Ethanol use in heavy-duty engines: alternatives and technical problems to solve

FAPESP
FAPESP Workshop on Ethanol Based Engines for TransportationBiodiversidade & Química
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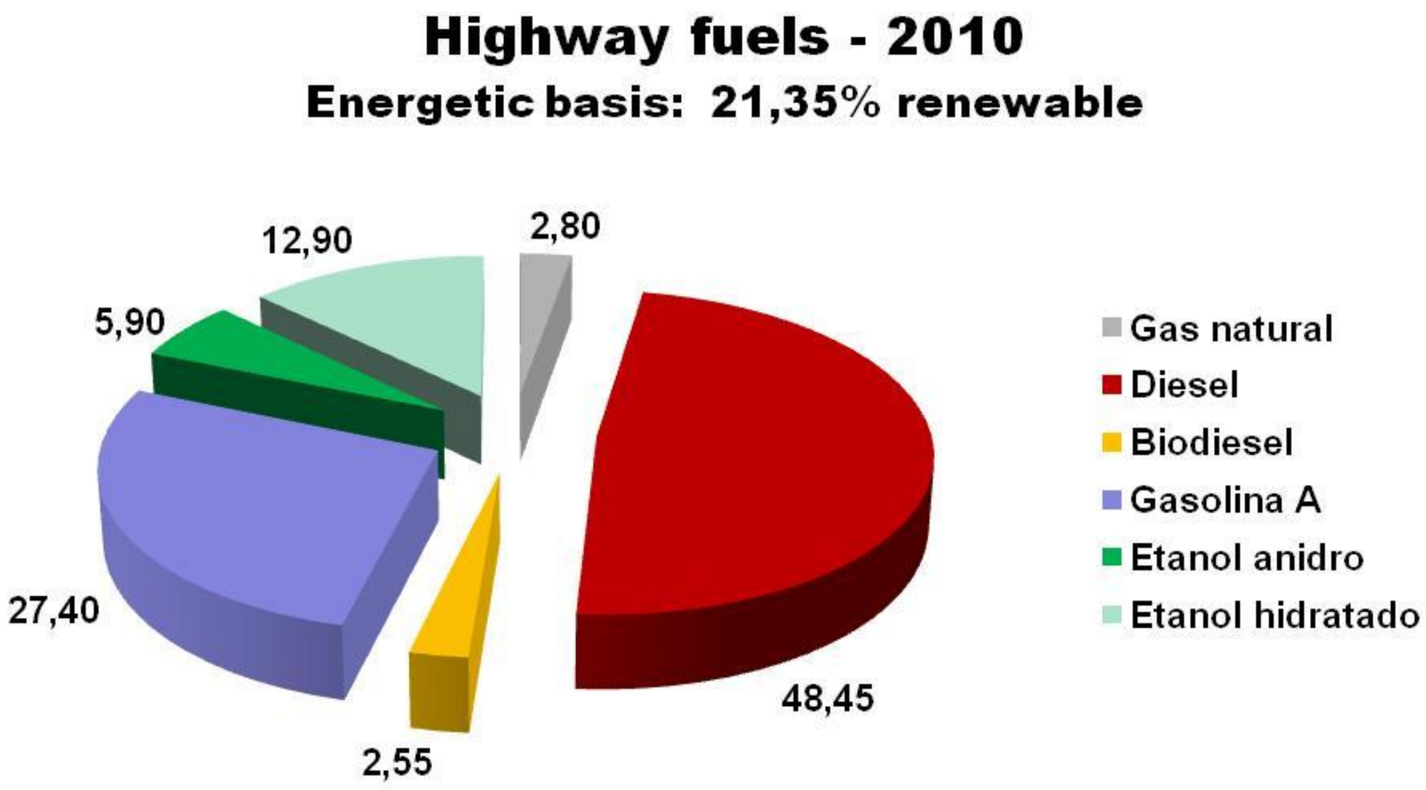
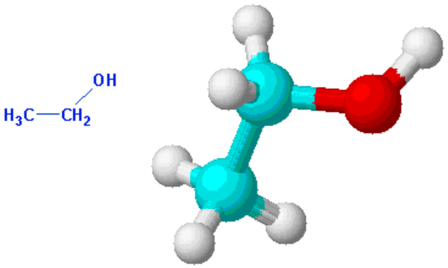
FAPESP – São Paulo, 04 de outubro de 2012

Renewable vehicle fuels in Brasil

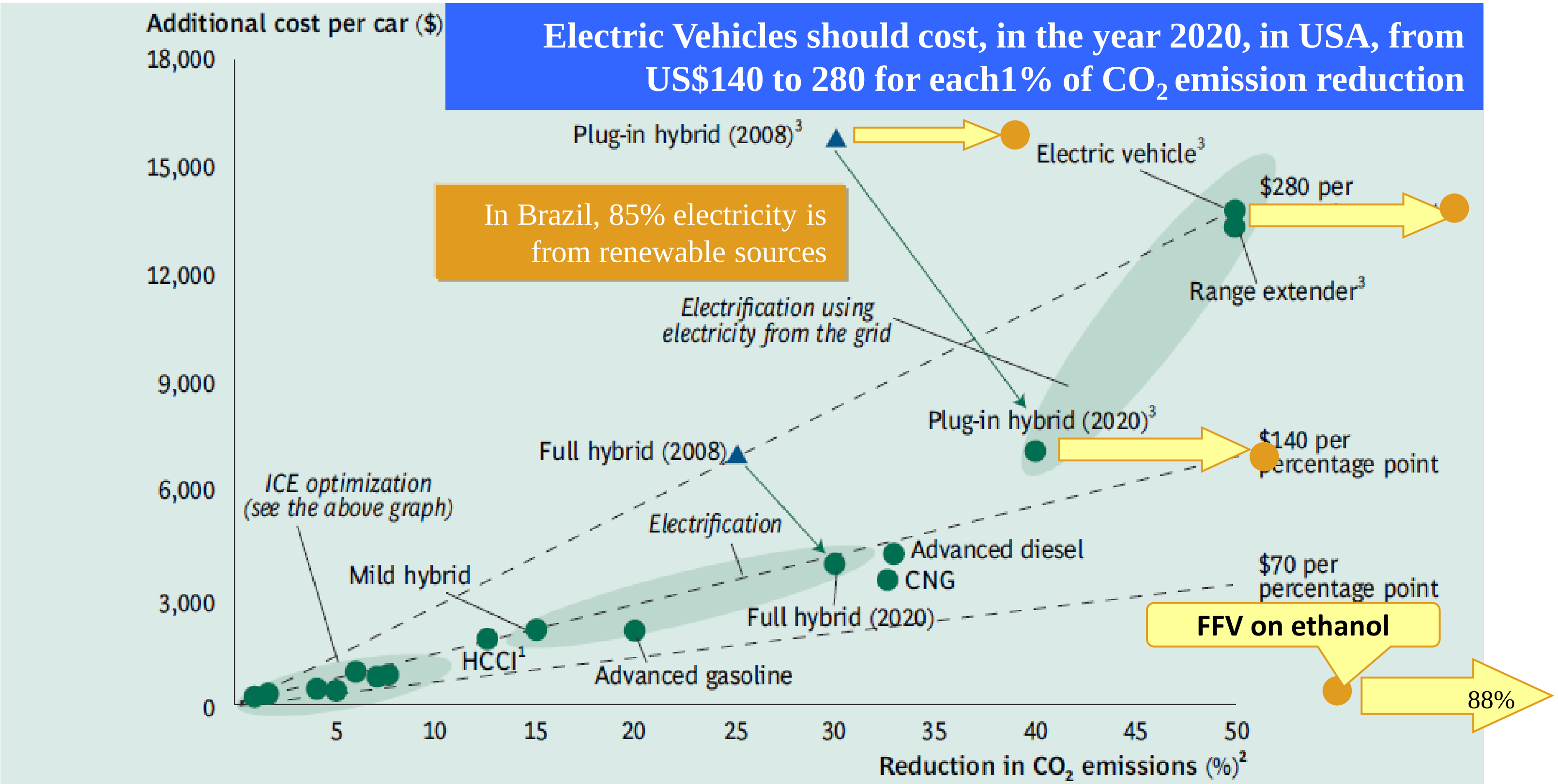


Ethanol is a good fuel for S-I engines

- **Ethanol is an alcohol, a pure substance composed by C_2H_5OH molecules.**
- **The sugarcane ethanol contains also some water and traces of impurities from production process.**
- **Two types of ethanol are employed as fuel in Brazil:**
    - **Anhydrous ethanol – low water content (0,4% by volume, max.); it is obtained from the regular ethanol by water elimination (molecular sieve). This product is to be blended with gasoline (20 to 25% v/v).**
    - **Regular ethanol – wet – up to 4,9% water by volume. Produced by direct distillation. Used as pure fuel in ethanol or Flex-fuel engines.**



Ethanol and CO2 emissions



Source: BCG analysis.
Note: Each label in italic type represents a set of technologies.
[1]HCCI = Homogeneous charge compression ignition.
[2]All CO_2-improvement numbers refer to a base gasoline engine.
[3]Values are calculated assuming 586 grams per kilowatt-hour (g/kWh) of carbon intensity from power generation.

The Boston Consulting Group - "The Comeback of the Electric Car?" - jan/2009

The problem: renewable fuel for C-I engines

- **Possible renewable substitutes for diesel:**
  - **Straight vegetable oils**
  - **Biodiesel (poli-esters of vegetable oil or animal fat)**
  - **Ethanol (and its difficulties)**
  - **Diesel from renewable raw materials (some from sugar cane → yet to prove technical and economic feasibility)**

Straight vegetable oil in engines: problems

Brasil: 60h of operation with sunflower oil – tractor engine.

Biodiesel option: cost, seeds and taxes

Blend evolution (Law n.11.097/ 2005)

2005 to 2007	2008	2009	2010	2013 and after
2% Permited	2% Mandatory	2% Mandatory	2% Mandatory	5% Mandatory
	2% jan-jun 3% jul-dec	3% jan-jun 4% jul-dec	5% jan 2010	

Biodiesel option: cost, seeds and taxes

Challenges to biodiesel increase its participation in the Brazilian energy matrix:

- **Reduction of production costs (today is much greater than diesel oil from petroleum)**
- **Development of non – food raw material for biodiesel → there are lots of non–edible types of seeds, but insufficient knowledge; technology and productivity to be developed**
- **To evolve to a market-driven condition; it must be competitive without huge tax exemptions**
- **Today → Biodiesel program is still under Federal umbrella**

Heavy-duty vehicles and ethanol

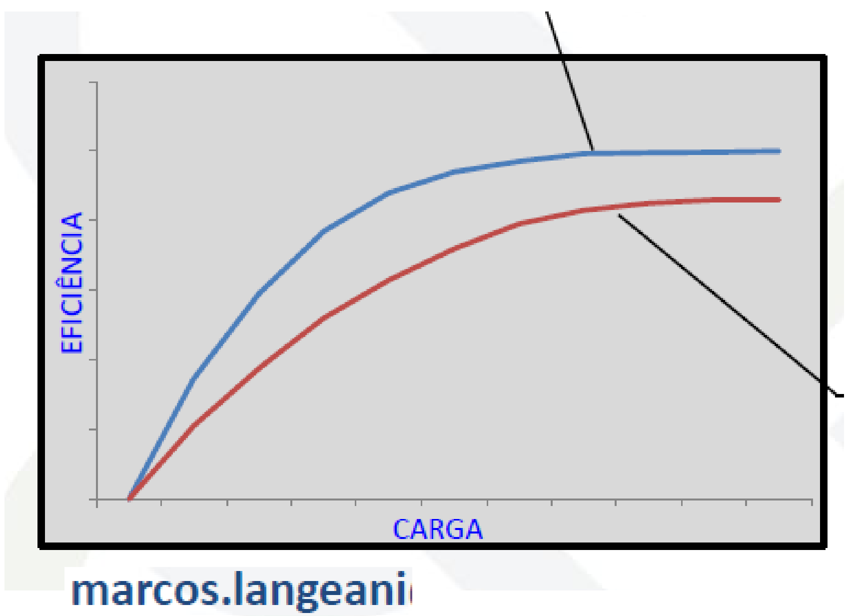
Challenges to employ ethanol fuel in C-I engines:

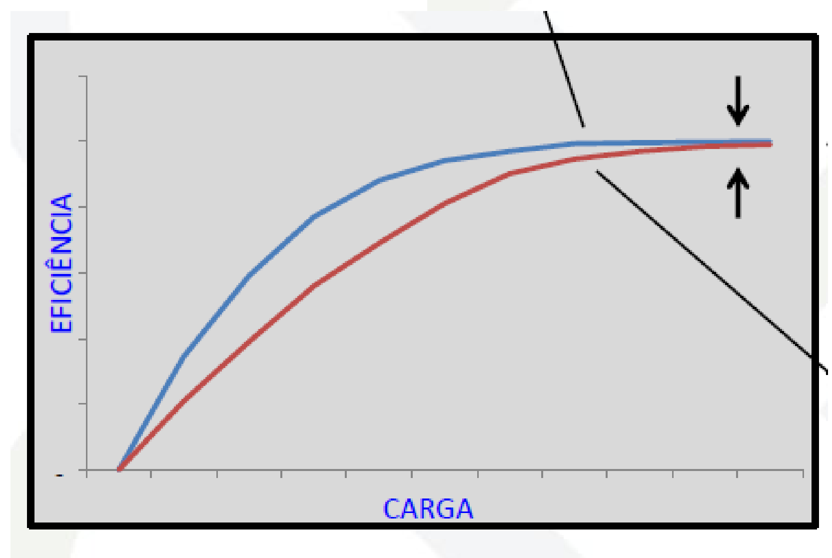
- **Since ethanol has high ON, it is a poor C-I fuel; its lubricity is also smaller than required by the injection system;**
- **How to use ethanol in C-I engines?**
  - **To transform the C-I engine in a S-I engine**
  - **To blend ethanol with diesel (also some co-solvent)**
  - **To use the dual concept: create an homogeneous mixture of ethanol and air (fumigation or injection) to substitute the diesel partially (diesel auto-ignition acts as a spark)**
  - **To use surface ignition with glow plug**
  - **To use additives to improve ethanol CN and lubricity**

Transformation of C-I engine in a S-I engine:

- This option was analyzed in the 80's but was abandoned;
- The option implies in modify the engine to adapt it to the available fuel; load control by air restriction; spark plug is added to begin the combustion; near stoichiometric mixtures; all advantages of the C-I engines are lost;
- There is loss of efficiency for high loads; at partial load, the reduction is even more dramatic;
- The increase of fuel consumption is high, due to smaller efficiency of the S-I engine and smaller heat content in the ethanol.
- The final balance proved uneconomical

There is, however, a recent study (Langeani, 2011) proposing an extensively modified ethanol S-I engine, which can overcome the drawbacks of this solution. Direct injection, turbo-charging, stratified charges and huge use of electronics to control engine are adopted.





Ethanol – diesel blends

Blends of ethanol and diesel (with some co-solvent), or emulsions (with some emulsifier); this strategy can achieve from 3% to 40% of ethanol in the diesel; technology developed again from 1999 to 2005.

Strategy to use ethanol in C-I engines without modifications → to reduce PM; but CO and HC emissions are increased.

Phase separation: above ~5%

Co-solvent needed for blends

Reduced CN and viscosity

Small amounts of ethanol have small effects on performance – but small benefits too.

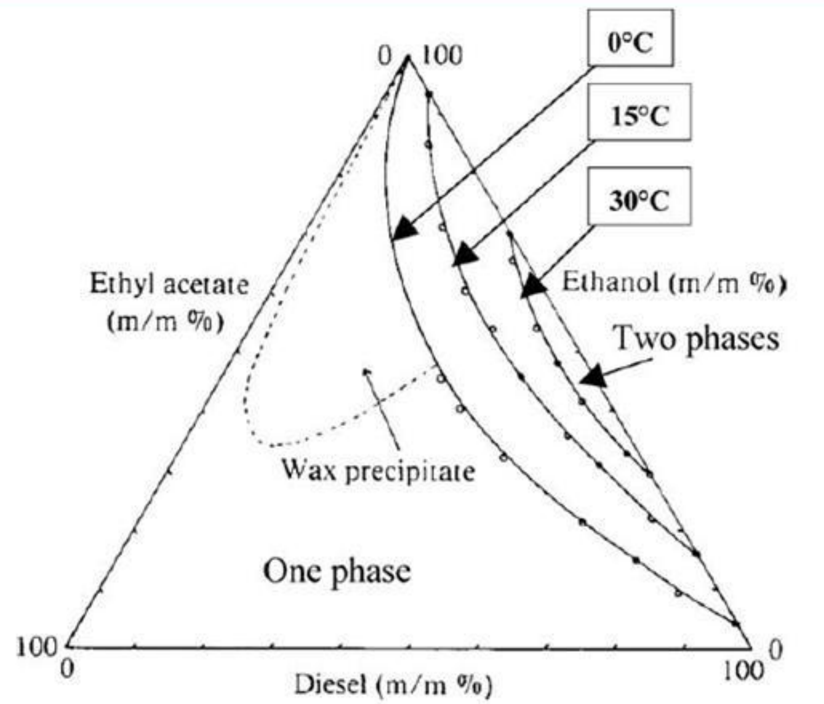


Fig. 2. Liquid–liquid ternary phase diagram for diesel fuel, ethyl acetate and dry ethanol mixtures (after Letcher, 1983).

Review Paper

Ethanol–diesel fuel blends—a review

Alan C. Hansen [a,*], Qin Zhang [a], Peter W.L. Lyne [b]

Bioresource Technology 96 (2005) 277–285

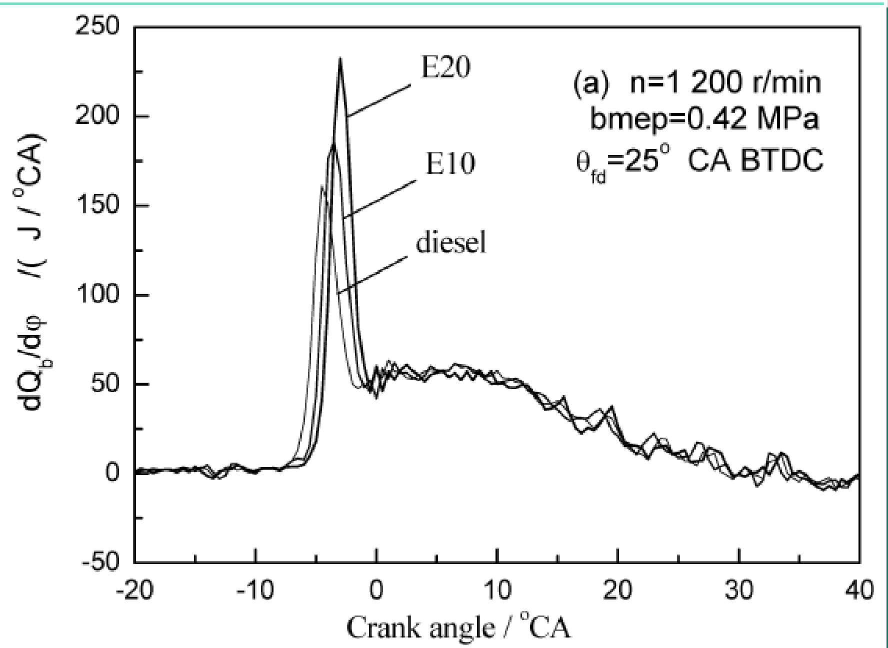
Ethanol – diesel blends → effects on combustion

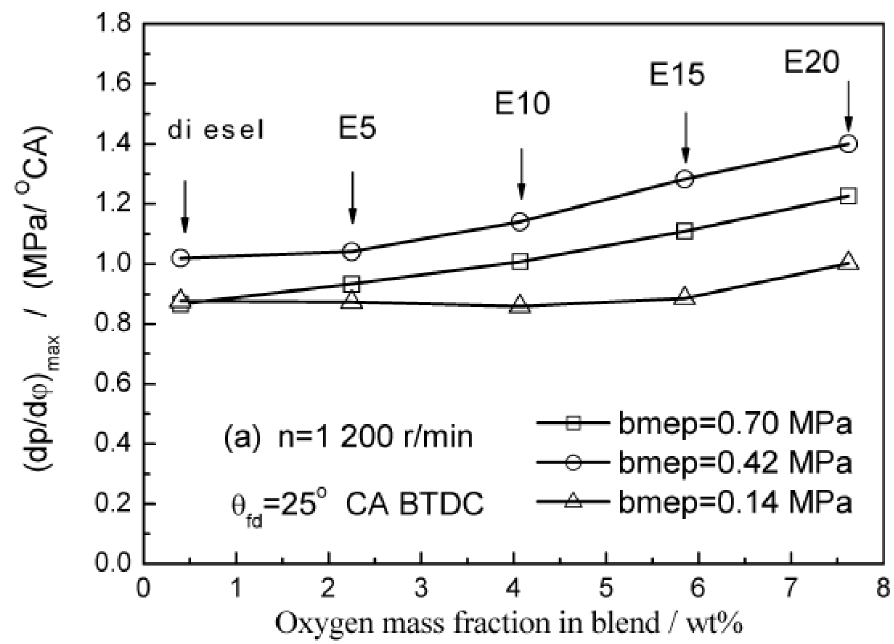
As the ethanol percentage increases, also increases the ignition delay and maximum rate of pressure rise.

Combustion characteristics of a compression ignition engine fuelled with diesel–ethanol blends

W Li, Y Ren, X-B Wang, H Miao, D-M Jiang, and Z-H Huang*

(2008)



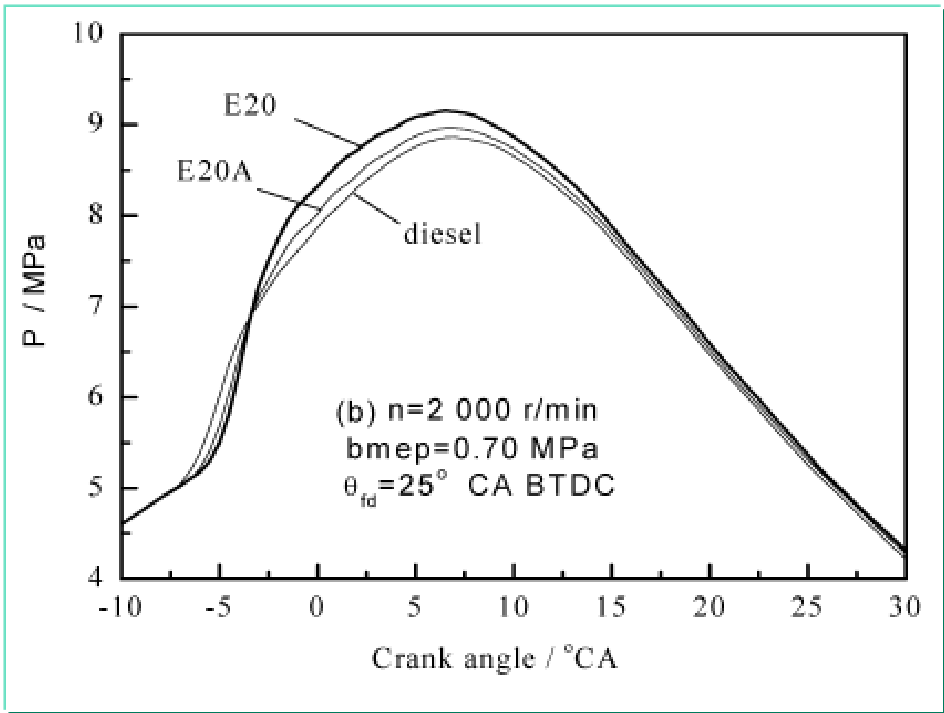


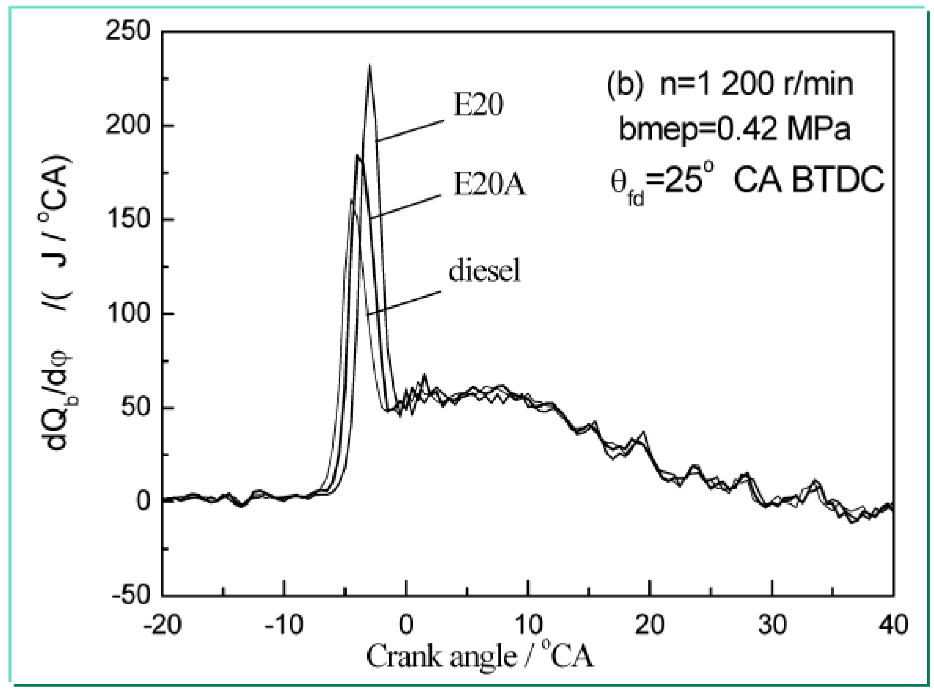
Proc. IMechE Vol. 222 Part D: J. Automobile Engineering

Ethanol – diesel blends → effects on combustion

An ignition improver can reduce the differences between ethanol blend and pure diesel combustion characteristics

(same source)

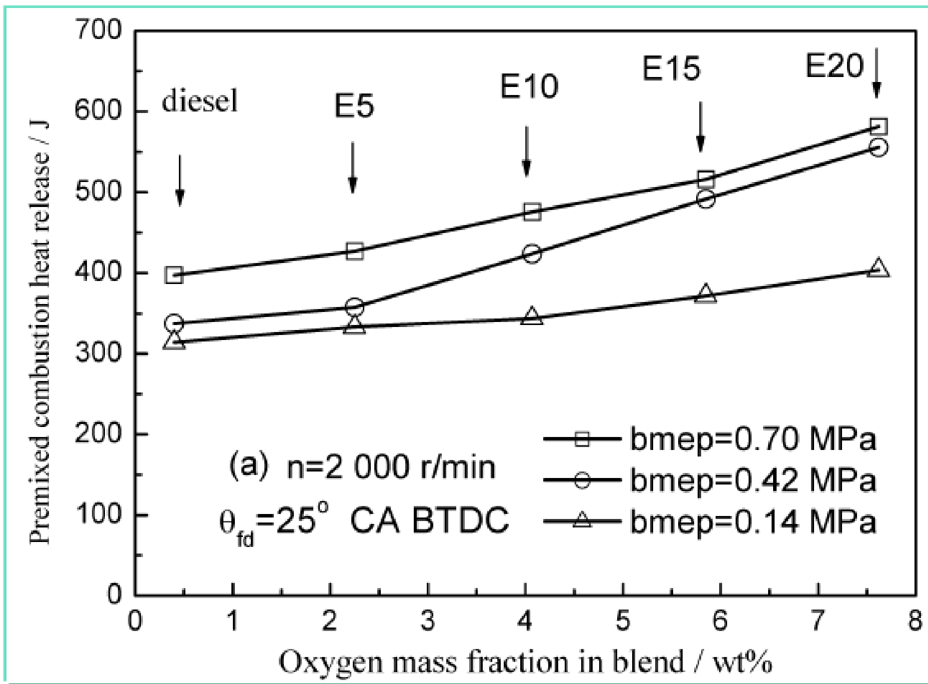


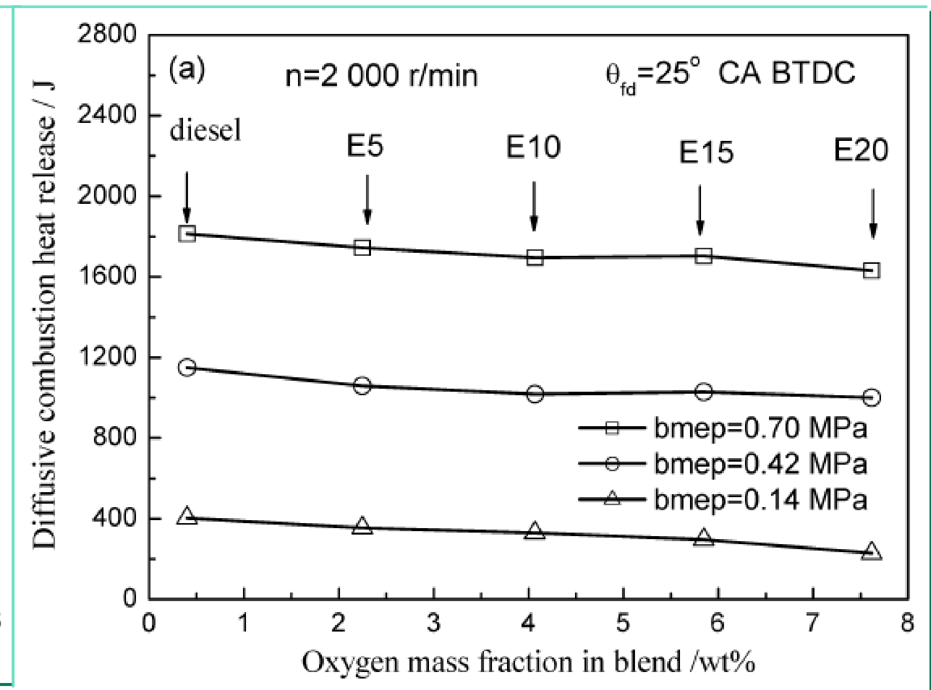


Ethanol – diesel blends → effects on combustion

Ethanol increases the importance of pre-mixed mode of heat release from combustion;

(same source)



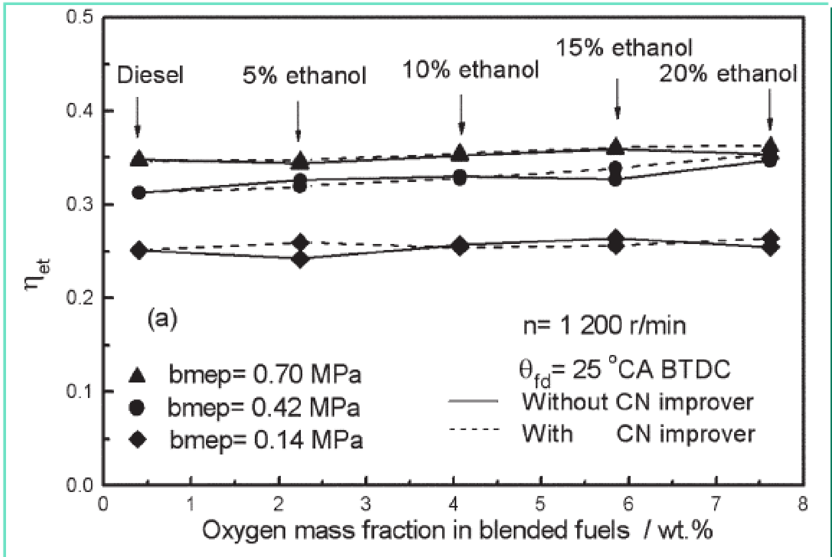


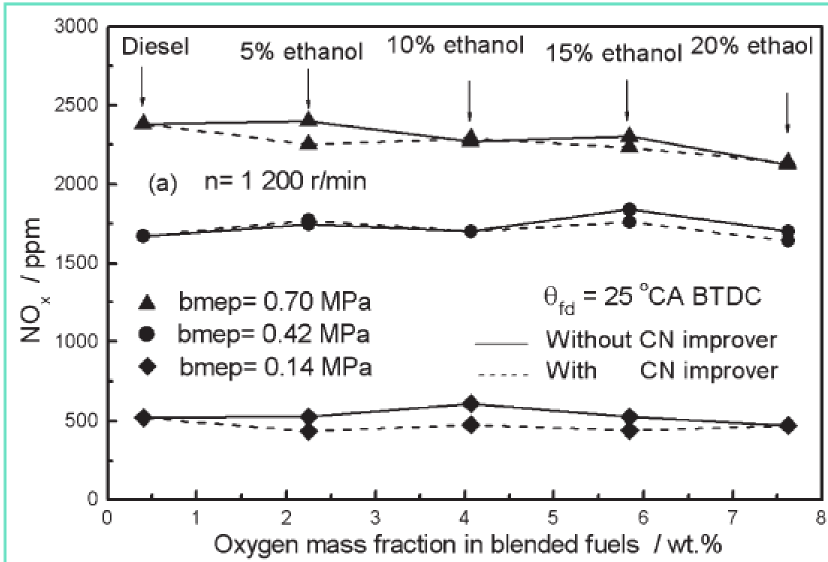
Ethanol – diesel blends → effects on emissions and efficiency

The fuel consumption is increased, but the thermal efficiency is almost constant; NOx emissions are almost constant. CO and HC emissions levels, however, are increased (not shown).

Effects of the addition of ethanol and cetane number improver on the combustion and emission characteristics of a compression ignition engine **(2008)**

Y Ren*, Z-H Huang, D-M Jiang, W Li, B Liu, and X-B Wang





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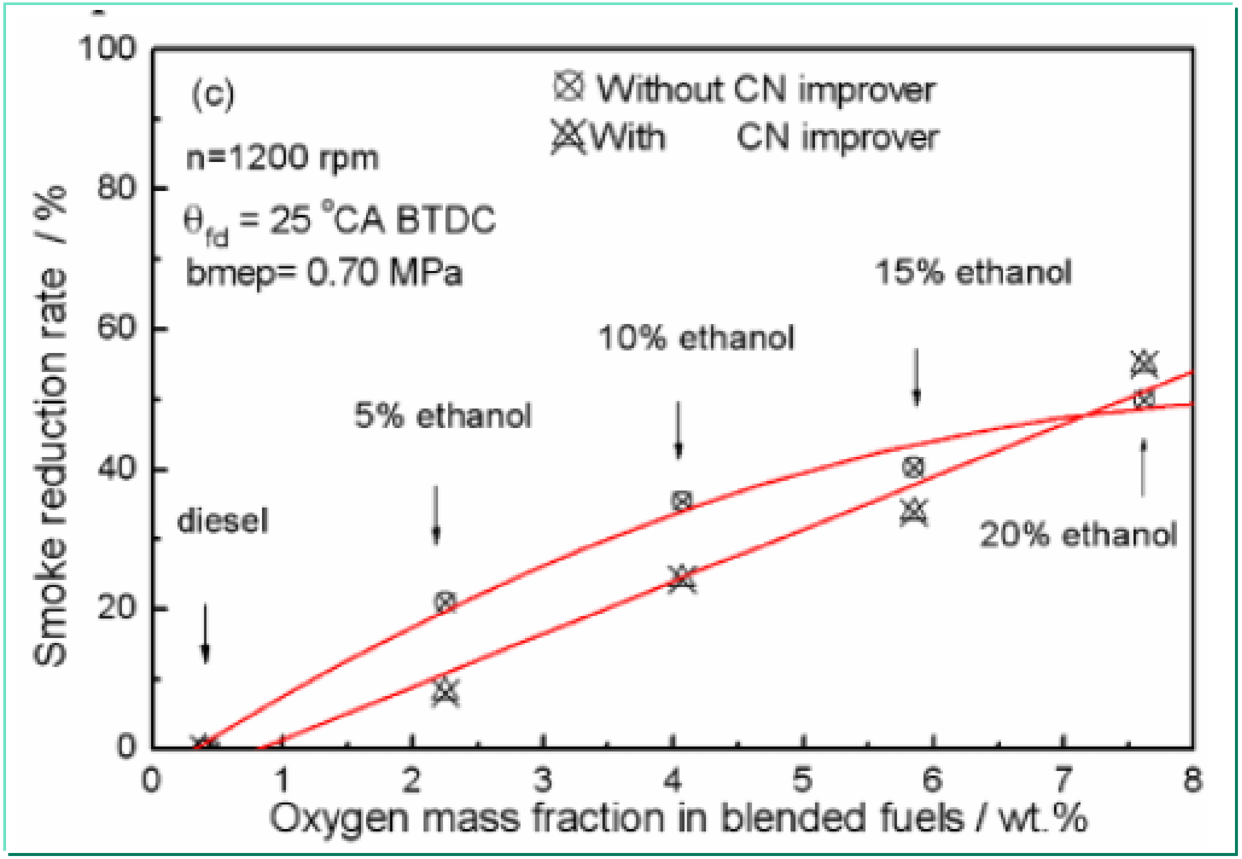
Ethanol – diesel blends → effects on emissions and efficiency

The best effect on regulated emissions is on PM: even with a small amount of ethanol, the smoke reduction can be of near 20%. On the other hand, with cetane improver the benefit is not so high. (same source)



BIOScopes

Blending ethanol in diesel

Carmen Millán Chacartegui – Abengoa Bioenergy
Juan Emilio Gonzalez Lopez – O2Diesel
Francisco Soriano Alfonso – Abengoa Bioenergy
Päivi Aakko – VTT Processes, Energy and Environment
Carlo Hamelinck – Ecofys
Geert van der Vossen – Ecofys
Hans Kattenwinkel – Ecofys

Ethanol – diesel emulsions

2007 Report

Table 2-1. Ethanol-diesel formulations from different manufacturers (Nylund et al. 2005).

Company /producer	**Sekab / Aspen Petroleum**	**O_2Diesel (AAE Technologies / Octel Starregon)**	**Pure Energy**	**Akzo Nobel**	**Sekab**
Product / denotation	**Dalco**	**O_2Diesel^{TM}**	**E-diesel**	**e-diesel**	**Etamix D3**
Type of					
Diesel	Swedish "MK 1"	Number 2 diesel	Number 2 diesel	Diesel fuel	Swedish "MK 1"
Alcohol	Fuel ethanol	Fuel ethanol	Ethanol	Anhydrous ethanol	Ethanol derivative
Additive	Dalco additive	AAE 07+ cetane improver	Puranol additive	Beraid ED10	Not specified
Blending	Mixing 20 h at 70 °C	Splash blending	Splash blending	Splash blending	Splash blending
Result	Emulsion	Micro emulsion	Micro emulsion	Micro emulsion	Micro emulsion
Composition					
Diesel	82 %	92 %	80 – 84 %	> 80 %	90 %
Ethanol	15 %	7.7 %	15 %	15 %	10 % (derivative)
Additives	3 %	< 1 %	1.5 - 2 %	0.5 – 5 %	Not specified

Ethanol – diesel emulsions

Diesel: 10ppm S; RME30: 30% biodiesel; DI-EtOH: 10% ethanol
Engine: Euro 3

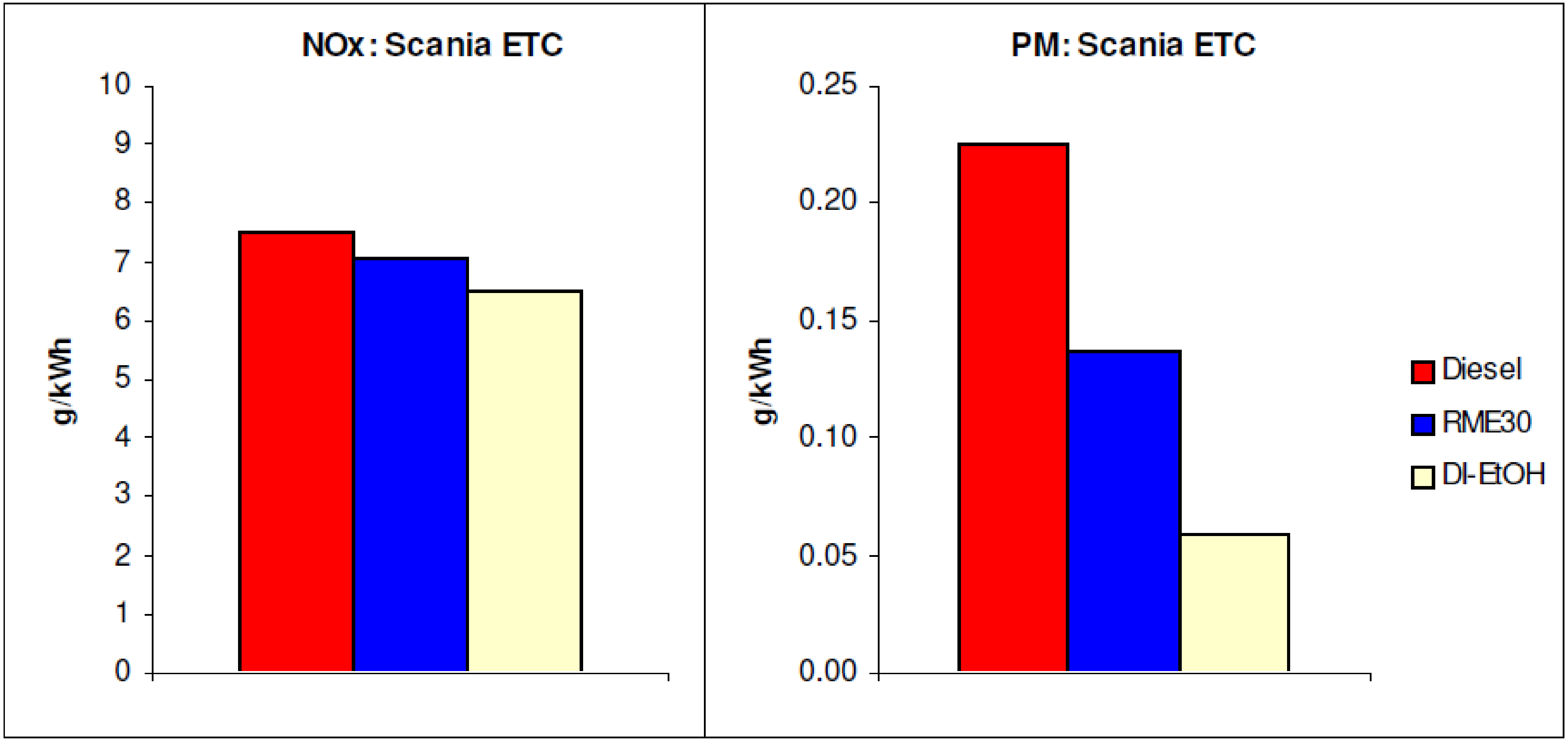


Figure 12. NO_x and PM emissions over the ETC test cycle with Scania engine using biofuels.

Dual fuel system: partial substitution of diesel by ethanol:

- **Previous experience, also in the 80's: ethanol was carbureted; diesel injection acts as ignition source for air–ethanol mixture; some degree of substitution is possible, but with a huge increase in CO and HC emissions (engines without post-treatment); poor load control.**
- **In recent works, ethanol is injected in the inlet port and electronic load control is employed; in some cases, ethanol is evaporated to obtain a more homogeneous mixture with air.**
- **In this option, the engine can run only on diesel, or in dual fuel mode; PM can be reduced; a small NOx reduction can also be obtained. CO and HC emissions, however, increase.**

Dual fuel system: partial substitution of diesel by ethanol:

Ethanol Fumigation of a Compression-Ignition Engine Using Advanced Injection of Diesel Fuel

Jonathan Chaplin, Rimfiel Bin Janius

1987 ASAE Trans. V30 p. 611-614

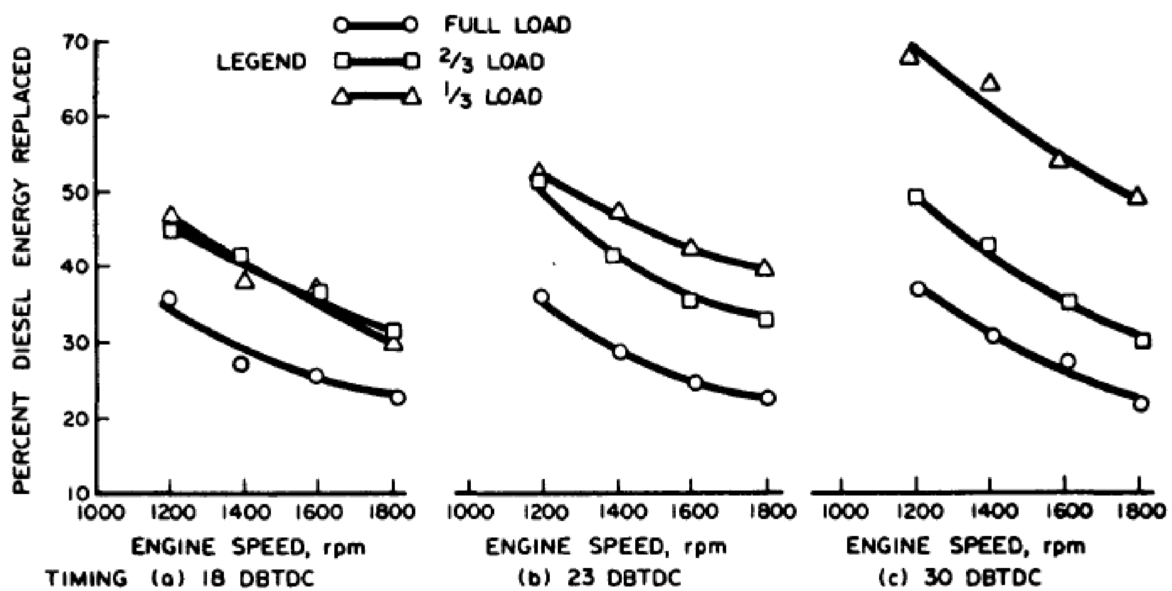


Fig. 7—Percentage of diesel fuel replaced by ethanol at 45 g/min fumigation rate.

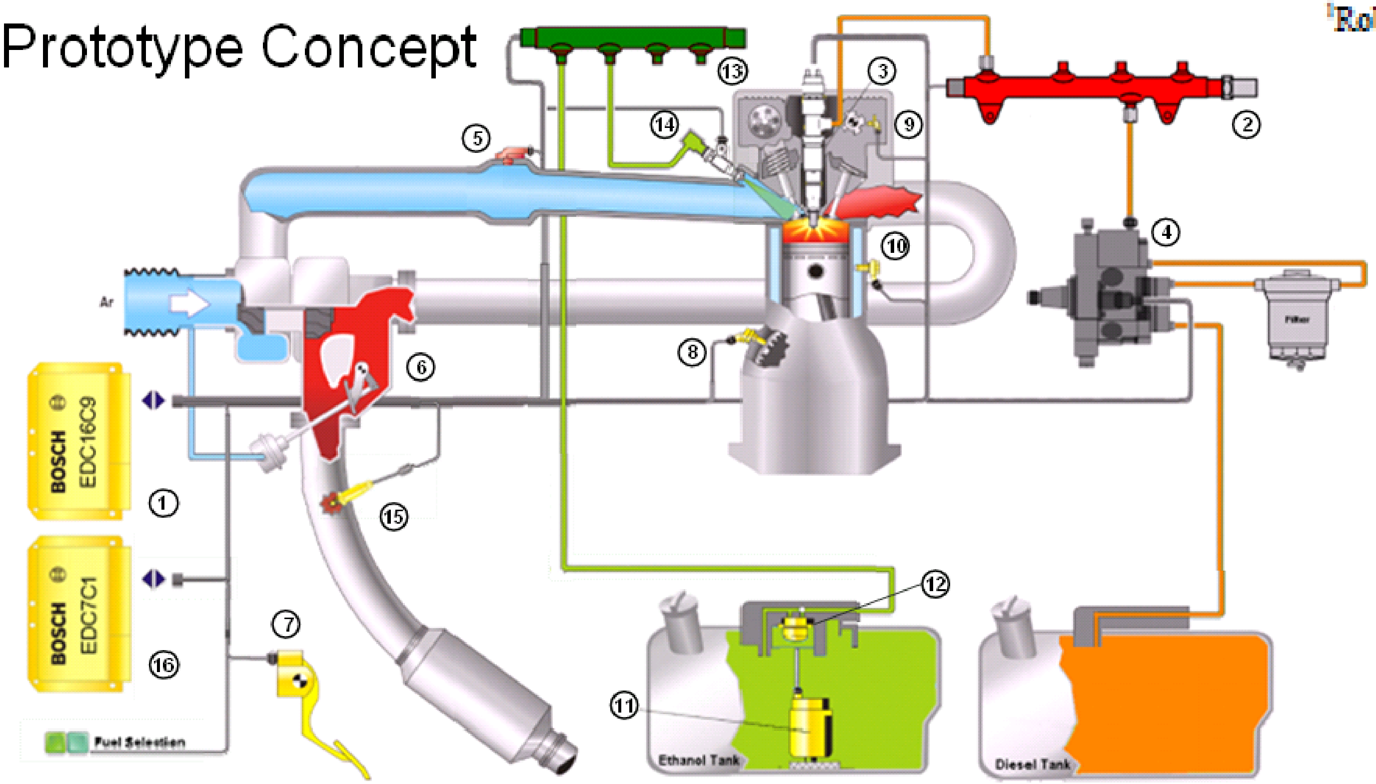
Dual fuel – injected ethanol experience in Brazil

An Experimental Study of Diesel-Ethanol Combustion Controlled Electronically

Salles, Eduardo[1]
Zambotti, Anibal[1]

[1]Robert Bosch Ltda

1st Prototype Concept



01 – ECU Diesel
02 – Rail Diesel
03 – CRI - Diesel
04 – Diesel Presure Pump
05 – Boost Pres/temp Sensor
06 – Boost Actuator
07 – Accelerator Pedal
08 – Engine Speed Sensor
09 – Engine Phase Sensor
10 – Coolant Temp. Sensor
11 – Ethanol Fuel Pump
12 – Ethanol Pressure Regulator
13 – Ethanol Rail
14 – Ethanol Injector
15 – Oxigen Sensor
16 – ECU Ethanol - Slave

Dual fuel – injected ethanol experience in Brazil

Partial substitution of diesel by ethanol:

- **Some results are shown in the figures below: stable combustion was achieved;**
- **The combustion of an homogeneous mixture of ethanol and air produced a very rapid heat release**

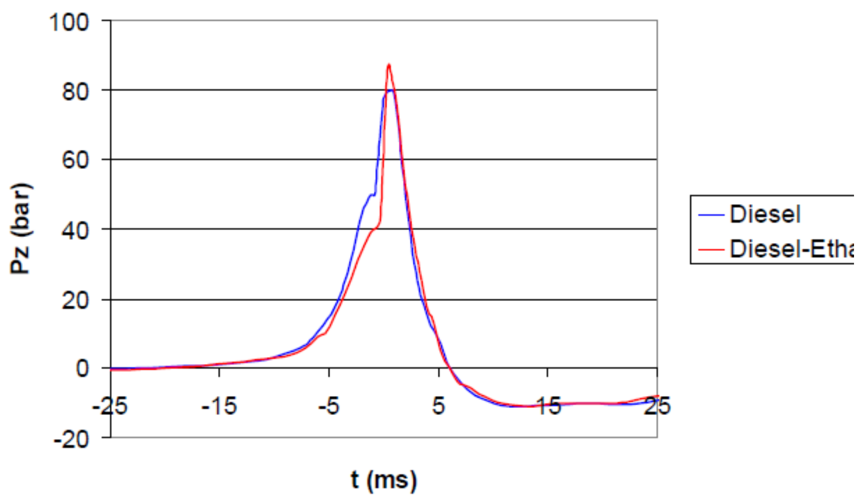


Figure 8- Comparison of combustion pressure curves

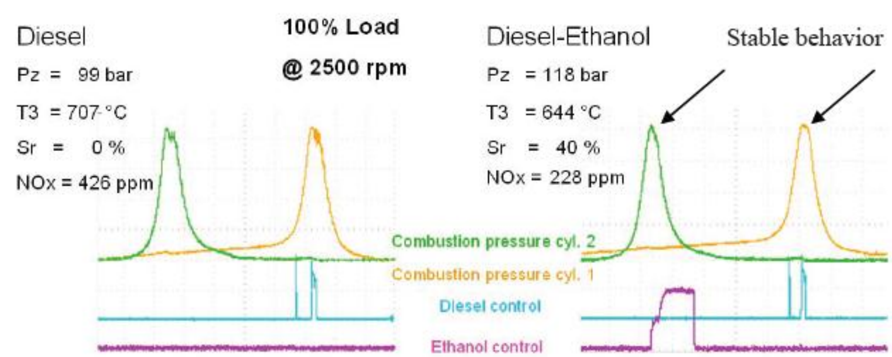


Figure 7- Comparison between Diesel and Diesel-Ethanol combustion behavior

Dual fuel – injected ethanol experience in Brazil

Partial substitution of diesel by ethanol:

- **With adequate calibration, the torque of diesel engine can be reproduced, as shown below**

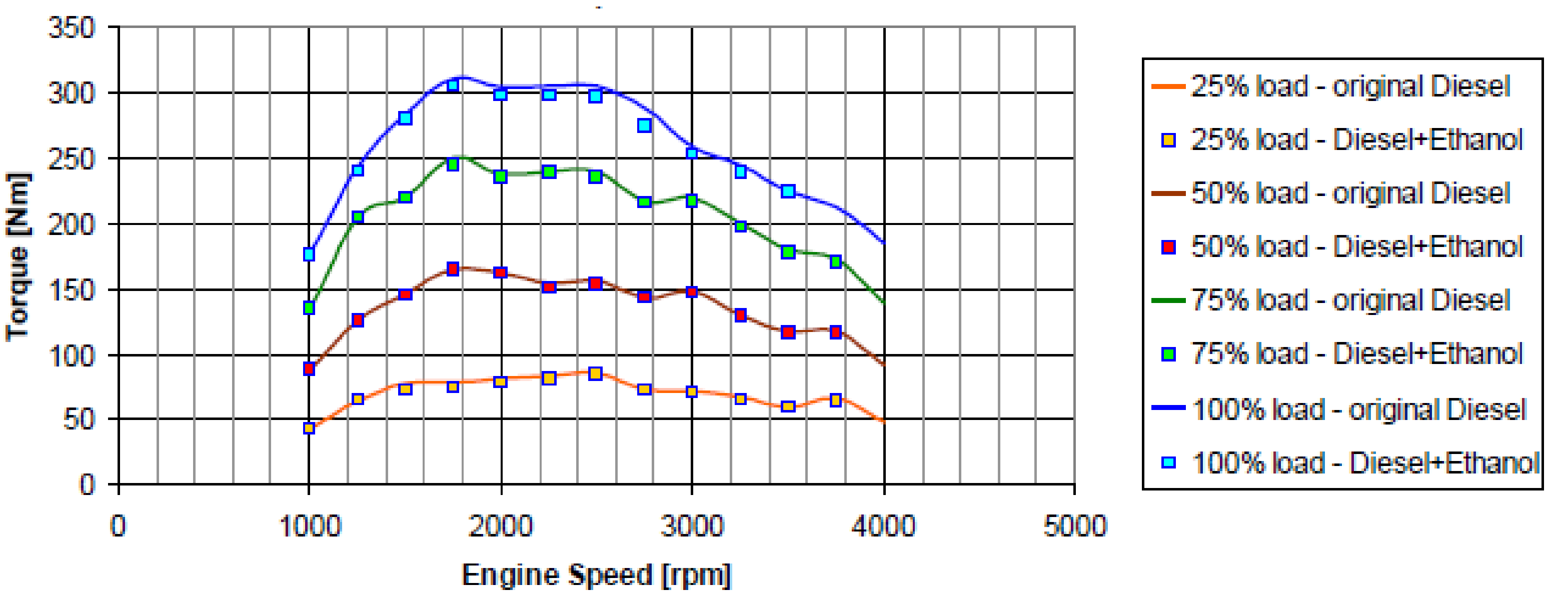


Figure 11 – Torque evaluation and breakpoint calibration definition

Dual fuel: Bosch system and Iveco truck

Ethanol Diesel Truck Engine

SAE TECHNICAL PAPER SERIES 2011-36-0319 E

Henrique Augusto Pires Rezende
Eduardo Ferreira Salles
Evandro Carlos Odlevak
Roberto Lopes Elizardo
Evandro Cruz
Sergio Molgori
Rafael Cosentino Furquim

Dataset	Speed Km/h	GCW (ton)	Diesel substitution
Diesel/Ethanol	30.57	80 (Full Load)	37.63%
Diesel/Ethanol	49.23	25 (Empty)	37.60%

Table 2 – Diesel substitution rate

Diesel substitution Ratio @ 100% Load

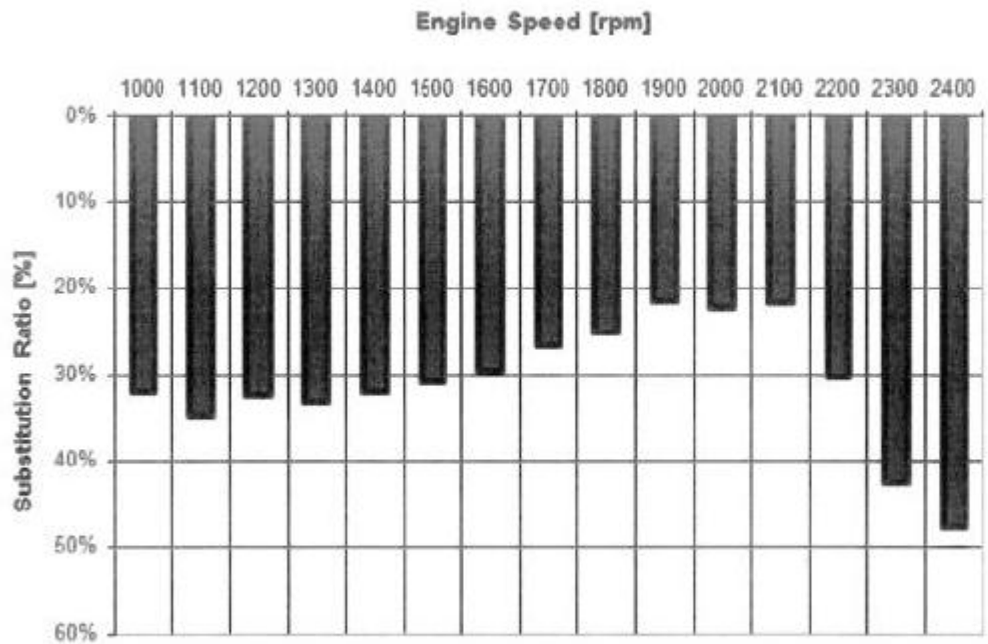
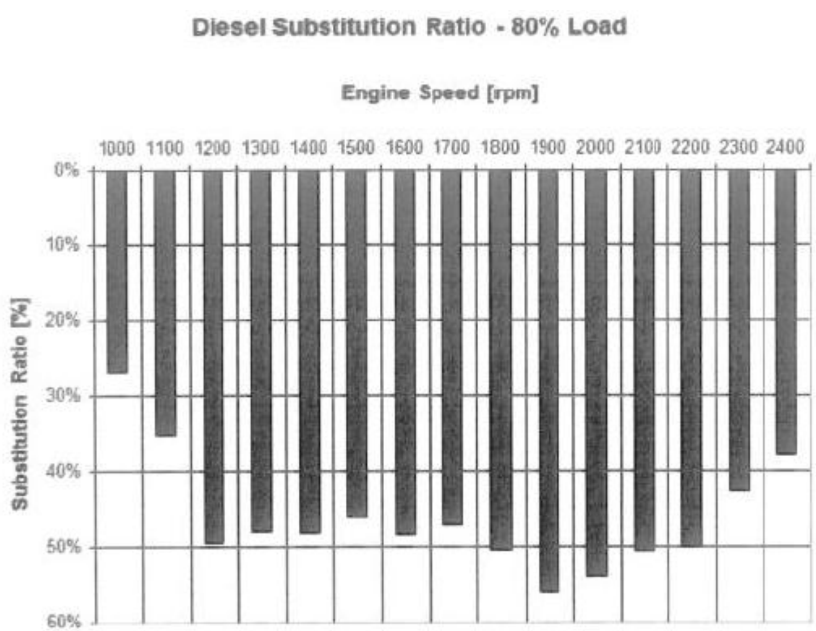


Figure 4 – Diesel substitution ratio (100% load)

Dual fuel: Bosch system and Iveco truck

The goals: same performance on dual mode

To offer a truck for sugarcane industry (market niche).



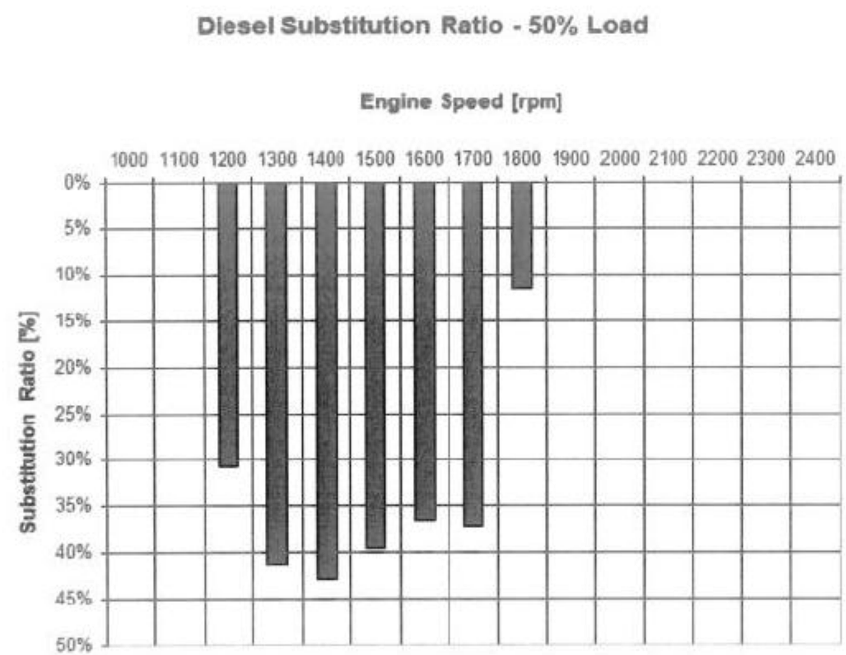


Figure 5 – Diesel substitution ratio (80% load)

Dual fuel: MAN truck (Brazil)

Presented at FENATRAN 2011. Ethanol: single point injection

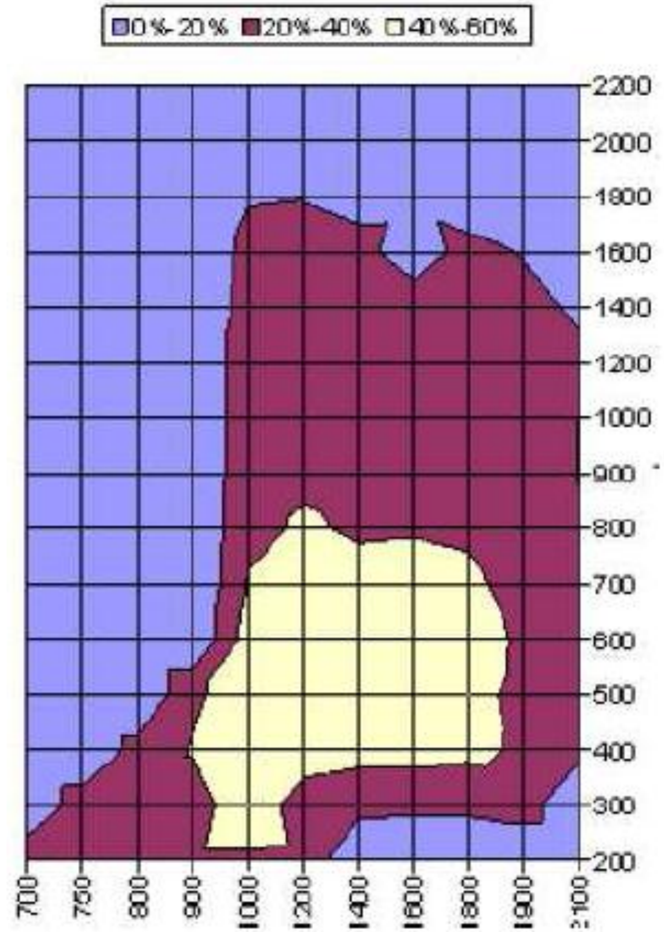
CAMINHÃO MAN TGS 33.440 6X4 FLEX DIESEL/ETANOL

PROJETADO SOB MEDIDA PARA A APLICAÇÃO CANAVIEIRA

Autor: Gian Gomes Marques

Figura 3 – Principais Características Técnicas Caminhão Flex Diesel/Etanol

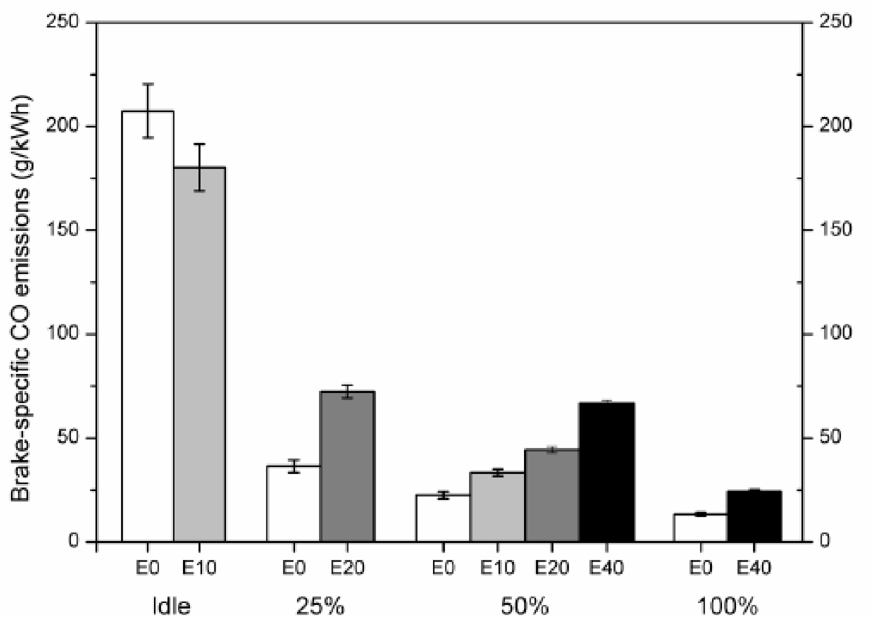
MOTOR	
Modelo	MAN D2676LF Flex Diesel/Etanol
N° cilindros/clindrada (cm^3)	6 em linha / 12.400
Potência máxima - cv @ rpm	440 @ 1.900
Torque máximo - Nm @ rpm	2300 @ 1.050
Padrão de emissões	Proconve P7

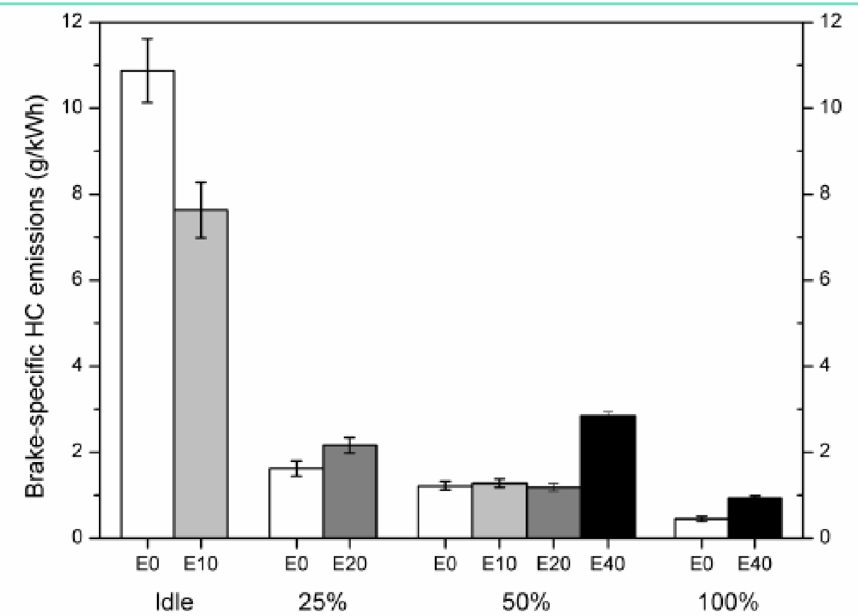


Dual fuel: evaporated ethanol

Gaseous and particle emissions from an ethanol fumigated compression ignition engine

Nicholas C. Surawski[a,b], Zoran D. Ristovski[a*], Richard J. Brown[b], Rong Situ[b,1]



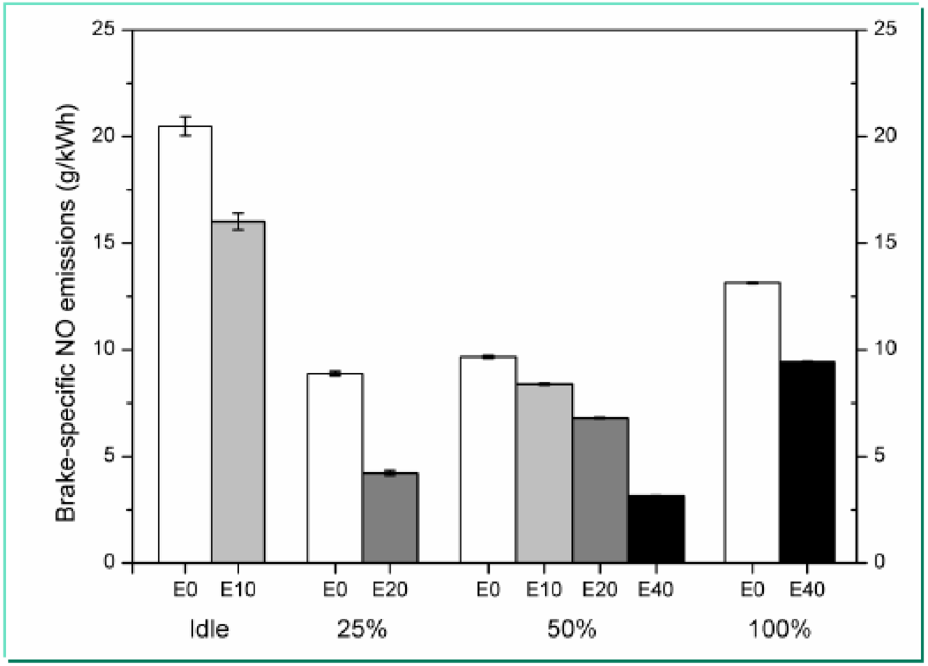


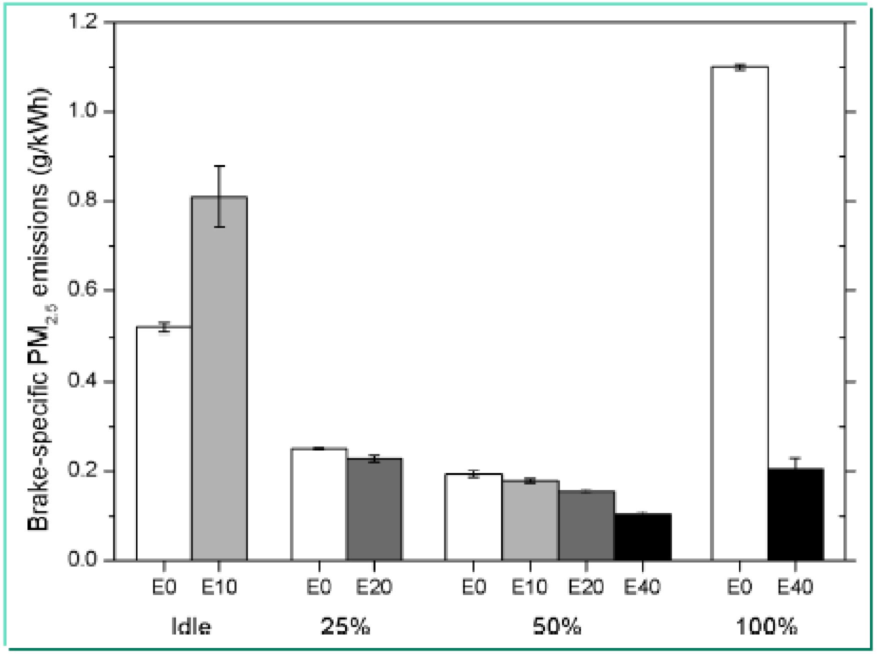
in Energy Conversion and Management, [VOL 54, ISSUE 1, (2012)] DOI: 10.1016/j.enconman.2011.10.011

Dual fuel: evaporated ethanol (same source)

Substantial PM reduction at high loads;

But: values for old I-C engine (Pré – Euro I)



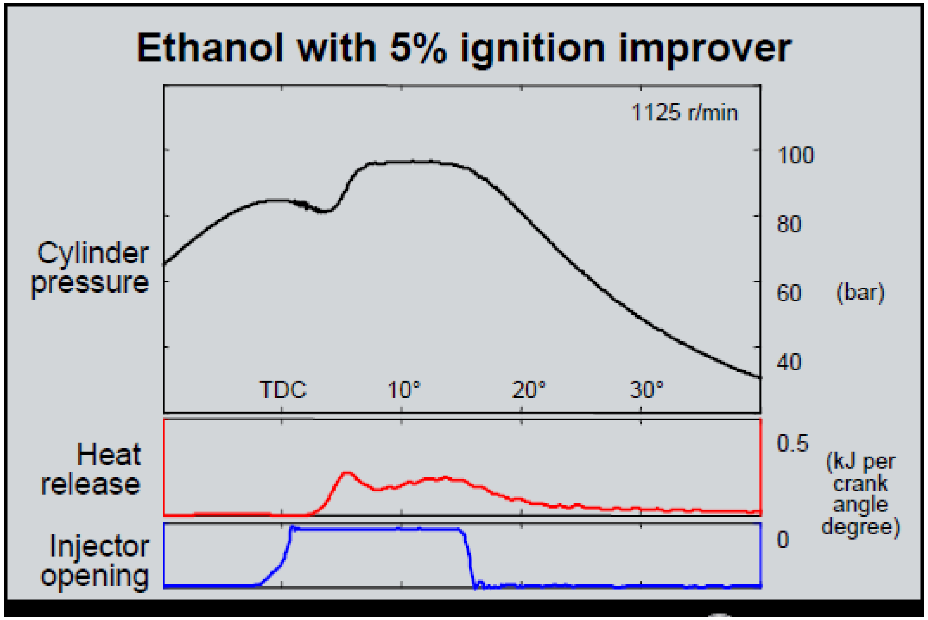


To use additives to improve CN and lubricity

- This option also was studied in the oil crisis in the 80's;
- The cetane number improver usually is a light explosive; most of time, some kind of nitrite.
- The idea is to use as much additive as necessary to obtain, with ethanol, auto-ignition like that of diesel fuel;
- Usually, a co-solvent is adopted; biodiesel can be used to this role and increase the lubricity of ethanol;
- Stockholm buses adopt ethanol with additives to reduce urban emissions since the early 90's (NOx and PM);
- This solution can be adopted only by environmental motivation, since cost is high (GHG emissions);

Ethanol with additives: Scania solution

- The engine was modified to a very high compression ratio (28:1) and uses a ethanol resistant fuel system
- Lubricating system adopts an oil compatible with ethanol
- Increased flow injectors
- Reduced service interval
- Oxidizing catalyst
- EGR (NOx)



Ethanol fuel in diesel engines for energy efficiency

Björn Westman
Engineering Director

Ethanol with additives: Scania solution

- **The fuel (by mass): 92,2% wet ethanol (6,4% water) + 5% ignition improver +2,8 MTBE and isobutyl alcohol**
- **Ignition improver: SEKAB EtamaxD (patented)**
- **Heat of combustion: 25,7 MJ/kg X 44,5 MJ/kg**
- **Thermal efficiency: up to 43%**
- **Oxidising catalyst to reduce CO and HC emissions**
- **EGR to reduce NOx emissions**

Scania 2012 – ethanol C-I engine option in Brazil

	250 hp	*270 hp etanol*	*310 hp*
Motor	DC09 250	DC9 E02 270	DC09 310
Combustível	Diesel	Etanol	Diesel
Volume	9,3 litros	8,9 litros	9,3 litros
Sequência de ignição	1-2-4-5-3	1-2-4-5-3	1-2-4-5-3
Cilindros	5 em linha	5 em linha	5 em linha
Cabeçotes de cilindro	5	5	5
Válvulas por cilindro	4	4	4
Diâmetro x curso	130x140 mm	127x140 mm	130x140 mm
Taxa de compressão	17:1	28:1	17:1
Controle de injeção de combustível	Scania PDE	Scania PDE	Scania PDE
Controle de emissões	Scania SCR/Proconve P7	Proconve P7	Scania SCR/Proconve P7
Potência máx.	184 kW (250 hp)	198 kW (270 hp)	228 kW (310 hp)
a rpm	1900	1900	1900
Torque máx.	1150 Nm	1.200 Nm	1.550 Nm
a rpm	1000-1300	1100-1400	1100-1350
Frenagem máx. do motor	173 kW	170 kW	173 kW
a rpm	2400	2400	2400

Ethanol with additives: Scania solution

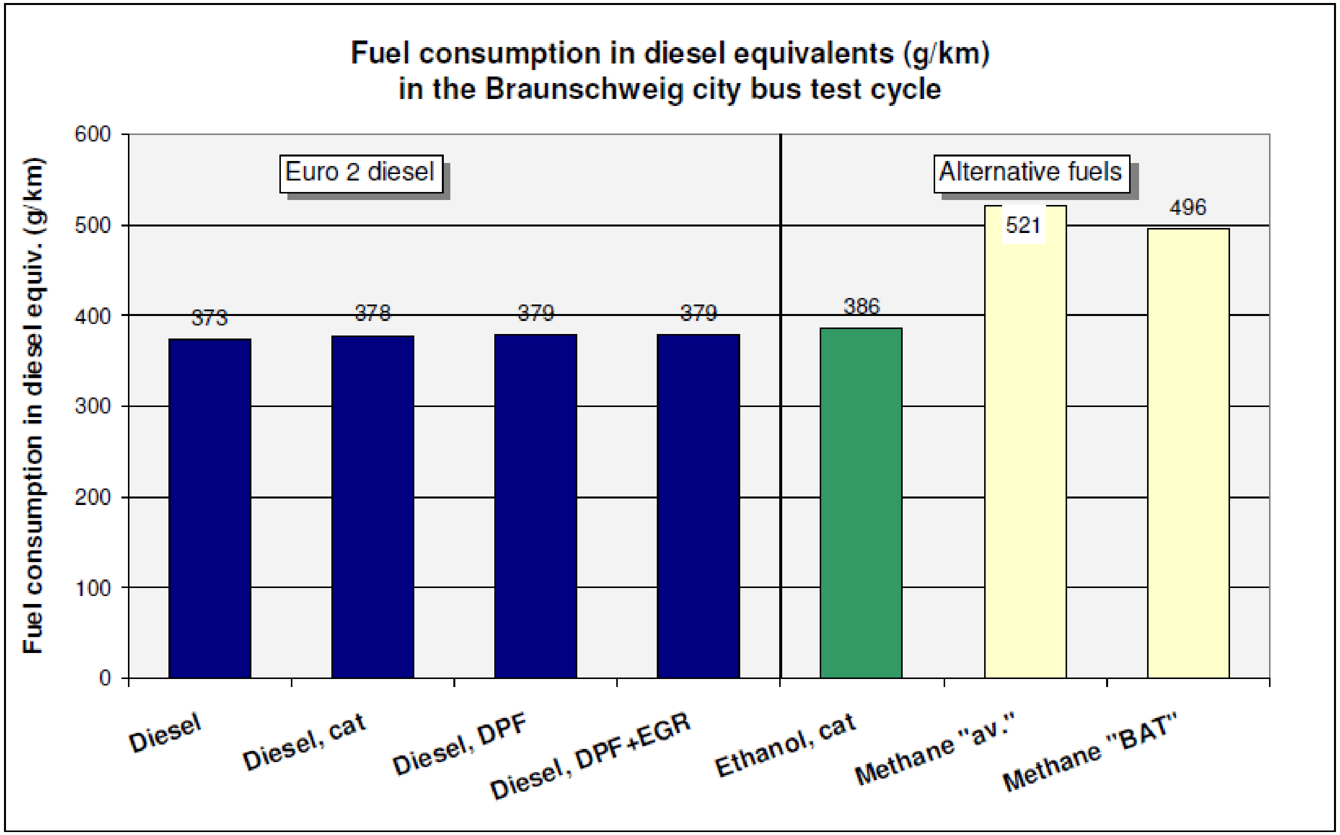
Fuel consumption comparison

Heavy-duty ethanol engines

Final report for Lot 2 of the Bioscopes project

Björn Rehnlund (Atrax) – Lot 2 coordinator
Karl-Erik Egebäck (BAFF)
Charlie Rydén (BAFF)
Peter Ahlvik (Ecotraffic)

Publication date:
February 2007



Ethanol with additives: Scania solution

Increased cost in vehicle: from 400 to 1000 Euros

Increased maintenance costs (lube oil, filters, etc.)

Cost of additives: from 7 to 10 Euro cents increase in ethanol cost

Fuel composition		
Ethanol 95%	% by weight	92,2
Ignition improver	% by weight	5,0
MTBE	% by weight	2,3
Isobutanol	% by weight	0,5
Corrosive inhibitor	ppm	90
Colour (red)		

Diesel from sugarcane

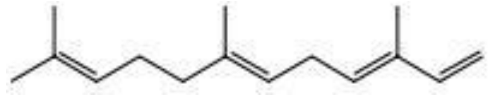
There are some research to obtain diesel–like renewable fuels using modern bioengineering and knowledge on metabolism of specific micro-organisms.

- **This route is called 3th generation bio–fuels, or bio–refineries.**
- **The objective is to obtain renewable diesel, or gasoline or aeronautical kerosine.**
- **These fuels does not require modifications in the engines or engine systems → optimal solution, from engine manufacturer viewpoint**
- **The final goal is to reduce GHG emissions**

Diesel from sugarcane

There are two enterprises working in this area in Brazil: Amyris and PS9; almost all information is confidential.

- **The Amyris route is based in genetically engineered yeast**
- **There are many possible products from pharmaceutical to renewable diesel.**
- **A blend of 10% of the diesel of Amyris + 90% of S10 diesel (containing 5% of biodiesel, by Law) was tested in a bus fleet in S. Paulo. A new test is beginning in Rio de Janeiro (2011)**
- **The principal product obtained in the bio–refinery is called Farnesene – a hydrocarbon with some isomers, containing 15 carbon atoms, 3 methyl radicals and 4 double-bonds. One of the isomer is pictured below.**



Diesel from sugarcane

PS9 route is also based in genetically modified microbe.

- **Even less information is available from this enterprise**

In both cases, Brazil was elected to development of the technology due to the availability of an efficient raw material: sugarcane; it is very important to obtain high efficiencies in the production of the sugarcane diesel, from costs viewpoint

- **The production of a renewable diesel is in the research and development phase. It is not a proven technology.**
- **The economic feasibility of this route must be shown**

Concluding remarks

C-I engines still lack a renewable substitute:

- **Straight vegetable oils needs large engine modifications**
- **Biodiesel needs new oil sources and reduction of costs**
- **Ethanol did not present regulated emission benefits when compared with Euro-5 (PROCONVE 7) diesel engines**
- **Biofuels of third generation are in their initial development**

- **GHG emissions, social development in agriculture and energetic security are the driving forces to use renewable fuels in C-I engines;**
- **All the above described routes need research and technical development, specially with regard of post-treatment devices now adopted to control regulated emissions.**