Bio-Ethers as Transportation Fuel: A Review

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What Are Bio-Ethers

- Bio-Ethers are produced by dehydration of bio based alcohols

- Bio-Ethers have superior combustion and emission characteristics as compared to other bio-fuels

What Are Bio-Ethers

- Can Be Produced by :

- Partial oxidation of biomass to synthesis gas and then to alcohols and then dehydrating them to Ethers using suitable catalysts

- The achievable yield of bio-ether from biomass via the gasification/synthesis gas route is higher than via the hydrolysis/fermentation route

- In gasification/synthesis gas route all carbon can be converted to fuel while in fermentation rout only carbon convertible to sugar can yield fuel

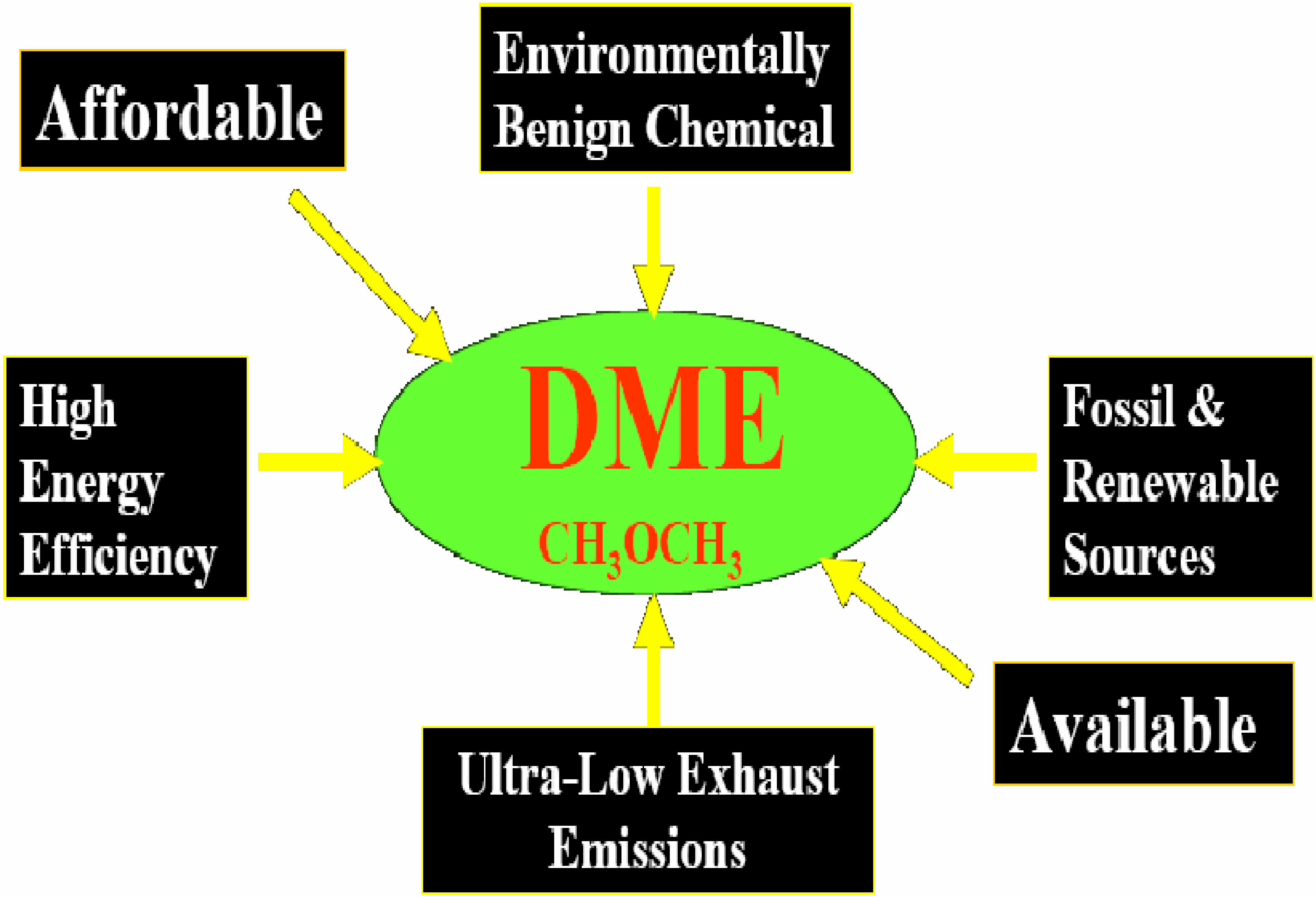
Ethers in Fuel Industry

Dimethyl Ether (DME)	✓ Alternative Fuel for CI engines
Diethyl Ether (DEE)	✓ Used as a ignition Improver ✓ Possible Alternative Fuel For CI engines
Methyl Tertiary-Butyl Ether (MTBE)	✓ Additive for gasoline
Ethyl *ter*-butyl ether (ETBE)	✓ Additive for gasoline
T*er*-amyl methyl ether (TAME)	✓ Additive for gasoline
Ter-amyl ethyl Ether (TAEE)	✓ Additive for gasoline ✓ Increases the solubility of ethanol in diesel

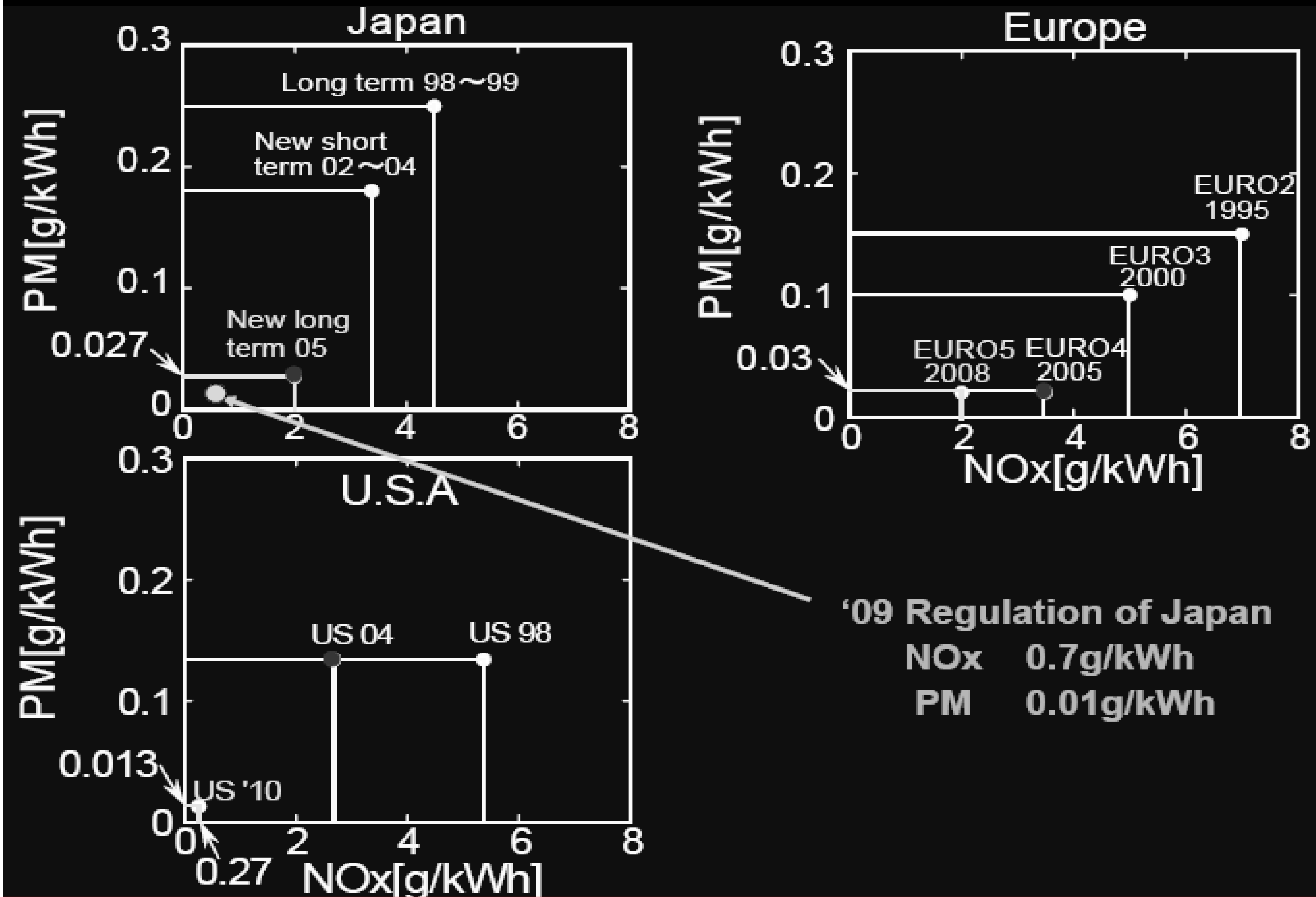
Comparison of Properties of Potential Fuel Components*

Property	DF-2 Diesel	FT Diesel	Bio-diesel	Gasoline	CNG	Methanol	Ethanol	DME	DEE
Boiling Point, ºF	370 - 650	350 – 670	36 - 640	80 – 437	n.a.	149	172	**-13**	**94**
RVP, psi @ 100 ºF	<0.2	n.a.	n.a.	8 – 15	n.a.	4.6	2.3	**116**	**16.0**
Cetane Number	40 – 55	>74	>48	13 – 17	Low	Low	<5	>55	>125
Auto ignition Temperature, ºF	~600	~600	-	495	990	867	793	**662**	**320**
Stoichimetric Air/ Fuel Ratio, Wt/Wt.	15.0	15.2	13.8	14.5	16.4	6.45	9.0	**8.9**	**11.1**
Flammability Limits, Vol. %: Rich	7.6	-	-	6.0	13.9	36.9	19.0	**27.0**	**9.5 36.0**
Flammability Limits, Vol. %: Lean	1.4	-	-	1.0	5.0	7.3	4.3	**3.4**	**1.9**
Lower Heating Value, Btu/lb	18,500	18,600	16,500	18,500	20,750	8,570	11,500	**12,120**	**14,571**
Viscosity, centipoises at ( )ºF	40 (68)	2.1 100)	3.5 (100)	3.4 (68)	-	3.5 (100)	1.19 (68)	**-**	**0.23 (68)**
Density, lb/gal	7.079	6.520	7.328	6.246	-	7.328	6.612	**5.50**	**5.946**

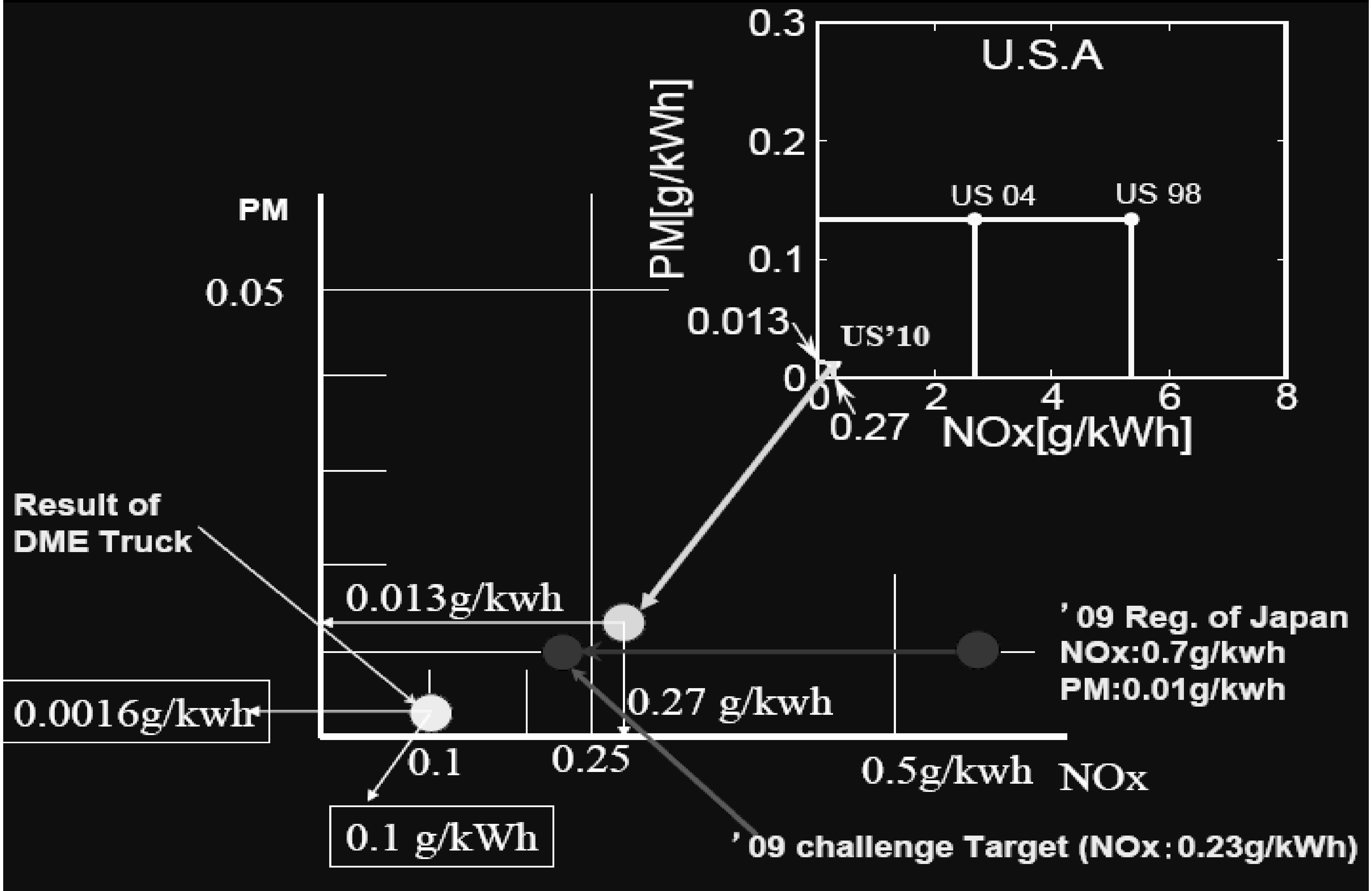
* Table compiled by N.R. Serer, Southwest Research Institute. SAE paper No : 972978


Affordable
Environmentally Benign Chemical
High Energy Efficiency
DME
CH3OCH3
Fossil & Renewable Sources
Ultra-Low Exhaust Emissions
Available

Emission Regulations



Role of DME in meeting Emission Regulations



Engine Studies

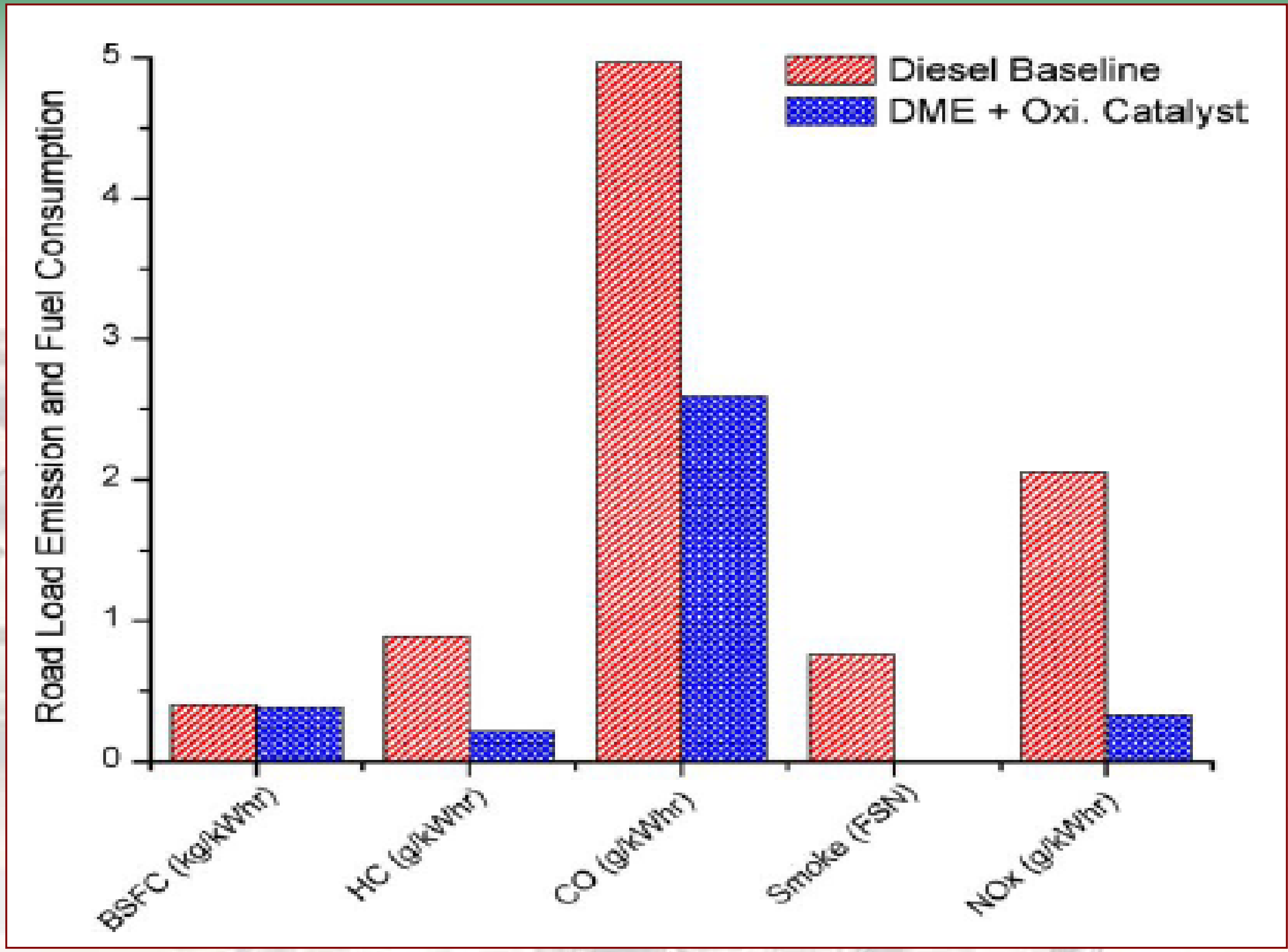
- Due to expensive production initially DME was considered as ignition improver for other fuels, mainly methanol
- DME has been tested in a number of direct injection diesel engines, ranging in size from 273 to 1220 cm^3/cylinder
- In all of these studies, soot-free operation has been observed
- NOx emission is found to be generally lower with DME, however some studies have reported equal or even higher NOx emission as compared to diesel

Benefits of DME

- High Cetane Number
- Smokeless combustion
- High Volatility
- LPG Infrastructure can be used for transportation and Storage.

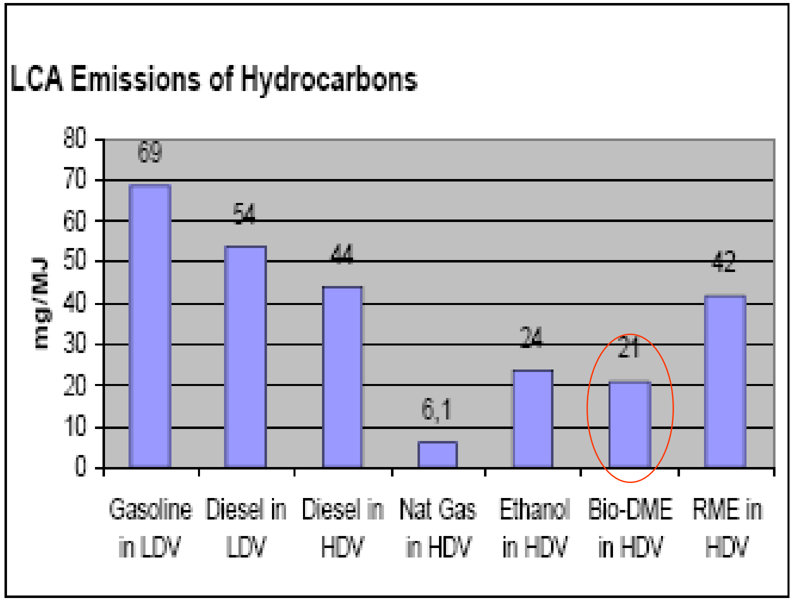
Challenges with DME

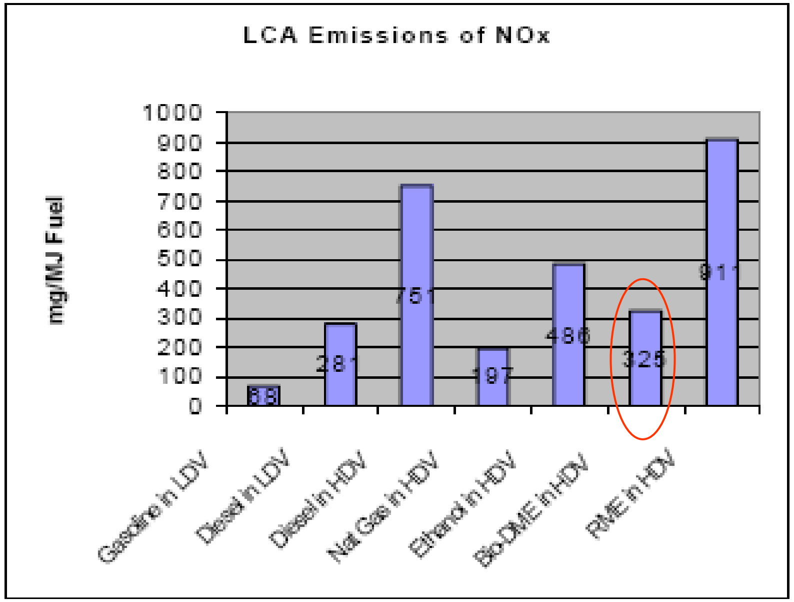
- Low Viscosity
- Low Lubricity
- Storage System
- Seal Compatibility

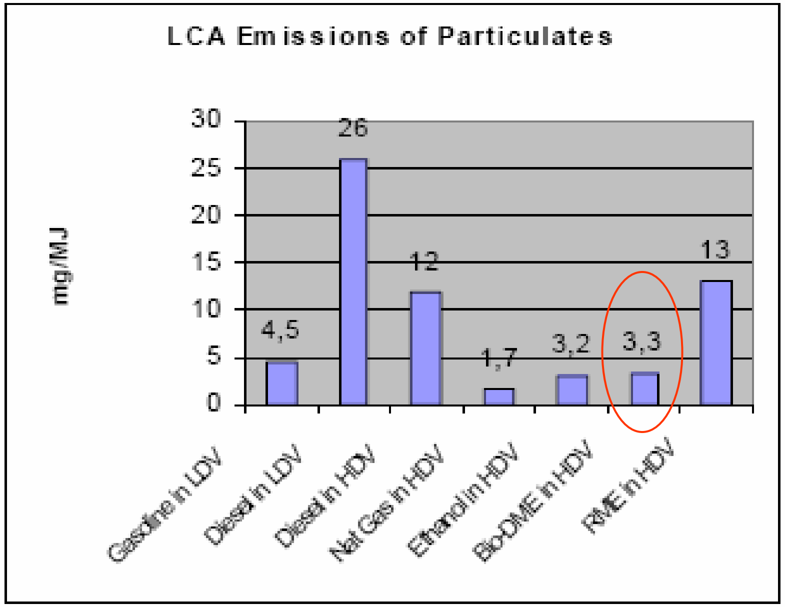


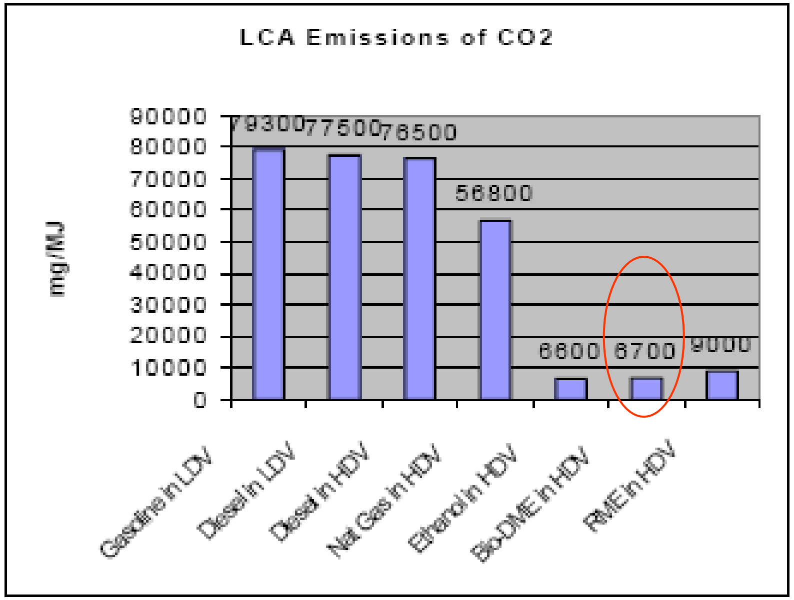
Road load test data comparing engine emissions using diesel and neat DME

J. McCandless, DME as an Automotive Fuel: Technical, Economic and Social Perspectives Energy Frontiers Conference, 2001









Combined Emissions from Production, Distribution and Use in vehicles from various Fuels

Data obtained from the Swedish Petroleum Institutes 1999

DME Vehicles

Estimated Costs of Meeting US 2007 HDD Emissions

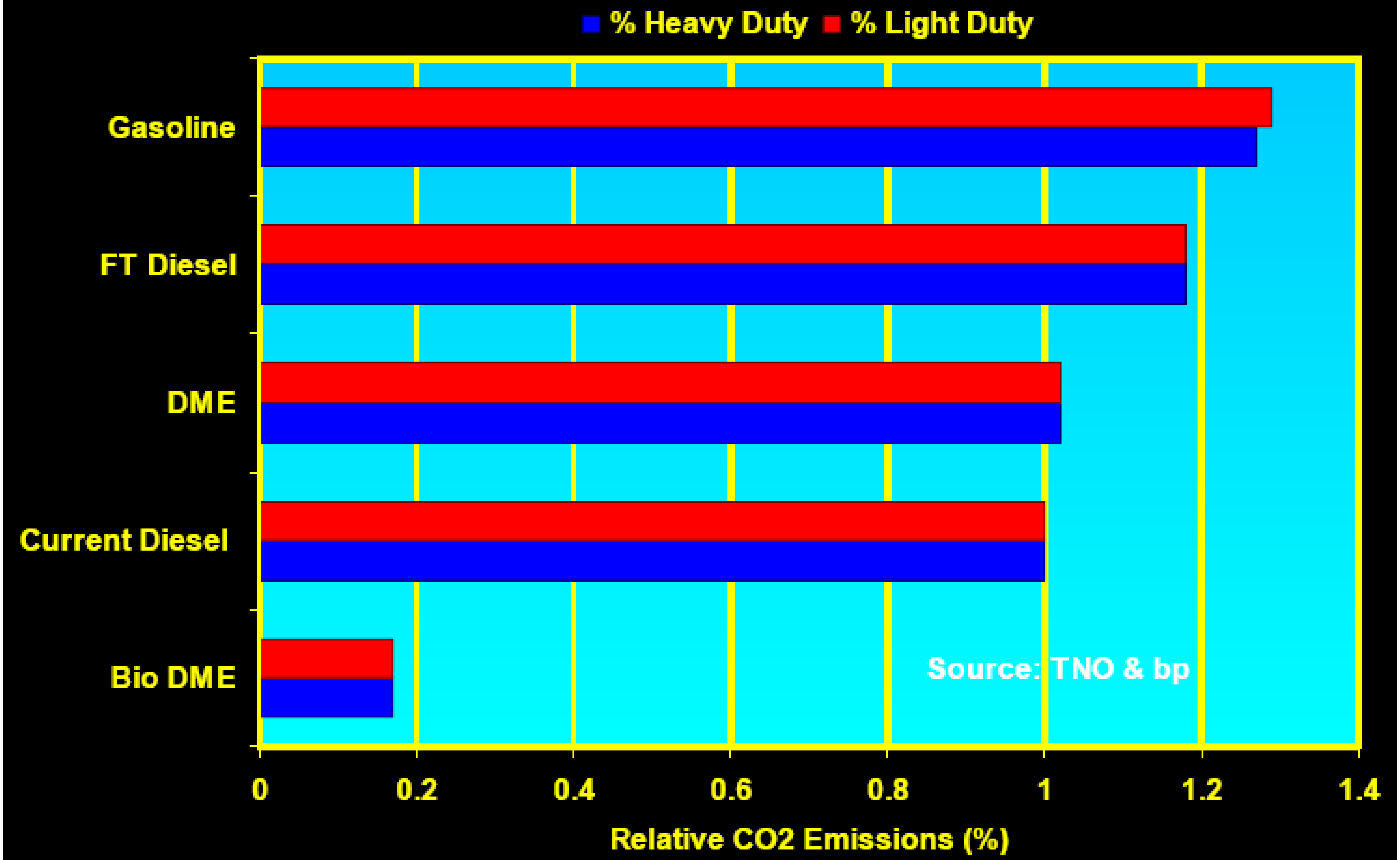
Emissions Control Device	Cost for Diesel	Cost for DME	Source
Base Engine	$18,000	$18,000	est.
Injection System	$1,800	$1,000	est./Quotes
Fuel Storage & Conditioning	$500	$1,000	est./Quotes
Cooled EGR System	$439	$439	EPA
VG Turbo	$373	$373	EPA
Electronics	$500	$500	est.
Catalyzed Particulate Trap	$1,103	0	EPA
NOx Adsorber	$1,456	0	EPA
Oxidation Catalyst	$338	$338	EPA
Total Cost	$24,509	$21,650	
Cost Savings		$2,859	

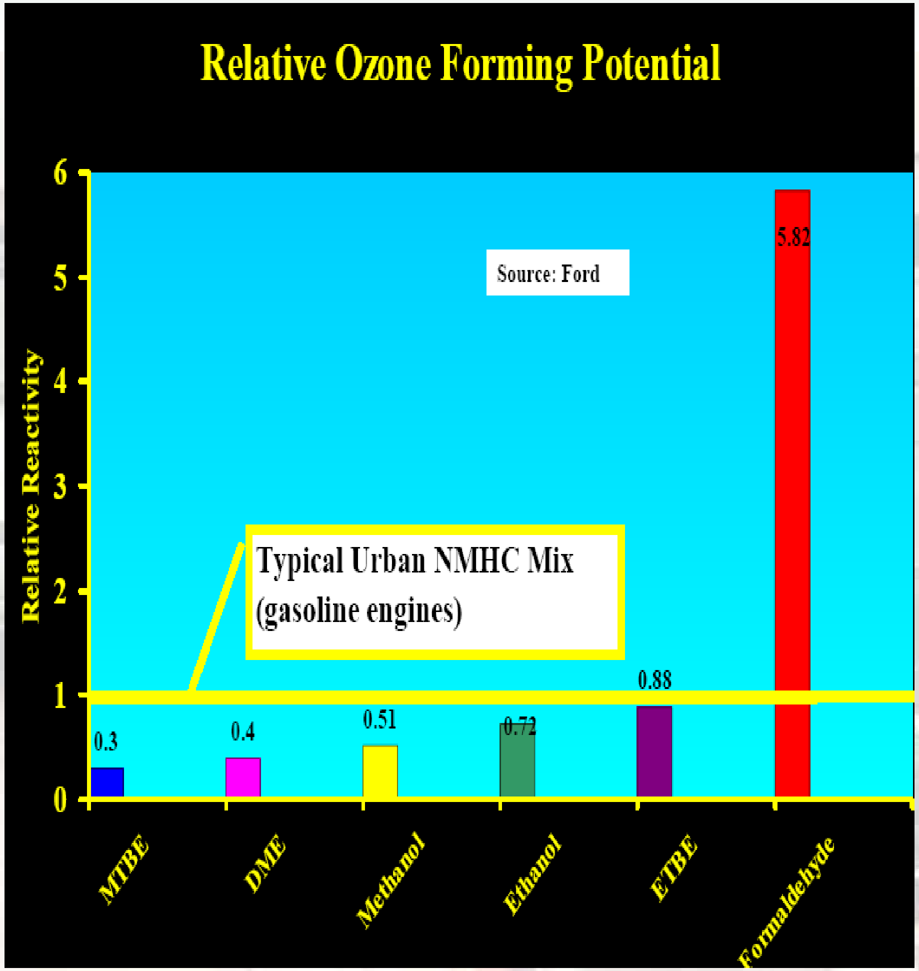
Source: AVL Power train Technologies, Inc

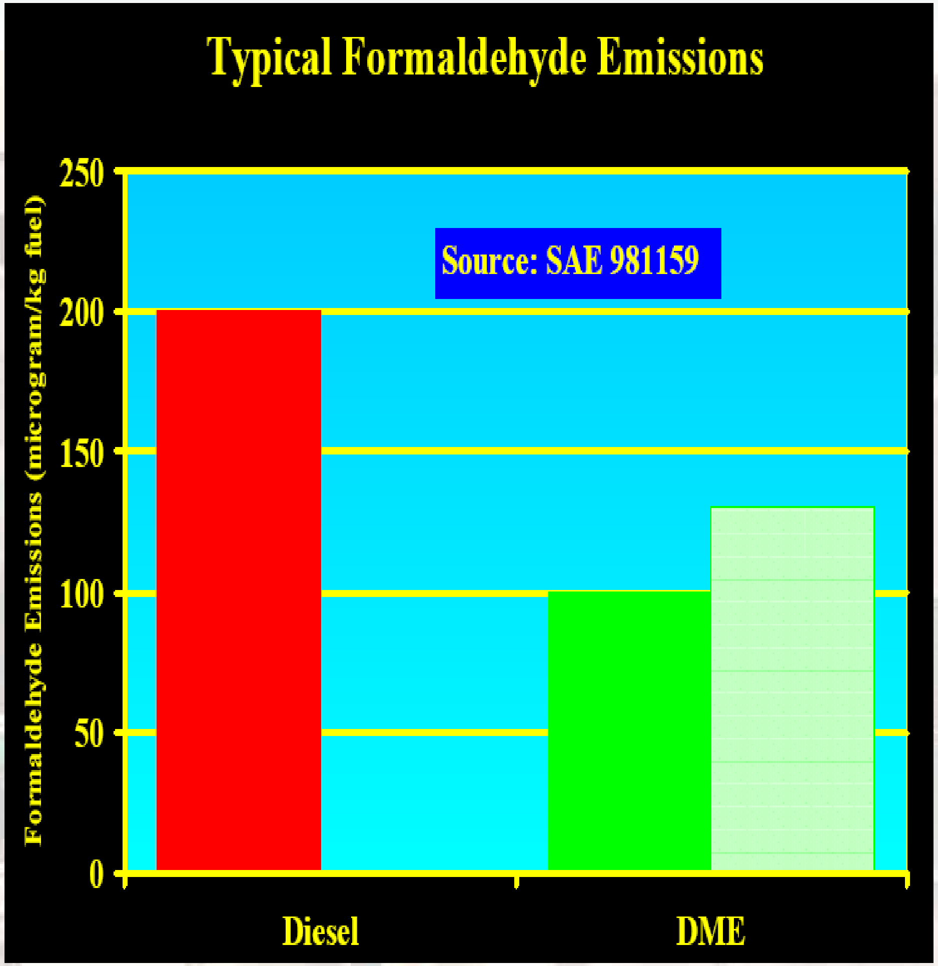
Environmental Concerns

- Non-Toxic to Humans
- Not Carcinogenic and Non Mutagenic
- Very Low Reactivity
- Short Half- Life in Troposphere
- Long, Positive Experience

Relative Well to Wheel CO_2 Emissions




Relative Ozone Forming Potential
Source: Ford
Relative Reactivity
6
5
4
3
2
1
0
5.82
Typical Urban NMHC Mix
(gasoline engines)
0.88
0.3
0.4
0.51
0.72
MTBE
DME
Methanol
Ethanol
ETBE
Formaldehyde


Typical Formaldehyde Emissions
Source: SAE 981159
Formaldehyde Emissions (microgram/kg fuel)
250
200
150
100
50
0
Diesel
DME

Economics of Production

- The investment cost for a commercial scale ***Bio-DME plant producing 200,000 tons of DME per year*** has been estimated at approximately ***€ 390 Millions*** at a green field location

- However, if oxygen and utilities can be purchased “over the fence” at an industrial site the total investment may be reduced by about € 100 Millions

- For these two location alternatives, the production cost of Bio-DME has been estimated at ***€ 393 - € 438 per ton of DME or about € 0.49 - € 0.55 per litre of diesel equivalent***

The Bio-DME Project Report to Swedish National Energy Administration, 23April 2002

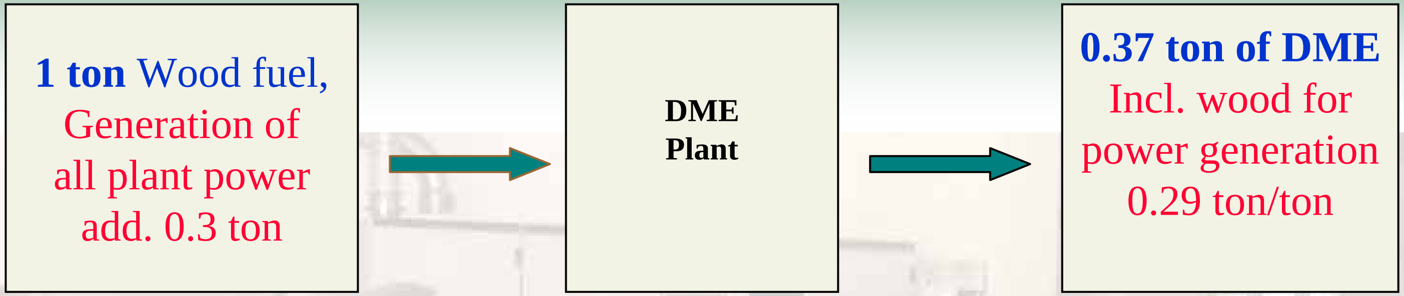


Figure: Yield of DME ton/ton of biomass feed

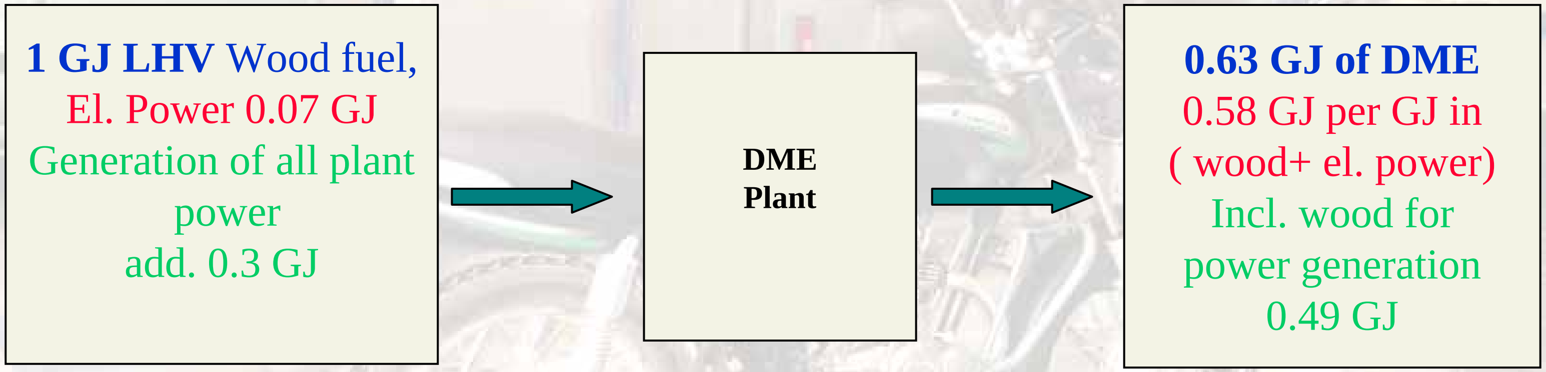
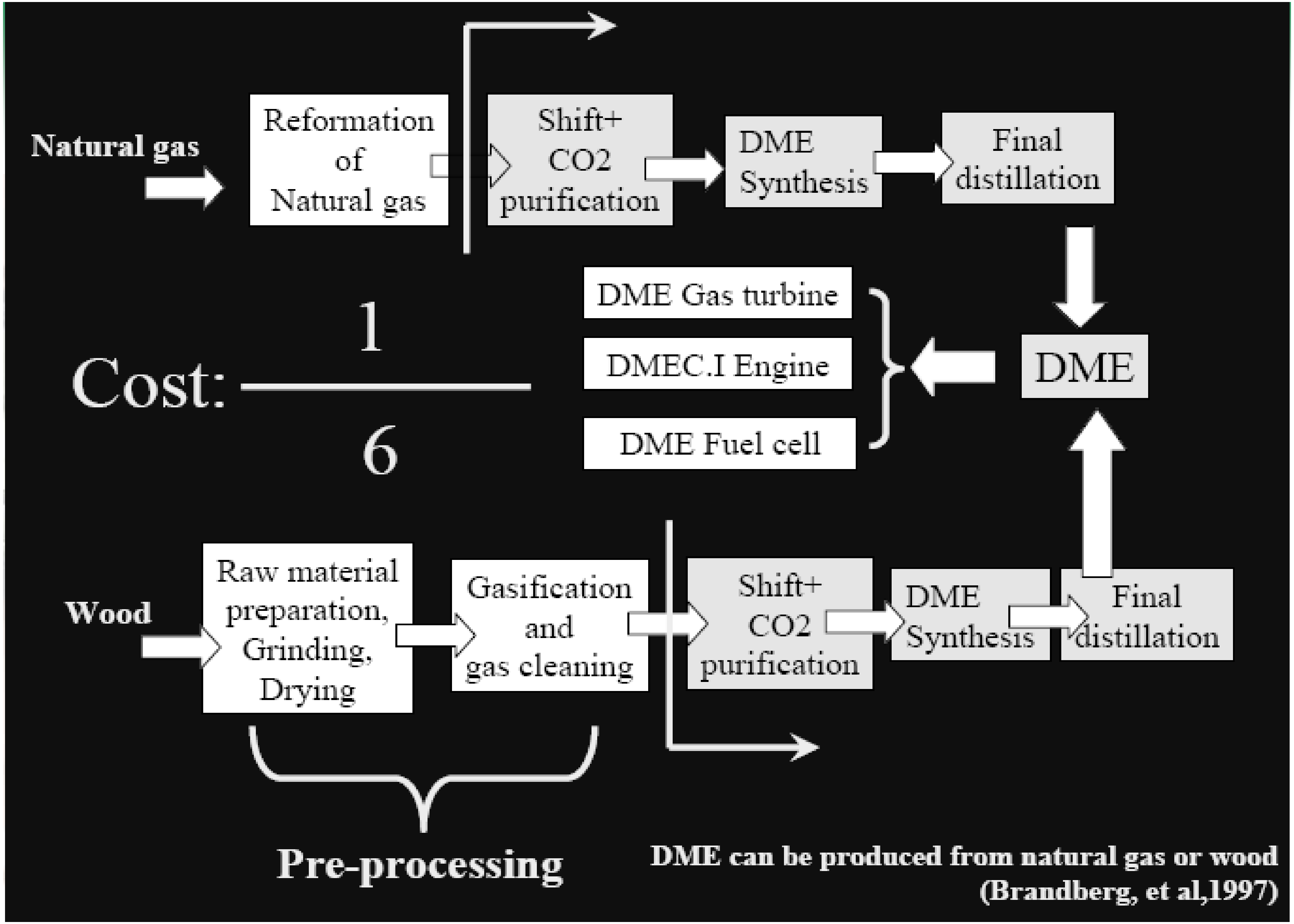


Figure: Energy efficiency for production of DME from biomass

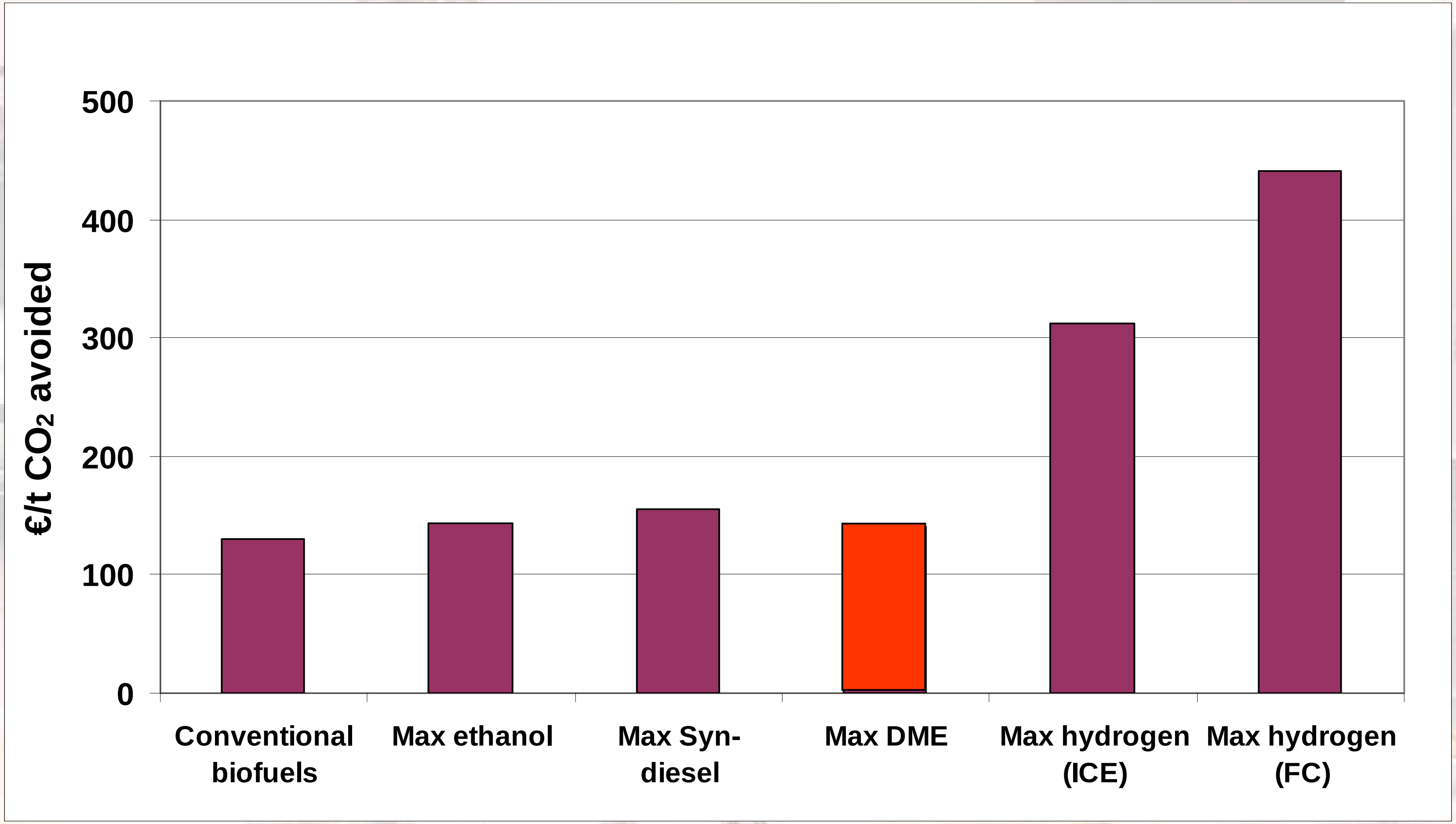
The Bio-DME Project Report to Swedish National Energy Administration, 23April 2002


Natural gas
Reformation of Natural gas
Shift+ CO2 purification
DME Synthesis
Final distillation
DME Gas turbine
DMEC.I Engine
DME Fuel cell
DME
Cost: 1/6
Wood
Raw material preparation, Grinding, Drying
Gasification and gas cleaning
Shift+ CO2 purification
DME Synthesis
Final distillation
Pre-processing
DME can be produced from natural gas or wood
(Brandberg, et al,1997)

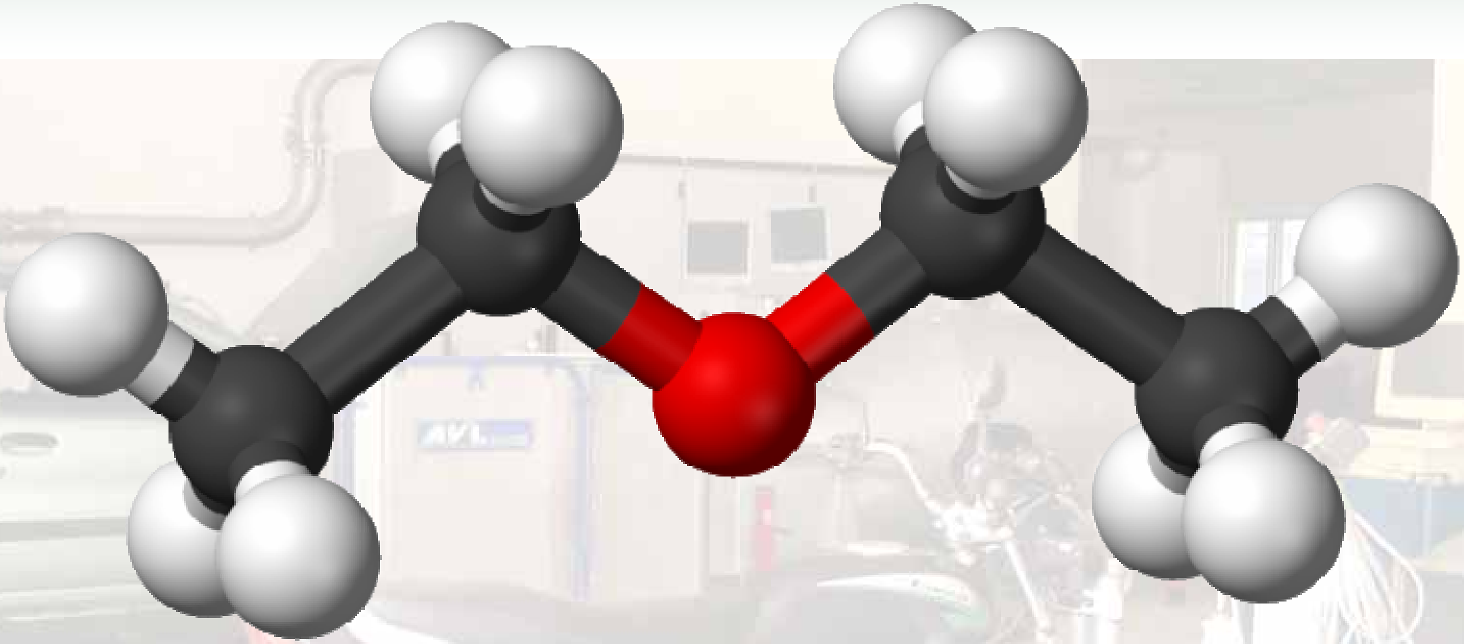
- Ahlvik, P. and Brandberg, (2001) showed that bio-DME is the most energy efficient bio-fuel to produce both in terms of fuel production and well-to-wheel efficiency (total system efficiency)

- The EUCAR/CONCAWE/JRC well-to-wheel project reached the conclusion that net emission of CO2 from a diesel engine running on bio based DME are very low

Cost of CO_2 Avoidance with Biomass



Well to Wheel analysis of future automotive fuels and powertrains in the European context
Jean-François Larivé, CONCAWE ,June 2006



Diethyl Ether

Background

- First ether engine was a combined water-ether steam engine. It was built in Marseilles in 1850 for marine application

- From 1919-1923 in British Guiana an alcohol based motor fuel named Alcolene was produced from sugarcane molasses which consisted of ***63% ethanol, 35% DEE, and 1%*** gas oil and pyridine

- Near the end of World War II., blending DEE to ethanol was adopted as an acceptable method to improve performance of ethanol in Japan

- Antonini (1981) reported DEE as a option for diesel engine fuels by ***mixing it with vegetable oil and/or diesel fuel***

Benefits of DEE

- Very High Cetane Number
- Reasonable Energy Density
- Liquid at room temperature

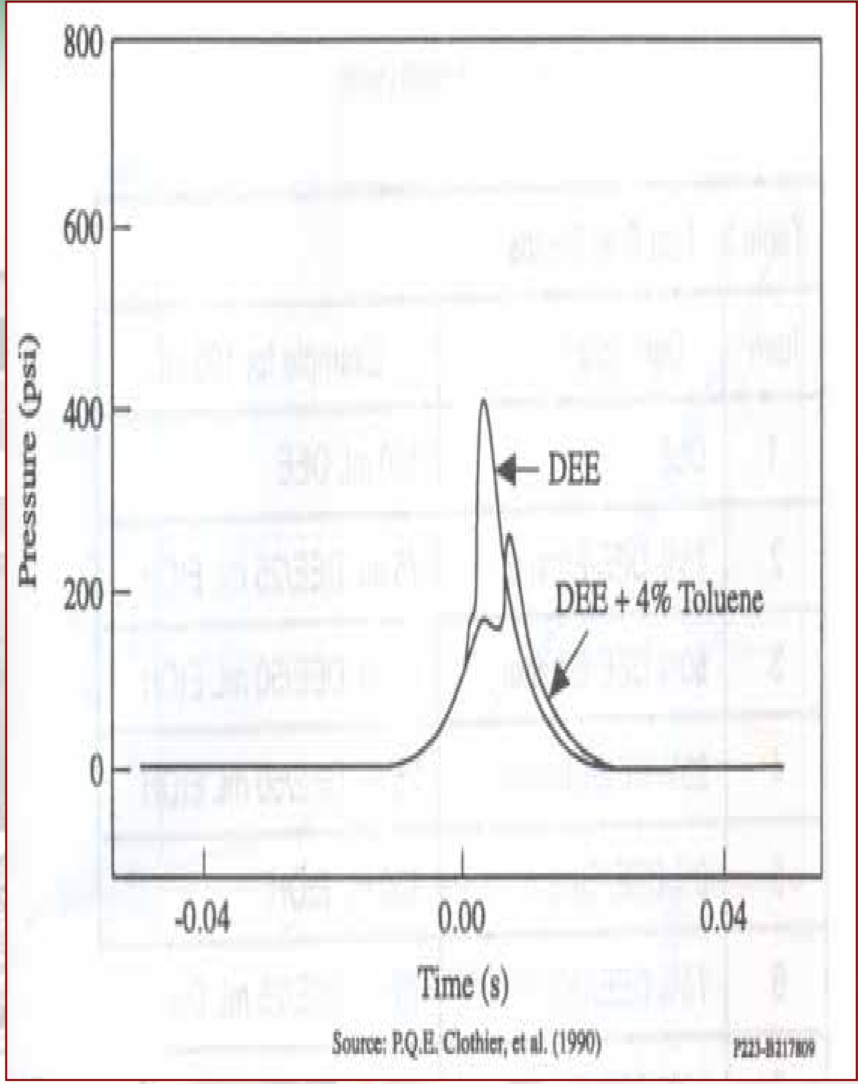
Challenges with DEE

- Stability in Storage
- Lower Lubricity
- Seal Compatibility

- Information available on engine testing on DEE is limited
- Particulate emission from a DICI Engine running on DEE were found very low relative to the diesel fuel
- It has been shown that 5% DEE/Diesel blend gives better performance and low emissions compared to other blends of DEE and diesel fuel
- Tests on Volvo AH10A245 diesel engine using ethanol DEE blends indicate that it is necessary to mix in at least 50% DEE in order to run the engine over the whole range of operation and 60% is recommended

Vol% Diethyl Ether	Vol% D-2	Cetane Estimate
100	0	158.2
75	25	102.2
50	50	68.5
25	75	51.5
0	100	42.9
Vol% Diethyl Ether	**Vol% Ethanol**	**Cetane Estimate**
75	25	61.1
50	50	19.0
25	75	12.2
0	100	12.1

Cetane Number Determination
[J. Erwin.1997]



Ignition Delay Impact from Toluene Blended with DEE. [Clotheir ,1990]

Diesel (ml)	DEE (ml)	Cetane Number
1000	0	49.2
950	50	53.2
924	76	52.8
900	100	50.8

Fuel	Cetane Number
Diesel	53.2
Diesel+10 %Ethanol	52.8
Diesel+10%Ethanol +10%DEE	50.8

Environmental Concerns

- Non-carcinogenic, non-teratogenic, non-mutagenic, and non-toxic
- Reactivity of DEE is 5 times higher than MTBE. DEE is estimated to be stable for approximately nineteen hours
- Studies about well-to-wheel green house gas emissions and tailpipe aldehyde emissions from DEE are required

Economics of Production

- DEE can be manufactured by dehydration of bio-ethanol using an acid clay catalyst with 90% conversion
- NREL conducted a process simulation exercise which showed that hydrous ethanol could be converted to DEE
- The analysis shows that the cost of fuel grade DEE would be only slightly higher than that of anhydrous ethanol

Benefits of Bio-ethers

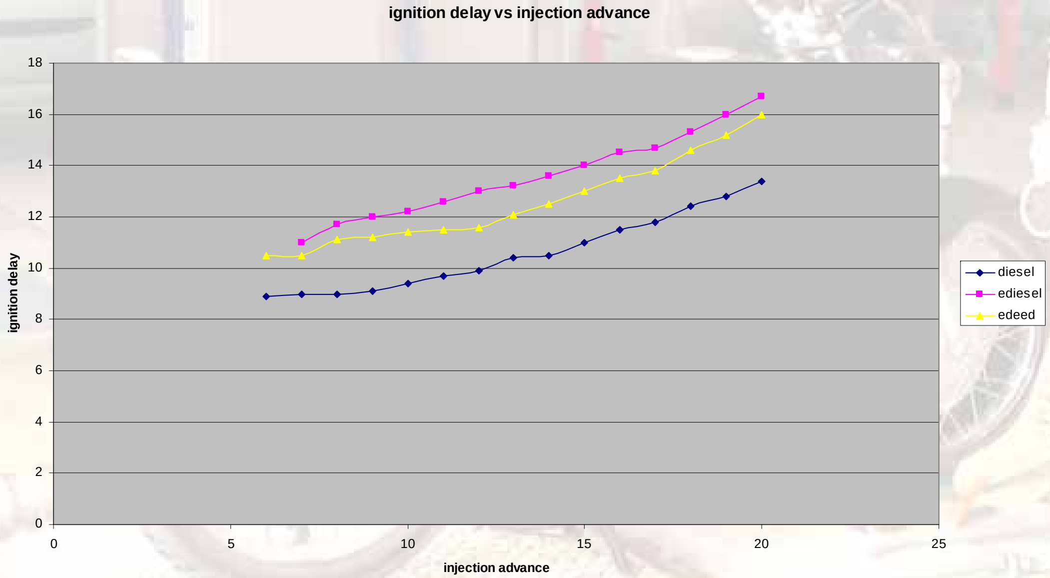
- Bio-ethers have a potential to substantially cut down GHG emissions
- Bio-ethers considerably reduces smoke and PM. This enables use of very high EGR rates for NO_X reduction without jeopardizing the life of engine due to excessive wear.
- Emissions of VOC and CO are of the same magnitude as diesel.
- Bio-ethers are non- corrosive to metals and do not require special materials for structural components of fuel systems.
- Bio-ethers are sulphur free; this facilitates the use of effective after treatment devices.
- Bio-ethers can be used in DI diesel Engines without major modifications. Therefore field retrofit is possible.

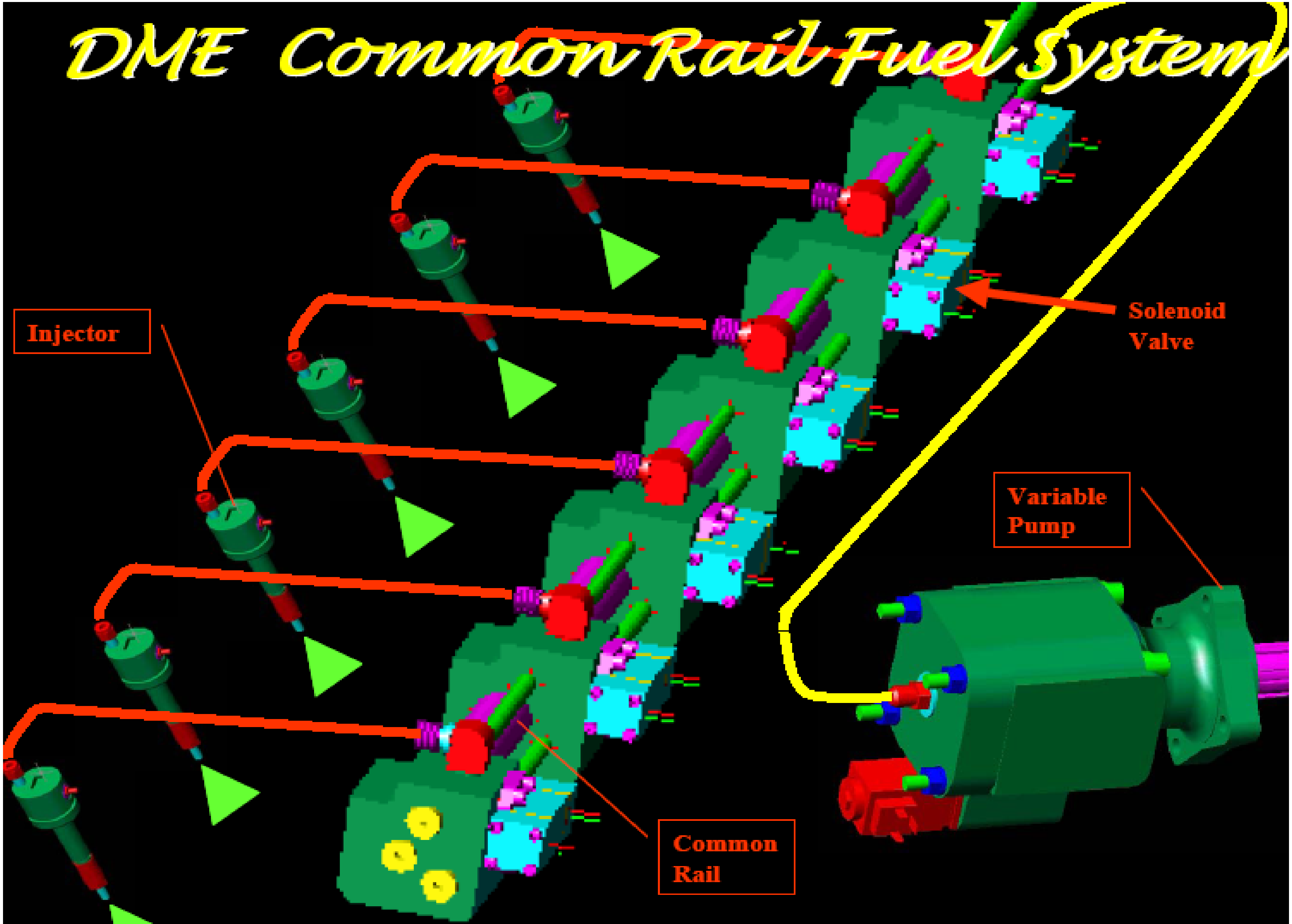
Conclusion

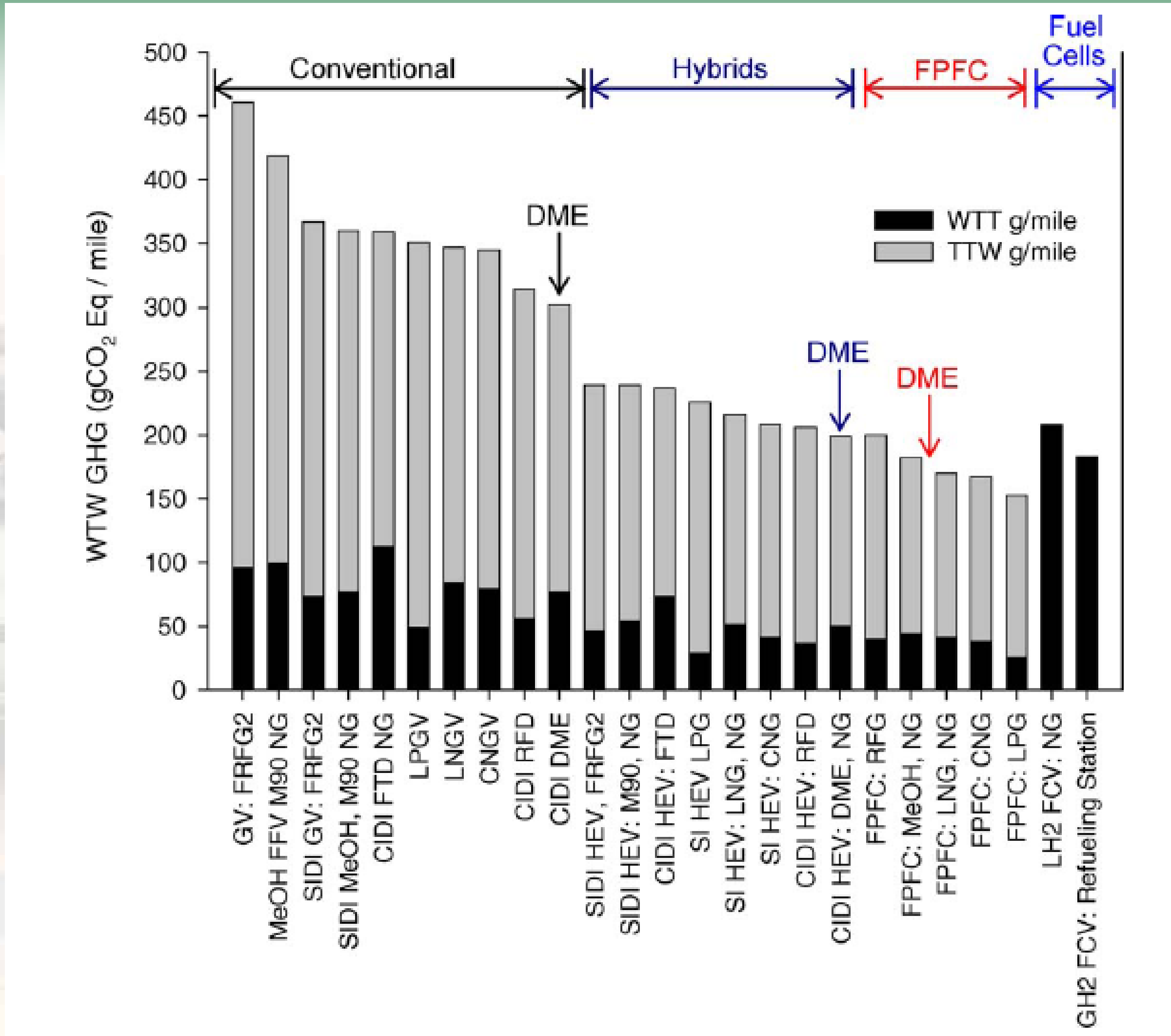
- **Among all the biofuels, bio-ethers seem to be very attractive as Alternative transportation fuel due to their energy efficient production, higher well-to-wheel efficiency and substantially low GHG emissions.**

Thank You

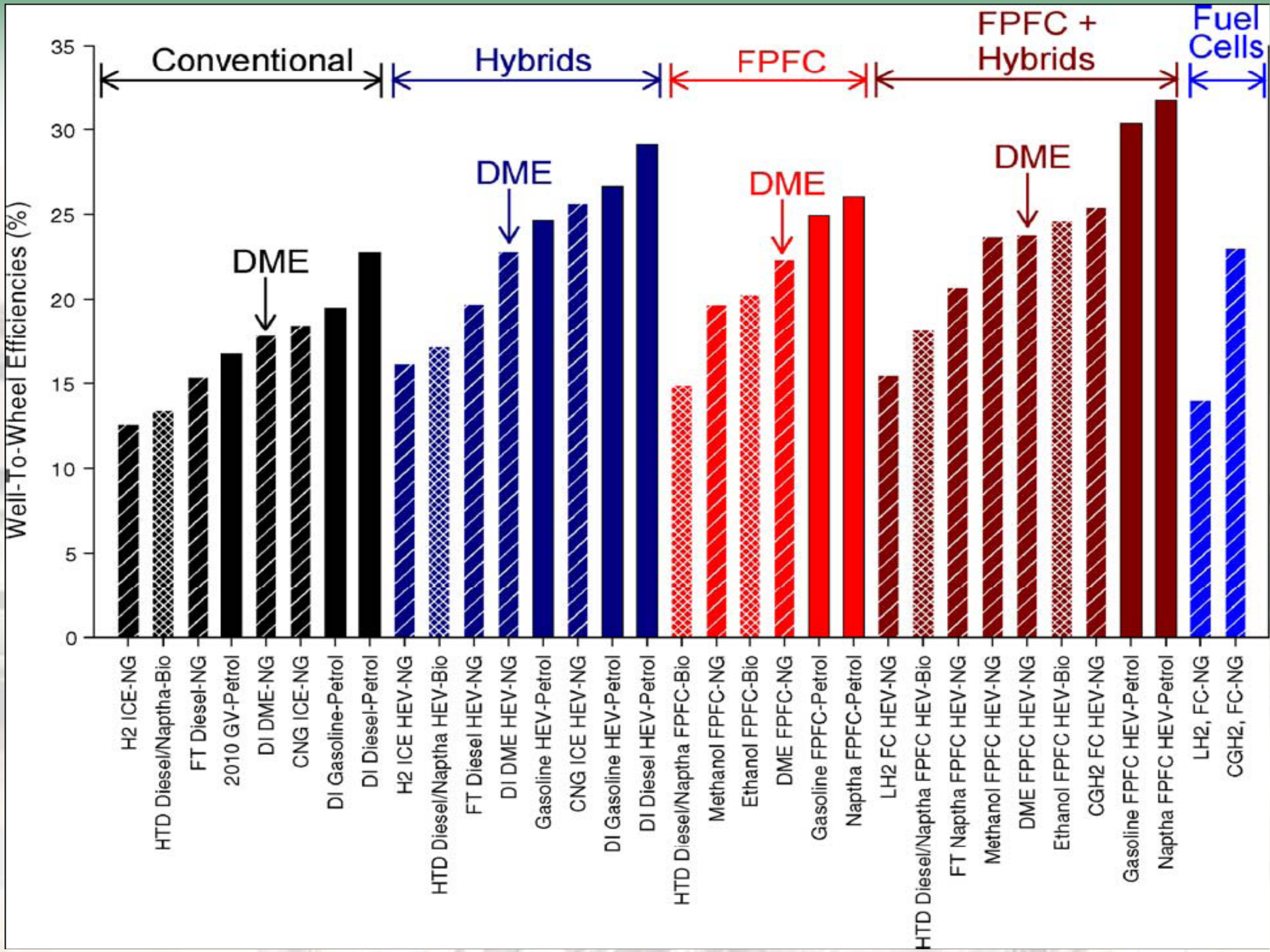

ignition delay vs compresion ratio
ignition delay
compression ratio
diesel
ediesel
edeed
0
5
10
15
20
25
30
0
2
4
6
8
10
12
14
16
18
20


ignition delay vs injection advance
ignition delay
injection advance
diesel
ediesel
edeed
0
2
4
6
8
10
12
14
16
18
0
5
10
15
20
25

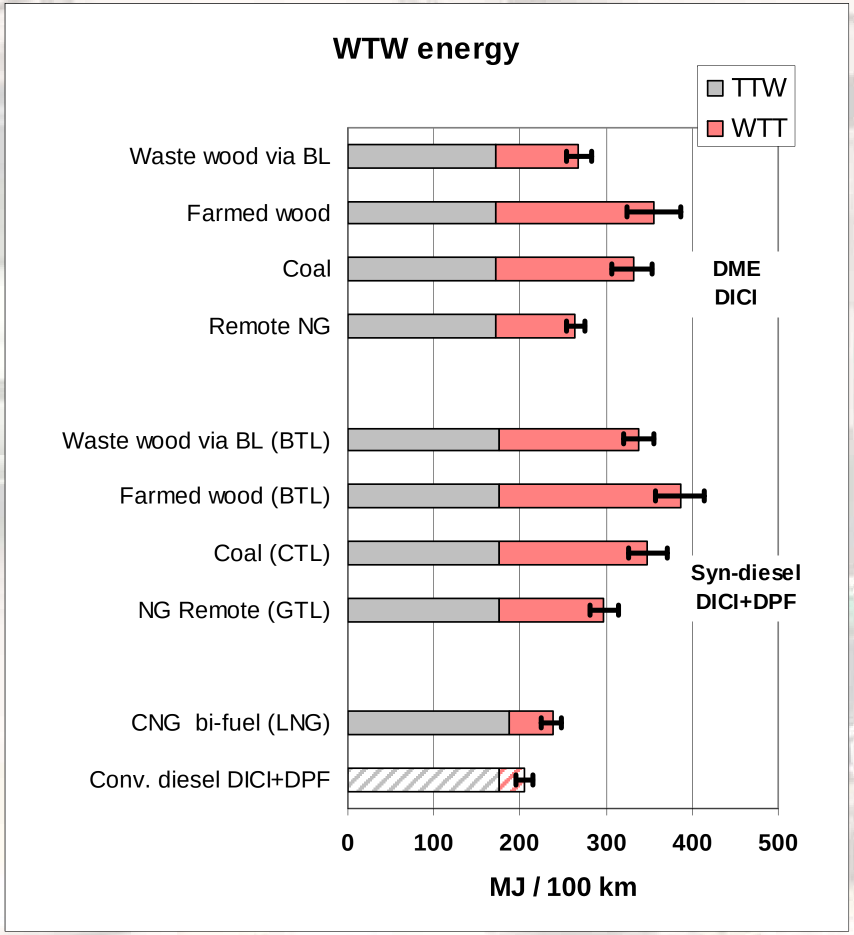

DME Common Rail Fuel System
Injector
Solenoid Valve
Variable Pump
Common Rail

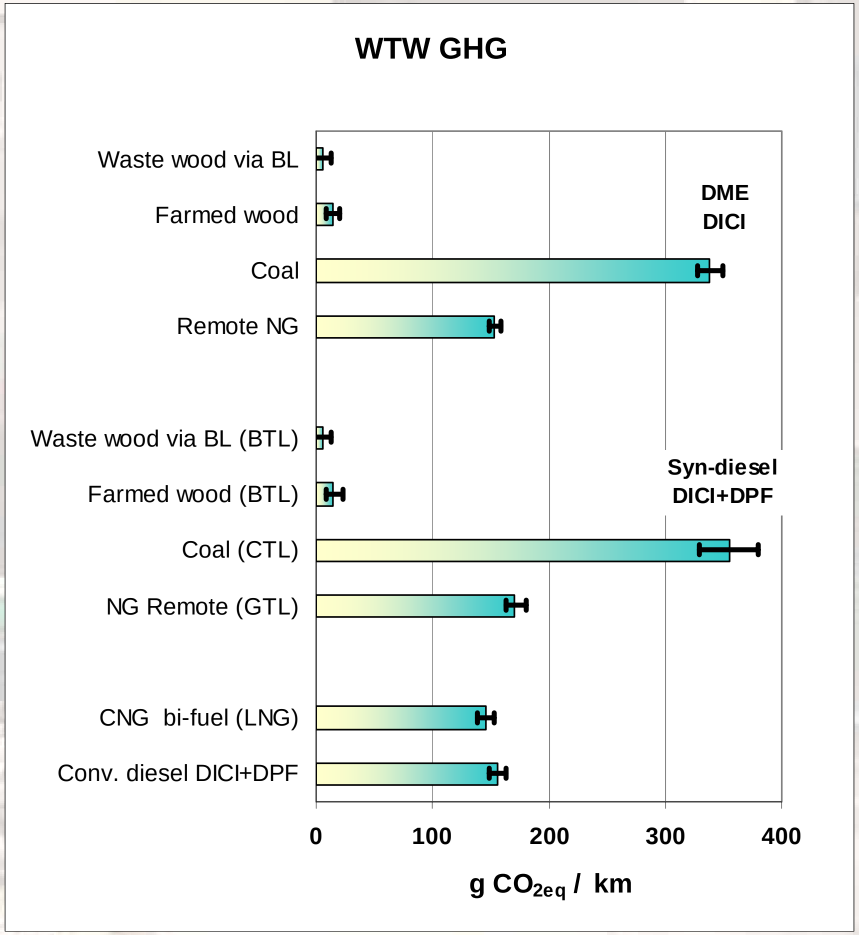


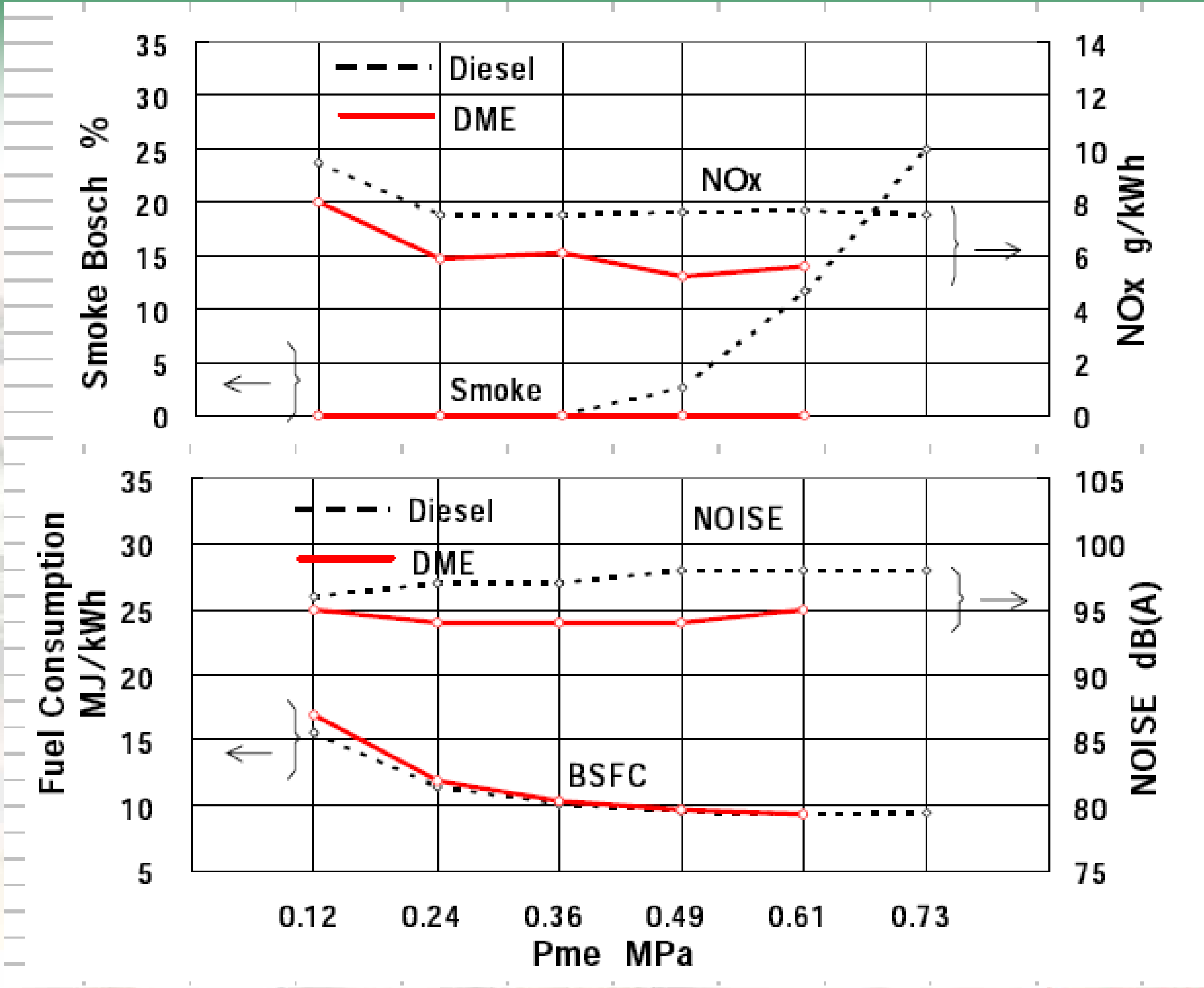
Well-to-wheels greenhouse gas emissions divided into the well-to-tank and tank-to-wheels contributions for various fuels, feedstock's, and vehicle technologies



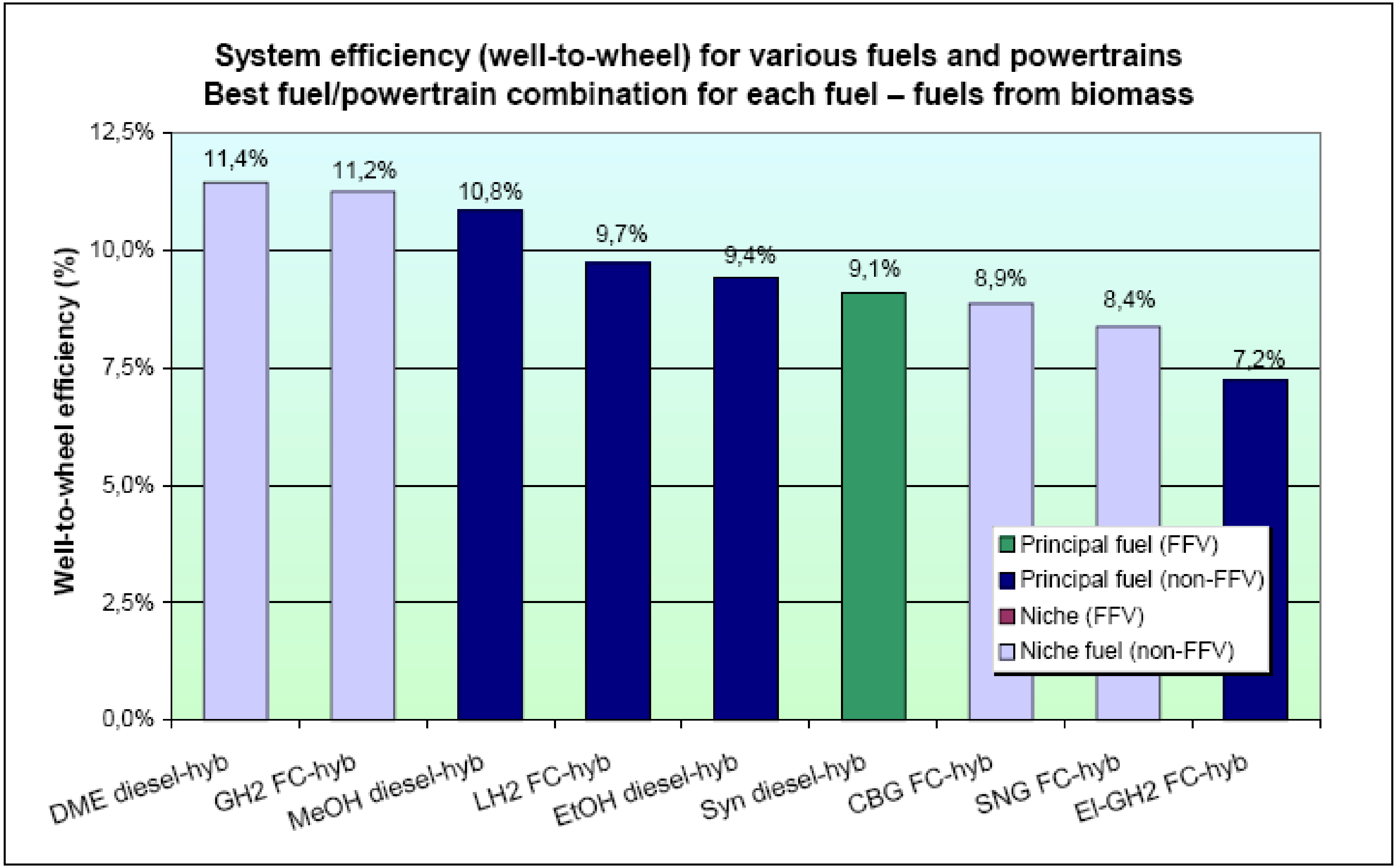
Well-to-wheel efficiencies for various fuels, feedstocks, and vehicle technologies. Solid bars are petroleum-based fuels, diagonal hatched bars are natural gas-based fuels, and the cross hatched bars are biomass-based fuels


WTW energy
TTW
WTT
Waste wood via BL
Farmed wood
Coal
Remote NG
Waste wood via BL (BTL)
Farmed wood (BTL)
Coal (CTL)
NG Remote (GTL)
CNG bi-fuel (LNG)
Conv. diesel DICI+DPF
DME
DICI
Syn-diesel
DICI+DPF
0
100
200
300
400
500
MJ / 100 km


WTW GHG
Waste wood via BL
Farmed wood
Coal
Remote NG
Waste wood via BL (BTL)
Farmed wood (BTL)
Coal (CTL)
NG Remote (GTL)
CNG bi-fuel (LNG)
Conv. diesel DICI+DPF
DME
DICI
Syn-diesel
DICI+DPF
0
100
200
300
400
g CO_{2eq} / km



Comparison Of Performance for DME and Diesel fuel at 2000rpm


System efficiency (well-to-wheel) for various fuels and powertrains
Best fuel/powertrain combination for each fuel – fuels from biomass
Well-to-wheel efficiency (%)
12,5%
10,0%
7,5%
5,0%
2,5%
0,0%
11,4%
11,2%
10,8%
9,7%
9,4%
9,1%
8,9%
8,4%
7,2%
DME diesel-hyb
GH2 FC-hyb
MeOH diesel-hyb
LH2 FC-hyb
EtOH diesel-hyb
Syn diesel-hyb
CBG FC-hyb
SNG FC-hyb
El-GH2 FC-hyb
Principal fuel (FFV)
Principal fuel (non-FFV)
Niche (FFV)
Niche fuel (non-FFV)