Aftertreatment solutions for Tier4 and beyond

Dr Mikael Larsson
Heavy Duty Diesel Applications Manager Europe
Johnson Matthey
19th February 2014
Presentation Outline

• Introduction to Johnson Matthey
• Existing aftertreatment technologies (the “tool box”)
  • DOC
  • CSF
  • SCR
  • ASC
  • SCRF®
• Rationale for aftertreatment technology on non-road machinery
  • Legislation
  • Implications of “Stage IV/Tier 4 final” aftertreatment legislation in 2014
• Future trends for efficient and compact aftertreatment solutions including SCRF®
  • Next stage legislation
  • SCRT® vs. SCRF®
• Summary & Conclusions
Presentation Outline

- **Introduction to Johnson Matthey**
  - Existing aftertreatment technologies (the “tool box”)
    - DOC
    - CSF
    - SCR
    - ASC
    - SCRF®
  - Rationale for aftertreatment technology on non-road machinery
    - Legislation
    - Implications of “Stage IV/Tier 4 final” aftertreatment legislation in 2014
  - Future trends for efficient and compact aftertreatment solutions including SCRF®
    - Next stage legislation
    - SCRT® vs. SCRF®
- Summary & Conclusions
Johnson Matthey Overview

• A speciality chemicals company and a world leader in sustainable technologies

• Origins date back to 1817, floated 1942, FTSE 100 company since June 2002

• Market capitalisation of just under £6 billion

• £10.7 billion revenue and underlying profit before tax* of £382.9 million for year ended 31st March 2013

• Operations in over 30 countries with 11,000 employees

• Leading global market positions in all its major businesses
Divisional Structure

Emission Control Technologies
- Light Duty Catalysts
- Heavy Duty Catalysts
- Stationary Emissions Control

Process Technologies
- Chemicals
  - Chemical Technologies (DPT)
  - Syngas
  - Chemical Catalysts (inc. Formox)

Oil and Gas
- Refineries
- Purification
- Tracerco

Precious Metal Products
- Manufacturing
  - Noble Metals
  - Colour Technologies
  - Chemical Products

Fine Chemicals
- Services
  - Platinum Marketing and Distribution
  - Refining
- Manufacturing
  - Active Pharmaceutical Ingredient (API) Manufacturing
  - Catalysis and Chiral Technologies
  - Research Chemicals

New Businesses
- New Business Development
- Water
- Battery Technologies
- Fuel Cells
Emission Control Technologies Division

- Products to reduce emissions from cars, trucks, buses and other pollution sources
- Ensure legislated environmental limits are met
- Products fitted to about a third of all cars produced worldwide

- First autocatalyst produced in Royston, UK in 1974
- Since then, many millions of tonnes of pollutants prevented from reaching the atmosphere
- A major impact on improving air quality around the world
Emission Control Technologies
Global manufacturing and technology centres
Presentation Outline

• Introduction to Johnson Matthey
• Existing aftertreatment technologies (the “tool box”)
  • DOC
  • CSF
  • SCR
  • ASC
  • SCRF®
• Rationale for aftertreatment technology on non-road machinery
  • Legislation
  • Implications of “Stage IV/Tier 4 final” aftertreatment legislation in 2014
• Future trends for efficient and compact aftertreatment solutions including SCRF®
  • Next stage legislation
  • SCRT® vs. SCRF®
• Summary & Conclusions
Existing aftertreatment technologies (the “tool box”)

**DOC**
Diesel Oxidation Catalyst

Oxidation of hydrocarbons, carbon monoxide and some soot.
Also used in the regeneration of filter and to promote the low temperature activity of SCR systems.

**CSF**
Catalysed Soot Filter

Capture and combust soot (passive or active)

**SCR**
Selective Catalytic Reduction

Removes NOx by a selective reaction with ammonia.
Addition of Adblue (or DEF) needed.

**ASC**
Ammonia Slip Catalyst

Removes traces of ammonia after the SCR catalyst.
Existing aftertreatment technologies (the “tool box”)

- **DOC**: Diesel Oxidation Catalyst
- **CSF**: Catalysed Soot Filter
- **SCR**: Selective Catalytic Reduction
- **ASC**: Ammonia Slip Catalyst

**CRT® or CCRT®**
Existing aftertreatment technologies (the “tool box”)

- **DOC**
  Diesel Oxidation Catalyst

- **CSF**
  Catalysed Soot Filter

- **SCR**
  Selective Catalytic Reduction

- **ASC**
  Ammonia Slip Catalyst
**SCRT® System Configuration**

- **DOC – Diesel Oxidation Catalyst**
  - Removes CO and HC
  - Oxidises fuel to drive active filter regeneration
  - Converts some NO into NO₂

- **CSF – Catalysed Soot Filter**
  - Traps particulate matter (carbon)
    - For subsequent removal by NO₂ and / or O₂
  - Enables particle number (PN) compliance

- **SCR – Selective Catalytic Reduction**
  - Removes NOx via reaction with NH₃

- **ASC – Ammonia Slip Catalyst**
  - Removes any ammonia (NH₃) slip and converts it to (predominantly) nitrogen (N₂)
Existing aftertreatment technologies (the “tool box”)

- **DOC**
  Diesel Oxidation Catalyst

- **CSF**
  SCR coated filter

- **SCR**
  Selective Catalytic Reduction

- **ASC**
  Ammonia Slip Catalyst
Presentation Outline

- Introduction to Johnson Matthey
- Existing aftertreatment technologies (the “tool box”)
  - DOC
  - CSF
  - SCR
  - ASC
  - SCRF®
- Rationale for aftertreatment technology on non-road machinery
  - Legislation
  - Implications of “Stage IV/Tier 4 final” aftertreatment legislation in 2014
- Future trends for efficient and compact aftertreatment solutions including SCRF®
  - Next stage legislation
  - SCRT® vs. SCRF®
- Summary & Conclusions
### On Road (EUVI, EPA10) vs Non Road Regulations

T4f has higher limits and no need for DPF on all engines.

<table>
<thead>
<tr>
<th></th>
<th>EU VI</th>
<th>EPA10</th>
<th>Stage IV Tier 4 final</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOₓ (mg/kWh)</td>
<td>400</td>
<td>270</td>
<td>400</td>
</tr>
<tr>
<td>PM (mg/kWh)</td>
<td>10</td>
<td>13</td>
<td>25</td>
</tr>
<tr>
<td>PN (#/kWh)</td>
<td>6 x 10^{11} (WHTC)</td>
<td>No limit</td>
<td>No limit</td>
</tr>
<tr>
<td></td>
<td>8 x 10^{11} (WHSC)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cycles</td>
<td>WHSC &amp; WHTC</td>
<td>FTP &amp; SET</td>
<td>NRTC &amp; NRSC</td>
</tr>
<tr>
<td>Introduction</td>
<td>31/12/13</td>
<td>1/1/10</td>
<td>1/1/14 (130-560kW)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1/1/15 (56-130kW)</td>
</tr>
</tbody>
</table>
Aftertreatment solution for “Stage IV/Tier 4 final”

• For stage ”Stage 3B/Tier 4 interim” various solutions has been used
  • No aftertreatment
  • Oxidation catalyst
  • CSF
  • SCR

• From ”Stage IV/Tier 4 final” three options will be widely used:
Aftertreatment solution for “Stage IV/Tier 4 final”

- **SCR** (Selective Catalytic Reduction)
- **ASC** (Ammonia Slip Catalyst)
- **DOC** (Diesel Oxidation Catalyst)
- **CSF** (Catalysed Soot Filter)
- **ASC** (Ammonia Slip Catalyst)
- **SCR** (Selective Catalytic Reduction)
Aftertreatment solution for “Stage IV/Tier 4 final”

- **SCR**
  Selective Catalytic Reduction

- **ASC**
  Ammonia Slip Catalyst

High NOx, low PM engines. Low or no EGR
NOx conversion > 98% for some systems

Pictures from Bauma 2013
Aftertreatment solution for “Stage IV/Tier 4 final”

DOC for beneficial for low temperature activity.

Picture from Bauma 2013
Aftertreatment solution for “Stage IV/Tier 4 final”

Pictures from Bauma 2013

Filter also as optional fit (e.g. Swiss market)

DOC
Diesel Oxidation Catalyst

CSF
Catalysed Soot Filter

SCR
Selective Catalytic Reduction

ASC
Ammonia Slip Catalyst
Presentation Outline

• Introduction to Johnson Matthey
• Existing aftertreatment technologies (the “tool box”)
  • DOC
  • CSF
  • SCR
  • ASC
  • SCRF®
• Rationale for aftertreatment technology on non-road machinery
  • Legislation
  • Implications of “Stage IV/Tier 4 final” aftertreatment legislation in 2014
• Future trends for efficient and compact aftertreatment solutions including SCRF®
  • Next stage legislation
  • SCRT® vs. SCRF®
• Summary & Conclusions
Stage V options

- JM assumes that Stage V will be filter forcing

- Possible system solutions
  - SCRT®
  - SCRF®
JM SCRF® market progress and key challenges

- SCRF® systems in series production for LDD applications
- JM can coat filters with all SCR catalyst types and reach high NOx conversion
- JM is working with OEMs towards future legislation targets
Typical HDD target = Maximum passive NO₂ based filter regeneration

SCRF® Challenge = Competition for NO₂

SCRF® Challenge: PM control
Influence of SCR function on soot removal

\[
\begin{align*}
\text{NO}_2 & \quad \rightarrow \quad \text{NH}_3 \\
\rightarrow & \quad \text{Soot} \quad \rightarrow \quad \text{Oxidation of soot} \quad \text{SLOW} \\
& \quad \rightarrow \quad \text{SCR reaction} \quad \text{FAST}
\end{align*}
\]
SCRF® options

Full passive soot regeneration

No passive soot regeneration
**SCRF® options**

Full passive soot regeneration

**Effect on performance**

**Temperature**

- **Cu SCRF® system**
  - High thermal durability required
  - Similar to passenger car system
  - Very compact system
  - Very good low temperature performance

- No passive soot regeneration

Very good low temperature performance

Very compact system

High thermal durability required

Similar to passenger car system
SCRF® system evaluation (NEDC)
SCRF® system can warm up faster than underfloor SCR system
SCRF® options

Full passive soot regeneration

Ageing

Temperature

DOC → SCRF® → SCR/ASC

Cu SCRF® system
High thermal durability required
Similar to passenger car system
Very compact system
Very good low temperature performance

No passive soot regeneration
Ageing of DOC + Cu SCRF®
Engine Ageing Profile

- Active regeneration: 30 min
- 600°C
- 2 WHTC, 1 h
- 200-350°C
- 2 WHTC, 1 h
Ageing of DOC + Cu SCRF®
NOx conversion before and after ageing

Cycle repeated 347 times ➔ Total 520 h and 173 h at 600°C
**SCRF® options**

**Full passive soot regeneration**
- **Cu or V SCRF®** system (Fe high T)
- Low PGM levels
- Lower thermal stress
- High overall SCR NOx conversion
- Good fuel economy

**Cu SCRF® system**
- High thermal durability required
- Similar to passenger car system
- Very compact system
- Very good low temperature performance

**Passive soot regeneration**

**Temperature**
SCRF® simulation results
Impact of temperature and NO₂/NOx

![Graph showing SCRF® soot loading (g/l) over time (h) at 350°C with high NO₂ level.](image)
SCRF® simulation results
Impact of temperature and NO$_2$/NOx
SCRF® simulation results
Impact of temperature and NO₂/NOx
SCRF® simulation results
Soot burn rate vs. temperature (soot burn after 1 h)
SCRF® options

Full passive soot regeneration
- Cu or V SCRF® system (Fe high T)
  - Low PGM levels
  - Lower thermal stress
  - High overall SCR NOx conversion
  - Good fuel economy

No passive soot regeneration
- Cu SCRF® system
  - High thermal durability required
  - Similar to passenger car system
  - Very compact system
  - Very good low temperature performance

Temperature

NOx/PM ratio
Passive soot oxidation with urea injection in WHTC

Impact of NOx/PM on passive soot oxidation

Engine with lower NOx and higher PM (EGR)
No balance point

Engine with high NOx and low PM (no EGR)
Typical CRT behaviour
**SCRF® options**

- **Urea injection**
  - Full passive soot regeneration
  - Cu or V SCRF® system (Fe high T)
  - Low PGM levels
  - Lower thermal stress
  - High overall SCR NOx conversion
  - Good fuel economy

- **NOx/PM ratio**

- **Temperature**
  - Cu SCRF® system
  - High thermal durability required
  - Similar to passenger car system
  - Very compact system
  - Very good low temperature performance

---

**DOC**

**SCRF®**

**SCR/ASC**
Influence of SCR on Passive Regeneration

- Actual BP with urea
- Expected BP without urea

- 20min, No urea injection
- 10 min, ANR = 1.1
SCRF® options

**Full passive soot regeneration**
- Cu or V SCRF® system (Fe high T)
- Low PGM levels
- Lower thermal stress
- High overall SCR NOx conversion
- Good fuel economy

**No passive soot regeneration**
- Cu SCRF® system
- High thermal durability required
- Similar to passenger car system
- Very compact system
- Very good low temperature performance

**Diagrams**
- Urea injection
- NOx/PM ratio
- Temperature
- Optimal coating
SCRF® with reference and optimised coating
NOx conversion at ANR=1.1
Passive soot oxidation with urea injection
Repeated NRTC, ANR = 1.0

Ave T = 315°C

Typical CRT behaviour
Passive soot oxidation with urea injection
Repeated NRTC, ANR = 1.0

![Graph showing the comparison between Optimised coating and Reference coating over the Number of NRTC (#)]
Passive soot oxidation with urea injection
Repeated NRTC, ANR = 1.0

Soot loading after repeating NRTC for 144 h
Reference coating = 6.4 g/l
Optimised coating = 2.6 g/l

Repeat for 150 h
SCRF® options

Full passive soot regeneration
- Cu or V SCRF® system (Fe high T)
- Low PGM levels
- Lower thermal stress
- High overall SCR NOx conversion
- Good fuel economy

DOC → SCRF® → SCR/ASC

Cu SCRF® system
- High thermal durability required
- Similar to passenger car system
- Very compact system
- Very good low temperature performance

Urea injection

NOx/PM ratio

Temperature

Optimal coating
Presentation Outline

• Introduction to Johnson Matthey
• Existing aftertreatment technologies (the “tool box”)
  • DOC
  • CSF
  • SCR
  • ASC
  • SCRF®
• Rationale for aftertreatment technology on non-road machinery
  • Legislation
  • Implications of “Stage IV/Tier 4 final” aftertreatment legislation in 2014
• Future trends for efficient and compact aftertreatment solutions including SCRF®
  • Next stage legislation
  • SCRT® vs. SCRF®
• Summary & Conclusions
Summary & Conclusions

- Aftertreatment systems for Stage IV/Tier 4 final will all consist of SCR systems sometimes combined with DOC and CSF (56 – 560 kW).

- For next stage, filter expected to be needed to meet PN regulation.

- Fuel economy & packaging requirements → Highly optimised systems & high SCR NO\textsubscript{X} conversion

- JM SCRF\textsuperscript{®} technology offers system volume reduction whilst maintaining high NO\textsubscript{X} conversion and good passive regeneration
Thank you for your attention

Acknowledgements
Dr Kaneshalingam Arulraj, Dr Gudmund Smedler, Anna Thorén and Dr Andy Walker