Effects of Fuel Properties on Particle Emissions from Gasoline Vehicles: Role of the PM Index

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HEI WORKSHOP ON EFFECTS OF FUEL COMPOSITION ON PM

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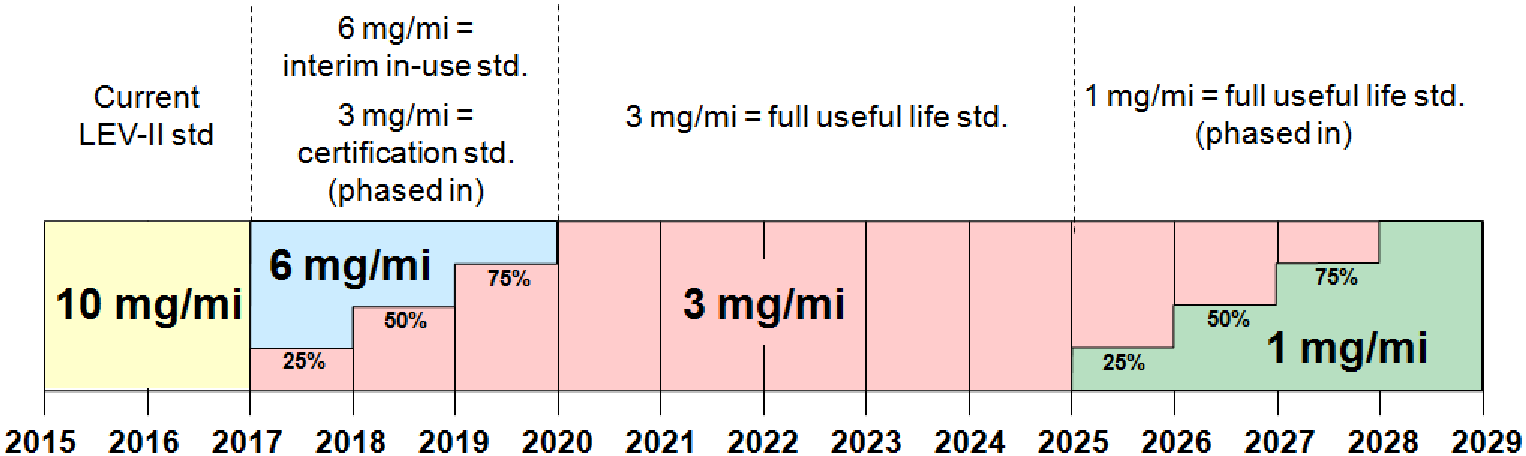
Outline

- PM Composition for Different Technology Engines
- Engine Hot-Start Number & Size-Parking Lot
- Fuel Composition and PM Index
- PM Correlation with Fuel PM Index
- PM Lack of correlation with Fuel PM Index
- Conclusion

Regulations

- CARB LEV III and US Tier 3 Regulations (Particle Mass Only)

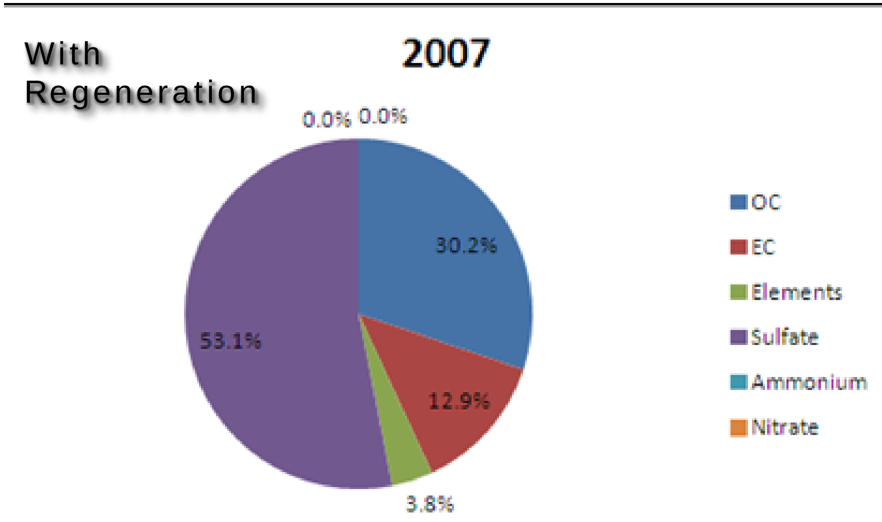


CARB LEVI III only for now, EPA may follow

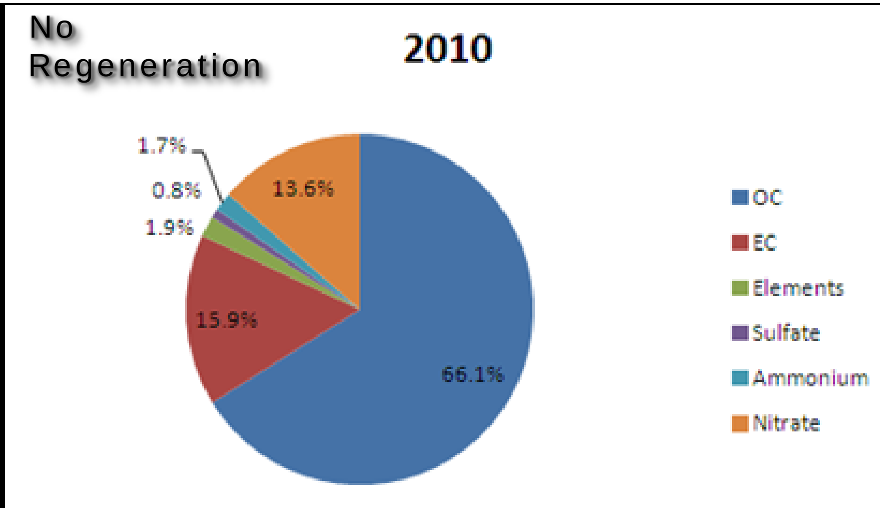
- Euro 6 (Number and Mass)
  - 4.5 mg/km
  - 6×10^{12} part/km (2014-2016)
  - 6×10^{11} part/km in 2017 **(More Stringent than 2025 CARB LEV III)**

Particulate Matter Composition in Modern Highway Engines

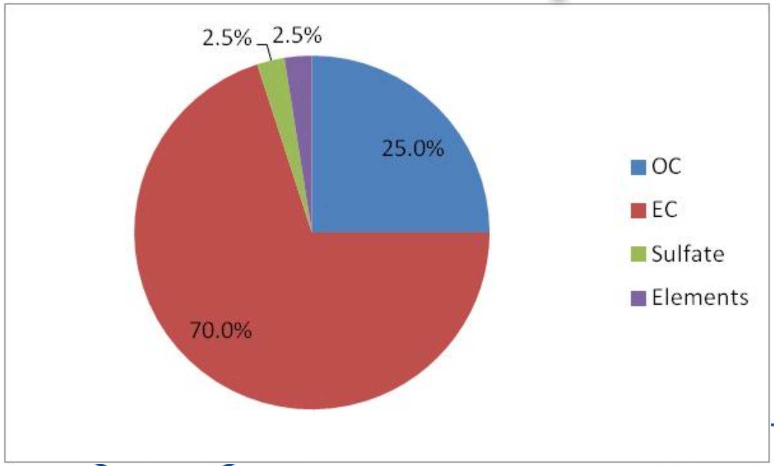
2007: Diesel with DPF



2010: Diesel with DPF+SCR



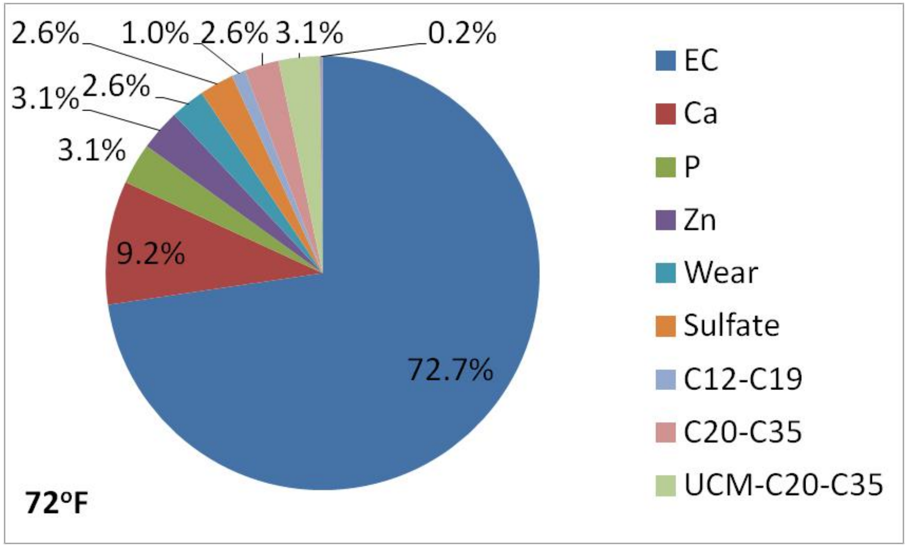
Gasoline Direct Injection

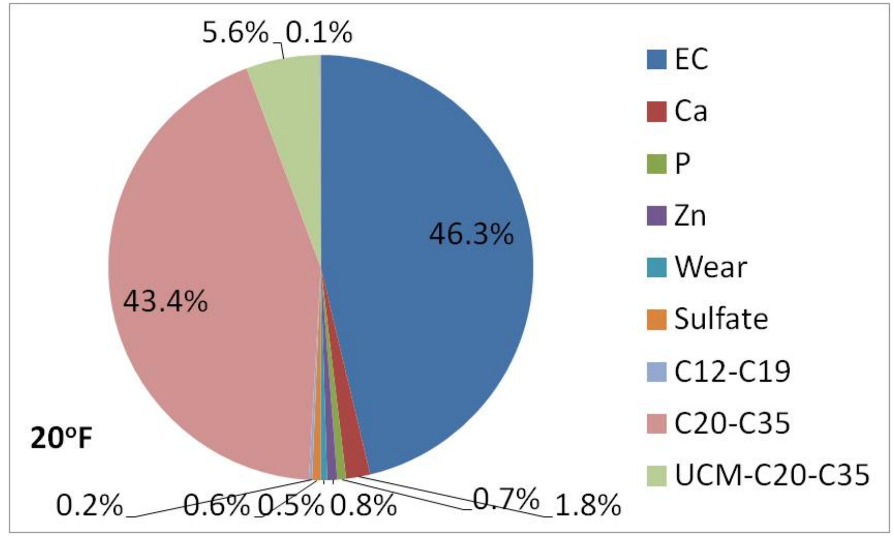


Engine exhaust aerosol composition is a mixture of organic and inorganic species and elemental carbon

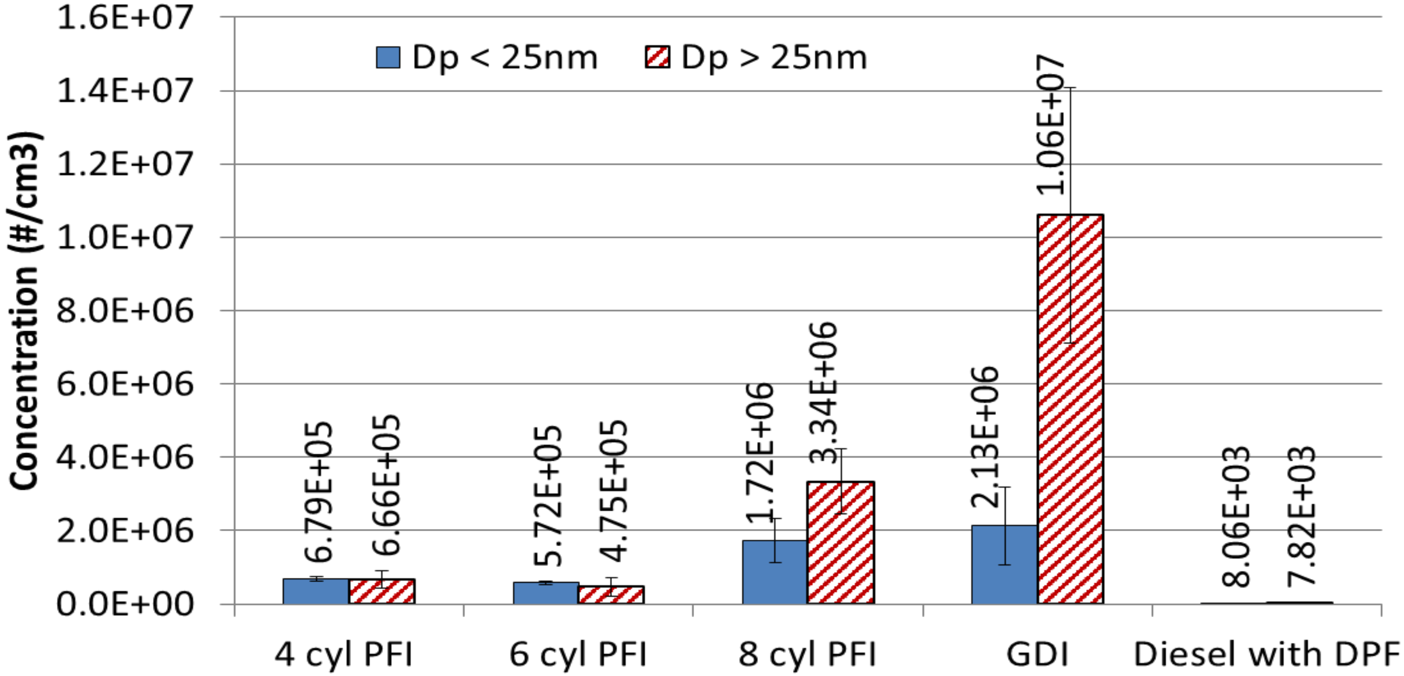
PM Composition-PFI Gasoline

- Total PM: 0.3 mg/mi (72°F)
- Total PM: 5.2 mg/mi (20°F)



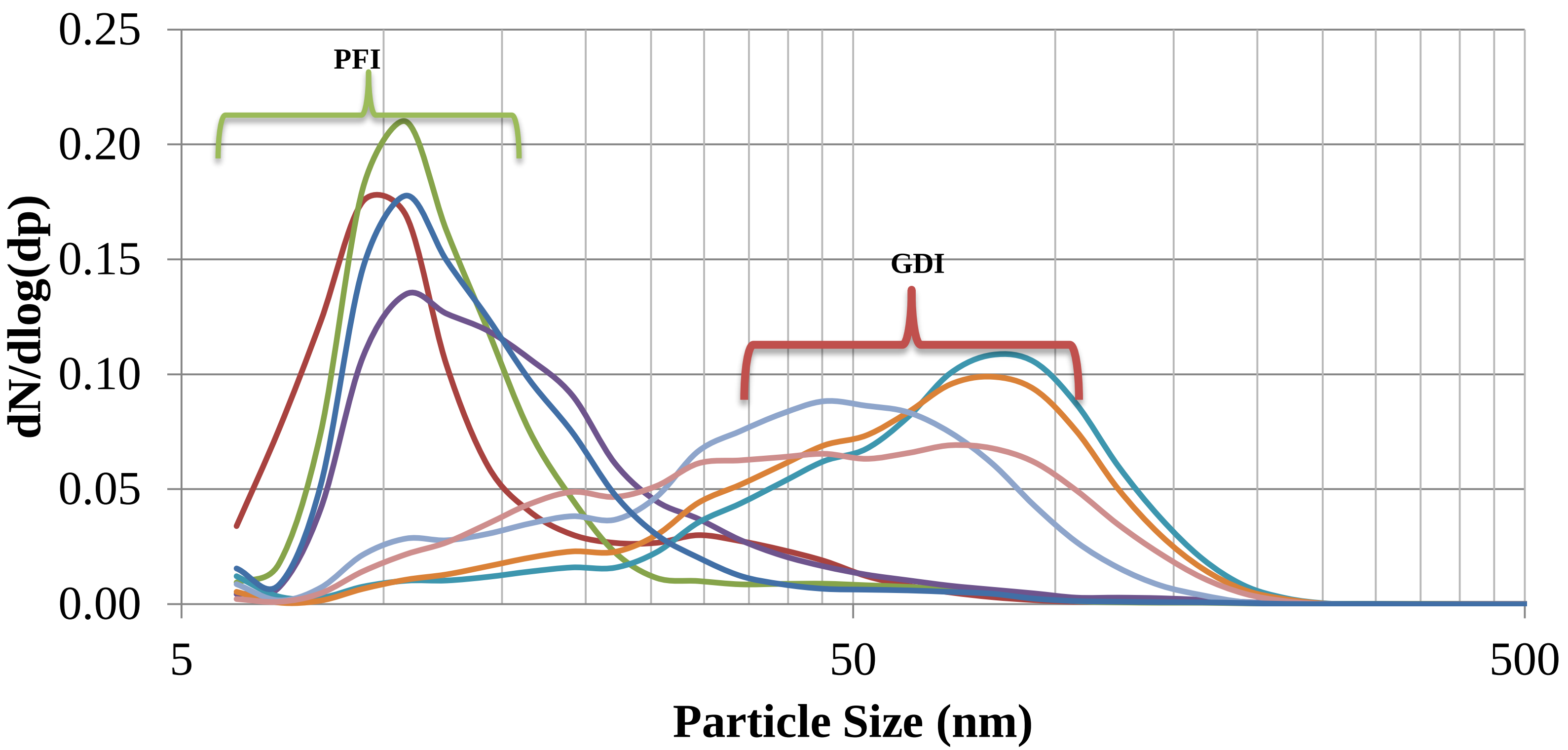


Number Concentration During Engine Start-Up (Parking Lots)



- Particle concentration increases as engine size increases for PFI vehicles, especially 8 cylinder PFI
- GDI engines were the highest particle emitters and diesel with DPFs were the cleanest
- Average particle concentration was a factor of 100 to 10000 higher than a typical ambient background environment of ~5000 part./cm^3

Size Distributions of PFI and GDI



- Geometric number mean diameter shows GDI engines high in accumulation mode particles (> 25nm)
- For PFI, the mean diameter was well below 25 nm (~12nm)
- Current EU number method misses the majority of PFI particles since they are less than 23 nm

Effect of Fuel Properties on Engine Start-up (Cranking)-Vehicle on Chassis Dynamometer

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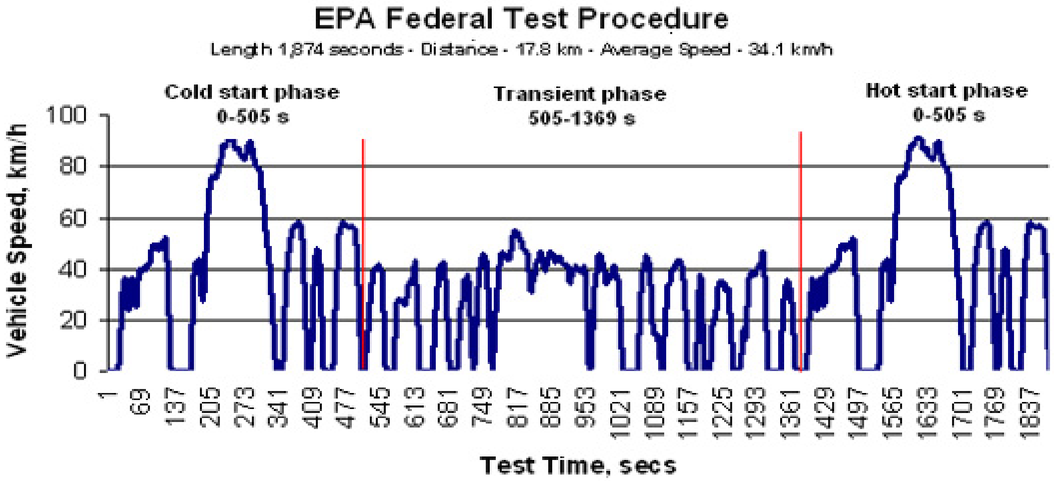
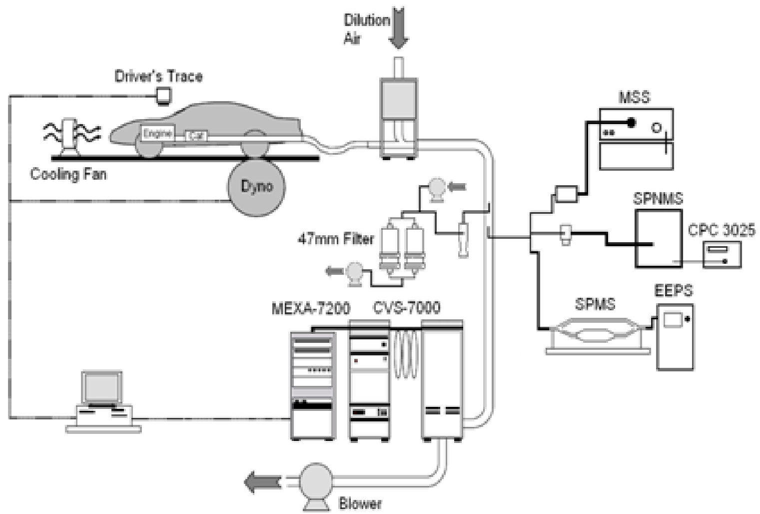
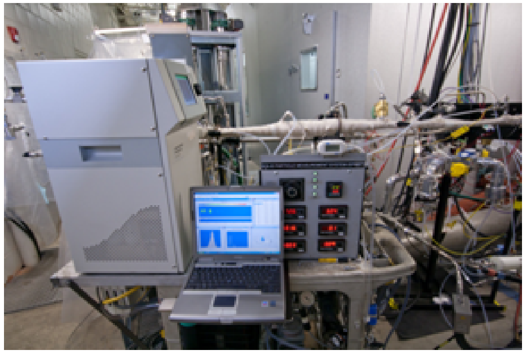
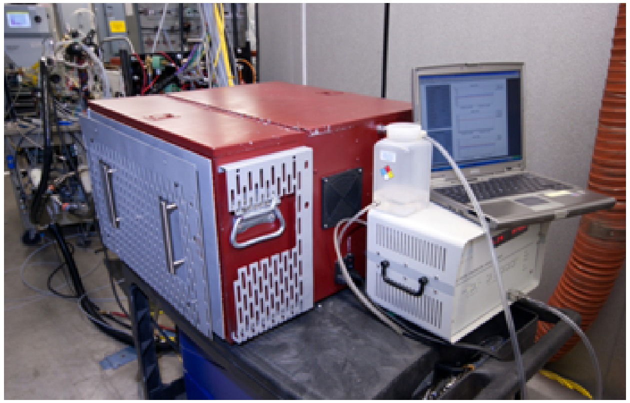


Engine Start-UP-Chassis Dynamometer (2010 GDI Vehicle)





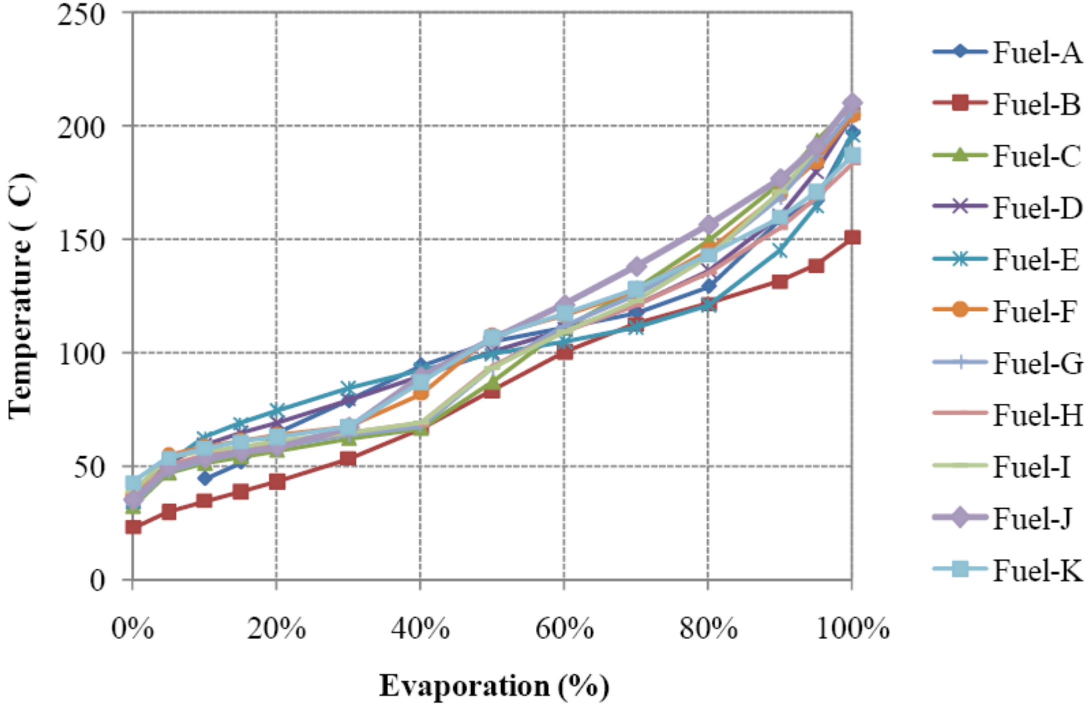
SwRI Solid Particle Sampling System (SPSS) Plus TSI Engine Exhaust Particle Sizer (EEPS)



SwRI Catalytic-Stripper-Based Solid Particle Number Measurement System (SPNMS)

AVL Micro-Soot Sensor (MSS)

Fuel Properties



NAME	CODE	ORIGIN
Fuel-A	7014	Haltermann
Fuel-B	7276	Fairbanks, AL
Fuel-C	7602	Las Vegas, NV
Fuel-D	7604	Phoenix, AZ
Fuel-E	7605	Phoenix, AZ
Fuel-F	7607	Chevron
Fuel-G	7600	Las Vegas, NV
Fuel-H	7609	New Orleans, LA
Fuel-I	7610	Houston, TX
Fuel-J	93548	SwRI - "High PM Fuel"
Fuel-K	7797	SwRI - Distilled Fuel C

	CARBON wt%	HYDROGEN wt%	OXYGEN wt%
Fuel-A	86.3	13.7	-
Fuel-B	87.0	13.0	-
Fuel-C	83.1	13.6	3.3
Fuel-D	85.8	14.2	-
Fuel-E	85.4	14.6	-
Fuel-F	82.9	13.8	3.3
Fuel-G	83.6	13.6	2.8
Fuel-H	83.4	13.5	3.1
Fuel-I	82.6	13.8	3.6
Fuel-J	86.6	13.4	-
Fuel-K	83.0	13.5	3.5

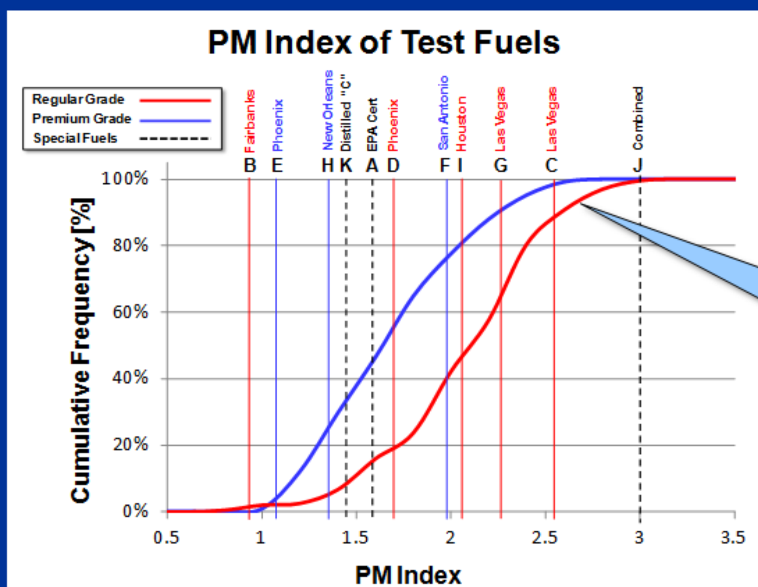
- Fuel A is a certification fuel with sulfur content of 1 ppm (rest of fuel has ~ 25 ppm)
- Fuel J is mixed of high molecular weight gasoline fuel residuals at SwRI
- Fuel K is same as Fuel C but distilled by SwRI to remove high molecular weight species

Gasoline Fuel Properties and the PM Index

"New" Fuel Property – PM Index

$$PM\ \ Index = \sum_{i=1}^{n} I_{[443K]} = \sum_{i=1}^{n}\left(\frac{DBE_i + 1}{V.P(443K)_i} \times Wt_i\right)$$

- Predicts the PM emission trend, based on the vapor pressure and DBE* of individual fuel components. (see backup slides)
- A high PM Index indicates that the fuel produces relatively high PM.

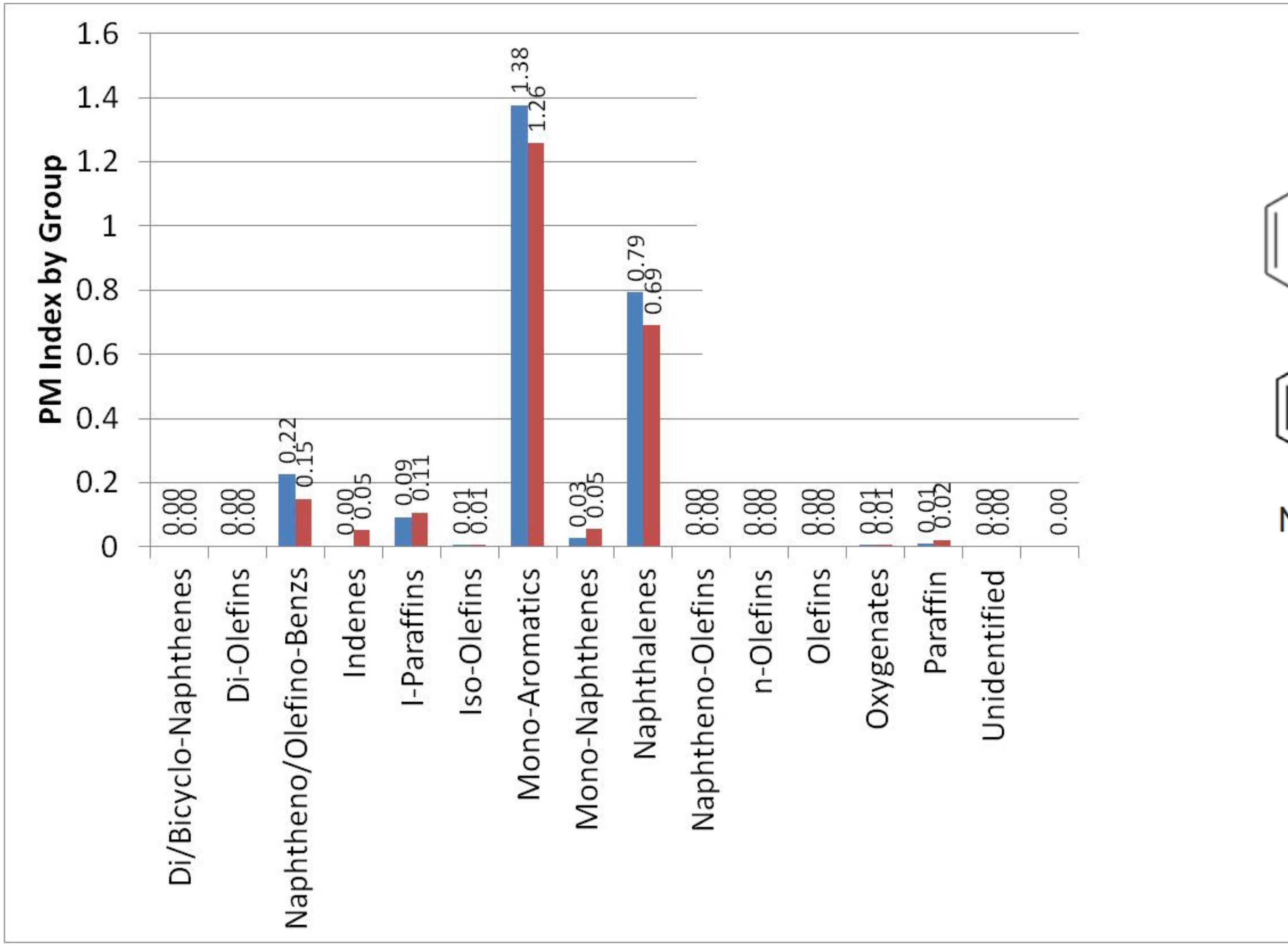


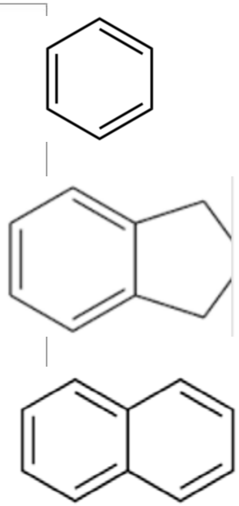
- The test fuels covered the range of PM Indices in the US market.

- Distribution of PM Indices in US market fuel.
- Determined through analysis of >300 fuel survey samples.

* DBE = Double Bound Equivalent

PM Index by Group of Compounds

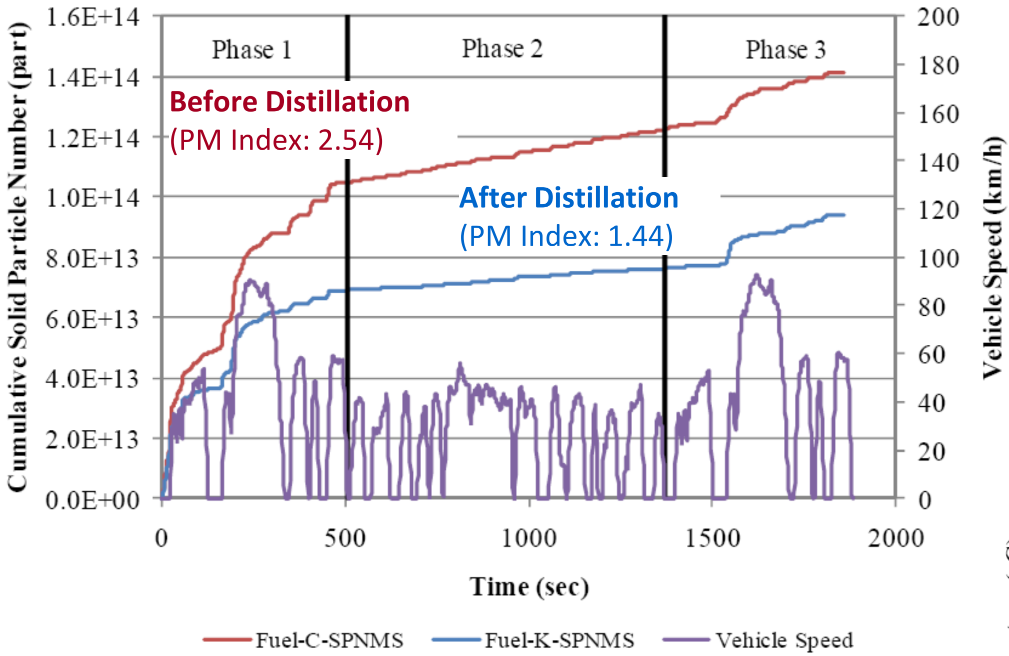




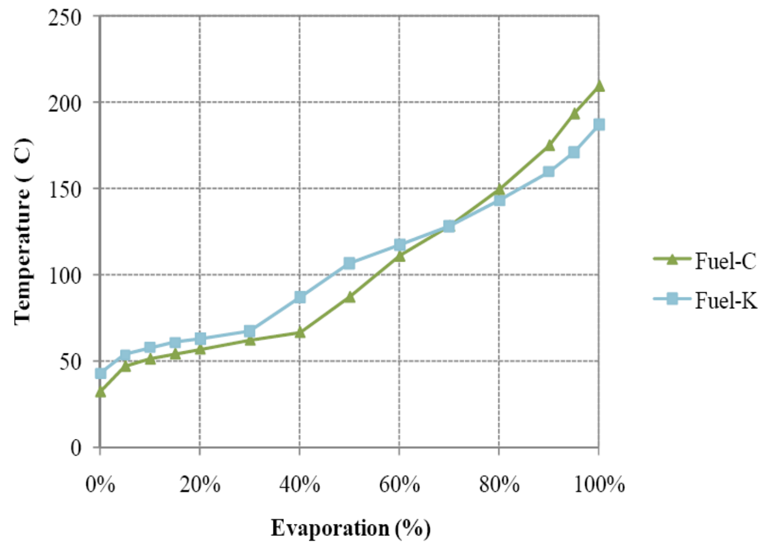
Naphthalene

Mono-Aromatics & Naphthalenes are the main contributor to PM index

Fuel Distillation Effects on Particle Emissions

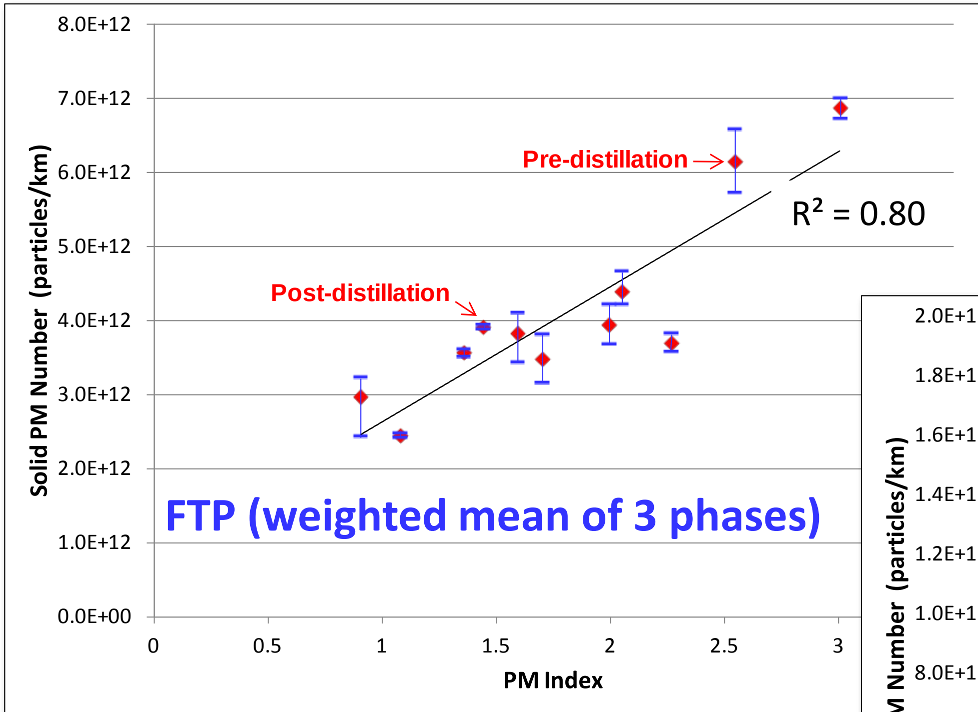


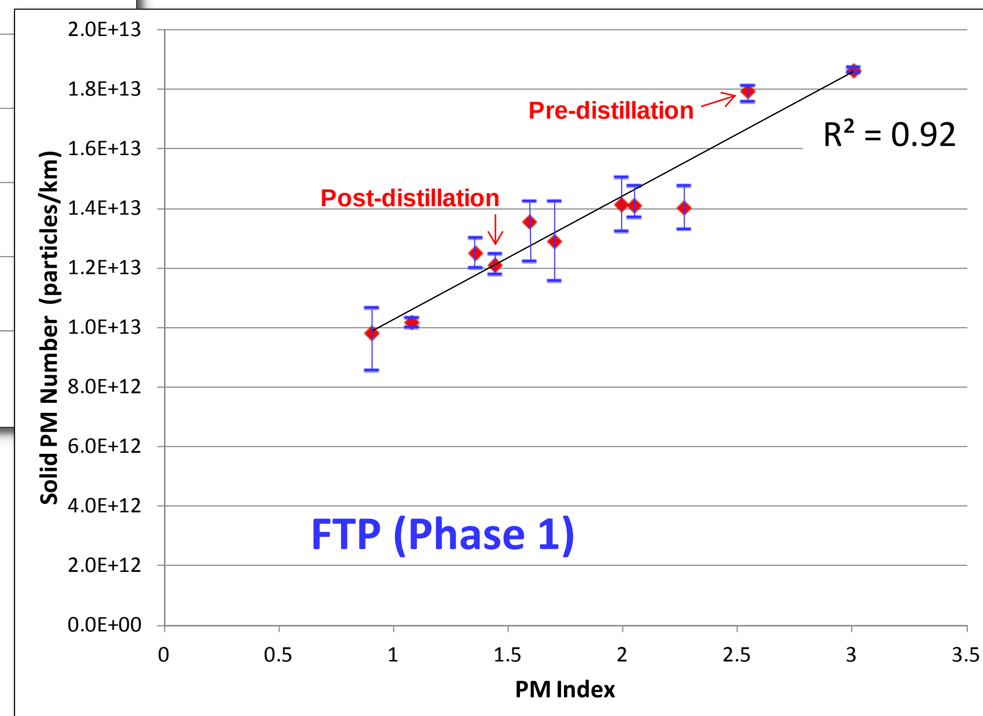
Distilled fuel   Remainder (>193°C)



- Fuel distillation substantially reduced the PN emissions
- Cold-start and acceleration event to high engine speed are major contributor to Solid PN emissions
- PN during cold start phase 1 represents more than 75% of the entire particle emissions for the cycle

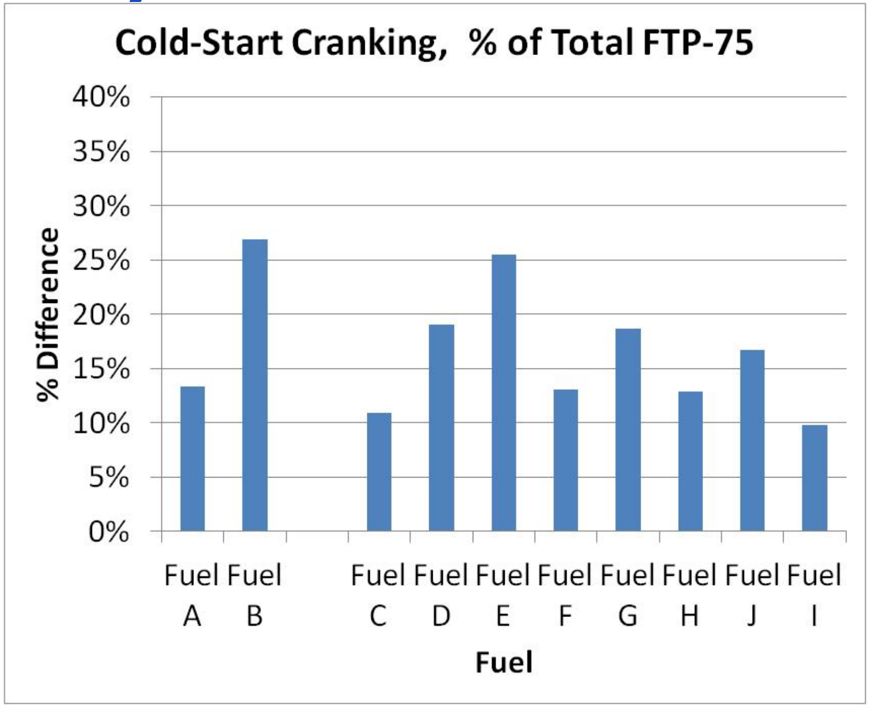
Correlation with PM Index

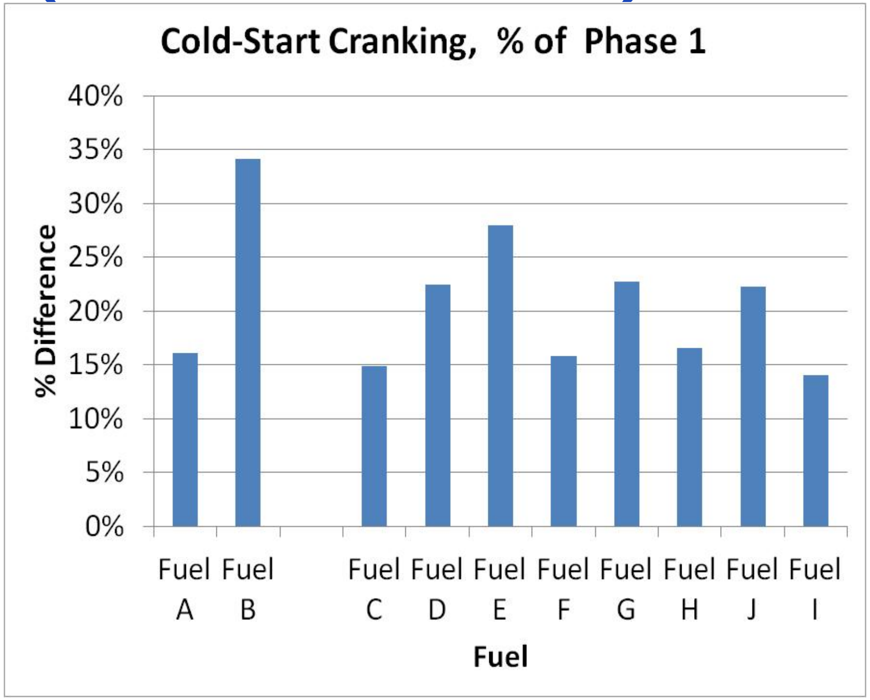




- Good correlation between measured PM number and the calculated PM Index of the fuel.
- Correlation in Phase 1 of the FTP was especially good.

Cold-Start Cranking Contribution to FTP-75 Drive Cycle Particle Emissions (First 25 seconds)

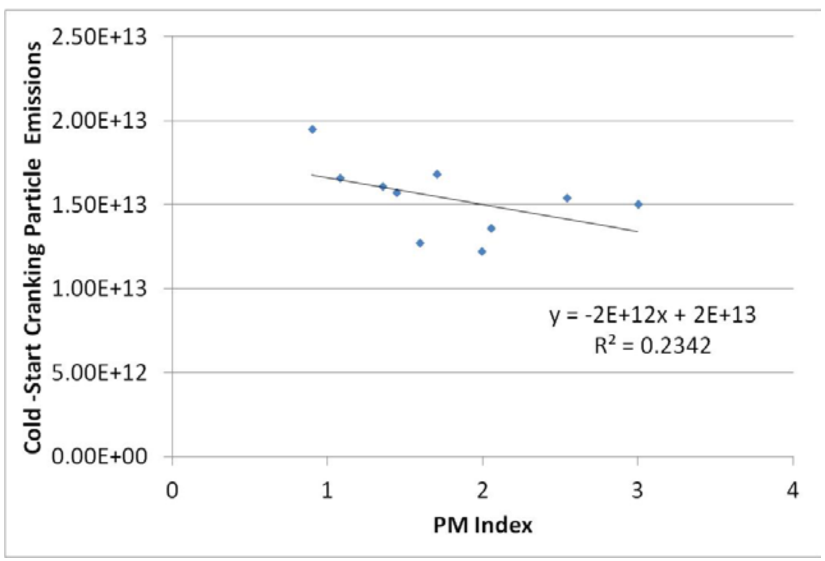


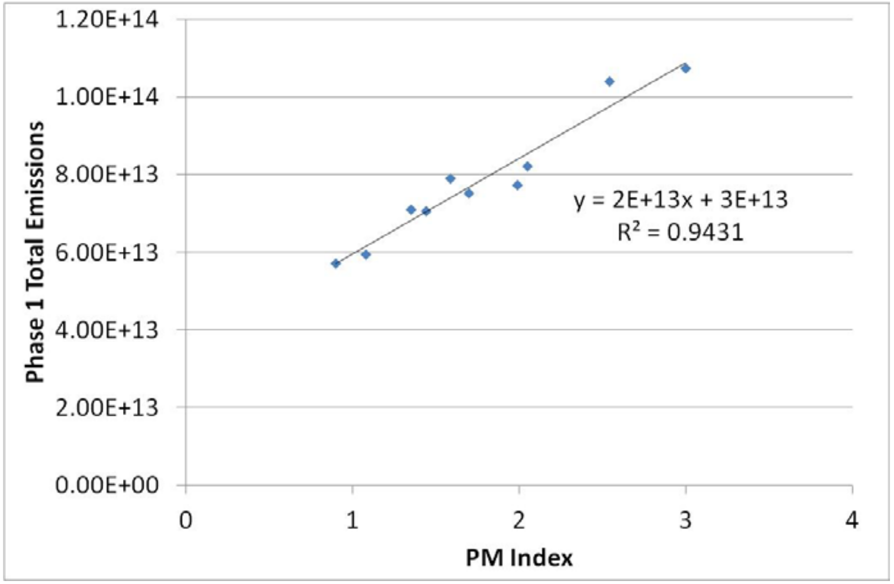


- Cranking event can contribute:
  - 10% to 25% of the overall cycle emissions
  - 15% to 35% of the cold-start phase of the cycle
- Different fuels behaved differently. It was not clear if there was a trend or it was a random process

Cold-Start Cranking vs. PM Index (No Correlation)

- While particle emissions during the cold-start phase of the FTP-75 correlated with the Fuel PM index,
  - No good correlation was observed for the cranking event particle emissions with the PM index. The trend although weak seems to have a negative slope
  - This was a surprise to us. Heavier fuel under cold-start and very rich condition may contribute less to soot formation?





Conclusions

- Engine cranking, especially under cold-start may be a significant source of solid particle emissions. Human exposure to particle emissions in busy parking areas and traffic jams where start-stop strategy is adopted could be high
- Gasoline PFI and especially GDI engines can contribute to particle emissions under cold-start:
  - Several orders of magnitude higher than diesel with DPF
  - PFI seems to emit particles below 23 nm under start-up. These particles are not included in the current EU Particle emissions regulation
- Minimizing particle emissions under cranking may contribute to 15 to 35 percent reduction in solid particle number for the cold-start phase of the FTP
- Particle emissions strongly correlate with the Fuel PM index, but not under cranking condition. The mechanism of particle formation under cranking seems to be different and almost independent of fuel properties.
  - More work is needed to better understand this phenomenon
- Fuel Mono-Aromatics and Naphthalene are major contributors to PM emissions