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

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

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

COMPILED BY: Mahe Gangal (CanmetMINING)

OCTOBER 2, 2012
MDEC Diesel Workshop

Tier 4 Diesel Engines and Maintenance (Underground Mines)

Toronto Airport Marriott Hotel
Ontario, Canada

Tuesday, October 2, 2012

07:30 – 08:30 Breakfast and Registration

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

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

12:00 – 13:00 Lunch

13:00 – 16:30

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

Discussion and Conclusion, David Young, Secretary/Treasurer MDEC
MDEC Diesel Workshop

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Emissions Regulation
an Overview

2012 MDEC Conference

J.P. Ouellette
Current & Future Emissions Regulation (USA)
Emissions Regulations on Non-Road SI Engine (19kW+)

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<td>1st Voluntary regulation (12.1 / 519)</td>
<td>2nd Voluntary regul. (40.0 / 610)</td>
<td>2nd Voluntary regul. (40.0 / 610)</td>
<td>2nd Voluntary regul. (40.0 / 610)</td>
<td>2nd Voluntary regul. (40.0 / 610)</td>
<td>2nd Voluntary regul. (40.0 / 610)</td>
<td>2nd Voluntary regul. (40.0 / 610)</td>
<td>2nd Voluntary regul. (40.0 / 610)</td>
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<tr>
<td>EU (2002/88/EC)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>0.065 L ≤ 0.1</td>
<td>Stage 1 (40.0 / 610)</td>
<td>Stage 1 (40.0 / 610)</td>
<td>Stage 1 (40.0 / 610)</td>
<td>Stage 2 (16.1 / 610)</td>
<td>Stage 2 (16.1 / 610)</td>
<td>Stage 2 (16.1 / 610)</td>
<td>Stage 2 (16.1 / 610)</td>
<td>Stage 2 (16.1 / 610)</td>
<td>Stage 2 (16.1 / 610)</td>
<td>Stage 2 (16.1 / 610)</td>
</tr>
<tr>
<td>0.225 L ≤ 0.450</td>
<td>Stage 3 (12.1 / 610)</td>
<td>Stage 3 (12.1 / 610)</td>
<td>Stage 3 (12.1 / 610)</td>
<td>Stage 3 (12.1 / 610)</td>
<td>Stage 3 (12.1 / 610)</td>
<td>Stage 3 (12.1 / 610)</td>
<td>Stage 3 (12.1 / 610)</td>
<td>Stage 3 (12.1 / 610)</td>
<td>Stage 3 (12.1 / 610)</td>
<td>Stage 3 (12.1 / 610)</td>
</tr>
</tbody>
</table>
## Current & Future Emissions Regulation (EU)

|------------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|

<table>
<thead>
<tr>
<th>Fuel Sulfur</th>
<th>0 ≤ P ≤ 8</th>
<th>8 ≤ P &lt; 10</th>
<th>10 ≤ P &lt; 30</th>
<th>37 ≤ P &lt; 56</th>
<th>56 ≤ P &lt; 75</th>
<th>75 ≤ P &lt; 130</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test Fuel Sulfur</td>
<td>Constant Speed Engine</td>
<td>Stage II (8.0/1.5/0.8)</td>
<td>Stage III A (7.5/0.6)</td>
<td>Stage II (8.0/1.5/0.8)</td>
<td>Stage III A (7.5/0.6)</td>
<td>Stage III A (7.5/0.6)</td>
</tr>
<tr>
<td>Test Fuel Sulfur</td>
<td>Stage I (9.2/3.0/0.8)</td>
<td>Stage II (7.0/1.3/0.4)</td>
<td>Stage III A (4.7/0.4)</td>
<td>Stage III B (4.7/0.025)</td>
<td>Stage II (7.0/1.3/0.4)</td>
<td>Stage III A (4.7/0.4)</td>
</tr>
<tr>
<td>Technical Review</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Technical Review Notes

- NOx or NOx+NMHC/PM or NOx/HC/PM Unit: g/kWh

---

### WORLD FUEL MAP

Diesel Fuel Sulphur Levels: Global Status
January 2011

- Information in parts per million (ppm)
- Sulphur levels are maximum allowable as of January 2011
- For additional details and comments per country, visit www.unep.org/pbd
EMISSION REGULATIONS
FOR EMERGING COUNTRIES

WORLD EMISSION REGULATIONS NOW

EU
Russia
Korea
China
Japan
Canada
USA (EPA)
California (CA90)
India
Singapore
2nd-3rd stage
1st stage
Developing
Summary of Emissions Regulation in India

1. Machine need approved at the timing of custom clearance.
   - CPCB (Central Pollution Control Board – Gen.Set.)
   - CMVR (Central Motor Vehicle Rules – Ag Tractor)

2. As part of machine approval, emission compliance of engine required.

3. Certification and COP (Compliance of Production) required.
   - (every 500 units at custom)

4. In principle, certification and COP to be handled domestically in India.

5. Gen.Set. <19kW additionally durability test of 500hrs (BIS inspection) required. (BIS: Bureau of Indian Standards)

6. Official Test Facility
   - ARAI (Automotive Research Association of India)
   - BUDNI (Central Farm Machinery Training & Testing Institute)

7. Certificate Holder
   - Engine: engine manufacturer, or its agency
   - Machine: equipment sales company located in India

---

Emissions Regulation in India (standards)

**Diesel Generator (CPCB Reg.)**

<table>
<thead>
<tr>
<th>Stage</th>
<th>Category</th>
<th>Effective Date</th>
<th>CO (g/kW-h)</th>
<th>HC (g/kW-h)</th>
<th>NOx (g/kW-h)</th>
<th>PM (g/kW-h)</th>
<th>Smoke (m^-1)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Test Method</td>
<td>ISO 897</td>
<td>kW ≤ 19</td>
<td>July-2004</td>
<td>3.5</td>
<td>1.3</td>
<td>9.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ISO C2</td>
<td>19 &lt; kW ≤ 50</td>
<td>July-2004</td>
<td>3.5</td>
<td>1.3</td>
<td>9.2</td>
</tr>
</tbody>
</table>

**Ag Tractor (CMVR Reg.)**

<table>
<thead>
<tr>
<th>Stage</th>
<th>Category</th>
<th>Effective Date</th>
<th>CO (g/kW-h)</th>
<th>HC+NOx (g/kW-h)</th>
<th>PM (g/kW-h)</th>
<th>Smoke (m^-1)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Test Method</td>
<td>ISO C1</td>
<td>ISO 12062-1987</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bharat Stage 2</td>
<td>Tractor</td>
<td>June-2003</td>
<td>9.0</td>
<td>15.0</td>
<td>1.0</td>
<td>3.25 (75H.S.U)</td>
</tr>
<tr>
<td></td>
<td>Power Tiller</td>
<td>Oct-2006</td>
<td>5.5</td>
<td>9.5</td>
<td>0.8</td>
<td>3.25 (75H.S.U)</td>
</tr>
<tr>
<td>Bharat Stage 3</td>
<td>Tractor</td>
<td>Oct-2005</td>
<td>5.5</td>
<td>9.5</td>
<td>0.8</td>
<td>3.25 (75H.S.U)</td>
</tr>
<tr>
<td></td>
<td>Power Tiller</td>
<td>Apr-2008</td>
<td>5.5</td>
<td>9.5</td>
<td>0.8</td>
<td>3.25 (75H.S.U)</td>
</tr>
</tbody>
</table>
Summary of Emissions Regulation In China

1. **Test Facility**: 14 (Jinan, Shanghai Internal Combustion Engine, Nanking...)

2. **Certification Test**: Bring engine to the facility to test

3. **Certification Application**: Engine manufacturer to apply online to SEPA (State Environmental Protection Administration), test facility to attach cert. data.

4. **Certification Label**: Required. (Sample shown in later) / Retroactive labeling on engines in the market if their emission levels are met / Stage 2 label can be installed if certified when Stage 1 be effective / Can install label if certified (even before effective date)

5. **Engine Serial Number**: Shown in label ➔ engraved (acceptable!)

6. **Exemptions**: Exported only, <37kW marine application, onroad application


8. **Family Concept**: 97/68/EC (Fuel Flow@Max.Torq/1st, @Rated/2nd)
### Emissions Regulation In China (standards)

<table>
<thead>
<tr>
<th>Net Power</th>
<th>Application</th>
<th>Effective Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>kW</td>
<td>Acceptable</td>
<td>Standards (g/kWh)</td>
</tr>
<tr>
<td>Stage I</td>
<td></td>
<td></td>
</tr>
<tr>
<td>75 ≤ P &lt; 130</td>
<td>2007.10.1</td>
<td>2008.10.1</td>
</tr>
<tr>
<td>5.0</td>
<td>1.3</td>
<td>9.2</td>
</tr>
<tr>
<td>37 ≤ P &lt; 75</td>
<td>2007.10.1</td>
<td>2008.10.1</td>
</tr>
<tr>
<td>6.5</td>
<td>1.3</td>
<td>9.2</td>
</tr>
<tr>
<td>18 ≤ P &lt; 37</td>
<td>2007.10.1</td>
<td>2008.10.1</td>
</tr>
<tr>
<td>8.4</td>
<td>2.1</td>
<td>10.8</td>
</tr>
<tr>
<td>8 ≤ P &lt; 18</td>
<td>2007.10.1</td>
<td>2008.10.1</td>
</tr>
<tr>
<td>8.4</td>
<td>12.9</td>
<td>-</td>
</tr>
<tr>
<td>0 &lt; P &lt; 8</td>
<td>2007.10.1</td>
<td>2008.10.1</td>
</tr>
<tr>
<td>12.3</td>
<td>18.4</td>
<td>-</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Stage II</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>75 ≤ P &lt; 130</td>
<td>2009.10.1</td>
<td>2010.10.1</td>
</tr>
<tr>
<td>5.0</td>
<td>1.0</td>
<td>6.0</td>
</tr>
<tr>
<td>37 ≤ P &lt; 75</td>
<td>2009.10.1</td>
<td>2010.10.1</td>
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<td>5.0</td>
<td>1.3</td>
<td>7.0</td>
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<tr>
<td>18 ≤ P &lt; 37</td>
<td>2009.10.1</td>
<td>2010.10.1</td>
</tr>
<tr>
<td>5.5</td>
<td>1.5</td>
<td>8.0</td>
</tr>
<tr>
<td>8 ≤ P &lt; 18</td>
<td>2009.10.1</td>
<td>2010.10.1</td>
</tr>
<tr>
<td>6.6</td>
<td>9.5</td>
<td>0.8</td>
</tr>
<tr>
<td>0 &lt; P &lt; 8</td>
<td>2009.10.1</td>
<td>2010.10.1</td>
</tr>
<tr>
<td>8</td>
<td>10.5</td>
<td>1.0</td>
</tr>
</tbody>
</table>

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

### Emissions Regulation in Russia

1. No emission regulation for nonroad equipment in Russia.
2. Certificate for equipment, engine and engine parts required at custom.
3. Need to verify EU Stage 2 level compliance when obtain emission certificate.
4. Certification data of EU, EPA and Japan Construction Regulation is acceptable while application.
5. Cannot use engine with sophisticated devices such as EGR for fuel quality issue in Russia.
6. Be careful when introducing EU Stage 3, EPA Tier 3/Tier 4 Int.(37kW<) leveled-new-models into Russia (High sulfur contents).
7. Distributor of KDG, obtained certificates of KBT engines.
8. Future responses:
   - Certify new models through our distributor in Russia.
   - Use KBT’s official data for models not certified by any authorities.
   - Certificates obtained can be provided to each OEM for free of charge.
Emissions Regulation in Korea for Construction Machinery

### Tier 3 Regulations:

<table>
<thead>
<tr>
<th>Engine Power</th>
<th>CO</th>
<th>NOx + HC</th>
<th>PM</th>
<th>Test Procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td>8kW &gt;</td>
<td>8.0g/kWh</td>
<td>7.5g/kWh</td>
<td>0.4g/kWh</td>
<td>ISO 8178 C1-8mode</td>
</tr>
<tr>
<td>8kW &lt;19</td>
<td>6.6g/kWh</td>
<td>7.5g/kWh</td>
<td>0.4g/kWh</td>
<td>ISO 8178 C1-8mode</td>
</tr>
<tr>
<td>19kW &lt;37</td>
<td>5.5g/kWh</td>
<td>7.5g/kWh</td>
<td>0.3g/kWh</td>
<td>ISO 8178 C1-8mode</td>
</tr>
<tr>
<td>37kW &lt;75</td>
<td>5.0g/kWh</td>
<td>4.7g/kWh</td>
<td>0.4g/kWh</td>
<td>ISO 8178 C1-8mode</td>
</tr>
<tr>
<td>75kW &lt;130</td>
<td>5.0g/kWh</td>
<td>4.0g/kWh</td>
<td>0.3g/kWh</td>
<td>ISO 8178 C1-8mode</td>
</tr>
</tbody>
</table>

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

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

---

### Summary of Emissions Regulation in Turkey

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

<table>
<thead>
<tr>
<th>Country</th>
<th>Regulation 1</th>
<th>Regulation 2</th>
<th>Regulation 3</th>
<th>Regulation 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turkey</td>
<td>50%</td>
<td>40%</td>
<td>30%</td>
<td>20%</td>
</tr>
</tbody>
</table>

**THANK YOU**
Cummins Tier 4 Technology Overview

Agenda

- Emissions legislation
- Cummins Tier 4 Technology
- Cummins Advantage
EMISSIONS LEGISLATION

Tier 4 Final requires a 90 percent reduction in PM & NOx compared to Tier 3.

Achieving more than emissions compliance:
- Reduced fuel consumption
- Improved engine performance
- Minimized installation impact
Euro 5 equivalent to EPA 2007-2010/Tier3
In terms of particulate mass

Exhaust 4 to 11 km (2.5 to 7 Miles)

Information from Prof. David Kittelson, U of Minnesota

Achieving ‘Near-Zero’ Emissions

- Emissions from 25 x Tier 4 Final machines will be equivalent to just 1 x Tier 1 machine
Notes:
1. Construction and Ag regulations phase-in by engine horsepower category. The above chart is for engines rated at 300hp.
2. Common standards does not imply the ability to sell a product without certification for that country. Actual regulations should be reviewed for introduction dates and certification requirements.
The machine, engine and aftertreatment are part of a single system designed to optimize performance, reliability, cost and emissions.

Building Blocks for Meeting Tier 4 Emissions

Possible Tier 4 Building Blocks

- Flexible Fuel Systems
- Combustion Optimization
- EGR Cooler
- Cooled EGR
- Air Handling
- Particulate Filter
- Advanced Controls
- SCR
- NOx Adsorber
On-Highway ≠ Nonroad

Sample Nonroad Application

Drivetrain
Many Suppliers Of Low Volume Components
Varied Drivetrain Requirements

Engine
Many Ratings
Several Product Families
High Load Factors

Cooling System
Limited Available Space
No Ram Air; fan HP Increases
More Auxiliary Coolers
Dusty Environment
High Vibration & Impact Loads

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

Many OEM’s, Global Business
Key Tier 4 Development Areas

- Heat Rejection
  - Minimization
  - Optimization of cooling systems

- Application Variation
  - Robust to installation variation
  - Cost impact for vehicle installation

- Environmental Robustness
  - Dust/Dirt
  - Surface temperature requirements
  - Vibration/Shock

- Develop a solution with the lowest initial and life-cycle cost

“In-Cylinder” Development

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

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

Recirculates the exhaust gas back into the cylinder reducing oxygen concentration. This lowers combustion temperature to reduce the formation of Oxides of Nitrogen (NOx). Variable geometry turbocharging is required to maintain correct pressure differential across the engine for ideal EGR flow.

- Upgraded cooling package mitigates increased engine heat rejection.
- EGR system sensitivity to high sulfur fuel made it less viable for Tier 3 application, but offers potential for Tier 4 with ULSD.
- Control valve modulates the % EGR returned to cylinder.

**Advanced Combustion**

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

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

Fuel Systems

- Cummins designs & manufactures high pressure common rail fuel systems
- Tier 4/Stage IIIB fuel systems requires:
  - higher fuel injection pressure
  - very fast response with multiple injection events
  - precise control of fuel metering timing
- Cummins next generation HPCR is recognized as industry leading technology
Aftertreatment Technology

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

Wall Flow Particulate Filter

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

** Diesel Oxidation Catalyst **
DOC catalytic material reacts above 572°F (300°C) in passive regeneration mode to generate Nitrogen Dioxide (NO2) which oxidizes the carbon soot.

** Diesel Particulate Filter **
Ceramic wall flow filter captures up to 95% of the carbon soot (PM) carried by the NO2. This collects on the filter to form Carbon Dioxide (CO2) 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 1022°F (550°C) ensures sufficient oxidation to remove soot.

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

---

Urea Based SCR: Overview

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

- The urea is converted to ammonia in the exhaust above 200 deg C
- NOx conversion efficiency is high above 250 deg C.
- Averages 70-85% NOx reduction
Selective Catalytic Reduction
Urea solution is injected ahead of the catalyst. This converts to ammonia in the exhaust stream above 392°F (200°C).
The ammonia reacts with Oxides of Nitrogen (NOx) over the SCR catalyst to form harmless nitrogen & water.
Urea is injected at a ratio of typically 5% to diesel fuel use, depending on duty cycle. Urea tank sizes vary, but must be refilled to ensure emissions compliance.

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

DPF & SCR Aftertreatment Configurations Examples

- Horizontal End-In End-Out
- Horizontal End-In Side-Out
- Horizontal Side-In End-Out
- Vertical Side-In End-Out
- Vertical End-In End-Out
- Horizontal Side-In Side-Out
Estimate of Application Impact of Cooled EGR & Aftertreatment for T4 QSB6.7

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

TIER 4
CUMMINS ADVANTAGE
Experience Counts

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

System Integration

- Unique in the industry – we design, build and integrate the complete system
## Clear Advantage: Fuel-Efficiency

<table>
<thead>
<tr>
<th>Description</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tier 4 Interim fuel saving over Tier 3</td>
<td>up to 5% typical</td>
</tr>
<tr>
<td>Tier 4 Final fuel saving over Tier 4 Interim</td>
<td>Preliminary estimates: additional 2-3% (more than offsetting DEF cost)</td>
</tr>
<tr>
<td>Typical fuel saving at 5% (2500 hours / 6 gals hr)</td>
<td>750 gallons per year $3000 saved</td>
</tr>
<tr>
<td>CO2 savings (1 gal = 22.2 lbs)</td>
<td>8 tons less per year</td>
</tr>
<tr>
<td>Power Output / Transient Response</td>
<td>Retain Tier 4 Interim high output &amp; improved response</td>
</tr>
</tbody>
</table>

---

## Off-Road Tier 4 Final Architecture

### MidRange Engines: 75 – 400 HP
- QSB 3.3
- QSB 4.5
- QSB 6.7
- QSL 9

### Heavy Duty Engines: 400 - 675HP
- QSX 11.9
- QSX 15

**CCC - SCR**
- Cummins Compact Catalyst
- Selective Catalytic Reduction

**CPF - SCR**
- Cummins Particulate Filter
- Selective Catalytic Reduction

Cooled EGR
Engines Pre-designed For Final

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

Tier 4 Interim and Tier 4 Final
**Tier4 Final QSB6.7 Architecture**

6.7L Tier4 Interim engine with increased fuel pressure

**Interim to Final: QSB6.7**

<table>
<thead>
<tr>
<th>2011/12</th>
<th>146-300 hp</th>
<th>2014/15</th>
</tr>
</thead>
</table>

Ultra-Clean Aftertreatment
CCC-SCR
Cummins Compact Catalyst
Selective Catalytic Reduction
Interim to Final: QSB6.7

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

- Balanced EGR with SCR aftertreatment
- ECM upgraded for faster processing & SCR logic
- Single VGT for 300 hp output
- Enhanced HPCR system with higher fuel injection pressure

QSB6.7 engine lineage

<table>
<thead>
<tr>
<th>QSB6.7 GT174hp</th>
<th>T3</th>
<th>T4i</th>
<th>T4F</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECM</td>
<td>CM850</td>
<td>CM2250</td>
<td>CM2350</td>
</tr>
<tr>
<td>Fuel pressure</td>
<td>1600 bar</td>
<td>1800 bar</td>
<td>2200 bar</td>
</tr>
<tr>
<td>Turbocharger</td>
<td>WGT</td>
<td>VGT</td>
<td>VGT</td>
</tr>
<tr>
<td>NOx control</td>
<td>DSA</td>
<td>Cooled EGR</td>
<td>Cooled EGR + SCR</td>
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<tr>
<td>Crankcase vent.</td>
<td>OCV, impactor only</td>
<td>OCV, coalescing filter</td>
<td>OCV, coalescing filter</td>
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<tr>
<td>Aftertreatment</td>
<td>None</td>
<td>DOC+DPF</td>
<td>DOC+SCR</td>
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</tbody>
</table>
QSL9

Tier4 Final QSL9 Architecture

8.9L Tier4 Interim engine with Cummins Fuel Systems XPI fuel system
Interim to Final: QSL9

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

Balanced EGR with SCR aftertreatment

Single VGT for 400 hp output

ECM upgraded for faster processing & SCR logic

XPI fuel system capable for Tier 4 Final
### QSL9 engine lineage

<table>
<thead>
<tr>
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<th>T3</th>
<th>T4i</th>
<th>T4F</th>
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<td>2100 bar</td>
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<tr>
<td>Aftertreatment</td>
<td>None</td>
<td>DOC+DPF</td>
<td>DOC+SCR</td>
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</tr>
</tbody>
</table>

### Program Schedule

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

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

Summary

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

Technologies to Address US EPA Emissions Requirements

- High Efficiency Clean Combustion
- Aftertreatment
- Waste Heat Recovery
- Idle Reduction
- Hybrids
- Low Carbon Fuels (Natural Gas)

Reduced CO$_2$ = Fuel Efficiency
- Questions?
Final Tier 4 Emission Engines

Darcy Thomson
Oct 2, 2012

Engine Portfolio
- Power from 49 HP to 600 HP

- 2.4L/3.0L 49-99 hp
- 2.9L 48-71 hp
- 4.5L 48-173 hp
- 6.8L 135-275 hp
- 9.0L 225-400 hp
- 13.5L 300-600 hp
JOHN DEERE Drivetrain Products

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

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

The next EPA hurdle...FINAL TIER 4

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

80% NOx Reduction
Technology Progression

Deere building block approach...

Tier 1
- Calibration
- HPCR
- CAC
- CEGR
- VGT

Tier 2
- HPCR
- CAC
- CEGR
- VGT
- DOC
- DPF

Tier 3
- HPCR
- CAC
- CEGR
- VGT
- DOC
- DPF

Tier 4
- Final

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

Engine & After Treatment System Optimization

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

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

Final Tier 4 System Layout
Agenda

- Introduction of Volvo Group and Volvo Penta
- SCR approach for Tier 4
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- Future engine range, Stage 4, engines and technology
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- Global Aftermarket support
- Summary and conclusion
- Questions
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Volvo Group Organisation
Our brands
Global Operations
Sales and Employees

- **North America**: Net Sales 19%
  - 15 427
  - 16%

- **Europe**: Net Sales 39%
  - 55 121
  - 56%

- **Asia**: Net Sales 24%
  - 19 924
  - 25%

- **South America**: Net Sales 11%
  - 1 234
  - 5%

- **Other**: Net Sales 7%
  - 2 456
  - 2%

Net Sales 2011: SEK bn 310
Employees 31 Dec 2011: 98 162

Sharing the same Powertrain

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

**Volvo Group Trucks Operations**
Engines, transmissions and trucks production, spare parts supply and logistics

**Volvo Group Truck Technology**
Product development of engines, transmissions and trucks, in addition to purchasing.
**Agenda**

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**Background**

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

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

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

Together with safety and quality, the environment is one of Volvo’s core values.
SCR or EGR?

- EGR: Lower combustion temperature
- SCR: Base engine
- Diesel Particulate Filter

Particulates g/kWh

- Stage 1/Tier 1 (1999)
- Stage 2/Tier 2 (2004)
- Stage 3A/Tier 3 (2006)
- Stage 3B/Tier 4i (2011)
- Stage 4/Tier 4F (2014)

NOx g/kWh

- High NOx engine – Low fuel consumption
- SCR: Lower NOx emissions

T4i Selective Catalytic Reduction (SCR)

- Exhaust gas (containing NOx) + AdBlue
- AdBlue tank
- SCR catalytic converter
- Nitrogen + Water to the environment

AdBlue pump
SCR Chemical Process

Pre-cat (if used):
NO + O2 -> NO2

NOx Reduction
Injection:
2 NH3 + H2O -> CO2 + N2 + H2O
SCR catalyst:
NOx + NH3 -> N2 + H2O
Clean-up catalyst:
4 NH3 + H2O -> 2 N2 + 6 H2O

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- Questions
What happens if off spec urea is used?

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

Consequences of poor handling and mixture

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

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

Clogging
Clogging

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

What is Urea (NH$_2$)$_2$CO?

- **Water soluble**
  - 32.5% solution gives lowest freezing point
  - Melting point 135 °C

- **Ad Blue/DEF – Diesel Emissions Fluid**
  - 32.5% Urea solution in DEIONISED water
  - Non-Toxic
  - Non-flammable
  - Odourless

- **Consumption**
  - Proportional to NOx reduction
  - Approx. 5% of diesel consumption

NOx reduction requires heat
Without heat, the Urea may crystallize
AdBlue standardization

- **ISO 22241 Diesel engines — NOx reduction agent AUS 32**

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

AdBlue/DEF product shelf life
(at constant temperature)

Shelf life versus temperature

- ≤10°C
- ≤25°C
- ≤30°C
- ≤35°C

Source: ISO/DIS 22241-3
Where to buy AdBlue today?

Examples of AdBlue supplier:
- Air1
- Yara
- Dureal
- Greenchem
- Statoil
- etc.

Licensed to use the trademark™:

SUM-UP

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

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

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

- 56 - 130 kW: NOx = 3.4 g/kWh, NMHC = 0.19 g/kWh, PM = 0.02 g/kWh
- 130 - 560 kW: NOx = 2.0 g/kWh, NMHC = 0.19 g/kWh, PM = 0.02 g/kWh

- Electronically controlled CR + eEGR + DPF (POC)
- Electronically controlled CR + SCR

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

- Excellent fuel economy = lower running costs for operator
  - Example. A customer operating a machine with a Volvo TAD1362VE (Tier 4i engine) commented “The machine powered with this engine is very economical compared to the Tier 3 engine it replaced”.

- Simple installation:
  - Fewer Tier 4 components to install: SCR muffler, tank
  - Simple control interface, engine to OEM panel

- Reduced heat rejection = smaller radiators, lower costs
- Less complex = increased reliability & lower capital cost
- Longer service intervals

Total Cost of Ownership D13 – 12000h

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

#### D5

<table>
<thead>
<tr>
<th>Product or Product Variant</th>
<th>Max power (kW)</th>
<th>@ speed (rpm)</th>
<th>Peak torque (Nm)</th>
<th>@ speed (rpm)</th>
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* Engines above 560 kW are not regulated.
Engine After Treatment System - EATS

Comprehensive scope of supply
Electrically driven urea pump

Volvo Penta

SCR Engine Range

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<tr>
<th>5L</th>
<th>7L</th>
<th>13L</th>
<th>16L</th>
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<td>TAD566VE</td>
<td>TAD1365VE</td>
<td>TAD1365VE</td>
<td>TWG1663GE *</td>
</tr>
</tbody>
</table>

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

*US Market only (Bi-Fuel)
**Designed for in-use compliance**

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

*) Engine idling excluded

---

**SCR – ”the most efficient solution”**

1. Lower fuel consumption (-10% compared to Tier 3)
2. Cooling package remains unchanged – improved visibility for mining applications
3. Greater power densities, smaller engine delivers more horsepower
4. Service intervals remain unchanged
5. Reliable & proven technology: SCR introduced by Volvo 2006 (Euro 4)
6. No need for regeneration – less downtime, easy and continuous operation
7. Easy service, no cleaning nor replacement of SCR-CAT needed through lifetime
8. Less complex engine = reduced maintenance
9. Low exhaust temperatures = no restrictions in operational areas
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Product Range T4f (2014)

- 5L: 105-160kW
- 8L: 160-235kW
- 11L: 235-265kW
- 13L: 285-405kW
- 16L: 405-500kW
Main technical changes from Tier 4i to Tier 4F:

- Increased size of SCR muffler
- New integrated pump and ACM, same functionality
- 5-8 liter (MD) Light EGR added (5-8 litre)
- 11-16 liter (HD) non cooled EGR added (11-16 litre)
- Electrical system update
- Increased fuel costs (Diesel + UREA) 1-2% T4i to T4F
- Small or no increase in heat rejection
  - 5-8 liter (MD) heat rejection + 10%
  - 11-16 liter (HD) T4F same requirements as T4i
- No Re-generation i.e. no DPF
- Same engines available Tier 2, 3 and 4
Tier 2 2001  Tier 3 2005  Tier 4i 2011  Tier 4f 2014

Simplicity
Optimized Fuel Consumption
Maximized Power Output

Tier 2 2001  Tier 3 2005  Tier 4i 2011  Tier 4f 2014

Maximized Uptime
Proven Technology
Easy to Install
### Volvo base engine platform 5 & 8L

#### D5
- 4 cylinders
- 105-160kW
- max torque 900Nm

#### D8
- 6 cylinders
- 160 - 235kW
- max torque 1300Nm

---

#### T4f Performance Ratings

**D5**

<table>
<thead>
<tr>
<th>Product or Product Variant</th>
<th>Max power (kW)</th>
<th>@ speed (rpm)</th>
<th>Peak torque (Nm)</th>
<th>@ speed (rpm)</th>
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**D8**

<table>
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<th>Product or Product Variant</th>
<th>Max power (kW)</th>
<th>@ speed (rpm)</th>
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<th>@ speed (rpm)</th>
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<td>TAD672VE</td>
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**D13**

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<th>Peak torque (Nm)</th>
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**D16**

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<th>@ speed (rpm)</th>
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<td>515</td>
<td>1800</td>
<td>3150</td>
<td>1000</td>
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</tbody>
</table>

Unregulated engines available above 560kW
Volvo base engine platform 11, 13 & 16L

- **D11**
  - 235-295 kW
  - max torque 1950 Nm

- **D13**
  - 295-405 kW
  - max torque 2650 Nm

- **D16**
  - 405-500 kW
  - max torque 3200 Nm

Power range Tier 4F 5-8L

<table>
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<tr>
<th>Product or Product Variant</th>
<th>Max power (kW)</th>
<th>@ speed (rpm)</th>
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<tbody>
<tr>
<td>TAD570VE</td>
<td>105</td>
<td>2300</td>
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<td>TAD571VE</td>
<td>129</td>
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<tr>
<td>TAD873VE</td>
<td>235</td>
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</table>
Volvo base engine platform 5 & 8L

**D5**
- 4 cylinders
- 105-160kW
- max torque 900Nm

**D8**
- 6 cylinders
- 160 - 235kW
- max torque 1300Nm

Volvo base engine platform 11, 13 & 16L

**D11**
- 235-295 kW
- max torque 1950 Nm

**D13**
- 285-405 kW
- max torque 2650 Nm

**D16**
- 405–495 kW
- max torque 3200 Nm
Agenda

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

Mining – key segment

- Volvo Penta has invested in certifying engine for use in mining applications
- Tier 4i engines offer low ventilation rates
- More engines will be certified
Introduction of Volvo Group and Volvo Penta
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- Global Aftermarket support
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- Questions

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

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- Summary and conclusion
- Questions
World-Class AM backed-up by Volvo Group

US Customised map

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

- Introduction of Volvo Group and Volvo Penta
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- Summary and conclusion
- Questions

Summary and conclusions

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

Thank you very much for your attention

www.volvogroup.com

47730, Product Management Industrial
“The DEUTZ Path to Tier 4 for Underground Mining Engines”

Greg Tremaine
DEUTZ Corporation

MDEC Conference
Tonroto ON
October 2, 2012

<table>
<thead>
<tr>
<th>Engine Type</th>
<th>Power Range</th>
<th>RPM Range</th>
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<tr>
<td>TCD 2.9</td>
<td>35 – 75 HP</td>
<td>2.200 – 2.600 rpm</td>
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<td>TCD 3.6</td>
<td>67 – 120 HP</td>
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<td>TCD 4.1 – 6.1</td>
<td>93 – 341 HP</td>
<td>1.800 – 2.300 rpm</td>
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<td>TCD 7.8</td>
<td>214 – 335 HP</td>
<td>1.800 – 2.200 rpm</td>
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<tr>
<td>TCD 12.0 – 16.0</td>
<td>323 – 697 HP</td>
<td>1.800 – 2.100 rpm</td>
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EPA Power Category

- Tier 4 final: 49.6 - 75.1
- Tier 4 interim: 75.1 - 100.6
- Tier 4 interim: 100.6 - 174.3
- Tier 4 interim: 174.3 - 751
- Tier 4 interim: 174.3 - 751

*additional ratings >75
**additional ratings <75
Overview DEUTZ product line-up
Technology Tier 4 Final for Industrial engines

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<thead>
<tr>
<th>MODEL</th>
<th>ECU</th>
<th>eEGR</th>
<th>FIE</th>
<th>Turbo</th>
<th>Charged</th>
<th>DVERT</th>
<th>Oxidation</th>
<th>Catalyst</th>
<th>Wall-Flow</th>
<th>System</th>
<th>Heat</th>
<th>Management</th>
<th>SCR</th>
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<td>Pressure</td>
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EPA Nonroad Diesel Emission Regulations Tier 1 - 4

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Nonroad Diesel Fuel Buffer Level
| 5000 ppm | 500 ppm | 15 ppm |

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

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

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**Tier 4i/4 Exhaust Aftertreatment Systems (EAT)**

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<td>PM reduction 90% DPF/DOC</td>
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<td>Tier 3</td>
<td>PM reduction 95% DPF</td>
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<td>Tier 3</td>
<td>PM reduction 93% DPF/SCR</td>
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<td>Nonroad Diesel Fuel Sulfur Level</td>
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DPF – Diesel Particulate Filter for PM reduction
DOC – Diesel Oxidation Catalyst for CO and HC reduction
SCR – Selective Catalytic Reduction for NOx reduction

Reduction percentage is compared to previous Tier emission level

---

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

- PM emissions to be reduced by 96%
- NOx emissions to be reduced by 95%

Tier 1 (1997-2002)
Tier 2 (2003-2006)
Tier 3 (2007-2011)
Tier 4 (2012-2014)
Tier 4i (2015+)

PM (g/kW-hr)
NOx (g/kW-hr)
To Achieve Tier 4 (> 25hp) Emission Levels

Requires a Three Segment “Systems Approach”

- Low/ultra low sulfur diesel fuel
- Engine technologies and control system working in unison with EAT
- EAT – Exhaust Aftertreatment

Tier 4 Emissions Level

Exhaust Gas Recirculation (EGR)

- Diesel engine exhaust contains excess oxygen
- Through EGR a part of the ingested intake air is replaced by exhaust air, thus reducing the oxygen surplus inside the cylinder
- Higher CO₂ level leads to lower combustion temperature peaks resulting in less NOx in the exhaust
- External Cooled EGR
  - Compared to un-cooled or internal EGR
    - Maximizes specific power
    - Maximizes NOx reduction
DEUTZ Common Rail (DCR) Fuel Injection System

DEUTZ® Oxidation Catalyst (DOC)

- Reducing CO and HC
- "Open" flow-through system – no clogging
- Optional DOC + DPF for mining applications
- Limited power density (max. 25kW/ltr.)
- Continuous control of low PM level engine out must be secured leading to less transient response

Customer's Benefits

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

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

DEUTZ Application Example

- TiC/D 2.9 < 55.4 kW Tier 4
- TD 3.6 ≤ 55.4 kW Tier 4
- TCD 3.6 56<P<90kW Tier 4i
DVERT® Particulate Filter (DPF)

- PM reduction at highest efficiency (>99%)
- Particulate number (PN) reduction at highest efficiency
- Need for regeneration
- Low SAPS* oil required
- Ash cleaning required
- <10-15 ppm sulphur fuel required

* sulphated ash, phosphorus and sulphur

Customer’s Benefits

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

Active regeneration Systems

Wall flow filter (DPF) + Burner

- PM reduction at highest efficiency (>99%)
- Automatic regeneration under all conditions
- Low SAPS* oil required
- Ash cleaning required
- <10-15 ppm sulphur fuel required
- High exhaust temperature during regeneration

* sulphated ash, phosphorus and sulphur

Customer’s Benefits

- 100% reliable regeneration w/o operation interference under all conditions
- Fully integrated installation
DEUTZ Particulate Filter Systems® and Function Signals

<table>
<thead>
<tr>
<th>DPF Function</th>
<th>Operator Display</th>
<th>Engine Warning lamp</th>
<th>Performance degradation</th>
<th>Message via CAN bus (J 1939)</th>
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<td>DPF Regeneration requirement</td>
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<td>Regeneration in xx minutes</td>
<td>Regeneration in xx minutes</td>
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<tr>
<td>DPF Regeneration continuous</td>
<td>continuous</td>
<td>none</td>
<td>Regeneration</td>
<td>none</td>
</tr>
<tr>
<td>DPF overloading xx - yy%</td>
<td>blinking</td>
<td>continuous</td>
<td>Regeneration not completed, Torque degrading xx%**</td>
<td>Regeneration not completed, Torque degrading xx%**</td>
</tr>
<tr>
<td>DPF overloading &gt;yyyy%</td>
<td>flashing</td>
<td>blinking</td>
<td>Power shut-off</td>
<td>Engine shut-off</td>
</tr>
</tbody>
</table>

Push button = Manual mode
- Regeneration request
- Regeneration release
- Regeneration interrupt
- Regeneration inhibit

*selectable parameter = OEM specified. Performance degrading is time dependent

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

Customer’s Benefits
- Reduced emissions and increased fuel efficiency
- Higher power densities – enables downsizing
- Proven technology used by heavy duty Truck industry
- Constant low exhaust temperature at end pipe
- No additional maintenance – only refill urea tank regularly
- Compared to ceEGR + DPF Solution
- Better fuel consumption
- No DPF maintenance (ash cleaning) required
- No cooler size increase, heat rejection to coolant = Tier 3
- Constant exhaust back pressure

DEUTZ Application Example

SCR

DEUTZ Application Example

TCD 4.1 / 6.1 / 7.8 Agri

TCD 12.0 / 16.0 Tier 4i

Customer’s Benefits
### DEUTZ – SCR system: Operator Notification and Inducement

<table>
<thead>
<tr>
<th>DEF (Urea) Threshold</th>
<th>Notification</th>
<th>Inducement</th>
</tr>
</thead>
<tbody>
<tr>
<td>With Level Indicator</td>
<td>Lamp - or - Message</td>
<td></td>
</tr>
<tr>
<td>&gt;15% full</td>
<td>none</td>
<td>none</td>
</tr>
<tr>
<td><strong>Stage 1</strong></td>
<td>DEF lamp solid</td>
<td>Warning message</td>
</tr>
<tr>
<td>&lt;15% full</td>
<td>Warning message</td>
<td>none</td>
</tr>
<tr>
<td><strong>Stage 2</strong></td>
<td>DEF lamp flashing (time duration – OEM Specified)</td>
<td>Increasing message duration and/or frequency</td>
</tr>
<tr>
<td>&lt;10% full</td>
<td>none</td>
<td>none</td>
</tr>
<tr>
<td><strong>Stage 3</strong></td>
<td>DEF lamp flashing Amber warning lamp solid</td>
<td>Inducement message (&quot;tank empty, 5Min till de-rating&quot;)</td>
</tr>
<tr>
<td>&lt;5% full</td>
<td>Amber warning lamp solid</td>
<td>none</td>
</tr>
<tr>
<td><strong>Stage 4</strong></td>
<td>DEF lamp flashing Amber warning lamp flashing</td>
<td>Inducement message (&quot;de-rating&quot;) De-rating</td>
</tr>
<tr>
<td>9Min. After last warning</td>
<td>Amber warning lamp flashing</td>
<td>none</td>
</tr>
</tbody>
</table>

### Tier 3 Transition into Tier 4

- **Tier 3 engine without EAT**
- **Tier 4 engine shown with full DPF and SCR system expected in 2014 for 174 - 751HP engines**
Exhaust aftertreatment for Tier 4 non-road engines
DEUTZ EAT solutions - Combined system DOC + SCR

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

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

Thank you
Ventilation Reduction Strategy
Underground Hard Rock Vehicles

MDEC 2012

Agenda

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

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

Surface - 3 Main Concepts:

<table>
<thead>
<tr>
<th>United States &amp; Canada</th>
<th>EU</th>
<th>Japan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tier 1</td>
<td>Stage I</td>
<td></td>
</tr>
<tr>
<td>Tier 2</td>
<td>Stage II</td>
<td>Step 1</td>
</tr>
<tr>
<td>Tier 3</td>
<td>Stage IIIA</td>
<td>Step 2</td>
</tr>
<tr>
<td>Tier 4i</td>
<td>Stage IIIB</td>
<td>Step 3</td>
</tr>
<tr>
<td>Tier 4f</td>
<td>Stage IV</td>
<td>Step 4</td>
</tr>
</tbody>
</table>

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

Industry focus is primarily on the following diesel emissions

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

- NOx and PM are inversely related, reduction in one generally causes increase in the other
Emissions Strategy

Our Strategy:

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

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

DPM & Vent Rate Reduction Path Forward
DPM & Vent Rate Reduction Technology MGPP

**Generation 1 – Ventilation Reduction (VR) Package**

**What is involved?**
- New engine software
- New injectors
- New turbo

<table>
<thead>
<tr>
<th></th>
<th>Rule of Thumb</th>
<th>CANMET</th>
</tr>
</thead>
<tbody>
<tr>
<td>R2900G</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vent Rate (CFM)</td>
<td>447 HP</td>
<td>Current</td>
</tr>
<tr>
<td></td>
<td>44,700</td>
<td>35,700</td>
</tr>
</tbody>
</table>
### Generation 1 (Ventilation Reduction Package)

**Customer Impact:**

<table>
<thead>
<tr>
<th>Tier 2/3 Baseline</th>
<th>Generation 1 VR Package</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel spec (sulfur ppm)</td>
<td>500 ppm</td>
</tr>
<tr>
<td>Bio fuel</td>
<td>B20</td>
</tr>
<tr>
<td>Fuel consumption</td>
<td>Baseline</td>
</tr>
<tr>
<td>Required oil spec</td>
<td>ECF-2 (CI-4)</td>
</tr>
<tr>
<td>Oil change interval</td>
<td>Baseline</td>
</tr>
<tr>
<td>DPF cleaning</td>
<td>N/A</td>
</tr>
<tr>
<td>CRS Service Kit</td>
<td>N/A</td>
</tr>
<tr>
<td>Overhaul life</td>
<td>Baseline</td>
</tr>
<tr>
<td>Overhaul parts required</td>
<td>Baseline</td>
</tr>
</tbody>
</table>

Limited to no O&O impact

---

### Generation 2 (VR Package + Flow-Through DPF)

**What is involved?**

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

**What are main challenges?**

- Durability
- Space claim
- Backpressure

Optional System: VR + Passive DPF (FTF)
## Flow-Through Filter vs Wall Flow Tech

### Flow Through DPF

- Sintered Metal Fleece
- Outlet
- Inlet
- Corrugated Mixing Foil

### Wall Flow DPF

- Inlet
- Porous Wall

Source: DCL International

## Generation 2 (VR Package + Flow-Through DPF)

### Customer Impact:

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

What is involved?

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

What are main challenges?

- Space claim

Optional Engine: T4

---

Generation 3 (Tier 4 Technology)

Customer Impact:

<table>
<thead>
<tr>
<th></th>
<th>Tier 2/3</th>
<th>Generation 1 VR Package</th>
<th>Generation 2 VR Package + DPF</th>
<th>Generation 3 Tier 4 Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel spec (sulfur ppm)</td>
<td>500 ppm</td>
<td>500 ppm</td>
<td>15 ppm</td>
<td>15 ppm</td>
</tr>
<tr>
<td>Bio fuel</td>
<td>B20</td>
<td>B20</td>
<td>B20</td>
<td>B20</td>
</tr>
<tr>
<td>Fuel consumption</td>
<td>Baseline</td>
<td>3-7% Improvement</td>
<td>3-7% Improvement</td>
<td>Up to 5% Improvement</td>
</tr>
<tr>
<td>Required oil spec</td>
<td>ECF-2 (CI-4)</td>
<td>ECF-2 (CI-4)</td>
<td>ECF-3 (CI-4)</td>
<td>ECF-3 (CI-4)</td>
</tr>
<tr>
<td>Oil change interval</td>
<td>Baseline</td>
<td>Baseline</td>
<td>Baseline</td>
<td>Baseline</td>
</tr>
<tr>
<td>DPF cleaning</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>5,000 hrs</td>
</tr>
<tr>
<td>CRS Service Kit</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>5,000 hrs</td>
</tr>
<tr>
<td>Overhaul life</td>
<td>Baseline</td>
<td>Baseline</td>
<td>Baseline</td>
<td>Baseline</td>
</tr>
<tr>
<td>Overhaul parts required</td>
<td>Baseline</td>
<td>Baseline</td>
<td>Baseline</td>
<td>DPF Exchange, CRS Kit</td>
</tr>
</tbody>
</table>
DPM & Vent Rate Reduction Path Forward

GEN 1
Ventilation Reduction

GEN 2
Ventilation Reduction and DPF

GEN 3
Near Zero Emission

Thank You
Engines for Underground Mining

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

MTU Update
Ownership Structure
MTU Update
New North American Headquarters

Effective February 27, 2012 Tognum America Inc will be headquartered in Novi, Michigan. A brand new facility that offers employees and business partners:

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

Aiken Accomplishments
• 30% less production space
• 50% greater throughput
• 30% increase in first pass yield
• 20% productivity increase

Recently broke ground on $40M expansion
• New research and development buildings
• Additional engine test benches
• Creating 20+ additional jobs

MTU Overview

Canton, MI (Training Center)

Brownstown, MI (Parts Warehouse)
MTU Production Facilities Worldwide

Plant I - Friedrichshafen  Plant II - Friedrichshafen
Mannheim  Detroit  Suzhou

Emission Compliance and Technology
Exhaust Emission Reduction Strategies for NO\textsubscript{x} and Particulate Matter

- Tier 4i / Stage 3B
- Tier 3 / Stage 3A
- Tier 2 / Stage 2
- Tier 4 / Stage 4

- EGR
- DPF
- SCR

For engines < 750hp

Engine Overview
Engine Overview
For TODAY…

<table>
<thead>
<tr>
<th>Emission level</th>
<th>Engine</th>
<th>Configuration (Cyl. / Inline or V)</th>
<th>Total Displacement</th>
<th>Rated Power kW</th>
<th>Rated Power bhp</th>
<th>Emission Strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tier 4 final</td>
<td>Series 1000</td>
<td>4, 6 / Inline</td>
<td>5.1, 7.7</td>
<td>110-240</td>
<td>134-348</td>
<td>EGR + SCR</td>
</tr>
<tr>
<td></td>
<td>Series 1100</td>
<td>6 / Inline</td>
<td>10.6</td>
<td>280-320</td>
<td>378-429</td>
<td>EGR + SCR</td>
</tr>
<tr>
<td></td>
<td>Series 1300</td>
<td>6 / Inline</td>
<td>12.8</td>
<td>340-380</td>
<td>458-569</td>
<td>EGR + SCR</td>
</tr>
<tr>
<td></td>
<td>Series 1500</td>
<td>6 / Inline</td>
<td>15.8</td>
<td>400-460</td>
<td>538-618</td>
<td>EGR + SCR</td>
</tr>
</tbody>
</table>

Engines
Tier 4 interim
### Tier 4i Solution: SCR Components

#### Optional component (needed, may be delivered by MTU)
- **Urea (DEF) Tank system**

#### Mandatory component certified (delivered by MTU must not be changed)
- **Engine**
  - Electronic components
    - Ambient & Humidity-Sensor
    - SCR/Exhaust Module
  - Pump unit
  - SCR-Catalyst

#### Customer component (needed, not delivered by MTU)
- **Vehicle wiring**
  - Wiring harness
  - Ambient Temp. sensor
- **Exhaust pipe**
- **Water/Air Urea (DEF) Piping**
  - Pipes, isolation fittings
- **Air filter/ Cooling System**

### Tier 4i Solution: SCR Engine Mounted Components

- **Dosing unit** delivers the right amount of UREA (DEF), always mounted on engine
- **Heater valve** Supplies the tank and pump unit with coolant for urea heat up
- **Urea (DEF) nozzle** Injects the urea/air mixture into exhaust pipe after turbocharger
- **Optimized internal engine components** (e.g. combustion engineering, pistons, parameter sets, injection nozzles, pipes)
- **Aerosol-pipe** connection between dosing unit and Urea (DEF) / Nozzle
- **Optional: Remote urea (DEF) nozzle** For special cases to optimize installation and aerosol mixing

Components must not be changed or relocated.
Engines for Tier 4 interim
S900 and S460

S924, 4-cyl. inline
4.8 ltr displacement

<table>
<thead>
<tr>
<th>[hp]</th>
<th>127</th>
<th>154</th>
<th>173</th>
<th>201</th>
</tr>
</thead>
<tbody>
<tr>
<td>[kW]</td>
<td>95</td>
<td>115</td>
<td>129</td>
<td>150</td>
</tr>
</tbody>
</table>

S926, 6-cyl. Inline
7.2 ltr displacement

<table>
<thead>
<tr>
<th>[hp]</th>
<th>235</th>
<th>262</th>
<th>282</th>
<th>302</th>
<th>322</th>
</tr>
</thead>
<tbody>
<tr>
<td>[kW]</td>
<td>175</td>
<td>195</td>
<td>210</td>
<td>225</td>
<td>240</td>
</tr>
</tbody>
</table>

S460, 6-cyl. Inline
12.8 ltr displacement

<table>
<thead>
<tr>
<th>[hp]</th>
<th>355</th>
<th>386</th>
<th>422</th>
<th>449</th>
<th>483</th>
<th>503</th>
</tr>
</thead>
<tbody>
<tr>
<td>[kW]</td>
<td>265</td>
<td>295</td>
<td>315</td>
<td>335</td>
<td>360</td>
<td>375</td>
</tr>
</tbody>
</table>

Tier 4 interim Features
S900

- Same engine footprint as Tier 3 S900
- Optimized combustion timing
- Centrally positioned injection nozzle
- Two inlet valves, one exhaust valve per cylinder
- Rear gear-train
- Improved efficiency and fuel economy
- VERY minimal heat rejection increase vs. tier 3
### Tier 4 interim Features S460

- Same engine footprint as Tier 3 S460
- Optimized combustion timing
- Centrally positioned injection nozzle
- Two inlet and exhaust valves per cylinder
- Rear gear-train
- Improved efficiency and fuel economy
- VERY minimal heat rejection increase vs. tier 3
- Wet cylinder liners

### Engines

Tier 4 final
Tier 4 Final Solution: EGR and SCR
Key Engine Technologies

Engines for Tier 4 final
S1000

<table>
<thead>
<tr>
<th>S1000, 4-cyl. inline 5.1 ltr displacement</th>
<th>S1000, 6-cyl. Inline 7.7 ltr displacement</th>
</tr>
</thead>
<tbody>
<tr>
<td>[hp]</td>
<td>134</td>
</tr>
<tr>
<td>[kW]</td>
<td>100</td>
</tr>
</tbody>
</table>
Engines for Tier 4 final
S1100 / S1300 / S1500

<table>
<thead>
<tr>
<th></th>
<th>S1100, 6-cyl. inline 10.6 ltr displacement</th>
<th>S1300, 6-cyl inline 12.8 ltr displacement</th>
<th>S1500, 6-cyl inline 15.6 ltr displacement</th>
</tr>
</thead>
<tbody>
<tr>
<td>[hp]</td>
<td>375</td>
<td>456</td>
<td>536</td>
</tr>
<tr>
<td>[kW]</td>
<td>280</td>
<td>340</td>
<td>402</td>
</tr>
<tr>
<td></td>
<td>320</td>
<td>460</td>
<td>510</td>
</tr>
<tr>
<td></td>
<td>320</td>
<td></td>
<td>577</td>
</tr>
<tr>
<td></td>
<td>340</td>
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</tr>
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<td></td>
<td>360</td>
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<td>380</td>
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<td>400</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>430</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>460</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

S1000
Tier 4 final Features

- Inline 4 and 6 cylinder versions
- 5.1 and 7.7 liter displacement
- OHC 4 valve per cylinder
- High pressure common rail fuel system
- Cooled EGR
- **Airless SCR!**
- Optional high performance exhaust brake
S1100 / S1300 / S1500
Tier 4 final Features

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

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

Summary and Conclusion
**Emission Technology Solutions: Overview**

**No DPF!!!  No DOC!!!**

<table>
<thead>
<tr>
<th>Tier 2</th>
<th>Tier 3</th>
<th>Tier 4i</th>
<th>Tier 4f</th>
</tr>
</thead>
<tbody>
<tr>
<td>DOC</td>
<td>NOT REQUIRED!!!</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DPF</td>
<td>NOT REQUIRED!!!</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EGR</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SCR</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Turbo</td>
<td></td>
<td></td>
<td>Single stage*</td>
</tr>
<tr>
<td>Control system</td>
<td></td>
<td></td>
<td>Common Electronic Platform</td>
</tr>
<tr>
<td>Fuel injection</td>
<td>Pump-Line-Nozzle (S60 with Unit Injection)</td>
<td></td>
<td>Common rail</td>
</tr>
</tbody>
</table>

* S1000 upper ratings with two-stage turbocharging

---

**MTU Summary**

- Solid plan for the future
- Comprehensive ratings coverage
- One basic concept…
  - Cooled EGR
  - Common rail fuel system
  - Mutli-valve per cylinder technology
  - OHC
- No DPF no DOC! …moving to Airless SCR for Tier 4 Final!
- Improved engine load acceptance
- Improved fuel economy
- We have the right balance!
- MTU…your knowledgeable and reliable partner!
Thank you for your time…

Questions?