2022-01-1014 Published 30 Aug 2022

Advanced Emission Controls and E-fuels on a Gasoline Car for Zero-Impact Emissions

Joachim Demuynck, Pablo Mendoza Villafuerte, and Dirk Bosteels AECC

Andreas Kuhrt, Maximilian Brauer, and Marc Sens IAV

John Williams, Christophe Chaillou, and Victor Gordillo Aramco

Citation: Demuynck, J., Mendoza Villafuerte, P., Bosteels, D., Kuhrt, A. et al., "Advanced Emission Controls and E-fuels on a Gasoline Car for Zero-Impact Emissions," SAE Technical Paper 2022-01-1014, 2022, doi:10.4271/2022-01-1014.

Received: 21 Apr 2022 Revised: 16 Jun 2022 Accepted: 17 Jun 2022

Abstract

The electrified internal combustion engine can contribute to further improving air quality and reducing impact on climate change. A previous publication looked into ultra-low initial cold-start emissions with the implementation of a state-of-the-art emission control system on a gasoline vehicle with market E10 gasoline. This paper reports additional investigations on different drop-in sustainable renewable fuels, including e-fuels. The gasoline demonstrator vehicle is equipped with a 48V mild-hybrid powertrain with a 1.5 L direct injection engine. The innovative emission control system consists of an electrically pre-heated catalyst (EHC) and first three-way catalyst (TWC) in close-coupled position, in combination with an underfloor catalysed gasoline particulate filter (cGPF), second TWC and ammonia slip catalyst (ASC). Pollutant emission tests are conducted on a challenging chassis dyno test for cold-start emissions at 23 °C and -10 °C. Tests that were done before on reference E10 fuel are repeated on Blue Gasoline and two e-gasoline fuels. Similar ultra-low pollutant emissions are measured on the sustainable renewable fuels compared to the reference E10. A Well-to-Wheel analysis is conducted to investigate the potential to reduce CO_2 emissions. The analysis follows the methodology of the JEC report v5 (JRC-EUCAR-Concawe). The results show that already significant reduction is possible today with Blue Gasoline. The e-gasoline shows potential for near-zero CO_2 emissions. With the combination, of advanced emission control technologies and sustainable renewable fuels, research is evolving towards reaching zero-impact emissions for both air quality and climate change.

Introduction

The impact of road transport to air quality and climate change has continuously improved with the introduction of new European legislation.

Pollutant Emissions

To improve air quality and reduce health impacts in the EU, successive European emission standards have been introduced to decrease pollutant emissions from road transport vehicles. Emissions under warm operation have nearly been eliminated for gasoline vehicles, compared to the levels before the existence of the standards. This is now also the case for gasoline ultra-fine particulates (PN) and diesel NOx emissions with the introduction of the Real Driving Emissions (RDE) procedure towards Euro 6d. Good control of gaseous and particulate emissions under relevant actual operating conditions is ensured by testing a car on public roads and over a range of different ambient and driving conditions.

The successive emission standards promoted innovation in catalyst and filter technology design as well as emissions control system layout. This has led to significant reduction in the pollutant emissions within an integrated approach of powertrain development in addition to progress in engine and combustion technology. Examples of state-of-the-art systems for the latest Euro 6d passenger car standards include close-coupled catalysts for cold-start, low speed, low load driving in the city, and underfloor catalysts for high speed, high load operation on the motorway for both diesel and gasoline passenger cars. Total catalysts and filter volumes are designed to cope with peak engine pollutant flow. On-road NOx and PN emissions have been reduced significantly as a consequence and this is confirmed by OEM data at Type Approval [1, 2] and independent third-party testing [3, 4].

Further evolution is expected towards Euro 7 for which the legislative development process is ongoing. It is expected the next pollutant emissions standard will consider modifications to limits and test procedures to ensure lowest possible vehicle pollutant emissions. The CLOVE consortium has worked on the topic on behalf of the European Commission and presented scenarios to the Advisory Group of Vehicle Emission Standards (AGVES) until April 2021 [5]. The actual

Euro 7 proposal from the European Commission is expected in July 2022, it was not yet available at time of writing of this paper.

Emission control research for gasoline vehicles focuses on further reducing the remaining emissions during the initial cold-start phase, as illustrated in literature with an analysis of emissions of Euro 6d-TEMP vehicles [6]. Additional aspects under investigation are further ensuring robust emission control under the widest possible range of driving conditions, and controlling currently non-regulated pollutants.

CO_2 Emissions

EU legislation reduced the fleet average tailpipe CO_2 targets in g/km for passenger cars to mitigate climate change. A new WLTP test procedure was introduced to make the emission targets more representable compared to those established on the NEDC. The fleet targets led to innovation in engine efficiency and hybridisation in addition to development of zero tailpipe emission vehicles. Regulations in the EU have also encouraged the development and incorporation of renewable fuels for transport with a view to reduce its carbon footprint through the Renewable Energy Directive. The most recent adopted version requires 14% of renewables to be applied in road transport on an energy basis. This is under further review as part of the European Commission ‘Fit for 55 package’ [7]. It is understood the ambition level for the uptake of sustainable renewable fuels is increased. But it is difficult to assess how much exactly because the proposal changes the approach for the target from ‘14% on an energy basis’ to ‘13% reduction in the carbon intensity of the fuels’. Although it opens the door to development of new type of fuels, for example advanced biofuels and e-fuels, the target levels within the proposal are not in line with the overall ambition to reduce EU’s GHG emissions by 55% compared to a 1990 reference.

Recent focus of the legislator is on the introduction of zero tailpipe emission vehicles. the ‘Fit for 55’ package’ is considering as one of the options to target 100% share of new vehicle sales as zero tailpipe emissions by 2035 to achieve carbon neutrality by 2050. However, it is expected most new vehicles will be equipped with an internal combustion engine for decades to come in a worldwide context, which is important for global warming. Additionally, all emissions that can be reduced now will have a significant impact on mitigating climate change due to the cumulative effect of every gram of CO_2 emitted into the atmosphere. Consequently, it is key to further improve the efficiency of an electrified internal combustion engine. Moreover, it is essential to operate as many vehicles as possible on sustainable renewable fuels. Data [8, 9, 10, 11, 12, 13] shows that a vehicle with an internal combustion engine meets the carbon neutral target, similar to a BEV on renewable electricity and a FCEV on green hydrogen.

Zero-Impact

Consequently, the electrified internal combustion engine can contribute to achieve the sustainability goals. This work looks into further reduction in initial cold-start pollutant emissions with the implementation of a state-of-the-art emission control system on a gasoline vehicle. The work includes the measurements of currently non-regulated pollutants. Additionally, the ultra-low pollutant emissions are validated on sustainable renewable fuels, which allow to significantly reduce the Well-to-Wheel (WtW) CO_2 emissions. Aim is to evolve towards reaching zero-impact emissions with this combination.

Materials and Methods

Base Vehicle

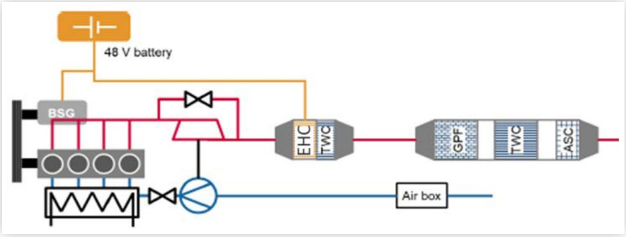
The base vehicle of the demonstrator is a Euro 6d C-segment car. The vehicle powertrain consists of a turbocharged 4-cylinder, 1.5 L gasoline engine with direct injection and a peak power of 110 kW. The engine is equipped with variable valve timing and cylinder deactivation. The powertrain includes a 48 V mild-hybrid system in P0 configuration (belt starter-generator, up to 9 kW as motor, 12 kW as generator). An open engine control unit was available to implement the control measures described below.

Demonstrator Emission Control System

The project was conducted in different phases. Ultra-low pollutant emission results achieved in a first phase were already published [14]. This paper focuses on the results of the second phase. The original emission control system of the vehicle was removed and replaced by the system described here, consisting of a close-coupled and underfloor canning as shown in Figure 1.

In the close-coupled position, a metallic substrate equipped with an electrically heated catalyst (EHC) connected to the 48 V system is followed by a cordierite Three-Way Catalyst (TWC) substrate with the same volume. The total close-coupled TWC volume is 1.57 L. The EHC consists of a heating disc with 135 cpsi cell density and a support catalyst with 800 cpsi. The cordierite TWC substrates targets maximised surface area for enhanced cold-start performance, with 900 cpsi and a wall thickness of 2 mil. In underfloor position, the system consists of a catalysed 1.64 L GPF (Gasoline Particulate Filter, 200 cpsi and 8 mil), a second 1.1 L TWC (600 cpsi and 2.5 mil) and a 0.82 L Ammonia Slip Catalyst (ASC, 600 cpsi and 2.5 mil). NH_3 reduction with the ASC is done in addition to improved lambda control during the

FIGURE 1 Advanced emission control system tested



catalyst warm-up period. The ASC relies on a combination of storage and oxidation functionality to reduce NH_3 emissions. Except for the modifications during the initial warm-up period, with an early closed-loop control to match light-off of the ccTWC, the baseline lambda control approach is used (wide-band sensor before the ccEHC|TWC and 2-step lambda sensor behind ccEHC|TWC. The lambda control parameters were fine-tuned to the catalyst system.

The EHC is activated 8 s before engine cranking (pre-heating) and kept active until the temperature downstream the close-coupled TWC reaches 370 °C (interrupted temporarily if the heating disc temperature reaches 900 °C). The vehicle board net allows to apply 4.5 kW heating. An additional investigation of 60 s pre-heating in combination with secondary air supply in the exhaust manifold was investigated as an outlook to vehicles with a higher degree of electrification, for example a full hybrid or plug-in hybrid [15], but this is not part of the results presented in this paper.

The emission control components are bench aged as a system, targeting 160k km, except for the EHC which was added at a later stage. This part was hydrothermally aged as a component.

Test Conditions

This paper focuses on chassis dyno measurements conducted in the project, which were repeated on the different fuels described below. Emission tests on the reference fuel were also done over a wide range of on-road driving conditions [14]. An RDE-derived trace is used for tests on the chassis dyno. This test is aimed to be on the boundary of Euro 6d RDE with respect to vxa_{pos} (Euro 6d RDE boundary condition for driving dynamics, vehicle speed multiplied with vehicle acceleration (only positive values used)). The test is designed to be challenging for the initial cold-start emissions because it is characterized by only a short time between engine start and drive off (4 s) in combination with a first acceleration going up to the maximum allowed velocity of 60 km/h. The test is conducted at an ambient temperature of 23 °C and -10 °C. Tests are always conducted with a cold-start after the vehicle has been soaked overnight at the ambient temperature of the test, so both engine and emission control system have this ambient temperature as initial temperature.

Measurement Equipment

Three gas sampling points are foreseen, before (1) and after (2) the close-coupled TWC, and at the tailpipe (3). Standard gas analysers are foreseen in each position. Fourier Transform InfraRed spectroscopy (FTIR) analysers are used in position 2 and 3. Particulates are measured in the dilution tunnel according to a set-up with a cut-off at 10 nm (PN10). Additional instrumentation is available to monitor temperatures and pressures in between the different components.

Fuels

The measurements are repeated on different EN228-compliant fuels. Reference tests are done with market RON95 E10 gasoline fuel. Tests are then repeated on different sustainable renewable fuels to validate the ultra-low pollutant emissions while investigating Well-to-Wheel CO_2 emissions reductions.

Blue Gasoline is tested as a fuel which is already available [16], targeting a 20% CO_2 reduction compared to full fossil gasoline. Then, two different e-gasoline fuels are tested.

The first e-gasoline, provided by Aramco R&D, is a formulated gasoline that replicates physico-chemical characteristics of a fully EN228 compliant gasoline based on conversion from low-carbon methanol (also known as MtG, methanol to gasoline). Today, hydrocarbon production from low-carbon C1 or C2 alcohols is still in a pilot development phase, with a significant potential to be scaled to industrial production in the upcoming decade. Methanol production from CO_2 and low-carbon (blue or green) hydrogen is a means of sourcing ultra-low GHG emission feedstock for refineries, and MtG process itself represents an opportunity to revamp existing assets into green refineries. This MtG e-gasoline 1 as formulated in the present work has the potential to be 100% renewable, without using any fossil blend stock for achieving its target properties.

The second e-gasoline is a development sample provided by Porsche from its activities in the field of regenerative fuels (named POSYN fuel) towards CO_2 neutrality [17]. The POSYN fuel is a EN228 compliant test fuel compliant which can be blended with current commercial fuels. The specific sample tested is POSYN CI11 which contains 65% renewable content from a MtG synthesis. Other components, e.g., ethers, also have the potential to be renewable. It is a RON98 fuel in contrast to the other fuels which are RON95.

An overview of fuel properties is given in Table 1. Fuel property data is from specific analysis of the fuel sample in case of Blue Gasoline and e-gasoline. For E10 reference fuel it is an average representative for the entire range of fuel samples delivered to the test facility.

Well-to-Wheel Calculation Method

The method used for calculating well-to-wheel CO_2 emissions derives from the one used in the JEC WtW report v5 [18]. $CO_{2,WtW}$ in g/km is calculated with equation (1).

$$CO_{2,WtT,fuel\ production}\left[\frac{g}{km}\right] - CO_{2,biocredits}\left[\frac{g}{km}\right] + CO_{2,TtW}\left[\frac{g}{km}\right] \quad (1)$$

TABLE 1 Fuel properties

	E10 reference	Blue Gasoline	e-gasoline 1	e-gasoline 2
RON	96	95	96	99.2
LHV (MJ/kg)	41.8	41.7	41.9	42.32
Density (kg/l)	0.7425	0.7477	0.7239	0.742
%C	82.9	82.7	83	84
%H	13.6	13.5	14.0	13.76
$\%O_2$	3.4	3.6	3.0	2.24

The $CO_{2,WtT,fuel\ production}$ is calculated with equation (2).

$$\frac{Q_{fuel}\left[\frac{MJ}{100km}\right]}{100} * \left(\sum_{all\ compounds,i} CO_{2,intensity,WtT,i} \left[\frac{gCO_2}{MJ}\right] * NRJ_i \right) \tag{2}$$

Where Q_{fuel} is the measured fuel energy in MJ used by the vehicle for 100 km driven on the chassis dyno, $CO_{2,intensity,WtT,i}$ are the Well-to-Tank CO_2 emission factors for the compound i blended in the fuel, NRJ_i is the share of energy of the compound i blended in the fuel. The biocredits are calculated in a similar manner based on the value for each component blended in the fuel which is not from fossil origin.

The specific composition of e-gasoline 2 and required data for the WtW calculation is not available to the authors, so the calculations are done for E10, Blue Gasoline and e-gasoline 1.

An overview of all the data used is given in Table 2. Well-to-Tank input data is coming from the JEC WtW report, except for Blue Gasoline, where it is from the product specification sheet. Also MtG gasoline is not available in the JEC report, this is taken from literature [9]. Tank-to-Wheel input data is from chassis dyno experiments.

Well-to-Tank data from the JEC report is expressed in CO_{2eq} emissions as also the impact of other greenhouse gases is considered. This is not the case for the measured Tank-to-Wheel values.

Results and Discussion

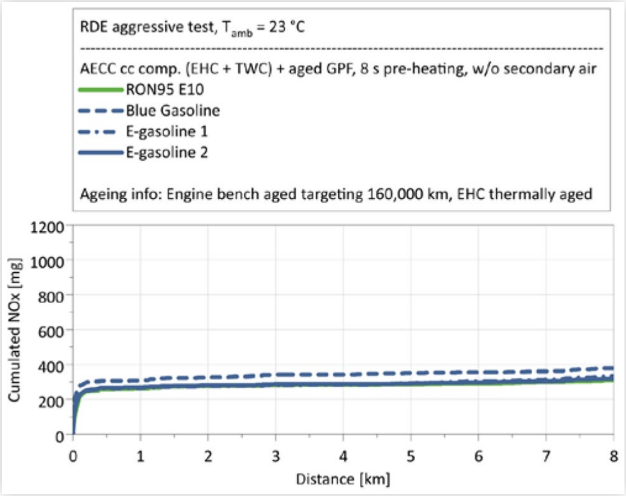
Pollutant Emissions

Cumulative NOx emissions at 23 °C are plotted in Figure 2 for the 4 tested fuels. Very similar ultra-low emissions are measured on all fuels tested. Initial cold-start peak varies between 260 and 271 mg within the first kilometer of driving. This is a significant reduction of 56-58% compared to the 625 mg measured on the same test with the Euro 6d configuration [15] due to the combination of EHC and TWC with maximized surface area. Near-zero emissions are achieved under all driving conditions after the initial cold-start peak. Urban NOx emissions including cold-start range between 27 and 31 mg/km, when evaluated after 16 kilometers. Total test results vary between 9 and 11 mg/km.

TABLE 2 Well-to-Wheel input data

	E10 reference	Blue Gasoline	e-gasoline 1
$CO_{2,intensity}$ (gCO_2/MJfuel)	72.72	72.7	72.63
WtT $CO_{2,emission\ factor}$ (gCO_2/MJfuel)	17.64	16.5	2.6
$CO_{2,biocredits}$ (gCO_2/MJfuel)	-4.58	-17.7	-72.63

FIGURE 2 Cumulative NOx emissions at 23 °C.



The corresponding traces at -10 °C are shown in Figure 3. Also here, very similar ultra-low NOx emissions are measured on all fuels. Initial cold-start ranges between 500 and 754 mg within the first kilometer. This is again a significant reduction of 40-60% compared to the 1250 mg measured on the same test with the Euro 6d configuration. The result on the two e-gasolines is lower, but this is mainly due to driver impact during the initial drive-off. Emissions increased compared to 23 °C due to the increase in heat-up time of the close-coupled components. Once the system is at operation temperature, also near-zero emissions are achieved over the range of driving conditions tested. Urban NOx including cold-start ranges between 39 and 60 mg/km (evaluated at 16 km), total NOx between 9 and 17 mg/km.

Cumulative PN10 emissions at 23 °C are plotted in Figure 4, those at -10 °C in Figure 5. No significant differences can be observed between the different fuels. Urban PN emissions including cold-start vary between 1.3 and 1.8x10^{10} #/km for the entire range of ambient temperatures tested. Total PN emissions observed are between 6.7 and 9.9x10^9 #/km. It is to be noted that the ageing status of the GPF reached a condition

FIGURE 3 Cumulative NOx emissions at -10 °C.

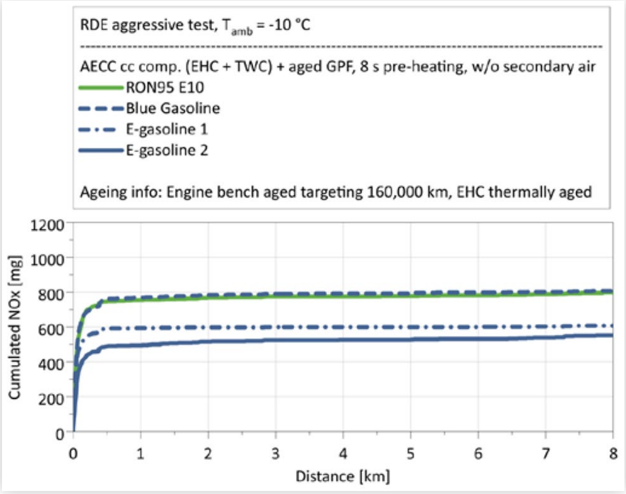


FIGURE 4 Cumulative PN10 emissions at 23 °C.

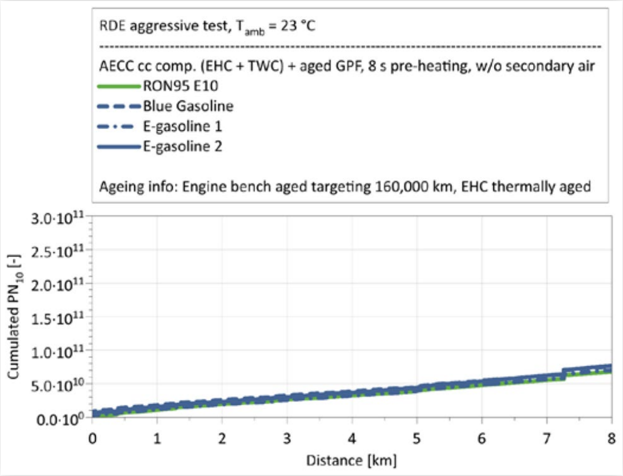
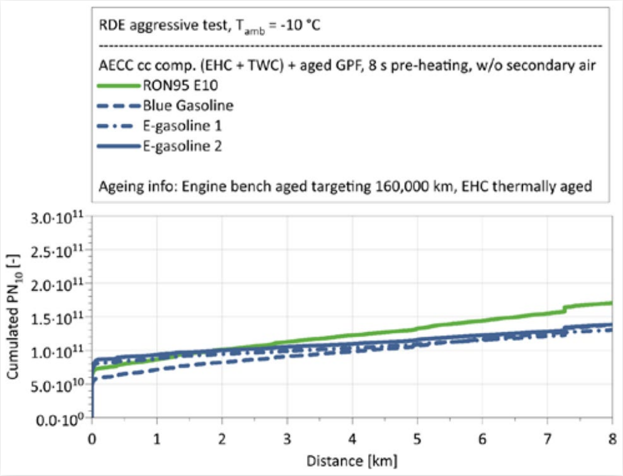


FIGURE 5 Cumulative PN10 emissions at -10 °C.



without nearly any initial cold-start peak, which was not the case during tests earlier in the project or with a fresh part [15].

Non-Methane Organic Gases (NMOG) emissions are shown in Figure 6 and Figure 7. Ultra-low levels are measured. At 23 °C, NMOG varies between 9 and 15 mg/km when evaluated at 16 km including the initial cold-start. At -10 °C, results vary between 37 and 57 mg/km. Near zero-emissions are measured after the initial cold-start peak, total test values remain below 12 mg/km including at -10 °C. No significant differences are observed between the fuels tested at 23 °C. The differences observed at -10 °C are due to test-tot-test variability in the initial drive-off. These are not due to the different fuel.

CO emissions were mainly determined by an initial cold-start peak, which was impacted by the initial ambient temperature. At -10 °C, urban CO emissions at 16 km including initial cold-start peak varied between 123 and 135 mg/km, whereas this was between 59 and 72 mg/km at 23 °C. Results were very similar for all fuels.

Also no differences were observed for the other pollutants measured. Maximum urban or total NH_3 measured during all tests was below 4 mg/km, for N_2O this was 5 mg/km and methane this was 7 mg/km.

FIGURE 6 Cumulative NMOG emissions at 23 °C.

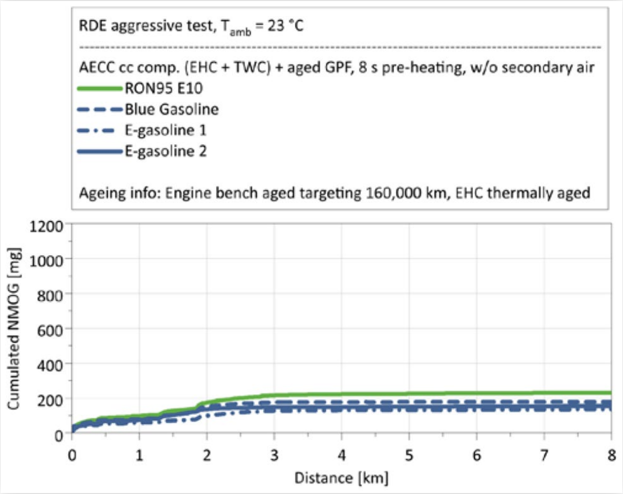
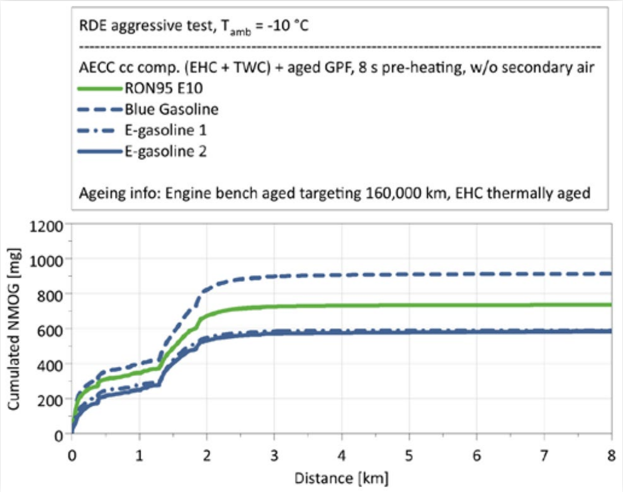


FIGURE 7 Cumulative NMOG emissions at -10 °C.



CO_2 Emissions

Measured CO_2 emissions at 23 °C are plotted in Figure 8. Overall, very similar tailpipe CO_2 emissions are measured, and differences are within test-to-test variability. CO_2 emissions vary between 128.6 and 130.9 g/km. This is an expected result, as CO_2 intensities of the different fuels estimated from their fuel properties are very similar.

Final Well-to-Wheel CO_2 emissions calculated are shown in Figure 9. The reference E10 emissions are 154.1 g/km CO_{2eq}.

Blue Gasoline results in 127.5 g/km CO_{2eq}. This is already a significant reduction of 17% compared to the E10 fuel, which can be obtained with a fuel that is already on the market. It is important to note that the 20% CO_2 reduction advertised for this fuel is based on a comparison with the emissions of 100% fossil gasoline fuel. Our comparison is made with E10, which

FIGURE 8 Measured tailpipe CO_2 emissions at 23 °C.

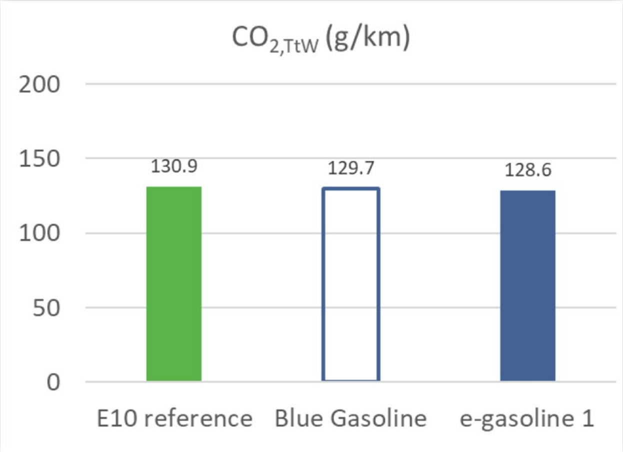
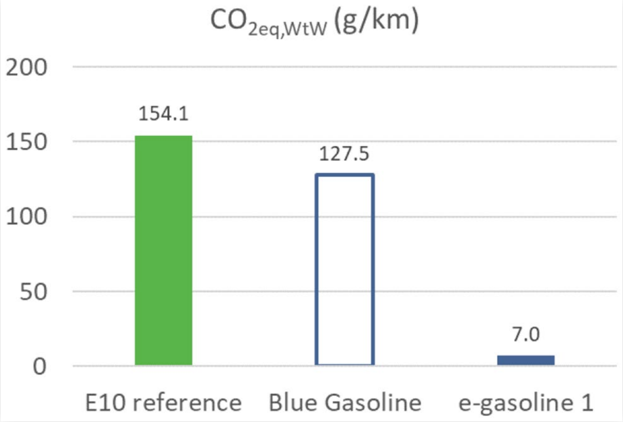


FIGURE 9 Calculated Well-to-Wheel CO_2 emissions.



already has a reduced carbon footprint due to its renewable ethanol content.

The e-gasoline 1 result shows it is possible to reduce the CO_2 emissions even further to a near-zero value with 100% sustainable renewable fuel. The resulting WtW value is 7 g/km.

Even if the analysis is expanded to a full Cradle-to-Grave (CtG) approach, ultra-low CO_2 emission levels would still be obtained. On a CtG basis, the emission factor of MtG would increase to 9.9 gCO_2/MJfuel (wind energy source) or 20.8 gCO_2/MJfuel (photovoltaic solar energy source) instead of 2.6 gCO_2/MJfuel (WtW basis) [9]. The resulting CtG CO_2 emissions would vary between 20 and 40 g/km in this case.

Summary and Conclusions

This paper described the implementation of an advanced emission control system on a gasoline demonstrator vehicle equipped with a 48 V mild-hybrid powertrain to achieve ultra-low initial cold-start and non-regulated emissions. The results shown were significantly lower than the already low Euro 6d level reported before.

Pollutant emission tests were repeated on different drop-in sustainable renewable fuels. It was shown that similar results were achieved on all fuels. Minor emissions differences were observed at -10 °C due to test-to-test variability in the initial drive-off, these were not due to the different fuel. Ultra-low initial cold-start peak is measured and near-zero emissions are reached within the first kilometer of driving, independent of the ambient temperatures tested (23 °C and -10 °C).

A Well-to-Wheel analysis was conducted to investigate CO_2 reductions that can be achieved. It was shown that a significant reduction compared to E10 reference fuel is already possible with Blue Gasoline which is available on the market today. An MtG e-gasoline fuel shows to have the capability to reach near-zero WtW CO_2 emissions from an internal combustion engine.

The paper shows research is evolving towards reaching zero-impact emissions with a combination of advanced emission control technologies and sustainable renewable fuels.

References

1. ACEA RDE Monitoring Database, https://www.acea.be/publications/article/access-to-euro-6-rde-monitoring-data.
2. JAMA RDE Monitoring Database, http://www.jama-english.jp/europe/publications/rde.html.
3. Green NCAP, https://www.greenncap.com.
4. Bernard, Y., Dallmann, T., Lee, K., Rintanen, I. et al., “Evaluation of Real-World Vehicle Emissions in Brussels,” *The Real Urban Emissions (TRUE) Initiative* (November 2021).
5. Advisory Group of Vehicle Emission Standards (AGVES), European Commission expert working group documents on Circabc, https://circabc.europa.eu/ui/group/f57c2059-ef63-4baf-b793-015e46f70421/library/6325a200-9d24-40fc-8fef-ba1fe4da9702.
6. Demuynck, J., Sileghem, L., Verhelst, S., Mendoza Villafuerte, P., and Bosteels, D., “Insights for post-Euro 6, Based on Analysis of Euro 6d-TEMP PEMS Data,” International Transport and Air Pollution Conference, 2021.
7. European Green Deal: Commission Proposes Transformation of EU Economy and Society to Meet Climate Ambitions, https://ec.europa.eu/commission/presscorner/detail/en/ip_21_3541.
8. Ternel, C., Bouter, A., and Melgar, J., “Life Cycle Assessment of Mid-Range Passenger Cars Powered by Liquid and Gaseous Biofuels: Comparison with Greenhouse Gas Emissions of Electric Vehicles and Forecast to 2030,” *Transp. Res. Part D Transp. Environ.* 97 (2021): 102897. https://doi.org/10.1016/j.trd.2021.102897.
9. Yugo, M., Gordillo, V., Shafiei, E., and Megariti, A., “A Look Into the Life Cycle Assessment of Passenger Cars Running on Advanced Fuels,” In Proceedings of the SIA Powertrains & Power Electronics Conference, Paris, France, 9-10 June 2021.

10. Bothe, D., and Steinfort, T., “Cradle-to-Grave-Lebenszyklusanalyse im Mobilitätssektor, Metastudie zur CO2-Bilanz alternativer Fahrzeugantriebe,” FVV study, June 2020.
11. Andersson, Ö. and Börjesson, P., “The Greenhouse Gas Emissions of an Electrified Vehicle Combined with Renewable Fuels: Life Cycle Assessment and Policy Implications,” *Applied Energy* 289 (May 2021): 116621. https://doi.org/10.1016/j.apenergy.2021.116621.
12. Hill, N., Amaral, S., Morgan-Price, S., Nokes, T. et al., Determining the Environmental Impacts of Conventional and Alternatively Fuelled Vehicles Through LCA; Ricardo Energy & Environment on behalf of the European Commission DG-CLIMA: Brussels, Belgium, 2020.
13. Demuynck, J., Dauphin, R., Yugo, M., Mendoza Villafuerte, P. et al., “Advanced Emission Controls and Sustainable Renewable Fuels for Low Pollutant and CO2 Emissions on a Diesel Passenger Car,” *Sustainability* 13 (2021): 12711. https://doi.org/10.3390/su132212711.
14. Demuynck, J., Mendoza Villafuerte, P., Bosteels, D., and Randlshofer, G., “Ultra-low Emissions of a 48V Mild-Hybrid Gasoline Vehicle with Advanced Emission Control Technologies and System Control,” SAE Technical Paper 2021-24-0070 (2021), https://doi.org/10.4271/2021-24-0070.
15. Demuynck, J., et al., “Zero-Impact Emissions from a Gasoline Car with Advanced Emission Controls and e-fuels,” 43rd Vienna Motor Symposium, 2022.
16. Ebberg, J., “Bosch, Shell, and Volkswagen develop renewable gasoline with 20 percent lower CO_2 emissions”, Bosch Press release, May 2021.
17. Casal Kulzer, A., “eFuels: a Further Step Towards Sustainable Mobility,” SAENA 15th International Conference on Engines & Vehicles, Keynote Speech, 2021.
18. Prussi, M., Yugo, M., De Prada, L., Padella, M. et al., *JEC Well-To-Wheels report v5, EUR 30284 EN* (Luxembourg: Publications Office of the European Union, 2020, ISBN 978-92-76-20109-0), doi:10.2760/100379 JRC121213

Contact Information

Joachim Demuynck, AECC
Boulevard Auguste Reyers 80, B-1030 Brussels
Belgium
33Tjoachim.demuynck@aecc.eu33T

Acknowledgments

The authors would kindly like to thank members of the Association for Emissions Control by Catalyst (AECC aisbl) and the International Platinum Group Metals Association (IPA) for the financial support, the supply of catalyst parts and for their highly valuable contributions to this study. The authors acknowledge Bosch for the supply of the Blue Gasoline and Porsche for the supply of the POSYN fuel. The authors appreciate VW allowed to use vehicle and engine hardware.

Definitions/Abbreviations

ASC - Ammonia Slip Catalyst

cc - close-coupled

CO - carbon monoxide

CO_2 - carbon dioxide

GPF - Gasoline Particulate Filter

NH_3 - ammonia

N_2O - nitrous oxide

NMOG - Non-Methane Organic Gases

NOx - nitrogen oxides ($NO+NO_2$)

PEMS - Portable Emissions Measurement System

PN10 - Particle Number with 10 nm lower cut-off size

RDE - Real Driving Emissions

THC - total hydrocarbons

TWC - Three-Way Catalyst

vxa_{pos} - Euro 6d RDE boundary condition, vehicle speed multiplied with vehicle acceleration (only positive values used)

uf - underfloor

WLTC - World harmonized Light duty Testing Cycle

ISSN 0148-7191