# EXHAUST EMISSION REDUCTION PROBLEMS OF INTERNAL COMBUSTION ENGINES FUELED WITH BIOFUELS

**Antoni Jankowski**
*Institute of Aeronautics, BK*
*Al. Krakowska 110/114, 02 - 256 Warszawa, Poland, ajank@ilot.edu.pl*
**Alexander Sandel**
*The National Automotive Center, Warren, MI 48397-5000, USA*
*sandela@tacom.army.mil*

***Abstract***

*Automotive engines are bigger one-greenhouse gas emitters. Continuous increase of $CO_2$ contains, and other greenhouse gases, in atmospheric air cause activity to limit these emissions. The Kyoto protocol duties is to states that will limit these emissions. Introduction of biofuels to fueling of automotive engines is the one method to decrease emissions of greenhouse gases. The $CO_2$ from biofuels, is emitted during combustion and absorbed during growth of tree end plants. The results of biofuels applying in viewpoint of exhaust emissions are presented in this paper. The most promising of biofuels for fueling of internal combustion engines are esters of vegetable oils and ethanol. These biofuels can be applied as blends or sole fuels. Ethanol can be used for fueling spark ignition engines and compression ignition engines but vegetable oil esters can be used in compression ignition engines only. The paper describes an increase of $CO_2$ content in atmospheric air and advantages and concerns from using of biofuels.*

## 1. Introduction

The initial impetus for applying ethanol as an alternative fuel to gasoline in the oil embargo of 1973 caused oil prices to increase rapidly, creating much concern over the security of energy supplies. The second impact was the 1997 Kyoto Conference on Climate Change, when many industrialized countries have adopted strategies to reduce $CO_2$ – emissions, and the Buenos Aires Conference of November 1998, when the strategy on fighting global warming was elaborated. The conclusions made based on both conferences are as follows: global warming is made by man-made climatic gases, $CO_2$ emissions are a consequence of energy production form fossil recourses, rational use of energy is of primary importance, sustainable use of renewable energy has a high potential in combating global warming, worldwide energy production will increase and in consequence $CO_2$ emission.

The United States provisionally committed to reduce its GHG emissions by 7% by around 2012 relative to its 1990 GHG emissions level. Under the business-as-usual case, the GHG emissions from the transportation sector which account for 29% of the total GHG emissions, will continue to increase because the number of vehicle miles traveled will rise. Substantial reductions in USA transportation GHG emissions per vehicle mile will traveled will be necessary to achieve the Kyoto goal. Using ethanol to fuel motor vehicles helps reduce GHG emissions. Fuel ethanol that is produced in USA from corn has been used in gasohol or oxygenates of up to 10% by volume since the 1980. These gasoline fuels contain ethanol at concentration of 10% by volume. The result is that transportation sector in USA consumes now about 4.5 billion liters of ethanol annually. In this form, about 1% of total consumption of gasoline in USA is ethanol. Recently domestic automakers have announced plan to produce a significant number of flexible fueled vehicles (FFV) that can apply an ethanol blend E85 (85% of ethanol and 15% of gasoline by volume) alone or in any combination with gasoline. Production of a significant number of such vehicles would significantly increase the potential for ethanol contains fuels.

The UE - member states have decided upon reduction by 8.1% considering 1990 emissions for 2012. This goal can only be realized with an important share of renewable, where biomass plays a major role. In 2002 developing cleaner and more energy efficient transport solutions as a priority to foster sustainable development, the European Commission set a political objective of 20% substitution by new or alternative fuels in the road transport sector in the year 2020. The three types of alternative motor fuels that could potentially reach a significant market are: biofuels (coming to maturity up to 2010), natural gas (coming to maturity in the years 2010 - 2015) and hydrogen (coming to maturity in the years 2015 - 2020). These tasks will be realized as a priority in Framework Program of UE in the years following 2003, because all analysis show clearly that the role of fossil fuels will decrease - not only for environmental concern, but due to operation of actually known reserves. Increase of global concentration of anthropogenic carbon dioxide in the atmosphere is shown in Fig. 1. Development of global carbon dioxide emission in the World in 1995 - 2015 years is presented in Fig.2. In Fig.3 real and forecasted changes of exhaust emissions in 1990 - 2020 are presented. Currently two types of biofuels are accepted as a alternative fuels for fueled automotive engines: biodiesel from vegetable oils which is applied in compression ignition engines and ethanol fuels which can be applied in spark ignition engines or in compression ignition engines (Diesel engines). In Fig.4 estimated lifetime of recoverable fossil fuel reserves in the Earth is shown.

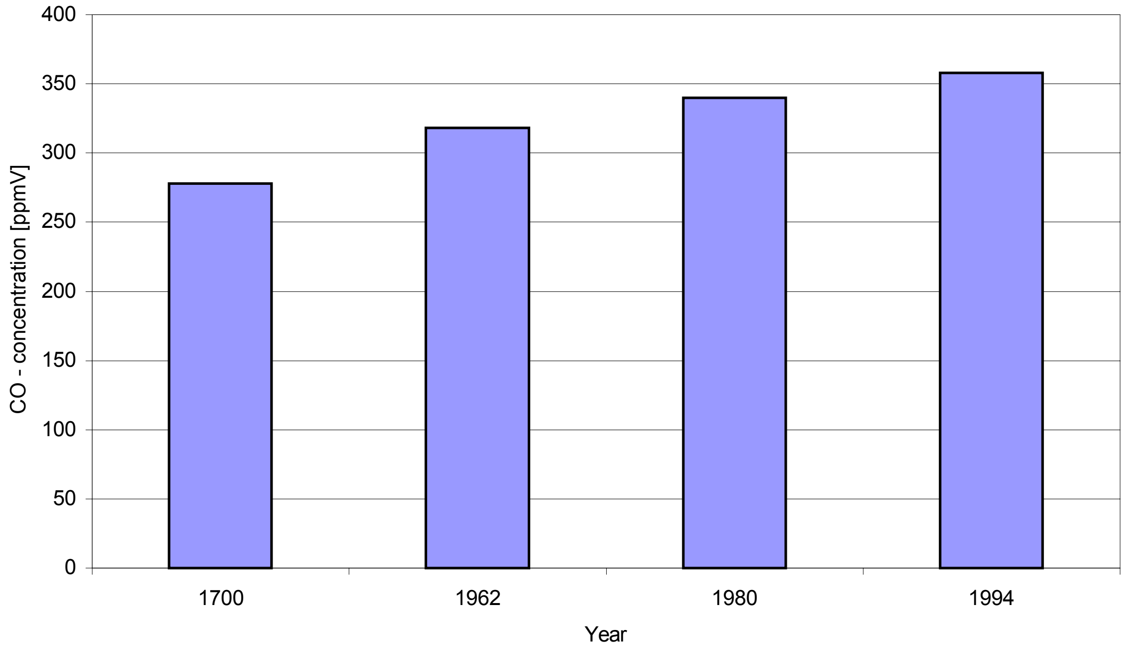


*Fig. 1. Increase of concentration anthropogenic of global carbon dioxide in the atmosphere*

Diesel fuel from vegetable oils is produced from chemically modified triglicerydes in form of monoalcohol fatty acid ethers, mainly methylesters. Row materials in the EU are mainly rapeseed oil, but promising trials are conducted with the use of sunflower oil in France and Spain, soybean oil in USA and Italy, palm oil in South East Asia and frying oils in Austria and Germany. Biodiesel can be used as a sole fuel or as a blend with Diesel oil. The provisional requirements for biodiesel properties in Europe are shown in Table 1.

Ethanol fuels are produced by fermentation from sugar containing vegetable materials (potato, wheat, rye, corn, sugarcane etc.). Materials rich in starch can be fermented after enzymatic or chemical transformation of starch into glucose.

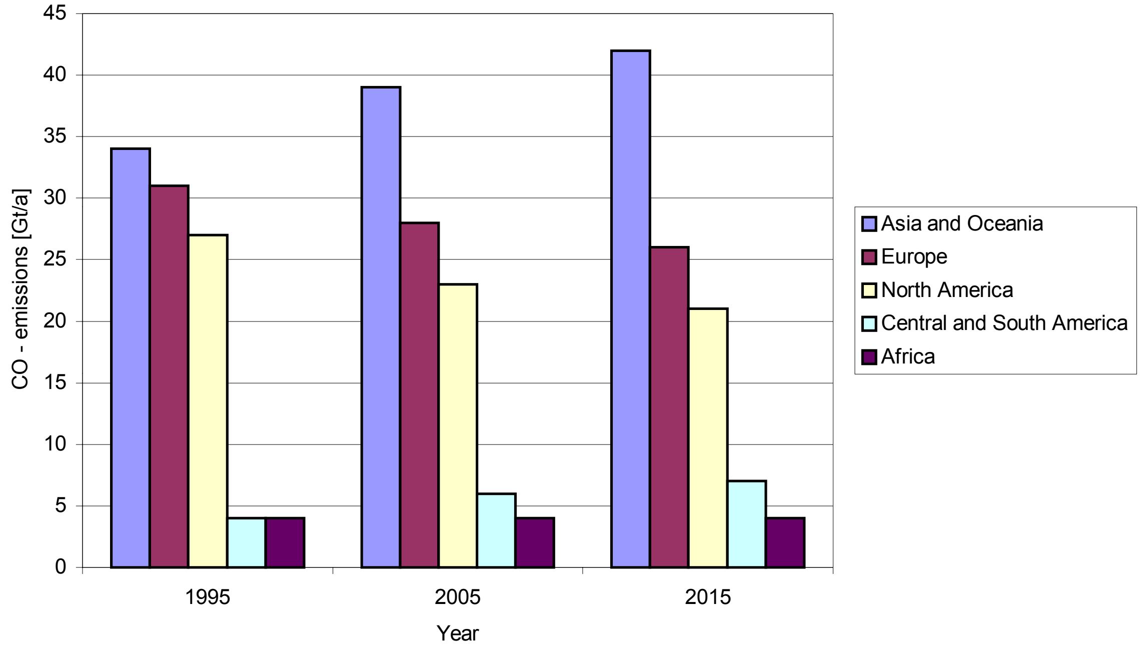


*Fig. 2. Development of global carbon dioxide emissions in the World in 1995-2015 years*

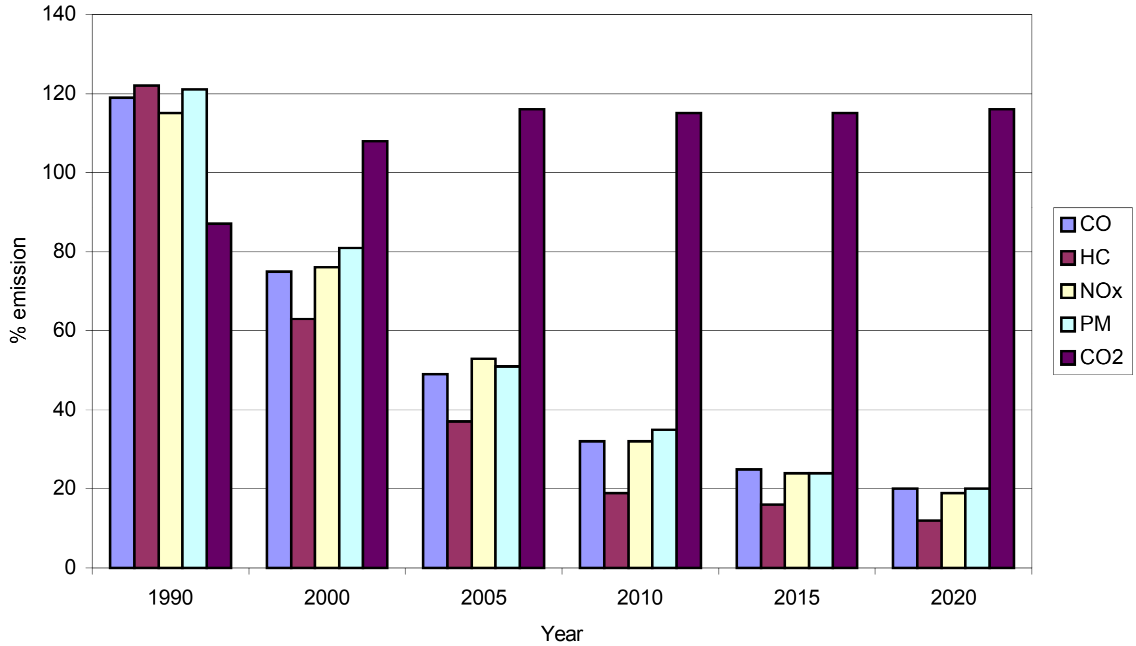


*Fig. 3. Relative changes of exhaust emissions in European transport in 1990-2020 years in relation to 1995 year (100%)*

Cellulose materials (wood, straw, etc.) represent a large source for ethanol production. In this case, an additional step of hydrolysis is necessary. Ethanol can be applied as a blend with gasoline or straight fuel. If dehydrated (100%) ethanol is applied the engine requires adoption, but blends of 5% to 24% alcohol and gasoline are applied without adaptation.

Ethanol is oxygenate and octane improver. Ethanol derived product ETBE (ethyl-tertio-butyl-ether) is etherified ethanol. ETBE may replace MTBE as an oxygenate in gasoline. Adding up to 15% ETBE or MTBE does not require engine modifications. In Table 2. the properties of methanol, ethanol, gasoline and E85 (blend of 85% ethanol with gasoline) are compared.

The main disadvantage of biofuels is their costs, which is 2 to 3 times higher than the cost of mineral oil fuels. Substantial incentives are necessary in order to compete on the free market. But main advantages are connected with environmental effects (greenhouse gas emissions).

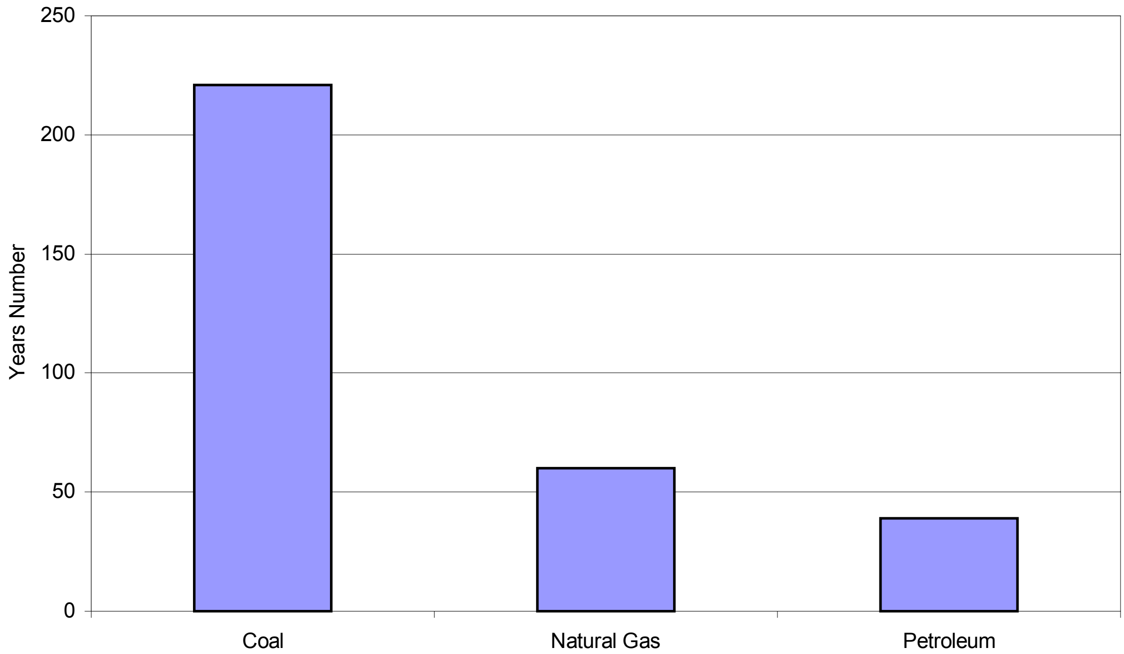


*Fig. 4. Estimated Lifetime (Yrs.) of Recoverable Fossil Fuel Reserves for the World*

## 2. Influence of alcohols on engine performance

Limited crude-oil reserves in the world, in combination with the availability of various other raw materials, which can be used as fuels, and environment protection problems resulted in using of biomass for production and applying alcohols and esters of plant oils as automotive fuels. The alcohols and plant oil esters are used as a component of Diesel oil or as a straight fuel for Diesel engines. Neat alcohols can be used as a component of gasoline or as a straight fuel for spark ignition engine. These fuels are renewable and they can produce lower atmospheric pollution than petroleum fuels. They are potentially $CO_2$ neutral.

Ethanol and methanol, as well as products derived from these alcohols, such as ethers, are under consideration or in use as alternative fuels or as a component of the fuels. Methanol offers very low particulate emissions but the problems are their toxicity, low energy density, low cetane number, high aldehyde emissions, and harmful influence on materials used in engine production. Ethanol seems to be the best candidate as a sole fuel as a component of either gasoline or Diesel oil. Up till now ethanol was recognized only as a component of gasoline and not as a component of Diesel oils. The properties of ethanol enable applying it also as a component of Diesel oil. The potential of oxygenates as means of achieving zero net $CO_2$ renewable fuel, has resulted in considerable interest in the production and application of ethanol. In many countries such as the United States of America, Canada, Australia, Brazil, South Africa, Denmark, Sweden and others ethanol programs are realized.

The research in ethanol programs is directed to identify factors that could influence engine performance and exhaust emissions. Understanding of these factors is necessary for the interpretation of the test results. Increased alcohol concentration in gasoline causes decrease of equivalence ratio and has a direct effect on the rate at which the various chemical reaction processes in the combustion chamber can take place. Thus, the equivalence ratio influences the timing, rate, and duration of combustion. Ignition timing has a significant effect on temperatures and pressures in the combustion chamber which influences the course and rates of various chemical reactions.

*Table 1. Properties of Biodiesel in Europe*

| | |
|---|---|
| *Specific gravity* | *0.88* |
| *Viscosity @ 20$^o$C (centistokes)* | *7.5* |
| *Cetane Index* | *49* |
| *Cold Filter Plugging Point ($^o$C)* | *-12* |
| *Net Heating Value (kilojoules per litter)* | *33.300* |

*EN 14214-2001 FAME table 3b - provisional only as at 2001*

| Property | Unit | Limits | | Test method |
|---|---|---|---|---|
| | | minimum | maximum | |
| Ester content | % (m/m) | 96.5 | | prEN 14103 |
| Density at 15$^o$C | kg/m | 860 | 900 | EN ISO 3675<br>EN ISO 12185 |
| Viscosity at 40$^o$C | mm$^2$/s | 3.5 | 5.0 | EN ISO 3104 |
| Flash point | $^o$C | above 101 | - | OSO/CD 3679 |
| Sulfur content | mg/kg | - | 10 | |
| Carbon residue (on 10% distillation residue) | % (m/m) | - | 0.3 | EN ISO 10370 |
| Cetane number | | 51.0 | | EN ISO 5165 |
| Sulfated ash content | % (m/m) | - | 0.02 | ISO 3987 |
| Water content | mg/kg | - | 500 | EN ISO 12937 |
| Total contamination | mg/kg | - | 24 | EN 12662 |
| Copper strip corrosion (3h at 50$^o$C) | rating | class 1 | | EN ISO 2160 |
| Thermal stability | | | | |
| Oxidation stability 110$^o$C | hours | 6 | - | prEN 14112 |
| Acid value | mg KOH/g | | 0.5 | prEN 14104 |
| Iodine value | | | 120 | prEN 14111 |
| Linolenic acid methyl ester | % (m/m) | | 12 | prEN 1403 |
| Polyunsaturated (minimum 4 double bonds) methyl esters) | % (m/m) | | 1 | |
| Methanol content | % (m/m) | | 0.2 | prEN 14110 |
| Monogliceride content | % (m/m) | | 0.8 | prEN 14105 |
| Diglyceride content | % (m/m) | | 0.2 | prEN 14105 |
| Triglyceride content | % (m/m) | | 0.2 | prEN 14105 |
| Free glycerol | % (m/m) | | 0.02 | prEN 14105<br>prEN 14106 |
| Total glycerol | % (m/m) | | 0.25 | prEN 14105 |
| Alkaline metals (Na+K) | mg/kg | | 5 | prEN 14 108<br>prEN 14109 |
| Phosphorus content | mg/kg | | 10 | prEN 14107 |

The heat of combustion of alcohols is significantly lower than that of gasoline. The stoichiometric air/fuel ratio of alcohols is also significantly lower. Because a spark ignition engine operates at constant equivalence ratio, specific fuel consumption can be expected to rise, as the alcohol concentration in the fuel blend is increased. Power output of an engine is largely a function of the amount of heat can be released in the combustion chamber which is determined by the amount of the air available and the properties of fuel. Despite the lower heat of alcohols combustion, their lower stoichiometric air/fuel ratio enables equivalent or greater amounts of energy to be released for a given amount of air, this theoretically enabling increased power output, should air/fuel ratio be optimal. The amount of energy that can be released per unit mass of air is proportional to the heat of combustion divided by the stoichiometric air/fuel ratio, and in the case of alcohols is higher than that for gasoline.

*Table 2. Properties of ethanol, methanol, gasoline, and E85*

| Property | Methanol | Ethanol | Gasoline | E85 |
|---|---|---|---|---|
| Formula | CH3OH | C2H5OH | C4 to C12 | |
| Main constituents | 38C 12H 50O | 52C 3H 35O | 85-88C 12-15H | 57C 13H 30O |
| Octane (RON+MON)/2 | 100 | 98-100 | 86-94 | 96 |
| Lower heating Btu/Ib | 8570 | 11500 | 18000-19000 | 12500 |
| Gallon (US) equiv. | X 1.8 | X 1.5 | 1 | X 1.4 |
| Mpg vs. gasoline | 55% | 70% | 100% | 72% |
| Reid Vapor Pressure | 4.6 | 2.3 | 8-15 | 6-12 |
| Ignition Point % fuel in air<br>Temperature $^{o}$F | 7-36<br>800 | 3-19<br>850 | 1-8<br>495 | |
| Specific Gravity | 0.796 | 0.794 | 0.72-0.78 | 0.78 |
| Cold weather start | poor | poor | good | good |
| Vehicle power | + 4% | + 5% | 0 | + 3-5% |
| Stoichometric ratio | 6.45 | 9 | 14.7 | 10 |
| Other properties | | | | |
| Molecular Weight | 32.1 | 46.1 | | |
| Boiling Point $^{o}$C | 64 | 78 | | |
| Freezing Point $^{o}$C | 97.7 | -114 | | |
| Vapour Pressure at 20$^{o}$C | 96mm Hg | 46mm Hg | | |
| Flash Point $^{o}$C | 11.1 | 12.7 | | |

Alcohols have the potential of increasing engine power output but unfortunately also increasing specific fuel consumptions. The water content of the combustion products increases significantly with alcohol or oxygen concentration. The increased water contents results in an increase in the specific heat of the combustion products. The increased charge mass and specific heat can significantly reduce temperatures throughout the cycle, which would tend to reduce $NO_x$ emissions. However, reduction in the duration of combustion can result in an increase in peak pressures and temperatures. Increased pressure and temperature can result in increased NOx and HC emissions. The addition of alcohols to gasoline could also influence performance and emissions by changing the rate of combustion and therefore the pressure and temperature time histories. The important properties of alcohols are their volatility and evaporative. The addition of alcohols to gasoline can change the properties this blend, reducing the evaporation mainly of the heavier hydrocarbons components and decreasing the temperature of charge in combustion chamber. The cooling effect can be expected to have a beneficial effect on power output and $NO_x$ emissions.

The presence of alcohols in blends with gasoline could thus influence exhaust emissions through the following mechanisms:

- Reduced stoichiometric air/fuel ratio, thus leaning out unless closed loop air/fuel ratio control is used.

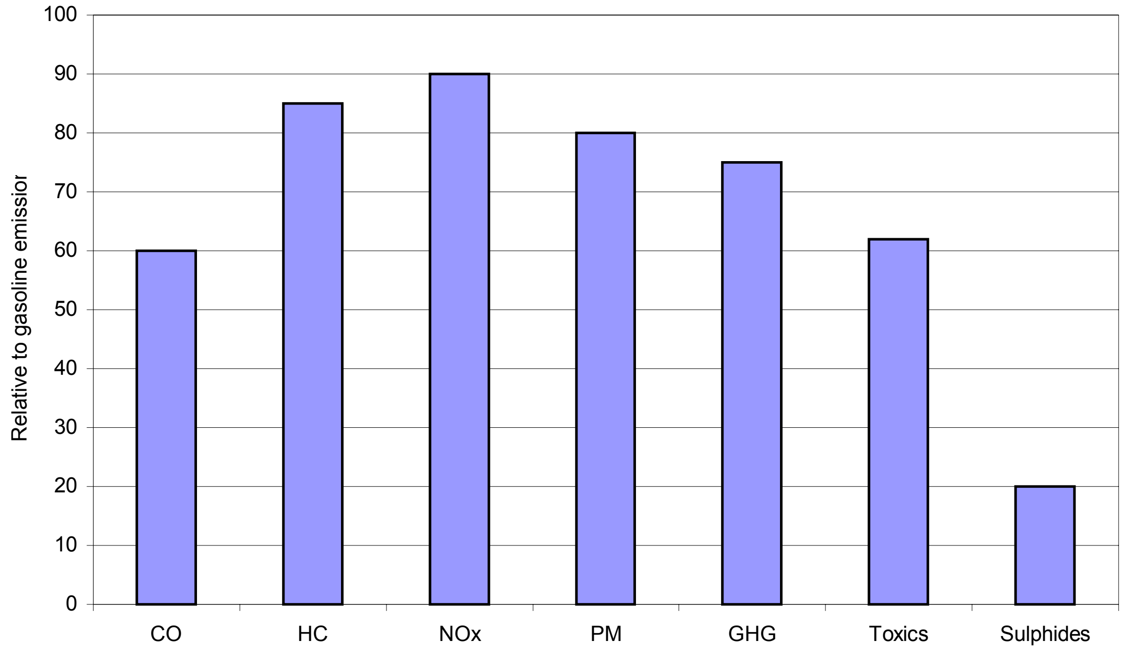


*Fig. 5. Relative to gasoline (100%) exhaust emissions of engines fueled with ethanol*

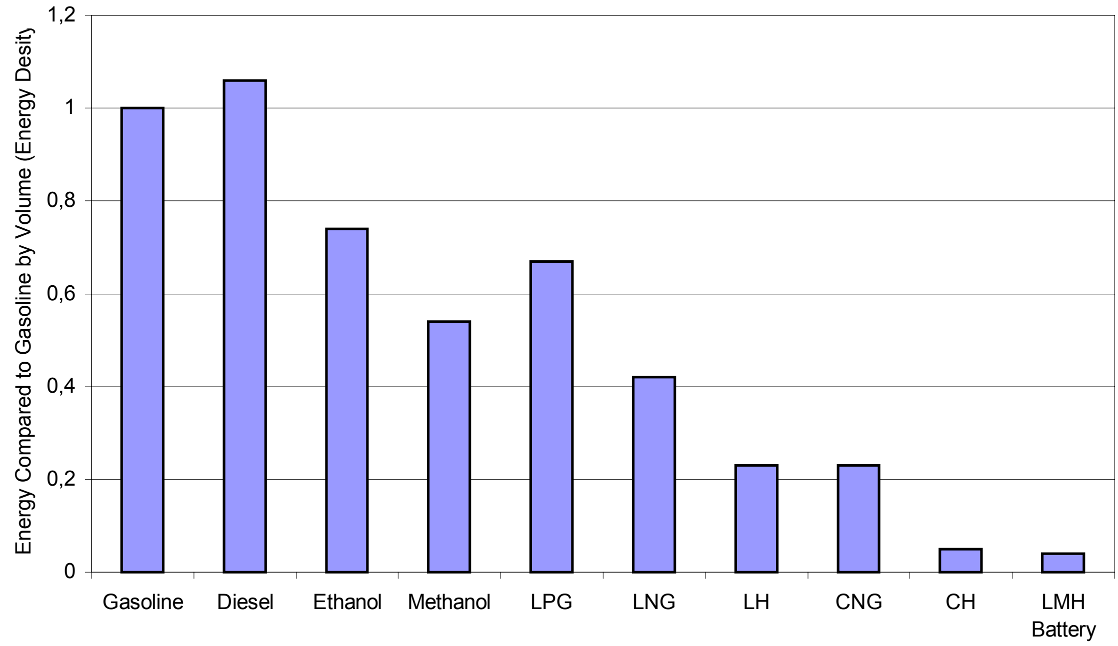


*Fig. 6. Energy of Alternative Fuels Relative to Gasoline*

- Changes in fuel distribution owing to the different evaporative characteristics of alcohols.
- Changes in charge temperature owing to evaporative cooling properties of alcohols.
- Increased gas specific heat and increased charge mass when closed loop air/fuel ratio control is used, leading to reduce combustion temperatures.
- Differences in the actual chemical reactions related to the combustion of alcohols, influencing the composition and reactivity or toxicity of the exhaust gasses.
- Changes in combustion rate yielding changes in gas temperature and pressures during

the cycle.

The presence of alcohols in gasoline blends could influence engine performance through the following mechanisms:

- Evaporative cooling of the charge in the inlet manifold and during the intake stroke, increasing charge density, and thus increasing the effective volumetric efficiency and power output.
- The combined effect of the stoichiometric air/fuel ratio and the heat of combustion enabling alcohols to release more heat of combustion enabling alcohols to release more heat for a given air charge, thus increasing power output.
- Changes in the timing, rate, and duration of combustion thus influencing the cycle efficiency, which influences the power output and specific fuel consumption.

The overall effect of the addition of alcohols to gasoline on performance and emissions would depend on the relative magnitudes of the above mechanisms. The full reducing potential of emission of the E85 fuel is presented in Fig.5. Energy density of fuels relative to gasoline is shown in Fig.6. The energy density of ethanol is 0.74 energy contained in gasoline.

The effect of the addition of alcohols to gasoline can be studied also theoretically. The mathematical model, which enables study of the influence of the different factors, of course heat release is following:

$$\frac{dQ_{ch}}{d\theta} = \left[\frac{\varphi}{\varphi-1}\cdot\frac{pdV}{d\theta}\right] + \left[\frac{1}{\varphi-1}\cdot V\cdot\frac{dP}{d\theta}\right] + V_{cr}\cdot\left[\frac{T'}{T_w} + \frac{T}{T_w(\varphi-1)} + \frac{1}{\phi\cdot T_w}\cdot\ln\left(\frac{\varphi-1}{\varphi'-1}\right)\right]\cdot\frac{dP}{d\theta} + \left(\frac{dQ_{hl}}{d\theta}\right)$$

where:

$$\frac{dQ_{nl}}{d\theta} = \frac{h_c\cdot SA\cdot(T-T_w)}{\omega_{eng.}}$$

where: $h_c$ is universally applicable expression derived by Woschni:

$$h_c = 131\cdot c_1\cdot B^{m-1}\cdot p^m\cdot T^{0.75-1.62m}\cdot(w_{chrg})^m$$

moreover, where the charge velocity, $\omega_{chrg}$, is related to piston movement, swirl, and combustion:

$$\omega_{chrg} = 2.28\cdot(S_p+U_{swirl}) + 3.24\cdot 10^{-3}\cdot c_2\cdot T_{ivc}\cdot\frac{V_d}{V_{ivc}}\cdot\frac{(p-p_m)}{p_{ivc}}$$

## 3. Biofuels for fueling of internal combustion engines

Biofuels are alcohols, ethers, esters, and other chemicals made from cellulose biomass, such as herbaceous and woody plants, agricultural and forestry residues, and a large portion of municipal solid and industrial waste. Biofuels can be used for power generation and on automotive applications. Biofuels, made from biological materials, which can be used in automotive, include bioethanol, biodiesel, biomethanol, and pyrolysis oils. This biological material can be used as automotive fuel in several ways:

- Plant oils (rapeseed, soybean, sunflower, etc.) can be converted (by transesterification process) into a diesel substitute to be blended with conventional Diesel or burnt as a sole fuel.
- Sugar beets, cereals and other crops can be fermented to produce alcohol (bio-ethanol),

which can either be used as a component in gasoline, or as motor fuel in pure form. Future developments may also make it possible to produce economically competitive bioethanol from wood or straw material.

Organic waste material can be converted into automotive fuel as waste oil (cooking oil) into biodiesel, animal manure, and organic household waste into biogas, plant waste products into bio-ethanol. The quantities of this feedstock are limited in most cases, but raw materials are free and waste recycling costs are reduced. In the medium term, also other liquid and gaseous biofuels produced by thermodynamic processing of biomass, such as biodimethylether, biomethanol, biooils (pyrolysis oils) and hydrogen derived from biomass could become competitive. These fuels are a renewable and inexhaustible sources of fuel, which can produce lower atmospheric pollution than petroleum fuels. They are potentially $CO_2$ neutral. They can use wastes that currently have no use. Biofuels can be domestically sourced to reduce dependence on foreign oil.

Biofuels are expensive and the energy consumption in producing bio diesel is such that roughly half of the $CO_2$ benefit is offset in the production process - more so for bioethanol. This offset can be reduced by using in the production process of waste material from crops (straw), but this tends to further increase costs.

Majority of car manufacturers permit to use biofuels up to 10% by volume ethanol, MTBE or ETBE without car modifications. There are many brands of biofuels but bioethanol and biodiesel are the most frequently applied and therefore they are main objectives of this paper.

There are many programs of biofuels developed worldwide. They are most popular in Brazil, the United States, Canada, Denmark, France and Australia.

### 3.1. Biodiesel

Biodiesel is a biodegradable transportation fuel for use in Diesel engines that is produced through thansesterification of organically derived oils or fats. Biodiesel (mono alkyl esters) is a variety of ester based oxygenated fuel made from renewable resources (plant oils / animal fats) and includes all fatty acid methyl ester (FAME).

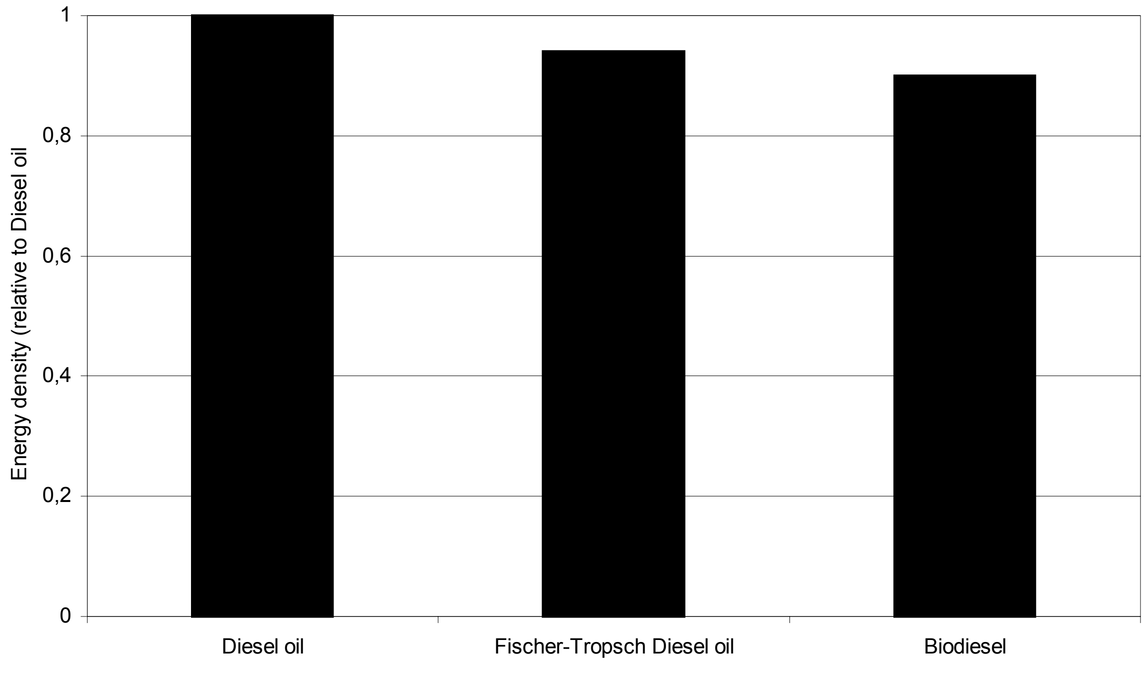


*Fig. 7. Energy density of biofuels in comparison to Diesel oil*

Fuels which come from a variety of sources include VOME - vegetable oil methyl esters such as SOME/SME - soya bean methyl esters, olive oil, RAME/RME rapeseed methyl esters, peanuts, cottonseed, sunflower seed, hemp. UVOME - used vegetable oils, fuels made from used (recycled) cooking oils, TME - tallow methyl ester, animal oils including waste oils resulting from the rendering of animal carcasses. Also ethyl esters such as REE - rape ethyl ester and SEE - soy ethyl ester. Use of unmodified vegetable oils for fueling engines results in severe deposit formation on engine parts and hence use of their esters is preferred.

Because biodiesel has similar properties to Diesel oil, it is an alternative fuel capable of being successfully used directly in any existing, unmodified Diesel engine and can be blended in any ratio with Diesel oil. Biodiesel can be stored anywhere that Diesel fuel is stored and maintains the payload capacity and range of Diesel. Properties may differ slightly in terms of energy content, cetane number or other physical properties. In Fig.7 the energy density of biodiesel in comparison with Diesel oil is presented.

Currently biodiesel is produced by a process called transesterification, whereby the vegetable oil/animal fat is first filtered, then processed with alkali to remove free fatty acids. It is then mixed with an alcohol (usually methanol but can also be ethanol) and a catalyst (typically sodium or potassium hydroxide), reacting to form fatty esters such as methyl ester or ethyl ester, and glycerol, which products are then separated and purified. Glycerol (used in pharmaceuticals and cosmetics) is produced as a co-product.

Methylesters of vegetable oils are obtained by following process:

$$
\begin{array}{lclll}
CH_2 - OOC - R & & & CH_3 - COO - R & CH_2OH \\
| & & & & | \\
CH - OOC - R' + 3CH_3OH & & \xrightarrow{\text{catalyst}} & CH_3 - COO - R' & CHOH \\
| & & & & | \\
CH_2 - OOC - R'' & & & CH_3 - COO - R'' & CH_2OH
\end{array}
$$

where: R, R’, R” are straight chains with or without double bonds and which usual number of carbon atoms is 17, though it can be placed between 15 and 23.

Biodiesel fuels can be also produced from biomass by Fischer - Tropsch method. These fuels avoid sulfur and therefore can reduce exhaust emissions from Diesel engines. This process is derived from synthesizing hydrocarbons (coal, natural gas) and such fuels are used in Germany and South Africa. They have been blended with Diesel oil in California to meet the Diesel fuel quality standards of this state. The tests showed that Fischer – Tropsch. Fuels can be substituted in unmodified trucks and buses without any detectable loss in performance. The tested Fischer - Tropsch fueled vehicles emitted about 12% less nitrogen oxide and 24% less particulate matter than vehicles fueled with conventional Diesel oil. Average emissions from Diesel trucks operating in California State on the Diesel oil, a 50% Fischer - Tropsch Diesel blend and 100% Fischer - Tropsch Diesel fuel are shown in Fig.8. In Fig.9. compared percent emission reduction using Fischer - Tropsch Diesel blend with California Diesel oil is shown.

Environmental advantages of biodiesel are as follows:

- its tailpipe gate emissions of $CO_2$ are zero and its life cycle emissions are about 80% less than those from Diesel fuels;
- emissions of sulfur and volatile organic compounds are also lower than for Diesel fuels;
- emissions of other air pollutants - carbon monoxide and particulates - are similar for those from diesel, however differences are not marked.

In Fig.10 the exhaust emissions of SW 680 engine fueled with Diesel oil and RME tested by authors are shown.

Biodiesel and conventional Diesel fuel are produced through significantly different pathways. In order to properly understand their relative environmental performance it is useful to calculate the emissions in fuel cycle that arise directly from the vehicle operation itself and also indirectly during the production of the fuel. In the case of biodiesel substantial emissions arise during the production of fertilizers. The life cycle paths for Diesel fuels and biodiesel are presented in Table 3.

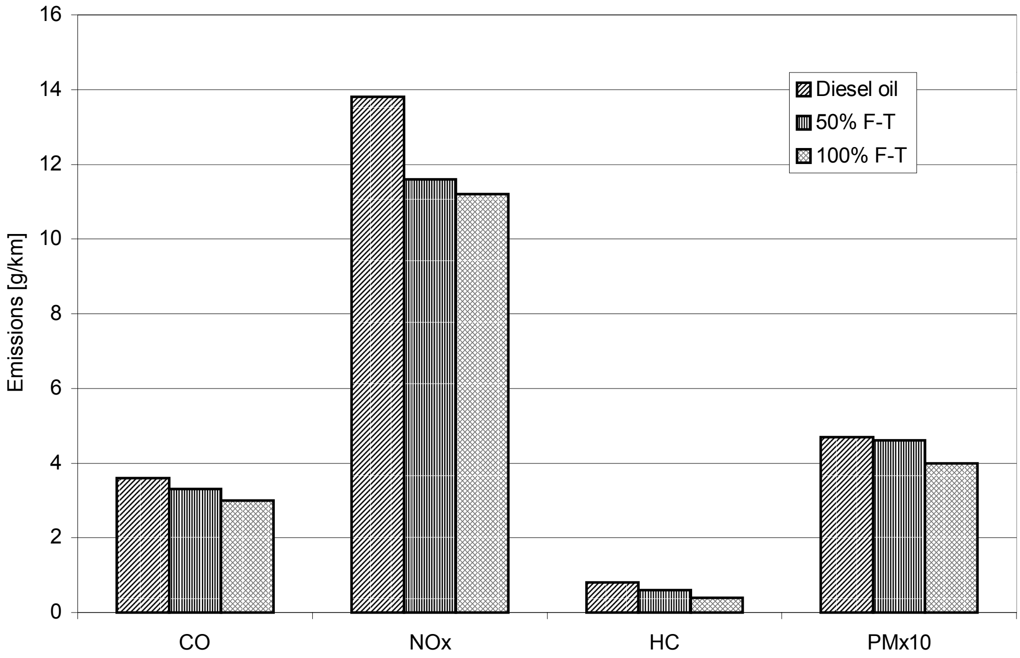


*Fig .8. Comparison of emissions from Diesel truck operating on Diesel oil, 50 % Fischer-Tropsch Diesel blend, and 100 % Fischer-Tropsch Diesel fuel*

*Table 3. Life-cycle paths for Diesel fuel and biodiesel production*

| Diesel fuel | Biodiesel |
|---|---|
| Exploration and Extraction | Production of agricultural inputs |
| Shipping of crude | Agriculture |
| Refining | Processing and esterification |
| Distribution and retailing | Distribution and retailing |
| Emissions during vehicle operation | Emissions during vehicle operation |

*Table 4. Emissions of greenhouse gases [g/km]*

| Diesel fuel | g/km | Biodiesel | g/km |
|---|---|---|---|
| Extraction 1 | 15.84 | Fertilizer production | 64 |
| Transport | 2.74 | Fertilizer production | 12 |
| Refining | 13.63 | Agricultural machinery | 24 |
| Distribution | 0.95 | Oil production/processing | 21 |
| Vehicle operation | 245 | Transport | 5 |
| | | Vehicle operation | 0 |
| Total | 278 | Total | 125 |

The energy balance of life cycle for diesel fuel and biodiesel is depending on many factors e.g. yields of biomass plants, different energy efficiency and emissions data for fertilizer

production, and different nitrous oxides emissions from the fertilizer manufacture process.
The total emissions of greenhouse gases from the biodiesel life cycle remain substantially lower (about 55%), than life-cycle emissions from conventional Diesel fuel. The emission arising from the production of biodiesel, including nitrous oxide from fertilizer production and use are still small as compared to the vehicle emissions. The greenhouse gases emissions in fuel cycle are presented in Table 4.

Life-cycle emissions of $CO_2$ from biodiesel are only about a quarter of Diesel fuel. In Table 5 the life cycle emissions of $CO_2$ are shown. It is assumed that the crushing and the esterification processes that converts oil into the fuel rape methyl ester are unchanged for both processes.

### 3.2. Bioethanol

Bioethanol is ethyl alcohol, which is produced biologically from the fermentation of various sugars from carbohydrates found in agricultural crops and cellulostic residues from crops or woods.

Since World War I till 1970 petroleum progressively displaced biomass in virtually every product category. Today, crude oil accounts for the majority of global transport fuels, and more than 95 percent of industrial organic chemicals. Petrol and diesel fuel are important because they are also major sources of tax revenues.

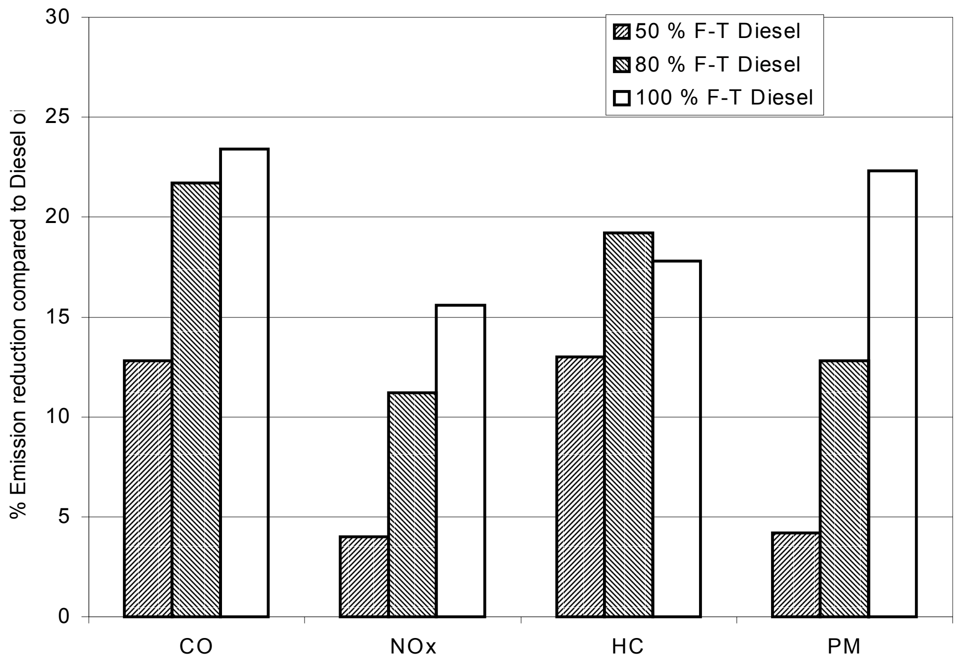


*Fig. 9. Percent emission reduction using Fischer-Tropsch Diesel blend compared to California Diesel Oil*

Establishing a national goal of replacing Australia's dependence on fossil transport fuels with renewable fuels, such as ethanol from biomass, over the next 50 years, would provide the necessary economic stimulus for a revival of biomass resource development generally on a national scale. It would also establish an economic rationale, and identify for the environment and over-exploitation of soils and water resources on a national and global basis. There are sufficient existing biomass resources, and potential new biomass resources associated with agriculture, forestry, and biomass in urban waste. To support the establishment of a target to produce 2% of Australian transport fuel in the form of renewable bioethanol/petrol blend by

2005; 5% of Australia's transport fuel in the form of ethanol/gasoline blend by 2010; 40% in the form of ethanol by 2025; and close to 100% by 2050. Despite the obvious benefits associated with fossil transport fuels yesterday, today the cost of global and national dependence on fossil fuels is equally pervasive in terms of deteriorating environmental quality caused by greenhouse and other emissions from the combustion of fossil fuels, such as air toxics, carbon monoxide, and ozone-forming volatile organic compounds. Biomass, the source of yesterday's industrial raw materials, fuel and power could once again, along with wind, solar and tidal energy, be put in the position to supply tomorrow's energy.

*Table 5. Emissions of $CO_2$ [g/km]*

| Diesel fuel | Emissions of $CO_2$ [g/km] | Biodiesel | Emissions of $CO_2$ [g/km] |
|---|---|---|---|
| Extraction | 14.53 | Fertilizer production | 17 |
| Transport | 2.72 | Fertilizer application | 0 |
| Refining | 13.62 | Agricultural machinery | 24 |
| Distribution | 0.91 | Oil production/processing | 20 |
| Vehicle operation | 245 | Transport | 5 |
| | | Vehicle operation | 0 |
| Total | 211 | Total | 66 |

The net reduction in greenhouse gas emission associated with the sustainable growth, harvesting, industrial processing, and use of biomass products such as ethanol fuel is significant. It is roughly equivalent to the level of fossil fuel displacement achieved.

- A 25% displacement of gasoline or diesel fuel by ethanol would deliver a net $CO_2$ emission reduction benefit equivalent to approximately 25% of the $CO_2$ emission from the production of the fossil transport fuel, and its use.
- GHG emissions in $CO_2$ equivalent from total petroleum fuel production and fuel in Australia is approximately 120 million tones each year.

Fossil alternative fuels such as CNG/LPG deliver no significant benefit in terms of net reduction in GHG emission. Currently renewable fuel ethanol is used in the form of a 10% blend with gasoline, or a 15% blend with Diesel fuel. Net replacement by ethanol of 2% of gasoline and Diesel oil used as transport fuel (a target achievable by 2005) would result in a net reduction of some 1.2 million tones of $CO_2$.

An intensive field trials of the range of vehicles fueled with the 10% ethanol blends and gasoline prove that using this blend offers significant benefits in terms of reductions in vehicle exhaust and greenhouse emissions. They are following trial effects:

- a decrease in carbon monoxide (CO) by approximately 32%,
- a decrease in total hydrocarbons (THC) approximately by 12%,
- reductions in carbon dioxide ($CO_2$) of approximately 7% on a full carbon cycle analysis.

Reductions in toxic exhaust emissions harmful to human health and the environment included:

- a decrease in 1-3 butadiene emission by approximately 19%,
- a decrease in benzene emission by approximately 27%,
- a decrease in toluene by approximately 30%,
- a decrease in xylenes by approximately 27%,

The blend of Diesel oil with ethanol is also applied as a fuel for internal combustion engines. This fuel is Diesohol. Diesohol is a practical clean burning fuel developed in Australia that achieves substantial reductions in particulate and other emissions from Diesel engines. A typical Diesohol fuel contains 84.4% Diesel oil by volume, 15% hydrated ethanol, and 0.6% emulsifier. The research effects proved following substantial benefits:

- Reductions from 20% to 50% in particulate emission from modern Diesel engines and from 60% to 70% from older Diesel engines.
- Reductions of up to 20% in CO emissions.
- Reductions of up to 25% in HC emissions.
- Reductions of up to 10% in $NO_x$ emissions.

Diesohol can be used interchangeably with Diesel oil in older or advanced Diesel engines with no or only minor engine modifications.

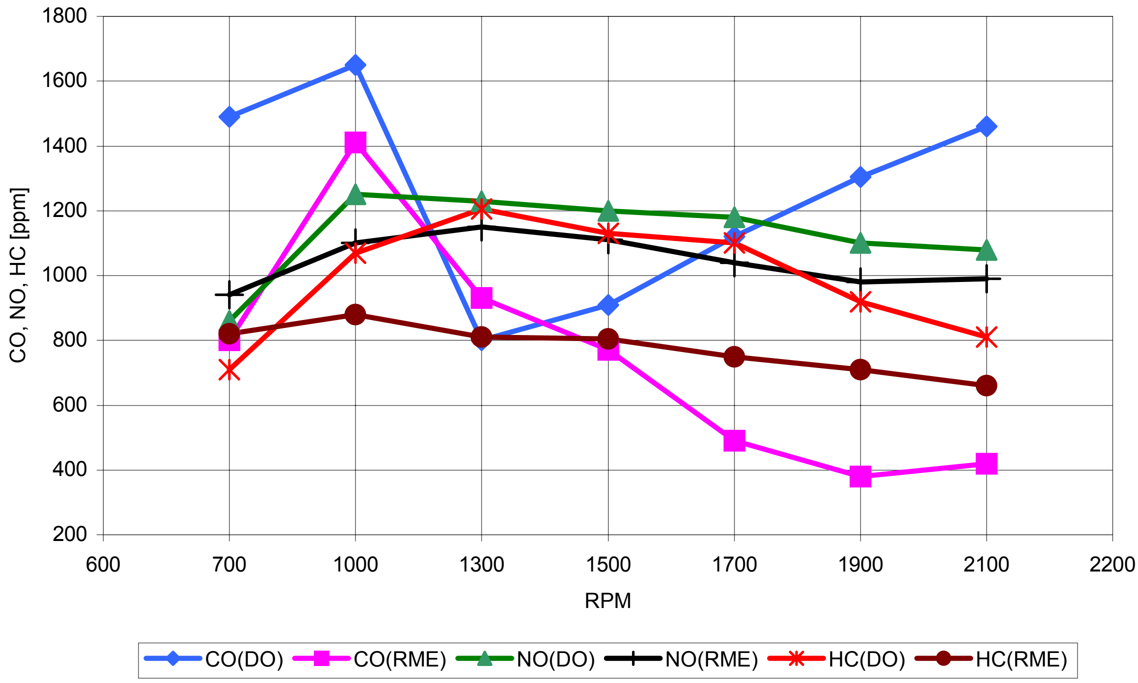


*Fig. 10. Exhaust emission of SW 680 engine fueled with Diesel oil and RME*

Bioethanol is a renewable fuel of low toxicity and is miscible with water. The risk posed by ethanol to the environment, land, water, and living species is thus significantly lower than that posed by oil and petroleum products. In addition to agricultural and forestry wastes and residues, bioethanol can be produced from a wide range of other waste materials including: brewery waste, brewery municipal biomass waste retail/commercial biomass waste, waste paper and cardboard, lawn and garden trimmings, whey from cheese making, woody weeds. Total wastes delivered to municipal sites around Australia each year are approximately 6 million tones. On average 40% of municipal waste is in the form of recoverable biomass, and would be suitable for conversion of renewable liquid or gaseous fuels.

Australia Government recommends the following milestones for consideration by transport fuel manufactures:

The production of 2% of Australia's transport fuels (more than 250 million liters) from biomass in the form of biofuels such as ethanol to year 2005. The net reduction of over million tones of fossil fuels carbon ($CO_2$) per year, from Australia's net annual GHG emissions, from the transport sector.

The production of 5% of Australia's transport fuels (more than 1.4 billion liters) from biomass in the form of biofuels such as ethanol to year 2010. The net reduction of over 3.5 million tones of carbon ($CO_2$) per year from Australia's net annual GHG emissions.

The production of 40% of Australia's transport fuels (more than 11 billion liters) from biomass in the form of biofuels such as ethanol to year 2025. The net reduction of over 29 million tones of carbon ($CO_2$) per year from Australia's net annual GHG emissions from the transport sector.

Production of 85% of Australia's transport fuels (more than 250 million liters) from biofuels such as ethanol to year 2040.

Close 100% of applied fuels in Australia will be derived from biomass resources to year 2050.

To fulfill these objectives it will be require introduction of innovative technologies and strategies for accelerating reductions in biofuel production.

## 4. Conclusions

- The Need for greenhouse gas emission reductions, including mainly $CO_2$, and the need for applying fuels of range extent in automotive transport cause that biofuels must be applied for fueling internal combustion engines.
- The best of properties, as a fuel for fueling of internal combustion engines, enable the ester of vegetable oils, ethanol, and their blends.
- Ethanol can be used for fueling spark ignition engine as well as for compression ignition engines (Diesel engine).
- Using ethanol blend with gasoline, up to 24% ethanol, does not require special engine modifications. The engine modifications are indispensable if ethanol contents in the blend are higher.
- The vegetable oil esters can be used in compression ignition engines only.
- The use of biofuels enables to decrease the greenhouse gas emissions, mainly $CO_2$, because quantity of $CO_2$ emitted during fuel combustion is balanced with quantity of $CO_2$ absorbed by plants and tree during their growth.
- Combustion of fossil fuels cause growth of the $CO_2$ contents in atmosphere, because this $CO_2$ is not balanced by plants absorption.
- Using the bioethanol for internal combustion engines fueling has the following benefits in terms of exhaust emissions: decrease of CO by approximately 40%, decrease of $NO_x$ by approximately up to 10%, decrease of hydrocarbons by approximately up to 15%, decrease of PM by approximately up to 20%, decrease of toxic substances up to 38% and sulfides up to 80%.
- Fischer - Tropsch method is a very good method for biofuels production from biomass. The Fischer - Tropsch fuels are characterized by very low emissions regulated and non-regulated chemical components, and very low sulfur emissions.
- The $CO_2$ emissions of fuel produced from biomass, in full cycle, are bigger than fossil fuels. Nevertheless, it is very important that the most $CO_2$ emissions during production process non-fossil fuel are non-fossil.
- Research results of engine fueled with Diesel fuel, a blend of Diesel fuel with 10% ethanol, and blend of Diesel fuel with 15% ethanol show that engine out can be significantly reduced if ethanol is added: PM emission was reduced by about 65% almost fuel engine map, but $NO_x$ emission up to 84%. There is an overlap between the regions of $NO_x$ and PM emissions reduction.

## References

[1] Aguiar C.: Alcohol and Other Biomass Fuels: an Opportunity for the Developing World.

Vehicle and Environment 1994. International Academic Publishers. 25th FISITA Congress.
[2] Beer T., et al: Comparison of Transport Fuels. Final Report No. EV45A /2/ F3C. Australian Greenhouse Office. Melbourne 2001.
[3] Grabowski M.S., Ross J.D., and McCormick: Transient Emissions from No.2 Diesel and Biodiesel Blends in a DDC Series 60 Engine. SAE Paper No. 961166.
[4] Hansen K.F., Jensen M.G.: Chemical and Biological Characteristics of Exhaust Emissions from a DI Diesel Engine Fueled with Rapeseed Oil Methyl Ester (RME). SAE Paper No. 971689.
[5] Jankowski A., et al: Rape Seed Oil Methyl Ester Fuel as Alternative Diesel Fuel for High Speed Diesel Engines for Urban Buses. ICE - Vol.24. Natural Gas and Alternative Fuels for Engines. ASME 1994.
[6] Knothe G., et al: Vegetable Oils as Alternative Diesel Fuels: Degradation of Pure Triglicerides during the Precombustion Phase in a reactor Simulating a Diesel Engine. Alternative Fuel for CI and SI Engines. SAE SP-900. 1992.
[7] Kremer F.G., Jardin J.L.F., Maia D.M.: Effects of Alcohol Composition on Gasohol Vehicle Emissions. SAE Paper No.962094.
[8] Norton P., et al: Emissions from Trucks Using Fischer-Tropsch Diesel Fuel. SAE Paper No.982526.
[9] Tinaut F.V., et al: Application of a Quasi - Dimensional Model for the Reduction of Pollutant Emissions in SI Engines. 27th FISITA'98 Congress Paris, 1998. No. F98T155.
[10] Turunen R.: On the Combustion and Heat Transport in High Speed Diesel Engine Operating with Rape Seed Oil Methyl Ester Fuel. Journal of Polish CIMAC. Vol.1, No.1, Warsaw 1994.