	US06	NEDC		JC08
	Ambient	+23 °C	-7°C	-18°C	+23 °C	+23 °C	+23 °C	-7°C	+23 °C
	Fuel								
Sierra 2500 HD	Diesel	√	√	√	√	√	√	√	√
	B20 CME	√			√	√			
	B20 HDRD	√	√		√	√			
	B100 HDRD	√	√		√	√			
Sierra 2500 BiFuel	E0	√			√	√			
	CNG	√			√	√			
Sierra 2500 FFV	E0	√	√		√	√			
	E85	√	√		√	√			
Sierra 1500 Hybrid	E0	√	√		√	√	√		√
	E10	√	√		√	√	√		

√ = test case in performed, with minimum of two (2), and up to six (6) runs
Note: Regulated emissions were collected on all tests
Unregulated emissions were only collected on specific tests
Fuel info: CME = canola methyl ester (comparable to FAME), B20 = 20% blend
HDRD = renewable diesel 1, B20 = 20% blend in diesel, B100 = neat fuel
Note RD = HDRD (hydrogenation-derived renewable diesel)

4.3.3 Test set-up and equipment

The vehicles were tested on a 122 cm diameter single roll electric dynamometer that is capable of simulating both road load power (RLP) and inertia weight (IW) of light- and medium-duty vehicles. The RLP is the power required to maintain a given constant vehicle speed on a level road without any wind. The dynamometer simulates the power required to overcome the rolling resistance, mechanical parasitic losses, and aerodynamic forces on the vehicle. The chassis dynamometer testing meets the requirements of Title 40 of the Code of Federal Regulations (CFR) 86 Subpart C specifically 86.208-94.

The total exhaust stream produced by the vehicles was collected and diluted using a constant volume sampling (CVS) system.. The dilution air was conditioned by removal of particulate matter using HEPA filtration. The total volume of raw exhaust was transferred from the truck exhaust to the CVS through a flexible stainless steel pipe. The raw exhaust was then diluted with HEPA filtered ambient air and the mixture was drawn through a dilution tunnel and critical flow venturi (CFV). During the exhaust emissions tests, continuously proportioned samples of the dilute exhaust mixture and the dilution air were collected and stored in Kynar® sample bags for analysis while continuous sampling was also undertaken through heated pump, filter and sample line systems for NO_x and THC. From separate probes in the dilution tunnel, samples bags were collected for the per-phase analysis of N_2O as well as CH_4 along with filters for PM.

Table 8 presents details related to the sampling and analysis of the tests performed in Canada.

Table 8: Sampling and analysis of the tests performed in Canada.

Compound	Analysis Method	Sample Collection
Carbon Monoxide (CO)	Non-Dispersive Infrared Detection (NDIR)	Kynar® bag
Carbon Dioxide (CO_2)	Non-Dispersive Infrared Detection (NDIR)	Kynar® bag
Oxides of Nitrogen (NO_x)	Heated Chemiluminescence Detection	Kynar® bag + continuous collection for diesel vehicle
Total Hydrocarbons (THC)	Heated Flame Ionization Detection (FID)	Kynar® bag + continuous collection for diesel vehicle
Particulate Matter (PM)	Gravimetric Procedure	47 mm Emfab Filters
Methane (CH_4)	Gas Chromatography – FID	Kynar® bag
Nitrous Oxide (N_2O)	Gas Chromatography with Electron Capture Detection	Kynar® bag
Fuel Consumption (FC)	Calculated based on Industry Standard Carbon Balance	

For the Hybrid vehicle:

State of Charge (SOC)	A power analyser, HIOKI, was used to measure battery terminal voltage and current with the use of a HIOKI 200A clamp-on amp probe and a fuse-protected voltage lead.
	These data were collected at a frequency of 300 kHz and recorded at a frequency of 2Hz in order to verify the tests met the net energy change (NEC) variance restrictions.
NEC	The net energy change (NEC) variance was determined for each test to verify the battery did not contribute/subtract more than 5% of the total energy required to run the drive cycle test (total cycle energy – TCE)

4.3.4 Fuel information

Tables 9a and 9b present information of the fuels used in the tests in Canada.

Table 9a: Information of the fuels used in the tests in Canada.

Analysis Parameters	Method	B0	B20 CME	B20 HDRD	B100 HDRD	E0	E10	CNG
Carbon Fuel Fraction, %-wt	ASTM D5291	0.876	0.855	0.870	0.846	0.846	0.824	0.722
Hydrogen Fuel Fraction, %-wt		0.132	0.129	0.135	0.151	0.134	0.134	
Oxygen Fuel Fraction, %-wt		0.000	0.022	0.000	0.002	0.000	0.033	0.000
Net Heating Value MJ/kg	ASTM D4809	42.8	41.7	43.0	37.2	42.9	41.7	47.8
NET Heating Value MJ/l		36.6	35.9	36.11	29.0	31.9	31.1	26.0
Specific Gravity (kg/L, 60/60°F)	ASTM D4052	0.856	0.861	0.841	0.781	0.7445		0.545
Density (kg/m^3 @ 15°C)		855.2	860.7	840.3	780.6	745.0	748.0	
Total Sulphur (ppm)	ASTM D5453	13	12	6.5	<1	37	32	
Cloud Point, max (°C)	ASTM D5773	-14.3	-11.9	-13.8	-11.6	n/a	n/a	
Cetane Number	ASTM D613	42.6	44.3	48.9	74.1	n/a	n/a	

Note: E0 = Tier II EEE Certification Fuel, E10 = Tier II EEE splash blended with ethanol

Table 9b: Information of the high-concentration ethanol fuels used in the tests in Canada.

Fuel Property	Unit	Method	E85 (summer) Test @ +23 °C	E75 (winter) Test @ -7 °C
Ethanol	volume %	ASTM D5501	82	73
DVPE	kPa	ASTM D5191	45	78
Net heat of combustion	MJ/kg	ASTM D4809	29	30
Density	kg/m3	ASTM D4502	781	782
Research Octane Number		ASTM D2699	107	107
Carbon	mass %	ASTM D2591	55.8	57.0
Hydrogen	mass %	ASTM D2591	13.0	13.0
Oxygen	mass %	ASTM D5291	28.8**	28**
Sulphur	mg/kg	ASTM D5453	6.2	8.5
Distillation IBP	°C	ASTM D86	40.6	53
T-10	°C		71.7	73.2
T-50	°C		77.5	77.7
T-90	°C		78.4	78.8
aromatics	volume %	ASTM D1319	5.5	<5
olefins	volume %		0.6	0.4
saturates	volume %		13	16.0
*Environment Canada In-house IR **CAN/CGSB-3.0 No.14.3				

4.4 Experimental work – China

4.4.1 Vehicles and fuels/powerplants

The following table 10 presents some data of the vehicles tested in China. Makes and models of the vehicles were not disclosed, but according to the preliminary report, vehicles A, B and C were of the same manufacturer, but with different engines, and vehicles D to F were of another make and model, but all identical to each other, only differing by the odometer readings at the time of testing.

Table 10: Vehicles tested in China.

Manufacturer and Make	Vehicle A	Vehicle B	Vehicle C	Vehicle D	Vehicle E	Vehicle F	Vehicle G
Make	A			B			
Model	A	B	C	D			
Fuel	Petrol / E10 / M15			Petrol / CNG			
Engine	1.6 L	1.6 L	2.0 L	1.6 L			
Emission Standard	Chinese standard GB18352.3-2005, equivalent to Euro 4						
Transmission	M5	Auto	Auto	M5	M5	M5	M5
Starting Odometer (km)	14728	2967	3230	3340	9560	7800	21313

4.4.2 Test programme: duty-cycles, fuels and ambient conditions

The following table 11 presents combinations of vehicle, fuel, duty-cycle and ambient temperature for tests performed in China.

Table 11: Combinations of vehicle, fuel, duty-cycle and ambient temperature for tests performed in China.

Vehicle	Test Cycle NEDC* @ +25 °C (±5 °C)			
	#93**	E10	M15	CNG
A	√	√	√	
B	√	√	√	
C	√	√	√	
D	√			√
E	√			√
F	√			√
G	√			√

*Type 1 of Chinese Regulation GB18352.3-2005, equal to Euro 4
** regular Chinese market petrol fuel, no ethanol (E0)

4.4.3 Test set-up and equipment

In the beginning, all vehicles were inspected and checked for soundness of the intake and exhaust systems, then subjected to an initial type I emissions test to ensure their suitability for the test program. Prior to commencement of tests on each fuel, the vehicle fuel tank was drained and flushed and filled with the new fuel.

Vehicles were tested over repeat cold start emissions tests (type I test) in accordance with Chinese standard GB18352.3-2005. For each vehicle/fuel combination duplicate tests were undertaken in order to provide some degree of confidence in the data set, with further tests run should duplicate back-to-back tests exceed the expected variability.

The type I emissions test is specified in the Chinese standard GB18352.3-2005 “Emissions testing of light duty vehicles”. This procedure is the same as the European standard Euro 4.

The vehicle is pre-conditioned by running a test cycle and then being soaked at a controlled temperature for between six and twenty-four hours. The test consists of driving the vehicle to a prescribed drive cycle on a chassis dynamometer. The dynamometer is set to simulate the inertia and road load of the test vehicle so that the amount of work done by the engine matches that seen on the road.

Emissions sampling begins from the moment the engine is started and continues throughout the test run. The emissions are constantly measured but the final result is derived from gas analysis of two sample bags into which the exhaust gas is sampled and collected. The first bag samples the exhaust during the four repeated drive cycles of the first phase. The second bag samples the exhaust during the second phase which consists of higher speed driving.

Results from the bag analysis were expressed as grams per kilometre for each pollutant and fuel consumption is computed from carbon balance and expressed as litre per 100 kilometres. The final result, as defined by the legislation, is a combined figure derived from a combination of the bag one and bag two results.

The analysers and sampling equipment are calibrated with reference gasses and the whole system has a demonstrable uncertainty of measurement in the region of 3%.

Figure 8 depicts the chassis dynamometer at China Automotive Research Centre (CATARC) that performed all testing.

Figure 8: Light duty vehicle emissions test cell at CATARC, China.

Table 12 is a compendium of the sampling and analysis methods used for regulated and non-regulated pollutants.

Table 12: sampling and analysis methods used for regulated and non-regulated pollutants test performed in China.

Compound	Analysis Method	Sample Collection
Carbon Monoxide (CO)	Non-Dispersive Infrared Detection (NDIR)	CVS Bag
Carbon Dioxide (CO_2)	Non-Dispersive Infrared Detection (NDIR)	CVS Bag
Oxides of Nitrogen (NO_x)	Heated Chemiluminescence Detection	CVS Bag
Total Hydrocarbons (THC)	Heated Flame Ionization Detection (FID)	CVS Bag
Carbonyl Compounds (i.e. Formaldehyde, Acetal-dehyde)	High Performance Liquid Chro-matography (Agilent 1200)	2,4-DNPH Coated-Silica Gel Cartridges
Volatile Organic Com-pounds (i.e. benzene, e-benzene, toluene, xylene) (VOC)	Gas Chromatography – Flame Ionization Detection with precon	Tenax TA adsorption tube (Markes)
Fuel Consumption (FC)	Calculated based on Industry Standard Carbon Balance	

<u>Unregulated pollutants tests</u>

The sample gas were selected from the CVS sample bag, using the constant flow pump (American SKC company, AirChek2000), the sample gas collect VOCs by Tenax TA adsorption tube (Markes) (This experiment concerns benzene, toluene, ethylbenzene, xylene, benzene BTEX as the aromatic of boiling in the range between 100 ~ 400 ℃, non-polar components and some organic matter with weak volatility (boiling point above 150 ℃). Sampling pump flow rate was set to 750 mL/min, sampling 20 minutes each condition. In order to ensure the accuracy of the sample gas flow rate, sampling pump accurately checked using the soap film flowmeter before and after the experiment.

The sample gas collect aldehydes and ketones by 2, 4- two, 4-dinitrophenylhydrazine (2, 4-DNPH) adsorption tube (Markes) (This experiment focus on formaldehyde and acetaldehyde), Aldehydes and Ketones with 2,4-DNPH to form a stable coloured hydrazine derivatives adsorbed on the sample tube thereby preserved. Sampling pump flow rate is set 1200mL/min, sampling 20 minutes each condition. In order to ensure the accuracy of the sample gas flow rate, sampling pump accurately checked using the soap film flowmeter before and after the experiment. After sampling the 2,4-DNPH sampling tube placed in the refrigerator seal shading below 4 ℃ preservation, within 7 days of pre-treatment, After sampling tube solid-phase extraction, using thermal desorption - gas High performance liquid chromatography (HPLC, Agilent 1200, USA) for the qualitative and quantitative process for aldehydes and ketones.

4.4.4 Fuel information

No specific data was disclosed of the fuels used other than the fact that Chinese base petrol (#93) has no ethanol (E0), and that the CNG used was normal commercial gas used in Beijing area. E10 fuel was made by blending 10 vol-% of bioethanol to regular #93 petrol, and subsequently, M15 fuel was prepared by adding 15 vol-% of methanol to regular #93 petrol.

4.5 Experimental work - Sweden

4.5.1 Vehicles and fuels/powerplants

Table 13 presents some data of the vehicles tested in Sweden. The electric version was from a limited experimental fleet by Volvo.

Table 13: Vehicles tested in Sweden.

Manufacturer and Make	**Volvo C30 2.0F**	**Volvo C30 DRIVe**	**Volvo C30 Electric**
Fuel	E85/E75*	diesel	electricity
Engine	2.0 L otto cycle (SI)	1.6 L diesel (CI)	Fully electrified power
Horsepower (hp / kW @	145/107@6000	109/80@3600	111 hp
Torque (lb-ft / Nm @ rpm):	136/185@4500	177/240@1750-2500	n/a
Emission Standard	Euro 5	Euro 5	Euro 5
Emission Control System	TWC	DOC and DPF	n/a
Transmission	M5	M6	
Auxiliary heating	n/a	Diesel-burning auxiliary heater	E85-burning auxiliary heater
Test Conditions			
Starting Odometer (km)	n/a	n/a	n/a
Test Weight (kg)	1360	20111360	1700
RLHP @ 50 mph	n/a	n/a	n/a

*E75 fuel was used at -7 °C tests

Information in RED was added later on by VTT from various non-original sources

4.5.2 Test programme: duty-cycles, fuels and ambient conditions

The following Table 14 presents combinations of vehicle, fuel, duty-cycle and ambient temperature for tests performed in Sweden.

Table 14: Combinations of vehicle, fuel, duty-cycle and ambient temperature for tests performed in Sweden.

		Test Cycle								
		NEDC	NEDC	ART	ART	ART	ART	ART	CADC	CADC
Ambient temperature		+23 °C	-7 °C	+23 °C	+23 °C	+23 °C	+23 °C	+23 °C	+23 °C	-7 °C
	Start type	cold	cold	cold	hot	hot	hot	hot	cold	cold
Vehicle	Fuel									
SI	E85/E75*	√,√	√,√	√,√	√,√	√,√	√,√	√,√		
CI	diesel	√,√	√,√	√,√	√,√	√,√	√,√	√,√		
EV	electricity	√,√							√,√	√,√
Use of Auxiliaries		all off	all off	in use	in use	in use	in use	in use	in use	in use

NB: each case was tested twice

*E75 fuel was used at -7 °C tests

in use =head lights on and air conditioning set at +20 °C. Diesel-burning auxiliary heater in automatic mode

ART URB =Artemis Urban Driving Cycle

ART RUR =Artemis Rural Driving Cycle

ART MWY =Artemis Motorway Driving Cycle

CADC =Combined Artemis Driving Cycle (Urban, Rural, Motorway)

NEDC =New European Driving Cycle, i.e. current EU Type Approval cycle

4.5.3 Test set-up and equipment

Chassis dynamometer

The tests were performed on an electric Clayton DC500 two-roller chassis dynamometer (500 mm rolls) at test cell temperatures of +23 °C and -7 °C. Relative humidity was maintained at 50% during the testing. The simulated inertia used for the vehicles where 1360 kg for the diesel vehicle, 1360 kg for the FFV vehicle and 1700 kg for the electric vehicle. The road load was simulated by adjusting the dynamometer in accordance to the manufacturer's instructions. In order to reduce the deformation of tires, caused by the double rollers, the tires were inflated to a pressure of 1.5 × the pressure recommended by the manufacturer.

CVS system

A Constant Volume Sampler (CVS) (Horiba, CVS-9300T) was used in the study. The CVS tunnel has a total length of 3150 mm with an inner diameter of 250 mm and is connected to the tailpipe via a 5 m long section of 110 mm diameter insulated stainless steel transfer tube. The transfer tube is connected to the tailpipe with a 30 cm section of flexible stainless steel tubing attached to the tailpipe. At a distance of 30 cm from the tailpipe, cleaned and HEPA filtered test cell air is introduced to the transfer tube, into the exhaust stream. The CVS-tunnel flow rate is controlled by use of a 9 m3/min critical venturi.

Regulated emissions including PM and PN measurements

The regulated gaseous emissions were measured using a Horiba Mexa 9000 series (9400D) system. The bag-sampling was performed using a set of 3 bags for exhausts, and 3 bags for dilution air sampling. The filters used for sampling of Particulate Matter (PM) were 47 mm diameter TX40 filters (PTFE bonded glass fibre filters; PALL) mounted in a filter holder. The instrumental set-up for particle number measurement was designed according to the PMP-protocol. The measurement principles for the different components are given in the table below (Tables 15a & b).

Table 15a: Sampling and analysis methods used for regulated pollutants for testing performed in Sweden.

Compound	Analysis Method	Sample Collection
Carbon Monoxide (CO)	Non-Dispersive Infrared Detection (NDIR)	bag (Horiba, CVS-9300T)
Carbon Dioxide (CO_2)	Non-Dispersive Infrared Detection (NDIR)	bag (Horiba, CVS-9300T)
Oxides of Nitrogen (NO_x)	Heated Chemiluminescence Detection (CLA)	bag + continuous collection for diesel vehicle, heated line 190 °C
Total Hydrocarbons (THC)	Heated Flame Ionization Detection (FID)	bag + continuous collection for diesel vehicle, heated line 190 °C
Particulate Matter (PM)	Gravimetric Procedure	47 mm TX-filters (PALL)
Particulate Number (PN)	Condensational Particle Counter (CPC)	on-line sampling and dilution, PMP method (AVL)
Fuel Consumption (FC)	Calculated based on Industry Standard Carbon Balance	

Table 15b: Methods and hardware for electric vehicle testing performed in Sweden.

For the electric vehicle:

Energy consumption measurements	The charge energy delivered from the mains supply to the electric vehicle was measured with an ABB T6824 active electric energy meter.
Specifications	Voltage: 230 V AC (-23% to +20%) Reference current: 10 A Max current: 80 A Start current: 25 mA Accuracy of measurement: Class B (Cl 1, ±1%) Temperature range: -40 to +55 °C

4.5.4 Fuel information

Table 16 presents some basic information of the fuels used in the tests in Sweden.

Table 16: Information of the fuels used in the tests in Sweden.

Analysis Parameters	diesel	E85	E75
Density (kg/m^3 @ 15^{o}C)	834	784	872
Lower heating value (MJ/kg)	42.9	29.4	30.2
RON	n/a	> 95.1	> 95
CFR	53.3	n/a	n/a
FAME (vol-%)	4.9	n/a	n/a

4.6 Experimental work - Finland

4.6.1 Vehicles and fuels/powerplants

Table 17 presents some data of the vehicles tested in Finland. The electric version of the Passat was an experimental vehicle converted from a VW Passat Variant by a Finnish company (Finnish Electric Vehicle Technologies, a.k.a. European Batteries) using commonly available industrial components. Main powertrain components were sources from Zytek (UK).

Table 17: Vehicles tested in Finland.

Manufacturer and Model	**Volkswagen Passat Variant**						
Model Year	2011	2011	2011	2011	2011	2011	2008
Curb weight (kg)	1507	1582	1505	1618	1557	1647	n/a
Fuel	petrol	petrol	diesel	diesel	FFV	CNG	electricity
Engine type (cm^3)	1.4 TSI (1390)	2.0 TSI (1984)	1.6 TDI (1598)	2.0 TDI (1968)	1.4 TSI MultiFuel (1390)	1.4 TSI Eco-Fuel (1390)	n/a
Power (kW @ rpm):	90@5000	155@5300	77@4400	125@4200	118@5800	110@5500	n/a
Torque (Nm @ rpm):	200 @ 1500-4000	280 @ 1700-5200	250 @ 1500-2500	350 @ 1750-2500	240 @ 1750-4500	220 @ 1500-4000	n/a
Compression Ratio	10:1	9.6:1	16.5:1	16:1	10:1	10:1	n/a
Emission Standard	Euro 5	Euro 5	Euro 5	Euro 5	Euro 5	Euro 5	n/a
Emission Control System	TWC	TWC	DOC + DPF	DOC + DPF	TWC	TWC	n/a
Transmission	DSG7 (autom.)	DSG6 (autom.)	M6	DSG6 (autom.)	DSG7 (autom.)	DSG7 (autom.)	M5
EV specific							Zytek
Motor Power (kW@rpm) Torque (Nm)							70@2200 300 Nm
Test Conditions & Set-up							
Starting Odometer (km)	34399	11199	6042	2888	3833	13237	10490
Test Weight (kg) (inertia setting)	1532	1626	1572	1673	1615	1672	1780

4.6.2 Test programme: duty-cycles, fuels and ambient conditions

The following table 18 presents combinations of vehicle, fuel, duty-cycle and ambient temperature for tests performed in Finland.

Table 18: Combinations of vehicle, fuel, duty-cycle and ambient temperature for tests performed in Finland.

Vehicle		Test Cycle											
		NEDC			ART URBAN			ART RURAL ROAD			ART MOTORWAY		
	Ambient °C	+23	+5	-7	+23	+5	-7	+23	+5	-7	+23	+5	-7
	Fuel	CS	CS	CS	CS	CS	CS	WS	WS	WS	WS	WS	WS
1.4 TSI	95 E10	√,√	√	√,√	√,√	√	√,√	√,√	√	√,√			
	E95RE	√,√	√	√,√	√,√	√	√,√	√,√	√	√,√			
2.0 TSI	95 E10	√,√	√	√,√	√,√	√	√,√	√,√	√	√,√	√,√	√	√,√
	E95RE	√,√	√	√,√	√,√	√	√,√	√,√	√	√,√	√,√	√	√,√
1.6 TDI	EN590(B7)	√,√	√	√,√	√,√	√	√,√	√,√	√	√,√	√,√	√	√,√
	HVO	√,√	√	√,√	√,√	√	√,√	√,√	√	√,√	√,√	√	√,√
2.0 TDI	EN590(B7)	√,√	√	√,√	√,√	√	√,√	√,√	√	√,√	√,√	√	√,√
	HVO	√,√	√	√,√	√,√	√	√,√	√,√	√	√,√	√,√	√	√,√
1.4 TSI FFV	95 E10	√,√	√	√,√	√,√	√	√,√	√,√	√	√,√	√,√	√	√,√
	RE85	√,√	√	√,√	√,√	√	√,√	√,√	√	√,√	√,√	√	√,√
1.4 TSI CNG	95 E10	√,√	√	√,√	√,√	√	√,√	√,√	√	√,√	√,√	√	√,√
	CNG	√,√		√,√	√,√		√,√	√,√		√,√	√,√		√,√
BEV	electricity	√		√	√		√	√		√	√		√

NB: CS = cold (engine) start; WS = warm (engine) start
√,√ = duplicated test, √ = single test run only
In NEDC no auxiliaries in use (as in standard protocol)
In ART cycles headlight and radio on, blower at 50% and target temperature + 20 °C, but no A/C.

4.6.3 Test set-up and equipment

Table 19 presents data of the sampling and analysis of the tests performed in Finland.

Table 19: Sampling and analysis methods used for regulated pollutants and methods & hardware for electric vehicle testing performed in Finland.

Compound	Analysis Method	Sample Collection
Carbon Monoxide (CO)	Non-Dispersive Infrared Detection (NDIR)	Tedlar™ bag
Carbon Dioxide (CO_2)	Non-Dispersive Infrared Detection (NDIR)	Tedlar™ Bag
Oxides of Nitrogen (NO_x)	Heated Chemiluminescence Detection (CLD)	Tedlar™ bag
Total Hydrocarbons (THC)	Heated Flame Ionization Detection (FID)	Tedlar™ bag
Particulate Matter (PM)	Gravimetric Procedure	47 mm Filters (Pallflex)
Methane (CH_4)	FTIR	continuous, from diluted sample
Nitrogen Oxide, Nitrogen Dioxide (NO, NO_2)	FTIR	continuous, from diluted sample
Nitrous Oxide (N_2O)	FTIR	continuous, from diluted sample
Fuel Consumption (FC)	Calculated based on Industry Standard Carbon Balance	

Figures 9 and 10 depict the test cell at VTT, Espoo, Finland. The cell has humidity and ambient temperature control from +30 down to -25 °C. It is large enough to be used to soak/precondition up to three cars simultaneously.

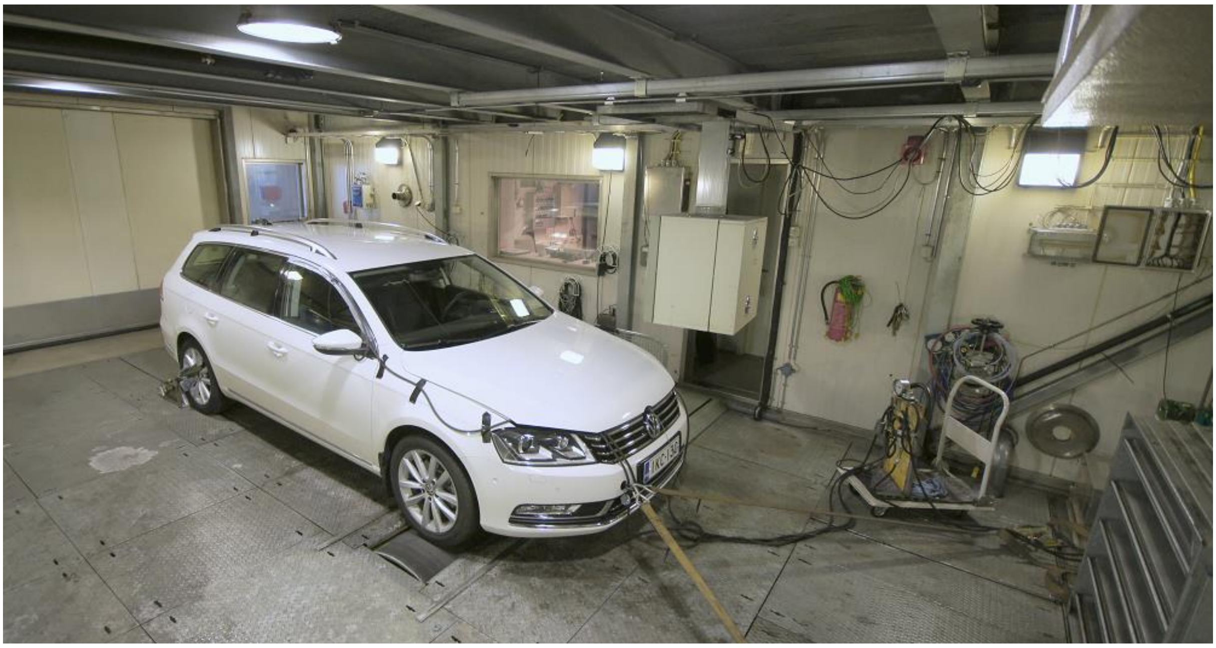

Figure 9: Emissions and fuel consumption test facility with a single-roller (1.0 m) 2WD dynamometer at VTT, Finland.

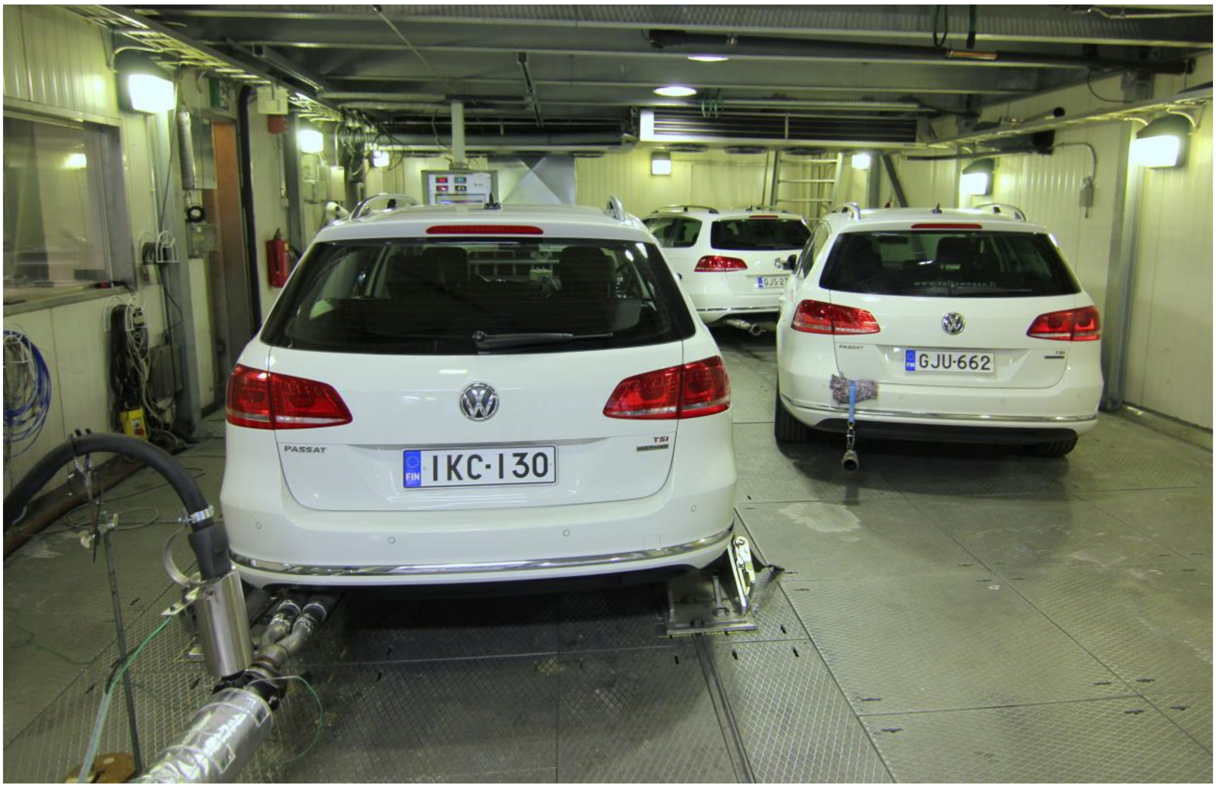

Figure 10: Test cell at VTT is large enough to be used to soak/precondition and test up to three cars simultaneously during a single 8-hour working day.

4.6.4 Fuels

Table 20 presents some information of the fuels used in the tests in Finland.

Table 20: Information of the fuels used in the tests in Finland.

Analysis Parameters	Method	95E10	E95RE	EN590 (B7)	HVO	RE85	CNG
Density (kg/m^3 @ 15 ^{o}C)	ENISO12185	746.3	747.0	844.9	779.6	784.9	
Vapour pressure (kPa)	EN13016-1	83.2	81.4			50.7	
Ethanol (vol-%)	EN1601	9.29	9.59			85.7	
Oxygen (vol-%)	EN1601	3.48	3.55			30.29	
Total oxygenates (vol-%)	ENISO22854	9.78	9.62			88.47	
Net Heating Value MJ/kg	ASTMD240	41.647	41.728			28.940	50.0
Net Heating Value MJ/l	ASTMD240	31.081	31.171			22.715	
Net Heating Value MJ/kg	ASTMD4809			42.388	43.932		
Net Heating Value MJ/l	ASTMD4809			35.814	34.249		
Carbon Fuel Fraction, %-wt	ASTM D5291	83.2		85.9	84.4		
Hydrogen Fuel Fraction, %-wt	ASTM D5291	13.2	13.10	13.2	14.9	13.2	
RON	ENISO5164	96.4	n/a			n/a	
MON	ENISO5163	85.0	n/a			n/a	
Cetane Number	ASTM D6890				81.7		
Total Sulfur (mg/kg)	ENISO20846	n/a	2.5	8.7	< 1		
Cloud Point max (^{o}C)	NM473			-5	-23		
CFPP (^{o}C)	EN116			-20	-21		

Alternative Methods:

NM249	NM291	NM40

4.7 Experimental work - USA

4.7.1 Vehicles and fuels/powerplants

The following Table 21 presents combinations of vehicle, fuel, duty-cycle and ambient temperature for tests performed in United States.

Table 21: Vehicles tested in U.S.

Manufacturer and Make	Hyundai Sonata	Hyundai Sonata Hybrid	Ford Fusion	Ford Fusion Hybrid
Model Year	2013	2011	2012	2010
Fuel	Gasoline	Gasoline	Gasoline	Gasoline
Engine	2.4 L I4	2.4 L I4 (Atkinson-cycle)	3.0 L V6	2.5L (Atkinson cycle)
Horsepower (hp@rpm):	198 @ 6300	166 @	240 @ 6550	156 @
Torque (lb-ft @ rpm):	184 @ 4250	154 @	223 @ 4300	136 @
Compression Ratio	11.3:1	n/a	10.3:1	n/a
Emission Standard	U.S. Tier II	US Tier II	US Tier II	US Tier II
Emission Control System	?	?	?	?
Transmission	A6	A6	Auto	Auto
Hybrid system specs				
Battery Capacity (Ah)	n/a	1.4 kWh	n/a	n/a
System Voltage (V)	n/a	270	n/a	275
Motor Power (kW @ rpm)	n/a	30	n/a	78
Test Conditions				
Test Weight (lbs/kg)	3500/1588	3750/1701	3744/1698	4000/1814

data retrieved by VTT from non-original sources

Figures 11 to 14 depict test vehicles photographed during each respective test session at the Advanced Powertrain Research Facility of Argonne National Laboratory (ANL), near Chicago, IL.

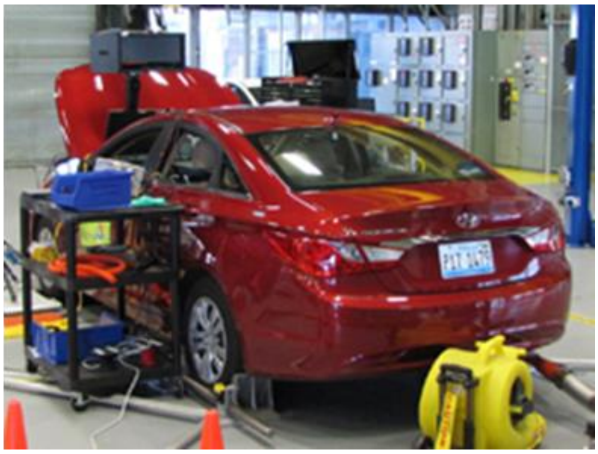

Figure 11: 2013 Hyundai Sonata during a test session at ANL.

Figure 12: 2013 Hyundai Sonata Hybrid during a test session at ANL.

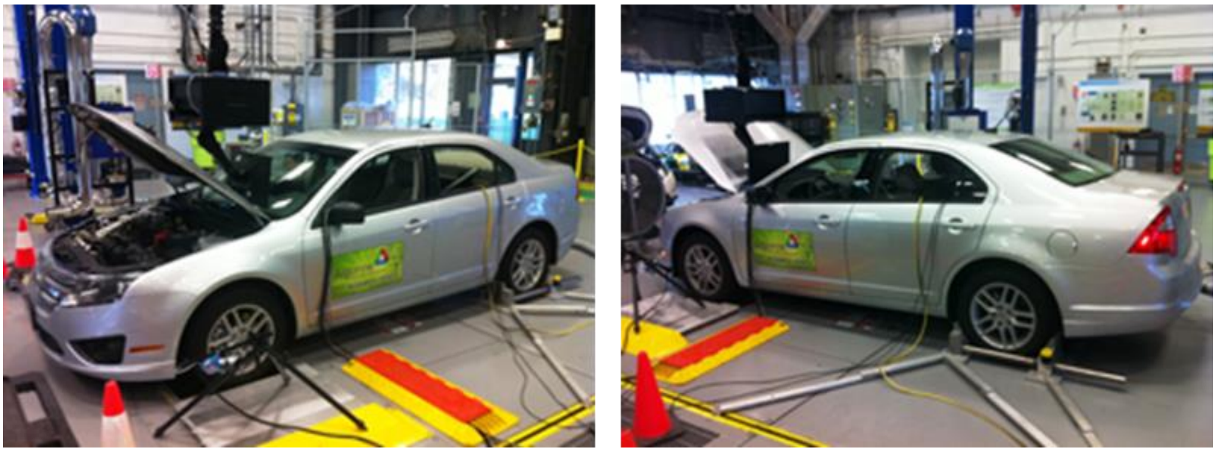

Figure 13: 2012 Ford Fusion during a test session at ANL.

Figure14: 2010 Ford Fusion Hybrid during a test session at ANL.

4.7.2 Test programme: duty-cycles, fuels and ambient conditions

The following table 22 presents combinations of vehicle, fuel, duty-cycle and ambient temperature for tests performed in U.S.

Table 22: Combinations of vehicle, fuel, duty-cycle and ambient temperature for tests performed in U.S.

Vehicle	Fuel	Ambient temp.	Test Cycle UDDS[1] cold	UDDS[1] hot	UDDS[1] hot	HWFET hot	US06 hot	NEDC cold	LA92[2] cold	JC08[3] cold	WLTP[4] cold	Cycle Start
Hyundai Sonata	gasoline #2	+21 °C	√	√	√	√	√	√	√	√	√	
Hyundai Sonata Hybrid	gasoline #3	+22 °C	√	√	√	√	√					
Ford Fusion V6	gasoline #2	+21 °C	√	√	√	√	√	√	√		√	
Ford Fusion Hybrid	gasoline #1	+23 °C	√	√	√	√	√					

[1] this three-phase combination also known as FTP 75 or FUDS or LA-4 [3] Japanese type approval cycle since 2011
[2] also known as California Unified Cycle (UC) [4] New World Harmonised Light-duty Test Procedure. 4 phases

4.7.3 Test set-up and equipment

Figure 15 depicts dynamometer the test facility at the Advanced Powertrain Research Facility of ANL (Argonne National Laboratory). The photo is sourced from the document "Chassis Dynamometer Testing Reference Document" by Henning Lohse-Busch, Kevin Stutenberg, Mike Duoba, Eric Rask, Forrest Jehlik and Glenn Keller; published by Advanced Powertrain Research Facility in July, 2013, to accompany the Downloadable Dynamometer Database, which is the source of the U.S. data at hand in this study. Full document is downloadable at http://www.transportation.anl.gov/D3/pdfs/ANL_APRF_DynoTestingReference_July2013.pdf.

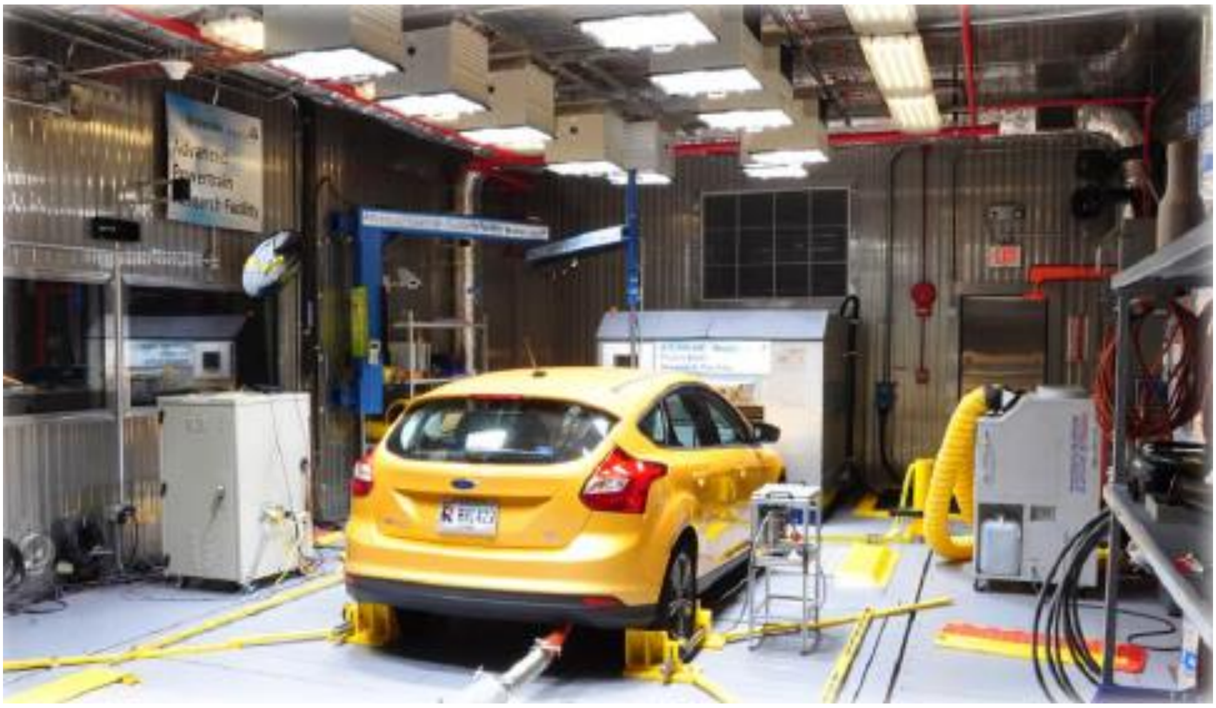

Figure 15: Dynamometer test cell at the Advanced Powertrain Research Facility of ANL.

According to the information provided by this reference document, Advanced Powertrain Research Facility (APRF) is purpose-built for vehicle benchmarking for the DOE. It furnishes a state-of-the-art 4WD chassis dynamometer and customised multi-input data acquisition flexible to evaluate various novel vehicle architectures (HEV, EV, Alternative Fuels).

Measurement of Vehicle Fuel Consumption is made either by determining tailpipe emissions and carbon balance calculations, when the mass of fuel consumed is based on the measured carbon products of the combustion event and the carbon weight fraction of the fuel, or by direct fuel flow metering that provides a faster mass flow reading compared to the 'instantaneous' modal fuel flow measurement from the emissions bench since the exhaust gases are subject to transport delays and gas diffusion through the exhaust system. (It is not, however, stated in the documentation, which alternative was used to produce the data delivered to be used in this study.)

Furthermore, the above-mentioned document states that APRF has full line of instruments capable of determining exhaust emissions from CARB/EPA SULEV (super-ultra-low emission vehicles) according to the U.S. EPA (Tier 2) emissions standards. However, no emissions data was released with the files submitted.

4.7.4 Fuel information

Table 23 presents some information of the fuels used in the tests in the U.S.

Table 23: Information of the fuels used in the tests in USA.

Analysis Parameters	Type of fuel: gasoline		
Trade name (reference)	Tier II EEE HF437		
Batch #	Batch #1	Batch #2	Batch #3
Carbon Fuel Fraction, %-wt	0.8631	0.8618	n/a
Hydrogen Fuel Fraction, %-wt	n/a	n/a	n/a
Oxygen Fuel Fraction, %-wt	n/a	n/a	n/a
Net Heating Value MJ/kg	42.81	42.67	42.34
Net Heating Value MJ/l	31.72	31.70	31.41
Density (kg/m^3 @ 15^{o}C)	741	743	742

5. Results and Discussion

5.1 Types of data assessment

Data evaluation is performed in two steps. First evaluation on the end-use performance is done by each individual participating country within the tested vehicle model family. The second evaluation is done using all the information generated.

The second evaluation phase combines the well-to-tank data of the test fuels to end-use performance data to provide information on the complete fuel cycle.

5.2 Results – Japan

In Japan, one vehicle platform with either gasoline or LPG (liquid injection) engine was tested at normal ambient temperature, using Japanese type-approval duty cycles. The data submitted by Japan includes fuel and energy consumption, emissions of CO_2, CO, HC and NOx. No non-regulated pollutants were reported, but the hydrocarbons were reported as non-methane (NMHC) and methane (CH_4) emissions, allowing $CO_{2(eq)}$ to be calculated using 23 as the equivalence factor for methane.

Figures 16 to 21 depict these test results per vehicle/fuel and driving cycle.

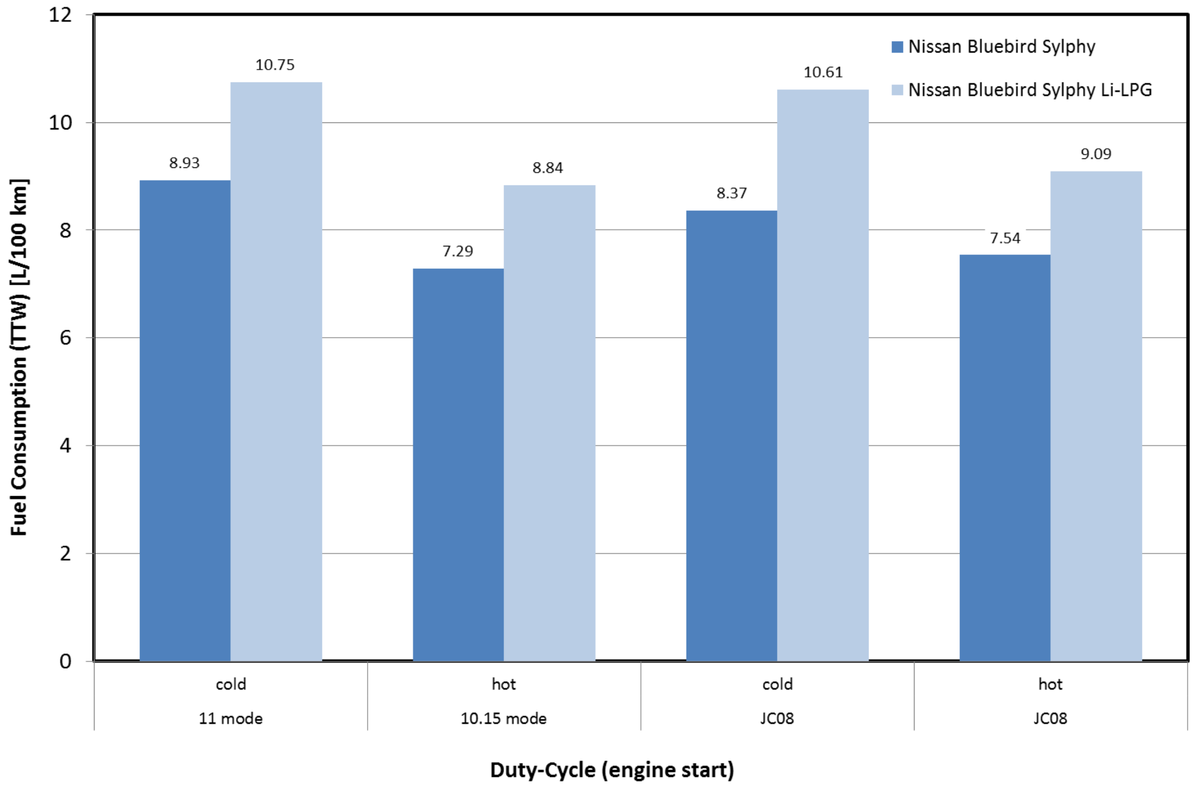

Figure 16: Fuel consumption of the two Nissan Bluebird cars tested in Japan.

Regarding fuel and energy consumption (Figures 16 and 17) we can note that despite of the lower numeric fuel consumption figures, the energy consumption was in most cases slightly lower for the LPG variant. However, in cold-start JC08 cycle this was in reverse, but all differences were very small, only a few %.

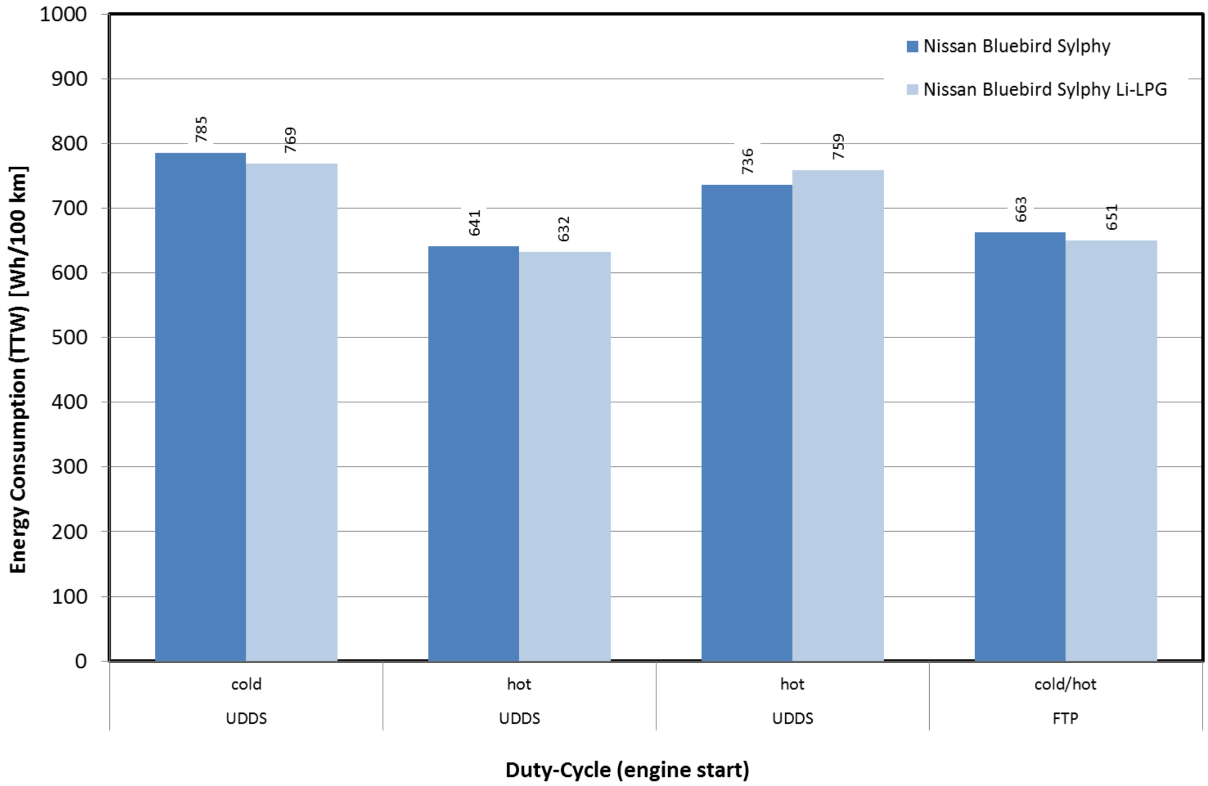

Figure 17: Energy consumption of the two Nissan Bluebird cars tested in Japan.

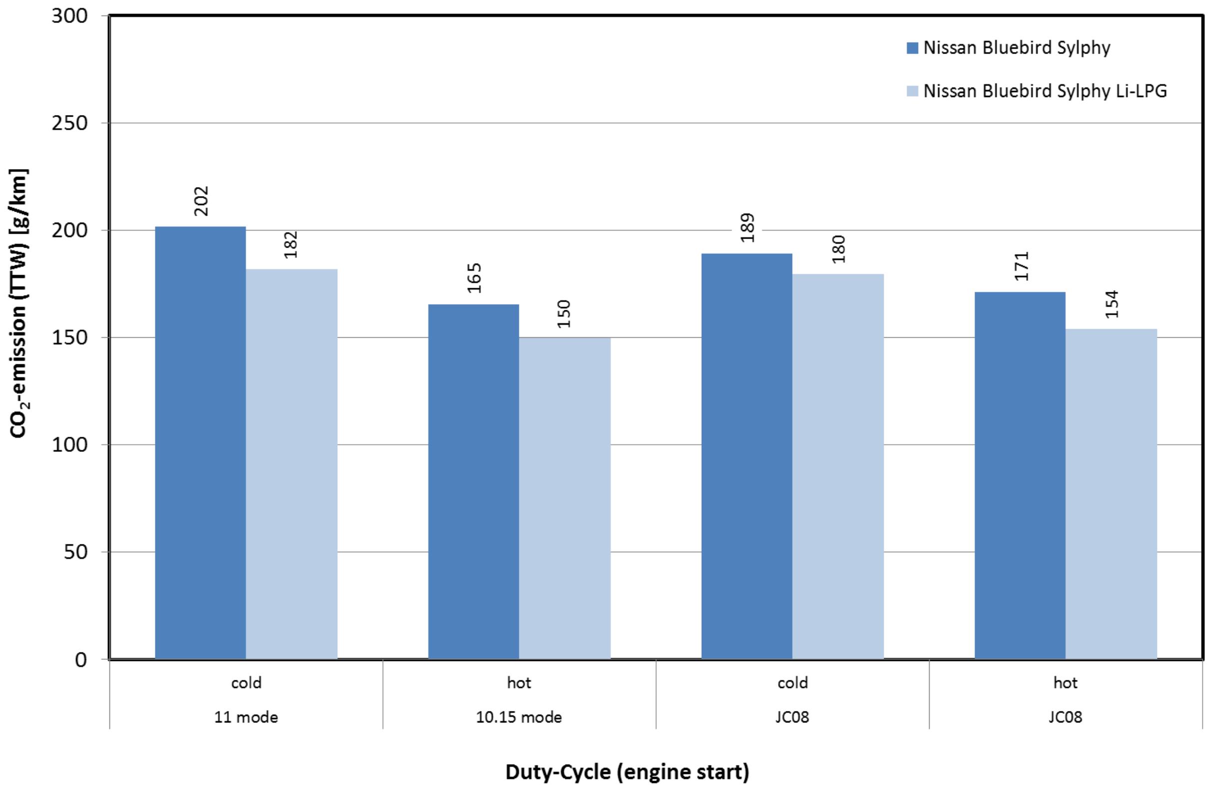

Figure 18: CO_2 emissions from the two Nissan Bluebird cars tested in Japan.

The TTW CO_2 emissions (Figure 18) were in all test cases lower with LPG than for gasoline. The difference was about 10 %, which is the same as the difference in carbon/energy –ratio of these fuels (65.7 for LPG vs. 73.3 for E0 gasoline).

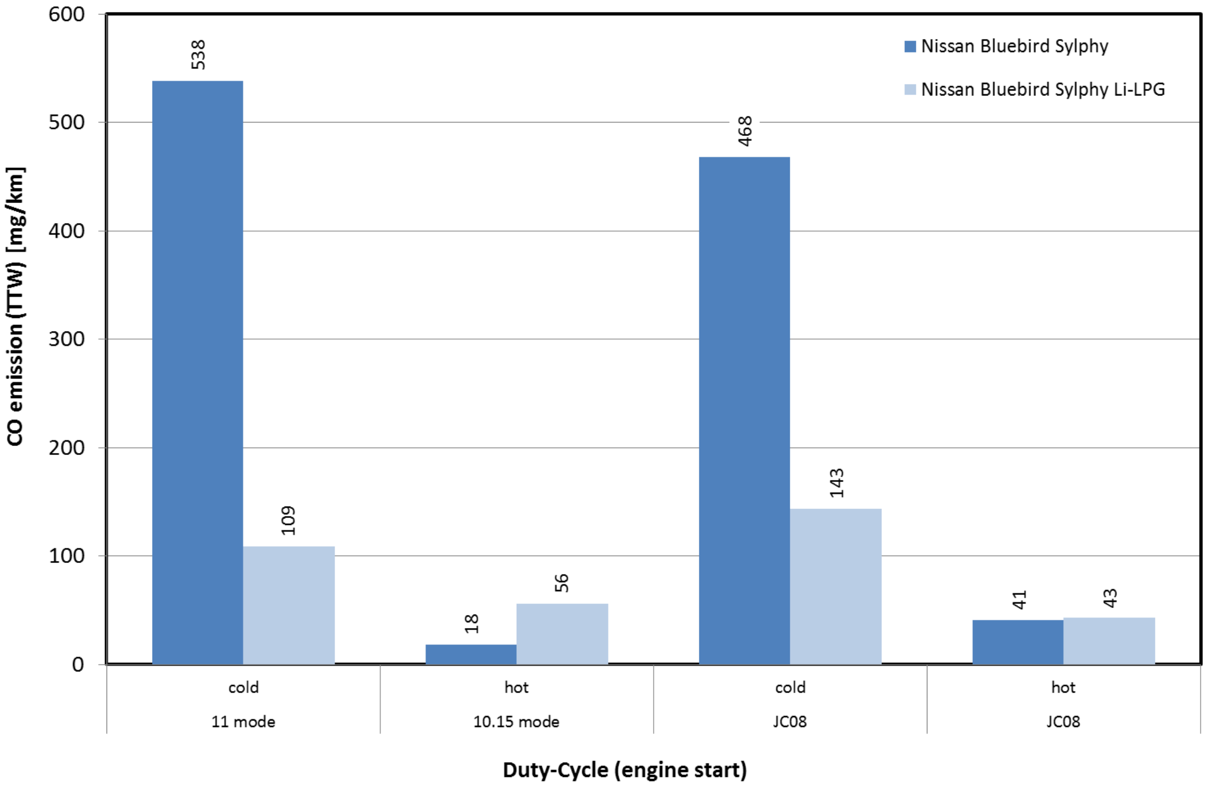

Figure 19: CO emissions from the two Nissan Bluebird cars tested in Japan.

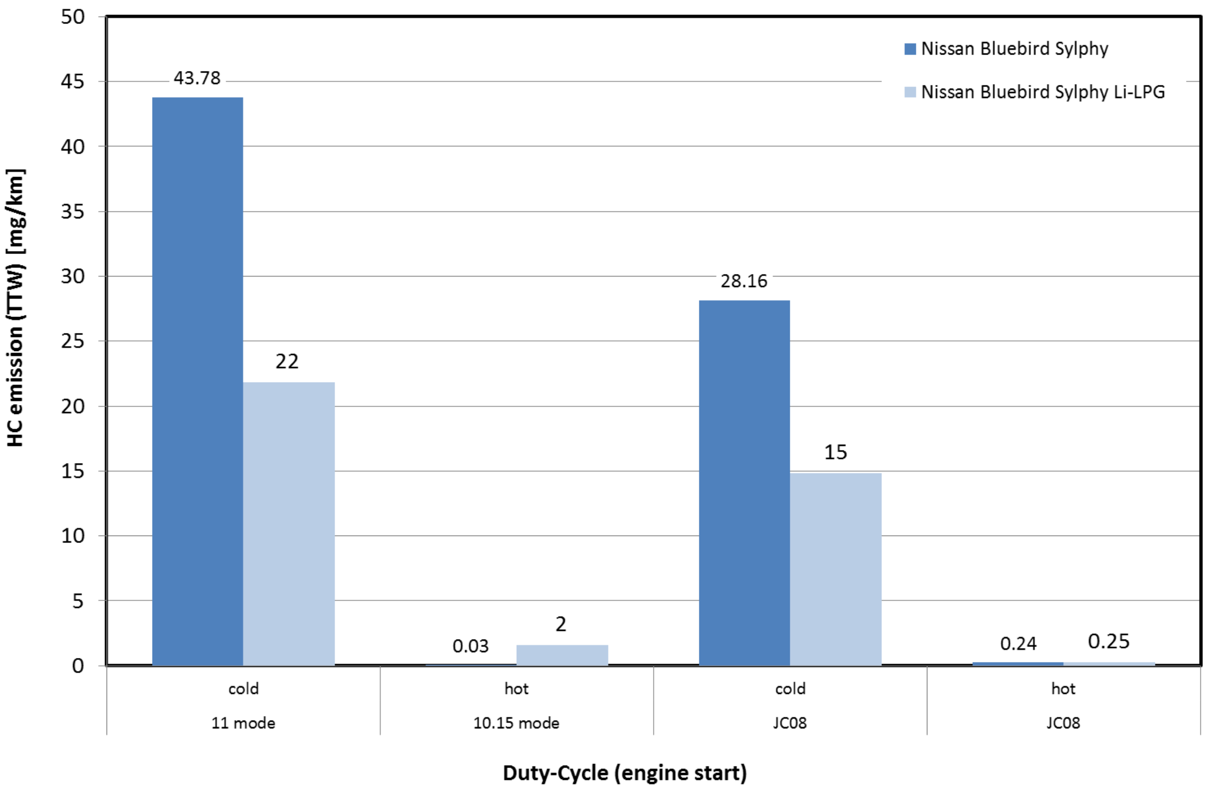

Figure 20: HC emissions from the two Nissan Bluebird cars tested in Japan.

With the cold-start cycles both CO and total HC were much lower with LPG compared to the gasoline-powered car’s results (Figures 19 and 20). In hot-start cycles

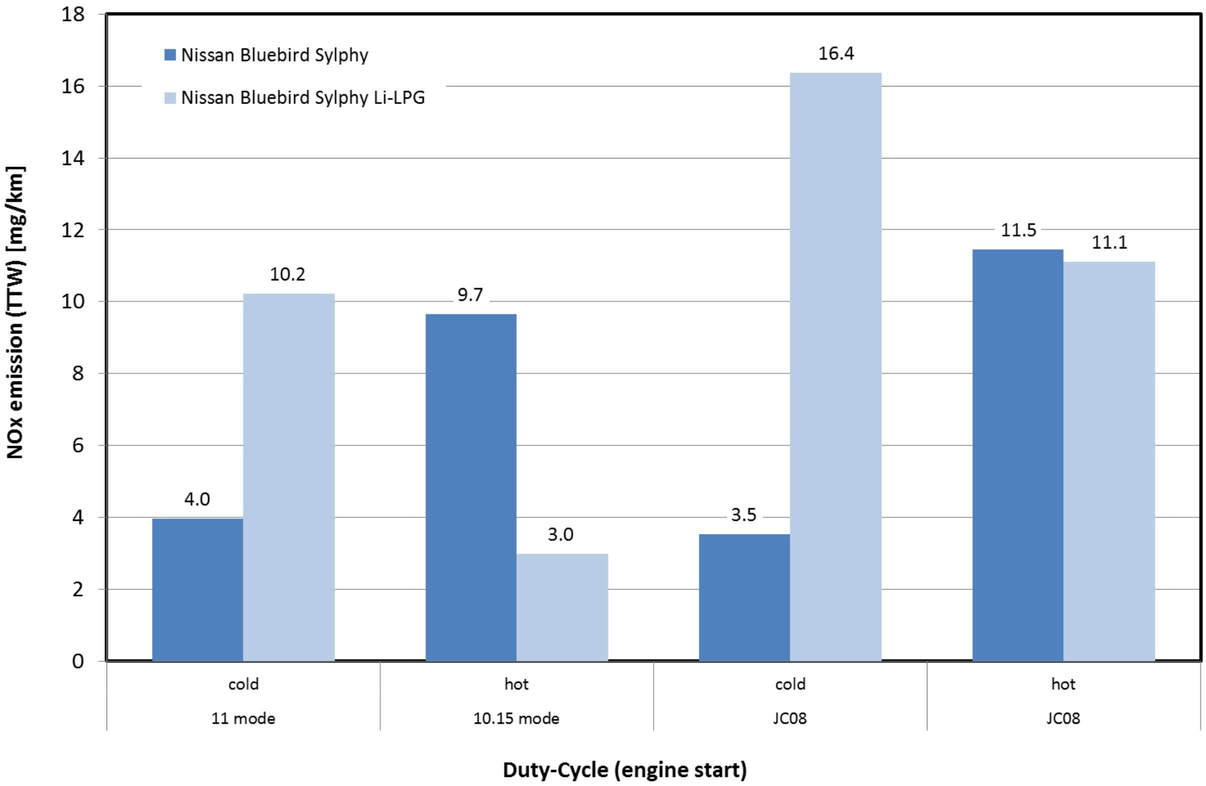

Figure 21: NOx emissions from the two Nissan Bluebird cars tested in Japan.

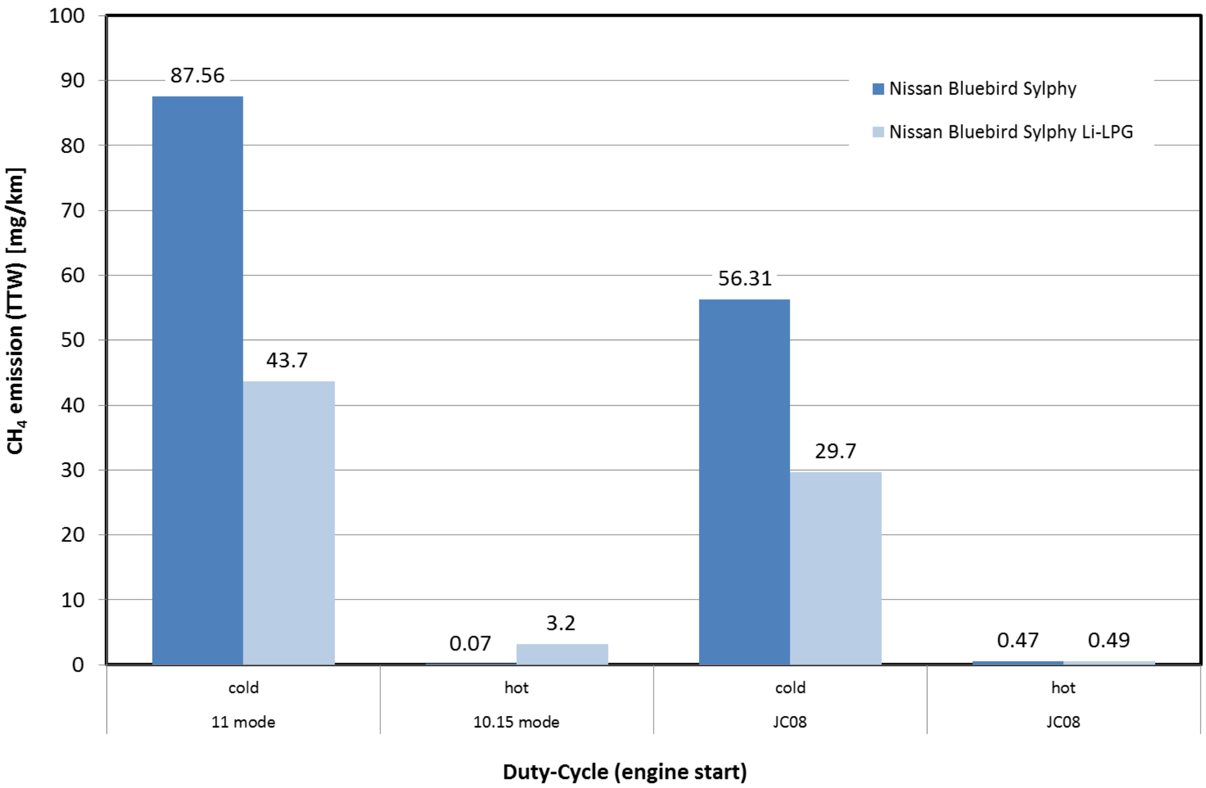

Figure 22: CH_4 emissions from the two Nissan Bluebird cars tested in Japan.

With the cold-start cycles NOx emissions were distinctly higher with LPG compared to the gasoline-powered car's results (Figure 21). However, for the methane (CH_4) portion of the hydrocarbons, the opposite was true (Figure 22).

5.3 Results – Canada

In Canada, one vehicle platform was tested, with four powerplant options (diesel, gasoline/CNG, gasoline/FFV and gasoline hybrid). Fuel options were either E0/E10, E85 or CNG for SI, and several different types/blends for diesel. In addition to normal ambient temperature (+23 °C), tests were run at -7 °C, and one test at -18 °C.

The data submitted by Canada includes fuel and energy consumption, emissions of CO_2, CO, HC, NOx, CH_4, N_2O and TPM.

5.3.1 Results for native fuel for each vehicle/engine

Figures 23 to 30 depict test results per vehicle/fuel and driving cycle for the basic/native fuel for each vehicle/engine, and in normal ambient temperature (+23 °C). However, the FFV version is represented with both E0 and E85 fuels.

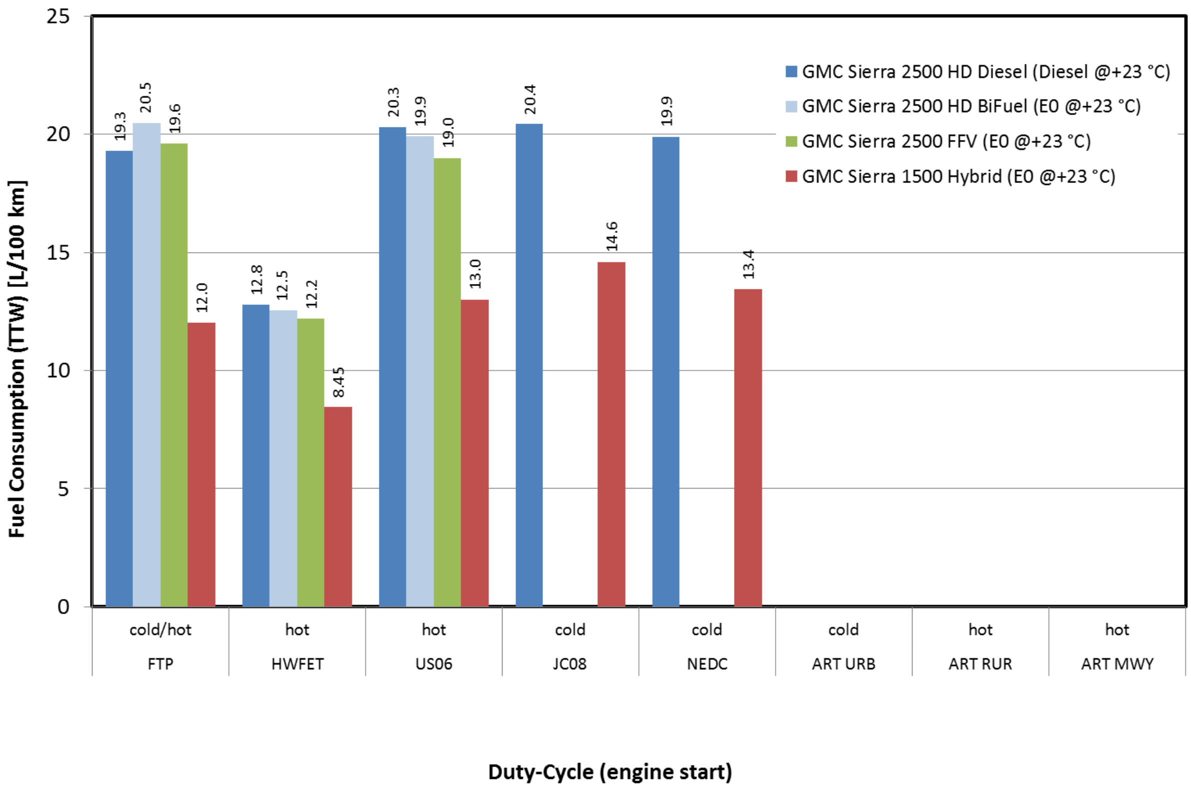

Figure 23: Fuel consumption of the four GMC trucks tested in Canada.

If we at first consider fuel and energy consumption (Figures 23 and 24) we immediately notice that the absolute values for both conventional ICE-powered options were quite high, mainly due to the large bulk of the vehicles. The diesel version was about three times heavier than typical vehicles tested by other partners, and the gasoline variant was roughly twice as heavy. However, the hybrid version was showing about 25 to 30 % lower figures compared to the conventional SI-powered variant. But this was not just due to the more efficient powertrain, as the hybrid version was also almost 30 % lighter than the heaviest (diesel), and almost 15 % lighter than the respective non-hybrid gasoline version.

All this was duly reflected in CO_2 figures, as well (Figure 25).

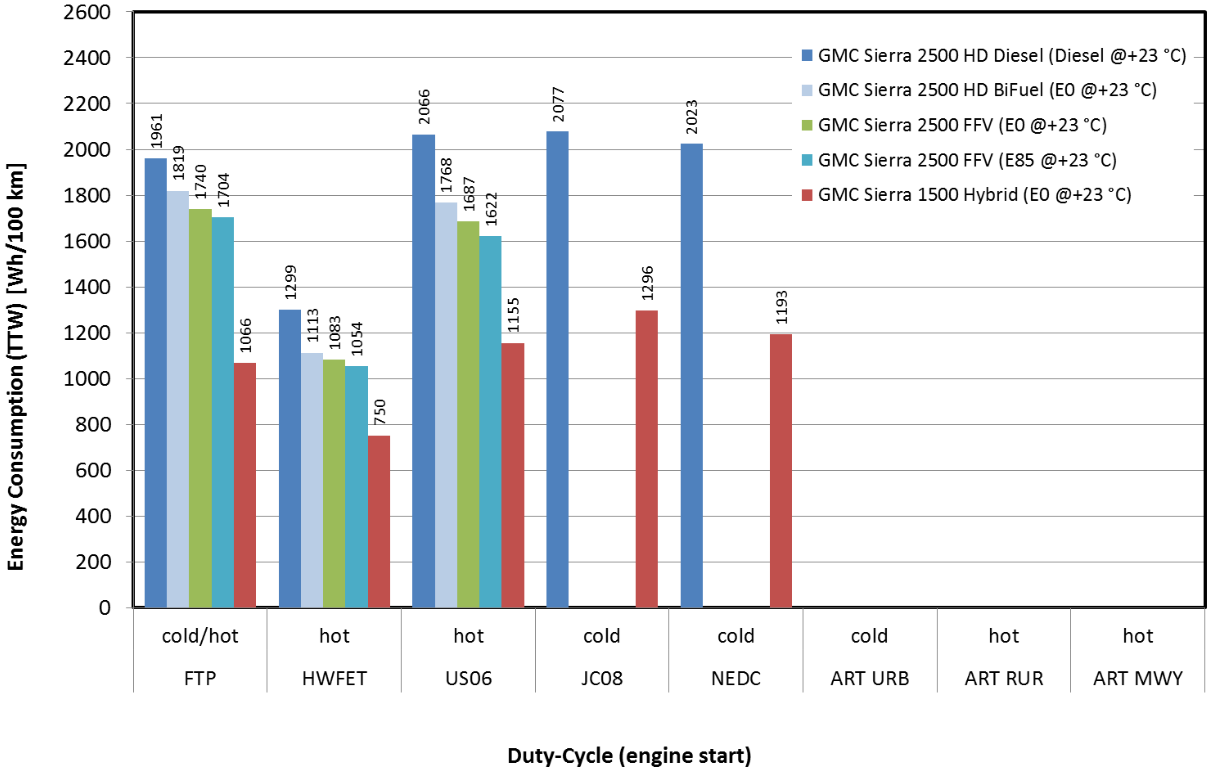

Figure 24: Energy consumption of the four GMC trucks tested in Canada.

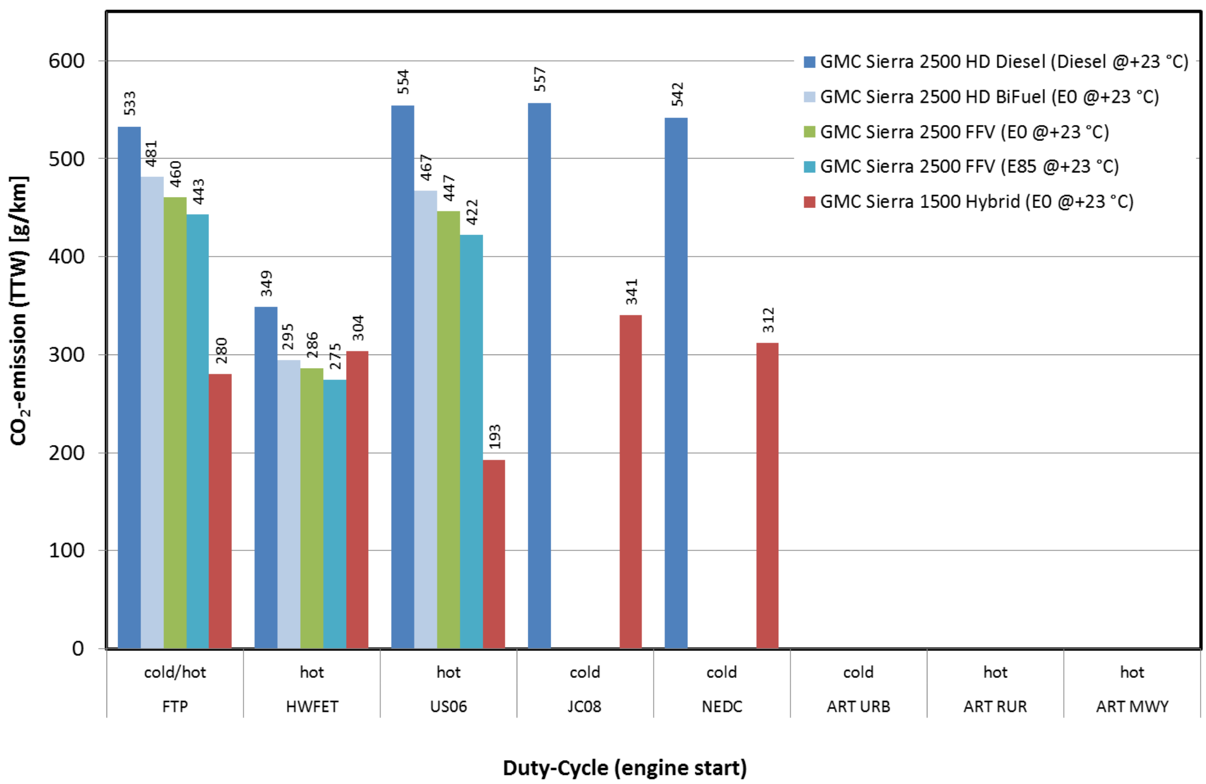

Figure 25: CO_2 emissions from the three GMC trucks tested in Canada.

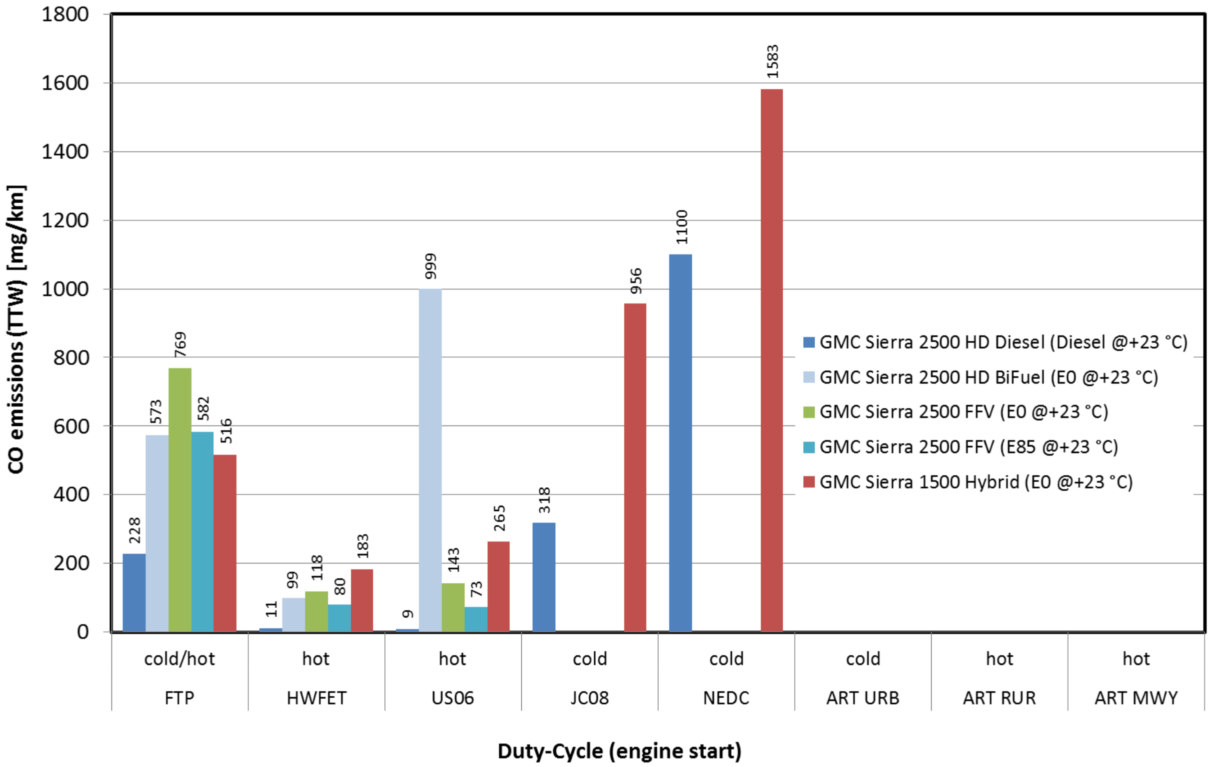

Figure 26: CO emissions from the three GMC trucks tested in Canada.

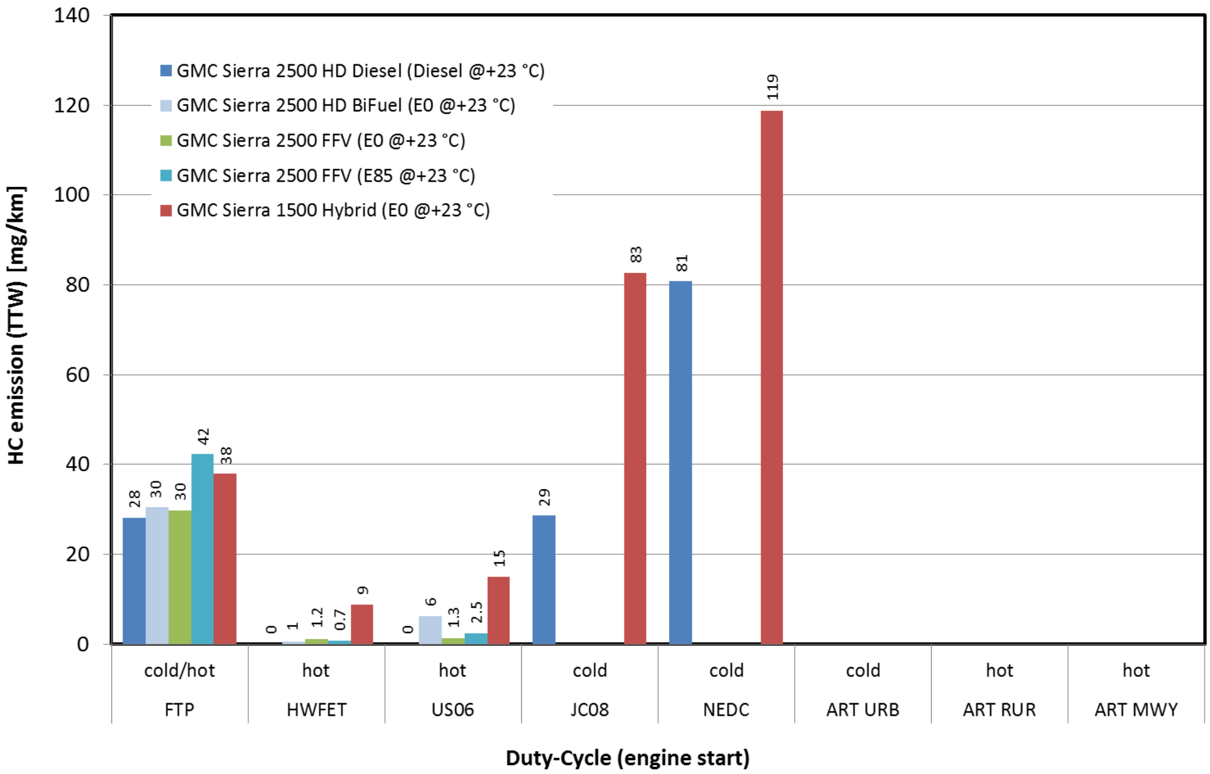

Figure 27: HC emissions from the four GMC trucks tested in Canada.

On the other hand for CO and HC emissions (Figures 26 and 27) the hybrid was clearly the worst case, with only some minor exceptions (CO for gasoline version in US06/hot).

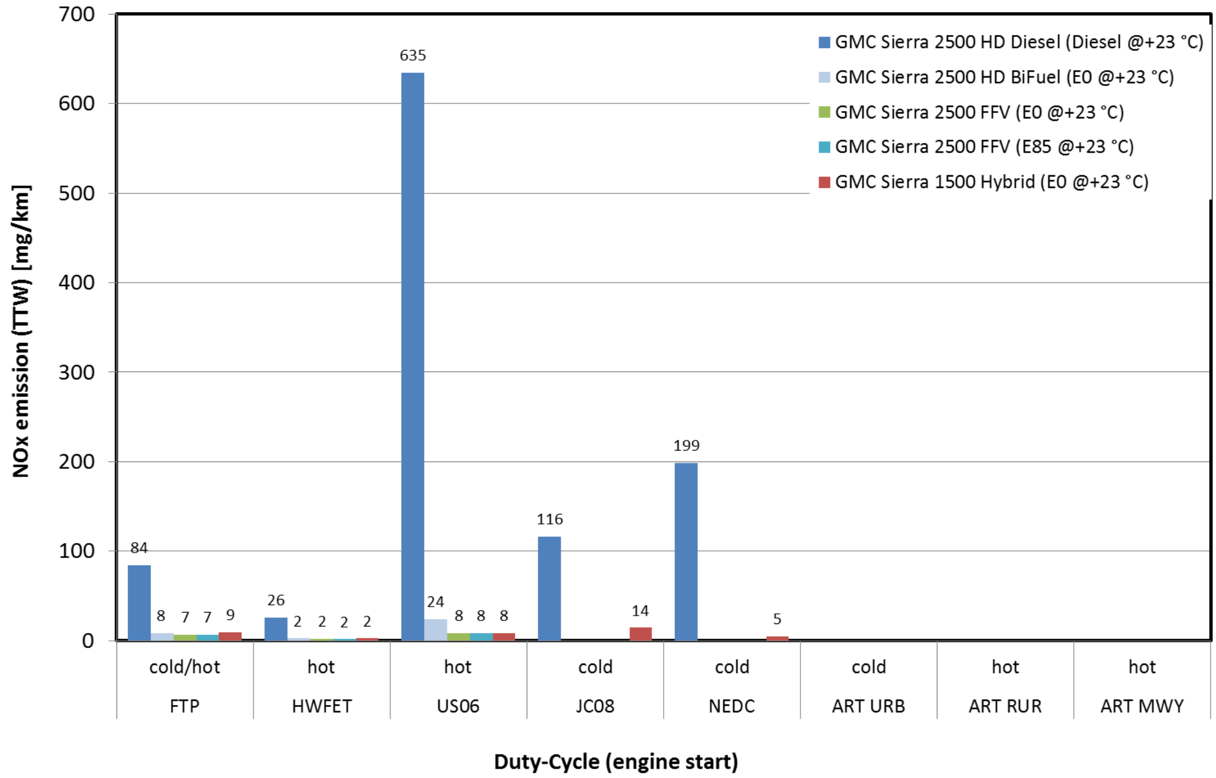

Figure 28: NOx emissions from the four GMC trucks tested in Canada.

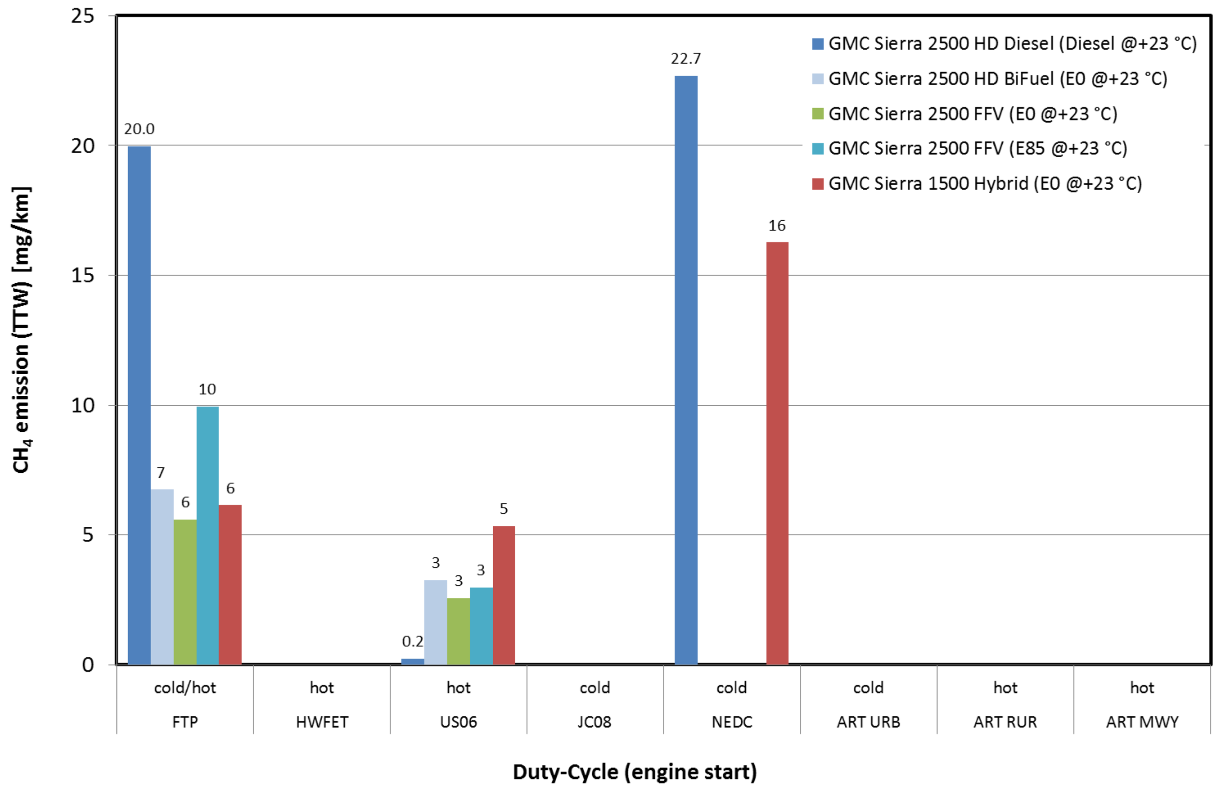

Figure 29: CH_4 emissions from the four GMC trucks tested in Canada.

Quite surprisingly, NOx emissions (Figure 28) were extremely high for the diesel-fuelled variant, especially in hot-started US06-cycle, even if the vehicle was equipped with an SCR-system that should reduce emissions effectively. Somewhat unexpected also were the results for CH_4 (Figure 29), as these were also very high for the diesel-powered option.

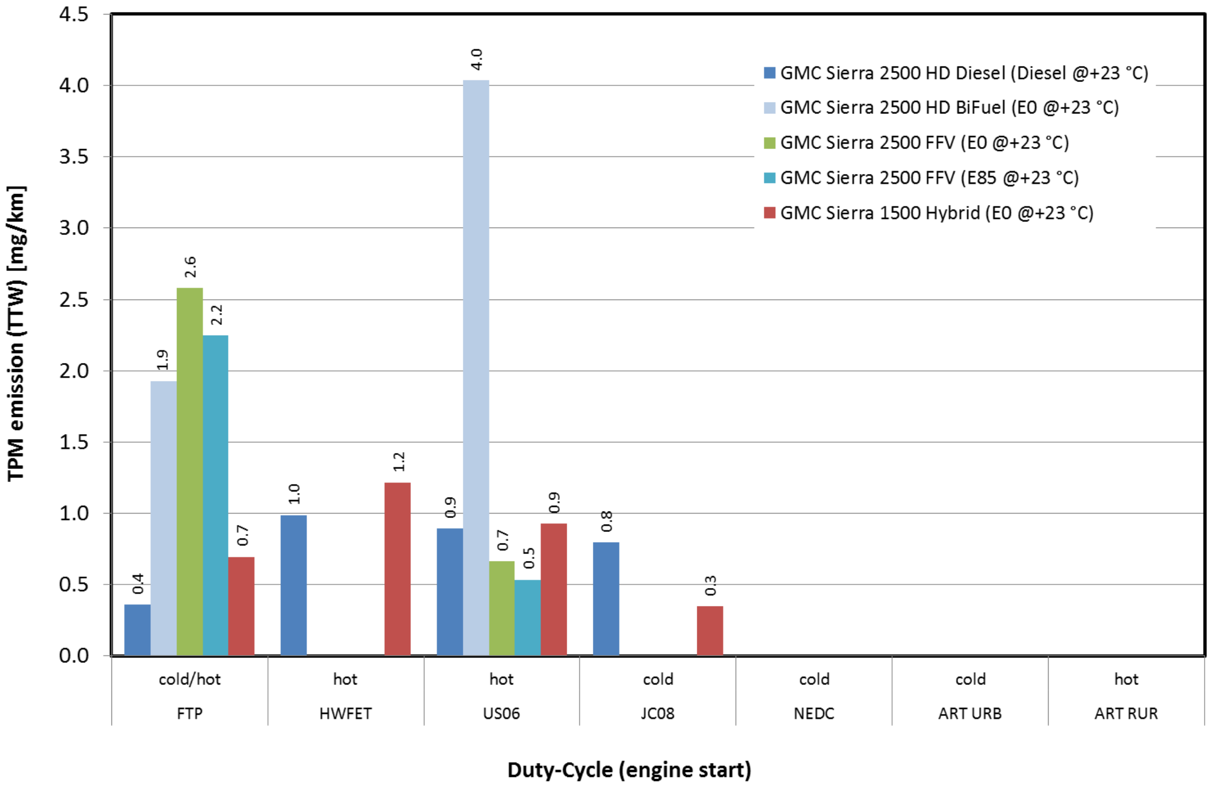

Figure 30: TPM emissions from the four GMC trucks tested in Canada.

Due to the presence of DPF in the diesel-powered truck, total particulate mass (TPM) emissions were by far the largest for the SI-engine running on gasoline. On the other hand, the hybrid version was on par with the diesel.

5.3.2 Results for additional fuels and cold ambient conditions

Apart from the tests with “native” fuel (regular mineral oil diesel), for the CI-engine version, four different fuels were tested, and for the three SI-engine versions (bi-fuel, FFV and hybrid), E0 and E10 gasolines, E85 (E75 in low ambient temperatures) as well as CNG (only for the bi-fuel version) was used. In addition to normal ambient temperature (+23 °C), tests were run at -7 °C, and for the CI version, one test even at -18 °C. Figures 31 to 48 depict the results from these tests.

It should also be noted that the bi-fuel vehicle when tested with CNG was started on gasoline and then switched to CNG at approximately 180 seconds for phase 1 of the FTP and after 30 seconds for phase 3 of the FTP. However, equivalent volumetric fuel consumption and energy consumption were based on an assumption the vehicle was powered with CNG over the full test cycle.

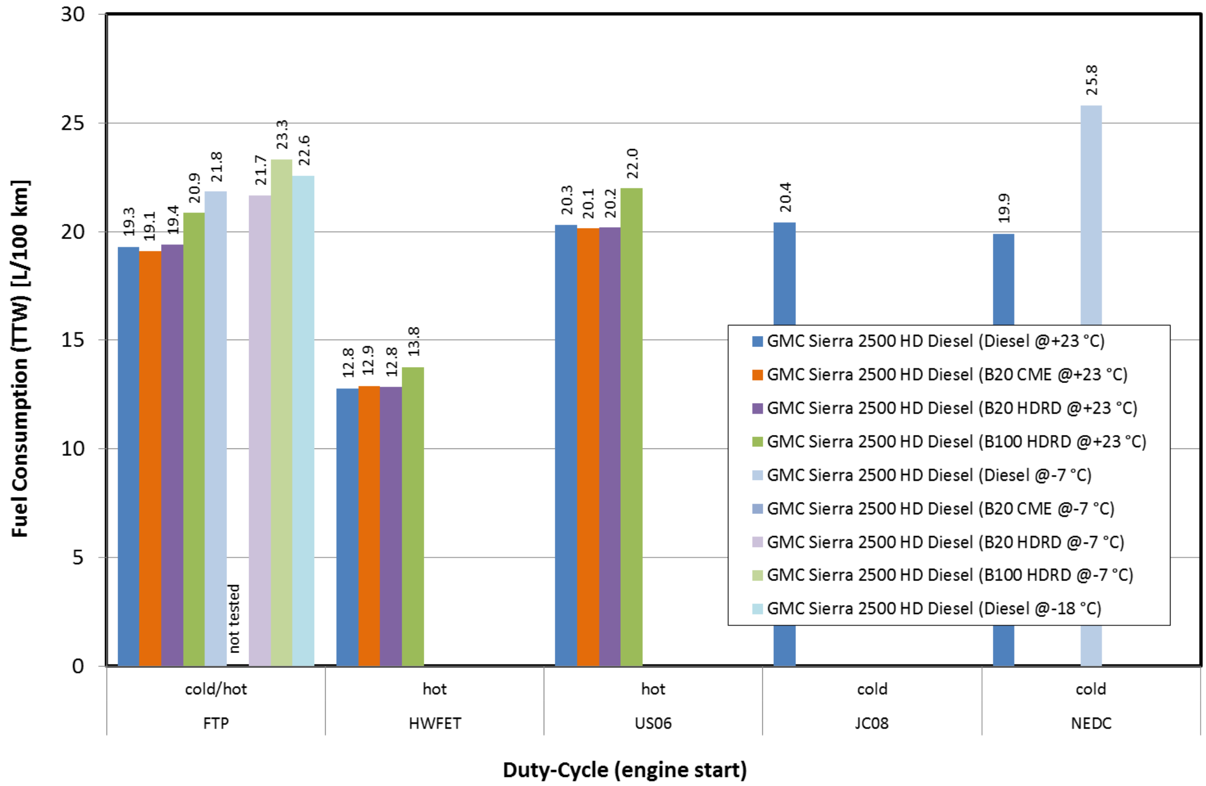

Figure 31: Fuel consumption of the CI-engine powered truck tested in Canada with different fuels at normal ambient temperature (+23 °C), as well as two lower ambients (-7 and -18°C).

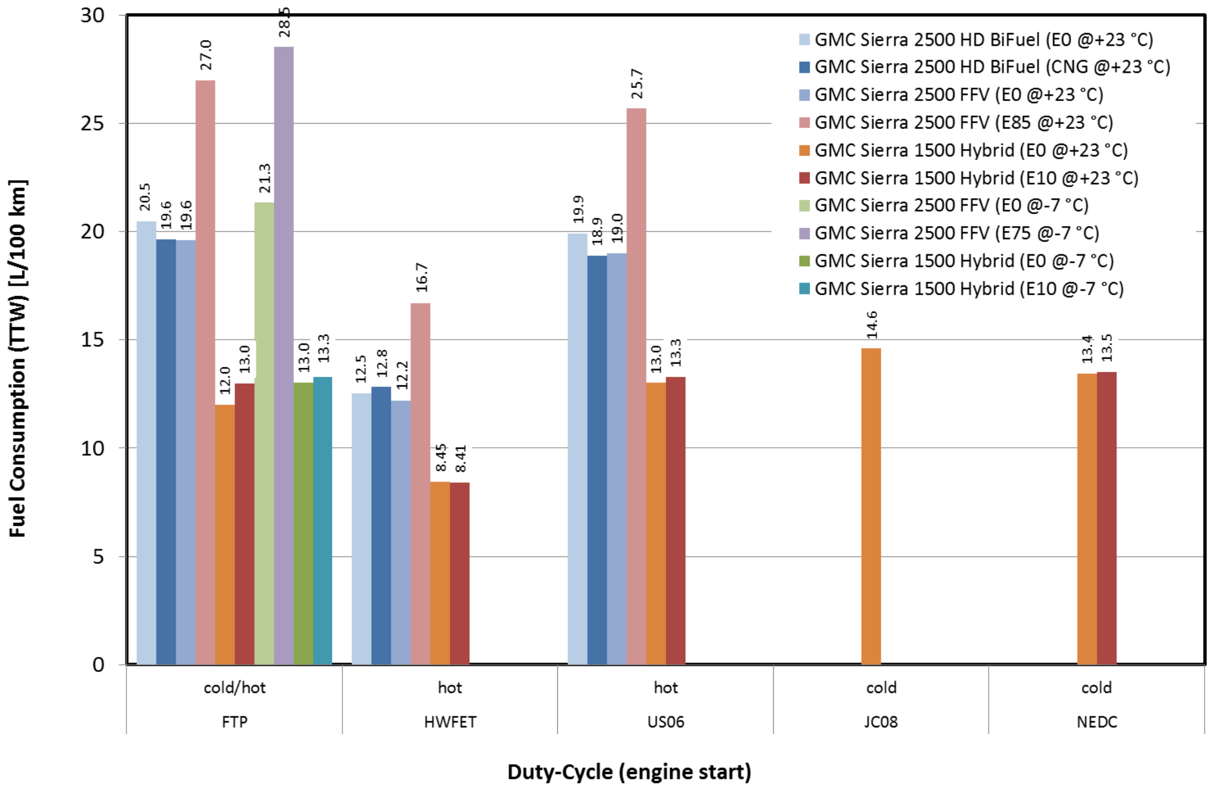

Figure 32: Fuel consumption of the three SI-engine powered trucks tested in Canada with various fuels at different ambient temperatures.

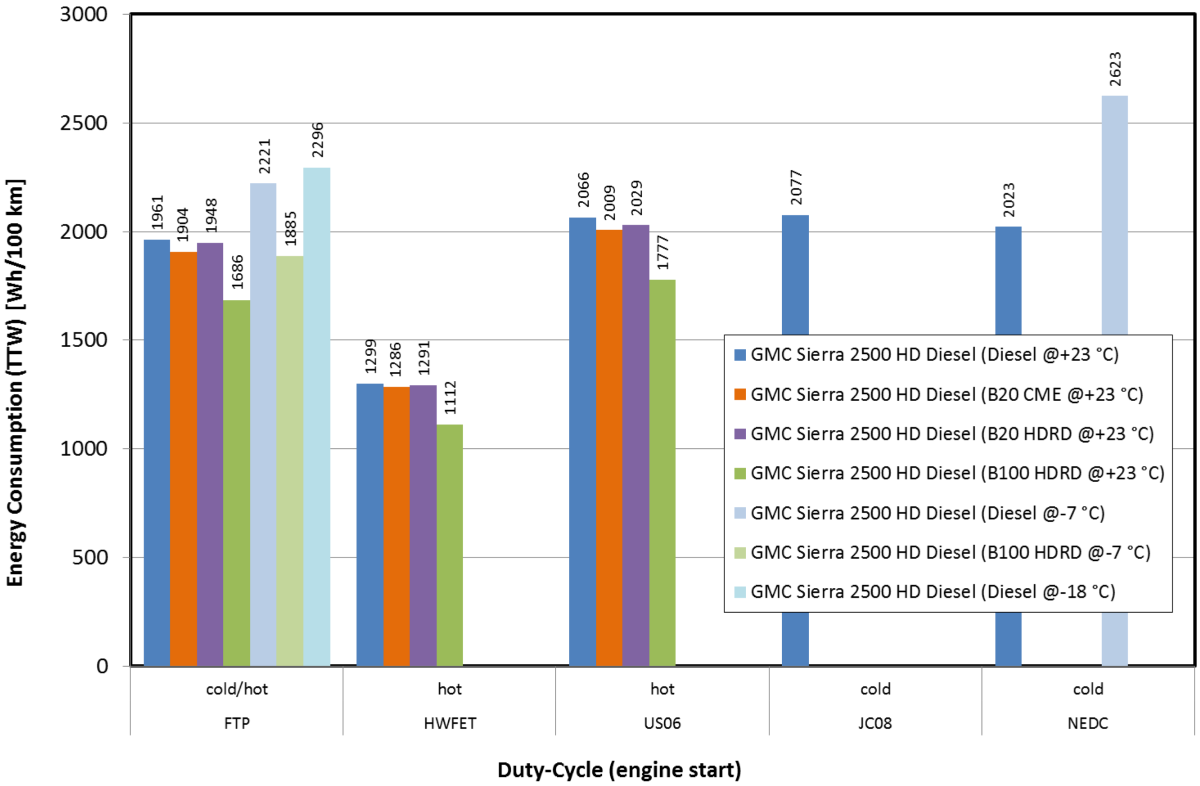

Figure 33: Energy consumption of the CI-engine powered truck tested in Canada with different fuels at normal ambient temperature (+23 °C), as well as two lower ambients (-7 and -18°C).

Volumetric **fuel consumption** showed some response to the switch of fuel. In the CI-engine version (Figure 31), about 8 % increase was recorded for the neat biodiesels (B100 xx), but this was mostly due to the 9 % drop in density (see Table 9 for fuel specs), compared to the regular mineral oil diesel. About the same response was seen both in cold start and hot start cycles, and even tests in tests at -7 °C. Furthermore, lowering of the ambient temperature increased volumetric fuel use by 13% (-7 °C) and 18% (-18 °C), when using neat mineral oil diesel.

Furthermore, considering the SI-engines, volumetric fuel consumption (Figure 32) increased in the hybrid version by some 8 %, when E10 gasoline was used instead of the non-alcohol (E0) grade, even if the densities of both fuels were very close to each other, and the net heating value of the E10 blend was only 2 % lower than the non-alcohol grade (see Table 8). The same order of increase was seen due to the lowering of the ambient temperature from +23 to -7 °C.

When we calculate **energy consumption** from the fuels use by using the net volumetric energy contents of the various fuels, we see (in Figure 33) that the energy use was some 14 to 15% lower with the B100x biodiesels, compared to mineral oil only grade. The same applies to all cycles used, and even in tests at -7 °C. On the other hand, lowering the ambient temperature increased energy consumption, when using straight mineral oil diesel fuel by 13% (at -7 °C) and by 17% (at -18 °C), in accordance with the increase measured in volumetric fuel use (Figure 31). Considering the SI-engines (Figure 34), an increase in energy consumption was inevitable from the increased volumetric fuel use.

Regarding **CO_2 emissions**, using blends of biodiesel resulted in lower tailpipe (TTW) emissions of CO_2 emissions compared to regular mineral oil diesel (Figure 35). This was some 2 to 3 % for the 20% blends and some 5 % for the neat biodiesels. However, lowering of the ambient temperature increased the CO_2 tailpipe (TTW) emissions on mineral-oil only diesel fuel (Figure 35). The same was true for the neat biodiesels (B100). The average increase was some 13 % at -7 °C and 15 % at -18 °C (mineral-oil diesel only) over the FTP cycle.

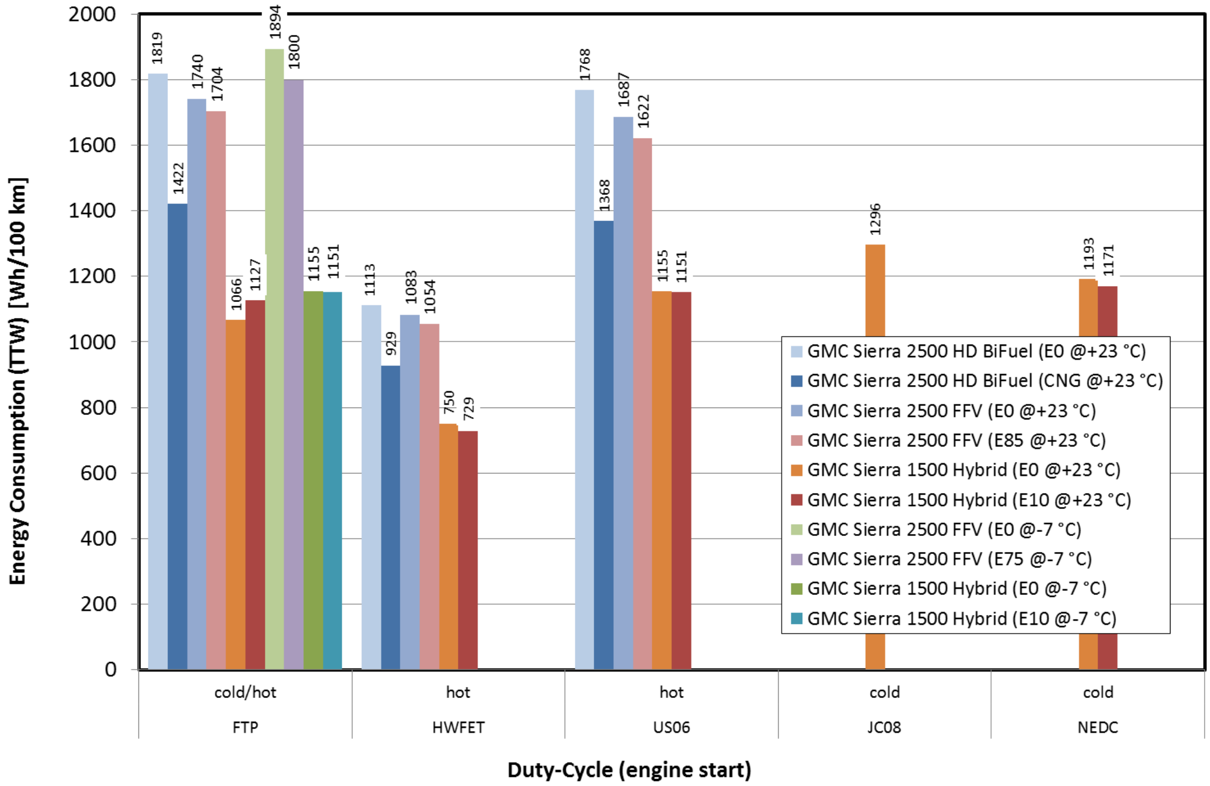

Figure 34: Energy consumption of the three SI-engine powered trucks tested in Canada with various fuels at different ambient temperatures.

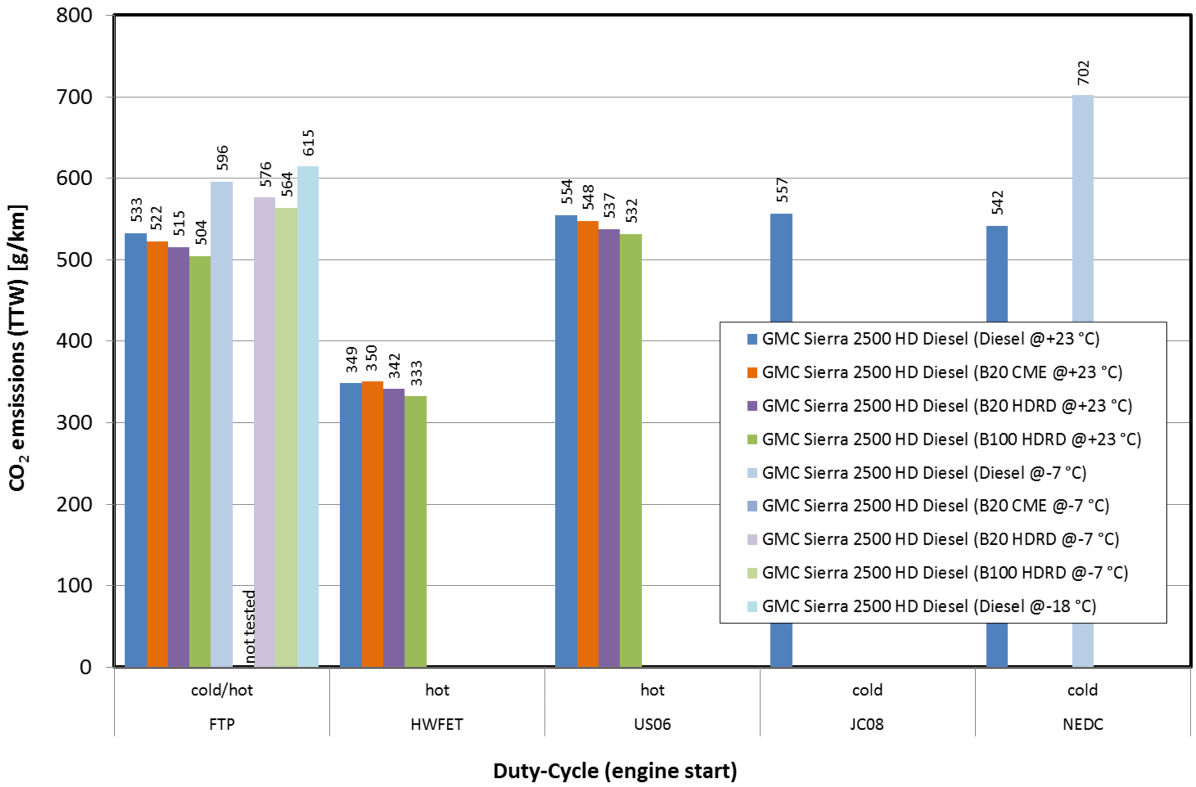

Figure 35: CO_2 emissions from the CI-engine powered truck tested in Canada with different fuels at normal ambient temperature (+23 °C), as well as two lower ambients (-7 and -18°C).

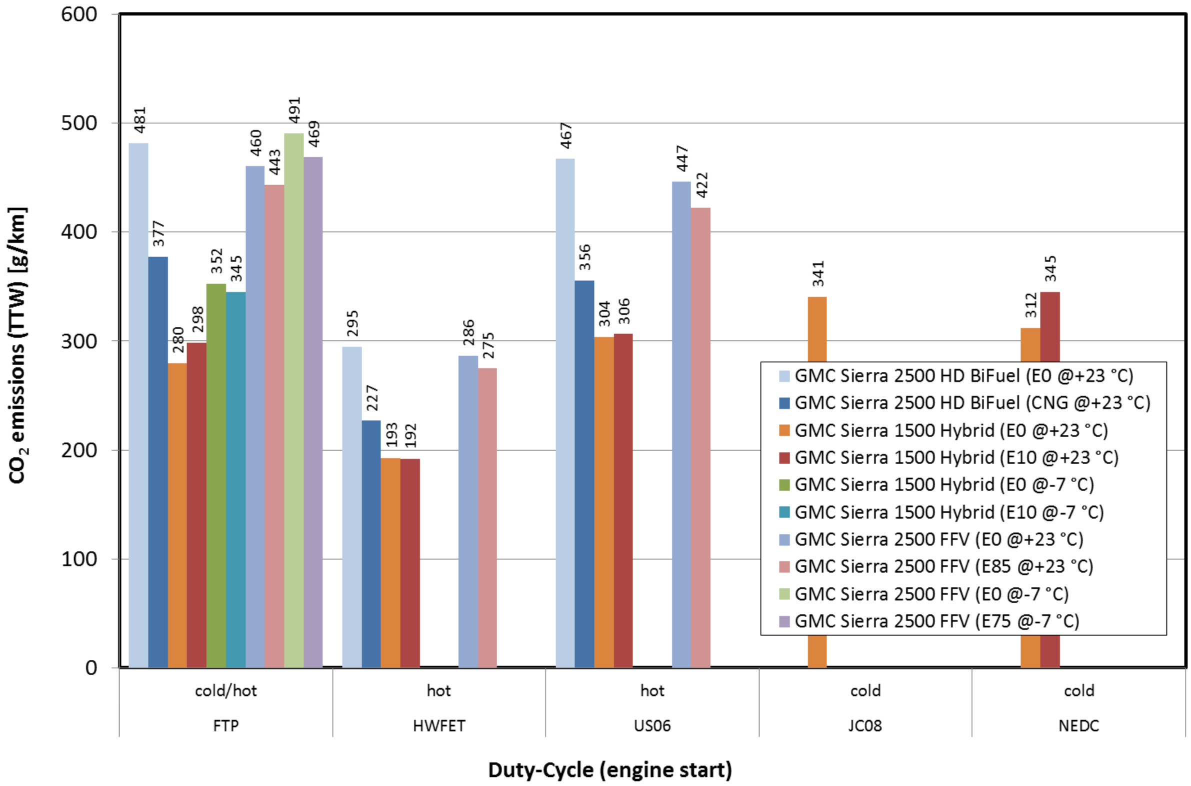

Figure 36: CO_2 emissions from the three SI-engine powered trucks tested in Canada with various fuels and at different ambient temperatures.

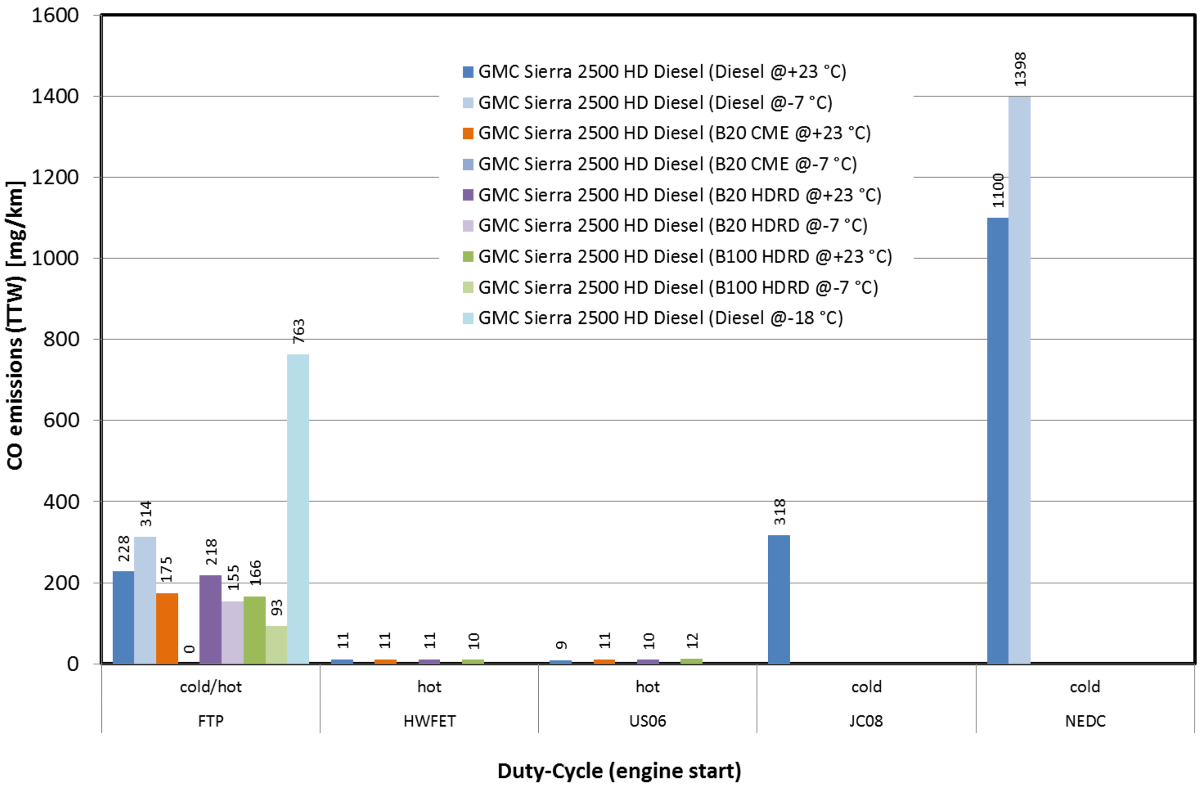

Figure 37: CO emissions from the CI-engine powered truck tested in Canada with different fuels at normal ambient temperature (+23 °C), as well as two lower ambients (-7 and -18°C).

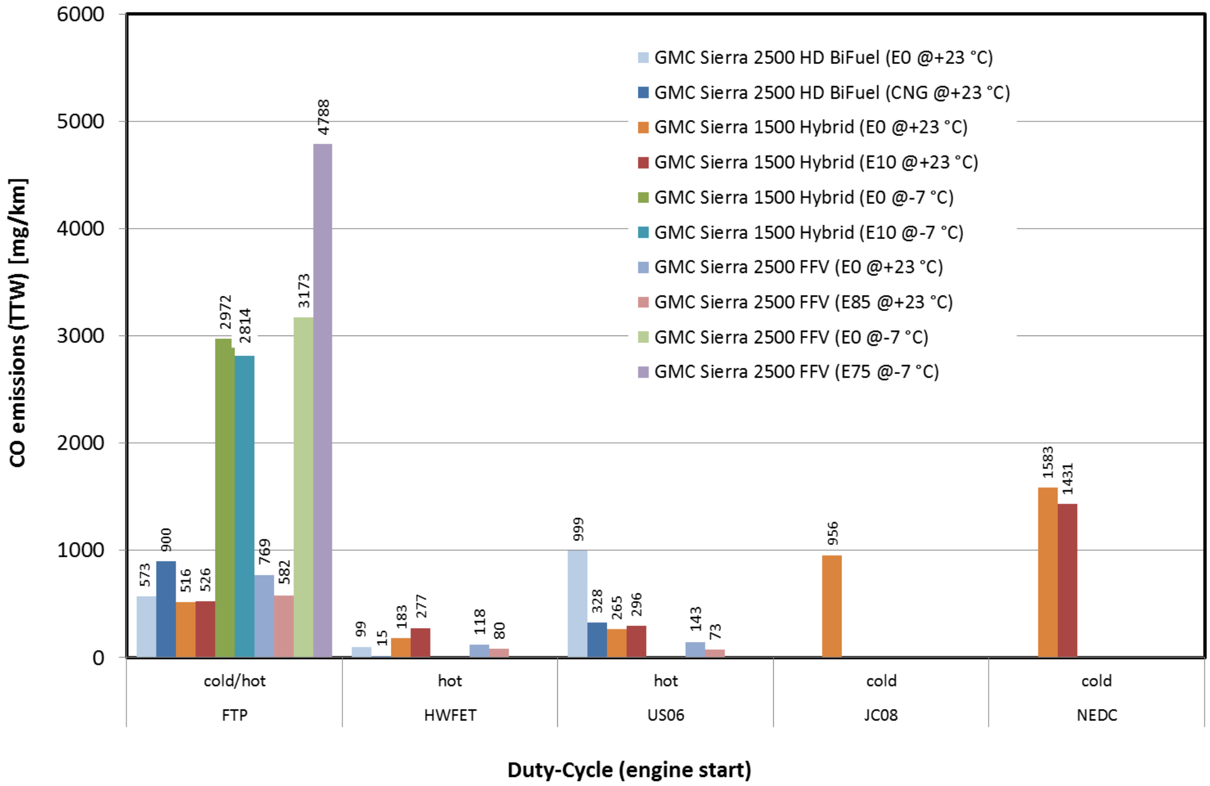

Figure 38: CO emissions from the three SI-engine powered trucks tested in Canada with various fuels and at different ambient temperatures.

Much stronger impact was recorded for NEDC, where the increase was almost 30 % at -7 °C compared to normal ambient (mineral-oil diesel only). This is most probably due to the greater relative influence of the cold-start portion in this duty cycle compared to FTP.

Of the SI-engine vehicles (Figure 36) the hybrid version emitted some 40 % less CO_2 over a cold-start FTP cycle, and some 60 % less over a hot-start US06 cycle, but some 20 % more over a HWFET cycle. However, this appears to be some kind of anomaly, as it is not consistent with the fuel consumption results that showed net positive difference for the hybrid version in all cases.

Furthermore, in the hybrid version, using 10% ethanol containing E10 gasoline resulted in slight increase in CO_2 emissions in the cold-started FTP cycle, but marginal degrease with the hot-start cycles (HWFET and US06). Subsequently, the lower ambient temperature (-7 °C vs. 23 °C) increased CO_2 emissions by 9 % when using regular non-ethanol gasoline (E0), but with E10 fuel the increase was only 3 %.

When considering **CO emissions** from the CI-engine powered version (Figure 37), we see at first that there was a striking difference between the cold-started and hot-started cycles. Furthermore, lowering the ambient temperature resulted in an increase in emissions, especially at the lowest temperature (-18 °C). While this was true for normal mineral-oil only diesel fuel, all cases using various blends of biodiesel, resulted in slightly lower CO at the lower ambient temperature (-7 °C vs. 23 °C). Also, all blends of biodiesel gave lower CO than the regular, mineral-oil only diesel grade.

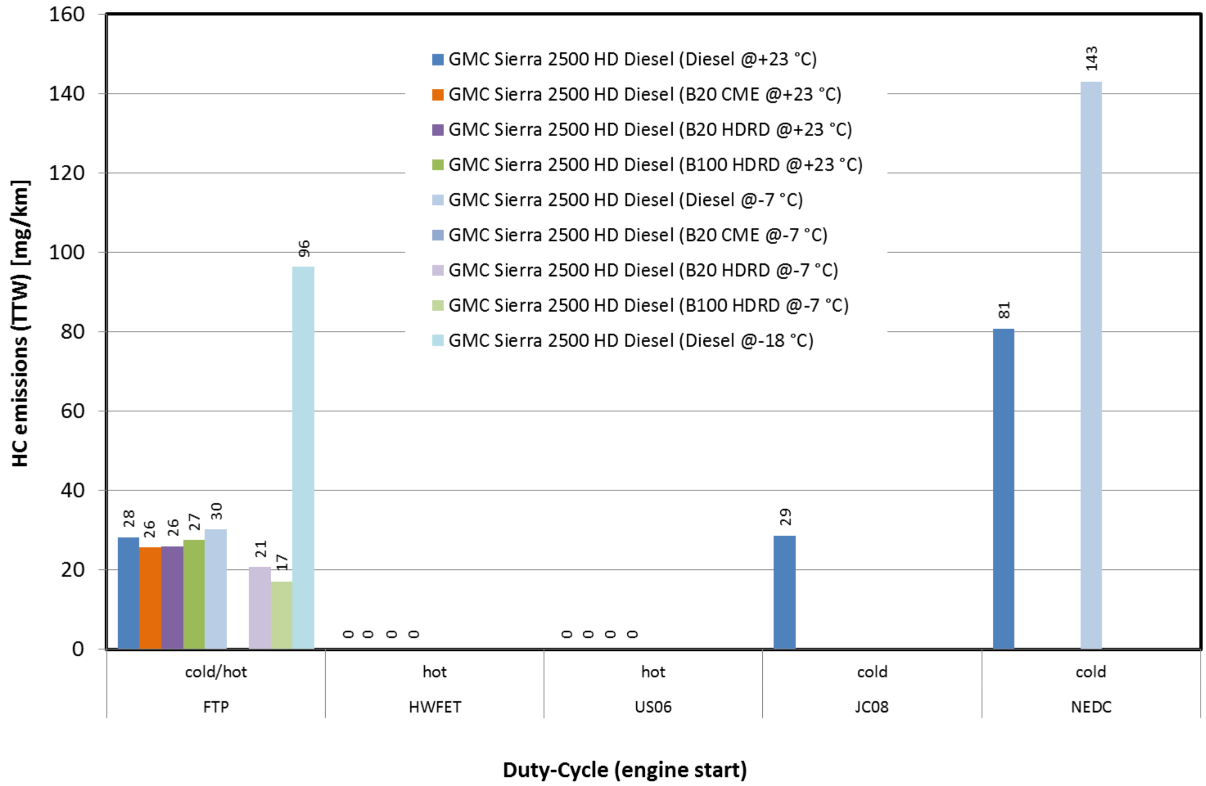

Figure 39: HC emissions from the CI-engine powered truck tested in Canada with different fuels at normal ambient temperature (+23 °C), as well as two lower ambients (-7 and -18°C).

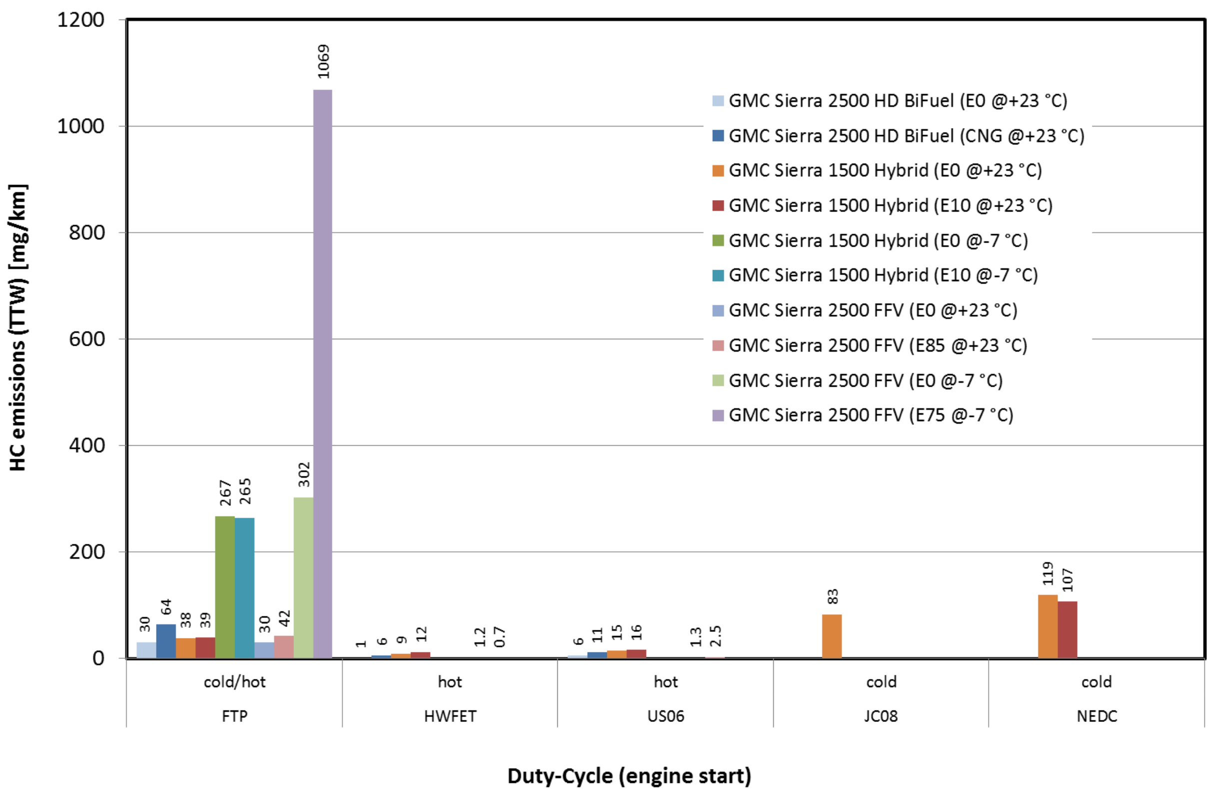

Figure 40: HC emissions from the three SI-engine powered trucks tested in Canada with various fuels and at different ambient temperatures.

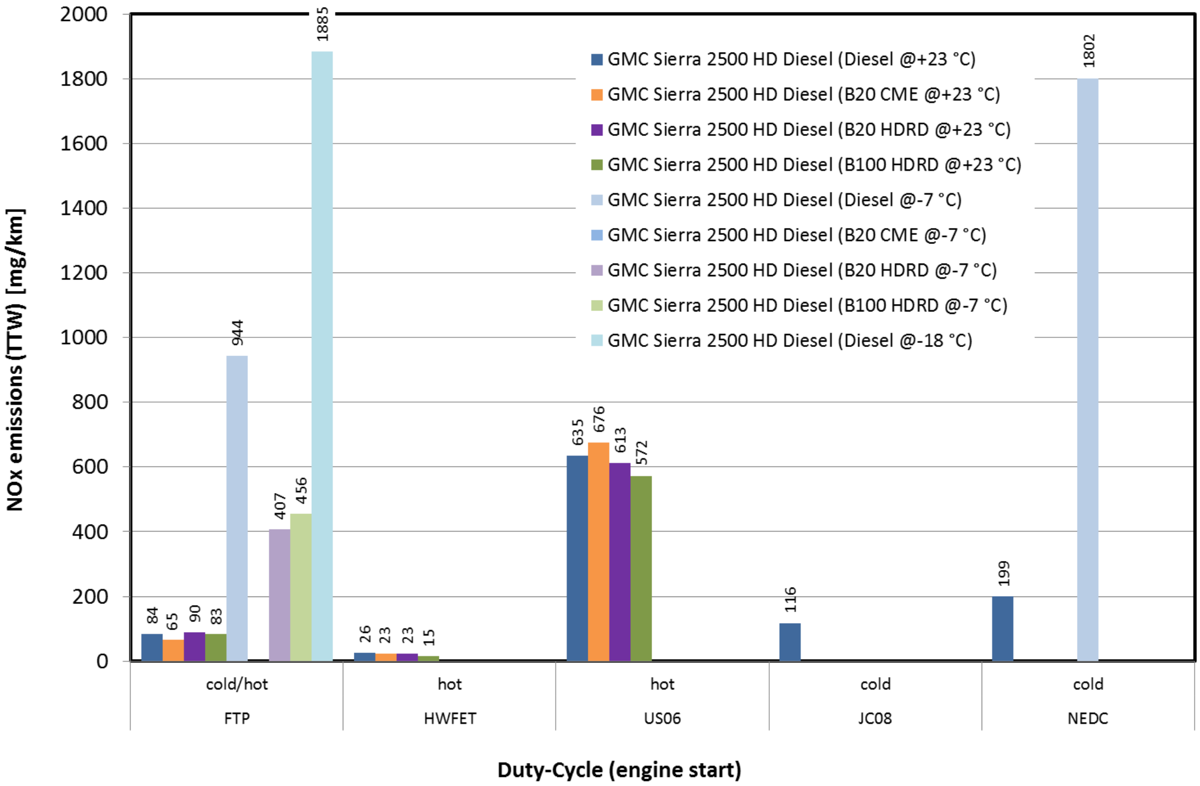

Figure 41: NOx emissions from the CI-engine powered truck tested in Canada with different fuels at normal ambient temperature (+23 °C) at normal ambient temperature (+23 °C), as well as two lower ambients (-7 and -18°C).

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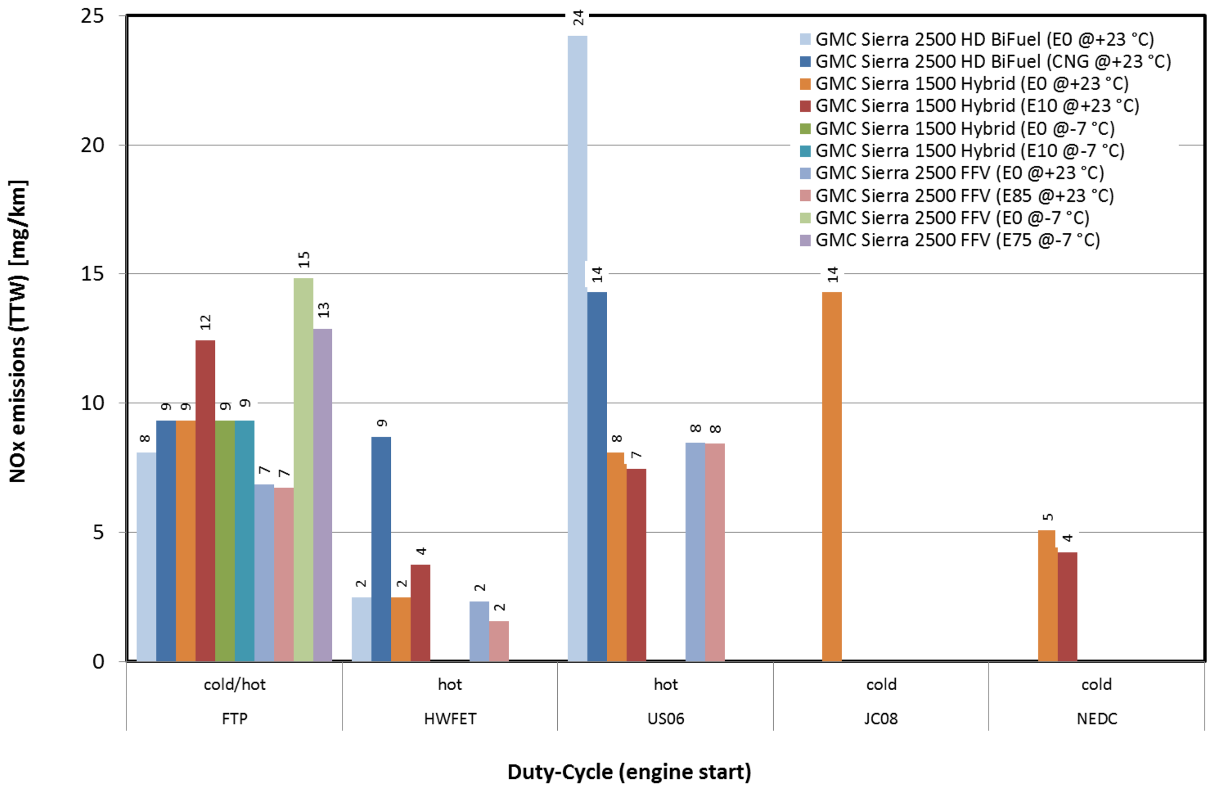


Figure 42: NOx emissions from the three SI-engine powered trucks tested in Canada with different fuels and at different ambient temperatures.

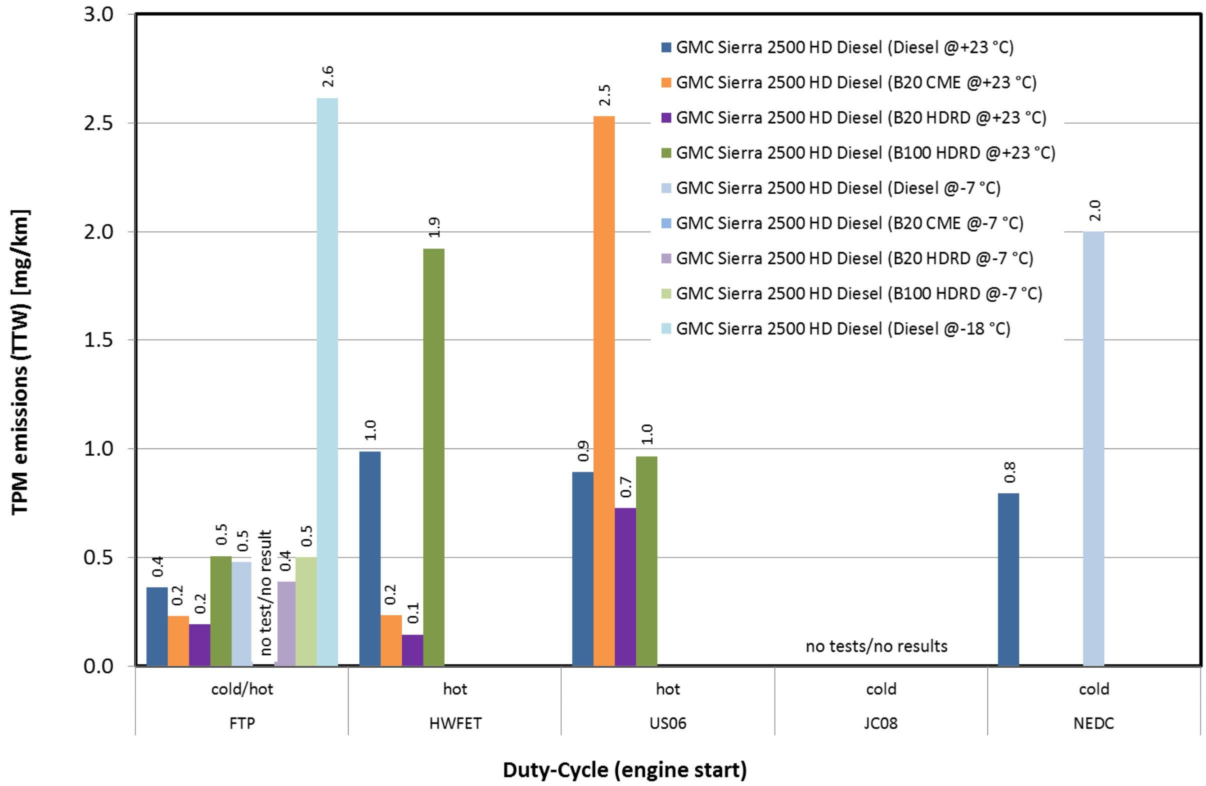


Figure 43: TPM emissions from the CI-engine powered truck tested in Canada with different fuels at normal ambient temperature (+23 °C) at normal ambient temperature (+23 °C), as well as two lower ambients (-7 and -18°C).

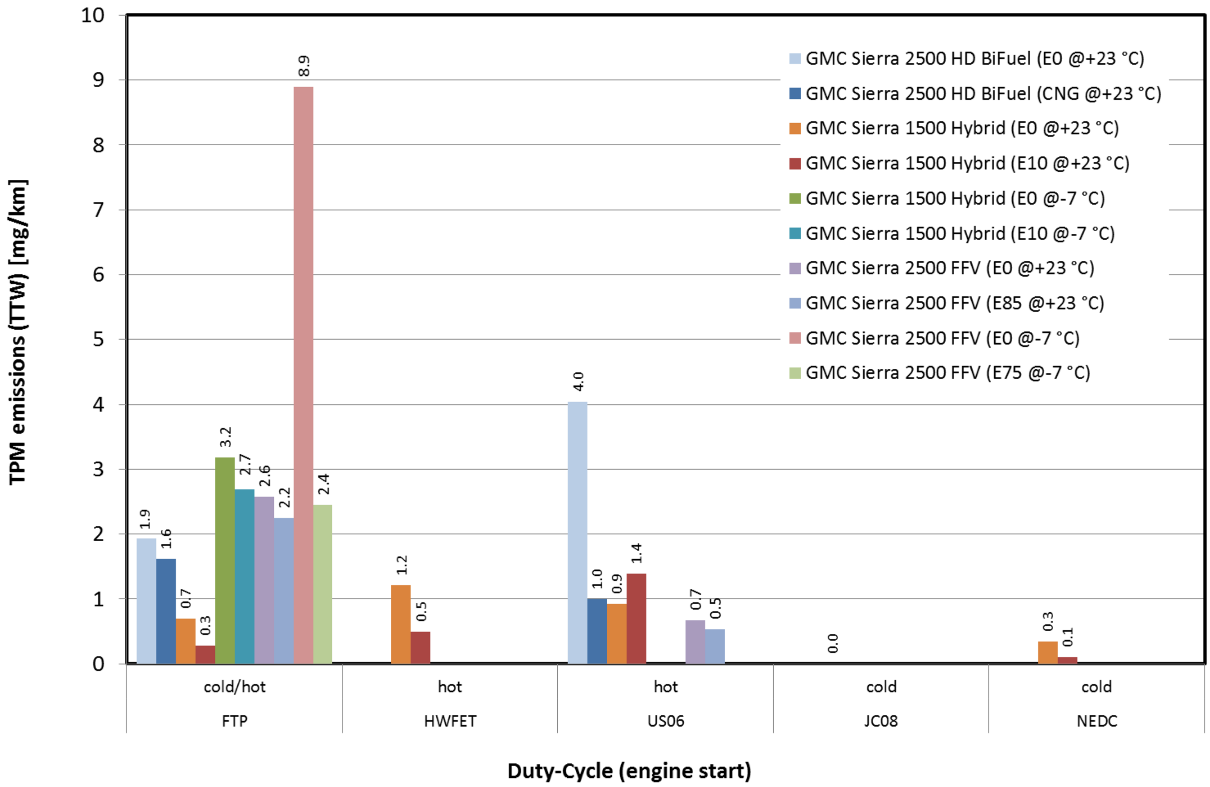


Figure 44: TPM emissions from the three SI-engine powered trucks tested in Canada with different fuels and at different ambient temperatures.

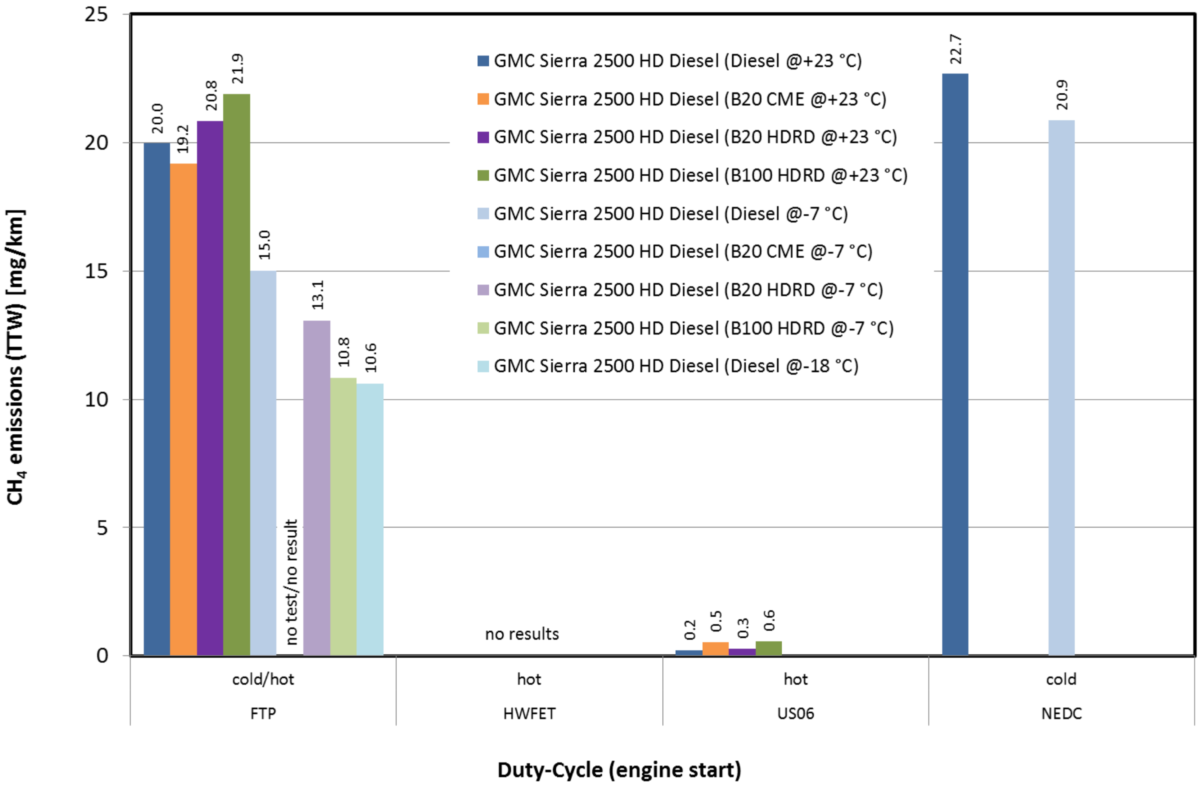


Figure 45: CH_4 emissions from the CI-engine powered truck tested in Canada with normal diesel fuel and different biodiesel blends at different ambient temperatures.

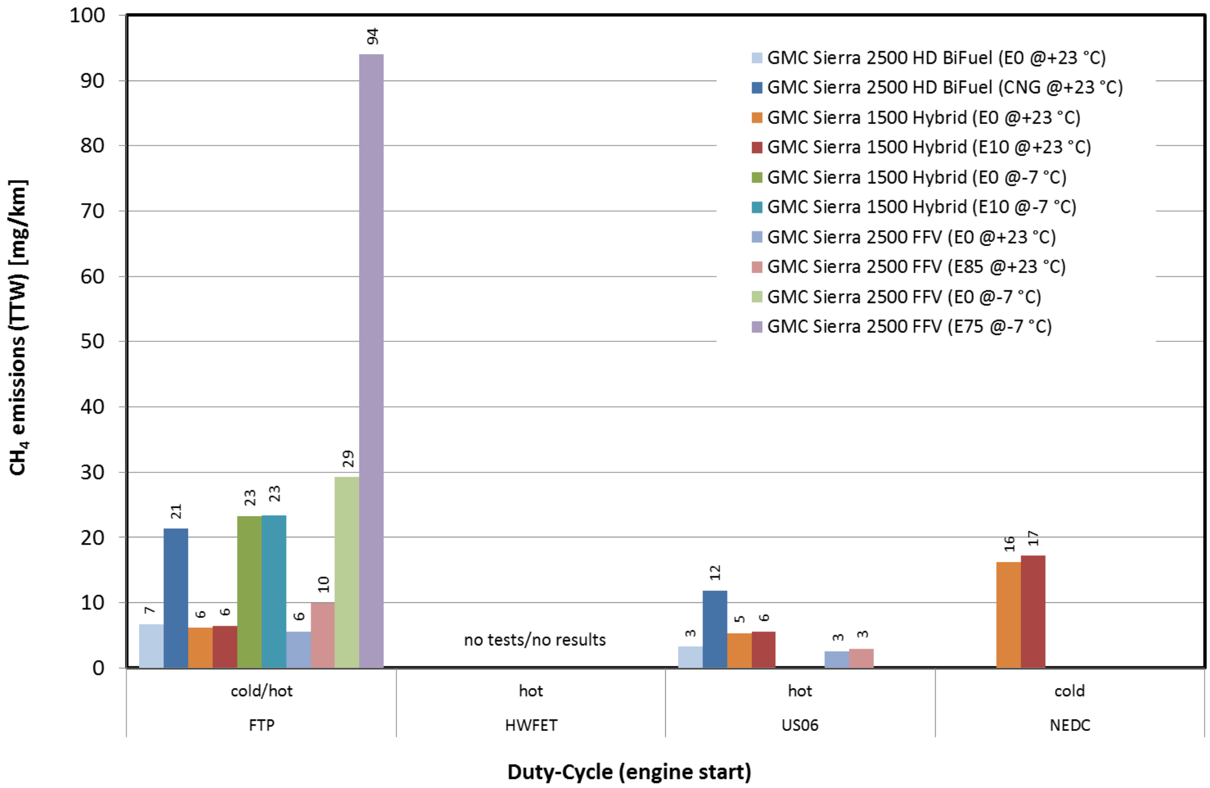


Figure 46: CH_4 emissions from the three SI-engine powered trucks tested in Canada with gasoline (E0, E10) and with CNG at different ambient temperatures.

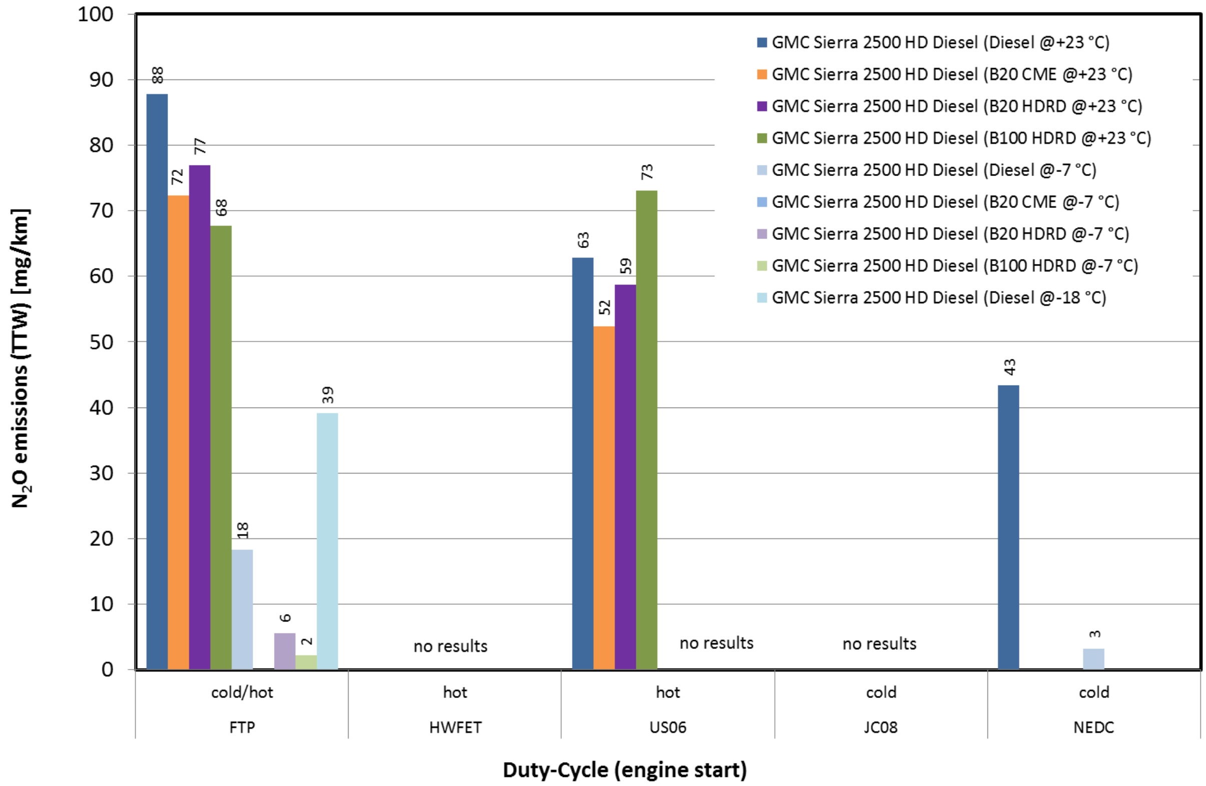


Figure 47: N_2O emissions from the CI-engine powered truck tested in Canada with normal diesel fuel and different biodiesel blends at different ambient temperatures.

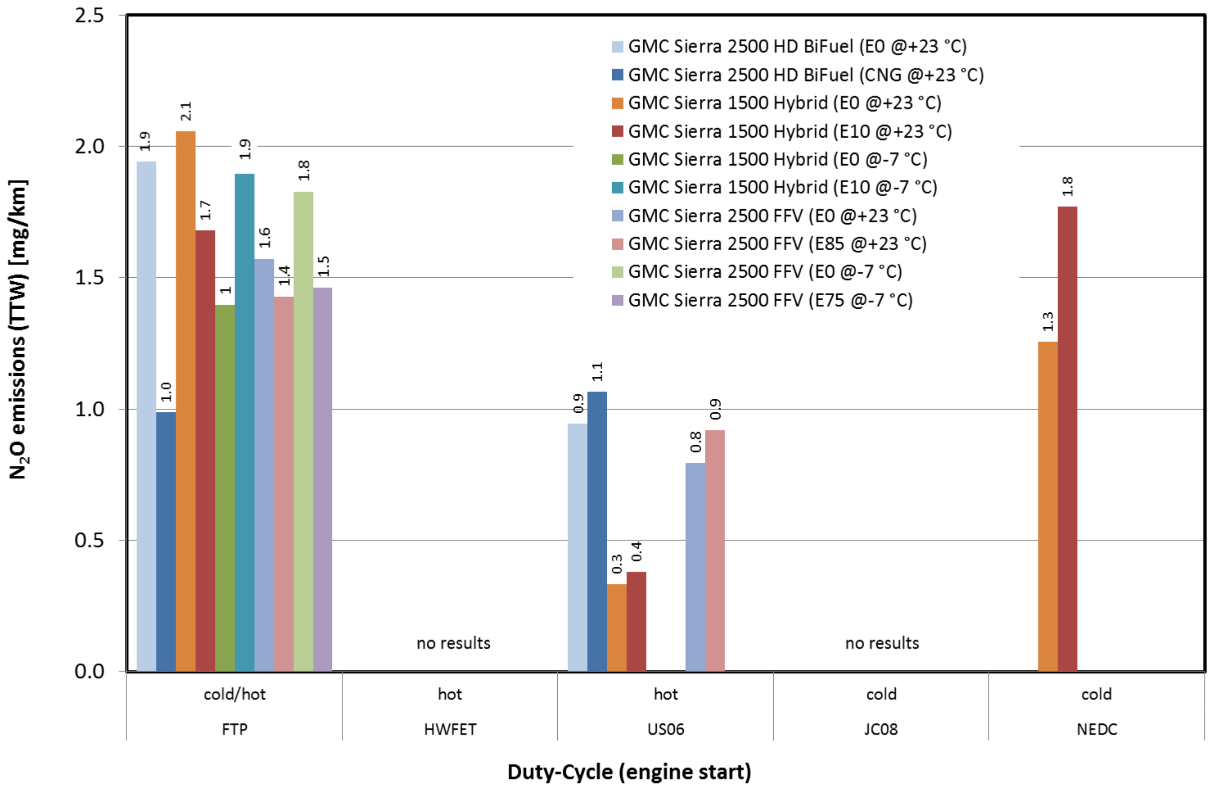


Figure 48: N_2O emissions from the SI-engine powered trucks tested in Canada with gasoline (E0, E10) and with CNG at different ambient temperatures.

Like with the CI-engine, also with the SI-engine powered versions (Figure 38) CO was higher in those cold-started cycles. The highest results were measured over the European NEDC cycle. At normal ambient temperature, there was no practical difference between the hybrid and non-hybrid variants in FTP cycle, but the hybrid showed higher emissions over the HWFET cycle, and vice versa over the US06 cycle. This was due to an almost constant emission rates for the hybrid over both duty-cycles, but with 1 to 10 difference in emissions between the cycles from the non-hybrid version, seemingly having difficulties in coping with the transient loads and speed changes prevalent in the US06 cycle.

Considering emissions of **hydrocarbon (HC)** from the CI-powered version (Figure 39), the pattern was much alike with the one for CO. However, the cold-start emissions at low ambient temperature were in relative terms even higher. This was also true for the SI-engine powered versions (Figure 40), with the exception that the emissions were highest at cold-start/low ambient temperature (FTP at -7 °C vs. 23 °C), whereas for CO, also cold-start NEDC resulted high emission rates even at normal ambient. Quite striking is also the high HC output for the high-concentration ethanol fuel at -7 °C, even if the fuel in these tests was the “winter quality” E75, and not the regular E85. The poor evaporation of ethanol is the cause for this kind of non-optimum performance. As well, acetaldehyde is a known combustion product of ethanol, and is contributing to the total HC output.

When we review the results for **oxides of nitrogen (NOx)**, we can see that for the CI-engine powered version, there was a strong influence of ambient temperature. According to the Figure 41, emission rates recorded over FTP-cycle at -7 °C were 10 times higher than for normal ambient, and up to twenty times higher at -18 °C vs. +23 °C. The same applies to NEDC, as the rates at -7 °C were 10 times higher than for normal ambient, but in both cases the level was about twice of that measured for FTP. The highest rates at normal ambient were recorded for US06 cycle, showing an average some seven times higher emissions than those in FTP. There was also an influence of the fuel, as the both HDRD blends showed lower emissions than the mineral oil diesel, but that effect was weaker:

For the SI-engine powered variants, the results depicted in Figure 42 show that the emissions were very low in all cases, and even the highest value measured for the BiFuel variant over US06 with E0 was on par with the lowest values for the diesel variant.

Turning into the results for **total particulate matter (TPM)** emissions, we can note from Figure 43 that for the CI-engine powered version, all TPM results were reasonably low, below 3 mg/km, due to the presence of diesel particulate filter (DPF). Furthermore, using low blends of either CME or HDRD components (B20 xx) seem to offer an advantage over the mineral-oil only diesel, but as neat (B100 xx), they appear to produce somewhat higher TPM rates. A clear exception to this was B20 CME in US06 test, where it gave the highest output, on par with the FTP-result for diesel at -18 °C.

As with the other pollutants the ambient temperature does have an influence to the TPM levels, as much as six times over FTP cycle in that one test at -18 °C. Much stronger impact is again seen in NEDC, where the TPM emissions were 2.5 times higher at -7 °C, compared to tests at normal ambient temperature. Also the overall rates measured over the NEDC cycle are two to four times higher than results from the tests over the FTP duty-cycle. This might be due to the different characteristics of the cycles, where the FTP contains quite strong accelerations early on in the cycle, leading to quicker warm-up of the engine compared to the NEDC, where the speed and acceleration levels are fairly low for the first four kilometres. Overall, these relative changes remain more “academic”, as the general level of emissions was so low.

The corresponding results for the SI-engine powered versions are depicted in Figure 44, and the first observation is that overall the emission rates are much higher that for the CI-engine. This is mainly due to the presence of diesel particulate filter (DPF) in the CI-engines, necessary in order to comply with the strict TPM limit value legislated with EPA Tier III standards. With SI-engines there are no filters – at least yet – although attaining the particulate number

(PN) standards implemented in Europe for Euro 6c for direct-injection gasoline cars may well necessitate having one, once the standard will become fully enforced.

Like with the other emissions, the hybrid version has much lower TPM emissions than the non-hybrids. Likewise, low ambient temperature increases the particulate emissions by a factor of five to ten, depending on whether E0 or E10 fuel is used. However, the highest result (8.9 mg/km) was obtained for the FFV version with E0 fuel and at low ambient temperature, when driving the cold-started FTP duty-cycle. It was about twenty times higher than average result for the CI-engine version over the same cycle, and subsequently three to five times greater than what was measured on average for other SI-options, even the E75 test at the same low temperature.

Emissions of **methane (CH_4)** were, according to Figure 45, in the CI-engine version around 19 to 22 mg/km in all cold-started tests at normal ambient temperature. Unlike most other emissions that increase at low ambient temperature, methane emissions seemed to be somewhat lower in those cold-started FTP-tests that were run at -7 °C or even at -18 °C. Using the NEDC duty-cycle yielded to almost similar results, but the difference was less noticeable. However, by far the lowest rates for methane were recorded for hot-start US06 tests. On average these were all well below 1 mg/km, which is only 1/20th of the typical level for cold-started FTP-tests.

Regarding methane emissions measured from the SI-engine powered versions (Figure 46), the average level for all versions with gasoline fuels (E0 and E10) was around 6 mg/km in FTP and US06 tests, with slightly lower rates in hot-start US06 than in FTP. However, in the European NEDC cycle the level of emissions from the hybrid was much higher, 16 to 17 mg/km, but the non-hybrid version was not tested with this cycle. Unlike with the CI-engine version, the SI-hybrid showed higher methane emissions at lower ambient temperature, and almost similar results for both fuels (E0 and E10). Furthermore, this temperature effect was much stronger in the FFV-version, where the result for low ambient temperature with the high concentration ethanol fuel (E75), was three time higher than the same test with E0.

Unsurprisingly, CNG fuel resulted in two to three times higher methane emission rates than gasolines, but somehow equal to the levels measured for CI-powered versions. Over FTP cycle the level at +23 °C ambient was about the same as for the gasoline hybrid at -7 °C. Methane is non-toxic and has a low reactivity rate in atmospheric chemistry and formation of smog and ozone. Hence it has no limit value in today's emission standards. However, it is a greenhouse gas with a CO_2-equivalence factor of 23.

The results submitted by Canada included also emission rates for **nitrous oxide (N_2O)**. This compound is quite a powerful greenhouse gas, with a CO_2-equivalence factor of 296.

For the CI-engine powered version, Figure 47 shows that the emission rates were at about the same level with both cold-start FTP cycles and hot-start US06-cycles. During these tests, the use of biodiesel did not increase N_2O emissions, in fact rates were lower when using B20 xx or B100 xx fuels compared to mineral-oil diesel only over the cold-start FTP cycle, but neat HDRD gave somewhat higher emissions over the hot-start US06 test. Furthermore, lowering the ambient temperature to -7 °C lowered also these emissions very effectively, but at -18 °C the emissions were again about two times higher.

For those three SI-engine powered versions, Figure 48 show that the overall level of emissions was much lower than with the CI-engine. Typical rates in cold-start tests were around 2 mg/km, and in hot-start US06, the level was from 0.5 to 1 mg/km. These are only some 1/10th to 1/20th of the levels recorded for the CI-engine powered version.

Because as already stated, methane (CH_4) and nitrous oxide (N_2O) emissions do contribute to the greenhouse gas inventory. Thus we have calculated CO_{2eg} emissions using the CO_2 emission result as the base, and adding these two with their corresponding equivalence factors. The calculations show that in case of the CI-engine, combined CO_{2eg} level is about 2 to 4 % higher than CO_2 only, but with the SI-engine the additional effect remains below 0.5 % in all cases due to much lower methane (CH_4) and nitrous oxide (N_2O) emissions compared to those from the CI-engine.

5.4 Results – China

The data submitted by China includes fuel and energy consumption, as well as emissions of CO, HC, NOx. Based on fuel consumption and fuel spec data, CO_2 values were calculated for comparisons. Of non-regulated pollutants, formaldehyde (HCHO), benzene and toluene were reported for on vehicle platform, with three fuel options (gasolines E0 and E10, M15).

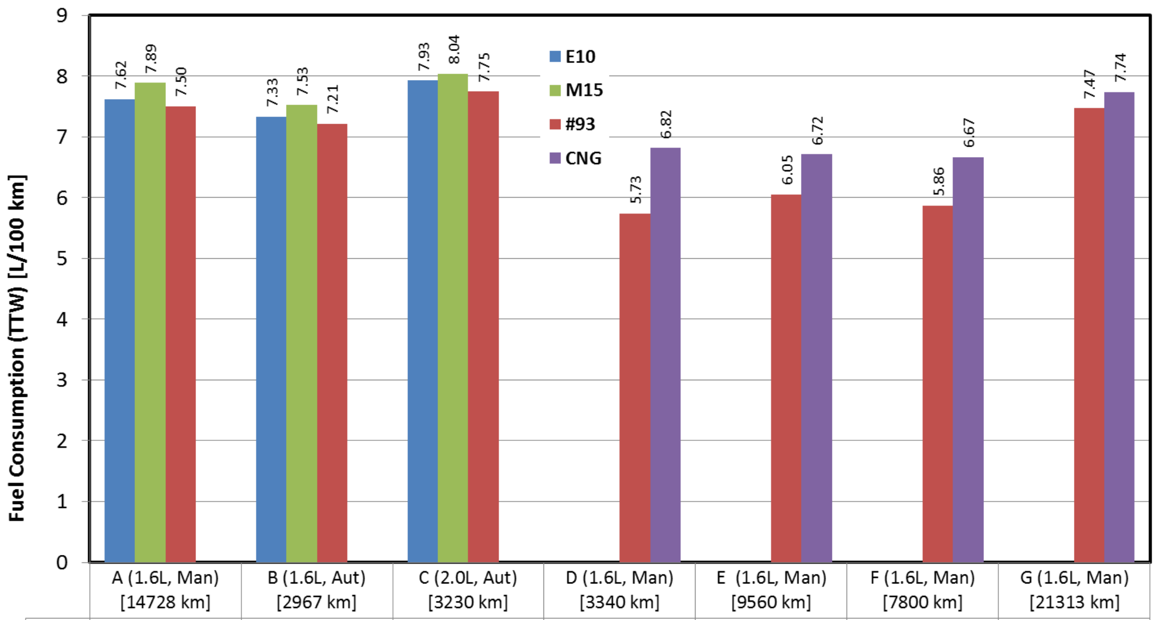
Two vehicle platforms were tested, one with three different engine/transmission options, and the other with four identical cars, but at different odometer readings.

Figures 49 to 57 depict these test results per vehicle/fuel for the NEDC driving cycle.

Regarding fuel (and energy) consumption (Figures 49 & 50), the choice of engine & transmission (vehicles A, B and C) looks quite logical, as the choice of larger engine (2.0, car C) shows somewhat higher consumption than the same configuration with smaller engine (1.6, car B). However, the comparison between cars A and B, where the engine size is the same, car B with automatic transmission has lower consumption, and with all fuel options. This is somewhat surprising, as usually automatic transmission results in higher fuel consumption than manual, but the underlying reason could be much higher odometer reading, as car A has almost five times higher amount of kilometres compared to car B.

The influence that the mileage has on consumption can be seen in cars D, E, F and G that are of same make/model/engine/transmission, but different mileages. At least the consumption with gasoline (#93) the consumption figures have the same rank order as the odometer readings. With CNG, this tendency is not as clear.

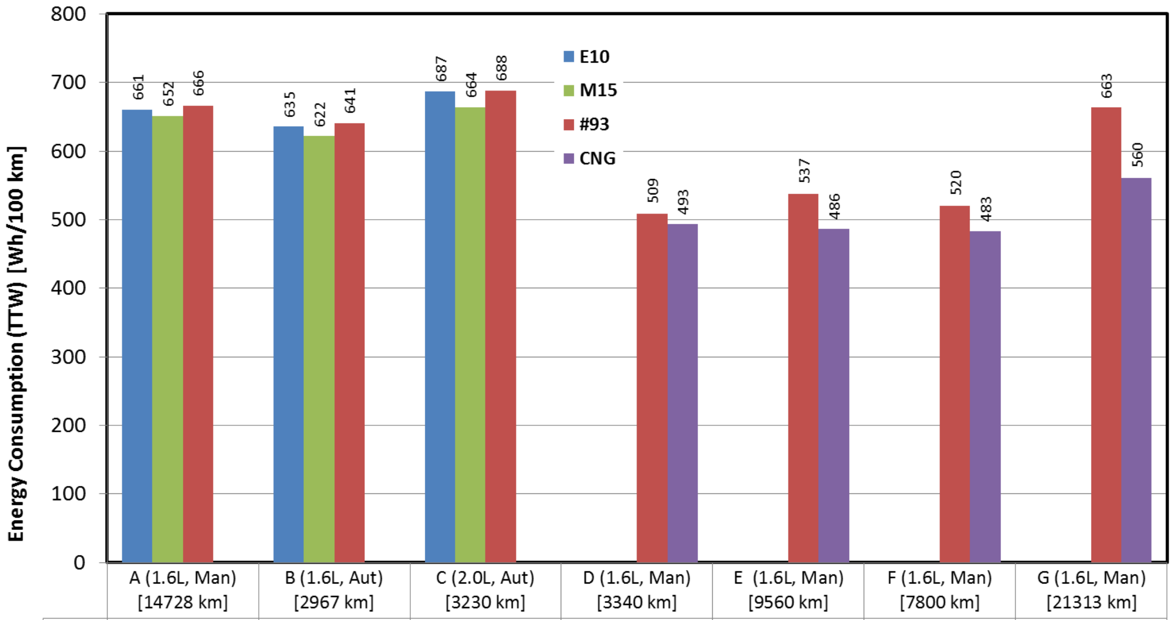
Considering regulated emissions (CO, HC, NOx), in Figure 52 we see that the overall level of CO was about twice in platform A cars (A, B, C) compared to the other platform B cars (D, E, F, G), when regular #93 gasoline was used as a fuel. With E10 or M15 fuels the levels were slightly lower, and also with CNG that gave the lowest levels of CO emissions.



	A (1.6L, Man) [14728 km]	B (1.6L, Aut) [2967 km]	C (2.0L, Aut) [3230 km]	D (1.6L, Man) [3340 km]	E (1.6L, Man) [9560 km]	F (1.6L, Man) [7800 km]	G (1.6L, Man) [21313 km]
E10	7.62	7.33	7.93				
M15	7.89	7.53	8.04				
#93	7.50	7.21	7.75	5.73	6.05	5.86	7.47
CNG				6.82	6.72	6.67	7.74

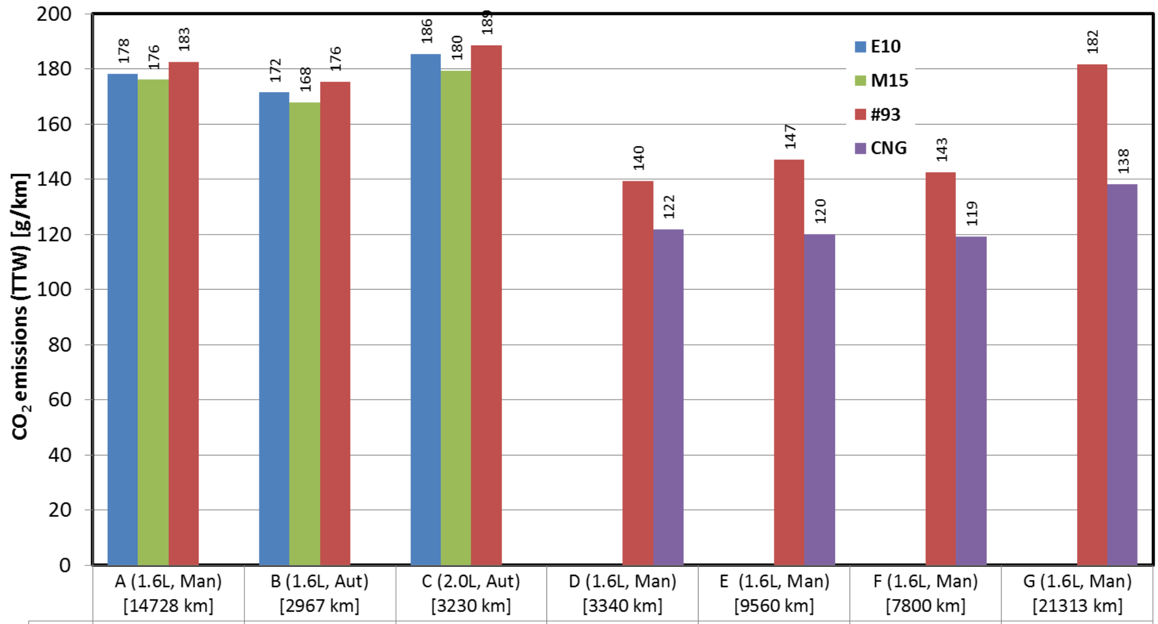
Vehicle (engine, transmission) [odometer reading]

Figure 49: Fuel consumption of the cars tested in China.



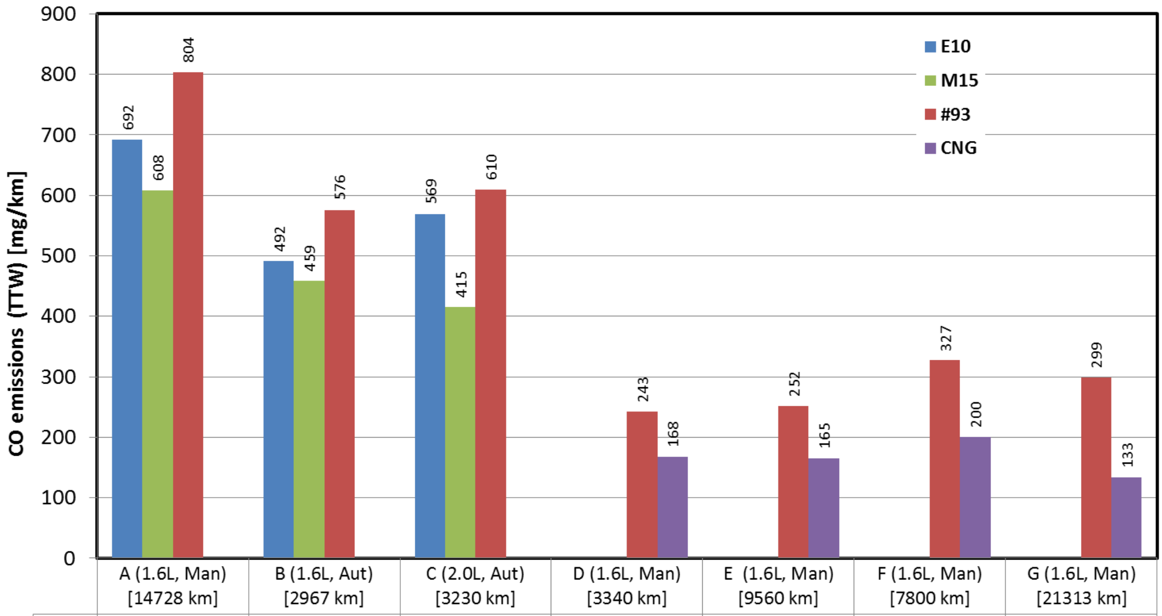
	A (1.6L, Man) [14728 km]	B (1.6L, Aut) [2967 km]	C (2.0L, Aut) [3230 km]	D (1.6L, Man) [3340 km]	E (1.6L, Man) [9560 km]	F (1.6L, Man) [7800 km]	G (1.6L, Man) [21313 km]
E10	661	635	687				
M15	652	622	664				
#93	666	641	688	509	537	520	663
CNG				493	486	483	560

Figure 50: Energy consumption of the cars tested in China.



	A (1.6L, Man) [14728 km]	B (1.6L, Aut) [2967 km]	C (2.0L, Aut) [3230 km]	D (1.6L, Man) [3340 km]	E (1.6L, Man) [9560 km]	F (1.6L, Man) [7800 km]	G (1.6L, Man) [21313 km]
E10	178	172	186				
M15	176	168	180				
#93	183	176	189	140	147	143	182
CNG				122	120	119	138

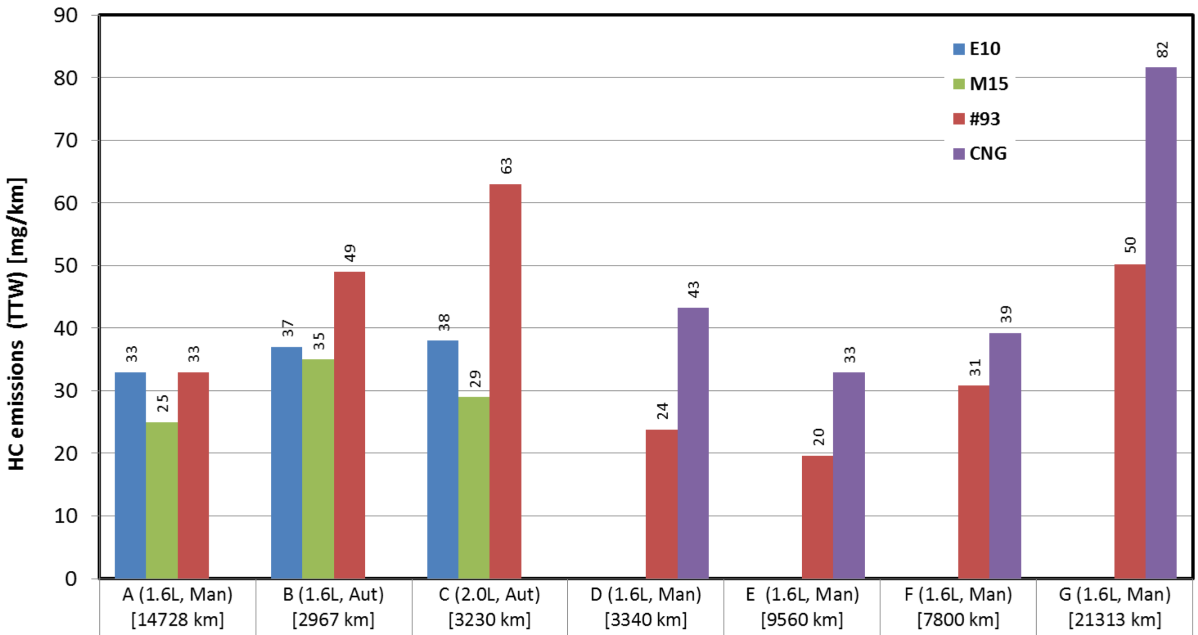
Figure 51: CO_2 emissions (calculated) for the cars tested in China.



	A (1.6L, Man) [14728 km]	B (1.6L, Aut) [2967 km]	C (2.0L, Aut) [3230 km]	D (1.6L, Man) [3340 km]	E (1.6L, Man) [9560 km]	F (1.6L, Man) [7800 km]	G (1.6L, Man) [21313 km]
E10	692	492	569				
M15	608	459	415				
#93	804	576	610	243	252	327	299
CNG				168	165	200	133

Vehicle (engine, transmission) [odometer reading]

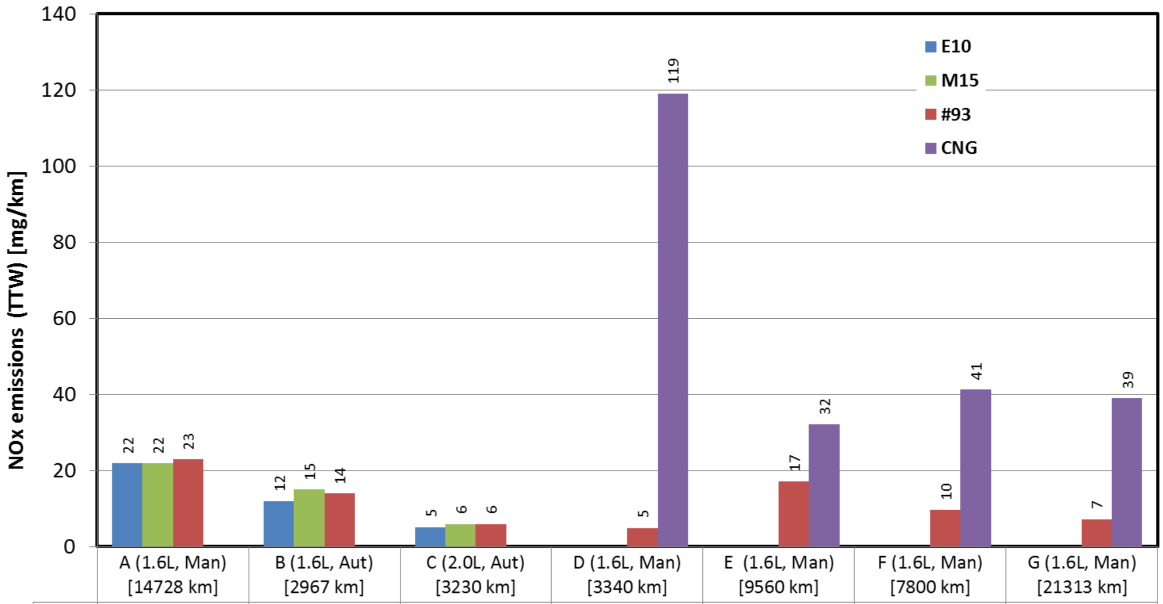
Figure 52: CO emissions for the cars tested in China.



	A (1.6L, Man) [14728 km]	B (1.6L, Aut) [2967 km]	C (2.0L, Aut) [3230 km]	D (1.6L, Man) [3340 km]	E (1.6L, Man) [9560 km]	F (1.6L, Man) [7800 km]	G (1.6L, Man) [21313 km]
E10	33	37	38				
M15	25	35	29				
#93	33	49	63	24	20	31	50
CNG				43	33	39	82

Vehicle (engine, transmission) [odometer reading]

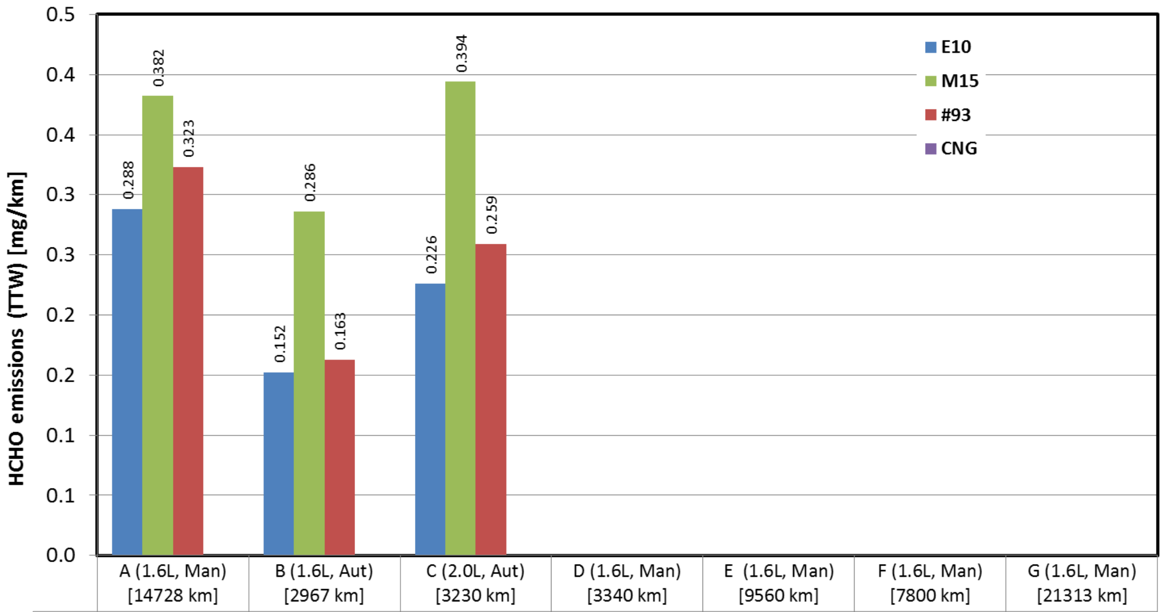
Figure 53: HC emissions for the cars tested in China.



	A (1.6L, Man) [14728 km]	B (1.6L, Aut) [2967 km]	C (2.0L, Aut) [3230 km]	D (1.6L, Man) [3340 km]	E (1.6L, Man) [9560 km]	F (1.6L, Man) [7800 km]	G (1.6L, Man) [21313 km]
E10	22	12	5				
M15	22	15	6				
#93	23	14	6	5	17	10	7
CNG				119	32	41	39

Vehicle (engine, transmission) [odometer reading]

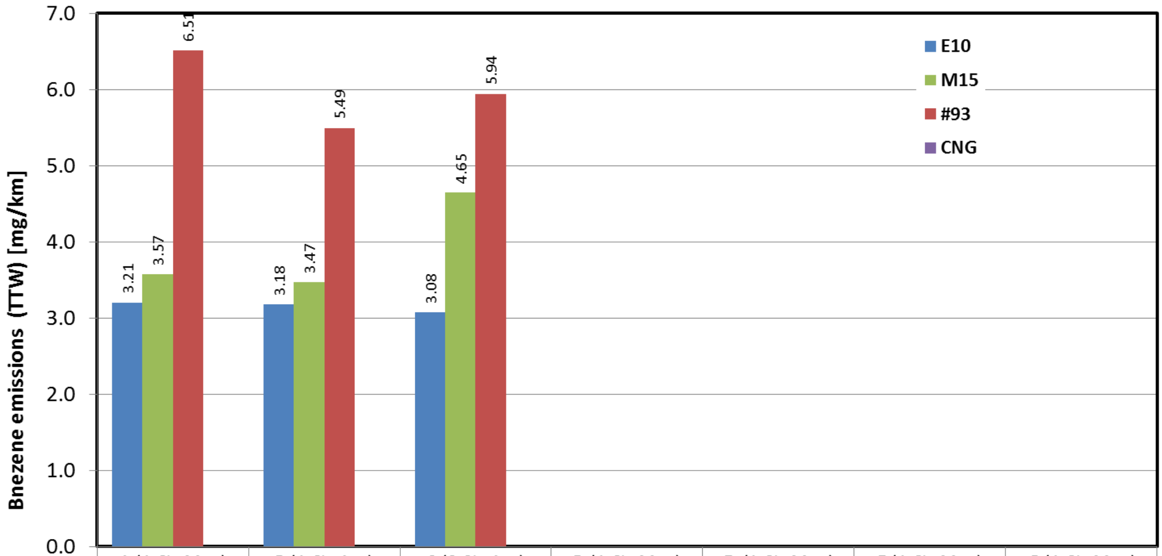
Figure 54: NOx emissions for the cars tested in China.



	A (1.6L, Man) [14728 km]	B (1.6L, Aut) [2967 km]	C (2.0L, Aut) [3230 km]	D (1.6L, Man) [3340 km]	E (1.6L, Man) [9560 km]	F (1.6L, Man) [7800 km]	G (1.6L, Man) [21313 km]
E10	0.288	0.152	0.226				
M15	0.382	0.286	0.394				
#93	0.323	0.163	0.259				
CNG							

Vehicle (engine, transmission) [odometer reading]

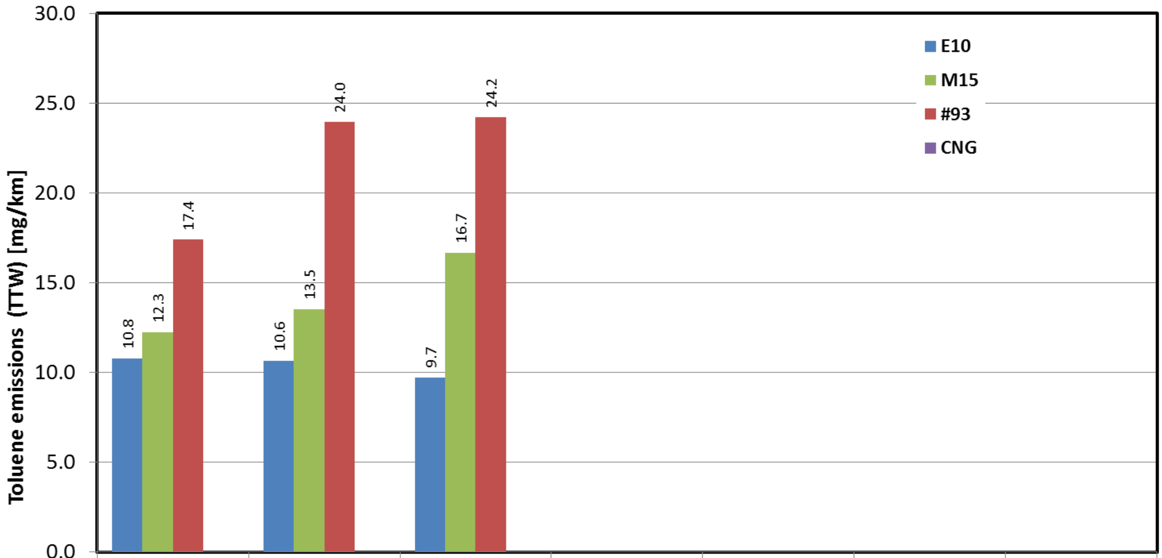
Figure 55: HCHO emissions for the cars tested in China. (Only one platform was tested).



	A (1.6L, Man) [14728 km]	B (1.6L, Aut) [2967 km]	C (2.0L, Aut) [3230 km]	D (1.6L, Man) [3340 km]	E (1.6L, Man) [9560 km]	F (1.6L, Man) [7800 km]	G (1.6L, Man) [21313 km]
E10	3.21	3.18	3.08				
M15	3.57	3.47	4.65				
#93	6.51	5.49	5.94				
CNG							

Vehilce (engine, transmission) [odometer reading]

Figure 56: Benzene emissions for the cars tested in China. (Only one platform was tested).



	A (1.6L, Man) [14728 km]	B (1.6L, Aut) [2967 km]	C (2.0L, Aut) [3230 km]	D (1.6L, Man) [3340 km]	E (1.6L, Man) [9560 km]	F (1.6L, Man) [7800 km]	G (1.6L, Man) [21313 km]
E10	10.8	10.6	9.7				
M15	12.3	13.5	16.7				
#93	17.4	24.0	24.2				
CNG							

Vehicle (engine, transmission) [odometer reading]

Figure 57: Toluene emissions for the cars tested in China. (Only one platform was tested).

On the contrary, CNG gave the highest total HC emissions (Figure 53), but supposedly, most of that emission was methane (CH_4) that was not reported separately. Both E10 and M15 fuels resulted in lower total HC than regular #93 gasoline. CNG gave also the highest readings regarding NOx (Figure 54). The highest reading for car D, over 100 mg/km, appears to be some sort of outlier, as the corresponding other cars of same platform and engine (D, E, F), but with higher mileages gave consistently a much lower level (around 40 mg/km or less)

Regarding non-regulated components that were reported only for platform A cars (A, B, C), as expected M15 fuel gave highest formaldehyde (HCHO, Figure 55), but for benzene (Figure 56) and toluene emissions (Figure 57), regular #93 gasoline was the worst, and E10 the best fuel option, while M15 fell in between, but quite close to E10.

5.5 Results – Sweden

In Sweden, one vehicle platform was tested, with three powerplant options (diesel, E85 and electric). The data submitted includes fuel and energy consumption, emissions of CO2, CO, THC, NOx, CH4 and TPM. Of non-regulated pollutants particulate number (PN) and NO/NO2 split were reported.

Figures 58 to 66 depict these test results per vehicle/fuel, ambient temperature and driving cycle.

Regarding fuel consumption (Figure 58), the volumetric **fuel consumption** was naturally the highest with high-concentration ethanol fuels (E85, E75), as their energy density is much lower than for diesel fuel. Compared to diesel, the average E85 consumption (in L/100 km) was about 2.4 in all tested cases. In **energy consumption** (Figure 59) this difference was still about 1.6, and from 1.37 to 1.74, depending on the duty-cycle, whereas the electric version used only a third of the energy of the diesel variant over the NEDC cycle.

The influence of the ambient temperature was some 5 % increase in energy use for high-concentration ethanol, but some 20 % for diesel in NEDC. Incidentally, the electric variant used less electricity at -7 °C than at +23 °C in tests using CADC. However, we must bear in mind that cabin heating in this car was by ethanol, and not by electricity.

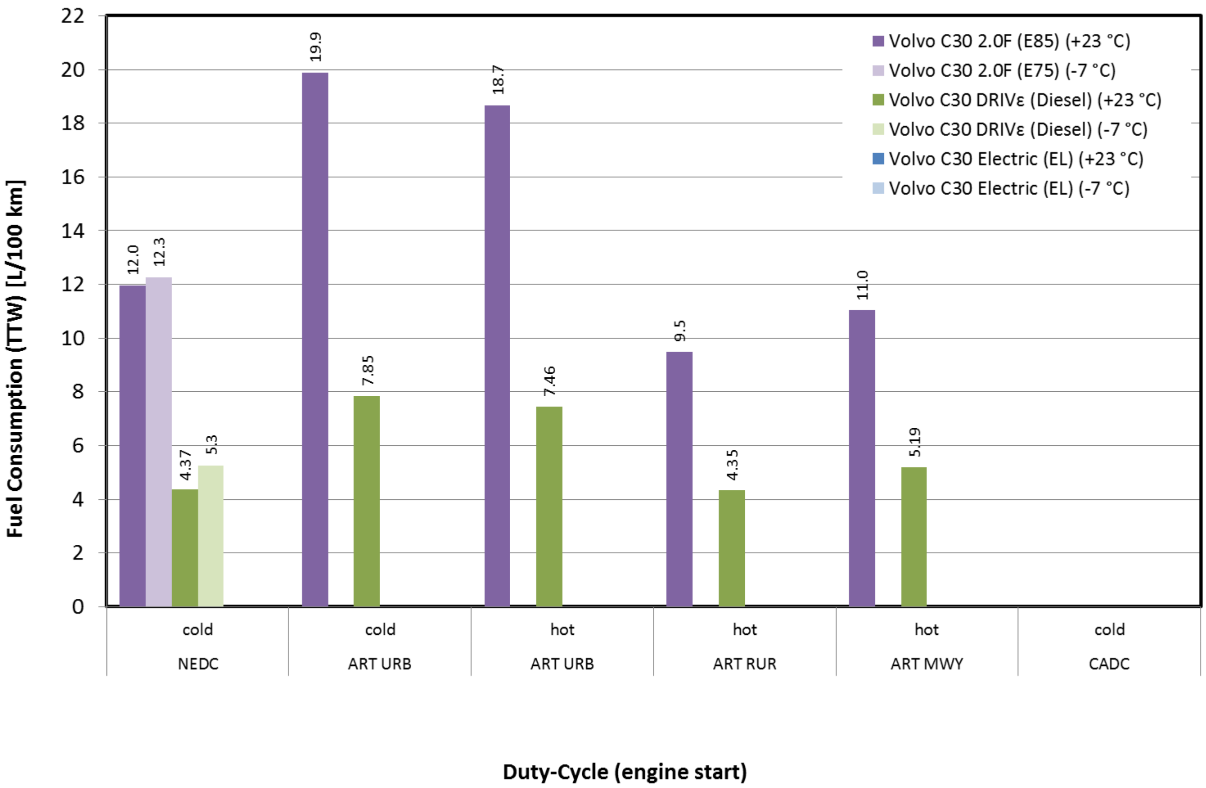


Figure 58: Fuel consumption of the three cars tested in Sweden.

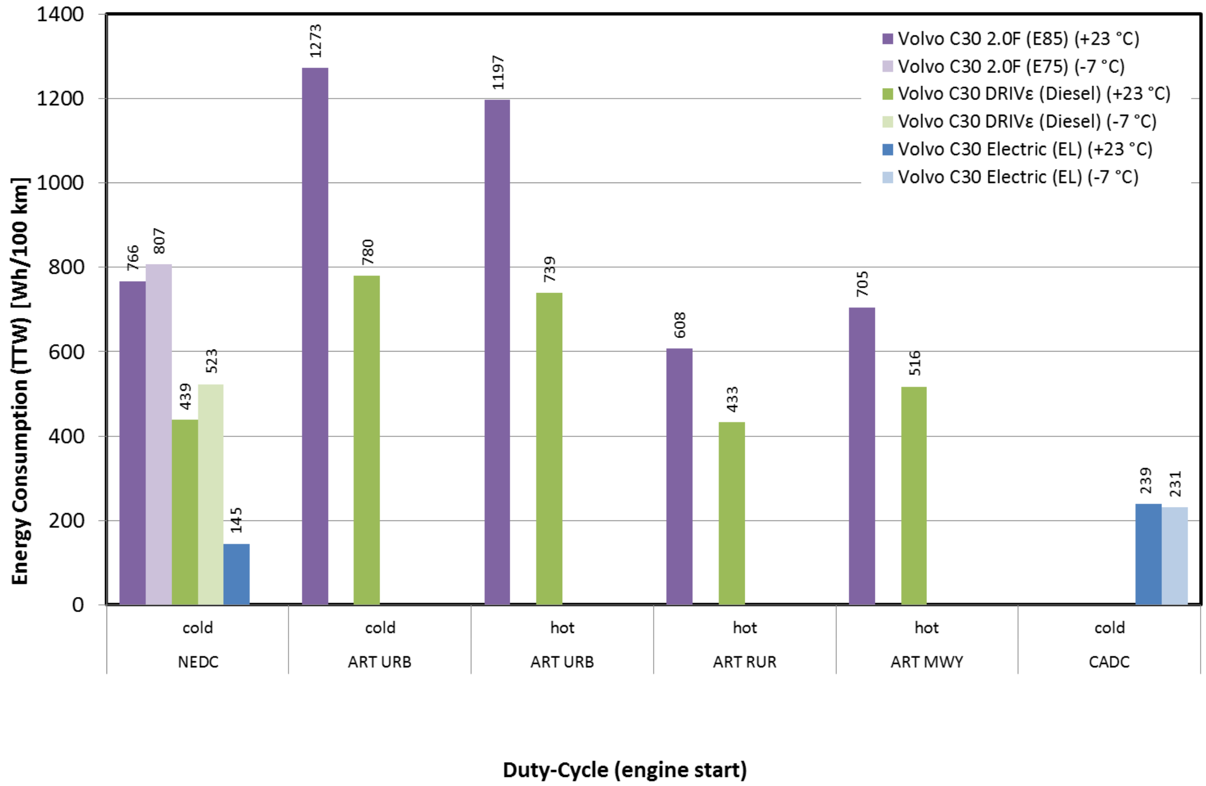


Figure 59: Energy consumption of the three cars tested in Sweden.

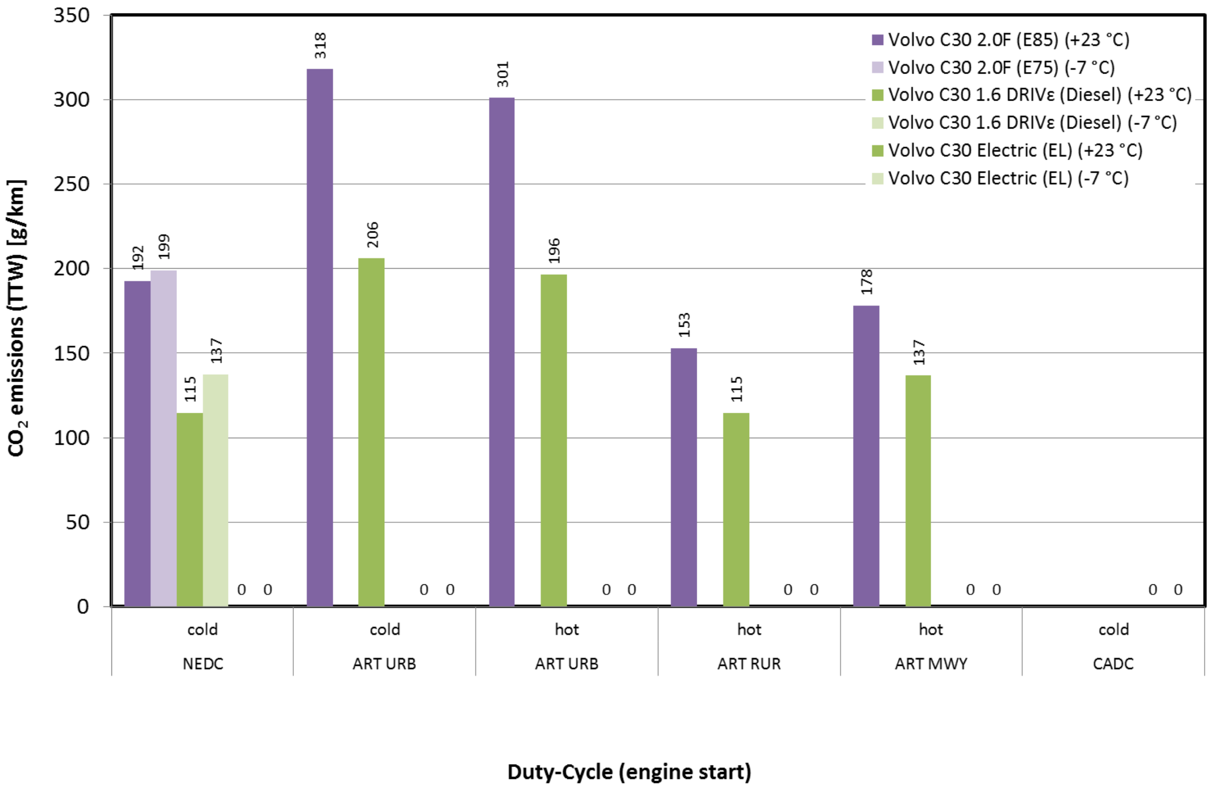


Figure 60: CO_2 emissions from the three cars tested in Sweden.

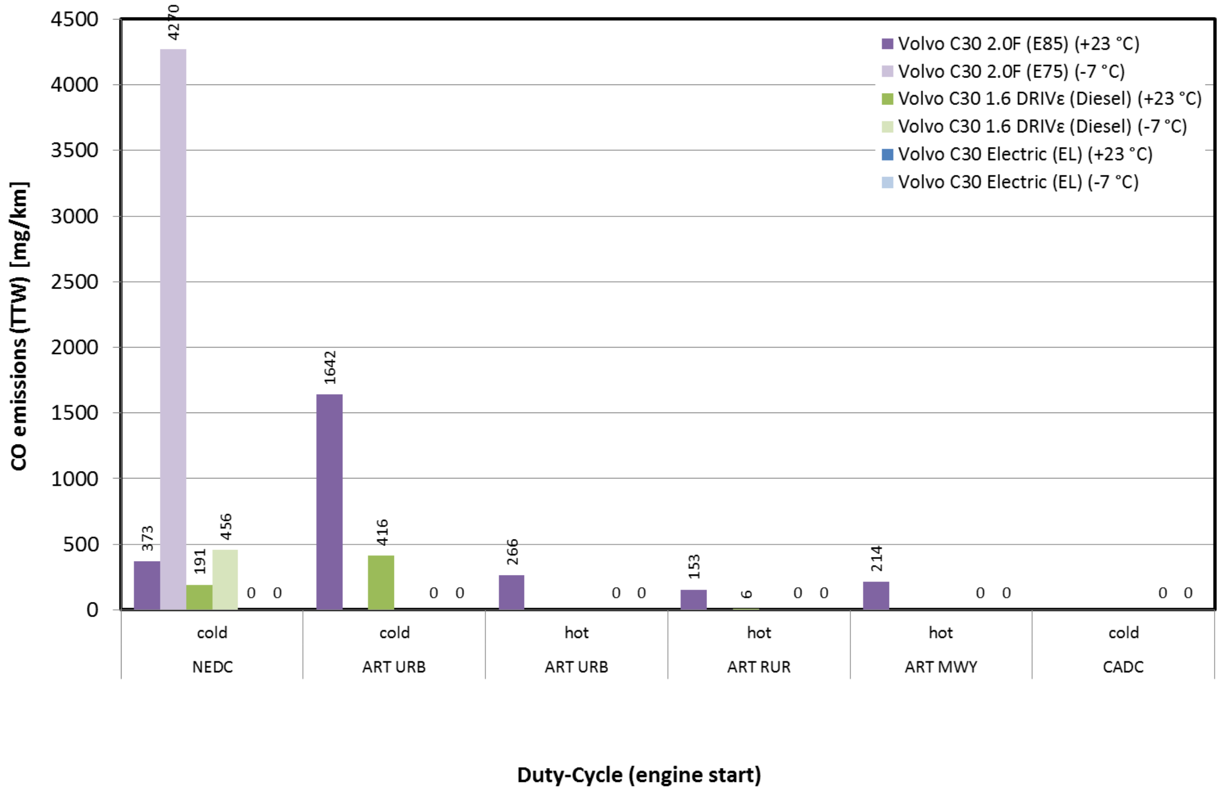


Figure 61: CO emissions from the three cars tested in Sweden.

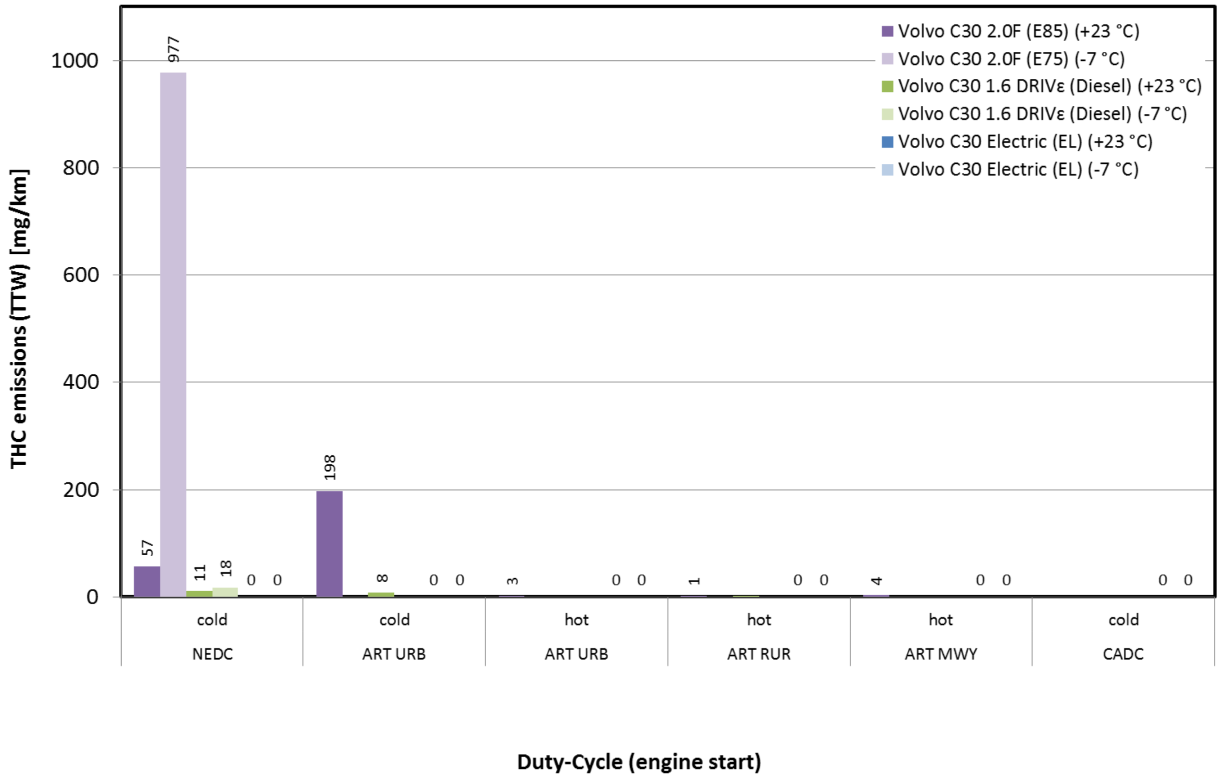


Figure 62: THC emissions from the three cars tested in Sweden.

Considering the **CO_2** emissions (Figure 60), we can see that the high-concentration ethanol version emitted about 1.3 to 1.7 times more CO_2 than the diesel-fuelled version. Obviously, the ambient temperature had the same influence as with fuel consumption: lowering the ambient temperature from +23 °C to -7 °C resulted in +3% for E85/E75, and +20% for diesel.

When contemplating the **CO** emissions (Figure 61), we immediately notice the high emissions measured for the high-concentration ethanol fuel (E75) in cold-start NEDC test done at low ambient temperature (-7 °C). The temperature effect is very strong, as these emissions are more than 11 times higher than what was measured for E85 at normal ambient temperature. With the diesel option, the emissions were only a fraction of these, and the low temperature multiplication factor was only 2.3. Cold-start ARTEMIS Urban test seemed to produce also quite notable emissions, much higher than in NEDC, with both fuel options. With E85 fuel, some CO was emitted also in hot-started ARTEMIS cycles.

Regarding total hydrocarbons (**HC**, Figure 62), the overall pattern was quite similar to CO, but at +23 °C, the multiplication factors between diesel and ethanol were different, from 5.4 (NEDC) to 25 (ARTEMIS Urban), and 4.5 (ARTEMIS Rural). However, the ambient temperature had even stronger impact on THC than on CO, as E75 fuel in the cold-start NEDC cycle test produced over 17 times higher THC emissions than E85 at +23 °C. Cold start at low ambient temperature is certainly an issue regarding the use of high-concentration ethanol fuels.

What comes to the emissions of nitrogen oxides (**NOx**, Figure 63), the set-up was totally reversed. With ethanol fuel the emissions were much lower than with diesel fuel. In tests at +23 °C, the emissions with ethanol fuel were only about 1/3 (NEDC) or even less, 23% (ART Urban, cold) and 5 to 6 % in hot-started ARTEMIS duty-cycles. Furthermore, the influence of low ambient temperature was almost non-existent for the ethanol fuels, but with the diesel fuelled version, NOx emissions rose by about 5 times, with lowering of the ambient temperature from +23 °C to -7 °C.

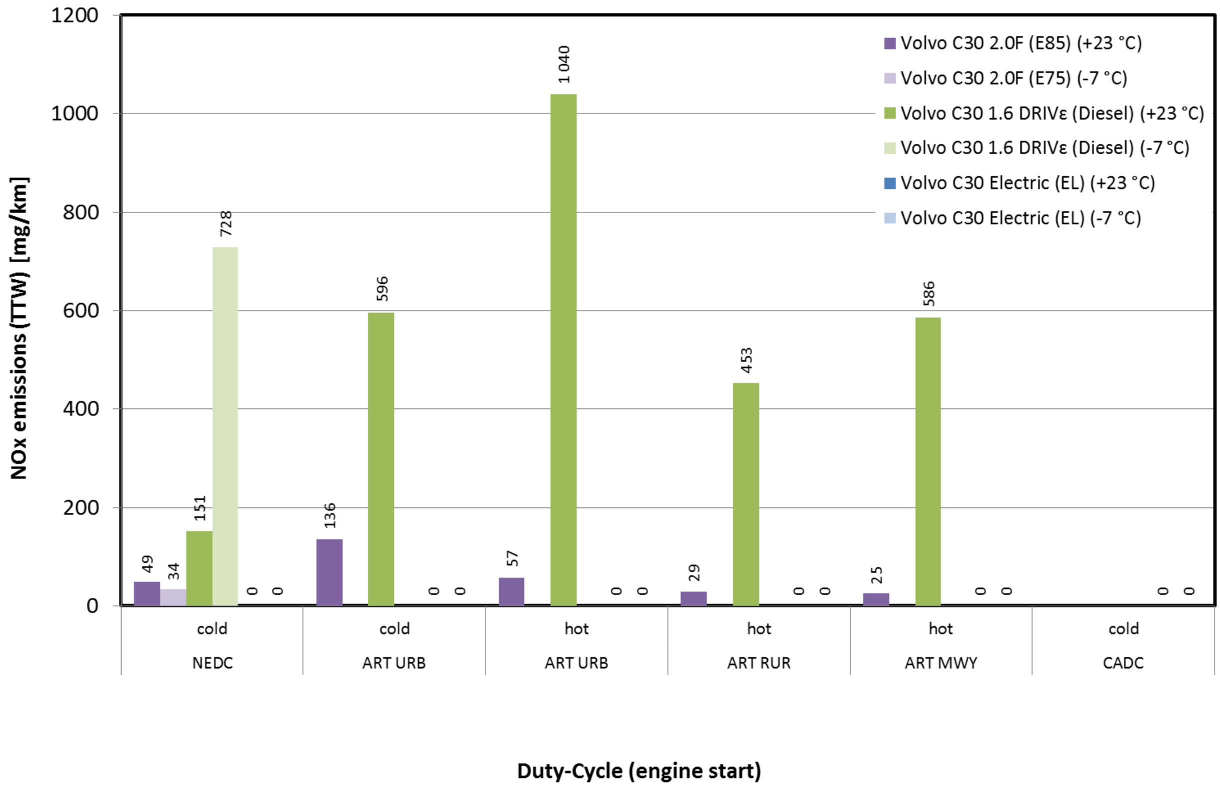


Figure 63: NOx emissions from the three cars tested in Sweden.

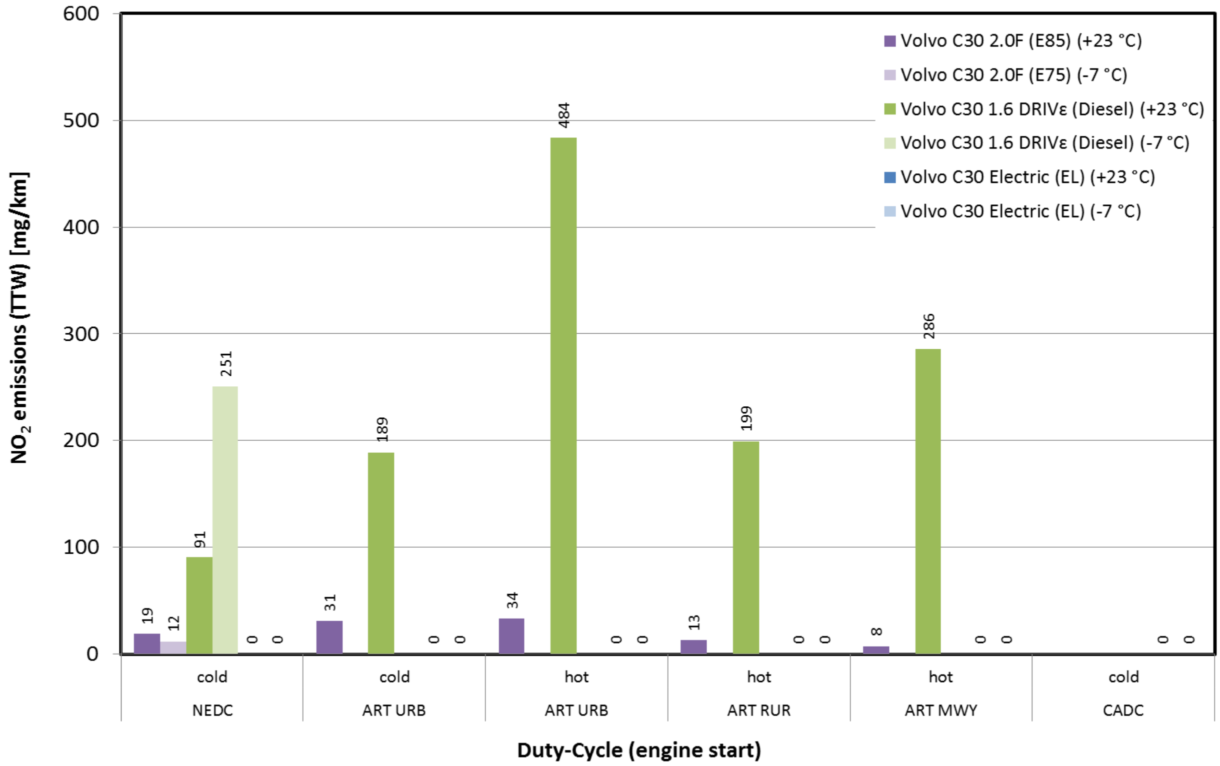


Figure 64: NO_2 emissions from the three cars tested in Sweden.

If we focus on **NO_2** portion of the total emissions of nitrogen oxides (Figure 64), we can see that the graph is almost a copy of the NOx graph, but with lower numerical values. This means that overall both technologies had roughly the same share of NO_2 of the total NOx emissions. However, these shares were quite high, between 23 to 45% (39% overall) for ethanol, and between 32% to 60% for the diesel.

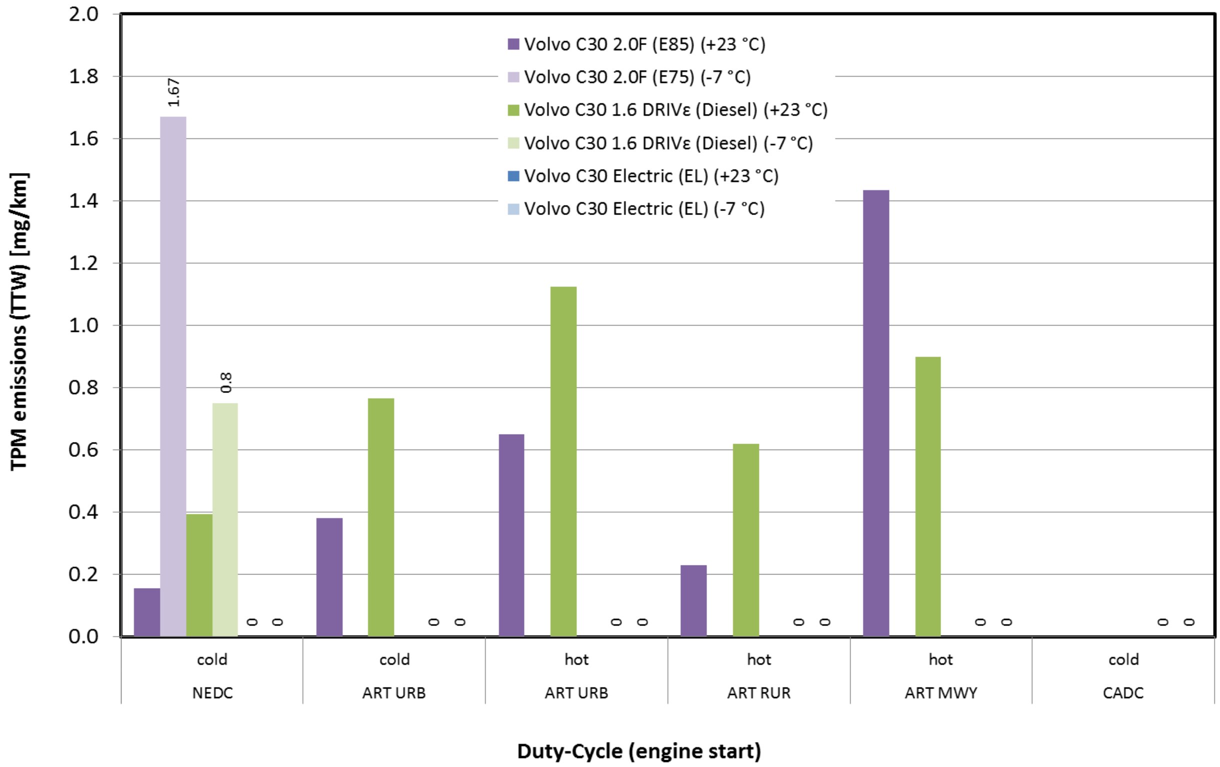


Figure 65: TPM emissions from the three cars tested in Sweden.

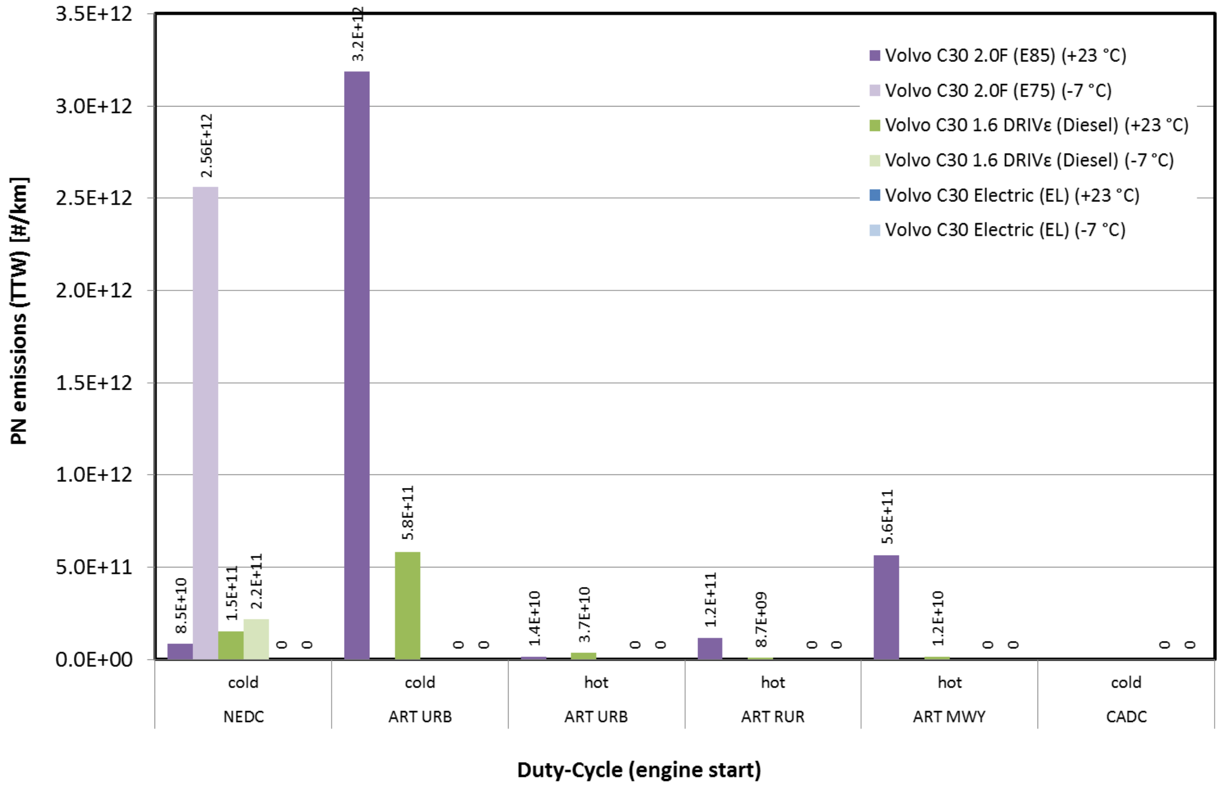


Figure 66: PN results for the three cars tested in Sweden.

Regarding the particulate mass emissions (**TPM**, Figure 65), the highest emissions were – once again – measured for the high-concentration ethanol version over the NEDC cycle at low ambient temperature -7 °C. The low temperature multiplication factor exceeds 10, whereas with the diesel version, the temperature effect was only about two. However, if we only compare the results for normal ambient temperature, diesel emitted more (about twice as much) in all but one case: ARTEMIS Motorway cycle. There the order was reversed.

Results for particulate number (**PN**, Figure 66) were close to TPM in NEDC tests. The high-concentration ethanol fuels produced the highest particulate numbers, but in this case the highest result was recorded over the cold-started ARTEMIS Urban cycle, and not in low temperature NEDC test like with TPM.

However, the cold ambient temperature had a significant influence, as the PN recorded for E75 at -7 °C was 30 times larger than what was measured for E85 over NEDC cycle at +23 °C. On the other hand, for diesel, the low temperature increased PN only by 45%, but at +23 °C the PN for diesel was some 40% higher than for E85. However, in cold-started ARTEMIS Urban cycle measurements E85-fuel produced almost 5.5 times higher PN emissions than diesel. In those hot-started ARTEMIS Rural and Motorway cycles the high-concentration ethanol (E85) fuel produced from 13 to nearly 50 times higher PN emissions compared to the corresponding results for diesel.

5.6 Results – Finland

Only one single vehicle platform was tested in Finland, but with six different IC-engines plus an electric-only version. Each IC was tested with two fuels, and all options were tested at normal ambient (+23 °C) and at low ambient temperature (-7 °C). With some exceptions, tests were also run at an intermediate temperature (+5 °C).

Data submitted included fuel and energy consumptions, and emissions of CO_2, CO, HC, NOx, and TPM. In addition NO_2 and N_2O were reported, as well as emissions of CH_4 and NH_3.

5.6.1 Performance with base fuel at normal ambient temperature

At first the results are presented for each vehicle using the “native” fuel of the ICE and at normal ambient temperature. In this case “native” refers to fuel that is the primary fuel for the engine. For regular SI engines it is gasoline, and for CI engines normal diesel fuel. For FFVs the “native” fuel is considered to be E85, and for the gas-fuelled option the primary fuel is CNG, even if both of these SI-engines can also run with gasoline. Figures 67 to 77 depict these results.

If we first try to evaluate the options by **fuel and energy consumption** (Figures 67 and 68), we see that the different energy contents of the fuel options “do the trick”, i.e. different volumetric fuel consumption figures may end fairly similar levels of Wh/100 km figures.

If we use the smaller, 1.6-liter diesel engine as baseline reference, and relate other powerplant options to it, we see that the smaller-displacement SI engine was overall some 10 % less efficient, whereas the larger-displacement 2.0 TSI engine was about 40 % less efficient, On the other hand, even the bigger 2.0 diesel was some 20 % less efficient than the 1.6 litre CI engine. The 1.4 litre FFV and CNG variants had also some 20 to 30 % higher energy consumption than the baseline engine, the 1.6 litre TDI diesel.

Energywise, the most efficient was of course the full-electric version with a margin of some 60% to the baseline.

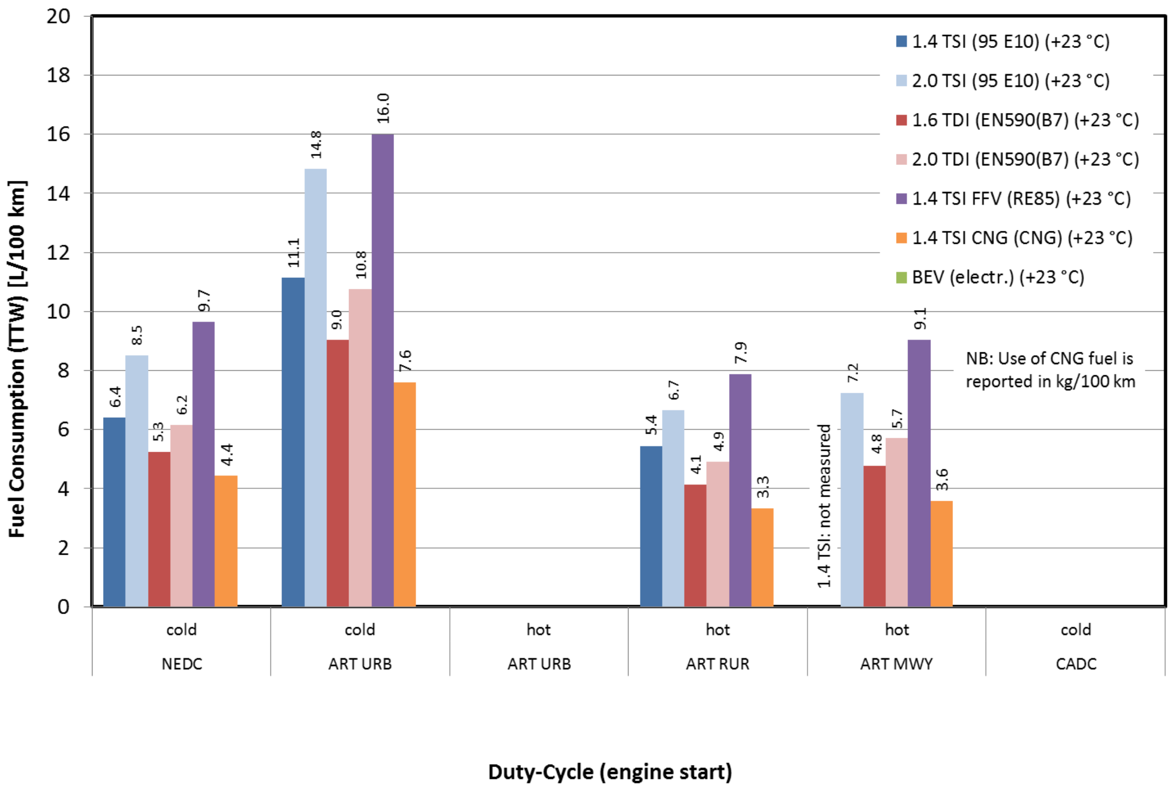


Figure 67: Fuel consumption of the cars tested in Finland.

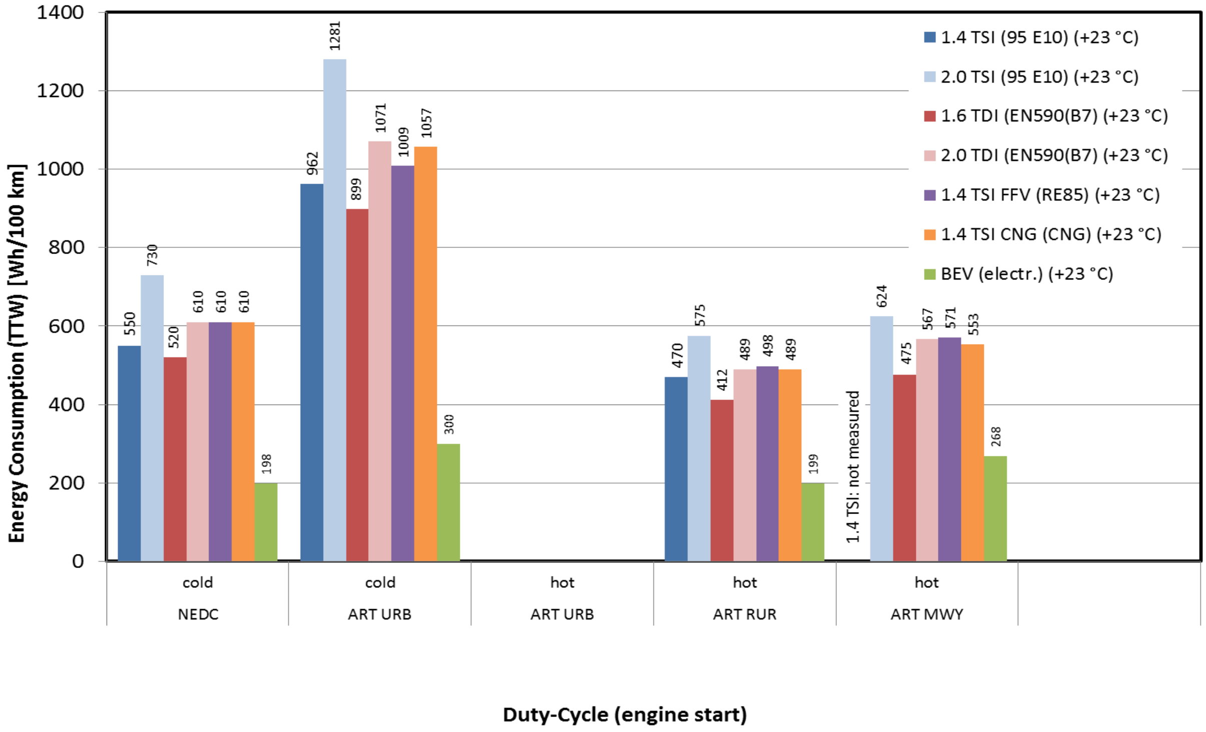


Figure 68: Energy consumption of the cars tested in Finland.

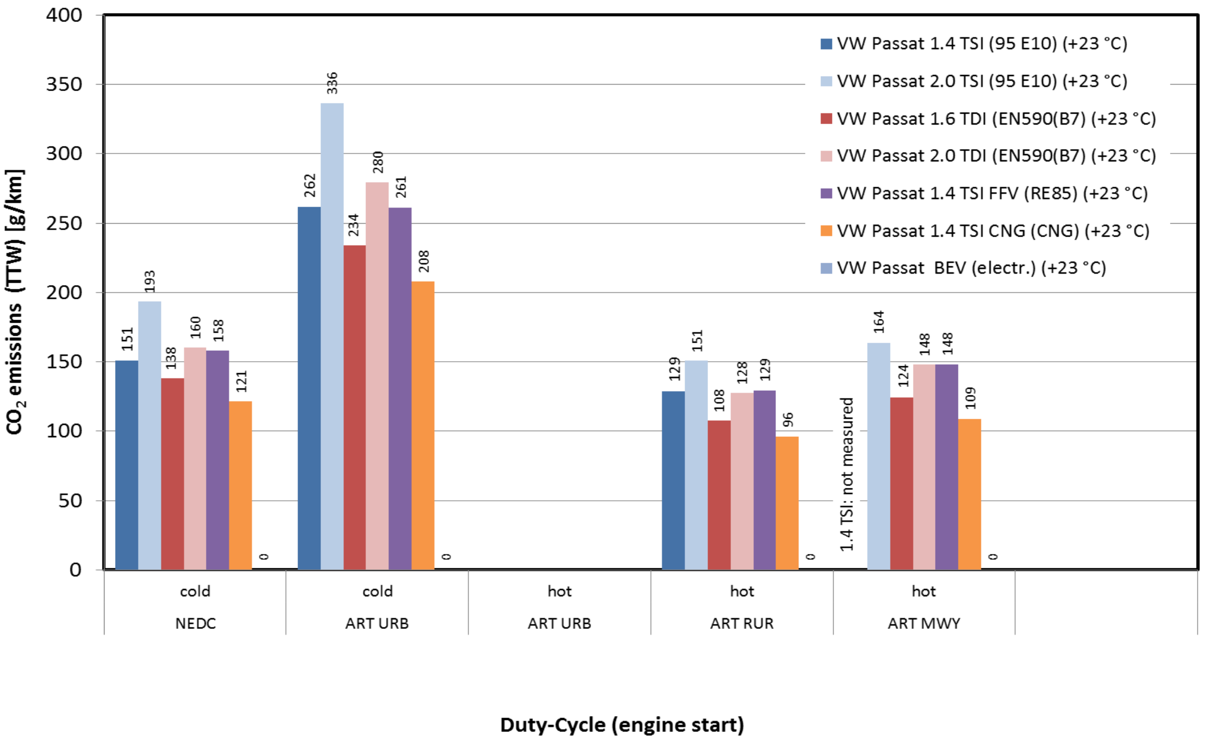


Figure 69: CO_2 emissions from the cars tested in Finland.

The fuel use results in **CO_2** emissions, depending on the specific carbon contents of the fuel. Results are plotted in Figure 69, and overall, the emissions appear to be higher in both cold-started cycles, when compared to the respective results from tests with warm engine start, which is only natural, as cold-start always induces higher fuel consumption. The highest values from all tested cases were recorded for the larger-displacement SI engine, irrespectively of the duty-cycle. The second-highest was the larger-displacement CI engine, but in many cycles the difference to 1.4 TSI (FFV version) with RE85 was quite marginal. The lowest emissions were observed for the 1.4 TSI (gas version) running on CNG.

Because the data submitted by Finland included also separately CH_4 and N_2O that are both string GHGs, it has been possible to calculate also CO_{2eq} that includes these additional compounds. In this calculation, equivalence factor of 23 has been used for CH_4, and 296 for N_2O. When this CO_{2eq} (not depicted) was compared to CO_2, it was found that the additive effect of including these compounds was overall very small, usually less than 1 %. However, with the high-concentration ethanol (E85) the add-on effect was clearly seen, especially in low ambient temperatures, where it could be nearly 4 %, at the utmost (ARTEMIS Urban at -7 °C).

Overall, if we again make the smaller-displacement CI engine as the baseline, the larger-displacement CI engine emits on average nearly 20 % more CO_2, whereas the smaller-displacement SI engine has only about 15 % higher emissions, but the larger-displacement SI engine grosses at 40 % higher CO_2 output. On their “native” fuels, the 1.4 TSI (FFV) on E85 fuel had almost 20 % higher CO_2 emissions, but the 1.4 TSI (GAS) on CNG emitted about 12 % less CO_2, when compared to the baseline (1.6 TDI).

Regarding emissions of carbon monoxide (**CO)**, depicted in Figure 70, the differences between engine and fuel options were quite notable. In cold-started cycles the smaller-displacement SI engine was the highest emitting, but in the hot-started duty cycles the larger-displacement SI version had the highest emissions. Overall, the lowest emissions were observed for the larger-displacement CI engine. The magnitude was -70 %, compared to the smaller-displacement CI engine, whereas the smaller-displacement SI engine had CO emission rates about twice of the baseline. However, the larger-displacement SI engine emitted CO quite sporadically: sometimes more than the baseline 1.6 TDI, but also sometimes less.

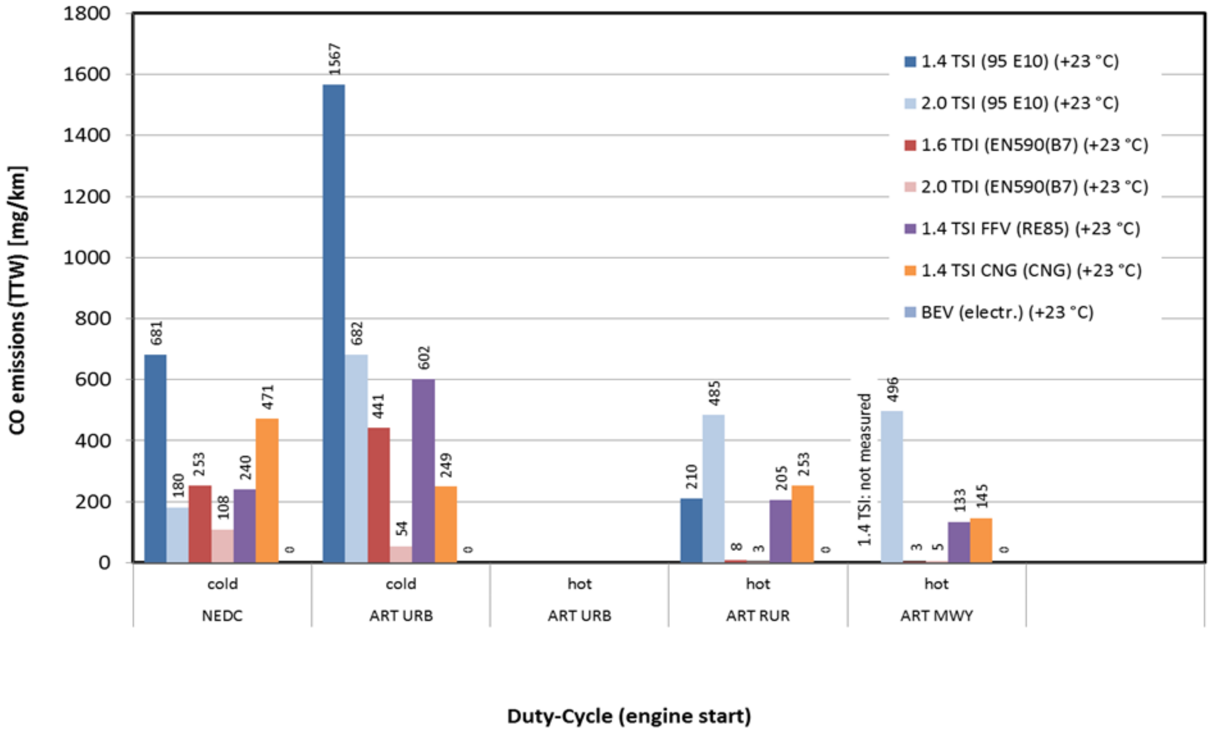


Figure 70: CO emissions from the cars tested in Finland.

What comes to total hydrocarbon emissions (**HC**), depicted in Figure 71, the lowest overall emissions were measured also here for the larger-displacement CI engine. On the other hand the highest emission rates were recorded in all tested cases for the CNG-fuelled Si engine. In some cases the magnitude could be four to ten times compared to the baseline. Most probably, this was due to the high methane content in the exhaust, so in spite of the high rate, the emissions were probably less harmful than the same level of emissions from SI-engines running on petrol.

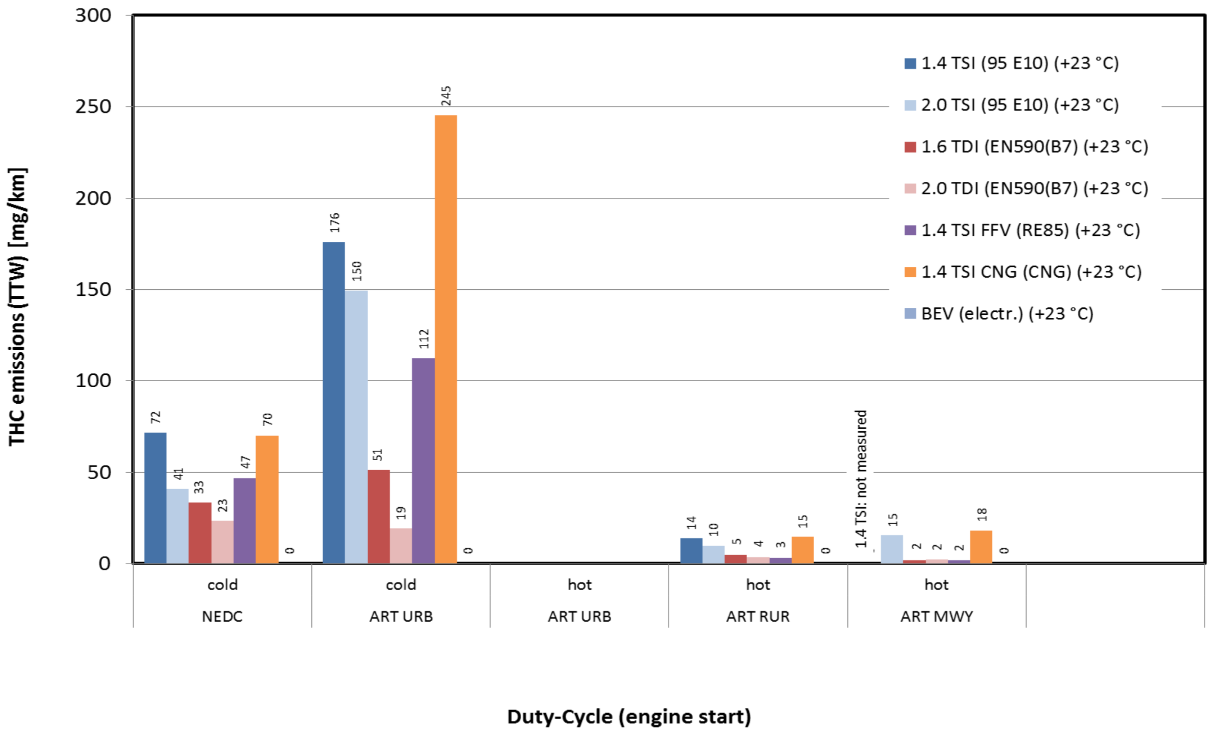


Figure 71: HC emissions from the cars tested in Finland.

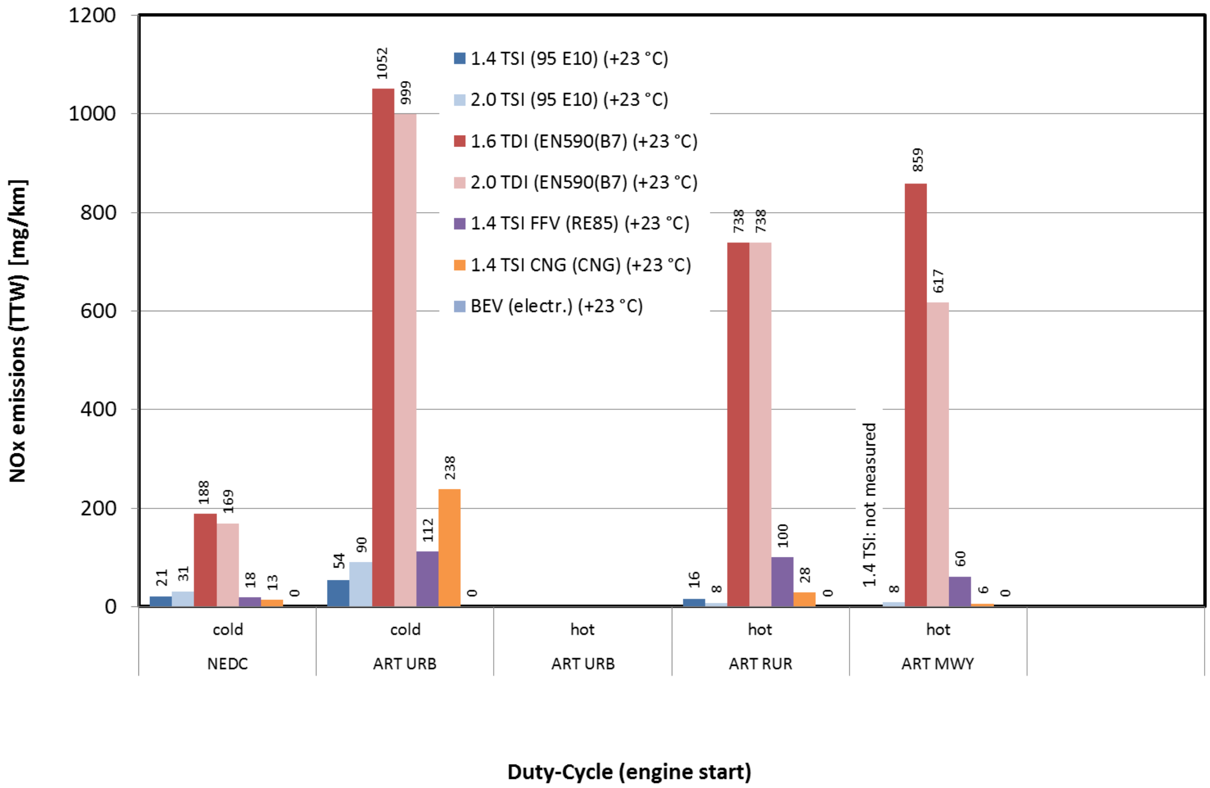


Figure 72: NOx emissions from the cars tested in Finland.

Probably the most conflicting emission in this exercise was **NOx**, depicted in Figure 72. By far the highest rates were measured for the two CI-engines, and the lowest for the SI-engines. In cold-started cycles all SI engines irrespectively of the fuel option, emitted less than 10 % of the corresponding rates of the CI-engines. The difference between the displacement options in CI engines was quite small, but always for the favour of the larger displacement. In terms of SI, in cold-start cycles the smaller-displacement engine was cleaner, but in the hot-started tests, vice-versa. However, the margins were then extremely thin, but all ARTEMIS cycles seemed to induce much higher emission rates. This might have something to do with the fact that according to the VIN number check, both CI-engines were of the types that were in October 2015 declared by VAG to contain the malicious “defeat device”. In these types the engine management system was aware of a test situation, and used then test-optimised settings. Otherwise, it used other settings that were producing higher emissions, probably in favour of lower fuel consumption. It was most probably, that the ARTEMIS cycles were not those observed by the system. Of the various SI engine versions the highest NOx emissions were recorded for the 1.4 TSI engine running on CNG in cold-started ARTEMIS Urban duty-cycle.

The division between CI and SI comes even stronger, if we consider the **NO_2** portion of the NOx, depicted in Figure 73. It is not possible to settle the worst-case, as between the two CI engines there were two cases where the emissions were about the same (NEDC and ARTEMIS Rural), but in the remaining two cycles, the smaller-displacement version had higher emissions than the larger-displacement version in one case, but in the other case vice versa.

The share of NO_2 of total NOx varied in the CI-engines between 13 and 47 %, but were in almost all cases below 16 % in normal SI-engines running on petrol. However, the 1.4 TSI MultiFuel on E85 showed diesel-like shares up to 50 %, but since the total NOx level in those cases were quite low, the emissions of NO_2 remained also quite marginal.

For the various SI engine versions the emissions level were always very low. In only one case, ARTEMIS Motorway cycle, the 1.4 TSI running on E85 showed some emissions.

The Finnish dataset includes also results for N_2O emissions, determined with an FTIR instrument. As Figure 74 shows, the levels were quite equal between all tested engine/fuel-combinations. The highest rates of emissions were recorded over the cold-started ARTEMIS Urban duty-cycle, exceeding 10 mg/km in two instances (1.6 TDI diesel and 1.4 TSI E85). In almost all other cases the rates were around 5 mg/km, or even less.

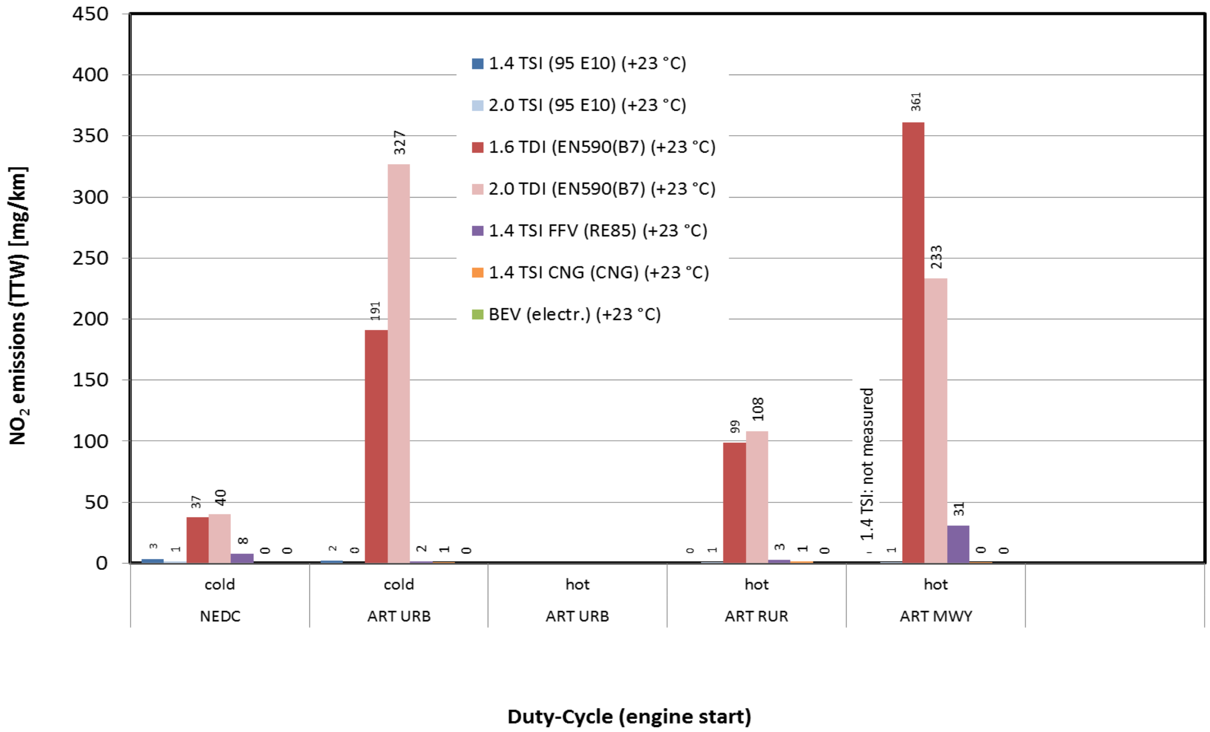


Figure 73: NO_2 emissions from the cars tested in Finland.

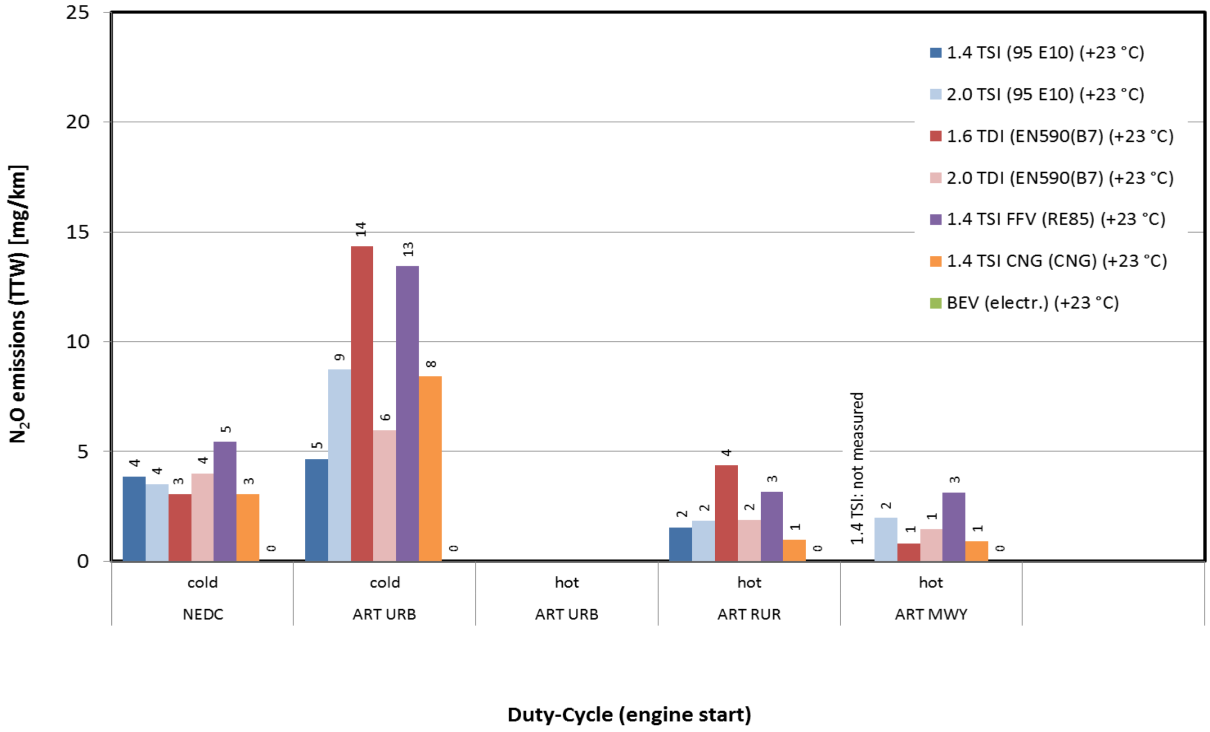


Figure 74: N_2O emissions from the cars tested in Finland.

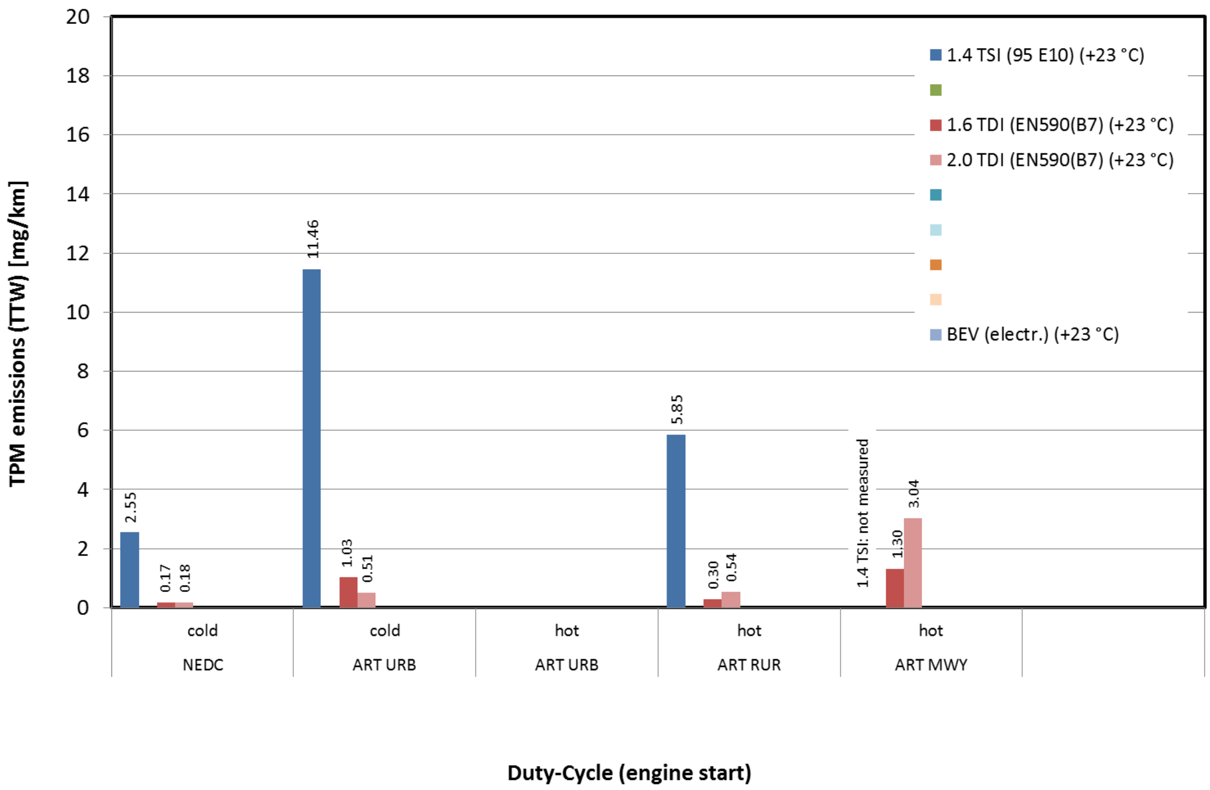


Figure 75: TPM emissions from selected cars tested in Finland.

Regarding total particulate matter (**TPM**), depicted in Figure 75, the DPFs in the CI-engines kept particulate mass emission very low, and the highest recorded emissions were attributed to the smaller-displacement SI-engine. However, no other SI-engine versions were measured due to restriction in instrument availability. Anyhow, the emissions for the SI-engine were in NEDC test about 50 % of the limit value applicable to CI engines (5 mg/km). In the cold-start ARTEMIS Urban cycle, this SI engine recorded over 11 mg/km emissions that can be considered high, as the diesels with DPF recorded levels that were 1/10th to 1/20th. However, in current legislation direct-injection SI engines (SIDI) are subjected to only particulate number standard (PN#), and not PM. At the time of this exercise, such measurement was not possible at VTT, though.

Of the non-regulated pollutants reported, Figure 76 depicts the emissions for **ammonia** (NH_3). As we can clearly see, both CI engines emitted only close-to-detection levels of ammonia, but the SI engines showed emissions up to over 50 mg/km. In two of the four tested cases the larger-displacement SI engine seemed to have the highest emission rates, while the smaller displacement version emitted around 50 to 70 % of that level. Of the alternative-fuelled versions, the CNG-fuelled SI engine showed usually somewhat higher rates, recording the highest-of-all value in both NEDC and ARTEMIS Rural cycles. The E85-fuelled counterpart matched the CNG-version in ARTEMIS Urban, where their emission rates were equal.

The last non-regulated pollutant that was included in the Finnish dataset was **methane** (CH_4), and Figure 77 depicts these emission rates. The E85-fuelled SI-engine recorded the highest emissions in both cold-started cycles (NEDC, ARTEMIS Urban), and the smaller-displacement SI running on petrol was the next, while its larger-displacement sibling had some 25 to 30 % lower emissions. The SI-CNG case showed some emissions also in the cold-started cycles, but negligible rates in hot-started tests.

The emission rates of methane were in all cases almost at the detection limit for both CI-engines running on diesel. This is quite in contrast to the levels of CH_4 measured and reported by Canada (Figure 45), where the rates were more than 20 mg/km. However, we must bear in mind that in case of the Canada exercise, a gas chromatograph (GC) was used for the analysis, whereas in the Finnish exercise, a FTIR analyser was used instead.

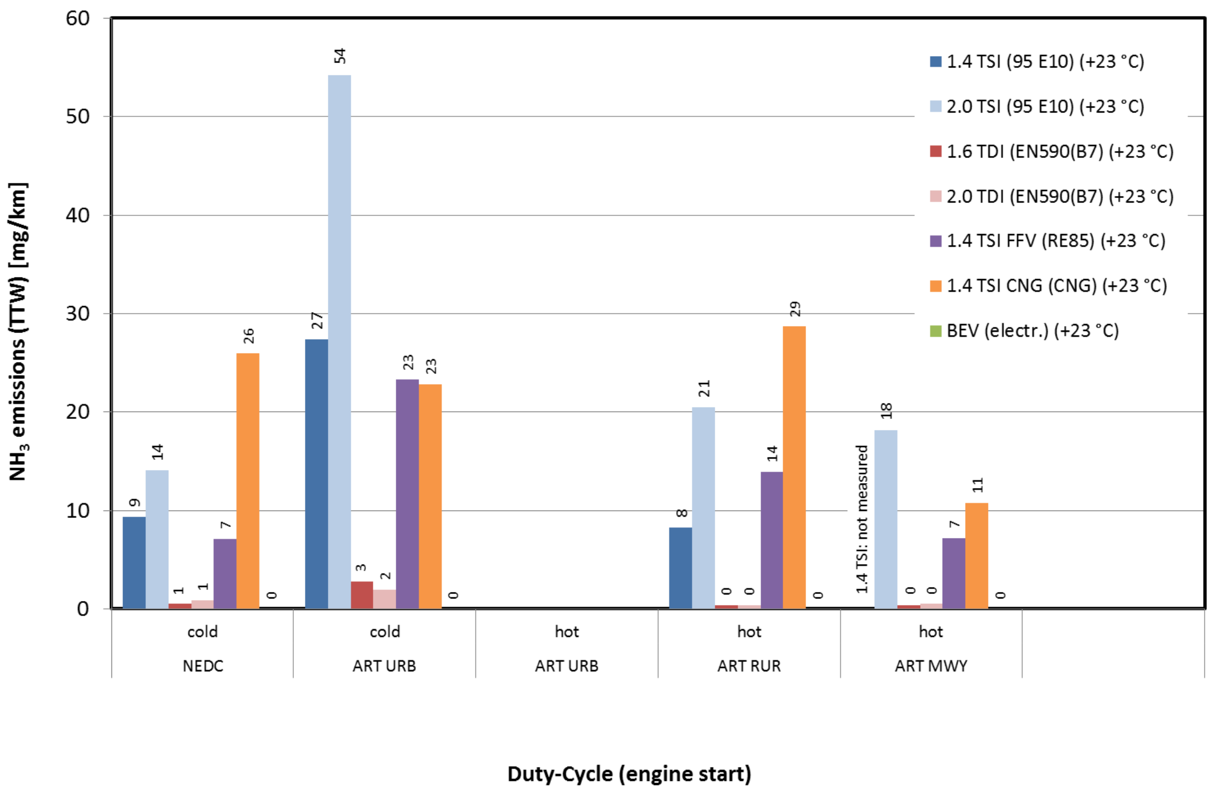


Figure 76: NH_3 emissions from the cars tested in Finland.

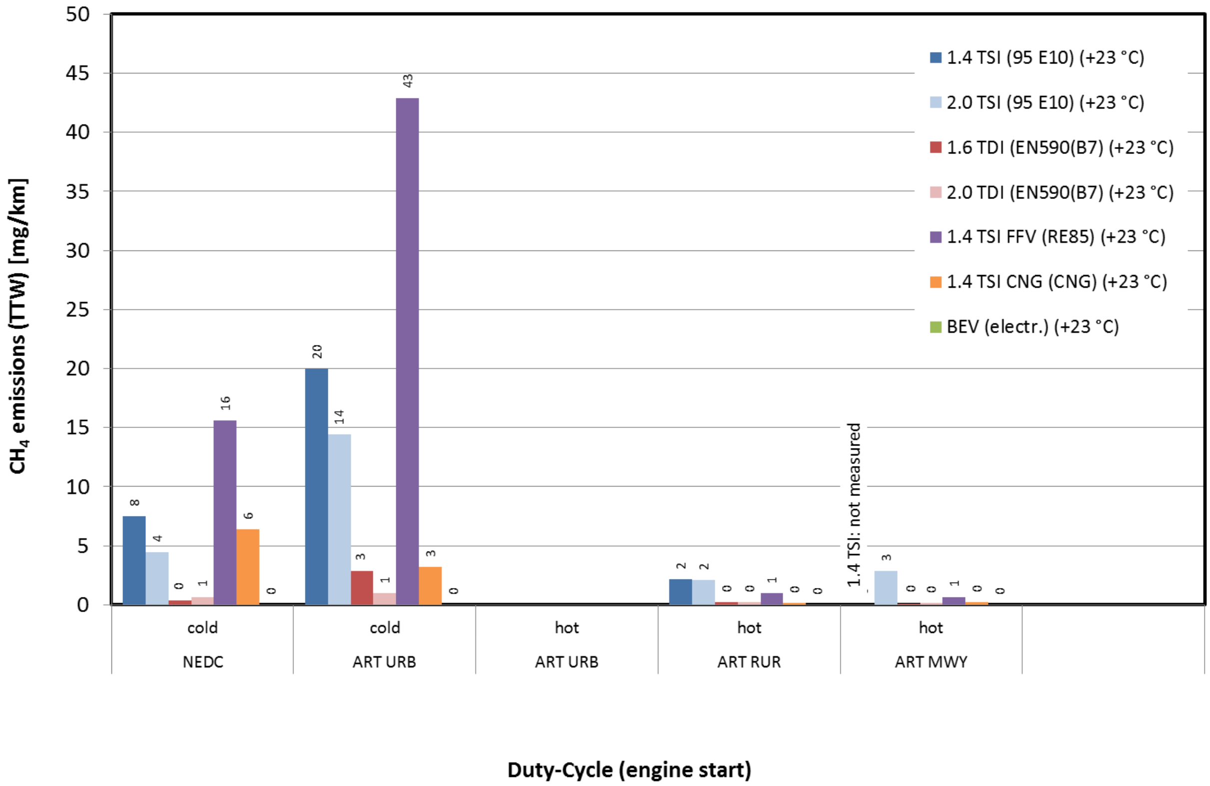


Figure 77: CH_4 emissions from the cars tested in Finland.

5.6.2 The effect of ambient temperature and fuel

In addition to the native fuel for each powerplant option, a secondary fuel was also measured with all cars. For gasoline-fuelled options the secondary fuel was “biogasoline”, i.e. blend that included bio-based hydrocarbons, but still conformed to EN228 standard. For EN590 diesel this secondary fuel was fully paraffinic, HVO type of fuel based totally on renewable raw materials. For FFV and bi-fuel CNG cars the secondary fuel was of course gasoline.

In addition to fuels, also ambient temperature was altered to address the impact of driving conditions. All options were tested at normal ambient (+23 °C) and at low ambient temperature (-7 °C). With some exceptions, tests were also run at an intermediate temperature (+5 °C).

Figures 78 to 95 depict results for each car with two fuels and three ambient temperatures. In this main part only fuel and energy consumptions as well as NOx-emissions are presented. The results for remaining emissions are presented in Appendix 3.

The test results for **volumetric fuel consumption** depicted in Figures 78 to 83 for different engines in this study show that lowering of the ambient temperature had a stronger influence than the fuel switch. This temperature effect was also stronger in those test cycles that were initiated with a cold start, but this was hardly any surprise, as this effect is well known.

For all four SI engines running on gasoline, this temperature effect was about +12 % at +5 °C, and about +18% at -7 °C. With the alternative-fuelled SI cases, high-concentration ethanol fuel was slightly more affected than CNG. Somewhat unexpected was though that falling ambient temperature had a strong influence also in CI engines, about +11 % at +5 °C, and as much as +21 % at -7 °C. This influence was also quite strongly divided between the two cases, as the smaller-displacement version suffered less from the cold than the larger-displacement version. The effect was +8 % at +5 °C and +17 % at -7 °C, but for the larger engine the corresponding figures were +13 % and +26 %. The colder conditions had some influence even in tests that were started with a fully- warmed engine, mostly less than 10 %.

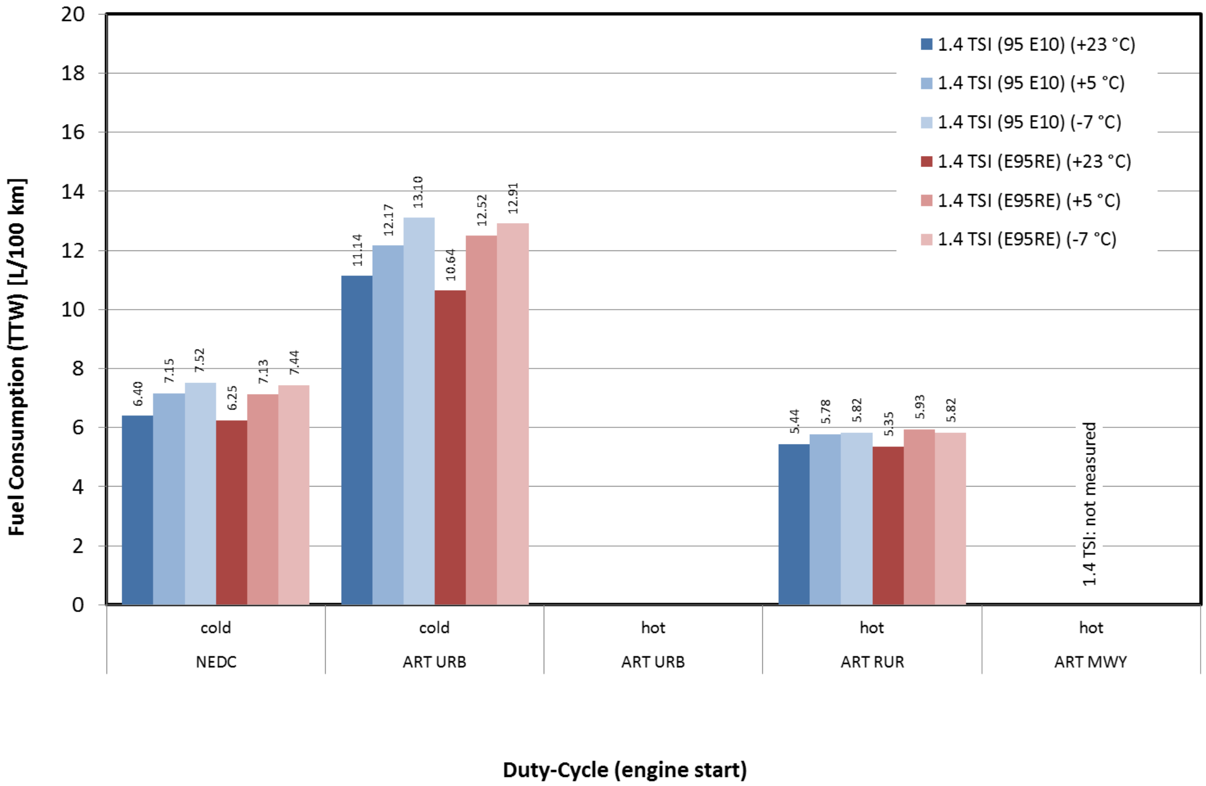


Figure 78: Fuel consumption for the 1.4 TSI (SI-engine) car tested in Finland with regular and "biogasoline", at +23, +5 and -7 °C ambient temperature; NEDC and ARTEMIS cycles.

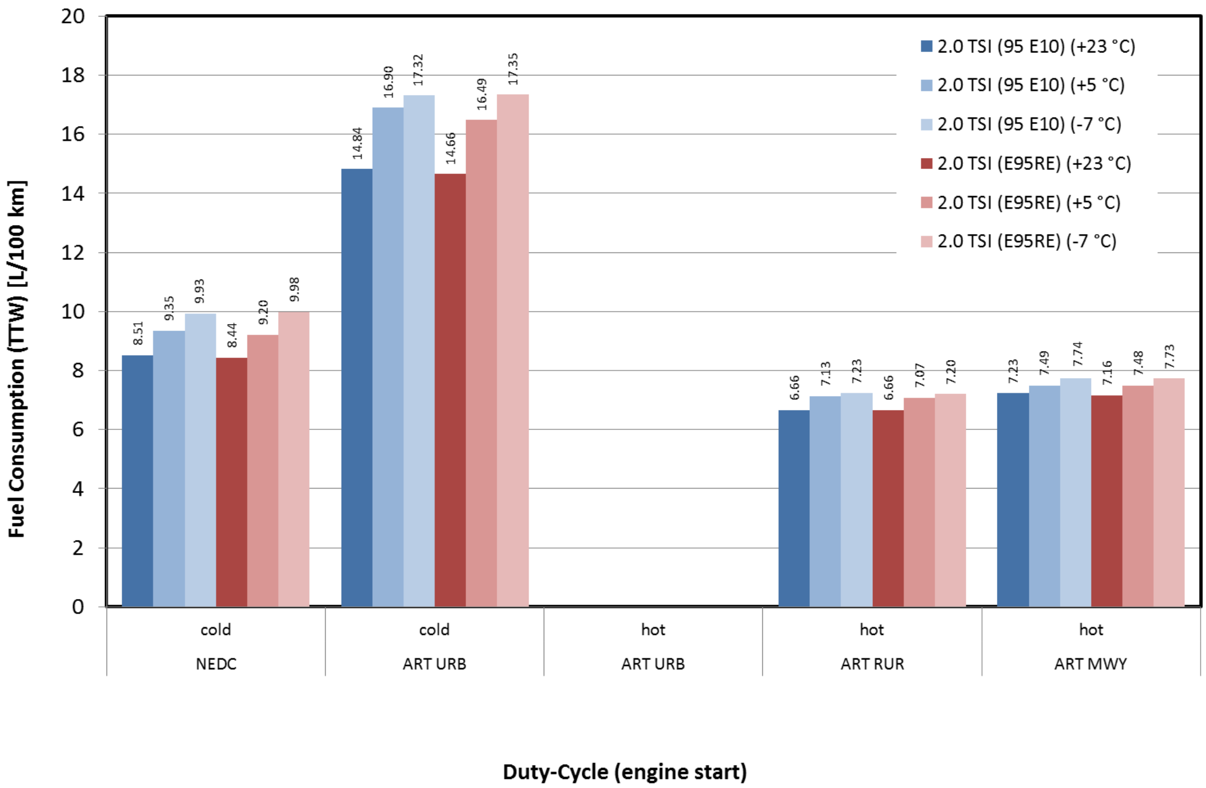


Figure 79: Fuel consumption for the 2.0 TSI (SI-engine) car tested in Finland with regular and "biogasoline", at +23, +5 and -7 °C ambient temperature; NEDC and ARTEMIS cycles.

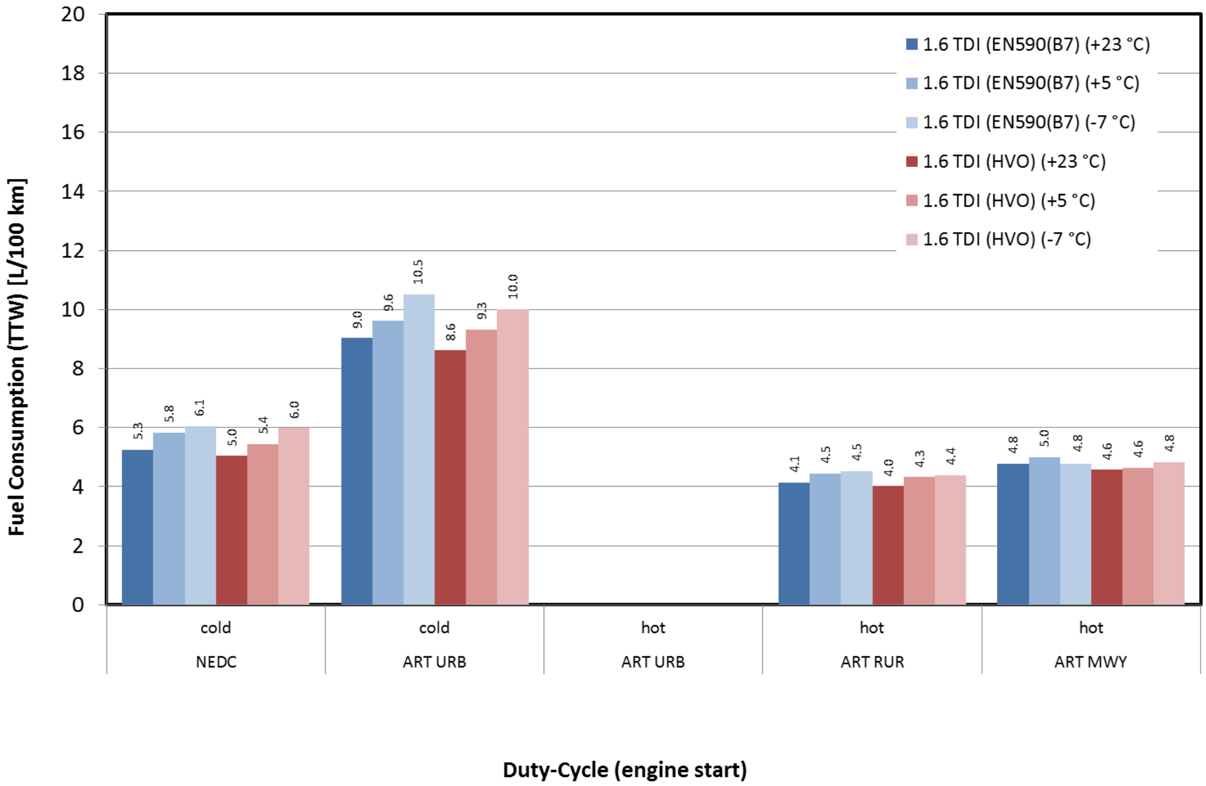


Figure 80: Fuel consumption for the 1.6 TDI (CI-engine) car tested in Finland with regular EN590 diesel and fully paraffinic fuel (HVO), at +23, +5 and -7 °C ambient temperature; NEDC and ARTEMIS cycles.

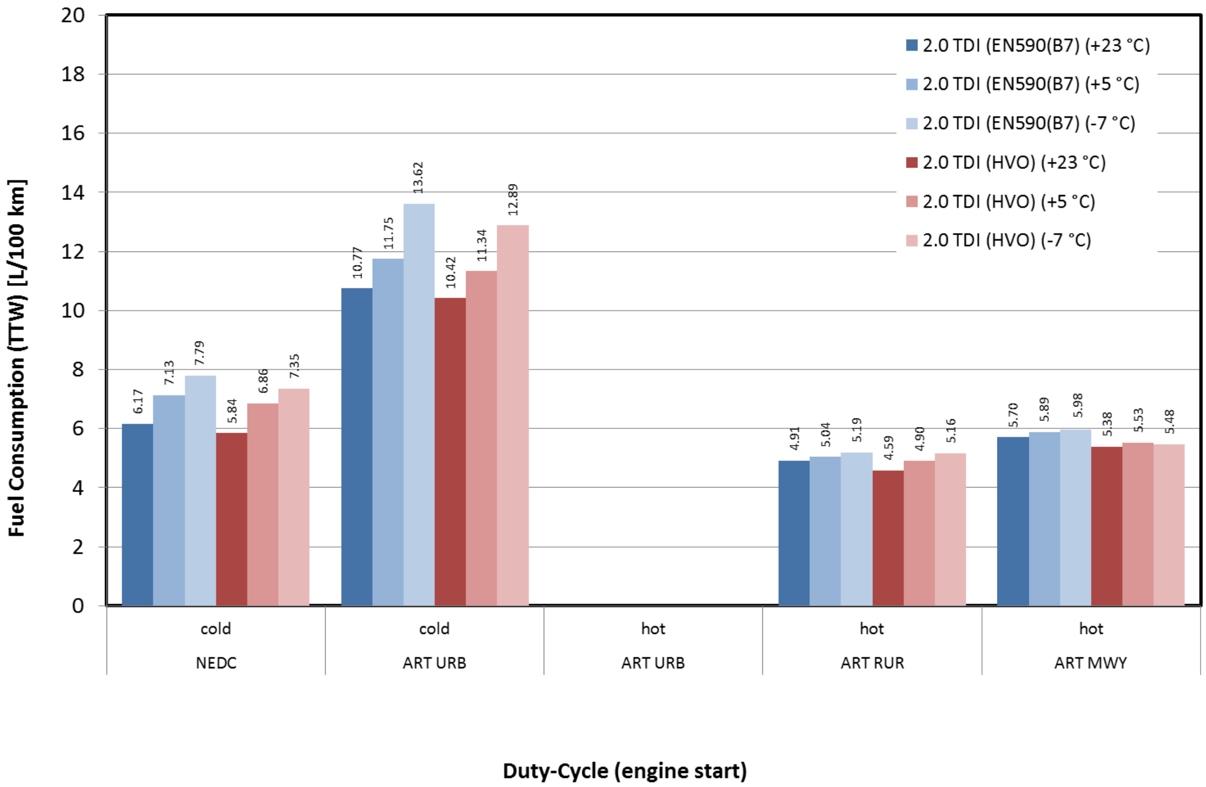


Figure 81: Fuel consumption for the 2.0 TDI (CI-engine) car tested in Finland with regular EN590 diesel and fully paraffinic fuel (HVO), at +23, +5 and -7 °C ambient temperature; NEDC and ARTEMIS cycles.

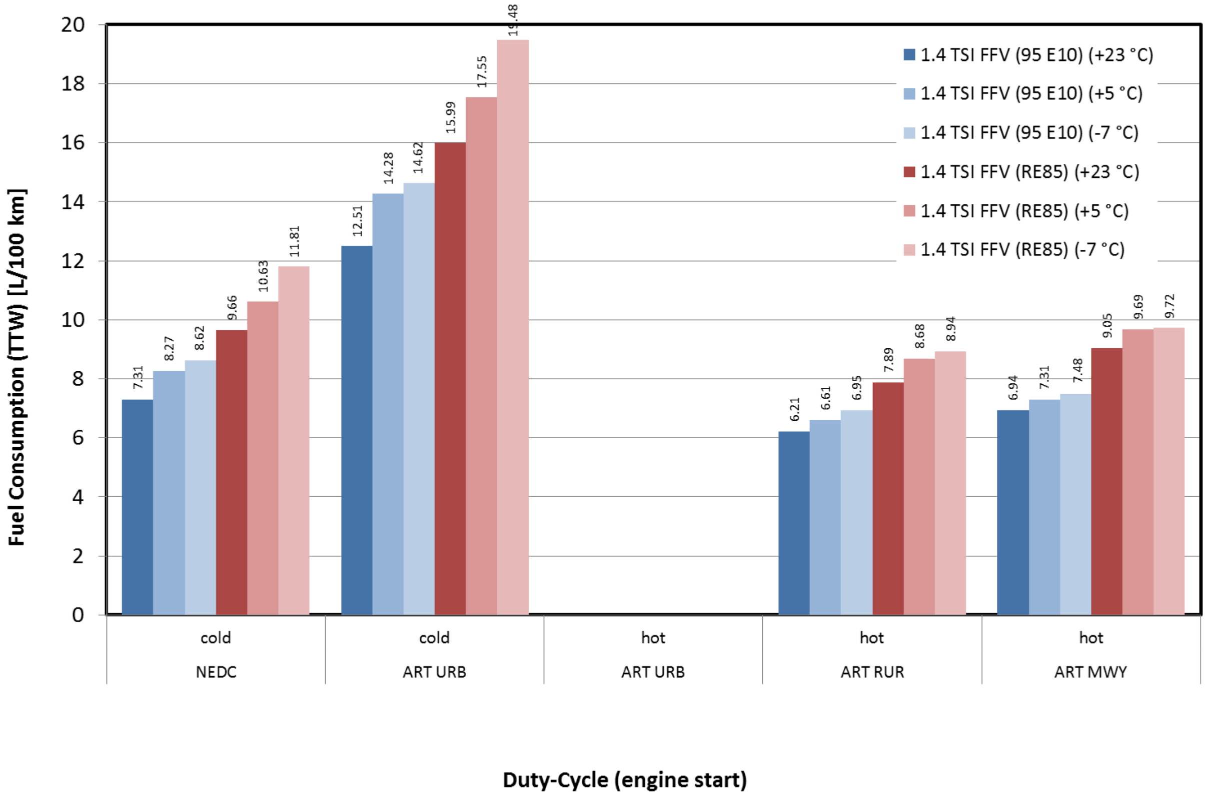


Figure 82: Fuel consumption for the 1.4 TSI FFV (SI-engine) car tested in Finland with regular and “biogasoline”, at +23, +5 and -7 °C ambient temperature; NEDC and ARTEMIS cycles.

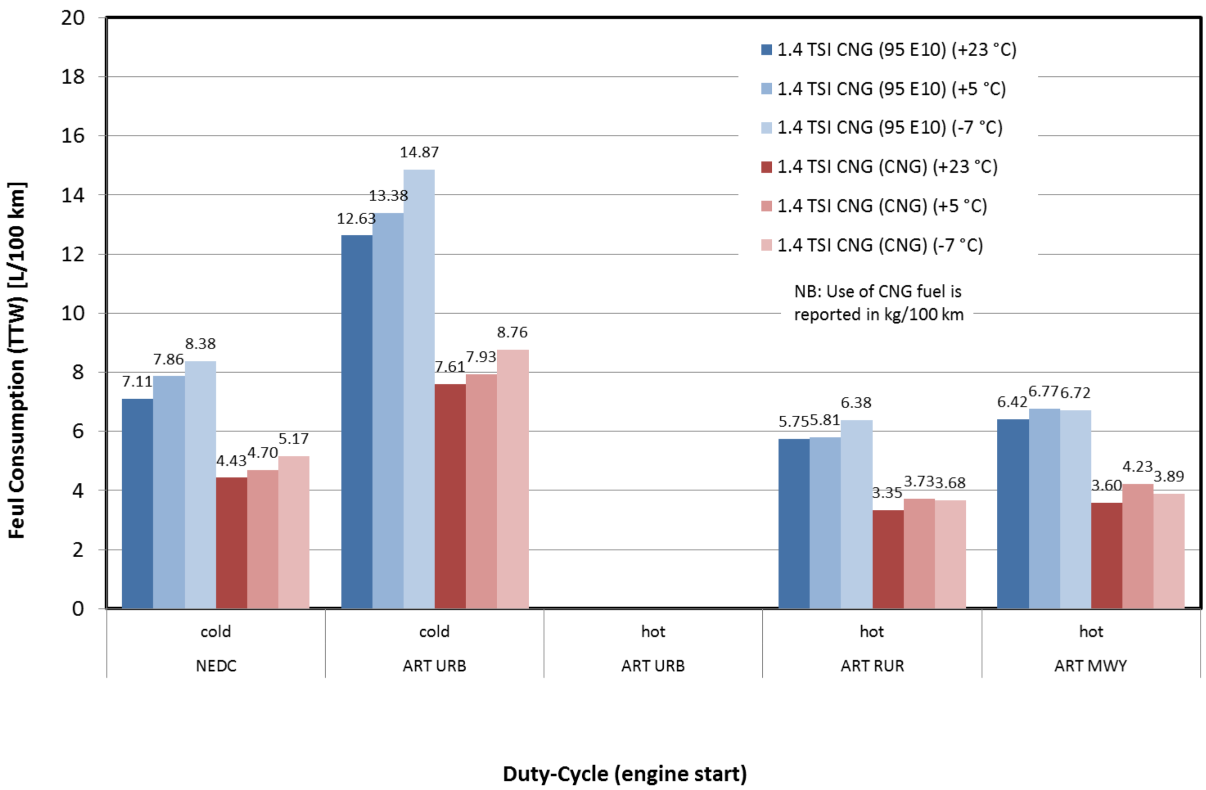


Figure 83: Fuel consumption for the 1.4 TSI CNG (SI-engine) car tested in Finland with regular gasoline and CNG at +23, +5 and -7 °C ambient temperature; NEDC and ARTEMIS cycles.

The test results for **energy consumption**, depicted in Figures 84 to 89, show that like with the volumetric fuel consumption lowering of the ambient temperature had more influence on the energy consumption than the change of fuel.

For all four SI engines running on gasoline, the lowering of the ambient temperature resulted to an increase of energy use that was about +12 % at +5 °C, and about +18 % at -7 °C. With the alternative-fuelled SI cases, high-concentration ethanol fuel was slightly more affected than CNG. As already commented, somewhat unexpectedly falling ambient temperature had quite an influence also in CI engines, although cold start has been seen predominantly as a challenge to SI engines. The effect was about +11 % at +5 °C, and as much as +22 % at -7 °C. Likewise, this influence was divided between the two cases. For the smaller-displacement version the effect was +7 % at +5 °C and +17 % at -7 °C, but for the larger engine +13 % and +26 %. The colder conditions had some influence even in tests that were started with a fully- warmed engine, but mostly less than 10 % at the most.

Furthermore, the choice of fuel also attributed to changes in energy consumption. In the normal SI-engines, use of “biogasoline” resulted in very slight decrease in energy spending. However, in case of CI-engines, the use of fully paraffinic HVO-type of renewable diesel attributed to about 8 % reduction in energy use, mainly due to the high cetane number of this fuel that was 81.7, whereas typical values for regular commercial EN 590(B7) fuel are about 54 to 55, 51 being the absolute minimum today.

When high-concentration ethanol fuel (E85) was used instead of normal gasoline in the 1.4 TSI MultiFuel engine, the calculated energy consumption was reduced by some 5 % (Figure 88). Furthermore, the same switch from gasoline to CNG in the corresponding 1.4 TSI EcoFuel engine showed overall only 1 % reduction (Figure 89).

Not depicted, but in the battery-electric version the lowering of the ambient temperature from +23 °C to -7 °C yielded to almost 20 % overall increase in energy use (+9 % to +29 %).

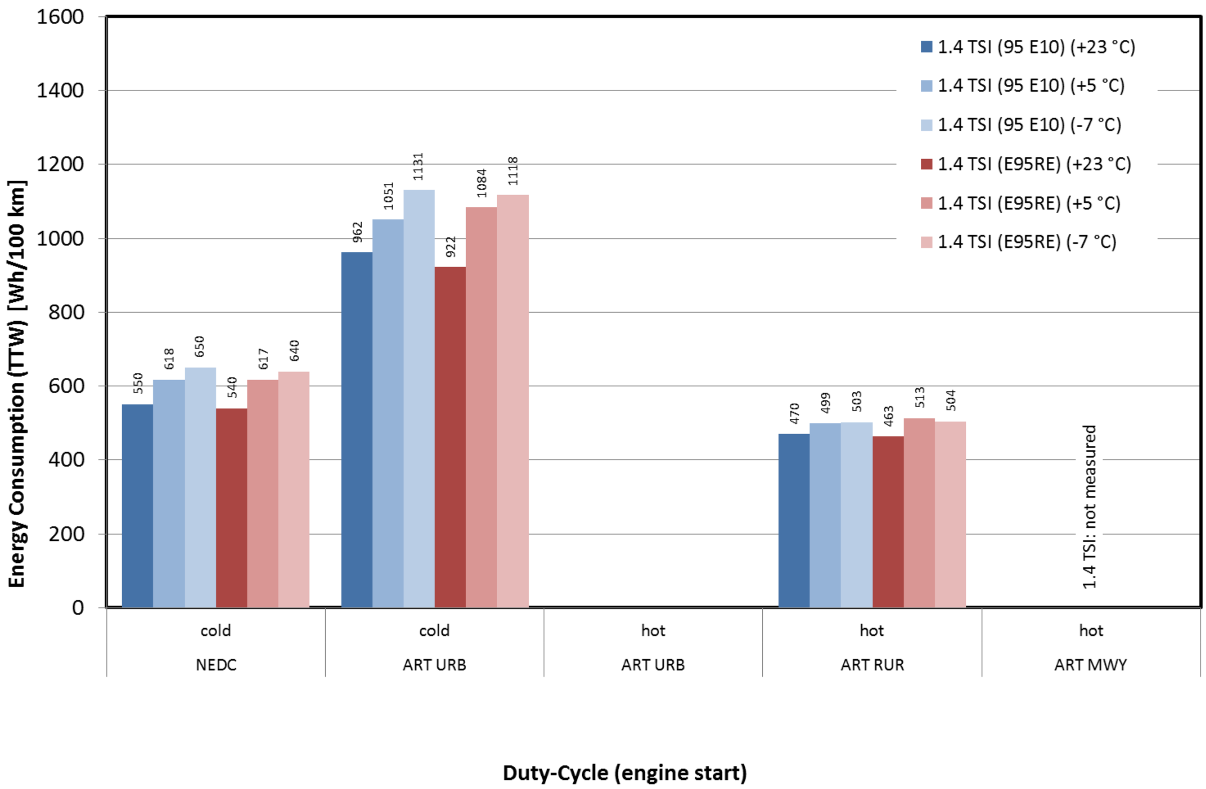


Figure 84: Energy consumption for the 1.4 TSI (SI-engine) car tested in Finland with regular and “biogasoline”, at +23, +5 and -7 °C ambient temperature; NEDC and ARTEMIS cycles.

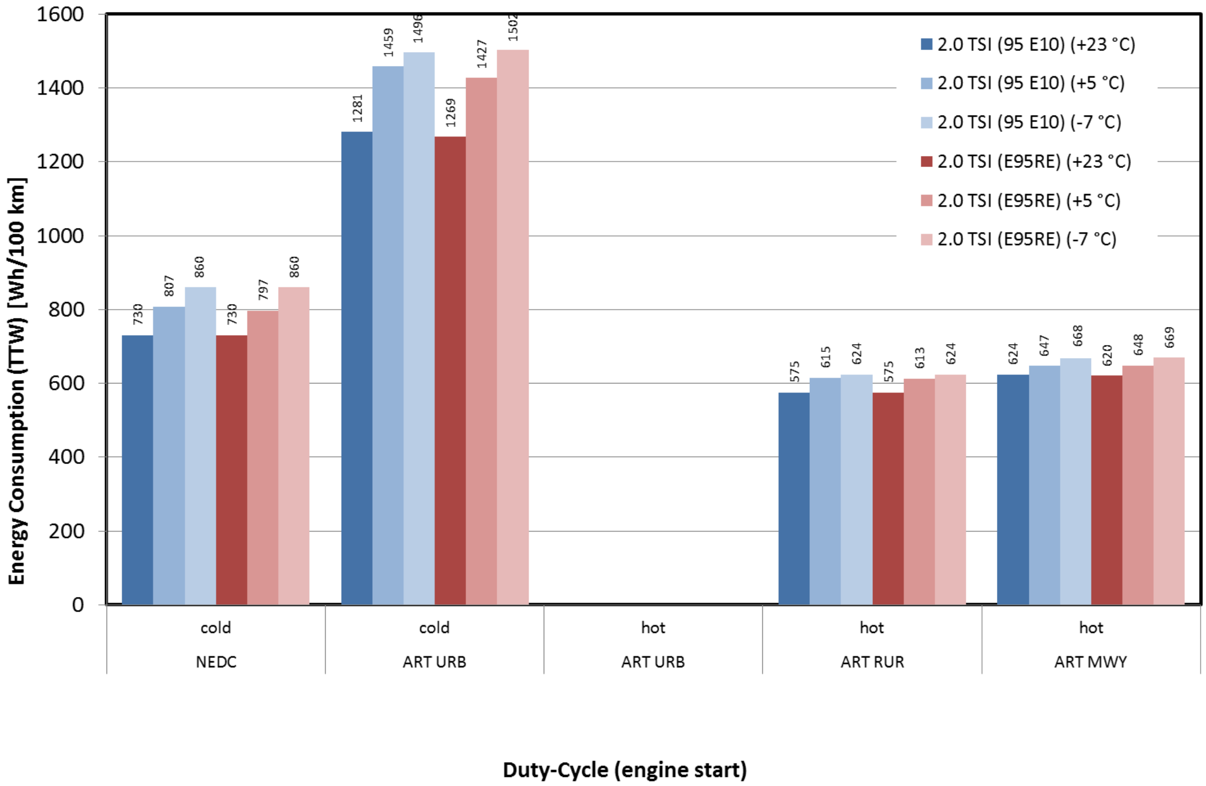


Figure 85: Energy consumption for the 2.0 TSI (SI-engine) car tested in Finland with regular and "biogasoline", at +23, +5 and -7 °C ambient temperature; NEDC and ARTEMIS cycles.

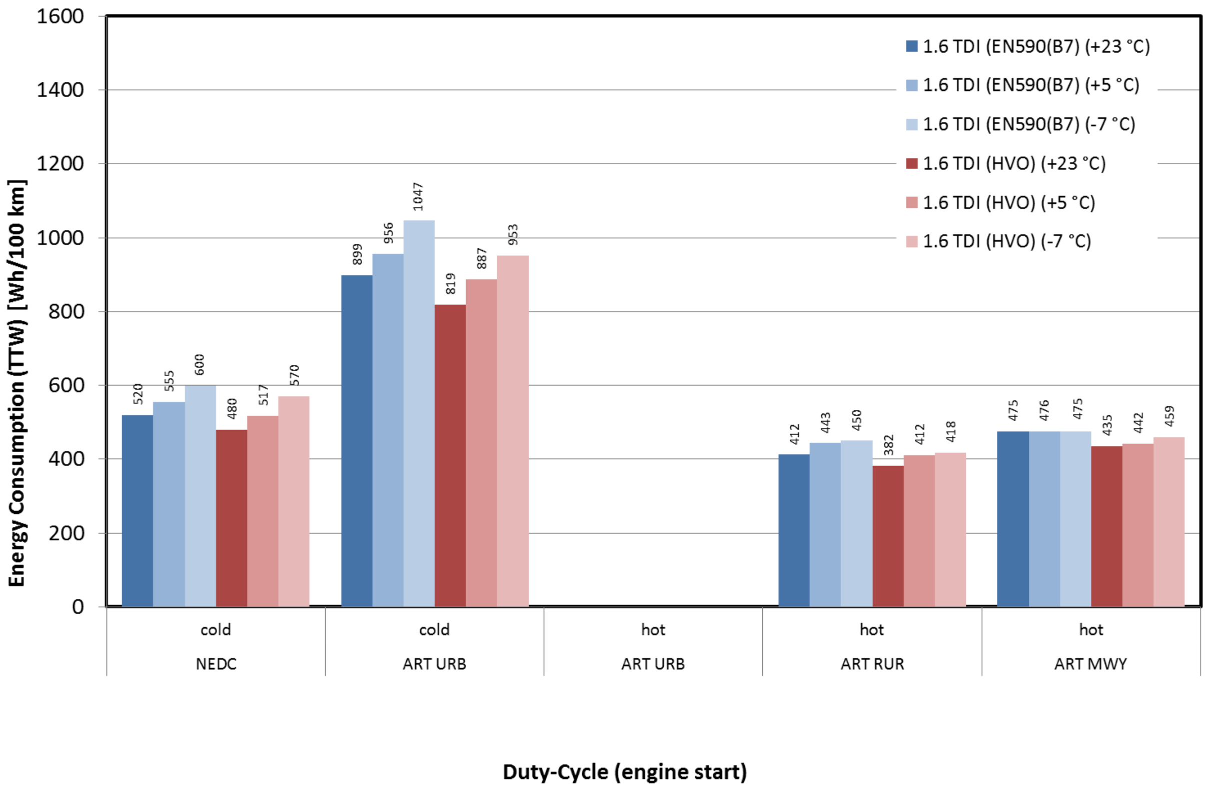


Figure 86: Energy consumption for the 1.6 TDI (CI-engine) car tested in Finland with regular EN590 diesel and fully paraffinic fuel (HVO), at +23, +5 and -7 °C ambient temperature; NEDC and ARTEMIS cycles.

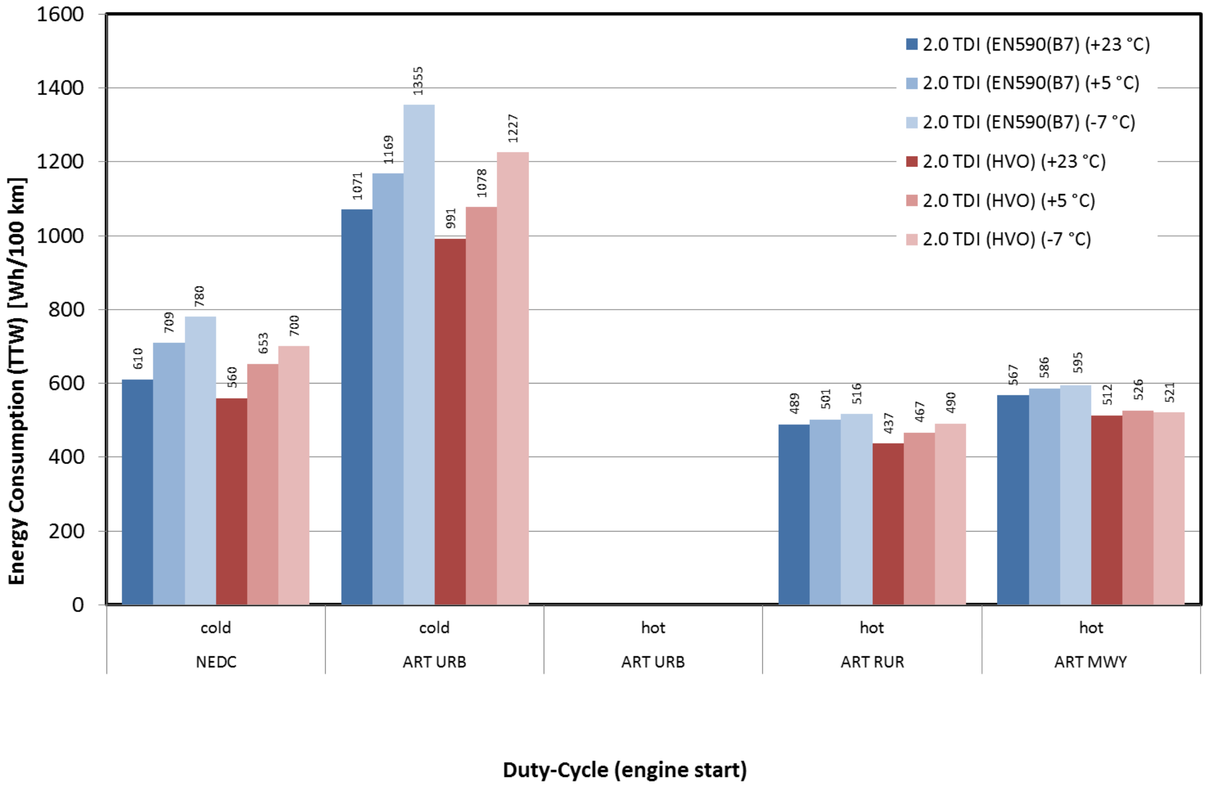


Figure 87: Energy consumption for the 2.0 TDI (CI-engine) car tested in Finland with regular EN590 diesel and fully paraffinic fuel (HVO), at +23, +5 and -7 °C ambient temperature; NEDC and ARTEMIS cycles.

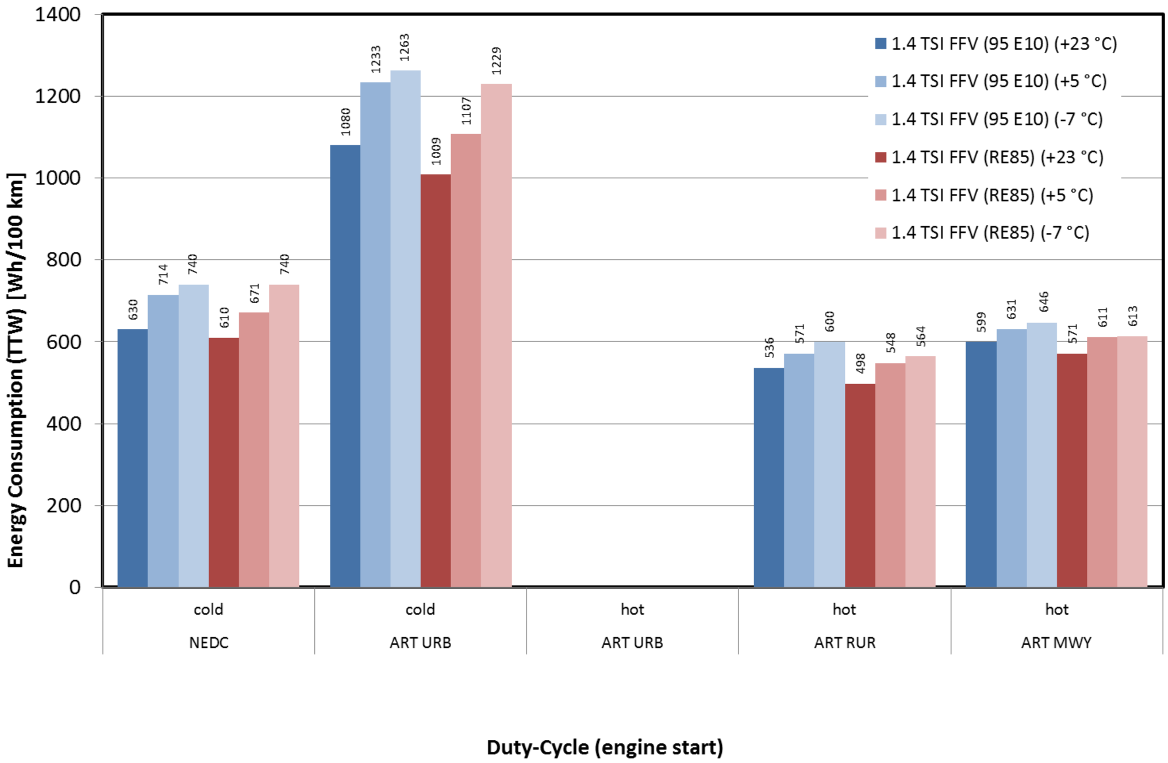


Figure 88: Energy consumption for the 1.4 TSI FFV (SI-engine) car tested in Finland with regular gasoline and with E85, at +23, +5 and -7 °C ambient temperature; NEDC and ARTEMIS cycles.

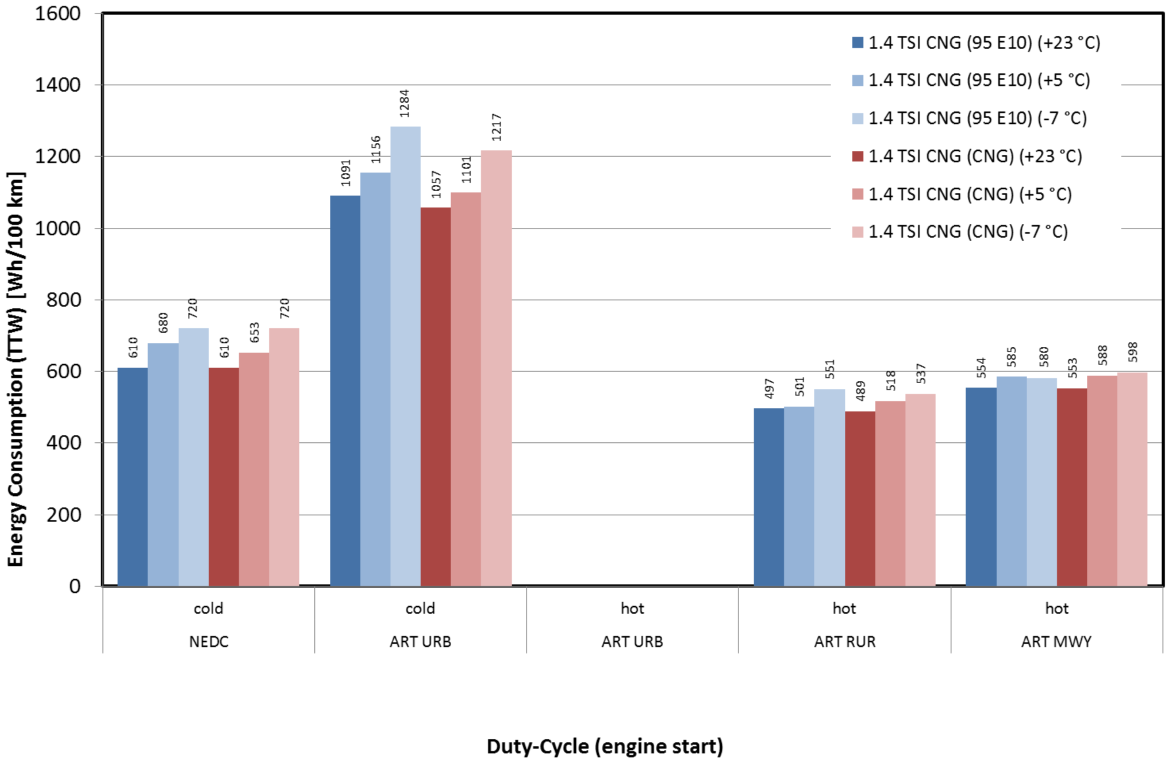


Figure 89: Energy consumption for the 1.4 TSI CNG (SI-engine) car tested in Finland with regular gasoline and CNG at +23, +5 and -7 °C ambient temperature; NEDC and ARTEMIS cycles.

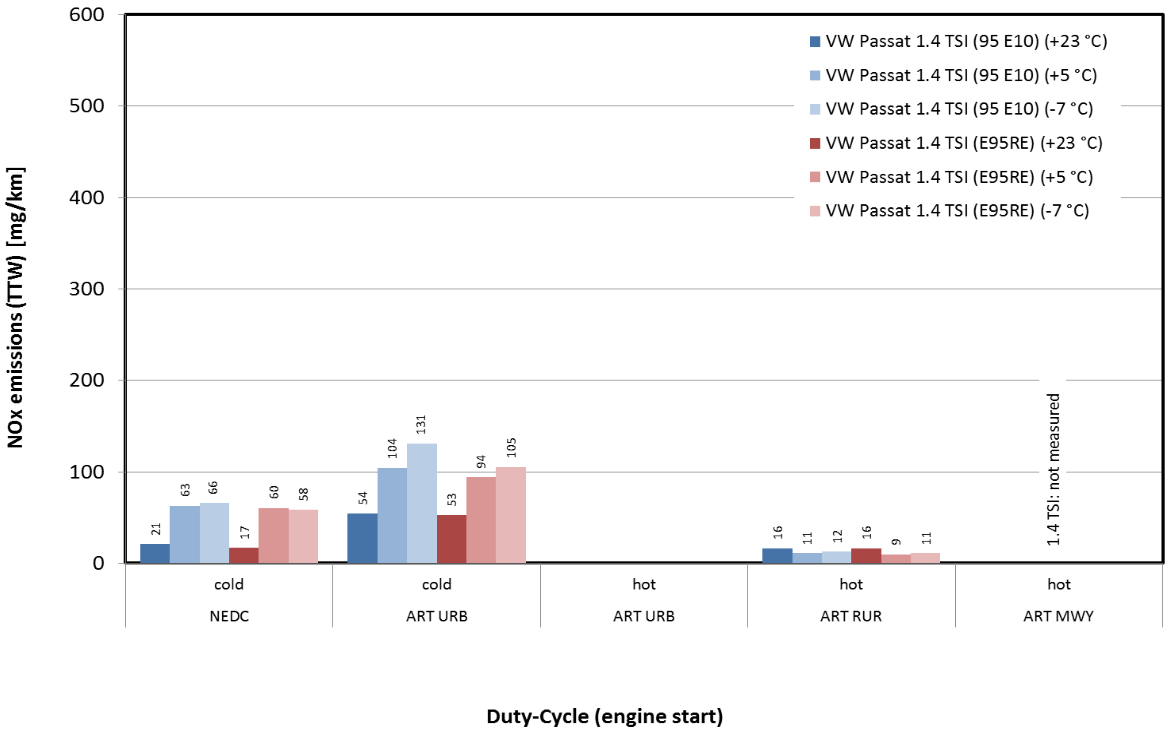


Figure 90: NOx emissions from the 1.4 TSI (SI-engine) car tested in Finland with regular and “biogasoline”, at +23, +5 and -7 °C ambient temperature; NEDC and ARTEMIS cycles.

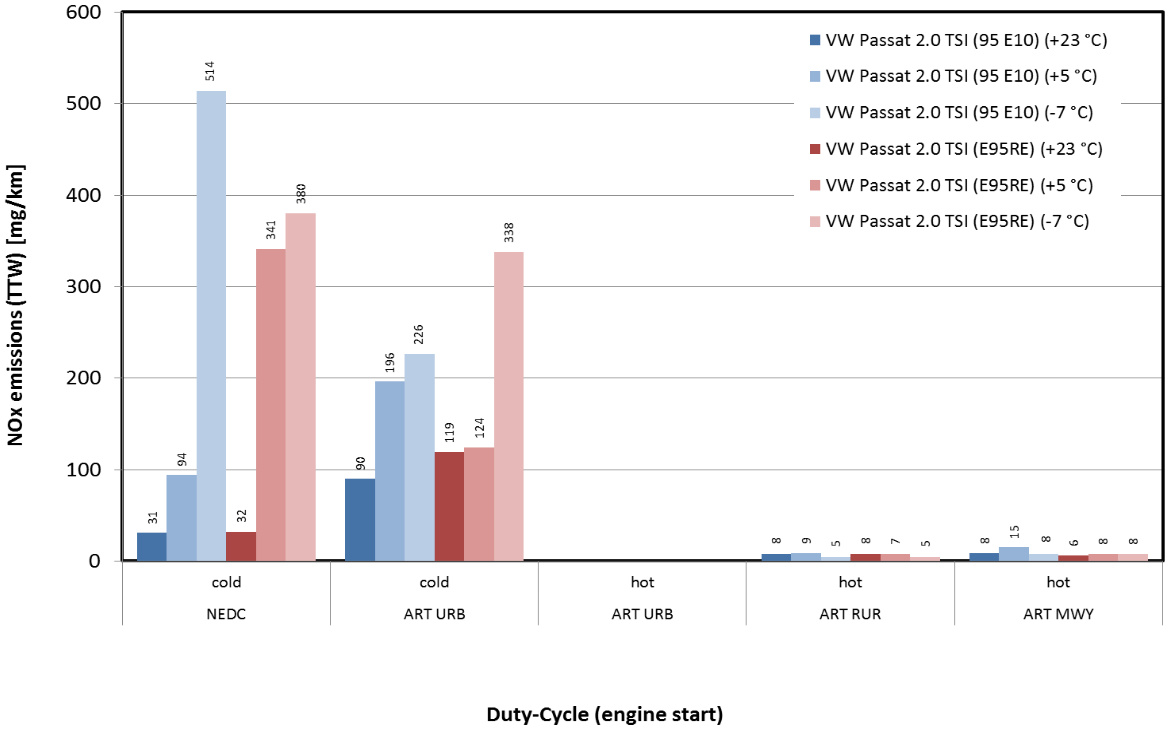


Figure 91: NOx emissions from the 2.0 TSI (SI-engine) car tested in Finland with regular and "biogasoline", at +23, +5 and -7 °C ambient temperature; NEDC and ARTEMIS cycles.

Considering the influence of ambient temperature and fuel switch to emissions of nitrogen oxides (NOx), temperature had much stronger effect, but the effects were also aggregated, so the implications of lowering the temperature were not the same for all fuels.

If we at first take a look at SI engine versions using regular or "biogasoline" (Figures 90 and 91), we can see that there was a strong difference in the levels of emissions between the cold-started duty-cycles (NEDC and ARTEMIS Urban) and the hot-started ones (ARTEMIS Rural and ARTEMIS Motorway). Regardless of fuel the ambient temperature had much less influence for the emissions from the smaller-displacement SI-version compared to the larger-displacement one. Where the smaller engine emitted less than 150 mg/kg in all cases (cycle, temperature, fuel), lowering of the ambient temperature made the emissions from the larger SI-engine increase, especially at the lowest test temperature (-7 °C), reaching as high as 500 mg/km. This gives the lowering of the temperature a multiplicative factor of more than 13, whereas for the smaller one the multiplication was only about 2.3. Also the fuel effect in the smaller engine seemed to be net positive, i.e. lower emissions with the alternate fuel ("bio-gasoline"). However, the larger engine did not respond as clearly, because depending on the test cycle, either normal or the alternate fuel produced higher emissions. It is quite difficult to find an explanation to this kind of responses, as basically, both cars seemed to be at their type-approval levels (20 mg/km for 1.4 TSI, and 30 mg/km for 2.0 TSI), but still their "off-cycle" (i.e. non-standard cycle and fuel) performance was very much different.

If we review the results from the two CI-engines, depicted in Figures 92 and 93, we see that in these cases the duty-cycle had less importance, as the emissions levels were not as clearly differentiated between the cold-started and hot-started tests. Also the difference between the small and large displacement engines in the overall levels of emissions was much smaller than in case of the SI engines. Furthermore, the type-approval value for smaller-displacement car was 100 mg/km, but what was measured was close to 200 mg/km in NEDC. For the larger-displacement versions the type approval level was higher, 150 mg/km, but the measured level was much closer to that, at 169 mg/km. Also, when assessing the emissions, we must bear in mind that both of these cars had engines that were later declared by VAG to contain the "defeat device", but there is no specific information, what the "defeat" would do in these cars. However, the relatively large difference between results for NEDC and ARTEMIS cycles gives a hint that the cars were much more "optimised" for NEDC.

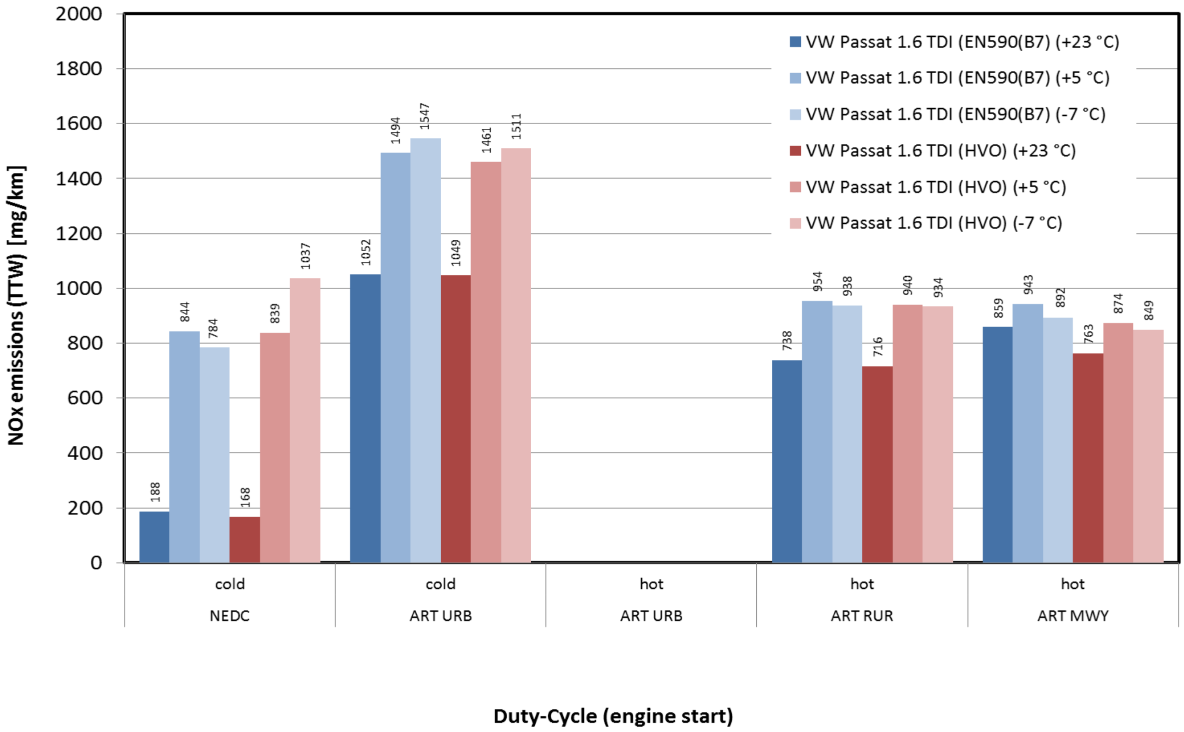


Figure 92: NOx emissions from the 1.6 TDI (CI-engine) car tested in Finland with regular EN590 diesel and fully paraffinic fuel (HVO), at +23, +5 and -7 °C ambient temperature; NEDC and ARTEMIS cycles.

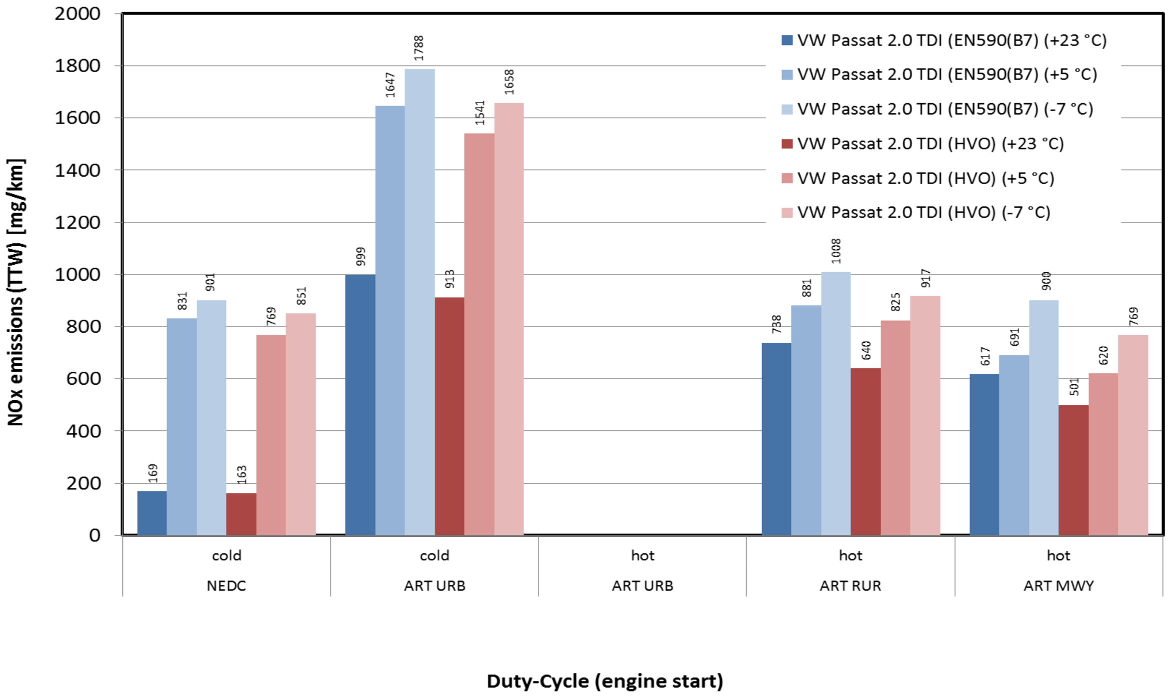


Figure 93: NOx emissions from the 2.0 TDI (CI-engine) car tested in Finland with regular EN590 diesel and fully paraffinic fuel (HVO), at +23, +5 and -7 °C ambient temperature; NEDC and ARTEMIS cycles.

Furthermore, the ambient temperature as well as fuel switch (from regular EN 590(B7) to HVO-type) was quite similar, especially in the cold-started cycles. Due to the lowering of the test temperature, emissions of NOx increased up to fourfold in both engines over NEDC cycle, but regarding ART Urban, the multiplication was only some +40 to +80 %. In the hot-started cycles the effect was even smaller. However, already at +5°C, the emissions over the cold-started cycles were highly elevated, so the temperature effect was strongly non-linear.

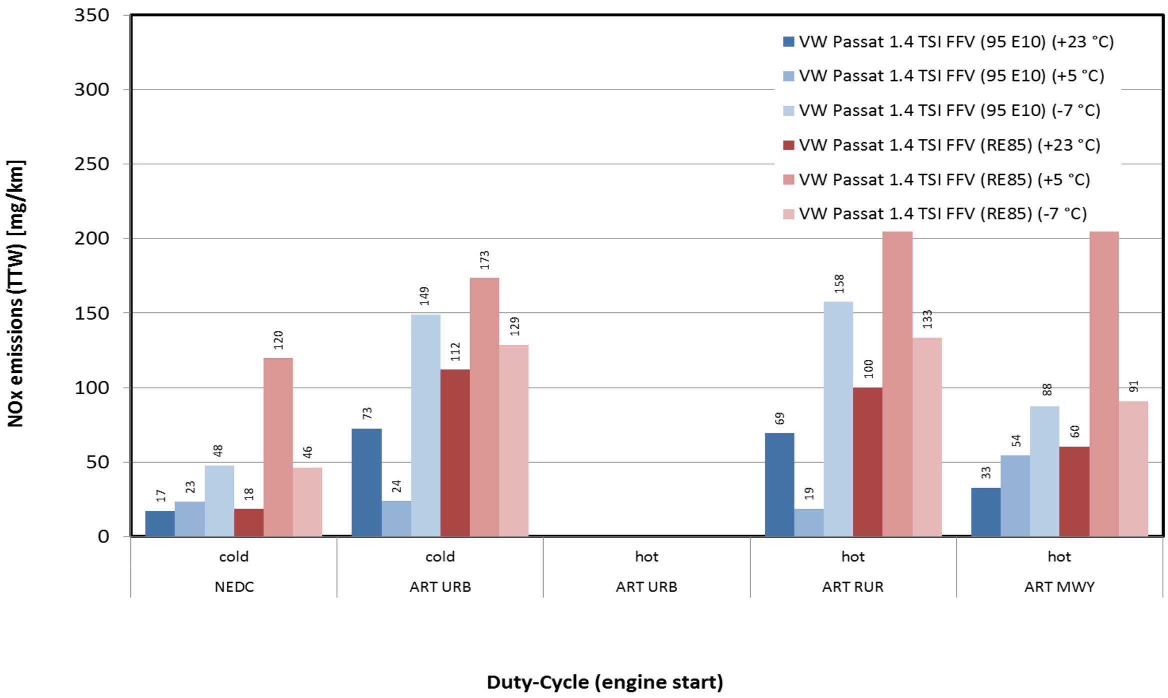


Figure 94: NOx emissions from the 1.4 TSI FFV (SI-engine) car tested in Finland with regular gasoline and with E85, at +23, +5 and -7 °C ambient temperature; NEDC and ARTEMIS cycles.

The use of HVO-type fuel with high cetane number reduced NOx-emissions overall by about 4 to 9 %, less in the smaller version, more in the larger-displacement version. The effect was stronger in the hot-started cycles than in the cold-started ones, and somewhat dependent on ambient temperature, as the reductions were larger in the normal ambient temperature tests than in the low-temperature tests.

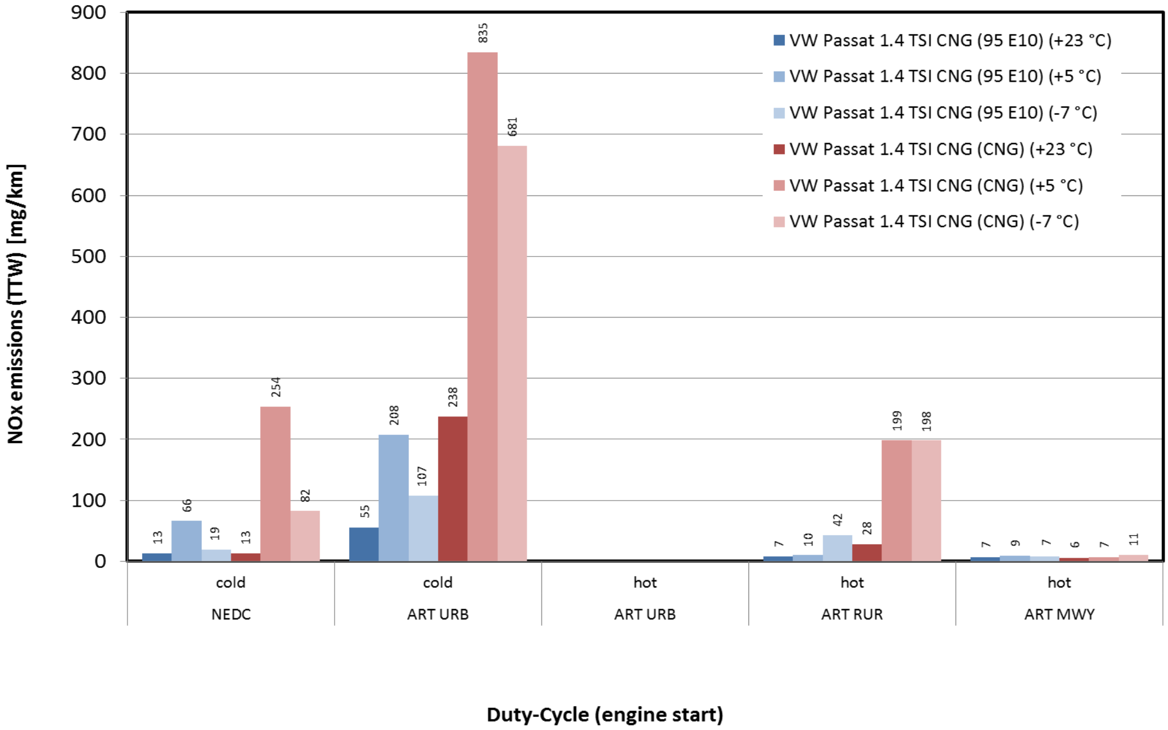


Figure 95: NOx emissions from the 1.4 TSI CNG (SI-engine) car tested in Finland with regular gasoline and CNG at +23, +5 and -7 °C ambient temperature; NEDC and ARTEMIS cycles.

In case of the alternative-fuelled engines the fuel alternatives, E85/E75 vs. regular gasoline or CNG vs. regular gasoline, were so much different that in these cases the fuel switch had more effects than the lowering of the temperature. Also, all the fuels had different responses to the ambient temperature.

Overall, the 1.4 TSI MultiFuel (Figure 94) had much lower emissions than the 1.4 TSI Eco-Fuel (CNG). The gasoline/ethanol engine emitted no more than 200 mg/km in any of the tested case, whereas the CNG-fuelled version showed abnormally high emissions (700 to 800 mg/km) over cold-started ARTEMIS Urban cycle at +5 and -7 °C ambient temperatures. In this cycle the effect was the strongest, but overall the CNG setting of the engine seemed to produce two to over fourfold emission compared to running on normal gasoline. However, in normal ambient temperature, both fuels emitted NOx at very low levels, only 13 or 18 mg/km. Quite positively, the cold-temperature calibration of this engine was far from optimum.

The results for remaining emissions are not depicted in this main part of the report, but presented in Appendix 3.

5.7 Results – U.S.A.

The test fleet in U.S. consisted of two gasoline-powered (SI-engine) vehicles, both either with an ICE only powertrain (with automatic transmission), or with an ICE-electric hybrid configuration. Gasoline was the only fuel option tested, and results submitted were limited to fuel and energy consumptions, but with multiple duty-cycles in use. All testing was done at normal ambient temperature (+23 °C).

The submitted results are depicted in Figures 96 and 97.

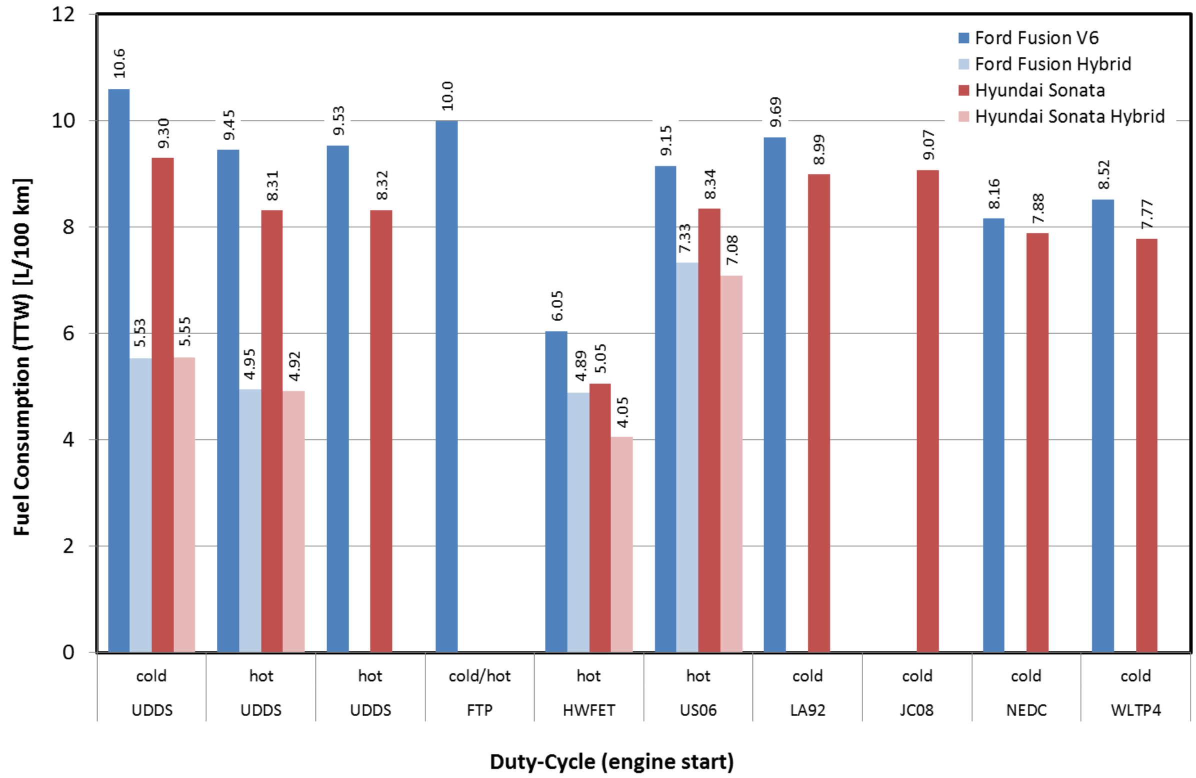


Figure 96: Fuel consumption of the two platforms of cars tested in U.S.

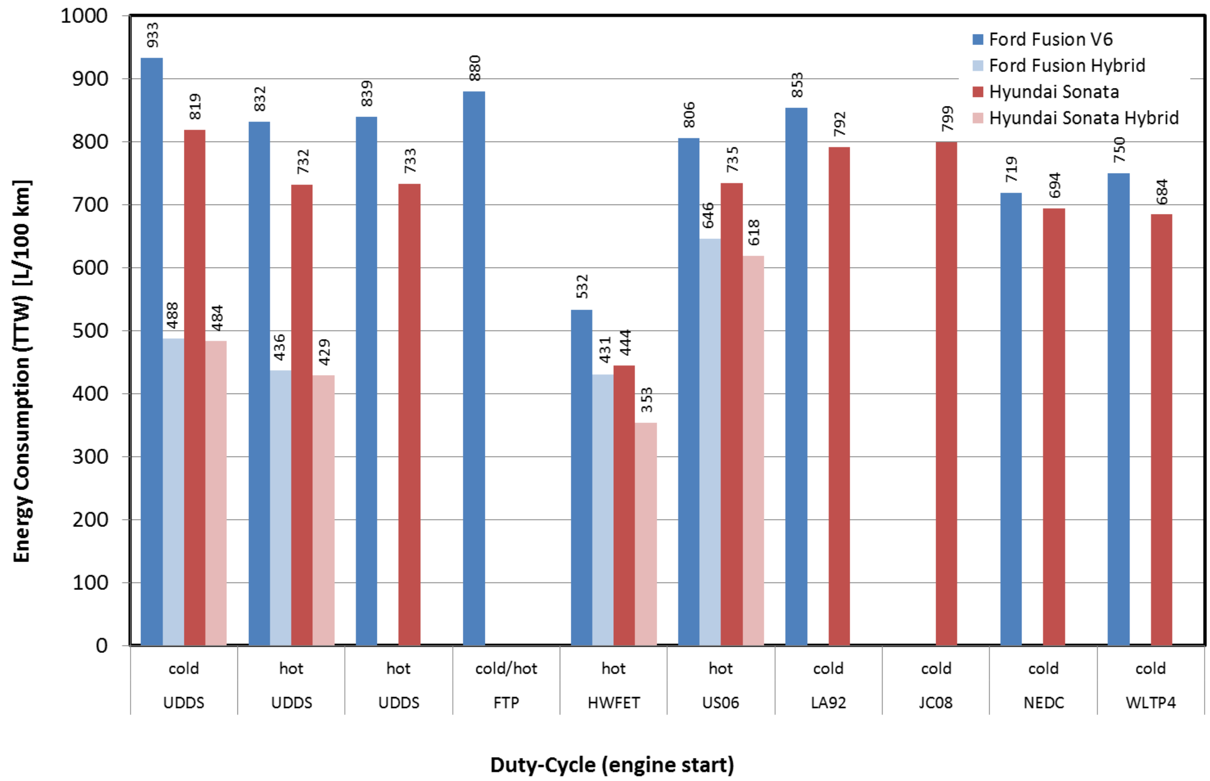


Figure 97: Energy consumption of the two platforms of cars tested in U.S.

Considering the fact that only one single fuel (gasoline) was used in all tested vehicles, in relative terms there is no difference between fuel consumption and energy use. Therefore, both are commented together.

Of the two platforms tested, the non-hybrid version of Hyundai Sonata was on average some 12 % more efficient than the other, Ford Fusion. The difference was somewhat more accentuated in urban driving cycles (+15 %) than in highway cycles (+8 %). Surprisingly, the net difference was only +4 % in NEDC, and 10 % over the new “world-harmonised” WLTP driving cycle.

When comparing both platforms as non-hybrid vs. hybrid configuration, the “hybridisation” effect was greater in the case of Ford, as in the urban driving cycles the hybrid was as much as 48 % more efficient than its non-hybrid counterpart. This difference was less, only about 20 % in the highway driving cycles. The corresponding figures for the other platform, the Hyundai Sonata, were -41 % (urban) and -18 % (highway).

In addition, we must bear in mind that both hybrid versions were about 7 % heavier than their nom-hybrid counterparts, adding to the higher apparent efficiency of the powertrain.

Even if the basic Ford Fusion was notably less efficient than the Hyundai Sonata in basic, non-hybrid configuration, the excellent hybridisation “boost” that Ford had managed to engineer in the hybrid version, it was only about 1 % less efficient in urban driving than the corresponding Hyundai Sonata hybrid. However, regarding highway driving, there was virtually no difference between these two hybrids.

6. Validation of results

All measurement results and other data in this report have been treated in "as received" condition, and each party is solely responsible for any errors and/or anomalies that it might contain. However, during the finalisation of the report, each partner had the possibility to screen the results and double-check that no apparent error should remain.

For some vehicle-related data VTT has - as the editor of the report - used other sources of information in order to fill-in some missing values e.g. describing the test vehicles. Those values that are not supplied by the participants are indicated in **red text**.

7. Synthesis of the results

The results of measurement submitted by the partners entail altogether 243 different cases, based on vehicle, engine, fuel, duty cycle and ambient temperature. Table 1 summarises the values of these key parameters.

Table 24 contains a break-down of the data, based on vehicle/fuel/engine and duty cycle to illustrate the coverage of the data. Some rare cases like FFV or CNG car on gasoline are excluded.

*Table 24: break-down of the tested cases on the basis of vehicle platform, fuel, engine type and size and duty cycle. The * denotes large vehicle platform.*

cycle	#	fuel	#	engine	displ.	FTP	JC-08	NEDC	ART Urb	ART Rural	ART Mwy
SI	41	gasoline (E0)	11	small	1.4-1.6			6			
				medium	2.0			1			
				large	>2.0	1+1*	1	1			
		gasoline (E10)	12	small	1.4-1.6			3	1	1	
				medium	2.0			2	1	1	1
				large	>2.0	1		1			
		E85	9	small	1.4			1	1	1	1
				medium	1.6			1	1	1	1
				large	6	1					
		LPG	1	medium	2.0			1			
		CNG/CBG	8	small	1.4			1	1	1	1
				medium	1.6-2.0			4			
				large	>2.0						
CI	20	diesel (B0)	3	small	1.6						
				medium	2.0						
				large	>2.0	1*	1*	1*			
		diesel (B5, B7)	9	small	1.6			2	1	1	1
				medium	2.0			1	1	1	1
				large	>2.0						
		HVO	8	small	1.6			1	1	1	1
				medium	2.0			1	1	1	1
				large	>2.0						
#	61		61			3	2	28	10	9	8

In this subdivision analysis we have identified that there were two categories of vehicle platforms: medium and large. The medium encompassed all the passenger cars plus the smallest of the LDTs tested by Canada. The large platform consisted of the two heavier LDTs. Of these 60 different cases, 40 are for SI-engine and 20 for diesel. We have also identified the engine size (displacement) as a parameter, using small/medium/large classes. The results for SI engines were representing gasoline (E0, E10), high-concentration ethanol (E85), LPG and CNG (or CBG). The diesel cases were for straight mineral-oil diesel (B0), or for small-concentration of biodiesel (B5, B7), or 100 % renewable, HVO-type of fuel.

The most common duty-cycle was NEDC with 28 cases, followed by ARTEMIS Urban, with 10 cases. The rest of the cycles were less represented.

Fuel consumption and/or CO_2 emissions were reported from all of these cases. Furthermore, the dataset contains also results for the regulated pollutants (CO, THC, NOx, and TPM) in most cases. The following tables 25 to 31 contain a summary of these results. For each pollutant, two tables are presented, one with actual emission values, and the other in relative scale, where the combination SI/E10/medium/NEDC was the reference case (=1).

In tables for absolute values, the lowest and the highest numerical value (or values) are highlighted with green and purple to help to identify the range of results. Furthermore, in the tables with relative values, the values that were lower than the reference case have a reading below 1, and those that were higher than the reference value, have a value more than 1. The extent of the deviation is also colour coded, so cases that are below the reference are shaded in green, and the larger the deviation is, the darker is the green. And the other way round: those higher-than-reference values are shaded in red, and when the deviation is 10 or more, the cell has the darkest red colour.

When assessing the figures, one should keep in mind that FTP, JC08, NEDC and ARTEMIS Urban are run with a cold start, the other ARTEMIS road cycles are with hot engine start.

Table 25: Summary of the CO emissions for different test cases.

Carbon Monoxide (CO, mg/km)					Duty Cycle					
platform	cycle	fuel	engine		FTP	JC-08	NEDC	ART Urb	ART Rural	ART Mwy
medium	SI	gasoline (E0)	small	1.4-1.6			440			
			medium	2.0		468	610			
			large	>2.0	516	956	1583			
		gasoline E10	small	1.4-1.6			622	1567	210	
			medium	2.0			374	682	485	496
			large	>2.0	526		1431			
		E85	small	1.4-1.6			240	602	205	133
			medium	2.0			373	1642	153	214
			large	6	582					
		LPG	medium	2.0		143				
		CNG/CBG	small	1.4			471	249	253	145
			medium	1.6-2.0			167			
	CI	diesel (B5, B7)	small	1.6			222	441	8	3
			medium	2.0			108	54	3	5
		HVO	small	1.6			122	135	8	4
			medium	2.0			29	26	5	5
large	SI	gasoline (E0)	large	>2.0	573					
	CI	diesel (B0)	large	>2.0	228	318	1100			

Table 26: CO emissions for different test cases, relative (SI/E10/medium/NEDC=1)

Carbon Monoxide (CO, mg/km)					Duty Cycle					
platform	cycle	fuel	engine		FTP	JC-08	NEDC	ART Urb	ART Rural	ART Mwy
medium	SI	gasoline (E0)	small	1.4-1.6			1.2			
			medium	2.0		1.3	1.6			
			large	>2.0	1.4	2.6	4.2			
		gasoline E10	small	1.4-1.6			1.7	4.2	0.6	
			medium	2.0			**1.0**	1.8	1.3	1.3
			large	>2.0	1.4		3.8			
		E85	small	1.4-1.6			0.6	1.6	0.5	0.4
			medium	2.0			1.0	4.4	0.4	0.6
			large	6	1.6					
		LPG	medium	2.0		0.4				
		CNG/CBG	small	1.4			1.3	0.7	0.7	0.4
			medium	1.6-2.0			0.4			
	CI	diesel (B5, B7)	small	1.6			0.6	1.2	0.02	0.01
			medium	2.0			0.3	0.1	0.01	0.01
		HVO	small	1.6			0.3	0.4	0.02	0.01
			medium	2.0			0.1	0.1	0.01	0.01
large	SI	gasoline (E0)	large	>2.0	1.5					
	CI	diesel (B0)	large	>2.0	0.6	0.8	2.9			

Regarding CO, large gasoline-fuelled SI engines are susceptible to high emissions, especially in cold-started cycles. Had we taken into this table also results from low ambient temperatures, the figures would have been much higher, at worst almost 10 times to these values. On the other hand, diesel engines can show extremely low CO values, below 10 mg/km, in hot-start road cycles.

Table 27: Summary of the THC emissions for different test cases.

Total Hydrocarbons (THC, mg/km)					Duty Cycle					
platform	cycle	fuel	engine		FTP	JC-08	NEDC	ART Urb	ART Rural	ART Mwy
medium	SI	gasoline (E0)	small	1.4-1.6			31			
			medium	2.0		28	63			
			large	>2.0	38	83	119			
		gasoline E10	small	1.4-1.6			47	176	14	
			medium	2.0			39	150	10	15
			large	>2.0	39		107			
		E85	small	1.4-1.6			47	112	3	2
			medium	2.0			57	198	1	4
			large	6	42					
		LPG	medium	2.0		15				
		CNG/CBG	small	1.4			70	245	15	18
			medium	1.6-2.0			49			
	CI	diesel (B5, B7)	small	1.6			22	51	5	2
			medium	2.0			23	19	4	2
		HVO	small	1.6			15	13	4	1
			medium	2.0			12	20	4	1
large	SI	gasoline (E0)	large	>2.0	30					
	CI	diesel (B0)	large	>2.0	28	29	81			

Table 28: THC emissions for different test cases, relative (SI/E10/medium/NEDC=1)

Total Hydrocarbons (THC, mg/km)					Duty Cycle					
platform	cycle	fuel	engine		FTP	JC-08	NEDC	ART Urb	ART Rural	ART Mwy
medium	SI	gasoline (E0)	small	1.4-1.6			0.8			
			medium	2.0		0.7	1.6			
			large	>2.0	1.0	2.1	3.0			
		gasoline E10	small	1.4-1.6			1.2	4.5	0.3	
			medium	2.0			**1.0**	3.8	0.2	0.2
			large	>2.0	1.0		2.7			
		E85	small	1.4-1.6			1.2	2.9	0.1	
			medium	2.0			1.4	5.0	0.0	0.1
			large	6	1.1					
		LPG	medium	2.0		0.4				
		CNG/CBG	small	1.4			1.8	6.2	0.4	0.3
			medium	1.6-2.0			1.3			
	CI	diesel (B5, B7)	small	1.6			0.6	1.3	0.1	0.03
			medium	2.0			0.6	0.5	0.1	0.03
		HVO	small	1.6			0.4	0.3	0.1	0.02
			medium	2.0			0.3	0.5	0.1	0.02
large	SI	gasoline (E0)	large	>2.0	0.8					
	CI	diesel (B0)	large	>2.0	0.7	0.7	2.1			

What comes to THC, the high-concentration ethanol fuel (E85) in SI engine gave the lowest figures in hot-start cycles, but diesel engines were also very close, all below 10 mg/km. In cold-start cycles the diesels were mostly better than E85 or gasoline. Highest reading was recorded for CNG in cold-start ARTEMIS Urban cycle, but that might be due to high methane release in cold-start.

Considering the emissions of all nitrogen oxides (NOx, Tables 29 and 30), the lowest result was for SI engine on LPG. However, gasoline SI engines were also below 10 mg/km, especially in hot-start tests. Clearly, diesel engines have high emission rates for NOx, and now high values are also recorded in hot-start tests. E85 and CNG are between these two.

Table 29: Summary of the NOx emissions for different test cases.

Oxides of Nitrogen (NOx, mg/km)					Duty Cycle					
platform	cycle	fuel	engine		FTP	JC-08	NEDC	ART Urb	ART Rural	ART Mwy
medium	SI	gasoline (E0)	small	1.4-1.6			13			
			medium	2.0		4	6			
			large	>2.0	9	14	5			
		gasoline (E10)	small	1.4-1.6			18	54	16	
			medium	2.0			18	90	8	8
			large	>2.0	12		4			
		E85	small	1.4-1.6			18	112	100	60
			medium	2.0			49	136	29	25
			large	6	7					
		LPG	medium	2.0		16				
		CNG/CBG	small	1.4			13	238	28	6
			medium	1.6-2.0			58			
	CI	diesel (B5, B7)	small	1.6			169	1052	738	859
			medium	2.0			169	999	738	617
		HVO	small	1.6			168	1049	716	763
			medium	2.0			163	913	640	501
large	SI	gasoline (E0)	large	>2.0	8					
	CI	diesel (B0)	large	>2.0	84	116	199			

Table 30: NOx emissions for different test cases, relative (SI/E10/medium/NEDC=1)

Oxides of Nitrogen (NOx, mg/km)					Duty Cycle					
platform	cycle	fuel	engine		FTP	JC-08	NEDC	ART Urb	ART Rural	ART Mwy
medium	SI	gasoline (E0)	small	1.4-1.6			0.7			
			medium	2.0		0.2	0.3			
			large	>2.0	0.5	0.8	0.3			
		gasoline (E10)	small	1.4-1.6			1.0	3.0	0.9	
			medium	2.0			**1.0**	5.0	0.4	0.5
			large	>2.0	0.7		0.2			
		E85	small	1.4-1.6			1.0	6.3	5.6	3.4
			medium	2.0			2.7	7.6	1.6	1.4
			large	6	0.4					
		LPG	medium	2.0		0.9				
		CNG/CBG	small	1.4			0.7	13.3	1.6	0.3
			medium	1.6-2.0			3.2			
	CI	diesel (B5, B7)	small	1.6			9.5			
			medium	2.0			9.4	56	41	34
		HVO	small	1.6			9.4	59	40	43
			medium	2.0			9.1	51	36	28
large	SI	gasoline (E0)	large	>2.0	0.5					
	CI	diesel (B0)	large	>2.0	4.7	6.5	11			

Table 31: Summary of the NO_2 emissions for different test cases.

Nitrogen Dioxide(NO_2, mg/km)					Duty Cycle					
platform	cycle	fuel	engine		FTP	JC-08	NEDC	ART Urb	ART Rural	ART Mwy
medium	SI	gasoline (E0)	small	1.4-1.6						
			medium	2.0						
			large	>2.0						
		gasoline E10	small	1.4-1.6			3	2		
			medium	2.0			1		1	1
			large	>2.0						
		E85	small	1.4-1.6			8	2	3	31
			medium	2.0			19	31	13	8
		LPG	medium	2.0						
		CNG/CBG	small	1.4				1	1	0
			medium	1.6-2.0						
	CI	diesel (B5, B7)	small	1.6			64	191	99	361
			medium	2.0			40	327	108	233
		HVO	small	1.6			40	300	232	323
			medium	2.0			42	226	179	197
large	SI	gasoline (E0)	large	>2.0						
	CI	diesel (B0)	large	>2.0						

Table 32: NO_2 emissions for different test cases, relative (SI/E10/medium/NEDC=1)

Nitrogen Dioxide(NO_2, mg/km)					Duty Cycle					
platform	cycle	fuel	engine		FTP	JC-08	NEDC	ART Urb	ART Rural	ART Mwy
medium	SI	gasoline (E0)	small	1.4-1.6						
			medium	2.0						
			large	>2.0						
		gasoline E10	small	1.4-1.6			2.8	1.5		
			medium	2.0			**1.0**		0.5	0.6
			large	>2.0						
		E85	small	1.4-1.6			6.7	1.4	2.6	26
			medium	2.0			16	26	11	6.4
		LPG	medium	2.0						
		CNG/CBG	small	1.4				0.9	1.1	0.2
			medium	1.6-2.0						
	CI	diesel (B5, B7)	small	1.6			54	162	84	306
			medium	2.0			34	277	92	198
		HVO	small	1.6			34	255	196	274
			medium	2.0			36	192	152	167
large	SI	gasoline (E0)	large	>2.0						
	CI	diesel (B0)	large	>2.0						

If we look at the NO_2 portion of the sum (Tables 31 and 32), which has direct negative impact on local air quality, we see that in SI engines, either with gasoline or CNG, the values are very low, below 5 mg/km in all shown cases. E85 comes close, but again, diesel engines are emitting very high amounts of NO_2, up to 300 mg/km and more, both in cold-start as well as hots-start tests.

Table 33: Summary of the TPM emissions for different test cases.

Total Particulate Mass (TPM, mg/km)					Duty Cycle					
platform	cycle	fuel	engine		FTP	JC-08	NEDC	ART Urb	ART Rural	ART Mwy
medium	SI	gasoline (E0)	small	1.4-1.6						
			medium	2.0						
			large	>2.0	0.70		0.35			
		gasoline E10	small	1.4-1.6			2.6	11.5	5.8	
			medium	2.0						
			large	>2.0	0.28		0.10			
		E85	small	1.4-1.6						
			medium	2.0			0.16	0.38	0.23	1.44
			large	6	2.25					
		LPG	medium	2.0						
		CNG/CBG	small	1.4						
			medium	1.6-2.0						
	CI	diesel (B5, B7)	small	1.6			0.28	1.03	0.30	1.30
			medium	2.0			0.18	0.51	0.54	3.04
		HVO	small	1.6			0.22	0.33	0.31	1.42
			medium	2.0			0.11	0.15	0.32	3.09
large	SI	gasoline (E0)	large	>2.0	1.9					
	CI	diesel (B0)	large	>2.0	0.4		0.80			

*Table 34: TPM emissions for different test cases, relative (SI/E10/small/NEDC=1)**

Total Particulate Mass (TPM, mg/km)					Duty Cycle					
platform	cycle	fuel	engine		FTP	JC-08	NEDC	ART Urb	ART Rural	ART Mwy
medium	SI	gasoline (E0)	small	1.4-1.6						
			medium	2.0						
			large	>2.0	0.27		0.14			
		gasoline E10	small	1.4-1.6			**1.0**	4	2	
			medium	2.0						
			large	>2.0	0.11		0.04			
		E85	small	1.4-1.6						
			medium	2.0			0.06	0.15	0.09	0.56
			large	6	0.88					
		LPG	medium	2.0						
		CNG/CBG	small	1.4						
			medium	1.6-2.0						
	CI	diesel (B5, B7)	small	1.6			0.11	0.40	0.12	0.51
			medium	2.0			0.07	0.20	0.21	1.2
		HVO	small	1.6			0.09	0.13	0.12	0.56
			medium	2.0			0.04	0.06	0.13	1.2
large	SI	gasoline (E0)	large	>2.0	1					
	CI	diesel (B0)	large	>2.0	0.14		0.31			

*In this table the reference is SI/E10/small/NEDC, because the basic reference SI/E10/medium/NEDC had no measurement value for TPM.

Regarding particulate matter (TPM, Tables 33 and 34), the overall image has changed since diesels became fitted with diesel particulate filters (DPF). DPF reduces particulates very efficiently, and thus SI-engines, in particular those of direct-injection GDI-type (SIDI), emit now more particulates, especially in cold-start occasions. Therefore, since Euro 6c level, the European emissions legislation is setting a limit value for SIDI engines, but it is a number-based standard (PN#), and not PM. Similar restriction is also applied to CI engines.

The reference case in Table 34 was the small SI-engine, as the medium SI-engine by a mis-hap with instrumentation lacked the particulate measurement value. We foresee, though, that the TPM level would be at the same level, as both the small and the medium SI engines were of GDI type.

Thus, the level of the particulates from the small SI-engine were the highest of all cases, es-pecially in the cold-start ARTEMIS Urban cycle. This level was about 10 to 60 times higher than the levels of TPM from CI-engines, and also about 25 times higher than the level of TPM from the large SI engine that was of conventional port fuel injection (PFI) type, that is less prone to particulate emissions.

Table 35: Summary of the CO_2 emissions for different test cases.

Carbon Dioxide (CO_2, g/km)					Duty Cycle					
platform	cycle	fuel	engine		FTP	JC-08	NEDC	ART Urb	ART Rural	ART Mwy
medium	SI	gasoline (E0)	small	1.4-1.6			157			
			medium	2.0		189	189			
			large	>2.0	280	341	312			
		gasoline E10	small	1.4-1.6			167	262	129	
			medium	2.0			189	336	151	164
			large	>2.0	298		345			
		E85	small	1.4-1.6			158	261	129	148
			medium	2.0			192	318	153	178
			large	6	443					
		LPG	medium	2.0		180				
		CNG/CBG	small	1.4			121	208	96	109
			medium	1.6-2.0			125			
	CI	diesel (B5, B7)	small	1.6			126	234	108	124
			medium	2.0			160	280	128	148
		HVO	small	1.6			131	223	104	119
			medium	2.0			152	271	119	140
large	SI	gasoline (E0)	large	>2.0	481					
	CI	diesel (B0)	large	>2.0	533	557	542			

Table 36: CO_2 emissions for different test cases, relative (SI/E10/medium/NEDC=1)

Carbon Dioxide (CO_2, g/km)					Duty Cycle					
platform	cycle	fuel	engine		FTP	JC-08	NEDC	ART Urb	ART Rural	ART Mwy
medium	SI	gasoline (E0)	small	1.4-1.6			0.83			
			medium	2.0		1.0	1.0			
			large	>2.0	1.5	1.8	1.6			
		gasoline E10	small	1.4-1.6			0.88	1.4	0.68	
			medium	2.0			**1.0**	1.8	0.80	0.86
			large	>2.0	1.6		1.8			
		E85	small	1.4-1.6			0.8	1.4	0.7	0.8
			medium	2.0			1.0	1.7	0.8	0.9
			large	6	2.3					
		LPG	medium	2.0		0.95				
		CNG/CBG	small	1.4			0.64	1.1	0.51	0.58
			medium	1.6-2.0			0.66			
	CI	diesel (B5, B7)	small	1.6			0.67	1.2	0.57	0.66
			medium	2.0			0.84	1.5	0.67	0.78
		HVO	small	1.6			0.69	1.2	0.55	0.63
			medium	2.0			0.80	1.4	0.63	0.74
large	SI	gasoline (E0)	large	>2.0	2.5					
	CI	diesel (B0)	large	>2.0	2.8	2.9	2.9			

Tailpipe CO_2 emissions are directly proportional to fuel consumption, but the carbon contents of the fuel sets the ratio. According to the synthesis in Table 35, in all tested cases here, the highest reported CO_2 was measured for the large LDT with gasoline SI-engine. On the contrary: the lowest value was associated with a small CNG engine in rural driving. Due to the advantageous C to H ratio, it outperformed even the small diesel. However, if we only take into account the energy use, a small diesel is the best, and a large gasoline-SI the worst. In this comparison the range is about 1 to 5, between the lowest and the highest readings.

Table 37: Summary of the energy use results for different test cases.

Energy Use (Wh/100 km)					Duty Cycle					
platform	cycle	fuel	engine		FTP	JC-08	NEDC	ART Urb	ART Rural	ART Mwy
medium	SI	gasoline (E0)	small	1.4-1.6			575			
			medium	2.0		736	688			
			large	>2.0	1066	1296	1193			
		gasoline E10	small	1.4-1.6			615	962	470	
			medium	2.0			709	1281	575	624
			large	>2.0	1127		1171			
		E85	small	1.4-1.6			610	1009	498	571
			medium	2.0			766	1273	608	705
			large	6	1704					
		LPG	medium	2.0		759				
		CNG/CBG	small	1.4			610	1057	489	553
			medium	1.6-2.0			506			
	CI	diesel (B5, B7)	small	1.6			480	899	412	475
			medium	2.0			610	1071	489	567
		HVO	small	1.6			480	819	382	435
			medium	2.0			560	991	437	512
	EL	electricity	small				145			
			medium				198	300	199	268
large	SI	gasoline (E0)	large	>2.0	1819					
	CI	diesel (B0)	large	>2.0	1961	2077	2023			

Table 38: Energy use for different test cases, relative (SI/E10/medium/NEDC =1)

Energy Use (Wh/100 km)					Duty Cycle					
platform	cycle	fuel	engine		FTP	JC-08	NEDC	ART Urb	ART Rural	ART Mwy
medium	SI	gasoline (E0)	small	1.4-1.6			0.81			
			medium	2.0		1.0	1.0			
			large	>2.0	1.5	1.8	1.7			
		gasoline E10	small	1.4-1.6			0.87	1.4	0.66	
			medium	2.0			**1.0**	1.8	0.81	0.88
			large	>2.0	1.6		1.7			
		E85	small	1.4-1.6			0.86	1.42	0.70	0.81
			medium	2.0			1.08	1.80	0.86	0.99
			large	6	2.4					
		LPG	medium	2.0		1.1				
		CNG/CBG	small	1.4			0.86	1.5	0.69	0.78
			medium	1.6-2.0			0.71			
	CI	diesel (B5, B7)	small	1.6			0.68	1.3	0.58	0.67
			medium	2.0			0.86	1.5	0.69	0.80
		HVO	small	1.6			0.68	1.2	0.54	0.61
			medium	2.0			0.79	1.4	0.62	0.72
	EL	electricity	small				0.20			
			medium				0.28	0.42	0.28	0.38
large	SI	gasoline (E0)	large	>2.0	2.6					
	CI	diesel (B0)	large	>2.0	2.8	2.9	2.9			

Table 37 summarises the energy use for various tested options. In this table we have also the electric-powered options (highlighted in blue), and clearly they outperform even the best ICEs by “a country mile”, as their net energy use was only some 30 % in the urban cycles and some 40 to 50 % in the road cycles of the figures for comparable diesels. However, this comparison is not all “fair”, because we need to take into account the energy use and emissions of electric generation. This question is further discussed in the next chapter, dealing with “well-to-tank” (WTT), “tank-to-wheels” (TTW) and well-to-wheels” (WTW) analysis.

With argument we can claim that in a way NOx and CO_2 are the “most critical emissions”, as by large the air quality problems are in some way or another associated with high NOx emissions, either directly (high ambient NO_2 concentrations) or indirectly (high ground-level ozone concentrations, due to atmospheric chemistry reactions with HC). Furthermore, CO_2 is regarded as the primary greenhouse gas that needs to be abated. Therefore, we have made a graph NO_X vs. CO_2, shown as Figure 98.

This Figure clearly shows the distinct difference between SI and CI engines, as the NOx levels for CI-cases were all manifold compared to the SI-engine cases. Also the typical range for CO_2 was not so much different between CI and SI, if we exclude the large platform cases. In the mid-sized platform cases CO_2 was between 115 and 160 g/km for CI, but from 140 to 193 g/km for SI/gasoline, and between 120 and 161 g/km for SI/CNG -cases. Thus we can say that the lower CO_2 emissions usually associated with CI-engines come with a “high price”, as the higher NOx (and especially NO_2) emissions are a definitive drawback.

However, we need to bear in mind that all of the tested cars represented Euro 5 or equivalent emissions levels, and the latest Euro 6 (and especially U.S. Tier 3/Californian LEV III) impose much stricter control to NOx emissions. Therefore, this statement may not be as strong anymore in the future. This belief is corroborated with the result from an early Euro 6 homologated VW Passat 2.0 TDI with SCR-type of emission control tested in another (public) project at VTT. Its NOx value (70 mg/km is much closer to the cluster of the SI-engine cars. Nevertheless, based on results published for Euro 5 and Euro 6 cars, we believe that there will still be a noteworthy disparity between these basic concepts regarding NOx emissions.

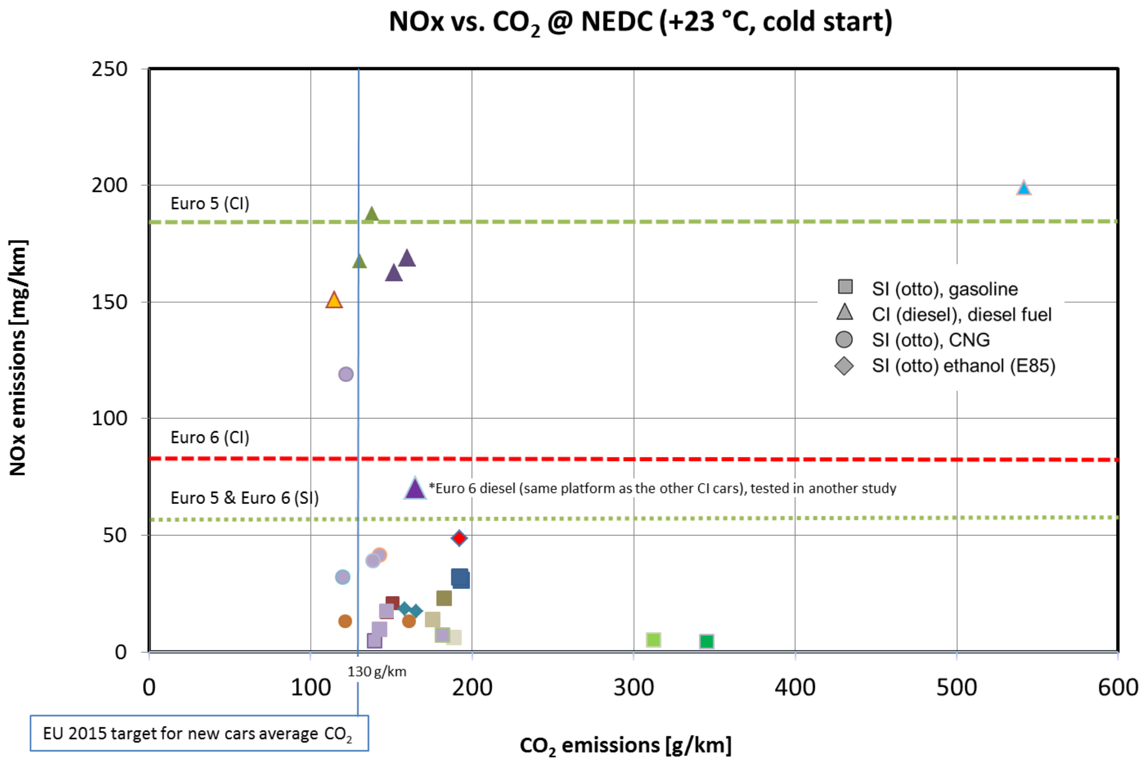


*Figure 98: NOx vs. CO_2 emissions for the cases tested over NEDC cycle at normal ambient temperature (+23 °C). *Denotes an EU 6 car that was tested in another study, but added as a reference.*

8. Full Fuel Cycle Data for Different Passenger Vehicles

One of the main objectives of this study was to perform a balanced and transparent "tank-to-wheels" (TTW) analysis of different passenger vehicle options regarding powerplant and energy. When this is combined with the data found in literature on "well-to-tank" (WTT) figures, we are able to calculate aggregated "well-to-wheels" (WTW) figures that represent co called "full fuel cycle" of each option. This chapter summarises the outcome of this type of analysis.

Table 39 summarises the "tank-to-wheels" (TTW) portion of the assessment. It is taken from the best available source, the "Well-to-Tank Report" Version 4.a, JEC Well-To-Wheels Analysis, (Report EUR 26237 EN - 2014), released in April, 2014 /1/. This study is very extensive about different fuel production and pathway options, but in this context we have chosen only a few examples representing "best" and "worst" cases. In case of fossil fuels, an average figure is reported, as in this source study.

Table 39: "Well-to-tank" (WTT) energy use and CO_2 emissions of fuels used in this study.

Engine	Fuel	case	Energy expended (MJ/MJ final fuel)	WTT GHG emitted (gCO2eq/MJ final fuel)
SI	E0	avg	0.18	13.8
	E10	best	0.26	13.7
		worst	0.29	15.8
	E85	best	1.08	12.9
		worst	1.40	36.8
	LPG	avg	0.12	8.0
	CNG	best	0.1	7.8
		worst	0.29	22.6
	CBG	best	2.01	16.0
		worst	1.28	39.0
CI	B0	avg	0.2	15.4
	B5,B7	best	0.21	15.3
		worst	0.26	17.7
	HVO	best	0.16	12.4
		worst	1.12	44.0
EL	EL	best	0.12	0.0
		EU, avg	2.07	141
		worst	1.81	292

Source: JRC Study, Report EUR 26237 EN - 2014

We can then use energy consumption figures measured to calculate "Well-to-tank" (WTT) CO_2 emissions for each of our study case. The results of this calculation are presented in Table 40, both for the "best" and the "worst" fuel pathway cases.

After this we can combine the "Well-to-tank" (WTT) fuel emissions with the "tank-to-wheels" (TTW) results, and the outcome will be the full "well-to-wheels" (WTW) figures. When combining the WTT and TTW, we have used the measured TTW CO_2, but for fuels containing renewable biocomponent (E5, E10, E85, CBG, HVO) we have assumed their combustion to be carbon-neutral (i.e. zero), for the part of the biocomponent. Therefore, in the case of E85, we have used measured TTW CO_2, but multiplied it by 0.15, corresponding the 15% part of fossil fuel. In addition CBG and HVO are considered fully renewable with zero TTW emissions.

Table 40: "Well-to-tank" (WTT) CO_2 emissions for the "best" and the "worst" fuel pathway cases relevant to this study.

				WTT GHG emitted (gCO2eq) (best)				WTT GHG emitted (gCO2eq) (worst)			
platform	cycle	fuel	engine	FTP	JC-08	NEDC	ART Urb	FTP	JC-08	NEDC	ART Urb
medium	SI	gasoline (E0)	small			29.3				29.3	
			medium		37.7	34.2			37.7	34.2	
			large	53.0	64.4	59.3		53.0	64.4	59.3	
		gasoline (E10)	small			30.4	47.5			35.0	54.6
			medium			35.0	63.3			40.3	72.8
			large			57.8				66.5	
		E85	small			28.2	46.7			80.8	
			medium			35.4	58.9			101.5	
			large	78.8				225.8			
		LPG	medium		21.2	14.6			21.2	14.6	
		CNG	small			17.1	29.7			49.6	86.0
			medium			14.2				29.1	
		CBG	small			17.1	29.7			49.6	86.0
			medium			14.2				29.1	
	CI	diesel (B5, B7)	small			26.4	37.5			30.6	53.6
			medium			33.6	47.8			39.0	68.4
		HVO	small			21.4	36.6			76.0	129.8
			medium			25.0	44.3			88.7	157.0
large	SI	gasoline (E0)	large	90.4				90.4			
	CI	diesel (B0)	large	108.7	115.1	112.2		108.7	115.1	112.2	

Table 41 shows the outcome of this aggregation. Again, separate values are for the "best" and the "worst" fuel pathway cases.

Table 41: Combined "Well-to-wheels" (WTW) CO_2 emissions for the "best" and the "worst" fuel pathway cases relevant to this study.

				TOTAL CO_2 (g/km) (best fuel)				TOTAL CO_2 (g/km) (worst fuel)			
platform	cycle	fuel	engine	FTP	JC-08	NEDC	ART Urb	FTP	JC-08	NEDC	ART Urb
medium	SI	gasoline (E0)	small			191				191	
			medium		226	223			226	223	
			large	333	405	371		333	405	371	
		gasoline (E10)	small			181	283			185	290
			medium			205	366			211	376
			large			368				377	
		E85	small			52	86			105	39
			medium			64	107			130	48
			large	145				292			
		LPG	medium		202				202		
		CNG	small			138	238			171	294
			medium			139				154	
		CBG	small			35	61			86	148
			medium			29				71	
	CI	diesel (B5, B7)	small			147	246			151	263
			medium			186	313			191	334
		HVO	small			21	37			76	130
			medium			25	44			89	157
	EL	electricity (combustion)	small			74				153	
			medium			101	152			209	316
large	SI	gasol (E0)	large	572				572			
	CI	diesel (B0)	large	641	672	654		641	672	654	

NB: for electricity the best case is of course fully renewable, carbon free electricity with (close to) zero CO_2 emissions. Therefore, we have chosen to use EU28 average values for electricity "best" case, values with blue shading.

Considering the figures in Table 41, we can conclude that with the average emissions for electricity production, electricity can deliver low-carbon emissions that are about 50 to 60 % lower than with gasoline, about 50 % lower than comparable diesels and 30 to 50 % lower than CNG-fuelled cars. Additionally, using CBG (compressed biogas) instead can further reduce carbon emissions. Furthermore, for CI engines HVO type of fuels offer considerable reductions to fossil carbon emissions, especially if the raw materials are side-streams or waste from various industries. At best the emissions are the lowest for the non-electric options, and at worst about equal to CBG or combustion-based electricity, bettering also the high-concentration ethanol (E85).

The complete dataset for NEDC cycle that was most relevant common cycle is depicted in Figure 99. However, as LPG was tested only using the Japanese JC-08 cycle, we chose to use it for the sake of complicity Aggregated values are presented for the “best” and the ”worst” fuel pathways. The part of emission reduction that is due to the use of renewable fuel (or fuel component) is denoted separately.

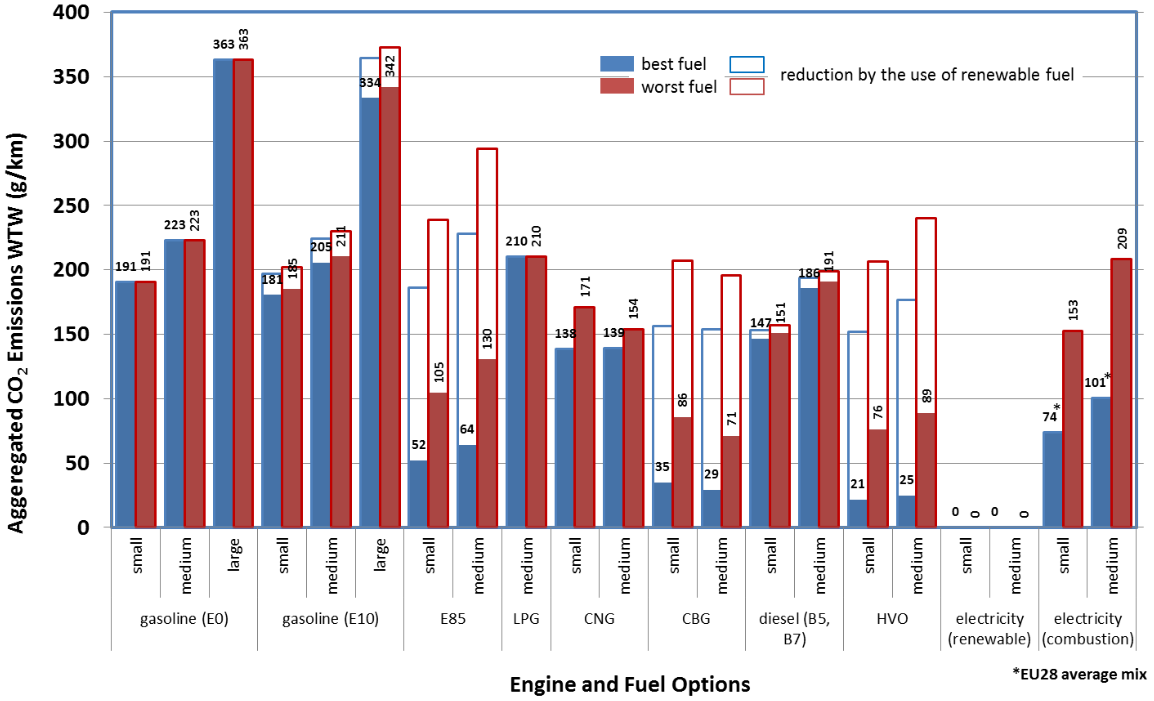


Figure 99. Aggregated well-to-wheels (WTW) CO_2 values for the “best” and the ”worst” fuel pathways.

9. Summary and Conclusions

The results of the study clearly indicate that there is no single solution that could solve all the challenges of road transport. Instead, the tested fuel and powertrain alternatives seem to have pros and cons depending on target-setting and the operating environment. Today the most common target is to reduce CO_2 emissions, but despite stringent emission control legislation, the alternatives still differ from each other in terms of local emissions implicating to air quality. Furthermore, energy use and CO_2, as well as emissions of harmful components seemed to suffer from lowering of the ambient temperature, but the options had different multiplication factors. Therefore, the best suitable option seems to vary with driving conditions and user needs.

In trying to look all options from as many standpoints and perspectives as possible, but without overcomplicating the analysis, we have come up with a scoring scheme with five (5) dimensions, those being 1) energy efficiency, 2) well-to-wheel (WTW) CO_2 emissions, 3) (harmful) local exhaust emissions, 4) sensitivity to cold ambient temperatures and 5) driving range with one fill-up of fuel/energy. In each dimension the best alternative gets a score of 5 and the rest are adjusted to this according to their relative values against the best option.

In this exercise, the values used for the options are those presented in Tables 25, 27, 29, 31, 33, 35 and 37, but only using data from NEDC, because that was the only cycle that was adequately populated with cases. When scoring the WTW CO_2 emissions, calculated to include both upstream (WTT) and downstream (TTW) portions, the average of the best and the worst options for each option was used (see Table 41). Furthermore, we have also assumed that if renewable biomass was used as raw material, the resulting CO_2 can be counted as zero for the share of the renewable energy.

For energy efficiency the measured values were used as such, but for the ambient temperature sensitivity, a “good engineering judgement” was used to rate the alternatives. Scoring for range was also somewhat simplified, and not directly based on any data in this study.

Tables 42, 43, 44, 45 and 46 present the scoring we have given to the options regarding each of the above-mentioned dimensions.

Table 42: Scoring of the energy efficiency.

type	Fuel alternative	Energy efficiency	
	weighting %	5 25 %	Score
SI	gasoline (E0)		1.2
	gasoline (E10)		1.1
	E85		1.2
	LPG		1.1
	methane (CNG)		1.5
	biomethane (CBG)		1.5
CI	diesel (B5, B7)		1.5
	HVO		1.7
EL	EU28 average		5.0
	fully renewable		5.0

Regarding Table 42 for **energy efficiency**, based on the measured energy use electric vehicle was clearly the most efficient option for various driving conditions, but they suffer from limited driving range due to the immatureness of the present-day battery technology. It goes without saying that the production type of electricity is not accounted, so regardless of the source of power, an equal rating is used, as we consider only the TTW part of the energy use. When we gave the energy consumption rate of electricity a relative value of 5, all ICE options fell between 1.1 and 1.7, where the lowest score was for SI/gasoline (or SI/LPG), and highest for CI/HVO. The SI/CNG or SI/CBG scored 1.5, but SI/E85 only 1.2.

If we then consider Table 43 for **<u>WTW CO_2 emissions</u>**, calculated to include both upstream (WTT) and downstream (TTW) portions, the best option was electricity, with zero carbon emissions, but the next-best was CI/HVO with a score of 4.0, closely followed by SI/CBG at 3.9, whereas both EU28 average electricity and SI/E85 yielded to the same level of 3.3. Fossil methane in SI-engine scored at 2.1, and CI with B7 fuel at 1.7, whereas SI/LPG and SI/gasoline options fell below 1.

Table 43: Scoring of the full fuel cycle (well-to-wheels) CO_2 emissions.

type	Fuel alternative	WTW CO_2	
	weighting %	5 25 %	Score
SI	gasoline (E0)		0.0
	gasoline (E10)		0.3
	E85		3.3
	LPG		0.9
	methane (CNG)		2.1
	biomethane (CBG)		3.9
CI	diesel (B5, B7)		1.7
	HVO		4.0
EL	EU28 average		3.3
	fully renewable		5.0

Because electricity can also be at best totally carbon-free, we have chosen to use for electricity both a zero-emission value as well as the EU28 average containing somewhat over 50% of combustion-based production as references. We feel that this is the most honest way of comparing the options. The scores are then calculated so that the best option (zero carbon emissions) got 5, the worst option was given the score of 0, and intermediate values were calculated based on their aggregated CO_2 value. Then, e.g. the best combustion based option CI/HVO with 53 g/km CO_2 got 4.0, and electricity with EU28 average carbon footprint (equalling 87 g/km CO_2) scores at 3.3.

For **<u>exhaust emissions,</u>** presented in Table 44, we have made a combined score, calculated as a composite of five emissions, being CO, THC, NOx, PM and non-reg pollutants, where each option was first scored component by component, and then a composite score was calculated, using weighting factors to reflect the importance of each pollutant in the composite. Such a weighting was chosen that NOx and TPM had the highest rank (5), followed by non-regs (3), THC (2), and finally CO (1). In calculating the individual ranks, each pollutant was scored so that the best option got a score of five (5), and the others got a proportional score according to the values of their respective composite score.

As Table 44 shows, CI/HVO had the highest score, 3.3, mainly due its good performance in lower-than regular PM, as well as CO and THC emissions. Due to low NOx, SI/Gasoline or SI/LPG became next, but in this comparison the methane-fuelled options (CNG or CBG) were the least successful. However, due to the fact that this analysis was based on the results of a limited number of vehicles, this may reflect more the performance and adaptation of the given engines – all not perhaps fully optimised for CNG - rather than the overall performance of methane fuel.

Table 44: Scoring of exhaust emissions and composite score.

type	fuel alternative		Emissions of CO	Emissions of THC	Emissions of NOx	Emissions of PM	Emissions of non-reg	emissions composite score	
		rank	1	2	5	5	3		
		weight	0.31	0.63	1.56	1.56	0.94	5	
		%	6 %	13 %	31 %	31 %	19 %	100 %	5
SI	gasoline (E0)								2.8
SI	gasoline (E10)								2.6
SI	E85								2.7
SI	LPG								2.8
SI	CNG								2.1
SI	CBG								2.1
CI	diesel (B5, B7)								2.4
CI	HVO								3.3
EL	EL		n/a	n/a	n/a	n/a	n/a	n/a	n/a

According to Table 45, the highest rank on (in)sensitivity to **cold ambient conditions** was awarded to engines using CNG or CBG, as they suffer less from the lowering of the temperature. LPG was given a lower score, because it consists of gases having higher boiling points than methane. Normal diesel was considered equal, but HVO has very good cold properties, hence the 0.5 addition. The score for electricity should be high, because electric motors do not suffer from cold conditions practically at all. However, we have also taken into consideration the fact that due to the increase in driving resistances with falling temperature, electric cars suffer as much as the regular cars, and shortening of the range is inevitable. Furthermore, cold ambient conditions call for cabin heating and ventilation, and this may have even stronger negative impact on range. In this respect the ICE powerplants have an upper hand, due to the surplus heat provided by the recovery of heat losses in the combustion process.

Table 45: Scoring of sensitivity to cold ambient temperatures.

type	Fuel alternative	Cold ambient	
	weighting	3	Score
	%	15 %	
SI	gasoline (E0)		2.5
SI	gasoline (E10)		2.5
SI	E85		1.0
SI	LPG		3.0
SI	methane (CNG)		4.5
SI	biomethane (CBG)		4.5
CI	diesel (B5, B7)		3.0
CI	HVO		3.5
EL	EU28 average		3.0
EL	fully renewable		3.0

Based on the tests at -7 °C, the option that was most heavily affected was high concentration ethanol (E85). Due to the high demand of temperature and energy for evaporation, ethanol suffers from lowering of the cold-start temperature. Therefore, the concentration of ethanol is usually adjusted to a lower level during the cold months.

The last dimension in our assessment was **driving range**, presented in Table 46, which was taken in to reflect the differences in energy density of the fuels and their respective storages.

In practice a normal diesel car with a ca. 60 litre fuel tank can be driven around 1000 km with one fill-up, and a gasoline-fuelled one about 850 km. Due to the lower energy density of the ethanol, an FFV with similar fuel tank capacity, using E85 has a range of 650 km. So, in practice all the liquid fuels offer sufficient range, because even at worst the range is far longer than a normal driver is willing to drive non-stop. However, longer range is more of a "comfort feature", as frequent fill-ups can be considered as a nuisance.

In some sense this score also adjusts to the availability of the fuel and coverage of the refuelling infrastructure. Therefore, we have given bio-methane (CBG) a slightly lower score than for fossil methane, as the bio-option is not always available. The same applies to LPG, which is usually linked with areas of strong presence by petroleum industry, and has not a continent-wide supply chain. We have penalised also E85 with a 0.25 score reduction due to the fact that this fuel is not found everywhere, even in countries where it is available.

In this dimension, electricity is by far the "underdog", because of the immature battery technology, short driving range is a problem as least for a while, and 200 km can be considered as typical value for today's offerings that is available in most climatic conditions. The score will then be 1.0 in this scale. In the future we can expect the range to be longer, but still the long recharging time required to replenish the energy storage remains.

Table 46: Scoring of driving range on one fill-up or full charge.

type	Fuel alternative	Driving range	
	weighting %	2 10 %	Score
SI	gasoline (E0)		4.3
	gasoline (E10)		4.3
	E85		3.0
	LPG		1.8
	methane (CNG)		2.0
	biomethane (CBG)		1.8
CI	diesel (B5, B7)		5.0
	HVO		5.0
EL	EU28 average		1.0
	fully renewable		1.0

When compiling the **combined score** based on these five dimensions, we have assumed also a weighting. The score for energy efficiency, WTW CO_2 and exhaust emissions (composite value) are all 20% each of the combined score. The remaining 20 % was divided between the sensitivity cold ambient temperature (12 %) and driving range (8 %). In case of electricity, in cases that were not directly applicable to this form of energy (i.e. CO_2 and exhaust emissions), we assumed the score to be 5. Regarding total WTW CO_2 we must, however, bear in mind that even if there is no emissions while driving, the well-to-wheel CO_2 emissions of electric vehicles appear to be most sensitive to the upstream energy production among the available powertrain options. Therefore, the score for non-renewable electricity is lower, reflecting the true WTW CO_2 levels presented in Tables 41 and 43.

Table 47 presents the final outcome of this synthesis and analysis.

Table 47: Synthesis and scoring of the options.

type	Fuel alternative	Energy efficiency	WTW CO_2	Exhaust emissions	Cold ambient	Driving range	Combined score	
	weighting	5	5	5	3	2		20
	%	25 %	25 %	25 %	15 %	10 %		100 %
SI	gasoline (E0)							1.8
	gasoline (E10)							1.8
	E85							2.3
	LPG							1.9
	methane (CNG)							2.3
	biomethane (CBG)							2.8
CI	diesel (B5, B7)							2.4
	HVO							3.3
EL	EU28 average			n/a				3.9
	fully renewable							4.3

Based on the combined score, electric vehicle powered with carbon-free electricity seemed to be the overall winner, with a score of 4.3. A few notches lower is an electric car running on electricity having the average EU28 carbon footprint (score=3.9). However, the best ICE was CI-engine with HVO-type of fuel with a score of 3.3, closely followed by SI/CBG at 2.8 and SI/CNG at 2.3. The SI/E85 option scored also 2.3. Furthermore, the score for CI/B7 was slightly better (2.4), but SI/gasoline and SI/LPG options were all at the low end with scores of 1.8 to 1.9.

Furthermore, when addressing the effect of fuel quality we can see that for SI/gasoline, there was no apparent difference between E0 and E10, but E85 had some 25% better score, mainly due to the low carbon emissions provided by the high amount of renewable component. The same way using renewable bio-methane (CBG) instead of fossil-only methane CNG, the score was improved by nearly 20%. Even greater impact was seen in CI, where the HVO option scored 37% higher than the regular B7 diesel quality. Even the type of electricity generation has an impact to the score of the electric vehicle, as with fully carbon-free electricity the combined score was 10% better for fully renewable, zero-emission electricity compared to EU28-mix with carbon emissions.

This gives us rights to claim that **use of more sophisticated fuels may still be well justified**, not only as they help to reduce tailpipe emissions even from all traditional vehicles, in spite of effective emission control technology employed in all cars, but fuels with high amounts of renewable contents also help to reduce well-to-wheel (WTW) CO_2 emissions in a meaningful way.

However, it is fair to mention that since the technology in this study was limited to Euro 5, the newest and most stringent Euro 6 level may change this claim, at least somewhat.

References

/1/ Well-to-Tank Report" Version 4.a, JEC Well-To-Wheels Analysis, (Report EUR 26237 EN-2014), released in April, 2014

Publications

The following publication is based on the data of the Finnish study:

Nuottimäki, Jukka; Laurikko, Juhani; Nylund, Nils-Olof, Performance Evaluation Of Passenger Car, Fuel And Powerplant Options. Paper F2014-CET-040, Proc. of 2014 FISITA World Automotive Congress, Maastricht, Belgium, June 2014, 9 pages.

Appendices

Appendix 1	Graphs of duty-cycles used in this study
Appendix 2	Summary of results [Tables per pollutant, divided to vehicle, fuel, test cycle, ambient temperature]
Appendix 3	Additional graphs of results from testing in Finland.

In the Following figures, driving cycles used in this investigation are depicted.

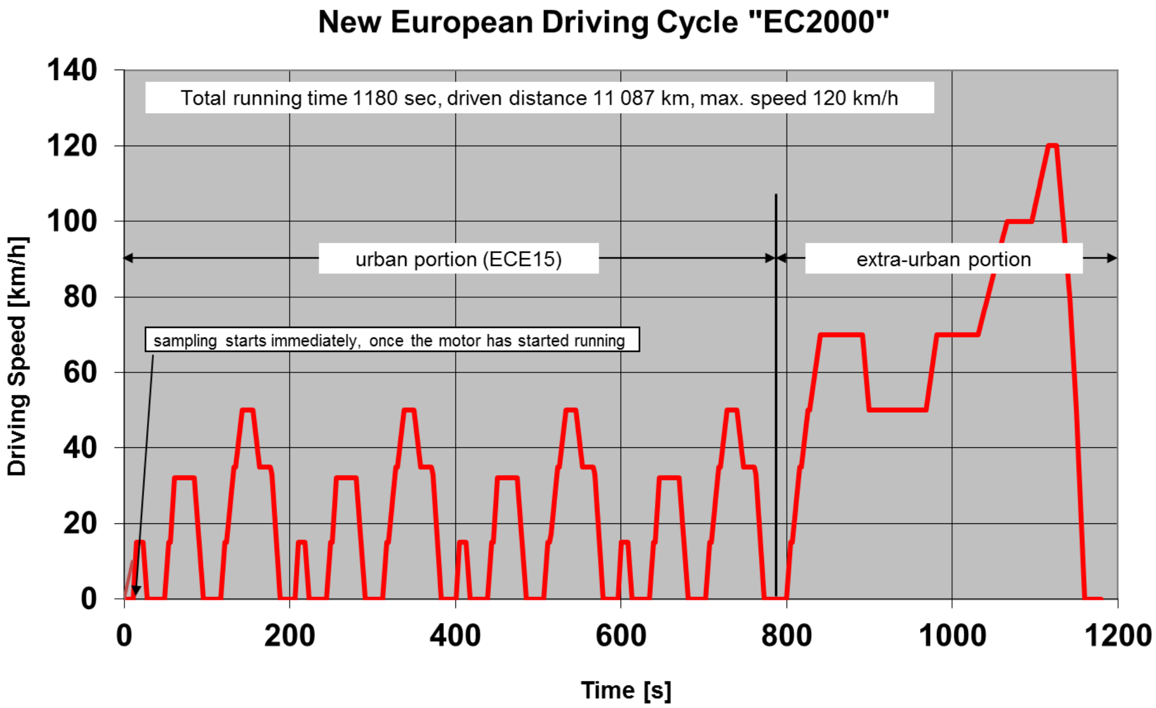


Figure 1-1: European type approval cycle (NEDC, Euro3 version, no pre-sampling idle)

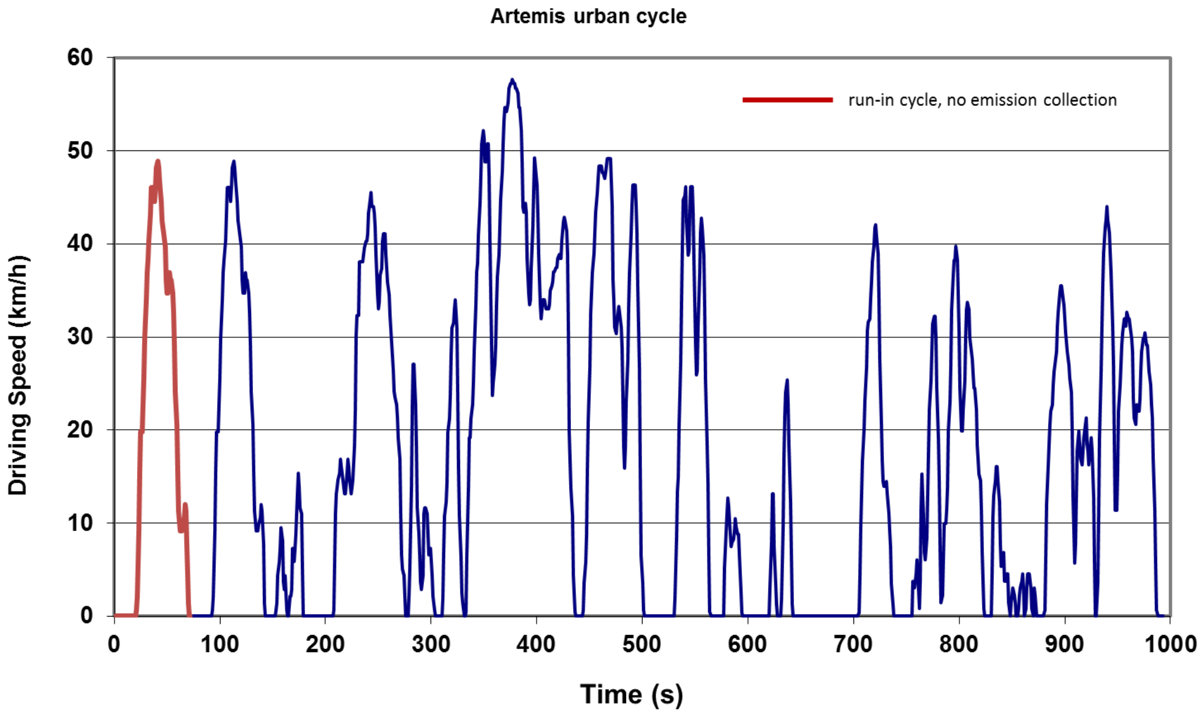


Figure 1-2: ARTEMIS Urban cycle (ART URB, with a 72 sec run-in cycle without sampling). Total duration 993 sec, total driven distance 4.87 km (4.47 km in bag), average speed 17.6 km/h.

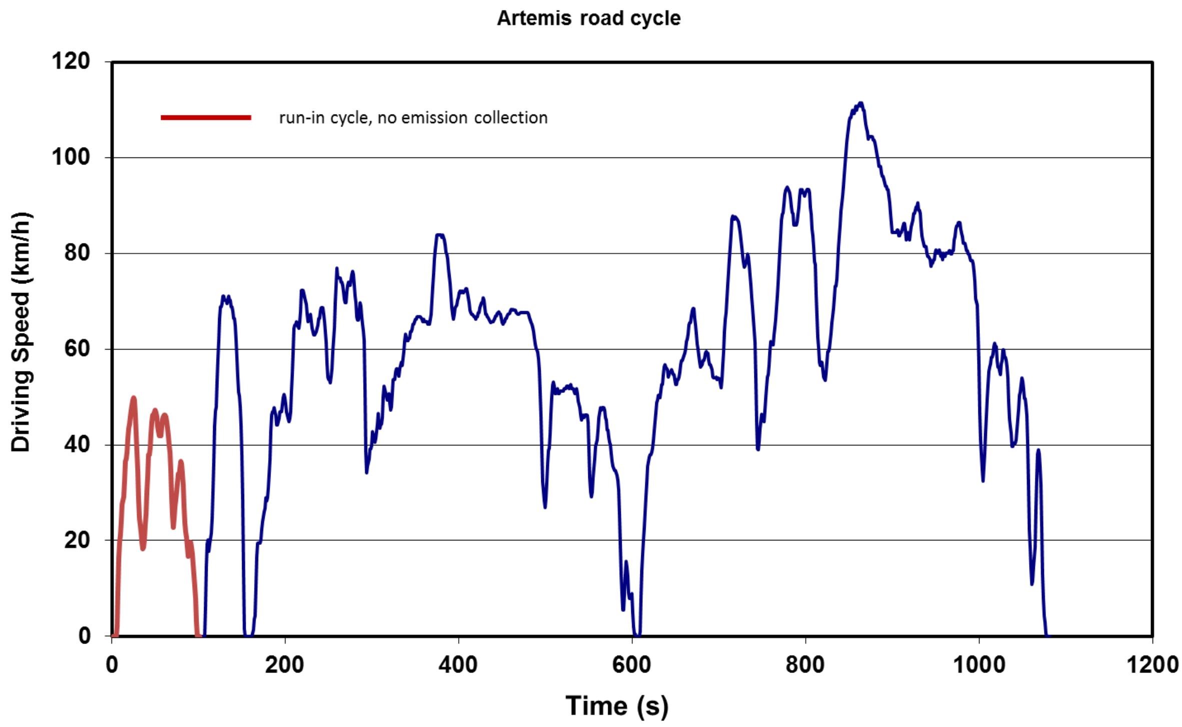


Figure 1-3: ARTEMIS Rural road cycle (ART RUR), with a 101 sec run-in cycle without sampling. Total duration 1082 sec, total driving distance 17.272 km (16.441 km in bag), average speed 57.5 km/h.

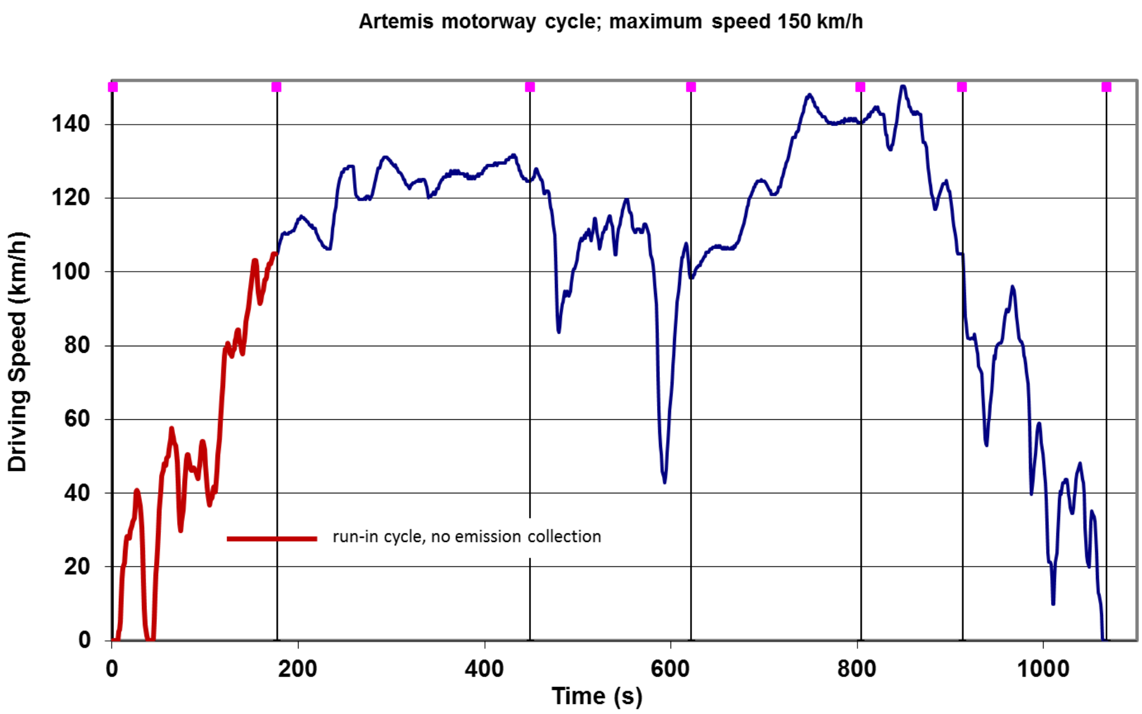


Figure 1-4: ARTEMIS Motorway cycle (ART MWY), with a 176 sec run-in cycle without sampling. Total duration driving distance 29.545 km (26.975 km in bag), average speed 96.9 km/h.

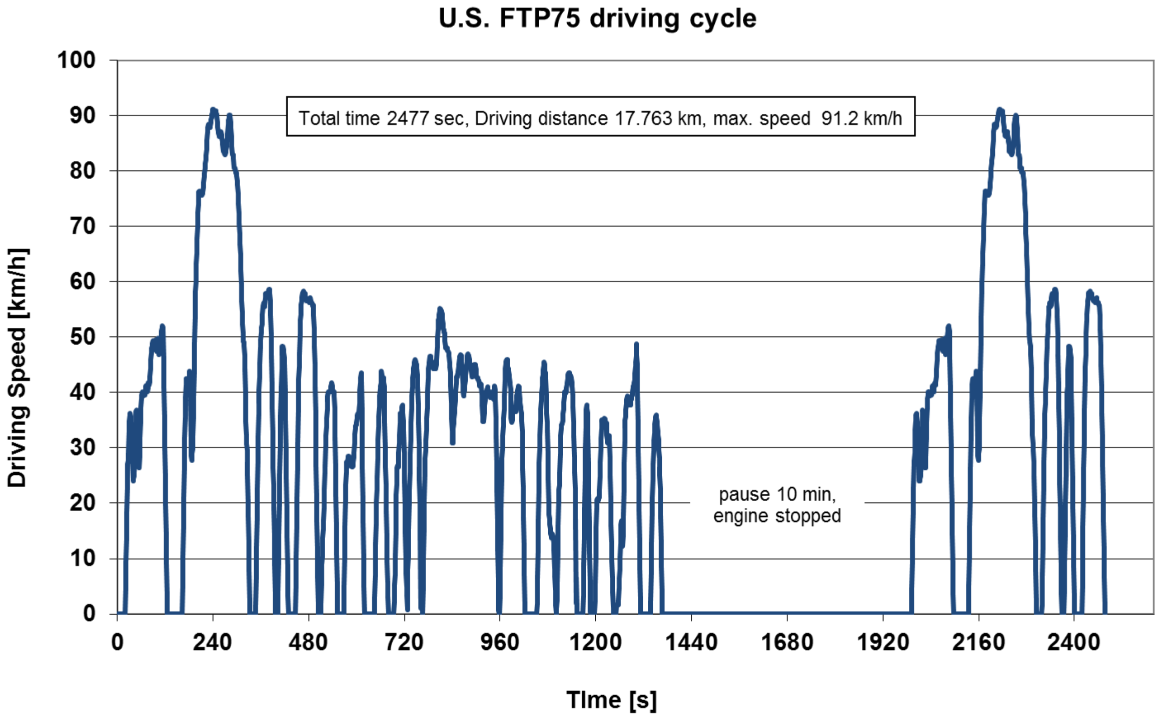


Figure 1-5: U.S. FTP 75 cycle: consist of cold-start phase (0-505 s), stabilised phase (506-1372 s), pause (10 min) and a re-run of the first 505 s after a warm restart (hot transient).

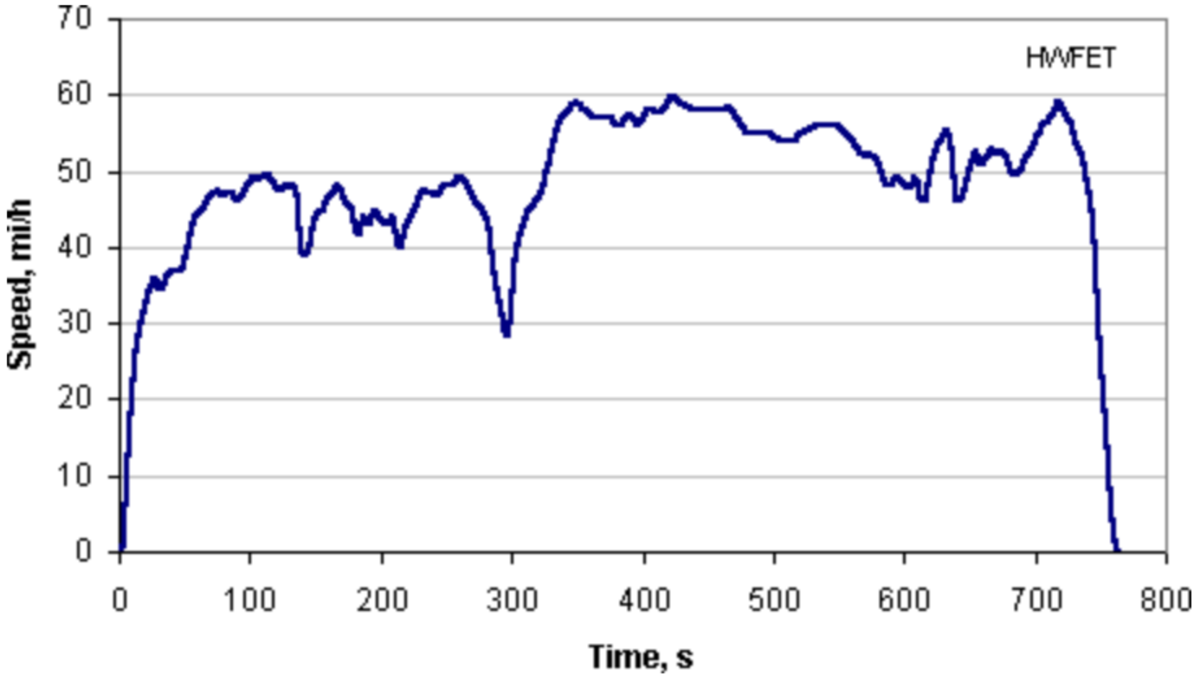


Figure 1-6: U.S. Highway Fuel Economy cycle (HWFET):Duration 765 sec, total driven distance 16.45 km, average speed 77.7 km/h. Usually, a warm-start cycle (Graph: courtesy of www.dieselnet.com).

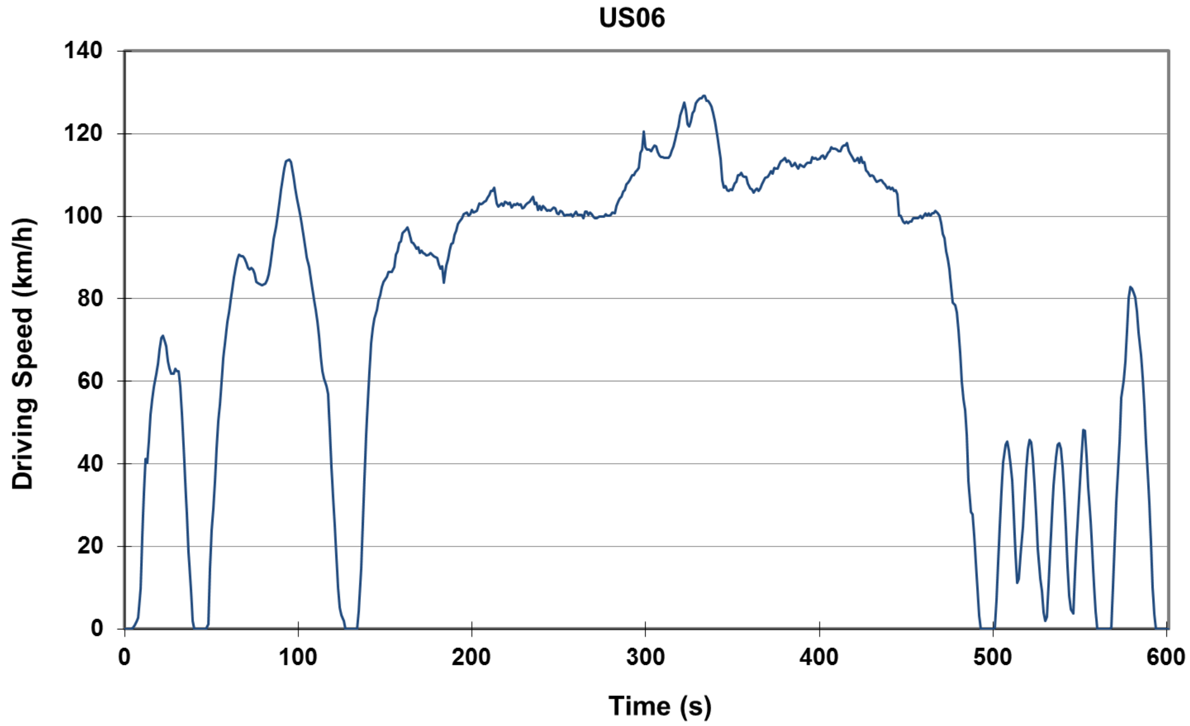


Figure 1-7: U.S.SFTP-06 cycle: total driving distance 12.8 km, average speed 77.9 km/h, max speed 129.2 km/h.Usually, a warm-start cycle.

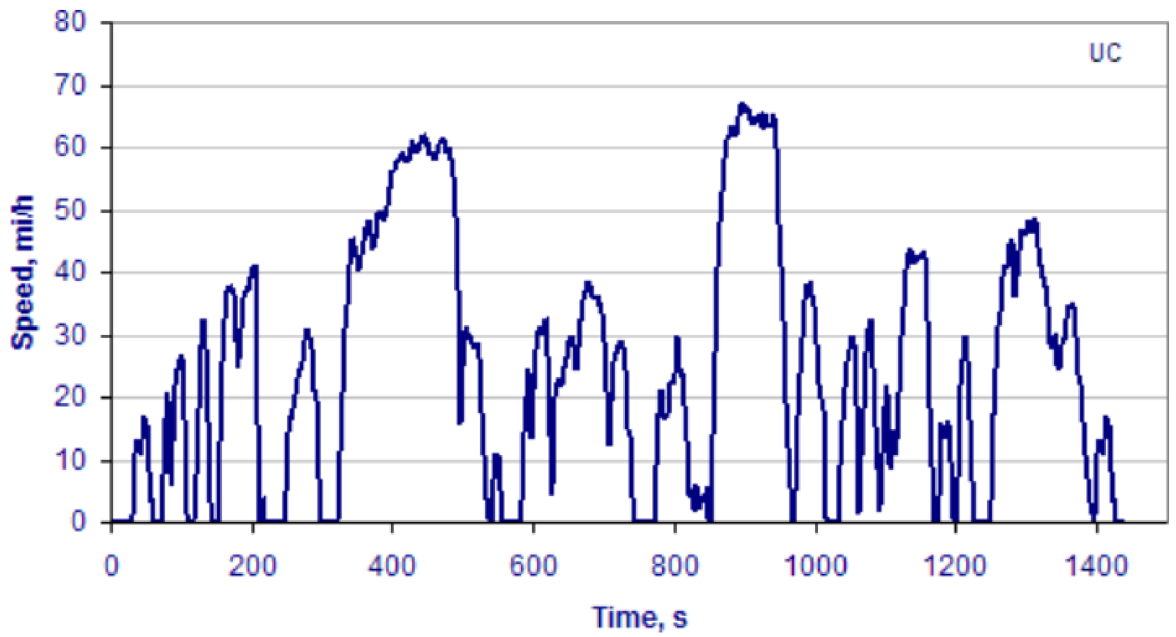


Figure 1-8:California Unified Cycle (LA-92): duration 1435 sec, total driving distance 15.7 km, average speed 39.6 km/h. (Graph: courtesy of www.dieselnet.com).

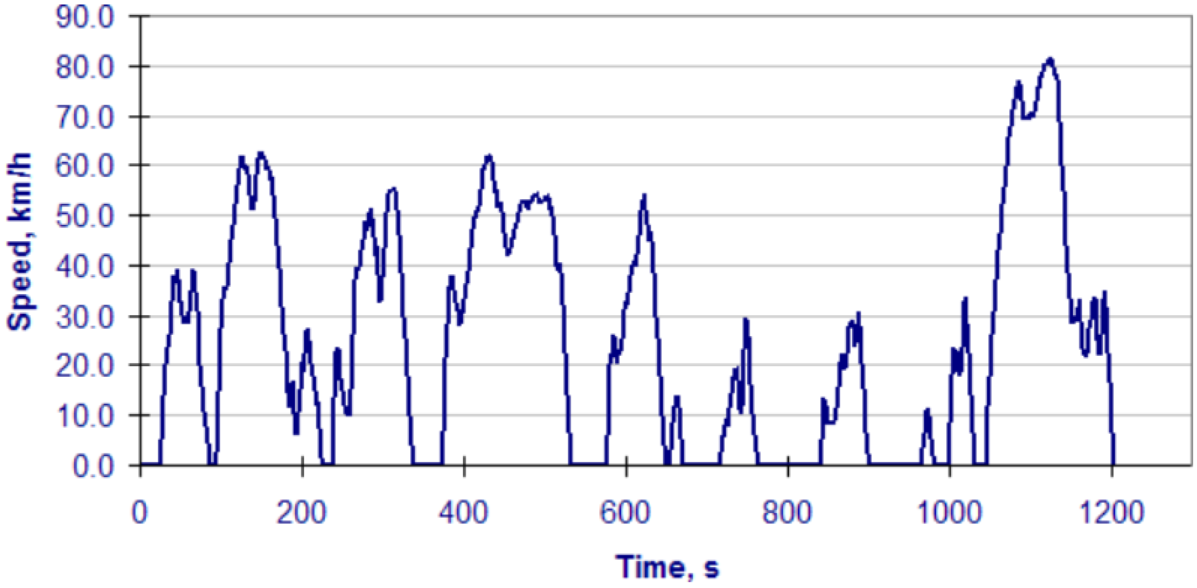


Figure 1-9: Current Japanese Type Approval driving cycle (JC08): duration 1204 sec, total driving distance 8.171 km, average speed 24.4 km/h, max. speed 81.6 km/h. (Graph: courtesy of www.dieselnet.com).

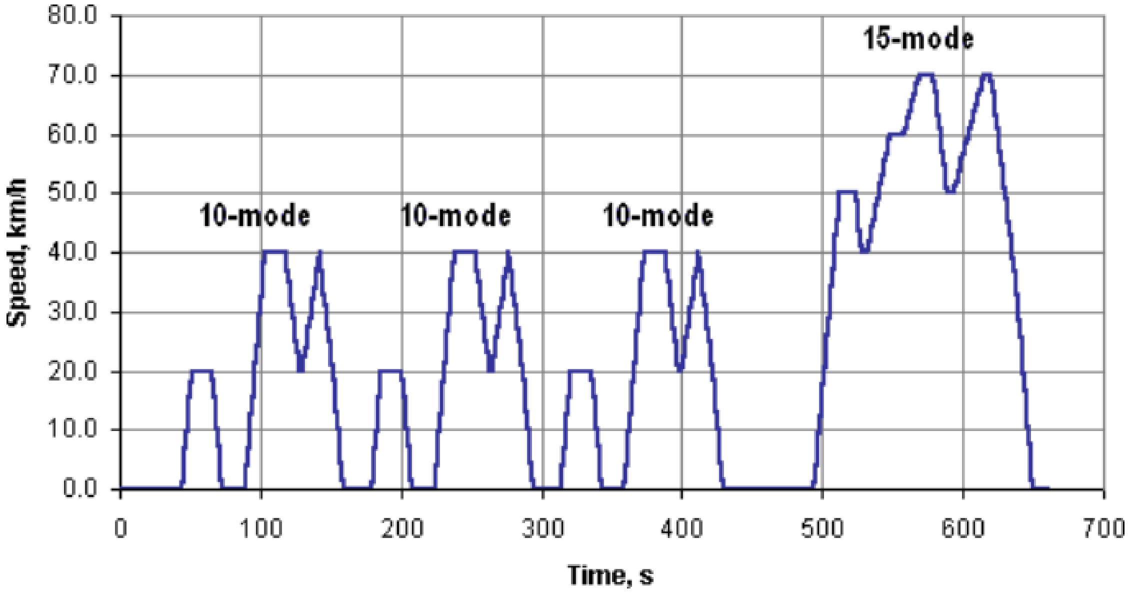


Figure 1-10: Former Japanese Type Approval driving cycle (10-15 mode): duration 892 sec, total driving distance 6.34 km, average speed 25.6 km/h, max. speed 70 km/h. (Graph: courtesy of www.dieselnet.com).

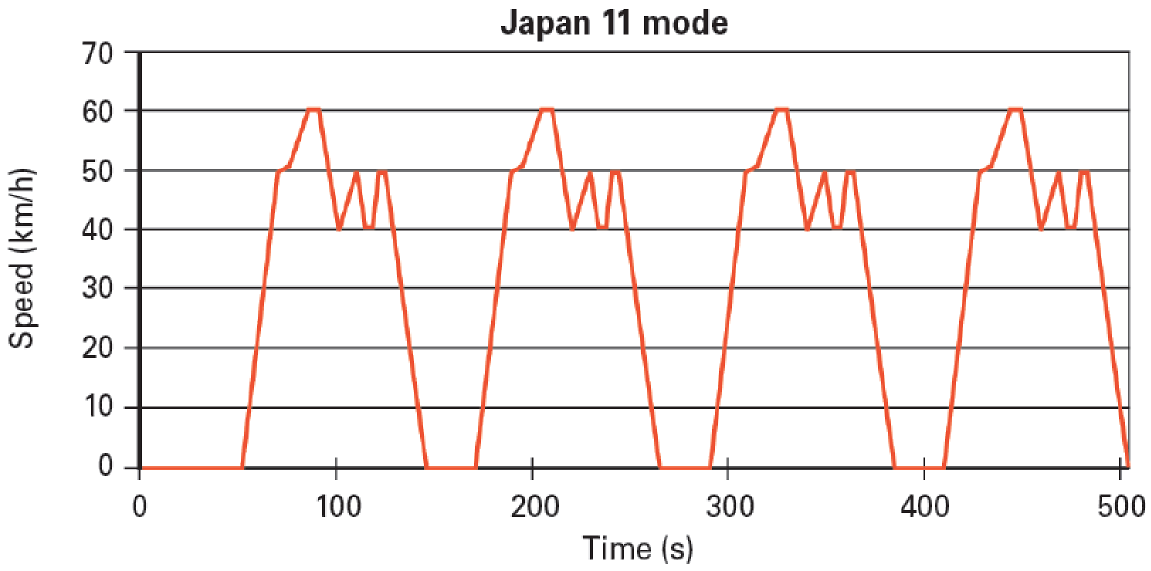


Figure 1-11: (Former) Japanese 11-mode driving cycle: duration 480 sec, total driving distance 4.084 km, average speed 30.6 km/h, max. speed 60 km/h. (Graph:courtesy of Dephi).

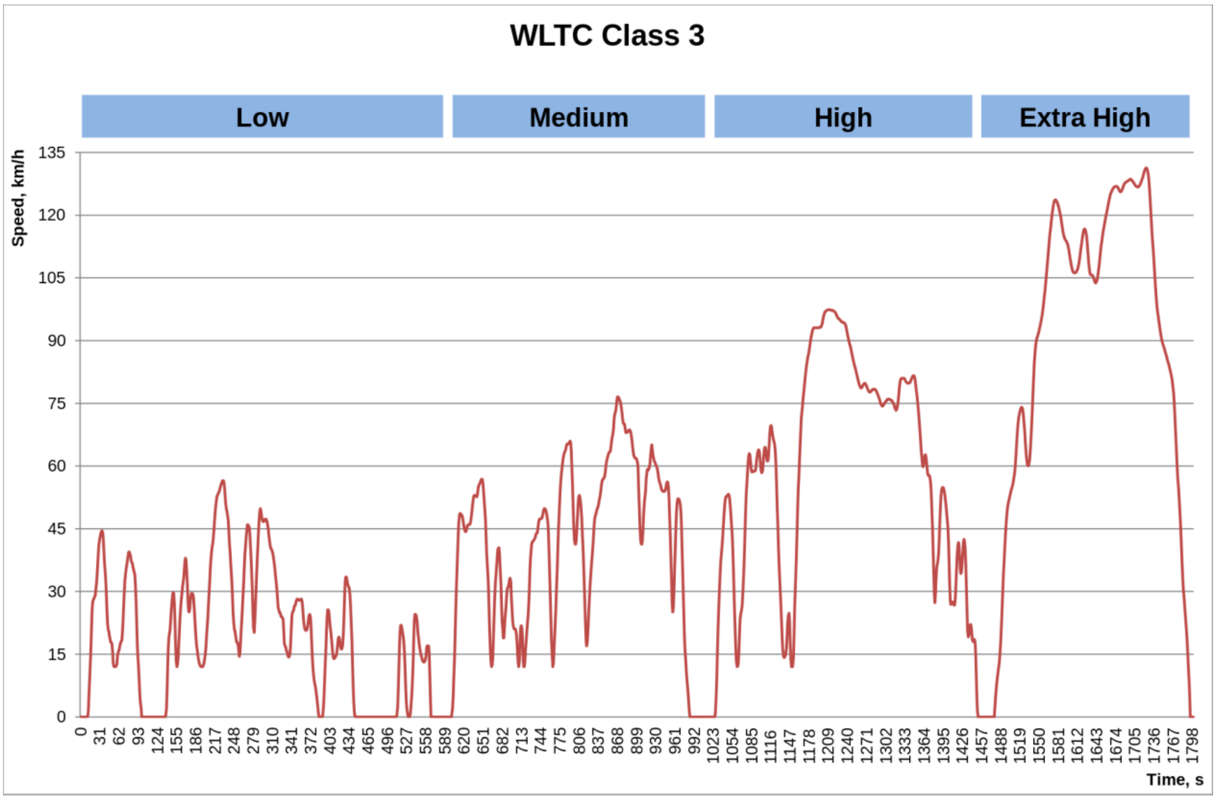


Figure 1-13: (upcoming) Global harmonised driving cycle for light-duty vehicles: duration 1800 sec, total driving distance 23.262 km, average speed 46.5 km/h, max. speed 131.6 km/h. (Graph:courtesy of Wikipedia).

Table 1-1: Main characteristics of the various driving cycles used in this study.

CYCLE	FTP	HWFET	US06	LA92	11 mode	10.15 mode	JC08	NEDC	ART URB	ART RUR	ART MWY	WLTP
start (typical)	cold/hot	hot	hot	cold	cold	hot	cold	cold	cold	hot	hot	cold
Origin	USA	USA	USA	USA/CA	JPN	JPN	JPN	EU	EU res.	EU res.	EU res.	ECE
Duration (s)	2477	765		1435	480	892	1204	1180	993 (-72)	1082 (-101)	1068 (-176)	1800
Total Distance (km)	17.763	16.45	12.8	15.7	4.084	6.34	8.171	11.087	4.87	17.272	29.545	23.26
Effective Distance (km)	17.763	16.45	12.5	15.7	4.084	6.34	8.171	11.087	4.47	16.441	26.975	23.26
Avg. Speed (km/h)	34.2	77.7	77.9	39.6	30.6	25.6	24.4	31.6	17.6	57.5	96.9	46.3
Max.speed (km/h)	91.2	96.4	129.2		60	70	81.6	120	57.7	111.5	150	131.6

RESULTS IN NUMBERS

Test Matrix: Vehicle - Fuel - Duty-cycle - Ambient temp **FUEL CONSUMPTION L/100 km**

Platform	Vehicle	Fuel	Ambient temp.	UDDS	UDDS	UDDS	FTP	HWFET	US06	LA92	11 mode	10.15 mode	JC08	JC08	NEDC	ART URB	ART URB	ART RUR	ART MWY	CADC	WLTP[4]	Cycle	
				cold	hot	hot	cold/hot	hot	hot	cold	cold	hot	cold	hot	cold	cold	hot	hot	hot	cold	cold	Start	
A	Hyundai Sonata	Gasoline #2	+21 °C	9.30	8.31	8.32		5.05	8.34	8.99			9.07		7.88						7.77		USA
	Hyundai Sonata Hybrid	Gasoline #3	+22 °C	5.55	4.92			4.05	7.08														
B	Ford Fusion V6	Gasoline #2	+21 °C	10.6	9.45	9.53	10.0	6.05	9.15	9.69					8.16						8.52		
	Ford Fusion Hybrid	Gasoline #1	+23 °C	5.53	4.95			4.89	7.33														
C	Nissan Bluebird Sylphy	Gasoline	+23 °C								10.75	8.84	10.61	9.09									JPN
	Nissan Bluebird Sylphy Li-LPG	LPG	+23 °C								8.93	7.29	8.37	7.54									
D	Sierra 2500 HD	Diesel	+23 °C				19.3	12.8	20.3				20.4		19.9								CDN
		B20 CME	+23 °C				19.1	12.9	20.1														
		B20 HDRD	+23 °C				19.4	12.8	20.2														
		B100 HDRD	+23 °C				20.9	13.8	22.0														
		Diesel	-7 °C				21.8								25.8								
		B20 CME	-7 °C				nt																
		B20 HDRD	-7 °C				21.7																
		B100 HDRD	-7 °C				23.3																
		Diesel	-18 °C				22.6																
	Sierra 2500 FFV	E0	+23 °C				19.6	12.2	19.0														
		E85	+23 °C				27.0	16.7	25.7														
		E0	-7 °C				21.3																
		E75	-7 °C				28.5																
	Sierra 2500 HD	E0	+23 °C				20.5	12.5	19.9														
		CNG	+23 °C				19.6	12.8	18.9														
	Sierra 1500 Hybrid	E0	+23 °C				12.0	8.45	13.0				14.6		13.4								
		E10	+23 °C				13.0	8.41	13.3						13.5								
		E0	-7 °C				13.0																
		E10	-7 °C				13.3																
E	A (1.6L, M)	#93	+25 °C												7.50								CHN
		E10	+25 °C												n/a								
		M15	+25 °C												n/a								
	B (1.6L, A)	#93	+25 °C												7.21								
		E10	+25 °C												n/a								
		M15	+25 °C												n/a								
	C (2.0L, A)	#93	+25 °C												7.75								
		E10	+25 °C												n/a								
		M15	+25 °C												n/a								
F	D (1.6L, M)	#93	+25 °C												5.73								
		CNG	+25 °C												6.82								
	E (1.6L, M)	#93	+25 °C												6.05								
		CNG	+25 °C												6.72								
	F (1.6L, M)	#93	+25 °C												5.86								
		CNG	+25 °C												5.86								
	G (1.6L, M)	#93	+25 °C												7.47								
		CNG	+25 °C												7.74								
															kg/100 km								

RESULTS IN NUMBERS

Test Matrix: Vehicle - Fuel - Duty-cycle - Ambient temp **FUEL CONSUMPTION L/100 km**

Platform	Vehicle	Fuel	Ambient temp.	UDDS cold	UDDS hot	UDDS hot	FTP cold/hot	HWFET hot	US06 hot	LA92 cold	11 mode cold	10.15 mode hot	JC08 cold	JC08 hot	NEDC cold	ART URB cold	ART URB hot	ART RUR hot	ART MWY hot	CADC cold	WLTP[4] cold	Cycle Start	
G	SI	E85	+23 °C												12.0	19.9	18.7	9.5	11.0	n/a			SWE
		E75	-7 °C												12.3	n/a	n/a	n/a	n/a	n/a			
	CI	Diesel	+23 °C												4.37	7.85	7.46	4.35	5.19	n/a			
			-7 °C												5.25	n/a	n/a	n/a	n/a	n/a			
	BEV	EL	+23 °C												n/a	n/a	n/a	n/a	n/a	n/a			
			-7 °C												n/a	n/a	n/a	n/a	n/a	n/a			
H	1.4 TSI	95 E10	+23 °C												0.61	0.00		0.00	n/a				FIN
			+5 °C												-0.01	0.00		0.00	n/a				
			-7 °C												0.00	0.00		0.00	n/a				
		E95RE	+23 °C												-0.04	0.00		0.00	n/a				
			+5 °C												0.00	0.00		0.00	n/a				
			-7 °C												-0.05	0.00		0.00	n/a				
	2.0 TSI	95 E10	+23 °C												0.46	0.00		0.00	0.00				
			+5 °C												0.30	0.00		0.00	0.00				
			-7 °C												0.37	0.00		0.00	0.00				
		E95RE	+23 °C												-0.18	0.00		0.00	0.00				
			+5 °C												0.00	0.00		0.00	0.00				
			-7 °C												0.00	0.00		0.00	0.00				
	1.6 TDI	EN590(B7)	+23 °C												NEDC	ART URB		ART RUR	ART MWY				
			+5 °C												cold	cold		hot	hot				
			-7 °C												6.40	11.14		5.44	0.00				
		HVO	+23 °C												7.15	12.17		5.78	0.00				
			+5 °C												7.52	13.10		5.82	0.00				
			-7 °C												6.25	10.64		5.35	0.00				
	2.0 TDI	EN590(B7)	+23 °C												7.13	12.52		5.93	0.00				
			+5 °C												7.44	12.91		5.82	0.00				
			-7 °C												8.51	14.84		6.66	7.23				
		HVO	+23 °C												9.35	16.90		7.13	7.49				
			+5 °C												9.93	17.32		7.23	7.74				
			-7 °C												8.44	14.66		6.66	7.16				
	1.4 TSI FFV	95 E10	+23 °C												9.20	16.49		7.07	7.48				
			+5 °C												9.98	17.35		7.20	7.73				
			-7 °C												5.26	9.03		4.14	4.78				
		RE85	+23 °C												5.84	9.61		4.45	5.00				
			+5 °C												6.06	10.52		4.52	4.78				
			-7 °C												5.04	8.61		4.02	4.58				
	1.4 TSI CNG	95 E10	+23 °C												5.44	9.32		4.33	4.65				
			+5 °C												5.99	10.01		4.39	4.83				
			-7 °C												6.17	10.77		4.91	5.70				
		CNG	+23 °C												**4.43**	**7.61**		**3.35**	**3.60**				
			+5 °C												**4.70**	**7.93**		**3.73**	**4.23**				
			-7 °C												**5.17**	**8.76**		**3.68**	**3.89**				
	BEV	electr.	+23 °C												n/a	n/a		n/a	n/a				
			-7 °C												n/a	n/a		n/a	n/a				

in kg/100 km

RESULTS IN NUMBERS

Test Matrix: Vehicle - Fuel - Duty-cycle - Ambient temp **ENERGY CONSUMPTION Wh/100 km**

Platform	Vehicle	Fuel	Ambient temp.	UDDS	UDDS	UDDS	FTP	HWFET	US06	LA92	11 mode	10.15 mode	JC08	JC08	NEDC	ART URB	ART URB	ART RUR	ART MWY	CADC	WLTP[4]	Cycle	
				cold	hot	hot	cold/hot	hot	hot	cold	cold	hot	cold	hot	cold	cold	hot	hot	hot	cold	cold	Start	
A	Hyundai Sonata	Gasoline #2	+21 °C	819	732	733		444	735	792			799		694						684		USA
A	Hyundai Sonata Hybrid	Gasoline #3	+22 °C	484	429			353	618														USA
B	Ford Fusion V6	Gasoline #2	+21 °C	933	832	839	880	532	806	853					719						750		USA
B	Ford Fusion Hybrid	Gasoline #1	+23 °C	488	436			431	646														USA
C	Nissan Bluebird Sylphy	Gasoline	+23 °C								769	632	759	651									JPN
C	Nissan Bluebird Sylphy Li-LPG	LPG	+23 °C								785	641	736	663									JPN
D	Sierra 2500 HD	Diesel	+23 °C				1961	1299	2066				2077		2023								CDN
D	Sierra 2500 HD	B20 CME	+23 °C				1904	1286	2009														CDN
D	Sierra 2500 HD	B20 HDRD	+23 °C				1948	1291	2029														CDN
D	Sierra 2500 HD	B100 HDRD	+23 °C				1686	1112	1777														CDN
D	Sierra 2500 HD	Diesel	-7 °C				2221								2623								CDN
D	Sierra 2500 HD	B20 CME	-7 °C																				CDN
D	Sierra 2500 HD	B20 HDRD	-7 °C				2178																CDN
D	Sierra 2500 HD	B100 HDRD	-7 °C				1885																CDN
D	Sierra 2500 HD	Diesel	-18 °C				2296																CDN
D	Sierra 2500 HD	E0	+23 °C				1819	1113	1768														CDN
D	Sierra 2500 HD	CNG	+23 °C				1422	929	1368														CDN
D	Sierra 2500 FFV	E0	+23 °C				1740	1083	1687														CDN
D	Sierra 2500 FFV	E85	+23 °C				1704	1054	1622														CDN
D	Sierra 2500 FFV	E0	-7 °C				1894	nt	nt														CDN
D	Sierra 2500 FFV	E75	-7 °C				1800	nt	nt														CDN
D	Sierra 1500 Hybrid	E0	+23 °C				1066	750	1155					1296	1193								CDN
D	Sierra 1500 Hybrid	E10	+23 °C				1127	729	1151						1171								CDN
D	Sierra 1500 Hybrid	E0	-7 °C				1155																CDN
D	Sierra 1500 Hybrid	E10	-7 °C				1151																CDN
E	A (1.6L, M)	#93	+25 °C												666								CHN
E	A (1.6L, M)	E10	+25 °C												661								CHN
E	A (1.6L, M)	M15	+25 °C												652								CHN
E	B (1.6L, A)	#93	+25 °C												641								CHN
E	B (1.6L, A)	E10	+25 °C												635								CHN
E	B (1.6L, A)	M15	+25 °C												622								CHN
E	C (2.0L, A)	#93	+25 °C												688								CHN
E	C (2.0L, A)	E10	+25 °C												687								CHN
E	C (2.0L, A)	M15	+25 °C												664								CHN
F	D (1.6L, M)	#93	+25 °C												509								CHN
F	D (1.6L, M)	CNG	+25 °C												493								CHN
F	E (1.6L, M)	#93	+25 °C												537								CHN
F	E (1.6L, M)	CNG	+25 °C												486								CHN
F	F (1.6L, M)	#93	+25 °C												520								CHN
F	F (1.6L, M)	CNG	+25 °C												483								CHN
F	G (1.6L, M)	#93	+25 °C												663								CHN
F	G (1.6L, M)	CNG	+25 °C												560								CHN

RESULTS IN NUMBERS

Test Matrix: Vehicle - Fuel - Duty-cycle - Ambient temp

ENERGY CONSUMPTION Wh/100 km

G	SI	E85	+23 °C	766	1273	1197	608	705	n/a	SWE
		E75	-7 °C	807	n/a	n/a	n/a	n/a	n/a	
	CI	Diesel	+23 °C	439	780	739	433	516	n/a	
			-7 °C	523	n/a	n/a	n/a	n/a	n/a	
	BEV	EL	+23 °C	145	n/a	n/a	n/a	n/a	239	
			-7 °C	n/a	n/a	n/a	n/a	n/a	231	
H	1.4 TSI	95 E10	+23 °C	550	962		470	n/a		FIN
			+5 °C	618	1051		499	n/a		
			-7 °C	650	1131		503	n/a		
		E95RE	+23 °C	540	922		463	n/a		
			+5 °C	617	1084		513	n/a		
			-7 °C	640	1118		504	n/a		
	2.0 TSI	95 E10	+23 °C	730	1281		575	624		
			+5 °C	807	1459		615	647		
			-7 °C	860	1496		624	668		
		E95RE	+23 °C	730	1269		575	620		
			+5 °C	797	1427		613	648		
			-7 °C	860	1502		624	669		
	1.6 TDI	EN590(B7)	+23 °C	520	899		412	475		
			+5 °C	555	956		443	476		
			-7 °C	600	1047		450	475		
		HVO	+23 °C	480	819		382	435		
			+5 °C	517	887		412	442		
			-7 °C	570	953		418	459		
	2.0 TDI	EN590(B7)	+23 °C	610	1071		489	567		
			+5 °C	709	1169		501	586		
			-7 °C	780	1355		516	595		
		HVO	+23 °C	560	991		437	512		
			+5 °C	653	1078		467	526		
			-7 °C	700	1227		490	521		
	1.4 TSI FFV	95 E10	+23 °C	630	1080		536	599		
			+5 °C	714	1233		571	631		
			-7 °C	740	1263		600	646		
		RE85	+23 °C	610	1009		498	571		
			+5 °C	671	1107		548	611		
			-7 °C	740	1229		564	613		
	1.4 TSI CNG	95 E10	+23 °C	610	1091		497	554		
			+5 °C	680	1156		501	585		
			-7 °C	720	1284		551	580		
		CNG	+23 °C	610	1057		489	553		
			+5 °C	653	1101		518	588		
			-7 °C	720	1217		537	598		
	BEV	electr.	+23 °C	198	300		199	268		
			-7 °C	245	322		257	292		

RESULTS IN NUMBERS

Test Matrix: Vehicle - Fuel - Duty-cycle - Ambient temp **CO_2 [g/km]**

Platform	Vehicle	Fuel	Ambient temp.	UDDS cold	UDDS hot	UDDS hot	FTP cold/hot	HWFET hot	US06 hot	LA92 cold	11 mode cold	10.15 mode hot	JC08 cold	JC08 hot	NEDC cold	ART URB cold	ART URB hot	ART RUR hot	ART MWY hot	CADC cold	WLTP[4] cold	Cycle Start	
A	Hyundai Sonata	Gasoline #2	+21 °C																				USA
	Hyundai Sonata Hybrid	Gasoline #3	+22 °C																				
B	Ford Fusion V6	Gasoline #2	+21 °C																				
	Ford Fusion Hybrid	Gasoline #1	+23 °C																				
C	Nissan Bluebird Sylphy	Gasoline	+23 °C								182	150	180	154									JPN
	Nissan Bluebird Sylphy Li-LPG	LPG	+23 °C								202	165	189	171									
D	Sierra 2500 HD	Diesel	+23 °C				533	349	554				557		542								CDN
		B20 CME	+23 °C				522	350	548														
		B20 HDRD	+23 °C				515	342	537														
		B100 HDRD	+23 °C				504	333	532														
		Diesel	-7 °C				596								702								
		B20 CME	-7 °C				nt																
		B20 HDRD	-7 °C				576																
		B100 HDRD	-7 °C				564																
		Diesel	-18 °C				615																
	Sierra 2500 FFV	E0	+23 °C				460	286	447														
		E85	+23 °C				443	275	422														
		E0	-7 °C				491																
		E75	-7 °C				469																
	Sierra 2500 HD	E0	+23 °C				481	295	467														
		CNG	+23 °C				377	227	356														
	Sierra 1500 Hybrid	E0	+23 °C				280	193	304				341		312								
		E10	+23 °C				298	192	306						306								
		E0	-7 °C				304																
		E10	-7 °C				306																
E	A (1.6L, M)	#93	+25 °C												183								CHN
		E10	+25 °C												178								
		M15	+25 °C												176								
	B (1.6L, A)	#93	+25 °C												176								
		E10	+25 °C												172								
		M15	+25 °C												168								
	C (2.0L, A)	#93	+25 °C												189								
		E10	+25 °C												186								
		M15	+25 °C												180								
F	D (1.6L, M)	#93	+25 °C												140								
		CNG	+25 °C												122								
	E (1.6L, M)	#93	+25 °C												147								
		CNG	+25 °C												120								
	F (1.6L, M)	#93	+25 °C												143								
		CNG	+25 °C												119								
	G (1.6L, M)	#93	+25 °C												182								
		CNG	+25 °C												138								

RESULTS IN NUMBERS

Test Matrix: Vehicle - Fuel - Duty-cycle - Ambient temp — **CO_2 [g/km]**

Platform	Vehicle	Fuel	Ambient temp.	UDDS	UDDS	UDDS	FTP	HWFET	US06	LA92	11 mode	10.15 mode	JC08	JC08	NEDC	ART URB	ART URB	ART RUR	ART MWY	CADC	WLTP[4]	Cycle	
				cold	hot	hot	cold/hot	hot	hot	cold	cold	hot	cold	hot	cold	cold	hot	hot	hot	cold	cold	Start	
G	SI	E85	+23 °C												192	318	301	153	178	n/a			SWE
		E75	-7 °C												199	n/a	n/a	n/a	n/a	n/a			
	CI	Diesel	+23 °C												115	206	196	115	137	n/a			
			-7 °C												137	n/a	n/a	n/a	n/a	n/a			
	BEV	EL	+23 °C												n/a	n/a	n/a	n/a	n/a	n/a			
			-7 °C												n/a	n/a	n/a	n/a	n/a	n/a			
H	1.4 TSI	95 E10	+23 °C												151	262		129	0				FIN
			+5 °C												157	256		131	0				
			-7 °C												170	282		138	0				
		E95RE	+23 °C												147	250		127	0				
			+5 °C												156	265		134	0				
			-7 °C												168	278		137	0				
	2.0 TSI	95 E10	+23 °C												193	336		151	164				
			+5 °C												212	377		161	170				
			-7 °C												225	389		164	175				
		E95RE	+23 °C												192	333		151	163				
			+5 °C												209	366		161	170				
			-7 °C												226	391		164	176				
	1.6 TDI	EN590(B7)	+23 °C												138	234		108	124				
			+5 °C												150	248		116	130				
			-7 °C												161	271		117	128				
		HVO	+23 °C												131	223		104	119				
			+5 °C												141	241		112	121				
			-7 °C												155	259		114	125				
	2.0 TDI	EN590(B7)	+23 °C												160	280		128	148				
			+5 °C												178	315		135	153				
			-7 °C												202	359		139	158				
		HVO	+23 °C												152	271		119	140				
			+5 °C												172	294		127	144				
			-7 °C												191	335		134	142				
	1.4 TSI FFV	95 E10	+23 °C												165	281		140	157				
			+5 °C												171	273		144	161				
			-7 °C												193	317		157	169				
		RE85	+23 °C												158	261		129	148				
			+5 °C												173	284		142	159				
			-7 °C												185	303		146	158				
	1.4 TSI CNG	95 E10	+23 °C												161	281		129	145				
			+5 °C												171	284		130	154				
			-7 °C												183	312		142	153				
		CNG	+23 °C												121	208		96	109				
			+5 °C												128	216		102	116				
			-7 °C												140	239		106	118				
	BEV	electr.	+23 °C												n/a	n/a		n/a	n/a				
			-7 °C												n/a	n/a		n/a	n/a				

RESULTS IN NUMBERS

Test Matrix: Vehicle - Fuel - Duty-cycle - Ambient temp **CO [mg/km]**

Platform	Vehicle	Fuel	Ambient temp.	UDDS	UDDS	UDDS	FTP	HWFET	US06	LA92	11 mode	10.15 mode	JC08	JC08	NEDC	ART URB	ART URB	ART RUR	ART MWY	CADC	WLTP[4]	Cycle	
				cold	hot	hot	cold/hot	hot	hot	cold	cold	hot	cold	hot	cold	cold	hot	hot	hot	cold	cold	Start	
A	Hyundai Sonata	Gasoline #2	+21 °C																				USA
	Hyundai Sonata Hybrid	Gasoline #3	+22 °C																				
B	Ford Fusion V6	Gasoline #2	+21 °C																				
	Ford Fusion Hybrid	Gasoline #1	+23 °C																				
C	Nissan Bluebird Sylphy	Gasoline	+23 °C								108.9	56.20	143.4	42.87									JPN
	Nissan Bluebird Sylphy Li-LPG	LPG	+23 °C								538.3	18.26	468.3	41.33									
D	Sierra 2500 HD	Diesel	+23 °C				228	11	9				318		1100								CDN
		B20 CME	+23 °C				175	11	11														
		B20 HDRD	+23 °C				218	11	10														
		B100 HDRD	+23 °C				166	10	12														
		Diesel	-7 °C				314								1398								
		B20 CME	-7 °C				nt																
		B20 HDRD	-7 °C				155																
		B100 HDRD	-7 °C				93																
		Diesel	-18 °C				763																
	Sierra 2500 HD	E0	+23 °C				573	99	999														
		CNG	+23 °C				900	15	328														
	Sierra 2500 FFV	E0	+23 °C				769	118	143														
		E85	+23 °C				582	80	73														
		E0	-7 °C				3173																
		E75	-7 °C				4788																
	Sierra 1500 Hybrid	E0	+23 °C				516	183	265				956		1583								
		E10	+23 °C				526	277	296						1431								
		E0	-7 °C				2972																
		E10	-7 °C				2814																
E	A (1.6L, M)	#93	+25 °C												804								CHN
		E10	+25 °C												692								
		M15	+25 °C												608								
	B (1.6L, A)	#93	+25 °C												576								
		E10	+25 °C												492								
		M15	+25 °C												459								
	C (2.0L, A)	#93	+25 °C												610								
		E10	+25 °C												569								
		M15	+25 °C												415								
F	D (1.6L, M)	#93	+25 °C												243								
		CNG	+25 °C												168								
	E (1.6L, M)	#93	+25 °C												252								
		CNG	+25 °C												165								
	F (1.6L, M)	#93	+25 °C												327								
		CNG	+25 °C												200								
	G (1.6L, M)	#93	+25 °C												299								
		CNG	+25 °C												133								

RESULTS IN NUMBERS

Test Matrix: Vehicle - Fuel - Duty-cycle - Ambient temp **CO [mg/km]**

Platform	Vehicle	Fuel	Ambient temp.	Test Cycle																			
				UDDS	UDDS	UDDS	FTP	HWFET	US06	LA92	11 mode	10.15 mode	JC08	JC08	NEDC	ART URB	ART URB	ART RUR	ART MWY	CADC	WLTP[4]	Cycle	
				cold	hot	hot	cold/hot	hot	hot	cold	cold	hot	cold	hot	cold	cold	hot	hot	hot	cold	cold	Start	
G	SI	E85	+23 °C												373	1642	266	153	214	n/a			SWE
		E75	-7 °C												4270	n/a	n/a	n/a	n/a	n/a			
	CI	Diesel	+23 °C												191	416	n.d.	6	n.d.	n/a			
			-7 °C												456	n/a	n/a	n/a	n/a	n/a			
	BEV	EL	+23 °C												n/a	n/a	n/a	n/a	n/a	n/a			
			-7 °C												n/a	n/a	n/a	n/a	n/a	n/a			
H	1.4 TSI	95 E10	+23 °C												681	1567		210	n/a				FIN
			+5 °C												3019	10448		279	n/a				
			-7 °C												4305	14511		488	n/a				
		E95RE	+23 °C												753	1510		209	n/a				
			+5 °C												3284	9971		673	n/a				
			-7 °C												4553	14313		645	n/a				
	2.0 TSI	95 E10	+23 °C												180	682		485	496				
			+5 °C												502	3306		574	322				
			-7 °C												273	2693		434	403				
		E95RE	+23 °C												167	419		485	417				
			+5 °C												327	4740		350	416				
			-7 °C												581	1915		334	367				
	1.6 TDI	EN590(B7)	+23 °C												253	441		8	3				
			+5 °C												711	950		31	6				
			-7 °C												944	1236		28	6				
		HVO	+23 °C												122	135		8	4				
			+5 °C												160	452		15	7				
			-7 °C												445	709		26	9				
	2.0 TDI	EN590(B7)	+23 °C												108	54		3	5				
			+5 °C												77	171		5	4				
			-7 °C												123	232		5	5				
		HVO	+23 °C												29	26		5	5				
			+5 °C												29	54		5	5				
			-7 °C												52	114		5	6				
	1.4 TSI FFV	95 E10	+23 °C												492	1839		902	628				
			+5 °C												8985	27185		4291	3104				
			-7 °C												1637	7501		911	520				
		RE85	+23 °C												240	602		205	133				
			+5 °C												782	2454		592	477				
			-7 °C												1434	7754		511	102				
	1.4 TSI CNG	95 E10	+23 °C												471	3499		1385	542				
			+5 °C												3619	10178		1341	396				
			-7 °C												3953	13324		1946	293				
		CNG	+23 °C												471	249		253	145				
			+5 °C												103	200		274	136				
			-7 °C												1141	312		215	106				
	BEV	electr.	+23 °C												n/a	n/a		n/a	n/a				
			-7 °C												n/a	n/a		n/a	n/a				

RESULTS IN NUMBERS

Test Matrix: Vehicle - Fuel - Duty-cycle - Ambient temp — **HC [mg/km]**

Platform	Vehicle	Fuel	Ambient temp.	UDDS	UDDS	UDDS	FTP	HWFET	US06	LA92	11 mode	10.15 mode	JC08	JC08	NEDC	ART URB	ART URB	ART RUR	ART MWY	CADC	WLTP[4]	Cycle	
				cold	hot	hot	cold/hot	hot	hot	cold	cold	hot	cold	hot	cold	cold	hot	hot	hot	cold	cold	Start	
A	Hyundai Sonata	Gasoline #2	+21 °C																				USA
	Hyundai Sonata Hybrid	Gasoline #3	+22 °C																				
B	Ford Fusion V6	Gasoline #2	+21 °C																				
	Ford Fusion Hybrid	Gasoline #1	+23 °C																				
C	Nissan Bluebird Sylphy	Gasoline	+23 °C								21.84	1.61	14.83	0.25									JPN
	Nissan Bluebird Sylphy Li-LPG	LPG	+23 °C								43.78	0.03	28.16	0.24									
D	Sierra 2500 HD	Diesel	+23 °C				28	0	0				29		81								CDN
		B20 CME	+23 °C				26	0	0														
		B20 HDRD	+23 °C				26	0	0														
		B100 HDRD	+23 °C				27	0	0														
		Diesel	-7 °C				30								143								
		B20 CME	-7 °C				n/t																
		B20 HDRD	-7 °C				21																
		B100 HDRD	-7 °C				17																
		Diesel	-18 °C				96																
	Sierra 2500 HD	E0	+23 °C				30	1	6														
		CNG	+23 °C				64	6	11														
	Sierra 2500 FFV	E0	+23 °C				30	1	1														
		E85	+23 °C				42	1	2														
		E0	-7 °C				302																
		E75	-7 °C				1069																
	Sierra 1500 Hybrid	E0	+23 °C				38	9	15				83		119								
		E10	+23 °C				39	12	16						107								
		E0	-7 °C				267																
		E10	-7 °C				265																
E	A (1.6L, M)	#93	+25 °C												33								CHN
		E10	+25 °C												33								
		M15	+25 °C												25								
	B (1.6L, A)	#93	+25 °C												49								
		E10	+25 °C												37								
		M15	+25 °C												35								
	C (2.0L, A)	#93	+25 °C												63								
		E10	+25 °C												38								
		M15	+25 °C												29								
F	D (1.6L, M)	#93	+25 °C												24								
		CNG	+25 °C												43								
	E (1.6L, M)	#93	+25 °C												20								
		CNG	+25 °C												33								
	F (1.6L, M)	#93	+25 °C												31								
		CNG	+25 °C												39								
	G (1.6L, M)	#93	+25 °C												50								
		CNG	+25 °C												82								

RESULTS IN NUMBERS

Test Matrix: Vehicle - Fuel - Duty-cycle - Ambient temp **HC [mg/km]**

Platform	Vehicle	Fuel	Ambient temp.	UDDS cold	UDDS hot	UDDS hot	FTP cold/hot	HWFET hot	US06 hot	LA92 cold	11 mode cold	10.15 mode hot	JC08 cold	JC08 hot	NEDC cold	ART URB cold	ART URB hot	ART RUR hot	ART MWY hot	CADC cold	WLTP[4] cold	Cycle Start	
G	SI	E85	+23 °C												56.5	198	2.5	0.9	3.5	n/a			SWE
		E75	-7 °C												977	n/a	n/a	n/a	n/a	n/a			
	CI	Diesel	+23 °C												10.5	8.0	n.d.	0.2	n.d.	n/a			
			-7 °C												17.5	n/a	n/a	n/a	n/a	n/a			
	BEV	EL	+23 °C												n/a	n/a	n/a	n/a	n/a	n/a			
			-7 °C												n/a	n/a	n/a	n/a	n/a	n/a			
H	1.4 TSI	95 E10	+23 °C												72	176		14	n/a				FIN
			+5 °C												397	1268		20	n/a				
			-7 °C												599	1981		11	n/a				
		E95RE	+23 °C												76	196		14	n/a				
			+5 °C												408	1129		25	n/a				
			-7 °C												655	1965		22	n/a				
	2.0 TSI	95 E10	+23 °C												41	150		10	15				
			+5 °C												179	693		10	18				
			-7 °C												261	552		6	17				
		E95RE	+23 °C												41	126		10	11				
			+5 °C												187	823		4	13				
			-7 °C												250	519		5	12				
	1.6 TDI	EN590(B7)	+23 °C												33	51		5	2				
			+5 °C												68	73		6	2				
			-7 °C												87	78		7	2				
		HVO	+23 °C												15	13		4	1				
			+5 °C												14	12		2	1				
			-7 °C												27	25		2	1				
	2.0 TDI	EN590(B7)	+23 °C												23	19		4	2				
			+5 °C												14	33		4	3				
			-7 °C												14	31		3	4				
		HVO	+23 °C												12	20		4	1				
			+5 °C												8	16		3	1				
			-7 °C												12	22		2	1				
	1.4 TSI FFV	95 E10	+23 °C												51	179		10	9				
			+5 °C												993	3261		54	20				
			-7 °C												241	1433		22	9				
		RE85	+23 °C												47	112		3	2				
			+5 °C												419	958		8	8				
			-7 °C												747	2436		18	3				
	1.4 TSI CNG	95 E10	+23 °C												70	325		19	14				
			+5 °C												770	1683		20	15				
			-7 °C												405	2016		55	10				
		CNG	+23 °C												70	245		15	18				
			+5 °C												244	512		24	11				
			-7 °C												188	440		34	28				
	BEV	electr.	+23 °C												n/a	n/a		n/a	n/a				
			-7 °C												n/a	n/a		n/a	n/a				

RESULTS IN NUMBERS

Test Matrix: Vehicle - Fuel - Duty-cycle - Ambient temp NOx [mg/km]

Platform	Vehicle	Fuel	Ambient temp.	UDDS cold	UDDS hot	UDDS hot	FTP cold/hot	HWFET hot	US06 hot	LA92 cold	11 mode cold	10.15 mode hot	JC08 cold	JC08 hot	NEDC cold	ART URB cold	ART URB hot	ART RUR hot	ART MWY hot	CADC cold	WLTP[4] cold	Cycle Start	
A	Hyundai Sonata	Gasoline #2	+21 °C																				USA
	Hyundai Sonata Hybrid	Gasoline #3	+22 °C																				
B	Ford Fusion V6	Gasoline #2	+21 °C																				
	Ford Fusion Hybrid	Gasoline #1	+23 °C																				
C	Nissan Bluebird Sylphy	Gasoline	+23 °C								10.23	2.98	16.38	11.12									JPN
	Nissan Bluebird Sylphy Li-LPG	LPG	+23 °C								3.97	9.65	3.53	11.46									
D	Sierra 2500 HD	Diesel	+23 °C				84	26	635				116		199								CDN
		B20 CME	+23 °C				65	23	676														
		B20 HDRD	+23 °C				90	23	613														
		B100 HDRD	+23 °C				83	15	572														
		Diesel	-7 °C				944								1802								
		B20 CME	-7 °C				n/t																
		B20 HDRD	-7 °C				407																
		B100 HDRD	-7 °C				456																
		Diesel	-18 °C				1885																
	Sierra 2500 HD	E0	+23 °C				8	2	24														
		CNG	+23 °C				9	9	14														
	Sierra 2500 FFV	E0	+23 °C				7	2	8														
		E85	+23 °C				7	2	8														
		E0	-7 °C				15																
		E75	-7 °C				13																
	Sierra 1500 Hybrid	E0	+23 °C				9	2	8				14		5								
		E10	+23 °C				12	4	7						4								
		E0	-7 °C				9																
		E10	-7 °C				9																
E	A (1.6L, M)	#93	+25 °C												23								CHN
		E10	+25 °C												22								
		M15	+25 °C												22								
	B (1.6L, A)	#93	+25 °C												14								
		E10	+25 °C												12								
		M15	+25 °C												15								
	C (2.0L, A)	#93	+25 °C												6								
		E10	+25 °C												5								
		M15	+25 °C												6								
F	D (1.6L, M)	#93	+25 °C												5								
		CNG	+25 °C												119								
	E (1.6L, M)	#93	+25 °C												17								
		CNG	+25 °C												32								
	F (1.6L, M)	#93	+25 °C												10								
		CNG	+25 °C												41								
	G (1.6L, M)	#93	+25 °C												7								
		CNG	+25 °C												39								

RESULTS IN NUMBERS

Test Matrix: Vehicle - Fuel - Duty-cycle - Ambient temp **NOx [mg/km]**

Platform	Vehicle	Fuel	Ambient temp.	UDDS	UDDS	UDDS	FTP	HWFET	US06	LA92	11 mode	10.15 mode	JC08	JC08	NEDC	ART URB	ART URB	ART RUR	ART MWY	CADC	WLTP[4]	Cycle	
				cold	hot	hot	cold/hot	hot	hot	cold	cold	hot	cold	hot	cold	cold	hot	hot	hot	cold	cold	Start	
G	SI	E85	+23 °C												48.5	136	57.0	29.0	25.0	n/a			SWE
		E75	-7 °C												34	n/a	n/a	n/a	n/a	n/a			
	CI	Diesel	+23 °C												151	596	1040	453	586	n/a			
			-7 °C												728	n/a	n/a	n/a	n/a	n/a			
	BEV	EL	+23 °C												n/a	n/a	n/a	n/a	n/a	n/a			
			-7 °C												n/a	n/a	n/a	n/a	n/a	n/a			
H	1.4 TSI	95 E10	+23 °C												21	54		16	n/a				FIN
			+5 °C												63	104		11	n/a				
			-7 °C												66	131		12	n/a				
		E95RE	+23 °C												17	53		16	n/a				
			+5 °C												60	94		9	n/a				
			-7 °C												58	105		11	n/a				
	2.0 TSI	95 E10	+23 °C												31	90		8	8				
			+5 °C												94	196		9	15				
			-7 °C												514	226		5	8				
		E95RE	+23 °C												32	119		8	6				
			+5 °C												341	124		7	8				
			-7 °C												380	338		5	8				
	1.6 TDI	EN590(B7)	+23 °C												188	1052		738	859				
			+5 °C												844	1494		954	943				
			-7 °C												784	1547		938	892				
		HVO	+23 °C												168	1049		716	763				
			+5 °C												839	1461		940	874				
			-7 °C												1037	1511		934	849				
	2.0 TDI	EN590(B7)	+23 °C												169	999		738	617				
			+5 °C												831	1647		881	691				
			-7 °C												901	1788		1008	900				
		HVO	+23 °C												163	913		640	501				
			+5 °C												769	1541		825	620				
			-7 °C												851	1658		917	769				
	1.4 TSI FFV	95 E10	+23 °C												17	73		69	33				
			+5 °C												23	24		19	54				
			-7 °C												48	149		158	88				
		RE85	+23 °C												18	112		100	60				
			+5 °C												120	173		274	293				
			-7 °C												46	129		133	91				
	1.4 TSI CNG	95 E10	+23 °C												13	55		7	7				
			+5 °C												66	208		10	9				
			-7 °C												19	107		42	7				
		CNG	+23 °C												13	238		28	6				
			+5 °C												254	835		199	7				
			-7 °C												82	681		198	11				
	BEV	electr.	+23 °C												n/a	n/a		n/a	n/a				
			-7 °C												n/a	n/a		n/a	n/a				

Test Matrix: Vehicle - Fuel - Duty-cycle - Ambient temp **NO [mg/km]**

Test Cycle

Platform	Vehicle	Fuel	Ambient temp.	UDDS	UDDS	UDDS	FTP	HWFET	US06	LA92	11 mode	10.15 mode	JC08	JC08	NEDC	ART URB	ART URB	ART RUR	ART MWY	CADC	WLTP[4]	Cycle	
				cold	hot	hot	cold/hot	hot	hot	cold	cold	hot	cold	hot	cold	cold	hot	hot	hot	cold	cold	Start	
A	Hyundai Sonata	Gasoline #2	+21 °C																				USA
	Hyundai Sonata Hybrid	Gasoline #3	+22 °C																				
B	Ford Fusion V6	Gasoline #2	+21 °C																				
	Ford Fusion Hybrid	Gasoline #1	+23 °C																				
C	Nissan Bluebird Sylphy	Gasoline	+23 °C																				JPN
	Nissan Bluebird Sylphy Li-LPG	LPG	+23 °C																				
D	Sierra 2500 HD	Diesel	+23 °C																				CDN
		B20 CME	+23 °C																				
		B20 HDRD	+23 °C																				
		B100 HDRD	+23 °C																				
		Diesel	-7 °C																				
		B20 CME	-7 °C																				
		B20 HDRD	-7 °C																				
		B100 HDRD	-7 °C																				
		B100 RD_2	-7 °C																				
	Sierra 2500 HD	E0	+23 °C																				
		CNG	+23 °C																				
	Sierra 2500 FFV	E0	+23 °C																				
		E85	+23 °C																				
		E0	-7 °C																				
		E75	-7 °C																				
	Sierra 1500 Hybrid	E0	+23 °C																				
		E10	+23 °C																				
		E0	-7 °C																				
		E10	-7 °C																				
E	A (1.6L, M)	#93	+25 °C																				CHN
		E10	+25 °C																				
		M15	+25 °C																				
	B (1.6L, A)	#93	+25 °C																				
		E10	+25 °C																				
		M15	+25 °C																				
	C (2.0L, A)	#93	+25 °C																				
		E10	+25 °C																				
		M15	+25 °C																				
F	D (1.6L, M)	#93	+25 °C																				
		CNG	+25 °C																				
	E (1.6L, M)	#93	+25 °C																				
		CNG	+25 °C																				
	F (1.6L, M)	#93	+25 °C																				
		CNG	+25 °C																				
	G (1.6L, M)	#93	+25 °C																				
		CNG	+25 °C																				

RESULTS IN NUMBERS

Test Matrix: Vehicle - Fuel - Duty-cycle - Ambient temp **NO [mg/km]**

				Test Cycle																			
Platform	Vehicle	Fuel	Ambient temp.	UDDS cold	UDDS hot	UDDS hot	FTP cold/hot	HWFET hot	US06 hot	LA92 cold	11 mode cold	10.15 mode hot	JC08 cold	JC08 hot	NEDC cold	ART URB cold	ART URB hot	ART RUR hot	ART MWY hot	CADC cold	WLTP[4] cold	Cycle Start	
G	SI	E85	+23 °C												29.5	105	23.5	16.0	17.5	n/a			SWE
		E75	-7 °C												22	n/a	n/a	n/a	n/a	n/a			
	CI	Diesel	+23 °C												61	407	556	254	300	n/a			
			-7 °C												478	n/a	n/a	n/a	n/a	n/a			
	BEV	EL	+23 °C												n/a	n/a	n/a	n/a	n/a	n/a			
			-7 °C												n/a	n/a	n/a	n/a	n/a	n/a			
H	1.4 TSI	95 E10	+23 °C																				FIN
			+5 °C																				
			-7 °C																				
		E95RE	+23 °C																				
			+5 °C																				
			-7 °C																				
	2.0 TSI	95 E10	+23 °C																				
			+5 °C																				
			-7 °C																				
		E95RE	+23 °C																				
			+5 °C																				
			-7 °C																				
	1.6 TDI	EN590(B7)	+23 °C																				
			+5 °C																				
			-7 °C																				
		HVO	+23 °C																				
			+5 °C																				
			-7 °C																				
	2.0 TDI	EN590(B7)	+23 °C																				
			+5 °C																				
			-7 °C																				
		HVO	+23 °C																				
			+5 °C																				
			-7 °C																				
	1.4 TSI FFV	95 E10	+23 °C																				
			+5 °C																				
			-7 °C																				
		RE85	+23 °C																				
			+5 °C																				
			-7 °C																				
	1.4 TSI CNG	95 E10	+23 °C																				
			+5 °C																				
			-7 °C																				
		CNG	+23 °C																				
			+5 °C																				
			-7 °C																				
	BEV	electr.	+23 °C																				
			-7 °C																				

RESULTS IN NUMBERS

Test Matrix: Vehicle - Fuel - Duty-cycle - Ambient temp **NO_2 [mg/km]**

Platform	Vehicle	Fuel	Ambient temp.	Test Cycle																			
				UDDS	UDDS	UDDS	FTP	HWFET	US06	LA92	11 mode	10.15 mode	JC08	JC08	NEDC	ART URB	ART URB	ART RUR	ART MWY	CADC	WLTP[4]	Cycle	
				cold	hot	hot	cold/hot	hot	hot	cold	cold	hot	cold	hot	cold	cold	hot	hot	hot	cold	cold	Start	
A	Hyundai Sonata	Gasoline #2	+21 °C																				USA
	Hyundai Sonata Hybrid	Gasoline #3	+22 °C																				
B	Ford Fusion V6	Gasoline #2	+21 °C																				
	Ford Fusion Hybrid	Gasoline #1	+23 °C																				
C	Nissan Bluebird Sylphy	Gasoline	+23 °C																				JPN
	Nissan Bluebird Sylphy Li-LPG	LPG	+23 °C																				
D	Sierra 2500 HD	Diesel	+23 °C																				CDN
		B20 CME	+23 °C																				
		B20 HDRD	+23 °C																				
		B100 HDRD	+23 °C																				
		Diesel	-7 °C																				
		B20 CME	-7 °C																				
		B20 HDRD	-7 °C																				
		B100 HDRD	-7 °C																				
		Diesel	-18 °C																				
	Sierra 2500 HD	E0	+23 °C																				
		CNG	+23 °C																				
	GMC Sierra 2500 FFV	E0	+23 °C																				
		E85	+23 °C																				
		E0	-7 °C																				
		E75	-7 °C																				
	Sierra 1500 Hybrid	E0	+23 °C																				
		E10	+23 °C																				
		E0	-7 °C																				
		E10	-7 °C																				
E	A (1.6L, M)	#93	+25 °C																				CHN
		E10	+25 °C																				
		M15	+25 °C																				
	B (1.6L, A)	#93	+25 °C																				
		E10	+25 °C																				
		M15	+25 °C																				
	C (2.0L, A)	#93	+25 °C																				
		E10	+25 °C																				
		M15	+25 °C																				
F	D (1.6L, M)	#93	+25 °C																				
		CNG	+25 °C																				
	E (1.6L, M)	#93	+25 °C																				
		CNG	+25 °C																				
	F (1.6L, M)	#93	+25 °C																				
		CNG	+25 °C																				
	G (1.6L, M)	#93	+25 °C																				
		CNG	+25 °C																				

RESULTS IN NUMBERS

Test Matrix: Vehicle - Fuel - Duty-cycle - Ambient temp **NO_2 [mg/km]**

Platform	Vehicle	Fuel	Ambient temp.	UDDS	UDDS	UDDS	FTP	HWFET	US06	LA92	11 mode	10.15 mode	JC08	JC08	NEDC	ART URB	ART URB	ART RUR	ART MWY	CADC	WLTP[4]	Cycle	
				cold	hot	hot	cold/hot	hot	hot	cold	cold	hot	cold	hot	cold	cold	hot	hot	hot	cold	cold	Start	
G	SI	E85	+23 °C												19.0	31	33.5	13.0	7.5	n/a			SWE
		E75	-7 °C												12	n/a	n/a	n/a	n/a	n/a			
	CI	Diesel	+23 °C												91	189	484	199	286	n/a			
			-7 °C												251	n/a	n/a	n/a	n/a	n/a			
	BEV	EL	+23 °C												n/a	n/a	n/a	n/a	n/a	n/a			
			-7 °C												n/a	n/a	n/a	n/a	n/a	n/a			
H	1.4 TSI	95 E10	+23 °C												3	2	0	n/d	n/a				FIN
			+5 °C												3	3	0	1	n/a				
			-7 °C												1	n/d	0	1	n/a				
		E95RE	+23 °C												1	1	0	2	n/a				
			+5 °C												1	n/d	0	1	n/a				
			-7 °C												3	n/d	0	1	n/a				
	2.0 TSI	95 E10	+23 °C												1	n/d	0	1	1				
			+5 °C												4	n/d	0	1	n/d				
			-7 °C												6	n/d	0	0	0				
		E95RE	+23 °C												n/d	n/d	0	1	0				
			+5 °C												15	n/d	0	n/d	0				
			-7 °C												20	n/d	0	1	1				
	1.6 TDI	EN590(B7)	+23 °C												37	191	0	99	361				
			+5 °C												106	212	0	244	391				
			-7 °C												105	225	0	205	363				
		HVO	+23 °C												40	300	0	232	323				
			+5 °C												220	411	0	342	408				
			-7 °C												214	379	0	339	379				
	2.0 TDI	EN590(B7)	+23 °C												40	327	0	108	233				
			+5 °C												189	291	0	240	265				
			-7 °C												214	319	0	247	297				
		HVO	+23 °C												42	226	0	179	197				
			+5 °C												217	363	0	234	253				
			-7 °C												226	333	0	245	281				
	1.4 TSI FFV	95 E10	+23 °C												7	3	0	1	17				
			+5 °C												n/d	n/d	0	1	3				
			-7 °C												17	5	0	n/d	45				
		RE85	+23 °C												8	2	0	3	31				
			+5 °C												7	47	0	29	17				
			-7 °C												18	5	0	0	47				
	1.4 TSI CNG	95 E10	+23 °C												n/d	n/d	0	0	0				
			+5 °C												2	6	0	0	2				
			-7 °C												n/d	n/d	0	n/d	1				
		CNG	+23 °C												n/d	1	0	1	0				
			+5 °C												22	44	0	17	1				
			-7 °C												7	n/d	0	n/d	1				
	BEV	electr.	+23 °C												n/a	n/a		n/a	n/a				
			-7 °C												n/a	n/a		n/a	n/a				

RESULTS IN NUMBERS

Test Matrix: Vehicle - Fuel - Duty-cycle - Ambient temp **N_2O [mg/km]**

Platform	Vehicle	Fuel	Ambient temp.	UDDS	UDDS	UDDS	FTP	HWFET	US06	LA92	11 mode	10.15 mode	JC08	JC08	NEDC	ART URB	ART URB	ART RUR	ART MWY	CADC	WLTP[4]	Cycle	
				cold	hot	hot	cold/hot	hot	hot	cold	cold	hot	cold	hot	cold	cold	hot	hot	hot	cold	cold	Start	
A	Hyundai Sonata	Gasoline #2	+21 °C																				USA
A	Hyundai Sonata Hybrid	Gasoline #3	+22 °C																				USA
B	Ford Fusion V6	Gasoline #2	+21 °C																				USA
B	Ford Fusion Hybrid	Gasoline #1	+23 °C																				USA
C	Nissan Bluebird Sylphy	Gasoline	+23 °C																				JPN
C	Nissan Bluebird Sylphy Li-LPG	LPG	+23 °C																				JPN
D	Sierra 2500 HD	Diesel	+23 °C				88	nt	63				nt		43								CDN
D	Sierra 2500 HD	B20 CME	+23 °C				72	nt	52														CDN
D	Sierra 2500 HD	B20 HDRD	+23 °C				77	nt	59														CDN
D	Sierra 2500 HD	B100 HDRD	+23 °C				68	nt	73														CDN
D	Sierra 2500 HD	Diesel	-7 °C				18								3								CDN
D	Sierra 2500 HD	B20 CME	-7 °C				nt																CDN
D	Sierra 2500 HD	B20 HDRD	-7 °C				6																CDN
D	Sierra 2500 HD	B100 HDRD	-7 °C				2																CDN
D	Sierra 2500 HD	Diesel	-18 °C				39																CDN
D	Sierra 2500 HD	E0	+23 °C				2	nt	1														CDN
D	Sierra 2500 HD	CNG	+23 °C				1	nt	1														CDN
D	GMC Sierra 2500 FFV	E0	+23 °C				2	nt	1														CDN
D	GMC Sierra 2500 FFV	E85	+23 °C				1	nt	1														CDN
D	GMC Sierra 2500 FFV	E0	-7 °C				2																CDN
D	GMC Sierra 2500 FFV	E75	-7 °C				1																CDN
D	Sierra 1500 Hybrid	E0	+23 °C				2	nt	0				nt		1								CDN
D	Sierra 1500 Hybrid	E10	+23 °C				2	nt	0						2								CDN
D	Sierra 1500 Hybrid	E0	-7 °C				1																CDN
D	Sierra 1500 Hybrid	E10	-7 °C				2																CDN
E	A (1.6L, M)	#93	+25 °C																				CHN
E	A (1.6L, M)	E10	+25 °C																				CHN
E	A (1.6L, M)	M15	+25 °C																				CHN
E	B (1.6L, A)	#93	+25 °C																				CHN
E	B (1.6L, A)	E10	+25 °C																				CHN
E	B (1.6L, A)	M15	+25 °C																				CHN
E	C (2.0L, A)	#93	+25 °C																				CHN
E	C (2.0L, A)	E10	+25 °C																				CHN
E	C (2.0L, A)	M15	+25 °C																				CHN
F	D (1.6L, M)	#93	+25 °C																				CHN
F	D (1.6L, M)	CNG	+25 °C																				CHN
F	E (1.6L, M)	#93	+25 °C																				CHN
F	E (1.6L, M)	CNG	+25 °C																				CHN
F	F (1.6L, M)	#93	+25 °C																				CHN
F	F (1.6L, M)	CNG	+25 °C																				CHN
F	G (1.6L, M)	#93	+25 °C																				CHN
F	G (1.6L, M)	CNG	+25 °C																				CHN

RESULTS IN NUMBERS

Test Matrix: Vehicle - Fuel - Duty-cycle - Ambient temp — **N_2O [mg/km]**

Platform	Vehicle	Fuel	Ambient temp.	UDDS	UDDS	UDDS	FTP	HWFET	US06	LA92	11 mode	10.15 mode	JC08	JC08	NEDC	ART URB	ART URB	ART RUR	ART MWY	CADC	WLTP[4]	Cycle	
				cold	hot	hot	cold/hot	hot	hot	cold	cold	hot	cold	hot	cold	cold	hot	hot	hot	cold	cold	Start	
G	SI	E85	+23 °C																				SWE
		E75	-7 °C																				
	CI	Diesel	+23 °C																				
			-7 °C																				
	BEV	EL	+23 °C																				
			-7 °C																				
H	1.4 TSI	95 E10	+23 °C												4	5		2	n/a				FIN
			+5 °C												n/a	n/a		n/a	n/a				
			-7 °C												6	8		2	n/a				
		E95RE	+23 °C												6	8		2	n/a				
			+5 °C												n/a	n/a		n/a	n/a				
			-7 °C												6	8		2	n/a				
	2.0 TSI	95 E10	+23 °C												4	9		2	2				
			+5 °C												n/a	n/a		n/a	n/a				
			-7 °C												15	18		2	3				
		E95RE	+23 °C												4	11		2	2				
			+5 °C												n/a	n/a		n/a	n/a				
			-7 °C												13	21		2	3				
	1.6 TDI	EN590(B7)	+23 °C												3	14		4	1				
			+5 °C												n/a	n/a		n/a	n/a				
			-7 °C												12	22		5	2				
		HVO	+23 °C												4	7		4	2				
			+5 °C												n/a	n/a		n/a	n/a				
			-7 °C												5	15		5	2				
	2.0 TDI	EN590(B7)	+23 °C												4	6		2	1				
			+5 °C												n/a	n/a		n/a	n/a				
			-7 °C												6	10		2	2				
		HVO	+23 °C												3	5		2	2				
			+5 °C												n/a	n/a		n/a	n/a				
			-7 °C												1	7		2	1				
	1.4 TSI FFV	95 E10	+23 °C												4	8		3	3				
			+5 °C												n/a	n/a		n/a	n/a				
			-7 °C												7	11		4	3				
		RE85	+23 °C												5	13		3	3				
			+5 °C												n/a	n/a		n/a	n/a				
			-7 °C												5	13		3	3				
	1.4 TSI CNG	95 E10	+23 °C												3	8		2	2				
			+5 °C												n/a	n/a		n/a	n/a				
			-7 °C												1	7		2	2				
		CNG	+23 °C												3	8		1	1				
			+5 °C												n/a	n/a		n/a	n/a				
			-7 °C												4	13		1	1				
	BEV	electr.	+23 °C												n/a	n/a		n/a	n/a				
			-7 °C												n/a	n/a		n/a	n/a				

RESULTS IN NUMBERS

Test Matrix: Vehicle - Fuel - Duty-cycle - Ambient temp **CH_4 [mg/km]**

Platform	Vehicle	Fuel	Ambient temp.	UDDS	UDDS	UDDS	FTP	HWFET	US06	LA92	11 mode	10.15 mode	JC08	JC08	NEDC	ART URB	ART URB	ART RUR	ART MWY	CADC	WLTP[4]	Cycle	
				cold	hot	hot	cold/hot	hot	hot	cold	cold	hot	cold	hot	cold	cold	hot	hot	hot	cold	cold	Start	
A	Hyundai Sonata	Gasoline #2	+21 °C																				USA
	Hyundai Sonata Hybrid	Gasoline #3	+22 °C																				
B	Ford Fusion V6	Gasoline #2	+21 °C																				
	Ford Fusion Hybrid	Gasoline #1	+23 °C																				
C	Nissan Bluebird Sylphy	Gasoline	+23 °C								43.7	3.23	29.7	0.49									JPN
	Nissan Bluebird Sylphy Li-LPG	LPG	+23 °C								87.6	0.07	56.3	0.47									
D	Sierra 2500 HD	Diesel	+23 °C				20	nt	0				nt		23								CDN
		B20 CME	+23 °C				19	nt	1														
		B20 HDRD	+23 °C				21	nt	0														
		B100 HDRD	+23 °C				22	nt	1														
		Diesel	-7 °C				15								21								
		B20 CME	-7 °C				nt																
		B20 HDRD	-7 °C				13																
		B100 HDRD	-7 °C				11																
		Diesel	-18 °C				11																
	Sierra 2500 HD	E0	+23 °C				7	nt	3														
		CNG	+23 °C				21	nt	12														
	GMC Sierra 2500 FFV	E0	+23 °C				6	nt	3														
		E85	+23 °C				10	nt	3														
		E0	-7 °C				29																
		E75	-7 °C				94																
	Sierra 1500 Hybrid	E0	+23 °C				6	nt	5				nt		16								
		E10	+23 °C				6	nt	6						17								
		E0	-7 °C				23																
		E10	-7 °C				23																
E	A (1.6L, M)	#93	+25 °C																				CHN
		E10	+25 °C																				
		M15	+25 °C																				
	B (1.6L, A)	#93	+25 °C																				
		E10	+25 °C																				
		M15	+25 °C																				
	C (2.0L, A)	#93	+25 °C																				
		E10	+25 °C																				
		M15	+25 °C																				
F	D (1.6L, M)	#93	+25 °C																				
		CNG	+25 °C																				
	E (1.6L, M)	#93	+25 °C																				
		CNG	+25 °C																				
	F (1.6L, M)	#93	+25 °C																				
		CNG	+25 °C																				
	G (1.6L, M)	#93	+25 °C																				
		CNG	+25 °C																				

RESULTS IN NUMBERS

Test Matrix: Vehicle - Fuel - Duty-cycle - Ambient temp **CH_4 [mg/km]**

Platform	Vehicle	Fuel	Ambient temp.	UDDS cold	UDDS hot	UDDS hot	FTP cold/hot	HWFET hot	US06 hot	LA92 cold	11 mode cold	10.15 mode hot	JC08 cold	JC08 hot	NEDC cold	ART URB cold	ART URB hot	ART RUR hot	ART MWY hot	CADC cold	WLTP[4] cold	Cycle Start	
G	SI	E85	+23 °C																				SWE
		E75	-7 °C																				
	CI	Diesel	+23 °C																				
			-7 °C																				
	BEV	EL	+23 °C																				
			-7 °C																				
H	1.4 TSI	95 E10	+23 °C												8	20		2	n/a				FIN
			+5 °C												n/a	n/a		n/a	n/a				
			-7 °C												37	157		4	n/a				
		E95RE	+23 °C												8	20		2	n/a				
			+5 °C												n/a	n/a		n/a	n/a				
			-7 °C												38	159		4	n/a				
	2.0 TSI	95 E10	+23 °C												4	14		2	3				
			+5 °C												n/a	n/a		n/a	n/a				
			-7 °C												18	55		2	3				
		E95RE	+23 °C												5	13		2	3				
			+5 °C												n/a	n/a		n/a	n/a				
			-7 °C												16	48		2	3				
	1.6 TDI	EN590(B7)	+23 °C												0	3		0	0				
			+5 °C												n/a	n/a		n/a	n/a				
			-7 °C												0	1		0	0				
		HVO	+23 °C												1	1		0	0				
			+5 °C												n/a	n/a		n/a	n/a				
			-7 °C												1	1		0	0				
	2.0 TDI	EN590(B7)	+23 °C												1	1		0	0				
			+5 °C												n/a	n/a		n/a	n/a				
			-7 °C												1	2		0	1				
		HVO	+23 °C												1	1		0	0				
			+5 °C												n/a	n/a		n/a	n/a				
			-7 °C												0	2		0	0				
	1.4 TSI FFV	95 E10	+23 °C												6	20		2	3				
			+5 °C												n/a	n/a		n/a	n/a				
			-7 °C												51	115		4	2				
		RE85	+23 °C												16	43		1	1				
			+5 °C												n/a	n/a		n/a	n/a				
			-7 °C												84	351		3	1				
	1.4 TSI CNG	95 E10	+23 °C												6	28		1	2				
			+5 °C												n/a	n/a		n/a	n/a				
			-7 °C												20	158		6	1				
		CNG	+23 °C												6	3		0	0				
			+5 °C												n/a	n/a		n/a	n/a				
			-7 °C												2	4		0	1				
	BEV	electr.	+23 °C												n/a	n/a		n/a	n/a				
			-7 °C												n/a	n/a		n/a	n/a				

RESULTS IN NUMBERS

Test Matrix: Vehicle - Fuel - Duty-cycle - Ambient temp **TPM [mg/km]**

Platform	Vehicle	Fuel	Ambient temp.	Test Cycle: UDDS	UDDS	UDDS	FTP	HWFET	US06	LA92	11 mode	10.15 mode	JC08	JC08	NEDC	ART URB	ART URB	ART RUR	ART MWY	CADC	WLTP[4]	Cycle	
				cold	hot	hot	cold/hot	hot	hot	cold	cold	hot	cold	hot	cold	cold	hot	hot	hot	cold	cold	Start	
A	Hyundai Sonata	Gasoline #2	+21 °C																				USA
	Hyundai Sonata Hybrid	Gasoline #3	+22 °C																				
B	Ford Fusion V6	Gasoline #2	+21 °C																				
	Ford Fusion Hybrid	Gasoline #1	+23 °C																				
C	Nissan Bluebird Sylphy	Gasoline	+23 °C																				JPN
	Nissan Bluebird Sylphy Li-LPG	LPG	+23 °C																				
D	Sierra 2500 HD	Diesel	+23 °C				0.4	1.0	0.9				nt		0.8								CDN
		B20 CME	+23 °C				0.2	0.2	2.5														
		B20 HDRD	+23 °C				0.2	0.1	0.7														
		B100 HDRD	+23 °C				0.5	1.9	1.0														
		Diesel	-7 °C				0.5								2.0								
		B20 CME	-7 °C				nt																
		B20 HDRD	-7 °C				0.4																
		B100 HDRD	-7 °C				0.5																
		Diesel	-18 °C				2.6																
	Sierra 2500 HD	E0	+23 °C				4.0	nt	13.7														
		CNG	+23 °C				2.5	nt	6.6														
	Sierra 2500 FFV	E0	+23 °C				2.6	nt	0.7														
		E85	+23 °C				2.2	nt	0.5														
		E0	-7 °C				8.9																
		E75	-7 °C				2.4																
	Sierra 1500 Hybrid	E0	+23 °C				0.7	1.2	0.9				nt		0.3								
		E10	+23 °C				0.3	1.2	1.4						0.1								
		E0	-7 °C				3.2																
		E10	-7 °C				2.7																
E	A (1.6L, M)	#93	+25 °C																				CHN
		E10	+25 °C																				
		M15	+25 °C																				
	B (1.6L, A)	#93	+25 °C																				
		E10	+25 °C																				
		M15	+25 °C																				
	C (2.0L, A)	#93	+25 °C																				
		E10	+25 °C																				
		M15	+25 °C																				
F	D (1.6L, M)	#93	+25 °C																				
		CNG	+25 °C																				
	E (1.6L, M)	#93	+25 °C																				
		CNG	+25 °C																				
	F (1.6L, M)	#93	+25 °C																				
		CNG	+25 °C																				
	G (1.6L, M)	#93	+25 °C																				
		CNG	+25 °C																				

RESULTS IN NUMBERS

Test Matrix: Vehicle - Fuel - Duty-cycle - Ambient temp **TPM [mg/km]**

Platform	Vehicle	Fuel	Ambient temp.	UDDS cold	UDDS hot	UDDS hot	FTP cold/hot	HWFET hot	US06 hot	LA92 cold	11 mode cold	10.15 mode hot	JC08 cold	JC08 hot	NEDC cold	ART URB cold	ART URB hot	ART RUR hot	ART MWY hot	CADC cold	WLTP[4] cold	Cycle Start	
G	SI	E85	+23 °C												0.16	0.38	0.65	0.23	1.44	n/a			SWE
		E75	-7 °C												1.67	n/a	n/a	n/a	n/a	n/a			
	CI	Diesel	+23 °C												0.40	0.77	1.13	0.62	0.90	n/a			
			-7 °C												0.75	n/a	n/a	n/a	n/a	n/a			
	BEV	EL	+23 °C												n/a	n/a	n/a	n/a	n/a	n/a			
			-7 °C												n/a	n/a	n/a	n/a	n/a	n/a			
H	1.4 TSI	95 E10	+23 °C												2.55	11.46		5.85	n/a				FIN
			+5 °C												0.00	36.08		1.53	n/a				
			-7 °C												12.63	70.51		2.77	n/a				
		E95RE	+23 °C												2.31	7.80		1.09	n/a				
			+5 °C												5.08	31.45		1.83	n/a				
			-7 °C												14.91	79.46		4.30	n/a				
	2.0 TSI	95 E10	+23 °C												n/a	n/a		n/a	n/a				
			+5 °C												n/a	n/a		n/a	n/a				
			-7 °C												n/a	n/a		n/a	n/a				
		E95RE	+23 °C												n/a	n/a		n/a	n/a				
			+5 °C												n/a	n/a		n/a	n/a				
			-7 °C												n/a	n/a		n/a	n/a				
	1.6 TDI	EN590(B7)	+23 °C												0.17	1.03		0.30	1.30				
			+5 °C												0.17	0.62		0.34	0.98				
			-7 °C												0.33	0.12		0.24	1.05				
		HVO	+23 °C												0.22	0.33		0.31	1.42				
			+5 °C												0.41	0.12		0.24	1.12				
			-7 °C												0.23	0.31		0.39	0.96				
	2.0 TDI	EN590(B7)	+23 °C												0.18	0.51		0.54	3.04				
			+5 °C												0.28	0.65		0.43	1.81				
			-7 °C												0.37	0.97		0.49	3.14				
		HVO	+23 °C												0.11	0.15		0.32	3.09				
			+5 °C												0.21	0.31		0.21	1.52				
			-7 °C												0.23	0.96		0.30	2.22				
	1.4 TSI FFV	95 E10	+23 °C												n/a	n/a		n/a	n/a				
			+5 °C												n/a	n/a		n/a	n/a				
			-7 °C												n/a	n/a		n/a	n/a				
		RE85	+23 °C												n/a	n/a		n/a	n/a				
			+5 °C												n/a	n/a		n/a	n/a				
			-7 °C												n/a	n/a		n/a	n/a				
	1.4 TSI CNG	95 E10	+23 °C												n/a	n/a		n/a	n/a				
			+5 °C												n/a	n/a		n/a	n/a				
			-7 °C												n/a	n/a		n/a	n/a				
		CNG	+23 °C												n/a	n/a		n/a	n/a				
			+5 °C												n/a	n/a		n/a	n/a				
			-7 °C												n/a	n/a		n/a	n/a				
	BEV	electr.	+23 °C												n/a	n/a		n/a	n/a				
			-7 °C												n/a	n/a		n/a	n/a				

RESULTS IN NUMBERS

Test Matrix: Vehicle - Fuel - Duty-cycle - Ambient temp **NH_3 [mg/km]**

Platform	Vehicle	Fuel	Ambient temp.	Test Cycle																			
				UDDS	UDDS	UDDS	FTP	HWFET	US06	LA92	11 mode	10.15 mode	JC08	JC08	NEDC	ART URB	ART URB	ART RUR	ART MWY	CADC	WLTP[4]	Cycle	
				cold	hot	hot	cold/hot	hot	hot	cold	cold	hot	cold	hot	cold	cold	hot	hot	hot	cold	cold	Start	
A	Hyundai Sonata	Gasoline #2	+21 °C																				USA
	Hyundai Sonata Hybrid	Gasoline #3	+22 °C																				
B	Ford Fusion V6	Gasoline #2	+21 °C																				
	Ford Fusion Hybrid	Gasoline #1	+23 °C																				
C	Nissan Bluebird Sylphy	Gasoline	+23 °C																				JPN
	Nissan Bluebird Sylphy Li-LPG	LPG	+23 °C																				
D	Sierra 2500 HD	Diesel	+23 °C																				CDN
		B20 CME	+23 °C																				
		B20 HDRD	+23 °C																				
		B100 HDRD	+23 °C																				
		Diesel	-7 °C																				
		B20 CME	-7 °C																				
		B20 HDRD	-7 °C																				
		B100 HDRD	-7 °C																				
		Diesel	-18 °C																				
	Sierra 2500 HD	E0	+23 °C																				
		CNG	+23 °C																				
	GMC Sierra 2500 FFV	E0	+23 °C																				
		E85	+23 °C																				
		E0	-7 °C																				
		E75	-7 °C																				
	Sierra 1500 Hybrid	E0	+23 °C																				
		E10	+23 °C																				
		E0	-7 °C																				
		E10	-7 °C																				
E	A (1.6L, M)	#93	+25 °C																				CHN
		E10	+25 °C																				
		M15	+25 °C																				
	B (1.6L, A)	#93	+25 °C																				
		E10	+25 °C																				
		M15	+25 °C																				
	C (2.0L, A)	#93	+25 °C																				
		E10	+25 °C																				
		M15	+25 °C																				
F	D (1.6L, M)	#93	+25 °C																				
		CNG	+25 °C																				
	E (1.6L, M)	#93	+25 °C																				
		CNG	+25 °C																				
	F (1.6L, M)	#93	+25 °C																				
		CNG	+25 °C																				
	G (1.6L, M)	#93	+25 °C																				
		CNG	+25 °C																				

RESULTS IN NUMBERS

Test Matrix: Vehicle - Fuel - Duty-cycle - Ambient temp **NH_3 [mg/km]**

Test Cycle

Platform	Vehicle	Fuel	Ambient temp.	UDDS	UDDS	UDDS	FTP	HWFET	US06	LA92	11 mode	10.15 mode	JC08	JC08	NEDC	ART URB	ART URB	ART RUR	ART MWY	CADC	WLTP[4]	Cycle	
				cold	hot	hot	cold/hot	hot	hot	cold	cold	hot	cold	hot	cold	cold	hot	hot	hot	cold	cold	Start	
G	SI	E85	+23 °C																				SWE
		E75	-7 °C																				
	CI	Diesel	+23 °C																				
			-7 °C																				
	BEV	EL	+23 °C																				
			-7 °C																				
H	1.4 TSI	95 E10	+23 °C												9	27	0	8	0				FIN
			+5 °C												n/a	n/a	0	n/a	0				
			-7 °C												27	100	0	32	0				
		E95RE	+23 °C												9	24	0	6	0				
			+5 °C												n/a	n/a	0	n/a	0				
			-7 °C												22	79	0	29	0				
	2.0 TSI	95 E10	+23 °C												14	54	0	21	18				
			+5 °C												n/a	n/a	0	n/a	n/a				
			-7 °C												24	122	0	20	19				
		E95RE	+23 °C												11	38	0	21	13				
			+5 °C												n/a	n/a	0	n/a	n/a				
			-7 °C												22	67	0	14	14				
	1.6 TDI	EN590(B7)	+23 °C												1	3	0	0	0				
			+5 °C												n/a	n/a	0	n/a	n/a				
			-7 °C												1	1	0	0	0				
		HVO	+23 °C												1	3	0	0	0				
			+5 °C												n/a	n/a	0	n/a	n/a				
			-7 °C												1	1	0	1	1				
	2.0 TDI	EN590(B7)	+23 °C												1	2	0	0	0				
			+5 °C												n/a	n/a	0	n/a	n/a				
			-7 °C												1	3	0	0	1				
		HVO	+23 °C												1	2	0	1	1				
			+5 °C												n/a	n/a	0	n/a	n/a				
			-7 °C												1	4	0	0	0				
	1.4 TSI FFV	95 E10	+23 °C												18	58	0	43	14				
			+5 °C												n/a	n/a	0	n/a	n/a				
			-7 °C												49	202	0	50	18				
		RE85	+23 °C												7	23	0	14	7				
			+5 °C												n/a	n/a	0	n/a	n/a				
			-7 °C												18	116	0	41	5				
	1.4 TSI CNG	95 E10	+23 °C												26	115	0	59	17				
			+5 °C												n/a	n/a	0	n/a	n/a				
			-7 °C												38	269	0	69	11				
		CNG	+23 °C												26	23	0	29	11				
			+5 °C												n/a	n/a	0	n/a	n/a				
			-7 °C												26	18	0	21	9				
	BEV	electr.	+23 °C												n/a	n/a		n/a	n/a				
			-7 °C												n/a	n/a		n/a	n/a				

RESULTS IN NUMBERS

Results for HCHO

Platform	Vehicle	Fuel	Ambient temp.	Test Cycle NEDC cold Cycle Start
				mg/km
E	A (1.6L, M)	#93	+25 °C	0.323
		E10	+25 °C	0.288
		M15	+25 °C	0.382
	B (1.6L, A)	#93	+25 °C	0.163
		E10	+25 °C	0.152
		M15	+25 °C	0.286
	C (2.0L, A)	#93	+25 °C	0.259
		E10	+25 °C	0.226
		M15	+25 °C	0.394
F	D (1.6L, M)	#93	+25 °C	n/a
		CNG	+25 °C	n/a
	E (1.6L, M)	#93	+25 °C	n/a
		CNG	+25 °C	n/a
	F (1.6L, M)	#93	+25 °C	n/a
		CNG	+25 °C	n/a
	G (1.6L, M)	#93	+25 °C	n/a
		CNG	+25 °C	n/a

RESULTS IN NUMBERS

Results for Benzene

Platform	Vehicle	Fuel	Ambient temp.	Test Cycle NEDC cold	Test Cycle Cycle Start
				mg/km	
E	A (1.6L, M)	#93	+25 °C	6.51	
		E10	+25 °C	3.21	
		M15	+25 °C	3.57	
	B (1.6L, A)	#93	+25 °C	5.49	
		E10	+25 °C	3.18	
		M15	+25 °C	3.47	
	C (2.0L, A)	#93	+25 °C	5.94	
		E10	+25 °C	3.08	
		M15	+25 °C	4.65	
F	D (1.6L, M)	#93	+25 °C	n/a	
		CNG	+25 °C	n/a	
	E (1.6L, M)	#93	+25 °C	n/a	
		CNG	+25 °C	n/a	
	F (1.6L, M)	#93	+25 °C	n/a	
		CNG	+25 °C	n/a	
	G (1.6L, M)	#93	+25 °C	n/a	
		CNG	+25 °C	n/a	

Results for Toluene

Platform	Vehicle	Fuel	Ambient temp.	Test Cycle NEDC cold	Cycle Start
				mg/km	
E	A (1.6L, M)	#93	+25 °C	17.4	
		E10	+25 °C	10.8	
		M15	+25 °C	12.3	
	B (1.6L, A)	#93	+25 °C	24.0	
		E10	+25 °C	10.6	
		M15	+25 °C	13.5	
	C (2.0L, A)	#93	+25 °C	24.2	
		E10	+25 °C	9.7	
		M15	+25 °C	16.7	
F	D (1.6L, M)	#93	+25 °C	n/a	
		CNG	+25 °C	n/a	
	E (1.6L, M)	#93	+25 °C	n/a	
		CNG	+25 °C	n/a	
	F (1.6L, M)	#93	+25 °C	n/a	
		CNG	+25 °C	n/a	
	G (1.6L, M)	#93	+25 °C	n/a	
		CNG	+25 °C	n/a	

Additional graphs of results from testing in Finland.

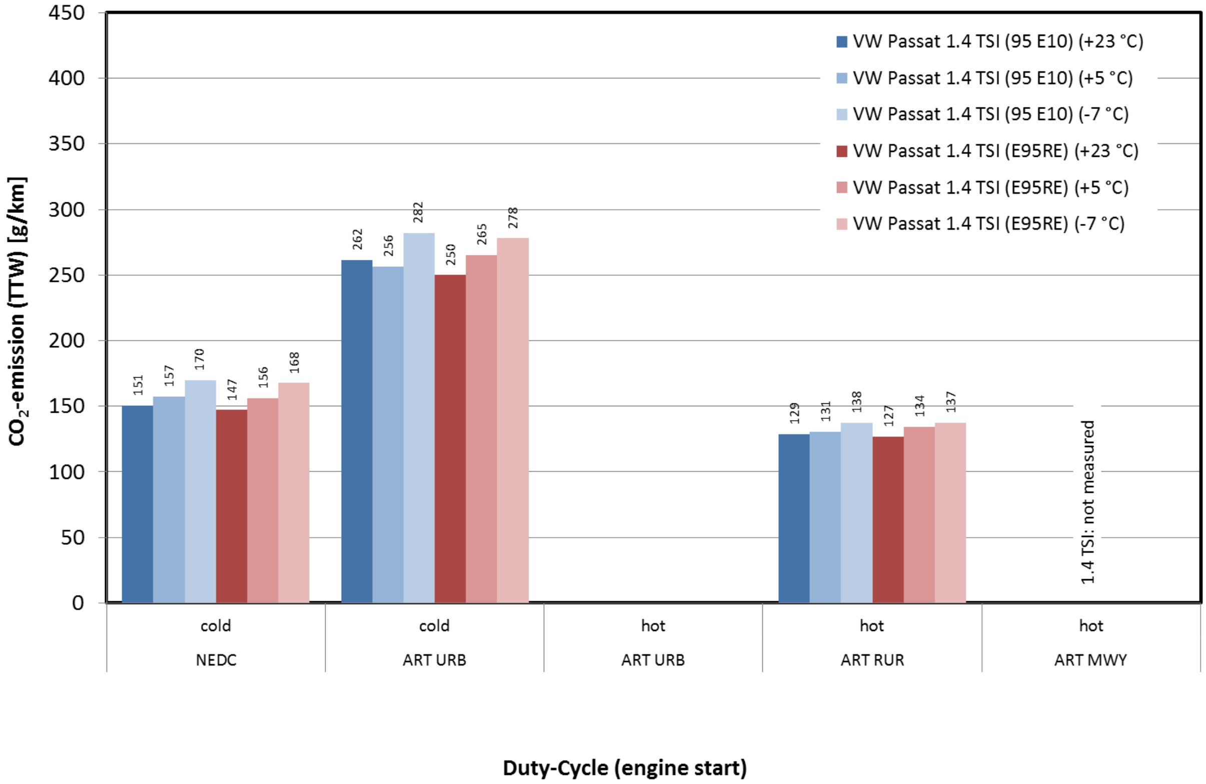


Figure 1: CO_2 emissions from the 1.4 TSI (SI-engine) car tested in Finland with regular and “biogasoline”, at +23, +5 and -7 °C ambient temperature; NEDC and ARTEMIS cycles.

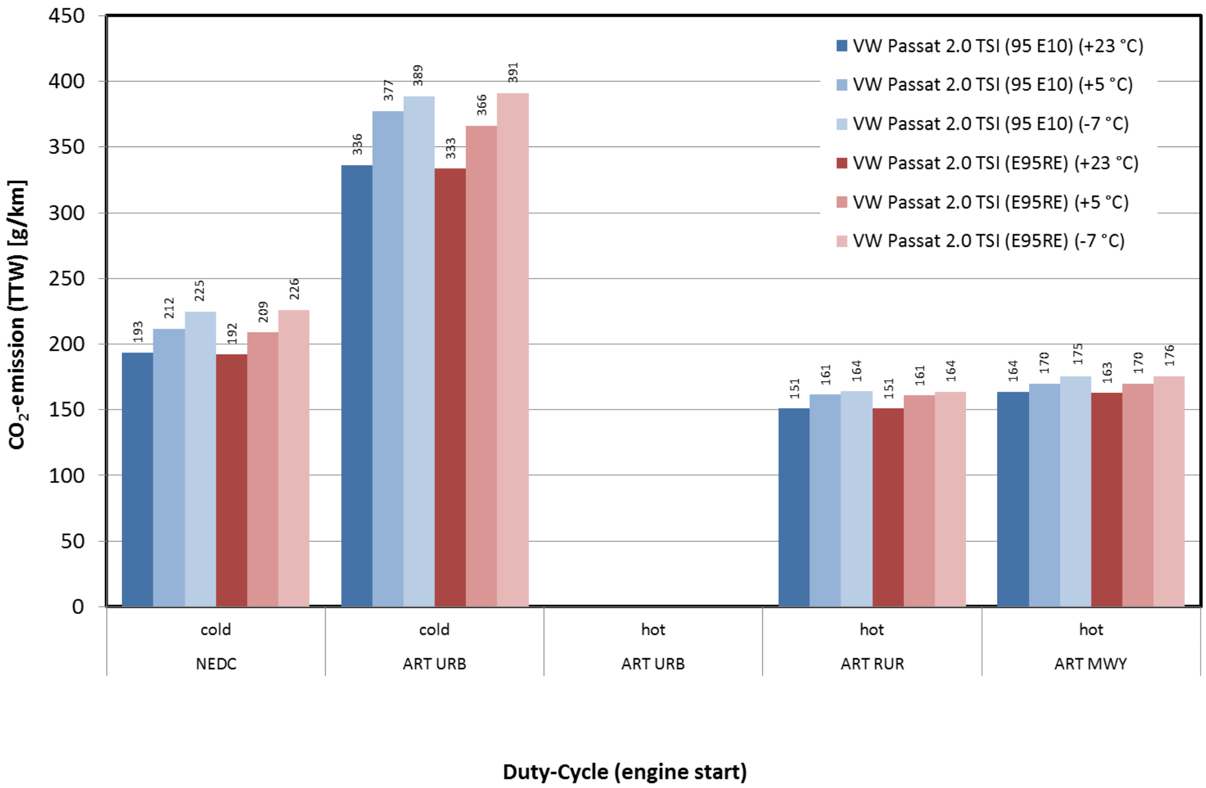


Figure 2: CO_2 emissions from the 2.0 TSI (SI-engine) car tested in Finland with regular and “biogasoline”, at +23, +5 and -7 °C ambient temperature; NEDC and ARTEMIS cycles.

Additional graphs of results from testing in Finland.

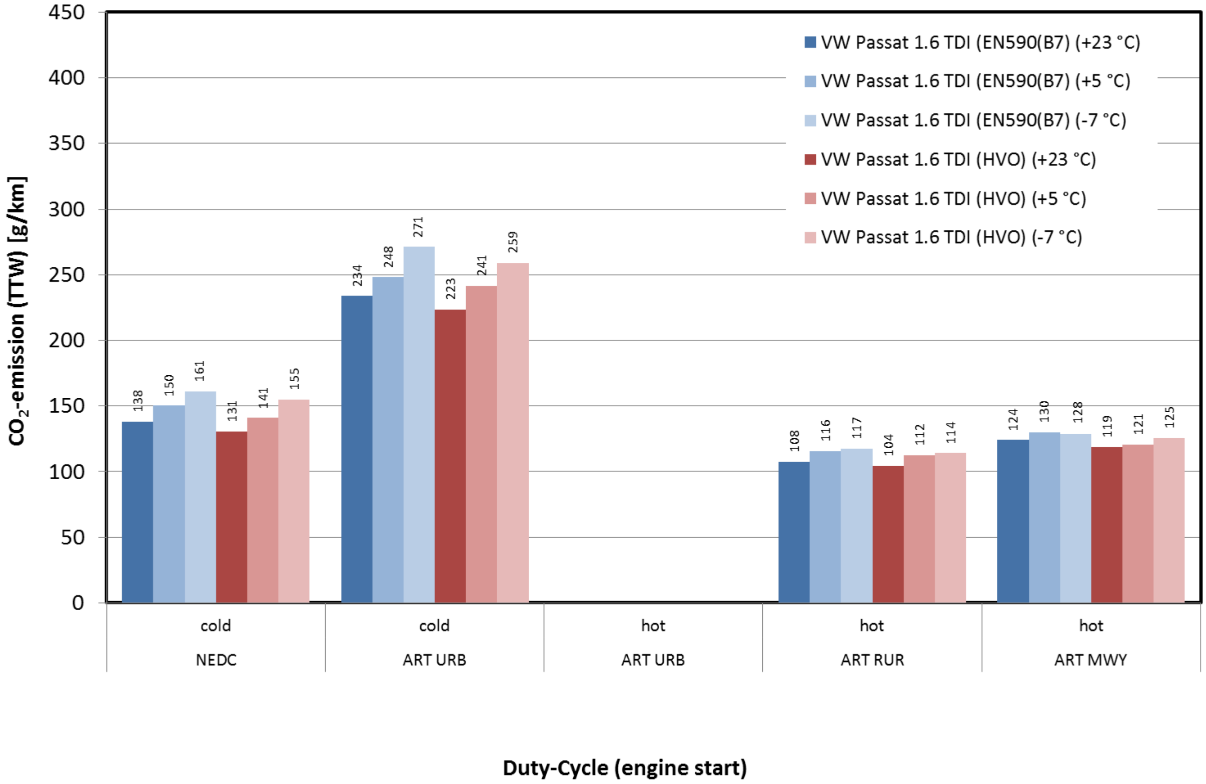


Figure 3: CO_2 emissions from the 1.6 TDI (CI-engine) car tested in Finland with regular EN590 diesel and fully paraffinic fuel (HVO), at +23, +5 and -7 °C ambient temperature; NEDC and ARTEMIS cycles.

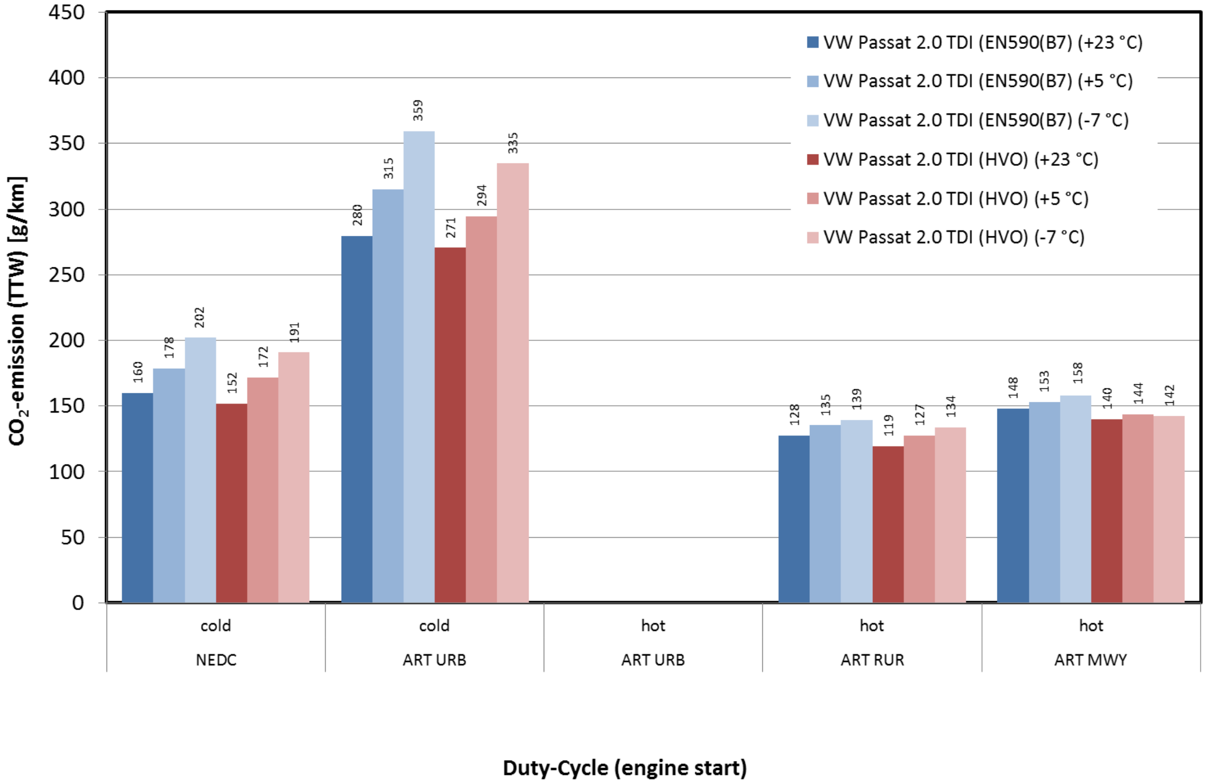


Figure 4: CO_2 emissions from the 2.0 TDI (CI-engine) car tested in Finland with regular EN590 diesel and fully paraffinic fuel (HVO), at +23, +5 and -7 °C ambient temperature; NEDC and ARTEMIS cycles.

Additional graphs of results from testing in Finland.

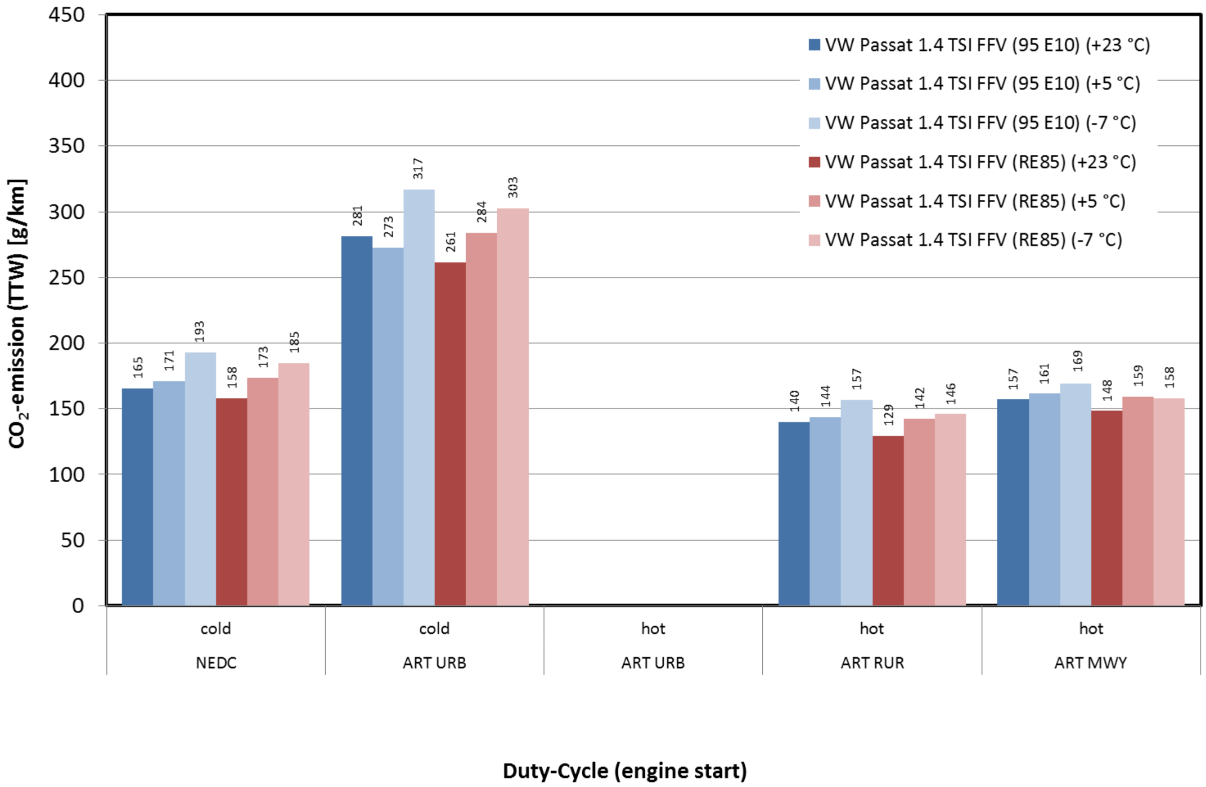


Figure 5: CO_2 emissions from the 1.4 TSI FFV (SI-engine) car tested in Finland with regular gasoline and with E85, at +23, +5 and -7 °C ambient temperature; NEDC and ARTEMIS cycles.

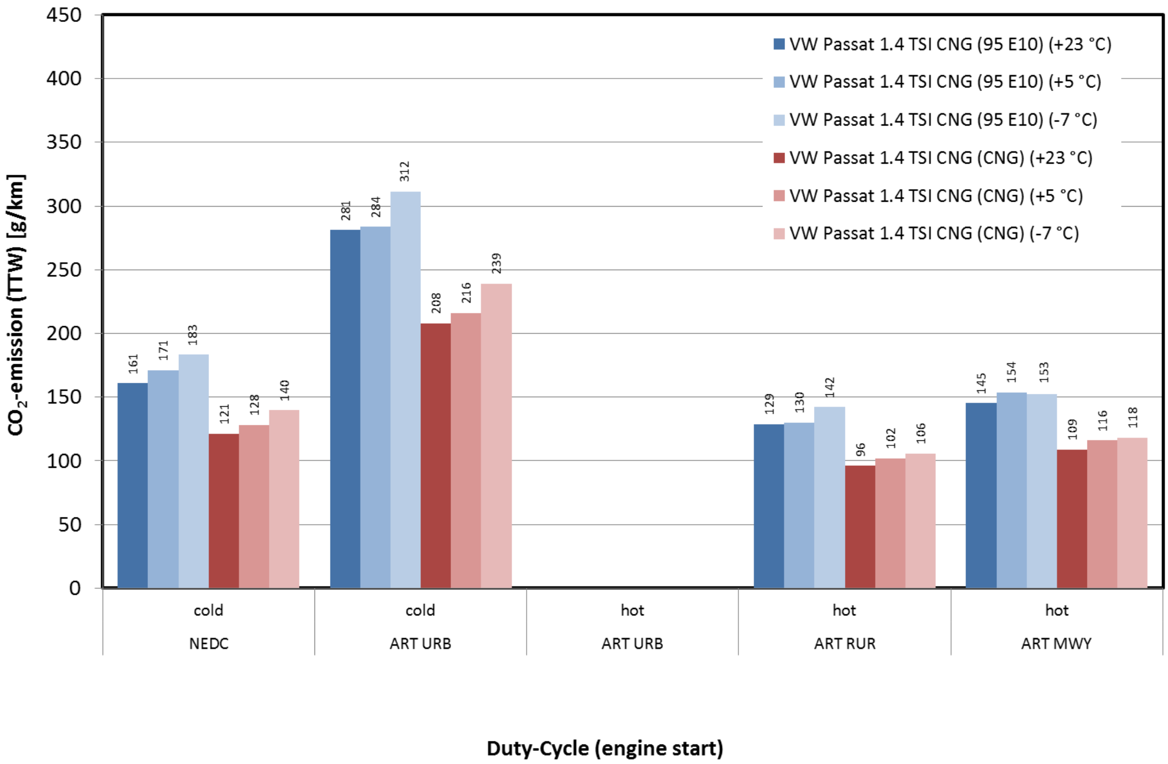


Figure 6: CO_2 emissions from the 1.4 TSI CNG (SI-engine) car tested in Finland with regular gasoline and CNG at +23, +5 and -7 °C ambient temperature; NEDC and ARTEMIS cycles.

Additional graphs of results from testing in Finland.

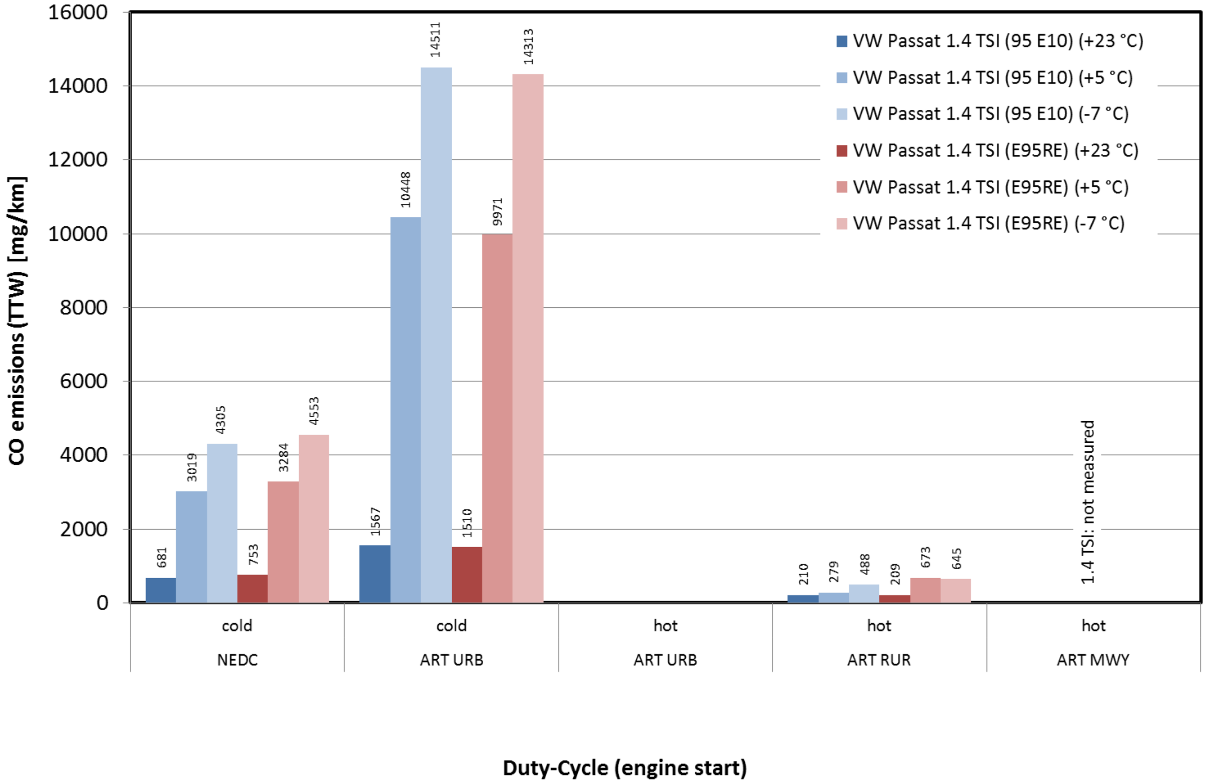


Figure 7: CO emissions from the 1.4 TSI (SI-engine) car tested in Finland with regular and “biogasoline”, at +23, +5 and -7 °C ambient temperature; NEDC and ARTEMIS cycles.

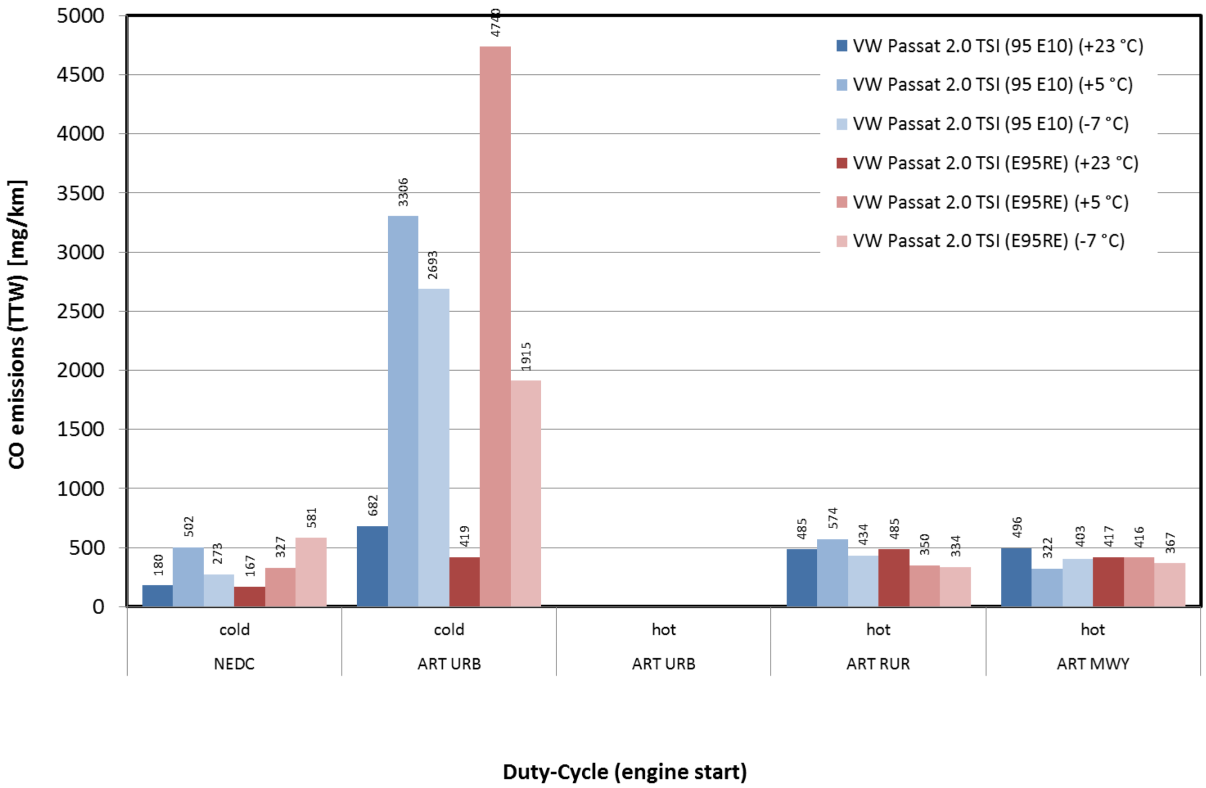


Figure 8: CO emissions from the 2.0 TSI (SI-engine) car tested in Finland with regular and “biogasoline”, at +23, +5 and -7 °C ambient temperature; NEDC and ARTEMIS cycles.

Additional graphs of results from testing in Finland.

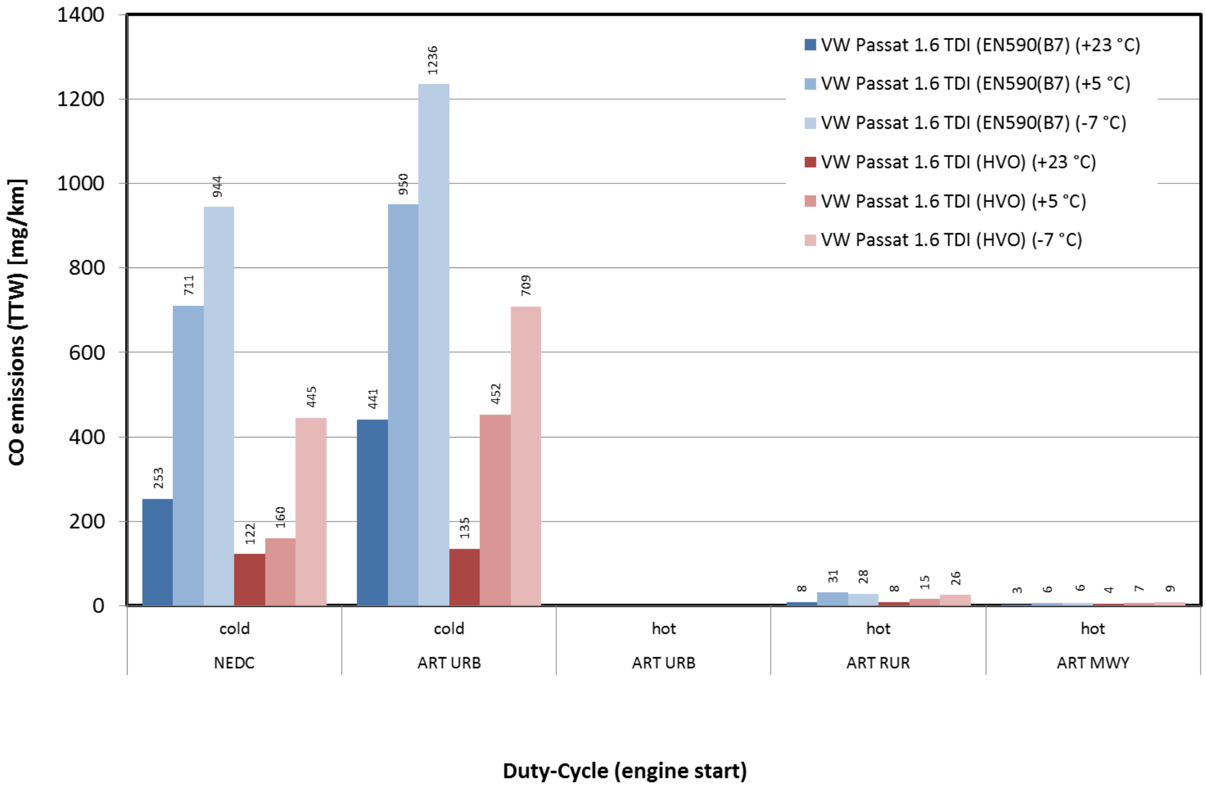


Figure 9: CO emissions from the 1.6 TDI (CI-engine) car tested in Finland with regular EN590 diesel and fully paraffinic fuel (HVO), at +23, +5 and -7 °C ambient temperature; NEDC and ARTEMIS cycles.

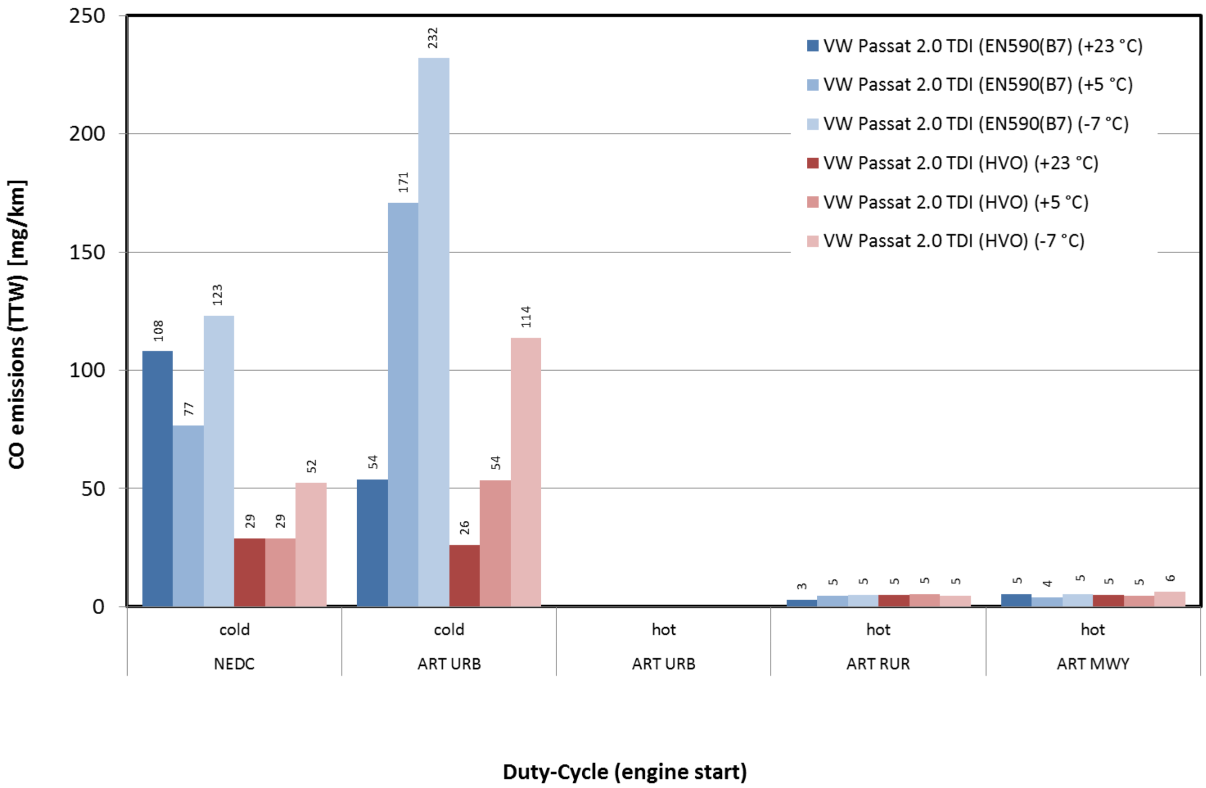


Figure 10: CO emissions from the 2.0 TDI (CI-engine) car tested in Finland with regular EN590 diesel and fully paraffinic fuel (HVO), at +23, +5 and -7 °C ambient temperature; NEDC and ARTEMIS cycles.

Additional graphs of results from testing in Finland.

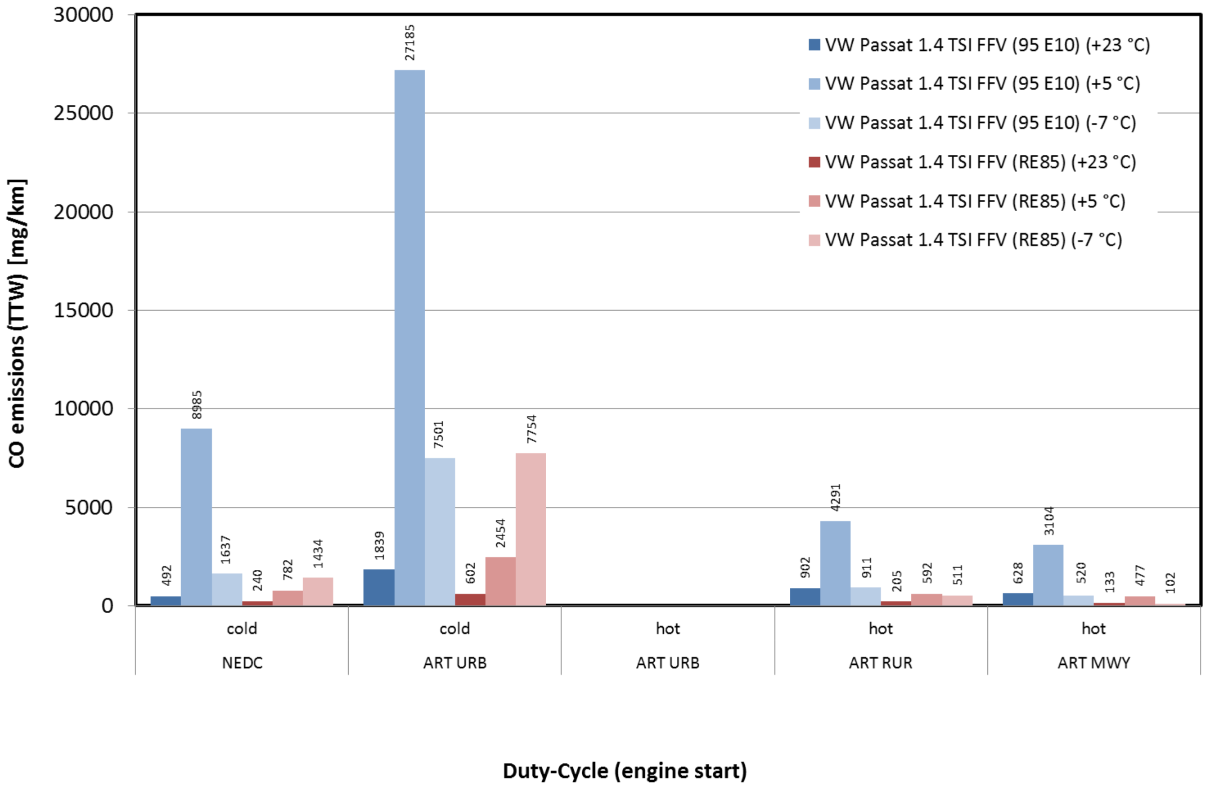


Figure 11: CO emissions from the 1.4 TSI FFV (SI-engine) car tested in Finland with regular gasoline and with E85, at +23, +5 and -7 °C ambient temperature; NEDC and ARTEMIS cycles.

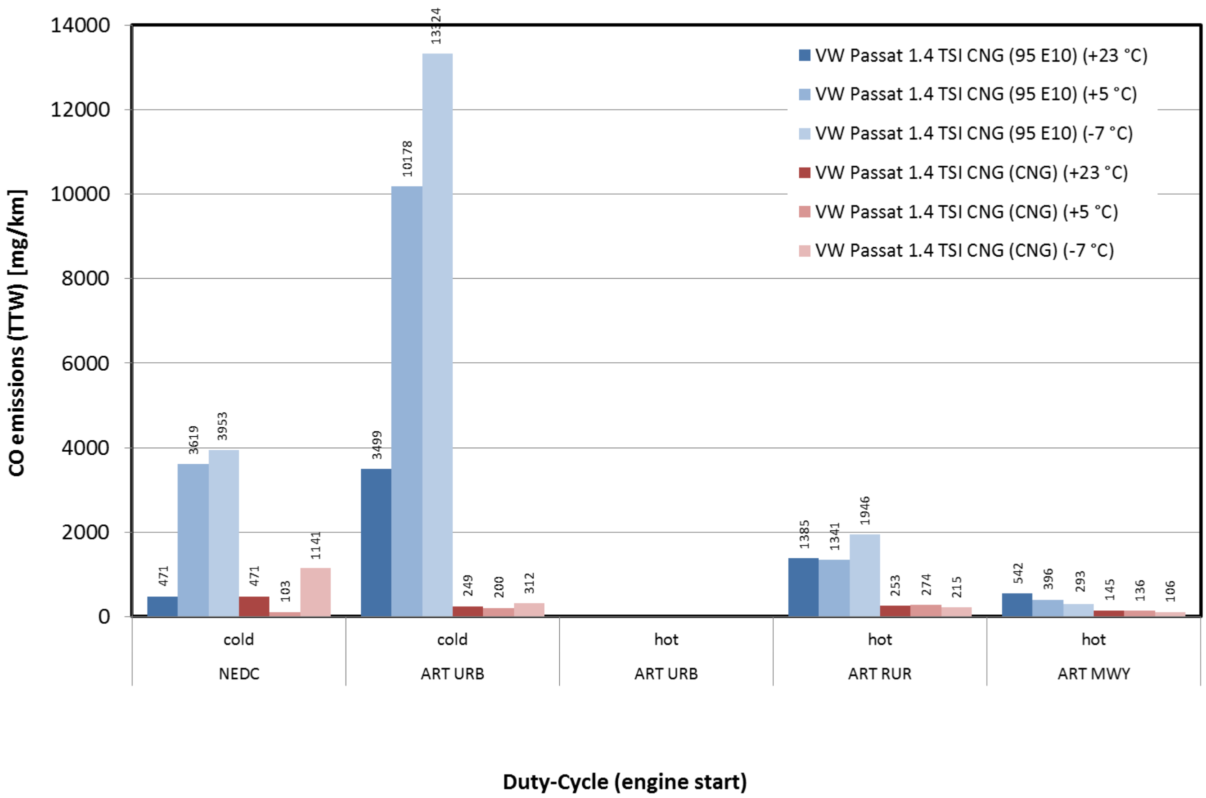


Figure 12: CO emissions from the 1.4 TSI CNG (SI-engine) car tested in Finland with regular gasoline and CNG at +23, +5 and -7 °C ambient temperature; NEDC and ARTEMIS cycles.

Additional graphs of results from testing in Finland.

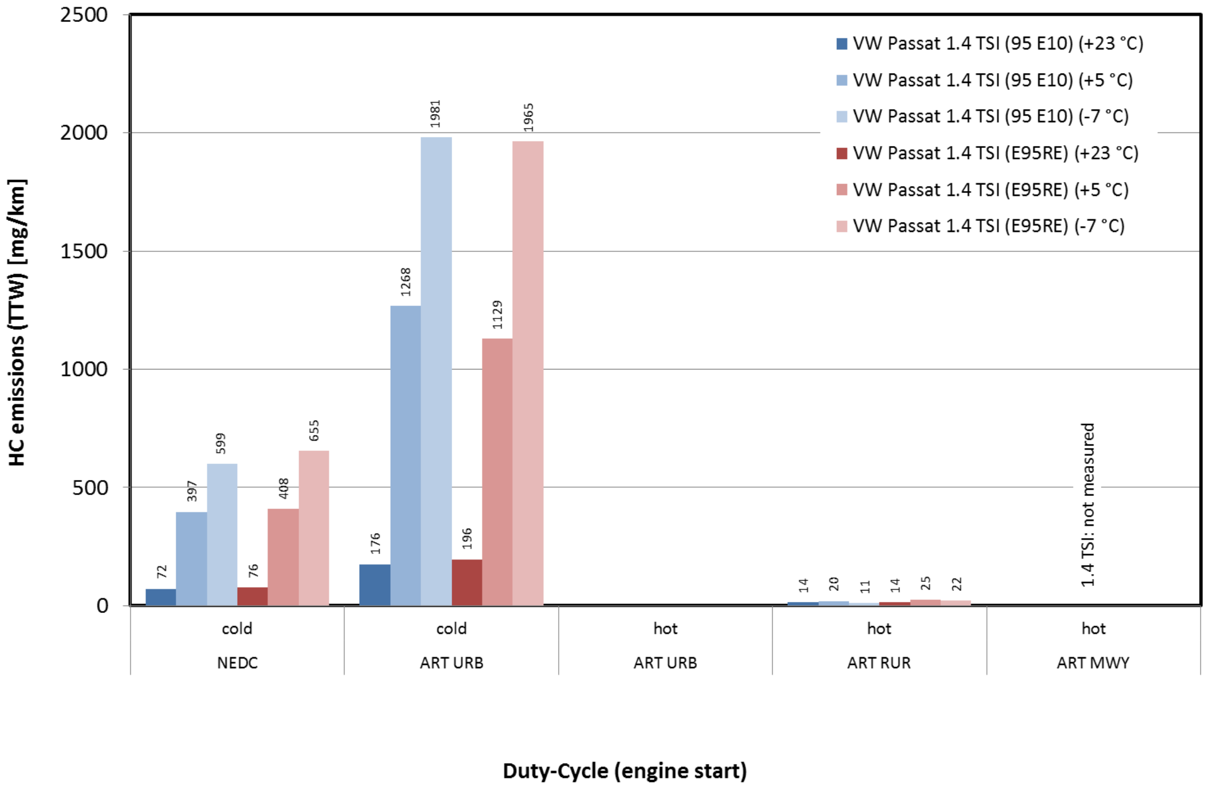


Figure 13: HC emissions from the 1.4 TSI (SI-engine) car tested in Finland with regular and “biogasoline”, at +23, +5 and -7 °C ambient temperature; NEDC and ARTEMIS cycles.

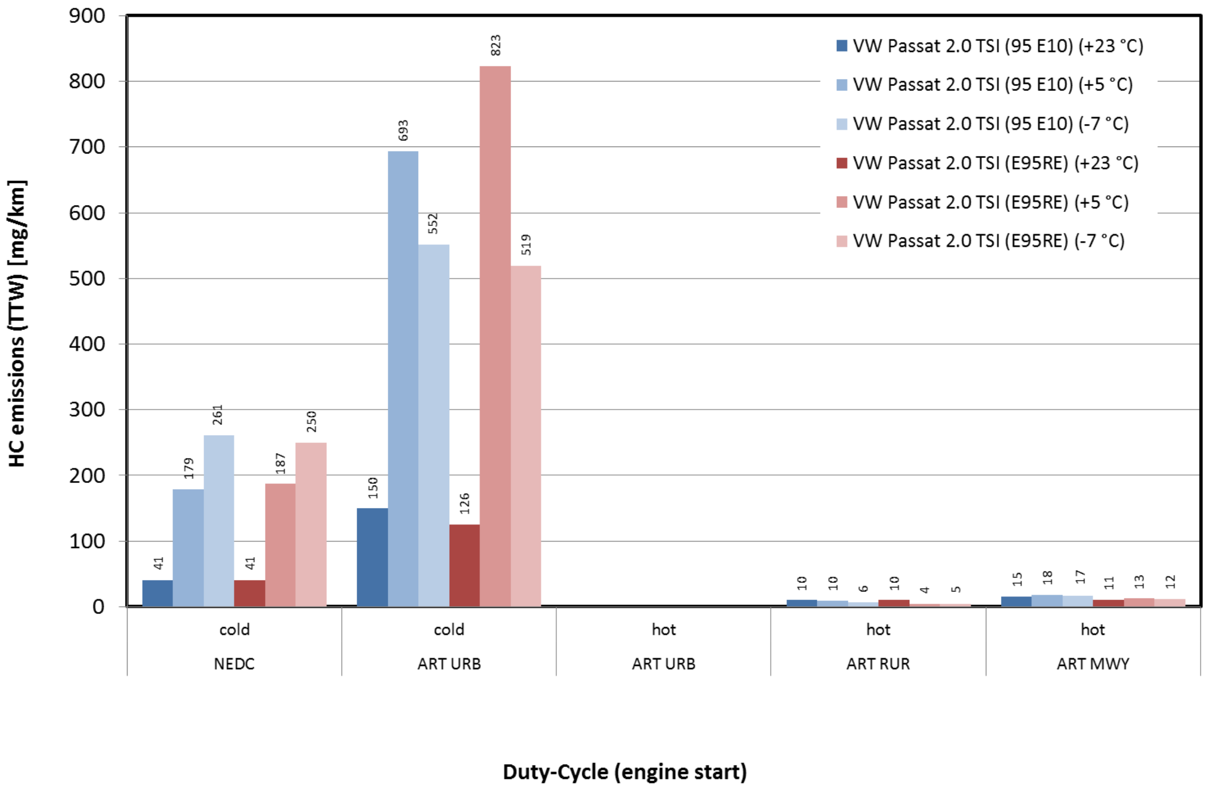


Figure 14: HC emissions from the 2.0 TSI (SI-engine) car tested in Finland with regular and “biogasoline”, at +23, +5 and -7 °C ambient temperature; NEDC and ARTEMIS cycles.

Additional graphs of results from testing in Finland.

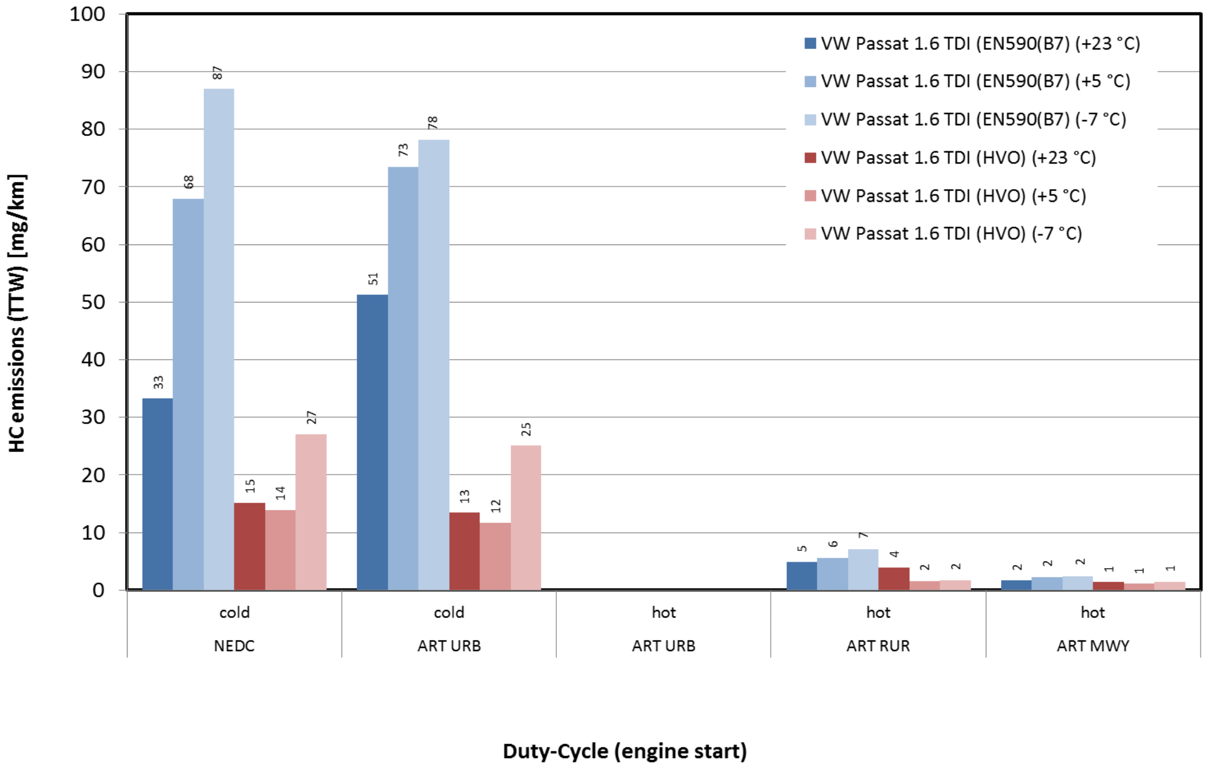


Figure 15: HC emissions from the 1.6 TDI (CI-engine) car tested in Finland with regular EN590 diesel and fully paraffinic fuel (HVO), at +23, +5 and -7 °C ambient temperature; NEDC and ARTEMIS cycles.

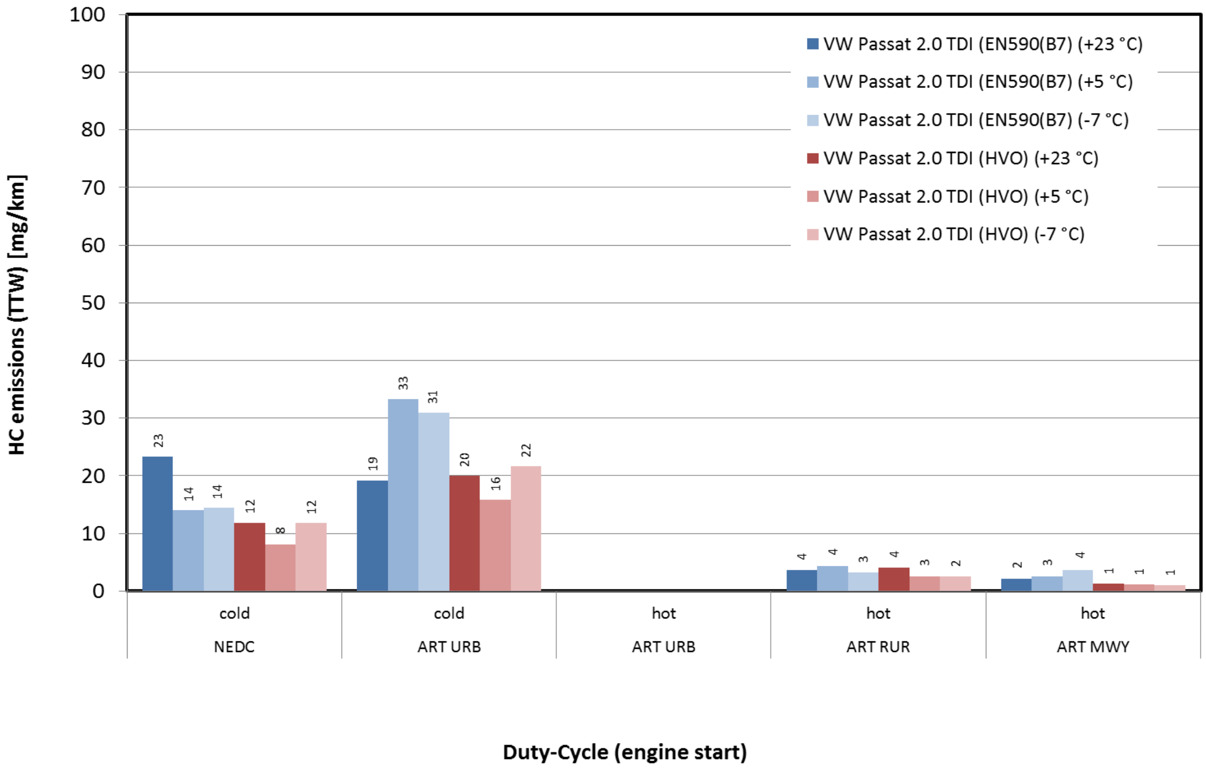


Figure 16: HC emissions from the 2.0 TDI (CI-engine) car tested in Finland with regular EN590 diesel and fully paraffinic fuel (HVO), at +23, +5 and -7 °C ambient temperature; NEDC and ARTEMIS cycles.

Additional graphs of results from testing in Finland.

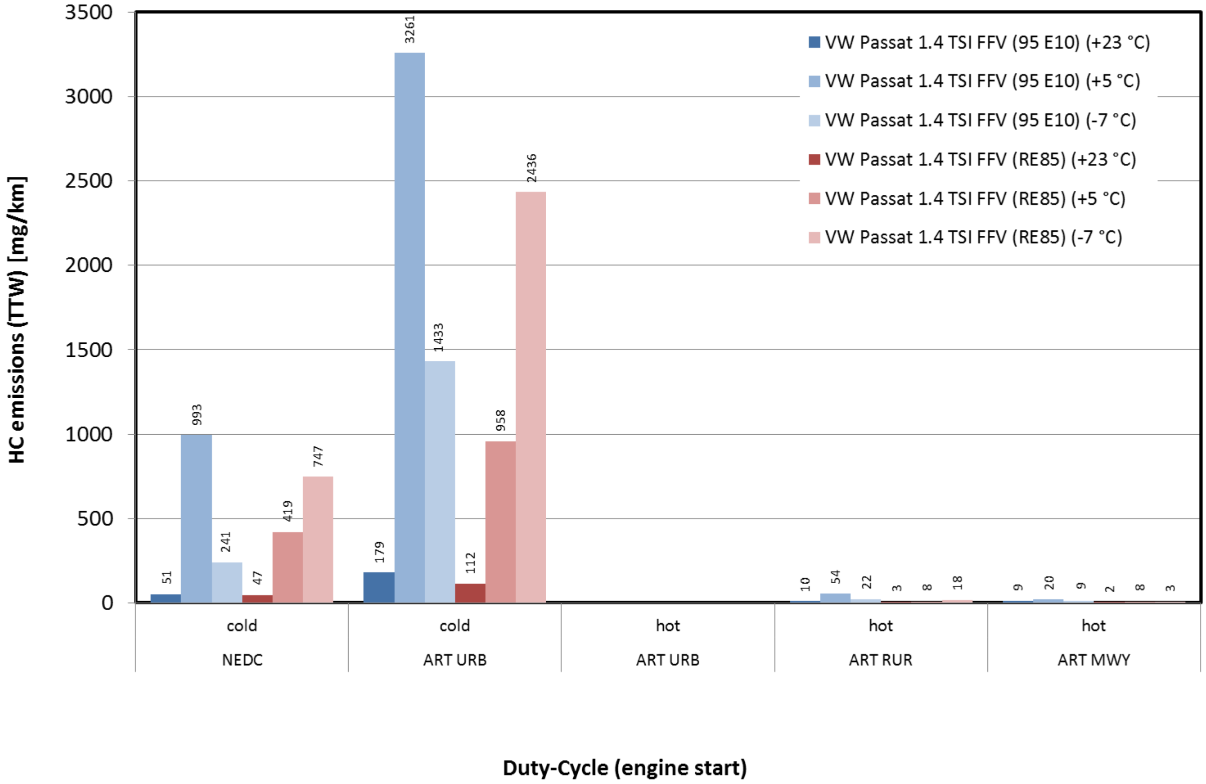


Figure 17: HC emissions from the 1.4 TSI FFV (SI-engine) car tested in Finland with regular gasoline and with E85, at +23, +5 and -7 °C ambient temperature; NEDC and ARTEMIS cycles.

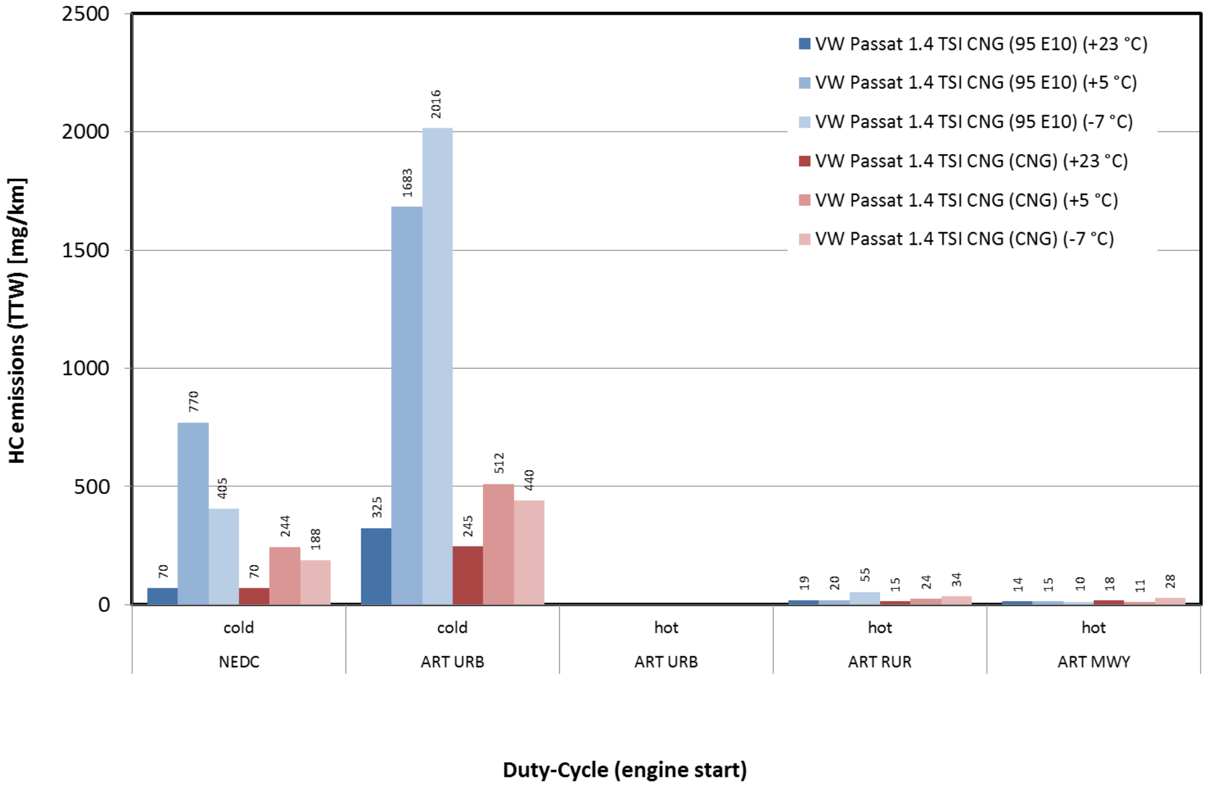


Figure 18: HC emissions from the 1.4 TSI CNG (SI-engine) car tested in Finland with regular gasoline and CNG at +23, +5 and -7 °C ambient temperature; NEDC and ARTEMIS cycles.

Additional graphs of results from testing in Finland.

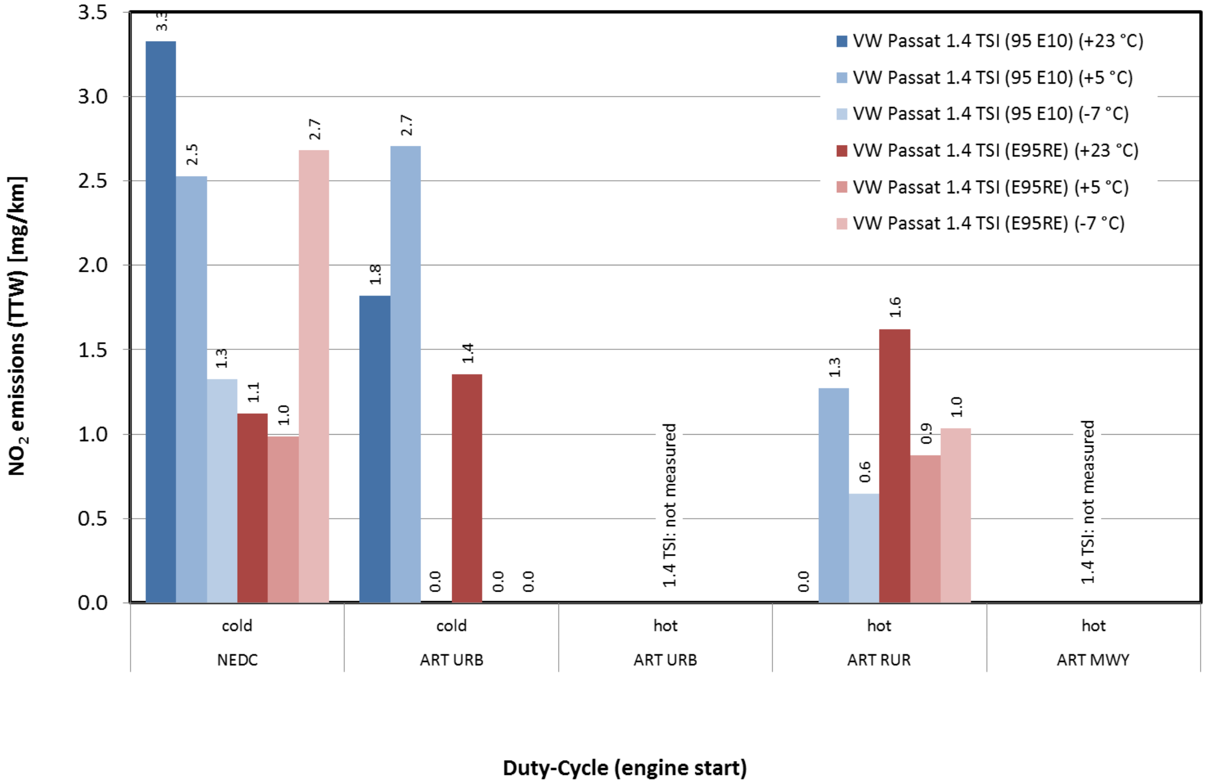


Figure 19 NO_2 emissions from the 1.4 TSI (SI-engine) car tested in Finland with regular and "biogasoline", at +23, +5 and -7 °C ambient temperature; NEDC and ARTEMIS cycles.

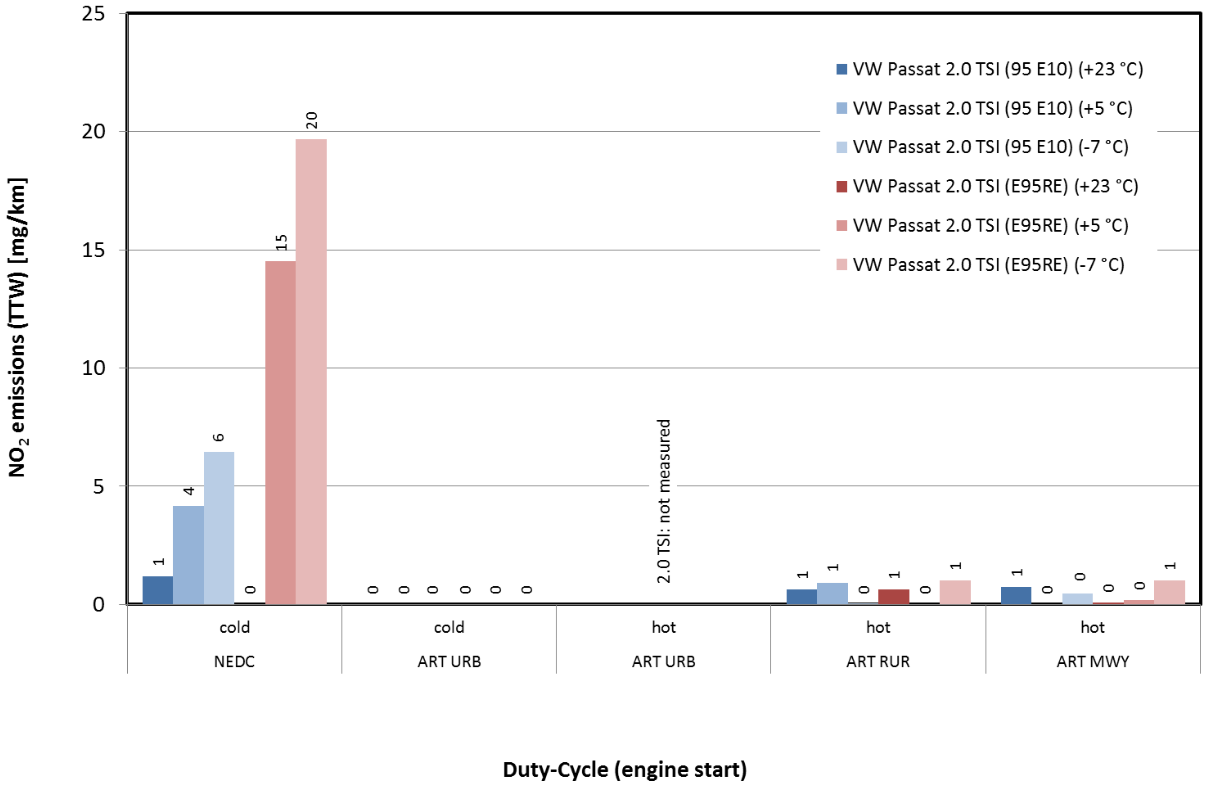


Figure 20: NO_2 emissions from the 2.0 TSI (SI-engine) car tested in Finland with regular and "biogasoline", at +23, +5 and -7 °C ambient temperature; NEDC and ARTEMIS cycles.

Additional graphs of results from testing in Finland.

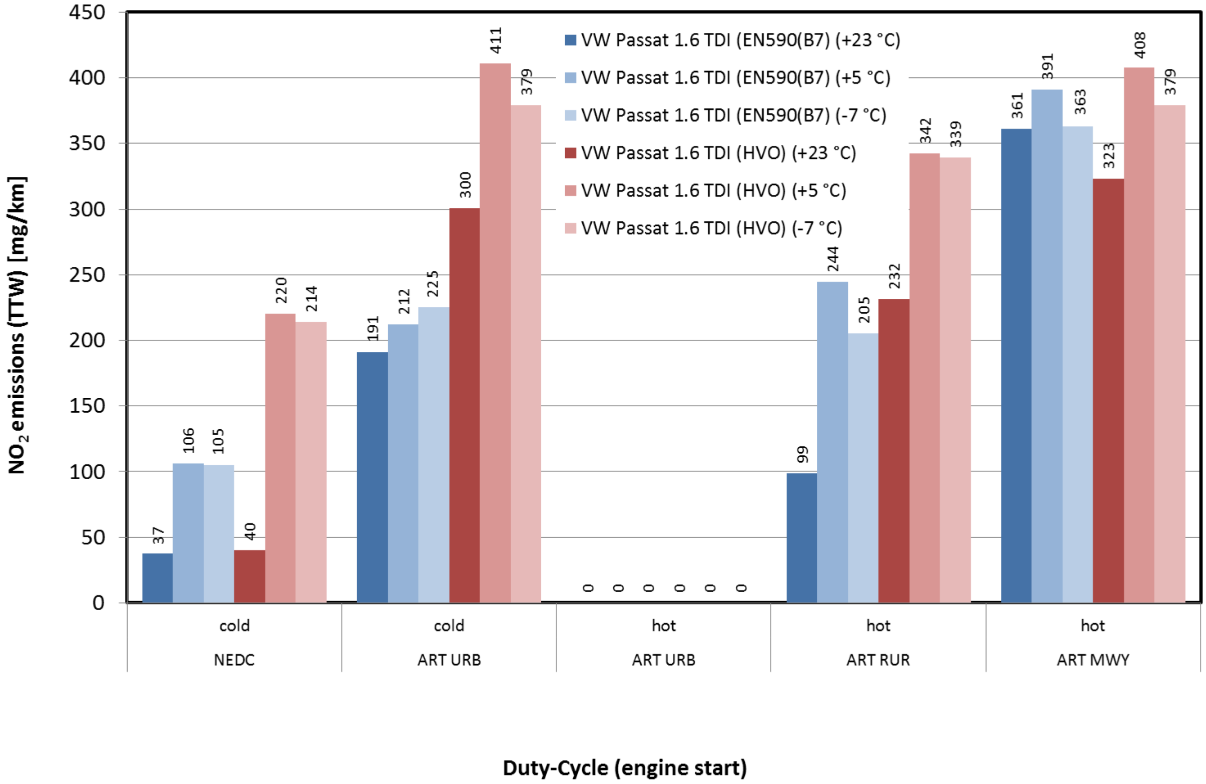


Figure 21: NO_2 emissions from the 1.6 TDI (CI-engine) car tested in Finland with regular EN590 diesel and fully paraffinic fuel (HVO), at +23, +5 and -7 °C ambient temperature; NEDC and ARTEMIS cycles.

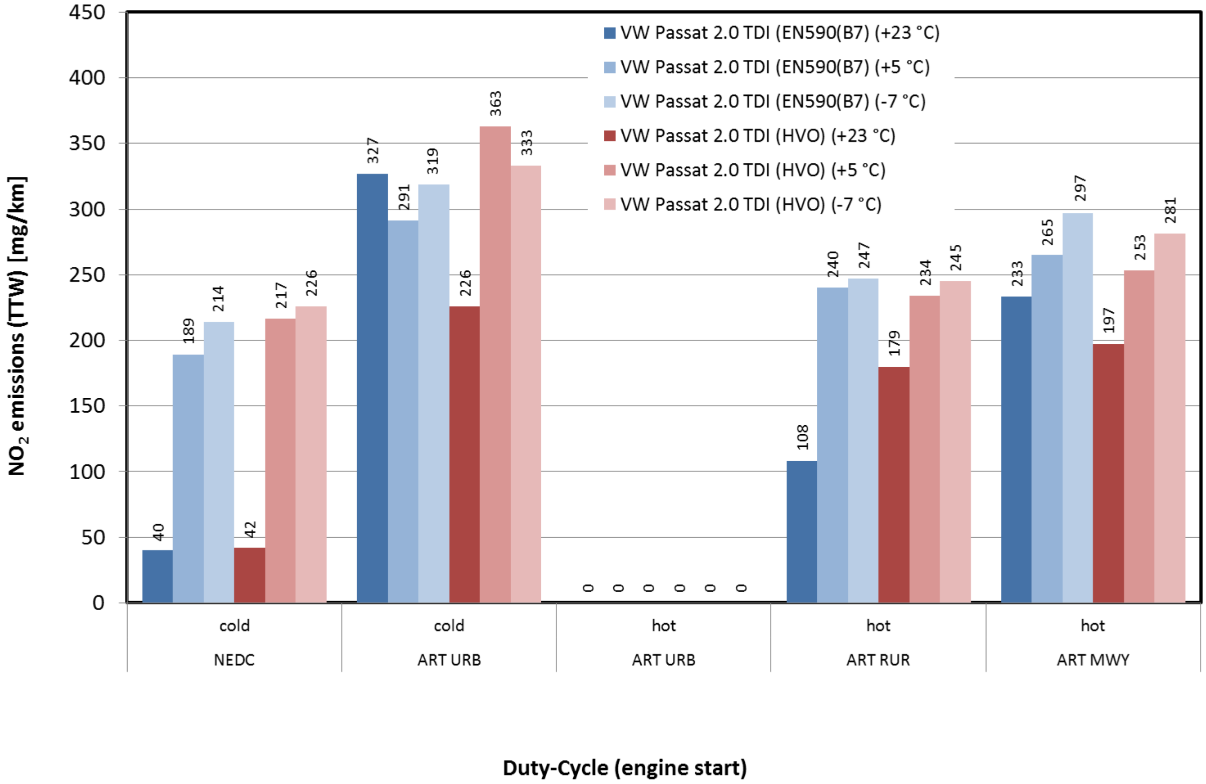


Figure 22: NO_2 emissions from the 2.0 TDI (CI-engine) car tested in Finland with regular EN590 diesel and fully paraffinic fuel (HVO), at +23, +5 and -7 °C ambient temperature; NEDC and ARTEMIS cycles.

Additional graphs of results from testing in Finland.

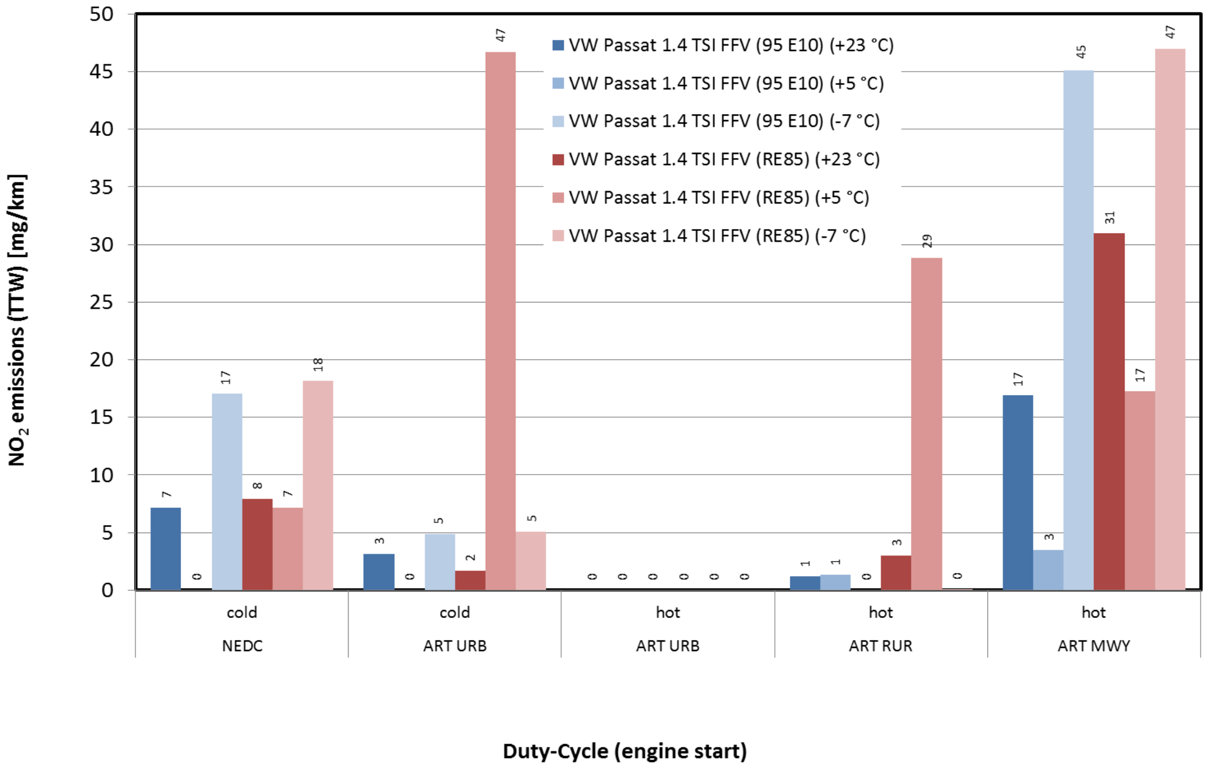


Figure 23: NO_2 emissions from the 1.4 TSI FFV (SI-engine) car tested in Finland with regular gasoline and with E85, at +23, +5 and -7 °C ambient temperature; NEDC and ARTEMIS cycles.

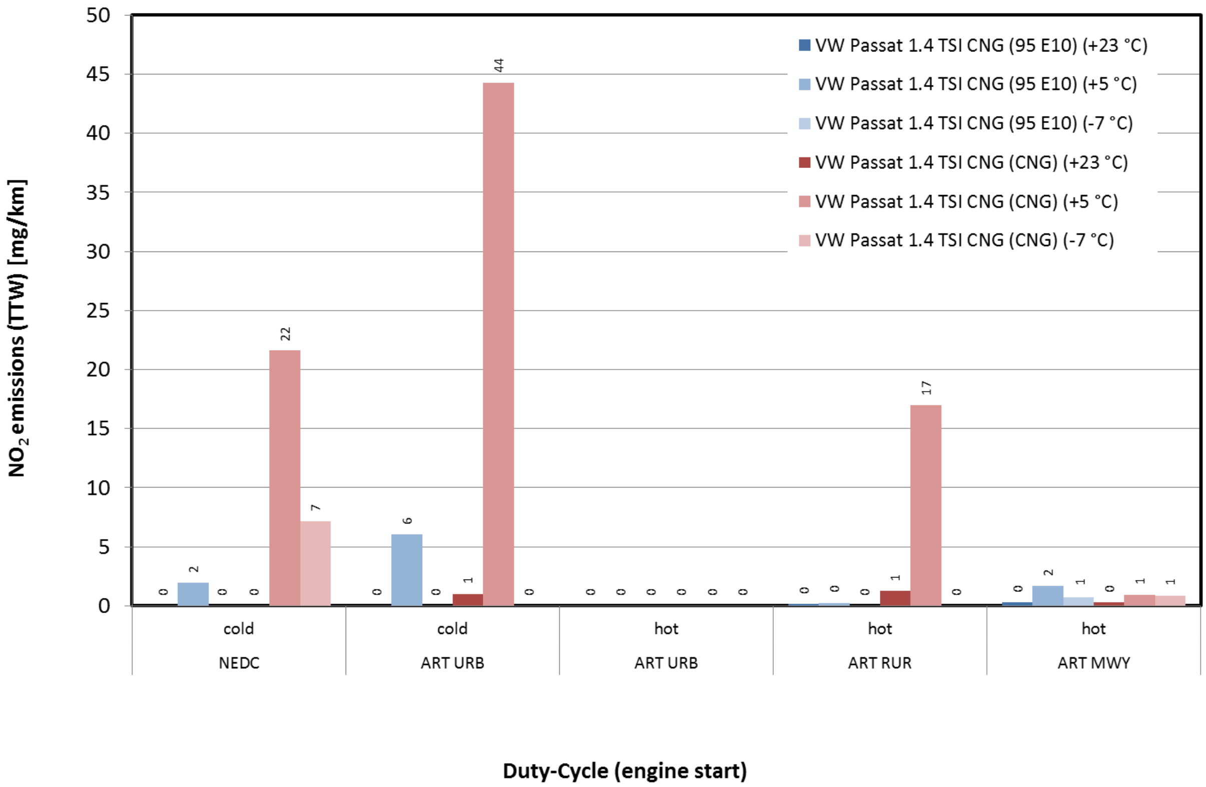


Figure 24: NO_2 emissions from the 1.4 TSI CNG (SI-engine) car tested in Finland with regular gasoline and CNG at +23, +5 and -7 °C ambient temperature; NEDC and ARTEMIS cycles.

Additional graphs of results from testing in Finland.

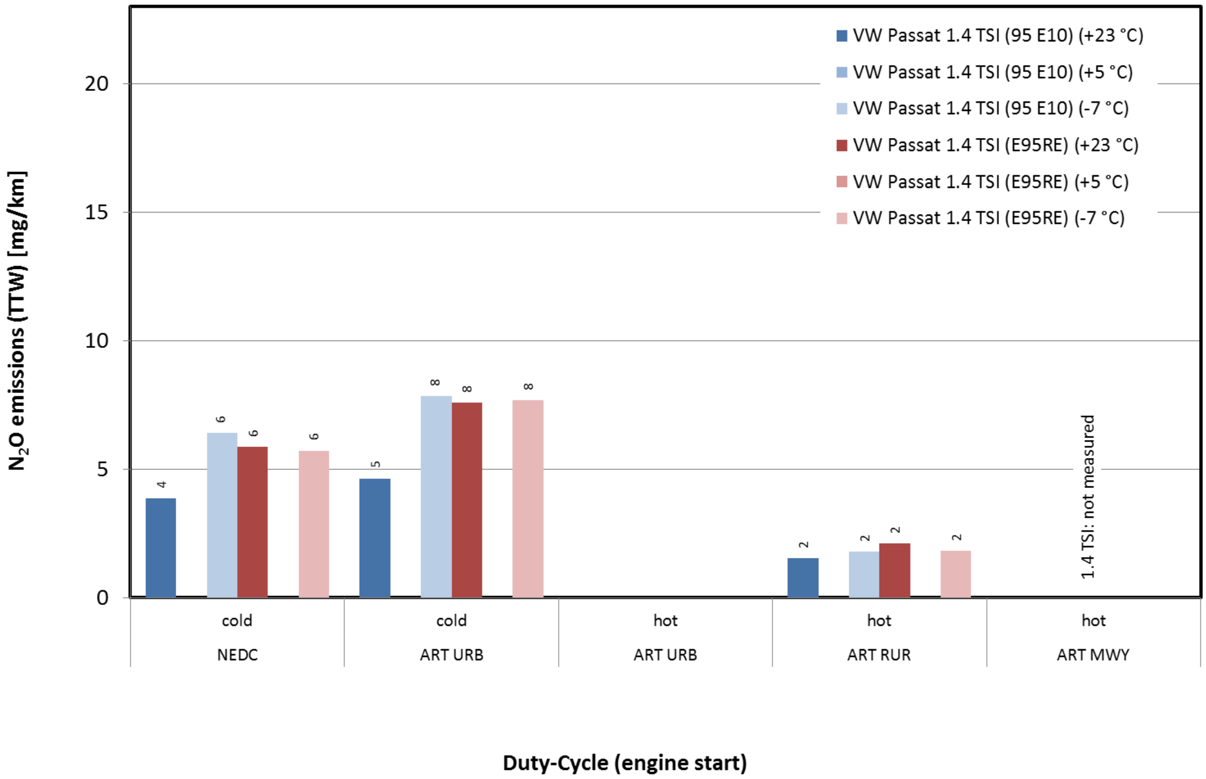


Figure 25: N_2O emissions from the 1.4 TSI (SI-engine) car tested in Finland with regular and "biogasoline", at +23, +5 and -7 °C ambient temperature; NEDC and ARTEMIS cycles.

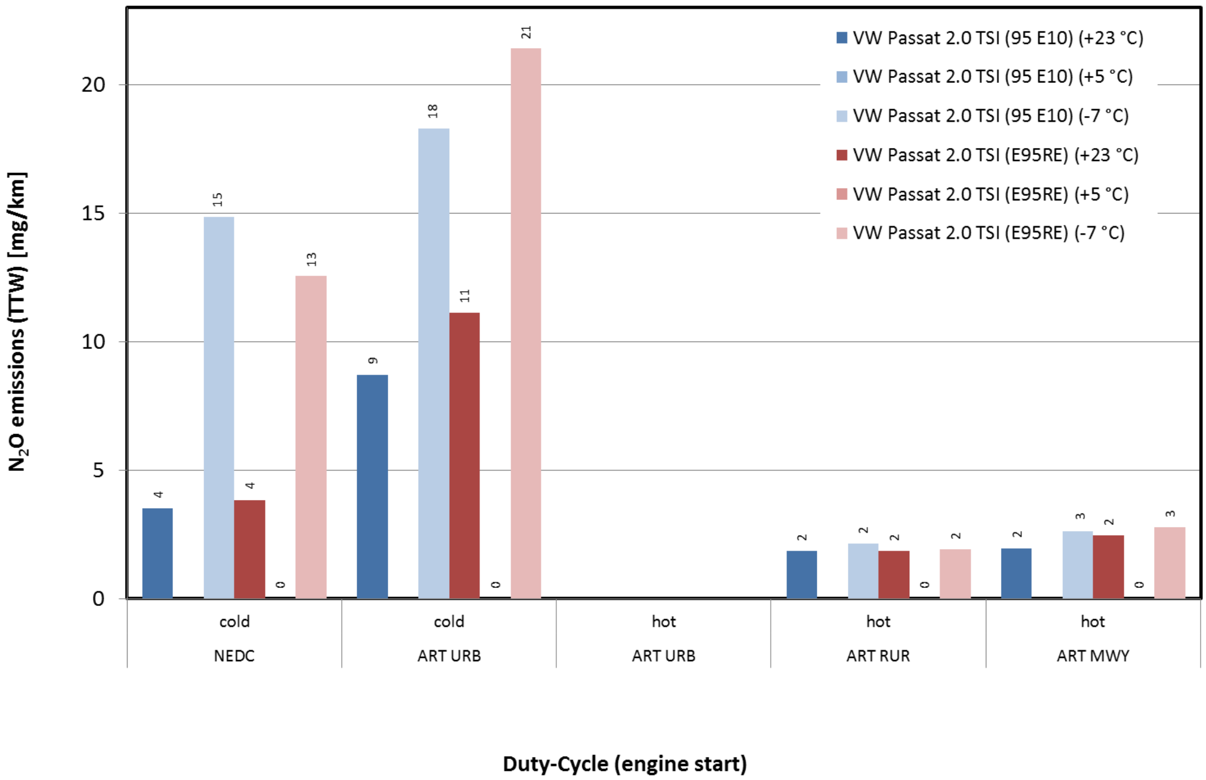


Figure 26: N_2O emissions from the 2.0 TSI (SI-engine) car tested in Finland with regular and "biogasoline", at +23, +5 and -7 °C ambient temperature; NEDC and ARTEMIS cycles.

Additional graphs of results from testing in Finland.

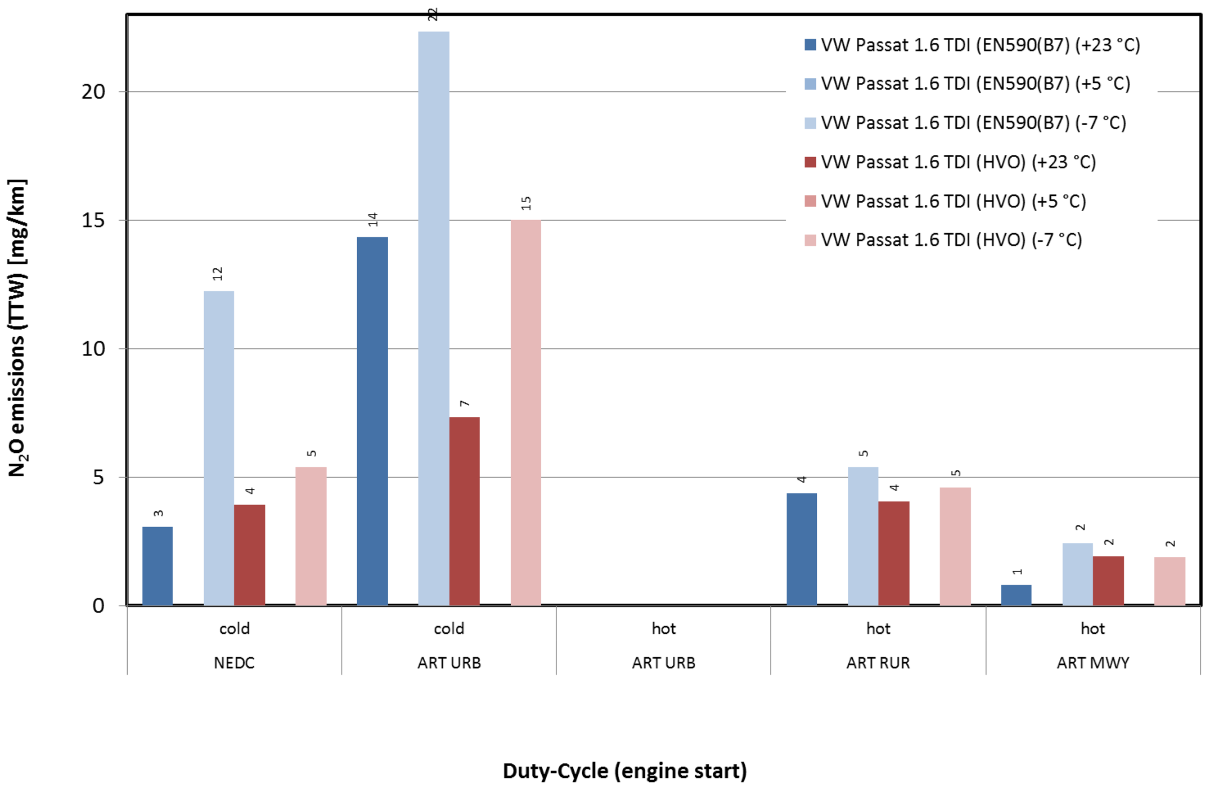


Figure 27: N_2O emissions from the 1.6 TDI (CI-engine) car tested in Finland with regular EN590 diesel and fully paraffinic fuel (HVO), at +23, +5 and -7 °C ambient temperature; NEDC and ARTEMIS cycles.

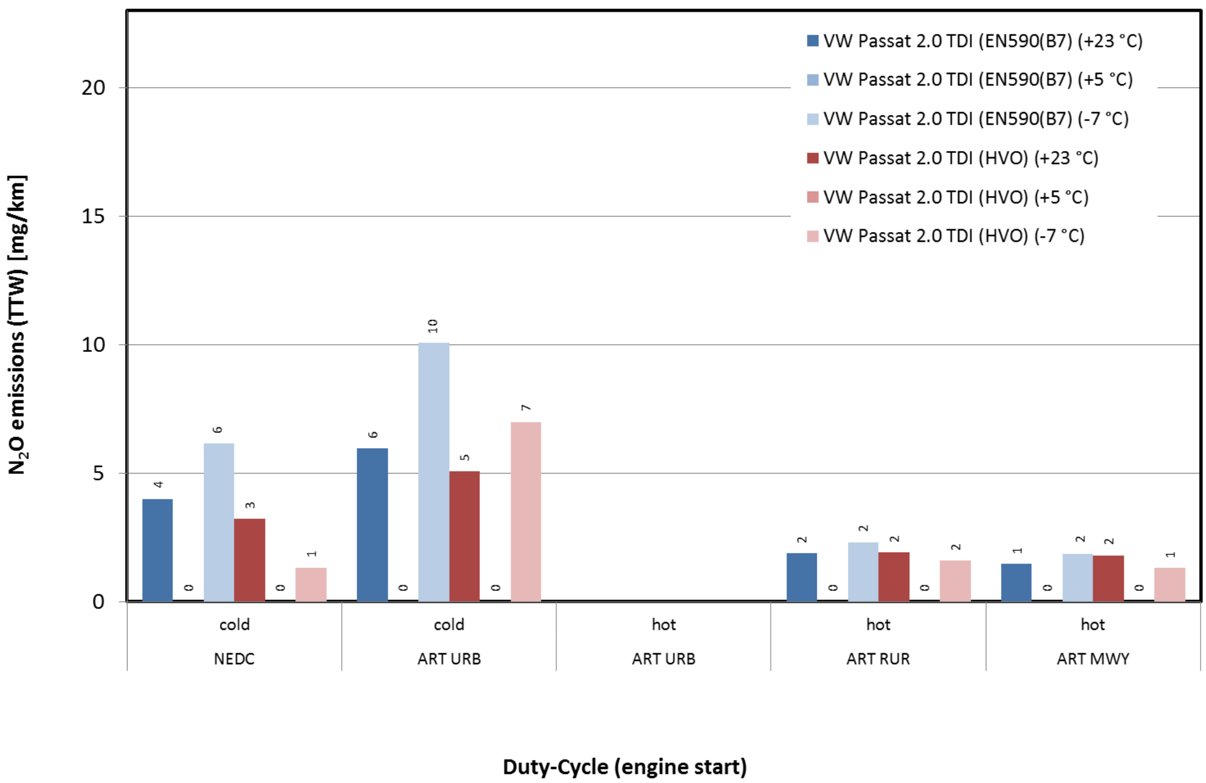


Figure 28: N_2O emissions from the 2.0 TDI (CI-engine) car tested in Finland with regular EN590 diesel and fully paraffinic fuel (HVO), at +23, +5 and -7 °C ambient temperature; NEDC and ARTEMIS cycles.

Additional graphs of results from testing in Finland.

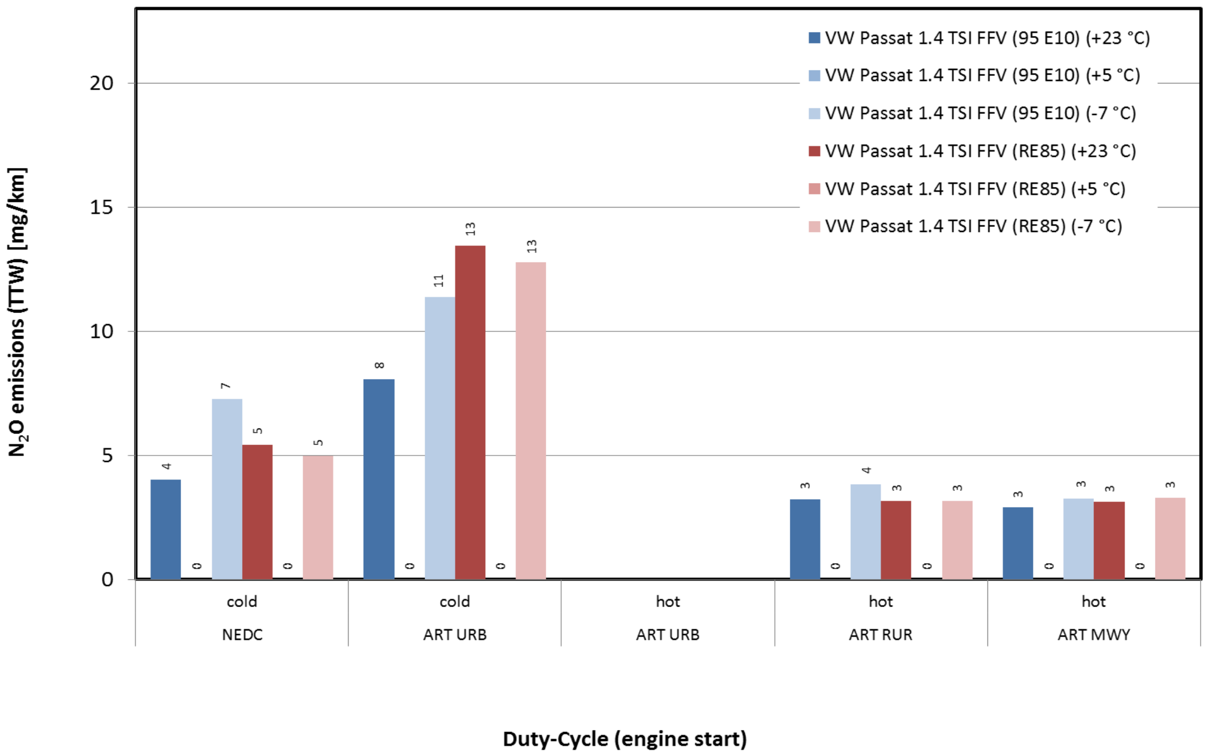


Figure 29: N_2O emissions from the 1.4 TSI FFV (SI-engine) car tested in Finland with regular gasoline and with E85, at +23, +5 and -7 °C ambient temperature; NEDC and ARTEMIS cycles.

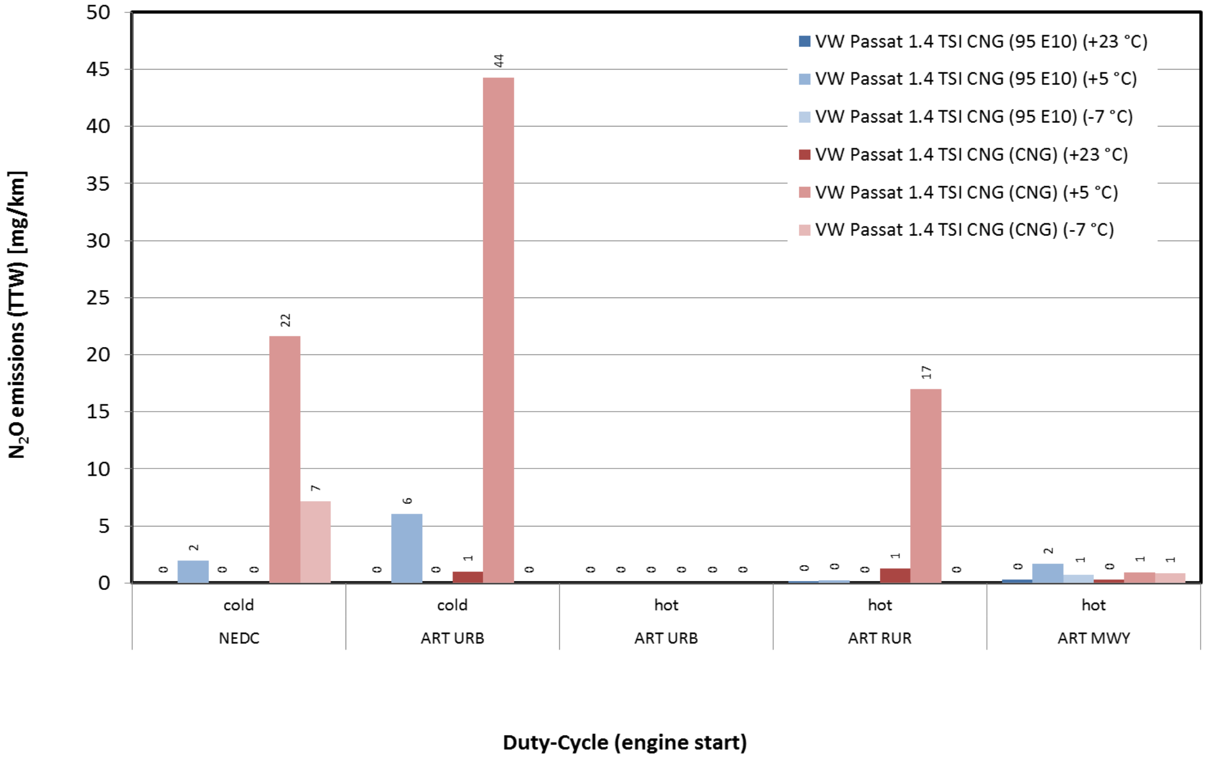


Figure 30: N_2O emissions from the 1.4 TSI CNG (SI-engine) car tested in Finland with regular gasoline and CNG at +23, +5 and -7 °C ambient temperature; NEDC and ARTEMIS cycles.

Additional graphs of results from testing in Finland.

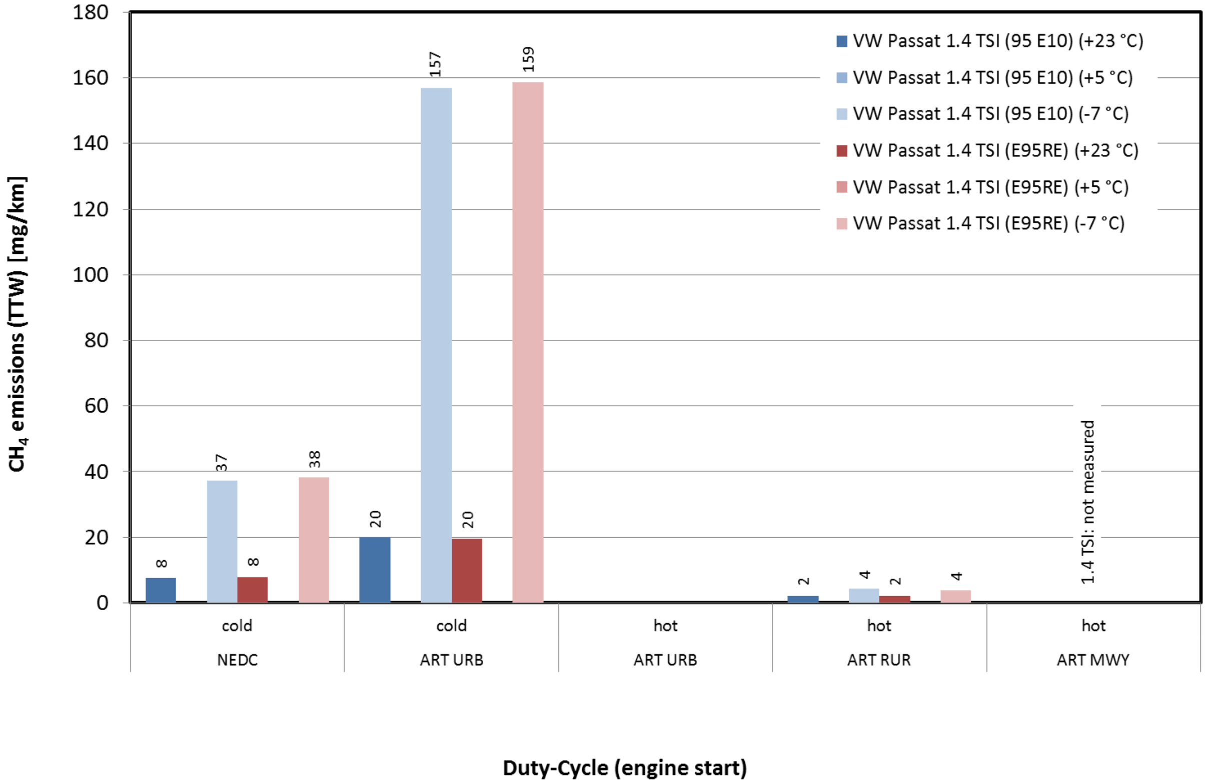


Figure 31: CH_4 emissions from the 1.4 TSI (SI-engine) car tested in Finland with regular and "biogasoline", at +23, +5 and -7 °C ambient temperature; NEDC and ARTEMIS cycles.

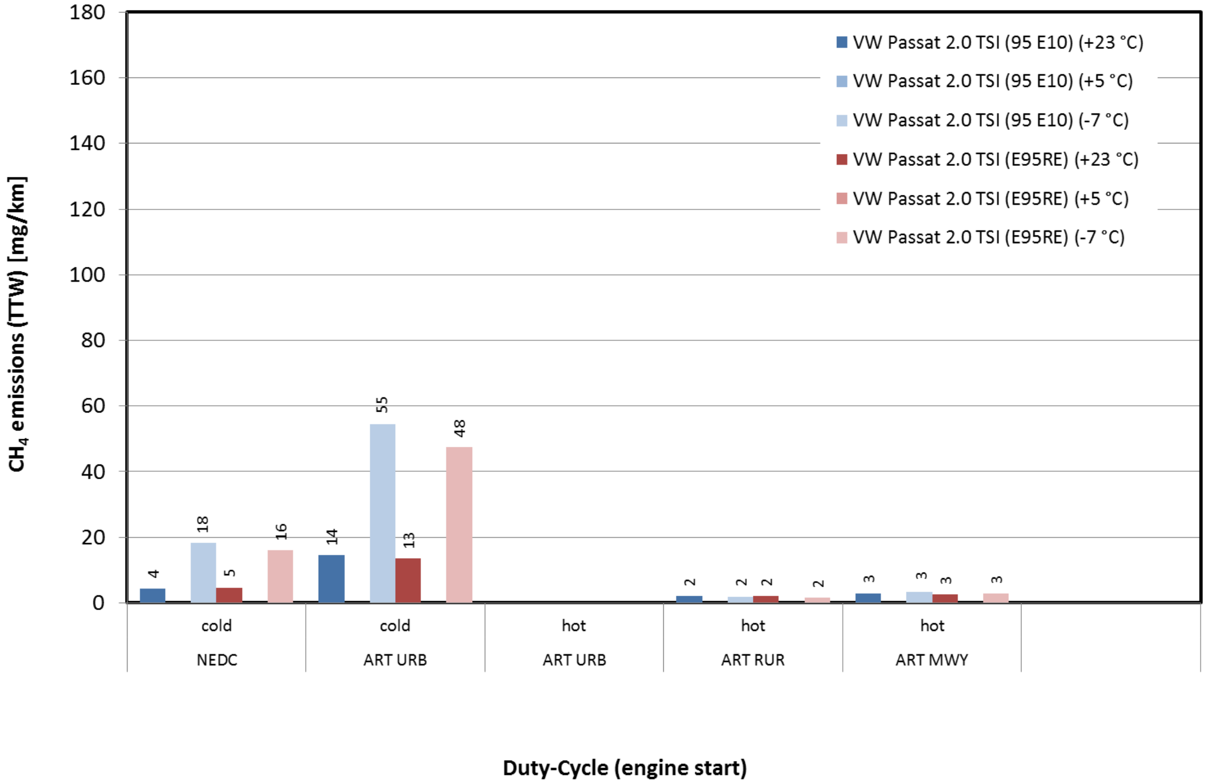


Figure 32: CH_4 emissions from the 2.0 TSI (SI-engine) car tested in Finland with regular and "biogasoline", at +23, +5 and -7 °C ambient temperature; NEDC and ARTEMIS cycles.

Additional graphs of results from testing in Finland.

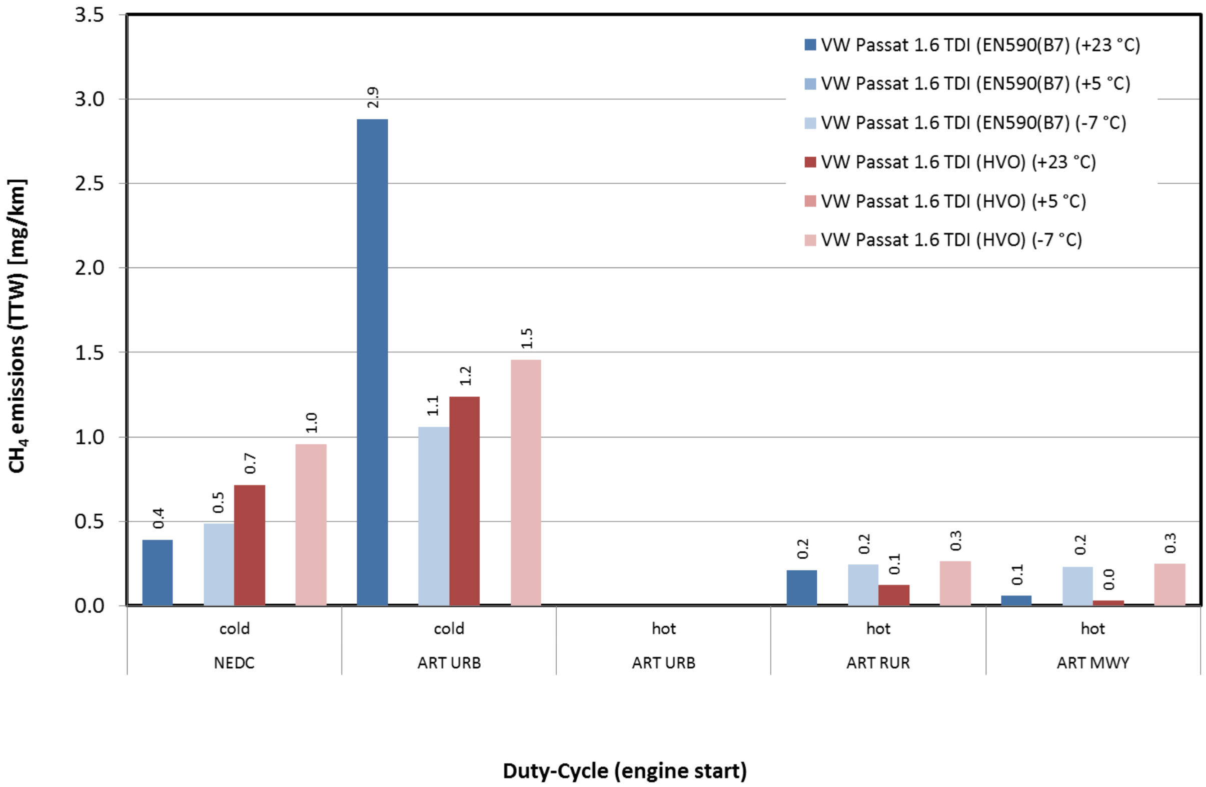


Figure 33: CH_4 emissions from the 1.6 TDI (CI-engine) car tested in Finland with regular EN590 diesel and fully paraffinic fuel (HVO), at +23, +5 and -7 °C ambient temperature; NEDC and ARTEMIS cycles.

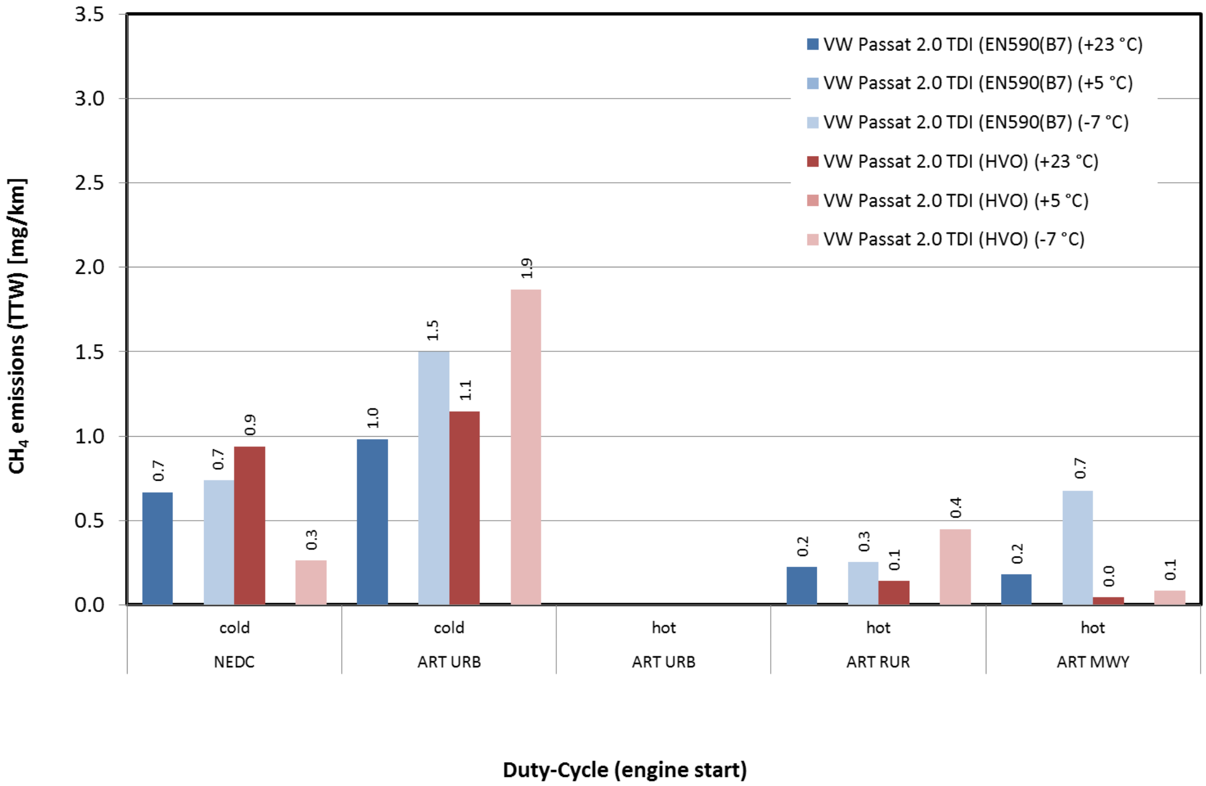


Figure 34: CH_4 emissions from the 2.0 TDI (CI-engine) car tested in Finland with regular EN590 diesel and fully paraffinic fuel (HVO), at +23, +5 and -7 °C ambient temperature; NEDC and ARTEMIS cycles.

Additional graphs of results from testing in Finland.

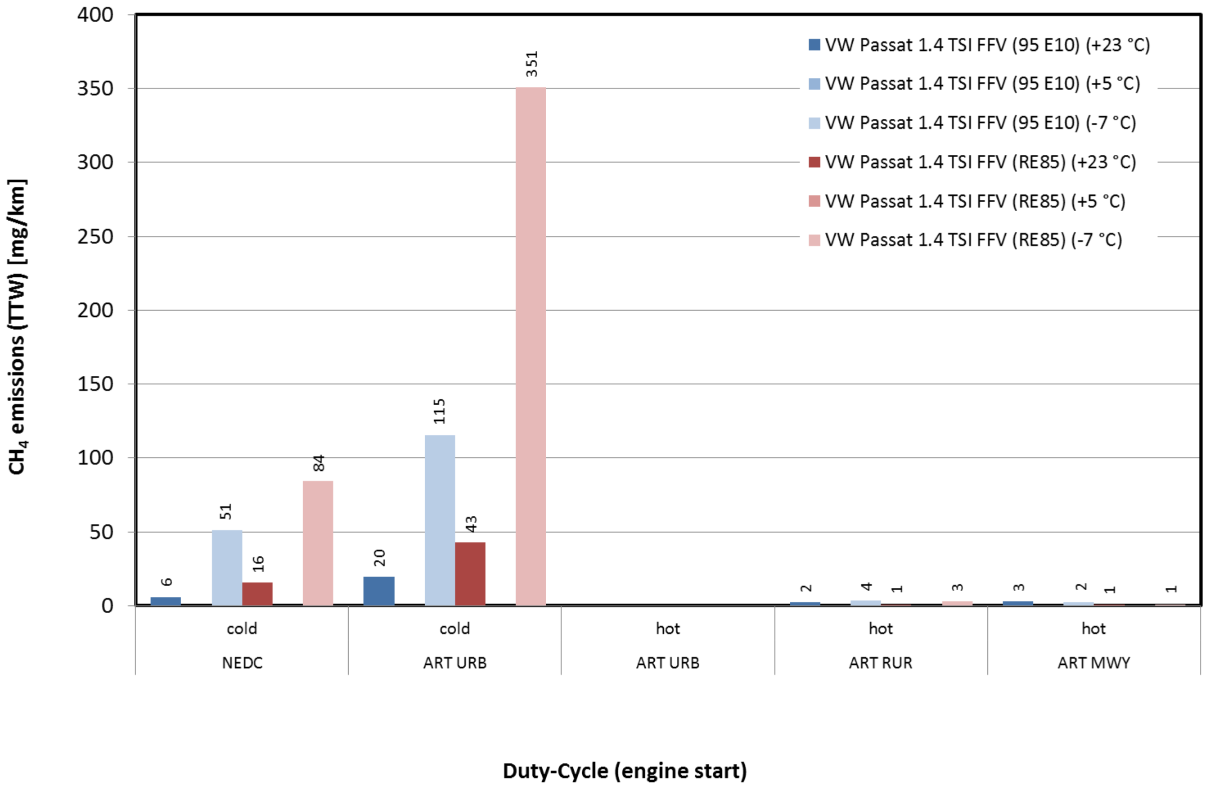


Figure 35: CH_4 emissions from the 1.4 TSI FFV (SI-engine) car tested in Finland with regular gasoline and with E85, at +23, +5 and -7 °C ambient temperature; NEDC and ARTEMIS cycles.

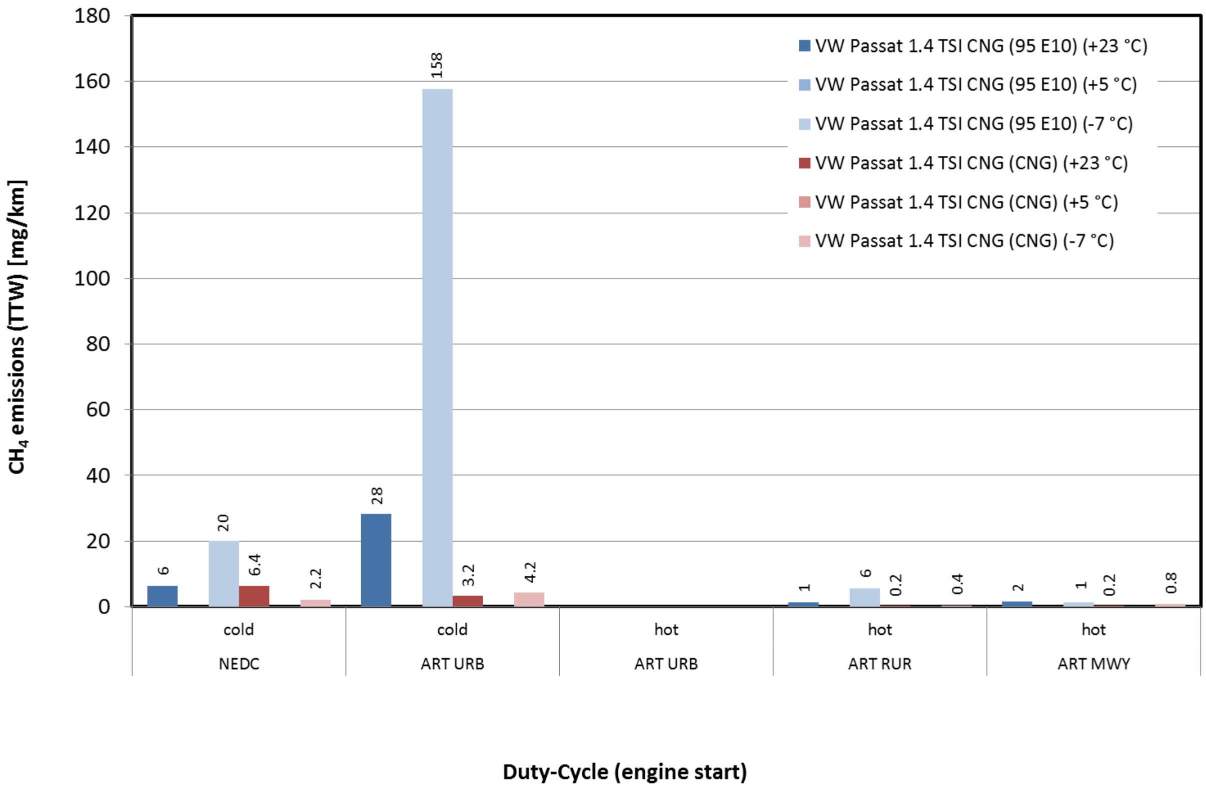


Figure 36: CH_4 emissions from the 1.4 TSI CNG (SI-engine) car tested in Finland with regular gasoline and CNG at +23, +5 and -7 °C ambient temperature; NEDC and ARTEMIS cycles.

Additional graphs of results from testing in Finland.

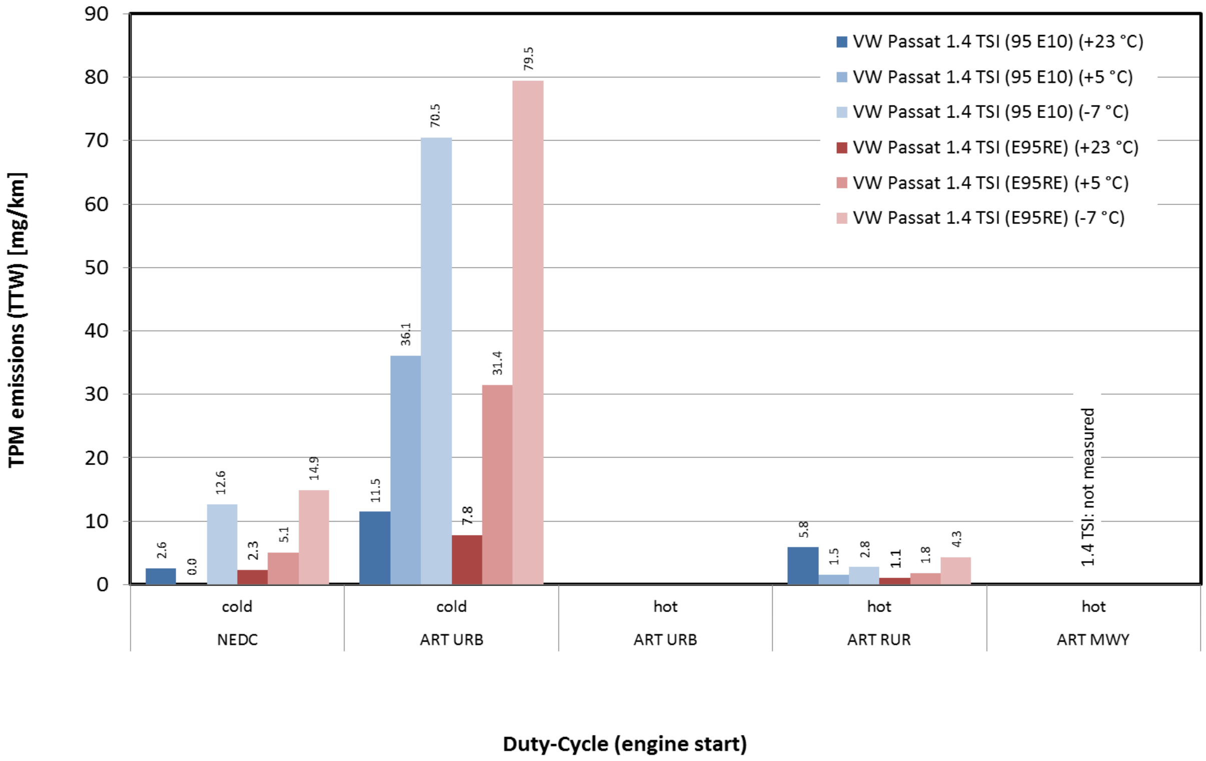


Figure 37: TPM emissions from the 1.4 TSI (SI-engine) car tested in Finland with regular and "biogasoline", at +23, +5 and -7 °C ambient temperature; NEDC and ARTEMIS cycles.

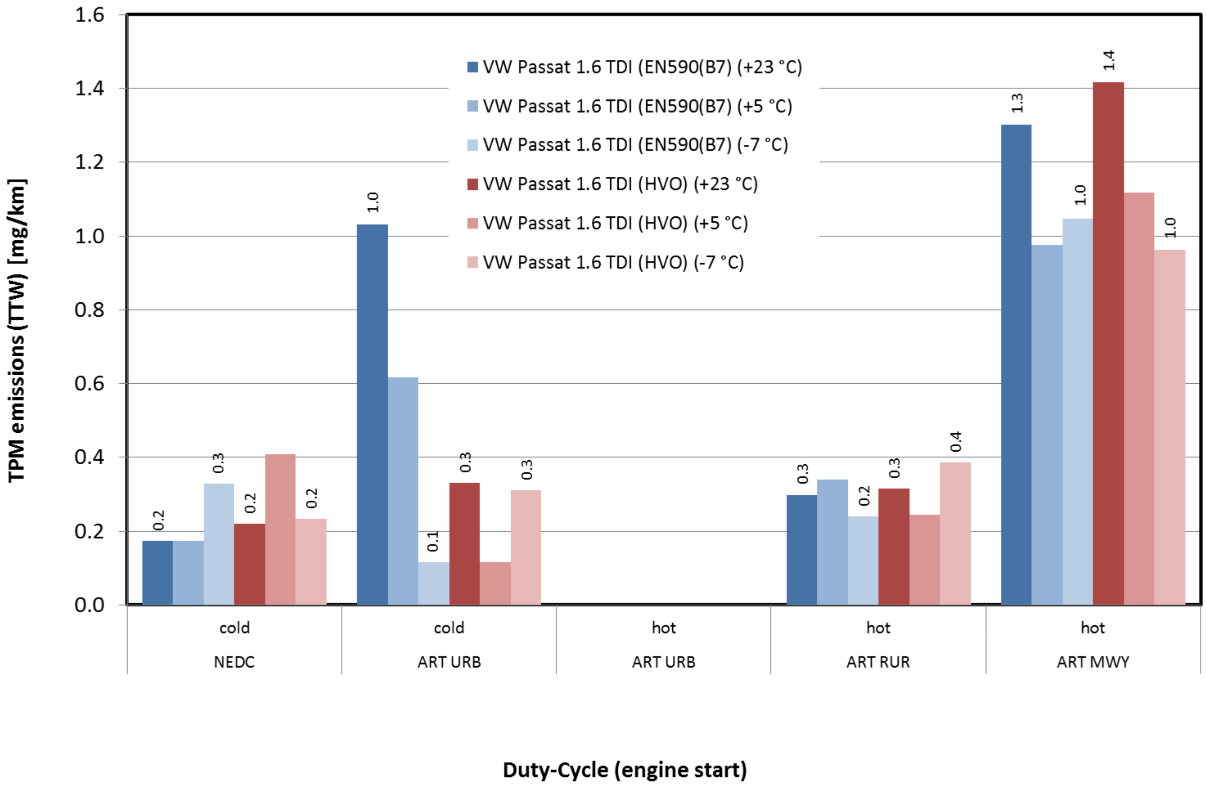


Figure 38: TPM emissions from the 1.6 TDI (CI-engine) car tested in Finland with regular EN590 diesel and fully paraffinic fuel (HVO), at +23, +5 and -7 °C ambient temperature; NEDC and ARTEMIS cycles.

Additional graphs of results from testing in Finland.

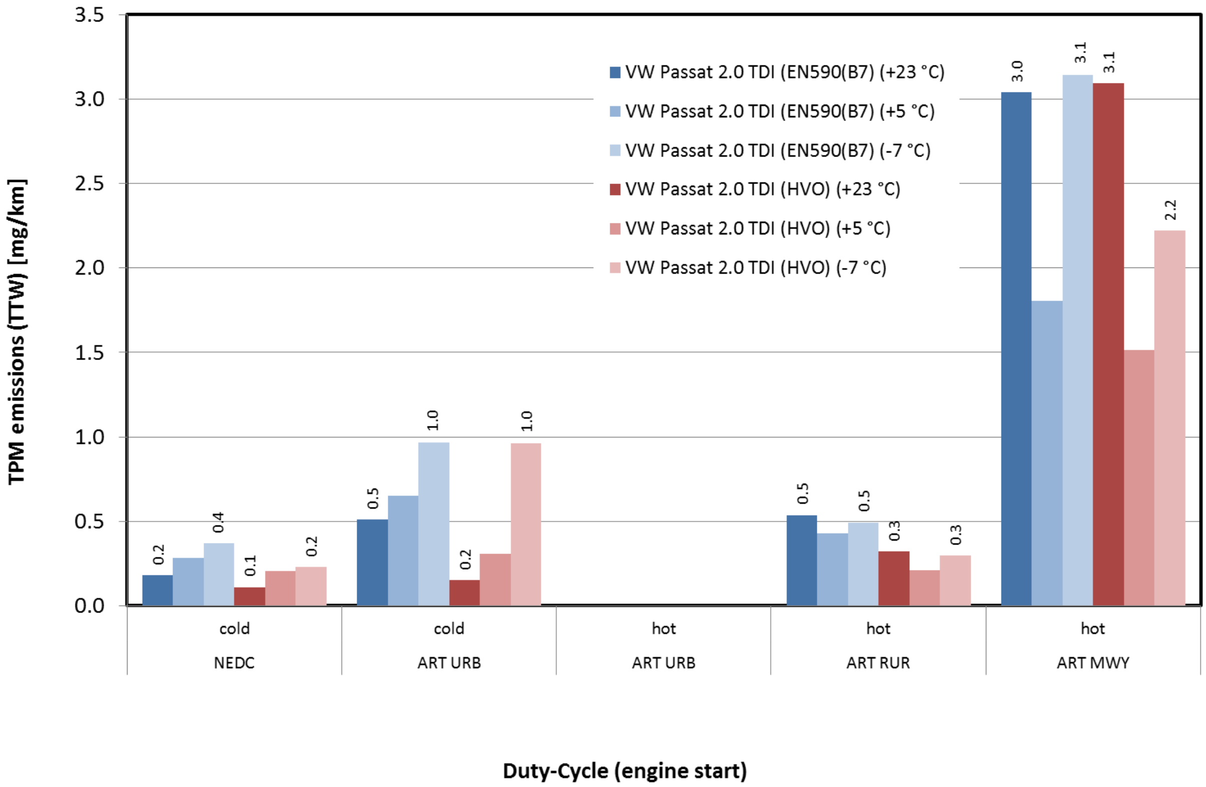


Figure 39: TPM emissions from the 2.0 TDI (CI-engine) car tested in Finland with regular EN590 diesel and fully paraffinic fuel (HVO), at +23, +5 and -7 °C ambient temperature; NEDC and ARTEMIS cycles.

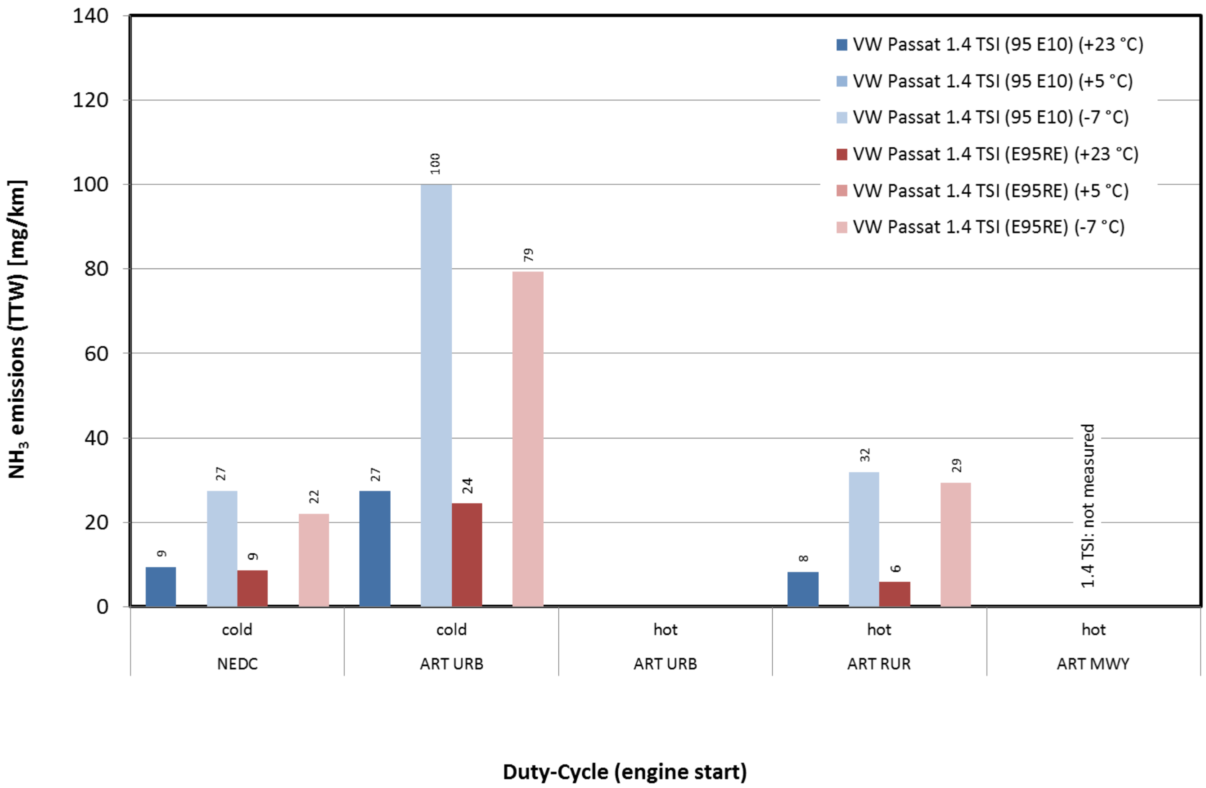


Figure 40: NH_3 emissions from the 1.4 TSI (SI-engine) car tested in Finland with regular and “biogasoline”, at +23, +5 and -7 °C ambient temperature; NEDC and ARTEMIS cycles.

Additional graphs of results from testing in Finland.

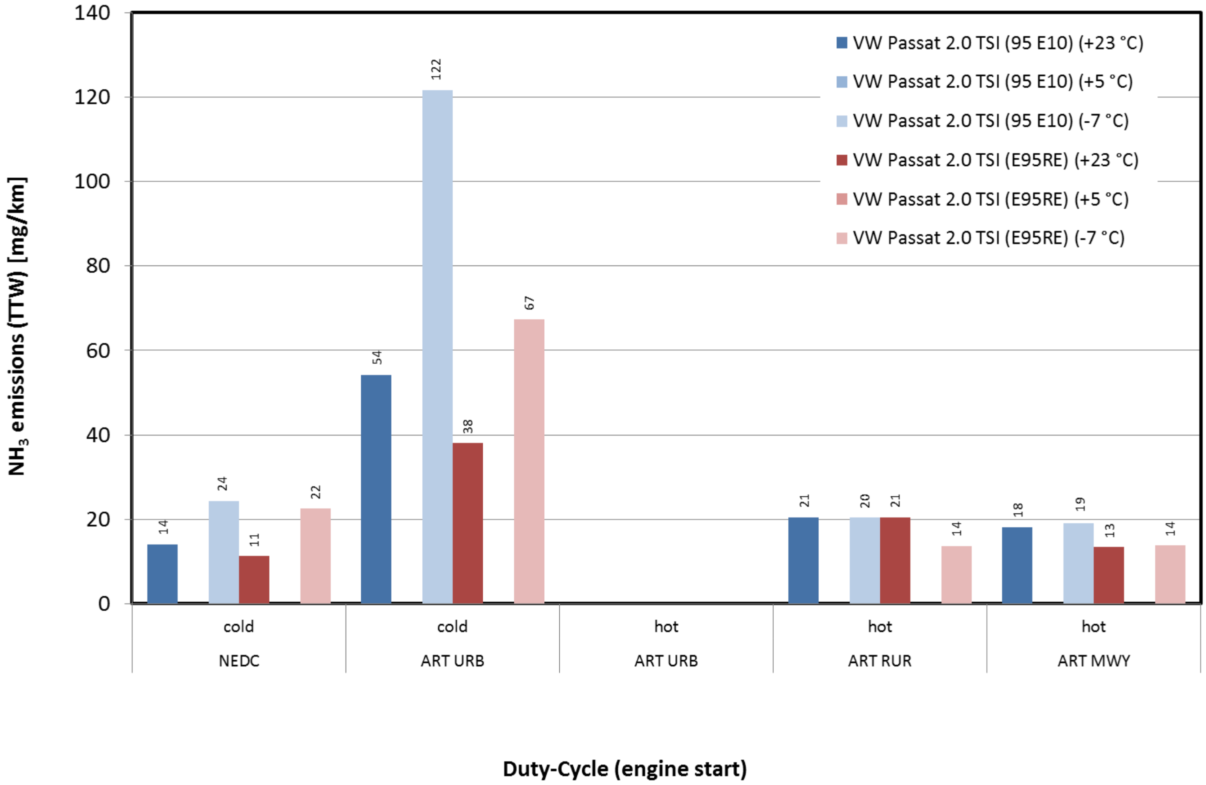


Figure 41: NH_3 emissions from the 2.0 TSI (SI-engine) car tested in Finland with regular and “biogasoline”, at +23, +5 and -7 °C ambient temperature; NEDC and ARTEMIS cycles.

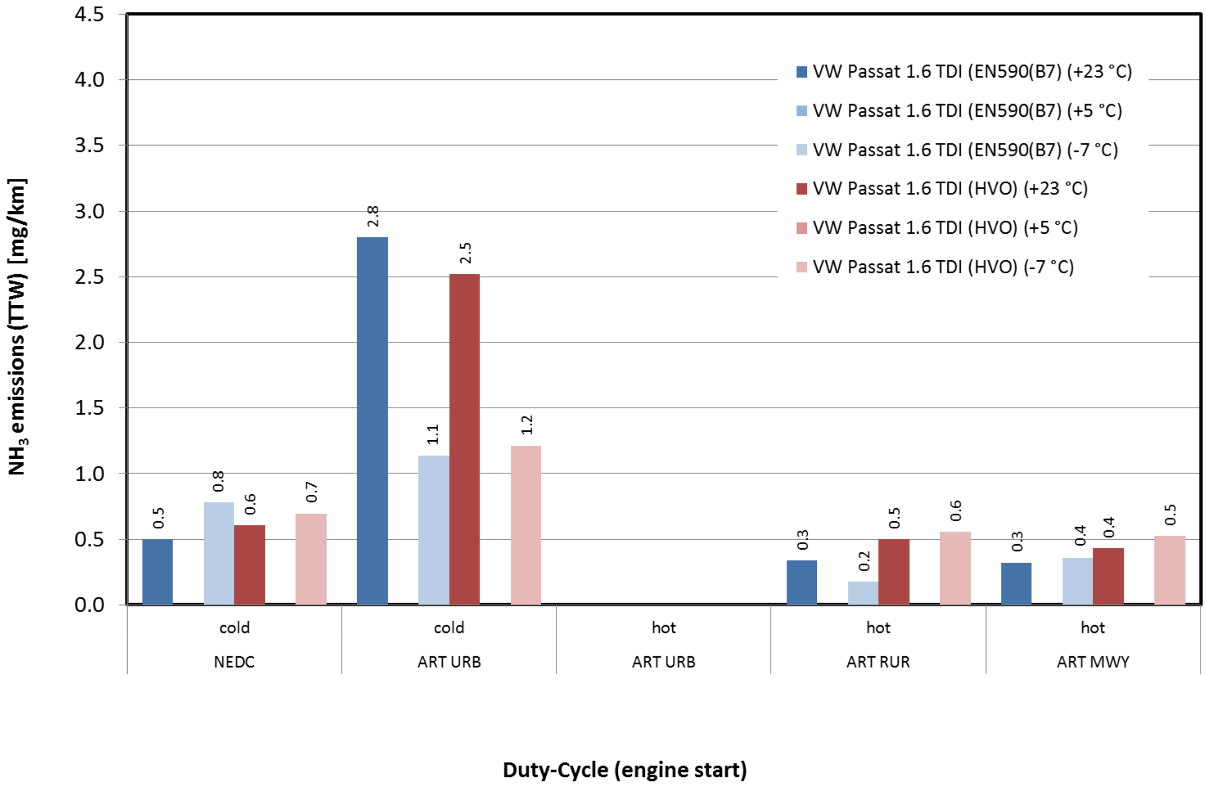


Figure 42: NH_3 emissions from the 1.6 TDI (CI-engine) car tested in Finland with regular EN590 diesel and fully paraffinic fuel (HVO), at +23, +5 and -7 °C ambient temperature; NEDC and ARTEMIS cycles.

Additional graphs of results from testing in Finland.

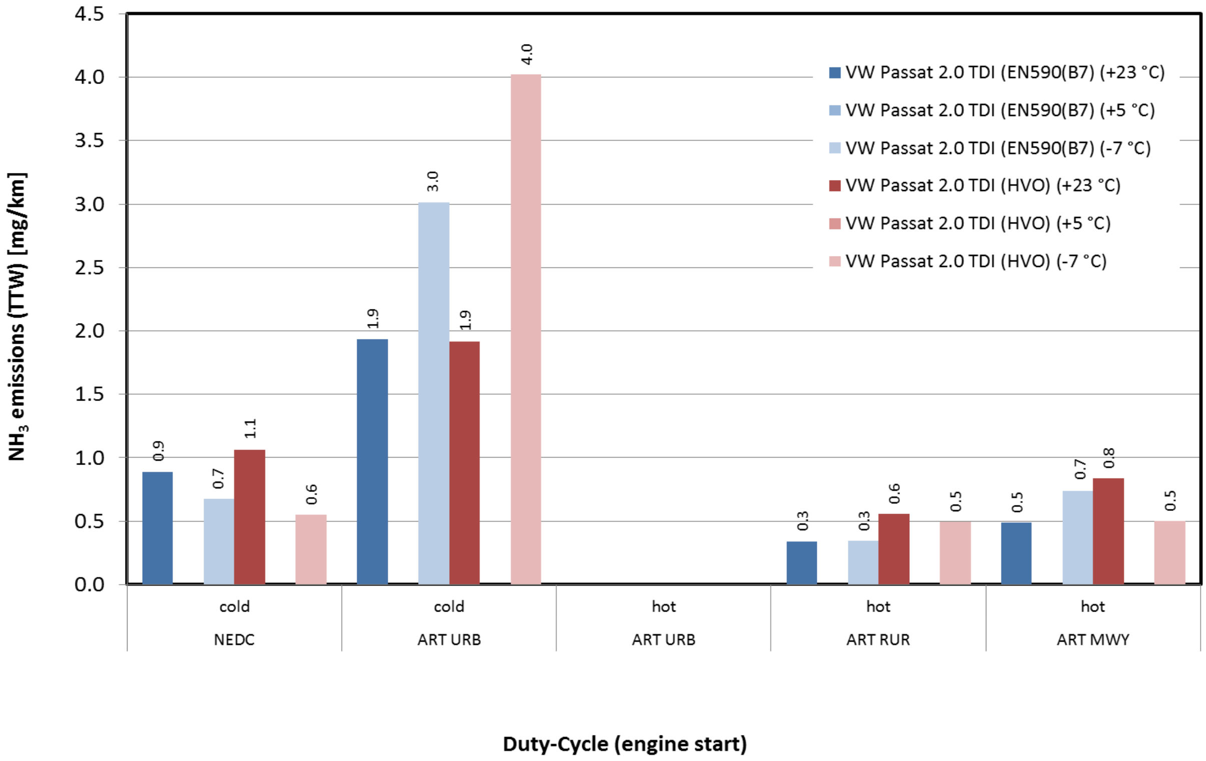


Figure 43: NH_3 emissions from the 2.0 TDI (CI-engine) car tested in Finland with regular EN590 diesel and fully paraffinic fuel (HVO), at +23, +5 and -7 °C ambient temperature; NEDC and ARTEMIS cycles.

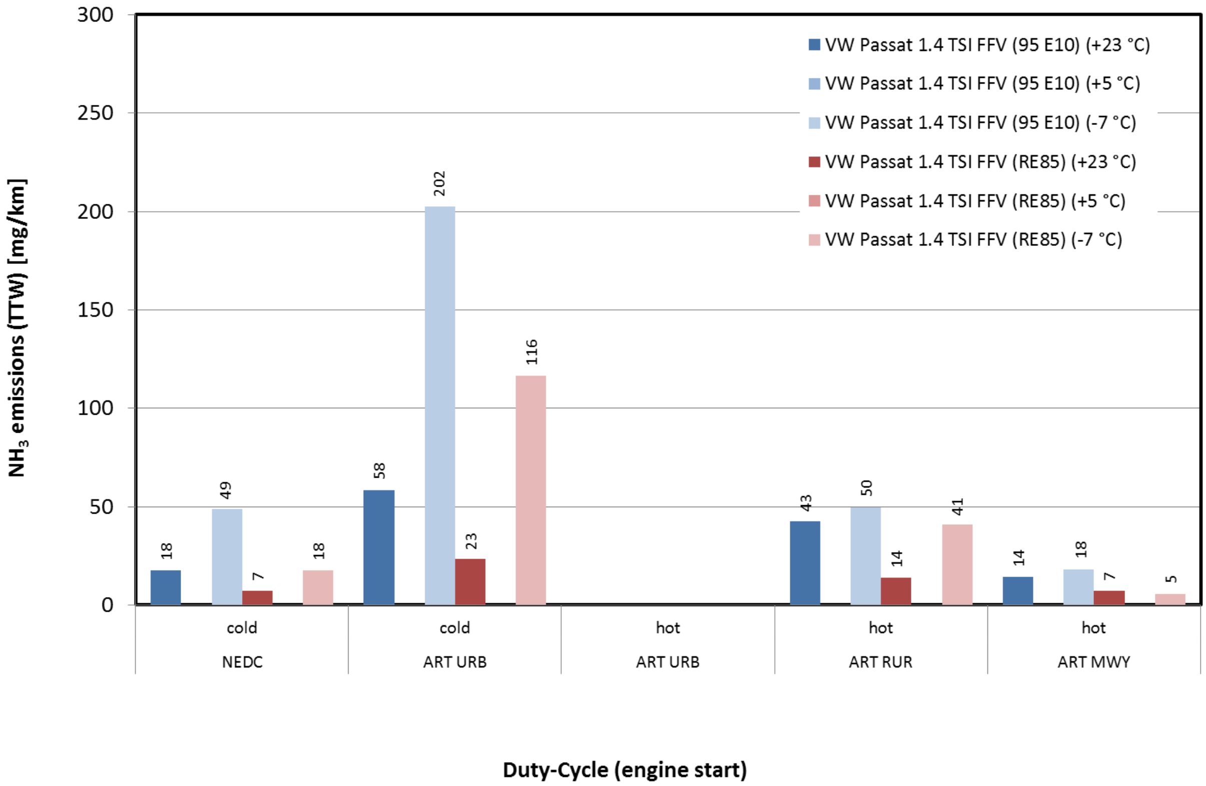


Figure 44: NH_3 emissions from the 1.4 TSI FFV (SI-engine) car tested in Finland with regular gasoline and with E85, at +23, +5 and -7 °C ambient temperature; NEDC and ARTEMIS cycles.

Additional graphs of results from testing in Finland.

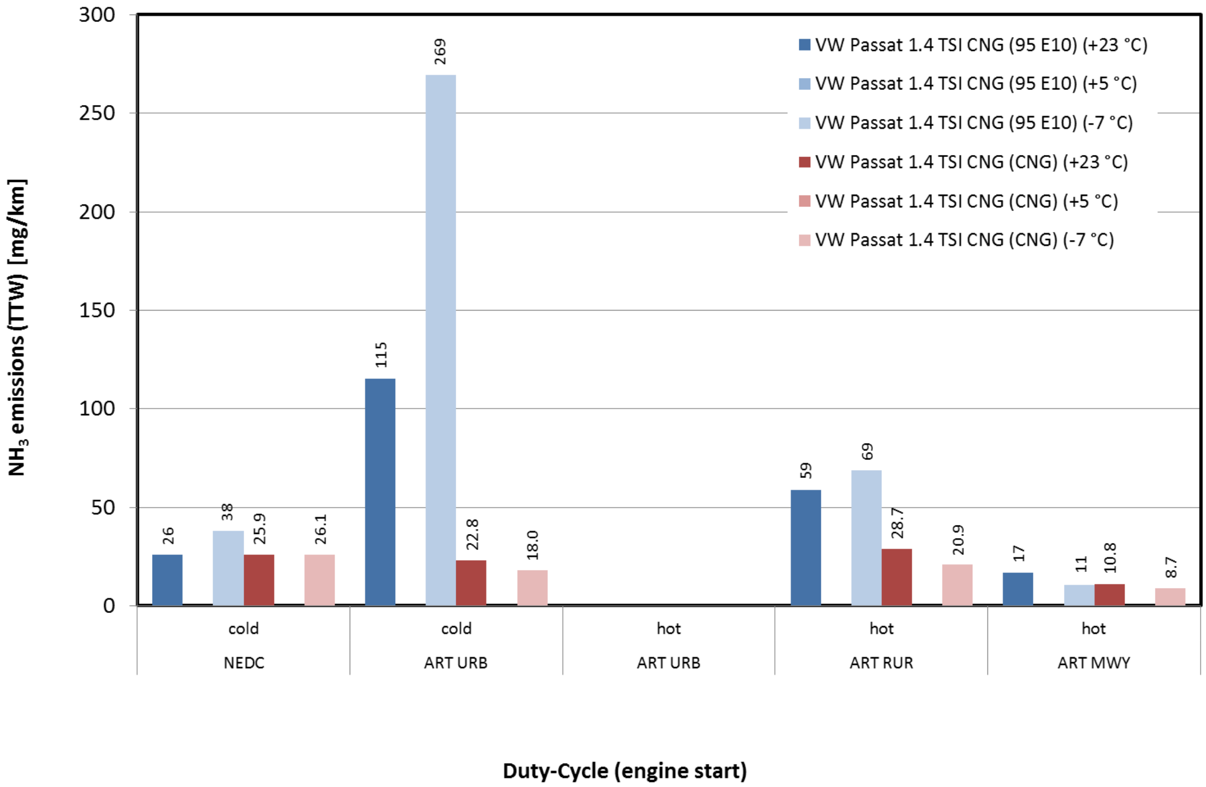


Figure 45: NH_3 emissions from the 1.4 TSI CNG (SI-engine) car tested in Finland with regular gasoline and CNG at +23, +5 and -7 °C ambient temperature; NEDC and ARTEMIS cycles.