Measurement and Characterization of Unregulated Emissions from Advanced Technologies

Agreement: 13604

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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 i… s from bio-fuels and oxyg…
- "…an important compo… deployed or prototype ne… development."
- "…combination of dyn…
- "…methods are in p…
- "Several peer-reviewed…
- "…the list of outside pa… universities, indicate th… collaborations."
- "…based upon accompli… likely to continue w…
- "The use of European ve…
- "The developed analytic… performance are notewo…
- "Work such as this is necessary to fend off the inevitable attacks over the toxicity of the emissions from any new fuel (biofuels as a…
- "Good wo…

Recommenda…
- "…while … - a sele… of emission topics o…
- "…the team needs to bett…
- "While staying … vehicles or tech…
- "…emerging co… suggest … range…."

Feedback: Agreement with concerns addressed re: new fuels and technologies
Action: Continue studies

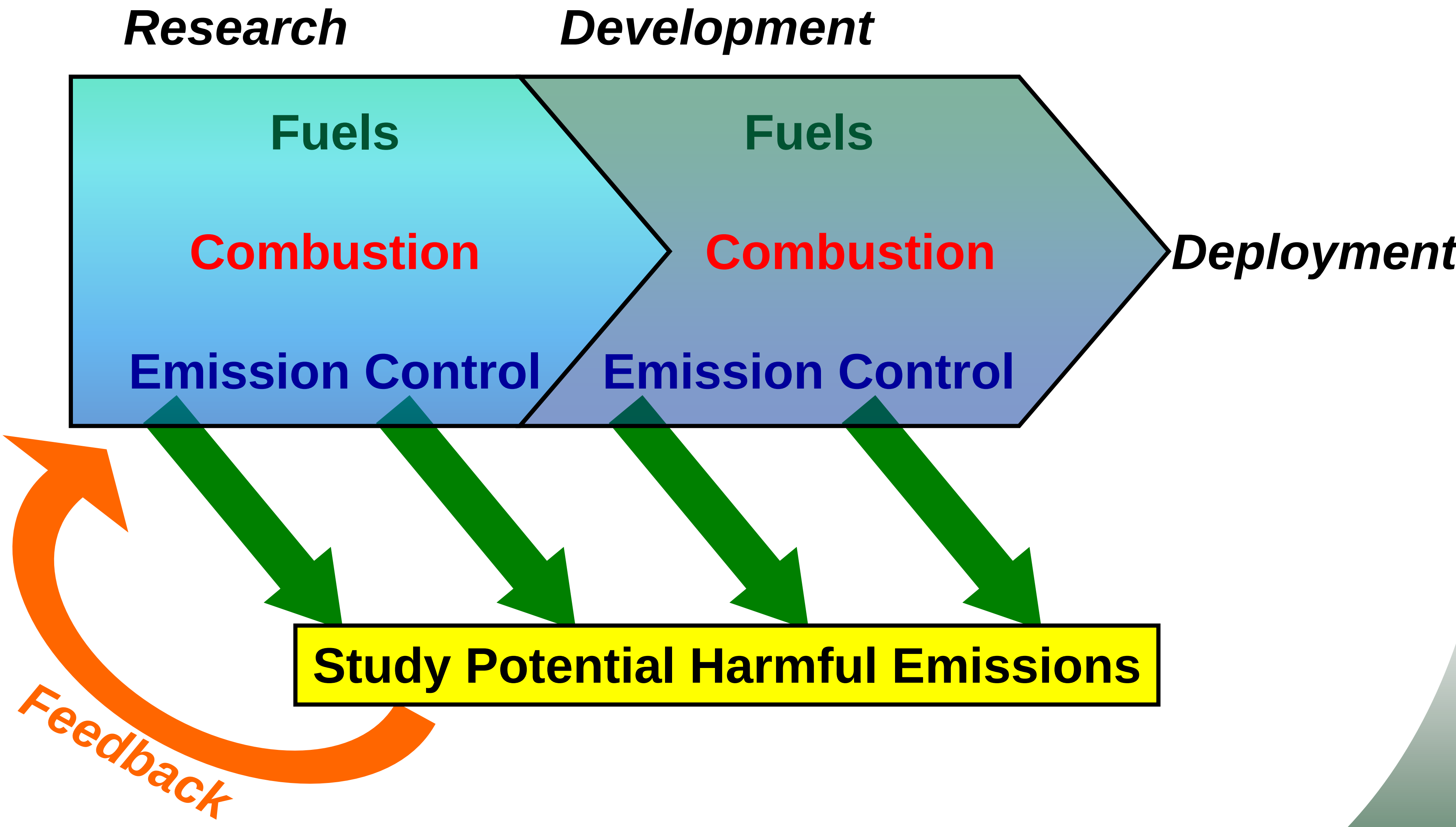
Feedback: Approach and use of methods/capabilities with dyno studies good
Action: Continue approach

Feedback: Positive feedback on interactions with other entities and progress made
Action: Continue

Feedback: How do findings fit into DOE/DOT/EPA future plans and selection strategies?
Action: Continue presenting results; consider future years

Feedback: Concern for ultrafine particulate health effects
Action: Working on it with existing and new instrumentation

Approach

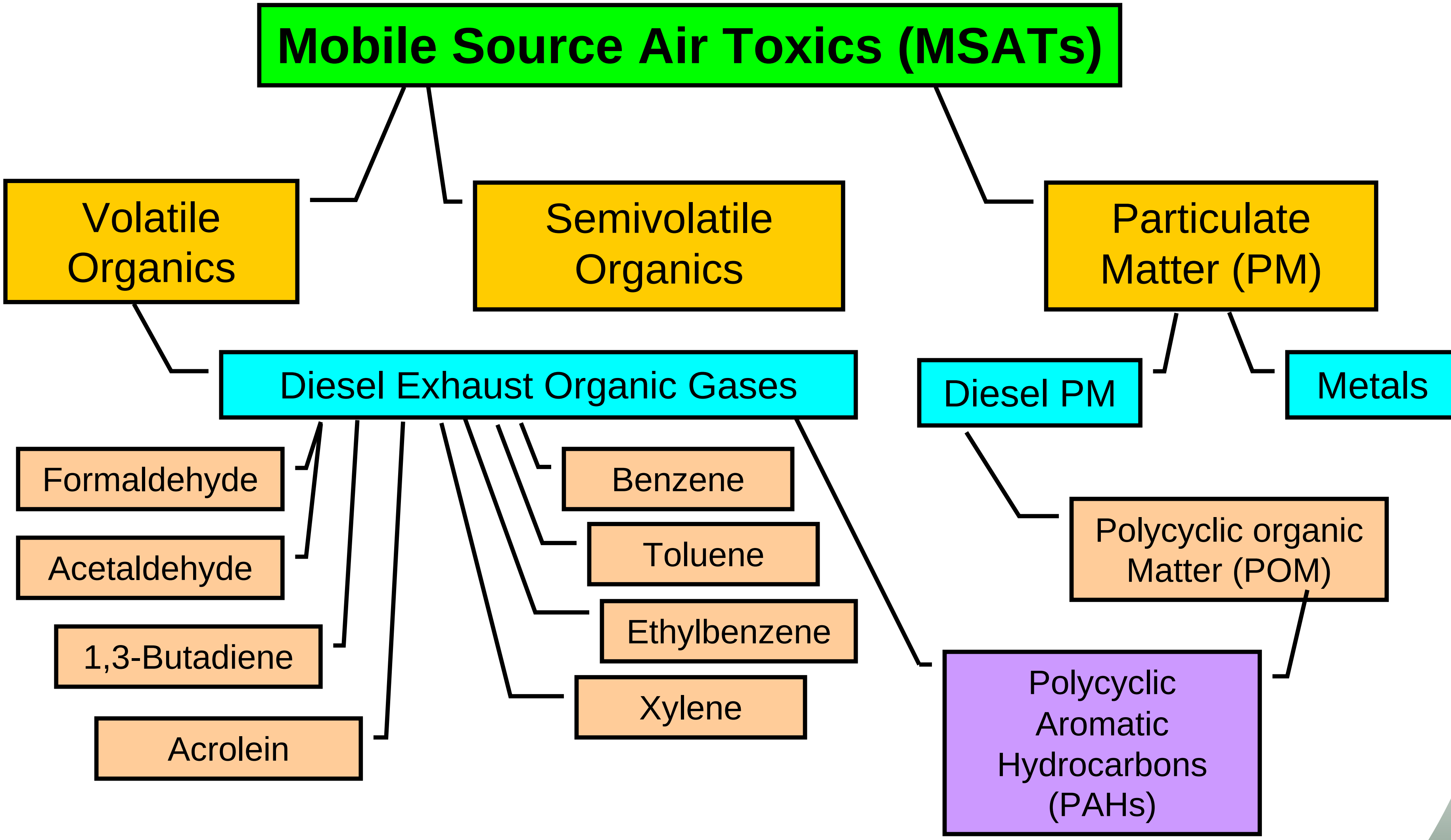

Research
Development
Fuels
Combustion
Emission Control
Fuels
Combustion
Emission Control
Deployment
Study Potential Harmful Emissions
Feedback

Performance Measures and Accomplishments

Since last review (June 2007):

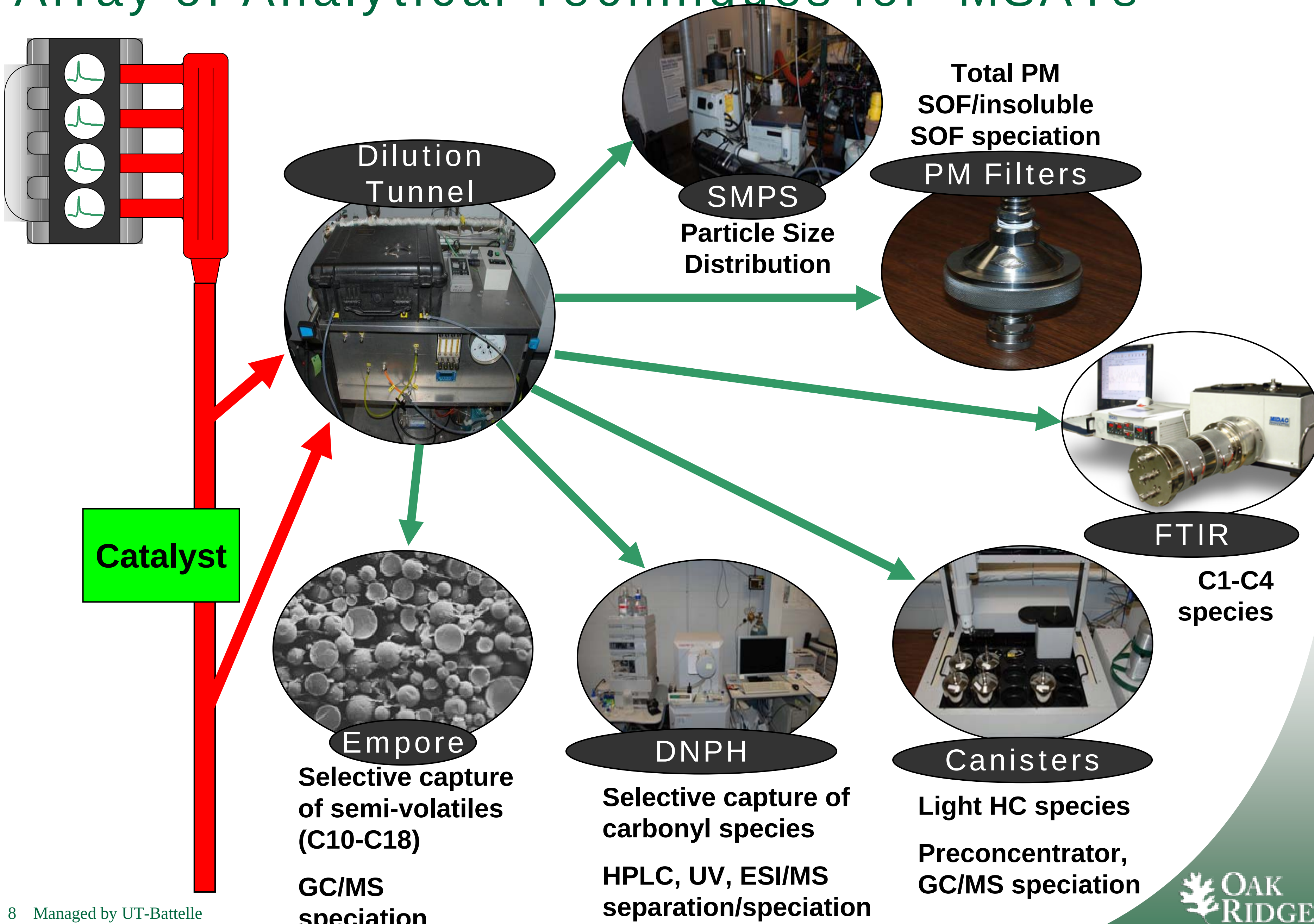
- **Characterized MSAT emissions from HCCI technology with diesel oxidation catalyst at various loads**
  - **Single cylinder HCCI engine with ULSD fuel**
  - **Gaseous and particulate species**
  - **Used low temperature diesel oxidation catalyst**
- **Characterized MSAT emissions from multi-cylinder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



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



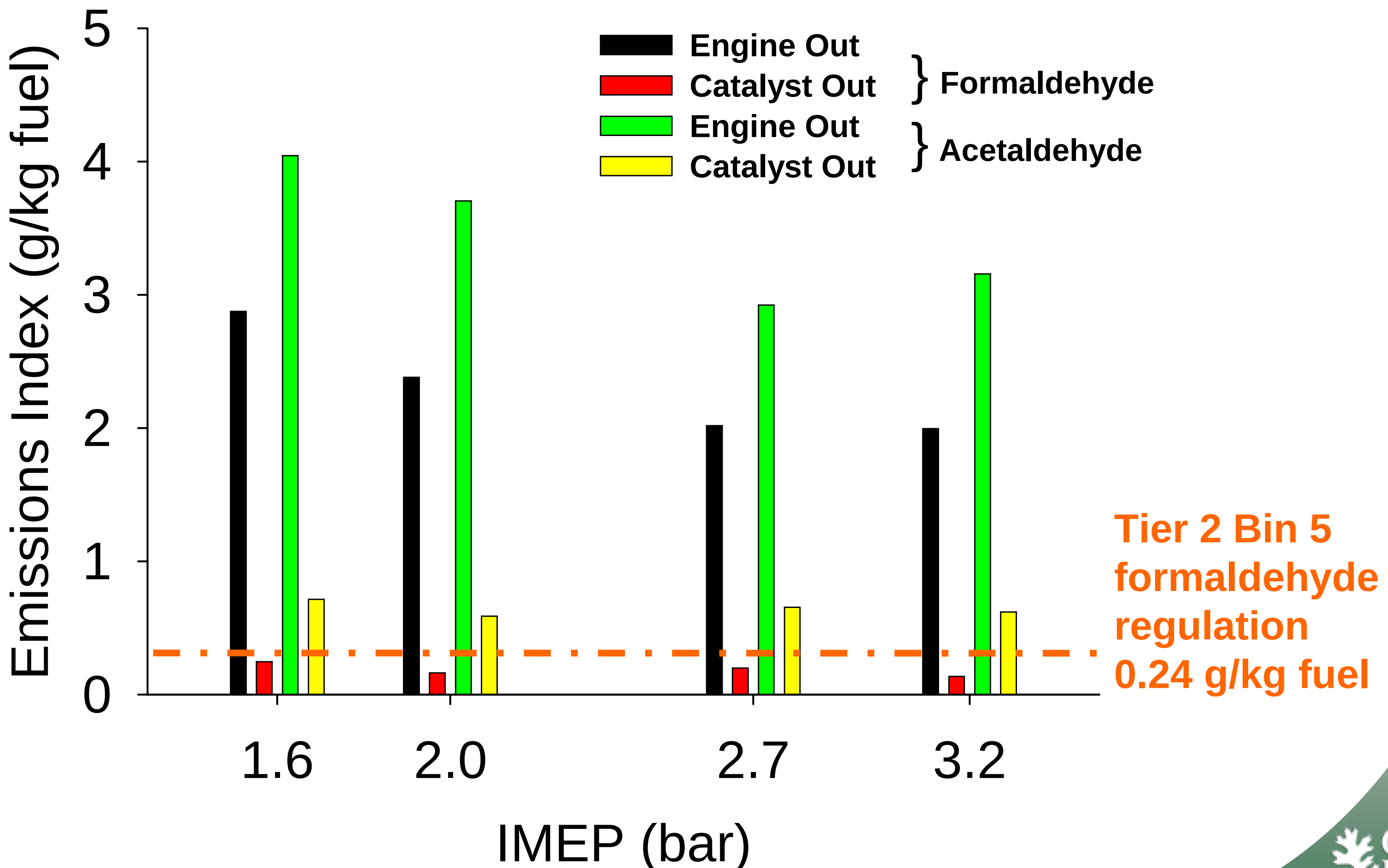
Engines operated at several speeds and loads which accomodate advanced combustion

- **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**

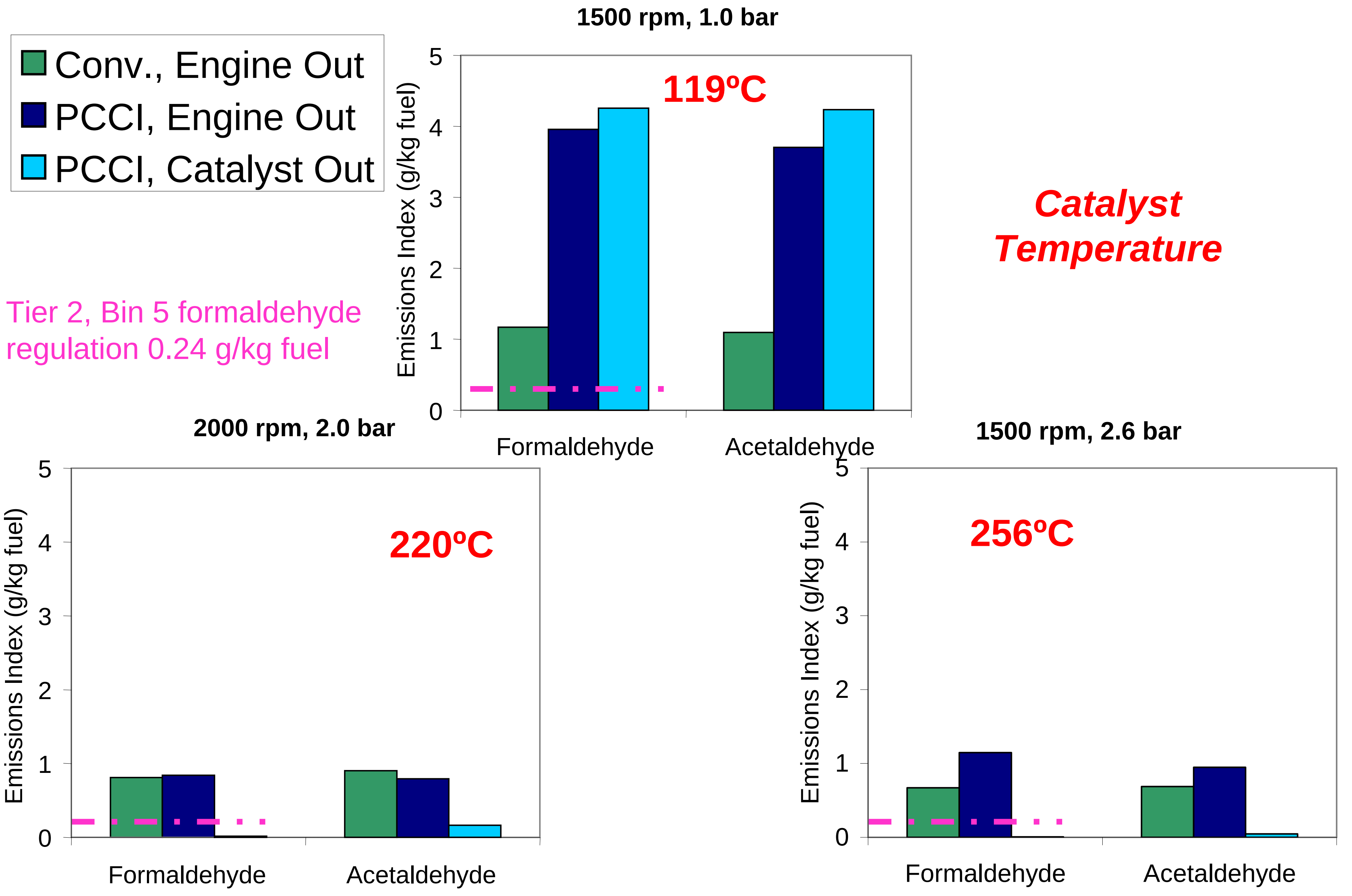
Highlights of technical accomplishments

- **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

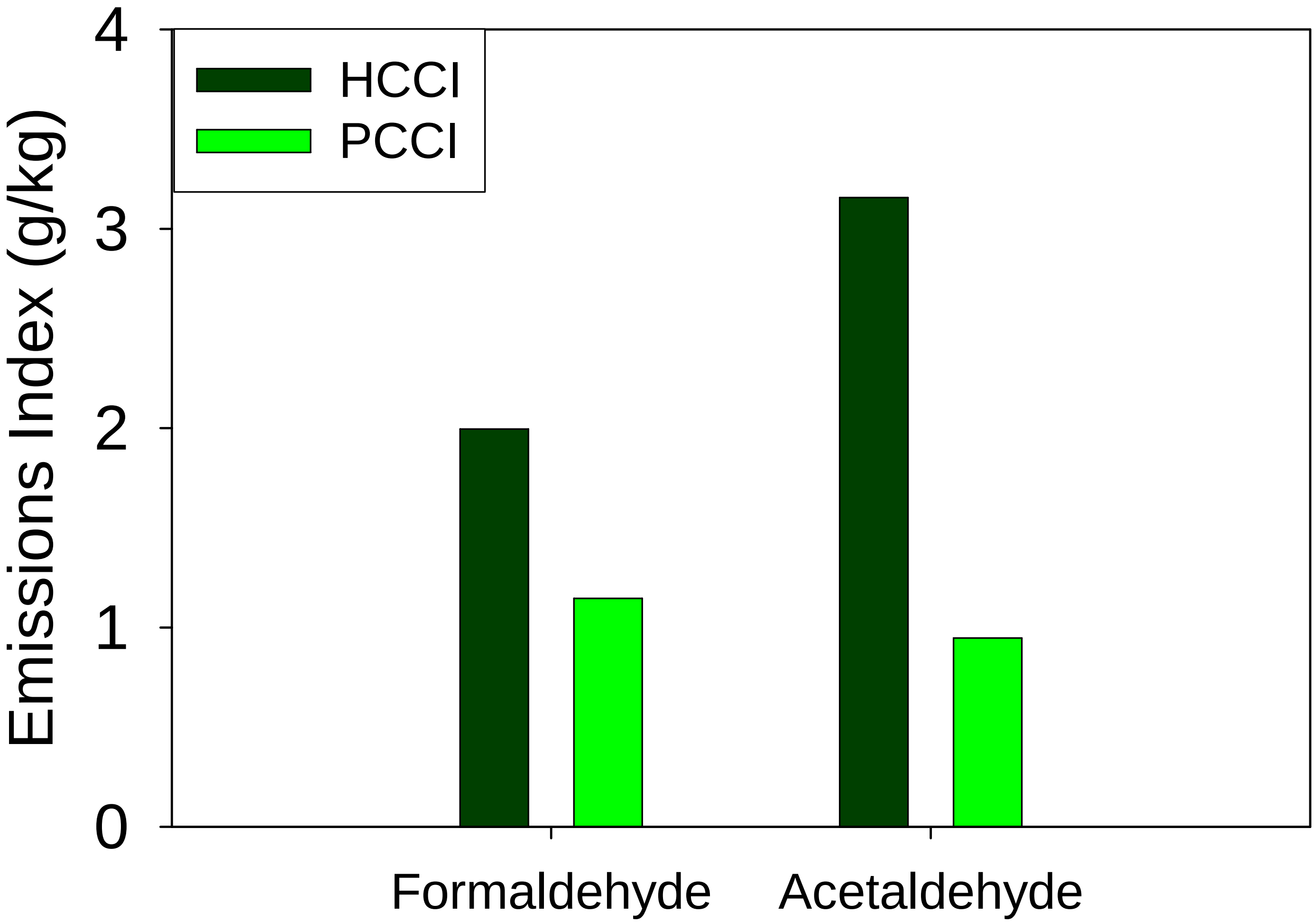


Low catalyst temperature presents challenges for tailpipe aldehydes in PCCI mode

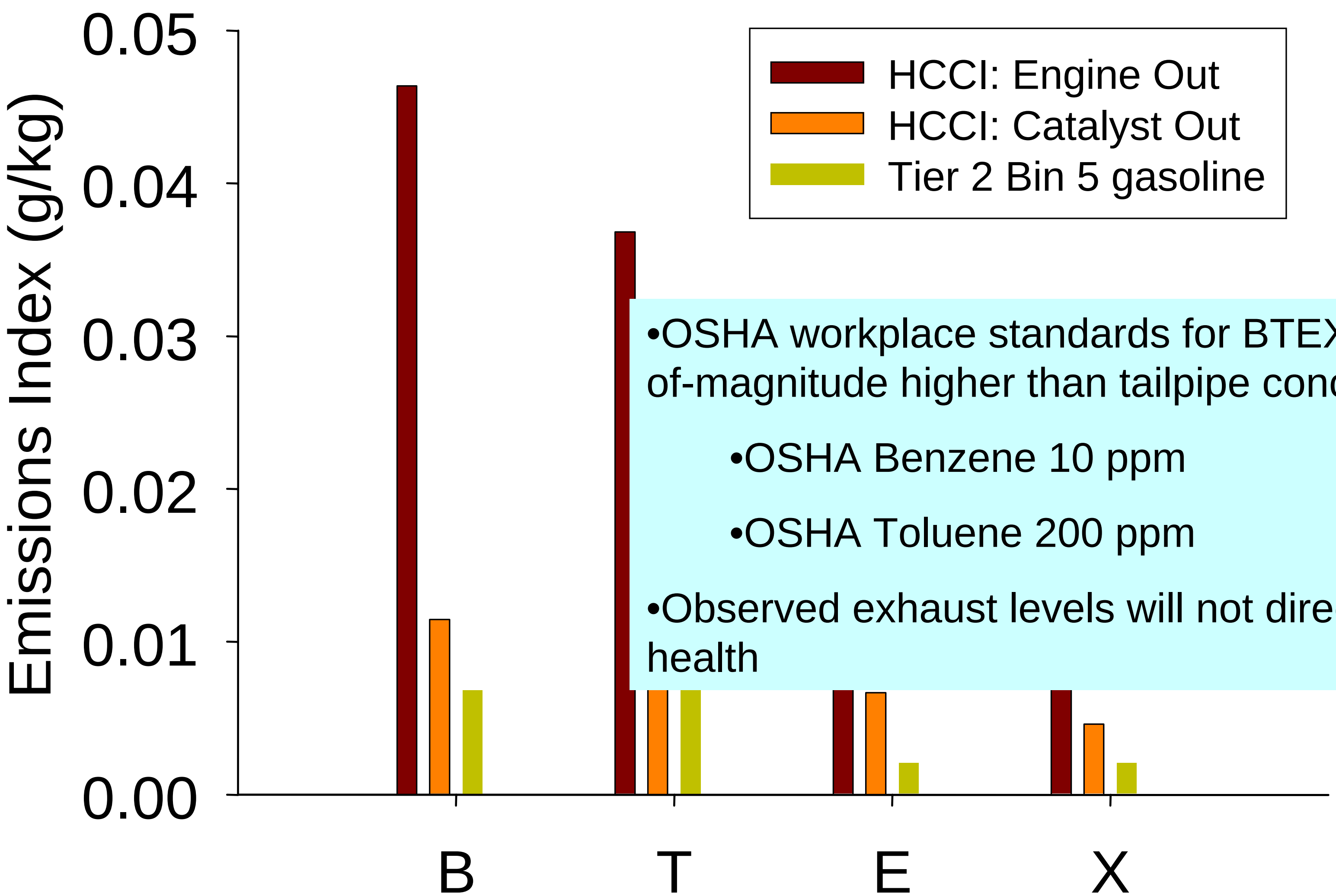


HCCI and PCCI aldehyde emissions are similar for similar engine conditions

HCCI: 1800 RPM, 3.1 IMEP PCCI: 1500 RPM, 3.2 IMEP

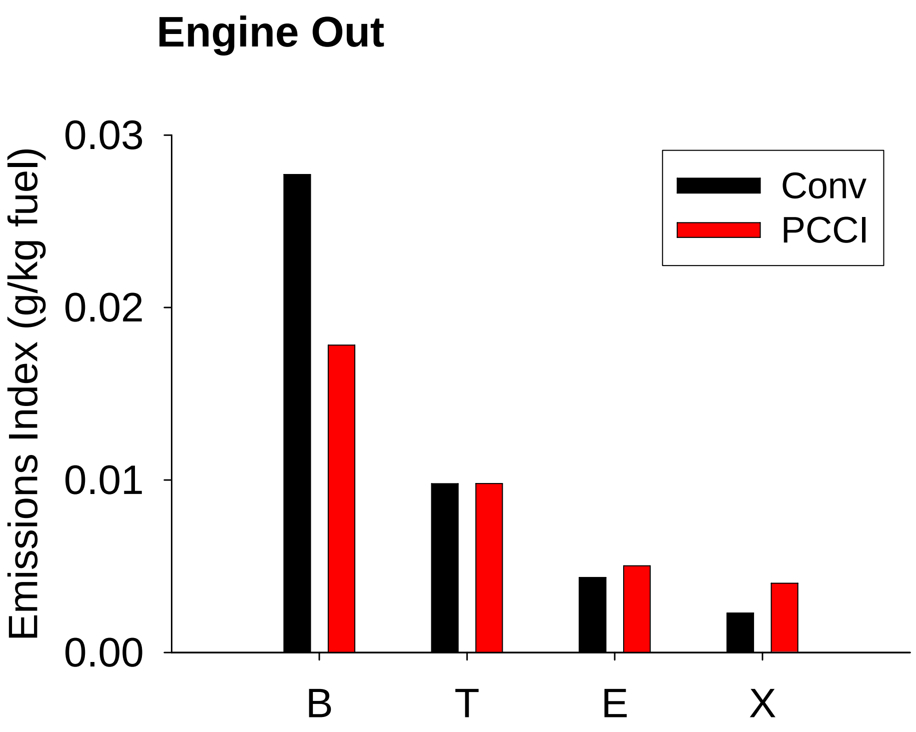


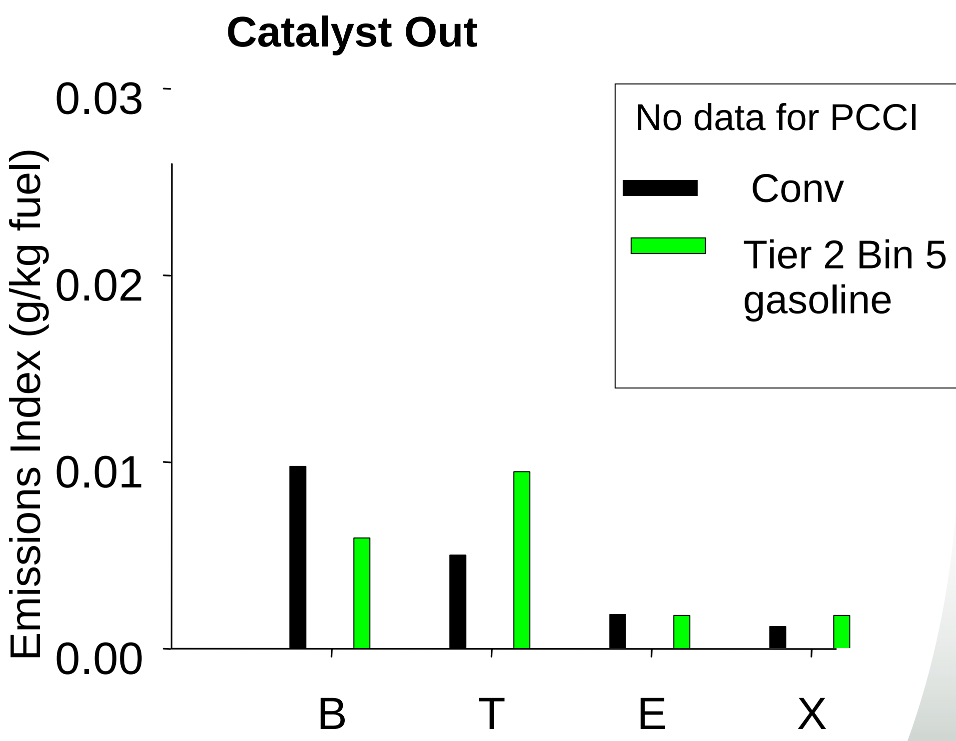
For HCCI engine exhaust, Benzene, Toluene, Ethylbenzene, Xylene are converted by catalyst
(1800 RPM, 1.5 IMEP)



- 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

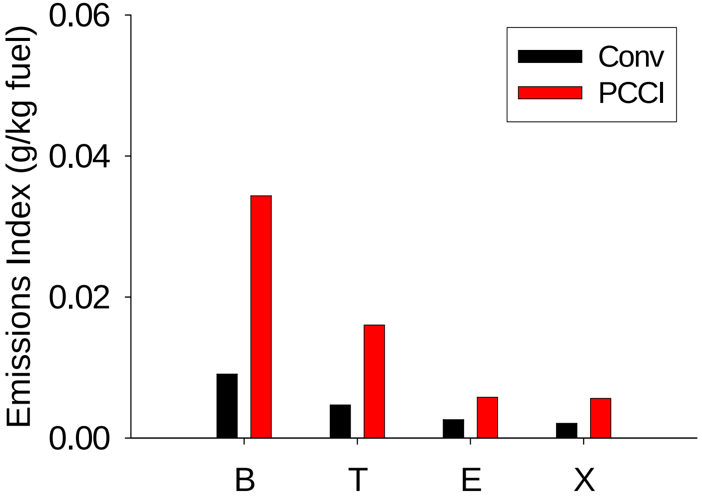




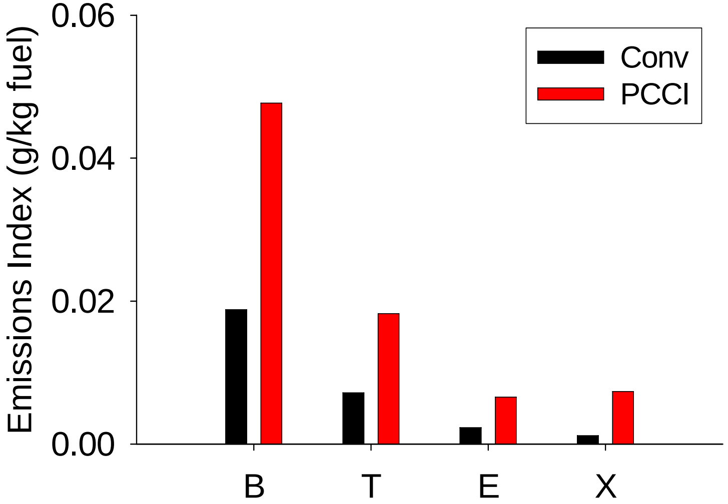
Bottom Line: Observed tailpipe levels of little concern for these MSATs

For cruise modes, PCCI engine out higher for Benzene, Toluene, Ethylbenzene, and Xylene; catalyst effective

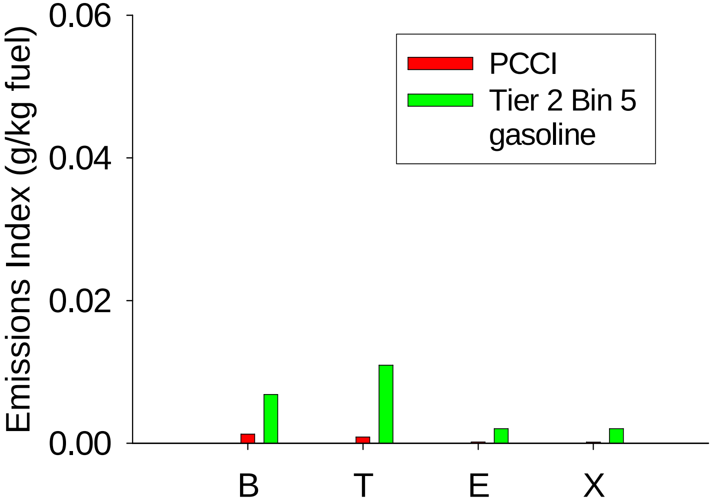
Engine Out – 1500 rpm, 2.6 bar



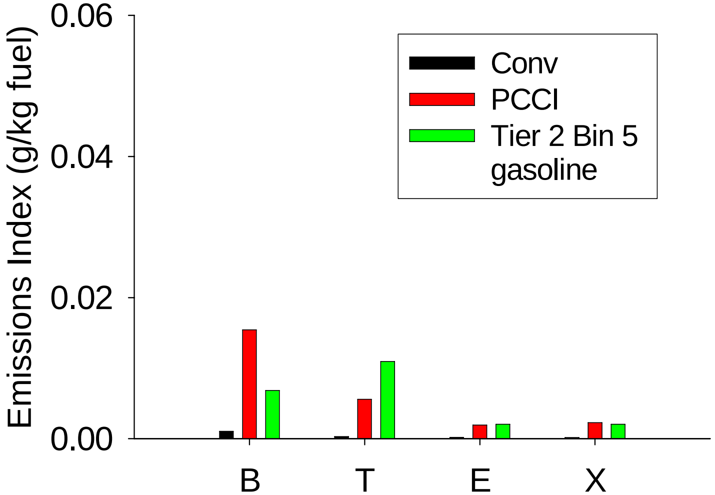
Engine Out - 2000 rpm, 2.0 bar



Catalyst Out - 1500 rpm, 2.6 bar



Catalyst Out - - 2000 rpm, 2.0 bar



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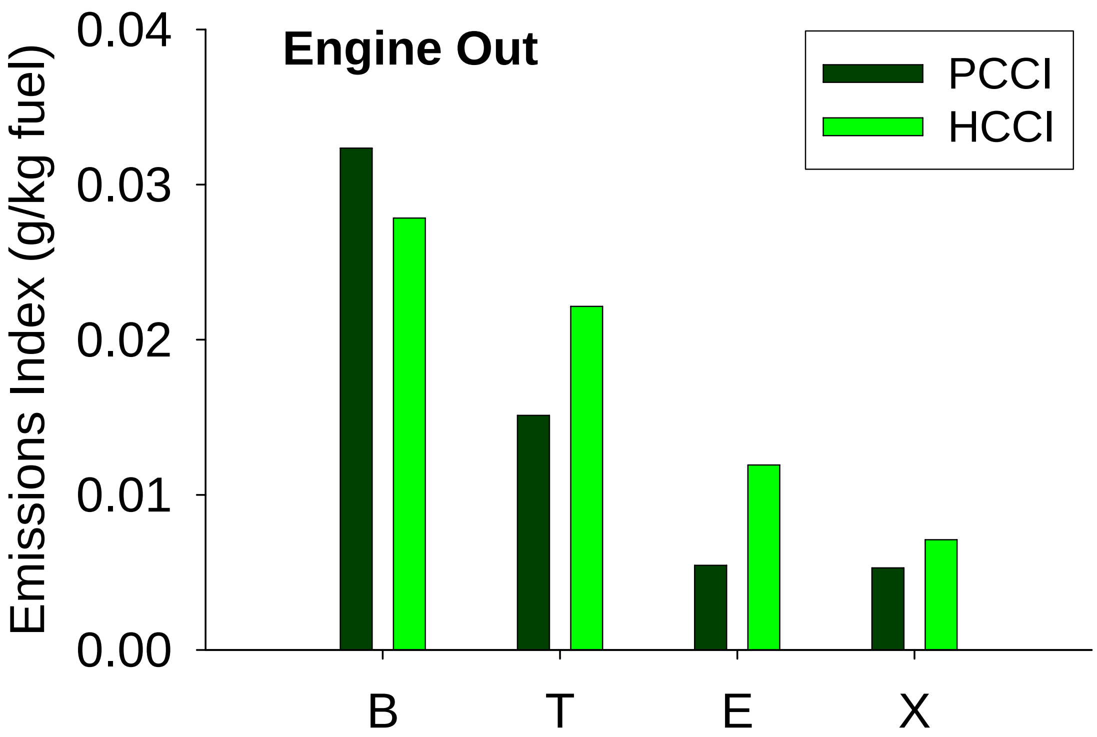
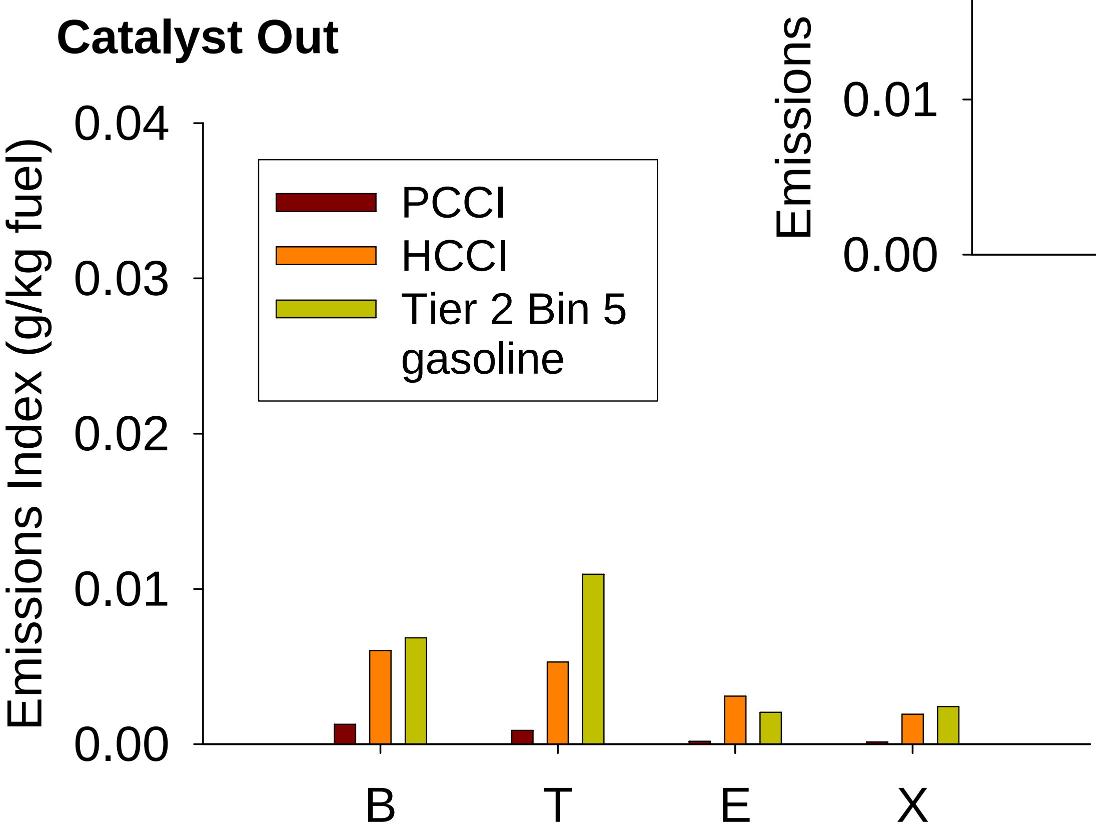
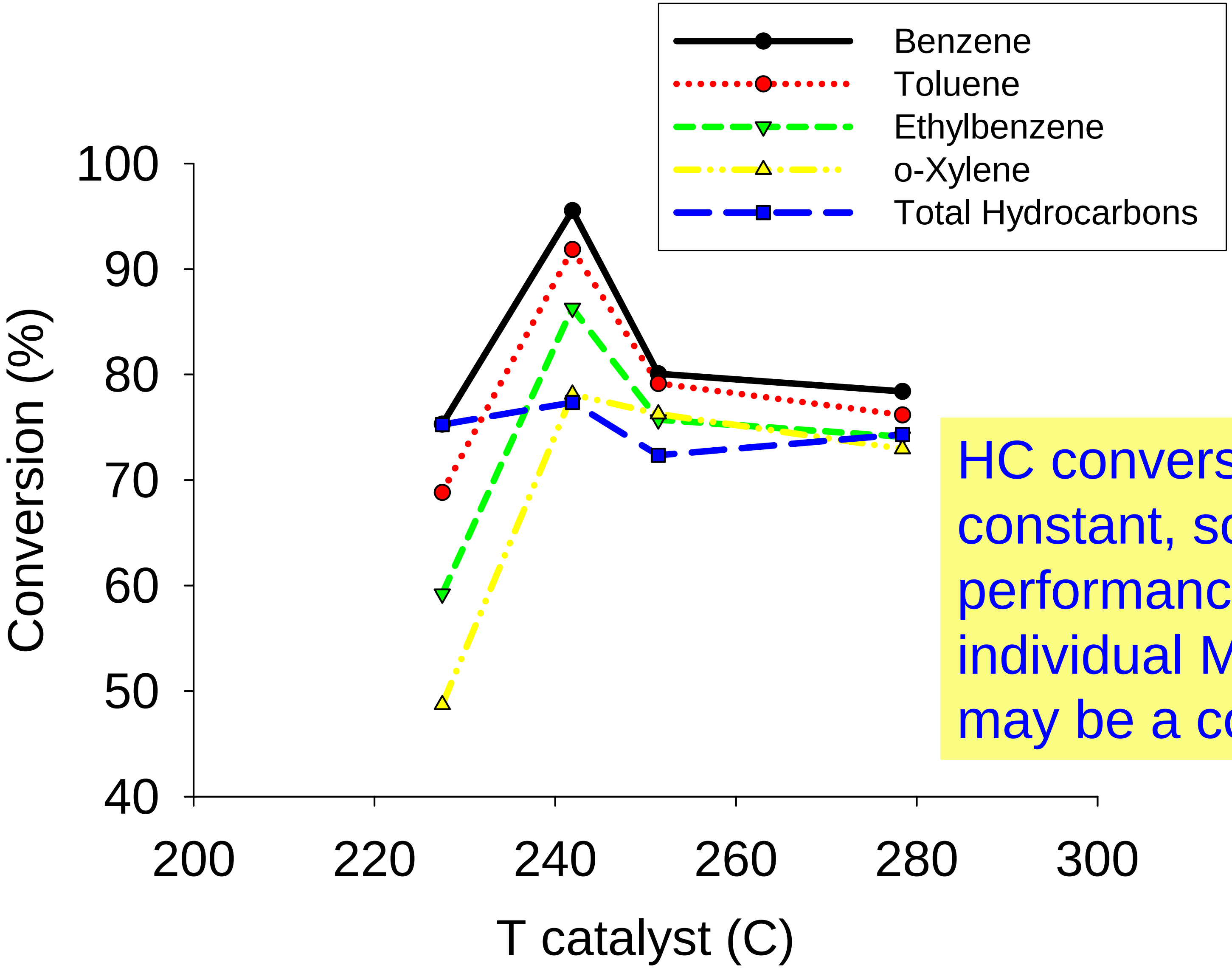
Benzene, Toluene, Ethylbenzene, Xylene at similar levels for HCCI and PCCI at similar IMEP (~3.2)

PCCI: 2.6 bar, 1500 RPM
HCCI: IMEP 3.2 bar, 1800 RPM





HCCI catalyst shows conversion higher for certain species

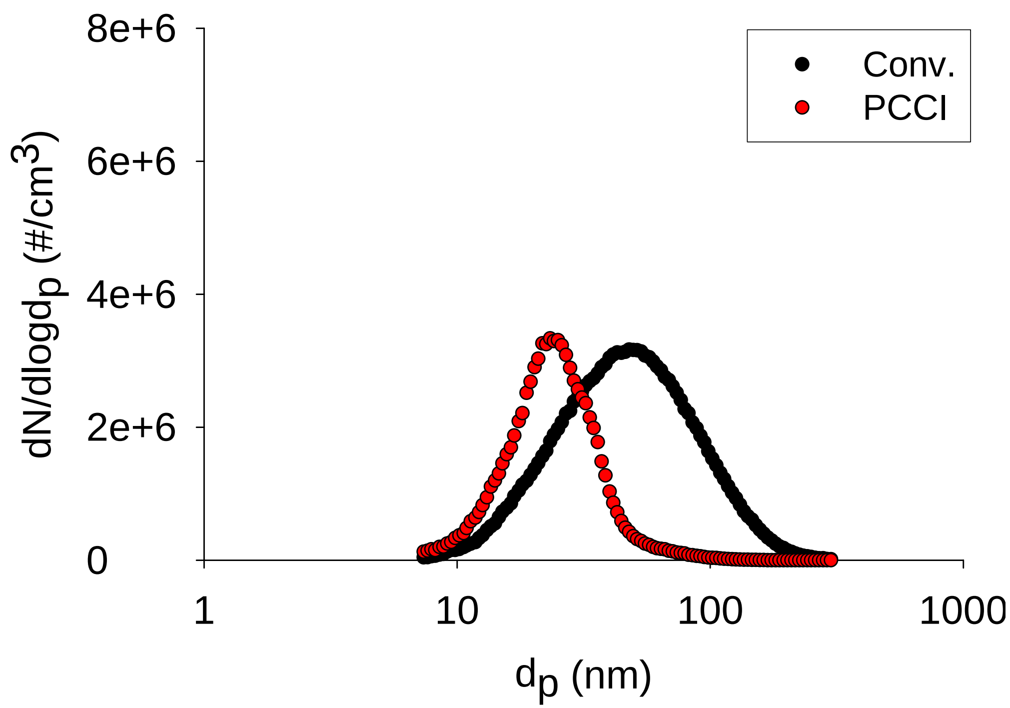


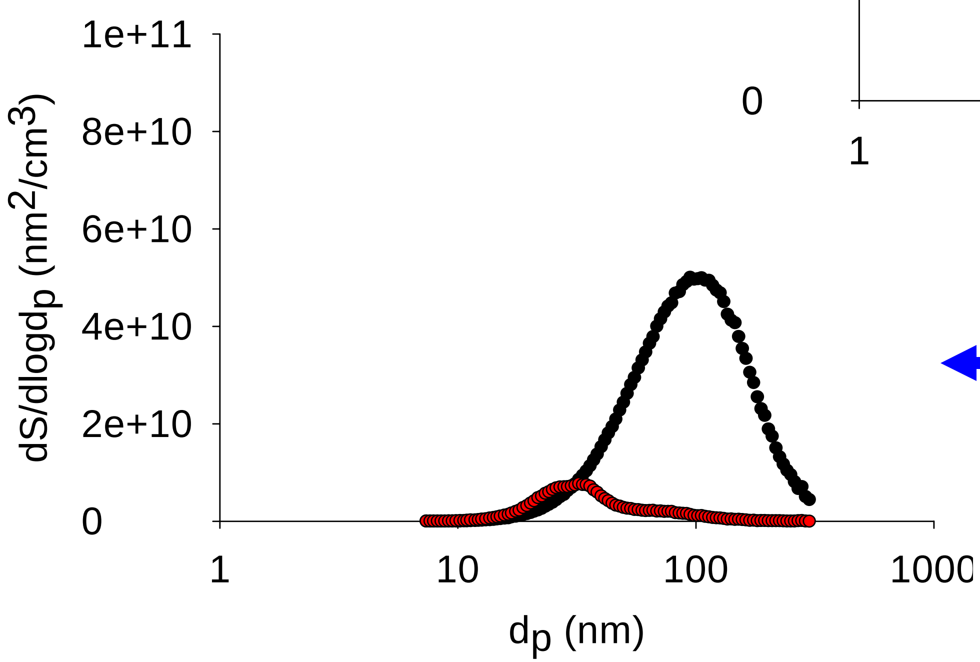
HC conversion fairly constant, so poor performance on individual MSATs may be a concern

Particle size measurements

At lowest load, PCCI PM smaller in size, and much lower in surface area than PM from conventional point

<u>Numbers</u> are similar, but PCCI particles much smaller

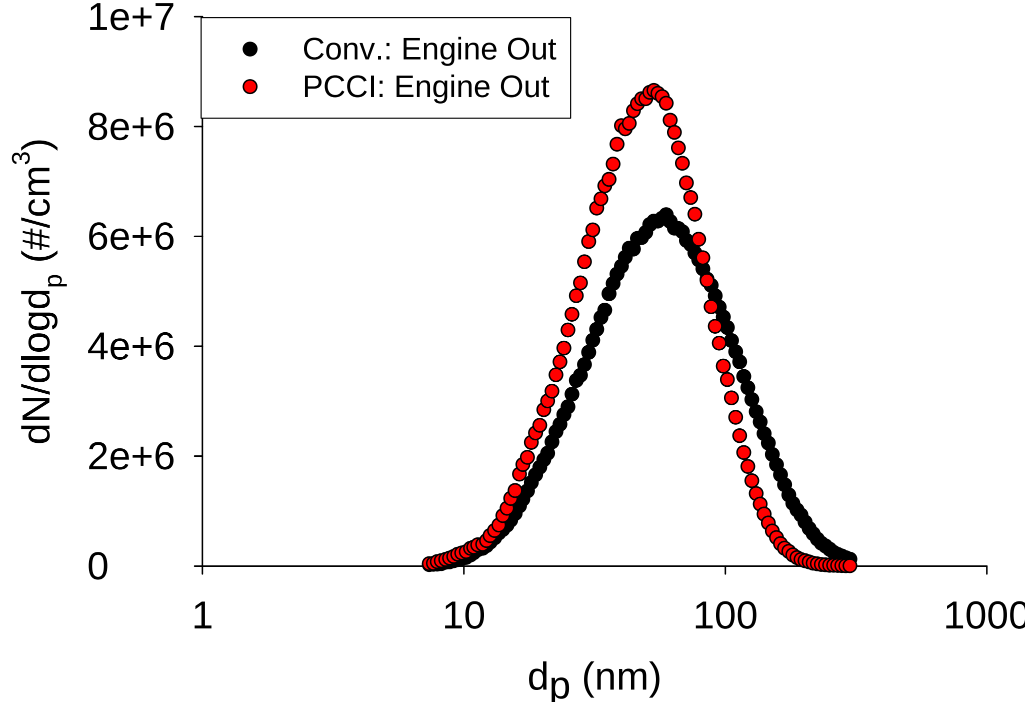


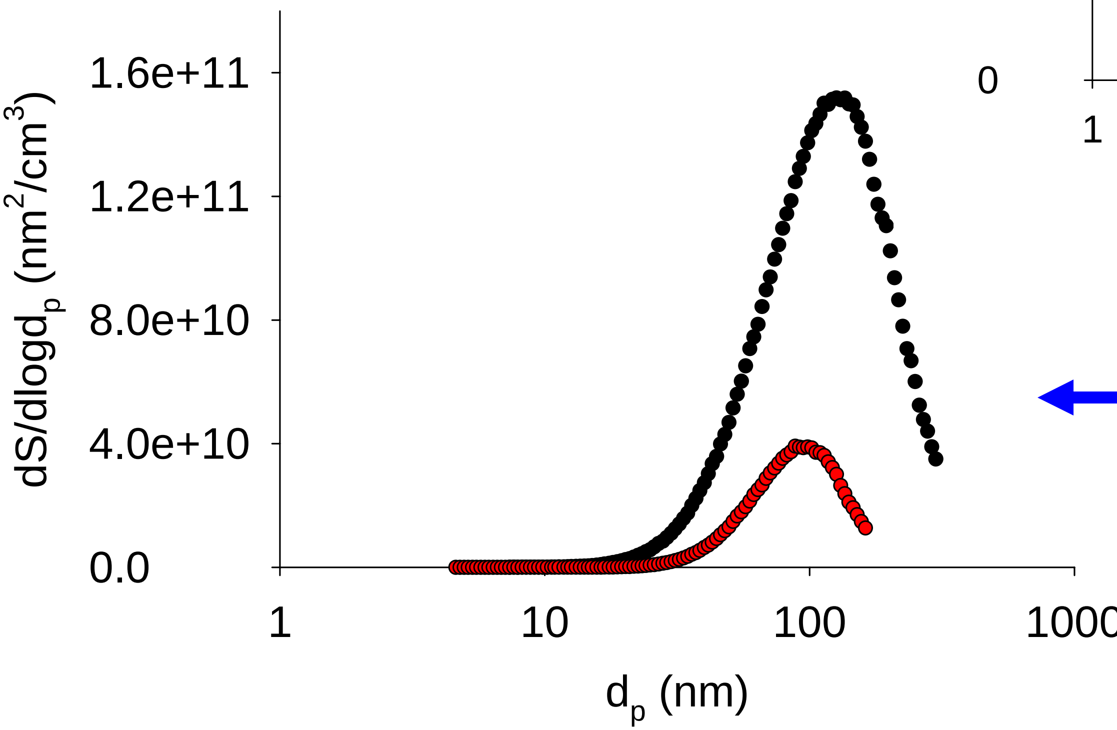


Overall **<u>surface area</u>** is much higher in conventional mode

PCCI at 1500, 2.6 BMEP shows higher numbers of particles <u>but</u> less surface area than conventional point

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

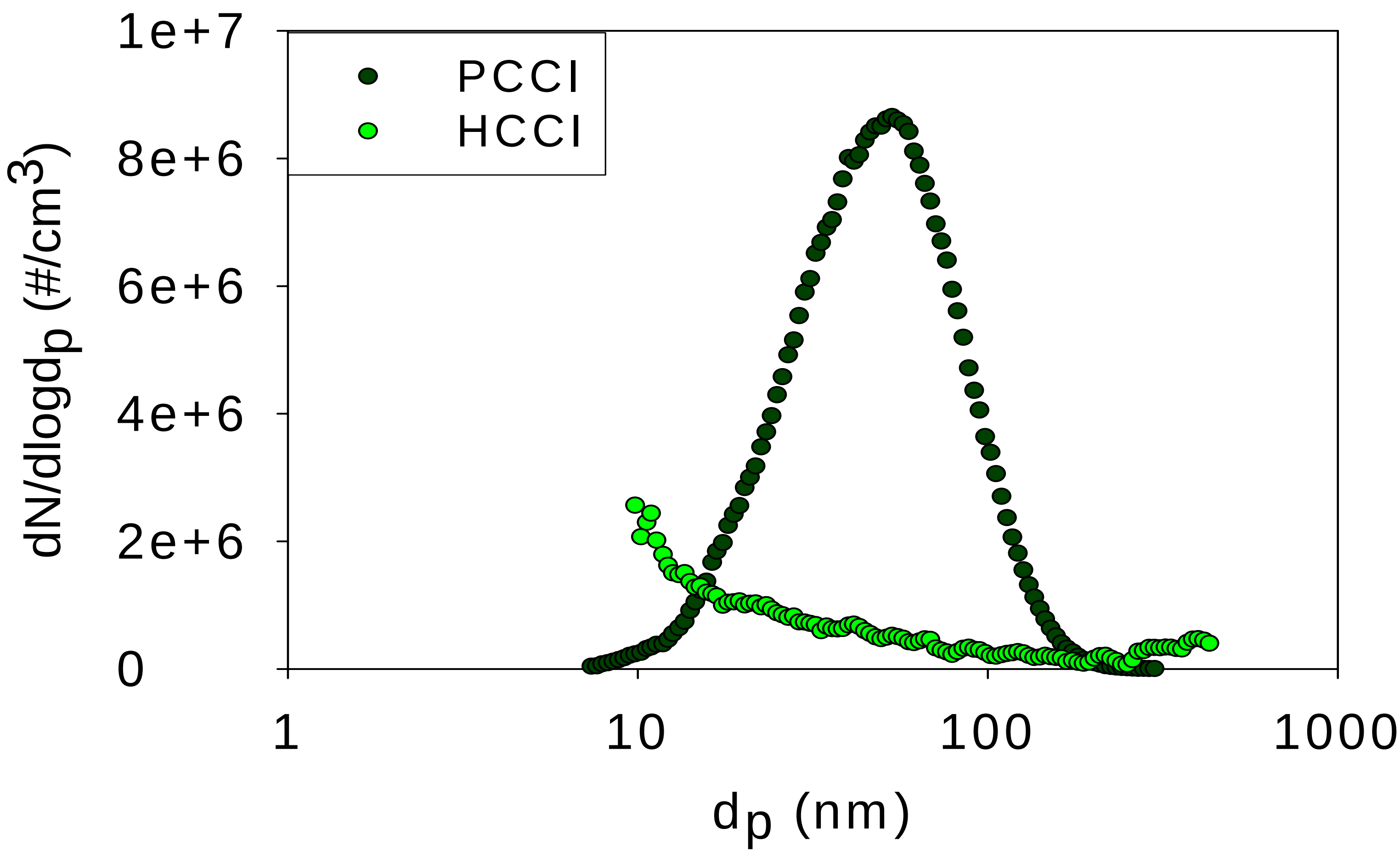




Larger soot particles in conventional mode mean more **surface area**

At the comparison setpoint, HCCI showed virtually no particle formation above 10 nm

PCCI: 1500 RPM, 3.2 IMEP HCCI: 1800 RPM, 3.1 IMEP



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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