Heavy-Duty Diesel Emission Control Technologies to Achieve Future Emission Reduction Goals

Mid-Atlantic Diesel Collaborative

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Conference Call

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Manufacturers of Emission Controls Association

www.meca.org
MECA Overview

- Technology Voice for the Emission Control Industry with Air Regulatory Agencies and Stakeholders since 1976
- 39 member companies commercializing emission control and combustion efficiency technologies for all sizes of internal combustion engines.
- Meeting future emission challenges requires a systems approach including engine, exhaust controls and fuels.
MECA Portfolio Covers Criteria and GHG Emission Control Technologies

- Fuel Combustion Controls
- Evaporative Controls
- Powertrain Electrification
- Air Handling
- Waste Heat Recovery
- Advanced Exhaust Controls
- Filters & Substrates
- OBD Sensors
Clean Diesel Technology Driven By a Decade of U.S. EPA Mobile Source Emission Regulations

**Average Benefit:Cost = 20:1**

**Tier 3 Light-Duty**
- final rule 2014
- fully phased in 2025
- Diesels held to same standards as gasoline vehicles
- **Diesel sulfur 15 ppm**

**Heavy-Duty Highway**
- final rule 2000
- **Sulfur 15 ppm**
- fully phased in 2007-2010

**Nonroad Diesel Tier 4**
- final rule 2004
- **Sulfur 15 ppm**
- fully phased in 2015

**Ocean-going Vessels**
- final rule 2009; IMO ECA in 2010
- ECA: **1000 ppm Sulfur in 2015**
- 80% lower NOx by 2016

**Locomotive / Marine Tier 4**
- final rule 2008
- **15 ppm Sulfur**
- fully phased in 2017
Heavy-Duty Diesel Regulations have Tightened Around the World

PM, g/kW-hr; ESC test

NOx, g/kW-hr; ESC test

Euro VI
DPF+NOx

Euro V
SCR

US2010
DPF+NOx

US2007
DPF

Japan 2009
DPF+NOx

Japan 2005 DPF or SCR

Euro IV
2005
SCR

Euro V
2008
SCR

Euro VI
2009 DPF or SCR

Euro III
2000
nothing
SCR Becoming a Dominant NOx Control Technology for Mobile and Stationary Engines

Power Plants

Heavy Duty Vehicles

Gas Turbines

Waste Incineration

Marine Engines

Diesel Passenger Cars

Stationary Engines

Tier 4 Off-Road Engines

Tier 4 Locomotive Engines

SCR Products
Diesel Emission Controls Have Evolved Since 2010

- Oxidation catalyst
- PM filter (DPF/CSF)
- Selective Catalytic Reduction
- Ammonia oxidation catalyst
- Urea dosing
- Sensors and control units

Must last over 435,000 miles

ACES Phase 2 Study looked at 2010 Technology
LEV III/Tier 3 Resets the Emissions Performance Bar for Light-duty Vehicles – Drives Innovation

LEV III Emission Limits, g/mi

- NMOG+NOx
  - 0.030 (SULEV or Tier 2, Bin 2)
  - 1 mg/mi LEV III
  - PM phase-in 2025-2028

- PM
  - 3 mg/mi phase-in 2017-2021

LEVs

- LDT2s
  - Phase-in 2025-2028

- PCs
  - Phase-in 2017-2021
CARB Voluntary Heavy-Duty Low NOx Standards

<table>
<thead>
<tr>
<th>NOx Level g/bhp-hr</th>
<th>% Below Current Standard</th>
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</thead>
<tbody>
<tr>
<td>0.2 (Current)</td>
<td></td>
</tr>
<tr>
<td>0.1</td>
<td>- 50%</td>
</tr>
<tr>
<td>0.05</td>
<td>- 75%</td>
</tr>
<tr>
<td>0.02</td>
<td>- 90%</td>
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</tbody>
</table>
Where are Diesel Exhaust Technologies Heading?

- Improved cold start performance
- Thermal management
- Fast catalyst heat-up
- Low temperature catalyst activity
- High NOx conversion
- Reduced backpressure
- Minimize soot regeneration
SULEV NOx Levels Demonstrated on Light-Duty Diesel Vehicles

Solid NH₃

NH₃ Based Reductant

Cummins DEER 10-2012
CO$_2$ vs. NOx of Certified HD Engines

![Graph showing CO$_2$ vs. NOx emissions for different years and technologies. The graph includes data points for various years (2002, 2004, 2007, 2010, 2013, 2014, +2015, 2016) and technologies like EGR, DPF, SCR, and WHR. The data points are distributed across different emission levels, indicating improvements over time. The graph also highlights future enabling technologies such as EGR + DPF + SCR and DPF + High Eff SCR.]
Active and Passive Thermal Management is Important for Cold Start and Low Temperature Operation

- Passive and Active thermal management
- Dual wall pipes and insulation
- EGR By-Pass Valve (EBV)
- Turbine By-Pass Valve (TBV)
- Close coupled catalysts
Passive NOx Adsorber Catalyst Replaces DOC

Extensive NOx storage at very low temperature
Substrates Optimized for Catalyst Loading, Low Backpressure and Low Thermal Mass

- High porosity incorporates catalyst into cell wall
- Lower backpressure for efficiency
- High cell density, thin wall designs reduce thermal mass
- Fast heat-up and earlier urea injection

CTI 2012 NOx Reduction

Catalyst: Cu-zeolite
SV: 100K h⁻¹
SCR Catalyst Improvements, Thermal Management and Urea Dosing Control Give High Conversion

Cu-SCR with Improved Low Temperature Efficiency

Fresh
\[ \frac{\text{NO}_2}{\text{NO}_x} \approx 58\% \text{ (WHTC avg.)} \]
\[ \frac{\text{NH}_2}{\text{NO}_x} = 1.2 \text{ (const.)} \]

![Graph showing NOx conversion over WHTC cycle](image)

![Diagram showing Urea Dosing and SCR-DPF system](image)

![Bar chart showing NOx conversion percent by temperature and process option](image)

SAE 2014-01-1525
SCR Coated DPFs Commercialized on Light-Duty

WLTC – Exhaust Gas Temperature

- Upstream SCR coated DPF Close coupled - 0.4 m from T/C
- Upstream SCR Underfloor - 1 m from T/C

Start injection

Time (s)
ARB/MECA HD Low NOx Test Program

- Demonstrate 90% NOx reduction (0.02 g/bhp-hr NOx emissions) on heavy-duty diesel and stoichiometric CNG engines.

- What’s needed to achieve 0.020 g/bhp-hr from state of the art diesel engine equipped with advanced efficiency technology:
  - 95% efficiency for cold start
  - 99% for hot start
  - 99% on steady-state cycle

- Engine calibration combined with exhaust control development.

- System integration and demonstration:
  - Emissions demonstrated over full useful life (435K miles, 22,000 hours)
  - Demonstration on certification cycles, as well as Vocational cycle with sustained low-load and low temperature operation
  - No negative impact on CO₂ emissions
Cold-Start Technologies Demonstrated on Heavy-Duty Engines

- Baseline
- Gaseous NH3: 80% NOx Conversion
- Pre-Stored NH3: 88% NOx Conversion
- TM+Pre-Stored NH3: 94% NOx Conversion

SAE 2015-01-0992
MECA Modeling Study Showed Cost Effective Emission Reductions from Heavy-Duty Engines

- On a national basis, potential NOx reductions from heavy-duty engines amounts to 223,000 tons in 2030, 490,000 tons in 2050 or 1,300 tpd.
- MECA incremental cost of on-road HD mobile controls range from $3,000-$4,000/ton.
- Tier 3 projected to deliver 750 tpd by 2030 at $2,400/ton
- Known stationary controls from EGUs cost around $12,000
- Regulations drive technology development for co-optimization of criteria and GHG emission reductions
• Your emission control technology resources on the web