POTENTIALS AND LIMITATIONS OF ALTERNATIVE FUELS FOR DIESEL ENGINE

by

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The primary energy consumption in the world has increased continuously. The most important primary energy source is oil. The supply of automotive fuels today is based almost entirely on oil, and the demand for liquid transportation fuels worldwide will rise significantly in the next fifty years.
Growing energy consumption and decreasing fossil resources are reasons for increasing prices of fossil fuel. Besides limited availability, contribution to greenhouse effect and pollutant emission represent another problem of fossil fuel. Both of these problems can be overcome by increased application of renewable biofuels.
Therefore, great effort is made to supplement the primary energy sources by including renewable energies. There are alternative fuels 1st and 2nd generation. Some of them show high potential for reduction of engine out emission. But there are economical and technical barriers when such fuels are applied.
This paper shows both advantage and disadvantage of alternative fuels, especially when used for diesel engines.

Key words: *alternative fuels, automotive industry, diesel engine*

Introduction

Global industrialization, population growth, high needs of current consumers and world wide motorization has stimulated the vast increase in energy demand. The primary energy consumption in the world is continuously growing. Thus, the consumption of primary energy worldwide had grown from 8.3 to 10.2 million tons crude oil equivalent (Mtoe) between 1994 and 2004. The most important primary energy source is crude oil (37%).

Future worldwide energy demand may be estimated through certain sustainable scenarios (fig.1) [1].

It can be seen from fig.1 that total energy demand will keep growing until 2060. It can also be noticed that by 2020 supplies will be predominantly from conventional energy sources: coal, crude oil, natural gas, nuclear and hydro power plants, and traditional wood-biomass [2].

This growing global energy consumption cannot be covered only by conventional and limited fossil sources. Recently, non-fossil, especially renewable energy has become more and more important worldwide.

According to EU Directive 2003/30/EC any gaseous or liquid fuel for transport produced from biomass can be considered as biofuel. Biomass means the biodegradable fraction of

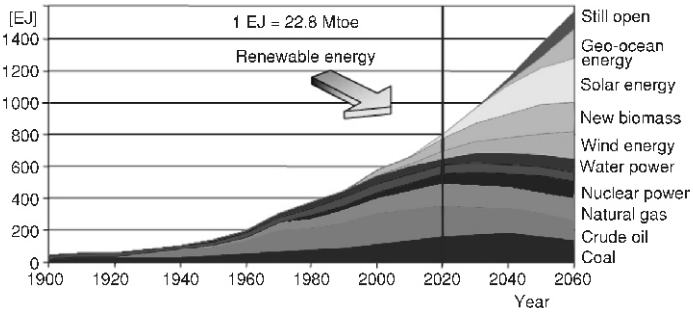

Figure 1. Worldwide energy demands

products, waste and residues from agriculture (including vegetal and animal substances), forestry and related industries, as well as biodegradable fraction of industrial and municipal waste.

Biofuels can play an important role towards the transition to a lower carbon economy by offering solutions that are both energy efficient and cost effective. Biofuels also combine the benefits of low greenhouse emissions with the reduction of oil imports, a fact that makes their introduction even more appealing for the European states. The role biofuels can play within these economies becomes clearer when their relatively developed agricultural sector is taken into account. Local agriculture can provide row materials for various biofuels and ensure the necessary supply chain without being highly affected by external factors, which is the advantage over fossil fuels.

The major challenges facing the industrialized nations are: the economical use of existing fossil and the development of alternative and renewable fuels bearing in mind their environmental impact. Reduction of emission to any great level without sacrificing fuel economy will be an enormous challenge. In order to meet more stringent emission standards exploitation of the well-known alternative fuels remains one of the most viable options.

Fuels are closely linked with economics, politics, and social and ecological systems. Currently practically 97% of transportation fuels are produced from crude oil. Increasing demand for transportation fuels, dwindling OPEC spare capacity and concern over current biofuel feed-stocks competing with food production is pressing the industry to find alternatives. It is anticipated that biofuel production will reach 1,8 million barrels a day by 2012, roughly double the 0,9 million barrels per day of 2006. Therefore different motives have been mentioned during the act of searching for fuels, which do not come from mineral oil. One of the main reasons is by the awareness of the limited of the natural mineral oil resources and by the concern about what will come after the mineral oil era. Another motive which is advantage over fossil fuels is the emission reduction and decrease of dependency in politically unstable regions (a crisis scenario that might occur between 2010 and 2015), which export mineral oil.

Transportation sector is major consumer of mineral oils, more then 50%. In this sector, diesel engines which have become dominant drive for heavy-duty vehicles and agricultural mechanizations, consume approximately 30% fuels, or about 11 million barrels per day worldwide and the growth of 2.5% per annum is expected to continue until 2020. The consumption of diesel and gasoline in EU during 2004 reached 270 million ton barrels while in 1985 it was 180 million tons. Estimations show that by 2020 the consumption will reach 325 million tons. It is considered that transportation sector in EU emits 25% of greenhouse gases. It is expected that transition to more efficient power units (fig. 2) will take place gradually, meaning that new engine technologies

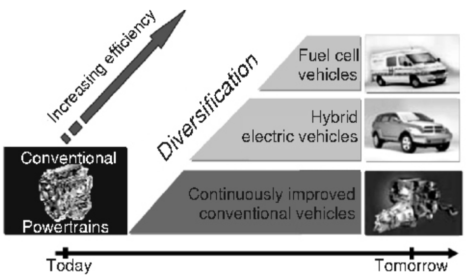

Figure 2. Diversification of drive in road traffic

will search for optimum fuel types with the best energy efficiency and lowest possible emissions [3]. Having in mind above facts and knowing that internal combustion engines will probably dominate until 2030, producing toxicity of exhaust emissions, particularly NO_x and particulate matters (diesel) it is of utmost importance to reduce fuel consumption and find new alternative fuels.

Demands for alternative fuels

Engine manufacturer demands for alternative fuels are:
– highest CO_2 potential, at highest yield per hectare,
– compatibility with existing and future engine technology,
– diversify of primary energy, not final product,
– compatibility with existing infrastructure,
– at least neutral in terms of emissions, and
– existing mileages to be maintained.

In the debate about alternative fuels, the question which fuel is best is frequently raised. The alternative fuels can be derived into two different categories. The first category is fuels produced from *fossil feedstock* and the second category is fuels produced *from biomass*. The fuel production is of two principal types, *thermo-chemical* (synthetic liquid fuel or synfuel) and *biochemical*, respectively. There are two different routes for the biochemical conversion via saccharification of celluloses feed-stocks and fermentation to ethanol or by anaerobic digestion to methane (biogas). Possible routes for gaseous and liquid fuels, respectively, are shown in figs. 3 and 4 [4].

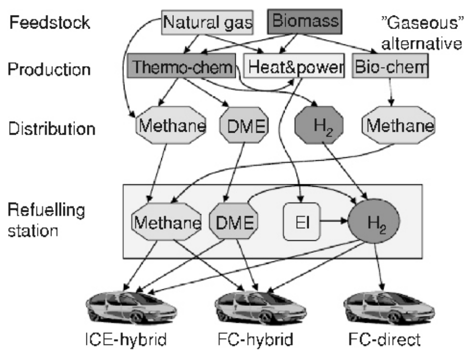

Figure 3. Alternative gaseous fuels

Liquid fuels, easily handled as gasoline and diesel oil today, will have a great advantage in distribution and refueling efficiencies and allow retaining of the refueling habits of the public. Synthetic fuels and biodiesel show high potential for a further reduction of engine emissions. Fuels obtained from biomass, being liquid, are very advantage for road traffic. The existing infrastructure for gasoline and diesel fuel can fully be used with the help of biofuels.

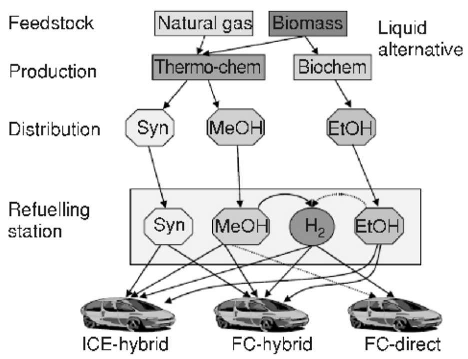

Figure 4. Alternative liquid fuels

In view of Kyoto Protocol, EU green document, and continuous growth of transportation sector by 1.7% per year, the vision of fuel diversification up to 40% from alternative sources will be one half from renewable sources and the other half will represent pure synthetic fuels based on natural gas and biomass.

During past decades various types of alternative fuels have been developed but only a small amount has reached the market. Nowadays we are speaking of two production generations of alternative fuels (fig. 5): the *1st generation* being biofuels based on grain crops, such as rape-

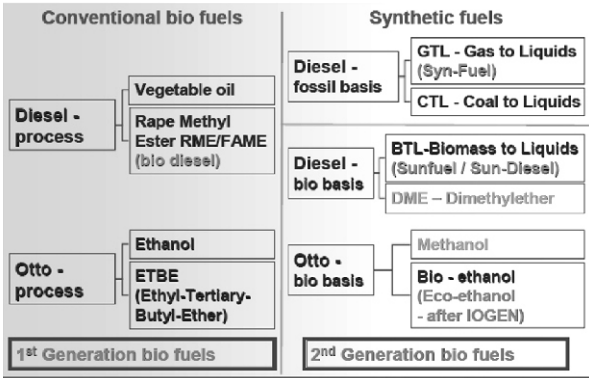

Figure 5. Production generations of alternative fuels

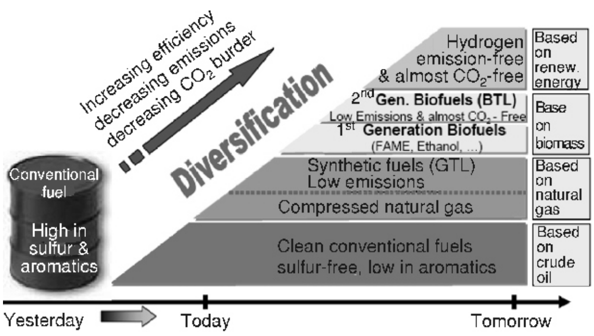

Figure 6. One of diversifications relating to future fuels and sources

seed, grain, maize, *etc.*, and the *2nd one* biofuel fully synthetic based on biogenic energy such as BTL (sun-diesel), DME [5]. Also, algae have great potential as sustainable feedstock for production of diesel-type fuels with a very small CO_2 footprint.

A picturesque scenario relating to evolution of future fuels and sources is illustrated in fig. 6. Conventional fossil fuels will become more and more cleaner in order to meet stringent emission regulations. Due to optimization of conventional fuels it is expected that they will be gradually substituted (2010 = 5.75%, 2015 = 8%, 2020 = = 15%) by alternative fuels [5].

Properties of alternative diesel fuels

A very important factor in the choice between fuels will be total efficiency for the complete system (on a well-to-wheel basis).

Physical-chemical properties of alternative diesel fuels are shown in tab. 1.

For a short term RME (commonly known as *biodiesel*) rapeseed oil transesterified with methanol to attain a higher cetane number and reduced viscosity, has been available fuel for compression ignition engines. Biodiesel is available in the EU market for several years. It is biodegradable, non-toxic and renewable biomass based fuel. Biodiesel leads to high CO_2 reduction of pollutant diesel exhaust emission, exception NO_x [6].

The main disadvantage of biodiesel is the storage (oxidation) stability. When exposed to heat, light, and stress, the fatty acid methil ester forms a radical, usually directly next to double bond. This radical quickly binds with the oxygen from the air, which is a diradical. A peroxide radical is formed. Now the rapid radical destruction cycle (rancidity) begins (unpleasant odor). Therefore, the consequences of oxidation are firstly that bio-diesel decomposes to form short-chain fatty acids (such as butric acid), and secondly that insoluble polymers (gums) are formed. Polymers (gums) may damage the engine and the fuel-injection system. For this reason in biodiesel a stabilizer – antioxidant (natural vitamin E) – must be added. The storage of 100% biodiesel requires special technical equipment, compared to petrol diesel. Results [7] from stability test recommended a fast circulation of B5 fuel (5% biodiesel in petrol diesel). A storage time of more than 6 months could become critical. Gaskets and thanks, for example have to be modified. The next disadvantage of biodiesel is low temperature performance, if the blending ratio, with mineral diesel, exceeds 30% methyl ester, as the pour point of the ester is higher.

Table 1. Physical-chemical properties of alternative diesel fuels [5-7]

Fuels	Diesel	Natural gas (NG)	Vegetable oil	Dimethyl ether (DME)	Rapeseed methyl esther (RME)	GTL	BTLL
Chemical formula	$C_{16}H_{34}$ (as cetan)	CH_4	$C_{57}H_{105}O_6$	CH_3OCH_3	$C_{21}H_{28}O_2$	C_{10-20} H_{21-42}	
Density (kgm^{-3}) (15 °C)	820-845	0.725	904	660 (40 °C)	875-950	778-788	775-785
Kinetic viscosity (40 °C)	2.0-4.5			0.12-0.15	3.5-5.0	3-4	2-4
Oxidation stability [gm^{-3}]	1				min. 6	2.2 hours	
Stoichiometric air/fuel ratio	14.5	17.25	12.7	9.0	12.61		
Sulfur content [$mgkg^{-1}$]	35 (10)				max. 10	<2	<1
Carbon [mass%]	86	75	77.6	52.2	77.48	85	
Hydrogen [mass%]	14	25	11.6	13	11.86	15	
Oxygen [mass%]	0	0	10.8	34.8	10.84	0	
CO_2 emission [gMJ^{-1}]	74.2	57.7		67.5	2.9 kg/l	48	
Water content	30						
Heat of combustion [$MJkg^{-1}$]	42.5	45	36.7	27.6	36.7-40.5	43-67	40
Cetane number	38-55 (51 min.)			60	51-58	73-82	85-99
Cetane index	50-54			50-92		50-92	98
Lubricity (HFFR wear) [mm]	375					280-400	405
Odour	strong				spec.	odourless	
IPB [°C]	174					211.5	216
FBP [°C]	363					354.5	321

In economic terms, the application of pure vegetable oils and their blends with mineral diesel (not exceeding 20% v/v oil) is now of significant interest, especially in countries with a relatively grown agricultural sector .

Direct use of vegetable oils as fuels offers several advantages especially in developing countries that lack the necessary industrial infrastructure and know-how to create biofuels but have a significant vegetable oil production. However, pure rapeseed oil used as fuel is very problematic. The use of blended diesel fuel with a high share of rapeseed oil in modern conventional diesel engines is connected with high risk of engine damage, such as severe coking on valves and injections nozzles, deposits at the piston and abrasion of the top piston ring. Thus, for a long term reliable and low emission operation of diesel engines using the diesel blends or pure rapeseed oil fuel, adaptation of the engine is required.

The second large fossil fuels resource (low cost) available today is *natural gas* (NG). Its direct use as compressed or liquefied gas has not been accepted as a transportation fuel in a large scale. Over long distance NG is exclusively transported as liquefied natural gas (LNG) in cryo-tanks at –162 °C. This is expensive and requires costly installations.

If NG is used as transportation fuel in urban areas like taxis, buses and delivery trucks it must be compressed at ~200 bar (CNG) fuel. However, if heavy duty diesel vehicles are retrofitted to NG, the energetic engine efficiency drops as NG is typical Otto-cycle fuel. This leads to a chain of multiple disadvantages, like lower efficiency due to a lower compression ratio (knock limit), lower efficiency due to throttle control at part load (which is the primary driving made in cities), high fuel volume and heavy tanks due to gaseous fuel storage and costly and/or time consuming refueling. This is motivation to search for chemical conversion of NG to liquid fuels GTL.

It can be seen from fig. 3, that that DME fuel is quite new in this scenario. As the vapor pressure of DME is approximately 5 bar (at 200 °C) it is exclusively transported, traded, and stored as a liquid, same as LPG. DME as an alternative to diesel fuel has good physiological properties, practical handling, excellent combustion related properties (minimum of harmful exhaust gas emissions, low noise level, non-toxicity, and environmental friendliness) and high energetic efficiencies achieved in both the engine and the fuel process. During range of city bus is 250 km per 200 l tank liquid DME to compare 90 km per 200 l tank CNG. Finally 3.6 kWh primary energy (crude oil is required for the diesel chain, and 4.6 kWh for both the DME and CNG chain.

In direct injection diesel engines the time for fuel evaporation and air mixing is considerably shorter than in Otto-cycle engine. Thus locally rich mixture may cause incomplete combustion of the fuel which results in soot formation. This can at least partly be prevented if the fuel contains oxygen.

The soot formation is completely suppressed if fuel oxygen content is higher than approximately 30% [8]. DME contains 34% oxygen and just exceed this level. Therefore, the main advantage of DME over diesel is absolutely no visible smoke even under transient operation. DME is a clean and highly efficient fuel [9, 10].

Very low viscosity of DME relative to one of diesel oil will affect the wear extent in existing pumps when fuelled by DME. By mixing the DME with very small quantities of additives (for ex. RME) the lubricity can be redressed. Elastomers used in distribution system can cause significant changes of DME.

BTL diesel (biomass-to-liquid fuels or sundiesel) is a hydrocarbon fuel derived from biological origins (solid biomass is first converted into a synthesis gas – $CO + H_2$ – which in Fisher-Tropsh synthesis is converted into hydrocarbons) having the same or superior properties in relation to the best existing diesel fuels such as gas-to-liquids (GTL) distillate fuels or Swedish class 1. BTL can be used up to 65-70 vol.% in diesels to full fill the minimum density required. Lubricity can easily be improved with additives which are commonly done with conventional sulfur free diesels. Pure BTL leads to highest CO_2 reduction and reduced total particulate emission by 28% and NO_x emission by 10% in relation to Swedish diesel class 1 [11, 12].

Potentials and limitations of alternative fuels

Biofuel optimization potentials can be either direct or indirect. Direct: mixture formation and combustion quality, optimal energy conversion during combustion, reduction of emissions (PM, CO, HC, CO_2) [6], they also are biogradable, non-toxic and available from renewable sources. Indirect: closing up CO_2 cycle-biofuel-plant, since plants absorb it for assimilation of chlorophyll during growing, reduction of C/H ratio, realization of new alternative combustion processes or improvement of existing ones – reduction of NO_x.

Although biofuels can be obtained from over 2000 various plants, only a few have found application due to various limitations and barriers.

The *first barrier* in using biofuel (biodiesel and bioethanol, above all) is insufficient quantities, fig. 7 [5].

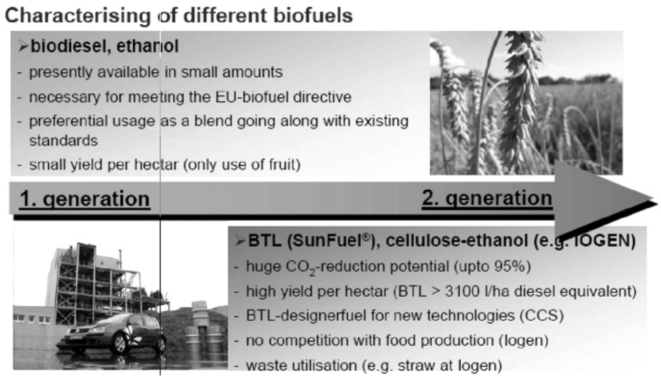

Figure 7. Advantages and shortcomings of alternative fuels

For example, to reach the goal of 5,75% bio fuel in EU it is essential to have more than 9% of agricultural land. If complete income of soya in USA was used for biodiesel it would cover only 6% of demands. If, however all plant oils and animal fat would be used the percentage would be 13.3 %.

The *second barrier* is of economy nature. Low yield and availability of cultivated soil. Biofuel production cost (with lower tax) is twice as high as the cost of mineral fuel.

Technical barriers: when using biofuel the following aspects are important:

First: poor performance at cold start,

Second: high tendency toward polymerization which can cause clogging of fuel and oil delivery lines with fatal consequences. Higher contents of olefins in biodiesel cause formation of deposits on atomizers (injectors) in combustion chamber,

– *Third*: production technologies must adjust to incoming raw material,

– *Fourth*: distribution systems, mixing in particular, require certain procedure to be observed and such mixtures are not to be stored longer than 6 months,

– *Fifth*: application of alternative fuels in wider engine population is not desirable since they can be incompatible with all engines,

– *Sixth*: bio fuel lubricating properties are often connected with sulphur content; for example, pure RME has good lubricating properties in high pressure pumps, but mixture in excess of 5% shows poorer properties therefore adhesive or fretting wear can occur on same HP pump elements; the second problem is the procedure of determining lubricating properties (HFRR test),

– *Seventh*: interactivity between biofuels (RME) and lubricating oil shortens oil life,

– *Eighth*: incompatibility with some elastomers (seals) and paints,

– *Ninth*: oxidation instability (RME) – instability during storing, formation of resins cause operating problems, stabilizations must be added, and

– *Tenth*: easier water absorption causes problems of microbiology nature and cold start.

Thus, realistic potential of diesel fuel can be attributed to DME, BTL (RME), and GTL.

Conclusions

Based on the presented material it can be said that:

– some of alternative fuels show high potential in respect of reducing diesel engine exhaust emissions, and CO_2 (with the exception of NO_x); gradually, these fuels will substitute mineral ones,
– they are bio degradable meaning that they do not cause pollution of water flows, they are not toxic and can be obtained from relative renewable sources,
– realistic potential of diesel fuel can be attributed to DME, BTL (RME), and GTL,
– alternative (bio)fuels future depend on economic and politic factors; considerable reduction or exemption of taxes will enable their better promotion, and
– the dependence on fuel import cannot be made smaller if the country does not invest in the development of local raw material bases for biofuels. Foreign currency spent for import of crude oil, whose cost constantly grows, will remain in the country helping to provide considerable economic development (of rural regions) and ecology benefits.

List of abbreviations

BTL – biomass to liquid
CNG – compressed natural gas
CTL – coal to liquid
DME – dimethylether
EtOH – ethyl alcohol
GTL – gas to liquid synthetic fuel
LNG – liquefied natural gas
MeOH – methyl alcohol
Mtoe – crude oil eqivalent
RME – rapeseed methyl ester

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