Measurement and Characterization of Unregulated Emissions from Advanced Technologies

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This presentation does not contain any proprietary or confidential information
Purpose of Work: Ensure that advanced petroleum-saving technologies “do no harm”

- Measurement of all types of emissions from advanced engine technologies and alternative fuels
  - Characterize Mobile Source Air Toxics (MSATs) from advanced combustion regimes
  - Determine efficacy of aftertreatment for MSAT treatment
  - Determine effects of alternative fuels in standard and advanced combustion modes
  - Identify any potential unregulated emissions issues with advanced aftertreatment systems
    - LNT, Urea SCR, HC-SCR, DPF
ORNL research activities address barriers identified in FCVT Multi-Year Plan

- **3.3.5.7 Market Challenges and Barriers**
  - A. Market Perception.
    - There is increasing public awareness of adverse health impacts related to vehicle emissions. As a result market acceptance is contingent upon improved understanding and knowledge that these new technologies have considered mitigation of known health impacts and will have no unknown potential health impacts.

- **3.3.5.8 Technical Challenges and Barriers**
  - B. Lack of actual emissions data on pre-commercial and future combustion engines.
    - The health impacts of future technologies (e.g., 2007/2010 compliant production engines) have to be evaluated well in advance of their market introduction and, therefore, lack actual real-world emissions data, not to mention the difficulty of measuring very low level emissions that are expected from them.
  - C. Lack of analytical tools (rapid assay techniques) relevant to human toxicity.
    - This includes lack of standardized “baseline case” inhalation exposure atmospheres and collected samples with which to compare in vivo and in vitro responses; the need for confirmation that in vitro toxicity test systems accurately mirror relative response of lungs to different exposures, and the poor ability to separate different components from “whole” emissions; or to selectively eliminate components for inhalation exposures.
  - D. Lack of credible validated models for emissions source apportionment.
    - There are no universally recognized molecular markers to distinguish between gasoline and diesel exhaust, as well as other fuel types, and little data from various source types to adequately apportion air toxics to their respective sources (cars vs. trucks). There is an inadequate understanding regarding engine operating conditions (and ambient conditions) that influence emissions from mobile sources and a lack of standardized “baseline” collected real-world emissions samples with which to compare the health response.
Address Previous Reviewer Comments

Strengths:

- "...the health impacts of unregulated emissions are becoming an important issue, especially such emissions as aldehydes from bio-fuels and oxygenated fuels."
- "...an important component of the DOE-FCVT Health Impacts Program strategy: examinations of the performance of deployed or prototype new vehicle technologies, providing information on new technology capabilities and areas for development."
- "...combination of dynamometer test bed emissions characterization and on-road testing is excellent."
- "...methods are in place and in use for dynamometer and on-road testing."
- "Several peer-reviewed publications and presentations attest to the research productivity of the project."
- "...based upon accomplishments, the project general direction of assessing emissions of a variety of new vehicles seems likely to continue with success."
- "The use of European vehicles and biofuel experience is to be encouraged."
- "The developed analytical capabilities for characterization of vehicle emissions from dynamometer test bed and on-road performance are noteworthy."
- "Work such as this is necessary to fend off the inevitable attacks over the toxicity of the emissions from any new fuel (biofuels as an example) in the future."
- "Good work."

Recommendations:

- "...while the selection of new technology vehicles for testing must be somewhat expeditious, is there - in fact or possibility - a selection strategy, perhaps involving the Department of Transportation or others, for vehicle selection or for identification of emission topics of concern?"
- "...the team needs to better describe where this fits into DOE's future plans."
- "While staying open to the unexpected innovation, is it possible (or does there already exist) a multi-year plan for specific vehicles or technical concerns?"
- "...emerging concerns for ultrafine particulate emissions effecting unexpected health hazards or exacerbated toxicities suggest reviewing or preparing for particle size-classified sampling and characterization well into the sub-micrometer size range... ."

Feedback:

- Agreement with concerns addressed re: new fuels and technologies
  Action: Continue studies
- Approach and use of methods/capabilities with dyno studies good
  Action: Continue approach
- Positive feedback on interactions with other entities and progress made
  Action: Continue
- How do findings fit into DOE/DOT/EPA future plans and selection strategies?
  Action: Continue presenting results; consider future years
- Concern for ultrafine particulate health effects
  Action: Working on it with existing and new instrumentation
Approach

Research

Fuels

Combustion

Emission Control

Development

Fuels

Combustion

Emission Control

Deployment

Study Potential Harmful Emissions

Feedback
Performance Measures and Accomplishments

Since last review (June 2007):

- Characterized MSAT emissions from HCCI technology with diesel oxidation catalyst at various loads
  - Single cylinder HCCI engine with ULSD fuel
  - Gaseous and particulate species
  - Used low temperature diesel oxidation catalyst

- Characterized MSAT emissions from multi-cylinder engine in PCCI and conventional operation with Lean NOx trap catalyst
  - Four cylinder 1.7 L engine with ULSD fuel
  - Gaseous and particulate species
  - Lean NOx trap technology
What are Mobile Source Air Toxics (MSATs)?

**Mobile Source Air Toxics (MSATs)**

- **Volatile Organics**
  - Diesel Exhaust Organic Gases
    - Formaldehyde
    - Acetaldehyde
    - 1,3-Butadiene
    - Acrolein

- **Semivolatile Organics**
  - Benzene
  - Toluene
  - Ethylbenzene
  - Xylene

- **Particulate Matter (PM)**
  - Diesel PM
  - Polycyclic organic Matter (POM)
    - Polycyclic Aromatic Hydrocarbons (PAHs)

**Note:** Specific health risks associated with each compounds are only known to varying degrees, but all MSATs raise concerns.
Array of Analytical Techniques for MSATs

- **Dilution Tunnel**
- **SMPS**
  - Particle Size Distribution
- **PM Filters**
- **Total PM SOF/insoluble SOF speciation**
- **Empore**
  - Selective capture of semi-volatiles (C10-C18)
- **GC/MS speciation**
- **FTIR**
  - C1-C4 species
- **Canisters**
  - Light HC species
  - Preconcentrator, GC/MS speciation
- **DNPH**
  - Selective capture of carbonyl species
  - HPLC, UV, ESI/MS separation/speciation
Engines operated at several speeds and loads which accommodate advanced combustion

- **HCCI engine** – single cylinder
  - 1800 RPM, 4 fueling rates, IMEP from 1.5 – 4
  - NOx <5 ppm; FSN < 0.3; HC 2200-2900 ppm; CO 1700-1900 ppm
  - Catalyst: MECA-supplied low temperature DOC

- **PCCI engine** – 4 cylinder, 1.7L turbocharged, DI
  - 3 modes in conventional and HECC operation
    - 1500 RPM, 1.0 bar BMEP – almost idle
    - 1500 RPM, 2.6 bar BMEP – 35 MPH cruise
    - 2000 RPM, 2.0 bar BMEP – low load cruise
  - In PCCI: NOx 20-35 ppm; FSN < 0.75, HC 700-2000 ppm, CO 2000-4000 ppm
  - Catalyst: MECA-supplied lean NOx trap
    - Lean-only oxidation – no rich operation sampled
Highlights of technical accomplishments

- A subset of data shown here:
  - formaldehyde, acetaldehyde
  - BTEX – (Benzene, Toluene, Ethylbenzene, Xylenes)
  - Exhaust nanoparticle characterization

- PCCI and HCCI often produce more engine out MSATs than conventional modes

- Catalyst temperatures are critical for advanced combustion implementation
  - Thermal management crucial at low loads to prevent MSAT emissions
HCCI aldehydes are removed by catalyst at all 4 load points - formaldehyde similar to Tier 2, Bin 5

Emissions Index (g/kg fuel)

Engine Out
Catalyst Out

Formaldehyde
Acetaldehyde

IMEP (bar)

Tier 2 Bin 5 formaldehyde regulation 0.24 g/kg fuel
Low catalyst temperature presents challenges for tailpipe aldehydes in PCCI mode

Tier 2, Bin 5 formaldehyde regulation 0.24 g/kg fuel
HCCI and PCCI aldehyde emissions are similar for similar engine conditions.

HCCI: 1800 RPM, 3.1 IMEP    PCCI: 1500 RPM, 3.2 IMEP
For HCCI engine exhaust, Benzene, Toluene, Ethylbenzene, Xylene are converted by catalyst (1800 RPM, 1.5 IMEP)

- OSHA workplace standards for BTEX are orders-of-magnitude higher than tailpipe concentration!
  - OSHA Benzene 10 ppm
  - OSHA Toluene 200 ppm
- Observed exhaust levels will not directly impact health
At 1500 RPM, 1.0 bar BMEP, Benzene, Toluene, Ethylbenzene, Xylene are at similar levels for Conventional and PCCI - with no catalyst, very close to Tier 2, Bin 5 levels

**Bottom Line:** Observed tailpipe levels of little concern for these MSATs
For cruise modes, PCCI engine out higher for Benzene, Toluene, Ethylbenzene, and Xylene; catalyst effective

Engine Out – 1500 rpm, 2.6 bar

Engine Out - 2000 rpm, 2.0 bar

Catalyst Out - 1500 rpm, 2.6 bar

Catalyst Out - - 2000 rpm, 2.0 bar
Benzene, Toluene, Ethylbenzene, Xylene at similar levels for HCCI and PCCI at similar IMEP (~3.2)

PCCI: 2.6 bar, 1500 RPM
HCCI: IMEP 3.2 bar, 1800 RPM
HCCI catalyst shows conversion higher for certain species

HC conversion fairly constant, so poor performance on individual MSATs may be a concern
Particle size measurements
At lowest load, PCCI PM smaller in size, and much lower in surface area than PM from conventional point

Numbers are similar, but PCCI particles much smaller

Overall surface area is much higher in conventional mode
PCCI at 1500, 2.6 BMEP shows higher numbers of particles but less surface area than conventional point

PCCI lacks **numbers** of particles >100 nm typical of soot from conventional combustion

Larger soot particles in conventional mode mean more **surface area**
At the comparison setpoint, HCCI showed virtually no particle formation above 10 nm.
Technology Transfer

- Strong interactions with CRC, EPA, and DOT
  - Information sharing with ACES team
  - Ongoing DPF project with EPA-OTAQ
  - Active on the TRB’s Transportation and Air Quality Committee

- Publications since last Merit Review (June, 2007):
  - DEER 2007 – Two posters
  - Paper and poster at CRC On-Road, March 2008
  - Abstract submitted for Fall 2008 SAE Powertrain Meeting
  - DEER 2008
Plans for Rest of FY08 and FY09

- **Rest of FY08**
  - Continue with ethanol studies
  - Add biodiesel blends to HCCI research
  - Further characterization of diesel particulate

- **FY09**
  - DPF effects on PCCI emissions
  - (Bio)Butanol effects/products
  - Urea-SCR products
Summary

• **Relevance**
  Improved understanding of emissions from advanced combustion, fuels, and emission control technologies is critical to ensuring new technologies avoid negative human health impacts

• **Approach**
  In-depth exhaust characterization of advanced combustion, fuels, and emission control devices in the laboratory

• **Accomplishments**
  • HCCI Combustion: Characterized MSATs and other emissions downstream of an oxidation catalyst on a single-cylinder diesel engine operating in HCCI mode
  • PCCI Combustion: Characterized MSATs and other emissions from multi-cylinder diesel engine operating in PCCI (relative to conventional operation) and determined the efficiency of a Lean NOx Trap catalyst to control the emissions

• **Collaboration**
  • Sharing information or involved directly with CRC, EPA, and DOT in the emissions/air quality/health impacts fields
  • Working closely with DOE-sponsored projects on advanced technologies

• **Future Research**
  • Investigate effect of alternative fuels on emissions from HCCI, SI vehicles
  • Study emissions downstream of urea SCR and DOCs with PCCI combustion

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