Agronomy Research **16**(S1), 977–984, 2018
https://doi.org/10.15159/AR.18.104

An assessment of stratification of exhaust gases from gasoline and diesel engine

A. Birkavs* and R. Smigins

Latvia University of Life Sciences and Technologies, Faculty of Engineering, Motor Vehicle Institute, 5 J.Cakstes blvd, LV3001 Jelgava, Latvia
*Correspondence: aivars.birkavs@llu.lv

Abstract. Research the aim of which was to find out stratification of main exhaust components outside the tailpipe of the vehicle was realized in Alternative Fuels Research Laboratory of Latvia University of Agriculture using two commercially produced testing vehicles (diesel and gasoline) and exhaust gas analytical system AVL SESAM FTIR. Additionally there was created a gas testing camera allowing to measure concentration of exhaust gas components in different heights and windless conditions. Regulated and unregulated emissions from gasoline and diesel engines were measured and discussed. Results obtained during the measurements showed main stratification of toxic components from both engine types from 0.6 to 1.1 m from the ground making a risk to get some health problems by inhalation, especially for children. Main components (NOx, CO, HC) of exhaust gases of gasoline engines stay in the air for about 15 minutes in height of 1.0 m from the ground level, while methane and acetylene stay in the air for a 15 minutes in height of 0.6 m from the ground level.

Key words: exhaust gases, stratification, diesel, gasoline, engine.

INTRODUCTION

Internal combustion (IC) engines are widely used in transport sector for a long time leaving a positive impact on almost any sector globally as any other invention. In addition IC engines leave also an important impact on environmental conditions as they have been considered as main contributors to environmental pollution based on the amount and consistence of emitted components. Main part of those components is the result of various processes taking part during the combustion of fuel in the cylinders of the engine – incomplete combustion, combustion of non-carbon components, different reactions between components under complicated conditions, etc. The main air quality affecting componets from diesel and gasoline engines, which are also regulated by EURO emission standards, are nitrogen oxides, carbon monoxide, hydracarbons and particulate matters. The concentration of those components are strongly connected with driving conditions, vehicle technology, maintenance of the vehicles, etc. Despite the fact that engine technology all the time is under improvement to meet more stringent emission standards, possibility to develop more efficient and low cost emission control systems becomes more complicated.

Despite to all improvements, growth in global road emissions are expected mainly due to a prognosed increase in growth of vehicle owners worldwide reaching 2 billion vehicles till 2050 (Rothengatter et al., 2011). Additional problem is also a gap between official and real-world emission results, which was intensively analyzed by researchers due to diesel emission scandal in recent years. The research realized by International Council on Clean Transportation (ICCT), analyzing 11 data sources covering 14 years and 6 countries, and almost 600,000 vehicles, have found that the gap between official vehicle CO_2 emissions and real-world CO_2 emissions continues to grow – from 8% in 2001 to 38% in 2014 (Tietge et al., 2015). It is expected that the widening gap will add 1.5bn additional tonnes of CO_2 for 2030 increasing the prospects of dangerous and uncontrollable climate changes (Mind the gap, 2015). Another research done due to a diesel emissions scandal discovered that diesel cars in EU meet official limit for NO_x mainly in laboratory conditions, but emit far more pollution in real driving on the roads and therefore the global human health impact from NO_x excess in exhaust emissions could result in at least 38,000 premature deaths due to heart and lung disease and strokes (Anenberg et al., 2017). Additionaly breathing of fuel fumes can affect human health causing irritation of eyes or respiratory tract. Despite to the fact that these effects could be experienced in short term, regular or prolonged exposure could be the reason for coughing, chestiness or even the risk of lung cancer or asthma.

Besides the direct impact of exhaust gas components emitted directly from fuel combustion there exists also synthesis of them in the atmosphere based on different chemical reactions. One of such examples is ozone, which is noxious pollutant at the ground level and is significant contributor of global warming (Johnson, 2017). Main ozone precursors are man-made and emitted mostly by transport, especially diesel engines, which are leading source of NO_x (Johnson, 2017). Formation of ozone is over a day, starting in the morning, when NO, HC and CO is emitted from tailpipes of the vehices till mid-afternoon, when NO_x in the presence of sunlight form ozone together with VOCs. The formation of ozone and secondary organic aerosols from gaseous organic compounds emitted by diesel and gasoline are confirmed by laboratory experiments (Harrison & Hester, 2017).

Based on background knowledge, this study is designed to identify concentration level of the main exhaust gas components in the air in current conditions from two general transport groups (diesel and gasoline vehicles) to highlight potential risks for public health. It is important also due to a fact that Latvia has one of the oldest car fleet in the EU – average age is about 12.5 years (Smigins & Shipkovs, 2014). And the structure of the fleet shows rapid increase in the number of diesel vehicles. Besides of that it was observed that the largest, slow-moving traffic flow usually forms at the entrance doors of shops, near kindergardens, near sidewalks during congestions. where usually is possible to meet a lots of people and children. This research gives possibility to understand movement of exhaust gas components in such places and explain why it is necessary to avoid prolonged stay in it.

MATERIALS AND METHODS

To achieve the objectives of this study, evaluation of exhaust gases were conducted in laboratory environment using two vehicles – one with diesel engine (*Volvo V70 2.5TDI*) and another with gasoline engine (*Audi A6 2.6*). *Volvo V70* engine is a fivecylinder, four stroke, OHC, water cooled, with effective power of 103 kW. *Audi A6* engine is a six-cylinder, four stroke, OHC, water cooled engine with effective power of 110 kW. Both engines are with industrial application and they have catalytic converters. Diesel fuel used in tests is based on standard EN590:2014 and gasoline based on standard EN228:2013.

Air sampling was realized in the Alternative Fuels Research Laboratory of the Latvia University of Agriculture in the laboratory controlled environment provided by gas testing camera and AVL SESAM FTIR multicomponent exhaust gas measurement system, which allows to measure up to 25 gases simultaneously and some components can be calculated from this process.

Gas camera with height of 2 m and a diameter of 0.6 m was prepared specially for experimental work. Gas supply valve was built-in 40 cm from the ground level for the regulation of gas inlet, as also gas exhaust valve was built in the top of gas camera. This allowed to measure concentration of exhaust gas components in different heights and windless conditions. Four different positions were chosen for measurements: 0.1 m, 0.6 m, 1.1 and 1.8 m. Measurements were started only when the engine was turned-off and camera was completely filled with exhaust gases realizing 0.5 min record for each position. Such measurements were realized 4 times with time interval 3 min. Overall, there is possible to highlight such measurement times: 0–2 min, 5–7 min, 10–12 min and 15–17 min. After each test gas camera was fully aired from exhaust gases. Filling of the camera with exhaust gases was realized in 5 minutes. During the tests each engine was operated in idle mode, following to the corresponding working temperature. Each vehicle was tested based on such methodology.

The schematic diagram of the experimental setup used for studying engine emission characteristics is shown in Fig. 1.

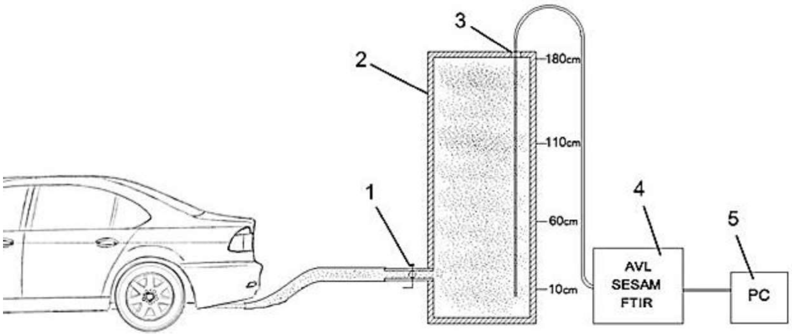

Figure 1. Schematic diagram of experimental setup: 1 – inlet valve; 2 – gas storage tank; 3 – probe loading aperture; 4 – multicomponent exhaust gas measurement system AVL SESAM FTIR; 5 – data recording PC.

During the research all gases were fixed, but detailed analysis were done only for the most essential regulated exhaust gas components: nitrogen oxides (NO_x), carbon monoxide (CO), carbon dioxide (CO_2) and unburned hydrocarbons (HC), sulphur dioxide (SO_2), as also unregulated exhaust gas components: ammonia (NH_3), methane (CH_4), acetylene (C_2H_2) and ethane (C_2H_6). The detected level of each component was averaged as the result of three replications to decrease the uncertainty. Each replication was the real time record with an interval of 1 sec.

Besides of that it was taken into account that stratification of gases was affected by the density of gas at defined pressure and temperature, which depends on its molecular weight.

RESULTS AND DISCUSSION

The experimental data, which characterizes the variation of different emissions for diesel engine based on time and height can be seen in figures below (Fig. 2). Results shows that main part of NO_x, CO and CO_2 emissions do not move in height for more than 0.6 m for a first 2 minutes after the blurring from tailpipe in environment. More substantial movement has been observed during next time period (5–7 min), when the gases divided evenly in all camera. After that it is possible to observe that all mentioned gases gradually settles and retains a significant concentration in next two measurements (10–17 min) in height up to 1.1 m. This is a height, which is freely accessible to children, pets and poses a significant health risk.

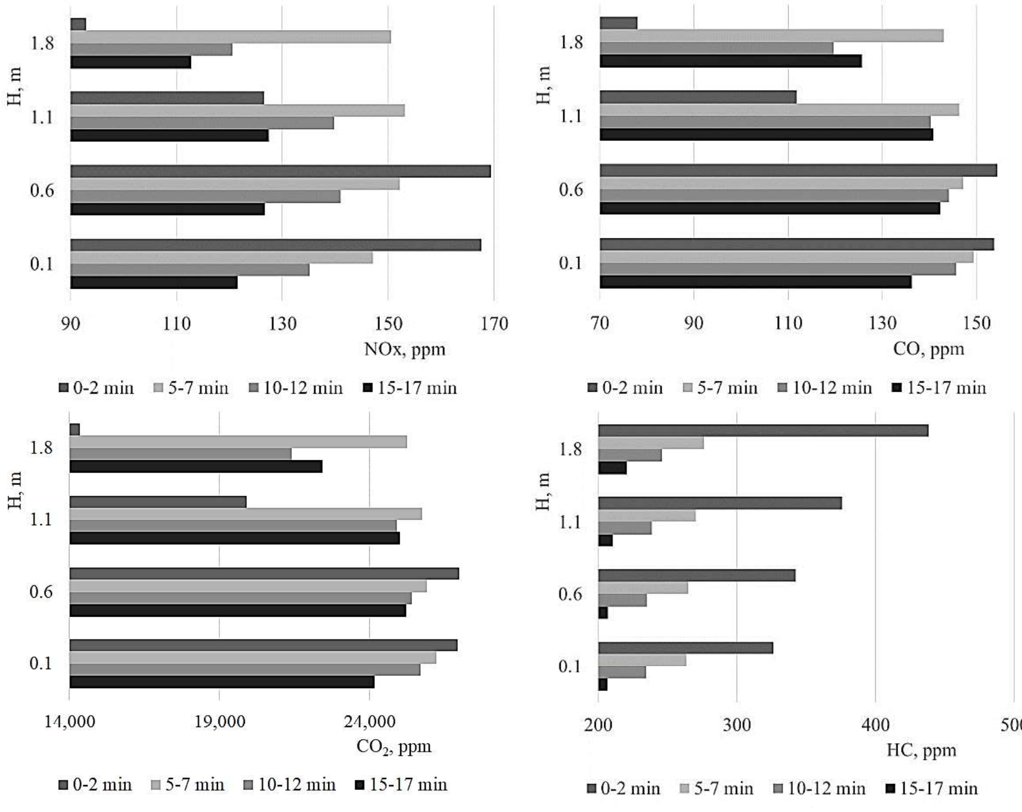

Figure 2. Variation of main regulated emissions (NOx, CO, CO_2 and HC) for diesel engine (Volvo V70 2.5TDI).

The situation is completely different for HC emissions, where the largest concentration in first two minutes after blurring from tailpipe in environment was registered in height of 1.8 m reaching 438 ppm. Significant HC concentration reduction till 206–220 ppm was observed in the next time periods with increasing of a time, but the gas was evenly spaced around the camera. It means that HC emissions also increase the risk to reach a human respiratory tract.

Very similar results with small derogations were observed in case of gasoline vehicle. The main difference is expressed in the big gap in concentration of the main components compared to the diesel emissions. Fig. 3 summarizes main results obtained during the tests. As presented in Fig. 3, that main part of NO_x, CO and CO_2 emissions concentrate in height of 0.1–1.1 m for a first 2 minutes after the blurring from tailpipe in environment. Gradually all mentioned gas component concentration decreases reaching the highest level of around 1.1 m in height during the next 15 minutes (431 ppm for NO_x, 26598 ppm for CO).

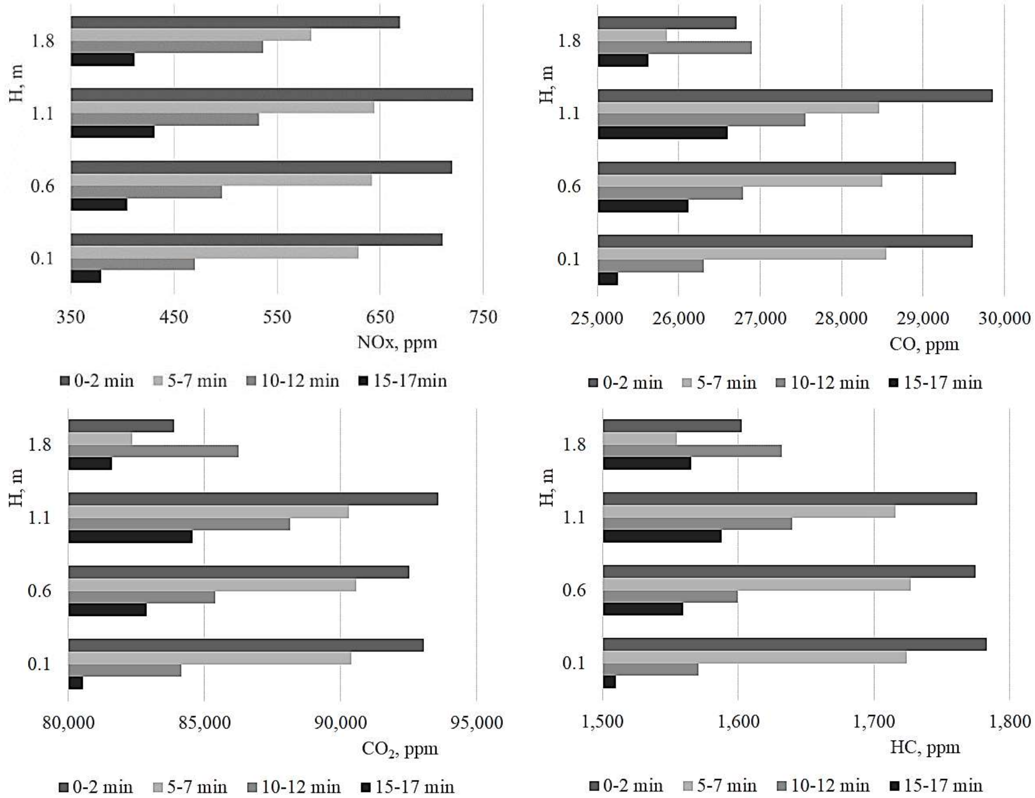

Figure 3. Variation of main regulated emissions (NO_x, CO, CO_2 and HC) for gasoline engine (Audi A6 2.6).

HC emissions are more pronounced in height of 0.1 m in a first 2 minutes gradually increasing concentration till 1.1 m in the next 10–15 min. Among all the pollutants, HC has the highest concentration in the air after defined period (10–15 min).

Differences in the amount of emitted components from gasoline and diesel engines could be explained by the difference in carbon (C) and hydrogen (H) content in fuel, which combine with oxygen (O) during combustion. This difference can vary in a couple of percentage between both fuels and therefore it is possible to observe variation of the produced emissions (especially, CO_2) during combustion.

Besides of those components, there was decided to turn attention on main unregulated emissions, like NH_3, C_2H_6 and others. Ammonia is one of the most abundant nitrogen compounds in the atmosphere and actively reacts with other compounds – in reaction with nitric acid it generates ammonium nitrate (NH_4NO_3), but in the reaction with sulphuric acid ($(NH_4)_2SO_4$) in the gas phase it generates particulate matters (Borsari & Assuncao, 2017). There was not found correlation between NH_3 and other emissions, but possible values of this compound could be lower if the catalyst is not used, because results in literature claims formation of this compound within the automotive catalyst (Borsari & Assuncao, 2017). Current research showed that reduction of NH_3 in different time periods is not as drastic as in case of other regulated compounds and it remains stable throughout the volume of test camera in different time periods for both fuel types (Figs 4, 5). Reduction level do not exceed 5–7% after first 5 minutes from the start of tests.

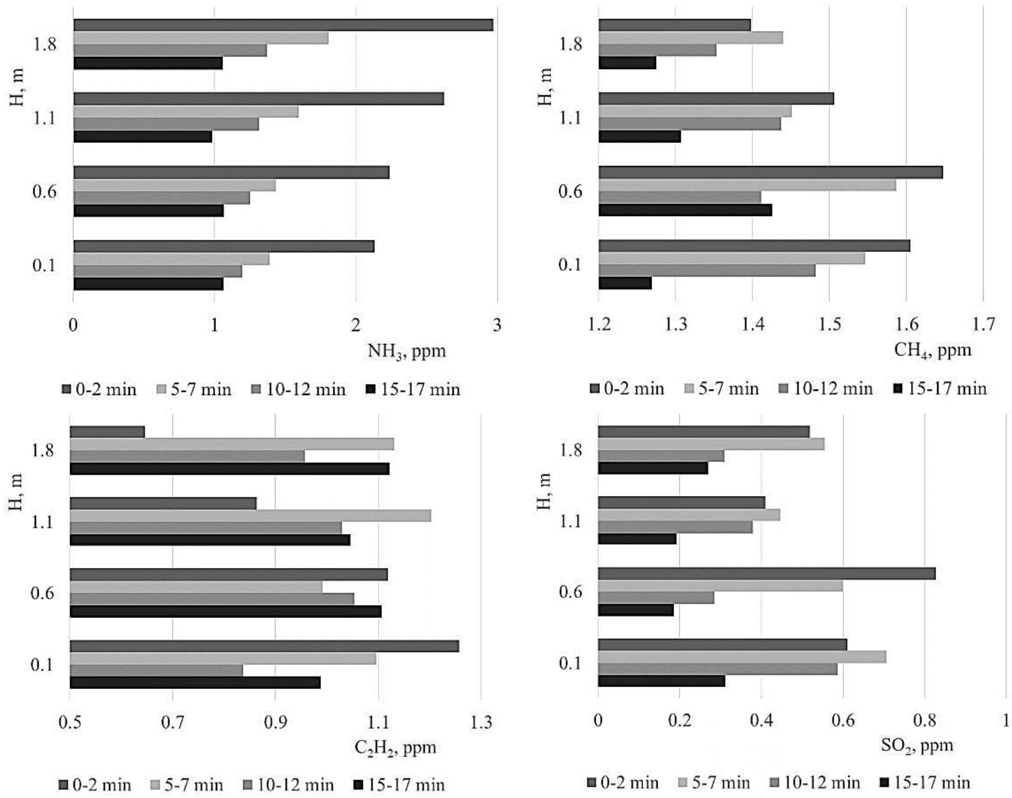

Figure 4. Variation of main unregulated emissions (NH_3, CH_4, C_2H_2 and SO_2) for diesel engine (Volvo V70 2.5TDI).

CH_4 is another important component, which participates in formation of GHG. This component cannot be estimated based on fuel carbon and usually are determined by combustion system type and control technology (Lipman & Delucchi, 2002). Methane emissions usually occur due to incomplete combustion along with unburned hydrocarbons (Lipman & Delucchi, 2002). In any case CH_4 emission level for gasoline engine is higher than for diesel and stratification nature is quiet similar – 15 minutes after the start of the test largest concentration of methane emission is at 0.6–1.1 m (Figs 4, 5). As it was mentioned before, this is a height, which is freely accessible to children and poses a significant health risk.

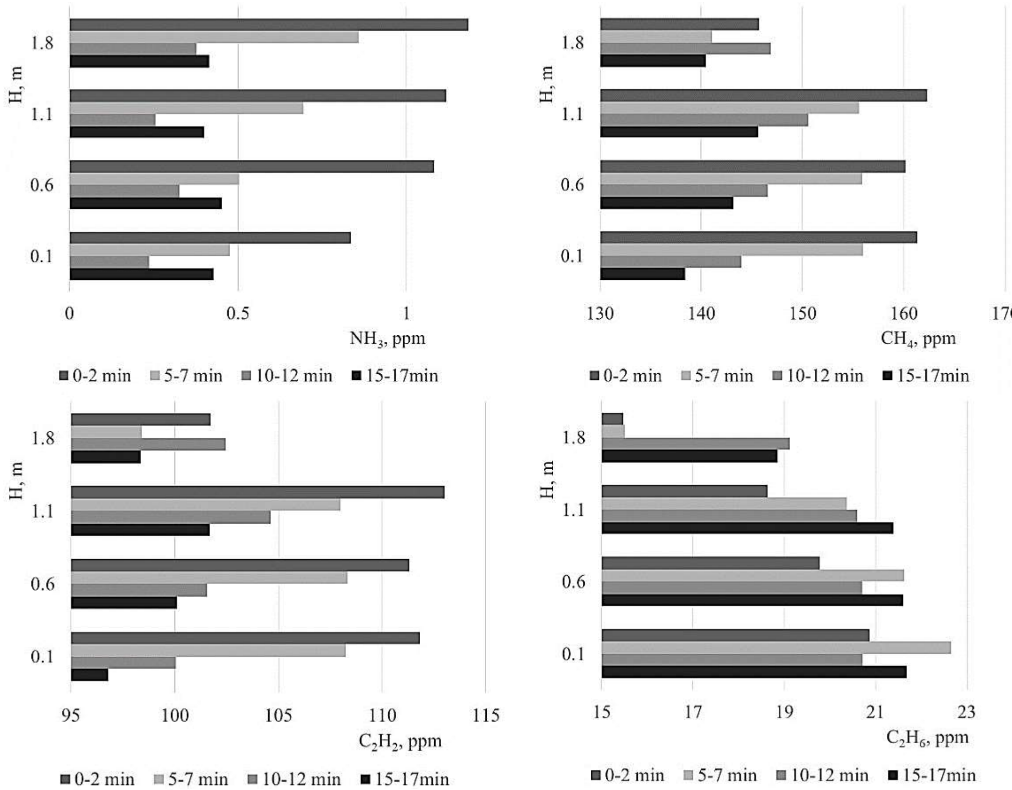

Figure 5. Variation of main unregulated emissions (NH_3, CH_4, C_2H_2 and C_2H_6) for gasoline engine (Audi A6 2.6).

Acetylene (C_2H_2) is another combustible gas, which could be found in engine emissions in negligible concentration. It is highly combustible and unstable gas, which produces high flame temperatures from 3,000 °C to 5,400 °C in combination with oxygen (Basha et al., 2016). Results on acetylene obtained during the tests did not show some united patterns as it was in case of other compounds, but it showed the similarity with methane – both of these gases reached maximal concentration in height of 0.6–1.1 m at the end of the test.

Sulphur dioxide (see Fig. 4), which is more characteristic for diesel engines did not show large concentration in air (max 0.82 ppm) and was mainly stratified in the height of the vehicle tailpipe (0.1–0.6 m). As it is known, presence of sulphur increase the risk of acid rain caused by SO_2, as also a fraction of this oxide can be converted in sulphuric acid, which is a particulate.

Ethane (C_2H_6) is another greenhouse gas, which is more characteristic for gasoline engines showed increase in concentration in the next time periods starting from 5th minute and almost in all volume of gas camera till 20–21 ppm (Fig. 5). This could be explained by different chemical reactions taking participation in the presence of other compounds in the exhaust emissions.

CONCLUSIONS

Results showed that the concentration of main regulated components (NOx, CO, HC) stratify in the height close to the height of children (0.6 – 1.1 m), but some of them also in height close to adult (about 1.8 m), while others (C_2H_2, C_2H_6) did not show clear reduction tendencies. In overall, it can leave an important impact on health in the long term, if it is necessary to be in such environment each day. The problematic could be age and technical condition of the vehicles, as also the place where the concentration of vehicles is constantly high (like, congestions, parking lots, etc.). Therefore it is desirable to avoid a subsistence in the following locations for a long time, especially with children. In addition, each of the gases can stay in atmosphere for a long time to become well mixed making unfavorable conditions also globally and contributing development of smog.

Results could be different, if the research would be realised in conditions close to the real, taking in account different temperature, pressure and wind flow regimes. Therefore further investigations must be done to determine such information.

REFERENCES

Anenberg, S.C., Miller, J., Minjares, R., Du, L., Henze, D.K., Lacey, F., Malley, C.S., Emberson, L., Franco, V., Klimont, Z. & Heyes, C. 2017. Impacts and mitigation of excess diesel-related NOx emissions in 11 major vehicle markets. *Nature* **545**, 467–471. DOI:10.1038/nature22086

Basha, S.K., Rao, P.S. & Gopal, K.R. 2016. Experimental Investigation of Performance of Acetylene Fuel Based Diesel Engine. *Int. J. Adv. Technol.* **7**(1), 151. DOI: 10.4172/0976-4860.1000151

Borsari, V. & Assuncao, J.V. 2017. Ammonia emissions from a light-duty vehicle. *Transportation Research* **Part D 51**, 53–61.

Harrison, R.M. & Hester, R.E. 2017. *Environmental Impacts of Road Vehicles: Past, Present and Future.* Royal Society of Chemistry, 264 pp.

Johnson, E. 2017. Cars and ground-level ozone: how do fuels compare? *Eur. Transp. Res. Rev*. 13 pp. https://link.springer.com/content/pdf/10.1007%2Fs12544-017-0263-7.pdf

Lipman, T. & Delucchi, M. 2002. Emissions of Nitrous Oxide and Methane from Conventional and Alternative Fuel Motor Vehicles. *Climatic Change* **53**, 477–516.

Mind the gap. *European Federation for Transport and Environment* AISBL, 2015. 18 pp. https://www.transportenvironment.org/sites/te/files/publications/TE_Mind_the_Gap_2015_FINAL.pdf

Rothengatter, W., Hayashi, Y. & Schade, W. 2011. *Transport Moving to Climate Intelligence: New Chances for Controlling Climate Impacts of Transport after the Economic Crisis*. Springer Science & Business Media, 316 pp.

Smigins, R. & Shipkovs, P. 2014. Biofuels in transport sector of Latvia: experience, current status and barriers. *Latvian Journal of Physics and Technical Sciences* **51**, 32–43. ISSN 0868-8257. DOI: 10.2478/lpts-2014-0004

Tietge, U., Zacharof, N., Mock, P., Franco, V., German, J., Bandivadekar, A., Ligterink, N. & Lambrecht, U. 2015. *From laboratory to road: A 2015 update of official and 'real-world' fuel consumption and CO_2 values for passenger cars in Europe.* International Council on Clean Transportation Europe, 56 pp.