Cummins/ORNL-FEERC CRADA: NOx Control & Measurement Technology for Heavy-Duty Diesel Engines
(Agreement #: 10030)*

Oak Ridge National Laboratory: W.P. Partridge (PI), J.-S. Choi, J. Parks

Cummins Inc.: N. Currier (PI), A. Yezerets, M. Ruth, S. Whitacre, M. Cunningham, K. Kamasamudram

Presenter: Bill Partridge
partridgewp@ornl.gov

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U.S. DOE Program Management Team:
Ken Howden, Gurpreet Singh, Steve Goguen

*This presentation does not contain any proprietary or confidential information.
Purpose of Work

Assist Cummins in addressing barriers to transportation-market penetration of fuel-efficient diesel engines

& by doing so
generate useful knowledge and enable products with broad public benefit

Major Focus for FY2008:

- Oil Dilution (from engine-managed catalyst regeneration)
- LNT-Catalyst Ammonia Chemistry
Guidance from FY 2007 Review

- Feedback was very positive
- Highest score achieved in three areas
  - Relevance
  - Technical Accomplishments
  - Tech Transfer
- “A useful industry partnership that has shown good progress and results.”
- No weaknesses or recommendations were cited.

- Previous review recommendations:
  - Using fully formulated catalyst (*implemented in ’07*)
  - Quantifying H₂S, NH₃, N₂O and SO₂ distributions (*implemented in ’07 except NH₃*)
  - *Major effort in FY2008 to quantify NH₃ chemistry*
CRADA Addresses Multiple DOE\VT Barriers

Oil Dilution (Engine System Section)

- Can result from emissions control system management and operation
- Oil dilution can cause durability issues
- Conventional methodologies slow development

LNT Ammonia Chemistry (Instrumentation & Bench Section)

- NH₃ must be controlled in viable catalyst systems:
  - Avoid NH₃ slip
  - Manage generation and utilization in LNT and hybrid LNT-SCR systems

Specific DOE\VT Multi-Year Program Plan Barriers Addressed:

- ‘Emissions. The key barriers … incomplete development of aftertreatment technology, especially for NOx;..”
- ‘Durability. .. system has to perform effectively for 120,000 miles…’
Oil Dilution Research
Performance Measures – Oil Dilution

Conventional methodologies:

- bottleneck development
- require extractive sampling
- off-line (often off-site) analysis

Performance measures designed to streamline development:

- Fast measurement ~15 min
- On-engine measurements
- Real-time feedback
Approach – Oil Dilution

- Inexpensive & compact laser-pointer sources
- Fluorescence of commercial diesel-fuel dye
- Two fiber-based designs implemented
- Sample-point agile optical fiber design
- Engine-cell safe closed system design
- Demonstrate on ORNL research diesel
  - Flexible engine control system
- Extract samples for ASTM method comparison
Results – Oil Dilution

- Slope indicates relative oil dilution rate
- Real-time on-engine feedback of oil dilution
  - ~ <15 min feedback time
- Laser-Induced Fluorescence (LIF) method
  - trends with ASTM
  - more sensitive than ASTM
- LIF Oil Dilution diagnostic realizes performance measures
LNT Ammonia Chemistry Research
Performance Measures – LNT Ammonia Chemistry

Ammonia is relevant to diesel product development:
- NH$_3$ slip management
- System design & calibration
- On-board detection of system state
- Cummins development emphasizes fundamental knowledge

Ammonia is difficult to measure w/ SpaciMS:
- Interferences with N$_2$, H$_2$O, NOx
- NH$_3$ is sticky
- Variable and different elution times

Performance Measures address diagnostic and information needs:
- Enable SpaciMS measurement of NH$_3$ inside operating LNT catalysts
- Map transient NH$_3$ distribution through catalyst
- Clarify NH$_3$ formation and utilization in LNT chemistry
Approach – LNT Ammonia Chemistry

- Catalyst core (3/4” x 3”) on bench reactor
- Washcoat: Pt/Ba/Al₂O₃ model catalyst
  - No cerium – oxygen-storage component
- CLEERS standard short cycling:
  - 60-s lean: 300ppm NO + 10% O₂
  - 5-s rich: 2% H₂
  - Common: 5% H₂O + 5% CO₂ + Ar balance
- \textit{Resolve species distributions along catalyst channel}
  - SpaciMS
  - NH₃ generation and utilization
  - NOx, N₂ and H₂
- Analyze distributed performance
  - Phase/timing of species puffs
  - Selectivity
Results – LNT Ammonia Chemistry

- Simultaneous N₂ & NH₃ generation at catalyst front
- NH₃ shifts to later times along catalyst length
- NH₃ consumed along catalyst length along with H₂

SpaciMS NH₃ measurements demonstrated
Must account for NH₃ regeneration role
Results – Vis-à-vis Literature Ammonia Chemistry

Nitrate Model:
‘fast’ & ‘slow’ storage sites

Dominant Literature NH₃ Theory:
NH₃ created at ‘slow’ sites, & NH₃ follows N₂ and reductant slip

- Our measurements show same sequence at outlet
- But simultaneous NH₃ and N₂ inside catalyst

NH₃ doesn’t always follow N₂
Literature NH₃ model incomplete
NH₃ not always from ‘slow’ sites
Technology Transfer

Via CRADA:

- All CRADA activities impact Cummins’ product development
- CRADA instrumental in the commercialization of the 2007 Dodge Ram engine-catalyst system

Outside of CRADA:

- Coordination with CLEERS impacts broad range of DOE interests
- Delphi improved reformer-catalyst models based on SpaciMS analysis
- Multiple industry inquiries into Oil Dilution diagnostic
- Hiden Analytical marketing commercial SpaciMS
- 2007 Cummins patent expands SpaciMS capabilities
Publications, Presentations, Patents

3 Publications:

- J.-S. Choi, W.P. Partridge, and C.S. Daw, “Sulfur impact on NO\textsubscript{x} storage, oxygen storage and ammonia breakthrough during cyclic lean/rich operation of a commercial lean NO\textsubscript{x} trap”, Applied Catalysis B: Environmental 77, 145-156 (2007).

4 Presentations:


1 Patent:

Future Activities

Engine-Systems Section:
- Apply oil-dilution diagnostic on development V engine at Cummins (scheduled - March 2008)
- Develop and apply methods to quantify cylinder and cycle dispersion

Instrumentation & Bench Section:
- Characterize NH$_3$ chemistry in LNT with oxygen-storage component (Umicore, CLEERS reference catalyst)
- Characterize sulfation impact on LNT catalyst reactions, including NH$_3$ formation and utilization and water-gas-shift
Summary

- **Relevance to DOE Objectives**
  - Reduce fuel consumption by enabling diesel market penetration

- **Approach**
  - Real-time on-engine measurement of oil dilution
  - Measure evolution of NH₃ generation and utilization inside catalyst

- **Technical Accomplishments**
  - Streamline engine calibration
  - Enable SpaciMS NH₃ measurements & clarify LNT catalyst reactions
  - Enable improved modeling of LNT and hybrid LNT-SCR systems

- **Technology Transfer**
  - Broad based transfer via Cummins products & outside CRADA

- **Future Plans**
  - Measure cylinder and cycle dispersion on development engines
  - Quantify distributed impact of sulfation on NH₃ LNT reactions
  - Designed to address Cummins’ technical barriers