MINING DIESEL
mdec
EMISSIONS COUNCIL

16th ANNUAL MDEC CONFERENCE
Hilton Toronto Airport, Ontario, Canada
October 5 – 8, 2010

MDEC DIESEL WORKSHOP
Tier 4 Diesel Engines and Biodiesel

PRESENTED BY: Greg Tremaine of Deutz
Andrew Suda of MTU Detroit Diesel
Darcy Thomson of John Deere
Brian Ahearn and Marc-Andre Poirier of Esso and
Kevin Morris of Kinross

FACILITATED BY: JP Ouellette of Kubota Canada Ltd., and
Mahe Gangal of NRCan

OCTOBER 5, 2010

MINING DIESEL mdec EMISSIONS COUNCIL

MDEC Diesel Workshop

Tier 4 Engines and Biodiesel Fuel

Hilton Toronto Airport Hotel
Ontario, Canada

Mississauga C Room

Tuesday, October 5, 2010

07:30 – 08:30 Breakfast and registration

08:30 – 12:00 Welcome – Mahe Gangal, Co-chair MDEC Conference
Introduction of Speakers – JP Ouellette, Co-chair MDEC Conference

Engine Technology – Tier 4 Engines

- Advanced Diesel Engines, Darcy Thomson (John Deere)
- Deutz Path to Tier 4 for Underground Mining Engines, Greg Tremaine (Deutz)
- Tier 4 Industrial Engine Technology, Andrew Suda (MTU Detroit Diesel)

12:00 – 13:00 Lunch

13:00 – 16:30 **Biodiesel**

- Regulatory overview, Brian Ahearn (Esso)
- Research projects, Marc-Andre Poirier (Esso)
- Testing at Kinross Gold Mine, Kevin Morris (Kinross Gold Mine)

- Discussion and Conclusion, JP Ouellette (Co-chair MDEC Conference)

(coffee breaks will be at about 10 AM and 3 PM)

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Contents

MDEC - 2010

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"The DEUTZ Path to Tier 4 for Underground Mining Engines"

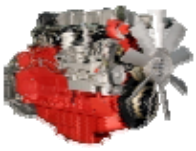
Greg Tremaine
DEUTZ Corporation

Mining Diesel Emission Council
Toronto ON
October 5-8 2010

Composition of Exhaust Gases from Diesel Engines

The engine company. DEUTZ

N_2 = 78.1%
O_2 = 20.9%
Ar, CO_2 + others = 1.0%
Diesel fuel



Gas phase	Solid phase
N_2 ~ 75%	Soot
O_2 ~ 8%	
CO_2 ~ 9%	
H_2O ~ 8%	
Pollutants < 1.0%	

- Diesel Engines operate with excess combustion air
- Pollutants take up a very small concentrations compared to the overall exhaust gas composition
  - Carbon Monoxide
  - Unburned fuel or hydrocarbons
  - Oxides of Nitrogen
  - Solid components: Soot

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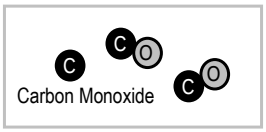
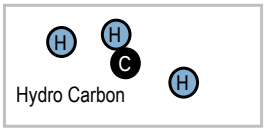
Harmful Effects of Gaseous and Particulate Matter

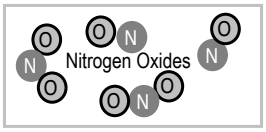
The engine company. DEUTZ



CO — Colorless, odorless gas which can cause drowsiness, asphyxiation.



HC — Product of incomplete combustion of fuel and lube oil, irritating the nasal passages & eyes.



NO_x — NO and NO_2, commonly referred to as NO_x, irritate the lining of the lungs, causing nausea.

C — Small visible particles, which when inhaled, can cause respiratory problems.

Introduction to Nonroad Diesel Engine Emission Regulations

The engine company. DEUTZ

- Non-road engines are virtually all engines that are not used in motor vehicles, excl. underground mining engines
- US EPA regulations for non-road diesel engines promulgated in 1996 for Tier 1 – 3 (40 CFR Part 89)
- Tier 4 interim and Tier 4 regulations were published in 2004 (40 CFR Part 1039)
- Engines categorized based on rated power in kW (kilo Watts) – for convenience values will be presented in Horsepower
- Regulated exhaust gas emissions expressed in g/kW-hr
  - Oxides of Nitrogen (NOx)
  - Hydrocarbons (HC)
  - Carbon Monoxide (CO)
  - Particulate Matter (PM)
- MSHA Regulations:
  - Underground Coal Mines
  - Underground M/NM Mines

Power Categories	
Tier 1, 2, 3	Tier 4i, 4
HP < 11	HP < 25
11 ≤ HP < 25	
25 ≤ HP < 50	25 ≤ HP < 75
50 ≤ HP < 100	
100 ≤ HP < 175	75 ≤ HP < 175
175 ≤ HP < 300	175 ≤ HP < 750
300 ≤ HP < 600	
600 ≤ HP < 750	
HP > 750	HP > 750

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Emission Improvement from Tier 1 to Tier 4 (100 – 174HP)

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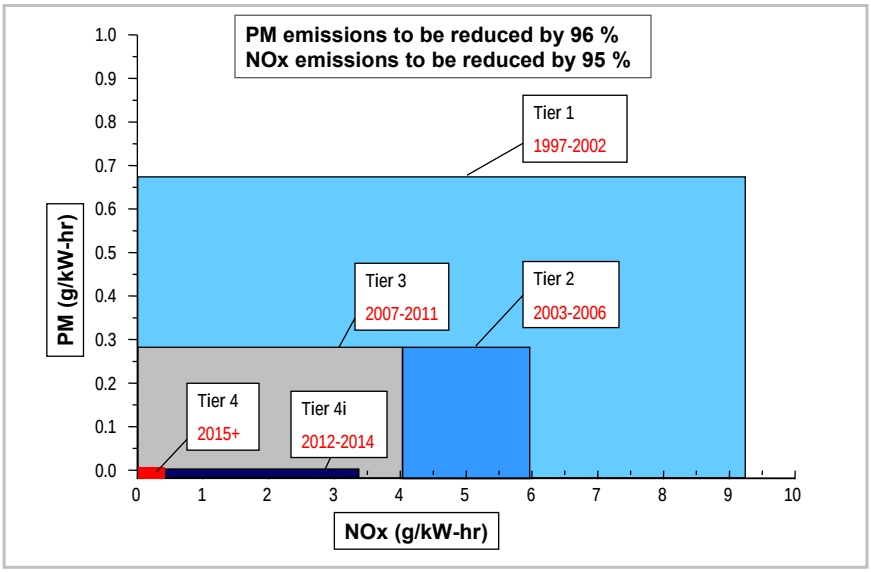

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EPA Nonroad Diesel Emission Regulations Tier 1 - 4

The engine company. DEUTZ

Regulated Emissions: NOx / HC / CO / PM - g/HP-hr

[NOx + HC] / CO / PM - g/HP-hr

Power	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
HP<11					[7.8] / 6.0 / 0.75					[5.6] / 6.0 / 0.60			[5.6] / 6.0 / 0.30									
11≤HP<25					[7.1] / 4.9 / 0.60					[5.6] / 4.9 / 0.60			[5.6] / 4.9 / 0.30									
25≤HP<50						[7.1] / 4.1 / 0.60				[5.6] / 4.1 / 0.45			[5.6] / 4.1 / 0.22					[3.5] / 4.1 / 0.02				
50≤HP<75						6.9 / -- / -- / --				[5.6] / 3.7 / 0.30			(Opt 1) [3.5] / 3.7 / 0.22					[3.5] / 3.7 / 0.02				
													(Opt 2) [3.5] / 3.7 / 0.30									
75≤HP<100						6.9 / -- / -- / --				[5.6] / 3.7 / 0.30			[3.5] / 3.7 / 0.30				2.5 / 0.14 / 3.7 / 0.01			0.30 / 0.14 / 3.7 / 0.01		
100≤HP<175						6.9 / -- / -- / --				[4.9] / 3.7 / 0.22			[3.0] / 3.7 / 0.22				2.5 / 0.14 / 3.7 / 0.01					
175≤HP<300					6.9 / 1.0 / 8.5 / 0.4					[4.9] / 2.6 / 0.15			[3.0] / 2.6 / 0.15				1.5 / 0.14 / 2.6 / 0.01			0.30 / 0.14 / 2.6 / 0.01		
300≤HP<600					6.9 / 1.0 / 8.5 / 0.4					[4.8] / 2.6 / 0.15												
600≤HP<750					6.9 / 1.0 / 8.5 / 0.4					[4.8] / 2.6 / 0.15												
Nonroad Diesel Fuel Sulfur Level	5000 ppm												500 ppm				15 ppm					

Tier 1 | Tier 2 | Tier 3 | Tier 4 Interim / Alt Nox | Tier 4 Final

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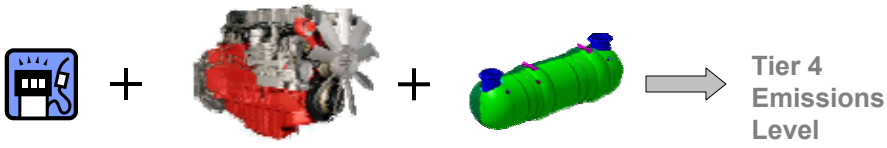
To Achieve Tier 4 (> 25hp) Emission Levels

The engine company. DEUTZ

Requires a Three Segment "Systems Approach"



Low/ultra low sulfur diesel fuel

Engine technologies and control system working in unison with EAT

EAT – Exhaust Aftertreatment

Tier 4 Emissions Level

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Diesel Fuel for Non-Road engines

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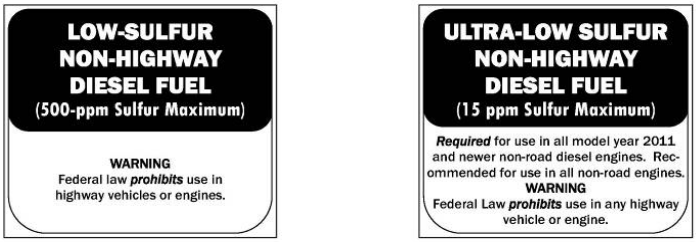
Year	2008	2009	2010	2011	2012	2013	2014	2015
Nonroad Diesel Fuel Sulfur Level	500 ppm			15 ppm				



- On-highway diesel fuel currently is at 15 ppm Sulfur (ULSD)

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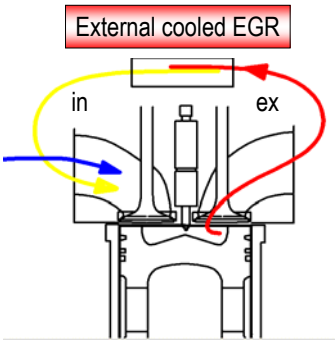
Exhaust Gas Recirculation (EGR)

- Diesel engine exhaust contains excess oxygen
- Through EGR a part of the ingested intake air is replaced by exhaust air, thus reducing the oxygen surplus inside the cylinder
- Higher CO_2 level leads to lower combustion temperature peaks resulting in less NOx in the exhaust
- External Cooled EGR
  - Compared to un-cooled or internal EGR
    - Maximizes specific power
    - Maximizes NOx reduction



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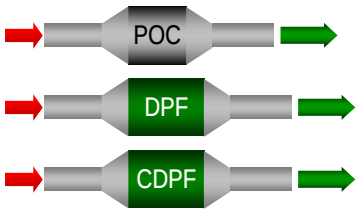
EAT Components

Aftertreatment devices can be divided in two main groups:

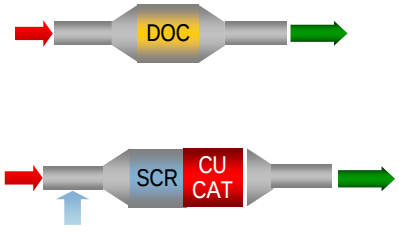
Filters that physically capture solid exhaust gas Particulates, made of ceramic monoliths or metal structure. The material for the canning is steel.

- Particulate Oxidation Catalyst (POC) Diesel Particle Filter (open DPF)
- Diesel Particle Filter (closed DPF)
- Coated Diesel Particle Filter (closed DPF)



Modules which convert toxic exhaust gases into harmless gases

- Diesel Oxidation Catalyst (DOC)
- Selective Catalytic Reduction (SCR)
- Clean Up CATalytic Converter (CU Cat)



GP – July 2009

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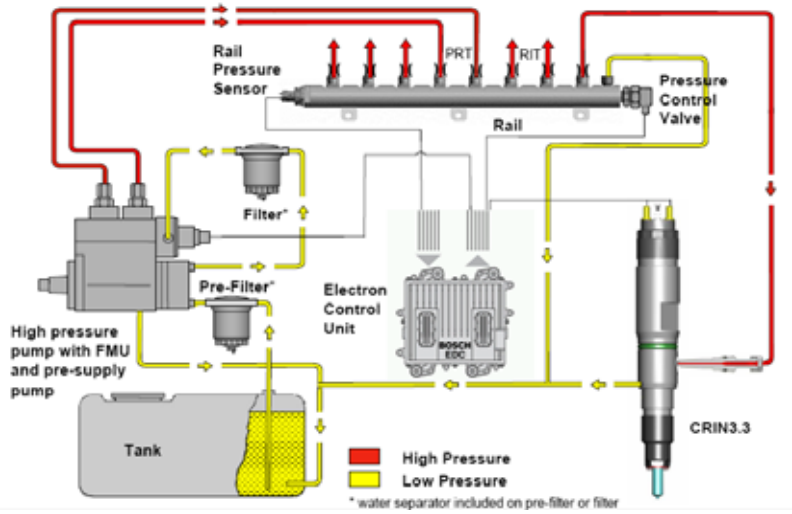
Conventional Common Rail Fuel Injection System



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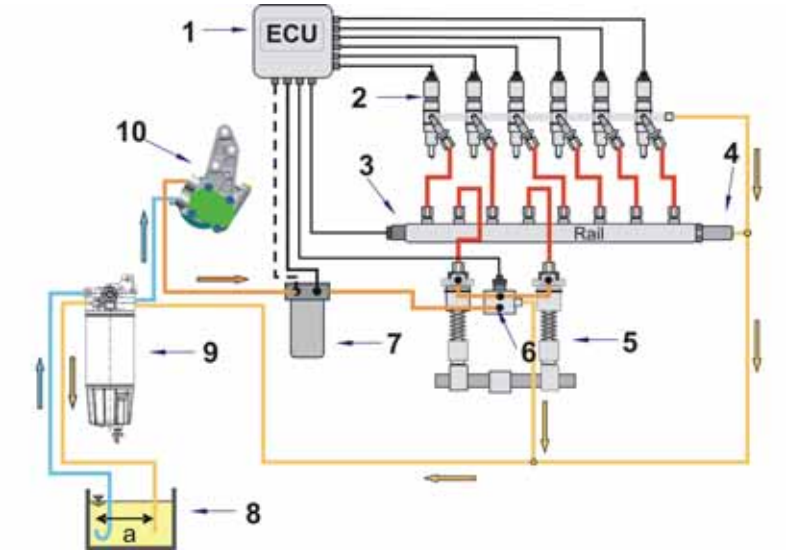
DEUTZ Common Rail (DCR) Fuel Injection System



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Tier 4i/4 Exhaust Aftertreatment Systems (EAT)

The engine company. DEUTZ

Power	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
HP<25	Tier 4									
25≤HP<75	Tier 4 Interim					PM reduction 90% DPF/DOC				
75≤HP<175	Tier 3				PM reduction 95% DPF			NOx Reduction 88% DPF + SCR		
175≤HP<750	Tier 3			PM reduction 93% DPF/SCR			NOx Reduction 80% DPF + SCR			
Nonroad Diesel Fuel Sulfur Level	500 ppm			15 ppm						

Tier 3 | Tier 4 Interim | Tier 4

DPF – Diesel Particulate Filter for PM reduction
DOC – Diesel Oxidation Catalyst for CO and HC reduction
SCR – Selective Catalytic Reduction for NOx reduction

Reduction percentage is compared to previous Tier emission level

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The engine company. DEUTZ

Diesel Particulate Filter (DPF) for Particulate Matter (PM) Reduction

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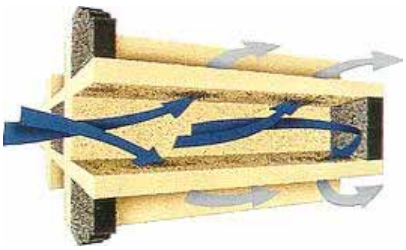
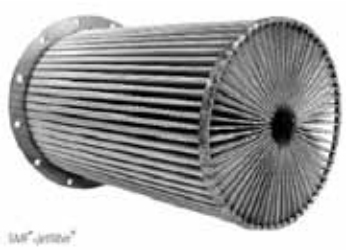
Diesel Particulate Filters (DPF)

- Physically capture diesel particulates
- Commonly available DPF are Wall-Flow Filters
- Made of ceramics or metal
- Individual channels are open and plugged at each end
- Particle trapping on surface of inlet channels
- High efficiency (~99% on solid fraction)





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DPF Regeneration – The Challenge

- Passive Regeneration
  - Uses exhaust heat to burn captured soot
  - Exhaust temp. should be high enough during normal duty cycle to trigger automatic regeneration
- Active Regeneration
  - DPF sized to accumulate PM during normal operational shift
  - Filter regenerated using an external heat source: burner system activated by exhaust back pressure
- If filter regeneration is inadequate
  - Filter may become overloaded with soot thereby increasing backpressure
  - Shorter service life of DPF
  - Eventually all Wall-Flow DPFs will need servicing or replacement due to ash buildup

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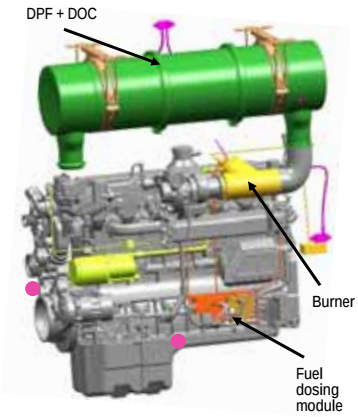
DEUTZ Particulate Filter System - Tier 4i



- Burner installed right after the turbocharger
- Regeneration is initiated when exhaust back pressure reaches a certain limit
- Regeneration could begin at any operating load
- Maximum engine output is always available

Tier 4 interim engine shown with a DPF system expected in 2012 for 75 - 175HP engines

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Selective Catalytic Reduction (SCR) System for NOx Reduction

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NOx Aftertreatment- Selective Catalytic Reduction (SCR)

The engine company. DEUTZ

- System basics
  - Reduces NOx from lean exhaust on catalyst with the presence of a reducing agent
  - Reducing agent identified by EPA as Diesel Exhaust Fluid (DEF)
  - DEF solution is sprayed upstream of the SCR catalyst
  - DEF is passively converted into ammonia (NH_3) on catalyst
  - NH_3 reacts with NOx and O_2 in exhaust to create N_2 and H_2O
  - Up to 85 - 90% NOx reduction possible
  - Up to 4% improved fuel economy
- Consequences for the engine installation and emission
  - SCR system volume
  - DEF tank and plumbing complexity
  - Release of un-reacted ammonia (ammonia slip)
    - Ammonia slip can occur if catalyst temperature is not optimal
    - Additional catalyst added to prevent ammonia slip

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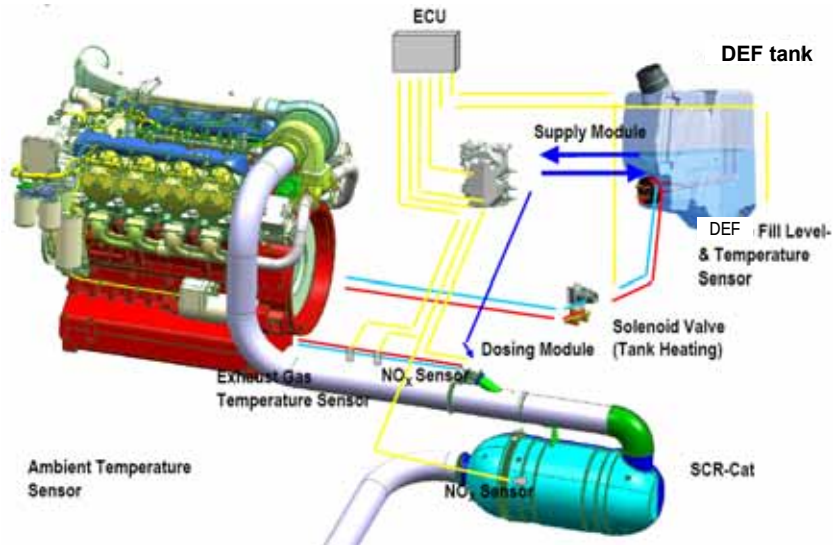
SCR System

The engine company. DEUTZ



20

SCR System

The engine company. DEUTZ

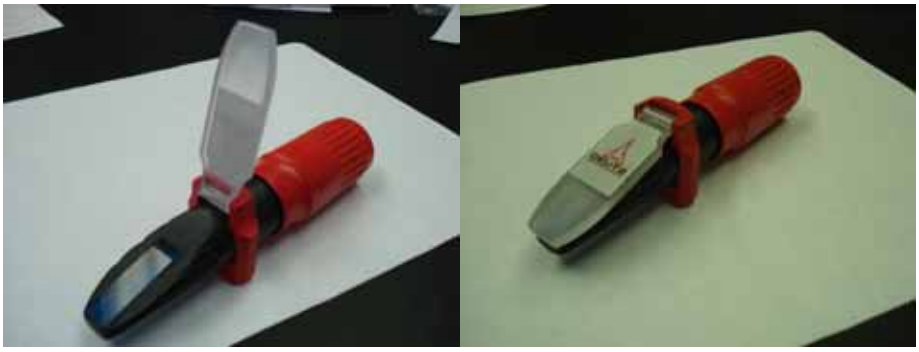
- Operator notification and inducement
  - DEF Level indicator on dashboard
  - Separate SCR warning light and warning message
  - Identification of incorrect reducing agent via NOx-Sensors
  - Detection of significant efficiency loss of SCR-system
  - Operator Inducement - torque reduction
  - Events are stored in ECU memory
- Diesel Exhaust Fluid (DEF)
  - DEF solution is 32.5% automotive grade Urea and the rest is purified de-ionized water
  - Urea is the carrying agent for ammonia (NH_3)
  - DEF quality is critical (use of refractometer in the field)
  - In Europe the DEF solution is called AdBlue
  - DEF tank heated by engine coolant (DEF solution freezes below +12°F)
    - Anticipated thawing time:
      - 20 min. @ +5°F
      - 40 min. @ -24°F

21

DEF Quality : Use of Refractometer

The engine company. DEUTZ

DEUTZ P/N 0293 7499



22

DEUTZ – SCR system: Operator Notification and Inducement

The engine company. DEUTZ

DEF (Urea) Threshold With Level Indicator	Notification Lamp - or - Message		Inducement
>15% full E F	none	none	none
Stage 1 <15% full E F	DEF lamp solid	Warning message	none
Stage 2 <10% full E F	DEF lamp flashing (time duration – OEM Specified)	Increasing message duration and/or frequency	none
Stage 3 <5% full E F	DEF lamp flashing Amber warning lamp solid	Inducement message (" tank empty, 5Min till de-rating")	none
Stage 4 5Min. After last warning	DEF lamp flashing Amber warning lamp flashing	Inducement message ("de-rating")	De-rating

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Tier 3 Transition into Tier 4

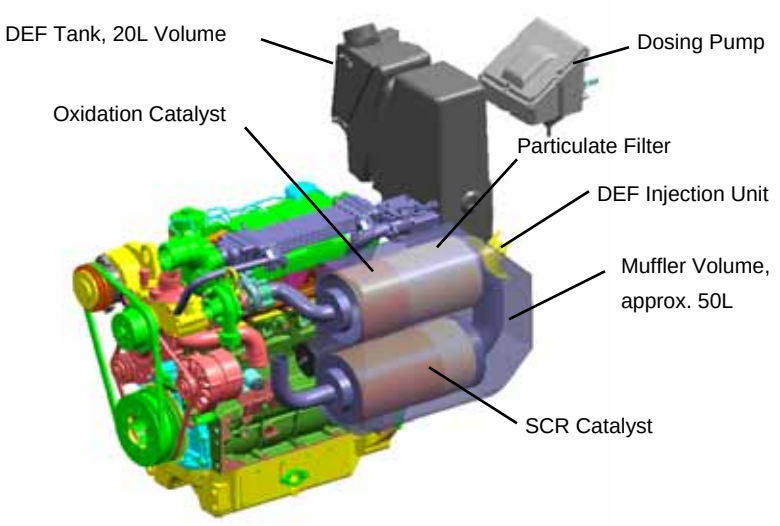
The engine company. DEUTZ

Tier 3 engine without EAT

Tier 4 engine shown with full DPF and SCR system expected in 2014 for 174 - 751HP engines

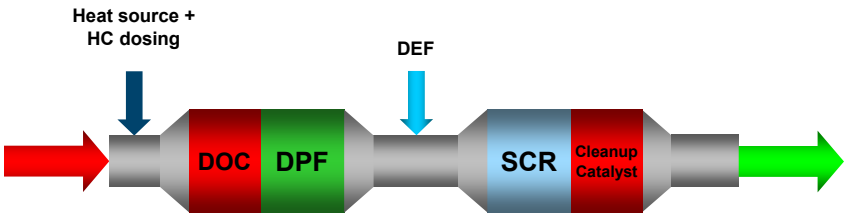
24

Future Engine Package ... (Tier 4 Final)



25

DPF and SCR System for Tier 4 Final (> 75hp Engines)



+ Up to 85% NOx reduction possible
+ Reduction of HC and CO emission
+ Particulate reduction through wall flow DPF
+ Up to 4% improved fuel economy

- Additional liquid (DEF) with own infrastructure
- More components to be installed apart from the engine

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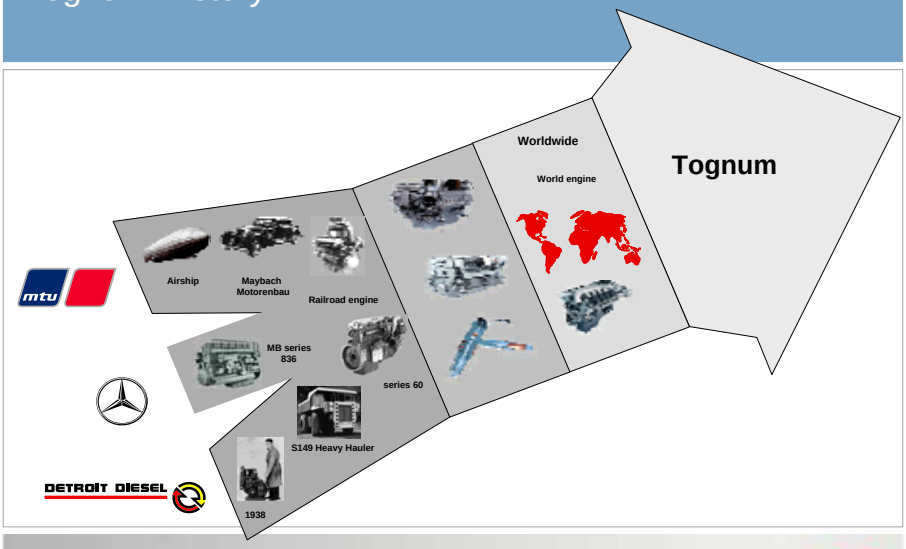
Tier 4 Industrial Engine Technology

Andrew Suda
MTU Detroit Diesel – Sr. Manager, Industrial, Mining and Rail Sales Engineering
October 5, 2010

Today‘s Agenda

01 Tognum / MTU History
02 T4 Emission Strategy
03 MTU Detroit Diesel Engine Line

Tognum History



Tognum – Production Facilities Worldwide

Plant I - Friedrichshafen

Plant II - Friedrichshafen

Mannheim

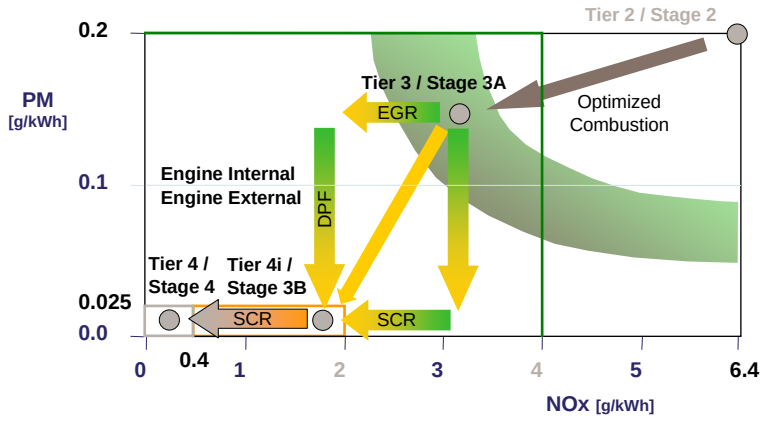
Detroit

Suzhou

Today‘s Agenda.

01 MTU History
02 T4i Emission Strategy
03 MTU Detroit Diesel Engine Line

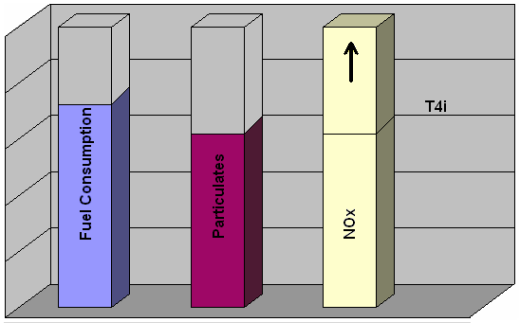
Exhaust Emission Reduction Strategies for NO_x and Particulate Matter



❖ For engines < 750hp

Emission Design Variables

This strategy results in SCR requirement
Fuel consumption remains lower



SCR and EGR Pros and Cons

SCR System

+

- Improved fuel efficiency (reported up to 5%)
- Minimal increase in heat rejection
- Passive operation
- All worldwide fuels acceptable
- Maintenance friendly

–

- DEF requirement
- Compressed air requirement

EGR with DPF

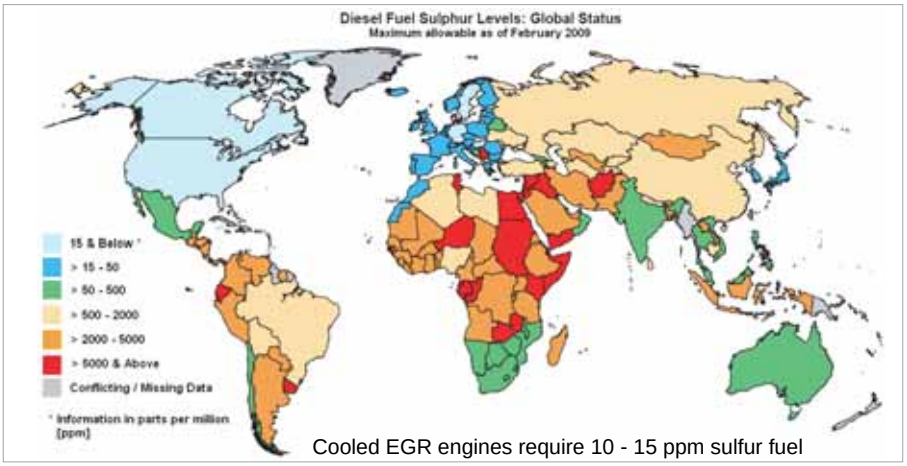
+

- EGR already in use
- No DEF necessary

–

- Greater than 20% increase in heat rejection = new higher-volume radiator design needed
- DPF Regen strategy different for individual applications = potential down time
- Ultra Low-sulphur diesel requirement
- Reduced oil change intervals due to higher soot content
- Potential DPF maintenance
- Potential Fuel Consumption Increase

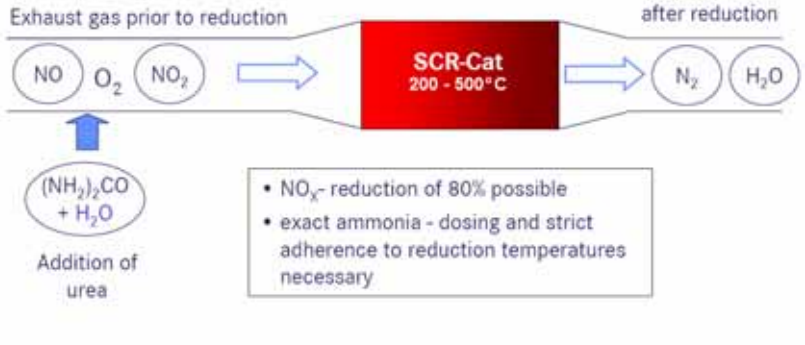
Diesel Fuel Quality



Cooled EGR engines require 10 - 15 ppm sulfur fuel

DEF Market Proliferation
North America Today

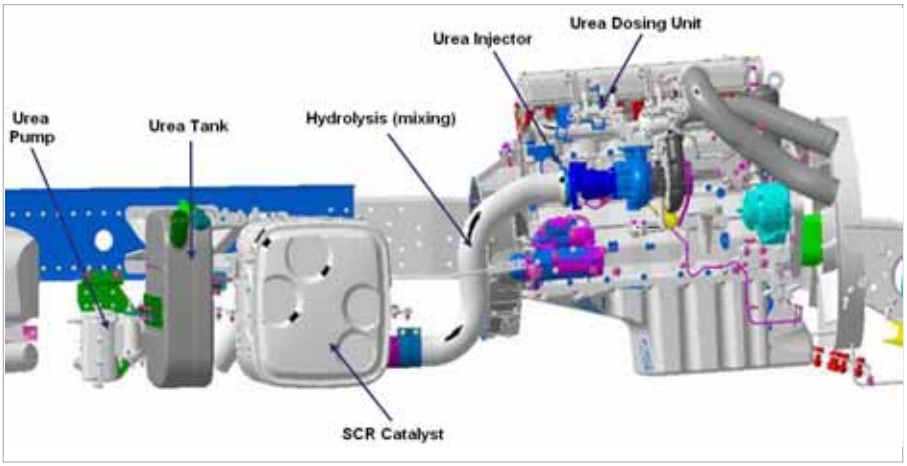
Selective Catalytic Reduction (SCR)



- NO_x- reduction of 80% possible
- exact ammonia - dosing and strict adherence to reduction temperatures necessary

Urea characteristics: **32.5% urea solution nontoxic, low viscosity freezing point: -11°C**

SCR Typical Components

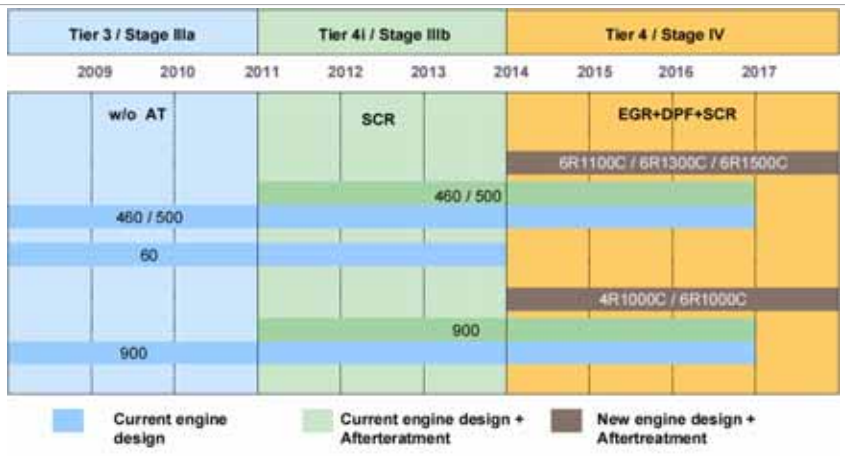


Today‘s Agenda.

01 MTU History
02 T4 Emission Strategy
03 MTU Detroit Diesel Engine Line

T4 Interim	❑ S900 SCR ❑ S460 SCR ❑ S500 SCR ❑ S60 (Tier 2 MSHA or Tier 3 EPA)
T4 Final	❑ S1000 SCR + EGR / DPF ❑ S1100 SCR + EGR / DPF ❑ S1300 SCR + EGR / DPF ❑ S1500 SCR + EGR / DPF

MTU Products through Tier 4 final
Ratings to 560 horsepower



Series 900
Tier 2 + MSHA
Tier 3 + MSHA
Tier 4 interim

101 to 322 hp

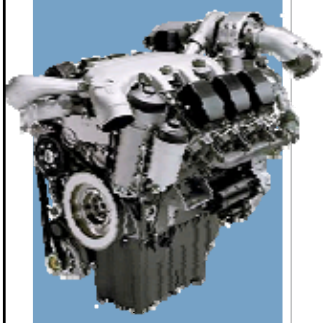
- Inline 4 and 6 cylinder
- Over 500,000 engines in service worldwide
- Over 125,000 engines in North America
- Proven in UGM applications
- No EGR or aftertreatment for off-highway engines (Tier 3)
- SCR only for Tier 4 interim
- T4i catalyst - multiple variations available
- No additional operator training required
- FAME (DIN EN14214) approved

Series 460
Tier 3
Tier 4 interim

323 to 483 hp

- Inline 6 cylinder
- 70,000 Engines in Service Worldwide
- Utilized in Combines, Cranes, etc
- No EGR or aftertreatment for off-highway engines (Tier 3)
- SCR only for Tier 4 interim
- No additional operator training required
- FAME (DIN EN14214) approved

Series 500
Tier 3
Tier 4 interim



308 to 660 hp

- V6 and V8 configuration
- 70,000 Engines in Service Worldwide
- Utilized in Combines, Cranes, etc
- No EGR or aftertreatment for off-highway engines (Tier 3)
- SCR only for Tier 4 interim
- No additional operator training required
- FAME (DIN EN14214) approved

Series 60
Tier 2 + MSHA
Tier 3

300 to 575 hp

- Inline 6 cylinder
- Extremely Popular in North America
- Proven in UGM applications
- 12.7L and 14L for Tier 2 + MSHA
- 14L Tier 3
- DDEC V Electronics

Series 1000
Tier 4 final

134 to 348 hp

- Inline 4 and 6 cylinder
- New engine design
- Common rail fuel system
- EGR with controlled recirculation rate
- DPF
- SCR
- Single or dual stage turbocharging (depends on rating)
- Wastegated fixed geometry turbos
- FAME (DIN EN14214) approved up to 7%

Series 1100
Series 1300
Series 1500
Tier 4 final

375 to 620 hp

- Inline 6 cylinder
- 10.6 ltr, 12.8 ltr, 15.6 ltr
- New engine design
- 4 ½ years of testing and development
- 5.6 million miles of testing (on-highway)
- Engineered for 2010 on-highway emissions
- EGR with electronically controlled recirculation rate
- DPF
- SCR
- FAME (DIN EN14214) approved up to 7%

Catalyst Changes – Tier 4 interim to Tier 4 final
6 Cylinder

Change Tier4 → Tier4i		DEF injection in catalyst		DEF injection in catalyst		DEF injection in catalyst	
Emission	Engine Type	Standard		Variant 1		Variant 2	
Tier4i	926		24.4 x 24 x 19.9 125 ltr		19.3 x 13.1 x 44.7 100 ltr		43.4 x 18.6 x 13.9 100 ltr
Tier4	6R 1000 C		43.2 x 33 x 22.4 ~ 340 ltr		42.9 x 34.2 x 22.4 ~ 340 ltr		42.9 x 32.2 x 20.5 ~ 340 ltr

Tier 4 interim = Catalyst is ~ 27% of engine size
Tier 4 final = Catalyst is ~ 45% of engine size

L x W x H dimensions in inches

Esso Imperial Oil

Biodiesel

Mining Diesel Emissions Council

16th Annual MDEC Conference

October 5 2010

S. Brian Ahearn

Slide 1

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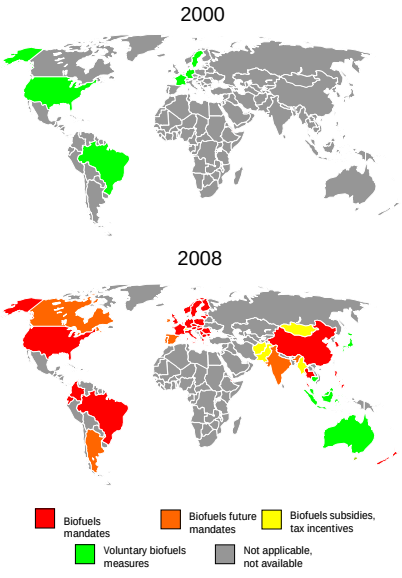
World – Regulatory Overview



Overview

- Biofuels expanding globally
- US / EU driving new technology
- Pace uncertain

2022 Potential % Biofuels	Ethanol	Biodiesel
US	26	2
Europe	16	11
Asia Pac	5	1
World	14	3

Slide 2

Biofuels

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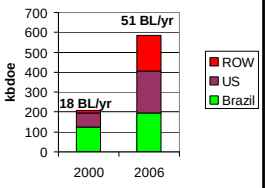
1st Generation Biofuels

- Ethanol from corn/wheat or sugar cane
- Biodiesel from vegetable oils or animal fats

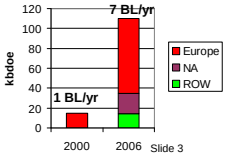


Fermentation → Ethanol

Raw Material | **Process** | **Fuel Product**

Esterification → Biodiesel*

* FAME Fatty Acid Methyl Esther



Slide 3

Canada Federal Renewable Fuel Standard RFS

Imperial Oil

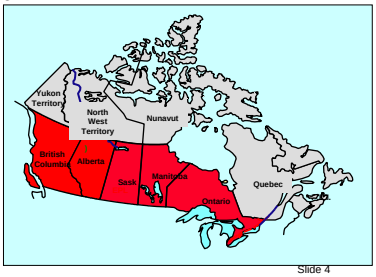
Federal RFS Overview

- Final regulation issued September 1 2010
- Ethanol - annual pool average of 5% effective Dec 15 2010 (1st compliance period 24.5 mons)
  - based on gasoline production & imports
- Biodiesel - provision for 2% pool average, with effective date to be determined (by RFS amendment)
  - based on diesel & heating oil production & imports
  - technical feasibility assessment (Natural Resources Can) of biodiesel under Canadian conditions underway
- No GHG emission limits; no 'biases' for next-generation biofuels
- Hydrotreated Vegetable Oil (HVO) and Biocrude co-processing permitted
- Geographical exemptions - north of 60° and Newfoundland (gasoline)
- Use exemptions - exports, kerosene and military diesel
- Provincial biofuel compliance count towards Federal compliance

Provincial RFS Overview

	Ethanol	Biodiesel
Ontario	5.0 %	-
Saskatchewan	7.5 %	-
Manitoba	8.5 %	2.0 %
British Columbia	5.0 %	3.0 % (5% by 2012)
Alberta*	5.0 %	2.0 %

* min 25% less carbon intensity than gasoline/diesel



Slide 4

RFS Biodiesel Compliance

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Federal RFS

- Government's drivers for Renewable Fuels Strategy are reduce GHGs from fuel use, encourage domestic biofuel production, accelerate new biofuel technologies, and provide new markets for agricultural/rural
- Environment Canada's RFS is under CEPA (Canadian Environmental Protection Act)
- Obligated parties are Primary Suppliers (a producer or importer of gasoline, diesel/heating oil)
- Compliance is on a company basis
- 5% ethanol & 2% biodiesel is annual pool average ie not every litre requires renewable fuel

RFS Biodiesel Compliance

- Typically, fuel providers will buy FAME biodiesel, and blend a B5 diesel at the truck loading rack
  - B5 is a 5% blend (5% FAME, 95% diesel)
  - B5 meets CGSB specification (Canadian General Standards Board)
- Biodiesel supply currently averaging 20/80 domestic/import (US)
- B5 currently offered in the Vancouver and Winnipeg supply orbits
  - future locations may include Edmonton and Montreal/Toronto supply orbits

Biodiesel Challenges

- Low-temperature operability/stability concerns
- OEM warranty limits of 5% forces other options to meet pool average
  - limited biodiesel in northern zones (ie colder than – 15 C cloud Low Temperature Operability)
  - standard customer offer blends capped at B5 to honour OEM warranties

Slide 5

Biodiesel

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Background

- Federal RFS proposes 2% renewable fuel content in diesel fuel and heating oil
- Conditional upon successful demonstration of renewable diesel under Canadian conditions
  - industry sectors and end-users raised questions for large-scale integration
  - National Renewable Diesel Demonstration Initiative (NRDDI) aimed to address these questions in advance of the proposed regulations coming into effect

Biodiesel Research Project

- Imperial Oil and Canadian Petroleum Products Institute (CPPI) have vested interest for successful transition to renewable diesel
- Main areas of concern:
  1) Cold flow performance of finished fuel
     - filterability/operability above cloud point, vehicle operability
  2) Stability
     - long term storage particularly at low temperatures
     - high temperature deposit formation in engines and furnaces
- Study conducted at the Imperial Oil Sarnia Research Centre

Slide 6

Biodiesel Research Project

Esso Imperial Oil

Overview

- Designed to understand technical issues, provide guidance for decision-makers, blending formulation and standard-setting bodies to set specifications to ensure "fit for service" fuels
- Imperial Oil supported by Technical/Advisory Committee for technical peer review - included federal government, CPPI, Canadian Oil Heat Association (COHA), Canadian Renewable Fuels Association (CRFA) and Canadian Trucking Alliance
- Leveraged ongoing work in industry such as long term operability of B2 & B5 diesel in on-road heavy-duty engines (Alberta Renewable Diesel Demonstration), and test method development (ASTM, National Renewable Energy Laboratory)

Key Technical Outcomes

1) Long-term furnace operation and performance was negligibly impacted by fuel up to B10

2) Deleterious impact of saturated mono-glycerides (SMG) in renewable diesel on the low temperature operability of filters in fuel handling systems was further confirmed underscoring the need to limit their content to prevent potential field issues

3) Long-term storage stability of renewable diesel fuel can be assured via the use of commercially available oxidation control additives

Slide 7

Research Summary & Full Reports – download at www.cppi.ca

Esso Imperial Oil

- contact Marc-Andre Poirier, Imperial Oil 519-339-2208

Biodiesel Research Project Final Report Summary

Funded by
Imperial Oil, Canadian Petroleum Products Institute and
Natural Resources Canada under National Renewable Diesel Demonstration Initiative (NI

Canadian Petroleum Products Institute | Institut canadien des produits pétroliers

Imperial Oil Esso L'Impériale

Natural Resources Canada | Ressources naturelles Canada

Canada

Research conducted by
Imperial Oil,
Products and Chemicals Division
Research Department
Sarnia, Ontario, Canada

R658-2009

December, 2009

Slide 8

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Research Department, Sarnia

R434-2010

Imperial Oil/CPPI Bio-diesel Research Project Funded Under NRDDI Program

16th Annual MDEC Conference

October 5, 2010

Marc-André Poirier

2

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Imperial Oil/CPPI Renewable Diesel Fuel Program

- Research program scoped to address concerns with FAME bio-diesel
  - Low temperature operability (HD on-road application)
  - Fuel storage at low temperature (all applications)
  - Thermal/oxidation/storage stability of bio furnace fuel
  - Canola, Soybean, Tallow and Palm Methyl Esters included in study
- Program builds upon existing expertise & leveraged by on-going work within and outside the company
  - Performance in light duty engines (Europe)
  - Optimum additives for cold flow, oxidation control…etc (Additive Suppliers)
  - Low temperature operability of SME and TME in on-road HD engines (CRC 650)
  - Low temperature operability in on-road HD engines (IOL/CPPI SAE 2008-01-2380)
  - Long term operability of B2 & B5 diesel in on-road HD engines (ARDD)
  - Test method appropriateness/method development (ASTM, NREL, CEN...etc)
- Presentation will report on the work to date with focus on
  - Phase separation above the cloud point

3

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Phase Separation Above the Cloud Point – Saturated Monoglycerides

- **Flint Hills Resources (IASH 2007, Tuscon, AZ)**
  - Plugging of Dispensing filters (nominal 30µm) at -18°C with B2.5 using BQ9000 compliant B100 SME
  - Filter plugging caused by saturated monoglycerides (SMG)
- **Infineum (April 2008 Presentation by Davis & Denecker)**
  - Precipitation above CP seen with all FAME in Bx – FBT (IP 387) used to detect
  - Filter plugging attributed to SMG in add-back experiments
- **Cosmo Oil Co. Ltd (SAE 2008-01-2505)**
  - Low temperature storage testing in lab & AWCD with B5 PME(3), B5 SME , B5 RME
  - B5 PME stored at 10°C produced crystals of C14 to C18 monoglycerides
    - Authors concluded that SMG was the cause and its content in FAME needs to be limited
- **B5 SME Filter Blocking Problem at US Terminal**
  - Occurred in above-ground tanks at 0-15°F with 10 µm mesh filter dispensing pumps
  - Cause attributed to SMG

4

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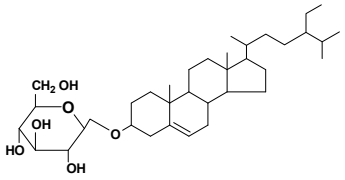
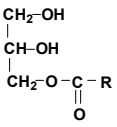
Problematic Impurities Found in Bio-Diesel (FAME)



Sterol Glucoside m.p. = 240°C



R = C_{12} to C_{20} alkyl chain

monoglycerides

- Sterol glucosides occur naturally in vegetable oils
  - Present at 10 to 120 wppm in crude FAME
  - Limit controlled by the Cold Soak Filtration Test (ASTM D7501)
- Monoglycerides are the result of incomplete trans-esterification
  - Current limits for monoglycerides in FAME:
    - No limit in ASTM D 6751
    - 0.8 wt% max EN 14214
    - 0.5 wt% max balloted at CGSB
  - Saturated monoglycerides have been implicated in filter plugging (m.p. = 71 - 81°C)
  - Currently no spec limit on saturated monoglycerides

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Cold Soak Filtration Test and Filter Blocking Tendency Test

- **Cold Soak Filtration Test (ASTM D7501)**
  - Apply to B100 (FAME)
  - FAME soaked at 4.4°C (40°F) for 16 hours
  - 3 or more hours to warm up to 20-22°C
  - Filter 300 mL, 47 mm diameter, 0.7µm glass fiber filter, 78kPa
  - ASTM D 6751 Pass if CSFT is < 360 sec and < 200 sec for operability < -12°C
  - CGSB ballot is csft < 200 sec.
- **Filter Blocking Tendency Test (ASTM D2068)**
  - Apply to B0 – B100
  - Filter 300 mL at a rate of 20 mL/min
  - 13 mm diameter, 1.6µm glass fiber filter
  - "Pass" considered to be FBT ≤ 1.4
    - 300 mL has been filtered and pressure is ≤ 105 kPa

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Low Temperature Storage Stability - Lab Program

Objective

To address wax settling and precipitation of material above the cloud point which could have significant impact on field performance

Test Protocol

Set # 1: Storage at 2-4°C above blend cloud point but below FAME cloud pt for 10 days

Set # 2: Storage at 1°C for 10 days

- Appearance (1 day, 2 day, 4 day, 5 day and 10 day)
- Warm up then Filter Blocking Tendency (ASTM D2068)

Fuels & FAME's

- Six Canadian low cloud ULSD fuels (LSD-25 to LSD-48)
- Aromatics content from 0 to 43 wt%
- CME, SME, TME and PME at B0, B2, B5 and B20
- Total of 57 fuels
- Properties of base fuels and FAME available upon request

7

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Correlation Between SMG Content and Filter Blocking Tendency

- FBT increases with increasing SMG content in the fuel
- Relatively good correlation between FBT and SMG (R2 = 0.85)
  - The CSFT of the PME used was >720 secs

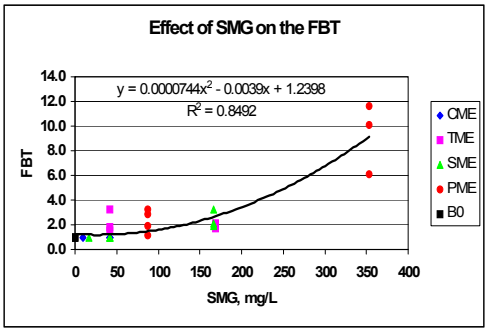
$$SMG_{mg/L} = FAME_{vol\%} \times d_{FAME} \times SMG_{mg/kg}$$

$SMG_{mg/L}$ = SMG in the fuel

$FAME_{vol\%}$ = Volume of FAME in the fuel

d_{FAME} = FAME density

$SMG_{mg/kg}$ = SMG in the FAME



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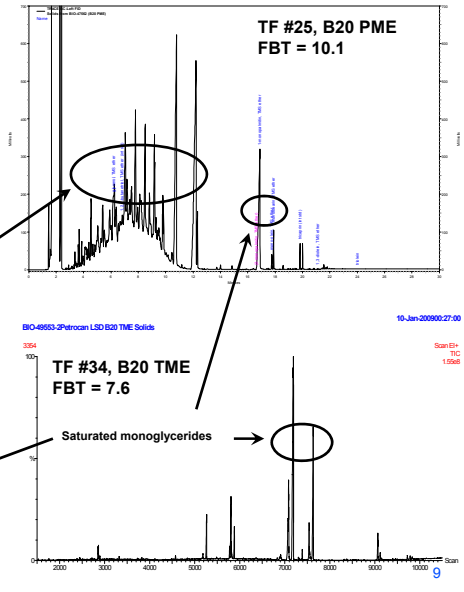
GC-MS Confirms SMG as Cause of High FBT

- GC-MS analysis confirmed the enrichment of SMG in the filter residue
  - 1-monopalmitin
  - 2- monopalmitin
  - 1-monostearin
  - 2-monostearin
- Presence of residual fuel



9

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Effect of SMG on the Operability of Class 8 Trucks Tested in AWCD

- **3 Class 8 trucks equipped with most popular engines**

Vehicle	Truck	Engine	Year
Freightliner	D	Detroit Diesel Series 60	2004
International	A	Cummins ISM	2005
International	B	Cummins ISM	2005

- **Fuel delivery system found critical for low temperature operability**
  - DD Series 60 has one 7 µm filter and 220W electric heater in fuel filter housing under the hood
  - Cummins ISM has one 7 µm filter outside cabin and no electric heater. Lower fuel recirculation than DD Series 60
- **Test fuel: B5 CME spiked with 150, 200 and 250 mg/L SMG (Total 18 tests)**
  - SMG was added to the CME and heated to 70 -80°C for 3-4 hours prior to blending into base fuel @ 5%
  - Base fuel is commercially available in Ontario
  - Pre-soaked at -16°C for 84-90 hours prior to the test
- **Test condition: -16°C (10°C above -26°C cloud point of fuel)**
  - 10 minutes idle followed by 1 hour at 80 kph steady speed
- **Decision on the next test based on the ΔP across the filter**
  - Repeat or continue next test with "old" filter
- **Failure = rough start, stall at idle and failure to reach 80 kph**

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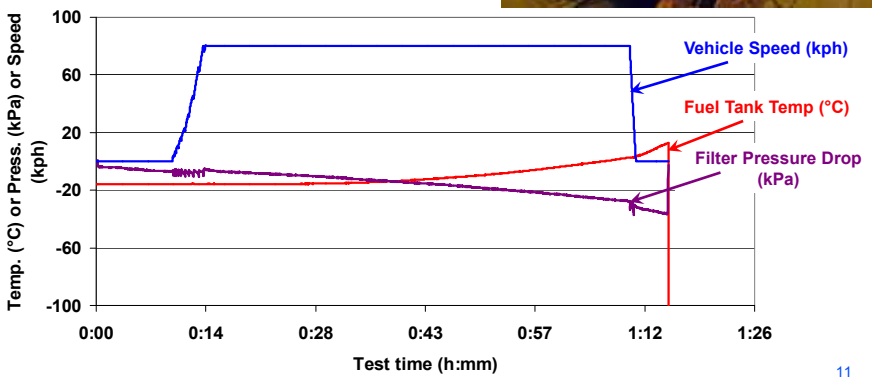
Imperial Oil

Research Department, Sarnia

Key Parameters Measured in AWCD Test

- Test cell and pre-soak chamber can be controlled independently from - 40 °C to +43 °C
- Specified computer controlled cool-down profile or fast cool-down rate
- Wind velocity can be synchronized to vehicle speed or independently controlled to 120kph



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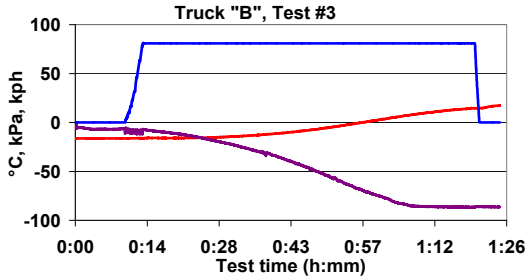
Imperial Oil

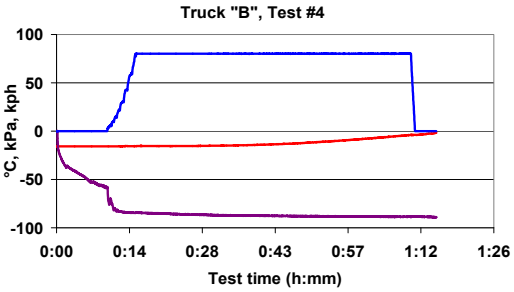
Research Department, Sarnia

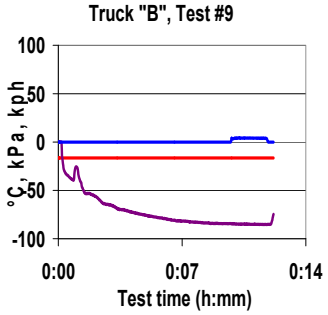
250 mg/L SMG in B5 CME Resulted in Operability Failure

	250 mg/L Performance Chart			
	International Cummins ISM			Fuel Tank
Truck	Test #	Fuel, L	Filter ΔP (EOT)	Temp.°C (EOT)
B	3	200	86	15
B	4	40	89	-1
B	9	200	85	-16

Fuel Tank Temperature (°C)
Fuel Filter Pressure (kPa)
Vehicle Speed (kph)







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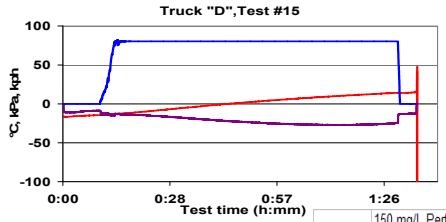
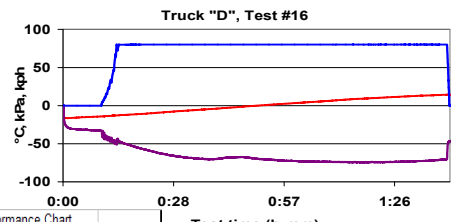
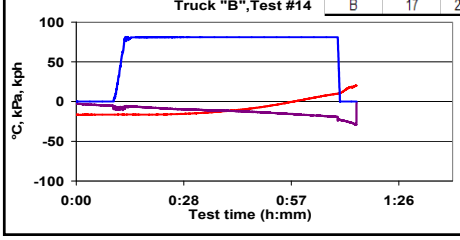
150 mg/L SMG in B5 CME Resulted in High Fuel Filter ΔP

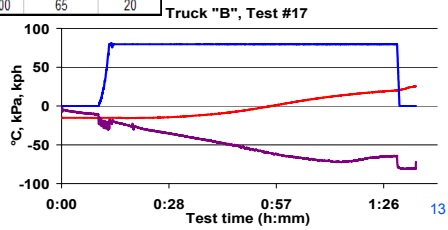




Fuel Tank Temperature (°C)
Fuel Filter Pressure (kPa)
Vehicle Speed (kph)

	150 mg/L Performance Chart			
	Freightliner DD S 60			Fuel Tank
Truck	Test #	Fuel, L	Filter ΔP (EOT)	Temp.°C (EOT)
D	15	317	26	14
D	16	350	70	14
	International Cummins ISM			
B	14	200	19	10
B	17	200	65	20





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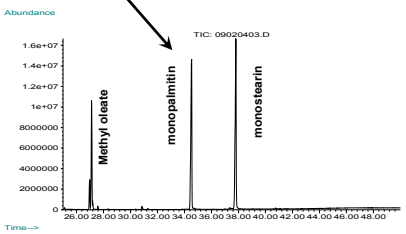
Accumulation of SMG on the Fuel Filter Caused Truck Failure

- Fuel spiked with SMG at 250 mg/L resulted in operability failure
  - SMG on filter confirmed by GC-MS
- Fuel spiked with SMG at 200 mg/L resulted in high ΔP and restricted fuel re-circulation
  - Predicted failure with 210L of additional fuel
- Fuel spiked with SMG at 150 mg/L resulted in high ΔP without fuel re-circulation problem
  - Predicted failure with 147L of additional fuel

At 250 mg/L SMG

SMG Confirmed by GC-MS for 250 mg/L and 150 mg/L



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Conclusions: SMG a Real Problem

Lab Tests

- Confirmed prior literature regarding negative impact of SMG
  - Unsaturated monoglycerides do not plug filters
  - Filters with high FBT are enriched in SMG
- FBT correlates relatively well with SMG content

AWCD Tests

- Based on spiking methodology used, SMG accumulate on the fuel filter, do not re-dissolve in the fuel and eventually will cause operability problems

Imperial Oil reports can be found on www.cppi.ca web site

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Imperial Oil

Research Department, Sarnia

Bio-Diesel Furnace Program

- Long term furnace operability study with bio-fuels underway
  - Evaluation of B5-B20 content fuel
- Riello burner and Kerr furnace are widely used in the marketplace
  - Riello burner BF3 Model, nozzle 0.5 USGPH, flame detector 5KΩ to 50KΩ, furnace 1200 CFM
- Furnace cycles defined with Riello, Kerr & IOL
- Total 120 days (4 months) per test cycle
  - 5 min on/20 off simulating Spring/Fall
  - 10 min on/10 min off simulating start-up endurance
  - 20 min on/10 min off simulating Winter cold snap
- Input provided by CPPI
- Test 1 & 2 completed successfully

Test #	Bio-Fuels	Start	End
1	B0, B5 & B20 CME	16-Apr-08	25-Aug-08
2	B10 TME, B20 CME & B20 SME	29-Aug-08	12-Jan-09
3	B20 TME, B15CME/B5TME, B15 SME/B5TME	19-Feb-09	30-Jun-09

Weekly Monitored Properties

Smoke No., CO, CO2, O2 NO, efficiency, nozzle/pump temperature, breach temp., excess air, over fire draft, cad cell resistance

16

MINING DIESEL mdec EMISSIONS COUNCIL

16th ANNUAL MDEC CONFERENCE – October 05, 2010

KINROSS

16th ANNUAL MDEC CONFERENCE

Biodiesel Test at Kinross Gold

Paracatu Mine - Brazil

KINROSS

MINING DIESEL mdec EMISSIONS COUNCIL

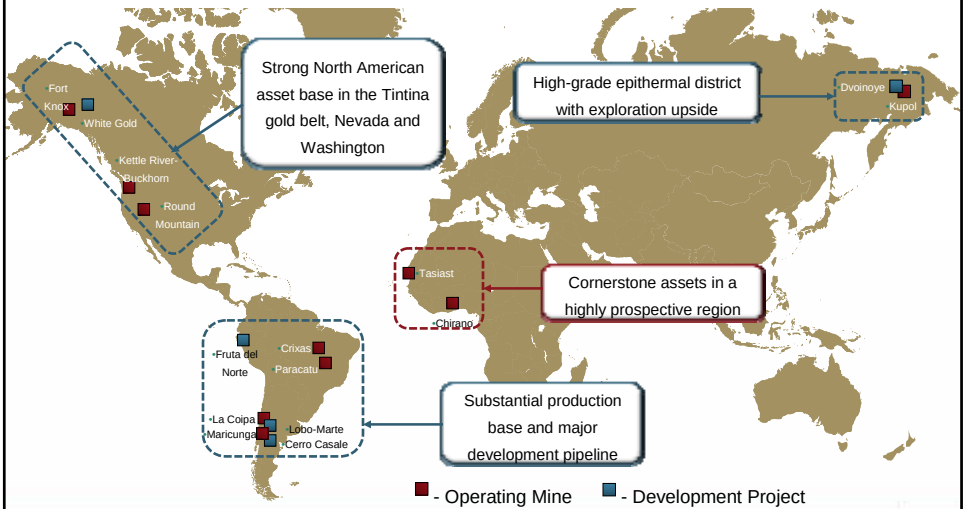
2

KINROSS – WHO ARE WE?

- Growing senior pure-gold producer
  - 2.2 million gold equivalent ounces in 2010
- 8 operating mines
- 5,500 employees worldwide
- Strong culture built on “The Kinross Way”
- Suite of world-class development projects
- Highly prospective exploration portfolio
- Commitment to outstanding corporate citizenship

Our core purpose
is to the lead the world in generating value through responsible mining.

Operations & Development Projects



BIODIESEL TEST AT Rio Paracatu Mineração

What is Biodiesel?

Biodiesel is basically a vegetable oil (or cooking oil) that he has been processed to remove glycerin. Pure biodiesel can be burnt in the place of diesel, but presently it is significantly more expensive than diesel. The additional expense to produce and blend the biodiesel fuel is normally compensated by credits and or other government subsidies.

Some Facts About Biodiesel

The use of the fuel biodiesel is a trend that is growing in some parts of the world. Biodiesel is more often used for transport trucks and in agriculture, however its popularity is growing. This is the result of three factors:

- ✓ Periodic diesel fuel shortages;
- ✓ Increases in the cost of the diesel fuel; and
- ✓ More stringent laws regarding emission from gas and diesel powered vehicles.

More Biodiesel Facts (in Brazil)

- ✓ In Brazil service stations must carry biodiesel;
- ✓ Presently biodiesel is sold as a blend of 1% and this will soon increase to 2%;
- ✓ Currently biodiesel is more expensive than straight diesel due to rising soya bean prices;
- ✓ The government is encouraging the use of biodiesel through insentive programs;
- ✓ Biodiesel has been persived as taking food away from the people;
- ✓ To remove this perception new crops of non food plants are being developed;
- ✓ Pinhão Manso and Mamona are non food crops being considered for biodiesel production; and
- ✓ Biodiesel is still in the development stage and the Brazilians believe they will eventually get it right.

Note: Ethanol fuels are sold every where in Brazil but there was a time when it did not perform so well. Over time it has been improved. They feel the same will become of biodiesel.

Sources of Biodiesel

The most common they are:

- ✓ Oil from soya beans;
- ✓ Used cooking oil; and
- ✓ Oil of Palm, Canola, or Colza Seed

The concentrations of biodiesel mixes are:

- ✓ B5 - 5% biodiesel to 95% diesel
- ✓ B20 – 20% biodiesel to 80% diesel
- ✓ B100 – pure biodiesel / also known as clear biodiesel

Note: The sale of biodiesel, in some parts of the world, is being strongly promoted through incentives and benefits. Some of these benefits have merit whereas others are not totally proven. These claims rarely show the potential problems that can occur by the use of biodiesel.

Biodiesel Test at RPM

- RPM until recently consumed around 9 million liters of diesel per year.
- With the expansion RPM expects to consume approx. 20 million liters of diesel per year.
- Other mines within the region consume around 2.7 million liters of diesel per year.

INFORMATION WAS COLLECTED BY CAT USING A DYNAMOMETER PRIOR TO FIELD TEST

Results From Dynamometer

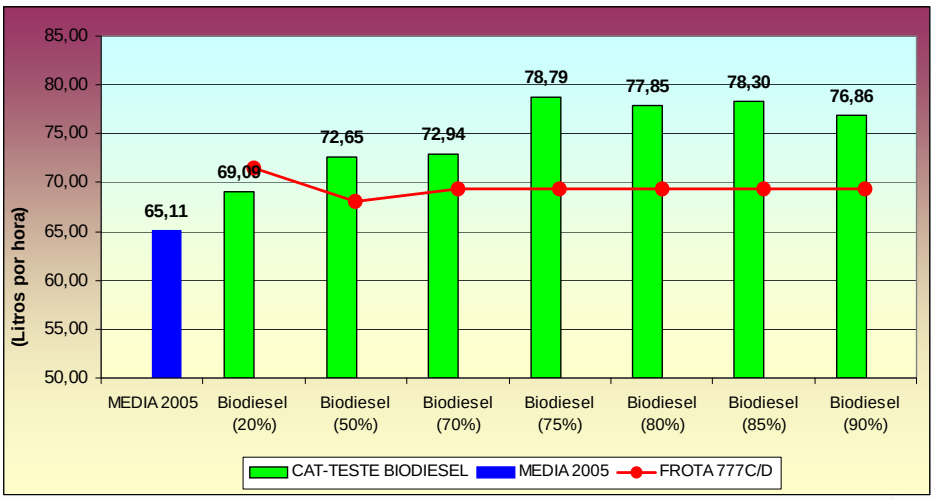
	Load		Torque		Gas Emissions	Combustion Temperature (ºC)
Tests	RPM	Theoretical (HP)	RPM	Load (lb/ft)		
Recondic.	1710	886	1290	3150	43.4	551/610
BIO 5%	1720	897	1300	3210	44.3	528/551
BIO 10%	1720	900	1290	3200	45.5	556/607
BIO 20%	1720	873	1300	3130	45.7	531/563
BIO 50%	1720	869	1310	3120	44.3	537/580
BIO 100%	1740	835	1320	2980	41.9	511/553

Conclusions From Dynamometer Test

Analyzing the performance of the CAT 3508 diesel engine, which is used in the 777C haul trucks, as per the dynamometer test, it was demonstrated that biodiesel did not significantly alter the power output for mixtures with percentages of 5 to 50%. For higher percentage mixtures, Caterpillar noted a reduction in the power. Caterpillar considers power loses below of 3% to be acceptable. However, for loses in the range of greater than 3% Caterpillar considers these to be problematic.

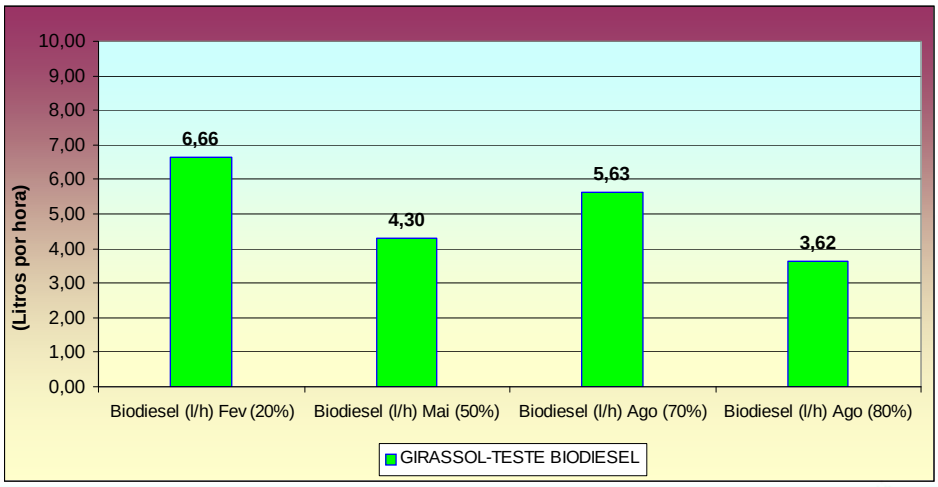
Tested Haul Truck CAT 777C – Capacity 86 tonnes

Biodiesel Burn Rate (Lit/Hr Avg.) – CAT 777C



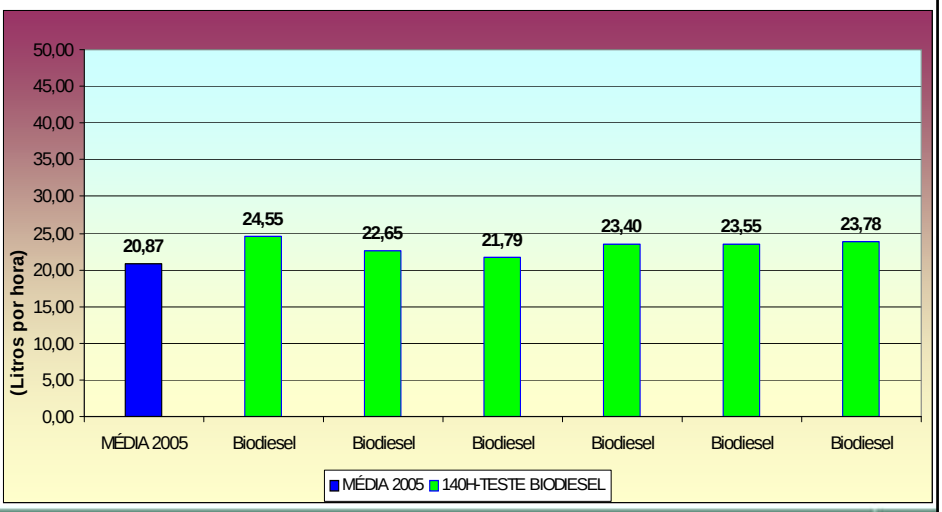
Volkswagon VW-17270 Test Fuel/LubeTruck

Biodiesel Burn Rate (Lit/Hr Avg.) – VW-17270



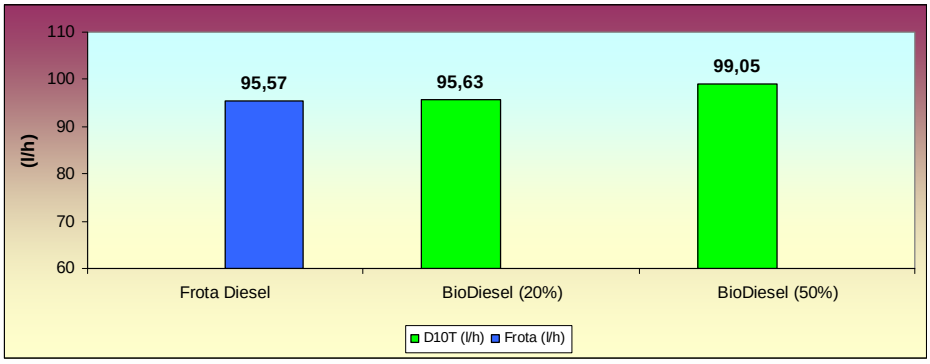
Tested Motor Grader – CAT140H

Biodiesel Burn Rate (Lit/Hr Avg.) – CAT140H



Tested Bulldozer – CAT D10T

Biodiesel Burn Rate (Lit/Hr Avg.) – CAT D10T



RPM Biodiesel Test Conclusions

- Equipment operators noted that the machines seem to have less power. They estimated 20%
- RPM determine that the only way to make Biodiesel viable would be to produce their own soya beans. Soya cake is still more valuable than soya oil.
- The test is no longer in progress.
- Vale is testing Biodiesel on their locomotives.

Pros and Cons of Biodiesel

PROS

✓ **Reduction in gas emmisions in diesel exhaust:**

Unburnt hydro carbons.....14%

Carbon Monoxide..... 9%

Particulates 8%

✓ Increase of the fuel lubricating properties due to its low viscosity.

✓ Ability to degrade in cases of fuel spills.

Pros and Cons of Biodiesel

CONS

Biodiesel can cause deposits that build up on the membranes of the fuel filters resulting in a rapid clogging. The problem worsening when the concentration of biodiesel increases.

Pros and Cons of Biodiesel

CONS

Increase in certain emissions in the exhaust gases
NOX 2%

Fuel Economy
Pure biodiesel is 5 to 7% less efficient than regular fuel.

Effect of Biodiesel on Fuel Filters

The fibers in the filter membrane are hygroscopic, and attract the water. The attraction between the filter and water is greater than the attraction between water and diesel. As the water continues being attracted by the filter, water drops form and increase of size until they cannot pass through the membrane and fall into the reservoir, where they are drained.

The ability of the fuel filter to work is based on the attraction between the filter membrane and the water being greater than the attraction of diesel and water. When the Biodiesel is added, it significantly increases the attraction with the water. Hence, the water will pass through the filter and will not be separate, rendering the filter effectively useless.

Biodiesel Promotes the Growth Microbes in Fuel

- Biodiesel acts as a catalyst that increases the growth of microbes that already exist in fuels
- Biodiesel is hygroscopic which means it absorbs the water. Regular diesel can contain as much as 60 ppm of water. While biodiesel can contain 1200 the 1500 ppm of water (20 times more).
- Water increases the probability of microbiological growth and corrosion. The microbes only need a very small amount of water to establish its ecosystem and to proliferate.

Issues Related to the Storage of Biodiesel

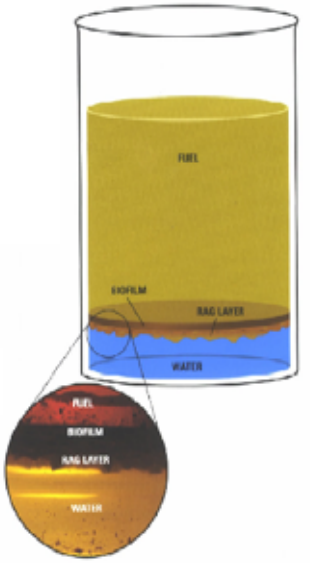
1. Biodiesel degrades two times faster than the conventional diesel fuel.
2. It cannot be stored for more than 3 months.
3. Biodiesel requires special storage and handling.

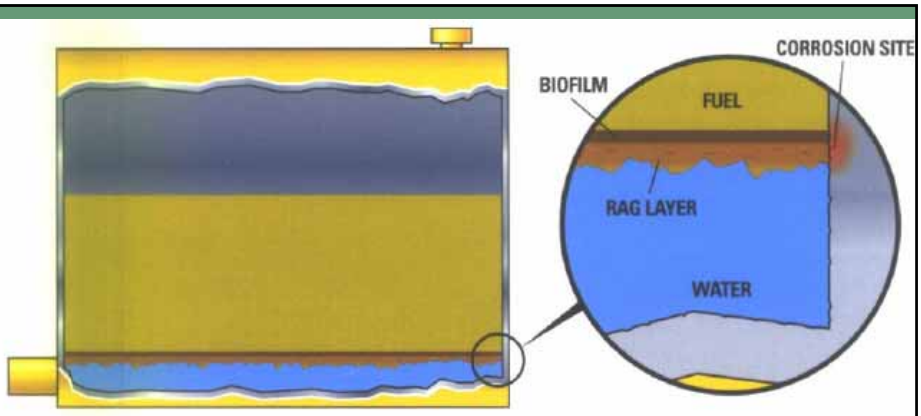
Biofilm

Biofilm is a complex colony of active microbiological organisms.

Rag Layer

Rag Layer is an active surface between biofilm and the water, where the microbiological growth occurs.





Acid is a by-product of the microbiological growth, it can cause severe corrosion to fuel tanks.

It can also degrade various types of seals used in the fuel system, such as certain elastic polymers and seals made of natural rubber.

Note: Ethanol fuels are sold every where in Brazil but there was a time when it did not perform so well. Over time it has been improved. They feel the same will become of biodiesel.