

20<sup>th</sup> ANNUAL MDEC CONFERENCE  
Toronto Airport Marriott Hotel, Canada  
October 7 – 9, 2014



MDEC DIESEL WORKSHOP  
OEM INTEGRATION OF TIER 4 ENGINES

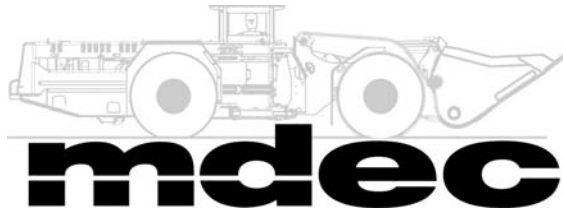
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Evelynn Stirling & Karsten Taudte (Cummins)  
JP Ouellette (Kubota)

COORDINATED BY

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OCTOBER 7, 2014



## **MDEC Diesel Workshop**

### **OEM Integration of Tier 4 Engines**

Toronto Airport Marriott Hotel  
Ontario, Canada

Tuesday, October 7, 2014

- |                      |  |
|----------------------|--|
| <b>07:30 – 08:30</b> | Breakfast and registration   |
| <b>08:30 – 12:00</b> | Welcome – Mahe Gangal, Co-chair MDEC Conference<br>Introduction of speakers – David Young, Secretary & Treasurer MDEC<br>Section 1 - Dale Rakochy (Sandvik Mining)<br>Section 2 - Darren Tasker, Dee Wise and Lars Bark (Volvo Penta)<br>Section 3 - Jaime Tomporowski (Atlas Copco) |
| <b>12:00 – 13:00</b> | Lunch  |
| <b>13:00 – 16:00</b> | Section 4 - Evelyn Stirling and Karsten Taudte (Cummins)<br>Section 5 - JP Ouellette (Kubota)<br>Discussion and Conclusion, JP Ouellette, Co-chair MDEC Conference   |

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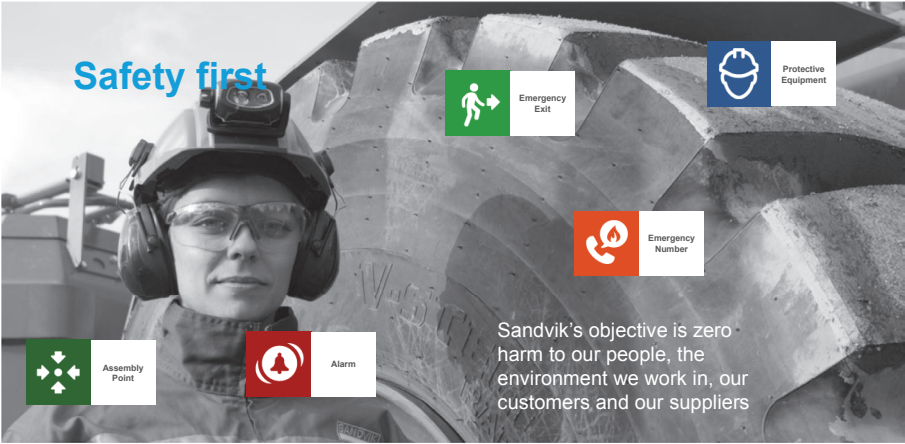
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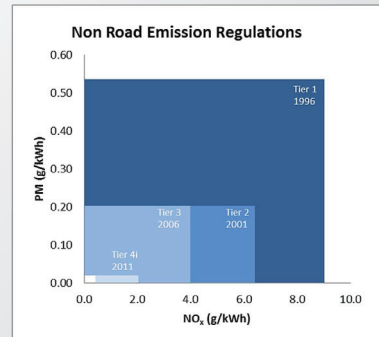
## Tier 4i engine integration

### The challenge in 2011

In 2011 serial production was ending for the Tier 2 Detroit Diesel Series 60 engine.

Sandvik needed an engine family for both the Tier 4i and 'non-regulated' markets:

- European Union (EU) Stage IIIB
- US EPA Tier 4i or MSHA/CANMET for underground mining in North America.
- US EPA Tier 2 or 3 for 'non-regulated' markets with higher sulphur diesel fuels.



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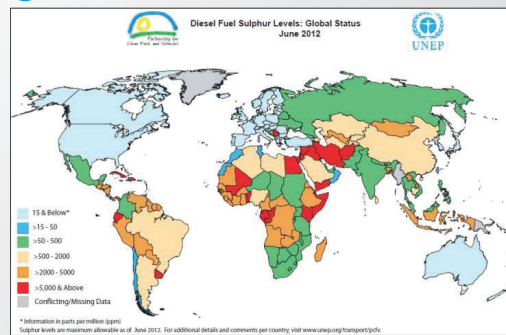
## Tier 4i engine integration

### Fuel requirements

Ultra low sulphur diesel fuel (ULSD) is required for Tier 4i.

Already mandatory in the following regions:

- Europe
- North America
- Australia & New Zealand
- Japan
- Korea



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## Tier 4i engine integration

### What was done?

Engine studies and supplier negotiations started in late 2008 / early 2009.

Engine selection was based on the following criteria:

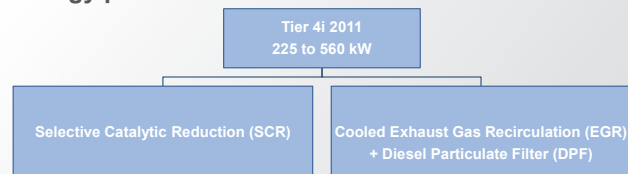
- World-wide support presence
- Suitable power range
- Simple, robust design
- Compact installation
- High performance, low fuel consumption
- Commonality of parts across all Tier engines



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## Tier 4i engine technology

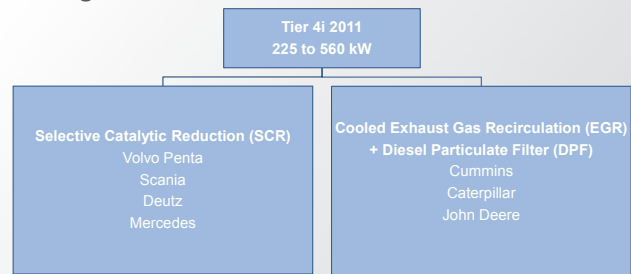
### Two technology paths



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## Tier 4i engine technology

Who was doing what?



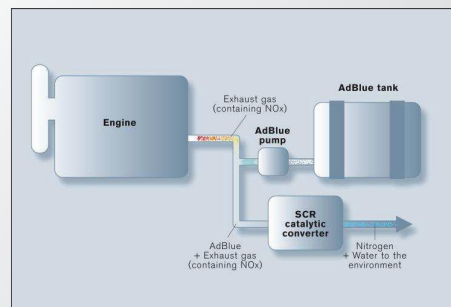
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## SCR

Typical system design

- The engine is tuned for high  $\text{NO}_x$  and low PM.
- DEF (AdBlue) is injected into the exhaust gas stream at a rate of 3 to 5 percent of diesel fuel consumed.
- DEF (AdBlue) reacts with the  $\text{NO}_x$  in the SCR catalytic converter to produce nitrogen and water.



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## SCR

### OEM challenges

- 'DEF' infrastructure required.
- SCR muffler must fit within frame.
- DEF (AdBlue) freezes at -11°C and decomposes slowly above 65°C. Tank heated by coolant and lines electrically heated.
- Operating practices:
  - 'DEF' contamination
  - Low 'DEF' – engine de-rate
  - System tampering
- ULSD required.



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## SCR

### OEM challenges

'Adblue' or "DEF" exhaust additive:

- Aqueous solution consisting of 32.5% urea and 67.5% water.
- Non-flammable and non-toxic.
- Readily available from most diesel fuel suppliers.
- Typically cheaper than diesel fuel.
- Corrosive to some metals (copper).



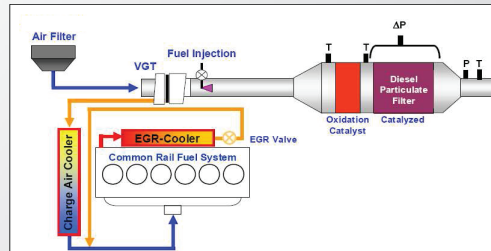
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## Cooled EGR + DPF

### Typical system design

- The engine is tuned for high PM and low NOx.
- Cooled exhaust gas is recirculated into the engine. Reduces oxygen concentration and combustion temperature to control NOx formation.
- PM is trapped in a particulate filter and oxidized by active regeneration.



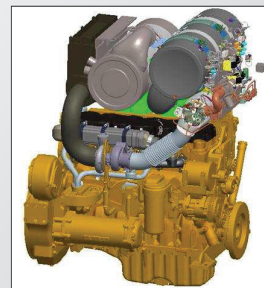
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## Cooled EGR + DPF

### OEM challenges

- Larger radiator required - up to 50% increase.
- Aftertreatment system must fit within frame.
- Exhaust gas  $>600^{\circ}\text{C}$  during active regeneration. Diff user required at tailpipe.
- Ash accumulation. DPF must be removed within 5000 hours.
- ULSD and low sulphated ash oil required.
- Reliability of active regeneration system in UG application?



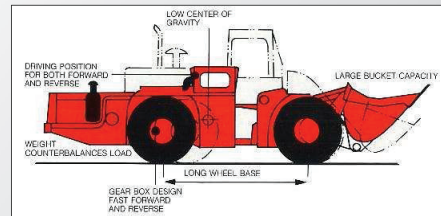
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## Tier 4i engine integration

### Design considerations

- An UG LHD has a low profile, enabling it to work under low roof heights and in confined spaces.
- Not suited to Cooled EGR + DPF layout used in construction equipment installations.
- Larger radiator → higher profile
- Increase radiator fins → increased clogging
- Aftertreatment system needs to be located high on the machine – limit water ingress.



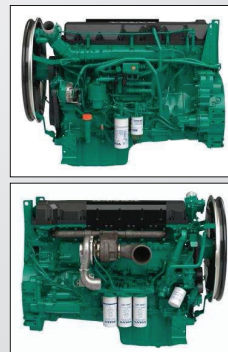
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## Tier 4i engine integration

### Design considerations

- Volvo Tier 4i envelope is similar to current engine with the SCR unit replacing the muffler.
- Proven SCR technology from on-road trucks.
- Simple, robust 'Tier 2' style base engine.
  - No variable geometry or dual stage turbocharging.
  - Unit injectors with no high pressure common rail fuel injection.
- No DPF or cooled EGR:
  - Larger radiator not required.
  - No periodic removal for cleaning
  - No high temperature regeneration.



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## Tier 4i engine integration

### UG loaders and trucks

- Volvo with SCR was selected as the best candidate for the 255 - 560 kW power range.
- Successful Tier 4i engine field testing was completed in 2010 (>3000 test hours).
- The Detroit Diesel Series-60 engine was replaced by:
  - Volvo D13 & D16 Tier 4i for markets with ULSD – Europe, North America and Australia.
  - Volvo D13 & D16 Tier 2 for non-regulated markets.



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## Non regulated markets

### Why Tier 2 ?

**Tier 2**  
 High NOx  
 Low PM  
 Lower Fuel Consumption  
 No EGR – simple



**Tier 3**  
 Low NOx  
 High PM  
 Higher Fuel Consumption  
 EGR – increased complexity

16

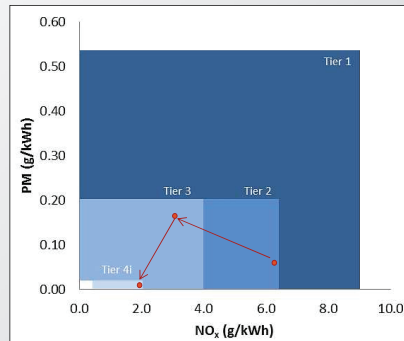


## Non regulated markets

### Tier 2 vs Tier 3

Our experience from Tier 2 → Tier 3:

- Increased diesel particulate emissions.
- Increased fuel consumption.
- Increased smoke at high altitude – transient fuelling not optimized.
- Blocked DPFs.



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SANDVIK

## Tier 4i engine integration

### What are the T4i advantages?

- Lower diesel particulate matter and exhaust gas emissions.
- Reduced fuel consumption.
- Improved performance.
- Reduced ventilation rates for countries that calculate ventilation on emissions output rather than rated power - MSHA, CANMET.



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SANDVIK

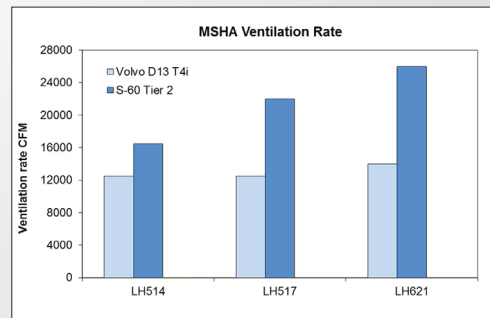
## Tier 4i engine integration

### MSHA Ventilation Rates

The Volvo Tier 4i engines were tested for MSHA approval to use in underground mines in the United States.

The reduction in ventilation rates compared to the Series 60 Tier 2 engines were:

- LH514 – 24%
- LH517 – 43%
- LH621 – 46%



19



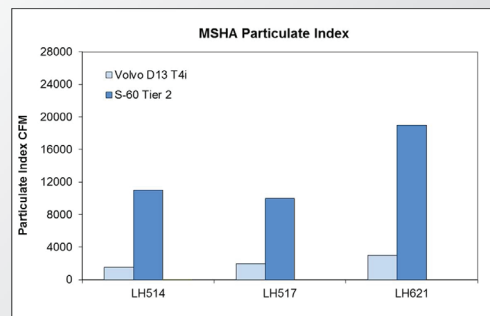
## Tier 4i engine integration

### MSHA Particulate Index

The MSHA Particulate Index (PI) was calculated to dilute PM to 1.0mg/m<sup>3</sup>.

The reduction in PI compared to Series 60 Tier 2 engines were:

- LH514 – 86%
- LH517 – 80%
- LH621 – 84%



20

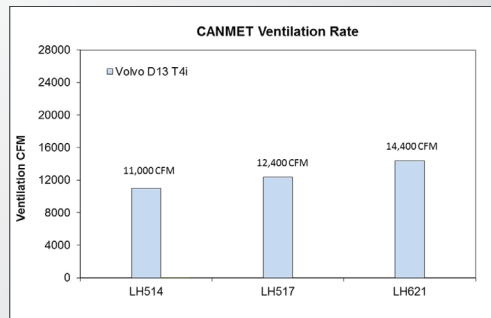


## Tier 4i engine integration

### CANMET Ventilation Rate

The Volvo Tier 4i engines were tested for CANMET-MMSL approval to use in underground mines in Canada.

The Tier 4i powered Sandvik 500 and 600 series loaders have the lowest ventilation rate in their size class.



21

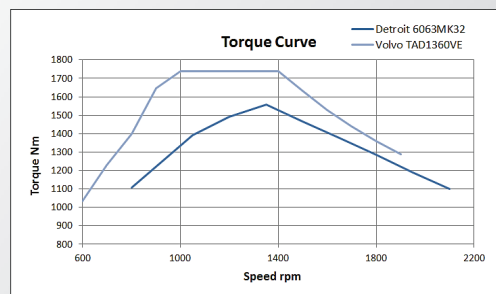


## Tier 4i engine integration

### Performance

The Volvo Tier 4i engines offer more broad usable torque for hydraulic load and good lugging ability.

- Good torque rise
- Flatter torque curve
- Increased torque at low rpm
- Improved throttle response



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## Tier 4i engine integration

### Aftermarket Support

- Sandvik worked with Volvo Penta to identify location of customer base and ensure global support was established.
- Volvo Penta is responsible for the industrial engine dealer support.
- Alternatively, Volvo Penta appoints a dealer from within the Volvo Group i.e. Volvo Construction Equipment.
- This allows access to the large dealership network of the Volvo group.



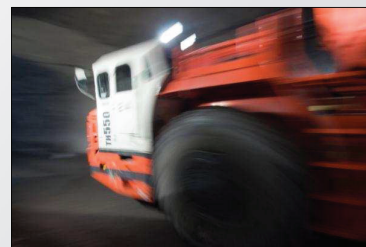
23

## Tier 4i engine integration

### Model vs Quantity

As of August 2014, Volvo Tier 4i engines have been supplied:

- in more than 150 Sandvik loaders and trucks.
- to Canada, USA, Europe, Japan, Australia.
- in 7 different loader and truck models.



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## Tier 4i engine integration

### Experiences

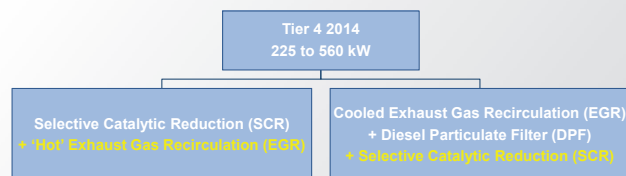
- SCR Muffler blockage:
  - LHD submersed in water – revised tail pipe design.
  - Excessive idling in very cold conditions.
- 'DEF' Contamination:
  - Unclean operating practices.
- Mixing of 'DEF' and 'Diesel':
  - Different quick fill connections implemented.
- Operating at low DEF tank level:
  - Ignore warning and engine de-rates.



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## Tier 4 Final

### SCR technology required



26

## Tier 4 Final

### Volvo solution

D13 & D16 Tier 4i → Tier 4 final:

- 80% reduction in NO<sub>x</sub>.
- 'Hot' EGR to keep SCR catalyst operating at optimum temperature.
- Cooling package remains unchanged.
- SCR muffler increases in size.
- Introduced into Sandvik loaders and trucks from 2014.



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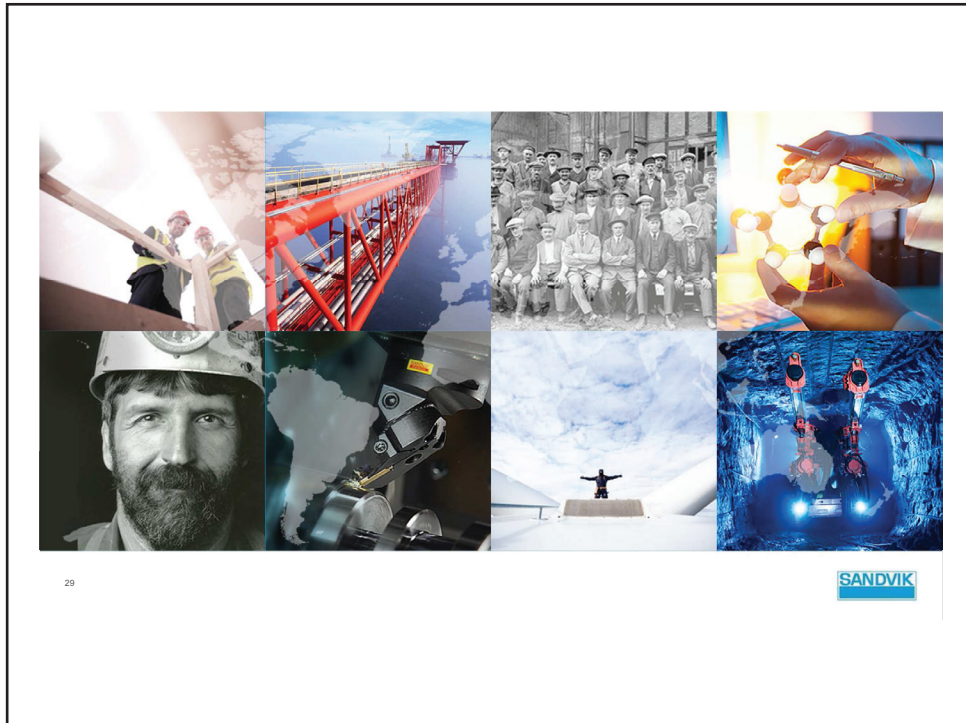


## Tier 4i engine integration

Thank You!

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# **VOLVO PENTA**

## **VOLVO PENTA**

**MDEC conference - October 7th, 2014**



**Volvo Penta Participants:**

**Darren Tasker     Director, Industrial Business**

**Dee Wise            Regional Sales Manager**

**Lars Bark            Engine Certification Engineer**

# Volvo Group Organization



Group Trucks Sales & Marketing EMEA

Group Trucks Sales & Marketing Americas

Group Trucks Sales & Marketing APAC

Group Trucks Operations

Group Trucks Technology

## BUSINESS AREAS



Construction Equipment

Volvo Buses

Volvo Penta

Governmental Sales

Volvo Penta  
3

**VOLVO PENTA**

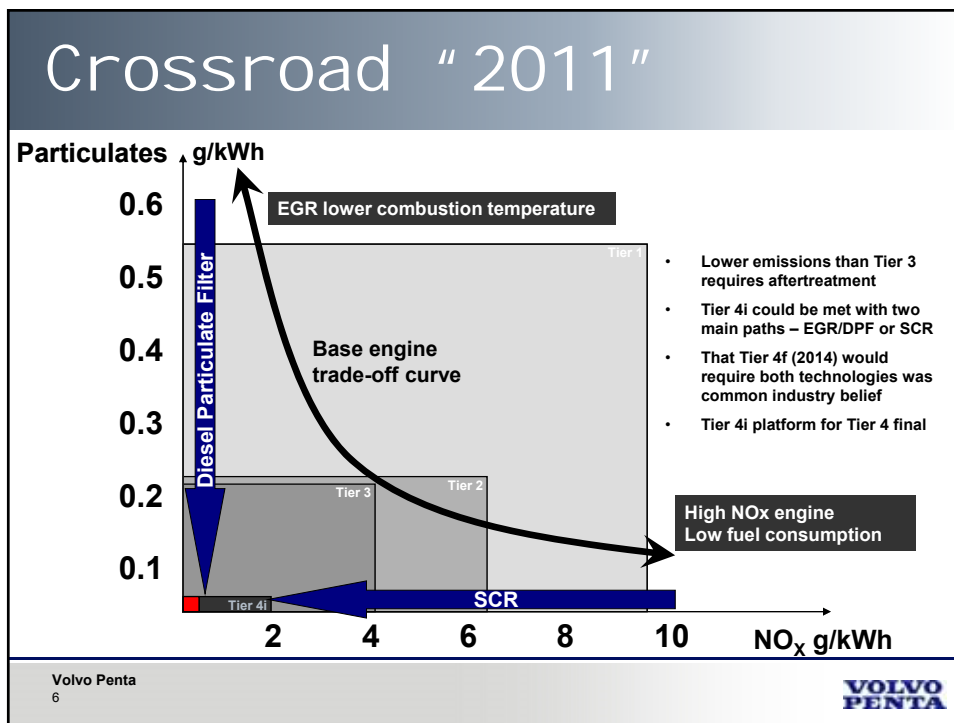
# Volvo group emission technologies

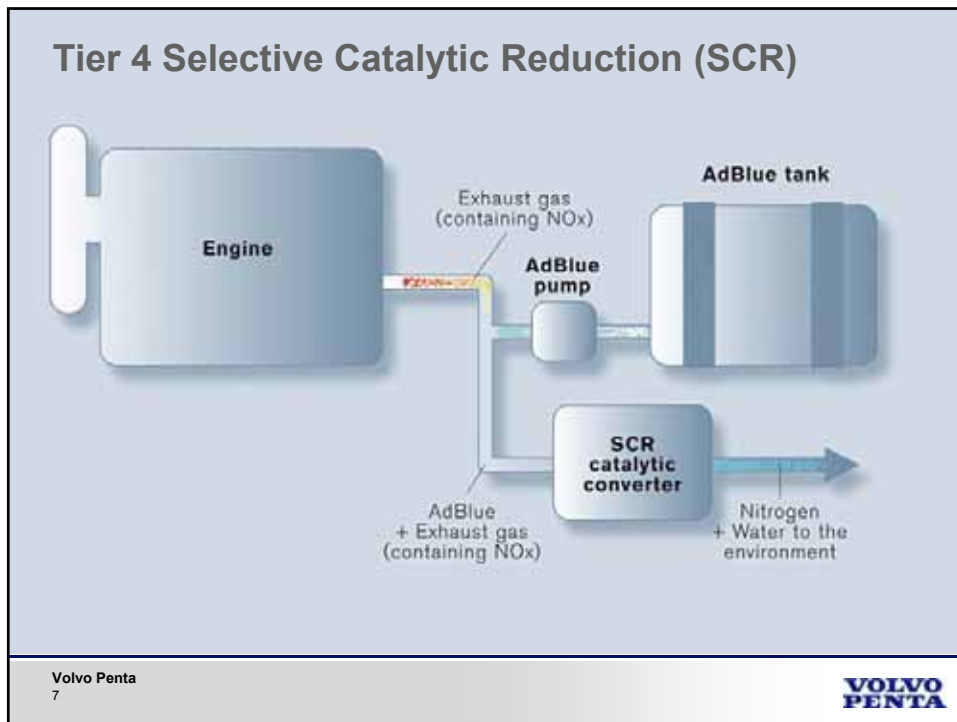
US02	Euro 4	Tier 3	US07	Euro 5	US10/13	Tier 4	Euro 6
							
EGR	SCR	IEGR	EGR + DPF	SCR	EGR + DPF + SCR	SCR	EGR + DPF + SCR
2002	2005	2006	2007	2009	2010	2011	2014

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4

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W2 - 2





## SCR – our choice for 2011

- Lower fuel consumption
- Base engine technology & envelope unchanged
- Cooling package remains unchanged
- Flexible installation of aftertreatment
- Reliable & proven aftertreatment
- Greater power densities
- No Diesel Particulate Filter
- No need for regeneration
- Service intervals remain unchanged

➔ **OEMs recommended to not take on big installation projects involving EGR/DPF for 2011. Rapid technology development!**

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8

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# SCR – our choice for 2014

Particle *mass* control directly by engine design and calibration

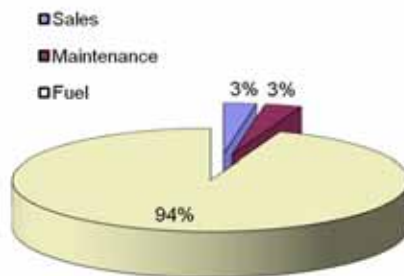
NO<sub>x</sub> to be controlled by an SCR after treatment system



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# Low fuel consumption



Example based on D13 engine:

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

- Automotive base engine
- SCR technology
- Limited amount of EGR
- Maximizes the amount of Oxygen
- Optimizes the Horsepower output
- PM from engine below Stage 4 level
- Optimizes Fuel Efficiency

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From 2011...



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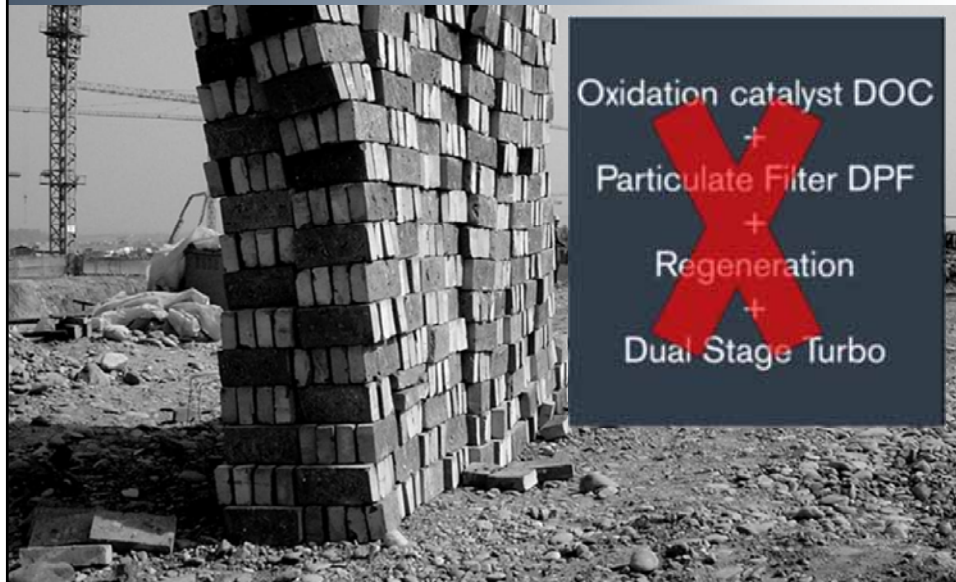
...To 2014



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# Keep it simple!



## SCR – our choice for 2014

- Lower fuel consumption
- Base engine technology & envelope unchanged
- Cooling package remains unchanged
- Flexible installation of aftertreatment
- Reliable & proven aftertreatment
- Greater power densities
- No Diesel Particulate Filter/ Oxidation Catalyst
- Vanadium SCR substrate
- No need for regeneration
- Service intervals remain unchanged

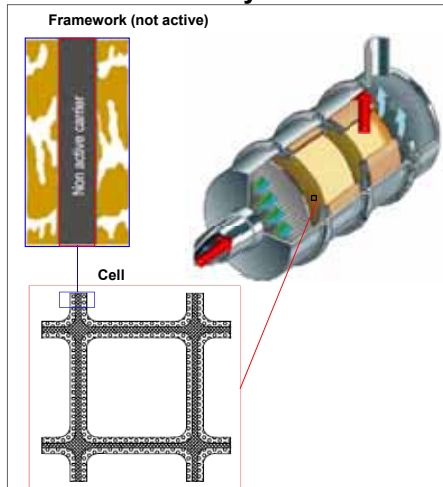


OEMs recommended to not take on big installation projects involving EGR/DPF for 2014. Rapid technology development!

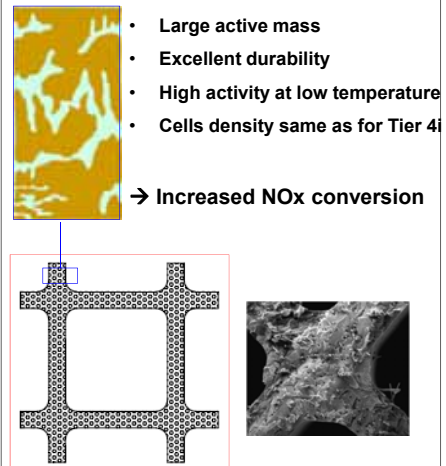


# SCR Substrate Evolution

## Washcoated catalysts Tier 4i



## Vanadium extruded catalyst Tier 4F



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# MHSA / CANMET

## Certifications

### Volvo Penta



Lars Bark



## Current certified engines

- **TAD941VE** Tier 2
- **TAD134XVE** Tier 2
- **TAD136XVE** Tier 4i
- **TAD164XVE** Tier 2
- **TAD166XVE** Tier 4i

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## Planned MMSA/CANMET certifications

5L



105-160kW (140-214HP)

8L



160-235kW (214-315HP)

11L



235-265kW (315-355HP)

13L



285-405kW (382-543HP)

16L



405-515kW (543-690HP)

POWER [kW (US HP)]



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## Authorities and certificates



MSHA is the only form of international standard for mining certificates

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## Ventilation rate

- The gaseous ventilation rate ( $Q_{\text{gas}}$ ) is the dilution air quantity required to reduce the specific (toxic) exhaust gases to the following levels:

	MSHA		Canmet
CO <sub>2</sub>	5000 ppm	CO <sub>2</sub>	5000 ppm
CO	50 ppm	CO	50 ppm
NO	25 ppm	NO	25 ppm
NO <sub>2</sub>	5 ppm	NO <sub>2</sub>	3 ppm
		SO <sub>2</sub>	2 ppm

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## Ventilation Rate (VR) MSHA

- **MSHA and Canmet have different ways of calculating the Ventilation Rate**
- **MSHA calculates the ventilation rate per gas component**
  - NO
  - NO<sub>2</sub>
  - CO
  - CO<sub>2</sub>

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## Ventilation Rate (VR) canmet

- **Canmet prefer to use a weighted calculation of all the components, EQI, Exhaust Quality Index**

$$EQI = \frac{CO}{50} + \frac{NO}{25} + \frac{DPM}{2} + 1.5 \left[ \frac{SO_2}{3} + \frac{DPM}{2} \right] + 1.2 \left[ \frac{NO_2}{3} + \frac{DPM}{2} \right]$$

- **If needed a similar method to MSHA is used, selecting the highest**
- **Ventilation Rate determined by a single component.**

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# Particulate Index (PI) MSHA

- Since MSHA VR exclude Particulate measurements there is an addition to the existing VR, which is called Particulate Index, "PI"
- The particulate index is the dilution air quantity (**Qdpm**) needed to reduce exhaust DPM concentration to 1000 µg/m<sup>3</sup>

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## VR and PI, MSHA

- Every approved engine gets a VR and a PI for MSHA.
- In practice, the highest of the two will be the "used indication number" for that engine.

Find it in MSHA:

Mine Safety and Health Administration  
MSHA - Protecting Miners' Safety and Health Since 1970

\*\*Note: To determine whether or not this report will fit on a standard 8.5 x 11 sheet of paper, click the Print Preview. If you would like to print this form in landscape format, click the Page Setup.

[Expand this report to excel](#)

Approval Number	Engine Manufacturer	Model	HP @ RPM at 1000ft Elevation	Ventilation Rate CFM	Particulate Index CFM	DPM grams/hr weighted-hr	DPM grams/hr for 5.0 grams/hr weighted	Filter Eff. for 5.0 grams/hr	Filter Eff. for 2.5 grams/hr
07-ENA110017	CUMMINS	Q583.3	99 @ 2200	4000	4000	6.38	0.11	22	61
07-ENA120001	VOLVO PENTA	TAD 1363VE requires DEF	469 @ 1900	14000	3000	4.62	0.02	0	46
07-ENA120001	VOLVO PENTA	TAD 1364VE requires DEF	510 @ 1900	14500	2500	4.07	0.02	0	39
07-ENA120001	VOLVO PENTA	TAD 1365VE requires DEF	551 @ 1900	16500	3000	4.4	0.02	0	43

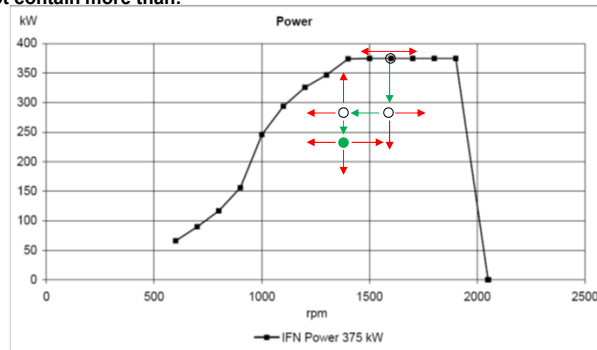
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# Test cycles canmet

## Rapid Toxic Gas Search

- The aim is to find the operating points with the highest NO<sub>x</sub> and CO concentrations
- The concentrations shall not contain more than:
  - 2500 ppm CO
  - 1500 ppm NO<sub>x</sub>
  - 150 mg/m<sup>3</sup> DPM



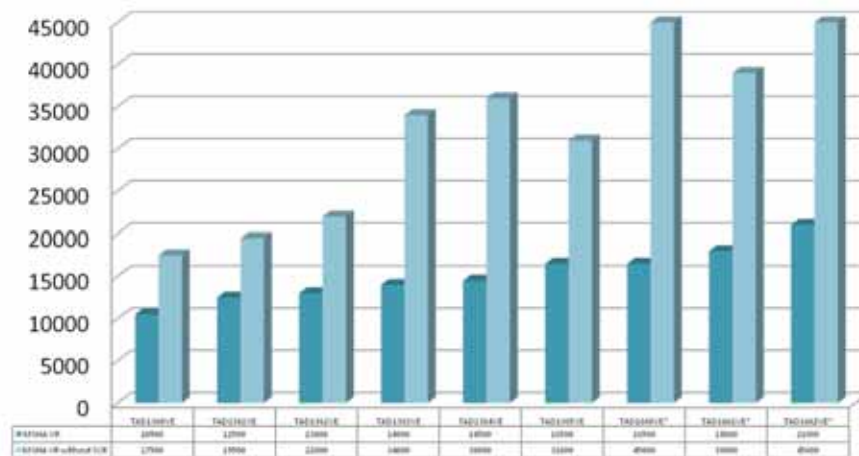
- For a Tier4f engine the test serves the purpose of finding these points and include them in the ventilation rate test (MAPTEST).

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# Ventilation rates Tier 4i

MSHA Ventilation Rates [cfm]

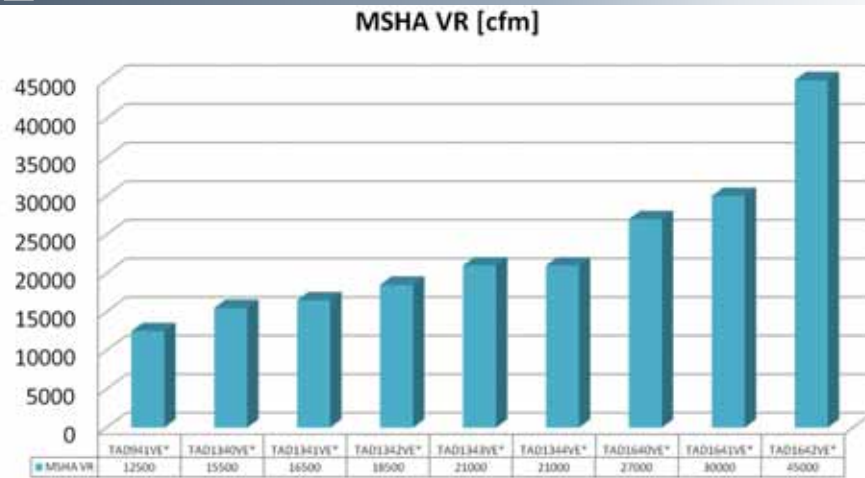


\*Official MSHA ventilation rate not received!

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# Ventilation rates Tier 2

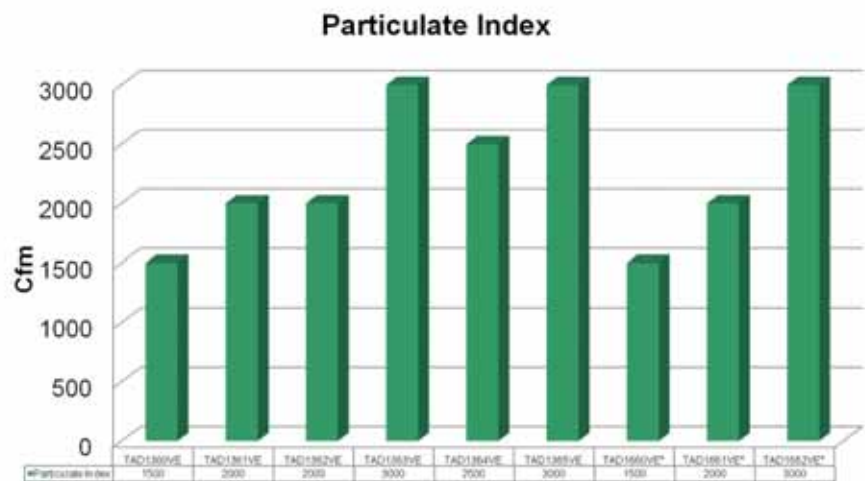


\*Official MSHA ventilation rate not received!

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27

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# Ventilation rates Tier 4i

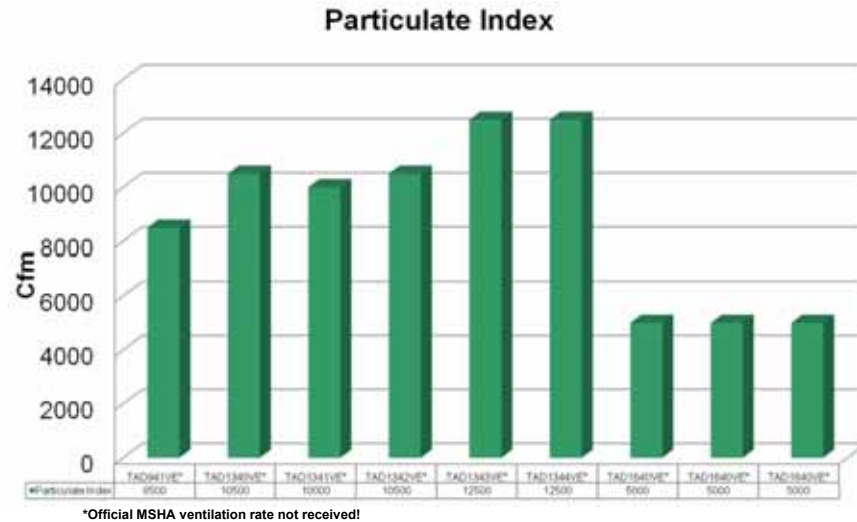


\*Official MSHA ventilation rate not received!

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28

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## Ventilation rates Tier 2



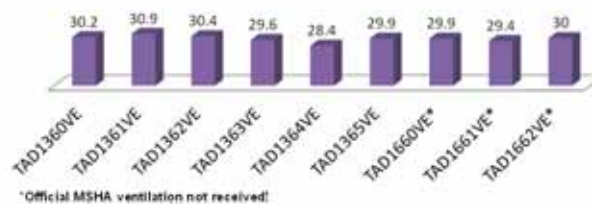
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## Ventilation rates/bhp (Tier 4i)

*To be able to compare various engines, the authorities use the unit [ventilation rate [cfm]/bhp] (MSHA)*

**MSHA [cfm/bhp]**

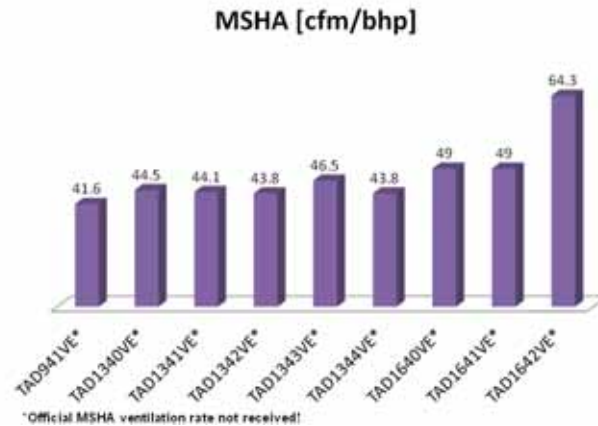


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# Ventilation rates/bhp (Tier 2)

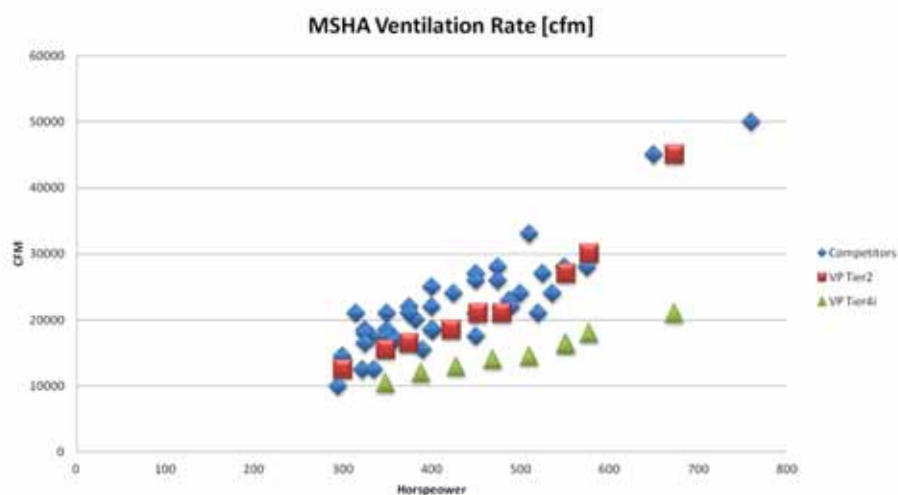
To be able to compare various engines, the authorities use the unit [ventilation rate [cfm]/bhp] (MSHA)



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# ventilation rates comparisons

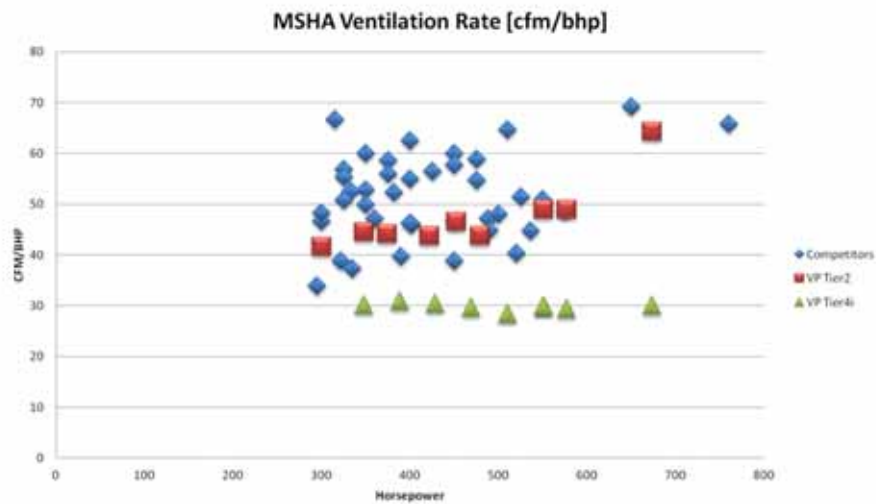


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32

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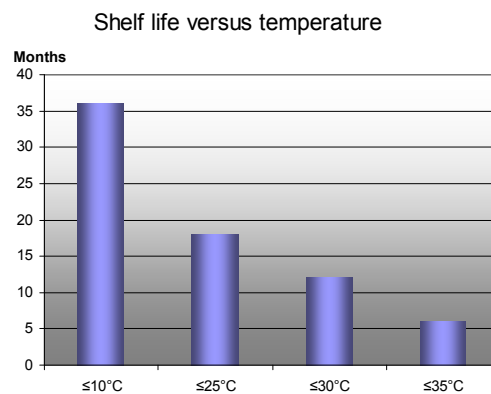
# ventilation rates comparisons



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33

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# DEF storage life

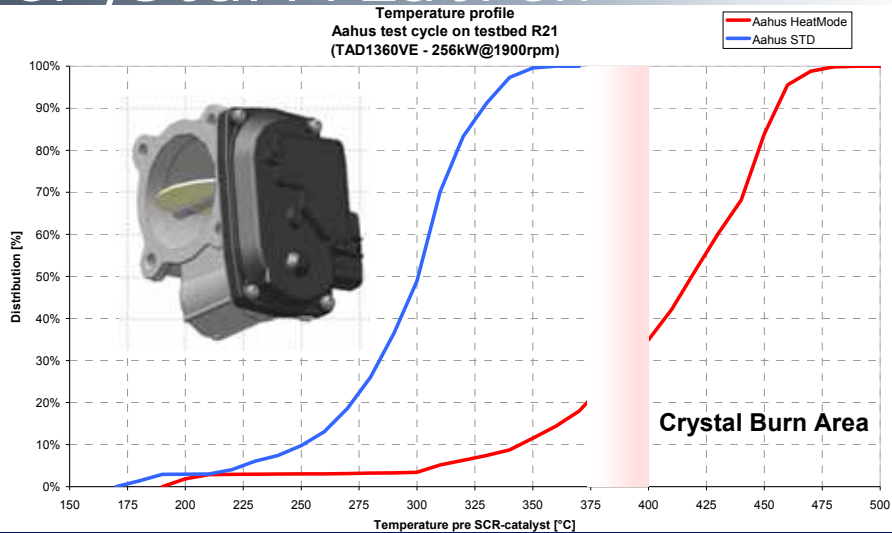


Source: ISO/DIS 22241-3

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34

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# Heat Mode eliminating crystallization



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35

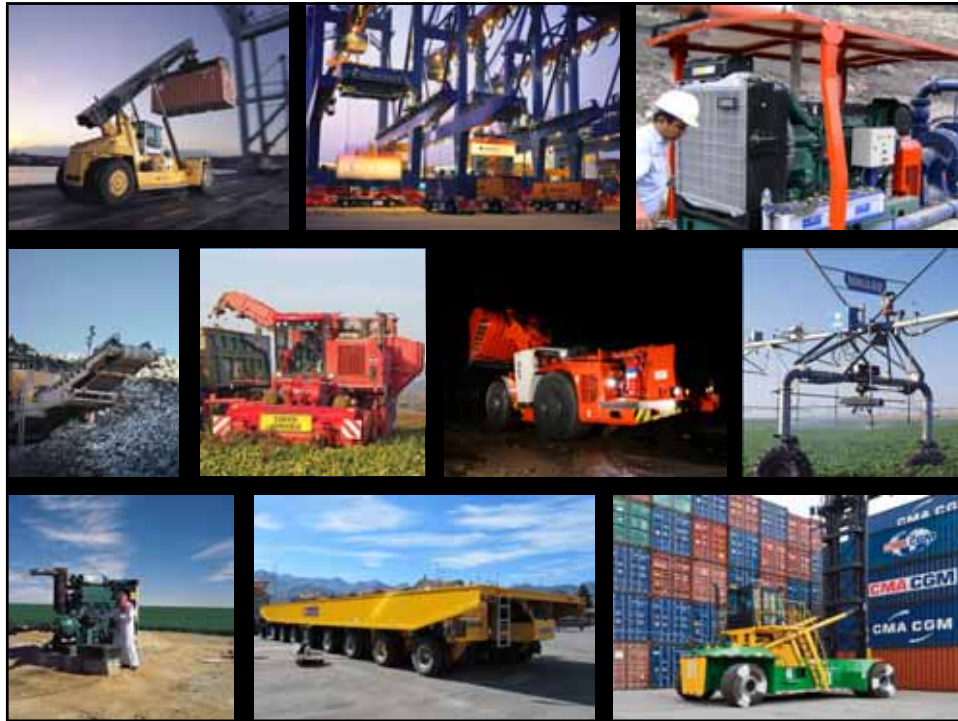
**VOLVO  
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## EU6 and stage V

- EU on-road Euro VI regulations introduce particle number limit - 2014
- EU commission have initiated discussions about Stage V but no legal draft is yet available
- New law expected to be published 2015, earliest
- Normal lead time for industry to comply is 5 years
- Stage V earliest by 2019
- Technology will change in the next 5 years

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***COMMITTED TO SUSTAINABLE PRODUCTIVITY***

We stand by our responsibilities towards our customers, towards the environment and the people around us. We make performance stand a test of time. This is what we call – Sustainable Productivity.

## CONTENT

General update about what has been done and what's ongoing

- Existing and coming legislations
- Engine info and cleaning technology



Atlas Copco

## SUSTAINABLE PRODUCTIVITY

Why do we do this?

- New legal demands in some countries
- Atlas Copco will commit to a sustainable environment
- Major mining houses outside of regulated areas start to request this to fulfill their companies environmental goals



Atlas Copco

## EXISTING AND COMING LEGISLATION

### Two different legislation is driving the development

- There is two different legislation/ratings existing
  - Europe (CE) is using the "Stage" ratings
  - US (Construction/EPA) is using the "Tier" rating
- They correspond accordingly:
  - Stage 3A = Tier 3
  - Stage 3B = Tier 4i
  - Stage 4 = Tier 4F
- Examples of other countries that don't belong to above regions but have same regulations as above are:
  - Japan
  - Israel
  - South Korea
- There are other legislations existing locally but are not corresponding to above:
  - US (Mining): MSHA
  - Canada: Canmet



## EXISTING AND COMING LEGISLATION

### Different power ratings has different dates

(Green=Current, red=has passed, Blue=will come)

- CE\*-directive 2004/26/EG (equal to US EPA\*)
  - Stage III A (EPA Tier 3)
    - 130 – 560 kW 2006-01-01
    - 75 – 130 kW 2007-01-01
    - 37 – 75 kW 2008-01-01
  - Stage III B (EPA Tier 4i)
    - 130 – 560 kW 2011-01-01
    - 56 – 130 kW 2012-01-01
    - 37 – 56 kW 2013-01-01
  - Stage IV (EPA Tier 4f)
    - 130 – 560 kW 2014-01-01
    - 56 – 130 kW 2014-10-01
  - Engines delivered to OEMs (Atlas Copco) before the effect date of the legislation may be used without any measures within CE. For EPA the term "with in reasonable time" is used.
  - Flexiplate allows limited usage of earlier Stage approved engines within CE.
  - Main source for knowledge about regional emission demands: [www.dieselnet.com](http://www.dieselnet.com)

\*) CE = European community  
EPA = U.S. Environmental Protection Agency



## GLOBAL REGULATIONS AND EXPECTATIONS

### Global Emissions Regulations.



Estimation done by Cummins Inc. Marked with \* is expected to happen

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## EXISTING AND COMING LEGISLATION

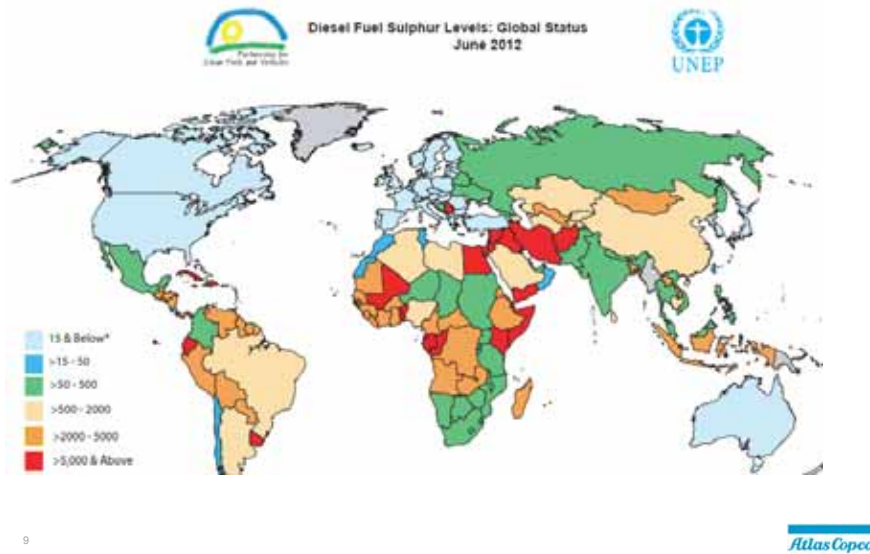
### Global sales of clean engine??

- It is allowed for a Customer Centre to offer a higher (cleaner) rating of the engine than the demands in that country but its up to the local Customer Centre to make sure that the demanded fuel quality is offered and available in that country.
- For Example a Stage 3B/Tier 4i or Stage 4/Tier 4F engine will demand a sulfur ratio below 15 ppm compared to a Stage 3A/Tier 3 engine that demands a ratio below 5000 ppm or percentage of weight, e.g. 0.05 % to 0.50% as per CANMET ratings
- This engines also need engine oils of "low ash" type. For example Deutz class DQC III **LA** or DQC IV **LA**.



Atlas Copco

## ULTRA LOW SULPHUR FUEL STATUS



## EXISTING AND COMING LEGISLATION

### Global sales of clean engine??

- The Customer Centre also needs to inform the customer that the Stage 3B/Tier 4i technique is based on a particle filter in the larger engines (115kw and upwards). When this filter is full it needs to be clean burned or otherwise the engine will downgrade the power and the machine will be extremely slow on tramping speed. Stage 3B/Tier 4i engine below 115kw has only catalyzer and not above process
- The clean burning has to be done approximately around every sixth engine hour for a Stage 3B/Tier 4i. The burning process takes approximately 20-30 minutes and needs a hot engine to do so. If the engine is shut down under this period the process has to start all over again.



- The Stage 4/Tier 4F engines will have a "simpler" burning process due to that they will be burning the filter continuously. The disadvantage with the Stage 4/Tier 4F engines is that they need Urea/Adblue. It is Customer Centre's responsibility to check that Urea/Adblue is available in the country before offering Stage 4/Tier 4F engines to the customer
- The CC also has to check with local dealers that they have been trained on these new engine types.



## EXISTING AND COMING LEGISLATION

How do AC handle machines with old engines when higher cleanliness is required?



- Its not possible to be ready with the engine change project to the start date of the new legislation due to possibility that engine supplier are not ready with their design in advance to the start date. When that happens their is two different way of supply "old" engines legally.
- **Pre-buy:** AC has ordered the engine from the supplier and got it delivered to our factory before the start date of the new legislation. This engine is allowed to deliver in any machine without any time limit (CE) even after the new legislation has started (or within reasonable time for the EPA regulations).
- **Flexiplate:** With in CE there is a system with an number of "exception-licenses". That means that AC for example receive 100 flexiplate ("exception-licenses") for the "36-55kw range" before the legislation starts. AC are then allowed to deliver 100 machines with an engine of the previous Stage-rating in the new legislation period but the engine can be purchased from the engine supplier even after the start date of the new legislation.
- **Combination of Pre-buy and Flexiplate:** To be able to meet Stage 4/Tier 4F regulations there is a possibility to combine above alternative (certain limitation exists). For example a *Pre-buy Stage 3A (bought during the 3B period)* engine together with a *flexiplate* is OK for Stage 4/Tier 4F.



## ENGINE INFO AND CLEANING TECHNOLOGY

12



## ENGINE INFO AND CLEANING TECHNOLOGY

### Available technics for Stage IIIB, Tier 4i

- **Exhaust Gas Recirculation, EGR**

Cooled exhaust gas reenters the cylinder in order to reduce  $\text{NO}_x$

- **Diesel Oxidation Catalyst, DOC**

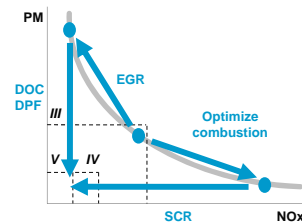
Converts carbon monoxide CO, hydrocarbons HC, and Nitrogen oxide NO into carbon dioxide  $\text{CO}_2$  and water.

- **Diesel Particulate Filter, DPF**

Filters about 99% volume of the Particulate matters, carbon monoxide CO, and hydrocarbons HC  
During regenerating PM are converted in carbon dioxide  $\text{CO}_2$  and ash

- **High Pressure Common Rail Fuel Systems**

Extremely sensitive to contamination (dirt) and water in the fuel system.



- **SCR - Selective Catalytic Reduction**

The Nitrogen oxides  $\text{NO}_x$  are chemically reduced to Nitrogen  $\text{N}_2$  and water vapor in a special catalyst.

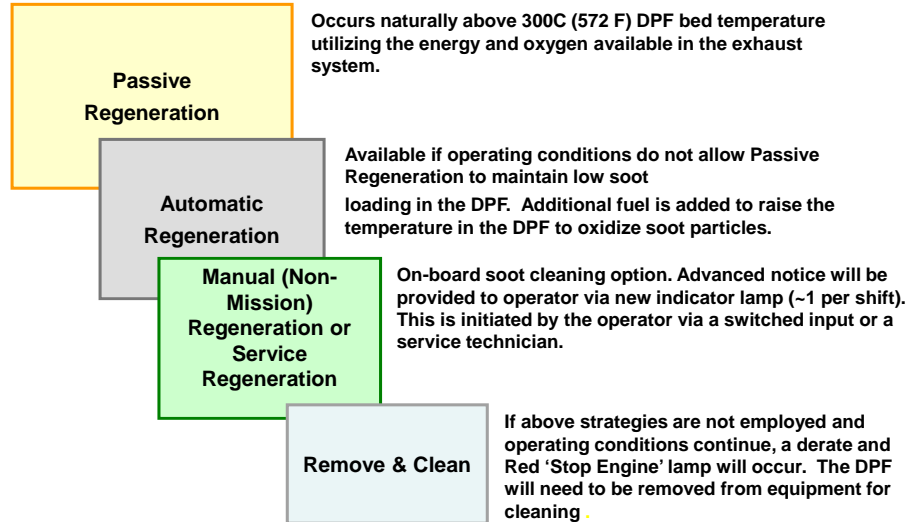
## REGENERATION MODES

- **Passive Regeneration** – Once soot accumulates to a certain level, the soot accumulation rate is balanced by a natural oxidation of collected soot.

- **Active Regeneration** – There are three different types of active regeneration.

- **Automatic Regeneration** – This occurs during “in mission” machine operation. Based on the inputs to the DPF, the control system will initiate automatic regeneration when necessary.
- **Manual (Non-Mission) Regeneration** – This is initiated by the operator via a switched input when the system has not been able to perform automatic regeneration during “in mission” operation. This mode of regeneration is only possible when the machine is “out of mission” and meet the configured entry conditions.
- **Service Regeneration** – This is done by a trained service technician

## DPF REGENERATION STRATEGY

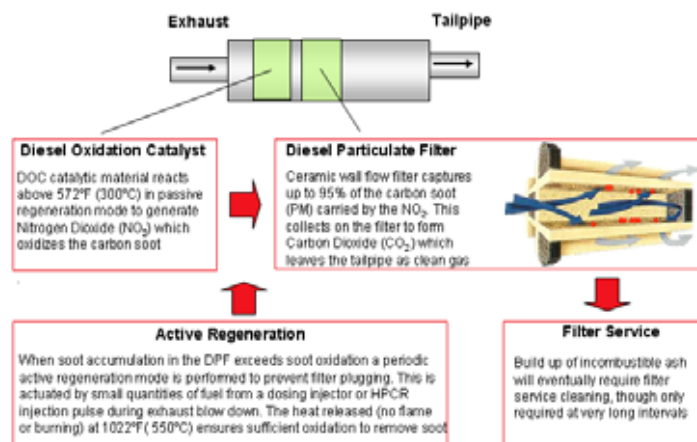


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## STAGE IIIB/TIER4I DPF

### How The DPF Works



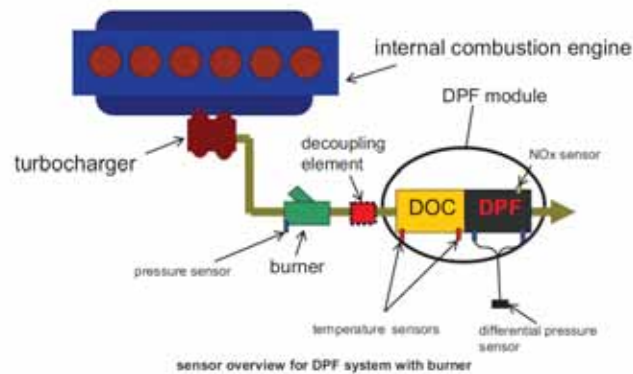
16

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## ENGINE INFO AND CLEANING TECHNOLOGY

Deutz selected technology for stage 3B, Tier 4i, larger engines

### Basic Principle of active DPF Regeneration System

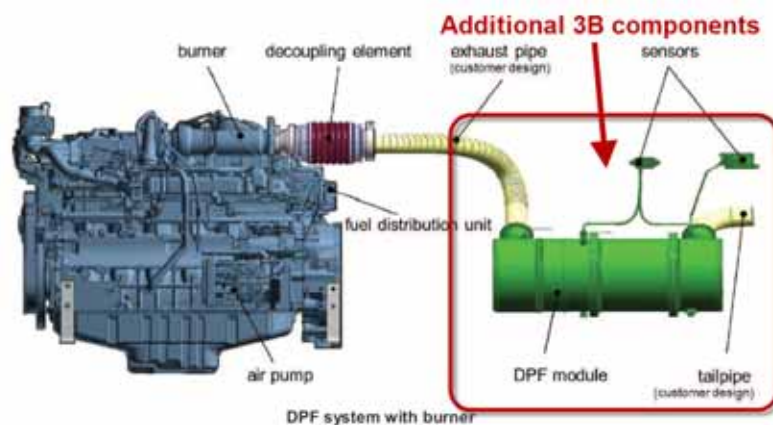


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17

## ENGINE INFO AND CLEANING TECHNOLOGY

Additional components on a Stage 3B, Tier 4i, larger engines

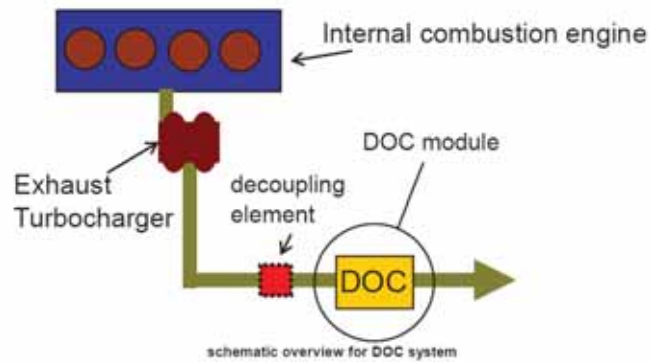


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## ENGINE INFO AND CLEANING TECHNOLOGY

Deutz selected technology for stage 3B, Tier 4i, smaller engines



## ENGINE INFO AND CLEANING TECHNOLOGY

Additional components on a Stage 3B, Tier 4i smaller engines



## INTRODUCTION

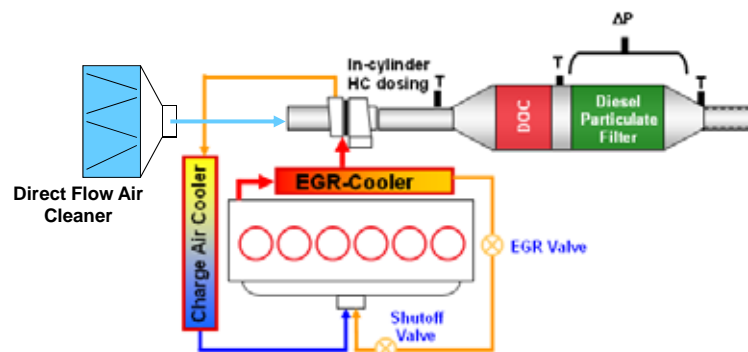
- During typical operation the Cummins Particulate Filter oxidizes collected particulate matter using only the energy and oxygen available in the engine exhaust.
  - Under these conditions, typically, the surface temperatures of the outer body of DPF will not exceed 400° C (752° F).
- However, when automatic regeneration is required, the system will intentionally elevate exhaust temperatures in order to create the conditions needed to oxidize the particulate matter.
  - These temperatures are higher than those normally encountered for the equivalent duty cycle.
  - OEM equipment design provisions are required to ensure that the higher temperatures have no adverse effects on equipment systems, bystanders or environment in the vicinity of the exhaust system components and outlet.
  - These temperatures may occur for extended periods of time up to 40 minutes.

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## STAGE IIIB/TIER 4 INTERIM ARCHITECTURE

- CEGR for NO<sub>x</sub> reduction
- Regenerating particulate filter (DPF) for PM reduction



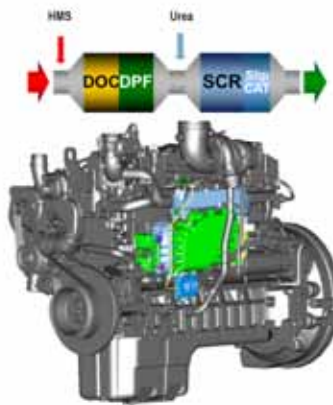
22



## ENGINE INFO AND CLEANING TECHNOLOGY

### Deutz selected technology for stage 4, Tier 4F

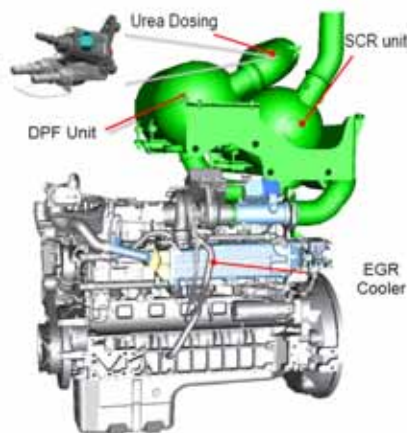
- Additional SCR with Urea additive for continually burning the filter (no burning brakes as on 3B/4i)



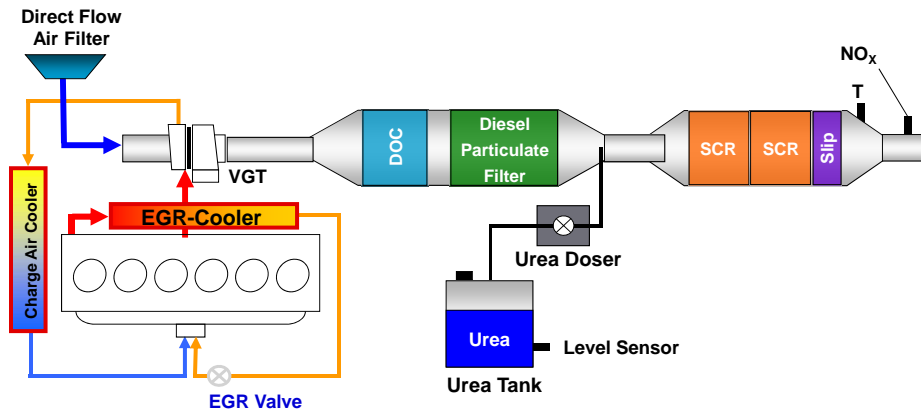
## ENGINE INFO AND CLEANING TECHNOLOGY

### Additional components on a Stage 4, Tier 4F

- Two boxes on top of engine compared with one on Stage 3B/4i
- Additional Urea tank and pump



## STAGE IV/TIER 4 FINAL SOLUTION



25



## STAGE IV/TIER4 FINAL SOLUTION

EcoFit by Cummins Emission Solutions leverages innovative designs to improve aftertreatment integration & performance



### Diesel Oxidation Catalyst (DOC)

Achieves required PM reduction and operates in passive only mode

### Selective Catalytic Reduction (SCR)

Reduces NOx emissions to near-zero levels through robust, extruded SCR substrate for maximum reduction & performance

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## LOW DEF CONSUMPTION

Subtitle Arial Bold 18 pt (copy and paste this text)

- Latest generation SCR system for Tier 4 Final enables an average DEF dosing rate of just 3% to fuel used
  - Dosing rate is determined by duty-cycle



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## STAGE IV/ TIER4F DIESEL EXHAUST FLUID

- DEF will be required for StageIV/Tier4F Engines
- DEF (or AdBlue) is a solution of 32.5% high purity urea and 67.5% deionized water
- Acts as a reactant to deliver ammonia to the SCR catalyst
  - Safe, stable and easy to handle:
    - Non-toxic
    - Non-polluting
    - Non-flammable
    - Non-hazardous
  - AirShield™ DEF available Cummins Filtration



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## ADVANTAGES OF NEW TECHNOLOGY ENGINES

- Lower Ventilation Requirements
- Reduced Emission  
90 percent reduction in Particulate Matter (PM) & Nitrogen Oxides (Nox)
- Reduced Fuel Consumption
- High Pressure Fuel System for Improved engine Response
- MSHA / CANMET Approved, On going testing still being done
- Lower Operational Cost

*All of the above mean improved conditions underground for personnel*

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## CHALLENGES FOR NEW TECHNOLOGY ENGINES

- Operator awareness regarding Regeneration and what happens if it does not happen as scheduled
- What are the effects of excess idling and low load conditions
- Will operation cycles for different equipment provide required loads for Regeneration? Some units have short peak loads and run below 50% load most of the time
- Hot surface Protection,
  - some sites prefer additional protection in terms of wraps and coatings. This is not possible with higher Stage and Tier engines.
  - Will there be changes required to protection and procedures due to higher surface temperatures during forced regeneration
- Additional requirements for operators and technicians, making sure DEF fluids are filled, checking back pressures, servicing DPF units
- How to effectively add technology to lower Stage/Tier engines, not to make them in higher levels, but to provide lower particulate emission

30







# Clearly Better.

Cummins Off-Highway Capability



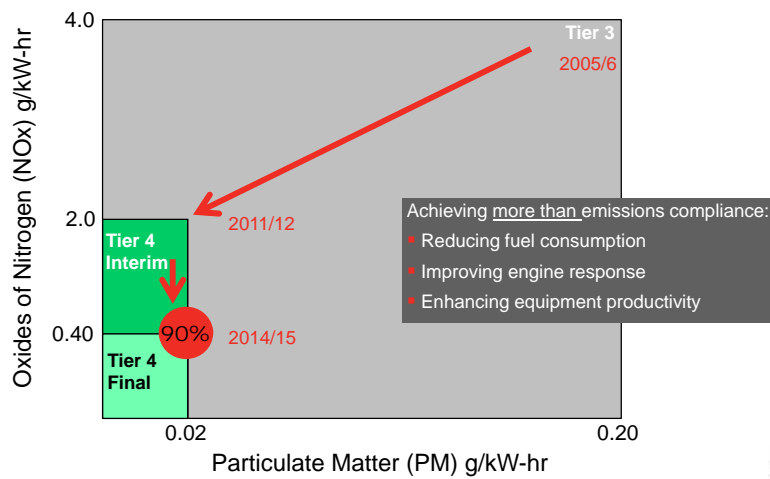
# Clearly Better.

Meeting Near-Zero Emissions



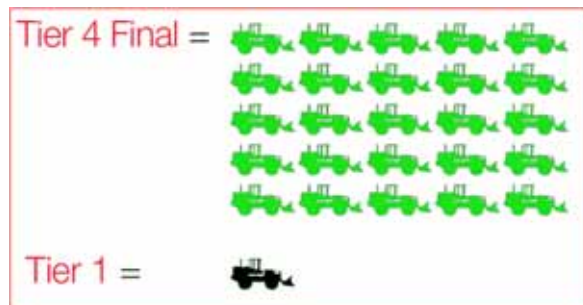
## Meeting 'Near-Zero' Emissions

A 90 percent reduction in PM & NOx emissions to 'near-zero' levels



## Meeting 'Near-Zero' Emissions

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



## Off-Highway Emissions

Staggered effect dates – EPA recognizes challenge meeting a much broader power range than on-highway



**2012**

All Above 74 HP Now At **Tier 4 Interim**

**2013**

Below 74 HP Moves To **Tier 4 Final**

**2014**

174-751 HP Moves To **Tier 4 Final**

**2015**

75-173 HP Moves To **Tier 4 Final**

Over 751 HP Moves To **Tier 4 Final**

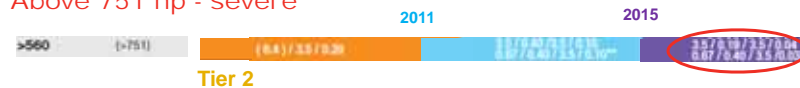
## Differing Emission Levels



Above 74 hp – most severe



Above 751 hp - severe



Below 49 hp – less severe



## Skid Steer To A Mine Haul Truck

- Cummins off-highway portfolio for mobile equipment spans a 49 to 4200 horsepower range
- From 2.8-liters to 95-liters

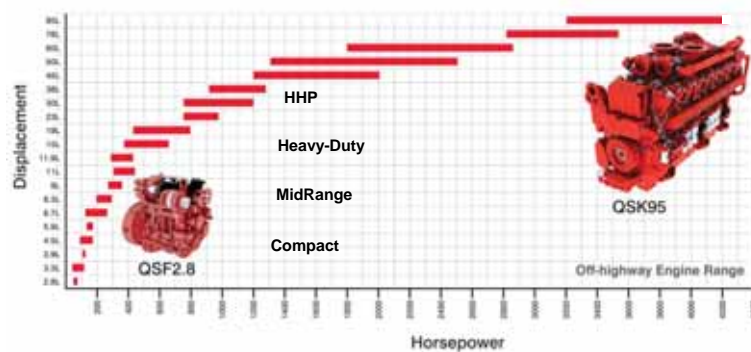


Clearly  
Better.



## Broad Engine Range

Cummins is ready for Tier 4 Final all the way from 2.8 to 95-liters with the 'right technology' for each power band



Clearly  
Better.



## A Huge Diversity Of Equipment

- Powering hundreds of OEMs
- Widest range of applications in the industry
- Unrivalled experience of duty cycles & load factors



Clearly  
Better.



## Building On Strong Technology

Cummins off-highway utilizes our proven on-highway technology – a major advantage



Application	Date	In-Cylinder only	Cooled EGR	NOx Adsorber	SCR	Diesel Particulate Filter	Compost Catalyst (DOC)
Tier 3 / Stage IIA 60-751 hp	2005	•					
Tier 2 751+ hp	2006	•					
Euro 4/5 On-Highway	2006/2009				•		
EPA 07 On-Highway	2007		•			•	
EPA 07/10 Pickup Truck	2007		•	•		•	
EPA 10 On-Highway	2010		•		•	•	
Tier 4 Interim/ Stage IIB 174-751 hp	2011		•			•	
75-173 hp	2012		•				•
Euro 6 On-Highway	2013		•		•	•	
Tier 4 Final/ Stage IV 40-74 hp	2013						•
75-400 hp	2014/2015		•		•	•	•
400-751 hp	2014		•		•	•	
751+ hp	2015				•		

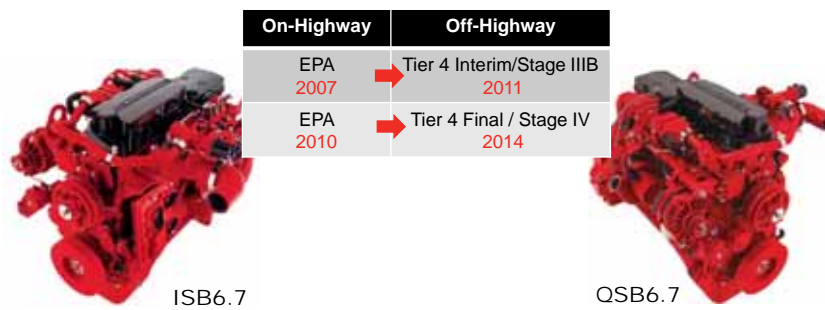
Clearly  
Better.





## Leveraging On-Highway

- Preceding on-highway experience allows Cummins to leverage proven base engines & technology for later off-highway use
- With the technology solution validated - we can focus on optimizing for off-highway applications and duty-cycles

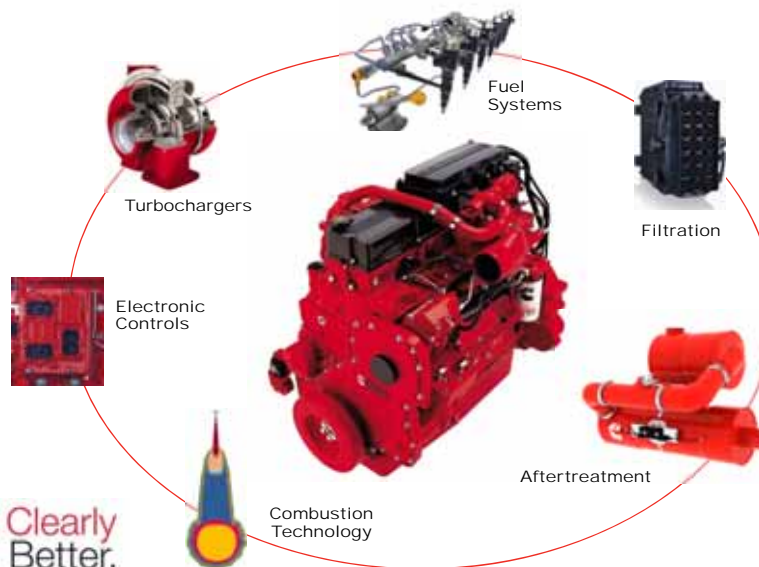


Clearly  
Better.



## System Integration

Cummins design, build & integrate the complete Tier 4 system from air-intake to exhaust





# Clearly Better.

Tier 4 Final Products 49-675 hp



Tier 4 Final: 49-173 hp

QSF2.8	QSF3.8	QSB4.5
49-74 hp 37-55 kW	85-130 hp 63-97 kW	121-173 hp 90-129 kW
Cummins Direct Flow™ Air Cleaner 3.8-Liter 4-Cylinder	Cummins Direct Flow™ Air Cleaner 3.8-Liter 4-Cylinder	Cummins Direct Flow™ Air Cleaner 4.5-Liter 4-Cylinder
		
Cummins Compact Catalytic Converter	Cummins Selective Catalytic Reduction	Cummins Compact Catalytic And Selective Catalytic Reduction

Clearly Better.



Tier 4 Final: 146-400 hp

**QSB6.7**

146-310 hp  
109-231 kW

Cummins  
Direct Flow™  
Air Cleaner



6.7-Liter  
6-Cylinder



Cummins  
Compact Catalyst  
And Selective  
Catalytic Reduction



**QSL9**

250-400 hp  
186-298 kW

Cummins  
Direct Flow™  
Air Cleaner



9-Liter  
6-Cylinder



Cummins  
Compact Catalyst  
And Selective  
Catalytic Reduction



Clearly  
Better.



Tier 4 Final: 335-675 hp

**QSG12**

335-512 hp  
250-382 kW

Cummins  
Direct Flow™  
Air Cleaner



12-Liter  
6-Cylinder



Cummins  
Particulate Filter  
And Selective  
Catalytic  
Reduction



**QSX15**

450-675 hp  
336-503 kW

Cummins  
Direct Flow™  
Air Cleaner



15-Liter  
6-Cylinder



Cummins  
Particulate Filter  
And Selective  
Catalytic  
Reduction

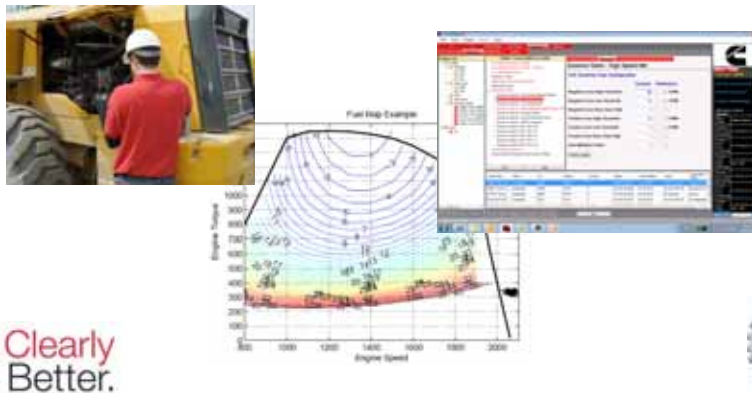


Clearly  
Better.



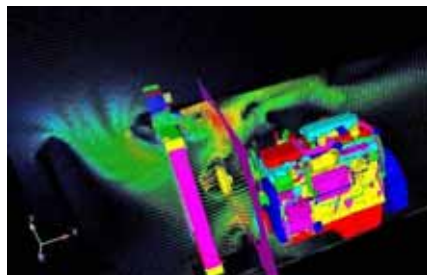
## Machine Integration

- We analysis specific duty cycles and identify opportunities to improve equipment performance & reduce fuel consumption
- 'Stop-Go' and torque shaping features created for the specific machine duty cycle



## Pre-designed For Final: Same Cooling

- Minimal or no change to equipment cooling package size moving from Tier 4 Interim to Final
- Heat rejection decrease with lower EGR flow balances  
small CAC heat rejection increase
- Advantage of using cooled EGR at Interim



Clearly  
Better.



## Selective Catalytic Reduction (SCR)

1,000,000+

- SCR systems supplied by CES since 2005 Euro 4
- Leveraging 26 billion miles of on-highway experience
- Cummins Emission Solutions industry leading expertise in catalyst coatings and system interactions



Diesel Oxidation Catalyst (DOC)

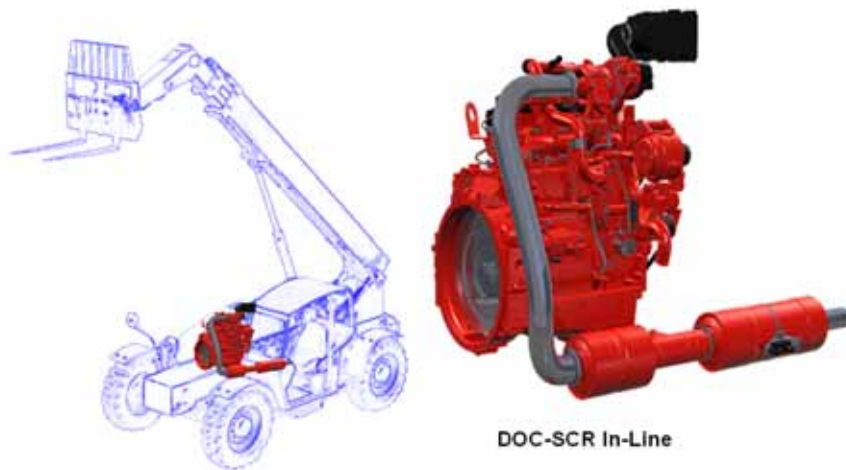
Selective Catalytic Reduction (SCR)

Clearly Better.



## Tier 4F: Aftertreatment Configurability

- Easier packaging without the compromise of a 'one-box' approach



DOC-SCR In-Line

QSB4.5 Example

Clearly Better.



### Tier 4F: Aftertreatment Configurability

- Custom fitted to the application



QSB6.7 Example

DOC-SCR U-Shape



Clearly  
Better.



### Tier 4F: Aftertreatment Configurability

- Adaptive to the machine envelope

DOC-Vertical SCR



QSL9 Example



Clearly  
Better.

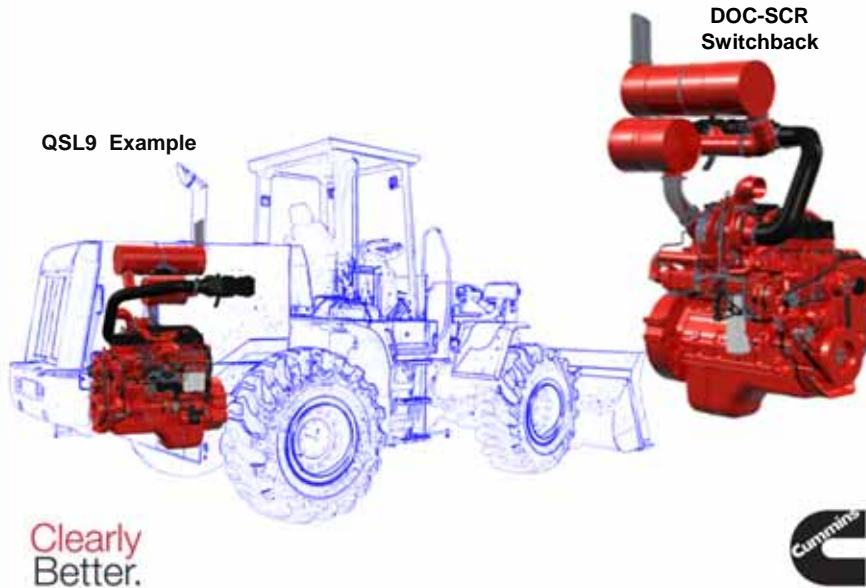




### Tier 4F: Aftertreatment Configurability

- Making most effective use of the available real estate

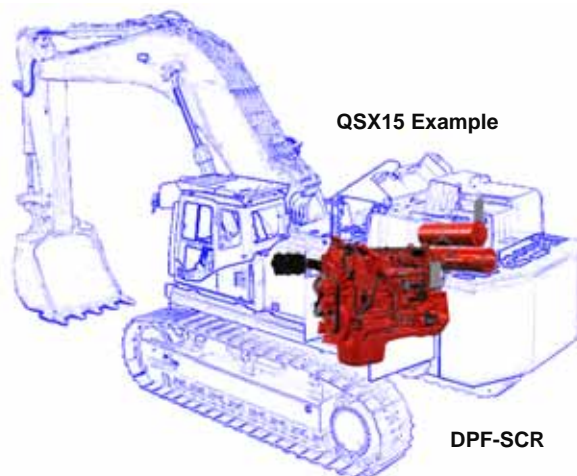
QSL9 Example



### Tier 4F: Aftertreatment Configurability

- Fully integrated with the engine

QSX15 Example



## Ready For More Uptime

- Cummins 'Expert Diagnostics System' (EDS) has introduced a rapid repair capability with a user-friendly approach over the last year
- Intuitively looks for previous diagnostics & repair for a specific fault
- Single tool for all Cummins electronic engines & aftertreatment



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Clearly  
Better.



## Tier 4 Final Field Test

200,000+

- Test hours to be accumulated by Cummins Tier 4 Final field test program
- Over 70 machines generating hours across many different applications
- Achieving uptime availability equivalent to Tier 3 engines



Clearly  
Better.








# Clearly Better.

Looking Ahead To Potential  
Future Emissions





## Proposed EU Stage V

Stage V now looks near certain for the EU

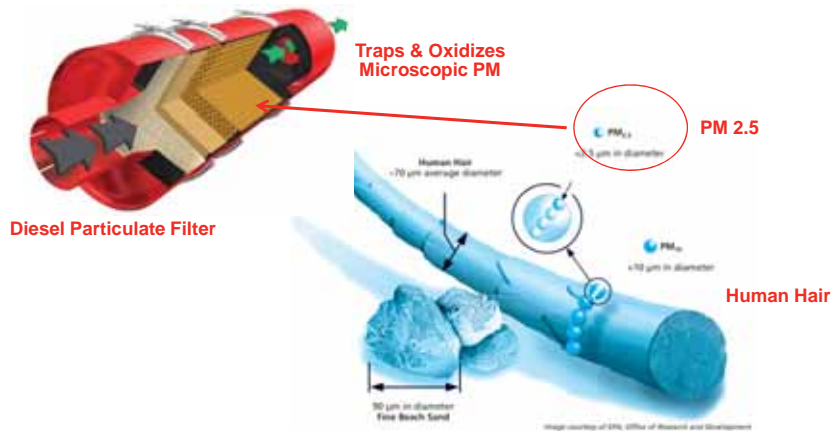


**EU NRMM Amended**

- Over 751 hp now included
- EU will require a new emission standard called Particle Number (PN) standard
- PN count standard would force the use of Diesel Particulate Filters (DPF) for 25-751 hp construction engines
- Particulate Matter (PM) mass standard will be lowered for Stage V compared to Stage IV
- Earliest likely date 1.1.2019



## Diesel Particulate Filter



Clearly  
Better.



## EPA Tier 5 ?

- The consensus in the engine industry is that the **EU** is ahead of the **EPA** with regard to PM count
- Over 751 hp already included in EPA Tier 4 Final for 1/1/2015
- It could be assumed that **any future Tier 5** will also focus on reducing greenhouse gases
- Tier 5 debate remains in its infancy – but Cummins has **initiated** technology planning



Clearly  
Better.



## Ready For Future Emissions

- Diesel Particulate Filter (DPF) is the only way of removing microscopically small PM below 2.5 micron - so reducing PN count to meet a PN standard
- Cummins next generation DPF design will achieve this
- Work underway to increase catalyst efficiency and a major reduction in aftertreatment size



Clearly  
Better.



Clearly  
Better.

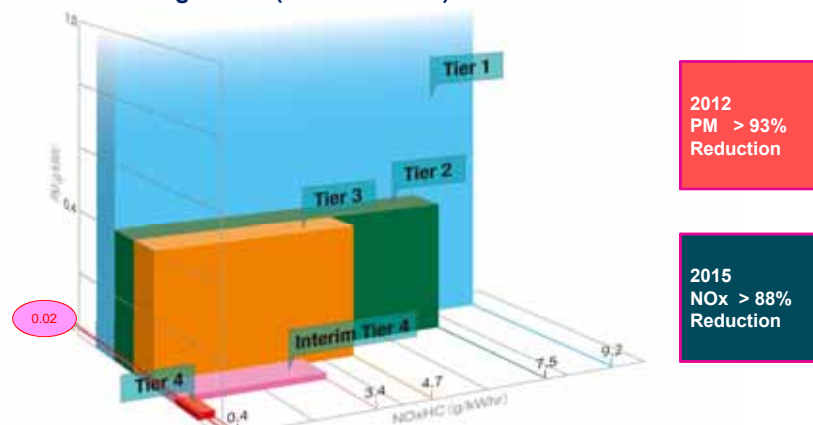
## KUBOTA'S T4 AFTER TREATMENT SOLUTION

MDEC Workshop  
October 7<sup>th</sup> 2014

For Earth, For Life  
**Kubota**

## Tier 4 / Int. Tier 4 Regulation & ATD Introduction

EPA Emission Regulation (56 kW-130 kW)



After treatment systems are necessary to meet Tier4 / Int.Tier4 regulation.

## Tier 4 / Int. Tier 4 Regulation & ATD Introduction

### KUBOTA's Solutions to meet EPA Emission Regulation

Model Year	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Power Range											
8 ≤ kW < 19				Engine Optimization (Same Engine Outline)							
19 ≤ kW < 37									CRS + EGR +(DPF) +(Turbo)		
37 ≤ kW < 56		Engine Optimization Closed Breather (Same Engine Outline)		Engine Optimization							
56 ≤ kW < 75				* Mechanical Timer , EGR , Turbocharger				CRS + EGR +DPF		de-NOx	
75 ≤ kW < 130								CRS , EGR , Intercooler			

**DOC (Diesel Oxidation Catalyst) with or without DPF (Diesel Oxidation Filter)**

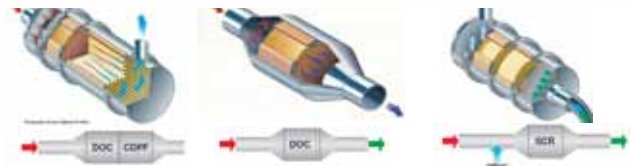
## Tier 4 / Int. Tier 4 Regulation & ATD Introduction

### After Treatment Solutions

No.	Name of ATD		PM	NOx	CO	HC	Configuration	Regeneration
1	DOC (Diesel Oxidation Catalyst)	Function	Oxidize	Oxidize	Oxidize	Oxidize	Flow Through	Passive Only
		Effect	* approx. 10-30%					
3	DOC + DPF (Diesel Particulate Filter)	Function	Oxidize & Trap	Oxidize	Oxidize	Oxidize	Wall Flow	Passive Active
		Effect	* approx. over 90%					
4	SCR (Selective Catalytic Reduction)	Function	None	Reduction	None	None	Dosing Urea Components	None
		Effect						

<Remarks>

\* Reference from Johnson Matthey homepage



**KUBOTA "DOC+DPF" solution is the most reliable and will work under all load conditions.**

## Differences between “DOC” and “DOC+DPF”

System	DOC + DPF	DOC Only
Basic Concept	PM is decreased by After Treatment Device	PM is decreased by combustion
Configuration	Wall Flow	Flow Through
PM Trap	Used	Not Used
Typical PM Reduction	Over 90%	10-30%
Regeneration	Passive / Active	Passive
* EPA Certification 56-130kW (-2012)	PM Emission	0.02 g/kw-hr
	PM Certificate	0.02 g/kw-hr

### ★ DOC Solution

PM is decreased by improving combustion with high pressure CRS, Variable Gate Turbo and Intercoolers  
DOCs reduce less PM than DOC+DPF.  
Kubota DOC T4F engines will require an intercooler

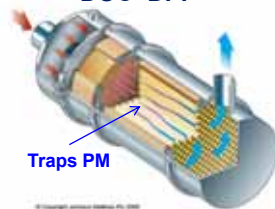
### ★ DOC+DPF Solution

Balanced PM and NOx are exhausted by optimized combustion.  
After Treatment traps over 90% of PM  
Kubota T4F engines do not require an intercooler

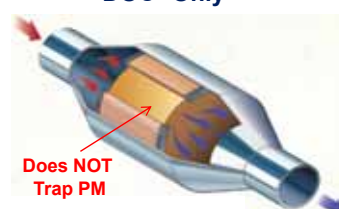
## Differences between “DOC” and “DOC+DPF”

System	DOC + DPF	DOC Only
Basic Concept	PM is decreased by ATD ( Over 90% PM is trapped by DPF )	PM is decreased by improving combustion (Using high-tech devices)
Configuration	Wall Flow	Flow Through
PM Trap	Used	Not Used
Typical PM Reduction	Over 90%	10-30%
Regeneration	Passive / Active	Passive
* EPA Certification 56-130kW (-2012)	PM Emission	0.02 g/kw-hr
	PM Certificate	0.02 g/kw-hr

DOC+DPF



DOC Only



## Differences between “DOC” and “DOC+DPF”

System	DOC + DPF	DOC Only
Basic Concept	PM is decreased by ATD ( Over 90% PM is trapped by DPF )	PM is decreased by improving combustion (Using high-tech devices)
Configuration	Wall Flow	Flow Through
PM Trap	Used	Not Used
Typical PM Reduction	Over 90%	10-30%
Regeneration	Passive / Active	Passive
* EPA Certification 56-130kW (-2012)		
PM Emission	0.02 g/kw-hr	0.02 g/kw-hr
PM Certificate	0.02 - 0.001 g/kw-hr	0.02 g/kw-hr

### DOC+DPF

#### Wall Flow

- ①Able to trap PM
- ②Able to oxidize PM (SOF) & PM (soot)



### DOC Only

#### Flow Through

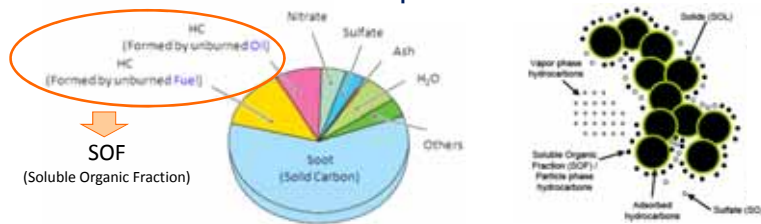
- ①Unable to trap PM (soot)
- ②Able to oxidize PM (SOF)



SOF=Soluble Organic Fraction

## Differences between “DOC” and “DOC+DPF”

### Make up Structure of PM



#### ★ DOC

DOC can not oxidize soot.  
Soot passes through the DOC.  
The DOC can reduce SOF which is part of PM.  
Some soot flows out into the atmosphere.

#### ★ DOC+DPF

DPF can reduce(oxidize) soot and SOF.

## Differences between “DOC” and “DOC+DPF”

System	DOC + DPF	DOC Only
Basic Concept	PM is decreased by ATD ( Over 90% PM is trapped by DPF )	PM is decreased by improving combustion (Using high-tech devices)
Configuration	Wall Flow	Flow Through
PM Trap	Used	Not Used
Typical PM Reduction	Over 90%	10-30%
Regeneration	Passive / Active	Passive
* EPA Certification 56-130kW (-2012)		
PM Emission	0.02 g/kw-hr	0.02 g/kw-hr
PM Certificate	0.02 - 0.001 g/kw-hr	0.02 g/kw-hr

### Passive Regeneration

Passive regeneration is an automated regeneration system using only the exhaust gas stream without additional energy such as post injection.

*The exhaust gas temp. typically must be above 250°C to keep passive regeneration.*

### Active Regeneration

Typical active regeneration occurs when there insufficient heat in the exhaust gas to oxidize PM being collected in the DPF.

Active regeneration is automatically controlled by ECU.

*Exhaust temp. is raised by injecting a small amount of fuel (Post injection) into the DOC.*

The resulting chemical reaction over the DOC raises exhaust gas temperatures high enough to oxidize the carbon from the filter.

*This is all done without any operator intervention / automatic.*

## Differences between “DOC” and “DOC+DPF”

System	DOC + DPF	DOC Only
Basic Concept	PM is decreased by ATD ( Over 90% PM is trapped by DPF )	PM is decreased by improving combustion (Using high-tech devices)
Configuration	Wall Flow	Flow Through
PM Trap	Used	Not Used
Typical PM Reduction	Over 90%	10-30%
Regeneration	Passive / Active	Passive
* EPA Certification 56-130kW (-2012)		
PM Emission	0.02 g/kw-hr	0.02 g/kw-hr
PM Certificate	0.02 - 0.001 g/kw-hr	0.02 g/kw-hr

### DOC+DPF

#### DOC Function

-- Passive Condition --

→ Requires temps above 250°C \*

1. HC & CO reduction
2. NO conversion to NO<sub>2</sub>
3. PM (SOF) reduction

-- Active Condition --

→ Requires additional fuel injection (post injection)

1 - 3 are same as passive condition.

4. Raises exhaust temp. to around 600°C

\*Typical requirement

### DOC Only

#### DOC Function

-- Passive Condition --

→ Requires temps above 250°C \*

1. HC & CO reduction
2. PM (SOF) reduction



## Differences between “DOC” and “DOC+DPF”

System	DOC + DPF	DOC Only
Basic Concept	PM is decreased by ATD ( Over 90% PM is trapped by DPF )	PM is decreased by improving combustion (Using high-tech devices)
Configuration	Wall Flow	Flow Through
PM Trap	Used	Not Used
Typical PM Reduction	Over 90%	10-30%
Regeneration	Passive / Active	Passive
* EPA Certification 56-130kW (-2012)		
PM Emission	0.02 g/kw-hr	0.02 g/kw-hr
PM Certificate	0.02 - 0.001 g/kw-hr	0.02 g/kw-hr

### DOC+DPF

#### DPF Function

- Passive Condition --
- Requires temps above **250°C \***
- 1. Trap PM
- 2. PM (Soot) reduction by **NO<sub>2</sub>**
- Active Condition --
- Requires temps around **600°C**
- 1. Trap PM
- 2. PM (Soot) reduction by **NO<sub>2</sub> & O<sub>2</sub>**

\*Typical requirement

### DOC Only

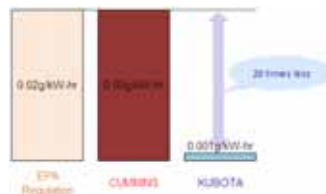
#### DPF Function N/A

< NOTE >  
 Oxidation by **NO<sub>2</sub>**  
 Temperature: Over 250°C  
 Effect :  
 Oxidation by **O<sub>2</sub>**  
 Temperature: Around 600°C  
 Effect :

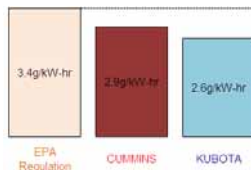
## Differences between “DOC” and “DOC+DPF”

**Certification Data:** “Cummins 3.3L with DOC only” VS “KUBOTA 3.8L with DOC + DPF”

1. Kubota has 20 Times Less PM



2. Kubota has Less NOx Amount



AIR RESOURCES BOARD				CUMMINS INC.		EXECUTIVE ORDER UAR-003-0883	
						New Off Road Compression Ignition Engines	
MODEL YEAR	ENGINE FAMILY	DISPLACEMENT (liters)		FUEL TYPE		USEFUL LIFE (hours)	
2012	CCEALUS3ADA	3.3		Diesel		8000	
SPECIAL FEATURES & EMISSION CONTROL SYSTEMS				TYPICAL EQUIPMENT APPLICATION			
Electronic Direct Injection, Turbocharger, Charge Air Cooler, Electronic Control Module, Exhaust Gas Recirculation, Diesel Oxidation Catalyst, and Diesel Particulate Filter				Loader, Generator Set, and other Industrial Equipment			
RATED POWER CLASS	EMISSION STANDARD CATEGORY	EXHAUST (g/kw-hr)			OPACITY (%)		
		HC	NOx	PM	ACCEL	LWB	PEAK
75 & kW + 130	Stationary Tier 4, I/LT NOx	STD	0.19	3.4	N/A	0.02	N/A
		CERT	0.08	2.8	---	0.02	---

AIR RESOURCES BOARD				KUBOTA Corporation		EXECUTIVE ORDER UAR-026-0914	
						New Off Road Compression Ignition Engines	
MODEL YEAR	ENGINE FAMILY	DISPLACEMENT (liters)		FUEL TYPE		USEFUL LIFE (hours)	
2012	C40KJ33-BAWD	3.770		Diesel		8000	
SPECIAL FEATURES & EMISSION CONTROL SYSTEMS				TYPICAL EQUIPMENT APPLICATION			
Electronic Direct Injection, Turbocharger, Charge Air Cooler, Electronic Control Module, Exhaust Gas Recirculation, Diesel Oxidation Catalyst, and Diesel Particulate Filter				Tractor, Other Industrial Equipment			
RATED POWER CLASS	EMISSION STANDARD CATEGORY	EXHAUST (g/kw-hr)			OPACITY (%)		
		HC	NOx	PM	ACCEL	LWB	PEAK
75 & kW + 130	Tier 4, I/LT NOx	STD	0.19	3.4	N/A	0.02	N/A
		CERT	0.003	2.8	---	0.001	---

“DOC Only” meets minimum PM limit – There is no margin

## DOC vs DOC+DPF

### DOC Only

Meets PM regulation certification with no margin at test condition.  
Operators can NOT detect abnormal PM level since the engine can NOT calculate PM without a filter and sensor  
May not be suitable for low load duty cycle.

### DOC+DPF

Has enough PM margin to meet regulation in field customer use.  
Never exceeds abnormal PM due to PM trapping .  
Can be used at any duty cycle.  
More suitable for **all** applications.

Status of Engine		Situation (Example)	DOC + DPF	DOC Only
EX-Gas Temp (Inlet of DOC)	Above 250	<ul style="list-style-type: none"> <li>Warm air temperature</li> <li>Heavy-load operation</li> <li>High engine speed</li> </ul>	Oxidation	Oxidation
	Below 250 <i>*Typical requirement</i>	<ul style="list-style-type: none"> <li>Cold air temperature</li> <li>Light load operation</li> <li>Low engine speed</li> </ul>	Trap PM	X May exceed PM levels
PM Amount (Inlet of DOC)	Above limit	<ul style="list-style-type: none"> <li>Combustion trouble</li> <li>Aged deterioration</li> <li>Using illegal fuel</li> </ul>	Oxidation & Trap PM	X May exceed PM levels
	Below limit	<ul style="list-style-type: none"> <li>Usual engine running</li> </ul>	Oxidation	Oxidation

## DOC vs DOC+DPF

### Cost of Installation

- ✓ Is the "DOC Only" solution a compact device ? ➡ **Only Slightly**
- ✓ Is the "DOC Only" easier to install compared to the "DOC+DPF" ? ➡ **NO**
- ✓ More precious metals are required for a DOC
- ✓ Charge-air cooler and Muffler are required = additional costs
- ✓ Fewer electronic connections
- ✓ No sensors are required

< Deutz TD 2.9 L4 >



< Kubota V2607 T4 >



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< Deutz TD 3.6 L4 >



## DOC vs DOC+DPF



TD2.9 & 3.6  
Deutz

	Length (mm)	Dia (mm)
Kubota	468	203
Deutz	528	190
Difference	60	-13

Deutz DOC Length +60 mm Diameter - 13 mm  
vs  
Kubota



Kubota V2607/V3307

Cummins DOC Length +26 mm Diameter +6 mm  
vs  
Kubota



QSB3.3  
Cummins

	Length (mm)	Dia (mm)
KBT	468	203
Cummins	494	209
Difference	26	6

Muffler is required

NO Muffler is required

DOC must be longer since oxidation must be completed while exhaust gases flow through the DOC

## Comparison chart of "DOC+DPF" vs "DOC Only"

Source: Kubota internal survey

Content	Item	DOC+DPF	DOC only	Comment
Service	Maintenance	★	★ ★ ★	"DOC+DPF" requires every 3000hr ash cleaning ("DOC only" requires no cleaning).
	Space cooling Package	★ ★ ★	★	Extra room for fitting an intercooler on application with "DOC only" engine should be secured
Performance	Space after treatment	★ ★	★ ★ ★	After treatment package of "DOC only" is smaller than "DOC+DPF".
	Noise	★ ★ ★	★ ★	
	Certification by the Swiss Federal Office for the Environment	★ ★ ★	-	
	Smoke	★ ★ ★	★ ★ ★	
	Vibration	★ ★ ★	★ ★ ★	
	Fuel efficiency	★ ★ ★	★ ★ ★	
	Output	★ ★ ★	★ ★ ★	Output of "DOC only" with intercooler is equivalent with one of "DOC+DPF".
	Extra operation	★ ★	★ ★ ★	"DOC only" does not require manual regeneration.
Other	Line up	★ ★ ★	★ ★	"DOC only" does not have natural aspiration models.
	Interface complexity	★ ★	★ ★ ★	"DOC only" requires less human machine interface.

## DOC vs DOC+DPF

	DOC+ DPF	DOC Only
<b>Operation</b>	No exhaust temperature limitation	Exhaust temperature must stay above 250 ° C
<b>Swiss Regulation</b>	DPF complies to Swiss regulation.	DOC does not comply with Swiss regulation.
<b>After Service</b>	DPF requires cleaning (3,000 hours)	DOC requires no cleaning
<b>Installation</b>	More compact unit with no muffler or charge-air cooler required.	Charge-air cooler and muffler are required raising the cost of installation

## Swiss Regulation

The Swiss Federal Council amended its Ordinance on Air Pollution Control (OAPC) on 2008. OAPC requires to equip the machines mentioned below with a particle filter system.

1. Construction machines manufactured in 2009 and later
2. Construction machines which have an output of < 37 kW

EU: There is recent movement to require < 37 kW engines to match EPA requirements. Also the EU is considering to regulate the “size” of PM versus current method of “by weight gathered. May require a DPF.



## CONCLUSION

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*DOC+DPF is the low risk / less limitation solution and better for the environment. We believe our solution can fit any application in any situation with environmental compatibility.*

*Kubota took a serious and guaranteed approach to meeting emissions under the real world use by customers and operating conditions.*



**For Earth, For Life**  
**Kubota**