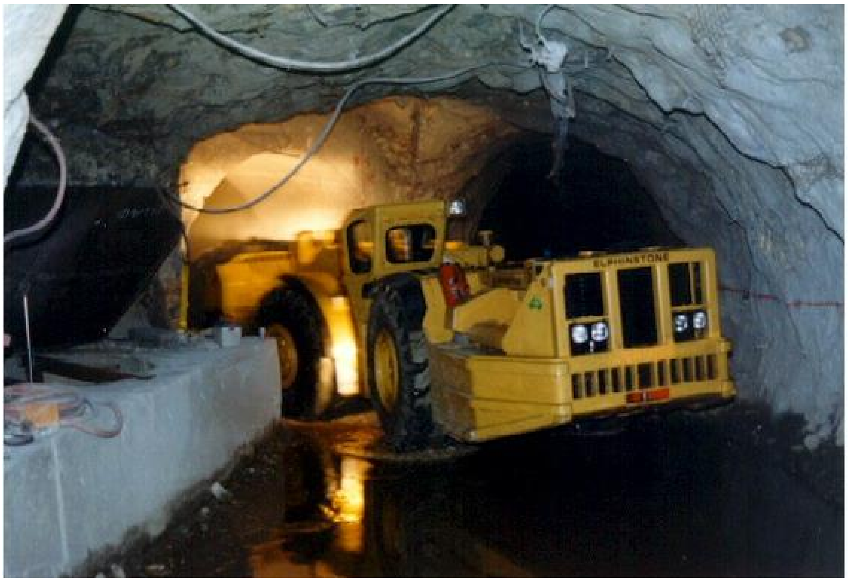
23rd ANNUAL MDEC CONFERENCE

Toronto Airport Hilton Hotel, Canada

October 3 – 5, 2017



MDEC DIESEL WORKSHOP

Diesel Workshop (Tier 4 Engine and Maintenance)

PRESENTED BY:

Evelynn Stirling (Cummins)

George Lin (Caterpillar)

J.P. Ouellette (Kubota)

Kevin Hedges (Ontario Workers Inc.)

Sean McGinn (MKNIZD Factors)

Erkki Lamminen (Dekati)

Paul Sheremeto & Brian Fleury (Pattern Discovery Technologies and WSN)

Blaine Vatcher (Atlas Copco)

Robert Anderson (TSI)

COORDINATED BY

David Young (Natural Resources Canada)

OCTOBER 3, 2017

MDEC Diesel Workshop

Diesel Workshop (Tier 4 Engine and Maintenance)

Hilton Toronto Airport Hilton & Suites
Ontario, Canada

Tuesday, October 3, 2017

07:30 – 08:30 Breakfast and registration

08:30 – 12:00 Welcome – *David Young and J.P. Ouellette*, Co-chairs MDEC

12:00 – 13:00 Lunch

13:00 – 16:00

MDEC – 2017
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Operation & TCO Comparison T3 to T4

July 2017

Cummins

Presentation Outline & Agenda

- Recap of recent and coming emission related product changes
  - -Industry technical overview & CMI specific
- Generic TCO example for B6.7 sized engine
  - -Fluid economy
  - -General maintenance highlights
  - -Detailed financial breakdown for TCO comparison
  - -Downsizing experience and potential moving forward
- Operator training considerations with newer products

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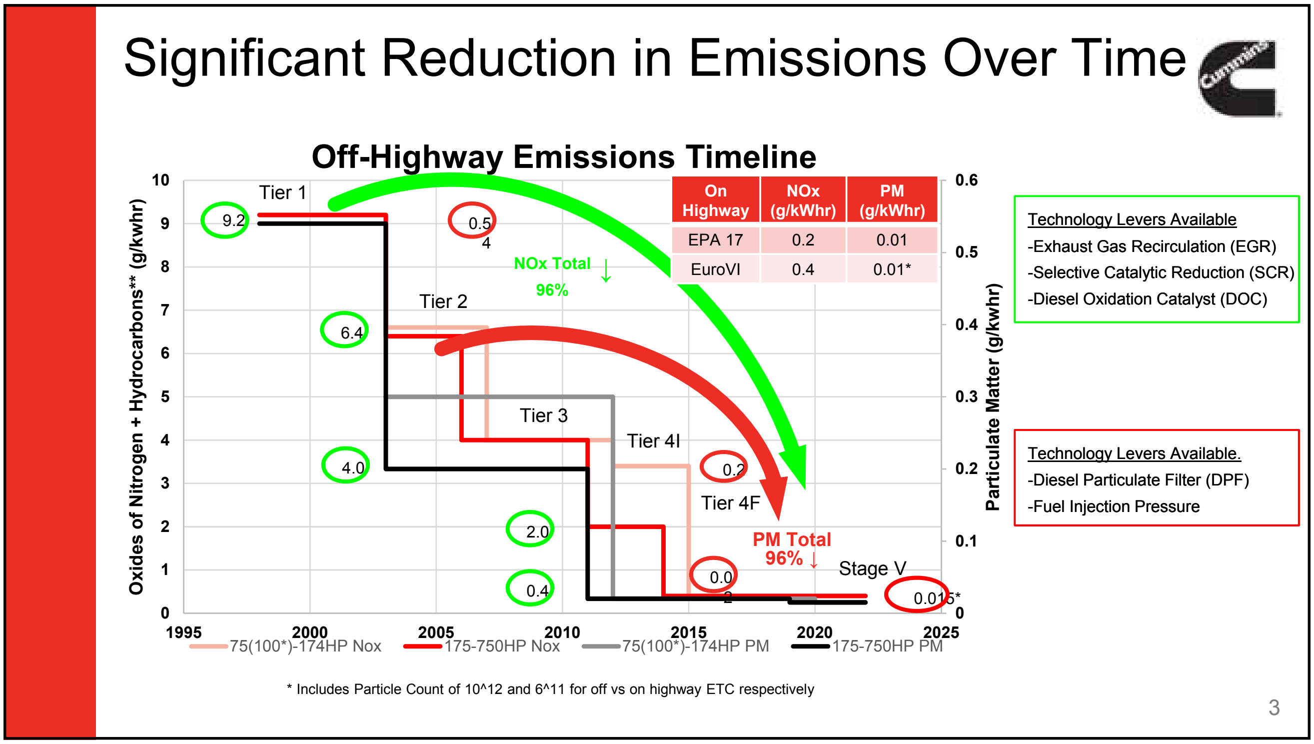
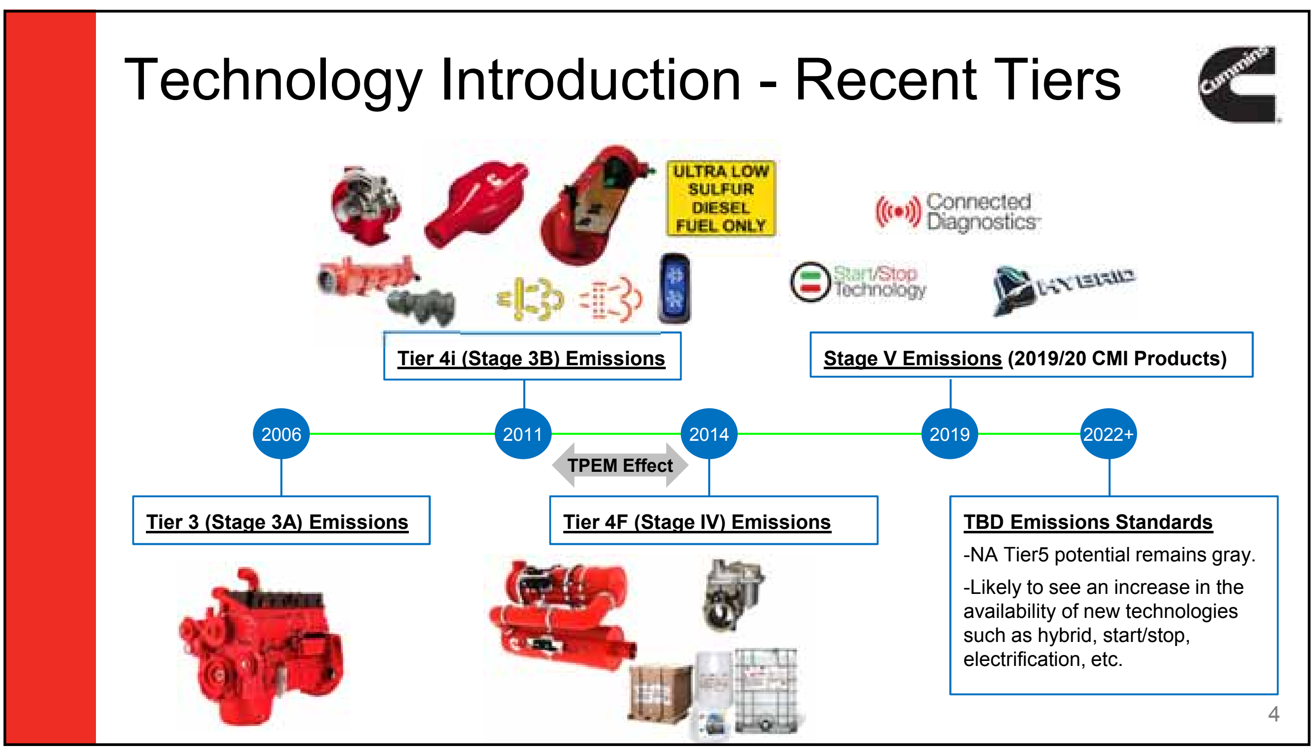
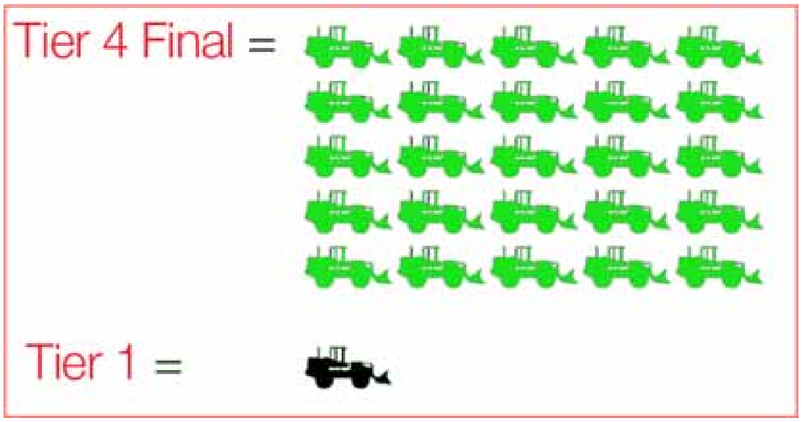

Significant Reduction in Emissions Over Time
Cummins
Off-Highway Emissions Timeline
Oxides of Nitrogen + Hydrocarbons** (g/kwhr)
Particulate Matter (g/kwhr)
Tier 1
Tier 2
Tier 3
Tier 4I
Tier 4F
Stage V
9.2
6.4
4.0
2.0
0.4
0.54
0.2
0.02
0.015*
NOx Total ↓ 96%
PM Total 96% ↓
On Highway | NOx (g/kWhr) | PM (g/kWhr)
EPA 17 | 0.2 | 0.01
EuroVI | 0.4 | 0.01*
1995 2000 2005 2010 2015 2020 2025
75(100*)-174HP Nox
175-750HP Nox
75(100*)-174HP PM
175-750HP PM
Technology Levers Available
-Exhaust Gas Recirculation (EGR)
-Selective Catalytic Reduction (SCR)
-Diesel Oxidation Catalyst (DOC)
Technology Levers Available.
-Diesel Particulate Filter (DPF)
-Fuel Injection Pressure
* Includes Particle Count of 10^12 and 6^11 for off vs on highway ETC respectively
3


Technology Introduction - Recent Tiers
Cummins
ULTRA LOW SULFUR DIESEL FUEL ONLY
Connected Diagnostics
Start/Stop Technology
HYBRID
Tier 4i (Stage 3B) Emissions
Stage V Emissions (2019/20 CMI Products)
2006
2011
2014
2019
2022+
TPEM Effect
Tier 3 (Stage 3A) Emissions
Tier 4F (Stage IV) Emissions
TBD Emissions Standards
-NA Tier5 potential remains gray.
-Likely to see an increase in the availability of new technologies such as hybrid, start/stop, electrification, etc.
4

Emission Changes – Real Implications



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CMI Recent Industrial Architectures

Platform	T4F / Stage IV	2019/2020 Products
F3.8 LP (74hp)	EGR+WGT+ETV w/ DOC	EGR+WGT+ETV w/ DOC+DPF
F3.8 HP	EGR+WGT+ETV w/ SCR or DOC+SCR	noEGR+WGT+ETV w/ DOC+DPF+SCR
B4.5 LP&HP	EGR+VGT w/ DOC+SCR	noEGR+WGT+ETV w/ DOC+DPF+SCR
B6.7	EGR+VGT w/ DOC+SCR	noEGR+VGT+IAT w/ DOC+DPF+SCR
L9	EGR+VGT w/ DOC+SCR	noEGR+WGT+ETV w/ DOC+DPF+SCR
X12	noEGR+WGT+ETV w/ DOC+DPF+SCR	
X15	EGR+VGT w/ DOC+DPF+SCR	

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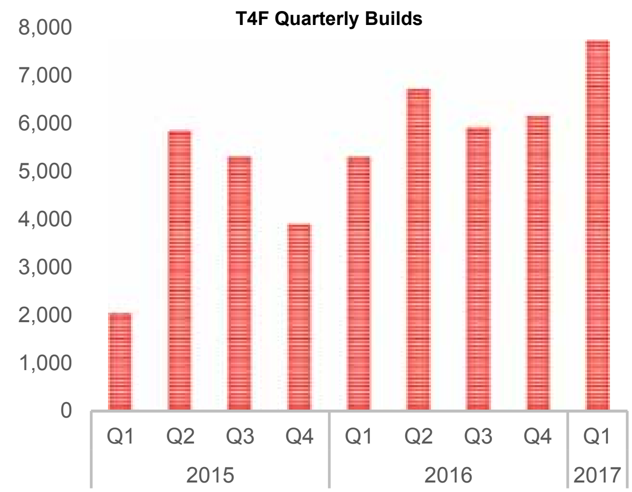
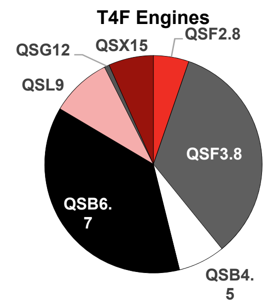
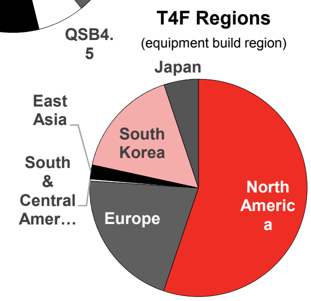
Over **50k** Tier 4 **Final** engines produced







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Major Maintenance Interval Comparison

Maintenance	QSB6.7 T3	QSB6.7 T4F	2019 B6.7
Oil & Filter Change	500 hours	500 hours	1000 hour options
Fuel Filter Change	500 hours	500 hours	1000 hours
Crankcase Filter Change	Service Free	2000 hours	Service Free
Overhead Adjust	5000 hours	5000 hours	5000 hours
Drive Belt Check	250 hours	1000 hours	2000 hours
DEF Dosing Pump Filter	N/A	4500 hours	4500 hours
DPF Ash Cleaning	N/A	N/A	Variable (5K+)*

*Duty cycle dependent, minimum planned to be 5,000 hours but many customers could see significantly longer.

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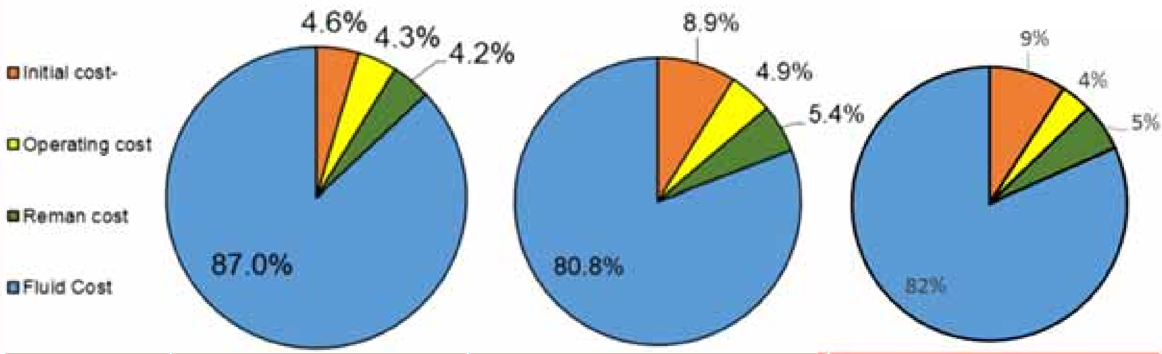
Operating TCO Comparison: 6.7L

T3 | **T4F** | **2019 B6.7**



Total Cost	1	0.93	0.91
Maint Cost	1	1.08	.78

**TCO savings realized with newer products is highly duty cycle dependent.*
**Regional diesel & DEF pricing have direct affects on the above.*

9

Power Advancements Support Downsizing

Proven downsizing success stories from the T3 to T4 transition.

http://www.hyster.com/north-america/en-us/announcements/press-releases/manufacturer-evaluation-proves-long-term-performance-and-durabilty-of-hyster-tier-4-engines/

Manufacturer Evaluation Proves Long-Term Performance and Durability of Hyster® Tier 4 Engines

-Tier 3 11L replaced with Tier 4 9L.

-Engine torn down at 10K hours revealing minimal wear to critical engine components!

"This test proves to the entire industry what Hyster, Cummins and our customers using Tier 4 engines have known all along: Tier 4 engines combine all of the performance, durability and toughness traditionally associated with Hyster® lift trucks, with significantly enhanced fuel economy and sustainability benefits to achieve compliance and help increase profitability," said Brett Schemerhorn, President of Big Trucks for Hyster.

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Future Increases Support Further Downsizing

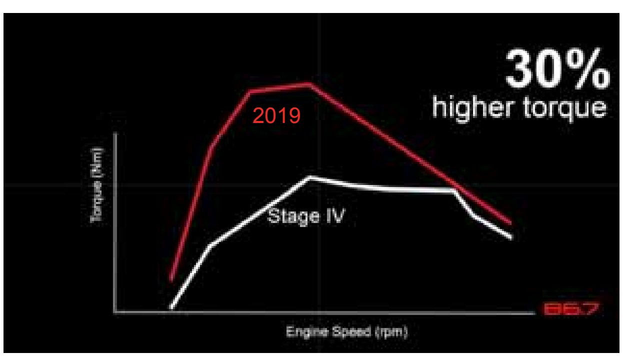
	2019 L9	QSL9 T4F / Stage IV	Improvement
Max. Power hp	430	400	8%
Ratings Range hp	275-430	250-380	
Peak Torque Nm	1846	1627	13%
	2019 B6.7	**QSB6.7 T4F / Stage IV**	**Improvement**
Max. Power hp	326	310	5%
Ratings Range hp	155-326	146-300	
Peak Torque Nm	1375	1030	31%
	2020 B4.5	**QSB4.5 T4F / Stage IV**	**Improvement**
Max. Power hp	200	173	16%
Ratings Range hp	120 -200	121-173	
Peak Torque	780	705	11%
	2020 F3.8	**QSF3.8 T4F / Stage IV**	**Improvement**
Max. Power hp	155	132	17%
Ratings Range hp	100-155	74-130	
Peak Torque	600	488	23%

Range Average Power Increase: over 10%

Range Average Torque Increase: almost 20%

2019 B6.7 Downsizing Case Study from L9

Power density increases have enabled OEMs to consider smaller displacement engines for existing installations.

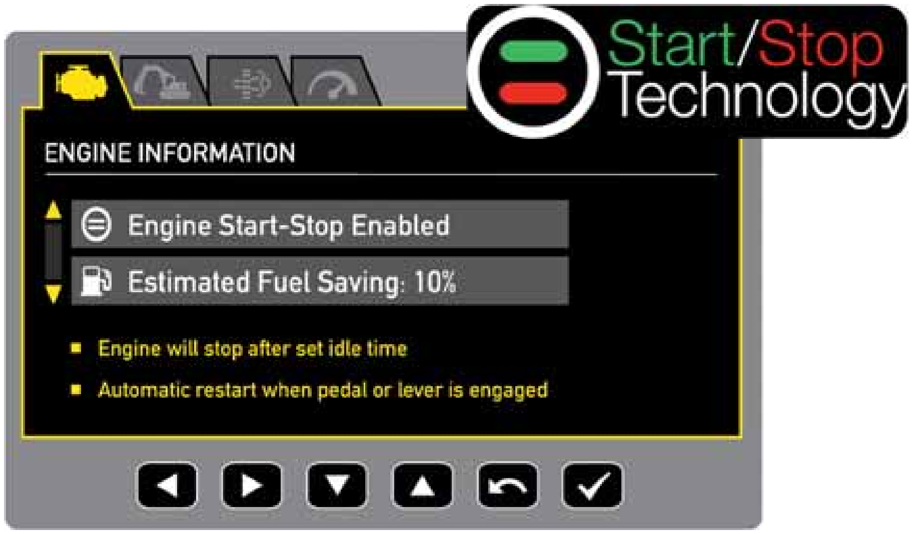


Application	Diesel Only*	Total Fluid (US)*
Forestry	+15.05%	+8.50%

*Sign Convention: (+) designates improvement vs. L9

Comparison above represents downsizing a low end rating from a 9L engine to the new top B6.7 curve.

New Tech Offers Further TCO Opportunities



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Start-Stop delivers value through superior idle management

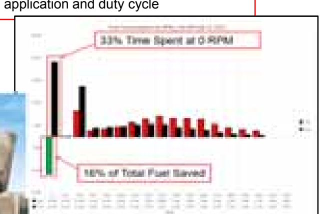
- **Fuel Savings**: improved operating cost by reducing fuel burned and urea consumed
- **Less Maintenance**: fewer engine run hours means reduced preventative maintenance and downtime
- **Machine Resale**: fewer run hours results in higher machine residual value

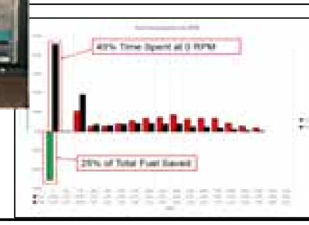
- Integration flexibility:
  - OEM choice of Cummins-supplied or 3rd-party system

Cummins Field Test:

16-25% total fuel saved!

Fuel savings will vary based on application and duty cycle





Electrification Brings Added Potential

we will be a leader in electrified power in all the markets we serve today.

OUR ELECTRIFICATION VISION

Similar to our current position in diesel.

Recognized as an industry expert.

Creating sustainable competencies.

Supporting all market segments.

15

Positioned for Success in Electrification

What CMI brings to the table…..

- Global Footprint of Support
- Capability Across Applications
- Scale to Products
- Security of Supply
- Choice of Portfolio

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Wide Range of Development in Progress

Purolator BEV Program	Quebec PHEV Program	DOE PHEV Program	CERC Program	SuperTruck 2 Program	
North America & Europe				North America	Region
Class 4 P&D	Class 7 & 8 Bus	Class 6 P&D	Class 5 P&D	Class 8 LH	Market
xEV (BEV)	xEV (REEV)			Mild Hybrid	Architecture
SAE J1772	SAE J3105 (WIP)	SAE J1772	SAE J2954 (WIP)	SAE J1772	Charging
No Engine	ISB 4.5L Diesel		ISF 2.8L SI	-	Gen Set
50 - 111 kWHr NMC & LTO Chemistries				5 kWHr (48V)	ESS Energy
2017	2018		2020	2021	Demos
2 years	3 years		5 years		Program
TM4 / Purolator	STL / TM4 / IVI	PACCAR / OSU / ANL / NREL	FCCC / ANL / OSU / Purdue / ORNL	Peterbuilt / Eaton / ORNL / NREL	Partners

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Higher Fuel Injection Pressures

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High Pressure Common Rail

- Increasing pressure capability (1800-2200 bar)
- Precise combustion control
- Improves combustion recipe
- Fuel cleanliness is critical

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Higher Injection Pressures in Operation

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SCR – Operational Considerations

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VGT – Operational Considerations

- Actuator cycles at key on/off.
- Exhaust pitch may change depending on nozzle position.
- Engine speed increase accompanied with exhaust pitch change during stationary exhaust cleaning event.

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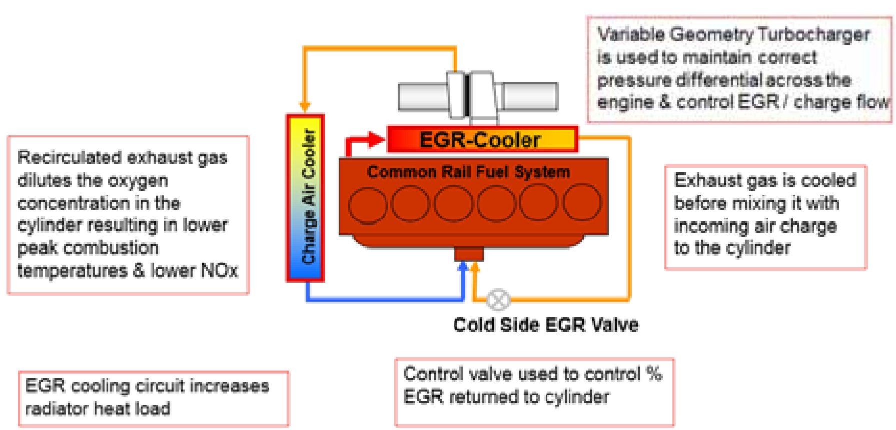
EGR – What is it?

- EGR is a lever available to reduce NOx emissions.



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EGR – Operational Considerations

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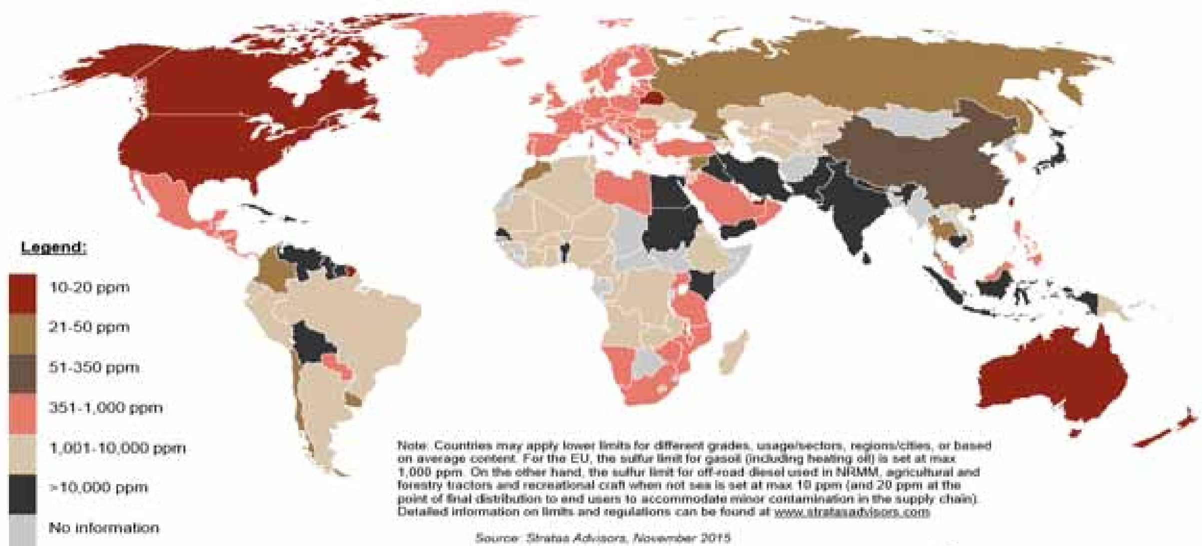
Current Maximum Off-road Diesel Sulfur Limits

Four Top 10 markets have off-road diesel grades with sulfur limits higher than 1,000 ppm



Note: Countries may apply lower limits for different grades, usage/sectors, regions/cities, or based on average content. For the EU, the sulfur limit for gasoil (including heating oil) is set at max 1,000 ppm. On the other hand, the sulfur limit for off-road diesel used in NRMM, agricultural and forestry tractors and recreational craft when not sea is set at max 10 ppm (and 20 ppm at the point of final distribution to end users to accommodate minor contamination in the supply chain). Detailed information on limits and regulations can be found at www.stratasadvisors.com

Source: Stratas Advisors, November 2015

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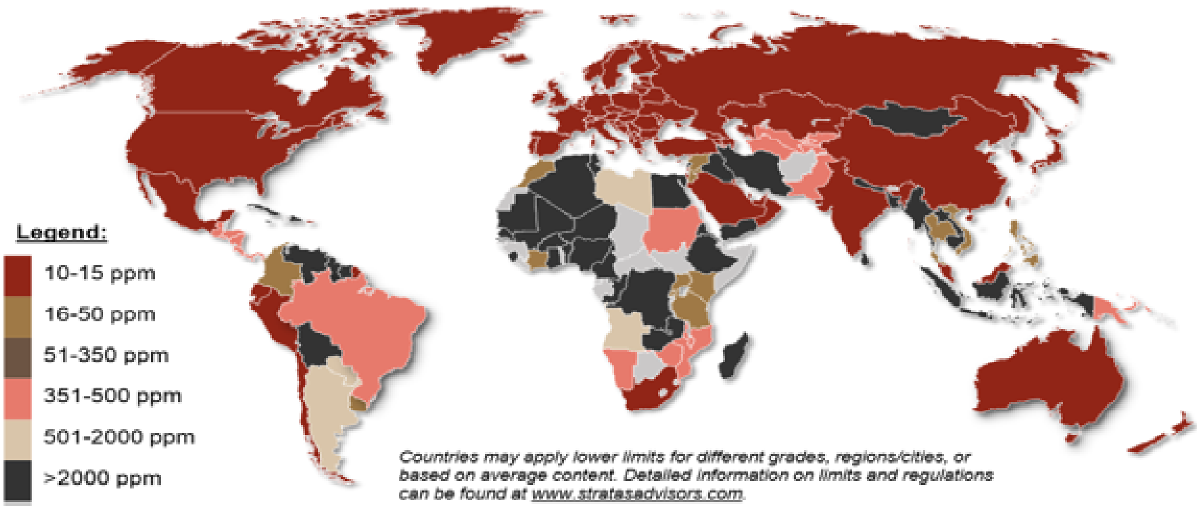
STRATASADVISORS

Max Sulfur Limits in On-Road Diesel, 2020

China, India, Malaysia, South Africa and Ukraine moving to 10 ppm by this time



Legend:

- 10-15 ppm
- 16-50 ppm
- 51-350 ppm
- 351-500 ppm
- 501-2000 ppm
- >2000 ppm
- No information

Countries may apply lower limits for different grades, regions/cities, or based on average content. Detailed information on limits and regulations can be found at www.stratasadvisors.com.

Source: Stratas Advisors, July 2015

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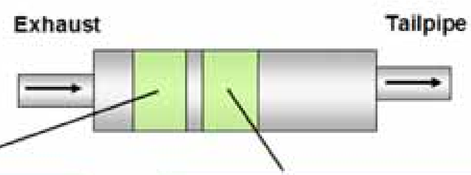
A HART ENERGY COMPANY

DOC & DPF – What are they?

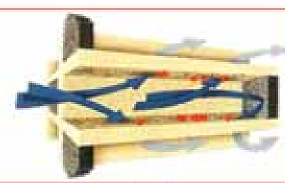


Diesel Oxidation Catalyst

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

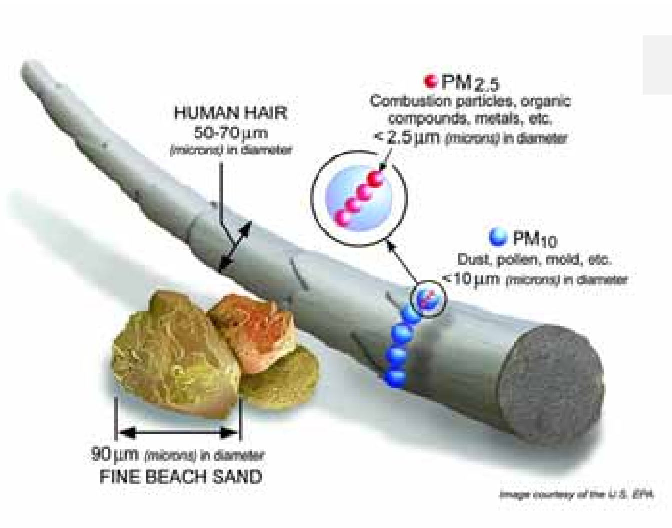
When soot accumulation in the DPF exceeds soot oxidation a periodic active regeneration mode is performed to prevent filter plugging. This is actuated by small quantities of fuel from a dosing injector or HPCR injection pulse during exhaust blow down. The heat released (no flame or burning) at 1022ºF(550ºC)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

26

DPF Particulate Capability 2019+



PM10 Coarse Particulate Matter - less than **10 micrometre (µm)** in diameter

PM2.5 Fine Particulates- less than **2.5 micrometres (µm)** in diameter

Ultrafine Particulates - less than **100 nanometres (nm)** in diameter

STAGE 5

Requires particles in the **23 nm to 2.5µm** range to be counted against the **$1x10^{12}$ / kWhr** limit

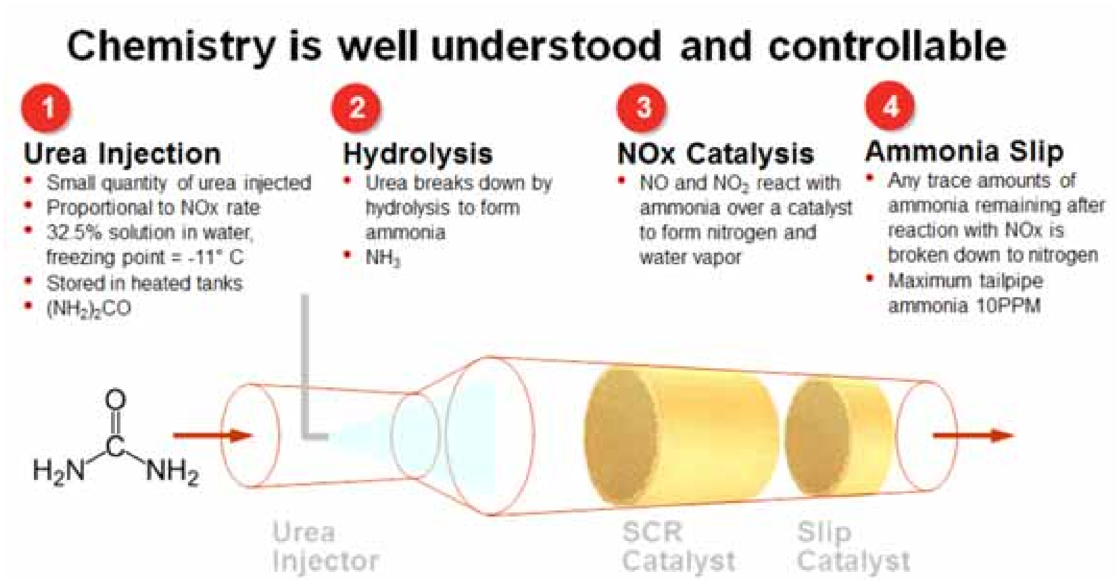
27

DOC &DPF – Operational Considerations

5K Hours

Rental Equipment Variety

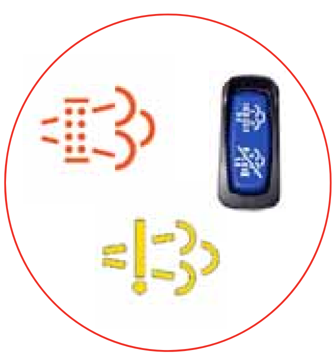
SCR – What is it?



29

2019 B6.7 Aftertreatment User Interface

- Cummins' 2019/2020 products will have optional operator interface to maintain the health of the aftertreatment system.
- Non-EGR+Throttles+Tuning Experience = Fit & Forget System

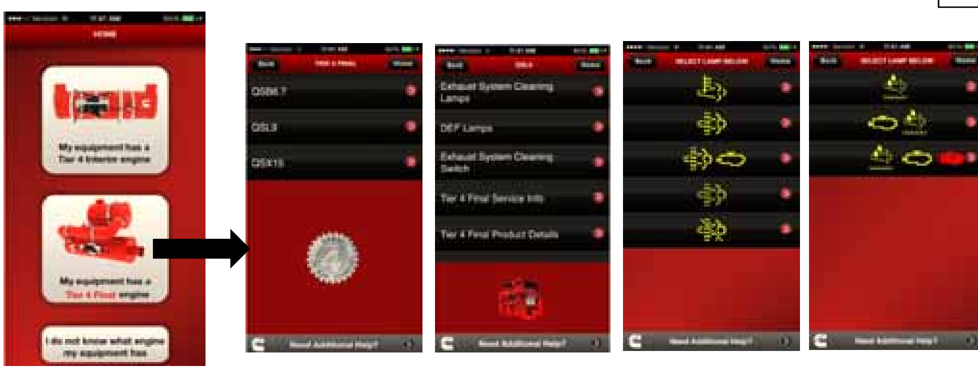


OR

30

Cummins Tier 4 Operator Support App

- Tier 4 information available for both Droid and Apple
- QR codes shipped with T4F engines for OEM placement



31

32

CATERPILLAR®

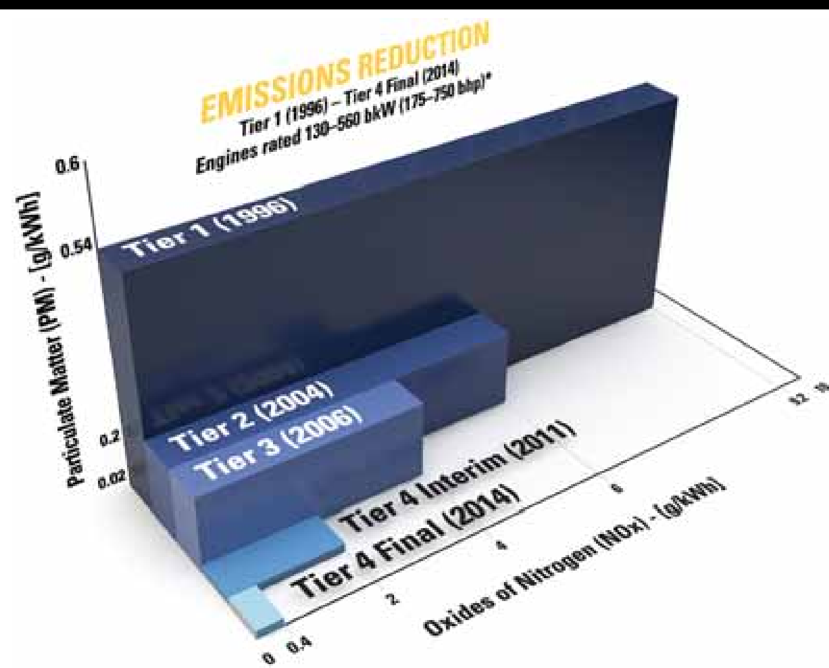
Tier 4 Final Equipment Use and Maintenance

George Lin

MDEC
October 3, 2017

U.S. EPA Nonroad Emissions Standards

CAT 2017-10-03



34

Aftertreament Configurations

CAT 2017-10-03

Engine Models	Power Category (kW)	Tier 4 Final NOx Limit g/(kW*hr)	Tier 4 Final PM Limit g/(kW*hr)	Aftertreatment		
C0.5 – C1.5	< 19	7.5 *	0.40	no aftertreatment		
C1.5 - C3.6	19 - 56	4.7	0.03	DOC	DPF	
C3.6 – C18	56 – 560	0.4	0.02	DOC	DPF	SCR
C18 – C32	> 560	3.5**	0.04**	DOC		
3500, C175						SCR

* NOx limit includes NMHC (non-methane hydrocarbons)

** Non-genset limit stated. Gensets >560kW have more stringent emission limits.

35

Aftertreatment Configurations

CAT 2017-10-03

Examples of engine + aftertreatment configurations:

C3.4

DOC+DPF

C4.4

DOC+DPF+SCR

C7.1

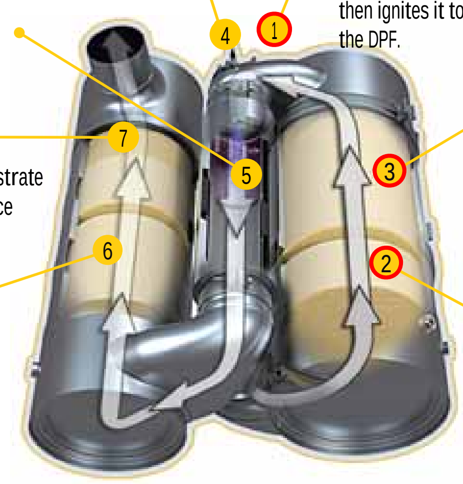
DOC+DPF+SCR

36

Cat Clean Emissions Module (CEM)

CAT 2017-10-03

C7.1 – C18 ACERT Engines



37

Diesel Oxidation Catalyst

CAT 2017-10-03

- The DOC reduces hydrocarbons (HC) and carbon monoxide (CO) into carbon dioxide (CO_2) and water (H_2O).
- Some PM is also oxidized in the process.

$$C_xH_y + O_2 \Rightarrow CO_2 + H_2O \quad (+\text{ Heat})$$

$$CO + O_2 \Rightarrow CO_2 \quad (+\text{ Heat})$$

38

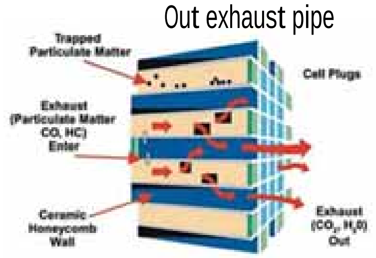
DPF & Regeneration

2017-10-03

- The DPF captures and holds particulate matter, a by-product of engine combustion.

$$C(s) + O_2 + (heat) \Rightarrow CO_2(g) + H_2O$$

Trapped in the DPF / In engine exhaust / From CRS / Out exhaust pipe



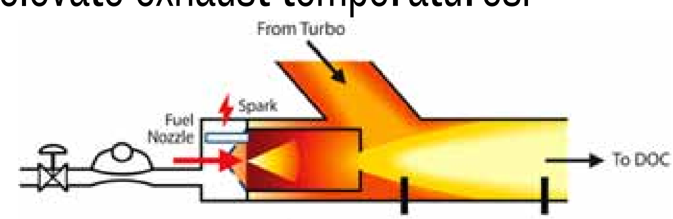
- DPF regeneration is the process of removing soot from the DPF, through oxidation.

39

DPF Regeneration

2017-10-03

- Two main classifications of Regeneration:
  - Passive Regeneration: Occurs at ~450˚C typically as a result of higher engine load.
    - All DPFs have some amount of passive regeneration.
  - Active Regeneration: System combusts air+fuel to elevate exhaust temperatures.



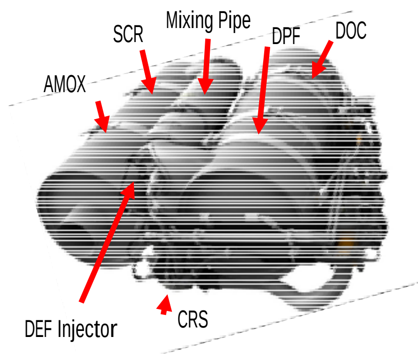
Combustion Air System

40

DPF Regeneration … cont'd

CAT 2017-10-03

- DOC/DPF solution
  - Enables passive regeneration in the C3.4B, C4.4 ACERT and C6.6 ACERT
- Cat Regeneration System (CRS)
  - Automatic active regeneration.
  - Provides precise measurement and control, minimizing fuel used during regeneration.
  - Provides excellent capability under low-load and cold-climates.
  - Maximizes machine uptime.



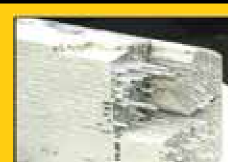
Clean Emissions Module with patented Cat Regeneration System (C7.1 ACERT – C18 ACERT)

41

ASH Cleaning

CAT 2017-10-03

- Ash is formed from lube oil additives that don't combust: sulfates, phosphates, and oxides of calcium, magnesium, and zinc.
- As ash builds up, exhaust backpressure increases and passive regeneration is reduced.
- Service is required to remove ash.
- U.S. EPA dictates cleaning intervals of no less than 3,000 hrs for <130kW, and 4,500 hrs for >130kW engines.



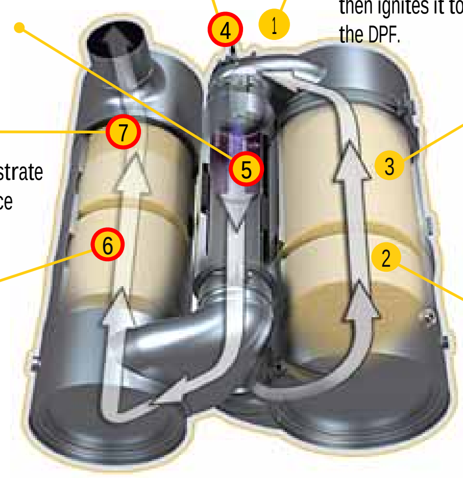
Ash Cleaning Tool

42

Cat Clean Emissions Module (CEM)

CAT 2017-10-03

C7.1 – C18 ACERT Engines



43

What are SCR and DEF?

CAT 2017-10-03

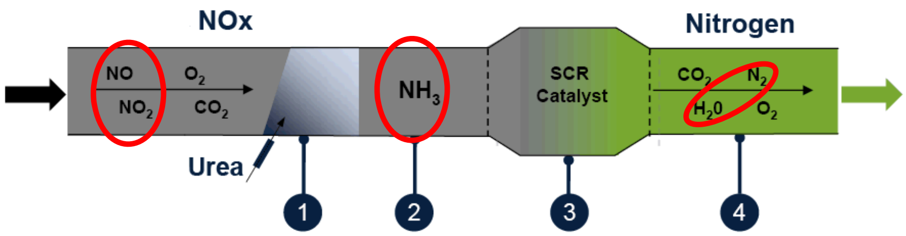
- Diesel Exhaust Fluid (DEF)
  - De-ionized Water (67.5 %) + urea (32.5%)
  - Meets ISO 22241
  - Used as reductant

- Selective Catalytic Reduction (SCR)
  - Selective: reductant reacts with NOx
  - Catalytic: assists in the chemical reaction
  - Reduction: NOx is reduced to Nitrogen (N_2)

44

SCR Chemical Reaction

2017-10-03



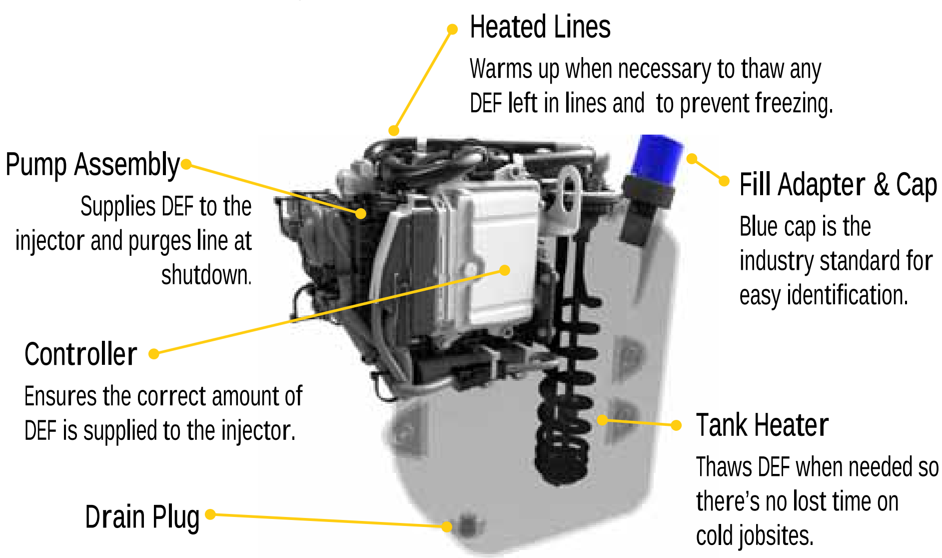
1. Injection of Urea into Exhaust Stream
2. Water evaporates and transforms urea to ammonia
3. NOx reduction when ammonia contacts SCR catalyst
4. Output of Nitrogen, N_2

45

Diesel Exhaust Fluid Pump & Tank

2017-10-03

C7.1 – C18 ACERT Engines



46

Operator Interface

CAT 2017-10-03

New Tier 4 Indicators & Features

- DEF Tank Level Gauge
- Automatic systems protect the engine
  - DEF Purge: to prevent lines from freezing
  - Delayed Engine Shutdown: Engine idles briefly after key off if cool-down needed
  - Wait to Disconnect Lamp: Illuminates until the product is ready for complete shutdown

Automatic emissions systems that simplify machine use and maintenance.

47

SRC/DEF Inducements

CAT 2017-10-03

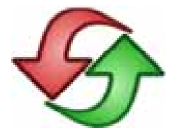
- What are "inducements"?
  - Features that encourage an operator to maintain the integrity of the emissions control system.
  - Includes visual and/or audible notifications, followed by engine derate.
  - Can culminate in engine shutdown if ignored.
- Causes of Inducement (Triggers)
  - DEF issues: Low level, Frozen, Poor quality, Dosing interruption
  - System tampering
  - Impeded EGR

48

SRC/DEF Inducement Override

CAT 2017-10-03

- To prevent (direct or indirect) loss of life, EPA allows inducements to be overridden in case of emergencies.
- Allows engine to operate for 120 hours.
- After the emergency is over, owners/operators must complete a form and request an override-reset by the engine manufacturer after each activation. (A lamp reminds the operator to reset the system.)
- In the U.S., manufacturers must send this information to EPA.



49

DEF Storage

CAT 2017-10-03

Follow recommended storage requirements.

Any commercial DEF meeting ISO 22241 specifications can be used.

Optimal temperature for storage is -10 °C to 25 °C.

Improper storage temperature and/or exposure to sunlight decreases shelf life.

Rate of decay significantly accelerates when stored in temperatures above 32 °C.

Freezes at -11 °C, but maintains the same concentration therefore DEF can be used when it’s partially thawed.

50

DEF Storage

CAT 2017-10-03

Improper storage reduces DEF shelf life; increases risk of contamination.

51

DEF Contamination Control

CAT 2017-10-03

Dirty jobsite conditions a reality; must clean around cap at refill.
Contaminated DEF may result in diagnostic fault codes or inducements.

These "before" pictures highlight just how dirty the area surrounding the blue DEF cap can become during normal operation.

That's why it is important to clean around the cap with every refill to avoid aftertreatment system component failures that result from

52

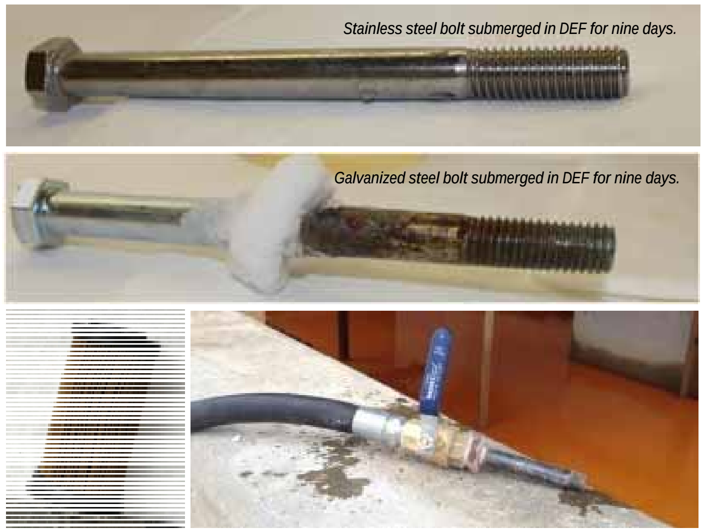
DEF Contamination Control

2017-10-03

Avoid internal contamination; use proper tooling and fittings.

DEF is a strong oxidizer. It is corrosive to many materials. Always use proper dispensing equipment & procedures to avoid contamination.

One incorrect fitting could potentially contaminate the entire DEF supply, possibly leading to emission system faults and engine shutdown.



53

Tier 4 Fuel and Oil Requirements

2017-10-03

1 Ultra Low Sulfur Diesel (ULSD) Fuel (15 ppm or less sulfur) for Tier 4

2 API CJ-4 (ECF-3) Low Ash Engine Oil

Biodiesel up to B20 can also be used when blended with ULSD.

54

Caterpillar Tier 4

CAT 2017-10-03

- 500M+ combined machine & engine hours
- 250,000+ Cat Tier 4 products in the field.

THANK-YOU

55

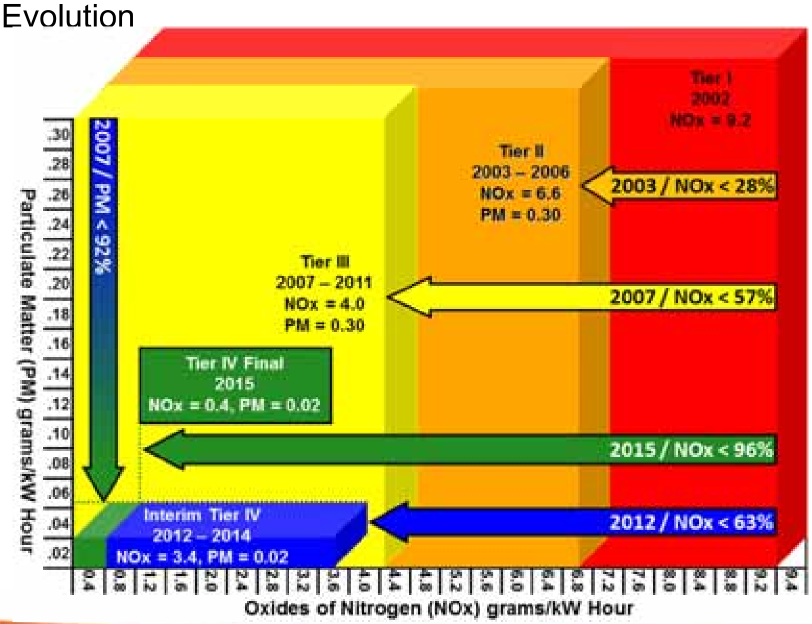
CAT 2017-10-03

56

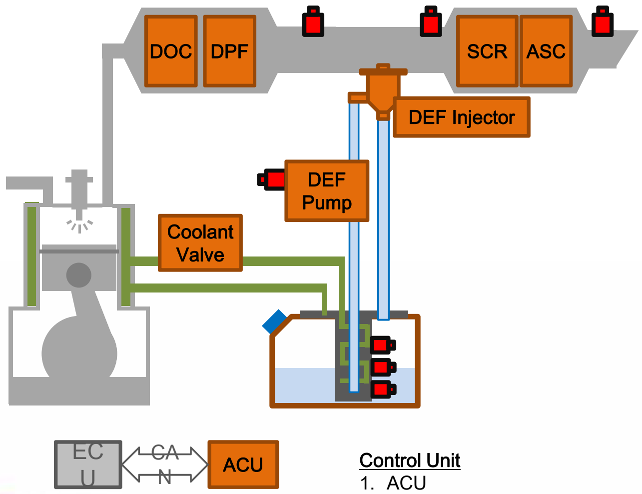
Tier 4 Final - SCR System

MDEC Workshop 2017
Service School Training

Emission Evolution



Tier 4 Components



Major Components

1. DOC
2. DPF
3. SCR catalyst
4. ASC
5. DEF Injector
6. DEF Pump
7. DEF Tank
8. Header Unit
9. DEF Tube (Suction)
10. DEF Tube (Delivery)
11. DEF Tube (Return)
12. Coolant Valve

Sensors

1. NOx (Pre)
2. NOx (Post)
3. SCR Inlet Temp.
4. DEF Tank Level
5. DEF Quality
6. DEF Temp.
7. DEF Pressure

Control Unit

1. ACU

Selective Catalyst Reduction (SCR)

- Oxides of Nitrogen (Nox) are controlled with SCR
- Ammonia Slip Catalyst (ASC) controls residual ammonia produced in operation of SCR

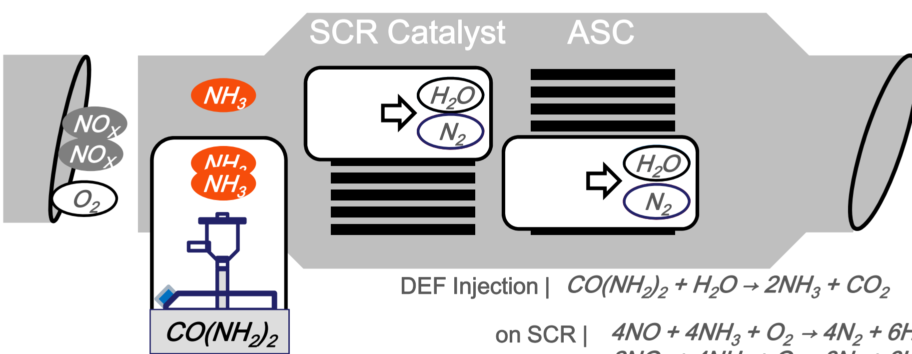
Selective Catalyst Reduction

Ammonia Slip Catalyst

Selective Catalyst Reduction

A1

SCR Chemical Process



DEF Injection | $CO(NH_2)_2 + H_2O \rightarrow 2NH_3 + CO_2$

on SCR | $4NO + 4NH_3 + O_2 \rightarrow 4N_2 + 6H_2O$
$2NO_2 + 4NH_3 + O_2 \rightarrow 3N_2 + 6H_2O$

on ASC | $4NH_3 + 3O_2 \rightarrow 2N_2 + 6H_2O$

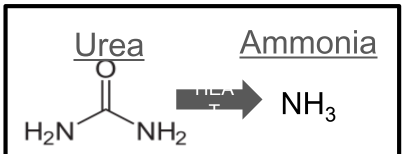
Slide 62

A1 Double check animation order from source files.

Audrey, 11/2/2015

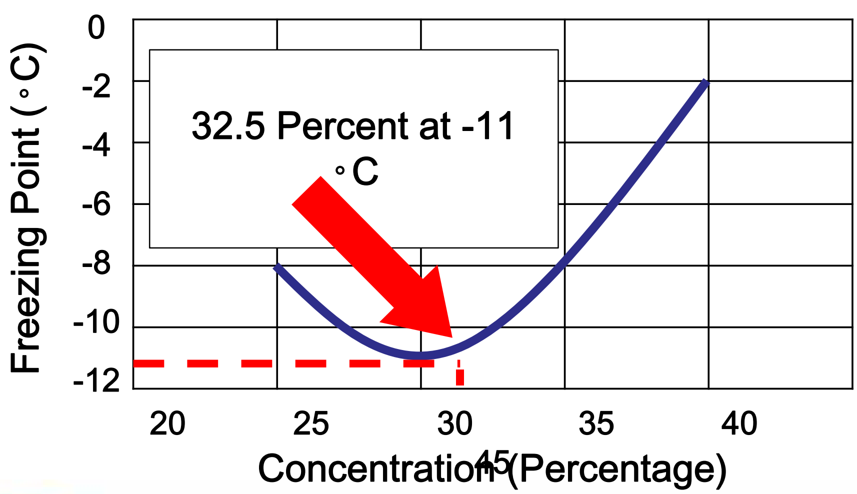
Diesel Exhaust Fluid (DEF)

- Diesel Exhaust Fluid (DEF)
  - ISO Standard 2224-1:2006
    - 32.5% Urea + 67.5% Deionized Water
      - Minimum Urea: 31.8%
      - Maximum Urea: 33.2%
  - Freezing/Melting Points:
    - Water (100%)
      - 32°F (0°C)
    - Urea (100%)
      - 271.4°F (133°C)
    - Urea/Water (32.5%/67.5%)
      - 12°F (-11°C)
  - WARNING: DEF is corrosive; immediately wash spilled DEF with water.
  - Required to meet ISO 22241



Heat changes urea into ammonia (NH_3)

DEF Concentration



DEF Safety – Eyes & Skin

Eyes:

Wear eye protection. If symptoms develop, move individual away from exposure and into fresh air. Flush eyes gently with water while holding eyelids apart. If symptoms persist or there is any visual difficulty, seek medical attention.

Skin:

Remove contaminated clothing. Wash exposed area with soap and water. If symptoms persist, seek medical attention. Launder clothing before reuse.

DEF Safety – Ingestion & Inhalation

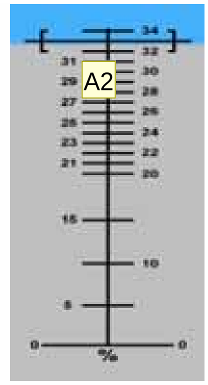
Ingestion

Seek medical attention. If individual is drowsy or unconscious, do not give anything by mouth; place individual on the left side with the head down. Contact a physician, medical facility, or poison control center for advice about whether to induce vomiting. If possible, do not leave individual unattended.

Inhalation

If symptoms develop, move individual away from exposure and into fresh air. If symptoms persist, seek medical attention. If breathing is difficult, administer oxygen. Keep person warm and quiet; seek immediate medical attention.

Testing DEF



A refractometer is used to measure DEF concentration level.

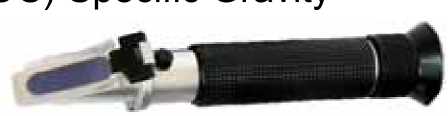
Testing DEF Refractometers

Measures Liquid Mixture Concentrations:

- Diesel Exhaust Fluid (DEF)
  - ✓ Urea / Water Ratio

Some combination tools can also test:

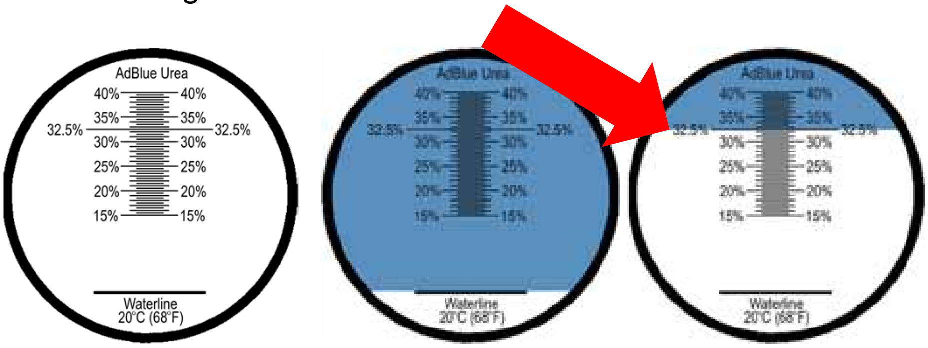
- Engine Coolant
  - ✓ Ethylene & Propylene Glycol
- Lead/Acid Battery
  - ✓ State of Charge (SOC) Specific Gravity



Slide 67

A2 Almon looking for new solution for this image (something more clear).
Audrey, 12/22/2015

Testing DEF - Reading a DEF Refractometer



No Liquid

Pure Distilled Water
(Calibration)

Diesel Exhaust Fluid (DEF) 32.5% Urea

The reading is made at the point where the shadow line crosses the scale.

DEF Storage
Time and Temperature

Storage Temperature	Storage Temperature	Shelf Life
50°F - 68°F	10°C - 20°C	24 Months
68°F - 86°F	20°C - 30°C	18 Months
86° F - 95°F	30° C - 35°C	12 Months
95° F - 104°F	35° C - 40°C	3 Months

* KBT KSOS Source

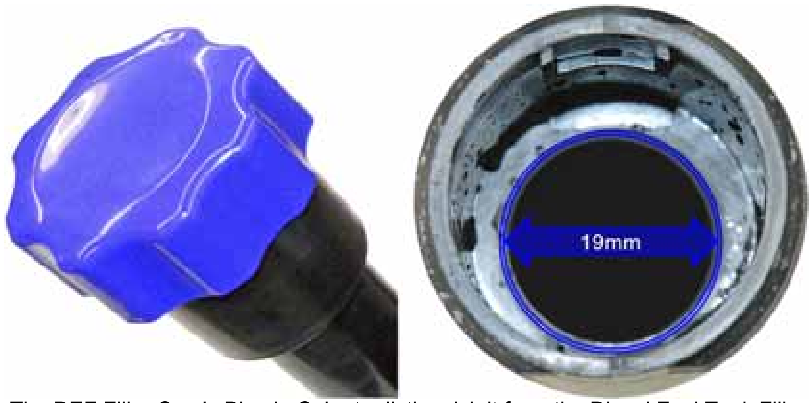
DEF Usage

Tank Type	Tank Type
Fuel Tank	340
DEF Tank	38

- 1 DEF refill for every 2 fuel refills
- DEF consumption is about 5 percent of the total fuel consumption

DEF Location

DEF Tank Assembly - Filler Cap & Filler Restriction

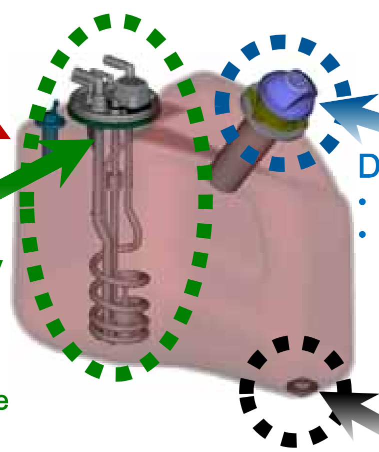


- The DEF Filler Cap is Blue in Color to distinguish it from the Diesel Fuel Tank Fill.
- At 19mm, the DEF Fill Pipe Restrictor is designed to minimize the chance of accidental DEF contamination with Diesel Fuel. (The diameter of a Diesel Fuel Nozzle is larger at 22mm.)
- For more information see ISO Standard: ISO 22241-4:2009

UNIVERSITY

DEF Tank Assembly - Purpose

DEF Tank:
- Stores DEF



DEF Tank:
- Filler Cap
- Filler Restriction

DEF Tank Assembly
- Measures:
  - DEF Level
  - DEF Quality
  - DEF Temperature
- Provides
  - Delivery & Return Connections
  - Heat Source

DEF Tank:
- DEF Drain

UNIVERSITY

DEF Tank Assembly - Location

DEF Tank Replacement Cost

1E506-19800	TANK ASSY DEF	$3,675.70

DEF Tank Assembly - Operation / DEF Flow

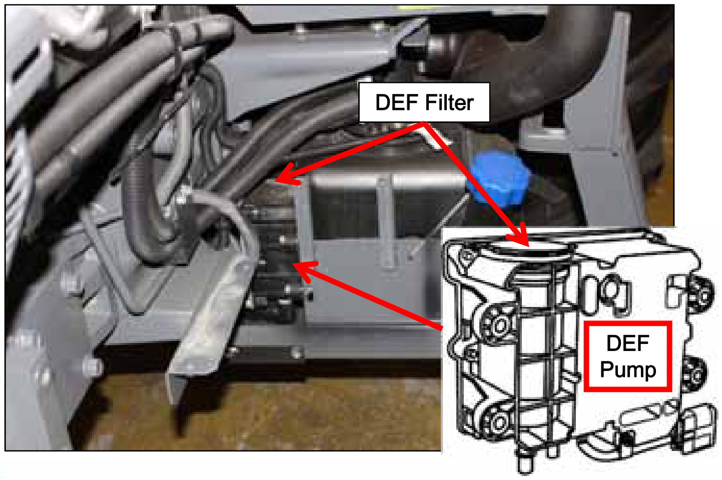
DEF Tank Assembly - Service / Urea Crystal Deposits

A few drop of water will completely remove any harmless Urea Crystal Deposits.

A4

DEF Pump Assembly

Location on M5 Tractor



DEF Pump Assembly

Location on M6 Tractor

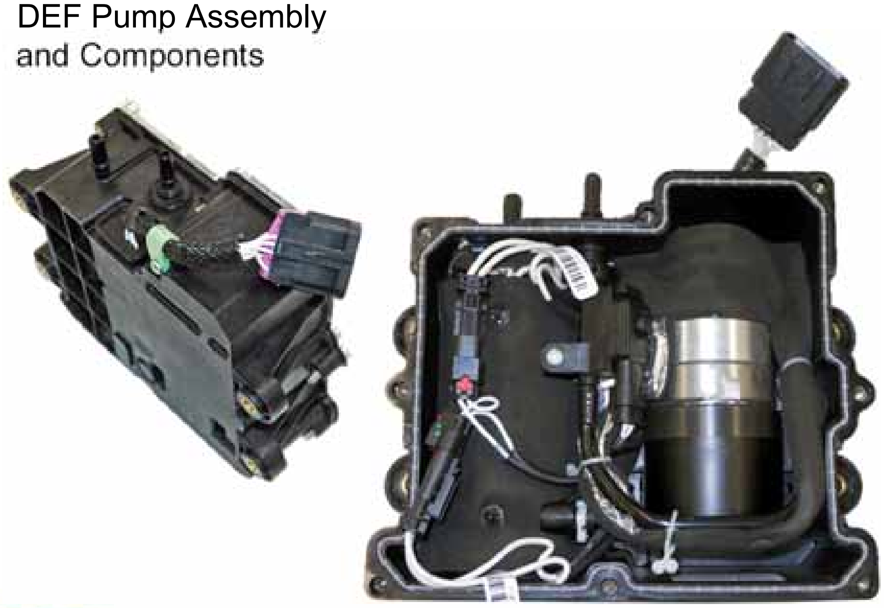
Slide 79

A4 Need to add when validated
Audrey, 11/5/2015

DEF Pump Assembly

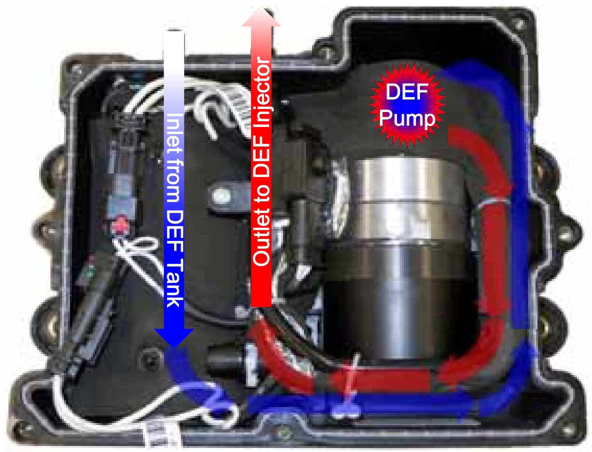
Location on M7 Tractor

DEF Pump Assembly
and Components



DEF Pump Assembly

Operation and DEF Circulation



DEF Pump Assembly

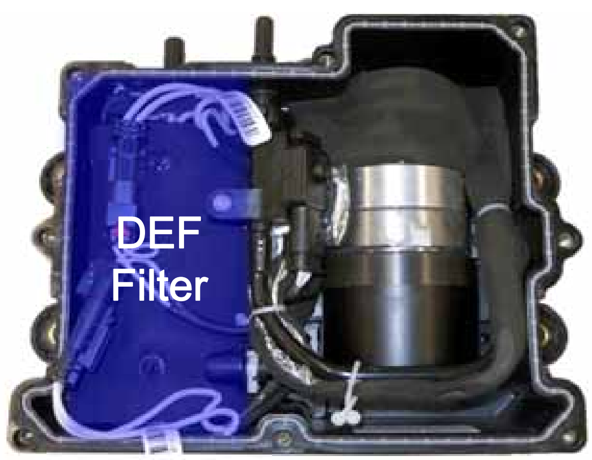
Operation and Reversible Pump

DEF Pump Assembly

Operation and DEF Pressure Sensor

DEF Pump Assembly

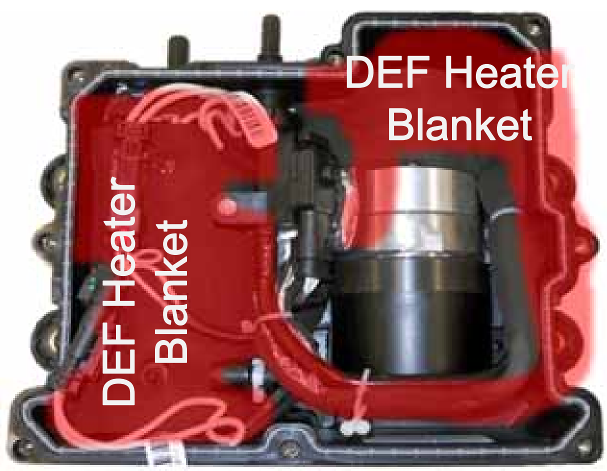
Operation and DEF Filter



DEF Filter Service

DEF Pump Assembly

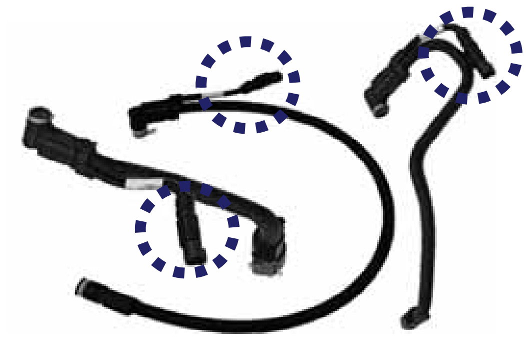
Operation and DEF Heater Blankets



DEF Electric Heating Elements

Components and Electrical Terminals

DEF Pump Assembly
Heating Elements



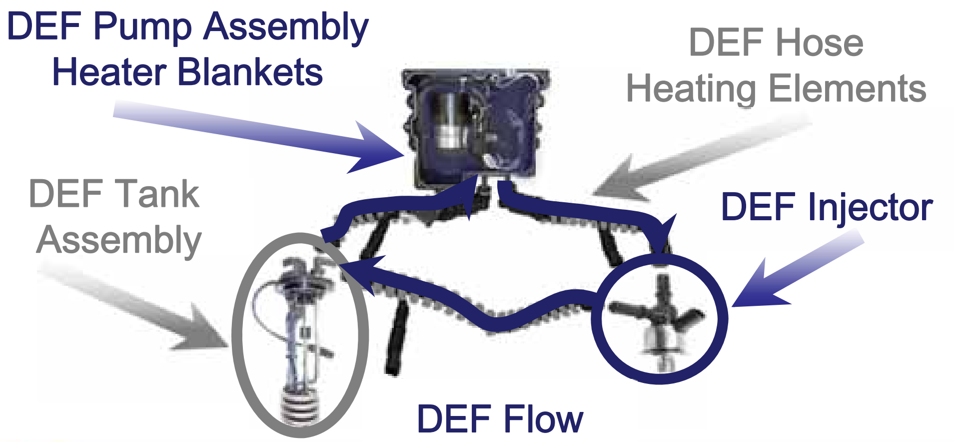
DEF Hose
Heating Elements

Cost to Replace DEF Pump

1J508-19653	PUMP ASSY	$2,699.00

DEF Electric Heating Elements

Locations



DEF Electric Heating Elements Control

Operation / Freeze Determination

Time

- After treatment Control Unit (ACU)
  - ✓ Within 2 Seconds of Engine Start

DEF Tank Temperature Sensor

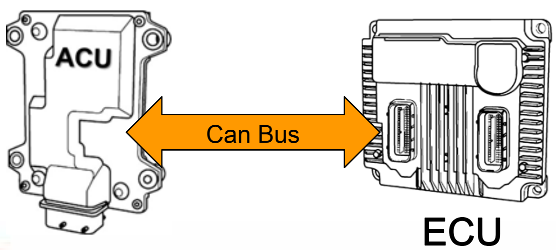
- After treatment Control Unit (ACU) Checks DEF temperature in the Tank Assembly

DEF Electric Heating Elements Control

Operation / Freeze Determination

Engine Intake Air Temperature

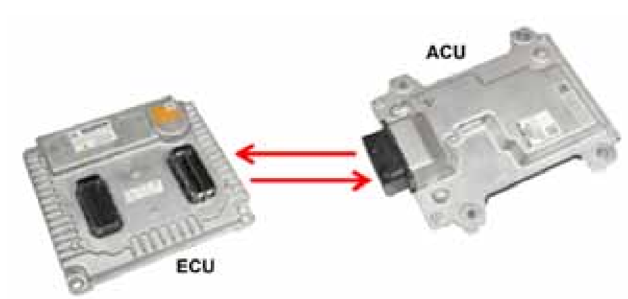
- Engine Control Unit (ECU) CAN Bus
  - ✓ Mass Air Flow (MAF) Sensor
    - Air Temperature Sensor



A5
A6
A7

- Replacement Cost for ECU and ACU

1H013-59090	ECU V38OEM	$2,094.60
1H010-60402	ECU ACUV38BB1	$2,365.20



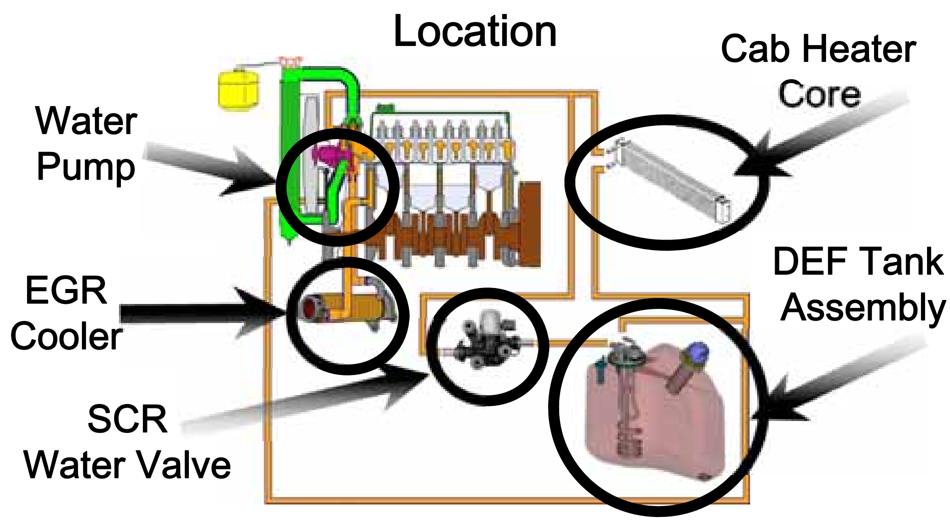
Slide 93

A5 Would like to get a new image of this.
Audrey, 11/9/2015

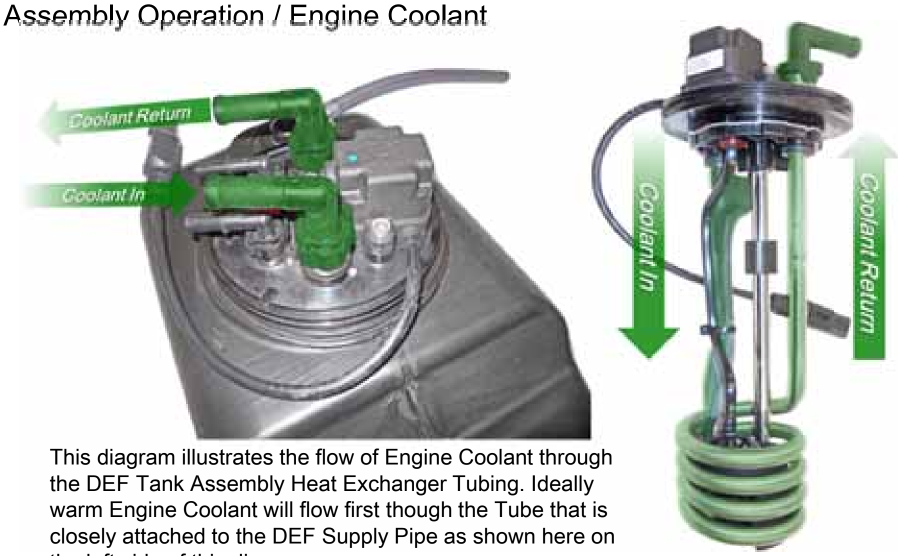
A6 (as this is not edit-friendly, as is)
Audrey, 11/9/2015

A7 These are still in .png format
Audrey, 11/9/2015

Selective Catalyst Water Valve



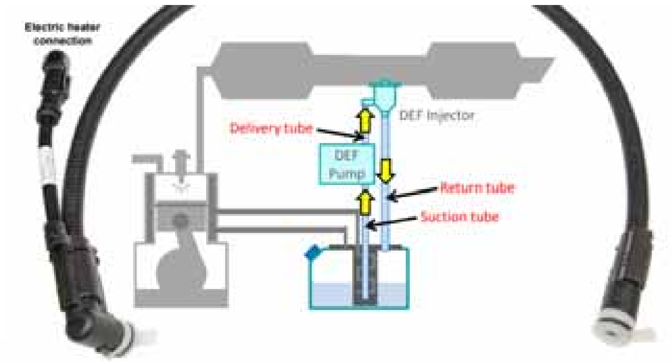
DEF Tank Assembly Operation / Engine Coolant



This diagram illustrates the flow of Engine Coolant through the DEF Tank Assembly Heat Exchanger Tubing. Ideally warm Engine Coolant will flow first though the Tube that is closely attached to the DEF Supply Pipe as shown here on the left side of this diagram.

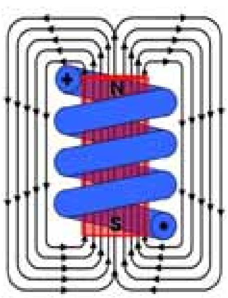
Replacement Cost of DEF Tubes

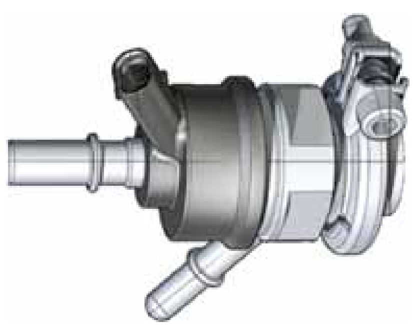
1J480-19910	TUBE ASSY DEF P	$367.60
1J480-19920	TUBE ASSY DEF R	$463.50

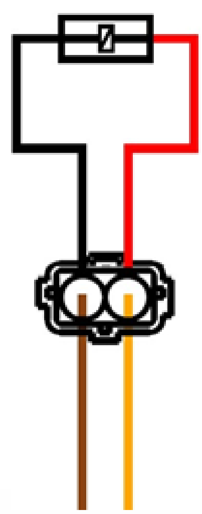


DEF Injector

Purpose

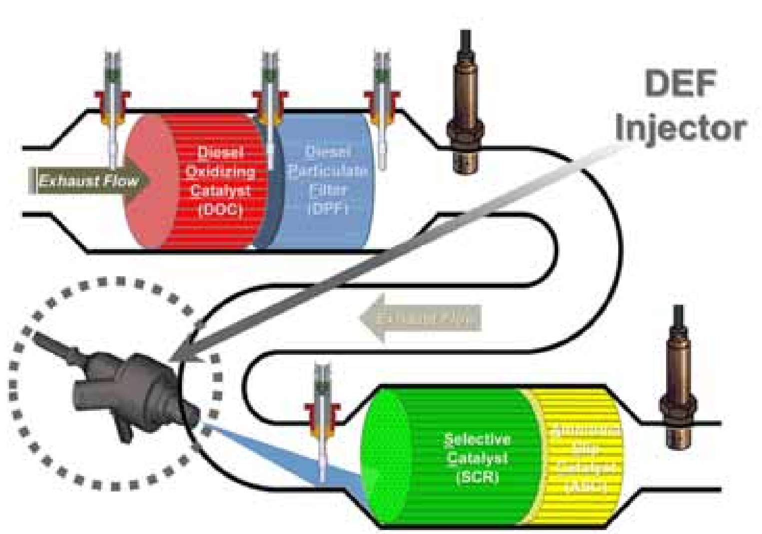






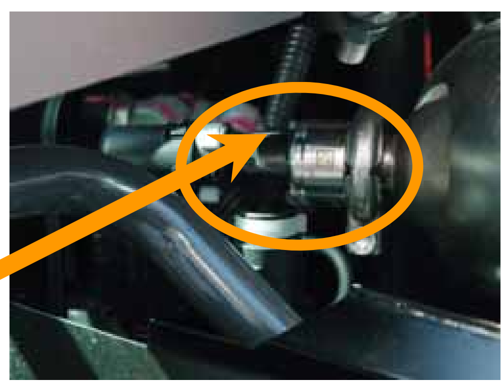
Electrical Resistance:
7.1 Ω (ohms)

Diesel Exhaust Fluid Injector - Location / System



DEF Injector

Location on M5 Tractor

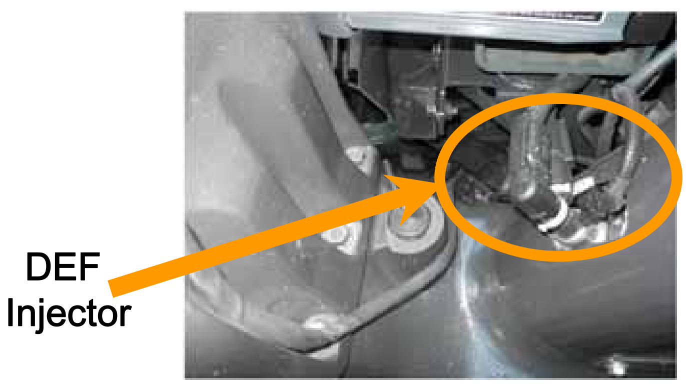


DEF
Injector

DEF Injector

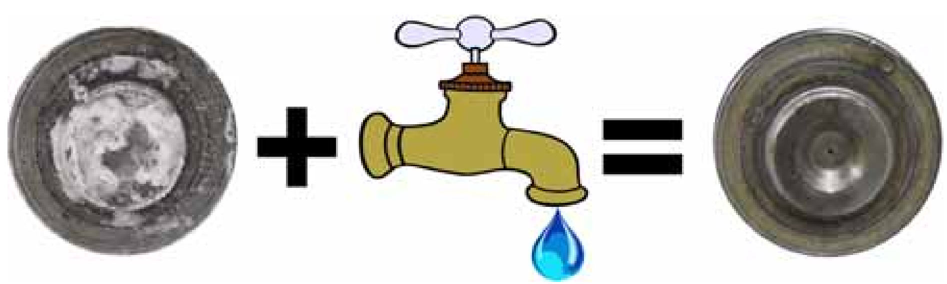
Location on M6 Tractor

DEF Injector - Location on M7 Tractor



Diesel Exhaust Fluid Injector Service / Urea Crystal Deposits

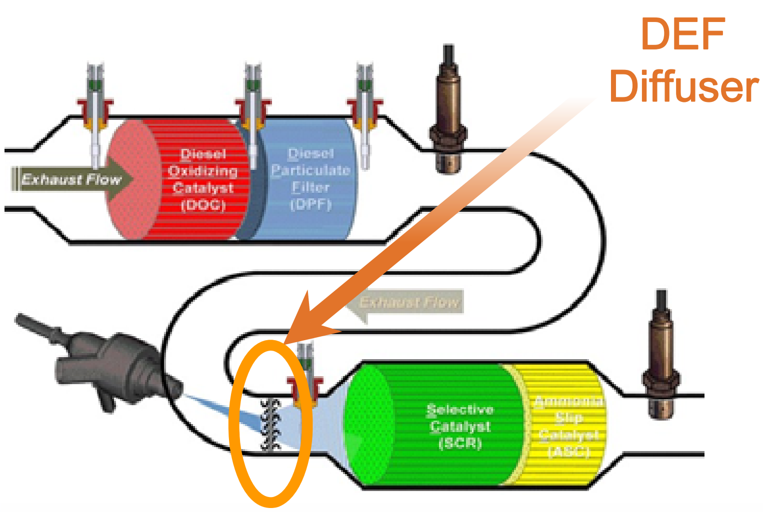
Diesel Exhaust Fluid Injector - Service / Urea Crystal Deposits



A few drops of water
Will completely remove
harmless Urea Crystals.

Diesel Exhaust Fluid Injector - “Injector Compensation (ACU)”

Diesel Exhaust Fluid Diffuser - Location / System



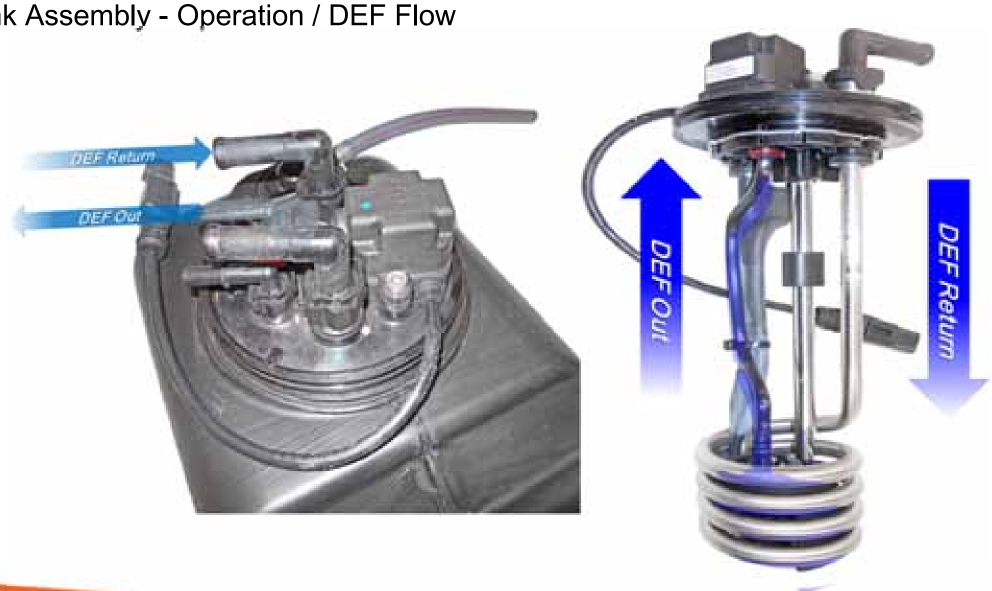
Replacement Cost of Sensors

1J508-19360	SENSOR NOX PRE	$1,402.70
1J508-19370	SENSOR NOX POST	$1,402.70

DEF Diffuser - Location on M5

Inside View
DEF Diffuser

DEF Tank Assembly - Operation / DEF Flow



DEF Tank Assembly - Operation / CAN Bus Electronics

DEF Warning System

DEF Warning System

All machines equipped with SCR must have DEF level indicator and warning system for the Operator Warning and Inducement system

- Panel displays and warning systems vary widely for different machines
- Typical warning system will work this way:

DEF tank 15% full:

- Operator's interface will display solid yellow symbol

DEF tank 5% full:

- Warning buzzer may sound intermittently
- Warns that system will soon reduce engine output
- Some machines may not have warning buzzer

ECU activates Inducement Level 1:

- Engine speed and torque reduced
- Yellow symbol flashes
- Malfunction Indicator Lamp lights

Before ECU activates Inducement Level 2:

- Flashing symbol turns red
- Warning buzzer may sound continuously

ECU activates Inducement Level 2:

- Engine speed reduced to idle
- Stop symbol lights

DEF tank must be refilled or fault corrected to cancel OWI and allow machine to operate normally

Kubota UNIVERSITY

DEF Tank Assembly - DEF Tank Level Sensor

Machine Operation	DEF Level			
	15% – 100%	5% - 15%	5% - 15% + 45 Minutes	0% - 5%
MIL	OFF	ON	ON	ON
DEF Lamp	OFF	ON	ON	ON
DEF LCD Displays	OFF	ON	ON	ON
DEF DTSC's	None	YES	YES	YES
DEF Pump	Normal	XXX	XXX	XXX
DEF Injector	Normal	XXX	XXX	XXX
Engine Power	OK	50% Torque	Idle Only	Idle Only
Engine RPM	OK	60% RPM	Idle Only	Idle Only

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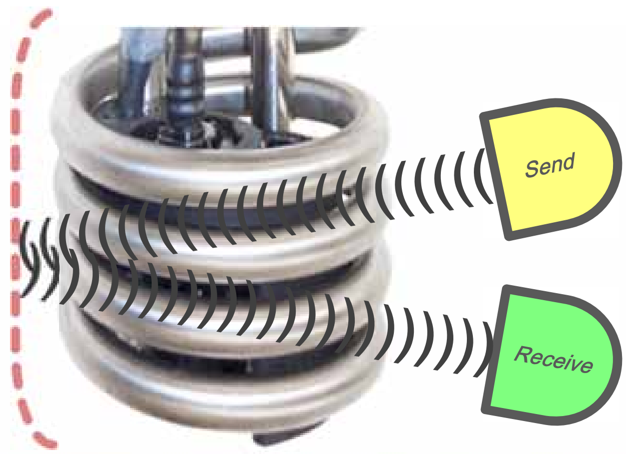
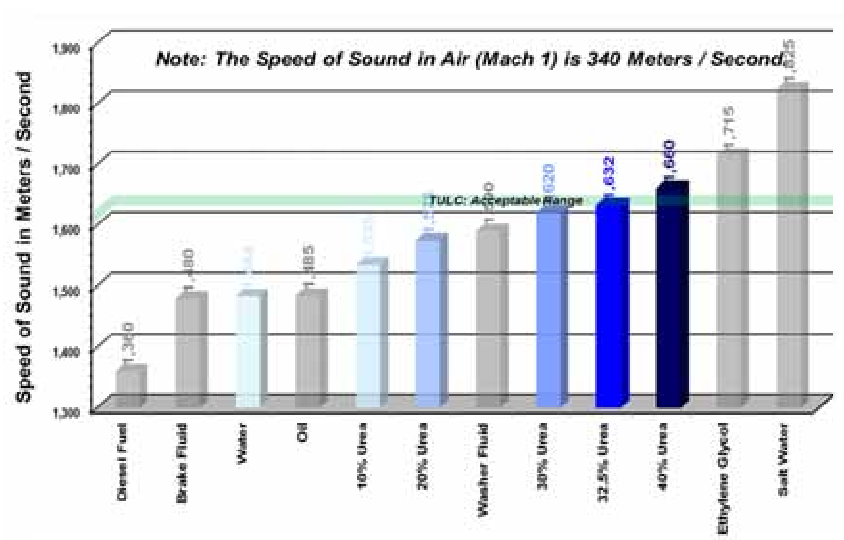
DEF Tank Assembly - DEF Tank Level Sensor

DEF Tank Assembly - DEF Quality and Temperature

DEF Tank Assembly - DEF Quality and Temperature



DEF Tank Assembly- DEF Quality and Contamination



DEF Tank Assembly - DEF Quality / TULC Sensor

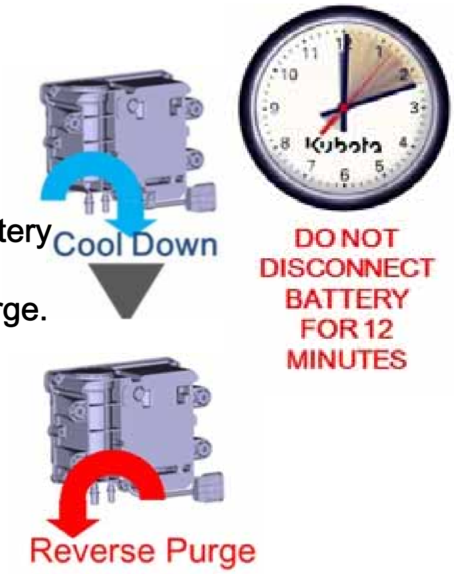
Machine Operation	Condition			
	Normal	Warning	De-Rate	Safe/Stop
Time	---	3 Hrs. 15 Min.	45 Min.	Over 4 Hours
MIL	OFF	XXX	XXX	XXX
DEF Lamp	OFF	ON	ON	ON
DEF LCD Displays	OFF	Time Remaining	Lv.1 + Time Remaining	Lv.2
DEF DTSC's	None	XXX	XXX	YES
DEF Pump	Normal	XXX	XXX	XXX
DEF Injector	Normal	XXX	XXX	XXX
Engine Power	OK	100% Torque	50% Torque	Idle Only
Engine RPM	OK	100% RPM	60% RPM	Idle Only

DEF Tank Assembly - Diagnostic Trouble Codes

P203A: Reductant Level Sensor "A" Circuit
P203B: Reductant Level Sensor "A" Circuit Range/Performance
P203C: Reductant Level Sensor "A" Circuit Low
P203D: Reductant Level Sensor "A" Circuit High
P203E: Reductant Level Sensor "A" Circuit Intermittent/Erratic
P203F: Reductant Level Too Low
P205A: Reductant Tank Temperature Sensor Circuit
P205B: Reductant Tank Temperature Sensor Circuit Range/Performance
P205C: Reductant Tank Temperature Sensor Circuit Low
P205D: Reductant Tank Temperature Sensor Circuit High
P205E: Reductant Tank Temperature Sensor Circuit Intermittent/Erratic
P206A: Reductant Quality Sensor
P206B: Reductant Quality Sensor Range/Performance
P206C: Reductant Quality Sensor Low
P206D: Reductant Quality Sensor High
P207F: Reductant Quality Performance
P209F: Reductant Tank Heater Control Performance
P20C9: Reductant Control Module Requested MIL Illumination
U010E: Lost Communication With Reductant Control Module

Engine Stop-Cool Down & DEF Purge

Warning - Do not disconnect battery for 12 minutes after shutdown to allow for cool down and DEF purge.



Test Your Knowledge

Question:

1. Why is it necessary for DEF pump to purge the lines?
2. How long should you wait before disconnecting the battery on T4 with SCR?
3. What CAN bus controller is responsible for SCR functions?
4. What should you used to clean crystallized urea from injector?

Answer:

1. To prevent DEF from freezing.
2. 12 minutes to allow complete purge of DEF from lines.
3. ACU – Aftertreatment Control Unit
4. Water

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Occupational Health Clinics for Ontario Workers Inc. (OHCOW).

Diesel emission reduction -

WHWB

So what is the big deal?

Organisation	Year	Comments
HEI[1]	1999	**Evidence not strong enough**
ACGIH[2]	2002	Recommended 0.02mg/m^3 (measured as REC)
ACGIH[2]	2003	Recommended limit withdrawn
MSHA[3]	2008	**Evidence becoming stronger -** Effective date for Occupational exposure limit (OEL) in the US for underground metal / non-metal 0.16mg/m^3 (TC) ~ 0.12 (REC)
IARC[1]	2012	**Strong evidence –** IARC monograph – confirmed carcinogen.
NCI / NIOSH[4]	2010 - 2013	Study findings support a much lower OEL which may have a significant impact on UG mining.
HEI[1]	2013	**Expert panel established**
HEI[1]	2014 6 March	Workshop held in Boston – open to public, academia, regulators , industry and engine manufacturers.
HEI[1]	Novembe	Expert panel review released. **Strong evidence!**

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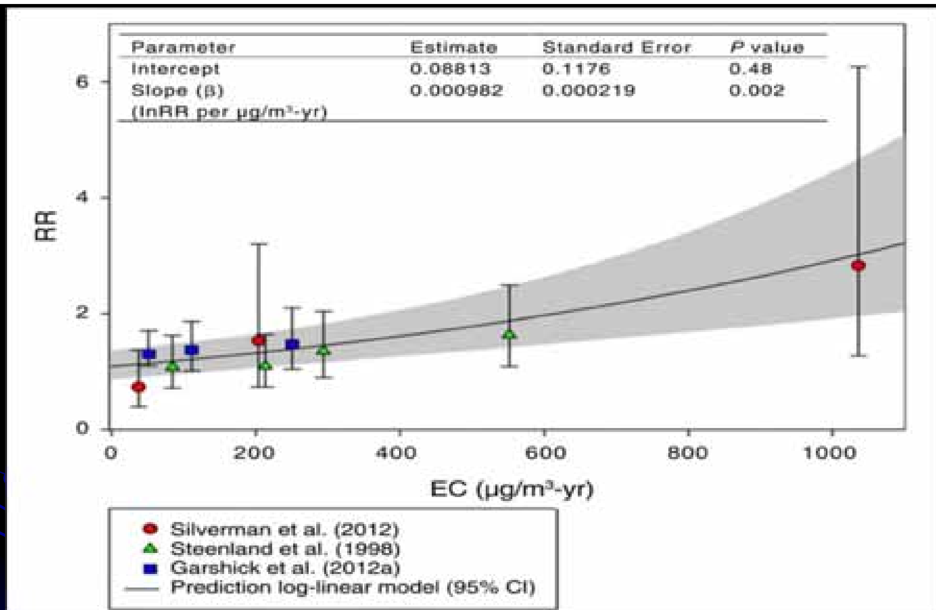

Relative risks were estimated using exposures lagged 15 years in Silverman et al. (2012) and 5 years in both the Garshick et al. (2012a and Steenland et al. (1998), based on the best model fit in each study. The authors presented sensitivity analyses to lag choices in supplemental material, available online. Elemental carbon was measured as REC in DEMS, as SEC in Garshick et al. (2012a), and as EC in Steenland et al. (1998). SOURCE: Vermeulen R, Silverman DT, Garshick E, Vlaanderen J, Portengen L, Steenland K. 2014b. Exposure–response estimates for diesel engine exhaust and lung cancer mortalitybased on data from three occupational cohorts. Environ Health Perspect 122:172–177. doi:

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Overall Panel Conclusions

- Both studies were well-designed and conducted according to high standards of epidemiological research.
- Both studies addressed many of the deficiencies that had limited earlier studies for quantitative risk assessment
- The results and data from both the Truckers and the DEMS can be usefully applied in quantitative risk assessments.
- The uncertainties within each study should be considered in deriving and characterizing an exposure-response relationship.
- The detailed evaluations of these studies by the HEI Panel and other analysts have laid the groundwork for a systematic characterization of the exposure-response relationship and associated uncertainties.

HEI

Courtesy of Katherine Walker Senior Scientist HEI

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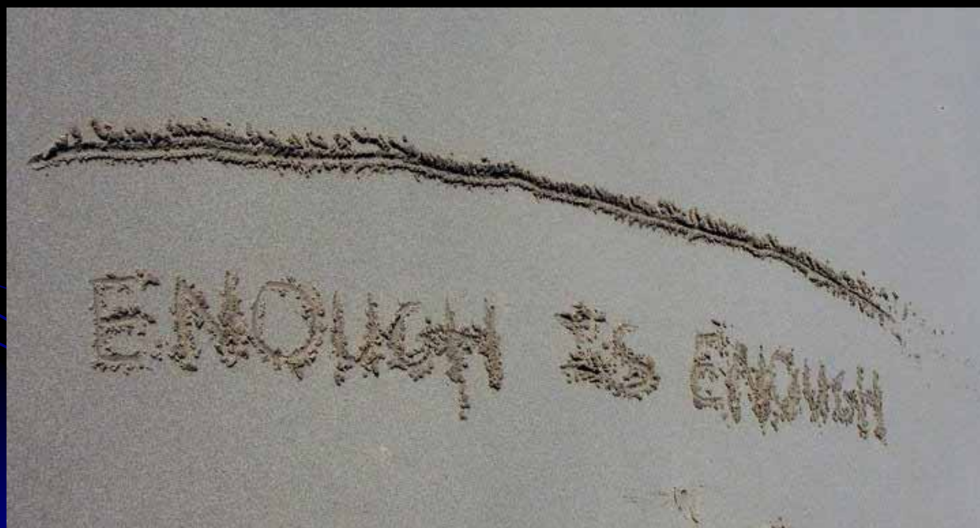
Health Canada (2016) – Human Health Risk Assessment for Diesel Exhaust

Health effects	Evidence
Lung cancer	**Sufficient**
Acute adverse r	**Sufficient**
Chronic advers s	**Sufficient**
Acute adverse c es	**Sufficient**
Immunological	**Sufficient**
Bladder cancer	Suggestive
Chronic adverse s	Suggestive
Reproductive and developmental effects	Suggestive
Central nervous system effects based on acute neurophysiological symptoms in overexposed workers	Suggestive

While safe levels of exposure promulgated as occupational exposure limits (OELs), are being discussed and debated, **it appears that previously acceptable OELs are no longer safe.**

Therefore it is important that the internal responsibility system be implemented and the precautionary principle approach be followed, especially as it may be some time before a suitably protective OEL specifically for diesel particulate matter (DPM) is promulgated.

There must be a line in the sand!



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Mining (differences between jurisdictions)

Canada	Early 1990's	1.5mg/m³
Ontario	2012	0.4mg/m³ TC equivalent to **0.31 EC**
MSHA American mines	2008	0.16mg/m³ TC equivalent to **~ 0.12 EC** (dividing TC by 1.3)
Australia		**0.1mg/m³ EC** (measured as submicron elemental carbon)

Note: Occupational Exposure Limit for Provinces in Canada are **3 X** US & Australia.

Is this acceptable?

Notes:

Newfoundland / Labrador is the same as ON
Quebec has changed from RCD to TC using NIOSH 5040 in early 2016 and reduced from 0.6 RCD to 0.4 TC in 2016.

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Dr. Rob McDonald VP Health and Hygiene, BHP Billition.

Australian Institute of Occupational Hygienists (AIOH), plenary December 2016.

- "Significant **lag** that exists between regulatory action and the level of science that informs health risk".
- "Should be managing exposure to diesel exhaust to as low as technically feasible".
- Interim target to be managing diesel exhaust to **0.03mg/m³** TWA 8-hrs measured as elemental carbon.

https://www.youtube.com/watch?v=n_iFh-BsECo&feature=youtu.be&a

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Plan

- Management Commitment?
- Hierarchy of Control (HOC) must also be utilised as part of planning i.e. deep mines!
- Limits?
- Emission based maintenance?
- Ventilation design?
- What actions will be carried out if limits are exceeded?

Do

- Procedures
- As part of procurement follow HOC
- Training
- Measure: raw exhaust, exposures, maintenance parameters.
- Emission based maintenance?

Check

- What are the trends for personal exposure monitoring and raw exhaust
- Benchmarking
- What are other operations doing?.

Adjust

- Maintenance
- After treatment devices
- Ventilation
- Work practices
- What actions will be carried out if limits are exceeded?

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Guidance

Guidance	Source	Link
MDG 29 Guideline - 2008	NSW DPI Australia	http://www.resourcesandenergy.nsw.gov.au/__data/assets/pdf_file/0011/419465/MDG-29.pdf
NIOSH – 2011	US NIOSH	https://www.cdc.gov/niosh/mining/works/coversheet748.html
Management Guideline - 2013	WA Australia	http://www.dmp.wa.gov.au/Documents/Safety/MSH_G_DieselEmissions.pdf
QGN 21 Guidance Note - 2014	Queensland Australia	https://www.dnrm.qld.gov.au/__data/assets/pdf_file/0019/240364/qld-guidance-note-21.pdf
WSN health effects of diesel exhaust in mines – June 2017	Ontario Canada	https://www.workplacesafetynorth.ca/news/news-post/health-effects-diesel-exhaust-mines
Occupational Cancer Research Centre – Controlling Diesel Particulate in Underground Mines – June 2017	**Canada**	**http://www.occupationalcancer.ca/2017/controlling-dpm-in-mining/**

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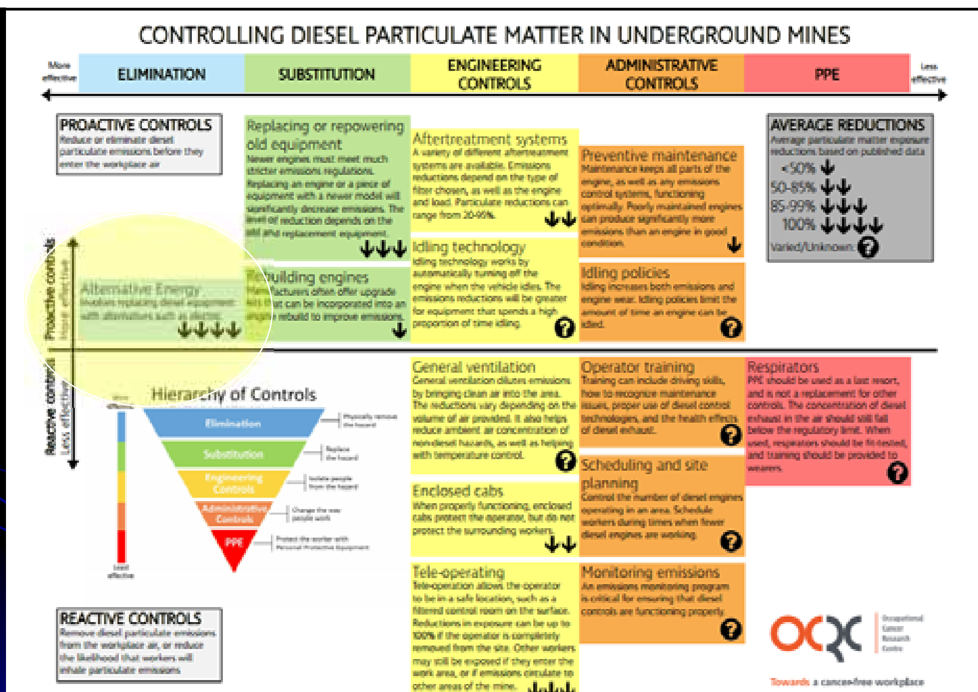
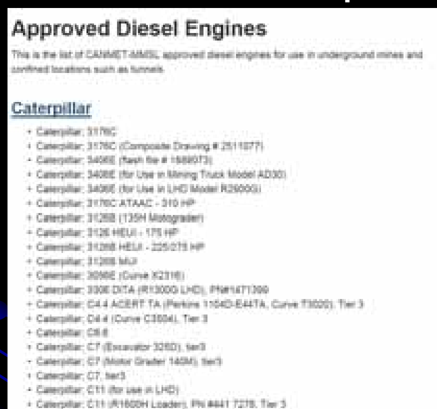


Reproduced with permission from OCRC

Plan
Is there adequate ventilation



https://www.nrcan.gc.ca/mining-materials/green-mining/approved-diesel-engines/8180

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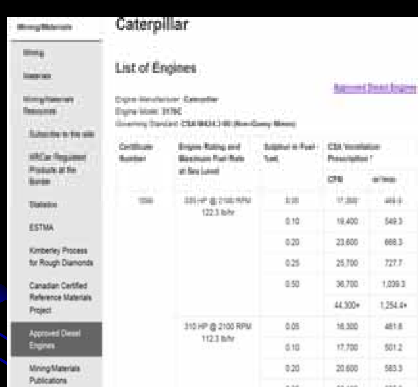
Plan
Is there adequate ventilation



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Plan

Is there a longer term strategy that aligns with the Hierarchy of Control

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GE and BHP Billiton announce global partnership to improve efficiency and reduce emissions in the mining sector

http://www.genewsroom.com/press-releases/ge-and-bhp-billiton-announce-global-partnership-improve-efficiency-and-reduce

Using battery powered vehicles ie. battery powered scoop used underground.
https://gereports.ca/breathing-easier-underground/

We have the technology!

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Must be action when line is crossed!

4.1 GASEOUS EXHAUST EMISSIONS

When tested in accordance with SECTION 5 *Monitoring of Diesel Engine Pollutants* the raw exhaust gas of the diesel engine shall;

a) not exceed the limits specified in *Table 3* below, and

b) be compared against the baseline limits as specified in *Table 4* below.

Description	CO (ppm)	NO (ppm)	NO_2 (ppm)	NO_x (ppm)
Type testing of new engines for unde[illegible] coal mines without methane injection[illegible]	[illegible]	900 (.09%)	100 (0.01%)	-
Type testing of new engines for unde[illegible] coal mines with methane injection[2]	[illegible]	900	100	1,000
In-service engines in underground co[illegible]	[illegible]	-	[illegible]	[illegible] (0.075%)
Engines in other underground environment	1,100	900	[illegible]	[illegible]

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Table 3 – Raw exhaust gas limits for diesel engines operating in underground environments

Notes:

1. Based on the coal legislation

ON Limit CO 600 ppm

In ON there is no requirement to measure NO, NO_2 , or NOx

"In NSW Australia Where **"failed"** - must be withdrawn from use underground"

Any engine which fails to meet the specified limits above must have the licensed laboratory report stamped with a 'FAIL' and must be withdrawn from use in the underground environment.

Source MDG 29 (2009) Guideline for the management of diesel pollutants underground.

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Nitrogen dioxide:

Caution there may be an **increase in nitrogen dioxide after installing a diesel oxidation catalyst (DOC)**.
NIOSH note

> " ***The concentration of nitrogen dioxide should also be monitored before and after the DOC. A history of this data should be stored to assess the activity of the DOC in increasing the concentration of this compound***".

NIOSH (2011): **Diesel Aerosols and Gases in Underground Mines: Guide to Exposure Assessment and Control**

See also MSHA: HEALTH HAZARD ALERT Underground Coal Mines Increased Nitrogen Dioxide (NO2) Emissions

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R.R.O. 1990, Reg. 854: MINES AND MINING PLANTS 183.1 (4)

The flow of air must reduce the concentration of toxic substances in diesel exhaust emissions to prevent exposure of a worker to a level in excess of the limits prescribed under section 4 of Regulation 833 of the Revised Regulations of Ontario, 1990 (Control of Exposure to Biological or Chemical Agents) made under the Act. O. Reg. 265/15, s. 11.

(5) The flow of air must,

(a) reduce the time-weighted average exposure of a worker to total carbon to not more than 0.4 milligrams per cubic metre of air; or

(b) reduce the time-weighted average exposure of a worker to elemental carbon, multiplied by 1.3, to not more than 0.4 milligrams per cubic metre of air.

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Occupational Cancer Research Centre (OCRC) (2017)

The Occupational Cancer Research Centre recommends reducing personal exposure to **0.02 mg/m^3** measured as elemental carbon.

More than a **10-fold reduction** from the current ON mining limit

Reg. 854: MINES AND MINING PLANTS 183.1 (4)

The current regulatory occupational exposure limit (OEL) does not offer an acceptable level of protection!

http://www.occupationalcancer.ca/2017/controlling-dpm-in-mining/

Think about the future!

Switzerland

Diesel engines used in new construction machines must comply with a Swiss particle number (PN) emission limit. The PN emission requirements ensures that all construction machines sold in Switzerland be fitted with diesel particulate filters.

https://www.dieselnet.com/standards/ch/

143

Mining (differences between jurisdictions)

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Québec	2003	0.6mg/m^3 RCD* **(This is coming down)**
Ontario	2012	0.4mg/m^3 TC equivalent to **0.31 EC**
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Note: Occupational Exposure Limit for Provinces in Canada are **3 X** US & Australia. **Is this acceptable?**

Notes:

Newfoundland / Labrador is the same as ON
Quebec plans to change from RCD to TC using NIOSH 5040 in early 2016 and reduce to 0.4 in early 2016.
Source Presentation by M Grenier NRC Canada (2014) adapted from CanmetMINING Report: CMIN-2015-2651-OA
https://www.workplacesafetynorth.ca/sites/default/files/resources/CanmetMINING%20-%20Diesel%20Particulate%20Matter%20in%20Mines.pdf

144

For Occupational / Industrial Hygienists

145

Need to understand what the exposures are by carrying out a baseline exposure assessment for diesel particulate matter (DPM) measured as total and elemental carbon.

146

NIOSH 5040

147

Measure nitrogen dioxide as well!

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SKC markets a passive sampler called the UMEx. http://www.skcltd.com/passive-samplers/9-uncategorised/270-umex-passive-samplers-3 and CASSEN offers analysis of these devices. http://www.cassen.ca/

The reported detection limit is 6 ppb for 8 hours.

Maxxam Laboratories has a passive environmental monitor http://maxxam.ca/services/air-services/passive-air-sampling-2 which is intended for 30 days exposure. The reported detection limit is 0.1 ppb for 30 days, which suggests a very similar detection limit for 8 hours.

(Courtesy John Petherick)

See Drager white paper

https://www.draeger.com/en-us_ca/Mining/Mine-Safety-No2-Limits

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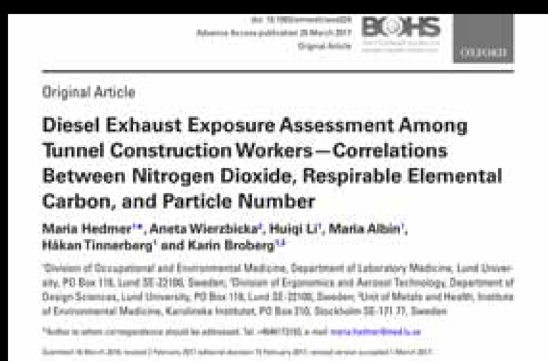


Original Article

Diesel Exhaust Exposure Assessment Among Tunnel Construction Workers—Correlations Between Nitrogen Dioxide, Respirable Elemental Carbon, and Particle Number

Maria Hedmer[1*], Aneta Wierzbicka[2], Huiqi Li[1], Maria Albin[1], Håkan Tinnerberg[1] and Karin Broberg[1,3]

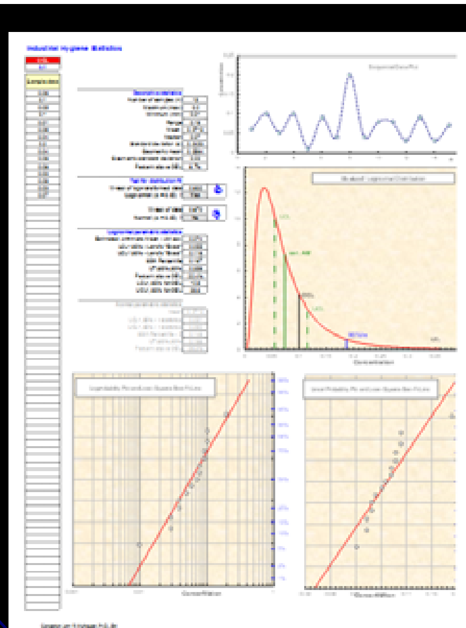
150

Carry out statistical analysis to understand exposure profiles, identify outliers and risk rank exposure groups to prioritize controls.

"Drill down" - clearly define similar exposure groups (SEGs).

Avoid pooling the data into a blancmange! YOU WILL GET FALSE READINGS

151



http://www.aiha.org/get-involved/VolunteerGroups/Pages/Exposure-Assessment-Strategies-Committee.aspx

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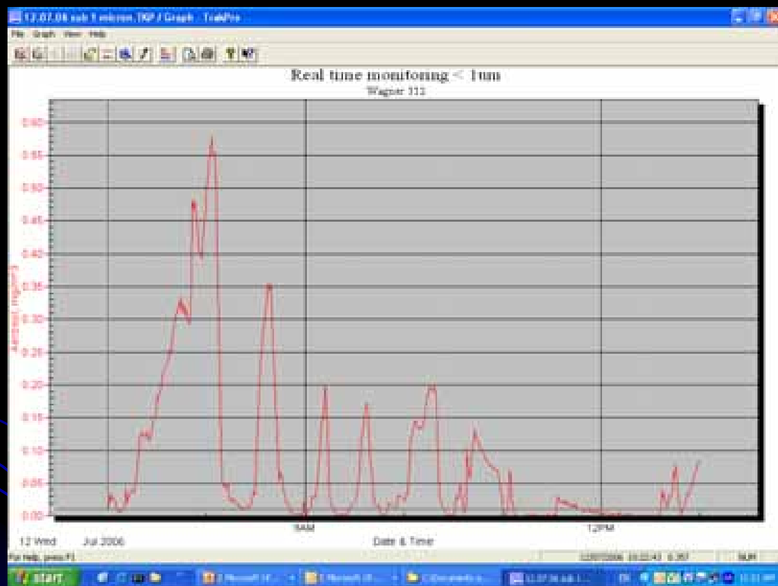
Carry out real time monitoring (inside cabin).



Average particulate matter 0.08 mg/m3.

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Examples of guidance / tools

Assessing acceptability of occupational exposures against occupational exposure limits

Agency	Tool
American Industrial Hygiene Association (Exposure Assessment Strategies Committee)	IHStat **https://www.aiha.org/get-involved/VolunteerGroups/Pages/Exposure-Assessment-Strategies-Committee.aspx**
British / Dutch Occupational Hygiene Society Sampling strategy guidance published in 2011 'Testing Compliance with OELs for Airborne Substances', BOHS/NVvA (Dutch occupational hygiene society) working group	BOHS / Dutch BWSatv2 **http://www.bohs.org/library/technical-publications/**
Australian Institute of Occupational Hygienists WES Adjustment tool for extended shifts	AIOH https://www.aioh.org.au/
University of Montreal NDExpo – Treatment of non-detects in industrial hygiene samples	University of Montreal http://www.dsest.umontreal.ca/recherche_rayonnement/NDExpo/nd7.htm

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Be careful!

Uncertainty must be considered.

- Speak with the laboratory - is the limit of quantitation going to be low enough?
- Is there a fixed ratio between elemental carbon and total carbon? What about below 0.05mg/m^3? (refer to a paper by Noll et al, 2015) http://www.ncbi.nlm.nih.gov/pubmed/25380085

(regulators take note!)

- Speak with the laboratory - is the limit of quantitation going to be low enough?
- What are the most sensitive methods to measure NO_2

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Risk management approach,

& apply:

Hierarchy of controls.

Must be explicit in legislation!

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- ✓ Nominate a champion.
- ✓ Establish a team.
- ✓ Measure the tail pipe emissions by carrying out a baseline assessment.
- ✓ Measure and monitor personal exposures.
- ✓ Ensure that there is an emissions based maintenance program.
- ✓ Have a short and longer term strategy.

Reduce / eliminate emissions from the engines!

Engage with experts:

Canadian resource: Sean McGinn
http://www.mknizdfactors.com

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Establish a diesel emission management program and nominate a champion.

Visibility to the highest level of management in a clear and concise way!

What gets measured gets noticed……what gets noticed gets action!

Engage all (at risk) workers & managers, across all Departments in raising awareness and management this important issue. Must be multi disciplinary and there is no silver bullet!

Develop performance measures!

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Can an exposure reduction (EC) be achieved in underground mining?

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What gets measured gets noticed, what gets noticed gets action:

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Australia Queensland Mines Inspectorate (QMI)

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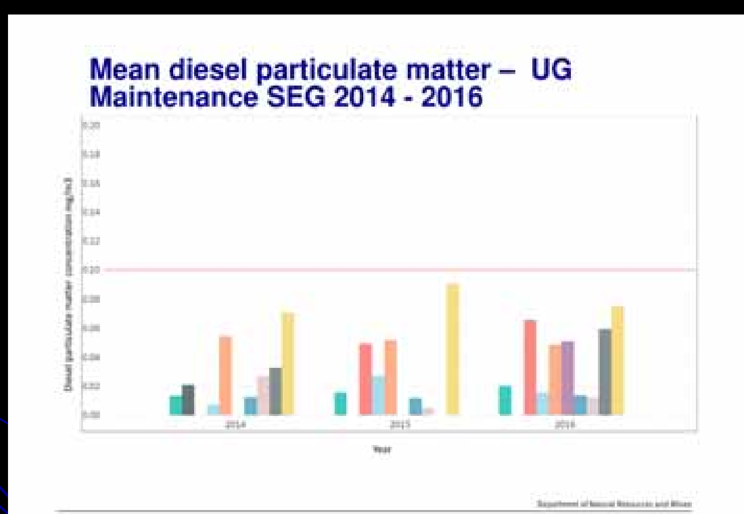
Australia Queensland Mines Inspectorate (QMI)



Courtesy of Fritz Djukic and Eliza Gill
Principal Occupational Hygienist | Mine Safety & Health Department of Natural Resources and Mines

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Diesel emission

- Causes harm – relatively high risk of lung cancer
- It can be measured
- Measurement is very important please measure.
- Hierarchy of control – eliminate if possible
- Benchmark
- Check current practices against good practices and improve

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Taking care of our future

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Every worker home safe and <u>HEALTHY</u> every day

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Resources

Information, research, and technology transfer:

Diesel technology forum
http://www.dieselforum.org/

Canadian Mining Industry Research Organization
Diesel Emission Evaluation Program
http://www.camiro.org/mining/diesel-emission-evaluation-program

The Australian Coal Industry's Research Program (ACARP)
http://www.acarp.com.au/

Centers for disease control and prevention (CDC / NIOSH)
http://www.cdc.gov/niosh/mining/topics/DieselExhaust.html

Mining Diesel Emissions Council (MDEC)
http://www.mdec.ca/

CanmetMINING, Natural Resources Canada
http://www.nrcan.gc.ca/mining-materials/green-mining/8178
http://www.nrcan.gc.ca/mining-materials/green-mining/approved-diesel-engines/8180

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Australian Institute of Occupational Hygienists (AIOH) Position paper on diesel particulate matter and occupational health issues
https://www.aioh.org.au/

Safe Work Australia
http://www.safeworkaustralia.gov.au/sites/swa/australian-strategy/vss/pages/dangers-diesel-exhaust-fumes-for-business
(there is a podcast!)

NSW Mine Design Guideline 29
http://www.resourcesandenergy.nsw.gov.au/__data/assets/pdf_file/0011/419465/MDG-29.pdf

Canada Mining Diesel Emissions Council (MDEC) http://www.mdec.ca/

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Tier IV and Advanced Mining Engine Technologies Finding Success – Avoiding Failure

Sean McGinn

MKNIZD | Factors

October 3rd, 2017

Overview

- Pitting Man vs Technology
- The On-Road Transition
- The Off-Road Transition
- Tier IV Mining Examples and Learnings
- Best Practices – Techniques and Tools
- Suggestions

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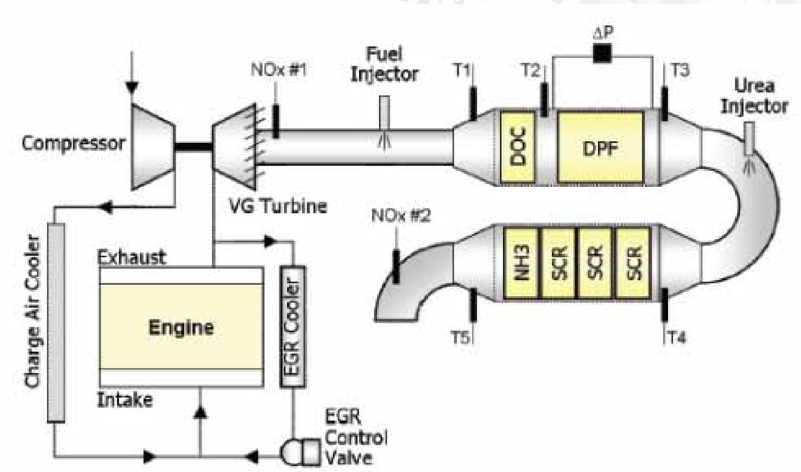
Pitting Man vs Technology



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Pitting Man vs Technology

- What once was is no more – fight or embrace it ?
- Cost !
- Time and Effort
- Reliability – availability, $/hr, life cycle, etc.
- Training and Tools
- Operation and override ability
- Change management

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On-Road Transition

- ~ 2010 for Class 8 highway tractors to Tier IV
- Resistance from industry "sky will fall"
- Glider kits – limits come into effect 2018
- Delete kits
- Majority today (actual rolling) are Tier IV engines
- Ongoing issues – urea quality, etc.

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On-Road Transition

Industry benchmark for rolling asset management

Emissions and GHG become a competitive advantage

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Off-Road Transition

Construction / Agriculture / Forestry

Since ~ 2014 with Tier IVi and Tier IV technology

Successfully adapted to change – very limited options

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Off-Road Transition

- Delete Kits
- Google “Diesel Emissions Delete Kits”
- Legal – until you get caught
- Federal / Provincial regulation and enforcement
- Example

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Tier IV Mining

Sandvik – Volvo TAD1361VE

SCR with no DPF Tier 4i

- Urea tank level and tank contamination (error codes)
- Idling and SCR plugging
- Urea freezing - cold weather shutdown procedure

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Tier IV Mining

Sandvik – Volvo TAD1361VE

Emissions results – baseline new

Test Location	Mean Value	Min. Value	Max. Value	Parameter Name
Outlet DOC	4	0	0	SMOKE
Outlet DOC	11	11	11.1	O2
Outlet DOC	17.1	15	20	CO
Outlet DOC	163	109	336	NO
Outlet DOC	2.2	1	5	NO2
Outlet DOC	7.3	7.3	7.3	CO2
Outlet DOC	357.4	336.7	374.4	T.GAS
Outlet DOC	165.2	110	341	NOx

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Tier IV Mining

Deutz TCD2013 L06

DPF / SCR Emissions Control

Adverse reaction to B50 – straight ULSD all good

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Tier IV Mining

Deutz TCD2013 L06

Emissions results ~ 1 year / 3000 hrs

LOCATION	AVG	MIN	MAX	PARAM
INLET	8	0	0	SMOKE
INLET	8.6	8.5	8.7	O2
INLET	52.9	49	64	CO
INLET	472.4	462	476	NO
INLET	33.3	30	37	NO2
INLET	9.1	9	9.2	CO2
INLET	709.3	693.5	722.9	T.GAS
INLET	32.1	30.4	33.8	MEQI
INLET	505.7	492	510	NOx
OUTLET	2	0	0	SMOKE
OUTLET	8.3	8.3	8.5	O2
OUTLET	0	0	0	CO
OUTLET	35.9	33	40	NO
OUTLET	1.5	1	3	NO2
OUTLET	9.3	9.2	9.3	CO2
OUTLET	533.8	531	543.2	T.GAS
OUTLET	1.9	1.7	2.6	MEQI
OUTLET	37.4	34	43	NOx

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Tier IV Mining

CAT – C4.4 Acert

DPF no SCR

- Adverse reaction to B50
- DPF plugging and soot sensor problems

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Tier IV Mining

CAT – C4.4 Acert

Emissions

- NO2 slip

LOCATION	AVG	MIN	MAX	PARAM
Inlet DPF	9	0	0	SMOKE
Inlet DPF	10.9	10.9	10.9	O2
Inlet DPF	227.2	223	232	CO
Inlet DPF	120.2	119	123	NO
Inlet DPF	39.9	39	40	NO2
Inlet DPF	7.4	7.4	7.4	CO2
Inlet DPF	537.7	536.1	539.7	T.GAS
Inlet DPF	27.2	27	27.3	MEQI
Inlet DPF	160.1	158	163	NOx
Outlet DPF	0	0	0	SMOKE
Outlet DPF	11	11	11	O2
Outlet DPF	0	0	0	CO
Outlet DPF	89	89	89	NO
Outlet DPF	81.3	80	82	NO2
Outlet DPF	7.3	7.3	7.3	CO2
Outlet DPF	521.6	521.6	521.6	T.GAS
Outlet DPF	30.7	30.2	30.9	MEQI
Outlet DPF	170.3	169	171	NOx

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Tier IV Mining

Kubota V3800-CR-TE4 Tier 4i

DPF no SCR

– Onboard manual regen functional

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Tier IV Mining

Kubota V3800-CR-TE4 Tier 4i

Emissions

– Very efficient and clean

– NO2 slip

Location	AVG	MIN	MAX	Param ID
Inlet DPF	7	0	0	SMOKE
Inlet DPF	12.3	12.2	12.4	O2
Inlet DPF	250.7	227	306	CO
Inlet DPF	219.4	201	234	NO
Inlet DPF	40.6	34	48	NO2
Inlet DPF	6.4	6.3	6.5	CO2
Inlet DPF	444.4	431.9	452.4	Tgas
Inlet DPF	32.3	29.8	36.3	MEQI
Inlet DPF	259.9	249	269	Nox
Outlet DPF	0	0	0	SMOKE
Outlet DPF	12.1	12.1	12.1	O2
Outlet DPF	0	0	0	CO
Outlet DPF	153.7	143	164	NO
Outlet DPF	110.6	108	112	NO2
Outlet DPF	6.5	6.5	6.5	CO2
Outlet DPF	309.7	303	324.5	Tgas
Outlet DPF	43	42.5	43.3	MEQI
Outlet DPF	264.2	255	272	Nox

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Tier III+ Mining

CAT R2900G – C15 VR Engine

Baseline Emissions

- Torque Stall 1950 rpm
- Boost 21 psi

PARA	UNIT	RPM	DUR	LOCATION	AVG	MIN	MAX
SMOKE	#	1950	0	Inlet DOC	6	0	0
O2	%	1950	0.5	Inlet DOC	11.6	11.6	11.6
CO	PPM	1950	0.5	Inlet DOC	83.8	76	105
NO	PPM	1950	0.5	Inlet DOC	434.2	423	446
NO2	PPM	1950	0.5	Inlet DOC	22.3	21	23
CO2	%	1950	0.5	Inlet DOC	6.9	6.9	6.9
Tgas	C	1950	0.5	Inlet DOC	388.1	379.2	395.2
Nox	PPM	1950	0.5	Inlet DOC	456.4	444	467
SMOKE	#	1950	0	Outlet DOC	5	0	0
O2	%	1950	0.5	Outlet DOC	13.2	13.2	13.2
CO	PPM	1950	0.5	Outlet DOC	36.2	34	39
NO	PPM	1950	0.5	Outlet DOC	366.9	355	377
NO2	PPM	1950	0.5	Outlet DOC	17.5	17	18
CO2	%	1950	0.5	Outlet DOC	5.7	5.7	5.7
Tgas	C	1950	0.5	Outlet DOC	372.7	364.6	379.2
Nox	PPM	1950	0.5	Outlet DOC	384.5	373	394

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Tier III+ Mining

CAT R2900G – C15 VR Engine

Life Cycle Emissions

- Torque Stall 1900 rpm
- Boost 15 psi
- No codes

PARA	UNIT	RPM	DUR	LOCATION	AVG	MIN	MAX
SMOKE	#	1900	0	Inlet DOC	9	0	0
O2	%	1900	0.5	Inlet DOC	8.8	8.8	8.9
CO	PPM	1900	0.5	Inlet DOC	285.6	283	289
NO	PPM	1900	0.5	Inlet DOC	533.5	515	544
NO2	PPM	1900	0.5	Inlet DOC	14.7	12	21
CO2	%	1900	0.5	Inlet DOC	8.9	8.9	8.9
Tgas	C	1900	0.5	Inlet DOC	497.2	486.3	506.5
MEQI	INDEX	1900	0.5	Inlet DOC	37.7	37	39
NOx	PPM	1900	0.5	Inlet DOC	548.1	535	556
O2	%	1900	0.5	Outlet DOC	11.4	11.3	11.4
CO	PPM	1900	0.5	Outlet DOC	32.8	32	35
NO	PPM	1900	0.5	Outlet DOC	407.3	406	415
NO2	PPM	1900	0.5	Outlet DOC	29.9	29	31
CO2	%	1900	0.5	Outlet DOC	7	7	7.1
Tgas	C	1900	0.5	Outlet DOC	389.5	367.1	405.9
MEQI	INDEX	1900	0.5	Outlet DOC	27.6	27.2	28.2
NOx	PPM	1900	0.5	Outlet DOC	437.3	435	446

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Tier III+ Retrofit DPFs

- Measurement systems in place to manage existing
- Essential – baseline performance optimum target
- Success / failure margin is very slim

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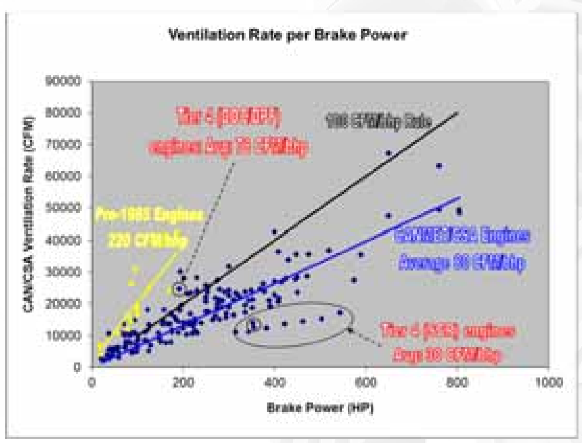
Best Practices

Use all available tools for selecting **your** engine technology



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Source: Brent Rubeli, NRCan CANMET

Best Practices

- Education and Training
- Know how to measure (emissions, pressures, temps, etc.)
- Ensure people can measure – interpret – make decisions

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Best Practices

The mining engine technology curve

- You can be ….
  - Behind it
  - On it
  - Ahead of it
- Just be open and honest about it and be the best you can possibly be for where you are at

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Suggestions

- Management of Change (MOC) … analyse the risk!
- Organizational attitudes … embrace change management
- Celebrate your wins and learn from your losses …. You will have plenty of both with advanced engine technologies in mining

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Challenges in and solutions to measurement of DPM at low concentrations

Erkki Lamminen, Ville Niemelä
Dekati Ltd.

DEKATI

Contents

- Introduction
- Measurement of DPM at low concentrations according to current standards & legislation – lessons from on-road vehicle measurements
- ISO 8178:2017 Vs. ISO 8178:2006 - PM
- What can be done to easily improve quality of filter measurements
- ISO 8178:2017 - PN
- Example of mining vehicle emission measurement directly from tailpipe

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Introduction

- Tailpipe DPM concentrations have been drastically reduced due to development of engine and aftertreatment technology
- This development presents new challenges for measurement technologies that are used to assess emissions from diesel powered vehicles
- It also presents a challenge for understanding what different measurement technologies actually measure and how results should be interpreted

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Measurement of DPM at low concentrations according to current standards & legislation – lessons from on-road vehicle measurements

- CRC project No. E-99: phase 2, Kent Johnson et al., U of California Riverside (from 27th CRC real world emissions workshop)
  - Partial flow dilution systems and exhaust flow meters work very well in terms of matching flows with full flow CVS systems
  - Transfer line effect on measurement results need to be investigated further
- Investigation of Alternative Metrics to Quantify PM Mass Emissions from Light-Duty Vehicles, Heejung Jung et.al. U of California Riverside (from 26th CRC real world emissions workshop)
  - Cycle dependency between alternative metrics and gravimetric mass attributed to greater sensitivity of gravimetric measurement to organic and semi-volatile PM collection compared to alternative metrics
- Comparison of aerosol instruments and regulated measurements, Matti Mariq et al., Ford Motor Company (from 26th CRC real world emissions workshop)
  - Filter artifact affects correlations at low concentrations (below 3mg/mi)
  - For GDI and PFI vehicles, DMM and EEPS instruments can provide good correlations with both particulate mass and number

DEKATI

ISO 8178:2017 Vs. ISO 8178:2006 - PM

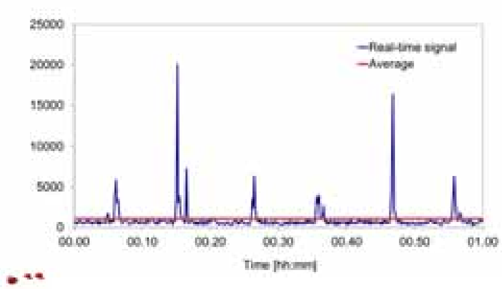
- Pre-classifier allowed
- 99.7% efficiency
- 47C +/- 5C everywhere 20cm upstream and downstream of filter media
- 0.9 -1 m/s filter face velocity
- Weighing room
  - 22 +/-1 C room temperature
  - 9.5 +/-1 C dew point
- Balance
  - Resolution 0.5 µg, repeatability 0.5 µg
  - Zero span and reference verifications within 12 hours of weighing
- Detailed instructions for avoiding static electricity effects
- Buoyancy correction
- Calibration procedures 54 pages
  - Including balance calibration

- No pre-classifier
- 95-99% efficiency, back up filters may be used
- 47C +/- 5C immediately upstream of filter holder
- 0.35-1 m/s filter face velocity
- Weighing room
  - 22 +/-3 C room temperature
  - 9.5 +/-3 C dew point
- Balance
  - Resolution 1 µg, Precision 2 µg
  - No calibration procedure
- Loose instructions to avoid static electricity effects
- No buoyancy correction
- Calibration procedures 17 pages
  - No balance calibration

DEKATI

Dekati® eFilter™

- Standard gravimetric PM filter holder
- Real-time measurement of PM accumulation on the filter
- Both standard and gravimetric measurements integrated in one instrument
- Fully automated operation



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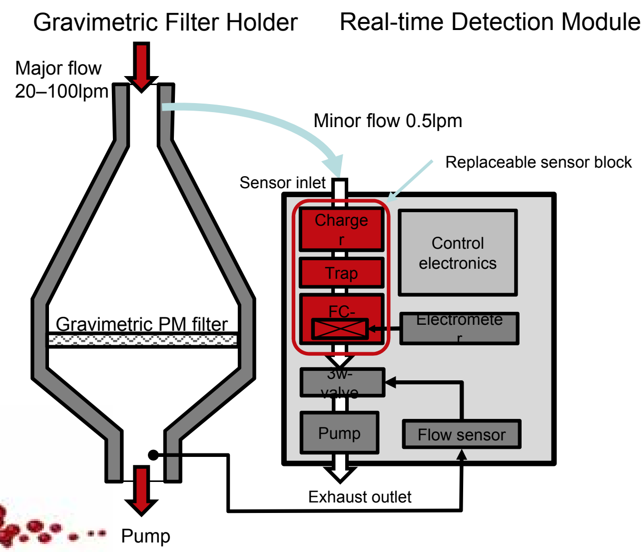
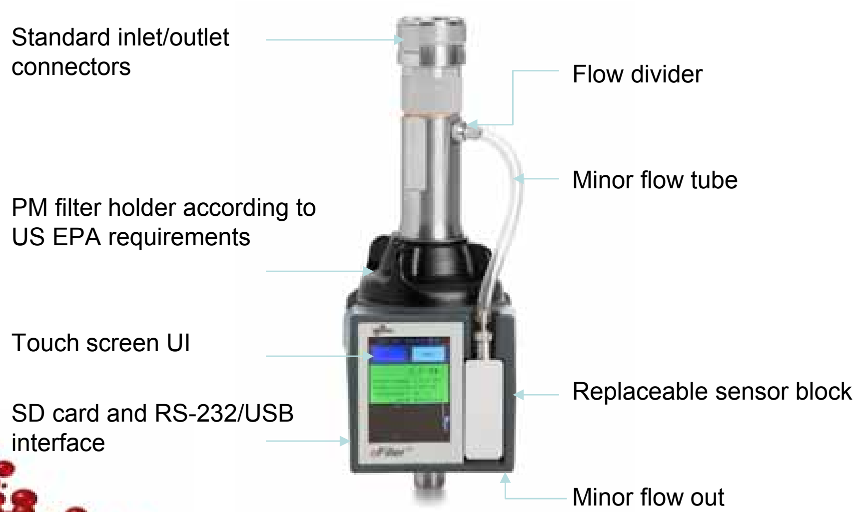
Dekati® eFilter™ Operation



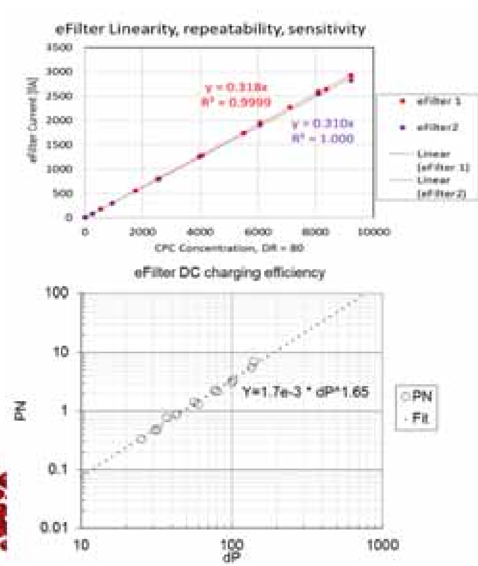
Dekati® eFilter™ Design

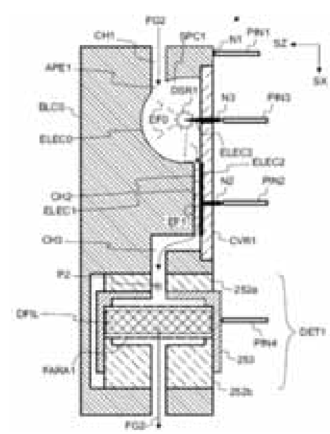


Dekati® eFilter™: Real-time Sensor

- Includes:
  - Diffusion charger with trap
  - Electrometer for real-time electrical detection of particles
- Saving interval 1s
- Separate pump is used for real-time detection
- Measurement starts when major flow is switched ON
- Does NOT affect gravimetric filter sampling

Miniature Diffusion Charger: Construction, Linearity and Calibration





Patents pending

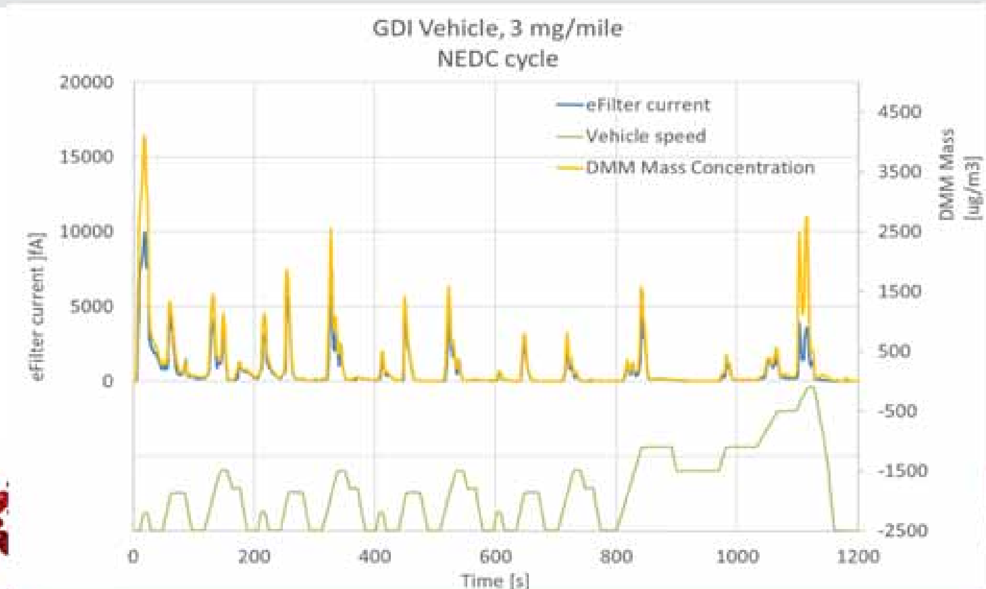
Dekati® eFilter™ Features

- Gravimetric PM filter holder that meets US EPA requirements
  - Compatible with existing filter holders and sampling systems
- Unaffected gravimetric PM measurement result
  - Total particle mass
- Electrical current from the diffusion charger electrometer
  - Fast response second-by-second data
- Real-time data benefits:
  - Repeatable
  - Sensitive
  - Detects DPF regeneration events and other anomalies
  - Real-time signal is more repeable than gravimetric PM result, therefore it can also be used for PM measurement quality control

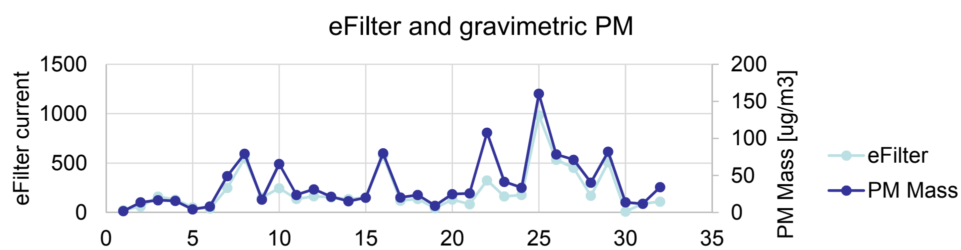
Vehicle Test Information

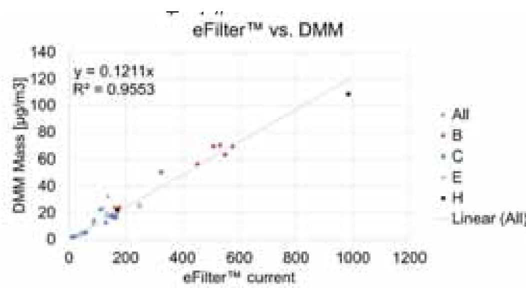
- Total of 88 test cycles at Ford RIC:
  - 10 * EPA75
  - 40 * US06
  - 4 * 4BagFTP
  - 34 * NEDC
- 8 different gasoline vehicles: 7 GTDI, 1 PFI ranging from about 0.1 to 5 mg/mile
- HF47 and room temperature sampling from CVS tunnel
- Instruments: Dekati® eFilter™, Dekati® DMM-230, Gravimetric PM measurement, AVL CPC, AVL MSS, TSI EEPS

Vehicle Tests: Example Data

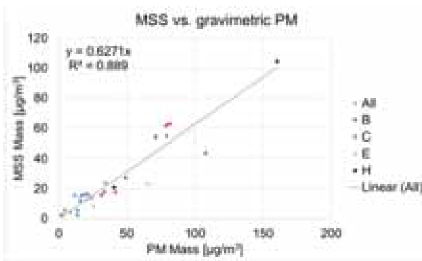


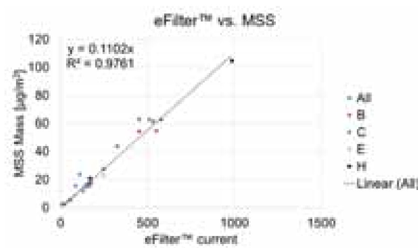
Vehicle tests: Stability and Correlation to Other Instruments, NEDC

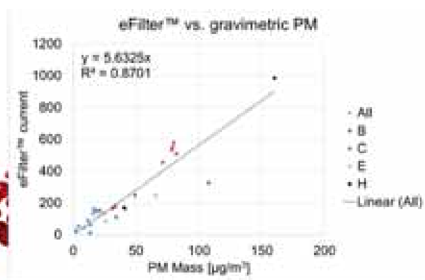




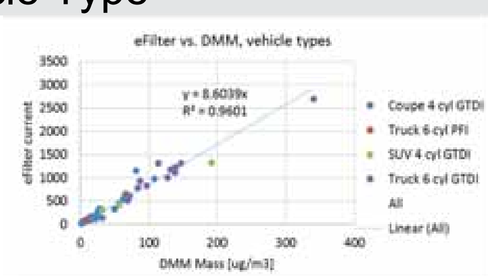
Vehicle tests: Stability and Correlation to MSS, NEDC

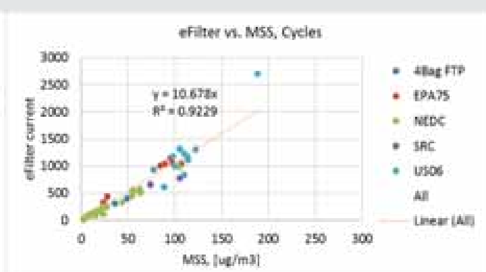


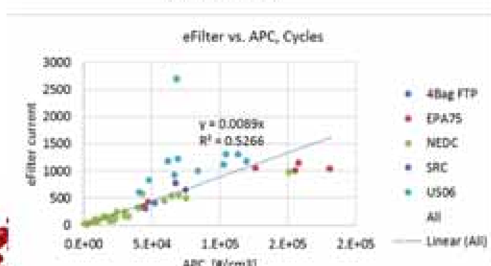


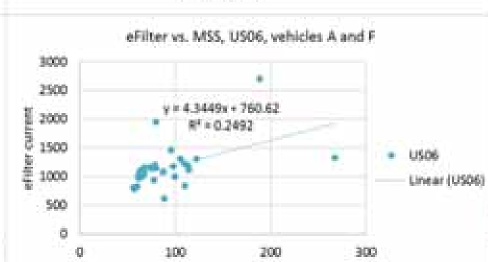


Vehicle Tests: Effect of Vehicle and Cycle Type









Good correlation to DMM (Total PM), more scatter in MSS correlation due to soot only measurement . US06 causes scattering due to aggressive driving and higher temperatures.

ISO 8178:2017 - PN

- Very similar to EU legislation for particle number masurement
  - Allows full flow dilution, partial flow dilution and raw exhaust measurement (with optional added dilution step) as sources
- Volatile particle remover – VPR
  - Minimum total dilution factor (pcrf) roughly 1000
- Particle number counter – PNC – linearity above 1 #/cm^3 in single counting mode
- Accuracy of +/- 10 % for both VPR PCRF and PNC counting

DEKATI

Measurement of DPM mass Vs. number according to legislation

- What sticks on a filter vs. counting of solid particles above 23 nm
- Correlation exists but highly dependent on particle size, amount of volatiles
- Measurement of PM on a filter is more representative of total emission than solid number count, although less sensitive

DEKATI

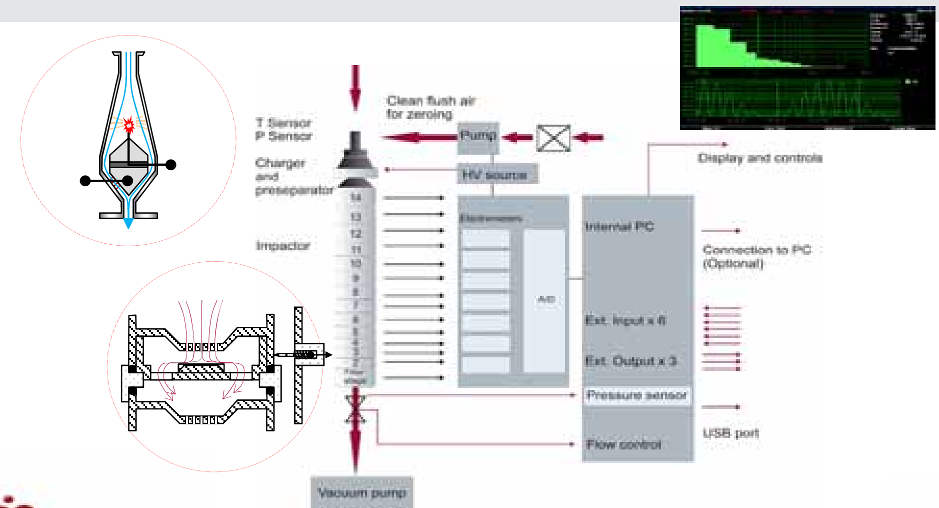
Example of mining vehicle emission measurement directly from tailpipe

- How to measure DPM size distribution and concentrations at low PM levels?
- What can be achieved in terms of sensitivity compared to legislative particle number measurement?

ELPI®+: Electrical Low Pressure Impactor

- Number size distribution and concentration
  - Real-time, 10 Hz
- 6 nm - 10 µm
  - 14 size fractions
  - 100 or 500 with High Resolution ELPI®+
- Particles are collected
  - Possibility for chemical analysis on the collected samples
- Wide dynamic range
  - From outdoor air to power plant stack concentrations

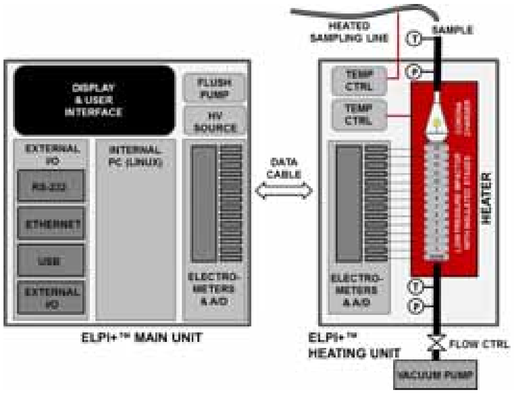
ELPI+™ Operating Principle



High Temperature ELPI®+

- All the features of the ELPI®+
- Direct hot aerosol sampling, max 180 °C
  - Calibration values provided for 20, 60, 120 and 180 °C
- Improved sensitivity as no dilution needed
- Integrated temperature control and option for additional external heater control

High Temperature ELPI+™



- Same operating principle as ELPI+™
- Charger+Impactor moved to external heating unit, max 180 °C
- Allows hot aerosol size and charge distribution measurement in real-time

KATI

Simple sensitivity analysis

- HT-ELPI+ particle number measurement noise above 23nm from all channels combined is ~90 #/cm^3
- For +/-10% noise to signal a concentration of 900 #/cm^3 is required
- As CVS + VPR combination results typically in a dilution factor of ~ 1000, required concentration for HT-ELPI+ translates to a concentration of 0.9 #/cm^3 at PNC

DEKATI

Measured diesel vehicles

- 3.6 l, Stage 4 (1)
- 13 l, Stage 4 (2)
- 11 l, Tier 2 with DPF (3)
- 11l, Tier 2 with DPF (few operating hours) (4)

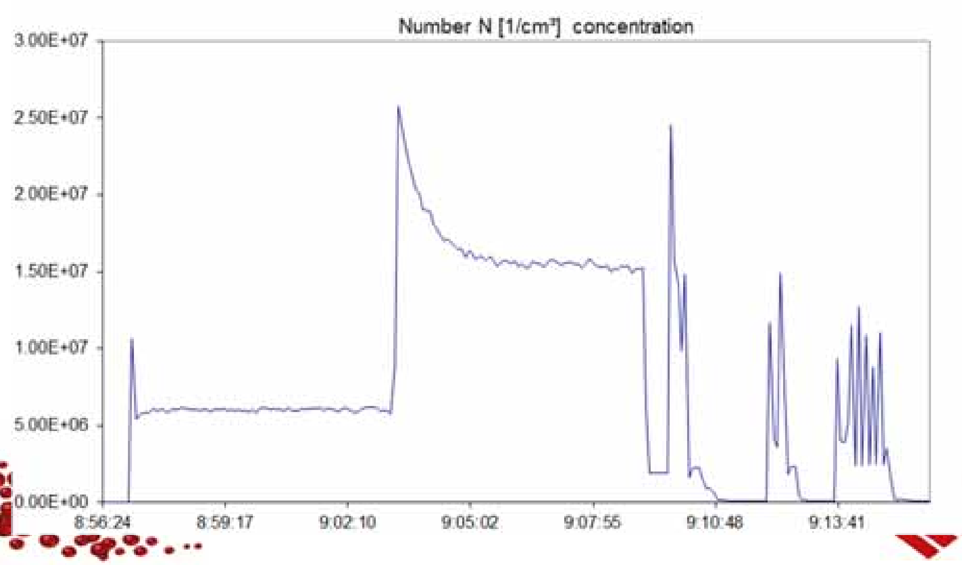
Setup

- HT-ELPI+ @ 180 degrees C
- Heated line with probe @ 200 degrees C
- Direct connection to tailpipe out with probe enetering roughly 20 cm into the tailpipe

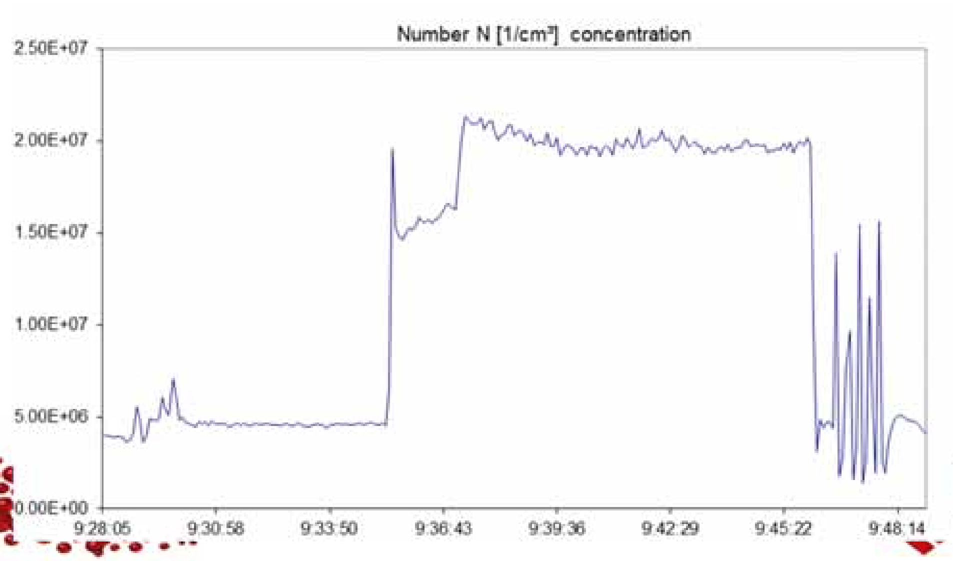
Measurement procedure

- Engine warm-up (not included in presented results)
- Low idle
- High idle
- Max. Engine load against brakes 5 repetitions

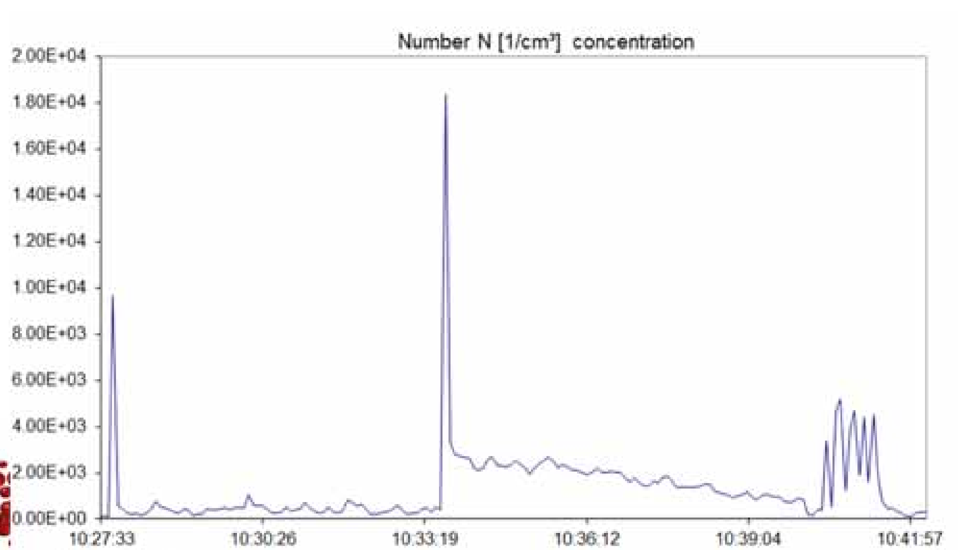
Results I – number concentrations – 3.6 l stage 4 (1)



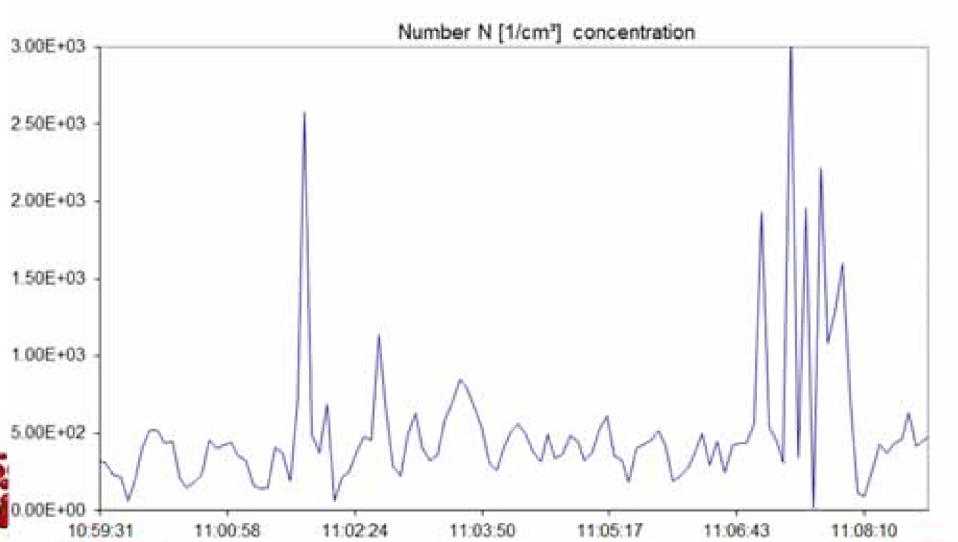
Results I – number concentrations – 13.6 l stage 4 (2)



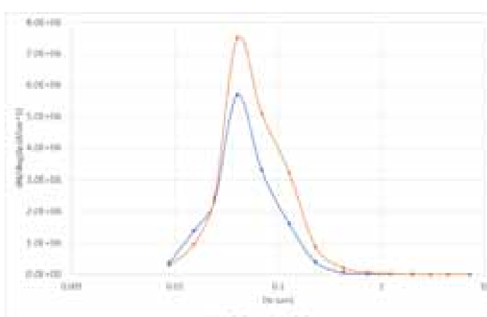
Results I – number concentrations – Tier 2 DPF (3)

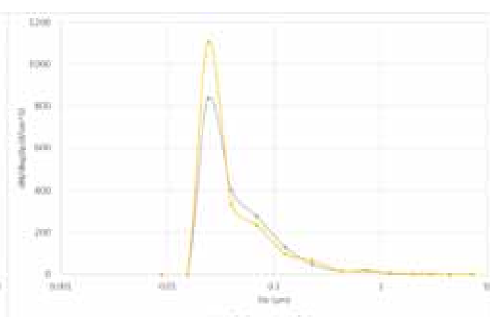


Results I – number concentrations – Tier 2 DPF (4)

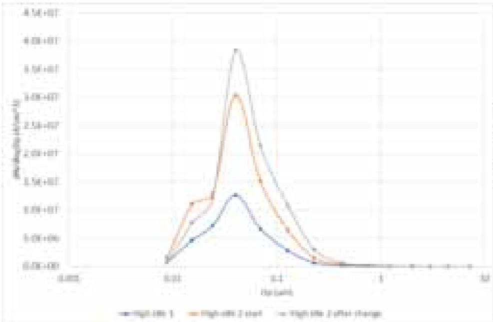


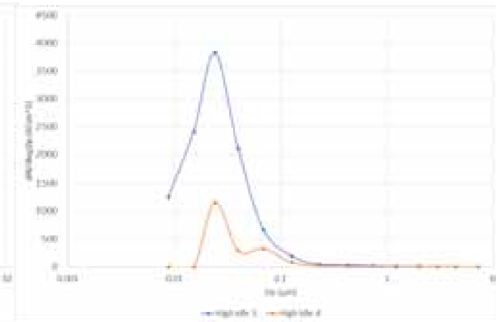
Results II – dN/DlogDp size distributions Low idle





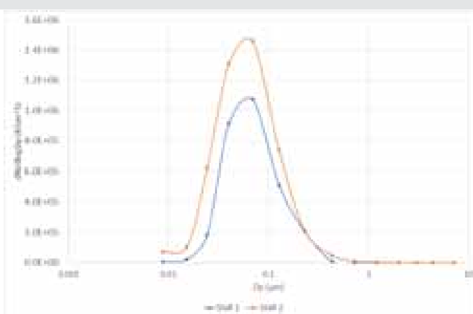
Results II – dN/DlogDp size distributions
High idle

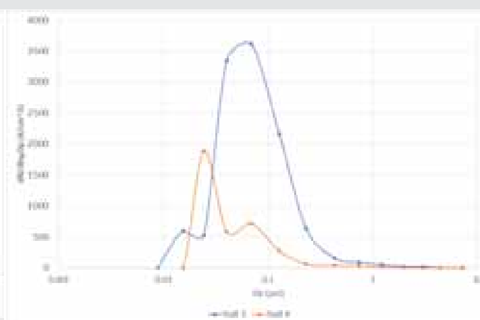




DEKATI

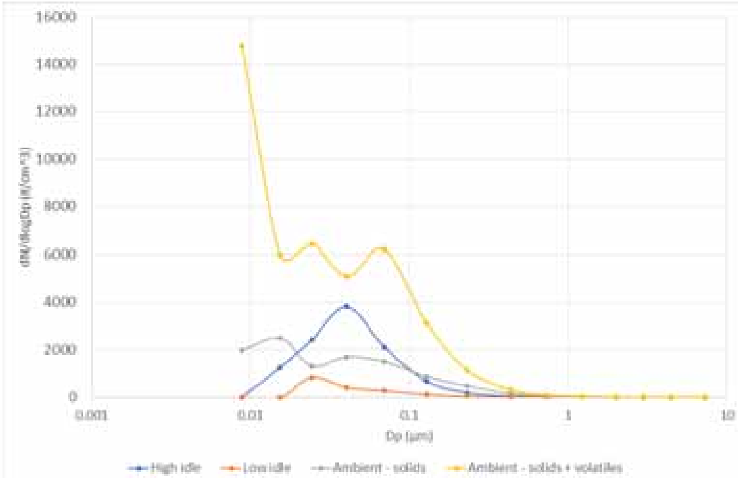
Results II – dN/DlogDp size distributions
Stall





DEKATI

What if we compare to ambient air at the site?



DEKATI

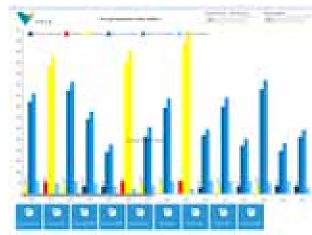
Conclusions

- Significant improvements to filter measurement and weighing process have been necessary to achieve reliable measurement results from vehicles that fulfill requirements of current and future legislation
- Measured DPF efficiencies were very high in all conditions, although high flow conditions presented higher than expected differences
- Direct measurement from tailpipe enables the use of measurement technology for size distribution measurements that can compete with sensitivity of a CVS + VPR + PNC system

DEKATI

Excellence in Particle Measurements

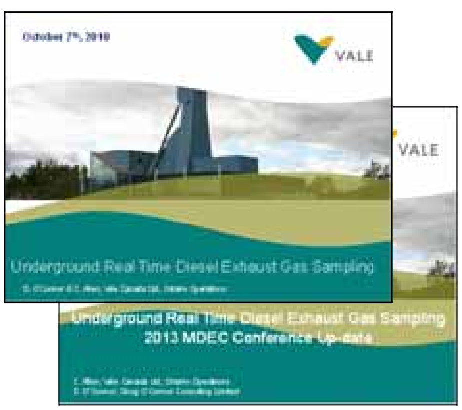
DEKATI

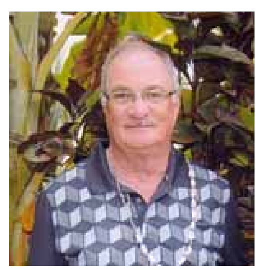


SenzLogic 2.0 and Emission*Insight*
On-board Monitoring of Diesel Equipment
Streamlining Maintenance in Mining

October, 2017

On-board Monitoring of Diesel Emissions





Doug O'Connor – 1950-2015

Continuation of the work spearheaded by Vale beginning in 2010

- **On-board monitoring provides significant insight into VOD requirements**
- **Eliminates inconsistent manual testing procedures**
- **True reflection of equipment under fully loaded conditions – Regulation 854**
- **Early indicator of potential engine health problems – reduce unexpected breakdowns**

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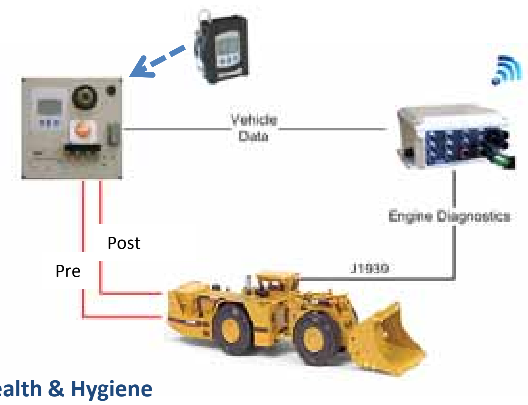
Phase 1 – Onboard Emission Monitoring Impact on Operations

Dräger

CO
NO
NO2
NOx
DPM
RH
O2



Engine Load
Engine Temp
Exhaust Temp
Exhaust Backpressure
Oil Temp
Oil Pressure
RPM
Fuel Temp
Fuel Pressure
Etc.

Human Health & Hygiene

Maintenance

Ventilation

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Evolution: On-board Emissions Measurement Device

SenzLogic *- Emissions measurement, controller, logging and communications capabilities in one platform*

Dräger

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Parameters Used In Analysis and Defining Working States

Aug. 24 - Dec. 6, 2015 – 3,184,836 records captured!

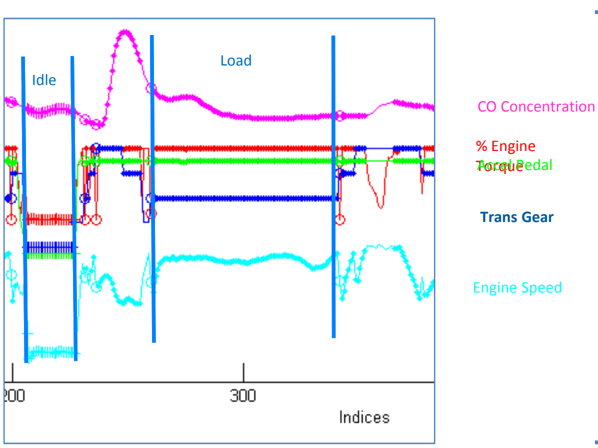
Column Name	Minimum	Maximum
row_id	1.00	1880892.00
date	24/08/2015	06/11/2015
measurement_cycle_id	0.00	573.00
channel_group_id	0.00	488.00
segment_id	391.00	829.00
Acc_Lat	-0.25	0.35
Acc_Vert	0.75	1.19
Acc_Long	-0.70	0.33
EngSpeed	0.00	16388.00
EngFuelRate	0.00	112.95
DragerState	0.00	6.00
MeasurementState	0.00	1.00
DragerChannel	0.00	2.00
DragerComState	0.00	3.00
DragerErrorState	0.00	32.00
MeasurementTime	0.00	905.00
COconcentration	0.00	1778.00
NOconcentration	0.00	891.00
NO2concentration	0.00	163.00
NOXconcentration	0.00	963.00
AccelPedalPos1	0.00	100.00
WheelBasedVehicleSpeed	0.00	186.76
EngCoolantTemp	-32766.00	124.00
TransOilTemp	0.00	0.00
TransOilPress	0.00	32761.50

Column Name	Minimum	Maximum
EngOilPress	0.00	16385.00
EngTurboBoostPress	0.00	32767.50
AirFilterRestriction	0.00	4.50
TransCurrentGear	0.00	4.00
TransSelectedDirection	0.00	7.00
BatteryVoltage	0.00	30.50
EngCoolantLevel	0.00	1.00
ActualEngPercentTorque	0.00	100.00
BrakeSwitch_1	0.00	1.00
TransRetarderSwitch	0.00	1.00
TorqueConvOilTemp	-40.00	170.00
BrakeOilCoolingTemp	-40.00	170.00
DumpHoistLeverStatus	0.00	240.00
DumpHoistLeverPos	0.00	100.00
IntakeManifoldAirTemperature	-3276.60	95.90
DumperBedPos	0.00	655.20
TransRetarderControl	0.00	655.20
ParkingBrakeSwitch	0.00	1.00
BoxV	12.42	12.80
BoxT	23.16	60.05
FuelLevel	0.00	100.00
EngTotalFuelUsed	0.00	41238.98
TotalVehicleHours	0.00	17879.26
TotalEngineHours	63.18	627.32

Engine Parameters Captured from Vehicle Telemetry System
Emission Concentration Measurements Captured
Used in defining Working State or Duty Cycles – see next slide

Graph of raw data – establishing Working State

Building models for classifying emissions



Transform Raw Data into Models that Describe Working States

- Low Idle
- High Idle
- Load
- Other

PATTERN DISCOVERY TECHNOLOGIES INC

Valid Emissions Measurements – Update to Dec. 6

Aug. 24, 2015 – Dec. 6, 2015 = 103 days = 242,152 tests at the exhaust (Channel 1)

Total Data Points Captured					
	3,184,836				
Valid Emission Measurements Captured					
	Total	Channel 1	Channel 2		
count	304,591	242,152	62,439		
seconds	304,591	242,152	62,439		
minutes	5,077	4,036	1,041		
hours	85	67	17		
Channel 1					
	242,152				
Working State	0-250	250-500	500-750	750-949	by State
All	63,155	66,531	73,688	38,778	**242,152**
High RPM	6,733	8,032	7,549	5,031	27,345
Load	22,029	17,391	22,378	11,925	73,723
Low RPM	13,016	13,728	18,367	7,446	52,557
Other	21,377	27,380	25,934	14,376	89,067

Approximate number of manual tests performed in 103 days = 6

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Visualization in Dashboard of Emissions Measurements

Average of all Working States over 250 hour increment

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Double Clicked on 0 – 250 with NO2 warning

Drill Down to 50 Hour Increments

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Double Clicked on NO2 warning in 100 hour interval

Drill to Hourly Increments on 100 hour interval

240

Drill down to raw data graph for Hour 108

PATTERN DISCOVERY TECHNOLOGIES INC

Per minute performance

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Drill down to raw data and corresponding engine contributions

PATTERN DISCOVERY TECHNOLOGIES INC

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By Working State – High RPM

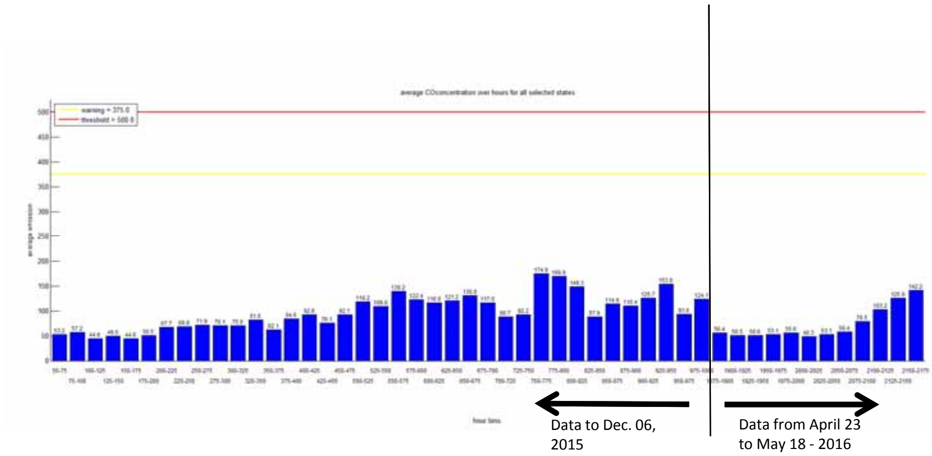
Average of all Working States over 250 hour increment

By Working State - Load

Average of all Working States over 250 hour increment

Most recent data

CO Concentrations over 25 hour averages



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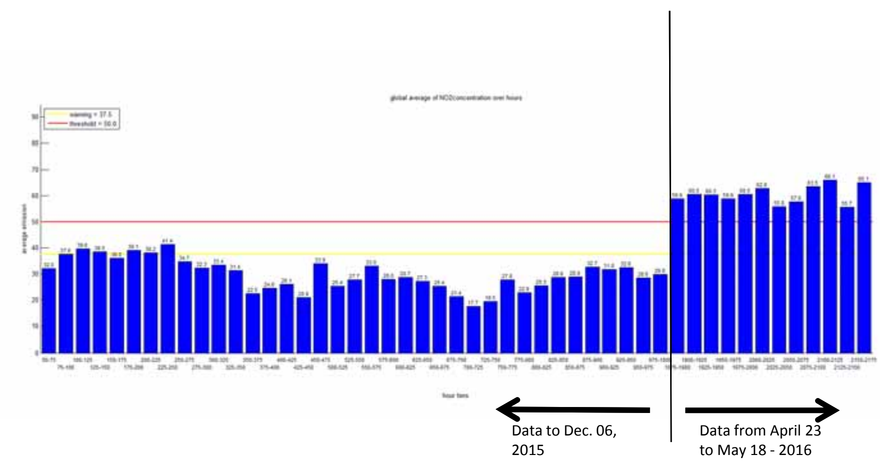
Most Recent Data

NO2 Concentrations over 25 hour averages



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Most Recent Data

NO2 Concentrations over 25 hour averages - Loaded

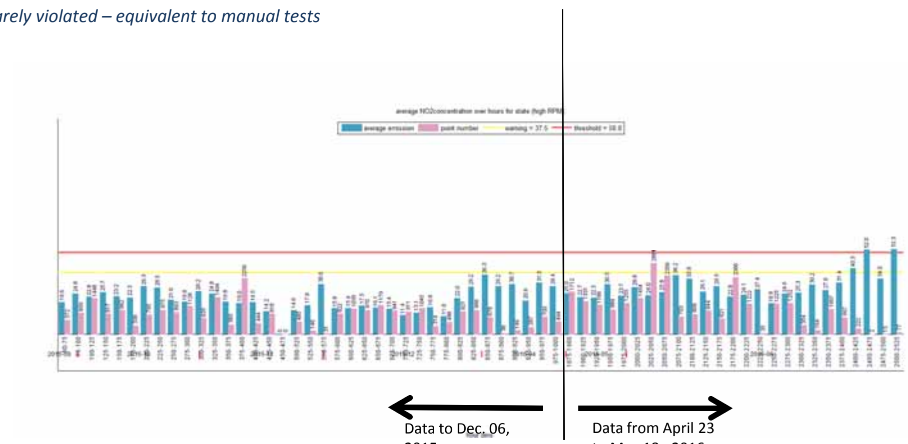
Data to Dec. 06, 2015

Data from April 23 to May 18 - 2016

Most Recent Data

NO2 Concentrations over 25 hour averages – High RPM

Threshold rarely violated – equivalent to manual tests



Data to Dec. 06, 2015

Data from April 23 to May 18 - 2016

Emission*Insight*™ for Underground Mining Equipment

Value to Mining Operations

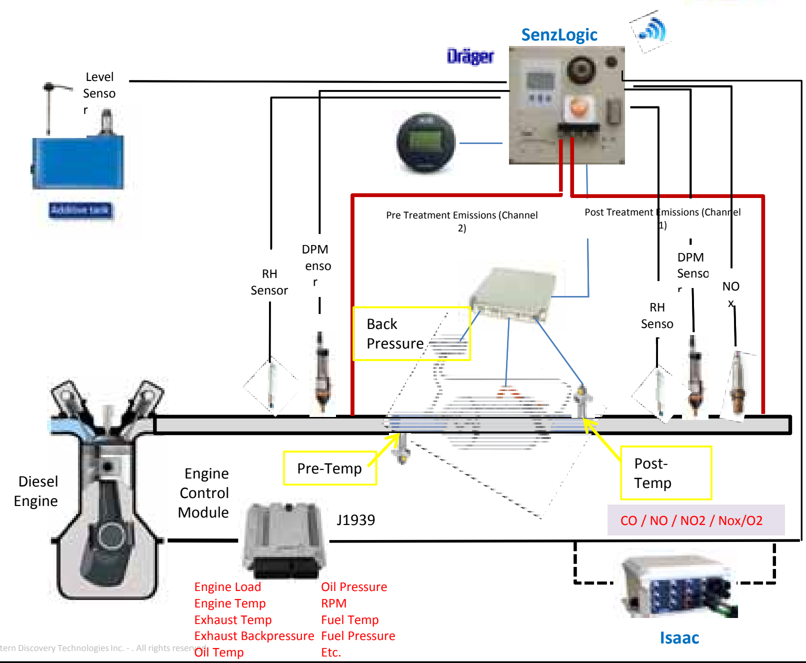
Assumptions	
Shift length	10.5
Seat hours/shift	7.5
Tons/shift/vehicle	500
Value/ton - Creighton	$ 400.00
Value/ton - Totten	$ 250.00
Wages	$ 34.00
Overhead markup	200%
Hours to perform manual test	1
# of mechanics to perform manual test/vehicle	2
# of tests per month	1
# of scoops	10
# of haulers	5
# of days lost to production for fleet (Todd V)	4
% improvement to downtime losses - reduce unexpected failures	25%

Vehicle Production Value	
# of vehicles	10
Shift length	10.5
Seat hours/shift	7.5
Tons/shift/vehicle	500
Tons/hour/vehicle	67
Value/ton - Creighton	$ 400.00
Value/ton - Totten	$ 250.00
Value/hour of each vehicle - Creighton	$ 26,800.00
Value/hour of each vehicle - Totten	$ 16,750.00

Production Value by Eliminating Manual Tests - Creighton	
Extra hours of operation by eliminating manual test/vehicle	1
Extra tons/month/vehicle	67
value/month/vehicle	$ 26,800.00
Value for fleet/month (based on 10 scoops)	$ 268,000.00
Overall value for fleet per year (x 12 months)	$ 3,216,000.00

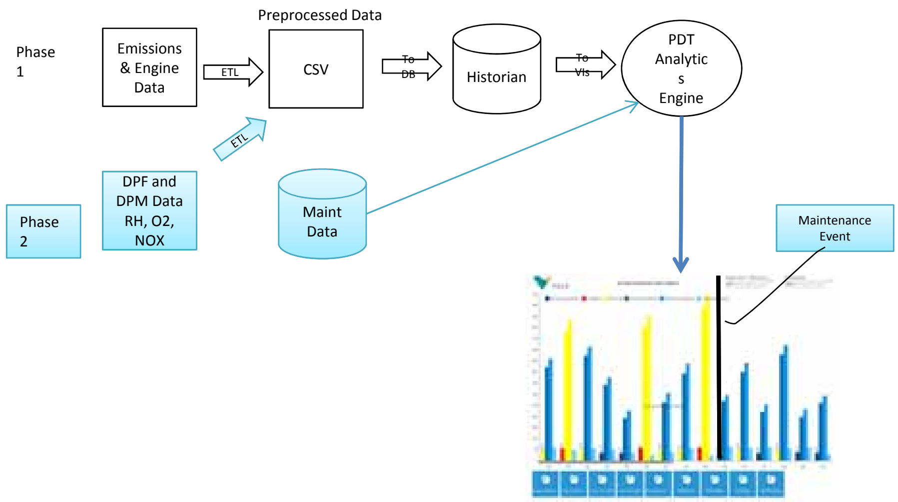
Reduced Downtime due to Unexpected Repairs - Creighton	
# of days/month/fleet	4
hours per day	15
total hours of downtime	60
% improvement to downtime losses	25%
additional tons month	1005
value per month	$ 402,000.00
value per year	$ 4,824,000.00

Phase 2 - SenzLogic, Engine Diagnostics, Value Add Sensors



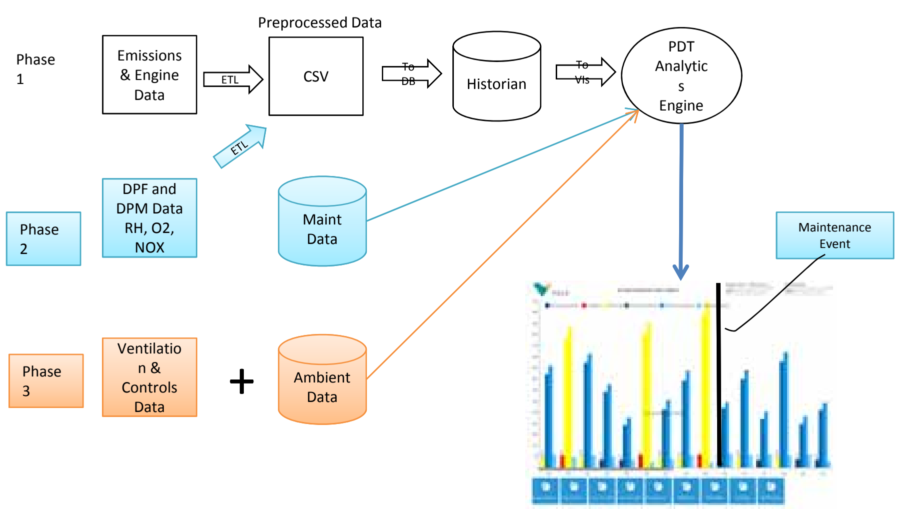
EmissionInsight 2.0+ - Development

Current and future development



EmissionInsight 2.0+ - Development

Current and future development



Journey to Streamlined Maintenance in Mining

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Emission*Insight*™

Questions and Answers

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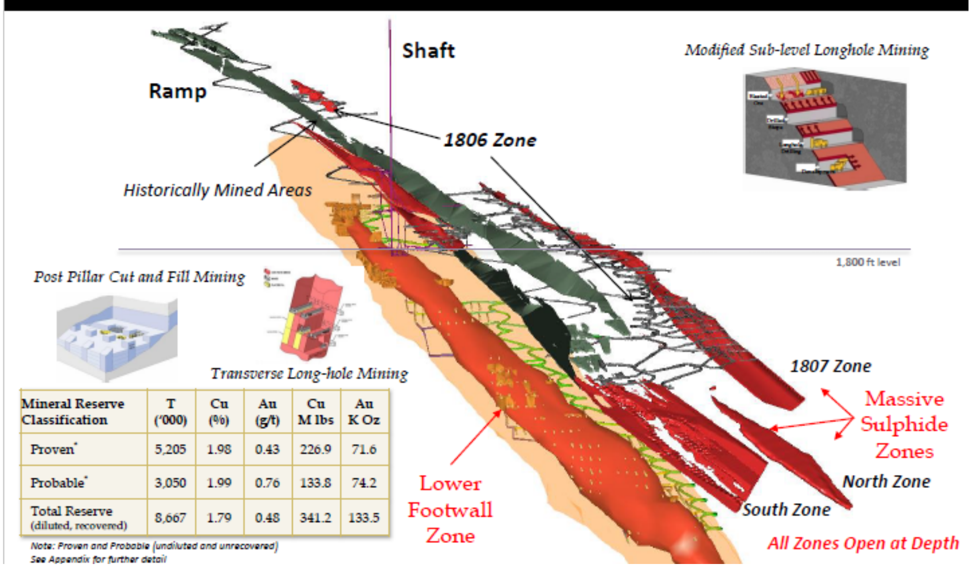
Ming Copper-Gold Mine



Mineral Reserve Classification	T ('000)	Cu (%)	Au (g/t)	Cu M lbs	Au K Oz
Proven*	5,205	1.98	0.43	226.9	71.6
Probable*	3,050	1.99	0.76	133.8	74.2
Total Reserve (diluted, recovered)	8,667	1.79	0.48	341.2	133.5

Note: Proven and Probable (undiluted and unrecovered)
See Appendix for further detail

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Atlas Copco

RAMBLER - FLEET

Description	Year
Boomer - 282	2008
Boomer - 282	2008
Scoop - ST 1030	2008
Truck - MT 436B	2008
Scoop - ST 1030	2008
Truck - MT 436B	2008
Truck - MT 436B	2008
Truck - MT 436B	2008
Boomer - 282	2010
Boomer - 282	2010
Truck - MT 42	2010
Truck - MT 42	2010
Scoop - ST 1030	2010
Scoop - ST 1030	2011
Truck - MT 42	2011
Scoop - ST 1030	2011
Truck - MT 42	2013
Scoop - ST14	2015
Scoop - ST 7	2015
Truck - MT 42	2016
Truck - MT 42	2017
Scoop - ST14	2017
Truck - MT 42	2017

Model	Qty
Boomer - 282	4
Scoop - ST 1030	5
Scoop - ST 7	1
Scoop - ST14	2
Truck - MT 42	7
Truck - MT 436B	4
Grand Total	**23**

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Atlas Copco

EQUIPMENT

GENERAL OVERVIEW

TIER LEVELS

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Atlas Copco

LOADER PORTFOLIO

Tunnel / Gallery size	Direct Control System	Rig Control System
Low seam		ST7LP 
Small	ST2G  L150 	ST7 
Medium	ST1030 	ST14 
Large		ST 18 

ST = Scooptram
ST14 = 14 tonne

Deutz BF4L 914, 72kW Stage II/ Tier 2
Deutz D914 L04, 55kW Stage IIIA/ Tier 3
Deutz TD 3.6 L04, 55kW Stage IIIB/ Tier 4i

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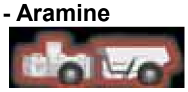
TRUCK PORTFOLIO

Tunnel / Gallery size	Direct Control System	Rig Control System
Low seam	MT436LP 	
Small	T16 - Aramine 	MT2010 
Medium	MT 431/MT436 	MT42 
Large		MT 5020 / MT 65 

MT = Minetruck
MT42 = 42 tonne

Cummins QSL9 EPA Tier 3
Cummins QSL9 EPA Tier 4 interim

Cummins QSK19 EPA Tier 2

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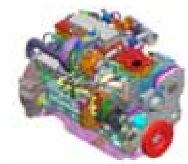
Scooptram ST14

Cummins QSM11 Tier 4 interim engine installation



- Cummins QSM11
  - Meets Tier 4 interim regulations
  - Tested for MSHA/CANMET
- The engine requires Ultra Low Sulphur Diesel (ULSD) fuel (15ppm)
- Exhaust temperatures will be higher during active regeneration
- Diesel Particulate Filter (DPF) is a part of the after treatment system

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MINETRUCK MT42

New engine alternative - Cummins QSX 15 - EPA Tier 4 final / EU Stage IV

- Tier 4 final and Stage V - bringing particulate matter (PM) and nitrogen oxides (NOx) to near zero levels
- Benefits
  - Lower exhaust levels (PM and NOx)
  - Engine installation integrated in design of MT42
  - Reduced fuel consumption vs Stage IIIA / Tier 3 engine
  - Lower noise level
  - Electronic retarder – "Telma"

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Please note! Only for markets with Ultra Low Sulphur Diesel (ULSD) and low ash engine oil.

MINETRUCK MT42

New engine alternative - Cummins QSX 15 - EPA Tier 4 final / EU Stage IV

Engine Manufacturer: **Cummins**
Engine Model: **QSX15, Tier 4F**
Governing Standard: **CSA M424.2-90 (Non-Gassy Mines)**

Certificate Number	Engine Rating and Fuel Rate at Sea Level	Sulphur in Fuel - ppm	Ventilation Prescription	
			CFM	m^3/s
1293	C535 (FR11112), 535 HP (399 kW) @ 2100 RPM, 188.3 lb/h	15	3,500	1.65
			19,800+	9.34+
	C472 (FR11391), 472 HP (352 kW) @ 2000 RPM, 163.8 lb/h	15	2,300	1.09
			18,000+	8.50+

+ These ventilation rates are recommended by NRCan/CanmetMINING where some of the gases govern ventilation rates rather than the EQI criterion.

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MINETRUCK MT42

Rambler Mine feedback:

- Why: TIM SANFORD, P. Eng. Vice President, Technical Services
  - OH&S requested us to consider Tier4 for lower NO_2 and improved ventilation
    - Goal reduce NO_2 to 0.2ppm from the 2ppm
  - Economic less ventilation requires less electricity
  - Improved environment for all employees

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Limited data from customer

MINETRUCK MT42

OH&S

- J Lindsay Mine engineer
  - Newfoundland OHS legislation allows for variance in the ventilation requirements (standard set a 144.8 CFM per BHP) when an engine has been tested by an approved laboratory. As per CANMET, the Tier 4F engines have a rated ventilation prescription of 19,800 CFM. This represents a 54% decrease (from 36,700 CFM) over the alternative Tier 3 engine.
- Corey Greenham, H&S - CSO, RSO, MRT
  - The initially PM emissions check does identify that the Tier four engine is a much cleaner burning engine.

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Atlas Copco

MINETRUCK MT42

New engine alternative - Cummins QSX 15 - EPA Tier 4 final / EU Stage IV

- Tier 4 final requirements at site:
  - Operations feedback:
    - We needed to train our operators on
      - the benefits
      - how TIER 4F works
      - proper use of DPF
      - what fuel to use
      - Follow up on any issues they brought up
  - Maintenance feedback:
    - Local engine support out of Nova Scotia and St John's
      - Inform, start up & warranty registration
    - Rambler was using the ultra low sulfur fuel
    - Training similar to operators to get "buy in"
    - AC stocked spare dpf filter locally
      - Replacing it every 5,000hrs
        - Increased operating costs with this filter

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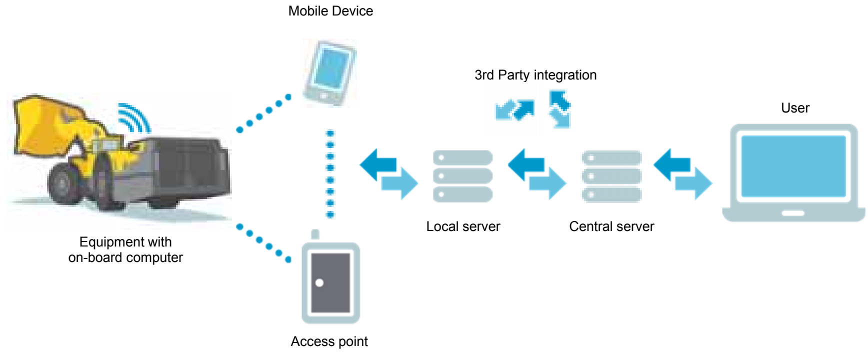
Atlas Copco

Machine status and follow up

TELEMETRICS DATA COLLECTION – “CERTIQ”

- We are currently collecting telemetrics from the ST14 & MT42



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Machine status and follow up

FLEET MANAGEMENT

- Machine information
  - Engine hours
  - Fuel consumption
  - Event logs
  - Machine alarms
  - Idle versus loaded
  - Tones moved
- Service planning
  - Service countdown
  - Service log
- Utilization

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