

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**

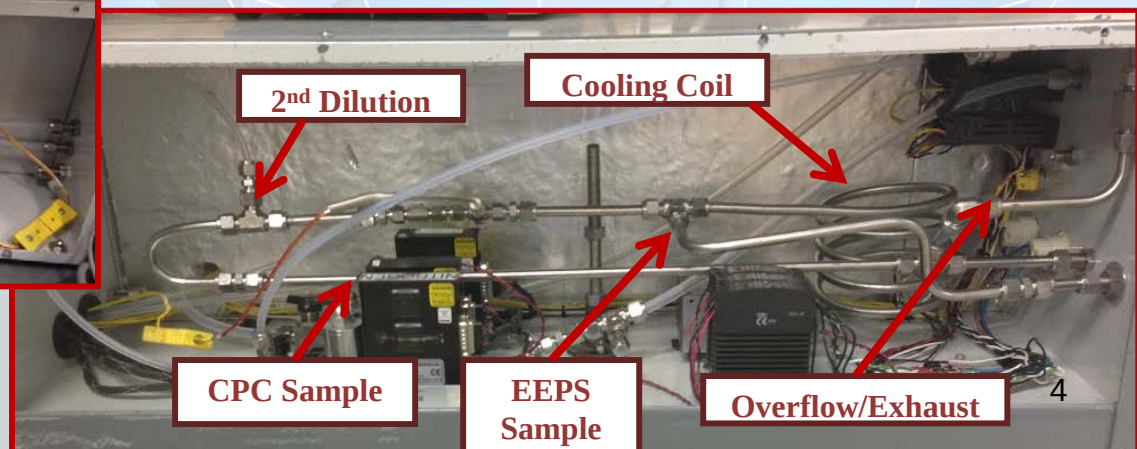
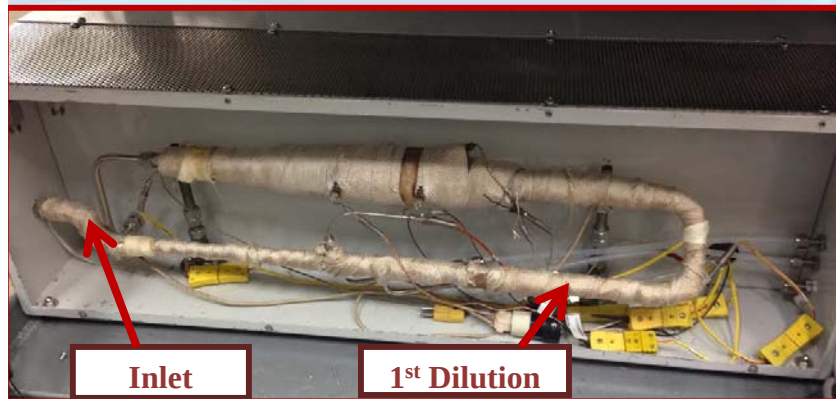
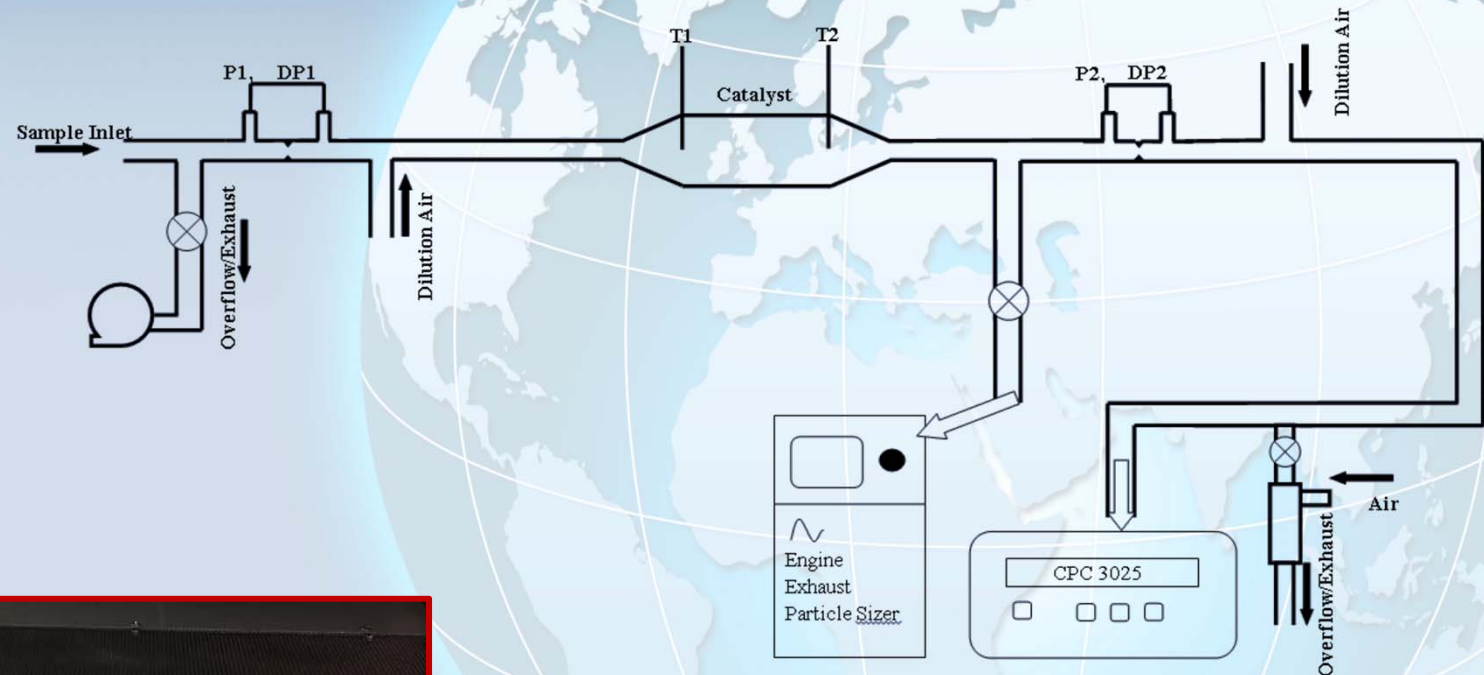


Background

- **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**



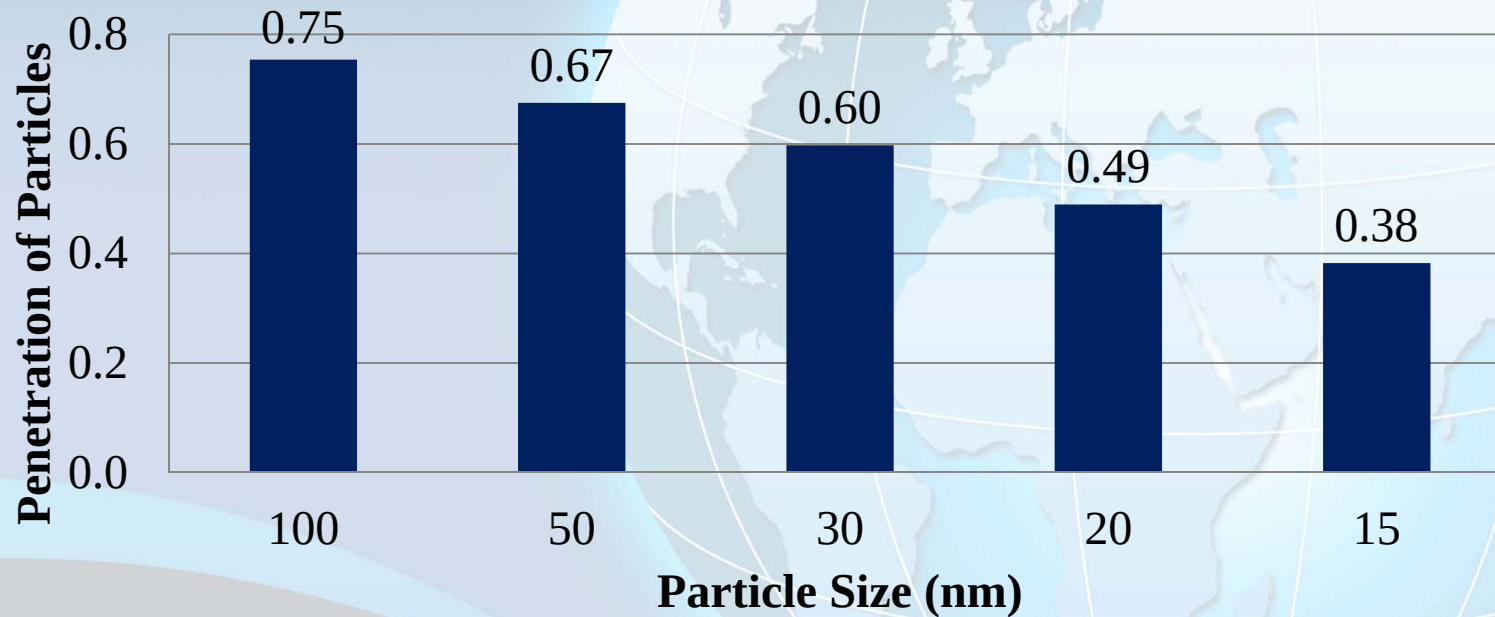
Dilution System-Solid Exhaust Particle Measurement Only



Particle Penetration as a Function of Size

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

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

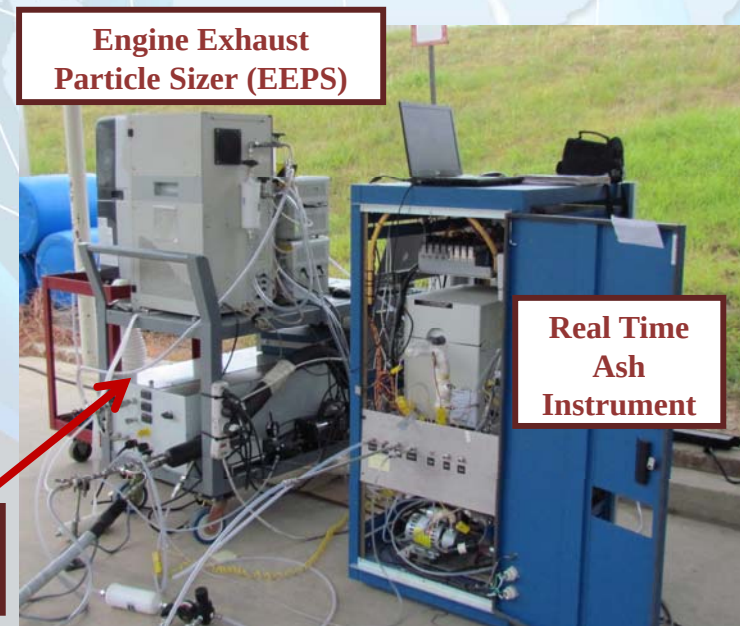


- Highest losses in Primary section – largely thermophoretic losses.

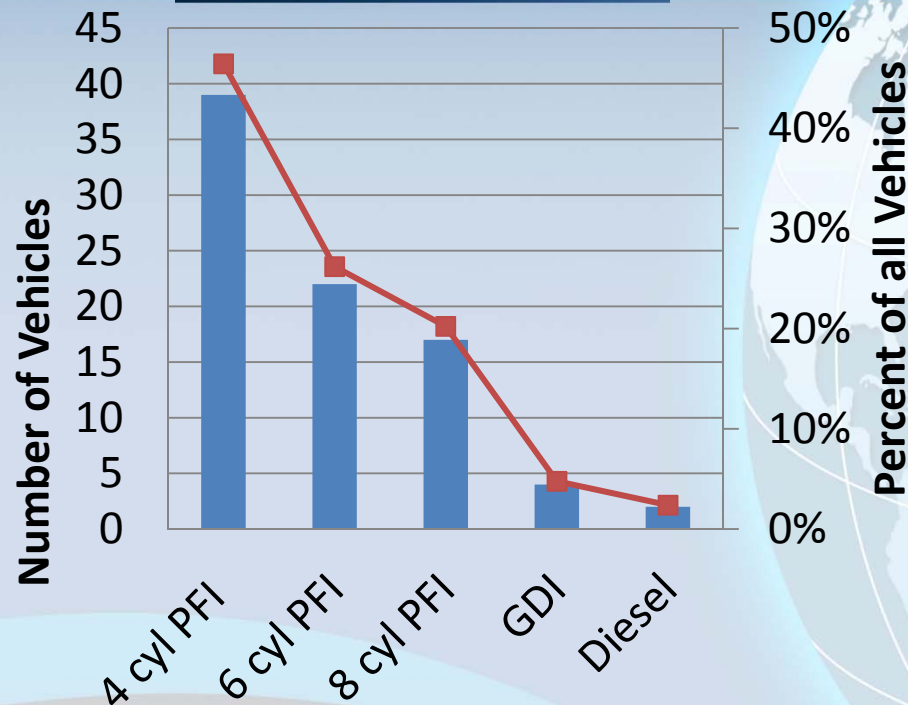


Testing Method

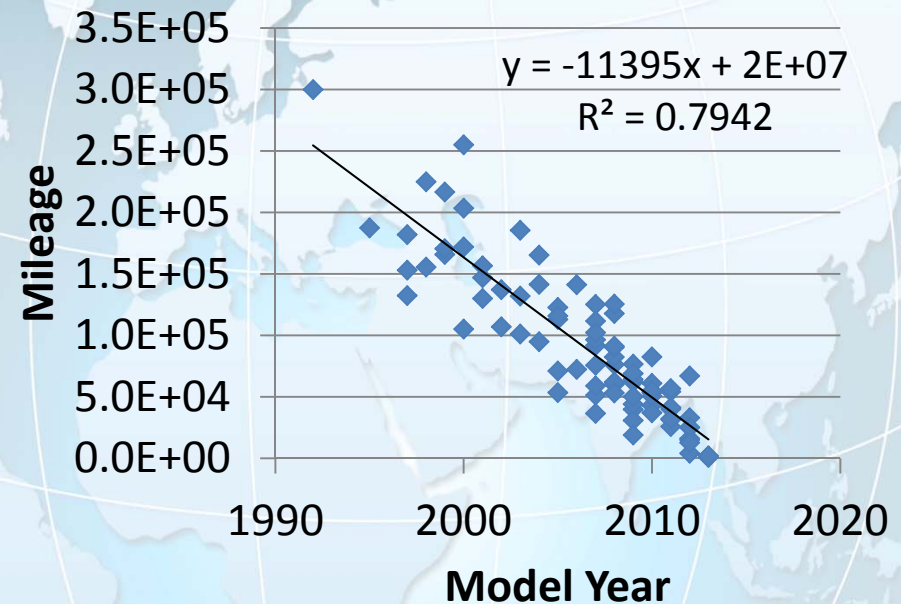
- **Vehicle approaches measuring station**
 - Turn off engine
 - Sample probe inserted in the tailpipe
- **As the vehicle was turned on, the “start-up” phase began**
 - ~ 20 to 30 seconds
- **Vehicle left to idle**
 - ~ 30 seconds
- **Probe removed from tailpipe**
- **Start-up test completed!**
- **Total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



Number of Vehicles Per Engine Type



Car Mileage vs. Model Year



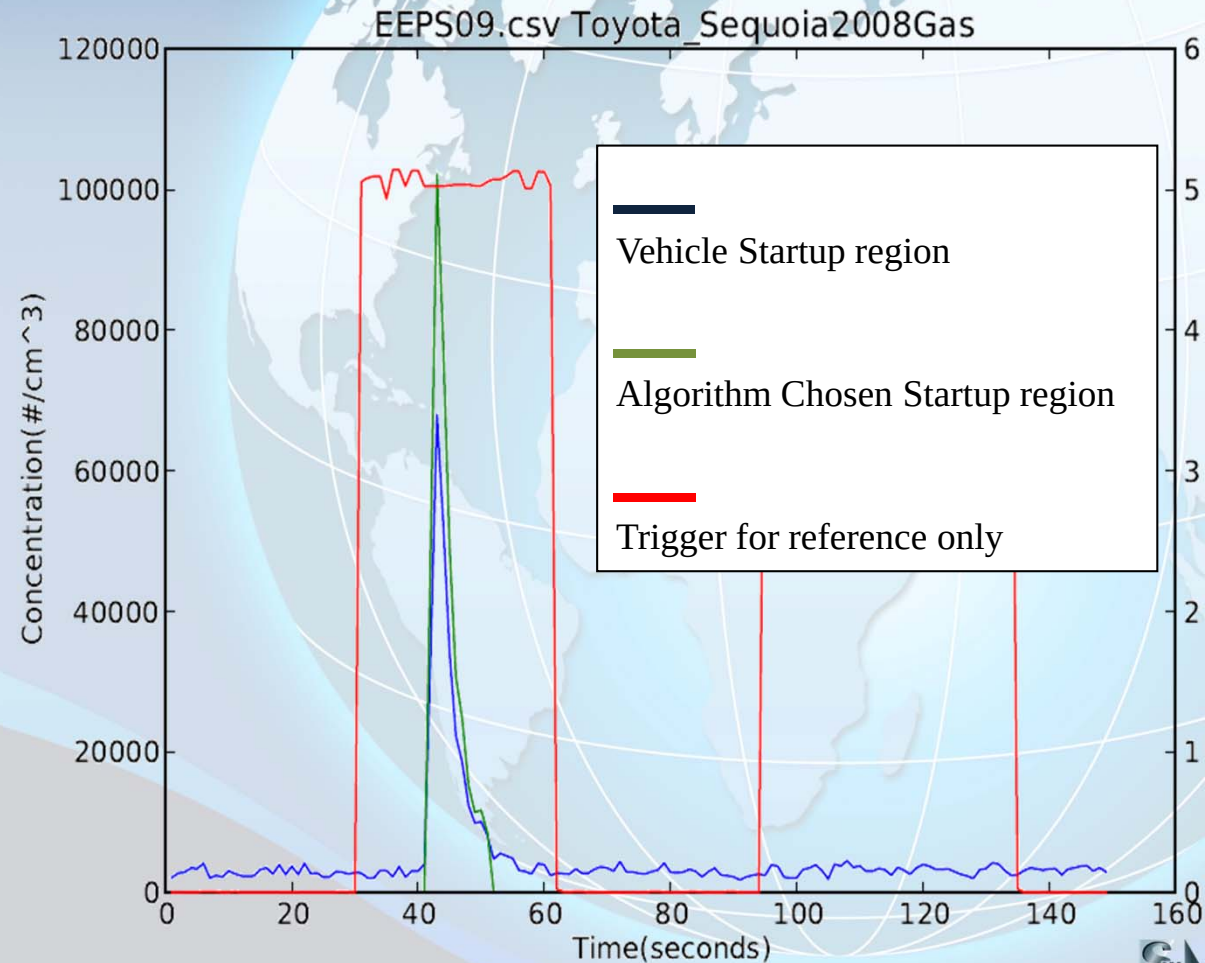
- Verification that the older the car is, the more mileage it has.

- 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**

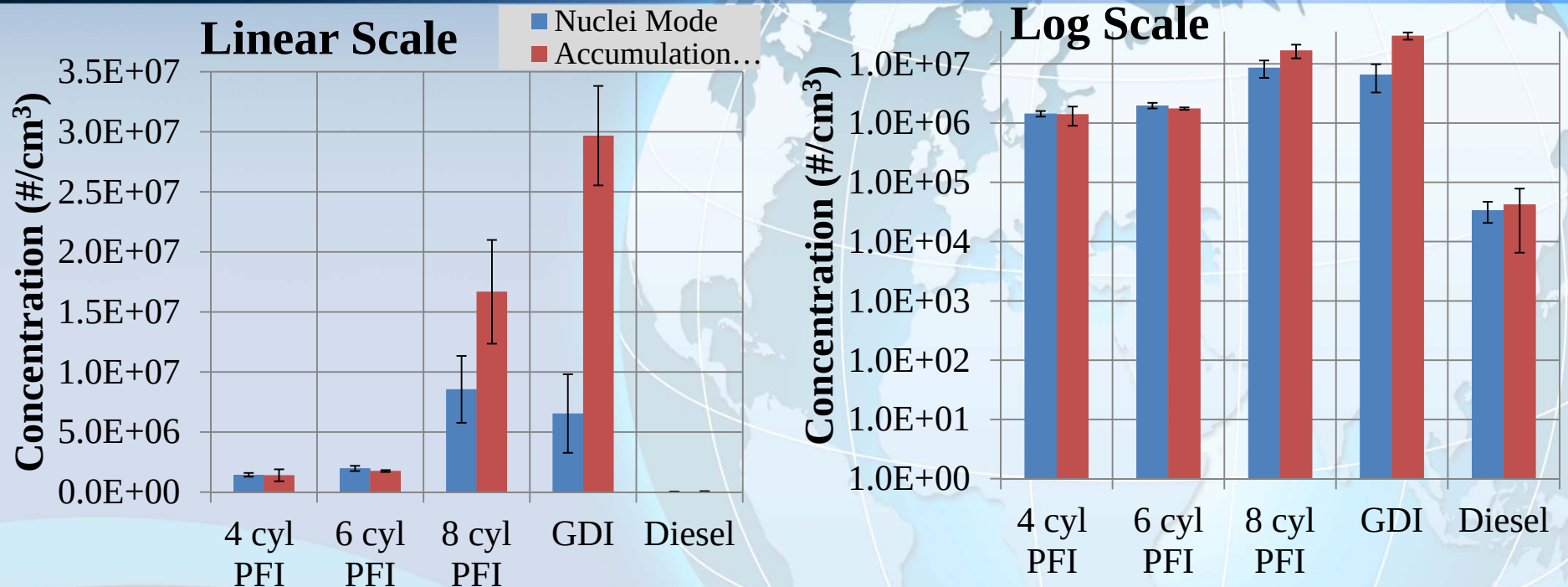


Identifying Start-up Region

- 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.



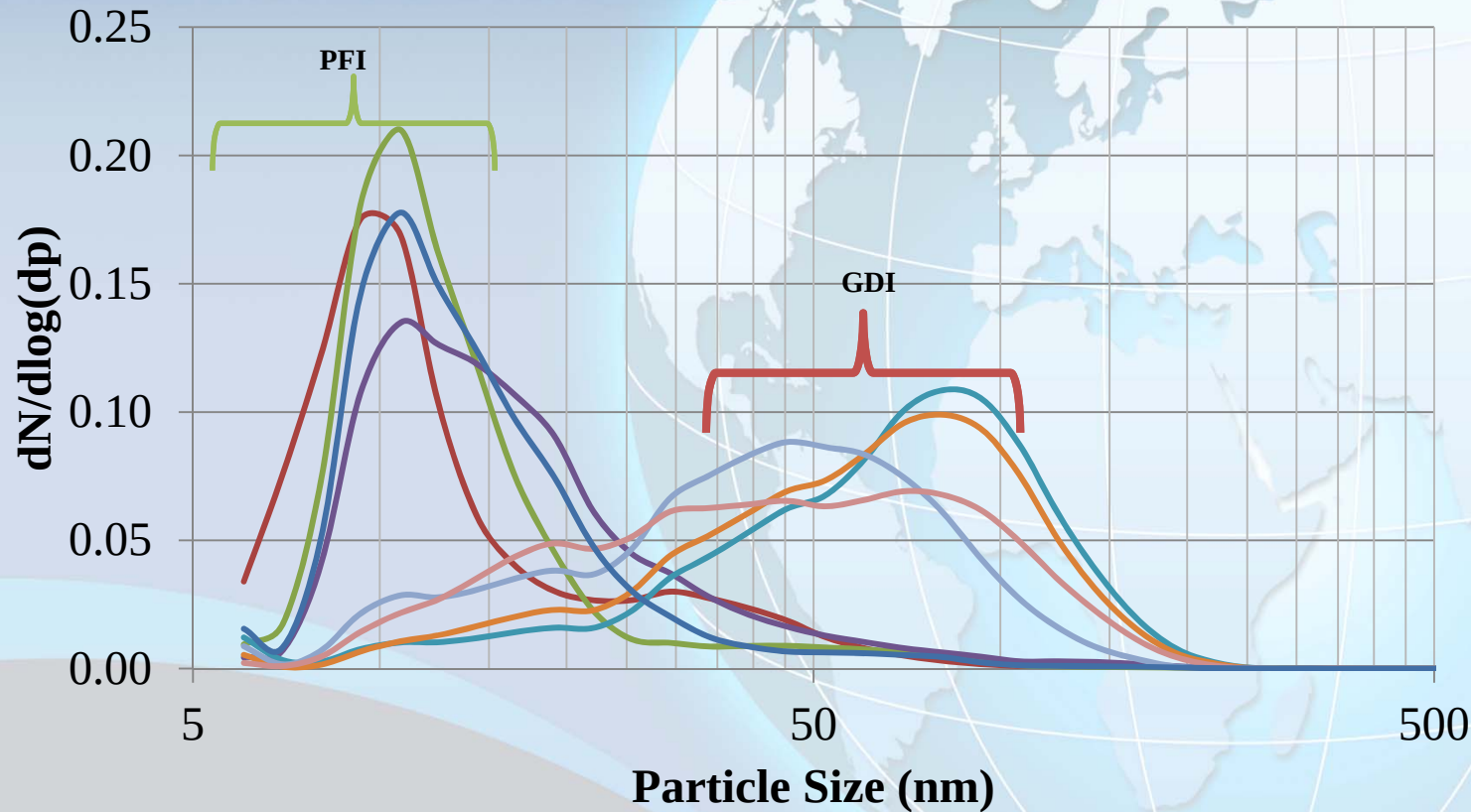
Average Particle Number Concentration



- 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 ($> 25\text{nm}$)
- Current PMP method does not detect PFI particles



Particle Number Indexing Concept

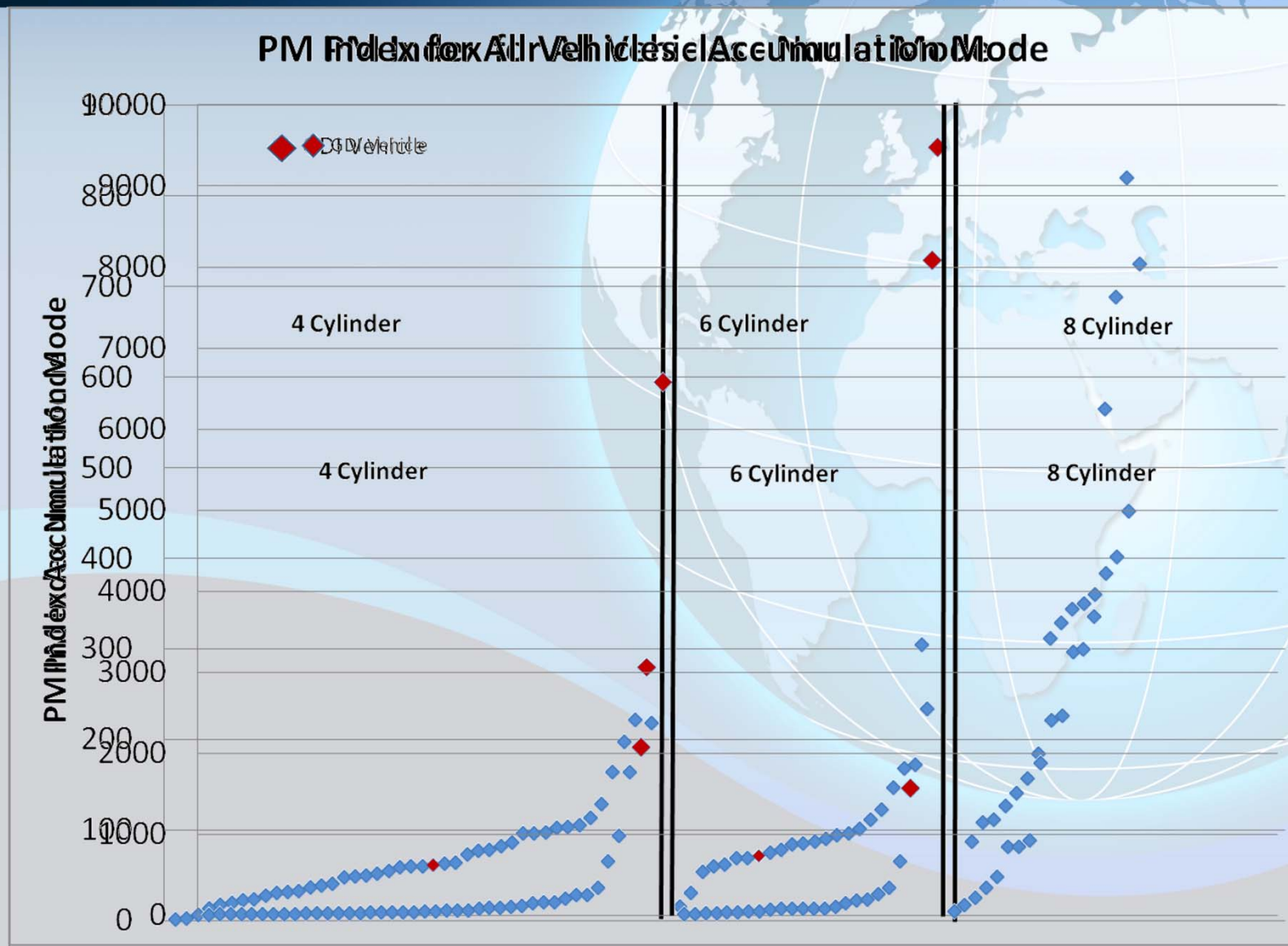
- Diesel with high efficiency DPF as the baseline/reference
 - **Best Available Technology**
- PN indexed each vehicle as compared to the Diesel Vehicle
- Average Concentration and Engine Size (L) obtained per group
 - Served as a basis for comparison for other vehicles in the group

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

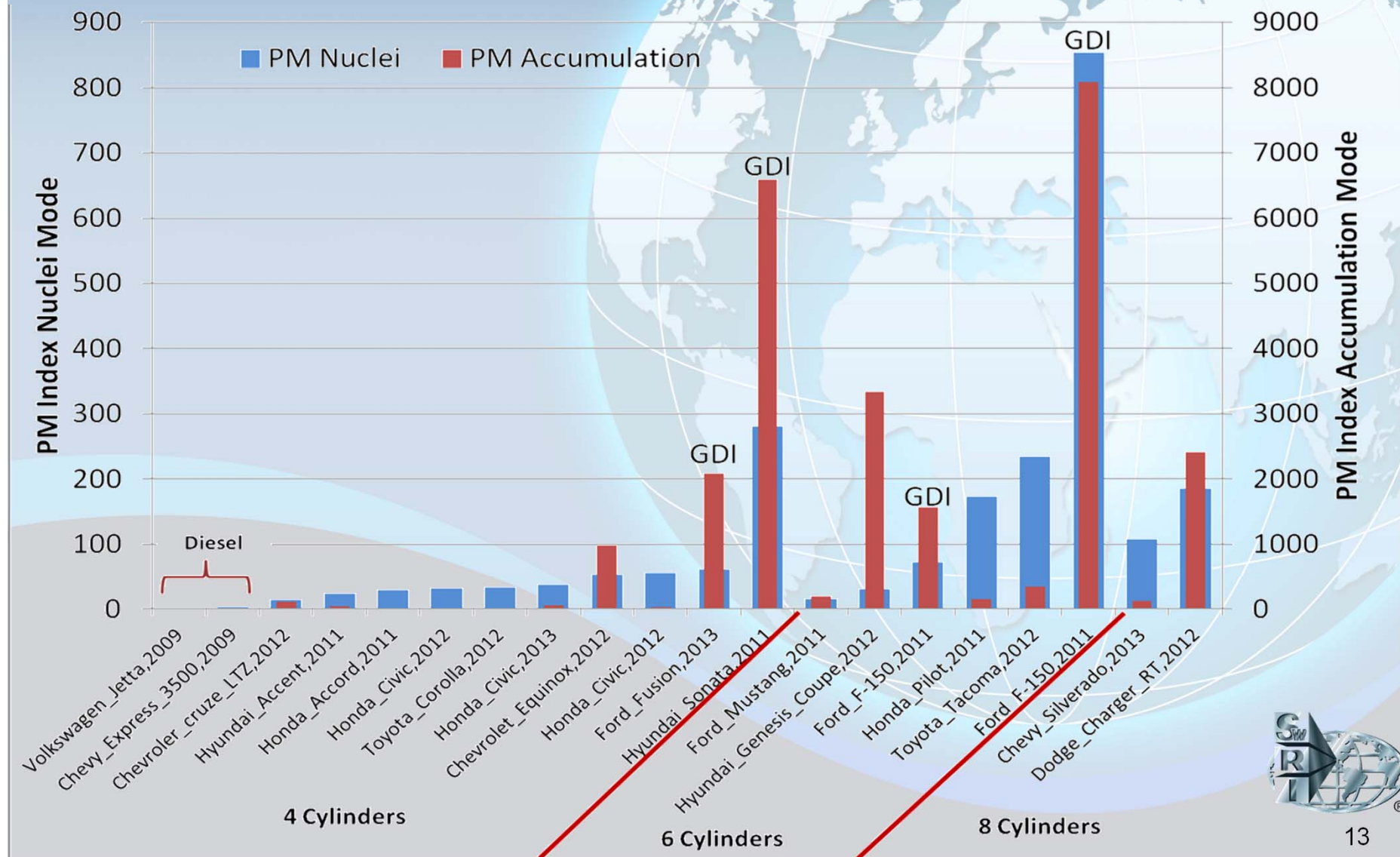
- Vehicles indexed for nuclei and accumulation mode
 - Rank from 1-900 (900 = worst) for Nuclei Mode
 - Rank from 1-9000 (9000 = worst) for Accumulation Mode



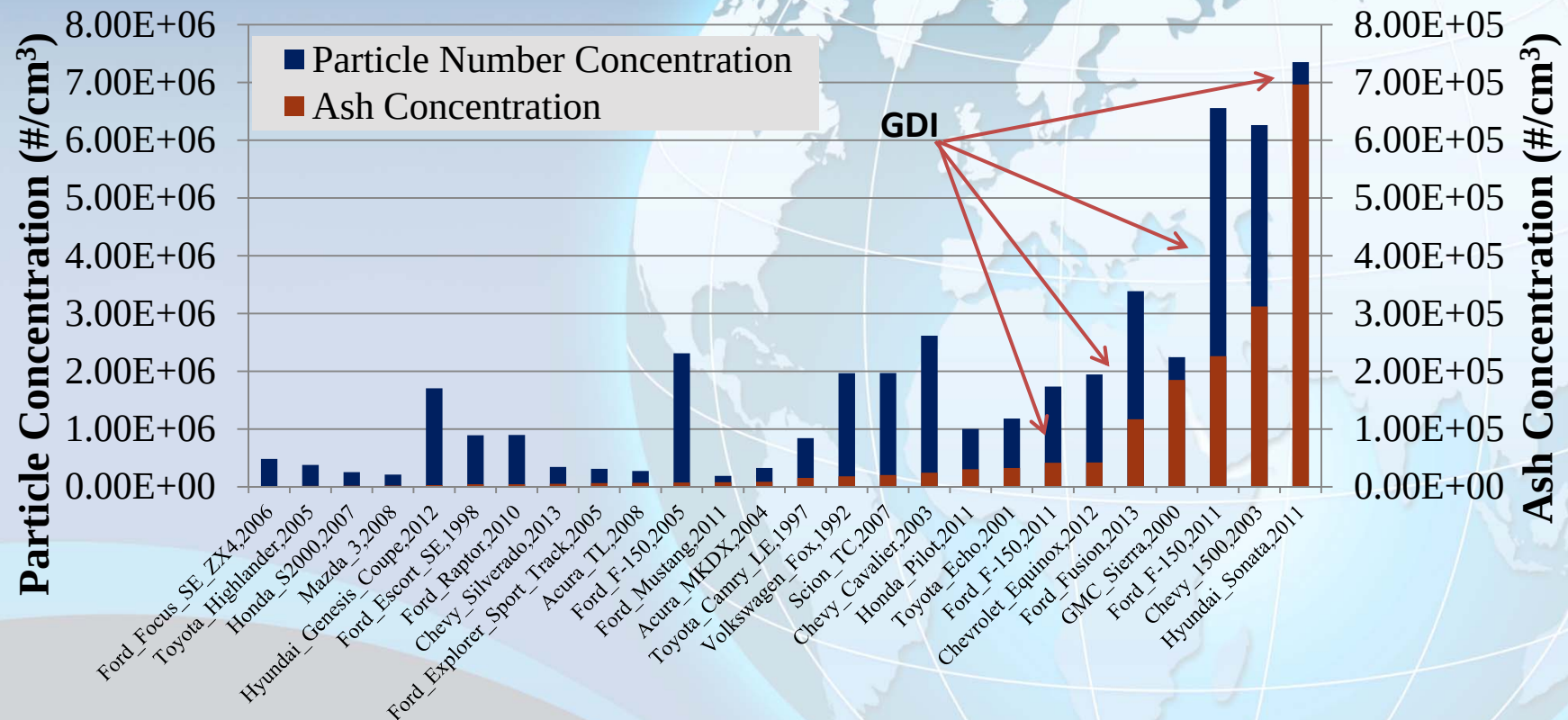
Particle Number Emission Index



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

