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„Meta-analysis for an E20/25 technical development study - Task 2: Meta-analysis of E20/25 trial reports and associated data“

Final Report

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Preamble

The following preamble is a brief overview of the expectations and conclusions which can be drawn from the present work. The main focus is done on a detailed consideration of the ethanol content between 15% and 25% (named E20/25 in this study). To get a comprehensive overview of the effects of ethanol as a blending component, higher mixing rates were examined with a comprehensive meta-analysis too (up to 100 % ethanol).

It should be noted, however, that the current study represents an actual state of currently available global literature and do not reflect specific directly done research results on this field. The vehicles and engines investigated in the literature sources are mostly production engines available on the market and were used for the combustion of ethanol, but were usually not optimized for E20/25. In summary there is a variety of different boundary conditions in the individual studies, therefore comparability is limited for some cases. Therefore, the literature was selected according to specific criteria, to create comparative conditions across all the studies.

Furthermore, it should be noted that in addition to the current E10 (10 % ethanol blend rate) vehicles and the specially adapted flexible fuel vehicles (FFV) which allow operation up to an ethanol concentration of 85%, neither vehicles specifically designed nor produced for the range of E20/25 are currently available. In addition to extensive modifications in the engine control software (motor electronics) further adjustments to mixture formation, ignition, fuel circuit and material adaptation need to be made to the engine corresponding to the higher ethanol content in the fuel.

With 1st September 2014 the EURO 6 emission standard for type approval for passenger car and light duty trucks comes into effect, registration and sale for new types of vehicles are following on 1st January 2015. During the study EURO 6 engines were only sporadically available on the market. For this engines however, there are no scientific studies regarding E20/25. Therefore, no EURO 6 vehicles are considered in this study.

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Abbreviation

ASTM	American Society for Testing and Materials
BMEP	Break mean effective pressure
BSFC	Brake specific fuel consumption
C	Cylinder
C_2H_2	Acetylene
C_6H_6	Benzene
CA°bTDC	Crank angle before top dead centre
CADC	Common Artemis Driving Cycles
CARB	California Air Resources Board
CH_4	Methane
CO	Carbon monoxide
CO_2	Carbon dioxide
COV	Coefficient of variance
CR	Compression ratio
CVS	Constant volume sampling
DI	Direct injection
DIN	German Institute for Standardization
DOHC	Double overhead camshaft
DOI	Duration of injection
ECE15	Urban Driving Cycle of the NEDC
ECU	Engine control unit
EPA	Environmental Protection Agency
FC	Fuel consumption
FFV	Flexible fuel vehicles
FID	Flame ionization detector
FSN	Filter smoke number
FTIR	Fourier transform infrared spectroscopy
FTP	Federal Test Procedure

H_2O	Water vapour
IMEP	Indicated mean effective pressure
ISFC	Indicated specific fuel consumption
MBT	Maximum break torque
MON	Motor Octane Number
MPI	Multi point injection
NA	Naturally aspirated
NEDC	New European Driving Cycle
NMHC	Non-methane hydrocarbons
NMOG	Non-methane organic gas
NONMHC	Non-oxygenated non-methane hydrocarbons
NO_x	Nitrogen oxide
OBD	On-board diagnostics
PAH	Polycyclic aromatic hydrocarbon
PFI	Port fuel injection
PM	Particulate matter
PN	Particle number
RON	Research Octane Number
RVP	Reid vapour pressure
SFC	Specific fuel consumption
SI	Spark ignition
SOHC	Single overhead camshaft
SOI	Start of injection
TC	Turbo charged
THC	Total hydrocarbons
TWC	Three-way catalyst
US06	Supplemental Federal Test Procedure (SFTP)
VVA	Variable valve actuation
WOT	Wide Open Throttle

Executive Summary

In this study, the Institute for Powertrains and Automotive Technology, Vienna University of Technology, has collected a variety of literature sources on the subject of ethanol blends. The focus of this study is on ethanol blending rates from 15% to 25%. For a better understanding of the influence of ethanol on fuel consumption and emissions, ethanol blends have been considered up to 100% ethanol additional. This study does not cover evaluation of evaporative emissions from the fuel tank system or the compatibility of plastics with ethanol.

In a first step, the selection of literature according to the PRISMA (see chapter 2.1) scheme was made. Studies that have been found to be relevant were used for the meta-analysis. The main focus of this analysis was the influence of the ethanol content in the fuel on the following parameters:

- Specific fuel consumption (fuel consumption based on the generated engine power)
- Efficiency
- CO_2 emissions
- CO emissions
- HC emissions
- NO_x emissions
- Particle emissions

The summary is based on a scientific analysis of an established literature review and **presents the current state of research, which has general (global) validity**. The different studies have different boundary conditions, which are not necessarily explicit in the literature. The literature was selected following criteria to create comparative conditions. No optimised E20/25 production vehicles exist, thus limiting meaningful insights at the moment. But previous experience do not show any fundamental problems, considering that the provided materials and control algorithms of the engine electronics are designed to operate this ethanol content. The technologies investigated in the studies are vehicles from serial production and engines which are adapted for the engine test bench. At the time the study was conducted only a few EURO 6 engines were available. However, no scientific studies regarding E20/25 have been carried out for those engines so far.

The results of the meta-analysis confirm the physical explanations. In particular, the results obtained from the study for E20/25 are in the respective trend from E5 to E100. The most important results of the meta-analysis are as follows:

- **Influence of E20/25 on specific fuel consumption**
  With E20/25 the over all specific fuel consumption increases about 3% in average.
- **Influence of E20/25 on engine efficiency**
  For E20/25 the thermodynamic efficiency (energy based) increases by 5% in average.
- **Influence of E20/25 on CO_2 emissions**
  The CO_2 end-of-pipe emissions decrease by about 2% for E20/25 in average.
- **Influence of E20/25 on CO emissions**
  Generally the CO engine-out emissions decrease by up to 10% in average and the CO end-of-pipe emissions decrease by about 20% in average for E20/25.
- **Influence of E20/25 on HC emissions**
  The HC engine-out emissions are also reduced by about 10% for E20/25 in average. The HC end-of-pipe Emissions decrease by about 5% for E20/25 in average.
- **Influence of E20/25 on NO_x emissions**
  The NO_x engine-out emissions increase for E20/25 by 20% in general. The NO_x end-of-pipe emissions are equivalent to E0.
- **Influence of E20/25 on Particle emissions**
  The Particle emissions have to be investigated further. In general there is the ability to decrease the particle emissions with E20/25.

The engine-out emissions give a good overview of the effects of ethanol on the combustion. This allows the evaluation of the combustion quality and the advantages of the used fuel. On the contrary, the end-of-pipe emissions show the emissions that are emitted into the environment. The reason for this is the exhaust aftertreatment system, which is located between the engine and the exhaust pipe. This is used to reduce the engine-out emissions so far thus the emission regulations are complied.

A summary of these results especially for E20/25 compared to E0 can be seen in Figure 0-1.

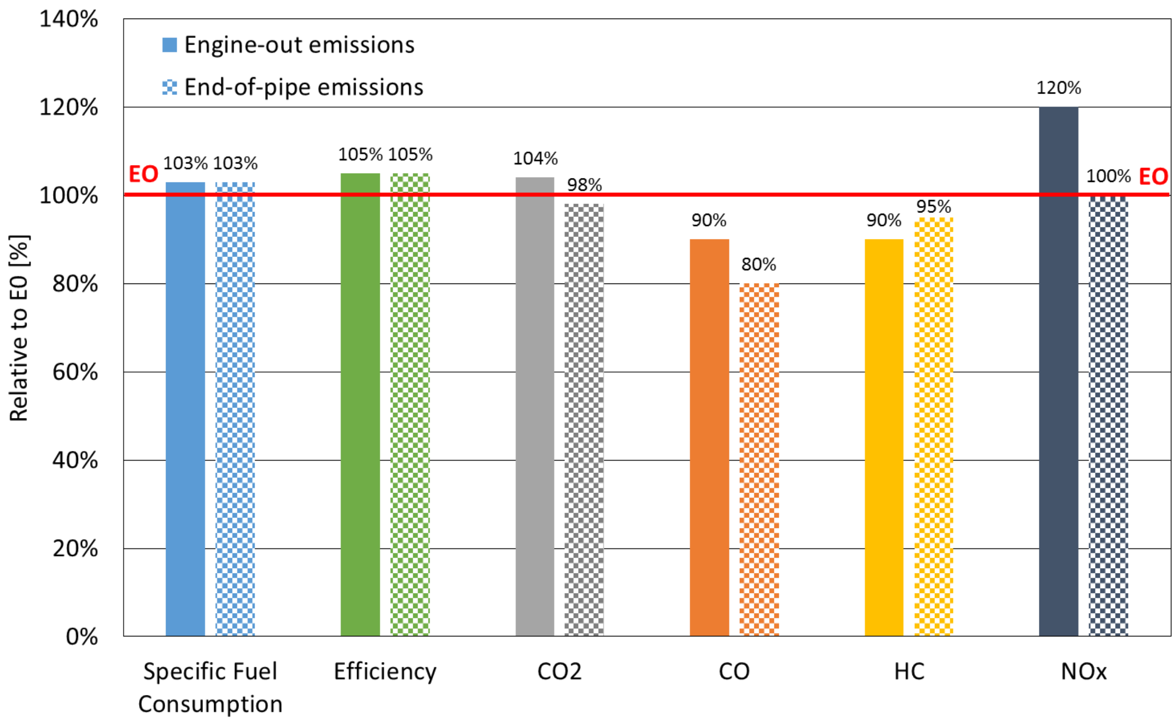

Figure 0-1: Results from the meta-analysis for E20/25 vs. E0

In addition to the results shown above, the addition of ethanol as a splash blend (admixture of different ethanol contents without changing the base fuel) increases the RON of the fuel. The higher knock resistance achieved in this way for E20/25-fuels offers the possibility to optimise the design of the engine (compression ratio) and thus increase the efficiency. But this assumes that only E20/25 or higher blending rates are used. The full exploitation of the ethanol/fuel potential therefore requires that the engines are only operated with the applied fuel (eg: E20/25). If you are forced to operate the engine with different fuels, the full theoretical potential of the fuel cannot be used. Exemplary the problem of bivalent vehicles (vehicles able to run on different fuels) should be mentioned here, such as vehicles that run on gasoline and CNG have shown.

As the studies evaluated for the meta-analysis have shown, especially for the use of E20/25 for internal combustion engines the following gaps could be identified:

- Particle emissions:
  In general there is the ability to decrease the particle emissions with E20/25. But it is essential to optimize the engine for higher ethanol contents.
- Optimized engines for E20/25

At the present time, no studies specifically for E20/25 optimized engines are available. The vehicles used in these studies were mainly for E20/25 capable cars. In order to realize the full potential of E20/25 an optimization of the engine operation is necessary.

- EURO 6 engines (passenger cars & light duty trucks)
  No study specifically for EURO 6 vehicles with regard to ethanol fuel is presently available. However, some studies show that particulate emissions can be significantly reduced using an appropriate motor design for ethanol fuels. This provides great potential - regarding to the upcoming limitation of the particle number with EURO 6.

Recommendation:

Ethanol blends between 15% and 25% (named E20/25 in this study) provide interesting potential regarding exhaust emissions and efficiency increase. However, no adequate studies on modern engines (EURO 6) for E20/25 with respect to the full utilization of the theoretical potential of ethanol are available. Further research is required, especially regarding the optimization of fuel consumption and the emission of particles.

1 Motivation

The present work is Task 2 of the E20/E25 technical evaluation study under agreement between the Commission of the European Union and the European Standardization Committee, CEN (ENER/C2/GA/449-2012/SI2.641582): Meta-analysis of E20/25 trial reports and associated data.

In order to assess whether the introduction of a new technology or a new energy source has consistently positive effects, a prior meta-analysis can prove useful. On the one hand, based on the available literature according to a comprehensive literature search, the current state of knowledge can be summarized very clearly and statistically processed. On the other hand, it reveals outstanding issues that need to be further investigated in detail prior to the introduction of a new technology.

2 Meta-Analysis

2.1 Methodology

The analysis of the collected data is performed using a statistical analysis. As defined in the contract a meta-analysis (1) can be performed. For this purpose, a systematic approach has been carried out and the collected data is processed as follows.
The selection and filtering of the literature was performed according to the PRISMA schema. Figure 2-1 illustrates the procedure for this method by means of flow chart.

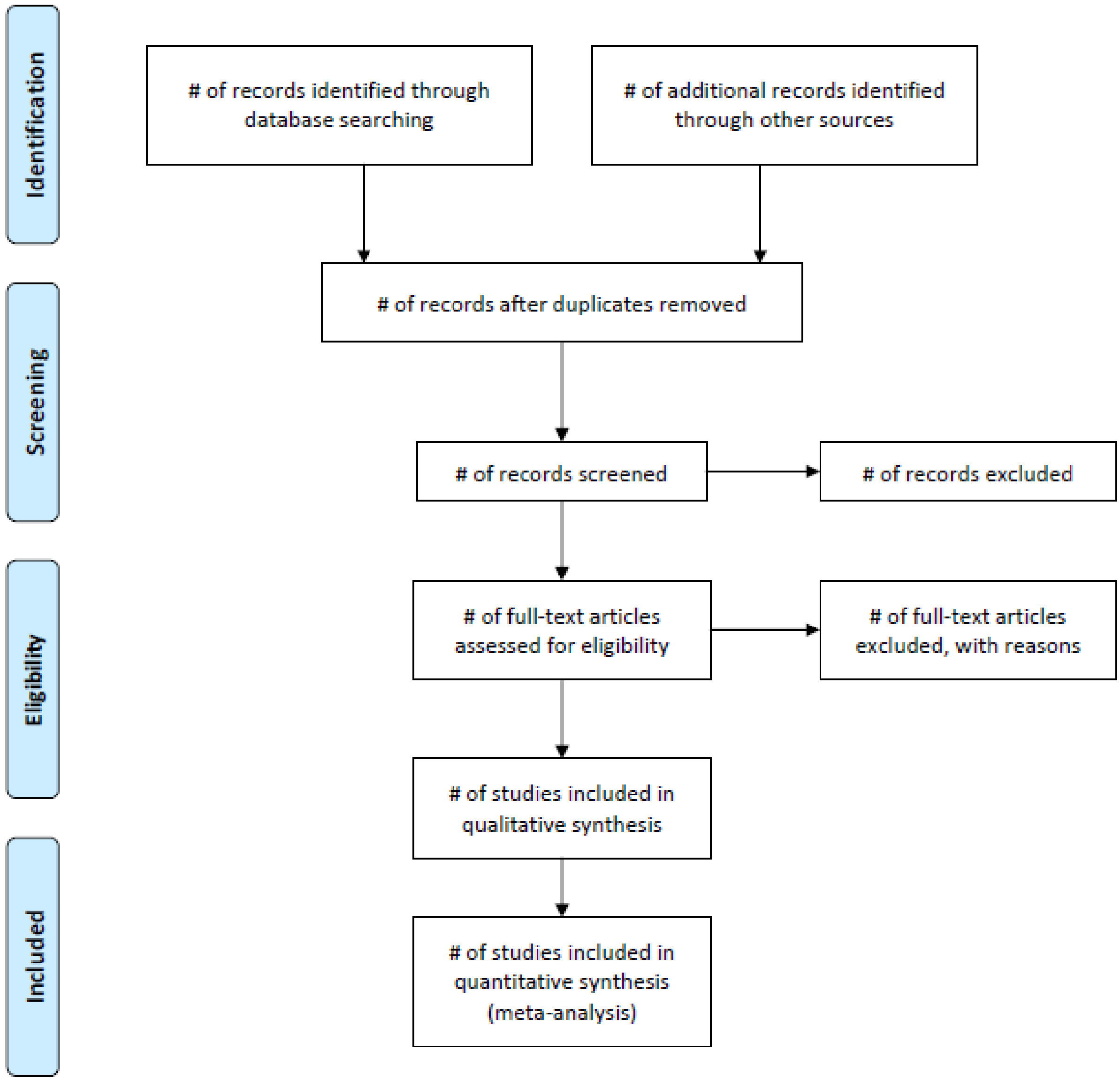

Figure 2-1: PRISMA Flow Diagram (2)

On the basis of a comprehensive literature search, in the first step (Identification) 200 studies were found. Subsequently the duplicates were discarded and on the basis of the abstracts a pre-selection was made. Approximately 100 studies were left after the “screening” phase. In the "eligibility" phase, the remaining studies were worked through in detail. On the basis of the boundary conditions and investigation priorities contained in the studies about half of them were likewise sorted out. Finally, 50 studies were included in the meta-analysis. As is generally known, almost all vehicles in Brazil are capable for ethanol-blends, but only a few studies have been included in this study. This topic will be discussed in detail in chapter 4.3.

Each study recorded in this investigation proceeds to a record in the respective category (emissions, fuel consumption, etc.). In studies, which contain more than one result an average over all available values was built, so that for each study only one value is considered in the evaluation. Furthermore, each study was weighted by the following criteria:

- reputation of the study authors;
- extent of the measurements; and
- boundary conditions (e.g. base fuel, engine, mixture preparation, …)

The resulting data sets are averaged over the respective ethanol content and in addition, the 90% confidence interval is evaluated. For clarity and because of the focus of the work on an ethanol content between 15 and 25 percent, the results are divided into the following ethanol-gasoline blend groups:

- E0: no ethanol content in fuel
- E5/10: ethanol content >0% and <15%
- E20/25: ethanol content between 15% and 25%
- E30/50/70: ethanol content >25% and <75%
- E85: ethanol content between 75% and 99%
- E100: 100% ethanol

Figure 2-1 shows the ethanol fractions of the respective studies, which were included in the meta-analysis. The y-axis shows the reference number of the investigated studies (see chapter 6.1). On the x-axis the different ethanol content of the individual studies are shown. A point in the figure indicates that in the particular study (line) the respective ethanol content (column) was examined. As can be seen from Figure 2-2 the data, included in the meta-analysis, in the range between 15 and 25 percent ethanol have a very good density focused on E20.

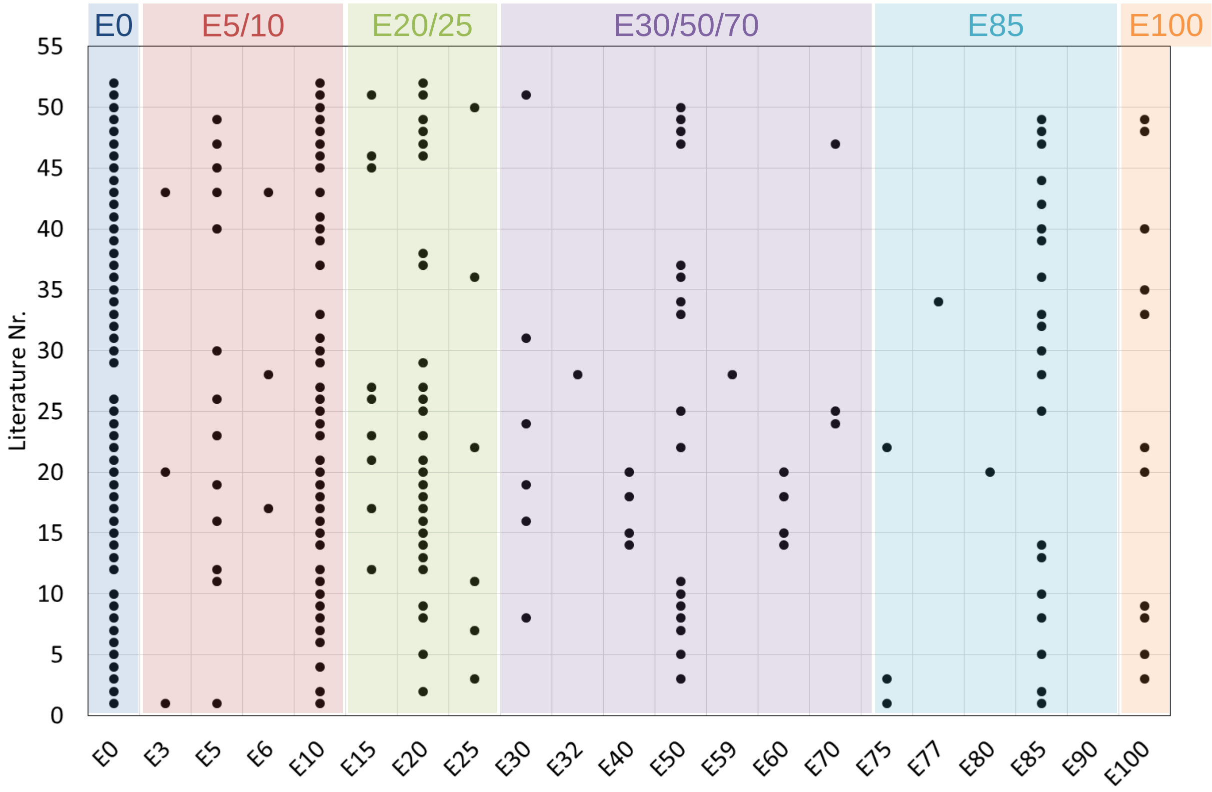

Figure 2-2: Investigated ethanol contents in the literature used for the meta-analysis.

To be able to compare the results from different studies it is necessary to normalize the results. So the base fuel (E0) always is represented by 100% and the variance for E0 is therefore always zero. In three literatures the base fuel was in the range of E5/10. For this studies, the influence of the ethanol content on the engine efficiency and emissions were based on the specific base fuel. To make the results comparable with the results of the studies with E0 as base fuel an offset was added to the data. The offset is obtained from the average value for the specific ethanol content of the base fuel, which was determined by the studies with E0 as base fuel.

If the value of an ethanol-gasoline blend group decreases below 100%, the absolute value is smaller than that of the comparative fuel (E0). If the value increases, however, this means that the absolute value also increases.

3 Basics for usage of alternative fuels in SI engines

This chapter serves as an introduction to the topic of alternative fuels for a better understanding of the results of the meta-analysis without being a technical expert in the field of internal combustion engines.

3.1 Increasing the efficiency by “Downsizing”

The increase in efficiency is an important step towards reducing fuel consumption. Figure 3-1 show the effect of shifting the actual operating point (A) toward higher loads and lower speeds (B) at the same power of 30kW. This so called *downsizing* is achieved by an increase of the load especially at low speeds. Due to the reduction of losses like the charge exchange losses, mechanical losses and the wall heat losses a higher efficiency is achieved. This subsequently results in a lower specific fuel consumption.

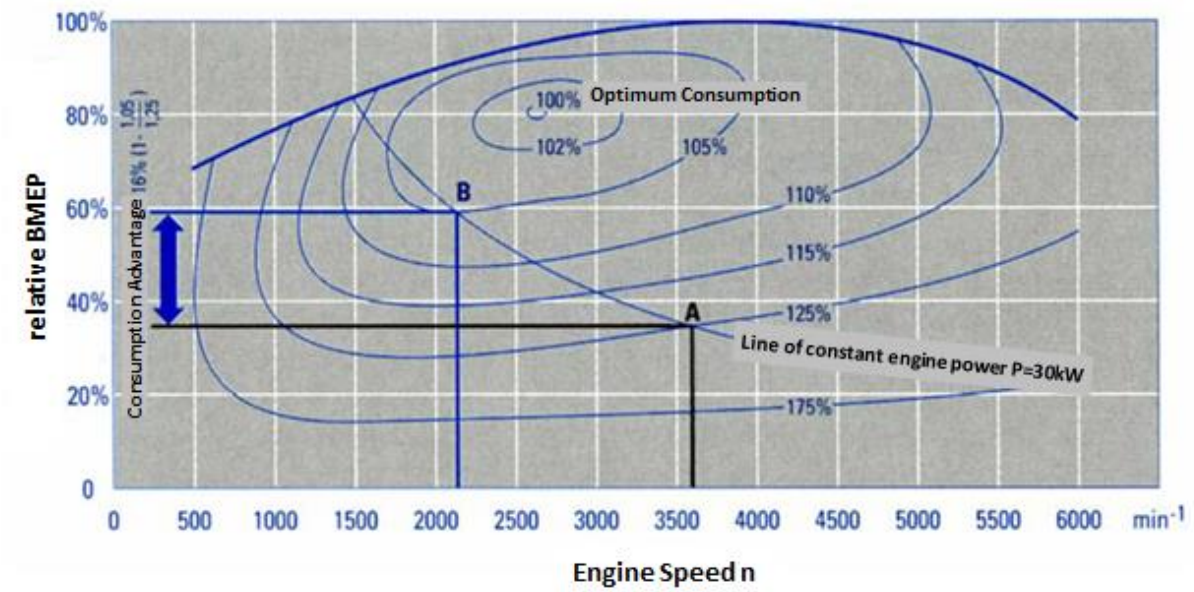

Figure 3-1: Characteristic fuel consumption map of a SI engine (3)

The downsizing concept as it is used today in many vehicles, has great potential for reducing CO_2 emissions. Downsizing and downspeeding are combined in order to achieve the desired fuel savings. An increase in the mean effective pressure is for such a fuel saving strategy essential (3) (4) (5). However, this increases the problem of irregular combustion phenomena.

Limits for downsizing

But this downsizing trend is limited by the high mean effective pressures and other increasing demands which lead to numerous restrictions:

- knocking
- pre-ignition phenomena
- higher thermal and mechanical load
- CO_2 emission limits
- costs

A modern more fuel-efficient engine must meet the following requirements today (3) (5) (6):

- high torque resp. quick response, even at low speeds in the stationary and dynamic operation
- the optimization of the tendency to knock at high loads
- high compression ratio (possible by direct injection)
- optimized centre of combustion which leads to higher efficiency
- reduced charge exchange losses even in the partial load range
- reduction of the area with mixture enrichment, especially at high loads and speeds according to component protection reasons

These requirements can only be achieved through the combination of different technologies and strategies, such as gasoline direct injection, variable valve train, supercharging, EGR, increasing the charge motion (swirl or tumble), and so on. As gasoline direct injection has a direct influence on the usable potential of alternative fuels, it is discussed in more detail below.

Gasoline Direct Injection (GDI)

By the gasoline direct injection the heat of vaporization of the fuel spray cools down cylinder charge, whereby the temperature of the cylinder charge is reduced. Cooling has also a positive effect on the knock- and pre-ignition tendency. Due to the cooling of the cylinder charge a higher compression ratio can be achieved. Furthermore the volumetric efficiency of the engine is also increased by the cooling of the cylinder charge.

In combination with variable valve trains substantial improvements in gas exchange are possible. Thus, the direct gasoline injection in combination with a supercharged downsizing engine is an essential part of modern gasoline engines (3) (5) (6).

3.2 Influence of Ethanol on RON (Knock-Resistance)

For fuel economy at part load modern gasoline engines have a high compression ratio. This results in highly supercharged engine concepts in the full load to critical conditions in the combustion chamber. Due to the propagating flame front a critical state occurs in the further compressed end gas and leads at one or more locations to self-ignition. The resulting very high pressure gradient (see Figure 3-3) spread in the form of pressure waves in the sound speed range and can cause severe material damage. Knocking combustion also produces a high thermal stress, which in turn can be trigger so called glow-ignitions (see pre-ignition phenomena).
Measures to improve the knock resistance are:

- **more knock resistant fuels**
- sufficient cooling of the combustion chamber and the intake air
- appropriate combustion chamber layout
- retarding the ignition timing (thermal efficiency ↓)
- reducing the boost pressure (thermal efficiency ↓)
- reducing the compression ratio (thermal efficiency ↓)

The above measures to avoid the knock problem show that in many ways only "trade-off" solutions can be found. Their optimization is a major challenge for engine designers (3) (4) (5) (7) (8).

Through the use of ethanol, almost all the points mentioned above can be positively influenced. As can be seen from Figure 3-2 the RON increases with increasing ethanol content.

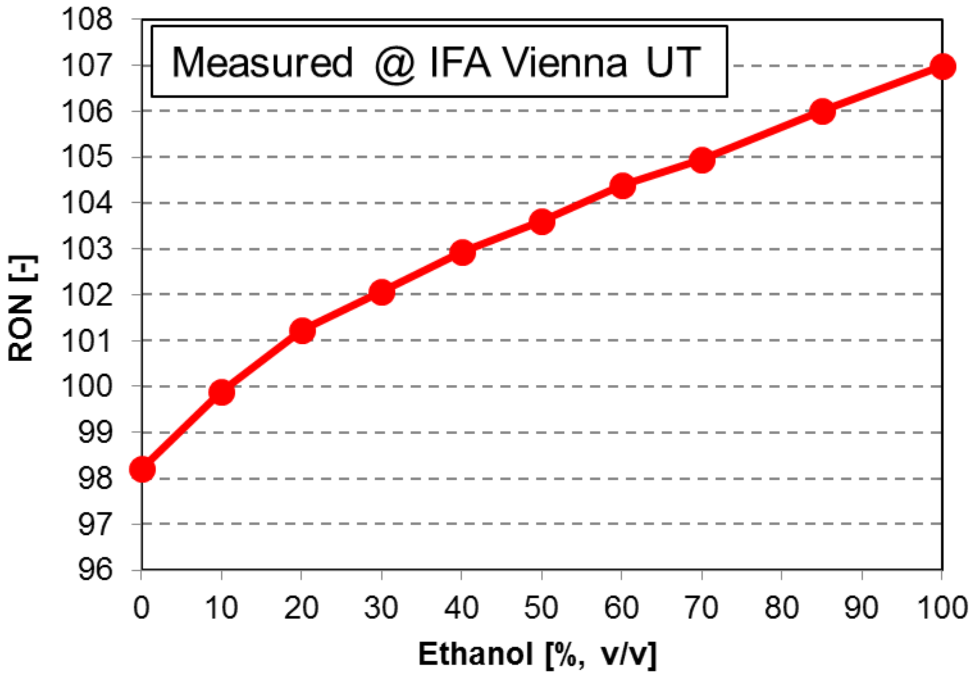

Figure 3-2: Influence of Ethanol content on RON for splash blends for base fuel RON 98

This characteristic is valid for all splash blends, regardless of the base fuel (possible country-specific differences in the base fuel - USA, Europe, China, Brazil must be considered). In match blends, however, the RON is kept constant over the proportioning rate. This is achieved by base fuels with lower RON.

Pre-ignition phenomenon

One of the main limits of downsizing engines are irregular combustion phenomena that mainly occur at high pressure, high temperature and low speeds. In contrast to knocking, the ignition of the mixture takes place before the combustion can be initiated by the spark. Knocking combustion can be prevented by a retardation of the ignition timing, whereas a pre-ignition is only partially influenced by the ignition timing. In Figure 3-3, the difference of a normal- and a knocking combustion as well as a pre-ignition are illustrated by their cylinder pressure curves.

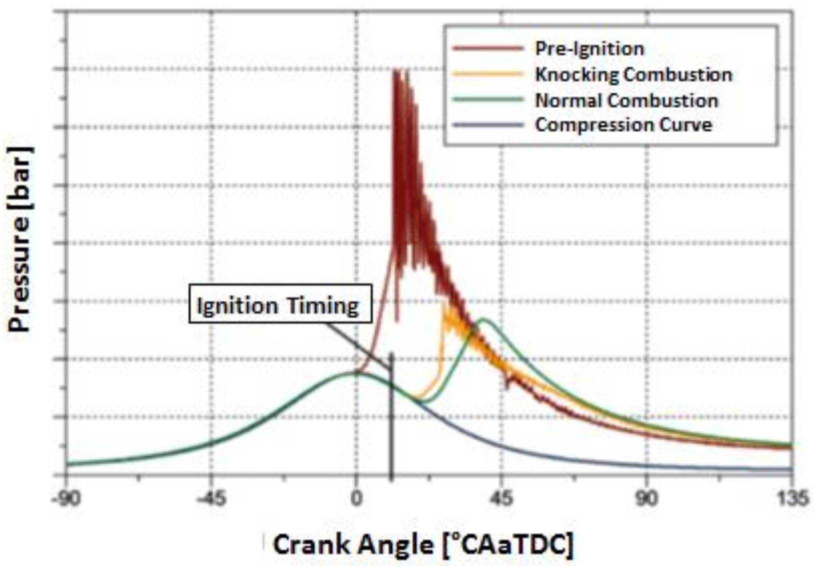

Figure 3-3: Cylinder pressure curves of a normal- and a knocking combustion as well as a pre-ignition (9)

Since pre-ignitions lead to a significant increase of the cylinder pressure (up to 250bar) often severe engine damage will occur. For this reason, the following pre-ignition causes must be avoided by appropriate measures:

- oil droplets and deposits (partially avoidable through crankcase ventilation and a good oil separator)
- "Hot spots" (critical hot spots, such as the spark plug can be constructively reduced)
- chemical reaction kinetics (e.g. radicals caused by high EGR-rates resp. hot residual gas can be avoided by appropriate valve timing) (5) (9)

Thermal and mechanical load

Increased thermal stress on the components that are in direct contact with the hot combustion gases, is also a result of high mean effective pressures, as it is the case for downsizing engines. Primarily, these are the cylinder head, piston and cylinder liner. Enhanced cooling measures are therefore an integral part of such concepts. The necessary of retarding the ignition timing by the knock control system causes an increased thermal load of the exhaust components. Exhaust valves, turbocharger and three-way catalyst must therefore be adequately protected. Although a mixture enrichment protects exhaust valves, turbocharger and three-way catalyst from thermal overload, but leads to an increase in fuel consumption, as well as to increased CO and HC emissions. **The cooling effect of the cylinder charge by**

using ethanol, as explained before, has a positive effect on above-mentioned problems (4) (5).

3.3 Alternative fuels for gasoline engines

Generally, there are several alternatives for the use of alternative fuels in conventional SI engines. Taking into account the engine characteristics, sustainability of fuels and the production expenses/ production facilities the following fuel components have great future potential.

- methanol (one C-atom)
- **ethanol (two C-atoms)**
- ethanol with a water content of 7 vol%
- 1-propanol (three C-atoms)
- 1-butanol (four C-atoms)

In Figure 3-4 the relevant properties of the substances listed above are shown.

Fuel	Methanol	Ethanol	1-Propanol	1-Butanol
Number of C – Atom	1	2	3	4
Heating Value [MJ/kg]	19,9	26,8	30,6	33,3
Boiling Point [°C]	65	78	97	118
RVP[mbar]	129	58	20,3	6,7
Densitiy [g/dm³]	790	790	800	810
Oxygen [%M]	49,9	34,7	26,6	21,6
Heat of Vaporization [kJ/kg]	1100	910	693	583
The higher the amount of C-Atoms	the higher the Heating Value the Boiling Piont the Stöchiometric Air requirement		the lower the Heat of Vaporization the Vapour Pressure	

Figure 3-4: Properties of different alcohols (10)

The listed fuel properties have a significant influence on the combustion process. Here especially the higher heat of vaporization of alcohol fuels in contrast to regular gasoline should be mentioned, which result in increased cooling of the cylinder

charge. The higher heat of vaporization of alcohol fuels leads to a number of positive effects on the combustion process.
Improved cooling of the mixture, among other things leads to a higher cylinder filling, and results in an increase of engine torque. This effect can be utilized much better in DISI engines than PFI engines. Strong wall wetting with fuel (due to high boiling points of the alternative fuels) ensure in PFI engines that the heat required for evaporation is partially removed from the intake manifold. In the homogeneous DISI engines the heat for evaporization is mainly removed from the cylinder charge. The cooling and, consequently, an advanced combustion position (MFB50% - defines the centre of combustion - is closer to the TDC) also provide a lower exhaust gas temperature.

The usually, at higher loads required enrichment (λ <1), to protect engine components, thus largely unnecessary. The normally required mixture enrichment at higher loads for component protection is for this reason largely unnecessary. A further advantage is the mitigation of knocking (undesirable combustion phenomena which can damage the engine). Especially in the knock-limited full load operation of the engine ethanol allows compared to regular gasoline a more efficient location of the centre of combustion.

An optimal centre of combustion not only leads to better efficiency, but also to a higher torque as is required for efficient downsizing engines. Further the use of ethanol allows an increase of the compression ratio due to the mitigation of the knock problem and thus lead to a further improvement of the thermal efficiency. Also, the lower the C-atom number and the higher the mass-based oxygen content of alcohols, the shorter the burning duration and the ignition delay (shown in Figure 3-5), since the higher the oxygen content increases the reactivity.

In Figure 3-5, different engine operating parameters are shown during a boost pressure variation. In Figure 3-5 a regular gasoline (E5 RON95) and two splash blends E20 and E85 are compared. The benefits of ethanol are clearly visible. With E85, the most optimal centre of combustion (MBF50%) can be achieved without any knock phenomena. The CoV value characterizes the engine running smoothness. Due to the most optimal centre of combustion E85 also shows the lowest CoV level.

The short ignition delay time and the fastest burning duration is explained in the higher reactivity of ethanol caused by the high content of oxygen. The importance of richer air-fuel-ratio to reduce thermal load, as seen in Figure 3-4, is not necessary with ethanol because of the cooling effect. The retardation of the ignition timing was only necessary on the basis of peak pressure limit (see PMAX-diagram in Figure 3-5). Accordingly, with E85 the highest indicated mean effective pressure and peak pressure can be achieved.

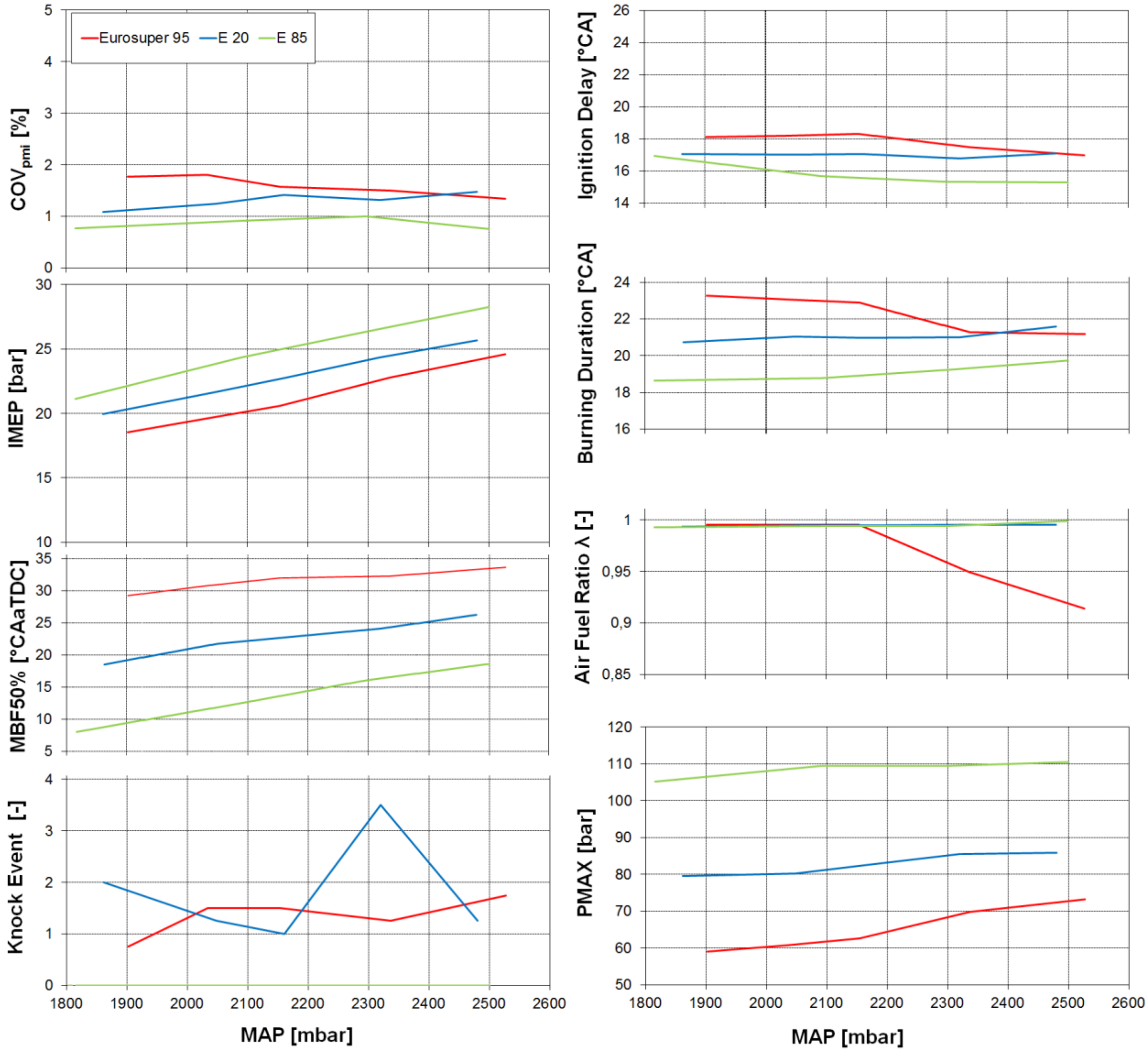

Figure 3-5: Engine parameters for different fuels at 2000rpm, WOT (5)

Alcohols with a lower number of carbon atoms, such as ethanol, have a lower stoichiometric air-to-fuel ratio, and a lower heating value. Due to the lower stoichiometric air-to-fuel ratio, more fuel must be introduced into the cylinder at the same air mass. The resulting additional cooling effect (more fuel to be evaporated) amplify above aspects, the disadvantage of the lower heating value (higher gravimetric and volumetric fuel consumption for the same energy content) remains, however. The higher boiling temperature and the lower vapour pressure of ethanol are responsible for their poor cold-start performance. At higher ethanol blend rates such as E85 the boiling temperature is, for example, higher than the beginning of the boiling range of regular gasoline.

Influence on the efficiency

Almost all the above factors lead to an increase in efficiency. A cooler combustion process has lower wall heat losses. Also the enrichment requirement (λ <1) at high temperatures thereby largely mitigated, which leads to a reduced fuel consumption and emissions advantages. Due to the higher knock resistance with appropriate engine application and a more optimal centre of combustion further efficiency benefits can be achieved. A shorter combustion duration and a more efficient combustion, as in the case of ethanol, also give an increase in the efficiency (5) (10) (11) (12) (13)

Influence on the pre-ignition tendency

The use of ethanol as a mixing component for regular gasoline (E5 RON95) lead to a significant decrease in pre-ignition frequency as described in (14). Depending on the different blend rates pre-ignitions can significantly be reduced. With E85 the best results were achieved. In (15) oxygenates, such as ethanol, are described to have a high resistance against pre-ignitions, assuming an ignition in the gas phase. Considering an ignition on hot surfaces so-called "hot spots" a decrease in the pre-ignition resistance with increasing ethanol content is observed in (16). A direct comparison between a DISI- and a MPI-engine during a boost pressure variation shows generally a higher pre-ignition frequency with external mixture formation. Due to admixing of ethanol a higher intake manifold pressure is reached in both cases. But only the DISI engine can utilize the full potential of ethanol, which is clearly evidenced by a very low pre-ignition frequency at high ethanol content and internal mixture formation (see Figure 3-6) (5) (17).

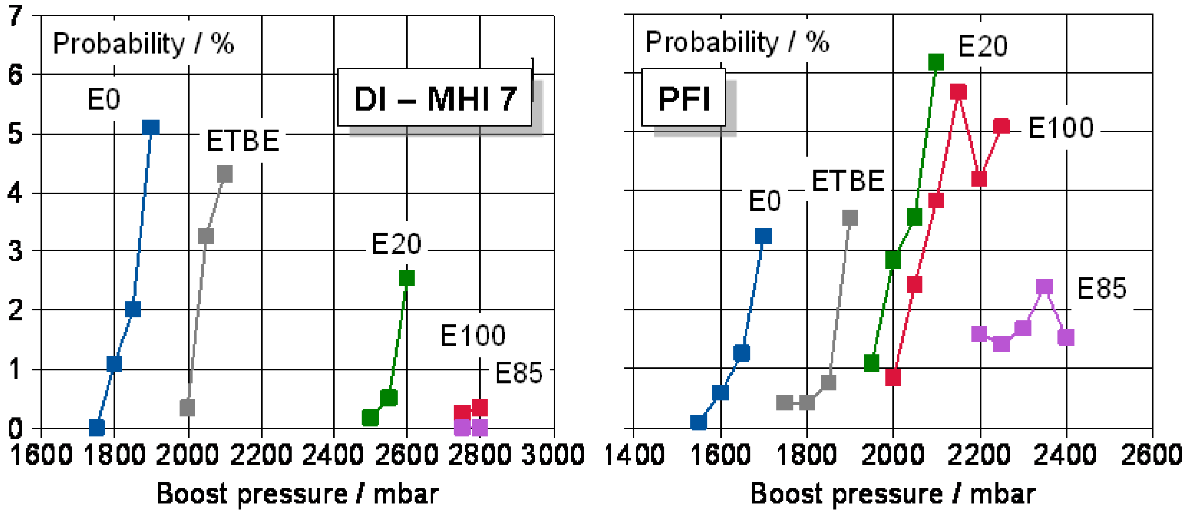

Figure 3-6: Pre-ignition frequency of the tested fuels during a boost pressure variation for a DISI- and a MPI-engine (17)

Cold start behaviour of ethanol

One reason for the poor cold-start performance of **E100** is that as single component fuel it has a fixed boiling point of 78°C and thus the volatile components as in regular gasoline are missing. Another reason is the high heat of vaporization, which is responsible for additional cooling of the mixture (18). In Figure 3-7 the different boiling temperatures and heat of vaporizations are plotted for gasoline and alcohols.

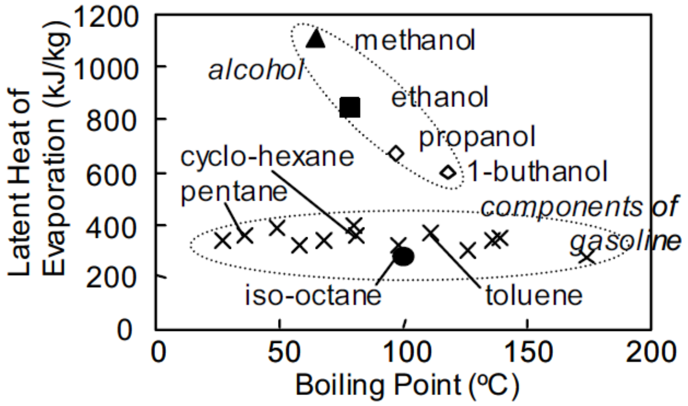

Figure 3-7: Difference of evaporation properties of different fuels (18)

However, this study focused on ethanol blending rates E20/25, thus no cold start problems are expected.

4 Results from the meta-analysis

The results of the evaluation of the meta-analysis are presented in this chapter and will be discussed in detail. The results are based on the literature listed in Chapter 7.1. The effects of ethanol blends were examined for the following properties:

- Fuel Consumption and Energy Efficiency (Chapter 4.1)
- Carbon dioxide emissions (CO_2) (Chapter 4.2)
- Carbon monoxide emissions (CO) (Chapter 4.2.2)
- Hydrocarbon emissions (HC) (Chapter **Error! Reference source not found.**)
- Nitrogen oxides emissions (NO_x) (Chapter 4.2.4)
- Particle emissions (Particle) (Chapter 4.2.5)

To enhance the readability and clarity of the study the individual analysed groups are divided always according to the same sequence. First, a brief understandable introduction to each topic, followed by the results of the present meta-analysis and the discussion of the results.

4.1 Fuel Consumption and Energy-Efficiency

Fuel Consumption and Energy Efficiency are one of the most important factors, when evaluating an alternative fuel for gasoline. Beside the Fuel properties it is of peculiar interest if there exist fundamental advantages and disadvantages.

Specific Fuel Consumption (SFC)

For a better understanding of the influencing variables of ethanol on the fuel consumption different aspects of the fuels must be considered. Generally, there are several possible alternative fuels for use in conventional SI Engine (see Chapter 3.3). Table 4-1 shows the differences in the fuel properties between regular unleaded gasoline and pure ethanol (19) (20) (21) (22).

	Gasoline	Ethanol
Chemical formula	≈C_5-C_{12}	C_2H_6O
Low Heating Value [MJ/kg]	43.5	26.8
Low Heating Value [MJ/l]	32	21.1
Latent heat of vaporization [a] [kJ/kg]	≈350	920
Reid Vapour Pressure [b] [kPa]	61	15.5
Stoichiometric air/fuel-ratio [-]	14.6	9
Density [kg/m^3]	720-775	794
Oxygen [%w]	2.7	34.7
Auto ignition temperature [°C]	257	425
Laminar flame speed [c] [cm/s]	≈33	≈39
Boiling Point [°C]	27-225	78
Water solubility [%]	0	100
Aromatics volume [%]	27.6	0
Research Octane Number RON [-]	95	109
Motor Octane Number MON [-]	85	90

Table 4-1: Fuel properties of unleaded regular gasoline and ethanol [3, 23, 28, 36]

a) at 25°C

b) at 37.8°C

c) laminar flame speed at 100kPa and 325°C

In particular, the following properties

- Low heating value (leads to increased fuel consumption)
- Latent heat of vaporization (influences knocking, enables aggressive downsizing)
- Reid vapour pressure (influences the cold-start performance)
- Water solubility (due to the hygroscopic behaviour of ethanol phase separation may happen when in contact with water)

have a strong impact on the key aspects of engine operation with pure ethanol resp. ethanol-gasoline blends. As seen before ethanol has a lower heating value as gasoline. That means, that one litre respectively one kilogram ethanol contains less energy than the same amount of gasoline. To assess how much fuel an internal combustion engine on the engine test bench consume we often use a so called *specific fuel consumption (SFC)*. The SFC gives the volumetric or gravimetric fuel consumption based on the generated engine power. Equation 4-1 shows the relationship between fuel consumption and the generated engine power.

$$SFC\left[\frac{kg}{kWh}\ or\ \frac{l}{kWh}\right] = \frac{\dot{m}_B}{P} \qquad \text{Equation 4-1}$$

Figure 4-1 shows the results from the meta-analysis for the specific fuel consumption.

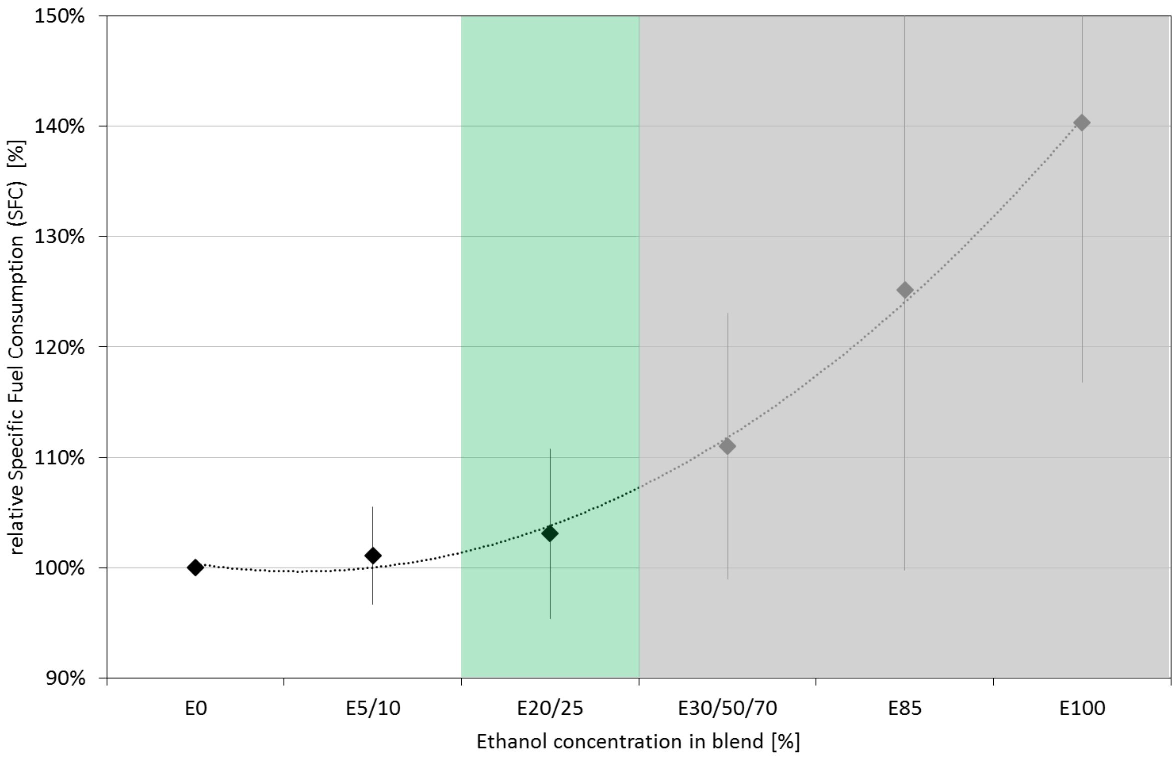

Figure 4-1: Specific fuel consumption

It turns out, as seen in Figure 4-1, that the SFC is rising consistent with increasing amount of ethanol in the fuel-blend, as mentioned before. Especially for E20/25 the meta-analysis show an increase by 3% in average.

Taking into account the lower heating value of ethanol, there results the image shown in Figure 4-2.

Theoretically, the fuel consumption when using E20/25 would rise by approximately 8%. The results from the meta-analysis, however, show only an increased consumption of about 3%, which reflects the increased thermodynamic efficiency due to the use of ethanol. These results are consistent with the data extracted from the meta-analysis for the engine efficiency.

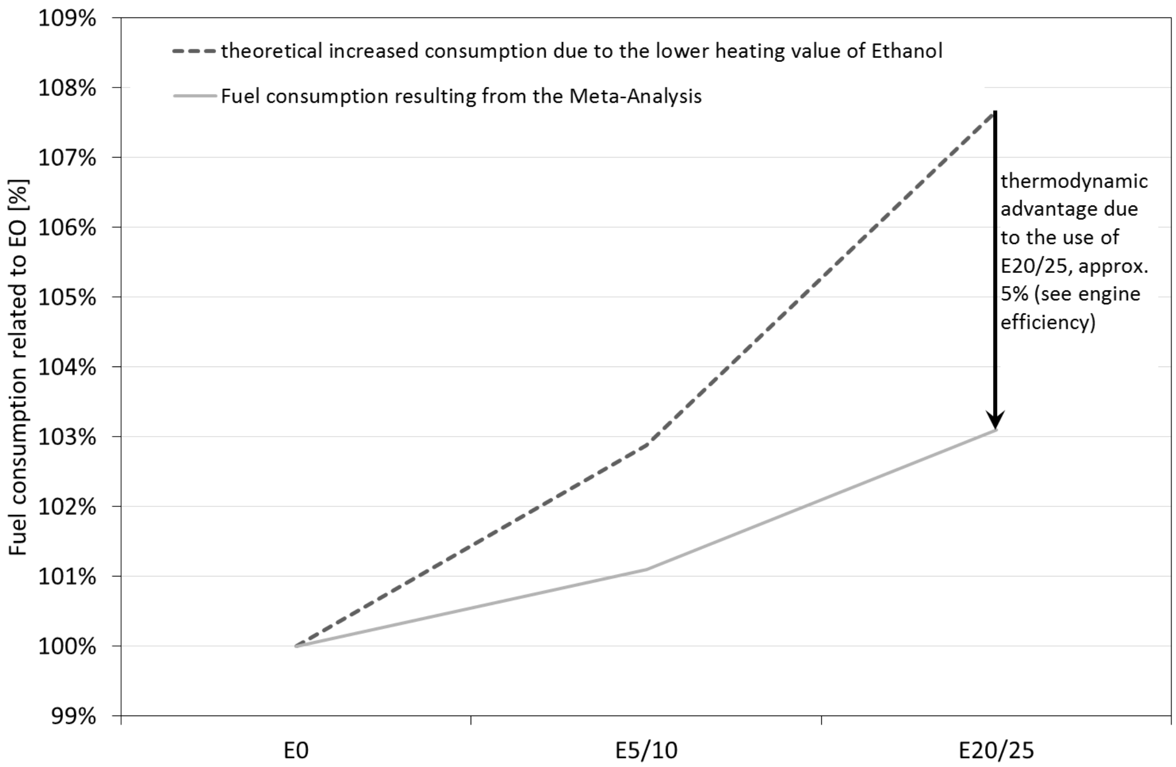

Figure 4-2: Theoretical fuel consumption due to the lower heating value of ethanol compared to the fuel consumption resulting from the meta-analysis

4.2 Emissions

In this study a distinction is made between the raw emissions (engine-out) and the end-of-pipe (tailpipe) emissions. The principal effect of ethanol blends on exhaust emissions can be significantly better illustrated using the engine-out emissions. In a real vehicle operation, the end-of-pipe emission of more importance as long as the exhaust aftertreatment system (3-way catalyst) is working properly.

In order to give in the following sections a better overview of the results of the emission results, the ideal chemical reaction equations for a particular gasoline model fuel (Equation 4-2) and ethanol (Equation 4-3) are compared [9].

$$C_7H_{13.3} + 10.33(O_2 + 3.785N_2) = 7CO_2 + 6.66H_2O + 39.1N_2 + 4.19MJ \quad \text{Equation 4-2}$$

$$3.44C_2H_6O + 10.33(O_2 + 3.785N_2) = 6.88CO_2 + 10.32H_2O + 39.1N_2 + 4.24MJ \quad \text{Equation 4-3}$$

According to the Equation 4-2 and Equation 4-3 it can be seen that ethanol has approximately 30% more triatomic molecules in exhaust gas than gasoline. The result is a higher specific heat capacity and therefore lower exhaust gas temperatures, lower wall heat losses and consequently a higher thermal efficiency [9]. This effect is further enhanced by the significantly higher latent heat of vaporization. In the real combustion, however, incur additional components, which results from incomplete combustion, for example. Among others the limited pollutants CO, HC, NOx and particles.

The exhaust aftertreatment system, for the SI engine, a 3-way catalyst has the task of reducing undesirable combustion products (limited pollutant emissions) and convert them into harmless components. The CO and HC are oxidized and the NO_x emissions are reduced, as shown in Equation 4-4, Equation 4-5 and Equation 4-6.

$$2\,CO + O_2 \rightarrow 2\,CO_2 \quad \text{Equation 4-4}$$

$$C_mH_n + \left(m + \frac{n}{4}\right) O_2 \rightarrow m\,CO_2 + \frac{n}{2}\,H_2O \quad \text{Equation 4-5}$$

$$2\,NO + 2\,CO \rightarrow N_2 + 2\,CO_2 \quad \text{Equation 4-6}$$

As shown in Figure 4-3 this conversions only work in a small Air/Fuel-Ratio window near the stoichiometric Air/fuel-Ratio.

The more important the property of ethanol is to keep the enrichment requirement as low as possible in the full load, as already explained above. Thus, the three-way catalyst can fulfil its function over a wider operating range, compared to E0.

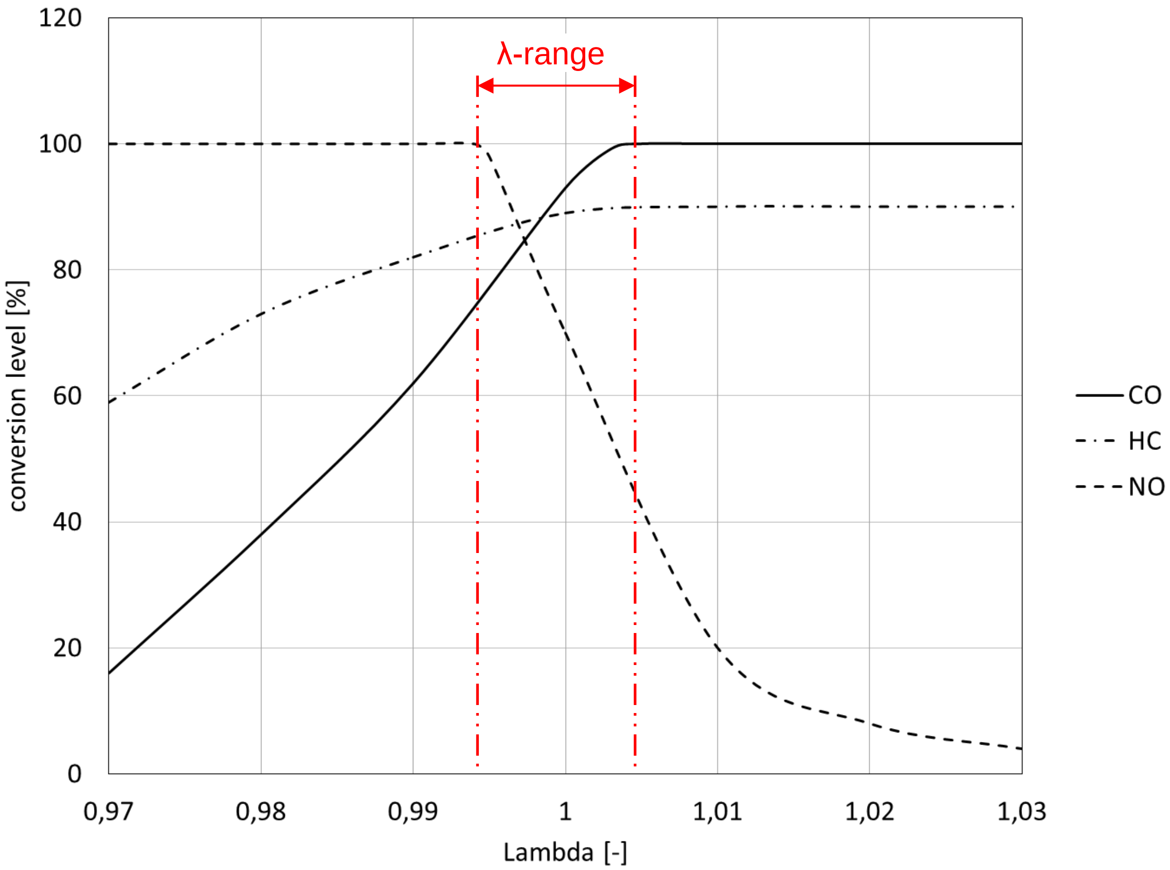

Figure 4-3: Schematic influence of the Air/Fuel-Ratio on the conversion level of the 3-way-catalyst (8)

4.2.1 CO_2 emissions

Carbon dioxide does not primarily belong to limited emissions, but is a final product of ideal combustion. Therefore, the CO_2 levels in exhaust gas give a measure of efficiency for the combustion.

Figure 4-4 shows the influence of different ethanol blends on the CO_2 emissions, which were evaluated for the meta-analysis. As Equation 4-7 shows, the CO_2 emissions in figure 4-4 are referred to the engine performance.

$$[CO_2] = \frac{kg}{kWh} \qquad \text{Equation 4-7}$$

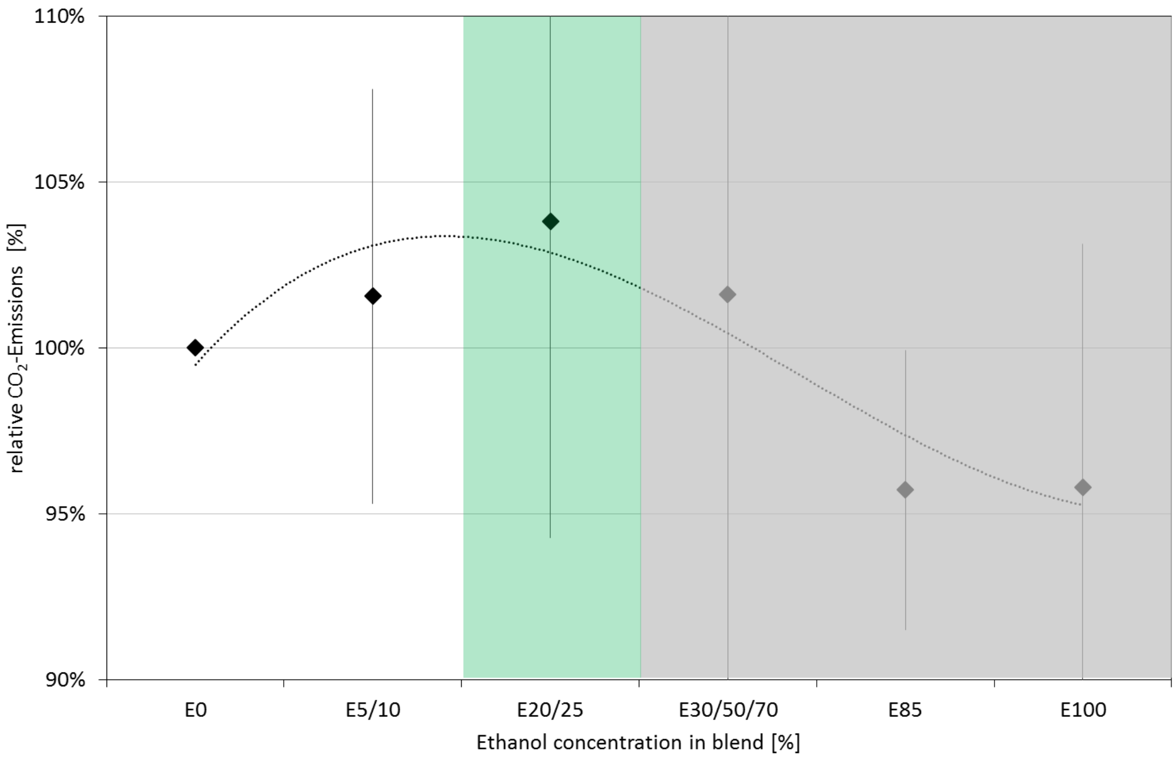

Figure 4-4: Engine-out CO_2 emissions

In the range between E0 and E50, the CO_2 emissions tend to rise. This is a sign of an improved combustion, especially in combination with reduced CO emissions (see Chapter 4.2.2). The decrease in CO_2 emissions above E50 does not mean that there is incomplete combustion again. There the favourable H/C ratio of ethanol comes into play and therefore more H_2O than CO_2 is formed.

The end-of-pipe CO_2 emissions, see Figure 4-5, also decrease at low ethanol content, as the conversion of CO and HC to CO_2 takes place in the catalyst. As has been shown earlier the efficiency of the catalyst also increases with increasing ethanol content. Apart from this, the catalyst can be operated in a wider range without full load enrichment (lambda=1) with increasing ethanol content. Since generally the CO- and HC emissions decrease in this area therefore CO_2 emissions are even lower after the catalyst.

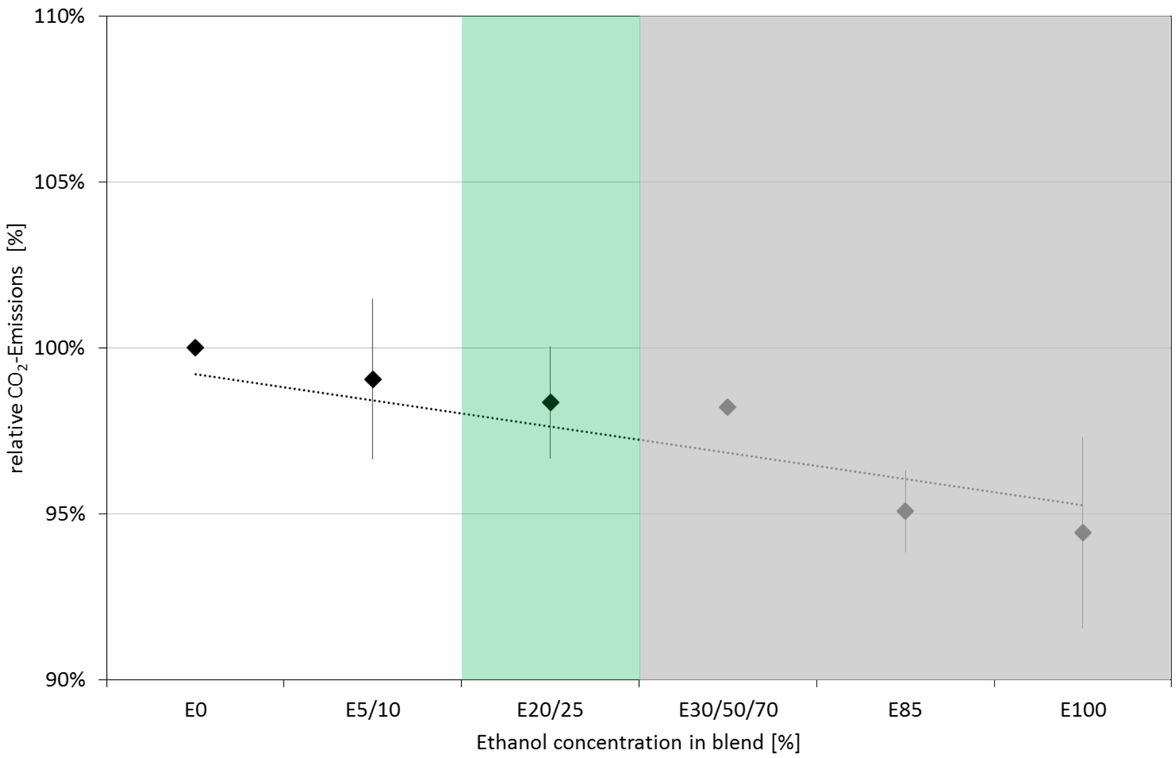

Figure 4-5: End-of-pipe CO_2 emissions

As can be seen from the meta-analysis results the CO_2 end-of-pipe emissions after complete combustion drop by approximately 5% for E100 compared to E0. This is consistent with the theoretical reduction of CO_2 emissions through the better C/H ratio of ethanol, as shown in Equation 4-2 and Equation 4-3.

4.2.2 CO emissions

Carbon monoxide results by combustion of fuel under oxygen deficient, if the carbon cannot be burnt completely. A full oxidation to CO_2 is only possible with sufficient oxygen. That means that the CO concentration in the exhaust gas increases with decreasing λ, as is the case for fuel enrichment (see Figure 4-6). (8).

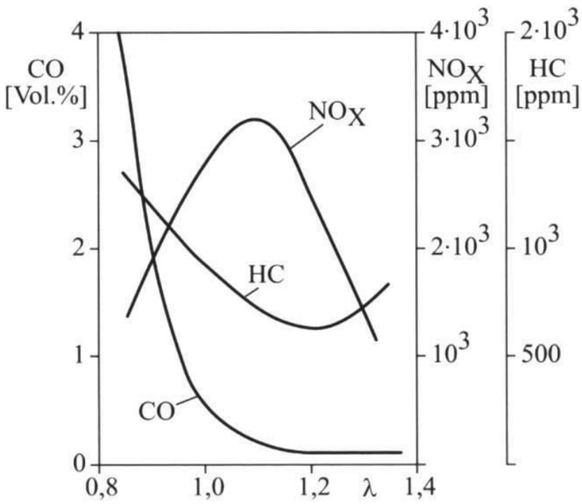

Figure 4-6: Pollutant formation as function of the air/fuel ratio (8)

Figure 4-7 shows the result from the meta-analysis for the engine-out CO emissions.

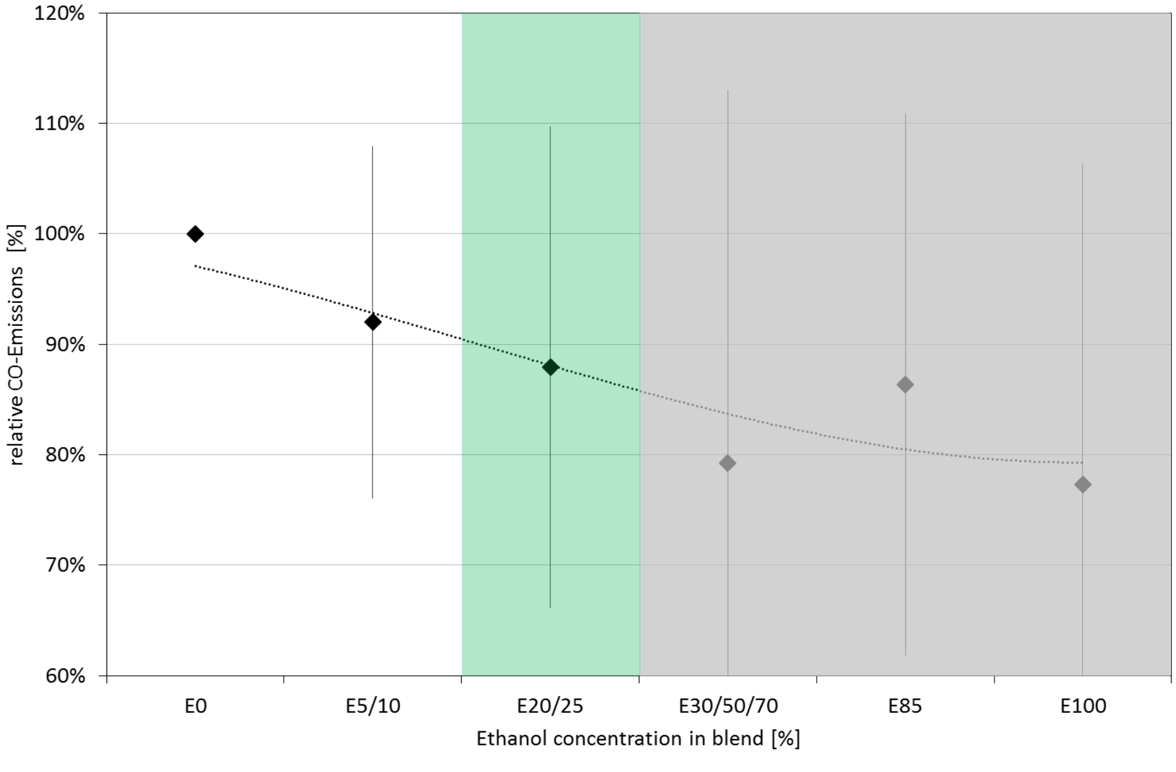

Figure 4-7: Engine-out CO emissions

Figure 4-7 shows a clear reduction in CO emissions with increasing ethanol concentration in blend. Especially for E20/25 the CO emissions can be reduced by approximately 10% in average. On one hand the need for fuel enrichment in a wide range of operating is unnecessary, which results in lower CO emissions due the combustion process, as previously mentioned. On the other hand fossil fuel (E0) contains about 30% more carbon than ethanol, which in turn can lead to a higher percentage of unburned carbon. At the same amount of air and Lambda this effect is almost equalized, due to the higher amount of fuel required at higher ethanol content. The faster and more complete combustion of ethanol, according to the higher oxygen content (see Figure 3-4), leads to a reduction of the unburned carbon.

As can be seen from Figure 4-8 the CO end-of-pipe emissions also can be reduced by increasing ethanol content in blend. The need for enrichment with E0 has an even greater importance here, because the three-way catalyst ensures only in a very narrow lambda window high conversion rates (see Chapter 4.2). If the motor can be operated stoichiometrically in a larger map range, as is possible with ethanol, the CO emissions can be reduced further because of the higher conversion rate of the 3-way-catalyst. Compared with Figure 4-7 the difference between E0 and E20/25 is quite more apparent and the advantage of ethanol is even better obvious.

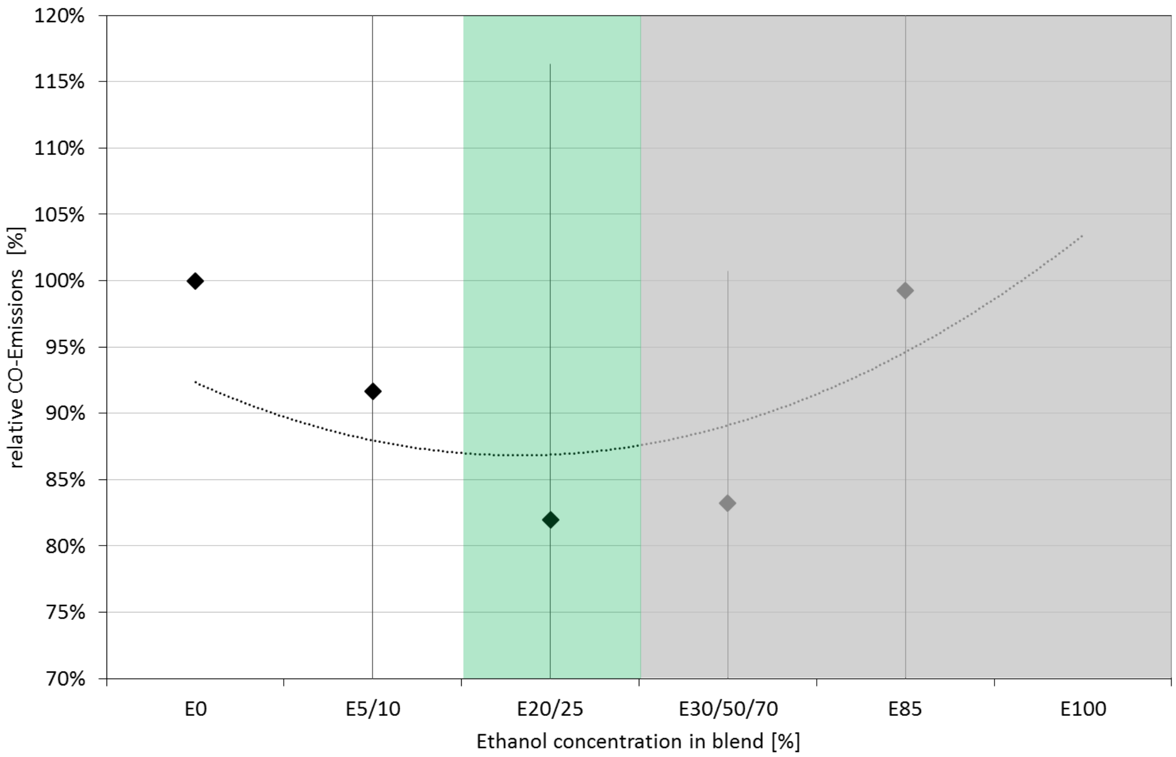

Figure 4-8: End-of-pipe CO emissions

4.2.3 HC emissions

HC emissions are unburned hydrocarbons. These occur during the combustion process mainly from lack of oxygen and cool local temperatures. Origin of HC's are a rich engine operation ($\lambda<1$) and formation of wall film, similar to the origin of the CO emissions. Wall film is the agglomeration of fluid fuel on components like the cylinder liner, the piston, and the cylinder head. At this places the flame front cools down so heavily, that the fuel cannot burn completely. Figure 4-9 shows the result for the engine-out HC emissions.

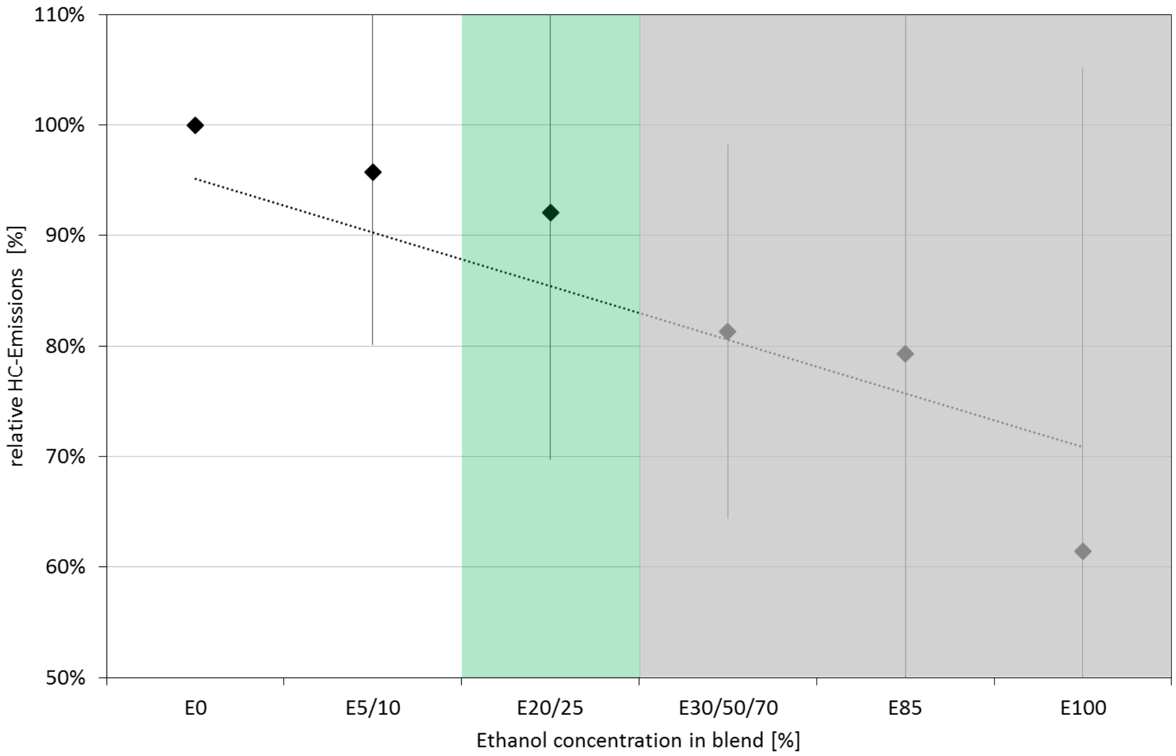

Figure 4-9: Result of the meta-analysis for the engine-out HC emissions

As it turns out the HC engine-out emissions decrease on average over the investigated studies with increasing ethanol content. For E20/25 the HC emissions decrease in general by approximately 10%. However, it should be noted that from an ethanol content of over 75% the standard deviation increases greatly. This is a result of reinforced wall film formation. This can be counteracted by a suitable motor application and an injector optimized for the use with ethanol. The generally recognizable reduction of HC raw-emissions is caused by the leaning effect due to the ethanol addition and significantly less high-boiling fuel components in the fuel. This in consequence means that the aromatic content decreases in the fuel. This high-boiling fractions are possibly responsible for wall film formation and would lead to significantly higher HC emissions, as seen by E0.

The results for HC emissions after the aftertreatment system show a more ambiguous picture, as shown in Figure 4-10.

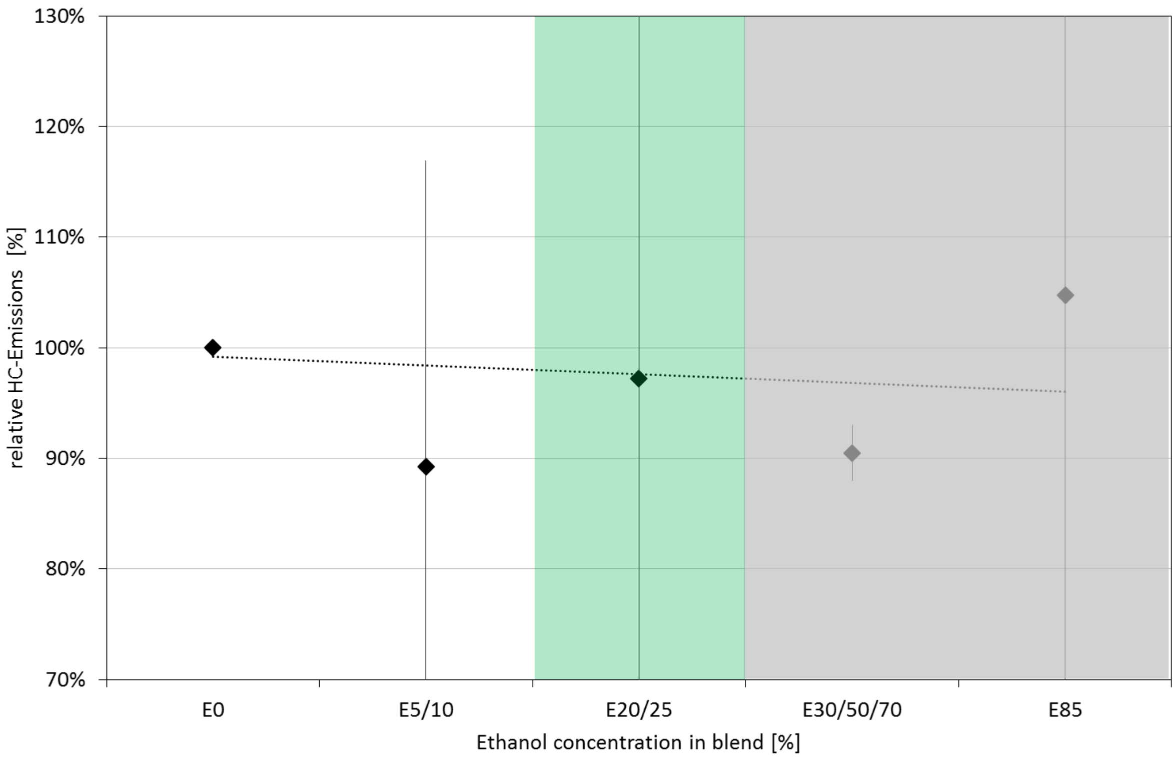

Figure 4-10: Result of the meta-analysis for the end-of-pipe HC emissions

Here also the tendency of decreasing HC emissions with increasing ethanol content is obvious. Especially for E20/25 the HC emissions decrease slightly by approximately 4% in average. It should be noted, that the large 90% confidence interval indicates, that the results depend strongly on the engine application.

4.2.4 NO_x emissions

The term nitrogen oxides NO_x stands for a plurality of nitrogen-oxygen compounds (NO, NO_2, N_2O, ...). Only the two representatives NO and NO_2 are produced in gasoline engines in larger quantities. Nitrogen oxides are jointly responsible for climate change. Especially NO_2 is directly harmful to humans. In addition, NO_2 reacts under UV radiation to ground-level ozone (O_3), which is for the people, even in small quantities an irritant gas (23).

Two mechanisms are mainly responsible for the NO_x formation during the combustion (24):

- Zeldovich mechanism
- Fenimore mechanism

In this context, the NO_x formation from fuel-bound nitrogen should be mentioned. In relation to the Zeldovich mechanism, illustrated in more detail below, the resulting amounts of NO are, however, negligible.

The Zeldovich mechanism is due to its high activation energy of 319 kJ/mol for the initiation reaction, extremely temperature dependent. The decisive factor is the availability of atomic oxygen, which is formed in internal combustion engines only at very high temperatures (>1600K). Due to the high temperatures required to initiate the Zeldovich mechanism it is also referred to as thermal NO formation (25).

Figure 4-11 shows the results from the meta-analysis for the NO_x engine-out emissions.

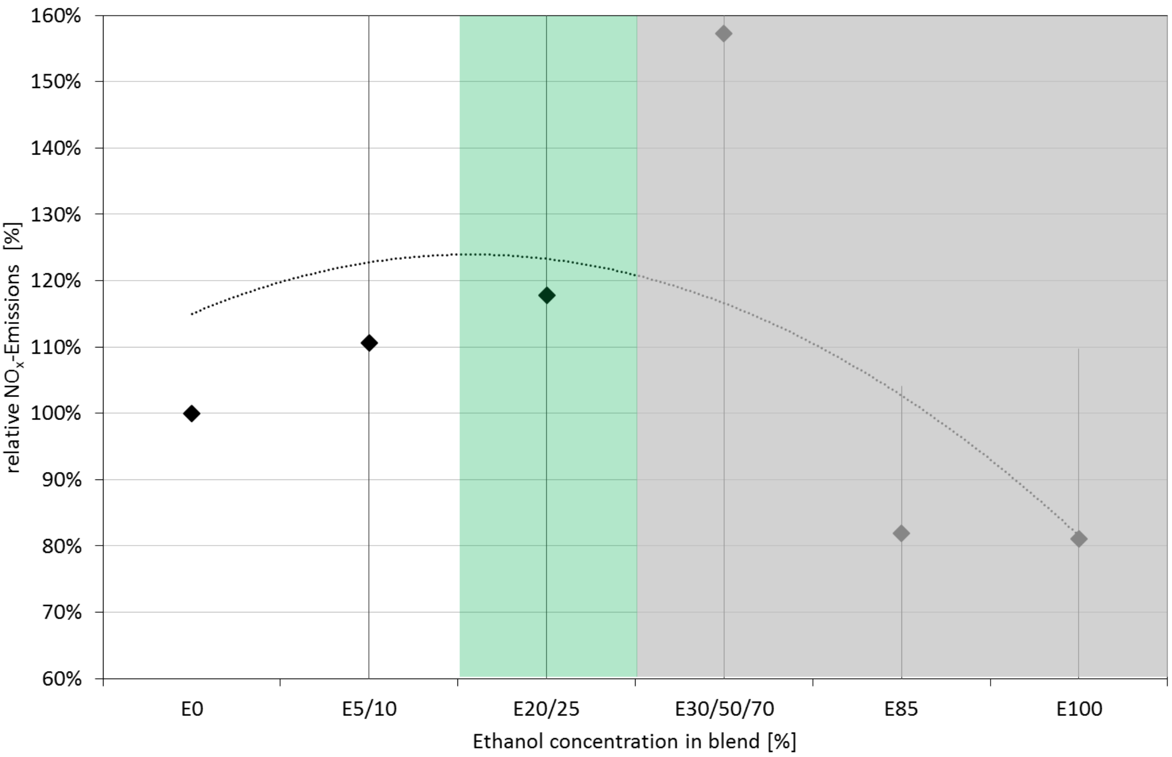

Figure 4-11: Engine-out NO_x emissions

As it turns out the NO_x emissions rise at first, before they start to decrease at an ethanol content of about 50%. Finally the NO_x emissions decrease below the value of E0. As already mentioned before a shorter burning duration in turn leads to an increased cylinder temperature and hence an increase in NO_x emissions. The cooling effect of alternative fuels can compensate this increased cylinder temperature above a certain blend ratio, and only then, alcohol fuels lead to reduced NO_x emissions. The bounded oxygen content in ethanol leads to a more homogeneous temperature distribution which amplifies this effect. Especially for E20/25 the NO_x emissions increase approximately by 20% in average.

Similar to the engine-out NO_x emissions the emissions after the aftertreatment system increase with low ethanol content and begin to decrease with an ethanol content greater than E20/25 continuously, see Figure 4-12.

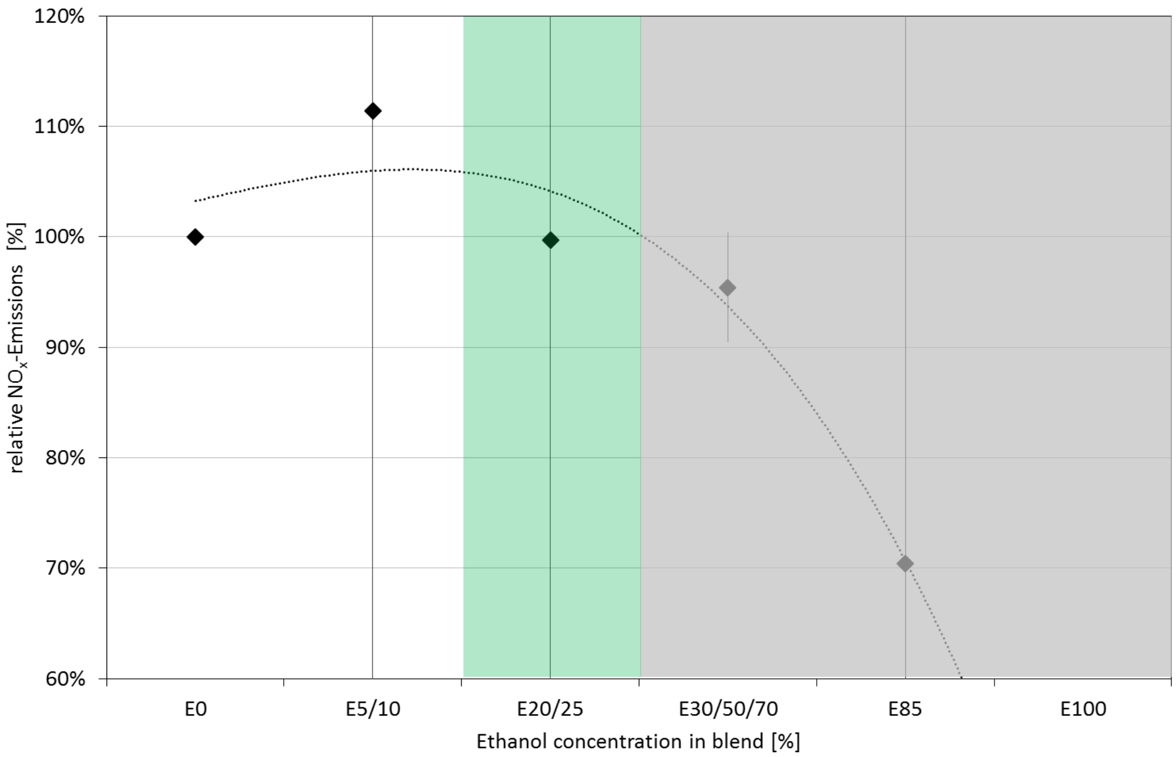

Figure 4-12: End-of-Pipe NO_x emissions

It's important to know, that because of the effective three-way catalyst system (conversion rate > 90%) the absolute level of the NO_x end-of-pipe emissions is very low. (in most cases < 100 ppm)

4.2.5 Particle emissions

The particulate emission of homogeneous operated gasoline engines is caused by an imperfection of mixture formation (26), which more clearly affects the direct-injection gasoline engine as PFI gasoline engine.

Due to the lower mixture formation time between the end of injection and the start of ignition locally very rich zones may be present, mainly fuel-wall interaction, which represent particle sources in the homogeneous spark-ignition engine. If there is not enough time for complete evaporation of the wall film, this burns in a highly sooting diffusion flame. Due to lack of oxygen, there are hardly any oxidation reactions of the formed soot (27).

Favourable conditions for particle formation are a locally rich combustion at locally high temperatures in the range of 1700 to 2600K (28). Figure 4-13 gives a schematic view of particle relevant physical sources.

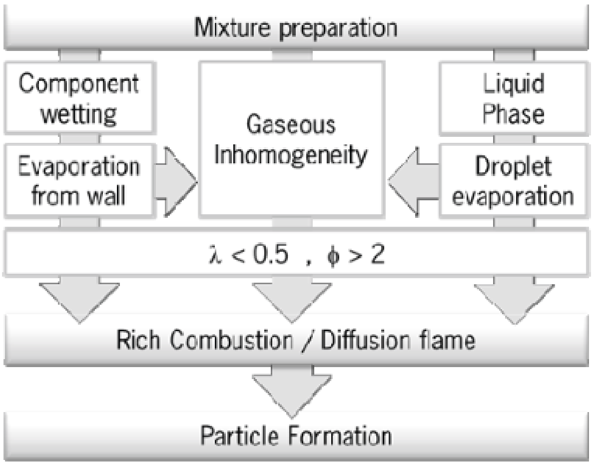

Figure 4-13: Schematic view of particle relevant physical sources (28)

The main in-cylinder particle sources are (28):

- piston wetting,
- liner wetting,
- combustion chamber roof wetting,
- interaction with intake valve,
- injector deposits (tip sooting) and
- inhomogeneity and diffusion flames

Particle emissions are strongly related to the aromatics components, which are boiling at high temperatures. Due to blending of high proportions of ethanol the aromatic components are decreased, which subsequently decreases soot precursors (29), (30). Further, the oxygen in ethanol results in more favourable local conditions and thus acts against the formation of particles (31).

It should be noted that currently only a small number of studies exist that deal with particle emissions in SI engines. The results of the meta-analysis are shown in Figure 4-14.

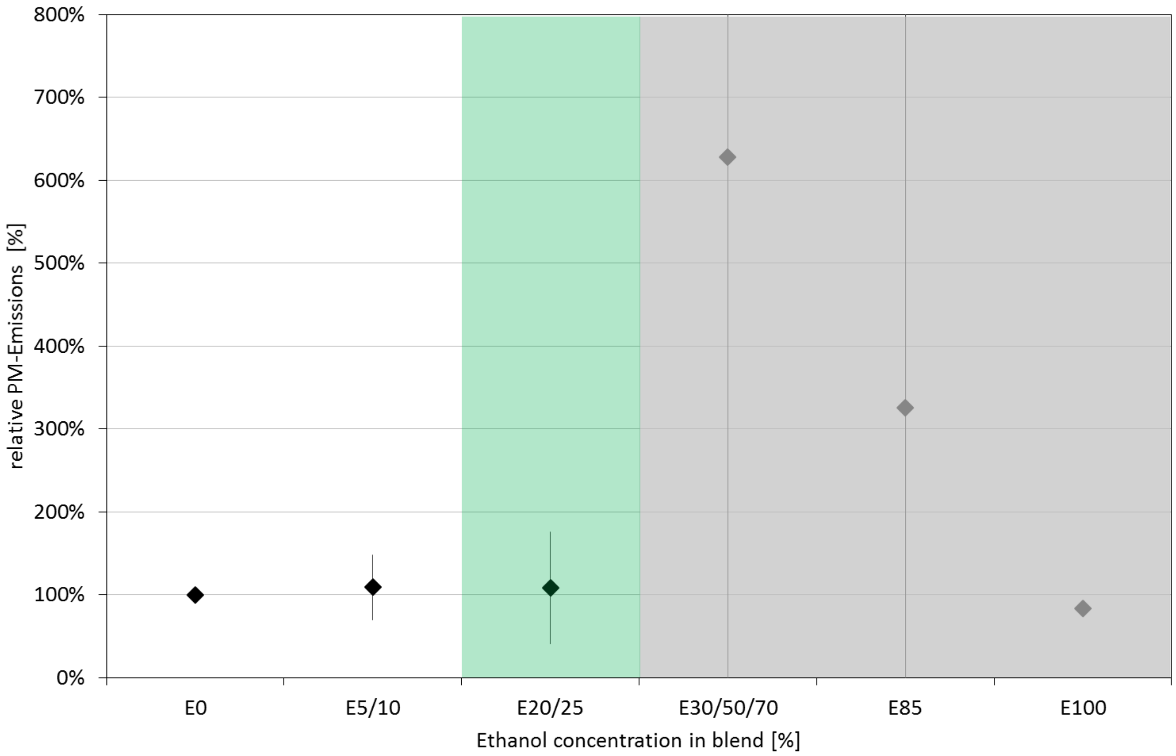

Figure 4-14: PM-Emissions

The engine-out emission in case of the particle emission are also representative for the tailpipe emissions, because today's gasoline vehicles have no particle filter, which is the only way to minimize particle emissions in the exhaust system.

The results of the meta-analysis for the particle number are shown in Figure 4-15.

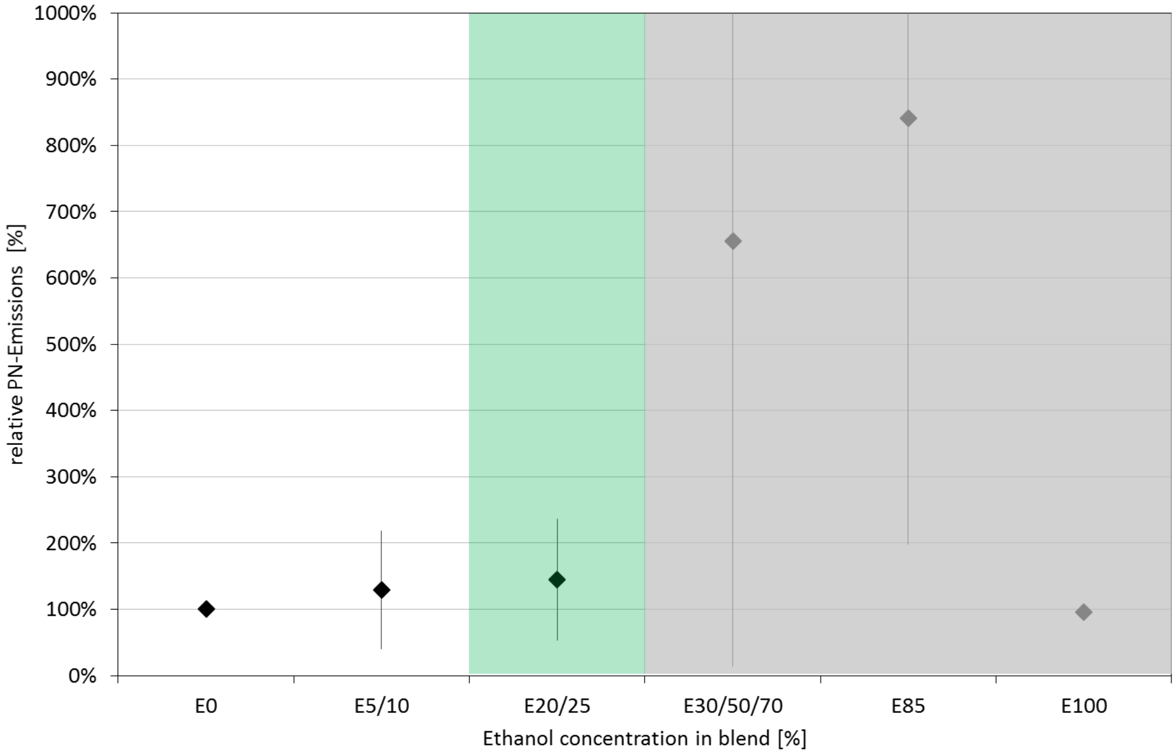

Figure 4-15: PN-Emissions

The reason for the increased particulate emissions (PM and PN), in spite of the theoretical trend of lower particulate emissions with increased ethanol content is as follows. The discussed engines in this analysis are all direct injection engines, since MPI engines hardly form particle emissions. The increase in particulate emissions is due to increased wall- and piston crown wetting of the direct-injection engines, if they are operated with high ethanol content.

Basically, it can be said that an engine which was not calibrated before for high ethanol blends can not use the more favourable properties of ethanol. In that case an increase in the particle emissions, as shown in Figure 4-15 is the consequence.

Direct-injected gasoline engines have a high potential for increasing the efficiency but they emit due to internal mixture formation a higher level of particulate emissions than PFI-engines (31). As shown by recent works, by proper application of the ECU the particle emissions can be drastically reduced as can be seen in Figure 4-16. Figure 4-16 shows the cumulated particle number [1/km] during the NEDC for a DISI engine at different ethanol-gasoline blends.

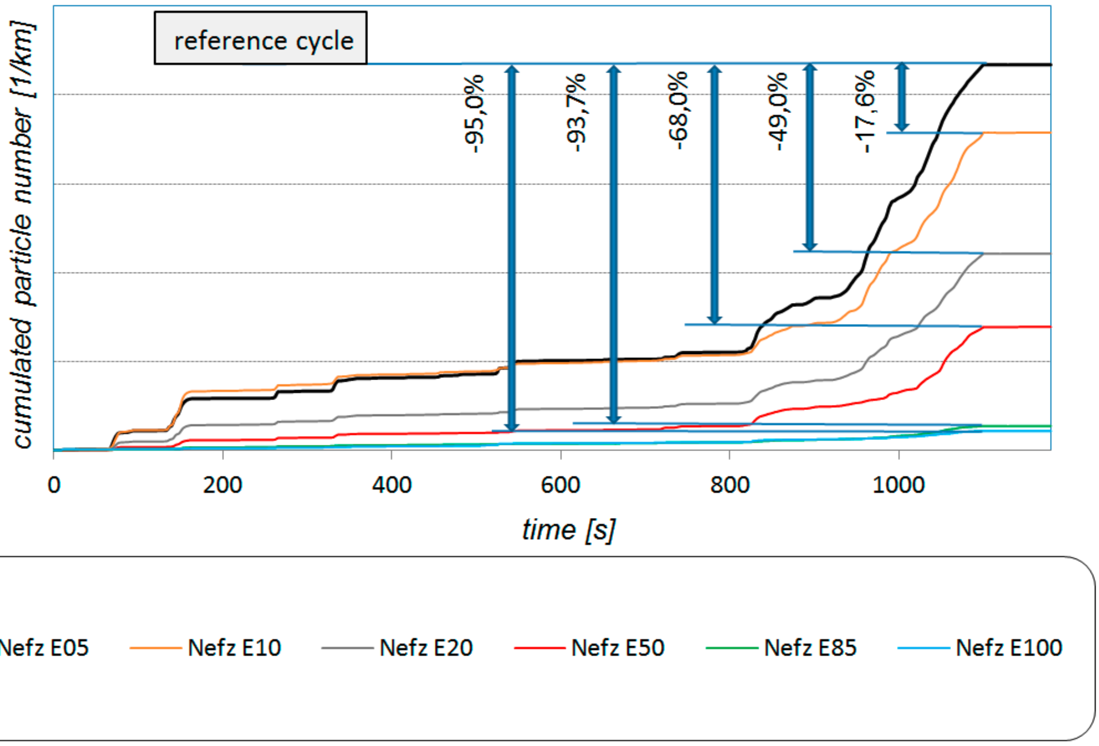

Figure 4-16: Reduction of the particle number during the NEDC in dependence of the ethanol content (31)

As can be seen from the study results shown in Figure 4-16 the particle-emissions can be reduced by approximately 50% for E20 by proper application of the ECU.

4.2.6 Efficiency

The thermal efficiency, see Equation 4-8, of an engine is known as the relationship between the power the engine can generate (E_{OUT}) considering the energy content in the fuel (E_{IN}).

$$\eta_{th} = \frac{E_{out}}{E_{in}} \qquad \text{Equation 4-8}$$

Figure 4-17 shows the influence of different ethanol blends on the engine efficiency, which were evaluated for the meta-analysis.

As already shown above the engine efficiency can be increased by admixing ethanol in the fuel combined with appropriate measures. Especially for E20/25 the efficiency increases by 5% in average. Figure 4-17 shows that the 90% confidence interval reach in all areas under the 100% line. This expresses that there have been no adjustments of the engines to use the advantages of increased ethanol content in the fuel.

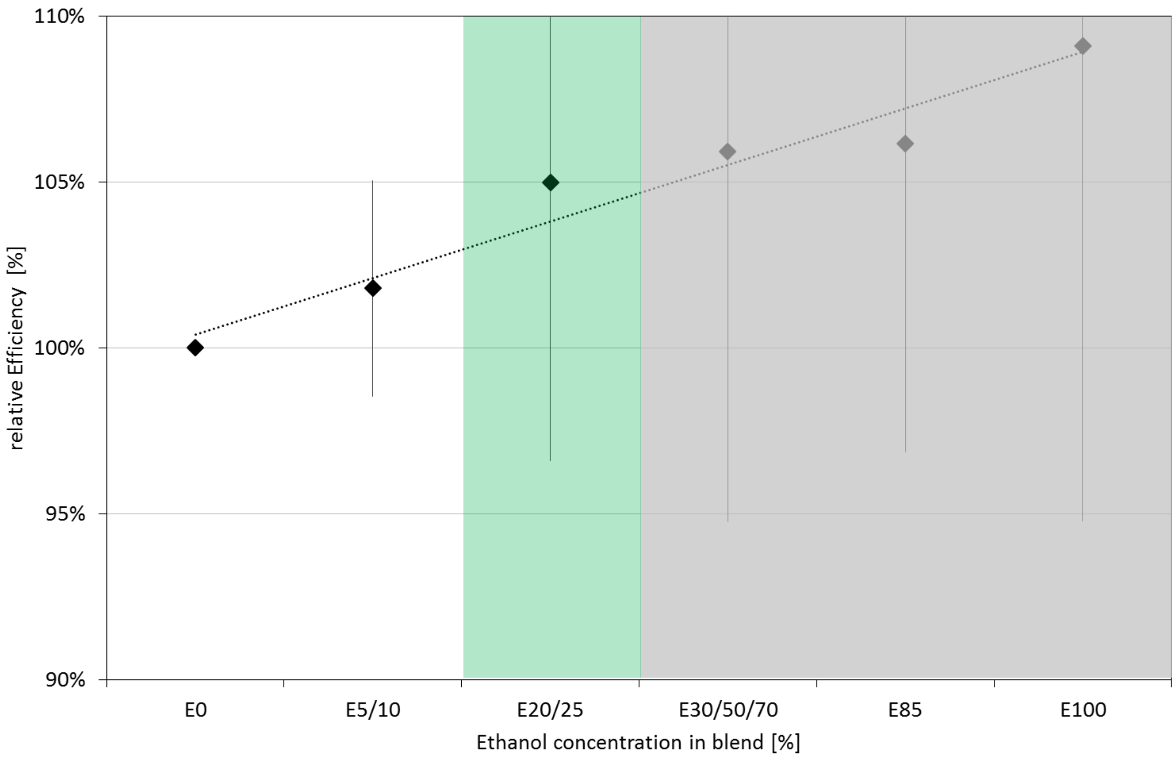

Figure 4-17: Engine efficiency

4.3 Brazil

The vehicles used in Brazil are mostly specially adapted to the climatic conditions and fuel properties in Brazil. These adjustments are mainly on the application level. This means that the engine hardware only is capable for ethanol, the engine electronic control algorithms are matched to the ethanol content. On the other hand this means, that those cars are not optimized for E20/25.In particular, in Brazil, the cold start behaviour, due to the higher average temperatures and lower customer claim, does not play a role as important as in Europe.

The basic physical relationships and properties of ethanol, when used in the internal combustion engine, were consistently confirmed by the meta-analysis, as shown above. These results are therefore in general and hence valid worldwide and can not be restricted to certain countries.

Although almost all vehicles in Brazil are capable for ethanol, only a few literatures from Brazil were identified in the identification phase (see chapter 2.1). During the “screening” and the “eligibility” phase this studies were sorted out, since in most literatures the relation to ethanol contents less E20/25 is missing.

5 Conclusion and further topics to be investigated

It has been proven that with increasing ethanol content the efficiency of the engine increases. However, for single studies the efficiency decreases, which indicates that there have been no adjustments to the engines to use the advantages of increased ethanol content in the fuel.

Therefore the energy related fuel consumption decreases despite a higher volumetric fuel consumption. Based on the volumetric fuel consumption, for low contents of ethanol (E5/10) there is a small (1% to 2%) statistically significant difference to E0, where as the use of E20/25 results in an increase by about 3% in average.
The main findings from the meta-analysis for the emissions are:

- The CO_2 end-of-pipe emissions decrease by about 5% for E100 in average. For E20/25 there is still a benefit by about 2% in average compared to E0.
- Generally the CO engine-out emissions decrease by up to 10% for E20/25 in average and by up to 20% for the end-of-pipe emissions. However, in individual cases, CO emissions also increase, especially at higher mixing rates. This is due to a lack of adaptation of the operating strategies of the increased ethanol content. This results in increased wall wetting with fuel.
- The HC engine-out emissions are also reduced by about 10% for E20/25 in average. But in some cases HC emissions increase for the same reasons as previously discussed for the CO emission. The HC end-of-pipe emissions decrease by about 5% for E20/25 in average.
- The NO_x engine-out emissions increase for E20/25 by 20% in general. The reasons are higher peak temperatures in the cylinder during the combustion. Because of the good conversion rate of the 3-way catalyst, the NO_x end-of-pipe emissions drop to the level of E0.
- The Particle-Emissions have to be investigated further. In general there is the ability to decrease the particle-emissions with E20/25. But it is essential to optimize the engine for higher Ethanol-contents.

Identified gaps

Certainly it cannot be assumed that every vehicle reacts in the same way on the addition of ethanol. As the study reveals, there are also cases where the emissions increase and the efficiency decrease, although according to the general trend it is not likely. The vehicles must be adapted to the higher ethanol blends, especially in terms of cold-start behaviour and particulate emissions for direct injection gasoline engines. In particular, the impact on particulate emissions have shown that in this area are **further investigations necessary** to be able to transfer the basic correlation into the real engine operation.

It is essential to optimize the vehicles for higher ethanol contents. Therefore it´s necessary to adapt the engine control unit (calibration), the mixture preparation and operating strategies.
Introducing higher ethanol blends without adapting the vehicles would amongst others lead to a small but increased volumetric fuel consumption since the energy content of ethanol is lower than for pure gasoline. In addition, ethanol affects certain plastic compounds and sealing elements and therefore a suitable material should be chosen.

Therefore, the proposed solution explained in „Terms of References for Meta-analysis for an E20/25 technical development study Task 2: Meta-analysis of E20/25 trial reports and associated data“ can be supported from a technical point of view.
The solution proposes the following three-step process:

1. First, that E20/25 capable cars are brought to market;
2. Second, once a sufficient number of these cars is available, E20/25 fuel will be introduced;
3. Third, once the fuel is in place, the auto industry would commercialize E20/25 optimized cars.

6 Annex

Numerical data for Figure 4-1: Specific fuel consumption:

	E0	E5/10	E20/25	E30/50/70	E85	E100
SFC	100,0%	101,1%	103,1%	111,0%	125,2%	140,3%

Numerical data for Figure 4-2: Theoretical fuel consumption due to the lower heating value of ethanol compared to the fuel consumption resulting from the meta-analysis:

	E0	E5/10	E20/25
THEORETICAL FC	100,0%	102,9%	107,7%
FC	100,0%	101,1%	103,1%

Numerical data for Figure 4-5: End-of-pipe CO_2 emissions:

	E0	E5/10	E20/25	E30/50/70	E85	E100
CO_2	100,0%	99,1%	98,3%	98,2%	95,1%	94,4%

Numerical data for Figure 4-17: Engine efficiency:

	E0	E5/10	E20/25	E30/50/70	E85	E100
EFF.	100,0%	101,8%	105,0%	105,9%	106,2%	109,1%

7 Literature

In the following Section 7.1 the various references that were used to develop the meta-analysis are listed in detail. In addition to the authors/titles the correspondent country, the boundary conditions, the fuels, the study focuses and an evaluation of the literature (0-1) are mentioned. Section 7.2 lists those references which were used for further evaluation of the use of ethanol, especially in the areas of cold start, downsizing and elastomer compatibility.

7.1 Literature for the meta-analysis

The literature listed here is not referenced in the text. It's the literature that is included in the meta-analysis. If a literature is used for the meta-analysis and is referenced in the text the literature is listed in chapter 7.2 too.

[001.] Blassnegger, J., Knauer, M., Urbanek, M., et. al.; *Endbericht zum Projekt BioE: „Untersuchung: Emissionen bei der motorischen Verbrennung von Biokraftstoffen und Kraftstoffmischungen"*, Institut Verbrennungskraftmaschinen und Thermodynamik, Graz, 2009

Country:

Europe / Austria

Boundary conditions:

Chassis Dynamometer (NEDC, CADC (urban, road, motorway), const. load point)

Gasoline (DIN EN 228, RON 95, E00)

Ethanol: E3, E5, E10, E85, E75 (winter operation) with Ethanol according to DIN 15376

Test vehicle/engine:

EURO 4 passenger car calibrated to operate as flex-fuel

Engine: Inline-4, PFI, Turbo, engine displacement 1984cm^3, 110kW @5100rpm, TWC

Studies:

CO_2, CO, HC, NO_x, PM, PN, particle size distribution, PAH, Nitro PAH, Carbonyls, mutagenicity, all "End of Pipe"

Loading:

0,9

[002.] Mahmoud K. Yassine, Morgan La Pan: *Impact of Ethanol Fuels on Regulated Tailpipe Emissions, Chrysler Group LLC, SAE International 2012-01-0872*

Country:

North America / USA

Boundary conditions:

Chassis Dynamometer (75FTP)

Gasoline E0/Tier II EPA certification fuel

Ethanol: E10, E20, E85 splash blends with certification fuel E0, 3x E85 with different RVP

Test vehicle/engine:

BIN 5 passenger car calibrated to operate as flex-fuel

Engine: V6, Port Fuel Injection, NA, engine displacement 3300cm^3, vehicle mass: 4500lbs TWC

Studies:
CO_2, CO, HC (THC, NMHC, NONMHC, NMOG), NO_x, Carbonyls
all "End of Pipe" at the three ambient temperatures under which emission certification testing is required in the US for EPA and CARB
Loading:
0,9
[003.] Broustail G., Halter F., Seers P., Moreac G., Mounaim-Rouselle C.: *Comparison of regulated and non-regulated pollutants with iso-octane/butanol and iso-octane/ethanol blends in a port-fuel injection Spark-Ignition engine*, Elsevier – Fuel 94 (2012) 251-261
Country:
North America / Canada, Europe / France
Boundary conditions:
Single cylinder engine test bench (two operating points: stoichiometric, lean)
Iso-octane as reference fuel.
Ethanol: E25, E50, E75, E100 splash blends with Iso-octane
Test vehicle/engine:
Single cylinder, PFI, NA, 4V, displacement 499cm^3, CR=9.5; oil- and coolant temperature constant at 80°C, intake air temperature at 23°C
Studies:
ISFC, CO_2, CO, THC, NO_x, Carbonyle, C_2H_2, C_6H_6
In addition, a reactor model (PSR...Perfectly Stirred Reactor (Chemkin package) - only pure substances) was used to verify the measurement results.
Loading:
0,9
[004.] Chen L., Braisher M., Crossley A., Stone R., Richardson D.: *The Influence of Ethanol Blends on Particulate Matter Emissions from Gasoline Direct Injection Engines*, University of Oxford and Jaguar Cars, SAE International 2010-01-0793
Country:
Europe / United Kingdom
Boundary conditions:
Two engine test benches (one operating point: rich, stoichiometric, lean)
Two base fuels:
- 65%-Iso-octane / 35% Toluene as base fuel for the single cyliner engine
- PURA (Unleaded Gasoline) from Shell for the V8-engine
Ethanol: E10 splash blend each with both base fuels
Test vehicle/engine:
Single cylinder: DI, NA, 4V, displacement 562cm^3, CR=11.1; optical access
V8-engine: DI, NA, 4V, displacement 4999cm^3, CR=11.5; EU4
Studies:
PM, PN, particle size distribution (pre- and post TWC)
Loading:
0,9
[005.] Catapano F., Di Iorio S., Lazzaro M., Sementa P., Vaglieco B. M.: *Characterization of Ethanol Blends Combustion Processes and Soot Formation in a GDI Optical Engine*, Istituto Motori CNR, SAE International 2013-01-1316
Country:
Europe / Italy

Boundary conditions:

Optical single cylinder engine test bench (two operating points: 2000rpm WOT, 4000rpm partial load – stoichiometric)

Commercial European gasoline and bio-ethanol produced by Grape Pomace.

Ethanol: E20, E50, E85, E100 splash blends with commercial gasoline

Test vehicle/engine:

Single optical cylinder, DI, NA, 4V, displacement 250cm^3, CR=10.5; 16kW @8000rpm, 20Nm @5500rpm

Studies:

PM, PN (in accumulation and nuclei mode), particle size distribution, opacity, HC, NO_x, median diameter of the particle (in accumulation and nuclei mode)

Loading:

0,5 (optical single cylinder engine)

[006.] Li-Wei Jia, Mei-Qing Shen, Jun Wang, Man-Qun Lin: *Influence of ethanol-gasoline blended fuel on emission characteristics from a four-stroke motorcycle engine*, Elsevier – Journal of Hazardous Material A123 (2005) 29-34

Country:

Asia / China

Boundary conditions:

Chassis Dynamometer (ECE15), five steady-state modes

Unleaded gasoline E0 base fuel produced by China National Petroleum Corp

Ethanol: E10 splash blend with base fuel

Test vehicle/engine:

HONDA CG125, Monocylinder, four-stroke, air-cooled, displacement 124cm^3, CR=9.0, 7kW @8000rpm

Studies:

HC, CO, NO_x

Loading:

0,3

[007.] Dedl P., Hofmann P., Geringer B.: *Biobenzin aus Bioraffinerien – Eignung und Potenzial von Alkoholen, Ethern, Furanen, BTL-Benzinen etc. Als Benzinkomponenten*, Institut für fahrzeugantriebe und Automobiltechnik TU Wien, Wien, 2011

Country:

Europa / Austria

Boundary conditions:

Two Engine test bench

Chassis Dynamometer NEDC, CADC (urban, road, motorway)

Base Fuel: super gasoline EN228 with 10.0 %V ETBE

Blend Fuel: Ethanol E10, E25, E50

Test vehicle/engine:

Single cylinder engine: SI, PFI, 4V, displacement 341cm^3, CR=12.1;

four cylinder engine & Test vehicle (FlexFuel): SI, DI, Turbo, 4V, displacement 1396cm^3, CR=10.0, 125kW;

Studies:

HC, NO_x, Efficiency, CO, CO_2, FC

Loading:

0,9

[008.] Turner D., Xu H., Cracknell R.F., Natarajan V., Chen X.: *Combustion performance of bio-ethanol of various blend ratios in a gasoline direct injection engine*, Elsevier – Fuel 90 (2011) 1999-2006

Country:

North America / USA, Europe / United Kingdom

Boundary conditions:

Engine test bench (operating point: 1500rpm @3,4bar IMEP, stoichiometric)

Typical gasoline E0 RON95 base fuel

Ethanol: E10, E20, E30, E50, E85, E100 splash blends with base fuel

Test vehicle/engine:

Single cylinder research engine, SI, 4V, spray-guided DI, 6-hole injector, centrally mounted, displacement 565,6cm^3, CR=11.5

Studies:

Indicated efficiency, HC, CO, NO_x

Loading:

0,9

[009.] Nakata K., Utsumi S., Ota A., Kawatake K., Kawai T., Tsunooka T.: *The Effect of Ethanol Fuel on a Spark Ignition Engine*, Toyota Motor Corporation, SAE International 2006-01-3380

Country:

Asia / Japan

Boundary conditions:

Engine test bench (two operating points: 2000rpm @2bar BMEP, 2800rpm @WOT, stoichiometric)

Gasoline A: RON92 – US regular gasoline

Gasoline B: RON100 – Japanese premium gasoline as reference fuel

Ethanol: E10, E20, E50, E100 splash blends with gasoline A

Test vehicle/engine:

Toyota Corolla engine (1NZ-FE), Inline-4, displacement 1496cm^3, CR=13, 4V, MPI

Studies:

Thermal efficiency, FC, THC, CO_2, NO_x

Loading:

0,9

[010.] Szybist J., Foster M., Youngquist A., et. al.: *Investigation of Knock Limited Compression Ratio of Ethanol Gasoline Blends*, Oak Ridge National Laboratory, Delphi Powertrain Systems, SAE International 2010-01-0619

Country:

North America / USA

Boundary conditions:

Engine test bench

Fuels:

- Regular gasoline (RG): certification gasoline (UTG-91)
- High octane gasoline (HO): certification gasoline (UTG-96)
- Ethanol Blends: (RG & E100 mixed) E10, E50, E85

Test vehicle/engine:

Single-cylinder-engine: VVA, SI, DI, NA, 4V, CR=9.2, 11.85, 12.87

Studies:

Varied CR from 9.2 to 12.87.

Higher CR for Ethanol-Blends to examine high-load knock-limits

Loading:

0,8

[011.] Bielaczyc P., Woodburn J., Klimkiewicz D., Pajdowski P., Szczotka A.: *An examination of the effect of ethanol–gasoline blends' physicochemical properties on emissions from a light-duty spark ignition engine*, *engine*, Elsevier – Fuel Processing Technology 107 (2013) 50-63

Country:

Europe / Poland

Boundary conditions:

Chassis dynamometer (NEDC)

Base fuel: typical European gasoline E5 according EN228

Ethanol: E10, E25, E50 splash blends with E0 (reference fuel)

Test vehicle/engine:

Unmodified European EU5 passenger car, displacement 1200cm^3, SI, 4V

Studies:

THC, CO, CO_2, NO_x, PN, PM, Ethanol, Toluene, NO, Carbonyls, Acetylene

Tailpipe- and pre-TWC- emissions

Loading:

0,8

[012.] Najafi G., Ghobadian B., Tavakoli T., Buttsworth D.R., Yusaf T.F., Faizollahnejad M.: *Performance and exhaust emissions of a gasoline engine with ethanol blended gasoline fuels using artificial neural network*, Elsevier – Applied Energy 86 (2009) 630-639

Country:

Asia / Iran, Australia / Australia

Boundary conditions:

Engine test bench (operating points: 1000-5000rpm @WOT, stoichiometric)

Base fuel: unleaded gasoline E0RON85

Ethanol: E5(RON90), E10(RON92), E15(RON94), E20(RON100) splash blends with E0 (reference fuel); bio-Ethanol from potato waste according ASTM Standard

Test vehicle/engine:

Kia 4 cylinder-inline engine, SOHC, 4V, SI, MPI, displacement 1200cm^3, CR=9.7, 47kW @5200rpm, 103Nm @2750rpm

Studies:

HC, CO, CO_2, NO_x

Loading:

0,8

[013.] Koç M., Sekmen Y, Topgül T., Yücesu H.S.: *The effects of ethanol–unleaded gasoline blends on engine performance and exhaust emissions in a spark-ignition engine*, Elsevier – Renewable Energy 34 (2009) 2101-2106

Country:

Europe / Turkey

Boundary conditions:

Engine test bench (operating points: 1500-5000rpm @WOT, stoichiometric)

Base fuel: unleaded gasoline E0. Ethanol: E20, E85 splash blends with base fuel

Test vehicle/engine:

Hydra research single cylinder engine, PFI, SI, CR=10, 11, displacement 449cm^3, 15kW @5400rpm,

Studies:

FC, CO, HC, NO_x

Loading:

0,6

[014.] Weinowski R., Sehr A., Rütten O., Thewes M., Nijs M.: *Einfluss des Ethanolanteils im Kraftstoff auf das Betriebsverhalten von PKW-Ottomotoren*, 17. Aachener Kolloquium Fahrzeug- und Motorentechnik 2008

Country:

Europe / Germany

Boundary conditions:

Engine test bench (operating points: 2000rpm @3bar/9bar, stoichiometric)

Base fuel: unleaded gasoline E0(RON95)

Ethanol: E10, E20, E40, E60, E85 splash blends with base fuel

Test vehicle/engine:

4 cylinder-inline engine, 4V, SI, TC, DI, displacement 1800cm^3, CR=9.8, calibrated to operate as flex-fuel

Studies:

Efficiency, HC, NO_x, cold start

Loading:

1,0

[015.] Topgül T., Yücesu H.S., Cinar C., Koca A.: *The effects of ethanol–unleaded gasoline blends and ignition timing on engine performanceand exhaust emissions*, Elsevier – Renewable Energy 31 (2006) 2534-2542

Country:

Europe / Turkey

Boundary conditions:

Engine test bench (operating points: 2000rpm @WOT, stoichiometric)

Base fuel: unleaded gasoline E0 (RON99)

Ethanol: E10, E20, E40, E60 splash blends with base fuel

Test vehicle/engine:

Hydra research single cylinder engine, PFI SI, CR=8, 9, 10, displacement 449cm^3, 15kW @5400rpm,

Studies:

FC, CO, HC,

Loading:

0,6

[016.] Hsieh W., Chen R., Wu T., Lin T.: *Engine performance and pollutant emission of an SI engine using ethanol–gasoline blended fuels*; Elsevier – Atmospheric Environment 36 (2002) 403-410; Department of Mechanical Engineering, National Cheng-Kung University & Southern Taiwan University of Technology, Taiwan, 2001

Country:

Asia / Taiwan

Boundary conditions:

Engine test bench

Fuels:

- E0 (ROZ 95)
- E5, E10, E20, E30

Test vehicle/engine:

Engine: MPI, NA, CR=9.5, original ECU, 4V

Studies:

Emissions: CO_2, CO, HC, NO_x

Loading:

0,3

[017.] Schifter I., Diaz L., Rodriguez R., Gómez J.P., Gonzalez U.: *Combustion and emissions behavior for ethanol–gasoline blends in a single cylinder engine*, Elsevier – Fuel 90 (2011) 3586–3592

Country:

North America / Mexico

Boundary conditions:

Engine test bench (operating points: 2000rpm @5,7bar, varying AFR)
Base fuel: unleaded gasoline E0(RON91) according ASTM standards
Ethanol: E6, E10, E15, E20 splash blends with base fuel

Test vehicle/engine:

Single cylinder engine by AVL model 5401, SI, DOHC, 4V, CR=10.5, displacement 500cm^3, 25kW @6000rpm,

Studies:

FC, CO, HC, NO_x

Loading:

0,6

[018.] Yücesu H.S., Topgül T., Cinar C., Okur M.: *Effect of ethanol–gasoline blends on engine performance and exhaust emissions in different compression ratios*, Elsevier – Applied Thermal Engineering 26 (2006) 2272-2278

Country:

Europe / Turkey

Boundary conditions:

Engine test bench (Operating points: 2000, 3500, 5000rpm @WOT, stoichiometric)
Base fuel: unleaded gasoline E0 (RON99) according ASTM standards
Ethanol: E10, E20, E40, E60 splash blends with base fuel

Test vehicle/engine:

Hydra research single cylinder engine, PFI SI, CR=8-13 displacement 449cm^3, 15kW @5400rpm,

Studies:

FC, CO, HC,

Loading:

0,6

[019.] Hsieh W.-D., Chen R.-H., Wu T.-L., Lin t.-H.: *Engine performance and pollutant emission of an SI engine using ethanol–gasoline blended fuels*, Elsevier – Atmospheric Environment 36 (2002) 403-410

Country:

Asia / Taiwan

Boundary conditions:

Engine test bench (operating points: 3000rpm @20%WOT, WOT)
Base fuel: unleaded gasoline E0(RON95) according ASTM standards
Ethanol: E5, E10, E20, E30 splash blends with base fuel

Test vehicle/engine:

Commercial engine – new Sentra GA16DE, SI, DOHC, 4V, CR=9.5, displacement 1600cm^3,

Studies:

FC, CO_2, CO, HC, NO_x

Loading:

0,6

[020.] Nakama K., Kusaka J., Daisho Y.: *Effect of Ethanol on Knock in Spark Ignition Gasoline Engines,* SAE-Paper: 2008-32-0020, 2008, Japan

Country:
Asia / Japan
Boundary conditions:
Engine test bench: single cylinder engine (operating points: 1500, 2000, 3000, 4000 rpm @ partial & full load)
Fuels: Reference Fuel (E0): RON 91 (55% iso-octane, 15% normal heptane, 30% toluene)
Ethanol: reference fuel blended with absolute Ethanol (RON 108) to E3, E10, E20, E40, E60, E80, E100
Test vehicle/engine:
Single-Cylinder Engine, 4V, PFI, 325 cm^3, CR=9.5, 11.0, 13.9, 15.0
Studies:
BSFC, Brake Thermal Efficiency, E0 – E100
Loading:
0,8

[021.] Knoll K., West B., Orban J., et. al.: *Effects of Mid-Level Ethanol Blends on Conventional Vehicle Emissions,* SAE International, SAE: 2009-01-2723, 2009, USA

Country:
North America / USA
Boundary conditions:
Chassis dynamometer (LA 92 drive cycle, also known as Unified Cycle)
Fuels:
- E0: certification gasoline (Indolene)
- Splash blends with E0: E10, E15, E20

Test vehicle/engine:
16 conventional vehicles (model year: 1999 – 2007)
Studies:
NMOG, NMHC, CO, NOx, Fuel Economy, Ethanol, Aldehyde
Loading:
0,9

[022.] Celik M.B.: *Experimental determination of suitable ethanol–gasoline blend rate at high compression ratio for gasoline engine*, Elsevier – Applied Thermal Engineering 28 (2008) 396-404

Country:
Europe / Turkey
Boundary conditions:
Engine test bench (operating points: 2000rpm @WOT, stoichiometric)
Base fuel: unleaded gasoline E0
Ethanol: E25, E50, E75, E100 splash blends with base fuel
Test vehicle/engine:
Lombardini LM250 single cylinder, Si, carburator, displacement 250cm^3, CR=6
Studies:
BSFC, CO_2, CO, HC, NO_x
Loading:
0,4

[023.] Masum B.M., Masjuki H.H., Kalam M.A., Rizwanul Fattah I.M., Palash S.M., Abedin M.J.: *Effect of ethanol–gasoline blend on NOx emission in SI engine*, Elsevier – Renewable and Sustainable Energy Reviews 24 (2013) 209-222

Country:
Asia / Malaysia

Boundary conditions:
detailed literature review
Ethanol: E5, E10, E15, E20
Test vehicle/engine:
-
Studies:
NOx
Loading:
1

[024.] Kumar A., Khatri D.S., Babu M.K.G: *An Investigation of Potential and Challenges with Higher Ethanol-gasoline Blend on a Single Cylinder Spark Ignition Research Engine*, SAE International 2009-01-0137

Country:
Asia / India
Boundary conditions:
Engine test bench (operating points: 1500, 2000rpm @WOT, stoichiometric)
Base fuel: unleaded gasoline E0 (RON95)
Ethanol: E10, E30, E70 splash blends with base fuel
Test vehicle/engine:
AVL single cylinder research engine, displacement $500cm^3$, CR=10
Tests were carried out with and without modifications to the ECU (DOI, ignition timing)
Studies:
CO, HC, NO_x
Loading:
0,9

[025.] Chen L., Stone R., Richardson D.: *A study of mixture preparation and PM emissions using a direct injection engine fuelled with stoichiometric gasoline/ethanol blends*, Elsevier – Fuel 96 (2012) 120–130

Country:
Europe / United Kingdom, Asia / China
Boundary conditions:
Engine test bench (Operating points: 1500rpm @0,5bar MAP and 20°C and 80°C coolant temperature, SOI=280°CAbTDC, stoichiometric)
Base fuel: unleaded gasoline E0 (RON95)
Ethanol: E10, E20, E50, E70, E85 splash blends with base fuel
Test vehicle/engine:
Optical single cylinder research engine, displacement $562cm^3$, CR=11, 4V, DISI
Studies:
PM, PN, particle size distribution
Loading:
0,9

[026.] Yüksel F., Ceviz M.A.: *Effects of ethanol–unleaded gasoline blends on cyclic variability and emissions in an SI engine*, Elsevier – Applied Thermal Engineering 25 (2005) 917-925

Country:
Europe / Turkey
Boundary conditions:
Engine test bench (operating points: 2000rpm @WOT, MBT timing, rich)
Base fuel: unleaded gasoline E0
Ethanol: E5, E10, E15, E20 splash blends with base fuel

Test vehicle/engine:
Fiat engine, displacement 1581cm^3, carburator, CR=9,2, SI, 4-stroke
Oil-temperature=50°C, coolant temperature=70°C, 62kW@5800rpm
Studies:
CO, HC, NO_x
Loading:
0,3

[027.] Karavalakis G., Short D., Hajbabaei M., Vu D., Villela M., Russel R., Dubin T., Asa-Awuku A.: *Criteria Emissions, Particle Number Emissions, Size Distributions, and Black Carbon Measurements from PFI Gasoline Vehicles Fuelled with Different Ethanol and Butanol Blends*, SAE International 2013-01-1147

Country:
North America / USA
Boundary conditions:
Chassis dynamometer (FTP-75, UC)
Base fuel: E10 RON93
Ethanol: E15, E20
Test vehicle/engine:
Three light duty vehicles with TWC
- 2007 Honda Civic 1.8l, 4-cylinder, PFI (BIN5/ULEV)
- 2007 Dodge Ram 5.7l, 8-cylinder, PFI (BIN4/LEV2)
- 2012 Toyota Camry 2.5l, 4-cylinder, PFI (BIN5/PZEV)

Studies:
THC, NMHC, CH_4, CO, NO_x, CO_2, Fuel economy, Carbonyls, PN, Black Carbon
Loading:
0,9

[028.] Stein R.A., Anderson J.E., Wallington T.J.: *An Overview of the Effects of Ethanol-Gasoline Blends on SI Engine Performance, Fuel Efficiency, and Emissions*, SAE International 2013-01-1635

Country:
North America / USA
Boundary conditions:
Very detailed study on the use of ethanol in modern SI engines
Chassis dynamometer (FTP-phase1)
Test vehicle/engine:
7 passenger cars (1x MY2006, 6x MY2007 FFV‘s)
Ethanol: E6, E32, E59, E85
Studies:
Carbonyls, Benzene
Loading:
1

[029.] Storey J.M., Barone T., Norman K., Lewis S.: *Ethanol Blend Effects on Direct Injection Spark-Ignition Gasoline Vehicle Particulate Matter Emissions*, SAE International 2010-01-2129

Country:
North America / USA
Boundary conditions:
Chassis dynamometer (FTP-75, US06)
Base fuel: E0 (RON97) as Federal certification fuel
Ethanol: E10, E20 splash blends with base fuel (supplier: Gage products)

Test vehicle/engine:
US legal stoichiometric turbocharged DISI vehicle (2007 Pontiac Solstice, displacement 2l)
Studies:
NMHC, CO, NO_x, fuel economy, carbonyls, benzaldehyde, PM
Loading:
0,9

[030.] Delgado R., Paz S.: *Effect of Different Ethanol-Gasoline Blends on Exhaust Emissions and Fuel Consumption*, SAE International 2012-01-1273
Country:
Europe / Spain
Boundary conditions:
Chassis dynamometer (NEDC)
Base fuel: E0 (RON96)
Ethanol: E5 splash blend with base fuel, E10 (RON97), E85 (RON107)
Test vehicle/engine:
Two test vehicles
- EU4 E10-vehicle (investigations: E0, E5splash, E10), displacement 1,4l
- EU4 FFV-vehicle (investigations: E0, E85), displacement 1,8l

Studies:
THC, NMOG, CH_4, CO, NO_x, CO_2, fuel consumption, carbonyls, PM, ethanol
Loading:
0,9

[031.] He B., Wang J., Hao J., Yan X., Xiao, J.: *A study on emission characteristics of an EFI engine with ethanol blended gasoline fuels,* Elsevier –Atmospheric Environment 37, S. 949-957, 2002
Country:
Asia / China
Boundary conditions:
Engine test bench with catalyst, different load points (idle to WOT)
Base fuel: E0 (RON92)
Ethanol: E10, E30 splash blends with base fuel
Test vehicle/engine:
MPI, NA, CR=8,2
Studies:
Engine-out & Tailpipe: THC, NOx, CO, BSFC, BSEC, Ethanol, Acetaldehyde
Loading:
0,8

[032.] Bäcker H., Tichy M., Achleitner E., Pischinger S., Lang O., Habermann K., Kreber-Hortmann K.: *Untersuchung des Ethanolmischkraftstoffs E85 im geschichteten und homogenen Magerbetrieb mit piezoaktuierter A-Düse*
Country:
Europe / Germany
Boundary conditions:
Single Cylinder Engine, E0 and E85
Test vehicle/engine:
Single Cylinder Engine (Siemens), displacement 500cm^3, DI, NA, 4V, central Position Injector and Spark Plug
Studies:
HC, NOx, CO, Smoke Number @ 2000 rpm, λ=1 for IMEP=2,7bar and WOT

Loading:
1,0

[033.] List R., Hofmann P., Urbanek M.: *The effects of Bio-Ethanol Mixtures on the SI-Engine Operation,* Vienna University of Technology

Country:
Europe / Austria

Boundary conditions:
Engine Test Bench @ 2 part load points
Base Fuel: unleaded gasoline (RON95)
Splash Blends: E10, E50, E85, E100

Test vehicle/engine:
MPFI

Studies:
HC, CO, NOx, BSFC, BSEC @ 2000rpm/2bar and 4000rpm/5bar

Loading:
1,0

[034.] Wallner T., Ickes A., Lawyer K., Ertl D., Williamson R.: *Higher Alcohols in Multi-Component Blends with Gasoline – Experimental and Analytical Assessment,* 14. Tagung: "Der Arbeitsprozess des Verbrennungsmotors", 24.-25. September 2013, Graz

Country:
North America / USA

Boundary conditions:
Engine Test Bench @ 5 load points
Base Fuel: certification gasoline (EEE) RON 97,1
Ethanol: E50, E77 (splash blends with EEE)

Test vehicle/engine:
NA, DI, 2,36ccm, CR=11,3 (Hyundai Theta II)

Studies:
Efficiency, Fuel Consumption, CO_2, CO, NO_x, HC @ 1500rpm/2,62bar, 4bar, 8bar, 3000rpm/4bar, 8bar

Loading:
1,0

[035.] i L., Liu Z., Wang H., Deng B., Xiao Z., Wang Z., Gong C., Su Y.: *Combustion and Emission of Ethanol Fuel (E100) in a small SI Engine*, SAE 2003-01-3262

Country:
Asia / Shanghai

Boundary conditions:
Engine Test Bench @ different air fuel ratio, different rpm, different load
Base Fuel: Gasoline, E100 (100% Ethanol)

Test vehicle/engine:
Four stroke, air cooled 125cc SI engine for motorcycles with a single point electronic gasoline fuel injection system modified with an ethanol fuel injection system

Studies:
The effect of fuel injection duration, spark timing, excess air/fuel ratio on engine power output, fuel and energy consumption, engine exhaust emission levels

Loading:
0,9

[036.] Oh H., Bae C., Min K.: *Spray and Combustion Characteristics of Ethanol Blended Gasoline in a Spray Guided DISI Engine under Lean Stratified Operation*, SAE International 2010-01-2152

Country:
Asia / Korea
Boundary conditions:
Engine test bench (Operating point: 1200rpm @ EOI-var and 80°C coolant temperature, no EGR, constant energy of 473,5 J/stroke, EOI=2°CA before first misfire occur)
Base fuel: unleaded gasoline E0 (RON96,4)
Ethanol: E25, E50, E85 splash blends with base fuel
Test vehicle/engine:
Single cylinder, spray guided DISI, CR=12, central mounted piezo injector, displacement 499cm^3
Studies:
Combustion efficiency, HC, NOx, FSN
Loading:
0,9
[037.] Gogos M., Savvidis D., Triandafyllis J.: *Study of the Effects of Ethanol Use on a Ford Escort Fitted with an Old Technology Engine,* SAE International 2008-01-2608
Country:
Europe / Greek
Boundary conditions:
Chassis dynamometer @ different speeds (30, 50, 90km/h) @ WOT
Base Fuel: LRP (Lead Replacement Petrol)
Ethanol: E10, E20, E50 splash blends
Test vehicle/engine:
Ford Escort 1.3, odometer reading 170000km, 4 Cylinders, 1297ccm, CR=9,3
Studies:
FC, SFC, NO_x, CO, CO_2, O_2, HC
Loading:
0,6 (Car without Close-Loop Lambda controller)
[038.] Nematizade P., Ghobadian B., Ommi F., Najafi G.: *Performance and exhaust emissions of a spark ignition engine using G-Series and E20 fuels,* International Journal of Automotive Engineering and Technologies, ISSN 2146-9067, 2013
Country:
Asia / Iran
Boundary conditions:
Engine test bench (WOT from 2000rpm to 4000rpm)
Base fuel: Gasoline
Ethanol: E20 splash blend (20v% Ethanol and 80v% Base fuel)
Test vehicle/engine:
4 cylinder engine, CR=9,25, Displacement=1761ccm
Studies:
FC, SFC, HC, CO, CO_2
Loading:
0,5
[039.] Beer T., Grant T.: *Life-cycle analysis of emissions from fuel ethanol and blends in Australian heavy and light vehicles,* Journal of Cleaner Production No. 15 (2007), 833-837
Country:
Australia / Victoria

Boundary conditions:
Literature study
Base fuel: Gasoline (Premium unleaded petrol)
Ethanol: E10, E85
Studies:
CO_2, PM10, NO_x, HC, CO
Loading:
0,8

[040.] Urbanek M., Hofmann P., Geringer B.: *Vehicle use of ethanol blends – Emission performance and potential for CO_2-Reduction,* 12th EAEC European Automotive Congress Bratislava, 2009

Country:
Europa / Austria
Boundary conditions:
Chassis dynamometer (NEDC, CADC)
Base fuel: RON95
Ethanol: E5, E10, E85, E100
Test vehicle/engine:
Conventional and Flex Fuel Vehicles
Studies:
HC, CO, NO_x, CO_2
Loading:
1,0

[041.] Pang X., Mu Y., Yuan J., He H.: *Carbonyls emission from ethanol-blended gasoline and biodiesel-ethanol-diesel used in engines,* Atmospheric Environment 42 P. 1349-1358, 2008

Country:
Asia / China
Boundary conditions:
Engine Test bench (different load points: WOT @ 1200-2800 and 1800 @ different loads)
Base fuel: RON93 (Chinese Market)
Ethanol: E10
Test vehicle/engine:
4 Cylinder, 1.993 ccm, CR=9,5, 76 kW, 155 Nm
Studies:
HC, CO, NO_x, SFC
Loading:
0,5

[042.] Eichelseder H., Grabner P., Eckhard G..: *Potential of E85 Direct Injection for Passenger Car Application,* FVV Frühjahrstagung 2012, Bad Neuenahr 2012

Country:
Europa / Austria
Boundary conditions:
Single Cylinder Research Engine
E0 (RON95), E85
Test vehicle/engine:
Single Cylinder Test Engine, CR=9 to 13.5
Studies:
HC, CO, NO_x, PM, PN

Loading:
0,9
[043.] Song C., Zhang W., Pei Y., Fan G., Xu G.: *Comparative effects of MTBE and ethanol additions into gasoline on exhaust emissions,* Atmospheric Environment 40 P. 1957-1970, 2006
Country:
Asia / China
Boundary conditions:
Engine test bench /various loads and speeds)
Base Fuel: RON92,5
Ethanol: E2, E5, E7, E10
Test vehicle/engine:
4 Cylinder, PFI, CR=7,6
Studies:
CO, HC, NO_x, Benzene, Aldehyde
Loading:
0,6
[044.] Jung H., Shelby M., Newman C., Stein R.: *Effect of Ethanol on Part Load Thermal Efficiency and CO_2 Emissions of SI Engines,* SAE International 2013-01-0254
Country:
North America / USA
Boundary conditions:
Engine Test bench (1500 & 2000 rpm @ Part Load) @ λ=1
Base Fuel: RON90.1
Ethanol: E85
Test vehicle/engine:
V8, Turbo, DI, VCT, 4951ccm, CR = 9,5
Studies:
BTE, BSFC, CO, HC, CO
Loading:
1,0
[045.] Sandquist H., Karlsson M., Denbratt I.: *Influence of Ethanol Content in Gasoline on Speciated Emissions from a Direct Injection Stratified Charge SI Engine,* SAE International 2001-01-1206
Country:
Europe / Sweden
Boundary conditions:
Engine Test bench (1000, 2000, 3000rpm @ Part Load)
Base Fuel: RON95
Ethanol: E5, E10, E15
Test vehicle/engine:
4 Cylinder, DI, CR=12,5, 1834ccm
Studies:
HC, Smoke, NO_x, CO, SFC, Acetaldehyde, Formaldehyde, Ethanol
Loading:
0,9
[046.] Al-Farayedhi A., Al-Dawood A., Gandhidasan P.: *Effects of Blending Crude Ethanol with Unleaded Gasoline on Exhaust Emissions of SI Engine,* SAE International 2000-01-2857

Country:
Asia / Saudi Arabia
Boundary conditions:
Engine Test bench (
Base Fuel: RON85
Ethanol: E10, E15, E20
Test vehicle/engine:
6 Cylinder, 2960ccm, CR=9,2
Studies:
CO, HC, NO_x
Loading:
0,5

[047.] Urbanek M.: *Der Einfluss von flüssigen und gasförmigen alternativen Kraftstoffen auf die Emissionen von Kraftfahrzeugen bei der ottomotorischen Verbrennung,* Dissertation TU Wien Institut für Fahrzeugantriebe und Automobiltechnik, 2010

Country:
Europe / Austria
Boundary conditions:
Chassis dynamometer (various vehicles (conventional and Flex Fuel)
Base Fuel: RON95
Ethanol: E5, E10, E20, E50, E65, E85
Test vehicle/engine:
Various vehicles (conventional and Flex Fuel
Studies:
CO, HC, NO_x, CO_2
Loading:
1,0

[048.] List R.: *Potenzialbewertung von Benzin-Ethanol Kraftstoffmischungen im ottomotorischen Betrieb,* Disserttation TU Wien Institut für Fahrzeugantriebe und Automobiltechnik, 2008

Country:
Europe / Austria
Boundary conditions:
Engine test bench (one PFI and one DI engine)
Base Fuel: RON95
Ethanol: E10, E20, E50, E85, E100
Test vehicle/engine:
- 4 Cylinder, PFI, 1598ccm, CR=10,5
- 4 Cylinder, DI, Turbo, 1396ccm, CR=10,0

Studies:
SFC, SEC, CO, NO_x, HC
Loading:
1,0

[049.] Teiner P.: *Potenzialvergleich der Laserzündung zur Funkenzündung beim Einsatz von Ethanolkraftstoffen in einem 1-Zylinder Ottomotor,* Diplomarbeit TU Wien Institut für Fahrzeugantriebe und Automobiltechnik, 2007

Country:
Europe / Austria
Boundary conditions:
Engine Test bench

Base Fuel: RON95
Ethanol: E5, E10, E22, E50, E85, E100
Test vehicle/engine:
1 Cylinder Research Engine, CR=11,12, 512ccm
Studies:
CO, HC, NO_x
Loading:
0,9

[050.] Dedl P., Hofmann P., Geringer B., Karner D., Lohrmann M.: *Suitability and Potential of Alternative Fuels fort he Use in Spark Ignition Engines,* 8th International Colloquium for Fuels, 2011

Country:
Europe / Austria
Boundary conditions:
Chassis dynamometer
Base Fuel: RON95
Ethanol: E10, E25, E50
Test vehicle/engine:
Conventional vehicle equipped with turbocharged, direct fuel injection engine
Studies:
HC, CO, CO_2, FC
Loading:
1,0

[051.] Yao Y., Tsai J., Wang I.: *Emissions of gaseous pollutant motorcycle powered by ethanol-gasoline blend,* Applied Energy 102 P. 93-100, 2013

Country:
Asia / Taiwan
Boundary conditions:
Chassis dynamometer (two motorcycles equipped with carburettor and PFI)
Base Fuel: RON95
Ethanol: E10, E15, E20, E30
Test vehicle/engine:
two motorcycles equipped with carburettor and PFI, 125ccm
Studies:
CO, HC, NO_x
Loading:
0,4

[052.] Graham L., Belisle S., Baas C.: *Emissions from light duty gasoline vehicles operating on low blend ethanol gasoline and E85,* Atmospheric Environment 42 P. 4498-4516, 2008

Country:
North America / Canada
Boundary conditions:
Chassis dynamometer (four-phase implementation of the FTP was used)
Base Fuel: RON86
Ethanol: E10 tailor blend, E20 tailor blend and E10 splash blend
Test vehicle/engine:
2002 Chrysler Caravans, 2004 Chrysler Sebrings
Both are equipped with Flex Fuel technology
Studies:
CO, NO_x, HC, Benzene, Acetaldehyde, Formaldehyde

Loading:
0,8

7.2 Further literature

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4. **Golloch, R.** *Downsizing bei Verbrennungsmotoren.* Berlin, Heidelberg, New York : Springer-Verlag, 2005. ISBN 3-540-23883-2.

5. **Martin, C.** *Innovative Zündsysteme für hochaufgeladene Downsizingmotoren, Diplomarbeit am IFA, TU-Wien.* Wien : s.n., Dezember 2011.

6. **Korte, V., et al.** *Effizientes Downsizing für zukünftige Ottomotoren.* s.l. : MTZ - Motortechnische Zeitschrift, 05/2011 72.Jahrgang.

7. **Geringer, B.** *Verbrennungskraftmaschinen Grundzüge. Skriptum zur Vorlesung.* TU Wien : s.n., 2006.

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10. **Dedl, P., Hofmann, P. and Geringer, B.** *Untersuchung des Volllastpotenzials unterschiedlicher Alkoholkraftstoffe für den ottomotorischen Einsatz im MPFI Saugmotor und DI Turbomotor.* 13. Tagung "Der Arbeitsprozess des Verbrennungsmotors", Graz : s.n., 09/2011.

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14. **Bobicic, N., et al.** *Einfluss von Ethanolkraftstoff auf die Vorentflammungsneigung von hochaufgeladenen Ottomotoren.* Tagung Berlin, Ottomotorisches Klopfen, Irrreguläre Verbrennung : s.n., 26.11.2010.

15. **Amann, M., Metha, D. and Alger, T.** *Engine Operating Condition and Gasoline Fuel Composition Effects on Low-Speed Pre-Ignition in High-Performance Spark Ignited Gasoline Engines.* Southwest Research Institute : SAE, 2011-01-0342.

16. **Hamilton, L. J., et al.** *Pre-Ignition Characteristics of Ethanol and E85 in a Spark Ignition engine.* U.S. Naval Academy : SAE, 2008-01-0321.

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18. **Nakata, K., et al.** The Effect of Ethanol Fuel on a Spark Ignition Engine. s.l. : SAE International 2006-01-3380, 2006.

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29. **Karavalakis, G., et al.** Criteria Emissions, Particle Number Emissions, Size Distributions, and Black Carbon Measurements from PFI Gasoline Vehicles Fuelled with Different Ethanol and Butanol Blends. s.l. : SAE International 2013-01-1147, 2013.

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