

Biogasoline Options - Possibilities for Achieving High Bio-share and Compatibility with Conventional Cars

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ABSTRACT

In this study, vehicle exhaust emissions and performance were studied using various renewable components with the aim of achieving a high bio-share in gasoline and compatibility with conventional cars. Several biogasoline components were included in the fuel matrix: ethanol, ETBE, isobutanol, n-butanol and renewable hydrocarbon gasoline produced from hydrotreated oils and fats. The share of bioenergy in the test fuel blends varied from 7 to 28 E_{eqv}%, and the oxygen content from 0 to 11 m/m%. Fossil gasoline was used as the reference fuel for emissions performance, and E85 fuel as an example of a typical market fuel for FFV cars. Experimental work was carried out at -7 °C with two conventional gasoline cars and one FFV car. The measurements included regulated and unregulated exhaust emissions. The results show the possibility of increasing the bioenergy content of gasoline to up to 30% for use with conventional gasoline-fuelled cars, which are not necessarily compatible with a fuel oxygen content higher than approximately 4 m/m%.

INTRODUCTION

The purpose of this study is to explore feasible gasoline biocomponents, such as ethers, butanols and renewable hydrocarbon components, as alternatives to ethanol, and to assess their exhaust emissions performance. Ethanol is the dominant liquid biofuel globally at present. The use of ethanol in conventional gasoline cars, however, is limited to 10-15 v/v% (approx. 7-10 as an energy equivalent percentage) due to technical restrictions. Generally, fuels with an oxygen content higher than approx. 4 m/m% are not necessarily compatible with conventional spark-ignited cars. Present conventional cars will, however, continue to take the major share of gasoline car fleets for the next 10 to 20 years at least, and it is therefore necessary to establish and assess alternative biocomponent options for them. Today, higher ethanol blending ratios are possible only by using Flexible Fuel Vehicle (FFV) technology designed to use any proportion of, for example, ethanol and gasoline in the blend.

The European Union requires biofuels to achieve at least a 10% share of transport energy by 2020, and even higher shares are being attempted regionally. Ethanol is readily available, and is used as a biocomponent and as a feedstock in the production of ethyl-tert-butyl-ether (ETBE). Other interesting alternative gasoline biocomponents are butanols and renewable hydrocarbons, which can be combined with ethanol and ether components to increase the share of bioenergy and to improve the quality of gasoline. Butanols and renewable hydrocarbon components are competitive with ethanol, for reasons such as their higher heating value compared with ethanol.

BIOCOMPONENT PRODUCTION PROCESSES

The most common process for producing bioalcohols is by the fermentation of a sugar-type feedstock using yeast. Alternative routes for converting various biomasses to bioalcohols include thermochemical processing, for example biomass gasification followed by alcohol synthesis [1], or gasification followed by fermentation using anaerobic bacteria [2]. New production processes are needed to enable the use of cellulosic feedstocks in the production of ethanol or butanol. For butanol production, new technologies are being developed by DuPont, BP, Gevo and others. In Russia, a biobutanol factory using woody biomass is expected in 2011 [3]. As a gasoline component, butanol has many advantages over ethanol: higher energy content, lower vapour pressure, lower phase separation risk and being less aggressive towards materials [4]. There are differences between isomers of butanol, for example the octane numbers of isobutanol are higher than those for n-butanol [5].

Ethanol can be further converted into ethyl-tertiary-butyl-ether (ETBE) by catalytic reaction with isobutylene, which at present is a fossil feedstock. Similarly, methanol is processed to methyl-tertiary-butyl-ether (MTBE). Both ETBE and MTBE have excellent fuel properties as gasoline components, for example high octane numbers, low vapour pressures, no phase separation risk and good performance with materials. As gasoline components, ethers are preferred over alcohols [6].

Liquid bio-hydrocarbons from biomass-sourced synthesis gas are produced by the Fischer-Tropsch process (F-T), for example, or by the methanol to gasoline (MTG) process. The variety of possible raw materials and developed technologies make thermochemical conversion an interesting option for bio-hydrocarbon and biogasoline production. Currently, the ExxonMobil Research and Engineering Company and Haldor Topsoe have their own MTG processes, and several companies are using or planning to use Fischer-Tropsch technology in diesel production from coal, natural gas or biomass [7, 8, 9, 10]. Sasol has an F-T-based production line specially designed for gasoline production.

Another approach to producing bio-hydrocarbons is the use of vegetable oils and fats as feedstocks. Fluid catalytic cracking (FCC) of vegetable oils has been reported as a promising way to produce high-quality biogasoline [11]. Similarly, hydroprocessing technology is presently available and a promising way to convert oils and fats to hydrotreated vegetable oil (HVO) products.

Gasoline range bio-hydrocarbons are advantageous since they are fully compatible with conventional gasoline, cars and current infrastructure. Bio-hydrocarbon products are not, however, consistent with each other, but depend on the production technology and feedstock used. Product quality ranges from high-aromatic and high-octane qualities to paraffinic low-octane hydrocarbon mixtures. Bio-gasoline mixtures may contain different amounts of olefins as well as oxygenates. In this study, a paraffinic, and oxygen-, aromatic- and sulphur-free, Neste Oil Renewable gasoline component, produced using NExBTL hydroprocessing technology, was used as an example of a hydrocarbon-type biogasoline [12].

BIOCOMPONENT EMISSIONS PERFORMANCE

Low-concentration ethanol fuels

There are a number of studies on the effects of low-concentration ethanol on exhaust emissions, but only a few with new cars from the 2000s, and very few covering measurements at low temperatures. In addition, different fuel blending strategies have been reported (“splash”- and “match”-blending). If oxygenate is splash-blended with gasoline, the dilution effect leads to a lower content of aromatics and olefins in the test fuel. In addition, for example, different fuel distillation characteristics may lead to contradictions in inter-study evaluations of exhaust emissions [13]. Generally, the major drawback of adding ethanol to gasoline is an increase in emissions of acetaldehyde, which is classified as a harmful “air-toxic” substance. A catalyst can efficiently remove aldehyde emissions, but not in all conditions, for example during a cold start. Ethanol generally has a positive impact on CO and HC tailpipe emissions. Conversely, NO_x emissions tend to increase when ethanol is added to gasoline. The ozone-forming potential tends to increase with ethanol/gasoline blends due to the increased evaporative, acetaldehyde and NO_x emissions. The ethanol content of fuel does not generally influence benzene and 1,3-butadiene emissions. Particulate matter emissions from gasoline-fuelled cars are typically low [13, 14, 15, 16, 17, 18, 19, 20].

High-concentration ethanol fuels

In studies with FFV cars, E85 is typically compared with E5 in the same car, and there is no comparison with an MPFI car. The fuel economy of E85 is generally 25-40% worse than

that of gasoline due to low energy content of ethanol. This is the case even though the better octane rating of ethanol enables a higher compression ratio, which can improve the energy efficiency of the engine. The performance of FFV cars suffers from the need to inject excess fuel during cold starts when using E85 fuel. E85/FFV cars generally produce lower CO, HC and particulate matter emissions than do gasoline cars, but emissions may be higher at low temperatures. NO_x emissions from FFV cars running on E85 fuel are lower than or the same as those from gasoline-fuelled cars. Methane emissions are reported to be higher for E85 fuel than for gasoline, but 1,3-butadiene and benzene emissions are lower, however. Acetaldehyde and ethanol emissions increase substantially with E85 when compared with gasoline, especially at low temperatures. When the catalyst is fully warmed-up, these emissions may be at the same level for E85 and gasoline [14, 21, 22, 23, 24, 25].

Butanol-containing fuels

Only limited studies are available on the performance of isobutanol and/or n-butanol as gasoline components. In one study with cars, CO, HC or NO_x emissions did not change significantly when 10% n-butanol blend was compared with gasoline in cars. Under highway conditions, n-butanol slightly reduced CO emissions [4]. In studies with direct-injection, four-cylinder, spark-ignition engines, no significant differences in CO and HC emissions were seen with 10% ethanol and 10% n-butanol blends [26] or 85% butanol blend [5] when compared with gasoline. Yang et al. [27] observed lower HC and CO emissions when butanol was added to gasoline. Cooney et al. [5] and Yang et al. [27] observed an increase in NO_x emissions when butanol was added to gasoline, but Wallner et al. [26, 28] reported a decrease in NO_x emissions when n-butanol or isobutanol were blended with gasoline.

Wallner et al. [28] reported that both formaldehyde and acetaldehyde emissions increased when n-butanol or isobutanol were blended with gasoline, but aromatic hydrocarbon emissions decreased. An increase was seen for propene, 1,3-butadiene and acetylene emissions, which are precursors for benzene and particulate matter emissions.

EXPERIMENTAL

FUELS

The fuel matrix included 13 biofuels and one fossil fuel. The test fuels represented different bioenergy contents, oxygen contents and fuel chemistries (Table 1, Appendix 1). Fuels, except E85 market fuel, were match-blended using fossil gasoline refinery components and gasoline biocomponents. Fuels were analyzed by Neste Oil.

The biocomponents used in fuel blending were ethanol, isobutanol, n-butanol, ETBE and a bio-hydrocarbon

component. In this study a paraffinic, and oxygen-, aromatic- and sulphur-free, Neste Oil Renewable gasoline component was chosen to represent liquid bio-hydrocarbons from different processes. This biogasoline component is a hydrotreated vegetable oil product (HVO) manufactured from vegetable oils and animal fats using Neste Oil's NExBTL hydroprocessing technology. The main product of the NExBTL technology is renewable diesel, but renewable gasoline is typically formed as a side product.

The test fuel matrix was divided into two sets: high-oxygen containing fuels (oxygen content 6 to 30 m/m%) and low-oxygen containing fuels (oxygen content 0 to 4 m/m%). Since fuels with an oxygen content higher than approx. 4 m/m%, are not necessarily compatible with conventional spark-ignited cars, five high-oxygen containing fuels were tested only with the FFV car. The low-oxygen fuel matrix contained nine fuels and was tested using both conventional cars and the FFV car. Oxygen-free fossil hydrocarbon gasoline was used as a reference fuel in both sub-matrices.

The bioenergy content of the biofuel was a major parameter in the fuel matrix. Bioenergy as an energy equivalent percentage (E_{eqv}%) was calculated using the lower heating values (LHV in MJ/l), given in the European Renewable Energy Directive 2009/28/EC, for both biocomponent and fossil gasoline, and the analyzed biocomponent concentrations for each fuel blend. Fossil energy was substituted with 7 to 56 E_{eqv}% bioenergy. Three bioenergy substitution levels (7, 14 and 21 E_{eqv}%) were used. The 7 E_{eqv}% bioenergy level represented currently used biocomponents, ethanol (10 v/v%) and ETBE (22 v/v%), whereas the 14 E_{eqv}% level represented either butanol or bio-hydrocarbon alternatives in concentrations of 15-17 v/v%. The highest bioenergy level, 21 E_{eqv}%, was designed to represent both oxygenated and non-oxygenated biocomponent alternatives. The 21 E_{eqv}% bioenergy level was achieved either by adding 15 v/v% non-oxygenated bio-hydrocarbon (14 E_{eqv}%) to the oxygenated component or purely by increasing the fuel's oxygenate content. Market fuel E85 represented the highest bioenergy substitution value, 56 E_{eqv}%.

When fuels were blended, their aromatic contents, densities, sulphur contents and vapour pressures were kept as constant as possible. The aromatic content of the high-oxygen content fuels was 16-21 v/v%, whereas the low-oxygen containing fuel aromatics were 27-35 v/v%. The benzene content was below 0.5 m/m% in all fuels. The density of all blended fuels was 740 to 756 kg/m³. The sulphur contents of all fuels were below 10 mg/km. The vapour pressure was 69±2 kPa, except for the market E85 fuel (35 kPa). Research Octane Numbers (RON) were within the measuring range of the ASTM D2699 method with low-oxygen containing fuels, whereas the RON

value of the high-oxygen containing fuels must be considered only indicative. Motor Octane Numbers (MON) in both fuel sets were from 86 to 92 and within the ASTM D2700 method measuring range. The E85(56) was commercial grade fuel, and its octane numbers were not measured. Typically, commercial grade E85 fulfils the Swedish standard SS 155480, with the RON around 104 and the MON around 88.

Fuels were labelled using the biocomponent abbreviation and the corresponding bioenergy content of the blend. For example, E+eth(19) fuel is an ethanol (E) and ETBE (eth) blend with a bioenergy content of 19 $E_{eqv}\%$. The abbreviations iB, nB and R were used for isobutanol, n-butanol and Renewable gasoline component, respectively. The generally recognized labelling E10, E30 and E85 was used for ethanol-containing fuels representing approximately 10, 30 and 85 v/v% ethanol.

Table 1.. Test fuels^a.

	Bioenergy $E_{eqv}\%$	Volume ^b v/v%	Oxygen m/m%	LHV MJ/kg
High oxygen content				
E85(56)	56	85	29.8	28.9
E30(20)	20	31	11.3	38.2
E+eth(19)	19	39	10.3	38.4
iB+eth(20)	20	36	7.3	40.1
iB(21)	21	25	5.8	40.9
Low oxygen content				
Fossil(0)	0	0	0.1	43.6
E10(7)	7	10	3.7	41.4
iB(14)	14	16	3.8	41.6
nB(15)	15	17	4.0	41.5
eth(7)	7	21	3.5	41.5
R(14)	14	15	0.0	43.4
R+E(22)	22	26	4.0	41.4
R+eth(21)	21	35	3.4	41.6
R+iB(28)	28	32	3.8	41.5

^aE = ethanol, eth = ETBE, iB = isobutanol, nB = n-butanol, R = renewable component. Number in parenthesis indicates fuel bioenergy content as $E_{eqv}\%$.

^bVolume of ethanol, i-butanol, n-butanol, ETBE and renewable component

CARS

Experimental work was carried out with three cars: a multi-point fuel injection car (MPFI), a direct-injection car (FSI) and an FFV car. The MPFI and FSI cars represent conventional cars, which are not necessarily compatible with fuels containing more than approx. 4 m/m% oxygen (corresponding to some 11 v/v% ethanol). An FFV car tolerates high-oxygen containing gasoline, e.g. up to 85% ethanol. The characteristics of the cars are shown in Table 2.

The MPFI car is equipped with a DOHC, 16-valve engine including Variable Valve Timing (Dual WT-i) and variable lifting of inlet valves (Valvematic). These features enable the timing of the inlet and exhaust valves to be adjusted, and efficient adjustment of the air flow into the engine. This enhances the engine's combustion efficiency and helps to improve the fuel consumption. The FSI car is equipped with a low-displacement engine that combines petrol direct injection with turbocharging. This enhances the engine's combustion efficiency, giving a power output much higher than that of conventional, naturally aspirated engines. The performance of the FFV car is optimised for fuel containing 85% ethanol. The engine control unit (ECU) detects the fuel's ethanol content, and increases the maximum turbocharger boost pressure and, consequently, the mass air flow and ultimate power [24]. The ECU dithers the air-to-fuel ratio somewhat depending on the oxygen content of the exhaust gases.

Table 2. Characteristics of cars.

	MPFI	FSI	FFV
Model year	2010	2010	2006
Displacement, litres	1.6	1.4	2.0
Engine	4-cyl., 16-v, DOHC, Valvematic	4-cyl.	4-cyl., turbo-charged
Fuel system	Multi-point fuel injection	Gasoline direct injection	Multi-point fuel injection
Power, kW/min ⁻¹	97/6400	90/5000	132/5500
Torque, Nm/min ⁻¹	160/4400	200/1500-4000	280/1800
Odometer, km	5 300	21 400	62 000
Fuel consumption, l/100 km ^a	6.6	6.2	9.2
CO ₂ , g/km ^a	153	144	230 ^b
Emission level	EU5	EU5	EU4

^aTechnical data sheet for car ^b Calculated

TEST MATRIX

The tests were carried out with fourteen fuels and three cars at -7 °C. In general, three replicate tests were carried out with each fuel and car combination. Fuels containing more than 4.0 m/m% oxygen were tested only with the FFV car. Two fuels, eth(7) and nB(15), were excluded from the test matrix with the MPFI car.

The measurements covered regulated emissions, CO, HC, NO_x, and a number of non-regulated emissions, e.g. particulate matter, CO₂, individual hydrocarbons and

^aE = ethanol, eth = ETBE, iB = isobutanol, nB = n-butanol, R = renewable component. Number in parenthesis indicates fuel bioenergy content as $E_{eqv}\%$.

aldehydes. In this paper, formaldehyde, acetaldehyde, 1,3-butadiene and benzene emissions were studied in detail.

METHODS

Measurement methods

Tests were carried out in the engine and vehicle emissions test laboratory at VTT, Finland. Cars were tested on a chassis dynamometer in a climatic test cell. All equipment used for the measurement of the regulated gaseous emissions (exhaust dilution and collection, concentration analysis, etc.) conforms to the specifications of the Directive 70/220/EEC and its amendments (European test). In addition, several parameters were recorded at one-second intervals, e.g. speed, carbon monoxide (CO), total hydrocarbons (HC) and nitrogen oxides (NO_x). The dynamometer and the basic equipment used for recording the test parameters are described in Table 3.

The standardized tests were run according to the European exhaust emissions driving cycle. The true oxygen contents and densities of the fuels were used in the calculation of the results. The European emissions test driving cycle, which totals 11.0 km, was divided into three test phases to study emissions behaviour at cold start and with warmed-up engines. The first and second test phases each consisted of 2.026 km driving, and the third test phase, the extra-urban driving cycle (EUDC), was 6.955 km.

Table 3. Test facilities for regulated emissions.

Chassis dyno	Froude Consine 1.0 m, DC, 100 kW
Constant volume sampler	AVL CVS i60 LD, Venturi-type
CO, HC, NO _x , CO ₂	Pierburg AMA 2000, triple bench

A high-capacity sampler was used to collect a sufficient mass of particles. This sampling system was originally developed at VTT in the 1990s for measurements of gasoline cars [30]. The high-capacity collection system included a dilution tunnel (Ø265 mm), a sample probe (Ø80 mm), two filter holders in parallel (Ø142 mm), a blower (Siemens ELMO-G, 2BH1 810-1HC36, 11 kW), a flow meter (Bronkhorst F-106C1-HD-V-12) and a controller (Stafsjö MV-E-80-P-TY-AC100-PN10). The sample flow can be controlled up to 2000 litres/minute. In these measurements, a flow of 700-850 litres/minute was used to obtain appropriate masses of particles. Two Ø142 mm filters were used in parallel to reduce face velocity and pressure drop on the filters. The filter type used was Fluoropore 3.0 µm FSLW. A Sartorius SE2-F microbalance was used for weighing.

Aldehydes were collected from the CVS diluted exhaust gas using dinitrophenylhydrazine (DNPH) cartridges. The DNPH derivatives were extracted with an acetonitrile/water mixture. Eleven aldehydes were analyzed using HPLC technology (HP

1050, UV detector, Nova-Pak C18 column): formaldehyde, acetaldehyde, acrolein, propionaldehyde, crotonaldehyde, methacrolein, butyraldehyde, benzaldehyde, valeraldehyde, m-tolualdehyde and hexanal.

The diluted exhaust gas for individual hydrocarbon analysis was collected from the same Tedlar bags that were used for measurement of the regulated emissions. The diluted exhaust gas was drawn from those bags and fed to the gas chromatograph. The hydrocarbons from C1 to C8 from diluted exhaust gas were speciated using an HP 5890 Series II gas chromatograph (AL2O3, KC1/PLOT column). Hydrocarbons were identified by retention times, and analyzed quantitatively using an external standard method. The hydrocarbons analyzed were methane, ethane, ethene, propane, propene, acetylene, isobutene, 1,3-butadiene, benzene, toluene, ethyl benzene and m-, p- and o-xylenes.

A number of compounds were measured on-line using Fourier Transformation Infra-Red (FTIR) equipment (Gasmeter Cr-2000). More than 10 exhaust components from the raw exhaust gas were measured at one-second intervals. However, the concentrations of many compounds are low with gasoline-fuelled cars. Alcohols measured with FTIR were used to calculate NMHC and NMOG emissions.

Risk factors

Risk factors for exhaust toxicity were calculated separately for regulated and unregulated emissions. Risk factors for regulated emissions were calculated using equation (1). Risk factors for regulated emissions were calculated using external costs for emissions defined by Directive 2009/33/EC for NMHC, NO_x and PM. National values defined in Finland were used for CO and HC emissions. In total, external costs used in calculation were as follows: CO €29/tonne, HC €62/tonne, NMHC €1000/tonne, NO_x €4400/tonne and PM €87000/tonne.

$$\text{“Regulated risk factor”} = \Sigma(F_x * E_x) \quad (1)$$

F = External costs of emission, €/tonne
E = Emission in exhaust gas, tonne/km
x = CO, HC, NMHC, NO_x, PM

Risk factors for unregulated emissions were calculated using equation (2). Unit risk factors (URF) defined by OEHA [31] were as follows: 1,3-butadiene 17×10^{-5} , benzene 2.9×10^{-5} , formaldehyde 0.6×10^{-5} and acetaldehyde 0.27×10^{-5} . Particulate matter emissions were already taken into account in equation (1) (URF is 30×10^{-5} for PM according to OEHA [31]).

$$\text{"Unregulated risk factor"} = \Sigma(\text{URF} * c)_x \quad (2)$$

URF = Unit risk factor (OEHHA, 2009), $(\mu\text{g}/\text{m}^3)^{-1}$
 c = Concentration in exhaust gas, $\mu\text{g}/\text{m}^3$
 x = Formaldehyde, acetaldehyde, benzene and 1,3-butadiene

The total risk factors for exhaust toxicity for each fuel were calculated as the sum of the normalized factors for regulated and unregulated emissions. The factors for regulated and unregulated emissions were normalized separately, so the factor for Fossil(0) fuel is 1 for each car. This compensates for emissions levels from different cars.

Calculation of HC emissions for FFV car

Total hydrocarbon emissions are measured with a flame ionisation detector (FID). In addition to hydrocarbons, all carbon-containing compounds, as well as oxygenates, give a response with an FID. This matter is discussed by Sandström-Dahl et al. [32]. In the US, the FTP emission measurement procedure takes into account the response of oxygenates with an FID by subtracting methane and ethanol emissions multiplied by their respective response factors from hydrocarbon emissions measured with an FID. In this way, so-called non-methane hydrocarbon emissions (NMHC) are obtained (equation 3). In the US, Non Methane Organic Gases (NMOG) are also calculated by taking oxygenates into account separately (equation 4).

In the European emissions regulations, the FID response of oxygenates is not taken into account. However, a higher exhaust gas density is used for the calculation of HC emissions with E85 fuel. In the European emissions test procedure for gasoline cars, a density of $0.619 \text{ g}/\text{dm}^3$ based on the formula $\text{C}_1\text{H}_{1.85}$ is used in the calculation of HC emissions. European Regulation No 692/2008 requires density $0.932 \text{ g}/\text{dm}^3$ ($\text{C}_1\text{H}_{2.74} \text{O}_{0.385}$) to be used for the calculation of HC emissions from E85 fuel. In the US, the HC density used for calculations is $0.619 \text{ g}/\text{dm}^3$ at 273 K ($0.5768 \text{ g}/\text{dm}^3$, $16.33 \text{ g}/\text{ft}^3$ at 293 K).

$$\text{NMHC} = \text{HC}_{\text{FID}} - 1.04 * \text{CH}_4 - 0.66 * \text{ROH} \quad (3)$$

$$\text{NMOG} = \Sigma \text{NMHC} + \Sigma \text{ROH} + \Sigma \text{RHO} \quad (4)$$

The effects of different calculation methods on the results are given here for the FFV car using E85 fuel (Table 4). Hydrocarbon emissions achieved using the European calculation method for E85 fuel are at the same level as the US NMOG emissions. The NMHC result is low, because methane emissions are not included and the higher density of ethanol is not taken into account. In this project, the fuel

matrix contained a wide set of fuels with different exhaust HC densities. Thus, HC results for all fuels were calculated using the European procedure with a density of $0.619 \text{ g}/\text{dm}^3$. The calculation method chosen gives lower HC emissions for E85 fuel than does the EC regulation 692/2008 method.

Table 4. HC emissions from FFV car using E85 fuel with different calculation methods.

	HC emissions (g/km)
European ^a , density $0.619 \text{ g}/\text{dm}^3$	2.4
European ^b , density $0.932 \text{ g}/\text{dm}^3$	3.6
NMHC (US)	0.6
NMOG (US)	3.4

^aDirective 70/220/EEC and its amendments

^bEC Regulation No 692/2008

Pre-conditioning of FFV car

The FFV car model tested requires special adaptation to the fuel. Instructions received from the manufacturer included driving in on-road conditions before preconditioning on a chassis dynamometer. The adaptation of the car to new fuel was monitored with the following parameters: charge air pressure, ignition timing, injection time and long- and short-term adjustments for fuel adaptation. Measurements were conducted after changing fuel and preconditioning at three constant loads (idle, 10 kW and 30 kW) using an Autocom OBD tester. In addition, data were recorded continuously during selected test runs using an ELM OBD diagnostic card.

With the FFV car, the charge air pressure was relatively constant for all fuels measured. The ignition timing was at the same level at idle and at 10 kW load. At the highest load (30 kW), the most significant difference was observed for E30(20) fuel (late timing), and R(14) and Fossil(0) fuels (early timing). The respective parameters were not measured for E85(56) fuel. Adjustment parameters for fuel adaptation behaved exceptionally in the case of the ETBE-containing fuel eth(7): the adjustment changed significantly at the end of the test. This test was therefore rejected from the final results. For the other fuels, the adjustments did not change over the replicate measurements.

RESULTS

EMISSIONS LEVELS OF CARS

Regulated emissions from MPFI, FSI and FFV cars over the European test cycle at -7°C are shown in Figure 1 and Appendix 2. Euro 5 limit values for light-duty vehicles are also presented. The stability of two cars was screened by measuring one of the test fuels at the beginning and at the end of the two-month measuring period. The stability of the cars was relatively good, with only the CO and HC emissions from the FSI car increasing to some extent.