# Characterization of GDI PM during start-stop operation with alcohol fuel blends

### Presenter: John Storey

Melanie DeBusk, Shean Huff, Sam Lewis, Faustine Li, John Thomas, and Mary Eibl

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Kevin Stork and Michael Weismiller Fuel and Lubricant Technologies Vehicle Technologies Office, DOE

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### **GDI Vehicle PM Emissions: Impact of cold start, fuels**

Will start-stop technology impact GDI PM emissions? Does bio-fuel impact PM?

- 2010, 2012: Observed high PM during cold start, ethanol reduced PM
- 2014: Detailed HC speciation showed changes in PAHs on PM



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### **GDI Vehicle PM Emissions: Impact of cold start, fuels**

# Will start-stop technology impact GDI PM emissions? Does bio-fuel impact PM?

- 2010, 2012: Observed high PM during cold start, ethanol reduced PM
- 2014: Detailed HC speciation showed changes in PAHs on PM (SAE 2010-01-2129; 2012-01-0437; 2014-01-1606)
- 2014-2015: Obtained and evaluated 2014 Malibu e-Assist vehicle
- Bio-fuel may impact both fuel and lube contribution to PM
- Focus on Start-Stop effect on PM mass, soot and number
  - Tier 3 regulations will lower PM mass standard
  - PM soot ≈ black carbon, a potent contributor to climate change
  - Particle number is regulated in Europe currently



### **GDI Vehicle on ORNL's Chassis Dynamometer**







Fuels splash- blended

- E0 = EEE Tier 2 cert
- E20 = EEE + 20% EtOH
- iBu12 = EEE + 12% i-BuOH



# Cold start dominates mass for all three fuels - Filter Mass Measurements



- FTP Composite: weighted average of cold and hot
- Start-stop only increases hot cycle PM for isobutanol



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### Soot emissions show similar trends to PM mass - Micro-Soot Sensor Measurements



- Soot emissions taken second-by-second
- Integrated over cycle and with exhaust flow to get mg/mile
- Wide variability in Hot, despite up to 27 runs



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Cold Start

Hot start

- Soot emissions taken second-by-second
- Integrated over cycle and with exhaust flow to get mg/mile
- Wide variability in Hot, despite up to 27 runs



### Particle number emissions trend lower for Start-Stop - Engine Exhaust Particle Sizer Measurements



- EEPS Total Particle Number includes PM< 23 nm</li>
- (#/cc) taken second-by-second (DR ~ 100)
- Integrated over cycle and with exhaust flow to get #/mile



### Particle number emissions trend lower for Start-Stop - Engine Exhaust Particle Sizer Measurements



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- (#/cc) taken second-by-second (DR ~ 100)
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# ANOVA (Analysis Of Variance)

Soot	F	р
Fuel (E0, E20, IB12)	5.19	0.0072
Mode (SS, no SS)	19.18	0
Fuel * Mode	14.54	0

Particle Number	F	р
Fuel (E0, E20, IB12)	1.31	0.273
Mode (SS, no SS)	1.78	0.1837
Fuel * Mode	56.86	0

- Null hypothesis: there is no difference between fuels or startstop modes
  - p< 0.05 means you reject the null hypothesis
  - o p< 0.05 is statistically significant</p>
- For soot production, Fuel, Mode, and their interaction produced a significant difference in soot.
- For particle number, Fuel and Mode did not produce a significant effect. But their interaction did.

## **EEPS** shows variability for same time intervals



- Variability between hot cycles observed (5 shown above)
- Wide bands, even with 9 cycles
- Data analysis ongoing to look at specific transients



# **EEPS** maps relate size, number to soot production



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## **Chemistry of GDI PM HCs**



## **Collection and direct thermal desorption/pyrolysis** of soot



- GDI PM collected from filter
  - Light suction on glass capillary
  - ~0.5 mg needed (70 or 90 mm)
- Transfer to pre-cleaned thimble
- TDP-GC-MS (2 chromatograms)
  - 1<sup>st</sup> Step Desorption to 325 °C
  - 2<sup>nd</sup> Step Pyrolysis direct to 500 °C



### **GDI Vehicle PM Emissions: Impact of cold start, fuels**

Does bio-fuel impact PM HCs?

- 2014: Collected soot under rich conditions with 3 fuels, E0, E30, iBu48
- Detailed HC speciation showed changes in PAHs on PM

![](_page_15_Figure_4.jpeg)

(SAE 2014-01-1606)

![](_page_15_Picture_6.jpeg)

### **Injection matters: Differences in adsorbed HCs apparent for two different platforms**

![](_page_16_Figure_1.jpeg)

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# Start-Stop Study: E20 fuel has lowest measured PM and PAH

- FTP cold-hot weighted mass data for start-stop
- Ethanol appears to reduce PAH formation in the soot

![](_page_17_Figure_3.jpeg)

![](_page_17_Picture_4.jpeg)

# Start-stop study: GC-MS didn't detect lube HCs on filter

![](_page_18_Figure_1.jpeg)

### Summary: GDI vehicle PM depends on fuel and mode

- Lowest Cold Start PM mass, soot and number = E20
- Hot start PM affected differently

Lowest value:	No Start-Stop	Start-Stop
PM Mass	E0 ≈ E20	E20
Soot Mass	iBu12	EO
Particle #	iBu12	EO

- Largest particles contribute to soot emissions in first 300 s
- PAHs affected by alcohols
- Injection technology has improved both mass and chemistry
- "Uncontrolled" burns may be associated with PAH
- How about lubricant contribution?
  - Not conclusive, no lubricant found in PM organic fraction by GC-MS
- Why is this research important?
  - Start-up has highest PM emissions for GDI
  - Start-stop could impact particulate filter operation if GPF needed in 2025
- Takeaway: Operation and fuel both have to be considered for PM control strategies

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- Contact: John Storey
  <u>storeyjm@ornl.gov</u> 865-946-1232

![](_page_20_Picture_5.jpeg)