Particle Emissions From Vehicle Exhaust During Engine Start-up

Pilot Study

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18th ETH Conference on Combustion Generated Nanoparticles,
June 23-25, 2014

Southwest Research Institute®

San Antonio, Texas

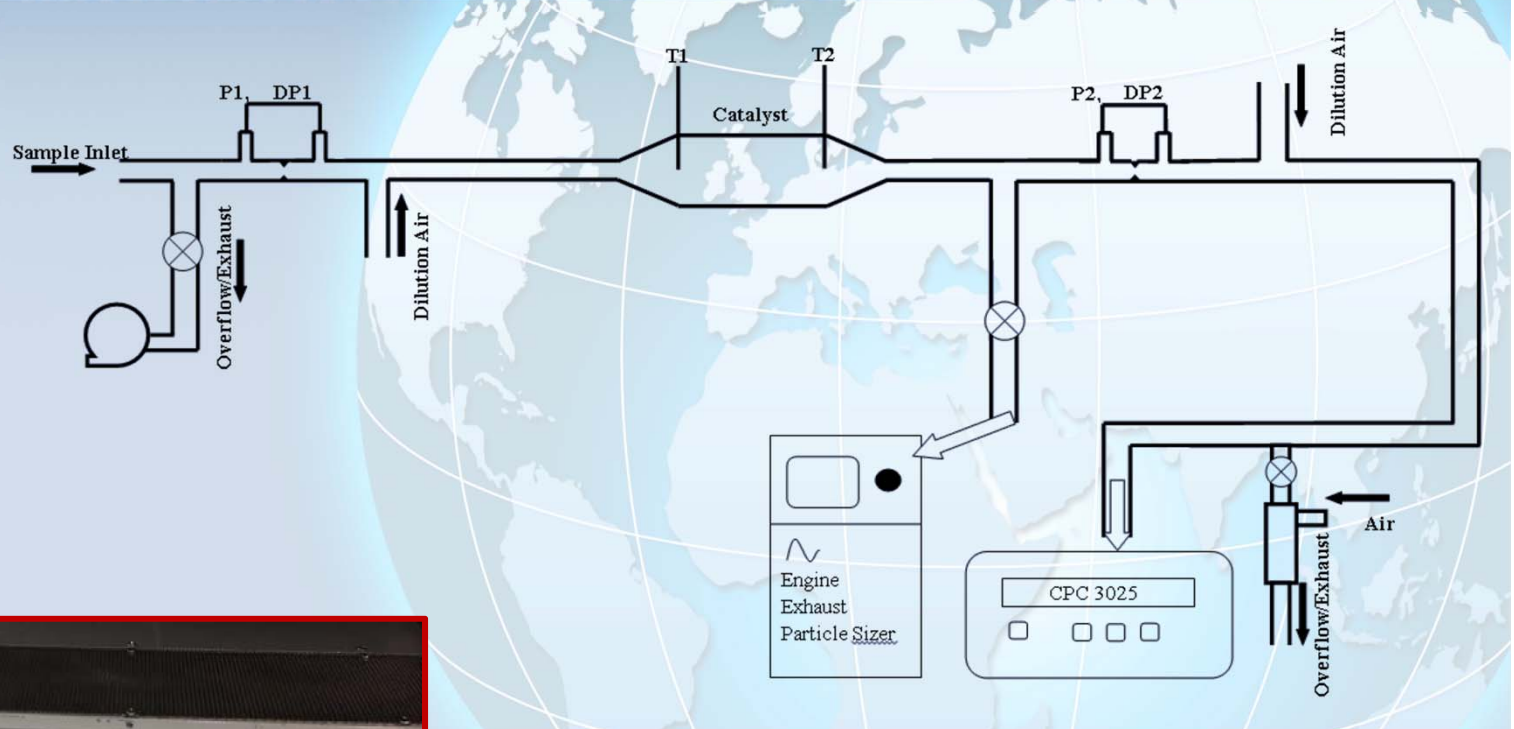
Purpose

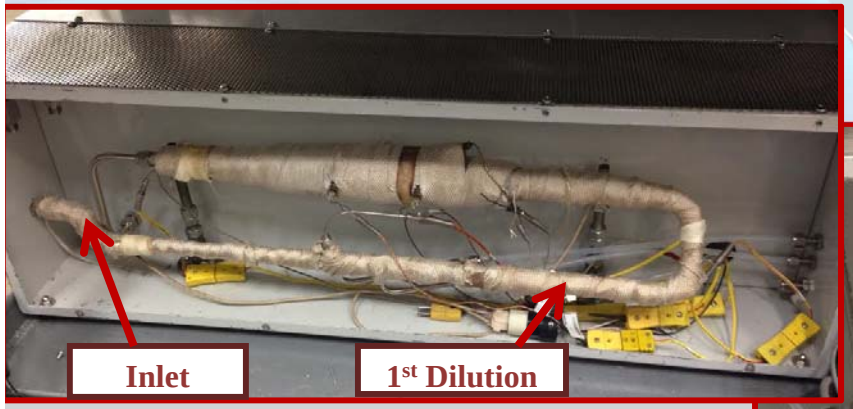
- **Develop a sampling system to measure :**
  - Real time solid particle number concentration (#/cm^3)
  - Solid particle Size distributions
  - Metallic ash particle number
- **Compare results from different engine types during engine start-up:**
  - Gasoline Port Fuel Injection (PFI)
  - Gasoline Direct Injection (GDI)
  - Diesel with Diesel Particulate Filters
- **Develop a method of ranking vehicles according to a particle number (PN) emissions index**

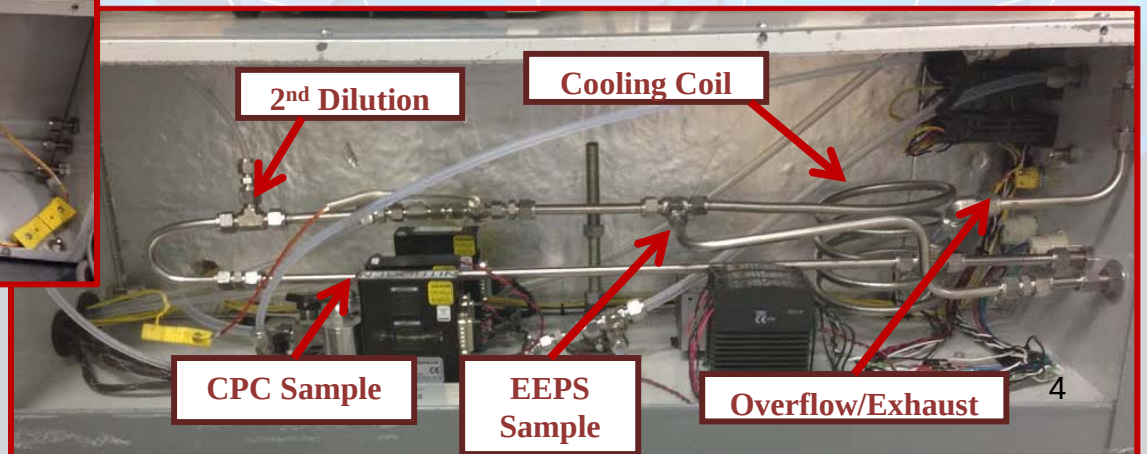
Background

- **Frequency of engine ignition (startup) is common in:**
  - Household garages
  - Parking lots
  - Hybrid vehicles alternating between engine and battery power
  - vehicles with frequent engine stops or shutdown
    - This is a common future trend for fuel economy saving
- **Human exposure to engine startup particle emissions can be significant in:**
  - Shopping centers parking lots
  - Traffic jams
  - Etc..
- **Engine start-up requires substantial fuel enrichment in gasoline vehicles, which can lead to a rise in particle formation**

Dilution System-Solid Exhaust Particle Measurement Only



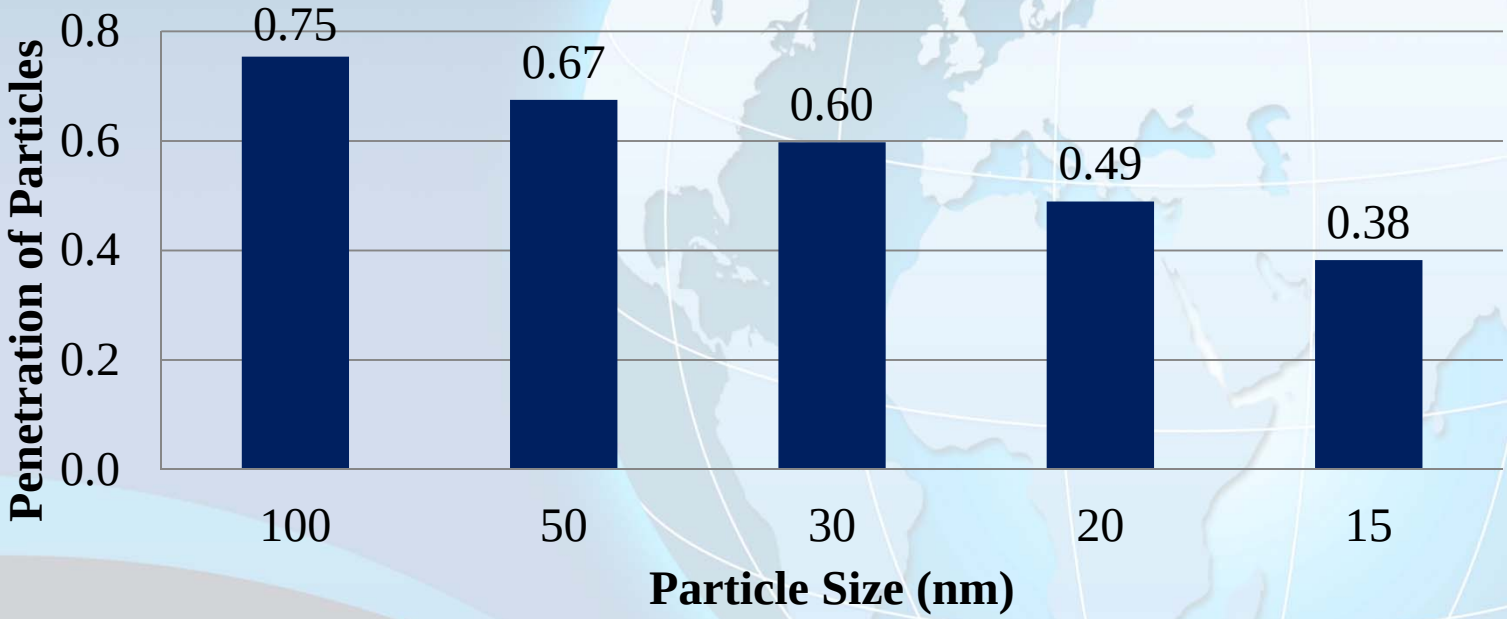




Particle Penetration as a Function of Size

$$CPC\ Downstream_{concentration} = CPC_{Concentraion} * Dilution\ Ratio$$

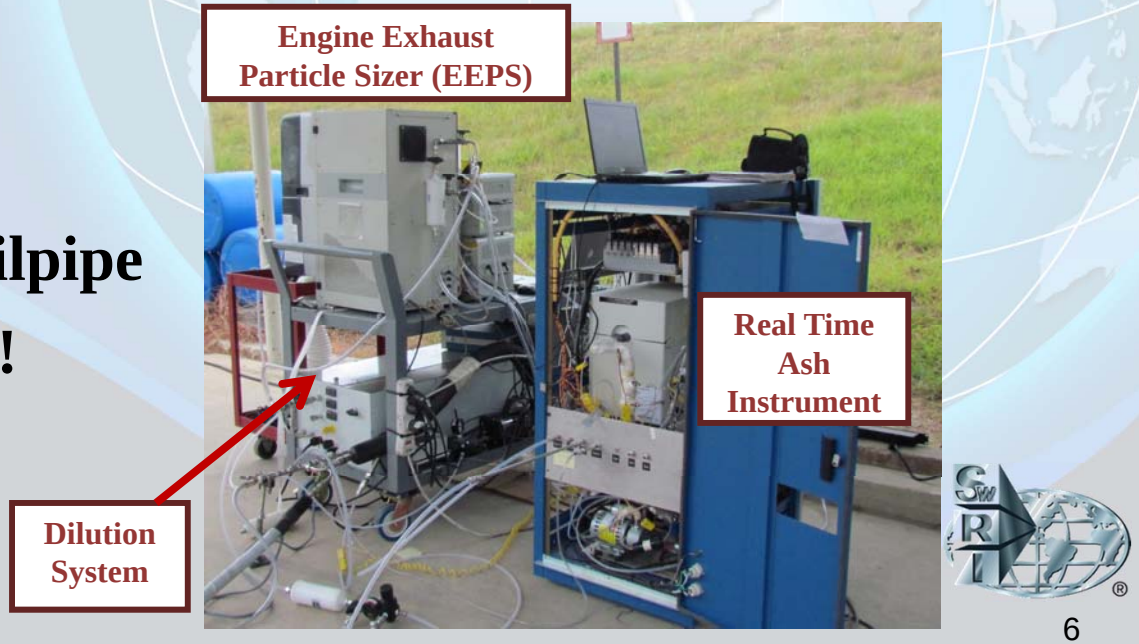
$$Penetration = \frac{CPC\ Downstream_{concentration}}{CPC\ Upstream_{Concentration}} * 100\%$$



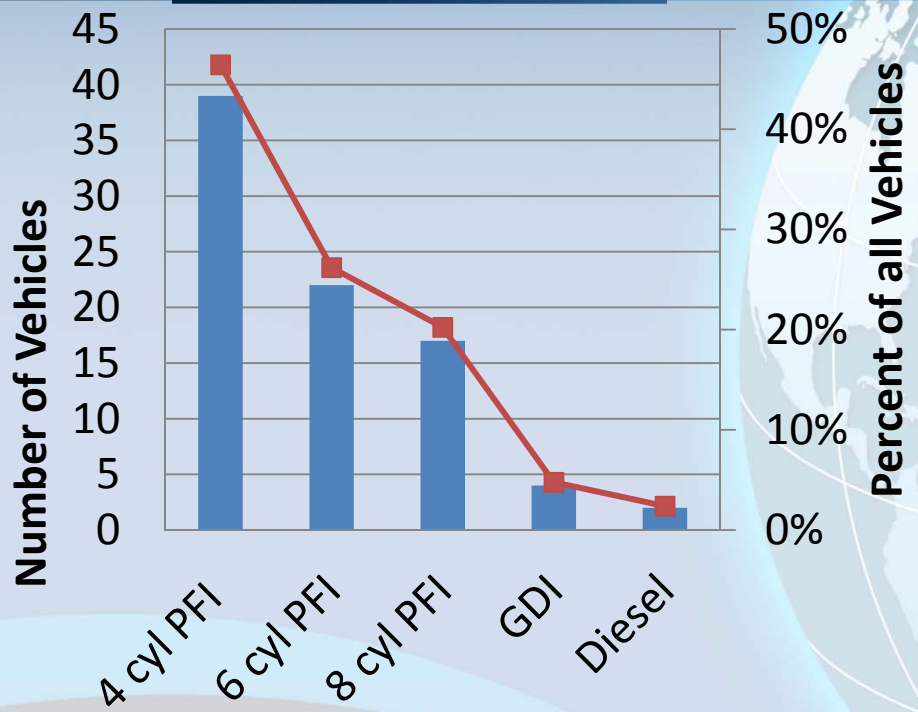
- Highest losses in Primary section – largely thermophoretic losses.

Testing Method

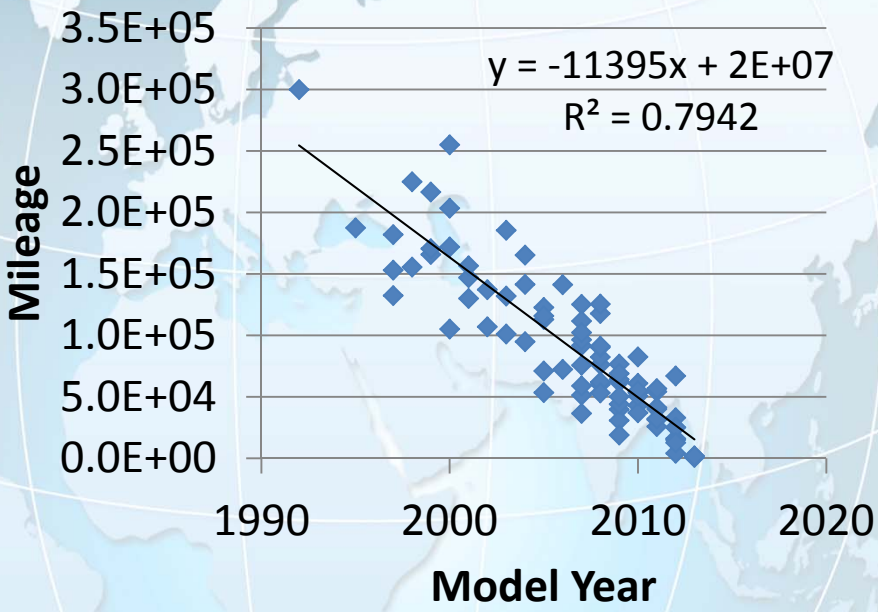
- **Vehicle approaches measuring station**
  - Turn off engine
  - Sample probe inserted in the tailpipe
- **As the vehicle was turned on, the "start-up" phase began**
  - ~ 20 to 30 seconds
- **Vehicle left to idle**
  - ~ 30 seconds
- **Probe removed from tailpipe**
- **Start-up test completed!**
- **Total time (~2 minutes)**



Number of Vehicles Per Engine Type



Car Mileage vs. Model Year

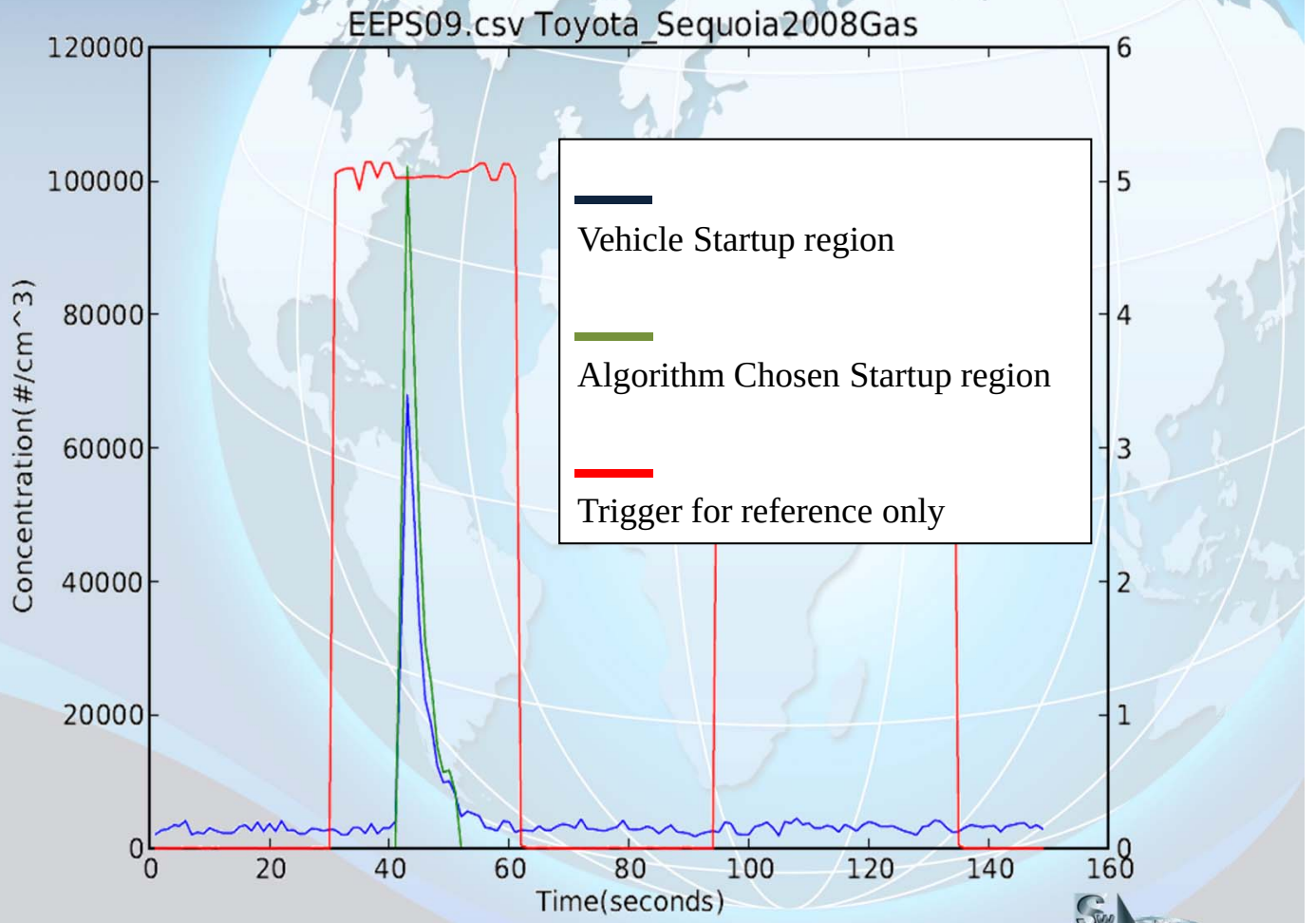


- Verification that the older the car is, the more mileage it has.

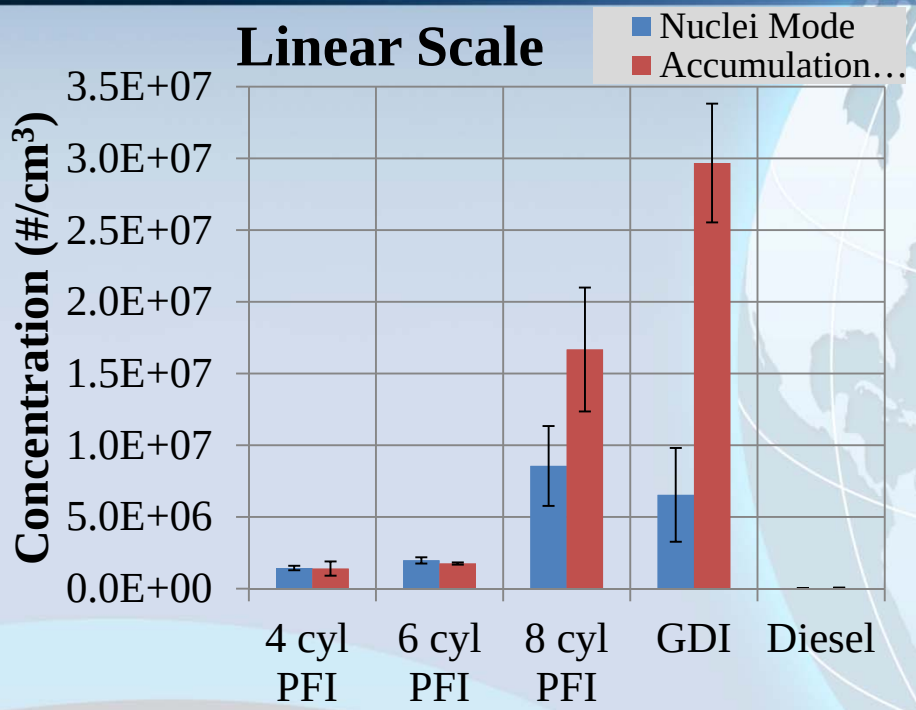
- Diesel vehicles are common in large engines and trucks in the USA but not for passenger type vehicles.
- GDI vehicle's market penetration is increasing (50% to 60% in 2016)
- Vehicles were tested in the parking lots of:
  - University of Texas-San Antonio Campus and Southwest Research Institute
  - **Ambient temperature was ~35°C**

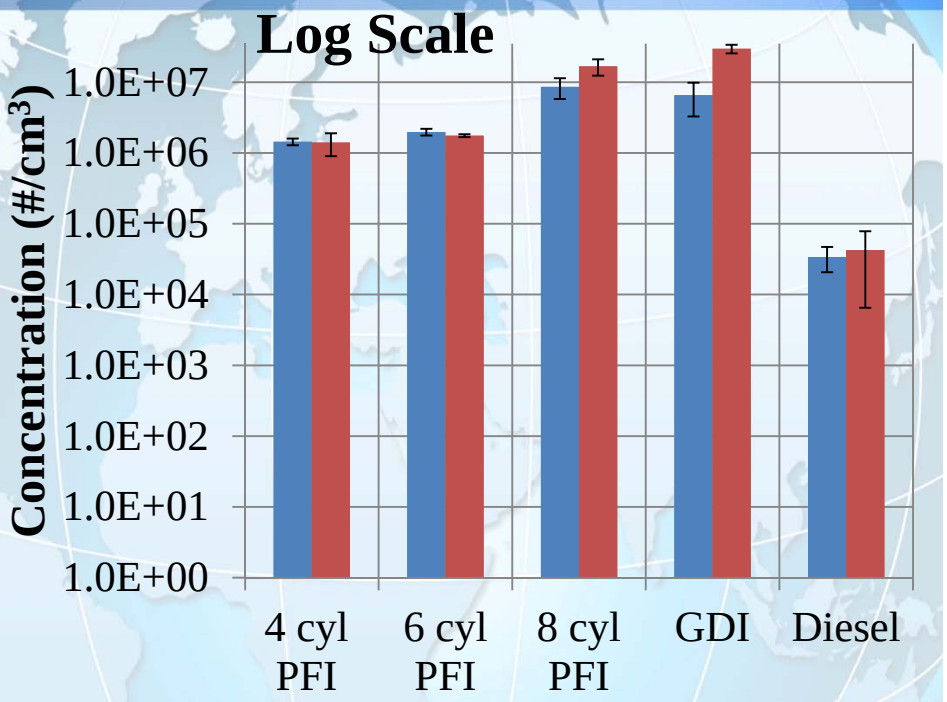
Identifying Start-up Region

- Automated algorithms can be used for identification of vehicle start-up region and data computation.
- Allows for processing of data from an array of vehicles at once.



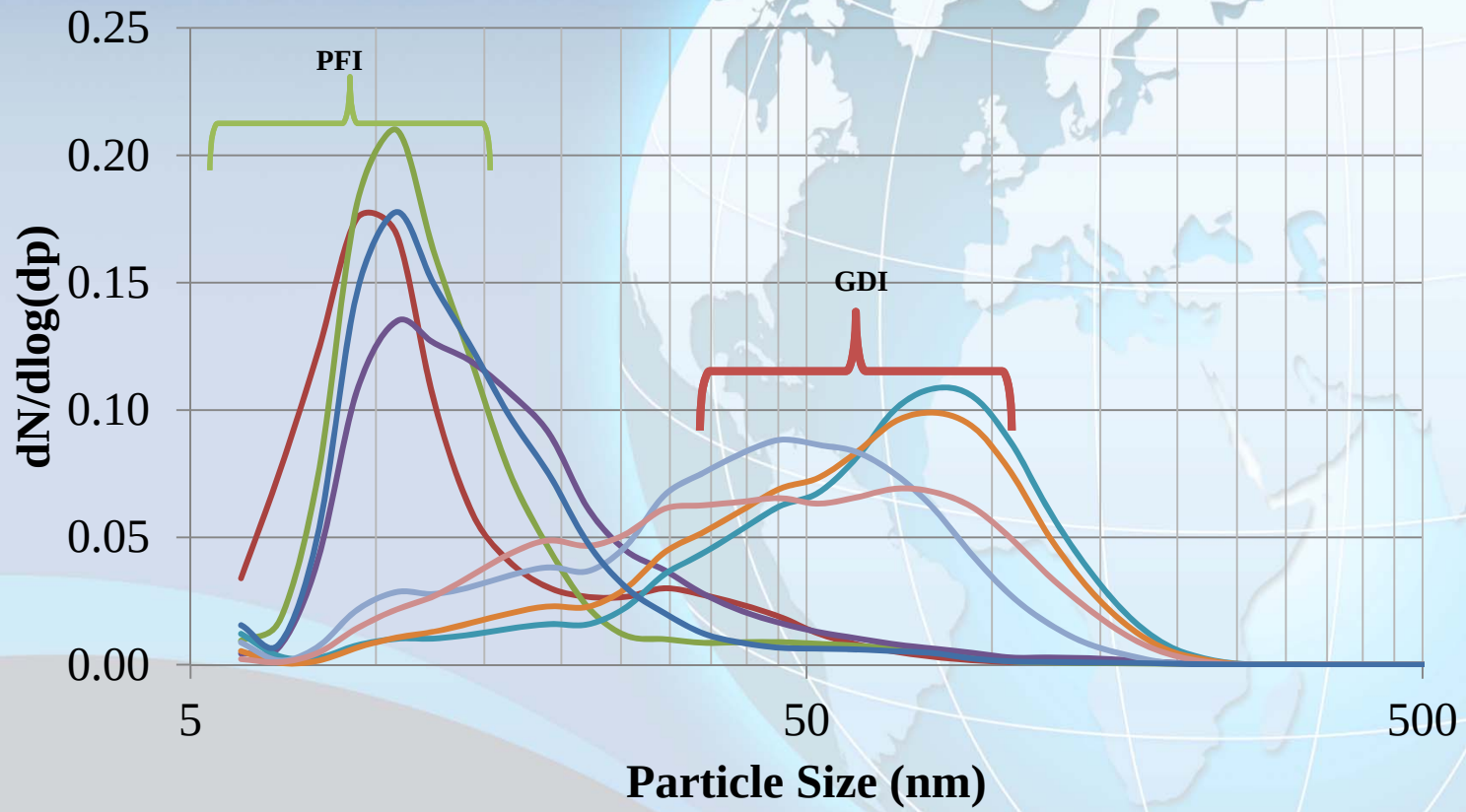
Average Particle Number Concentration





- Particle concentration increases as engine size increases for PFI vehicles
- GDI engines as highest particle emitters and Diesel with DPF's the cleanest

Size Distributions of PFI and GDI Engines



- **Geometric Mean Diameter shows GDI engines high in accumulation mode particles (> 25nm)**
- **Current PMP method does not detect PFI particles**

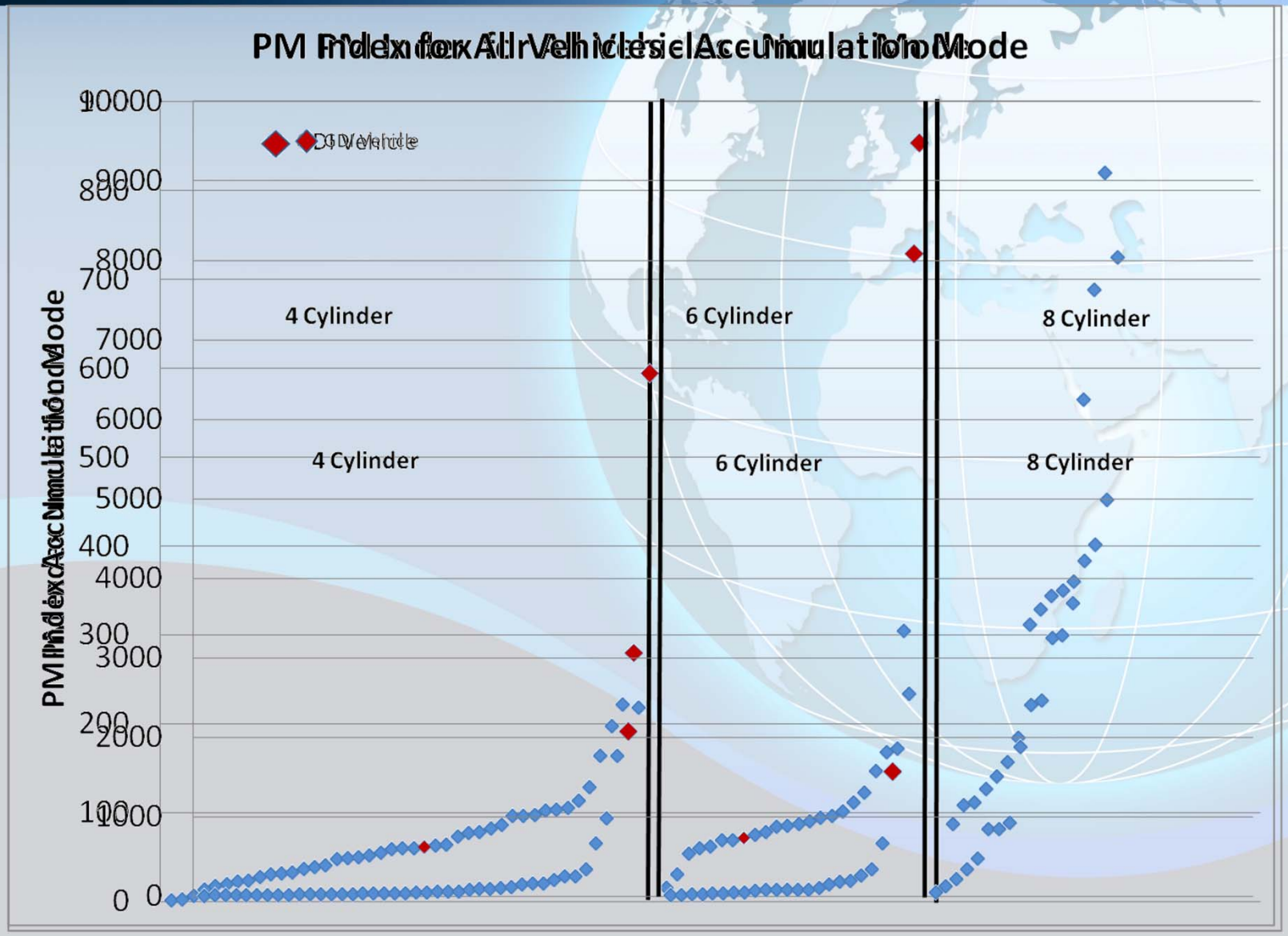
Particle Number Indexing Concept

- **Diesel with high efficiency DPF as the baseline/reference**
  - **Best Available Technology**
- **PN indexed each vehicle as compared to the Diesel Vehicle**
- **Average Concentration and Engine Size (L) obtained per group**
  - **Served as a basis for comparison for other vehicles in the group**

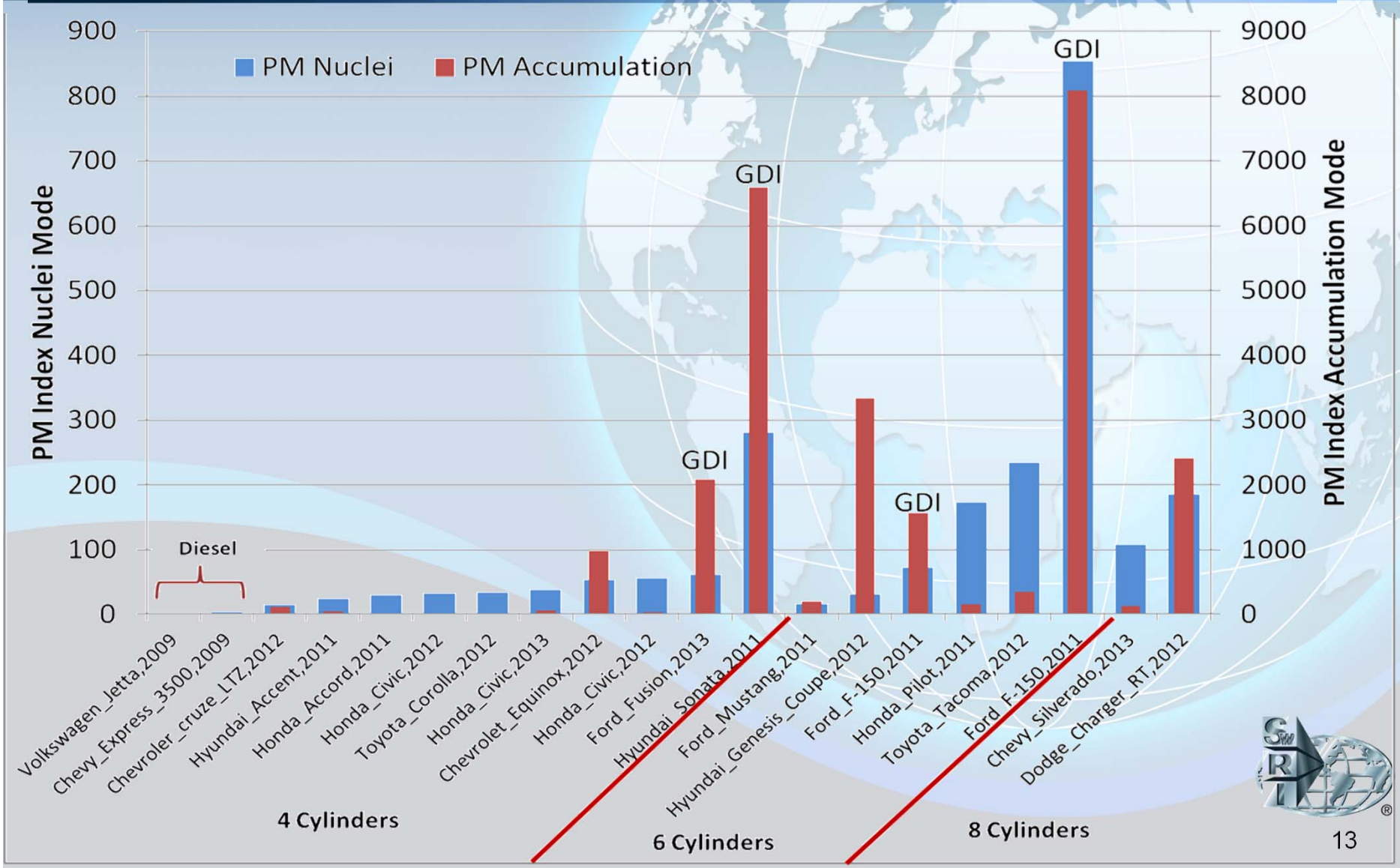
$$PM\ Index_i = \frac{Concentration_i}{Concentration_{Diesel}} * \frac{Engine\ Size\ (L)_i}{Engine\ Size\ (L)_{Diesel}}$$

- **Vehicles indexed for nuclei and accumulation mode**
  - **Rank from 1-900 (900 = worst) for Nuclei Mode**
  - **Rank from 1-9000 (9000 = worst) for Accumulation Mode**

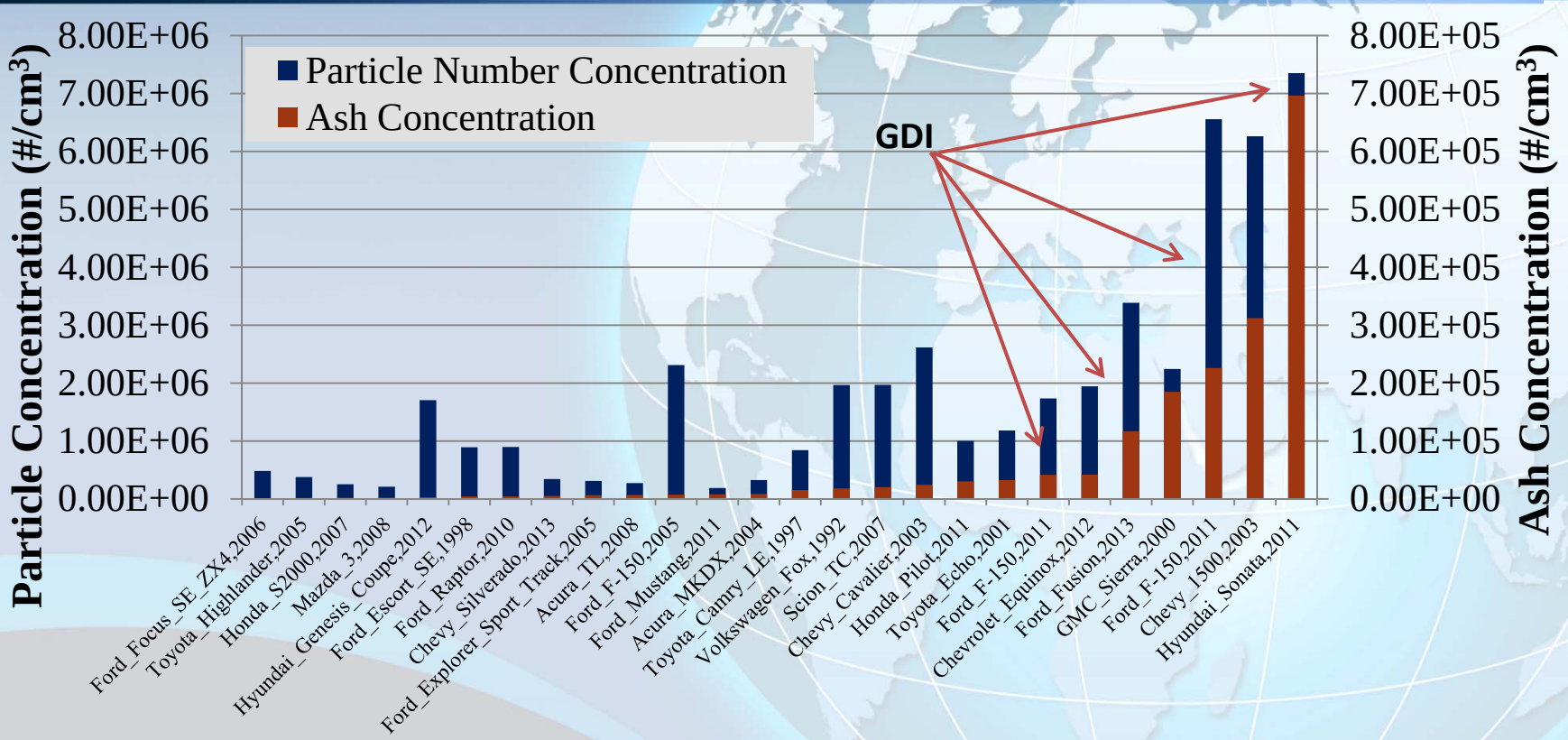
Particle Number Emission Index



PN Index for Post 2010 Vehicles



Particle Number and Ash Concentration



- **GDI engines have high Particle Number and Ash Concentration**
- **Soot particles may act as a carrier of ash**
- **Low soot content may result in ash deposits on exhaust walls**

Summary

- Engine startup can be a significant source of solid particle number
- Gasoline PFI and GDI vehicles can be a significant source, compared to diesel with DPF
- Compared to best available technology (diesel with DPF), the PN index can be as high as 9000. This is a factor of 9000 higher than best available technology
- This work was done at hot ambient temperature of 35°C. It will be of interest to expand this work to low temperature environment
- The PN emissions index is a concept that can be fine tuned and refined to reflect differentiating vehicles beyond the required emissions standard:
  - e.g. GDI vehicles meeting the same standard:
    - One with exhaust filter and one without an exhaust filter. The PN emissions index defined here will show a huge difference between the two

Acknowledgements

- **This work was supported by:**
  - **University of Texas at San Antonio as a part of an undergraduate honor thesis for Huzeifa Badshah, Mechanical Engineering, with Prof.** ***Randall Manteufel as faculty adviser.***
  - **Southwest Research Institute**

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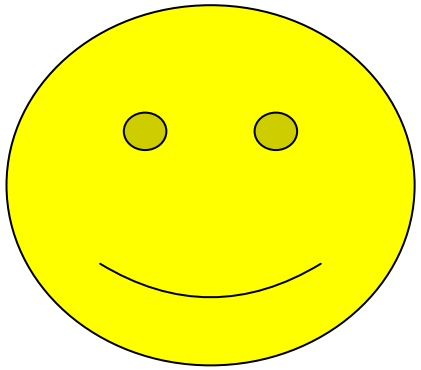

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