18th ANNUAL MDEC CONFERENCE
Toronto Airport Marriott Hotel, Canada
October 2 – 4, 2012

MDEC DIESEL WORKSHOP
TIER 4 DIESEL ENGINES AND MAINTENANCE (UNDERGROUND MINES)

ORGANISED BY: JP Ouellette (Kubota) and David Young (CanmetMINING)

COMPLIED BY: Mahe Gangal (CanmetMINING)

OCTOBER 2, 2012

MDEC Diesel Workshop

Tier 4 Diesel Engines and Maintenance (Underground Mines)

Toronto Airport Marriott Hotel
Ontario, Canada

Tuesday, October 2, 2012

07:30 – 08:30 Breakfast and Registration

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

- JP Ouellette, Kubota
- Evelynn Stirling, Cummins
- Darcy Thomson, John Deere
- Darren Tasker, Volvo Penta

12:00 – 13:00 Lunch

13:00 – 16:30

- Greg Tremaine, Deutz
- Daniel J. Brian, Caterpillar
- Dee Wise, MTU

Discussion and Conclusion, David Young, Secretary/Treasurer MDEC

MDEC Diesel Workshop

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Tuesday, October 2, 2012

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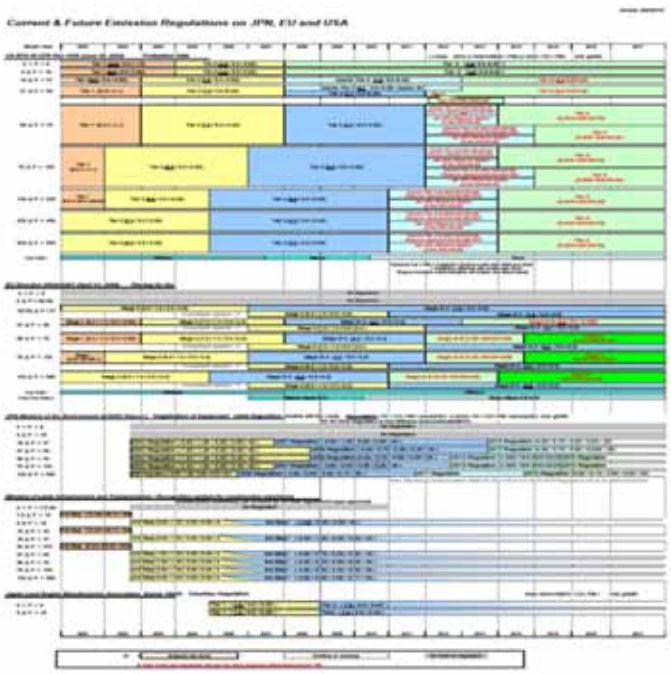
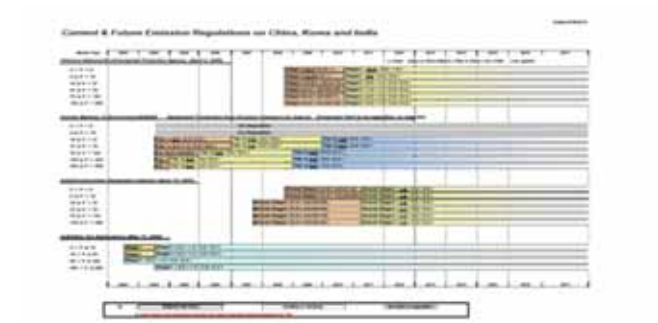
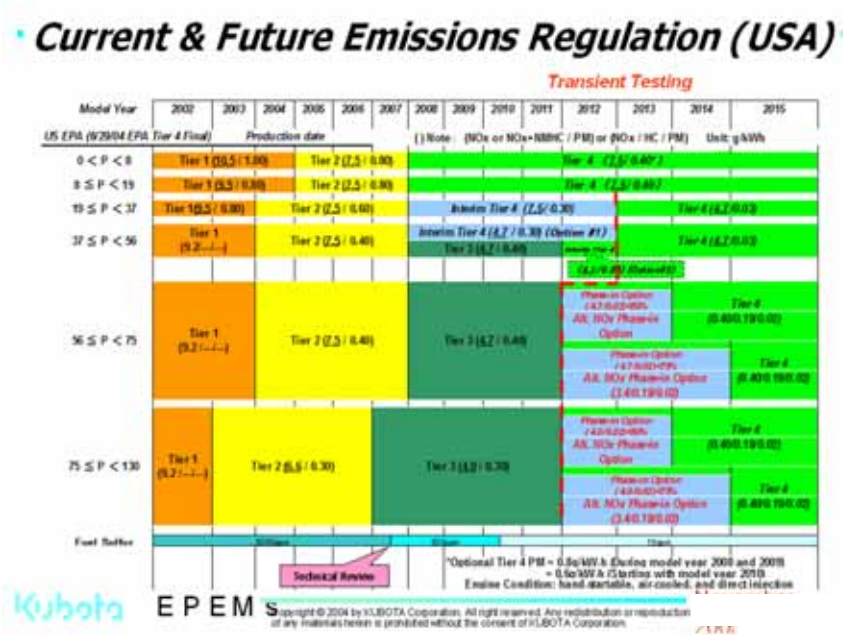
Emissions Regulation an Overview

2012 MDEC Conference

J.P. Ouellette






Current & Future Emissions Regulation (USA)
Transient Testing
Model Year
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
US EPA (9/29/04 EPA Tier 4 Final)
Production date
( ) Note : (NOx or NOx+NMHC / PM) or (NOx / HC / PM)
Unit: g/kWh
0 < P < 8
8 ≤ P < 19
19 ≤ P < 37
37 ≤ P < 56
56 ≤ P < 75
75 ≤ P < 130
Tier 1
Tier 2
Tier 3
Tier 4
Fuel Sulfur
Technical Review
*Optional Tier 4 PM = 0.0g/kW.h (During model year 2008 and 2009
= 0.5g/kW.h (Starting with model year 2010
Engine Condition: hand startable, air-cooled, and direct injection
Kubota
EPEMS
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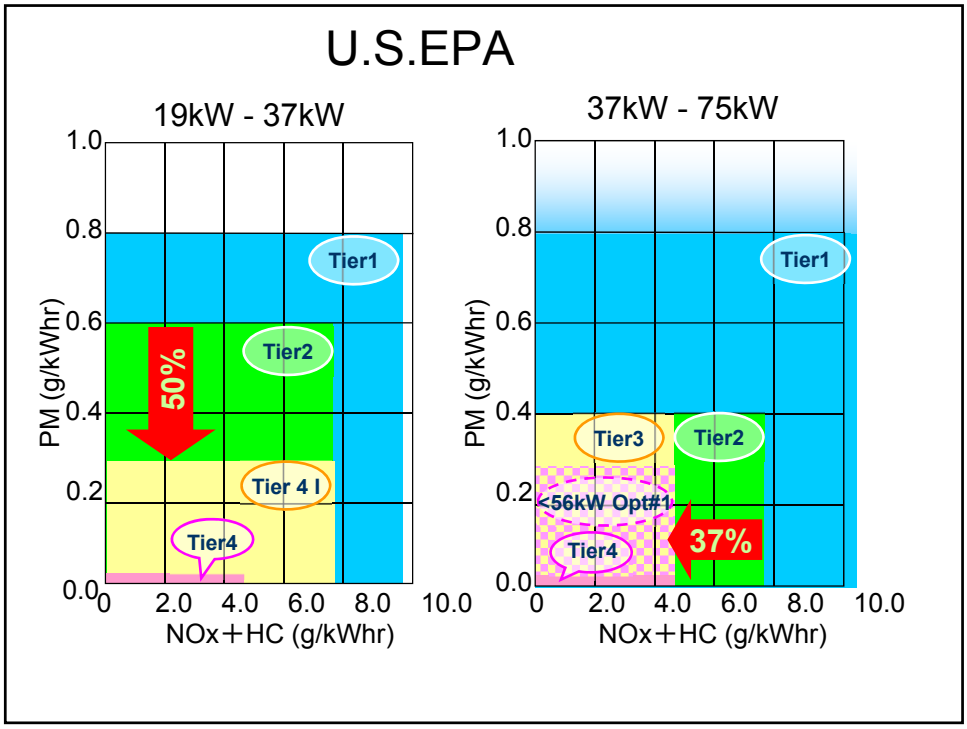


Emissions Regulations on Non-Road SI Engine (19kW >)

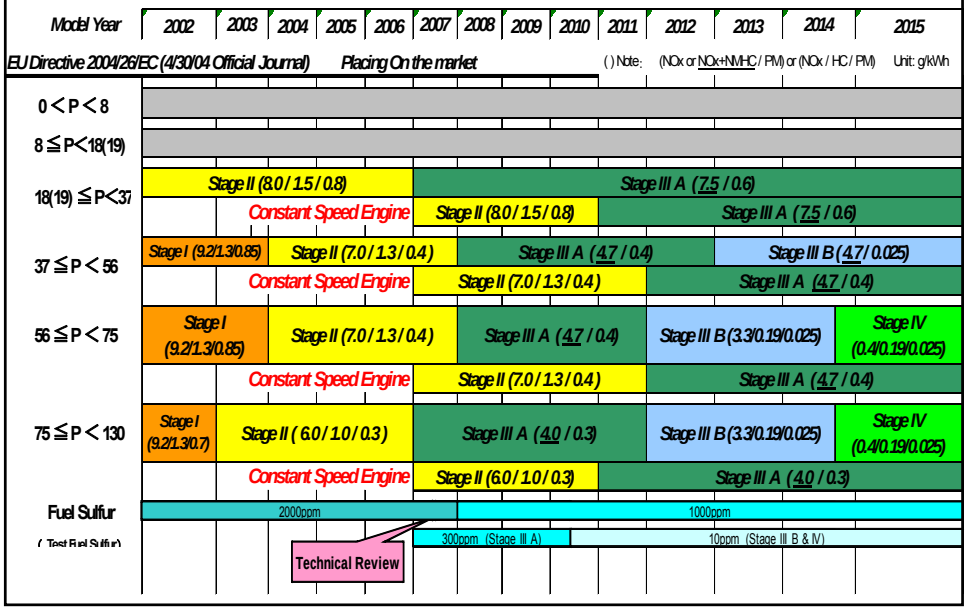
unit:HC+NO_X/CO (g/kWh)

	Displacement (L)	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
California State (CARB)	0.065<L<0.225	Tier 2 (16.1/549)				Tier 3 (10.0/549)					
	0.225≦L	Tier 2 (12.1/549)					Tier 3 (8.0/549)				
	19kW ≦ L≦1.0	Tier 2 (12.1/549)									
U.S. 50 State (EPA)	0.065≦L<0.1	Tier 2 (40.0/610)									Tier 3
	0.1≦L<0.225	Tier 2 (16.1/610)									Tier 3
	0.225≦L	15.0/610	13.6/610	Tier 2 (12.1/610)						Tier 3 (8.0/610) (Planning)	
	19kW < L<1.0	15.0/610	13.6/610	Tier 2 (12.1/610)						Tier 3 (8.0/610) (Planning)	
Canada	0.066≦L<0.1			Tier 2 (40.0/610)							
	0.1≦L<0.225			Tier 2 (40.0/610)							
	0.225≦L			Tier 2 (40.0/610)							
JPN (LEMA)	0.066≦L<0.1	1st Voluntary regulation (40.0/519※3)					2nd Voluntary reg. (40.0/610※3)				
	0.1≦L<0.225	1st Voluntary regulation (16.1/519※3)					2nd Voluntary reg. (16.1/610※3)				
	0.225≦L<1.0	1st Voluntary regulation (13.4/519※3)					2nd Voluntary reg. (12.1/610※3)				
EU (2002/88/EC)	0.066≦L<0.1		40.0/519※3	Stage Ⅱ (40.0/610※3)							
	0.1≦L<0.225		Stage Ⅰ (16.1/519※3)			Stage Ⅱ (16.1/610※3)					
	0.225≦L		13.4/519※3		Stage Ⅱ (12.1/610※3)						

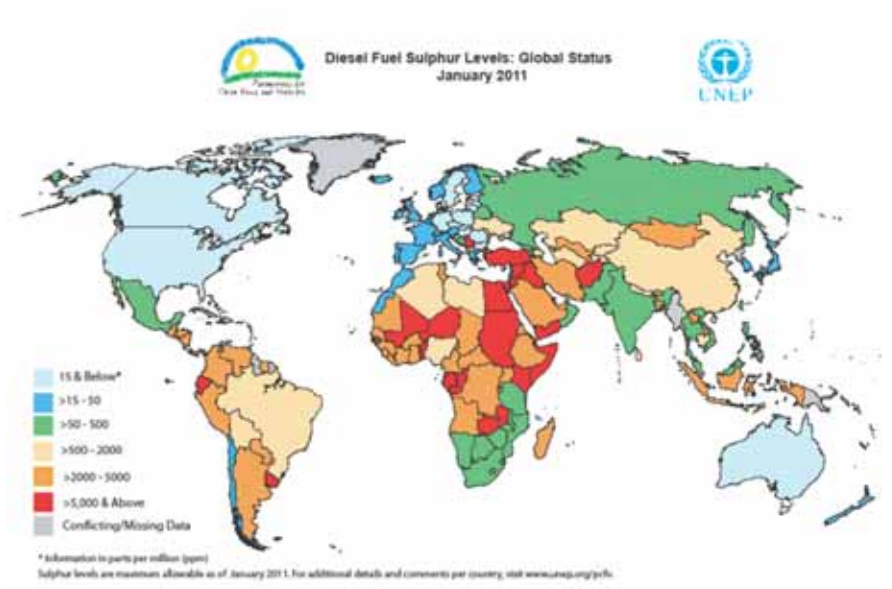
※3 1st Regulation for New engine / 2nd Regulation for in-use

	1st	2nd	3rd
CARB			
EPA			
CAN			
JPN			
EU			

Current & Future Emissions Regulation (EU)

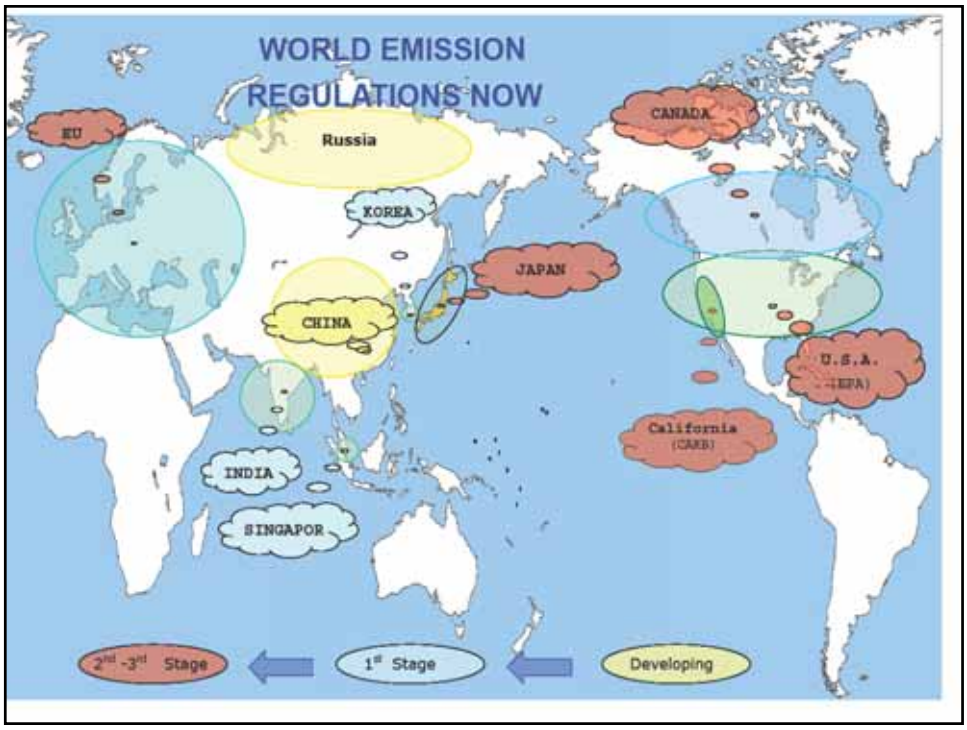


WORLD FUEL MAP



EMISSION REGULATIONS

FOR EMERGING COUNTRIES



Summary of Emissions Regulation in India

1. **Machine** need approved at the timing of custom clearance.
   - CPCB (Central Pollution Control Board – **Gen.Set**.)
   - CMVR（Central Motor Vehicle Rules—**Ag Tractor**）
2. As part of machine approval, emission compliance of engine required.
3. Certification and COP (Compliance of Production) required.
   (every 500 units at custom)
4. In principle, certification and COP to be handled domestically in India.
5. Gen.Set.<19kW additionally durability test of 500hrs (BIS inspection) required.（BIS: Bureau of Indian Standards）
6. Official Test Facility
   :ARAI （Automotive Research Association of India)
   :BUDNI (Central Farm Machinery Training & Testing Institute)
7. Certificate Holder
   Engine: engine manufacturer, or its agency
   Machine: equipment sales company located in India

Emissions Regulation in India (standards)

Diesel Generator（CPCB Reg.)

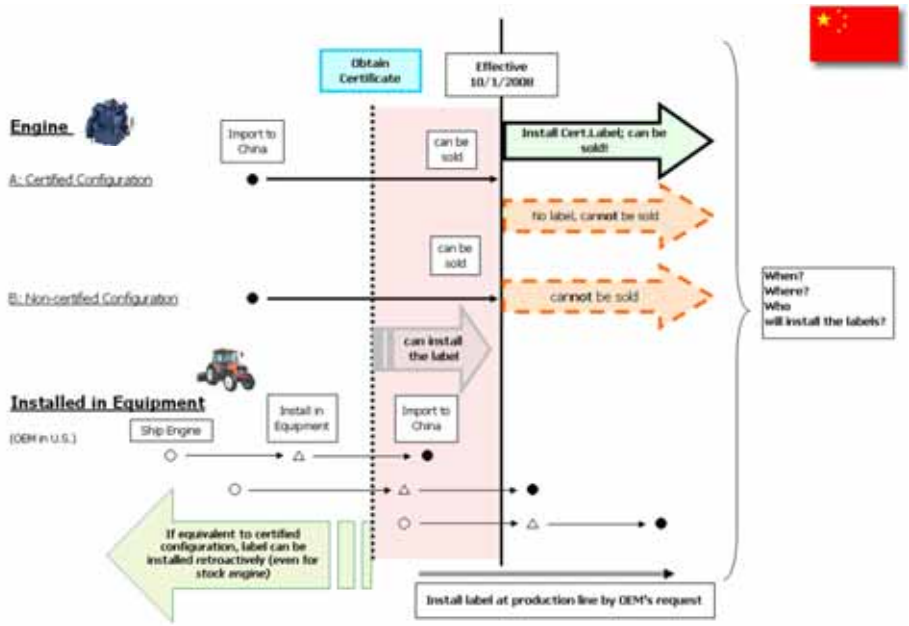
Stage	Category	Effective Date	CO (g/kW·h)	HC (g/kW·h)	NOx (g/kW·h)	PM (g/kW·h)	Smoke (m^{-1})
	Test Method		ISO D2				
	kW≤19	July-2004	3.5	1.3	9.2	0.3	0.7
	19 < kW ≤ 50	July-2004	3.5	1.3	9.2	0.3	0.7

Ag Tractor（CMVR Reg.)

Stage	Category	Effective Date	CO (g/kW·h)	HC+NOx (g/kW·h)	PM (g/kW·h)	Smoke (m^{-1})
	Test Method		ISO C1			IS 12062-1987
Bharat Stage 2	Tractor	June-2003	9.0	15.0	1.0	3.25 (75H.S.U)
	Power Tiller	Oct-2006				
Bharat Stage 3	Tractor	Oct-2005	5.5	9.5	0.8	3.25 (75H.S.U)
	Power Tiller	Apr-2008				

Summary of Emissions Regulation In China

1. **Test Facility**: 14 (Jinan, Shanghai Internal Combustion Engine, Nanking...)
2. **Certification Test**: Bring engine to the facility to test
3. **Certification Application**: Engine manufacturer to apply online to SEPA (State Environmental Protection Administration), test facility to attach cert. data.
4. **Certification Label**: Required. (Sample shown in later) / Retroactive labeling on engines in the market if their emission levels are met / Stage 2 label can be installed if certified when Stage 1 be effective / Can install label if certified (even before effective date)
5. **Engine Serial Number**: Shown in label → engraved (acceptable!)
6. **Exemptions**: Exported only, <37kW marine application, onroad application
7. **Regulation**: based on EU Directives (97/68/EC·2002/28/EC)for >19kW, EPA Part 89 for 19kW>. Test Cycle: ISO 8178 C/G/D Mode
8. **Family Concept**: 97/68/EC (Fuel Flow@Max.Torq/1st, @Rated/2nd)



Emissions Regulation In China (standards)

Net Power	Date		CO	HC	NOx	PM
kW	Application Acceptable	Effective date	Standards (g/kWh)			
Stage I						
75 ≤ P < 130	**2007.10.1**	**2008.10.1**	5.0	1.3	9.2	0.7
37 ≤ P < 75	**2007.10.1**	**2008.10.1**	6.5	1.3	9.2	0.85
18 ≤ P < 37	**2007.10.1**	**2008.10.1**	8.4	2.1	10.8	1.0
8 ≤ P < 18	**2007.10.1**	**2008.10.1**	8.4	12.9		-
0 < P < 8	**2007.10.1**	**2008.10.1**	12.3	18.4		-
Stage II						
75 ≤ P < 130	**2009.10.1**	**2010.10.1**	5.0	1.0	6.0	0.3
37 ≤ P < 75	**2009.10.1**	**2010.10.1**	5.0	1.3	7.0	0.4
18 ≤ P < 37	**2009.10.1**	**2010.10.1**	5.5	1.5	8.0	0.8
8 ≤ P < 18	**2009.10.1**	**2010.10.1**	6.6	9.5		0.8
0 < P < 8	**2009.10.1**	**2010.10.1**	8	10.5		1.0

⚠ Non-certified engine cannot be sold inside of China after effective date (also applied to stock engines)

Emissions Regulation in Russia

1. No emission regulation for nonroad equipment in Russia.
2. Certificate for equipment, engine and engine parts required at custom.
3. Need to verify EU Stage 2 level compliance when obtain emission certificate.
4. Certification data of EU, EPA and Japan Construction Regulation is acceptable while application.
5. Cannot use engine with sophisticated devices such as EGR for fuel quality issue in Russia.
6. Be careful when introducing EU Stage 3, EPA Tier 3/Tier 4 Int.(37kW<) leveled-new-models into Russia (High sulfur contents).
7. Distributor of KDG, obtained certificates of KBT engines.
8. Future responses:

- Certify new models through our distributor in Russia.
- Use KBT's official data for models not certified by any authorities.
- Certificates obtained can be provided to each OEM for free of charge.

Emissions Regulation in Korea for Construction Machinery

Tier 3 Regulations;

Engine Power	CO	NOx+HC	PM	Test Procedure
8㎾ >	8.0g/㎾h ≥	7.5g/㎾h ≥	0.4g/㎾h ≥	ISO8178 C1-8mode
8≤P<19	6.6g/㎾h ≥	7.5g/㎾h ≥	0.4g/㎾h ≥	
19≤P<37	5.5g/㎾h ≥	7.5g/㎾h ≥	0.3g/㎾h ≥	
37≤P<75	5.0g/㎾h ≥	4.7g/㎾h ≥	0.4g/㎾h ≥	
75≤P<130	5.0g/㎾h ≥	4.0g/㎾h ≥	0.3g/㎾h ≥	

Effective Date: Below 19kW 1/1/2011
19kW - 75kW 1/1/2010
At and above 75kW 1/1/2009

∗Production date of machine (Custom clearance for imported machine)

Summary of Emissions Regulation in Turkey

1. Turkey is not Member State of EU, but plans to introduce EU Directives.
2. Turkey accepts EU certifications.
3. Although the effective dates for Stage 1 & 2 have passed, not effective yet. Stage IIIA will be effective in 2010.
4. They follow EU's effective dates for IIIB only.
5. When introducing machine:
   - Need to confirm enforcement status,
   - Sulfur contents in commercial fuel (influence to above 37kW category)
6. Regulations for Ag. Tractor VS Nonroad Machinery

Standards of Emissions Regulation in Turkey

	Categories		Emissions Standard (g/kWh)				European Union		Turkey	
			CO	HC	Nox	PM	Type Approval	Effective Date	Type Approval	Effective Date
Stage I	B	75≤P<130	5.0	1.3	9.2	0.7	June 30 '98	Dec 31 '98		May 4 '03
	C	37≤P<75	6.5	1.3	9.2	0.85	June 30 '98	Mar 31 '99		May 4 '03
Stgae II	E	75≤P<130	3.5	1.0	6.0	0.2	Dec 31 '00	Dec 31 '01		Jan 1 '07
	F	37≤P<75	5.0	1.0	6.0	0.3	Dec 31 '01	Dec 31 '02		Jan 1 '07
	G	18≤P<37	5.0	1.3	7.0	0.48	Dec 31 '02	Dec 31 '03		Jan 1 '07
Stage IIIA	I	75≤P<130	5.0	4.0		0.3	Dec 31 '05	Dec 31 '06		Dec 31 '09
	J	37≤P<75	5.0	4.7		0.4	Dec 31 '06	Dec 31 '07		Dec 31 '09
	K	18≤P<37	5.5	7.5		0.6	Dec 31 '05	Dec 31 '06		Dec 31 '09
Stage IIIB	M	75≤P<130	5.0	0.19	3.3	0.025	Dec 31 '10	Dec 31 '11		Dec 31 '11
	N	56≤P<75	5.0	0.19	3.3	0.025	Dec 31 '10	Dec 31 '11		Dec 31 '11
	P	37≤P<56	5.0	4.7		0.025	Dec 31 '11	Dec 31 '12		Dec 31 '12

THANK YOU

Cummins Tier 4 Technology Overview

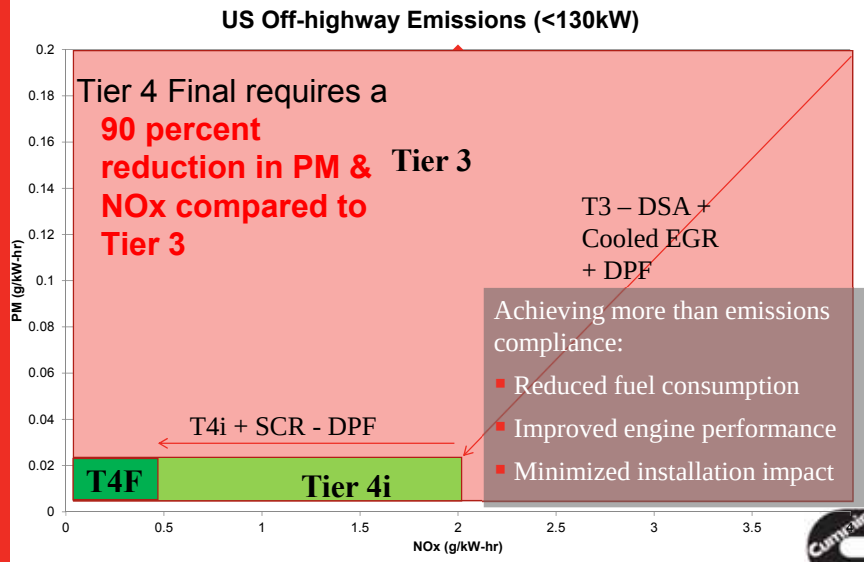
Agenda

- Emissions legislation
- Cummins Tier 4 Technology
- Cummins Advantage

TIER 4

EMISSIONS LEGISLATION

Emissions lineage

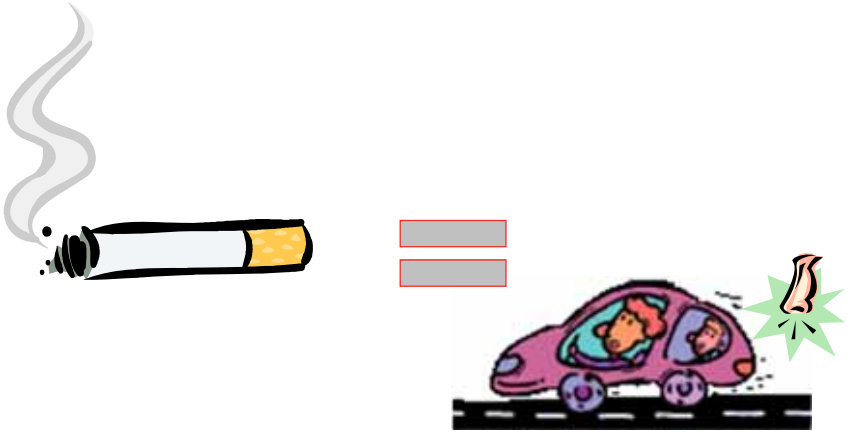


Achieving more than emissions compliance:

- Reduced fuel consumption
- Improved engine performance
- Minimized installation impact

Euro 5 equivalent to EPA 2007-2010/Tier3

In terms of particulate mass

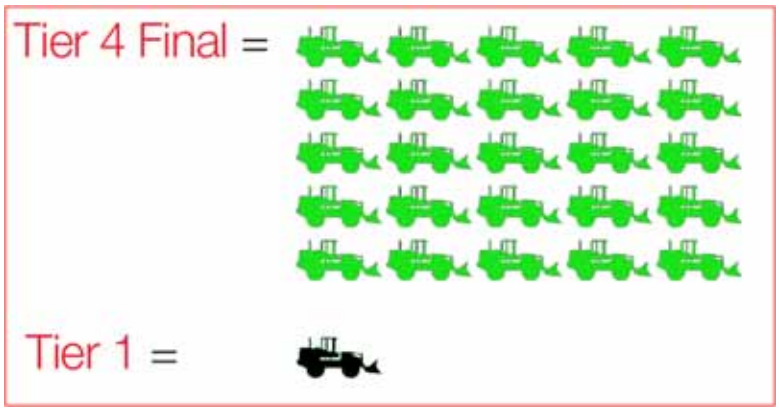


Exhaust 4 to 11 km (2.5 to 7 Miles)

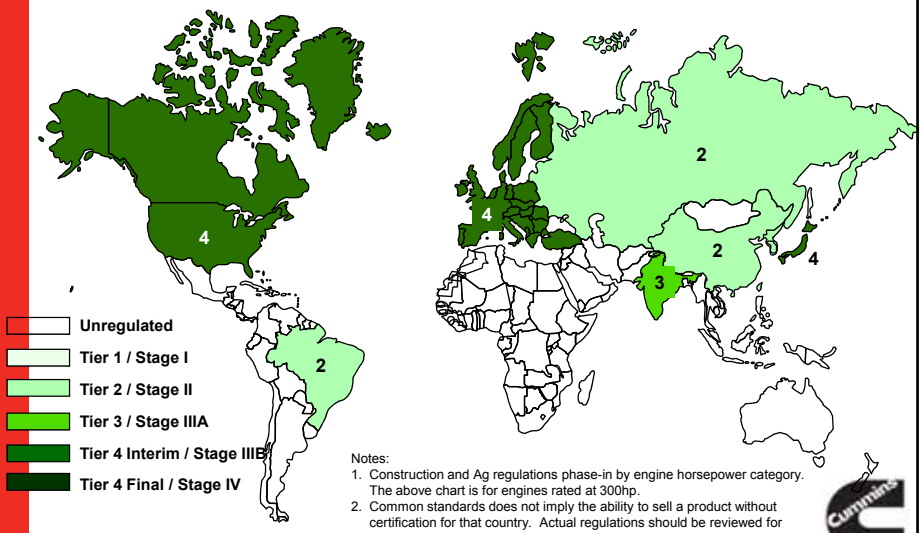
Information from Prof. David Kittelson, U of Minnesota

Achieving 'Near-Zero' Emissions

- Emissions from 25 x Tier 4 Final machines will be equivalent to just 1 x Tier 1 machine



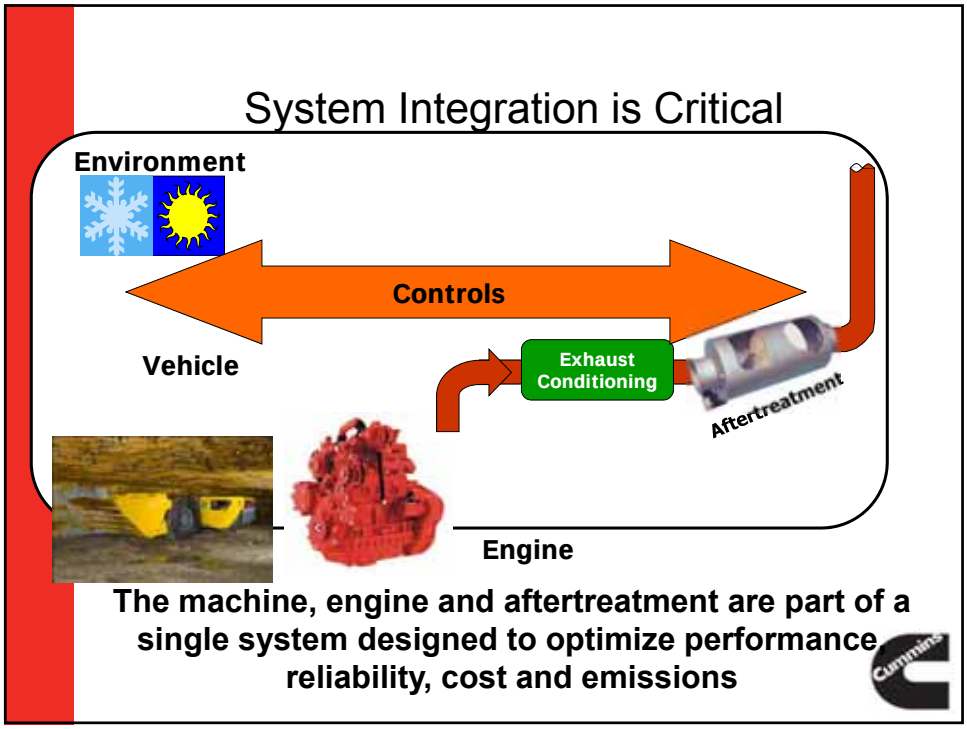
Construction and Ag - 2011

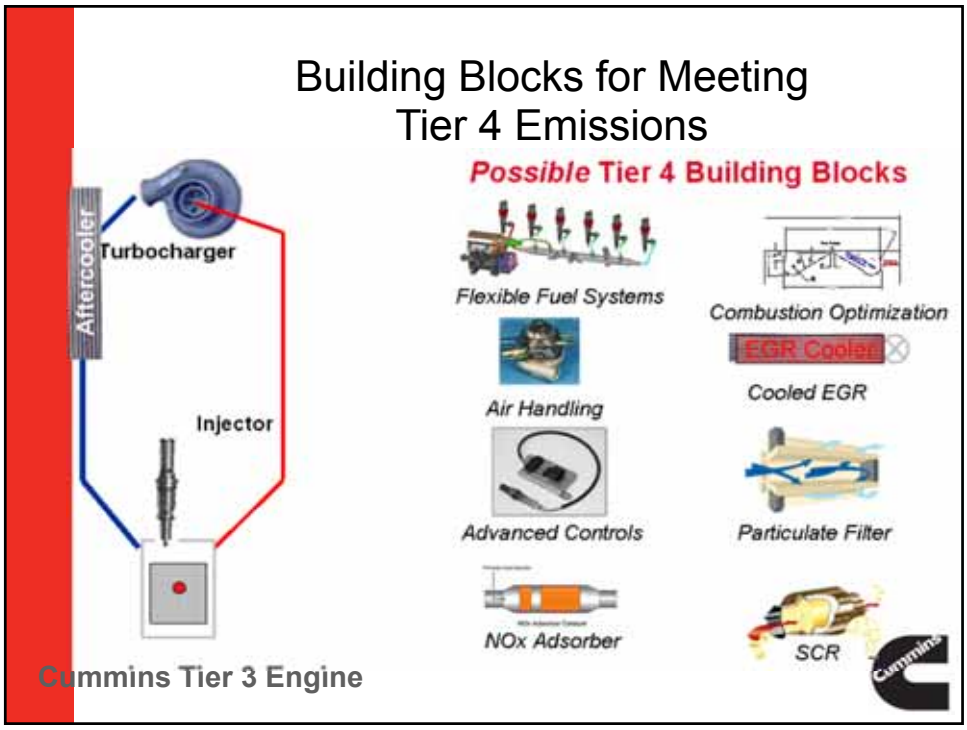


Notes:
1. Construction and Ag regulations phase-in by engine horsepower category. The above chart is for engines rated at 300hp.
2. Common standards does not imply the ability to sell a product without certification for that country. Actual regulations should be reviewed for introduction dates and certification requirements.

Tier 4

CUMMINS TECHNOLOGY REVIEW

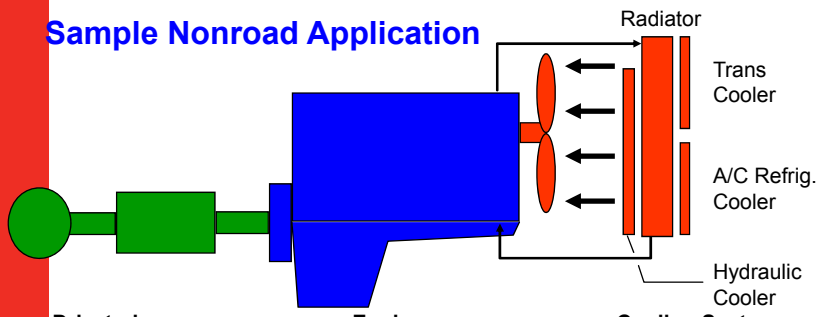

System Integration is Critical
Environment
Controls
Vehicle
Exhaust Conditioning
Aftertreatment
Engine
The machine, engine and aftertreatment are part of a single system designed to optimize performance reliability, cost and emissions


Building Blocks for Meeting Tier 4 Emissions
Aftercooler
Turbocharger
Injector
Cummins Tier 3 Engine
Possible Tier 4 Building Blocks
Flexible Fuel Systems
Combustion Optimization
Air Handling
EGR Cooler
Cooled EGR
Advanced Controls
Particulate Filter
NOx Adsorber
SCR

On-Highway ≠ Nonroad

On-Highway ≠ Nonroad

Sample Nonroad Application



Drivetrain	Engine	Cooling System
Many Suppliers Of Low Volume Components	Many Ratings	Limited Available Space
Varied Drivetrain Requirements	Several Product Families	No Ram Air; fan HP Increases
	High Load Factors	More Auxiliary Coolers
		Dusty Environment
		High Vibration & Impact Loads

Fuel sulfur content up to 5000 ppm, gone to 500 then 15 ppm in US by 2010.

Many OEM's, Global Business

Key Tier 4 Development Areas

- Heat Rejection
  - Minimization
  - Optimization of cooling systems
- Application Variation
  - Robust to installation variation
  - Cost impact for vehicle installation
- Environmental Robustness
  - Dust/Dirt
  - Surface temperature requirements
  - Vibration/Shock
- Develop a solution with the lowest initial and life-cycle cost

"In-Cylinder" Development

- Exhaust Gas Recirculation (EGR)
- Advanced Combustion
- Variable Geometry Turbocharging (VGT)
- Fuel System

How EGR Works

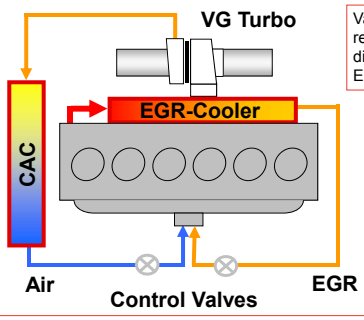
- Cooled exhaust gas recirculation for NOx reduction for Cummins Tier 4/Stage IIIB

Recirculates the exhaust gas back into the cylinder reducing oxygen concentration. This lowers combustion temperature to reduce the formation of Oxides of Nitrogen (NOx)

Variable geometry turbocharging is required to maintain correct pressure differential across the engine for ideal EGR flow

Upgraded cooling package mitigates increased engine heat rejection

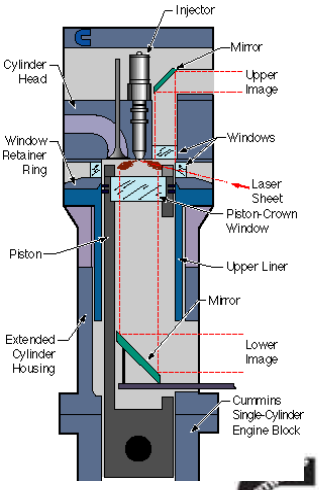
EGR system sensitivity to high sulfur fuel made it less viable for Tier 3 application, but offers potential for Tier 4 with ULSD



Control valve modulates the % EGR returned to cylinder

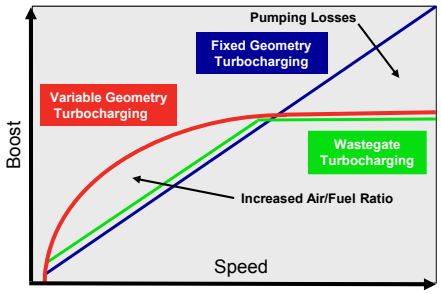
Advanced Combustion

- World class combustion research by Cummins & Sandia National Laboratories
- Laser-optical imaging of the combustion process gives precision modelling of injection spray & diffusion flame
- Enhances Cummins capability to meet emissions & optimize for fuel economy



Cummins VGT

- Cummins variable geometry turbocharger with patented sliding nozzle design
- Improves boost efficiency across all engine speeds/loads
- Proven technology for Tier 4/Stage IIIB



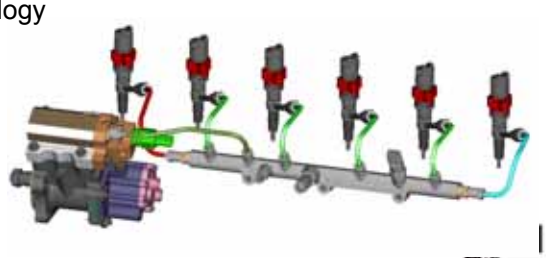
Turbo Technologies

Fuel Systems

- Cummins designs & manufactures high pressure common rail fuel systems
- Tier 4/Stage IIIB fuel systems requires:

- higher fuel injection pressure
- very fast response with multiple injection events
- precise control of fuel metering timing

- Cummins next generation HPCR is recognized as industry leading technology

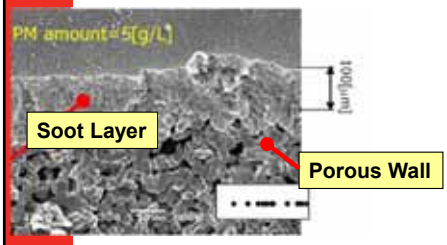


Fuel Systems

Aftertreatment Technology

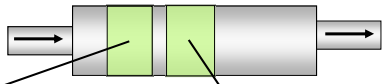
- Diesel Particulate Filters (DPF)
- Diesel Oxidation Filters (DOC)
- Selective Catalytic Reduction (SCR)

Wall Flow Particulate Filter



- A full filter consists of a porous ceramic honeycomb for collecting particles in the exhaust gas.
- The filter can be coated with precious metal for enhancing oxidation of hydrocarbons promoting low temperature oxidation of soot.
- On average, full filters reduce PM by about 90-95%.

How The DPF Works

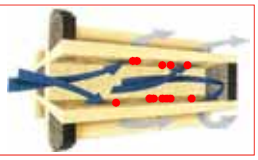


Diesel Oxidation Catalyst

DOC catalytic material reacts above 572ºF (300ºC) in passive regeneration mode to generate Nitrogen Dioxide (NO_2) which oxidizes the carbon soot

Diesel Particulate Filter

Ceramic wall flow filter captures up to 95% of the carbon soot (PM) carried by the NO_2. This collects on the filter to form Carbon Dioxide (CO_2) which leaves the tailpipe as clean gas



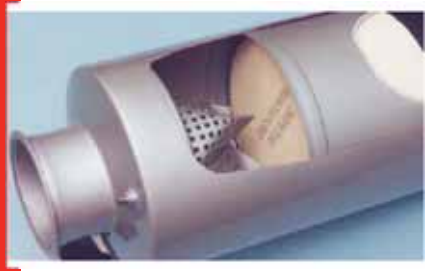
Active Regeneration

When soot accumulation in the DPF exceeds soot oxidation a periodic active regeneration mode is performed to prevent filter plugging. This is actuated by small quantities of fuel from a dosing injector or HPCR injection pulse during exhaust blow down. The heat released (no flame or burning) at 1022ºF(550ºC) ensures sufficient oxidation to remove soot

Filter Service

Build up of incombustible ash will eventually require filter service cleaning, though only required at very long intervals

Urea Based SCR: Overview



- A vanadia or zeolite based catalytic coating is applied to a honeycomb substrate
- A urea-water solution (“AdBlue” or “DEF”) is used as a reagent for converting NOx to N2

- The urea is converted to ammonia in the exhaust above 200 deg C
- NOx conversion efficiency is high above 250 deg C.
- Averages 70-85% NOx reduction

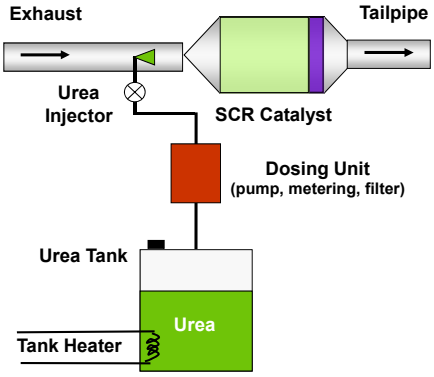
How SCR Works

Selective Catalytic Reduction

Urea solution is injected ahead of the catalyst. This converts to ammonia in the exhaust stream above 392ºF (200ºC)

The ammonia reacts with Oxides of Nitrogen (NOx) over the SCR catalyst to form harmless nitrogen & water

Urea is injected at a ratio of typically 5% to diesel fuel use, depending on duty cycle. Urea tank sizes vary, but must be refilled to ensure emissions compliance

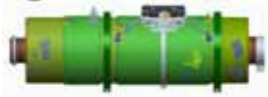


Urea Solution

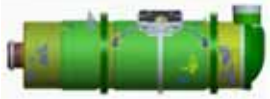
The urea-water solution (AdBlue in Europe, DEF in USA) is a clear liquid, non-hazardous & non-flammable with a 12 month shelf life. Heaters are required to prevent urea freezing at 11ºF (-11ºF)

DPF & SCR Aftertreatment Configurations Examples

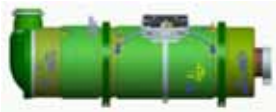
Vertical End-In End-Out



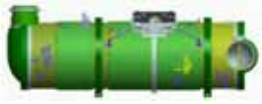
Horizontal End-In End-Out



Horizontal End-In Side-Out



Horizontal Side-In End-Out



Horizontal Side-In Side-Out

Vertical Side-In End-Out

44

Estimate of Application Impact of Cooled EGR & Aftertreatment for T4 QSB6.7

	Estimated Change from Tier 3
Heat Rejection to Coolant	40% increase
Heat Rejection to CAC	25% decrease
Engine Package	Addition of cooled EGR components
Aftertreatment Size	~ 12 inch diameter X 27 inch long canned with inlet & outlet sections
System Weight	Engine ~ 1180 (wet) Aftertreatment ~ 85 lb

TIER 4

CUMMINS ADVANTAGE

Experience Counts

- No engine manufacturer has this experience with Tier 4 technology:
  - 1,000,000 EGR Engines
  - 650,000 DPFs
  - 350,000 SCR systems produced
  - 100,000 XPI systems produced
  - 3 million VGTs produced
- The emissions requirement for later off-highway markets were part of the initial design profile of EGR, VGT & DPF
- We leverage our automotive platforms to develop products that are validated for the off-highway market

System Integration

- Unique in the industry – we design, build and integrate the complete system

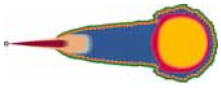
Filtration

Diesel Exhaust Fluid

Direct Flow

Electronic Controls

Aftertreatment System



Combustion Technology

Turbochargers

Fuel Systems

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Clear Advantage: Fuel-Efficiency

Tier 4 Interim fuel saving over Tier 3	up to 5% typical
Tier 4 Final fuel saving Over Tier 4 Interim	Preliminary estimates: additional 2-3% (more than offsetting DEF cost)
Typical fuel saving at 5% (2500 hours / 6 gals hr)	750 gallons per year $3000 saved
C02 savings (1 gal = 22.2 lbs)	8 tons less per year
Power Output / Transient Response	Retain Tier 4 Interim high output & improved response

Clear Advantage. Every Time.

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Off-Road Tier 4 Final Architecture

MidRange Engines: 75 – 400 HP

QSB 3.3
QSB 4.5
QSB 6.7
QSL 9

Cooled EGR

+

CCC - SCR

Heavy Duty Engines: 400 - 675HP

QSX 11.9
QSX 15

Cooled EGR

+

CPF - SCR

Engines Pre-designed For Final

- Tier 4 Interim engines pre-designed for Final
- No significant change to engine installation envelope
- Ready to integrate with incremental SCR aftertreatment

Tier 4 Interim and Tier 4 Final

QSB6.7

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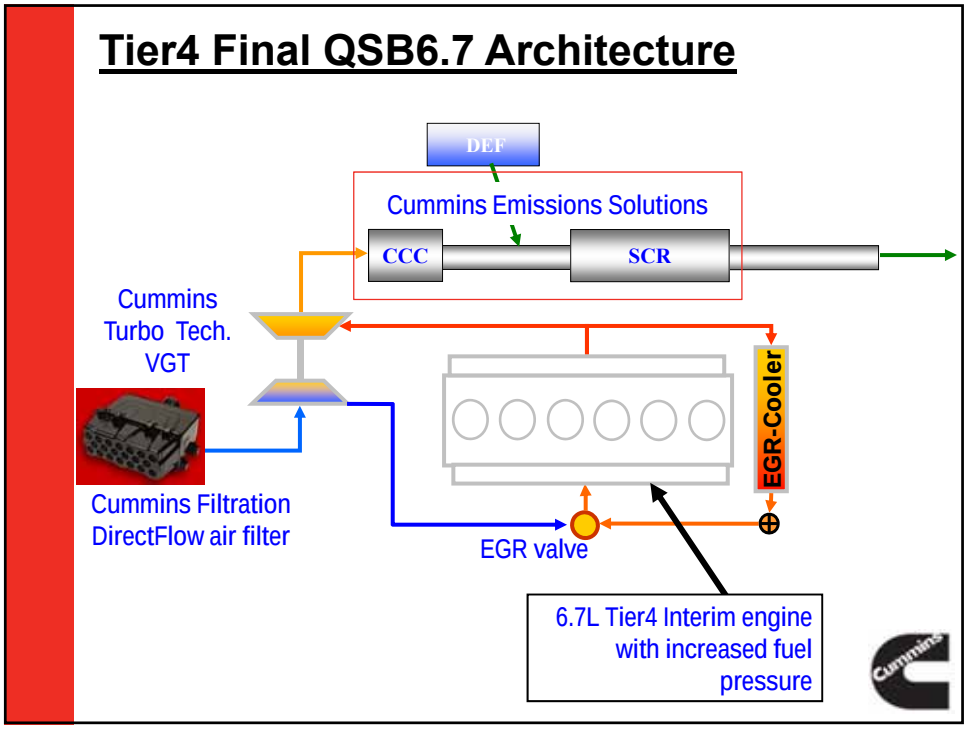
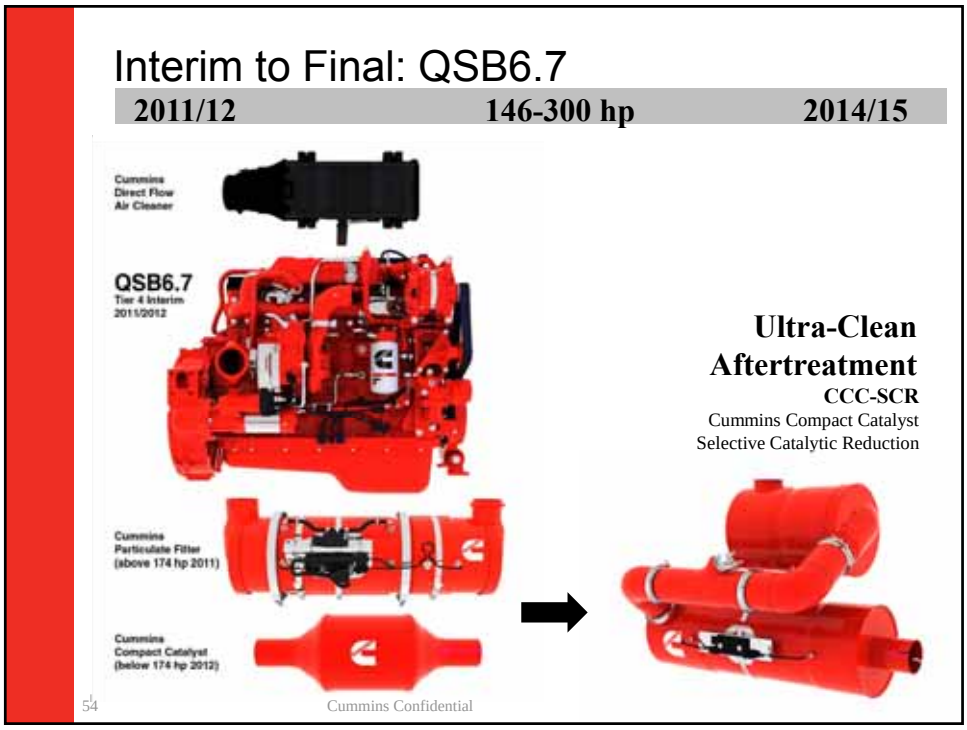

Tier4 Final QSB6.7 Architecture
DEF
Cummins Emissions Solutions
CCC
SCR
Cummins
Turbo Tech.
VGT
EGR-Cooler
Cummins Filtration
DirectFlow air filter
EGR valve
6.7L Tier4 Interim engine
with increased fuel
pressure


Interim to Final: QSB6.7
2011/12
146-300 hp
2014/15
Cummins
Direct Flow
Air Cleaner
QSB6.7
Tier 4 Interim
2011/2012
Cummins
Particulate Filter
(above 174 hp 2011)
Cummins
Compact Catalyst
(below 174 hp 2012)
Ultra-Clean
Aftertreatment
CCC-SCR
Cummins Compact Catalyst
Selective Catalytic Reduction
54
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Interim to Final: QSB6.7

- Same power output and performance
- Fuel consumption further reduced
- No change to engine installation

Balanced EGR with SCR aftertreatment

ECM upgraded for faster processing & SCR logic

Single VGT for 300 hp output

Enhanced HPCR system with higher fuel injection pressure

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QSB6.7 engine lineage

QSB6.7 GT174hp	T3	T4i	T4F
ECM	CM850	CM2250	CM2350
Fuel pressure	1600 bar	1800 bar	2200 bar
Turbocharger	WGT	VGT	VGT
NOx control	DSA	Cooled EGR	Cooled EGR + SCR
Crankcase ventilation	OCV, impactor only	OCV, coalescing filter	OCV, coalescing filter
Aftertreatment	None	DOC+DPF	DOC+SCR

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QSL9

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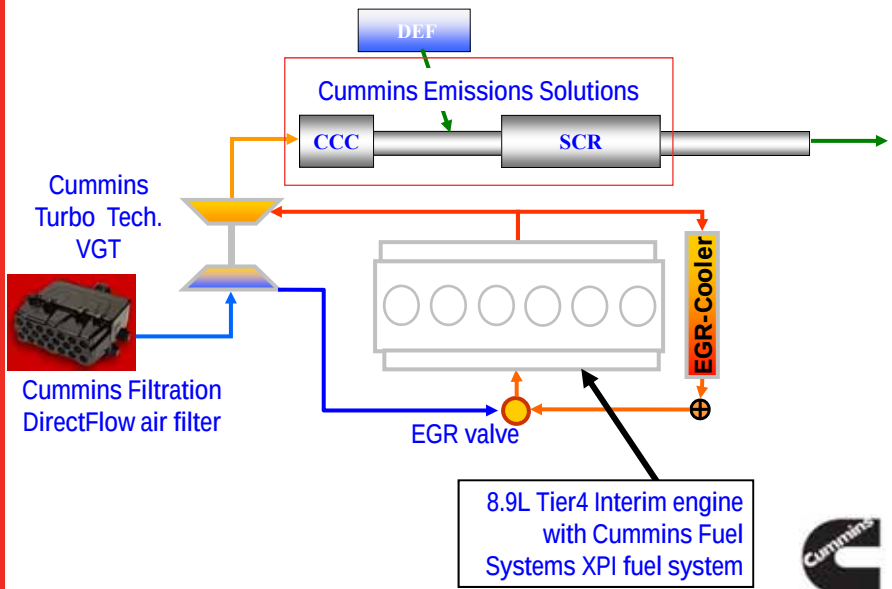
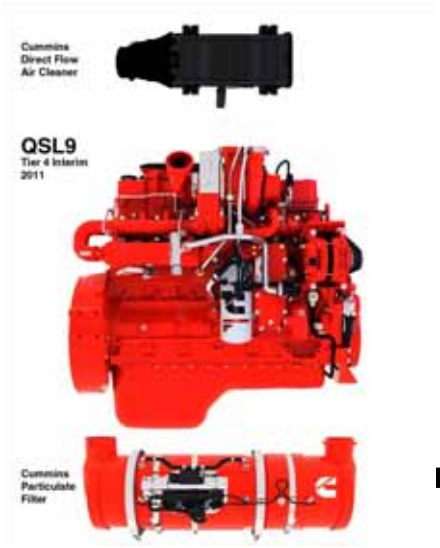
Tier4 Final QSL9 Architecture



Interim to Final: QSL9

2011 190-400 hp 2014



Ultra-Clean Aftertreatment

CCC-SCR
Cummins Compact Catalyst
Selective Catalytic Reduction

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Interim to Final: QSL9

- Same power output and performance
- Fuel consumption further reduced
- No change to engine installation

Balanced EGR with SCR aftertreatment

Single VGT for 400 hp output

ECM upgraded for faster processing & SCR logic

XPI fuel system capable for Tier 4 Final

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QSL9 engine lineage

QSL9	T3	T4i	T4F
ECM	CM850	CM2250	CM2350
Fuel pressure	1600 bar	2100 bar	2100 bar
Turbocharger	WGT	VGT	VGT
NOx Control	DSA	Cooled EGR	Cooled EGR + SCR
Crankcase ventilation	OCV, impactor only	OCV, coalescing filter	OCV, coalescing filter
Aftertreatment	None	DOC+DPF	DOC+SCR

Program Schedule

- Alpha build Q4 2011/Q1 2012
- Beta build Q4 2012/Q1 2013
- Limited Production Q4 2013
- Full Production - January 1, 2014

Field Test Activity

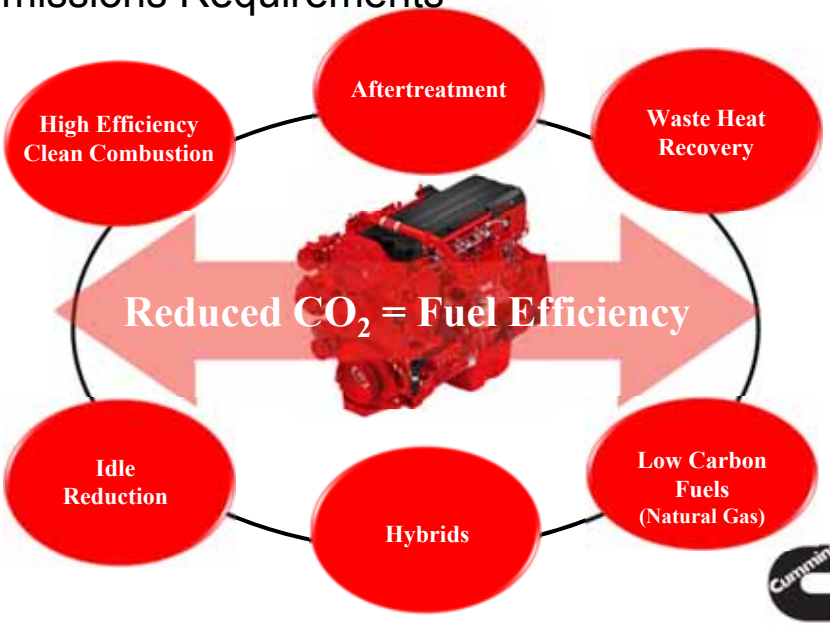
- Tier 4 VPI Service Team has compiled over 30,000 field test hours during Tier 4 Interim testing
- Tier 4 Final field test plan should achieve over 50,000 field test hours prior to launch
  - Several T4i field tests continuing on to T4F
- Field testing has incorporated 1) Cummins QSB6.7/QSL9 engines, 2) Cummins Emission Solutions Aftertreatment Systems, and 3) Cummins Filtration Direct Flow Air Filtration to understand how our Tier 4 solution performs as a package
- Field test engines are monitored daily for issues
- Ultimate goal release a reliable product

Summary

- Cummins Tier 4 work has been underway since 2004
- We are leveraging our on-highway experience with these potential technologies while using standard tools and processes to ensure we select the right technology for off-highway
- Cummins Inc. is uniquely positioned to deliver an integrated and optimized system for Tier 4

Where from here … ?

Technologies to Address US EPA Emissions Requirements



- Questions?

Final Tier 4 Emission Engines

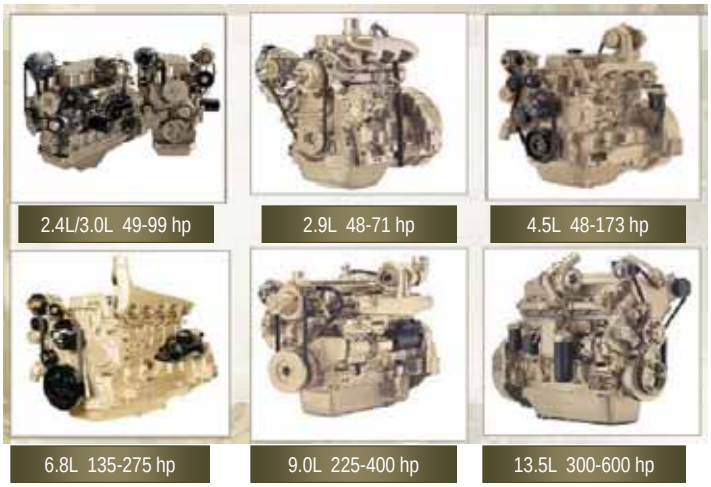
Darcy Thomson

Oct 2, 2012

JOHN DEERE

Engine Portfolio

- Power from 49 HP to 600 HP



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JOHN DEERE
Drivetrain Products

John Deere Coffeyville Works (JDCW) in Coffeyville, KS manufactures **Funk** branded power-transmission products for off-highway, industrial and agricultural equipment manufacturers

The Funk product line includes power shift transmissions up to 450 hp (336 kW), hydrostatic motor-driven transmissions, axles, planetary drives and a complete line of pump drives.

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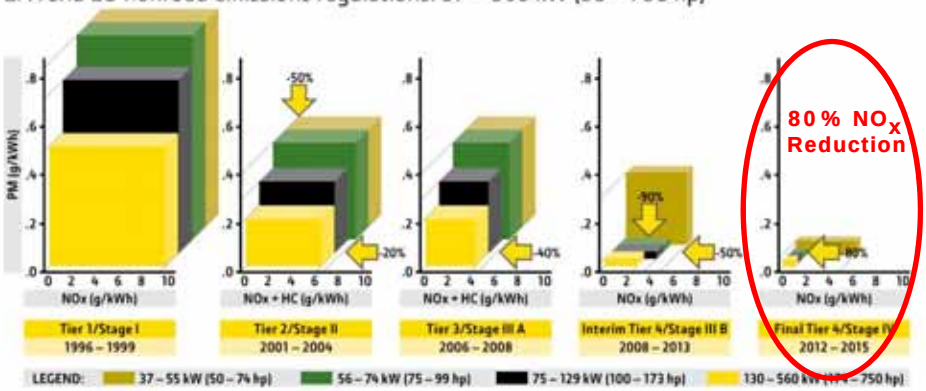
The next EPA hurdle…FINAL TIER 4

EPA and EU nonroad emissions regulations: 37 – 560 kW (50 – 750 hp)



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Technology Progression

Deere building block approach…

Calibration	HPCR CAC	HPCR CAC CEGR VGT	HPCR CAC CEGR VGT DOC DPF	HPCR CAC CEGR VGT DOC DPF SCR
Tier 1	Tier 2	Tier 3	IT4	Tier 4 Final

HPCR – High Pressure Common Rail
CAC – Charge Air Cooler
CEGR – Cooled Exhaust Gas Recirc
VGT – Variable Geometry Turbo
DOC – Diesel Oxidation Catalyst
DPF – Diesel Particulate Filter
SCR - Selective Catalytic Reduction

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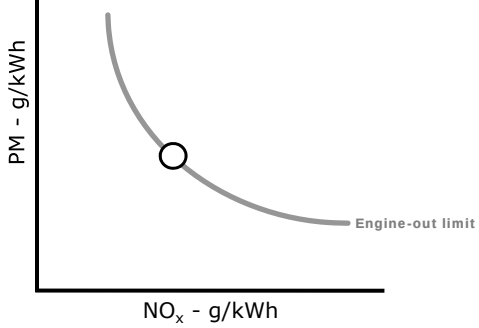
Engine & After Treatment System Optimization

Reducing PM:
- Engine calibration
- Higher pressure fuel systems
- Smart exhaust filter & ETM



Reducing NOx:
- Engine calibration
- 20-30% Enhanced cooled EGR
- SCR catalyst & DEF system

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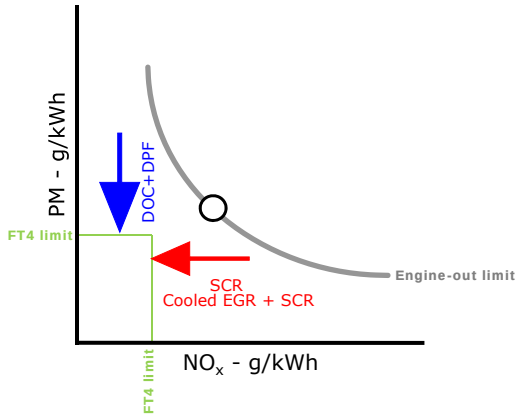
Engine & After Treatment System Optimization



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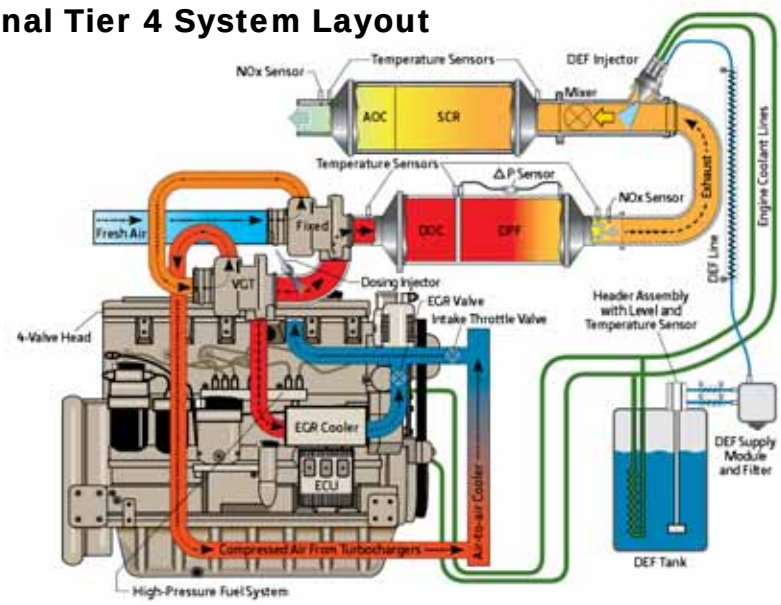
Final Tier 4 System Layout



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VOLVO PENTA

Your Engine Partner

MDEC conference
2nd October 2012

Agenda

- Introduction of Volvo Group and Volvo Penta
- SCR approach for Tier 4
- Characteristics of Urea (Adblue or DEF)
- Operational benefits of Volvo SCR based engines
- Current range, stage 3b, engines and technology
- Future engine range, Stage 4, engines and technology
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VOLVO PENTA

Volvo Group Organisation

Group Trucks Sales & Marketing EMEA	Group Trucks Sales & Marketing Americas	Group Trucks Sales & Marketing APAC	Group Trucks Operations	Group Trucks Technology	Trucks Joint Ventures

Construction Equipment	Business Areas	Finance & Business Support

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VOLVO PENTA

Volvo Penta
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VOLVO PENTA

Our brands

Volvo Penta
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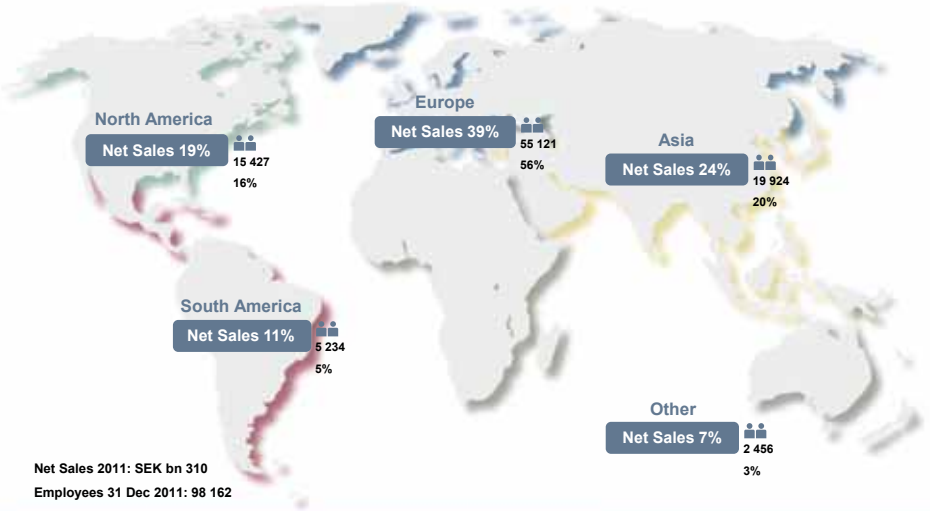
VOLVO PENTA

Global Operations

Sales and Employees



Net Sales 2011: SEK bn 310

Employees 31 Dec 2011: 98 162

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VOLVO PENTA

Sharing the same Powertrain

Volvo Trucks	Renault Trucks	Mack Trucks	UD Trucks	Buses	Construction Equipment	Volvo Penta

Volvo Group Trucks Operations

Engines, transmissions and trucks production, spare parts supply and logistics

Volvo Group Truck Technology

Product development of engines, transmissions and trucks, in addition to purchasing.

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VOLVO PENTA

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Background

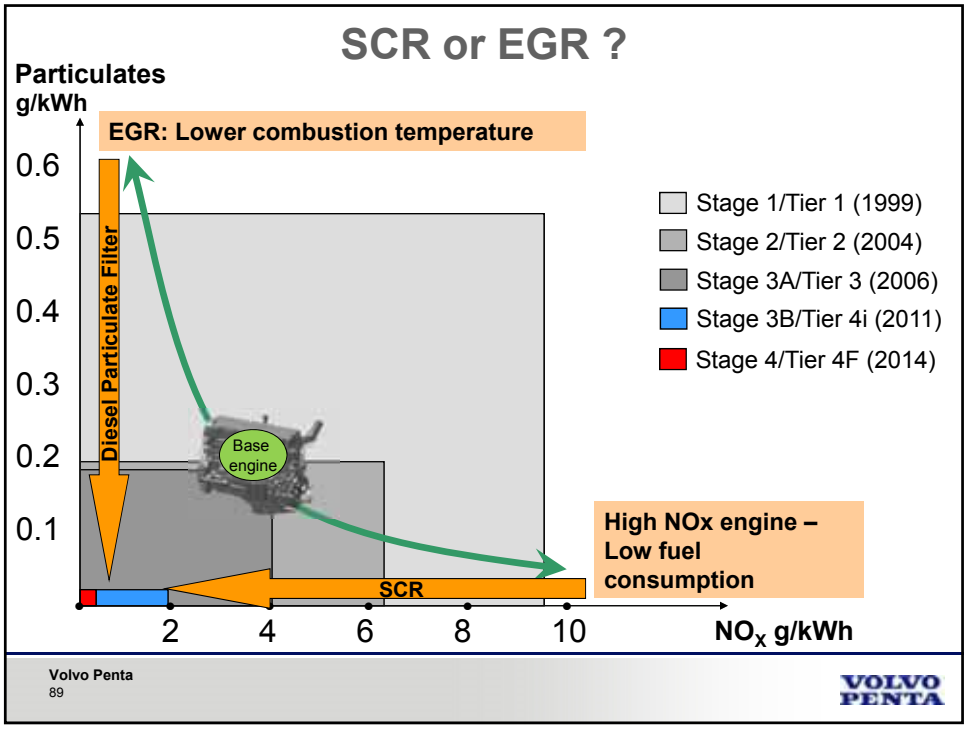
EU and US introduced new emission legislations
named Stage 3B and Tier 4A in January 2011.

Continue to grow within selected markets and segments
to fulfill Volvo Penta growth strategy.

Green Commitment - To offer the most modern engines that give maximum performance with minimal environmental impact to OEMs and operators

THE VOLVO PENTA
GREEN COMMITMENT

Together with safety and quality, the enviroment is one of Volvo´s core values.


SCR or EGR ?
Particulates
g/kWh
EGR: Lower combustion temperature
0.6
0.5
0.4
0.3
0.2
0.1
Diesel Particulate Filter
Base engine
SCR
High NOx engine – Low fuel consumption
Stage 1/Tier 1 (1999)
Stage 2/Tier 2 (2004)
Stage 3A/Tier 3 (2006)
Stage 3B/Tier 4i (2011)
Stage 4/Tier 4F (2014)
2
4
6
8
10
NOx g/kWh
Volvo Penta
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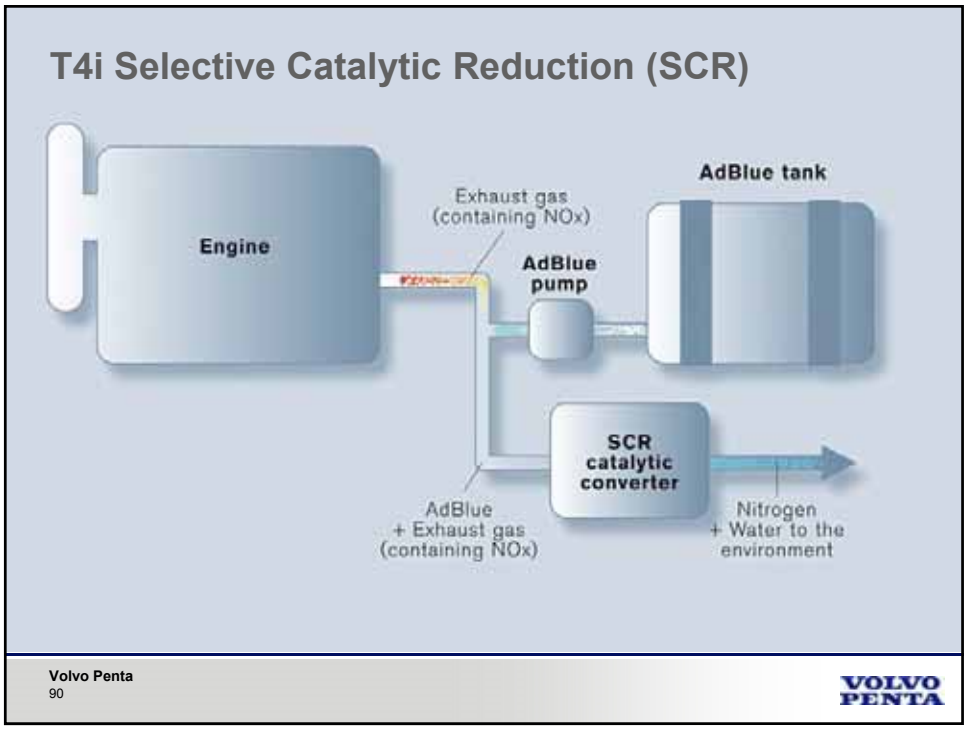
VOLVO PENTA


T4i Selective Catalytic Reduction (SCR)
Engine
Exhaust gas (containing NOx)
AdBlue tank
AdBlue pump
SCR catalytic converter
AdBlue + Exhaust gas (containing NOx)
Nitrogen + Water to the environment
Volvo Penta
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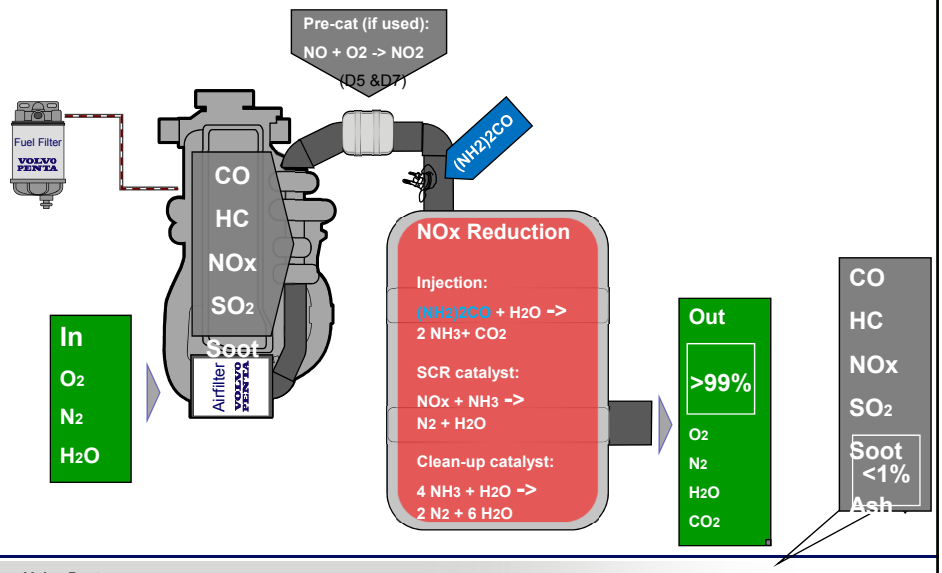
VOLVO PENTA

SCR Chemical Process



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What happens if off spec urea is used?

- Irreversible damage to the catalyst
- Use of agriculture grade urea (Only chemical produced shall be used according to ISO standard)
  - ✓ Damage to SCR-system
- Use of water instead of AdBlue/DEF
  - ✓ Damage to SCR-system
  - ✓ No NOx reduction
- Misfuelling may cause significant problems. Diesel in urea tank damage the SCR-system

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Global Training

Consequences of poor handling and mixture

Crystallization

Crystallization is caused by to much AdBlue/DEF injection at too low exhaust temperature. This can happen if you are running on low load for longer periods. Crystallization will occur at the coldest point on the inlet pipe to the catalyst

Clogging

If using AdBlue/DEF that not fulfil the correct ISO-standard, inorganic compounds and water solutions will clog the catalyst. The whole industry will have a learning process to understand the importance of using right quality AdBlue/DEF

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Global Training

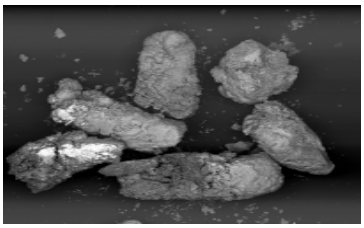
Crystallization

Volvo Penta

Global Training

VOLVO PENTA

Clogging



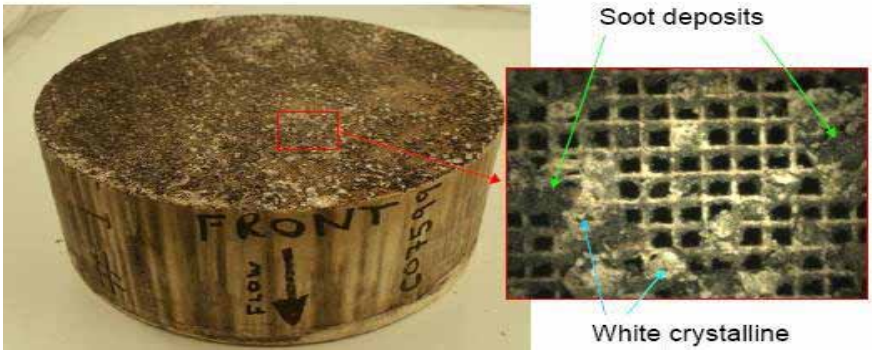
Volvo Penta

Global Training

VOLVO PENTA

Clogging

The deposits are not possible to get rid of, **not even with regeneration**.



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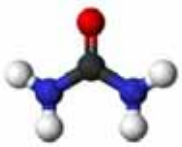
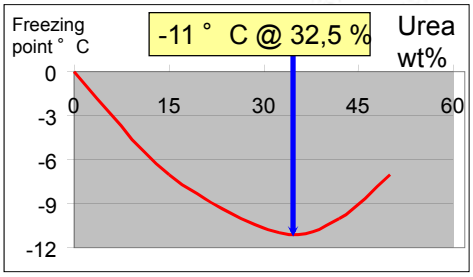
Global Training

What is Urea $(NH_2)_2CO$?



- Water soluble
  - 32,5% solution gives lowest freezing point
  - Melting point 135 °C
- Ad Blue/DEF – Diesel Emissions Fluid
  - 32,5% Urea solution in **DEIONISED** water
  - Non-Toxic
  - Non-flamable
  - Odourless
- Consumption
  - Proportional to NOx reduction
  - Approx. 5% of diesel consumption



NOx reduction requires heat

Without heat, the Urea may crystallize

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AdBlue standardization

- **ISO 22241 Diesel engines — NOx reduction agent AUS 32**
- **Four parts in ISO 22241**
  - ISO 22241-1 Quality requirements (Published 2006-10)
  - ISO 22241-2 Test methods (Published 2006-10)
  - ISO 22241-3 Handling, Transportation and Storage (Draft International Standard (DIS) published 2007-05)
  - ISO 22241-4 Refilling interface (Draft International Standard (DIS) published 2006-08)

INTERNATIONAL STANDARD

ISO 22241-1

Diesel engines — NOx reduction agent AUS 32 —
Part 1:
Quality requirements

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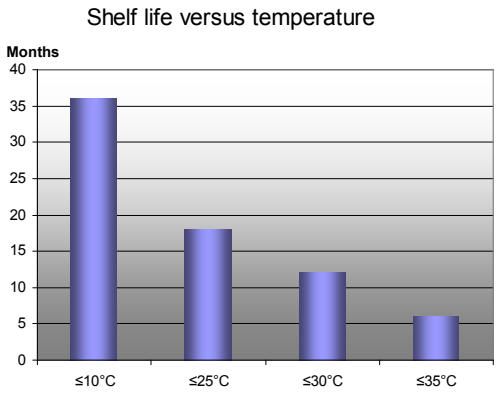
AdBlue/DEF product shelf life

(at constant temperature)



Source: ISO/DIS 22241-3

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Where to buy AdBlue today?

Examples of AdBlue supplier:

- Air1
- Yara
- Dureal
- Greenchem
- Statoil
- etc.

Licensed to use the AdBlue® trademark™:

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SUM-UP

- The whole industry will have a learning process
- DEF is widely used in the on-highway truck industry
- Operator Training (design and function) – Not only self studies
- Inform the customer initially about how to handle the system
- Handle and store DEF in a correct way
- Use DEF of good quality according to ISO-22241 from reliable suppliers to ensure correct content and concentration
- Warranty does not cover repair cost if poor quality DEF is used

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VOLVO PENTA

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VOLVO PENTA

Aftertreatment System

AVL

The following consideration focuses on the engine power classes from 56 up to 560 kW

To meet TIER 4i different exhaust aftertreatment concepts are in discussion

56 - 130 kW: NOx = 3,4 g/kWh, NMHC = 0,19 g/kWh, PM = 0,02 g/kWh

130 - 560 kW: NOx = 2,0 g/kWh, NMHC = 0,19 g/kWh, PM = 0,02 g/kWh

electronically controlled CR	electronically controlled CR
cEGR + DPF (POC)	**SCR**
30 – 32 kW/l	33 – 35 kW/l
93 -95 % FC of Tier 3 engine	86 - 90 % FC of Tier 3 engine

System choice will be influenced by various market requirements and technology status available (e. g. transfer of EU 5 or US07 on-road to NRM)

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VOLVO PENTA

Benefits of Volvo Penta engines

- Excellent fuel economy = lower running costs for operator
  - Example. A customer operating a machine with a Volvo TAD1362VE (Tier 4i engine) commented ”The machine powered with this engine is very economical compared to the Tier 3 engine it replaced”.
- Simple installation:
  - Fewer Tier 4 components to install : SCR muffler, tank
  - Simple control interface, engine to OEM panel
- Reduced heat rejection = smaller radiators, lower costs
- Less complex = increased reliability & lower capital cost
- Longer service intervals

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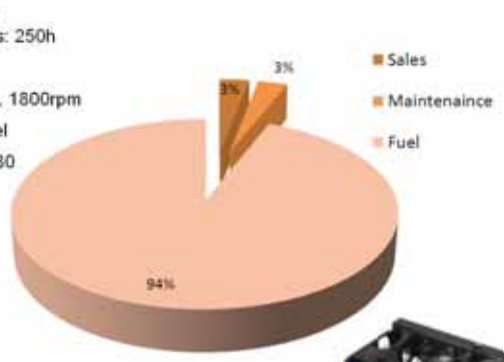
Total Cost of Ownership D13 – 12000h

Example Based on:

- Oil change intervals: 250h
- Fuel price: 1$/l
- Constant load 75%, 1800rpm
- 703,000 litres of fuel
- 6% saving = $42,180



Volvo Penta
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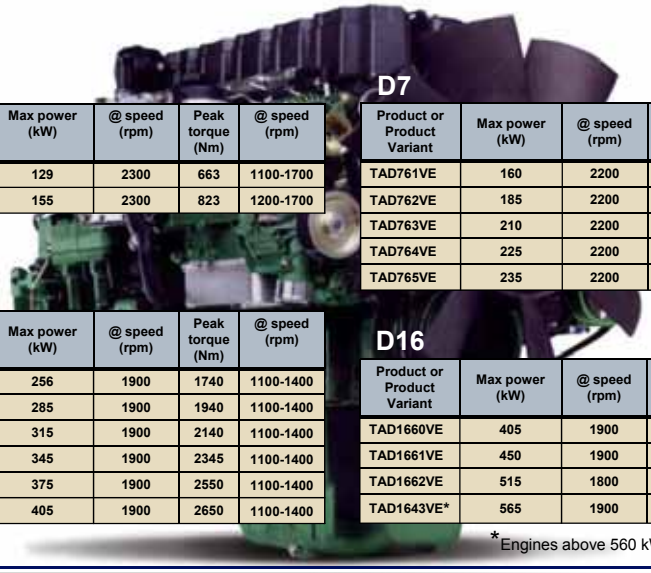
VOLVO PENTA

Performance Ratings



D5

Product or Product Variant	Max power (kW)	@ speed (rpm)	Peak torque (Nm)	@ speed (rpm)
TAD560VE	129	2300	663	1100-1700
TAD561VE	155	2300	823	1200-1700

D7

Product or Product Variant	Max power (kW)	@ speed (rpm)	Peak torque (Nm)	@ speed (rpm)
TAD761VE	160	2200	1178	1200
TAD762VE	185	2200	1178	1200-1400
TAD763VE	210	2200	1178	1200-1700
TAD764VE	225	2200	1250	1200-1700
TAD765VE	235	2200	1300	1200-1700

D13

Product or Product Variant	Max power (kW)	@ speed (rpm)	Peak torque (Nm)	@ speed (rpm)
TAD1360VE	256	1900	1740	1100-1400
TAD1361VE	285	1900	1940	1100-1400
TAD1362VE	315	1900	2140	1100-1400
TAD1363VE	345	1900	2345	1100-1400
TAD1364VE	375	1900	2550	1100-1400
TAD1365VE	405	1900	2650	1100-1400

D16

Product or Product Variant	Max power (kW)	@ speed (rpm)	Peak torque (Nm)	@ speed (rpm)
TAD1660VE	405	1900	2700	950-1430
TAD1661VE	450	1900	2855	960-1500
TAD1662VE	515	1800	3160	1000-1555
TAD1643VE*	565	1900	3287	1200

*Engines above 560 kW are not regulated.

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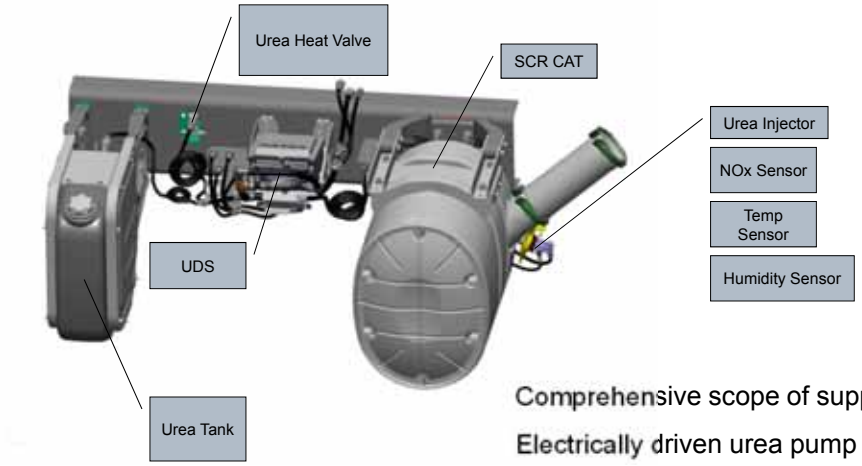
VOLVO PENTA

Engine After Treatment System - EATS



Comprehensive scope of supply

Electrically driven urea pump

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SCR Engine Range

5L	7L	13L	16L
TAD560VE TAD561VE	TAD761VE TAD762VE TAD763VE TAD764VE TAD765VE	TAD1360VE TAD1361VE TAD1362VE TAD1363VE TAD1364VE TAD1365VE	TAD1660VE TAD1661VE TAD1662VE TWD1663GE TWG1663GE *

*US Market only (Bi-Fuel)

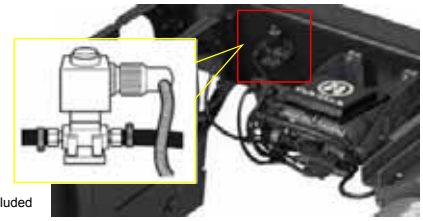
TAD 1360 VE

- Turbocharged
- Type of intercooling
  - A= Air-to-air
  - W= Water-to-air
- Diesel fuel
- Displacement indication (litre)
- Generation
- Version
- Type of application
  - G= Gen Set
  - V= Versatile industri application
- Exhaust emission certified

Volvo Penta

Designed for in-use complicance

- System drained to tank
- Defrosting time requirements*
  - -25°C (-13°F) < T < 0°C (32°F): 30 min
  - -40°C (-40°F) < T < -25°C (-13°F) : 60 min
- El heated DEF hoses
- Tank heat valve opens at +10°C (50°F) and closes at +15°C (59°F)



*) Engine idling excluded

SCR – ”the most efficient solution”

1. **Lower fuel consumption** (-10% compared to Tier 3)
2. **Cooling package remains unchanged – improved visibility for mining applications**
3. **Greater power densities**, smaller engine delivers more horsepower
4. **Service intervals remain unchanged**
5. **Reliable & proven technology** SCR introduced by Volvo 2006 (Euro 4)
6. **No need for regeneration –** less downtime, easy and continuous operation
7. **Easy service**, no cleaning nor replacement of SCR-CAT needed through lifetime
8. **Less complex engine =** reduced maintenance
9. **Low exhaust temperatures =** no restrictions in operational areas

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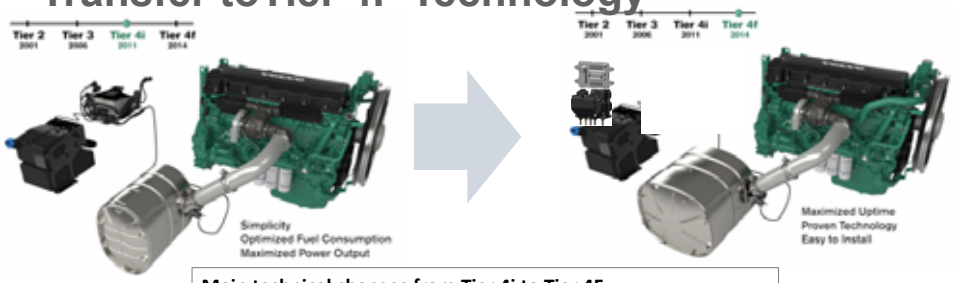
Product Range T4f (2014)

Transfer toTier 4F Technology



Main technical changes from Tier 4i to Tier 4F:

- Increased size of SCR muffler
- New integrated pump and ACM, same functionallity
- 5-8 liter (MD) Light EGR added (5-8 litre)
- 11-16 liter (HD) non cooled EGR added (11-16 litre)
- Electrical system update
- Increased fuel costs (Diesel + UREA) 1-2% T4i to T4F
- Small or no increase in heat rejection
  - 5-8 liter (MD) heat rejection + 10%
  - 11-16 liter (HD) T4F same requirements as T4i
- No Re-generation i.e. no DPF
- Same engines available Tier 2, 3 and 4

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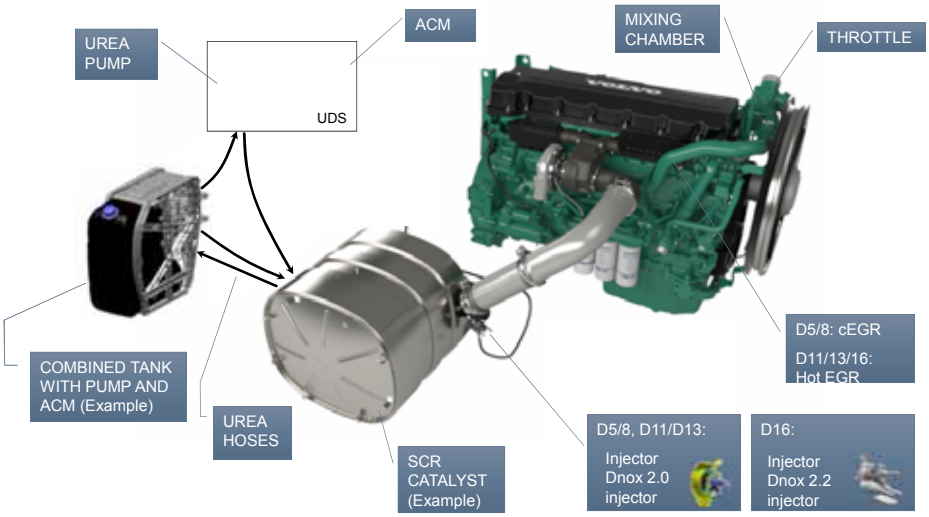
Tier 4F Technology



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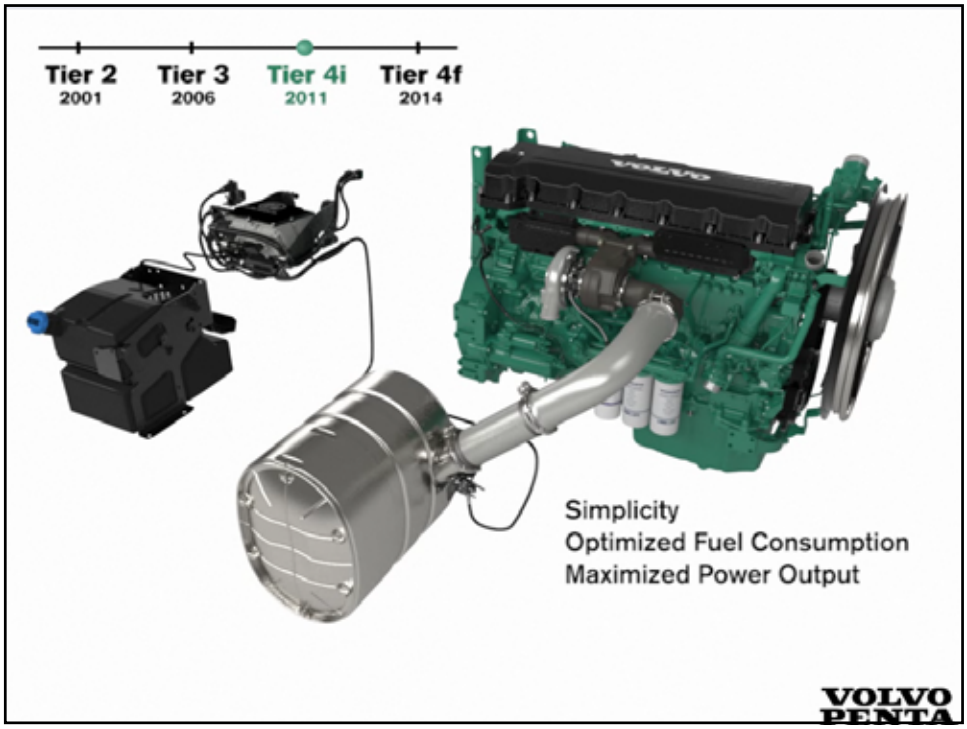
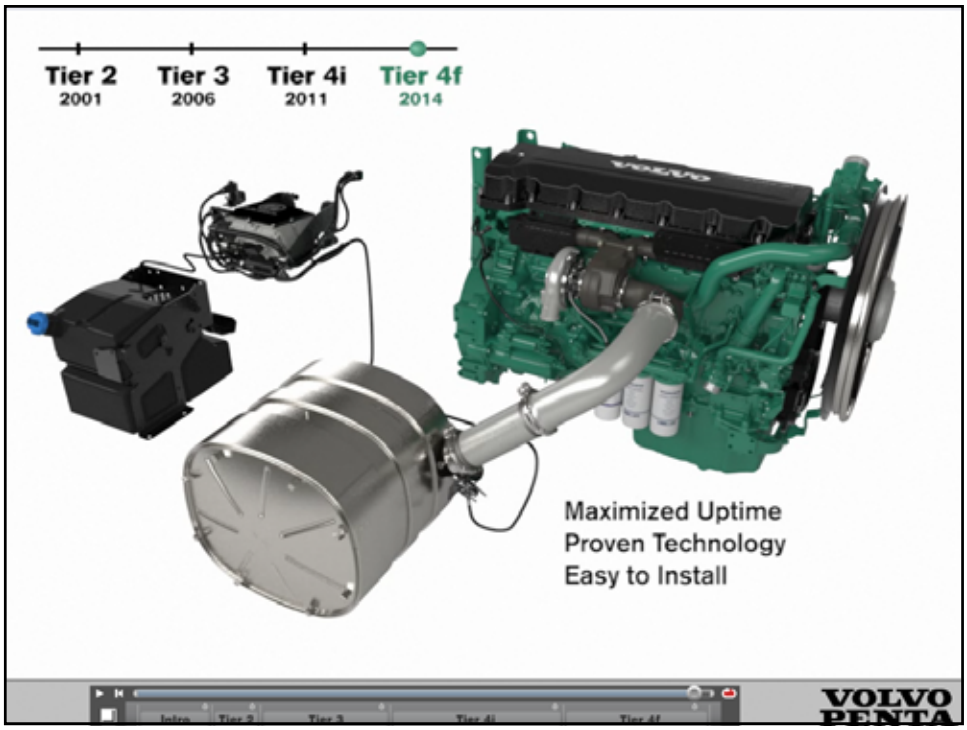

Tier 2
2001
Tier 3
2006
Tier 4i
2011
Tier 4f
2014
Simplicity
Optimized Fuel Consumption
Maximized Power Output
VOLVO PENTA


Tier 2
2001
Tier 3
2006
Tier 4i
2011
Tier 4f
2014
Maximized Uptime
Proven Technology
Easy to Install
VOLVO PENTA

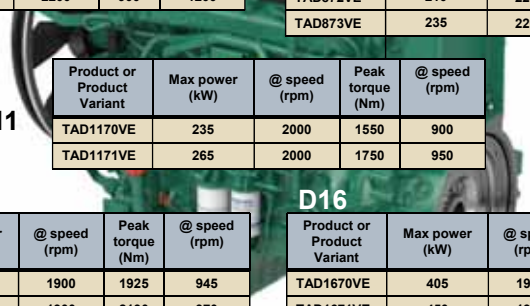
T4f Performance Ratings

D5

Product or Product Variant	Max power (kW)	@ speed (rpm)	Peak torque (Nm)	@ speed (rpm)
TAD570VE	105	2200	700	1000
TAD571VE	129	2200	800	1100
TAD572VE	160	2200	900	1200

D8

Product or Product Variant	Max power (kW)	@ speed (rpm)	Peak torque (Nm)	@ speed (rpm)
TAD870VE	160	2200	1050	1000
TAD871VE	185	2200	1150	1100
TAD872VE	210	2200	1250	1100
TAD873VE	235	2200	1300	1200



D11

Product or Product Variant	Max power (kW)	@ speed (rpm)	Peak torque (Nm)	@ speed (rpm)
TAD1170VE	235	2000	1550	900
TAD1171VE	265	2000	1750	950

D13

Product or Product Variant	Max power (kW)	@ speed (rpm)	Peak torque (Nm)	@ speed (rpm)
TAD1371VE	285	1900	1925	945
TAD1372VE	315	1900	2130	970
TAD1373VE	345	1900	2330	1000
TAD1374VE	375	1900	2540	1100
TAD1375VE	405	1900	2590	1150

D16

Product or Product Variant	Max power (kW)	@ speed (rpm)	Peak torque (Nm)	@ speed (rpm)
TAD1670VE	405	1900	2700	950
TAD1671VE	450	1900	2900	960
TAD1672VE	515	1800	3150	1000

Unregulated engines available above 560kW

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Volvo base engine platform 5 & 8L

D5

4 cylinders
105-160kW
max torque 900Nm

D8

6 cylinders
160 - 235kW
max torque 1300Nm

120

Volvo base engine platform 11, 13 & 16L

D11

235-295 kW

max torque 1950 Nm

D13

295-405 kW

max torque 2650 Nm

D16

405–500 kW

max torque 3200 Nm

121

Power range Tier 4F 5-8L

Product or Product Variant	Max power (kW)	@ speed (rpm)
TAD570VE	105	2300
TAD571VE	129	2300
TAD572VE	160	2300
TAD870VE	160	2200
TAD871VE	185	2200
TAD872VE	210	2200
TAD873VE	235	2200

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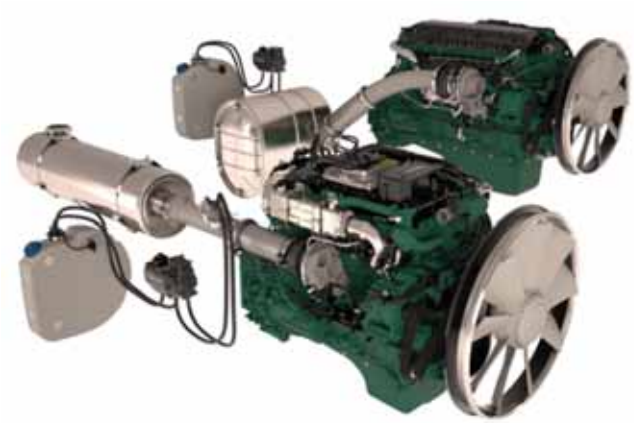
Volvo base engine platform 5 & 8L

D5
4 cylinders
105-160kW
max torque 900Nm

D8
6 cylinders
160 - 235kW
max torque 1300Nm



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Volvo base engine platform 11, 13 & 16L

D11
235-295 kW
max torque 1950 Nm

D13
285-405 kW
max torque 2650 Nm

D16
405–495 kW
max torque 3200 Nm

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Agenda

- Introduction of Volvo Group and Volvo Penta
- SCR approach for Tier 4
- Characteristics of Urea (Adblue or DEF)
- Operational benefits of Volvo SCR based engines
- Current range, stage 3b, engines and technology
- Future engine range, Stage 4, engines and technology
- Mining certification
- Installation and factory support
- Global Aftermarket support
- Summary and conclusion
- Questions

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Mining – key segment

- Volvo Penta has invested in certifying engine for use in mining applications
- Tier 4i engines offer low ventilation rates
- More engines will be certified

LIST OF APPROVED PRODUCTS
FEBRUARY 2012

The following products were approved or certified during February, 2012, and have been added to the Mine Safety and Health Administration's list of permissible equipment.

The following products were approved as having met Part 7, Title 30 CFR.

1. Models TAD 1363VE, TAD 1364VE, and TAD 1365VE Diesel Engines.
Approval No. 07-ENA120001-0, issued to AB Volvo Penta, Dept 47 436 Z2.1 Engine Cert, SE-405 08 Gothenburg Sweden, February 15, 2012.

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Agenda

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- Global Aftermarket support
- Summary and conclusion
- Questions

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Application Engineering Support

- Volvo Penta partnership provides application engineering support throughout the development cycle:
  - Local support, single point of contact
  - Product selection
  - Product specification, drawings and 3D models
  - Product packaging, concept through to final design
  - Testing : engine and cooling validation
  - Product training and documentation support
- Output
  - Improved machine performance/productivity
  - Lower operating costs
  - Longer operating hours
  - Reduced warranty/ repair cost

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Agenda

- Introduction of Volvo Group and Volvo Penta
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- Questions

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VOLVO PENTA

Global aftermarket a differentiator

May, 2012

130

World-Class AM backed-up by Volvo Group

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US Customised map

- **Volvo Penta can offer tailored aftermarket solution, eg near mines**
- **Volvo group service**
  - Parts
  - Logistics
  - Tools
- **Combining Volvo group structure with local support flexibility**

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Agenda

- Introduction of Volvo Group and Volvo Penta
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- Global Aftermarket support
- Summary and conclusion
- Questions

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Summary and conclusions

- **Volvo Penta products offer OEM and Operators advantages**
  - Operators:
  Low operating cost (fuel/maintenance)
  High operation (No re-generation)
  - OEMs:
  Low Heat rejection
  Simple installation
- **Comprehensive product range**
  - Tier 2,3,4
- **Global support**
- **Mining is recognised as a key segment**
  - Certification
  - Specification
- **Installation and application engineering**
- **Field tests**

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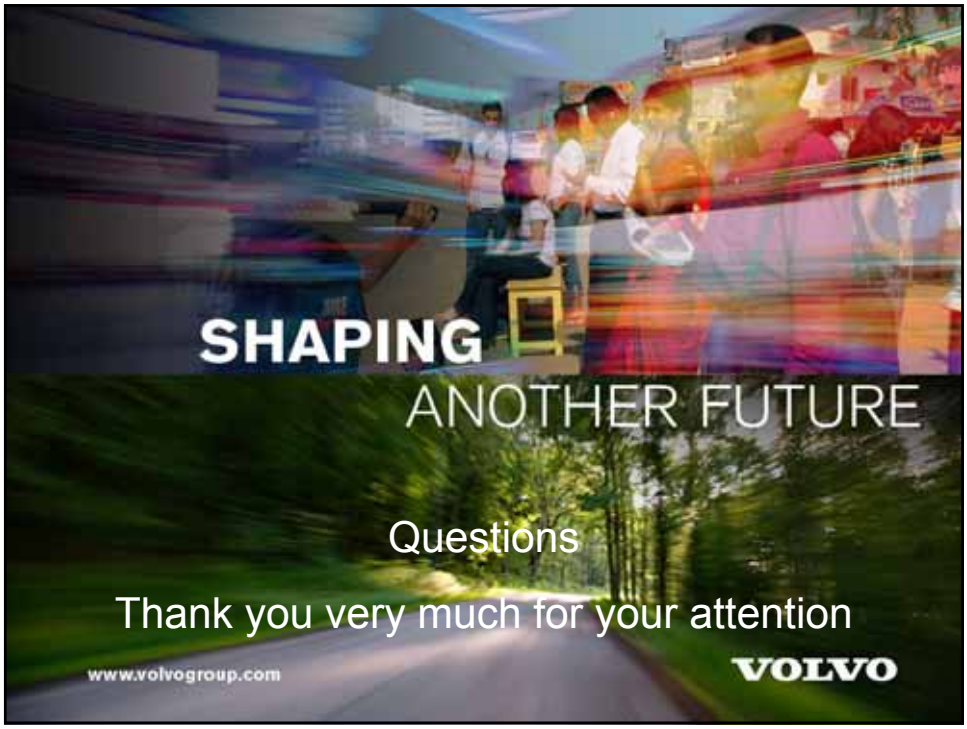


47730, Product Management Industrial

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

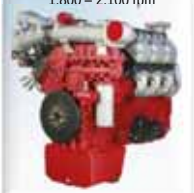
Greg Tremaine
DEUTZ Corporation

MDEC Conference
Tonroto ON
October 2, 2012

Overview DEUTZ product line-up TIER 4 interim & final

The engine company. DEUTZ

TCD 2.9	TCD 3.6	TCD 4.1 – 6.1	TCD 7.8	TCD 12.0 – 16.0
35 – 75 HP 2.200 – 2.600 rpm	67 – 120 HP* 2.300 – 2.600 rpm	93 – 241 HP** 1.800 – 2.300 rpm	214 – 335 HP 1.800 – 2.200 rpm	323 – 697 HP 1.800 – 2.100 rpm



EPA Power Category

TIER 4 final	TIER 4 interim	TIER 4 interim	TIER 4 interim	TIER 4 interim
49.6-75.1	75.1-100.6	100.6-174.3	174.3-751	174.3-751

*additional ratings >75

**additional ratings <75

VC-P AH

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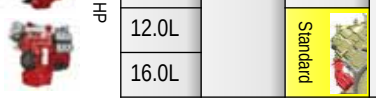
Overview DEUTZ product line-up
Technology Tier 4 Final for Industrial engines

The engine company. DEUTZ

DEVERT
DEUTZ Variable Emission Reduction Technology

	MODEL	ECU	ceEGR	FIE	Turbo Charger	DVERT Oxidation Catalyst	Wall-Flow system	Heat Management	SCR System
<75.1 HP	2.9L	EMR 4 Platform	Standard	High Pressure Common Rail (4-8 ltr: DCR)	WG	Standard	Option	Only intake throttle	
	3.6L								Standard >56kW ≥90% SCR efficiency
75.1-697 HP	4.1L				eWG or WG tbd.		Standard < 130kW		
	6.1L							Intake & exhaust throttle	
	7.8L				WG		Standard >130kW		
	12.0L		Standard		Electric WG			Only intake throttle	
	16.0L								



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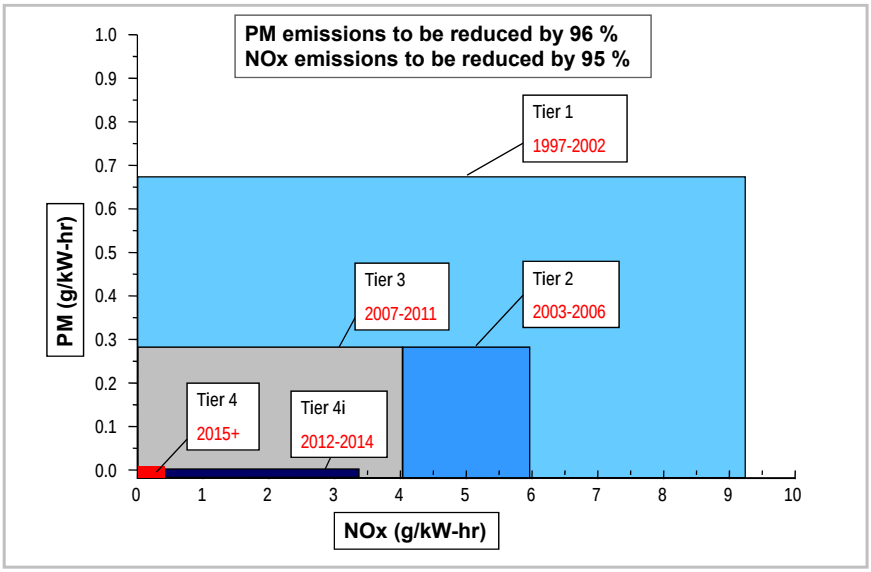
Emission Improvement from Tier 1 to Tier 4 (100 – 174HP)

The engine company. DEUTZ



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To Achieve Tier 4 (> 25hp) Emission Levels

The engine company. DEUTZ

Requires a Three Segment
"Systems Approach"

Tier 4 Emissions Level

Low/ultra low sulfur diesel fuel

Engine technologies and control system working in unison with EAT

EAT – Exhaust Aftertreatment

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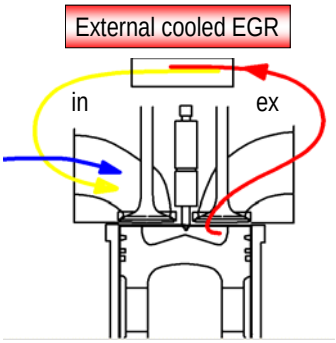
Exhaust Gas Recirculation (EGR)

The engine company. DEUTZ

- 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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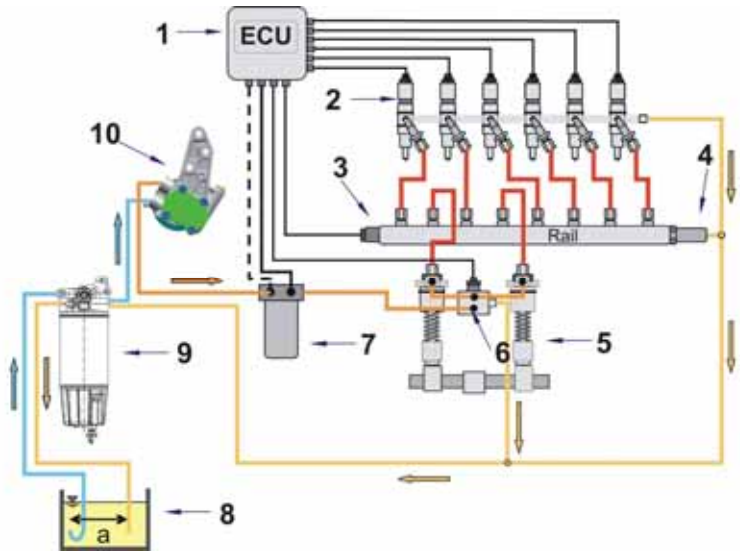
DEUTZ Common Rail (DCR) Fuel Injection System

The engine company. DEUTZ



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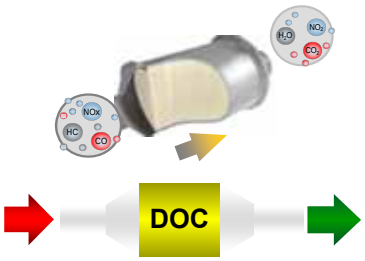
Exhaust aftertreatment for Tier 4 non-road engines
DEUTZ EAT solutions - Single system DOC

The engine company. DEUTZ



DEUTZ Application Example

T/C/D 2.9 ≤ 55.4kW Tier 4

TD 3.6 ≤55.4 kW Tier 4
TCD 3.6 56<P<90kW Tier 4i

DVERT® Oxidation Catalyst (DOC)

- ✓ Reducing CO and HC
- ✓ „Open“ flow-through system – no clogging

- × Optional DOC + DPF for mining applications
- × Limited power density (max. 25kW/ltr.)
- × Continous control of low PM level engine out must be secured leading to less transient response

Customer‘s Benefits

- Fully passive aftertreatment
- Simple flow-through oxidation
- Maintenance-free – fit and forget
- Easier to install than a DPF
- No change in operator interface

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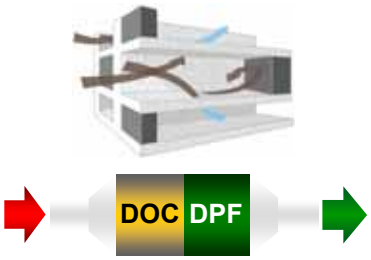
Exhaust aftertreatment for Tier 4 non-road engines
DEUTZ EAT solutions - Single system DPF

The engine company. DEUTZ



DEUTZ Application Example

TCD 4.1/6.1 Tier 4i Ind. <130kW TCD 3.6 L4 Tier 4i Ind. (opt.)

DVERT® Particulate Filter (DPF)

- ✓ PM reduction at highest efficiency (>99%)
- ✓ Particulate number (PN) reduction at highest efficiency

- × Need for regeneration
- × Low SAPS* oil required
- × Ash cleaning required
- × <10-15 ppm sulphur fuel required

*sulphated ash, phosphorus and sulphur

Customer's Benefits

- PM reduction at highest efficiency (>99%)
- Capable for all applications with PN count emission directives like e.g. TRGS 554, engines for indoor use or Swiss VERT
- Less variance – one solution for all markets
- No 2nd operating fluid needed

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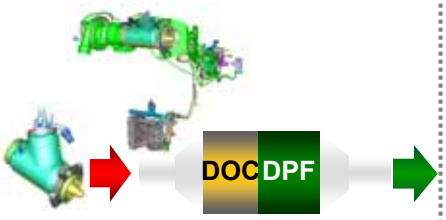
Exhaust aftertreatment for Tier 4 non-road engines
DEUTZ EAT solutions - Single system DPF - Burner Regeneration T4i

The engine company. DEUTZ



DEUTZ Application Example

TCD 6.1 L6 Tier 4i >130kW TCD 7.8 L6 Tier 4i

Active regeneration Systems
Wall flow filter (DPF) + Burner

- ✓ PM reduction at highest efficiency (>99%)
- ✓ Automatic regeneration under all conditions

- × Low SAPS* oil required
- × Ash cleaning required
- × <10-15 ppm sulphur fuel required
- × High exhaust temperature during regeneration

*sulphated ash, phosphorus and sulphur

Customer's Benefits

- 100% reliable regeneration w/o operation interference under all conditions
- Fully integrated installation

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DEUTZ Particulate Filter Systems# and Function Signals

The engine company. DEUTZ

DPF Function	Operator Display			Performance degradation	Message via CAN bus (J 1939)
DPF Threshold	DPF Function lamp	Engine warning lamp	Message		
DPF loading phase	none	none	None	none	none
DPF Regeneration requirement	blinking	none	Regeneration in xx minutes	none	Regeneration in xx minutes
DPF Regeneration	continuous	none	Regeneration	none	Regeneration
DPF Regeneration finalized	none	none	none	none	none
DPF overloading xx - yy%	blinking	continuous	Regeneration not completed, Torque degrading	Torque degrading xx%**	Regeneration not completed, Torque degrading xx%**
DPF overloading >yy%	flashing	blinking	Power shut-off	Engine shut-off	Engine shut-off
Push button = Manual mode - Regeneration request - Regeneration release - Regeneration interrupt. - Regeneration inhibit	blinking	none	Regeneration request Regeneration release Regeneration interrupt. Regeneration inhibit	none	Regeneration request Regeneration release Regeneration interrupt. Regeneration inhibit
* selectable parameter = OEM specified, Performance degrading ist time dependent					

#with closed filters

Breuer VC-P 15-04-10 149

Exhaust aftertreatment for Tier 4 non-road engines
DEUTZ EAT solutions - Single system SCR

The engine company. DEUTZ

DEUTZ Application Example

TCD 4.1 / 6.1 / 7.8 Agri

TCD 12.0 / 16.0 Tier 4i

SCR

- ✓ NOx reduction at highest efficiency (up to 95%)
  - ✓ „Open“ flow-through system – no clogging
  - ✓ More tolerant towards sulphur in fuel
- × Additional urea tank, supply module and urea dosing needed

Customer‘s Benefits

- Reduced emissions and increased fuel efficiency
- Higher power densities – enables downsizing
- Proven technology used by heavy duty Truck industry
- Constant low exhaust temperature at end pipe
- No additional maintenance – only refill urea tank regularly

Compared to ceEGR + DPF Solution

- Better fuel consumption
- No DPF maintenance (ash cleaning) required
- No cooler size increase, heat rejection to coolant = Tier 3
- Constant exhaust back pressure

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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

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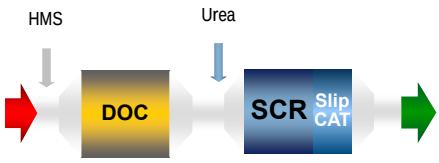
Exhaust aftertreatment for Tier 4 non-road engines
DEUTZ EAT solutions - Combined system DOC + SCR

The engine company. DEUTZ



DEUTZ Application Example

TCD 3.6 L4 Tier 4

DOC + SCR

- ✓ NOx reduction at highest efficiency (>90%)
  - ✓ „Open" flow-through system – no clogging, no ash cleaning
- × Not capable for applications with particulate number PN count emission directives like e.g. TRGS 554, engines for indoor use or Swiss VERT
- × limited power density (max. 25kW/l)
- × Continous control of low PM level engine out must be secured leading to less transient response
- × HMS required to achieve full performance

Customer's Benefits

- Combined simplicity
- Simple flow-through aftertreatment
- No additional maintenance – only refill urea tank regularly

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The engine company. DEUTZ

Thank you

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Ventilation Reduction Strategy
Underground Hard Rock Vehicles

MDEC 2012

WHEREVER THERE'S MINING

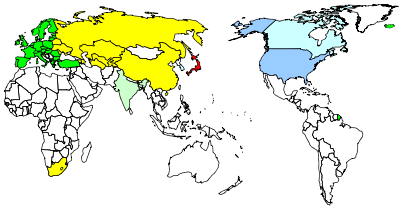
Agenda

- **Regulation Background**
  - Surface
  - Underground
- **UG emissions strategy**

156 / Caterpillar Confidential: GREEN / WHEREVER THERE'S MINING

Background

In many areas of the world, emissions regulations for Underground are not aligned with those for Surface.



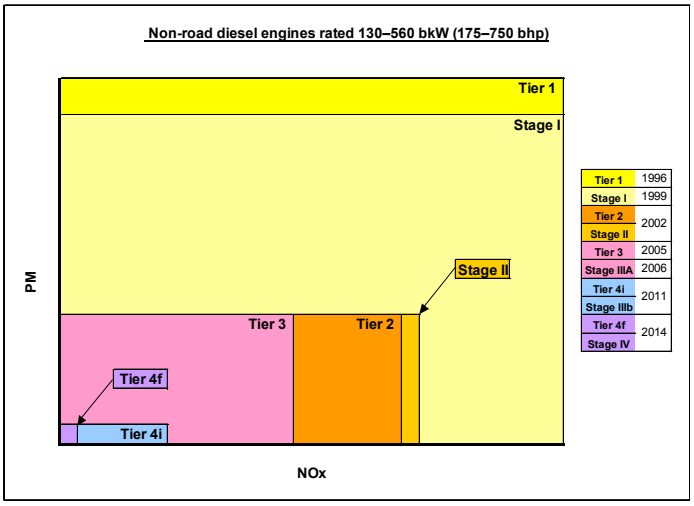
Surface - 3 Main Concepts:

United States & Canada	EU	Japan
Tier 1	Stage I	
Tier 2	Stage II	Step 1
Tier 3	Stage IIIA	Step 2
Tier 4i	Stage IIIB	Step 3
Tier 4f	Stage IV	Step 4

EU, China, and Japan are areas where Underground and Surface is aligned.

Background

Surface – Tier / Stage timing:



Background

Industry focus is primarily on the following diesel emissions

- NOx - Oxides of nitrogen: Gases that form when fuel is burned with excess air
- PM - Particulate Matter: Tiny bits of solids and liquids that form during the combustion process

•NOx and PM are inversely related, reduction in one generally causes increase in the other

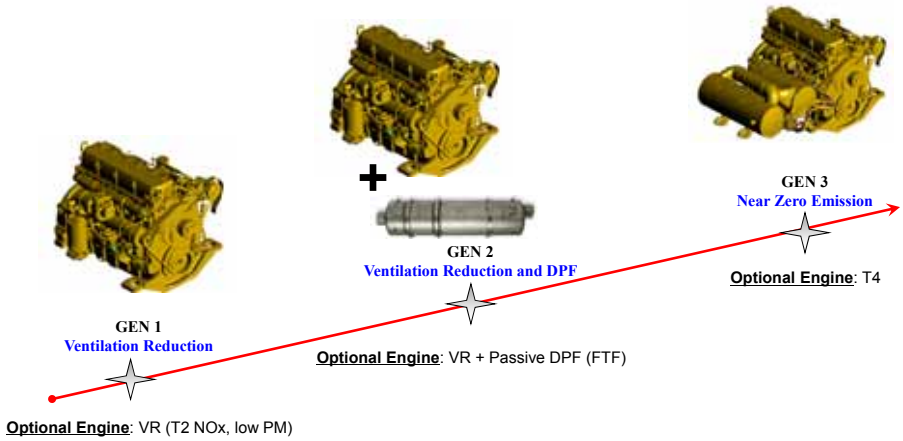
DPM & Vent Rate Reduction Path Forward

Our Strategy:

- Provide the best machine configuration for each market, based on
  - Regulations
  - Voice of Customer
  - Voice of Business

When possible we will provide options based on customer application requirements and environmental needs.

DPM & Vent Rate Reduction Technology MGPP



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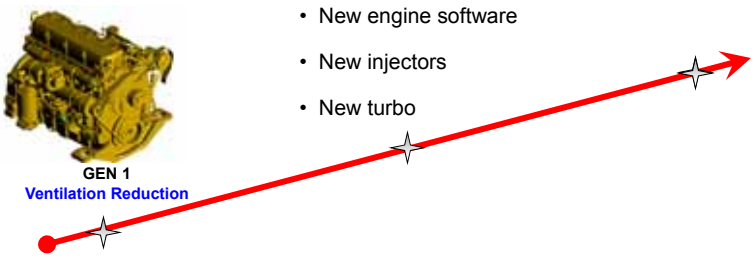
Generation 1 – Ventilation Reduction (VR) Package

What is involved?

- New engine software
- New injectors
- New turbo



Optional Engine: VR (T2 NOx, low PM)

R2900G	Rule of Thumb	CANMET	
	447 HP	Current	Gen 1
Vent Rate (CFM)	44,700	35,700	20,700

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Generation 1 (Ventilation Reduction Package)

Customer Impact:

	Tier 2/3 Baseline	Generation 1 VR Package
Fuel spec (sulfur ppm)	500 ppm	500 ppm
Bio fuel	B20	B20
Fuel consumption	Baseline	3-7% Improvement
Required oil spec	ECF-2 (CI-4)	ECF-2 (CI-4)
Oil change interval	Baseline	Baseline
DPF cleaning	N/A	N/A
CRS Service Kit	N/A	N/A
Overhaul life	Baseline	Baseline
Overhaul parts required	Baseline	Baseline

Limited to no O&O impact

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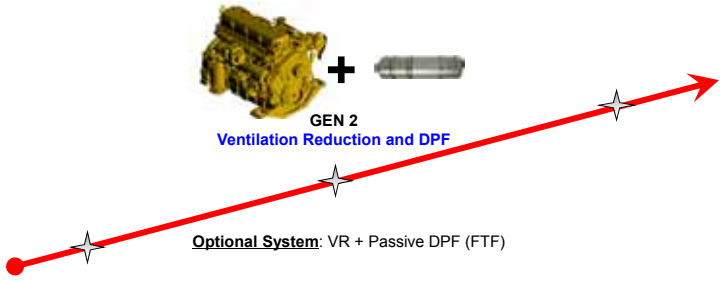
Generation 2 (VR Package + Flow-Through DPF)

What is involved?

- In addition to Gen 1…
- ULSD (15 ppm diesel)
- CJ-4 (low ash engine oil)

What are main challenges?

- Durability
- ~~Space claim~~
- ~~Backpressure~~



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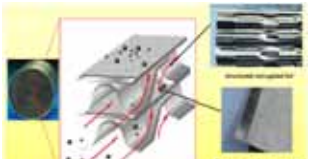
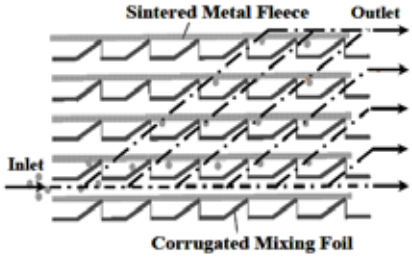
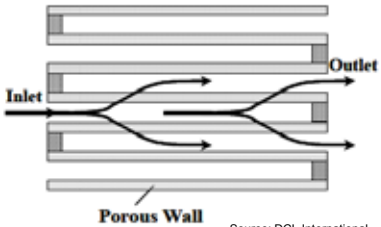
Flow-Through Filter vs Wall Flow Tech

Flow Through DPF



Wall Flow DPF





Source: DCL International

Generation 2 (VR Package + Flow-Through DPF)

Customer Impact:

	Tier 2/3 Baseline	Generation 1 VR Package	Generation 2 VR Package + DPF
Fuel spec (sulfur ppm)	500 ppm	500 ppm	15 ppm
Bio fuel	B20	B20	B20
Fuel consumption	Baseline	3-7% Improvement	3-7% Improvement
Required oil spec	ECF-2 (CI-4)	ECF-2 (CI-4)	ECF-3 (CJ-4)
Oil change interval	Baseline	Baseline	Baseline
DPF cleaning	N/A	N/A	N/A
CRS Service Kit	N/A	N/A	N/A
Overhaul life	Baseline	Baseline	Baseline
Overhaul parts required	Baseline	Baseline	Baseline

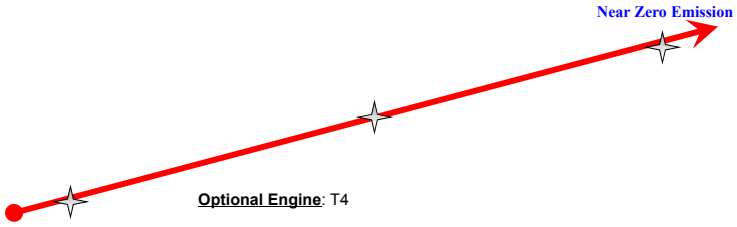
Generation 3 (Tier 4 Technology)

What is involved?

- DPF cleaning interval
- ULSD (15 ppm diesel)
- CJ-4 (low ash engine oil)

What are main challenges?

- Space claim

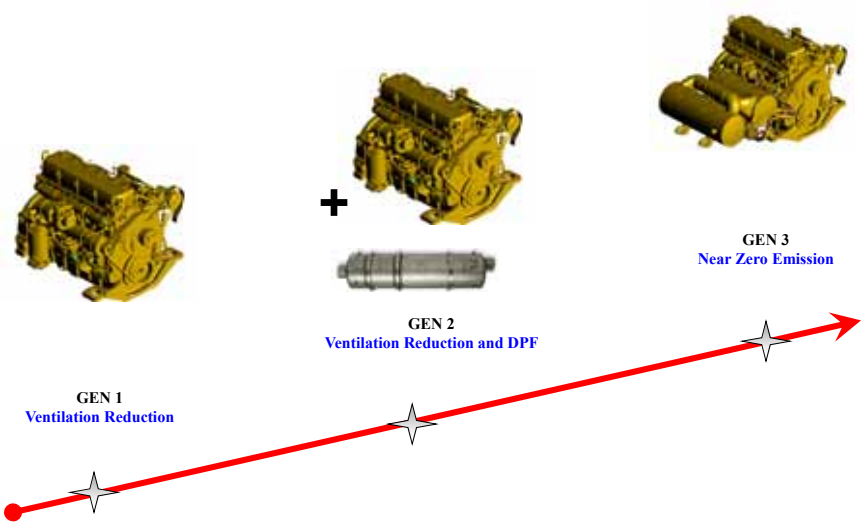


Generation 3 (Tier 4 Technology)

Customer Impact:

	Tier 2/3 Baseline	Generation 1 VR Package	Generation 2 VR Package + DPF	Generation 3 Tier 4 Technology
Fuel spec (sulfur ppm)	500 ppm	500 ppm	15 ppm	15 ppm
Bio fuel	B20	B20	B20	B20
Fuel consumption	Baseline	3-7% Improvement	3-7% Improvement	Up to 5% improvement
Required oil spec	ECF-2 (CI-4)	ECF-2 (CI-4)	ECF-3 (CJ-4)	ECF-3 (CJ-4)
Oil change interval	Baseline	Baseline	Baseline	Baseline
DPF cleaning	N/A	N/A	N/A	5,000 hrs
CRS Service Kit	N/A	N/A	N/A	5,000 hrs
Overhaul life	Baseline	Baseline	Baseline	Baseline
Overhaul parts required	Baseline	Baseline	Baseline	DPF Exchange, CRS Kit

DPM & Vent Rate Reduction Path Forward



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CAT

Thank You

Engines for Underground Mining

Dee Wise
Underground Mining Sales
deanne.wise@mtu-online.com
Office: 248-560-8598
Cell: 313-506-4623

MTU Update
Ownership Structure

MTU Update

Tognum

HOME OF POWER BRANDS

Tognum is the MTU holding company

mtu

MTU is the brand

MTU Update
New North American Headquarters

Effective February 27, 2012 Tognum America Inc will be headquartered in Novi, Michigan.

A brand new facility that offers employees and business partners:

- Totally redesigned workspaces
- Access to various meeting rooms
- Wireless technology throughout the building
- Conveniently located 30 minutes from the Detroit Metropolitan Airport

MTU Overview

Aiken Accomplishments

- 30% less production space
- 50% greater throughput
- 30% increase in first pass yield
- 20% productivity increase

Recently broke ground on $40M expansion

- New research and development buildings
- Additional engine test benches
- Creating 20+ additional jobs

MTU Overview

Canton, MI (Training Center)

Brownstown, MI (Parts Warehouse)

MTU Production Facilities Worldwide

Plant I - Friedrichshafen

Plant II - Friedrichshafen

Mannheim

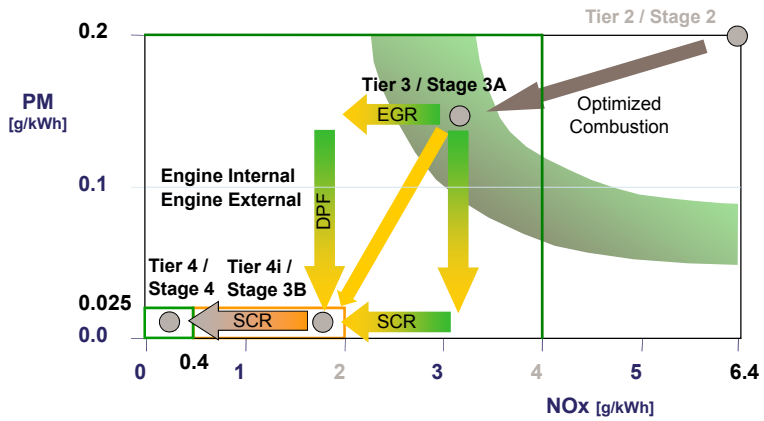
Detroit

Suzhou

1

Emission Compliance and Technology

Exhaust Emission Reduction Strategies for NO_x and Particulate Matter

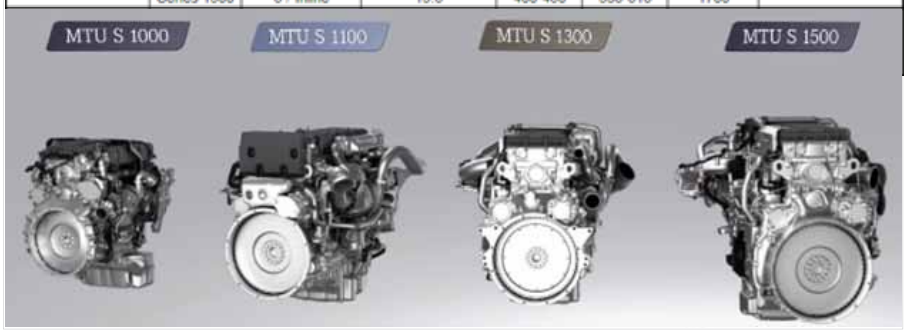


❖ For engines < 750hp

Engine Overview

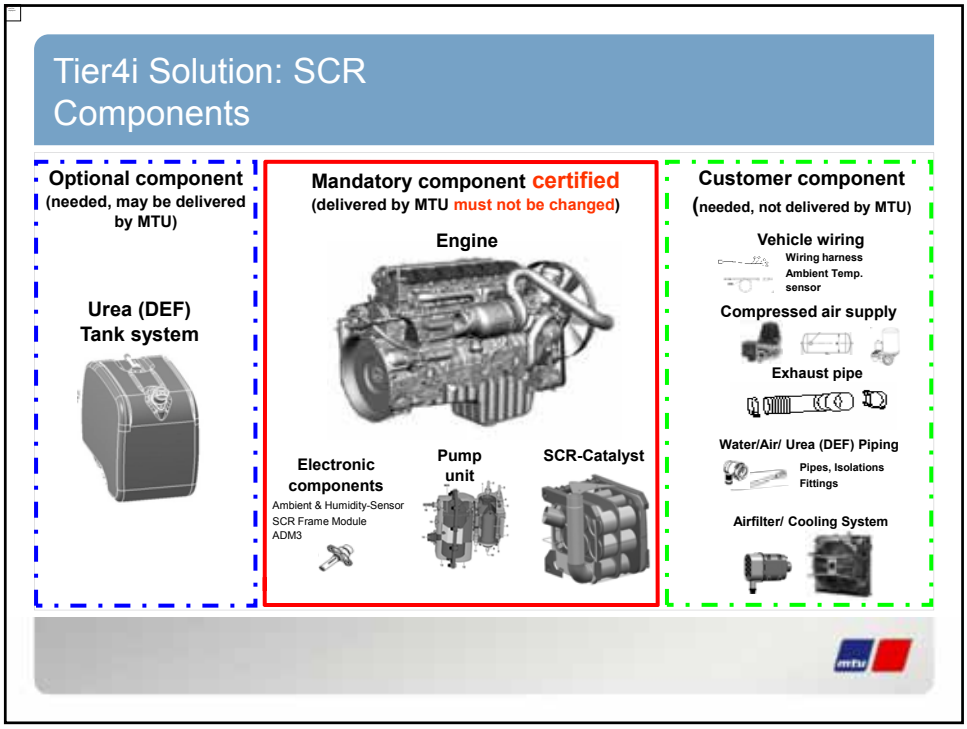
Engine Overview
For TODAY/TOMORROW…

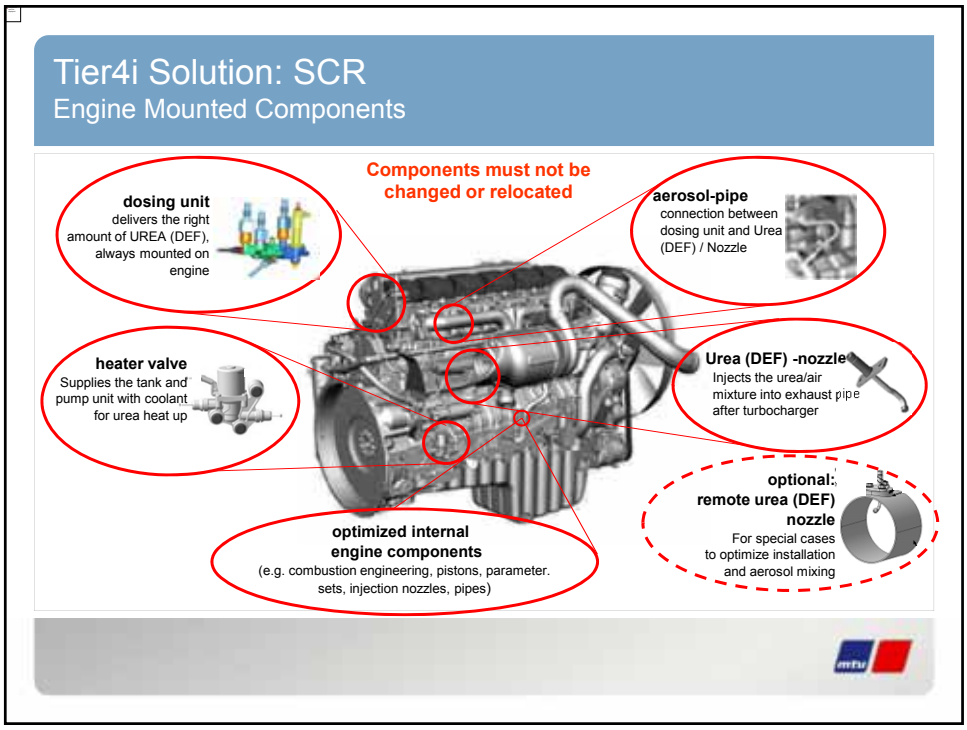
Emission level	Engine	Configuration (Cyl./ Inline or V)	Total Displacement (l)	Rated Power kW	bhp	rpm	Emission Strategy
Tier 4 final	Series 1000	4, 6 / Inline	5.1, 7.7	100-260	134-348	2200	EGR + SCR
	Series 1100	6 / Inline	10.6	280-320	375-429	1700	
	Series 1300	6 / Inline	12.8	340-380	456-509	1700	
	Series 1500	6 / Inline	15.6	400-460	536-616	1700	



Engines

Tier 4 interim


Tier4i Solution: SCR
Components
Optional component
(needed, may be delivered by MTU)
Urea (DEF) Tank system
Mandatory component certified
(delivered by MTU must not be changed)
Engine
Electronic components
Ambient & Humidity-Sensor
SCR Frame Module
ADM3
Pump unit
SCR-Catalyst
Customer component
(needed, not delivered by MTU)
Vehicle wiring
Wiring harness
Ambient Temp. sensor
Compressed air supply
Exhaust pipe
Water/Air/ Urea (DEF) Piping
Pipes, Isolations
Fittings
Airfilter/ Cooling System


Tier4i Solution: SCR
Engine Mounted Components
Components must not be changed or relocated
dosing unit
delivers the right amount of UREA (DEF), always mounted on engine
aerosol-pipe
connection between dosing unit and Urea (DEF) / Nozzle
heater valve
Supplies the tank and pump unit with coolant for urea heat up
Urea (DEF) -nozzle
Injects the urea/air mixture into exhaust pipe after turbocharger
optional: remote urea (DEF) nozzle
For special cases to optimize installation and aerosol mixing
optimized internal engine components
(e.g. combustion engineering, pistons, parameter. sets, injection nozzles, pipes)

Engines for Tier 4 interim S900 and S460

S924, 4-cyl. inline
4.8 ltr displacement

S926, 6.cyl. Inline
7.2 ltr displacement

[hp]	127	154	173	201	235	262	282	302	322
[kW]	95	115	129	150	175	195	210	225	240

S460, 6-cyl. Inline
12.8 ltr displacement

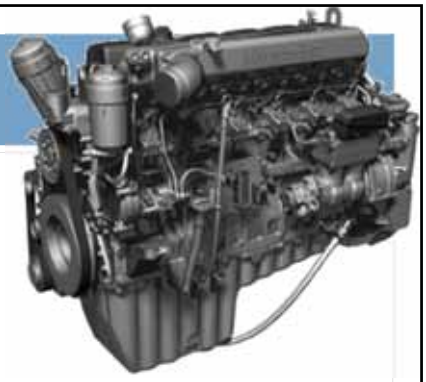
[hp]	355	396	422	449	483	503
[kW]	265	295	315	335	360	375

Tier 4 interim Features S900

- Same engine footprint as Tier 3 S900
- Optimized combustion timing
- Centrally positioned injection nozzle
- Two inlet valves, one exhaust valve per cylinder

- Rear gear-train
- Improved efficiency and fuel economy
- VERY minimal heat rejection increase vs. tier 3

Tier 4 interim Features S460



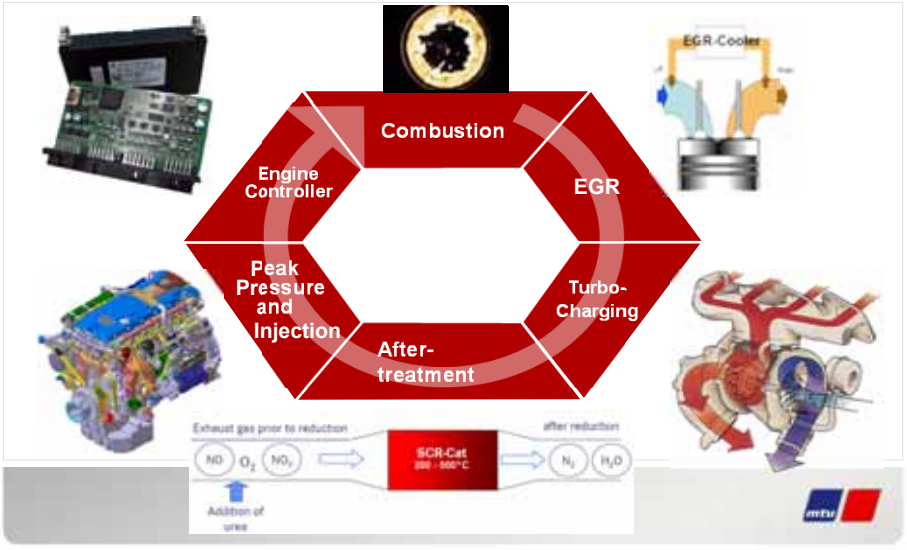
- Same engine footprint as Tier 3 S460
- Optimized combustion timing
- Centrally positioned injection nozzle
- Two inlet and exhaust valves per cylinder

- Rear gear-train
- Improved efficiency and fuel economy
- VERY minimal heat rejection increase vs. tier 3
- Wet cylinder liners

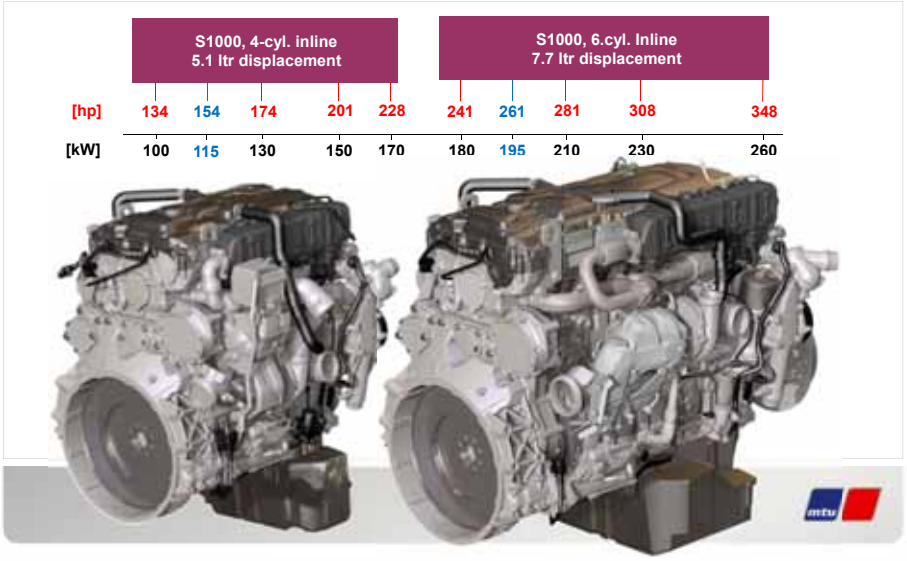
Engines

Tier 4 final

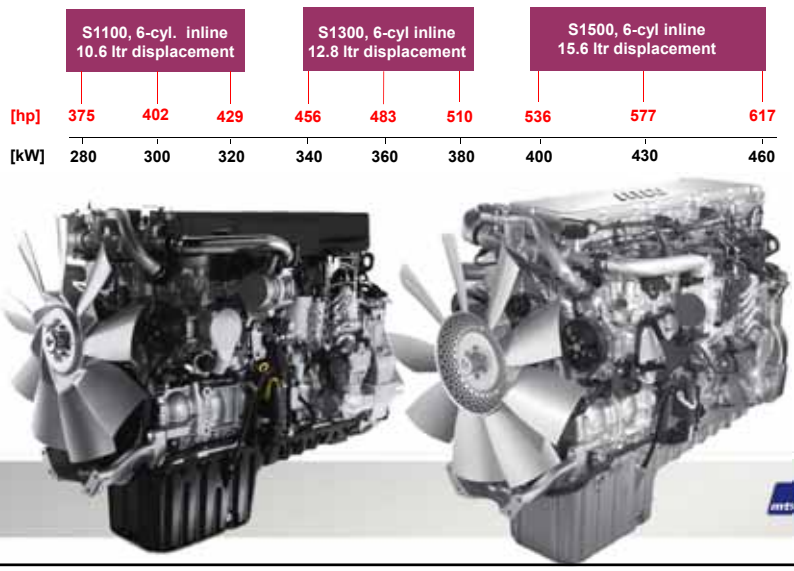
Tier 4 Final Solution: EGR and SCR
Key Engine Technologies



Engines for Tier 4 final
S1000



Engines for Tier 4 final
S1100 / S1300 / S1500



S1000
Tier 4 final Features

- Inline 4 and 6 cylinder versions
- 5.1 and 7.7 liter displacement
- OHC 4 valve per cylinder

- High pressure common rail fuel system
- Cooled EGR
- **Airless SCR!**
- Optional high performance exhaust brake

S1100 / S1300 / S1500
Tier 4 final Features

- Derivate of DD engines: proven performance
- Common rail fuel-injection system
- DOHC, 2-inlet and exhaust valves per cylinder

- **Airless SCR!**
- Wet cylinder liners
- Rear gear-train
- Optional high performance engine brake (up 90% of engine output)

Summary and Conclusion

Emission Technology Solutions: Overview
No DPF!!! No DOC!!!

	Tier 2	Tier 3	Tier 4i	Tier 4f
DOC	NOT REQUIRED!!!			
DPF	NOT REQUIRED!!!			
EGR				Cooled EGR
SCR			SCR	
Turbo	Single stage*			
Control system	Common Electronic Platform			
Fuel injection	Pump-Line-Nozzle (S60 with Unit Injection)			Common rail

* S1000 upper ratings with two-stage turbocharging

MTU Summary

- Solid plan for the future
- Comprehensive ratings coverage
- One basic concept…
  - Cooled EGR
  - Common rail fuel system
  - Mutli-valve per cylinder technology
  - OHC
- No DPF no DOC! …moving to Airless SCR for Tier 4 Final!
- Improved engine load acceptance
- Improved fuel economy

- We have the right balance!
- MTU…your knowledgeable and reliable partner!

Thank you for your time…

Questions?