



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

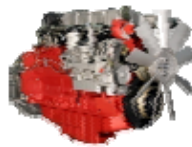
Greg Tremaine
DEUTZ Corporation

Mining Diesel Emission Council
Toronto ON
October 5-8 2010

Composition of Exhaust Gases from Diesel Engines




N₂ = 78.1%
O₂ = 20.9%
Ar, CO₂ + others = 1.0%
Diesel fuel



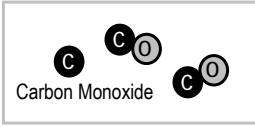
Gas phase	Solid phase
N ₂ - 75%	Soot
O ₂ - 8%	
CO ₂ - 9%	
H ₂ O - 8%	
Pollutants < 1.0%	

- 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

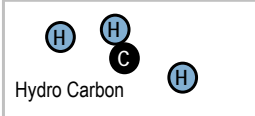
Harmful Effects of Gaseous and Particulate Matter



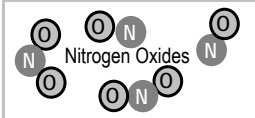
The engine company. **DEUTZ**




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 NO₂, 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.

GP - July 2009 3

Introduction to Nonroad Diesel Engine Emission Regulations

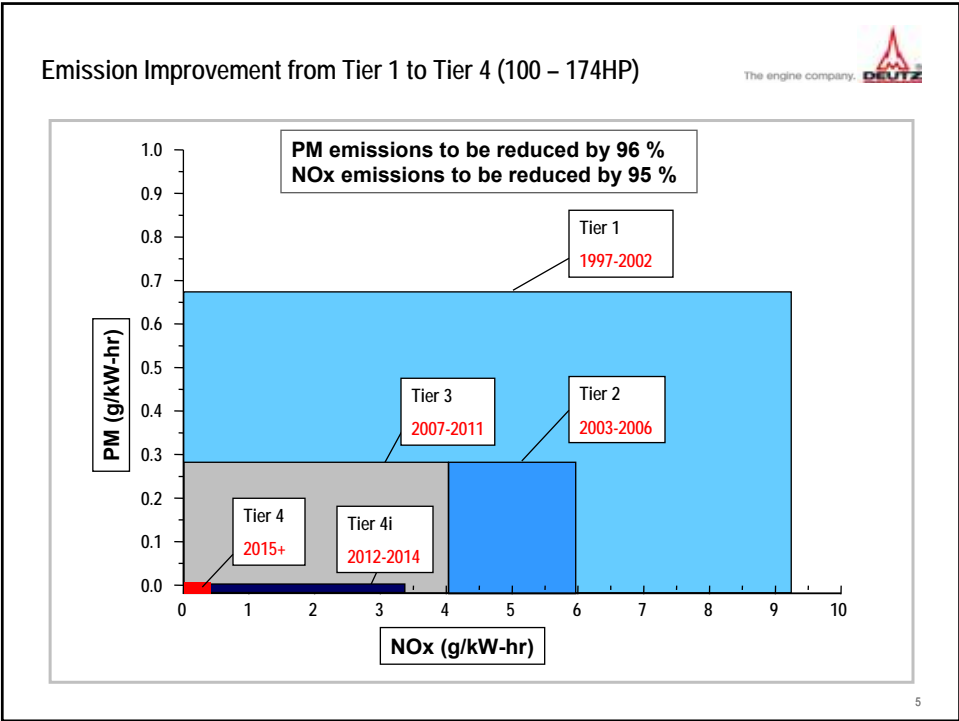


The engine company. **DEUTZ**

- 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 (NO_x)
 - 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	
300 ≤ HP < 600	175 ≤ HP < 750
600 ≤ HP < 750	
HP > 750	HP > 750

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EPA Nonroad Diesel Emission Regulations Tier 1 - 4

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			
75≤HP<100					6.9 / - / - / -					[5.6] / 3.7 / 0.30						(Opt 2) [3.5] / 3.7 / 0.30			[3.5] / 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			0.30 / 0.14 / 3.7 / 0.01
175≤HP<300					6.9 / 1.0 / 8.5 / 0.4					[4.9] / 2.6 / 0.15												
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

To Achieve Tier 4 (> 25hp) Emission Levels




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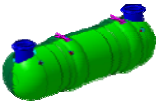
Requires a Three Segment "Systems Approach"




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				

**LOW-SULFUR
NON-HIGHWAY
DIESEL FUEL**
(500-ppm Sulfur Maximum)

WARNING
Federal law *prohibits* use in highway vehicles or engines.


**ULTRA-LOW SULFUR
NON-HIGHWAY
DIESEL FUEL**
(15 ppm Sulfur Maximum)

Required for use in all model year 2011 and newer non-road diesel engines. Recommended for use in all non-road engines.
WARNING
Federal Law *prohibits* use in any highway vehicle or engine.

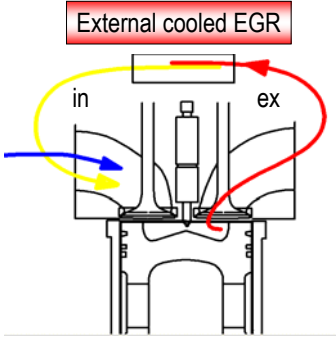
- On-highway diesel fuel currently is at 15 ppm Sulfur (ULSD)

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Exhaust Gas Recirculation (EGR)


The engine company. 

- 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 CO₂ level leads to lower combustion temperature peaks resulting in less NO_x in the exhaust
- External Cooled EGR
 - Compared to un-cooled or internal EGR
 - Maximizes specific power
 - Maximizes NO_x reduction



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EAT Components

The engine company. 

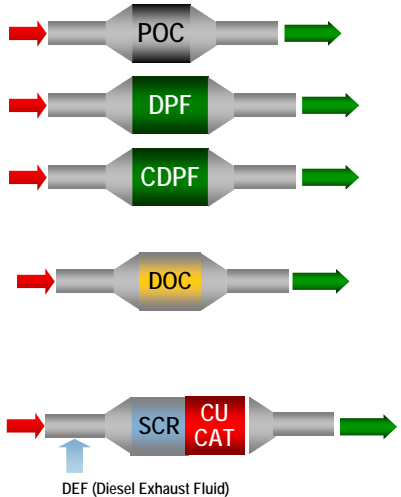
Aftertreatment devices can be divided in two main groups:

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

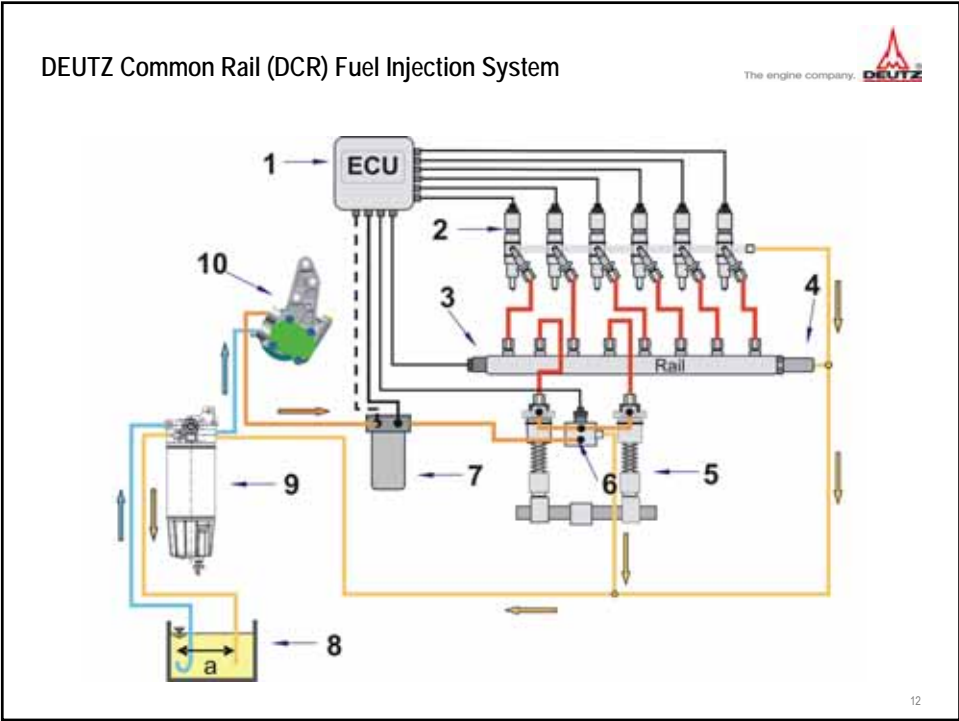
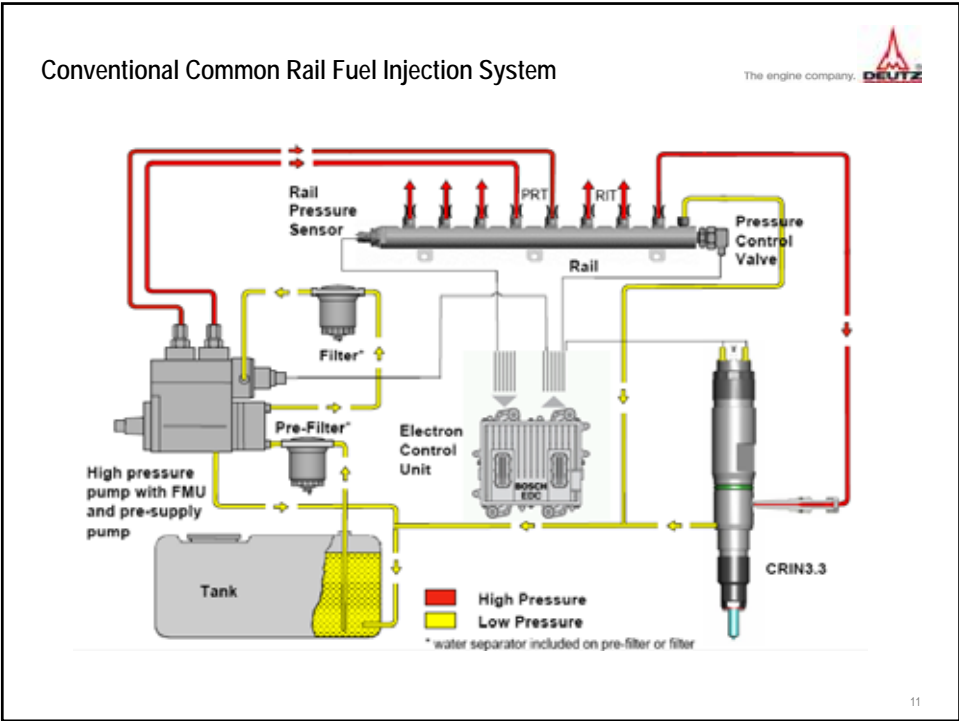
- Particulate Oxidation Catalyst (POC)
Diesel Particle Filter (open DPF)
- Diesel Particle Filter (closed DPF)
- Coated Diesel Particle Filter (closed DPF)


Modules which convert toxic exhaust gases into harmless gases

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



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The engine company. 

Tier 4i/4 Exhaust Aftertreatment Systems (EAT)

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. 

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

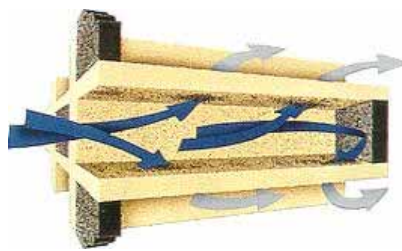


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Diesel Particulate Filters (DPF)



- 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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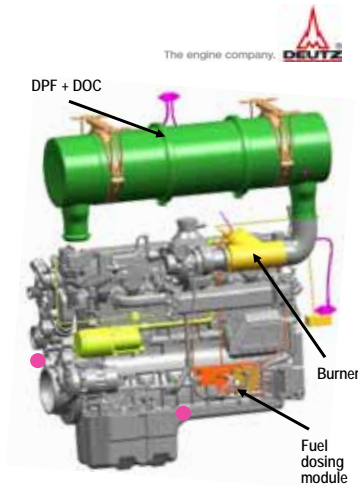
DPF Regeneration – The Challenge



- 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

Selective Catalytic Reduction (SCR) System for NOx Reduction



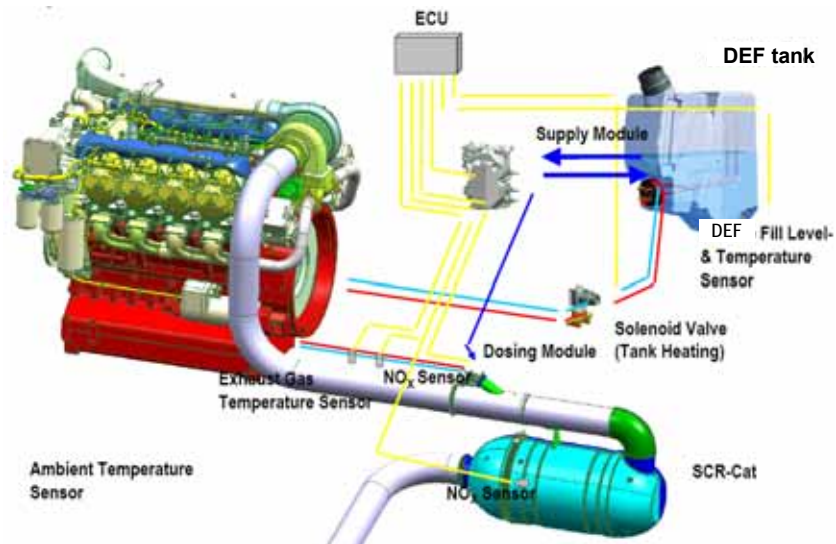
NOx Aftertreatment- Selective Catalytic Reduction (SCR)



- 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 (NH₃) on catalyst
 - NH₃ reacts with NOx and O₂ in exhaust to create N₂ and H₂O
 - 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



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SCR System



- 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 (NH₃)
 - 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

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DEF Quality : Use of Refractometer



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DEUTZ – SCR system: Operator Notification and Inducement



DEF (Urea) Threshold With Level Indicator	Notification		Inducement
	Lamp	- or - Message	
>15% full 	none	none	none
Stage 1 <15% full 	DEF lamp solid 	Warning message	none
Stage 2 <10% full 	DEF lamp flashing (time duration – OEM Specified) 	Increasing message duration and/or frequency	none
Stage 3 <5% full 	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



Tier 3 engine without EAT



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

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