Gasoline Engines: Ultrafine Particle Emissions

Matti Maricq
Physical & Environmental Sciences
Research & Innovation Center
Ford Motor Company

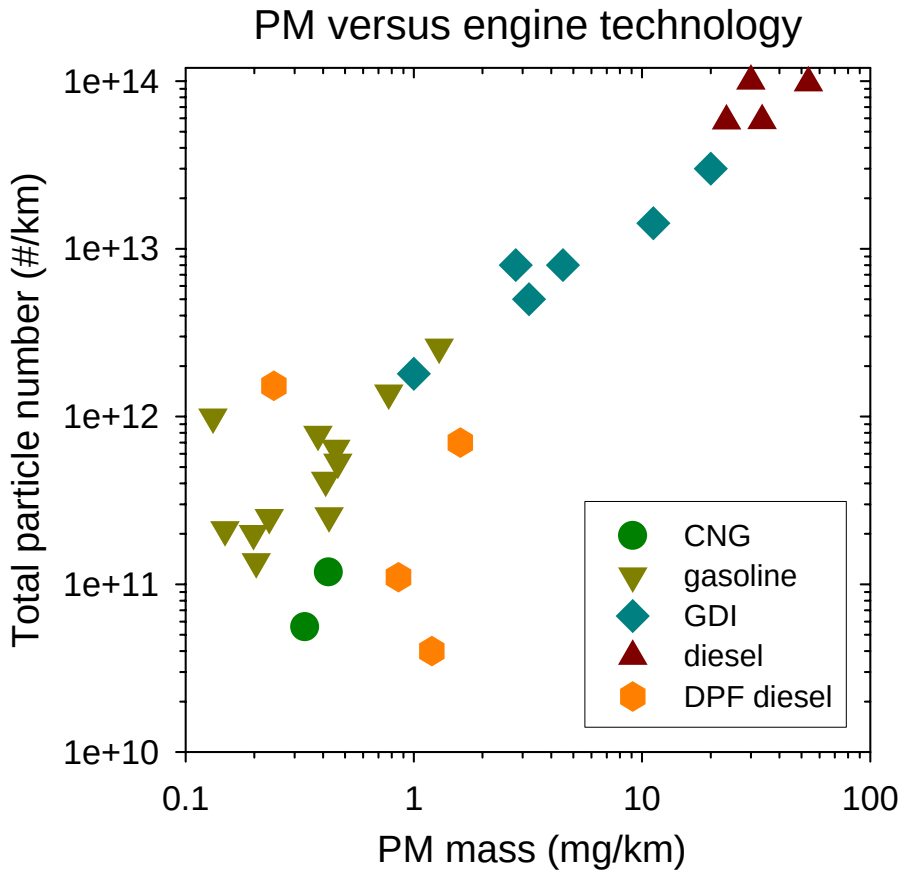
Outline

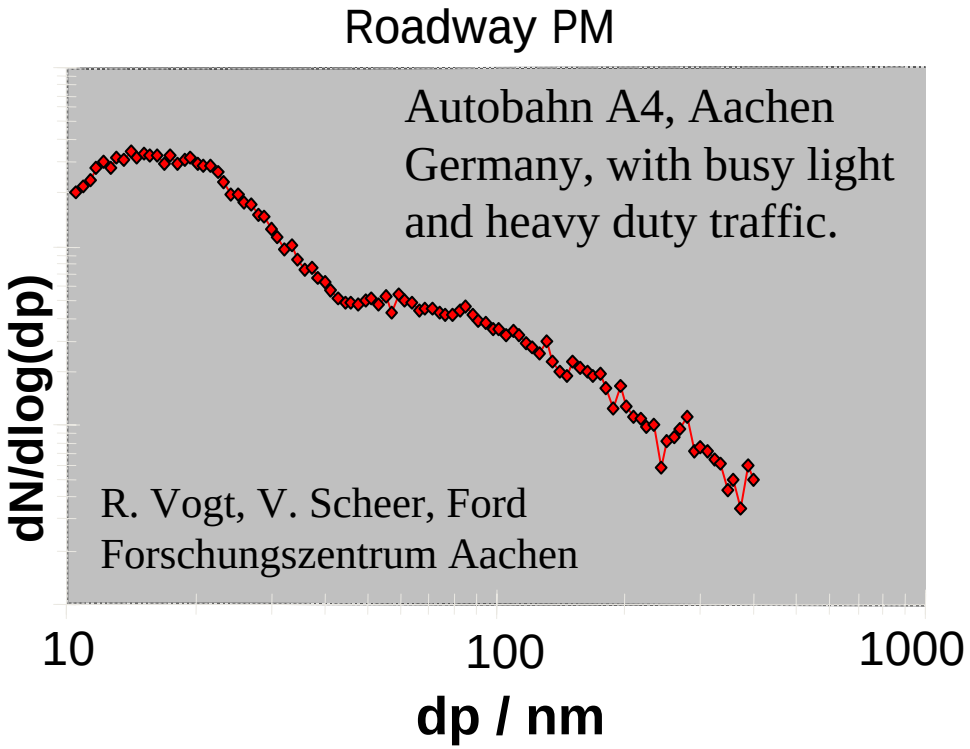
- Classifying vehicle exhaust particles
- How gasoline and diesel vehicle PM differs
- Real world emissions
- GDI versus PFI engines
- Gasoline PM at cold ambient temperatures

Underlying question: Vehicle emissions versus roadway PM?

Test cell data shows particle # to decrease with PM mass.

So why is roadway dominated by nucleation mode?

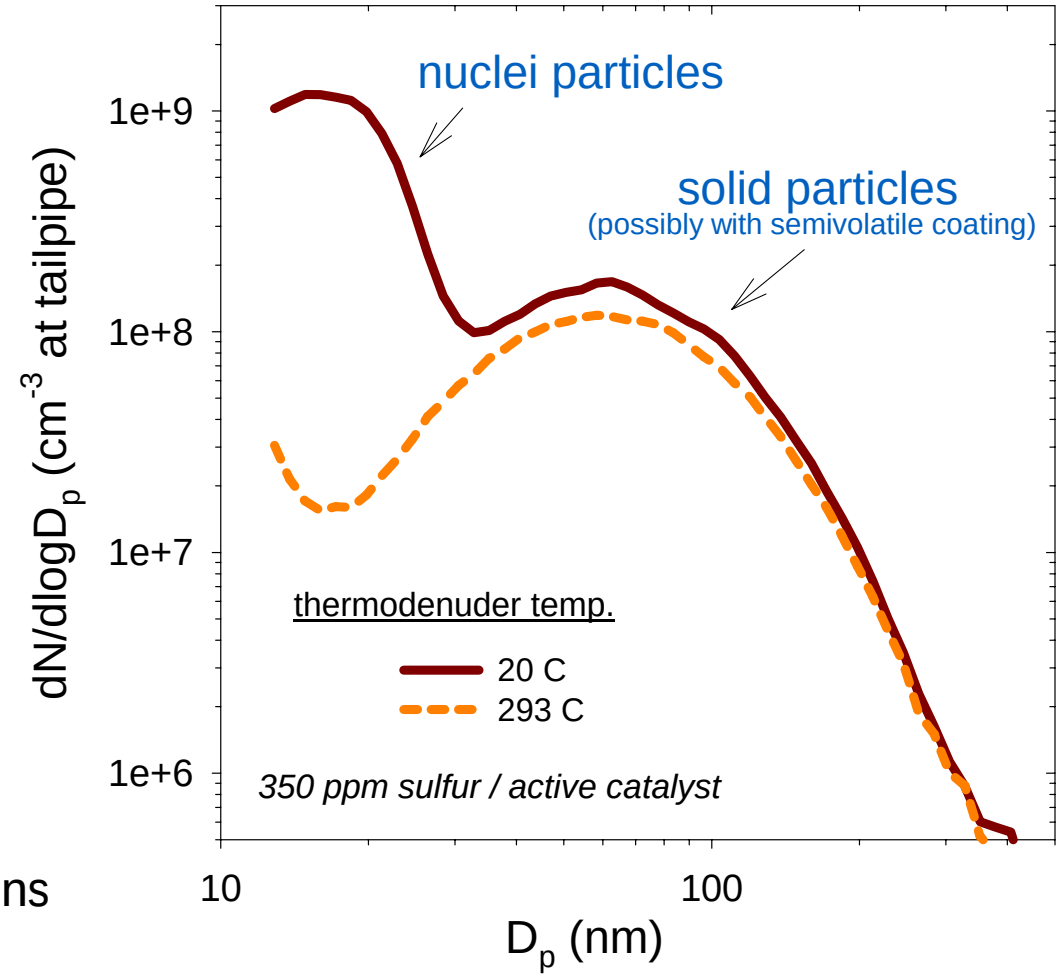




Differences between gasoline and diesel vehicle PM

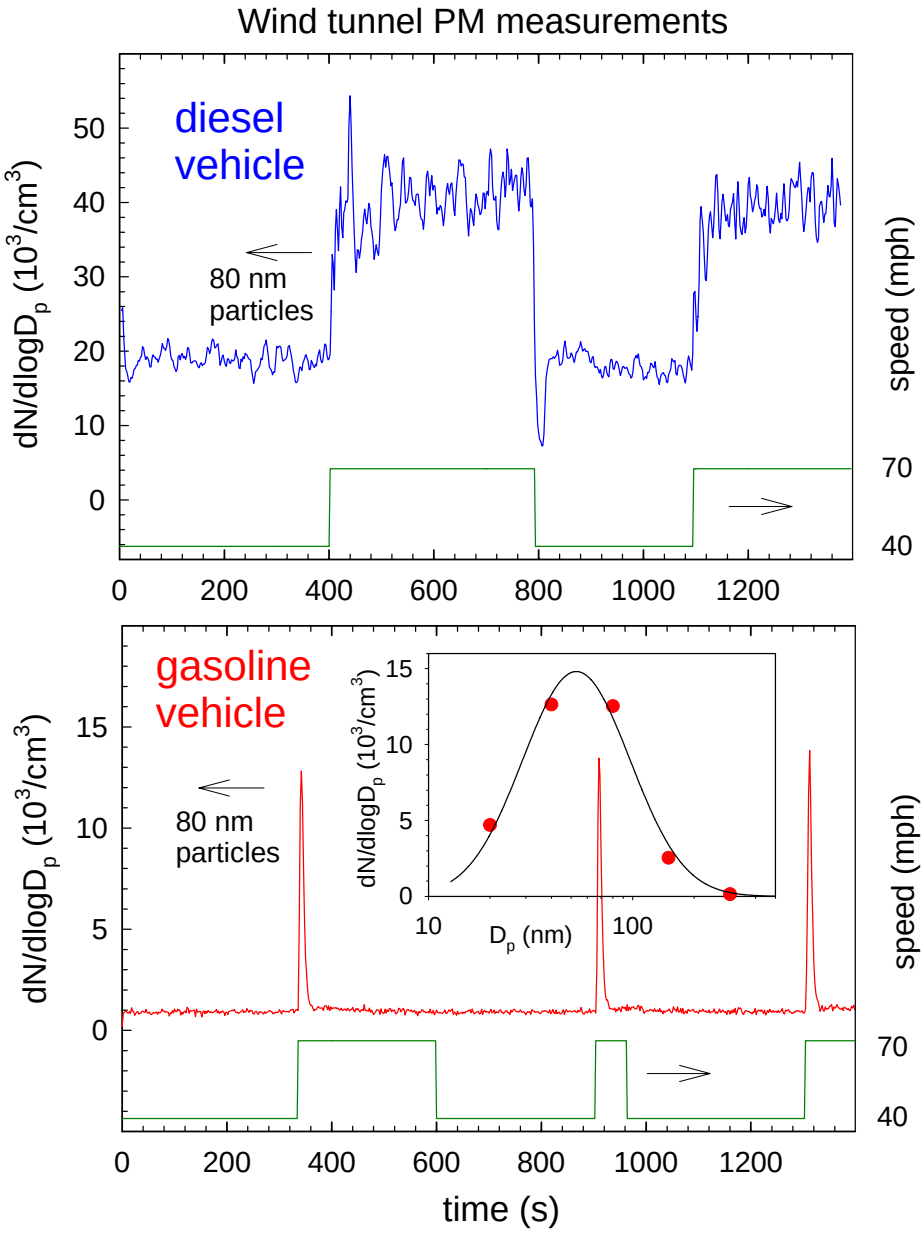
Types of particles in vehicle exhaust

- Soot mode
  - Particles formed in cylinder
  - Mainly solid – soot, ash
  - Coagulation → log-normal mode at 50 – 100 nm
  - Fractal like shape
  - Electrically charged
- Nucleation mode
  - Super saturation of volatile material from dilution
  - Mainly liquid
  - Spherical
  - Sulfate & heavy hydrocarbons
  - Electrically neutral



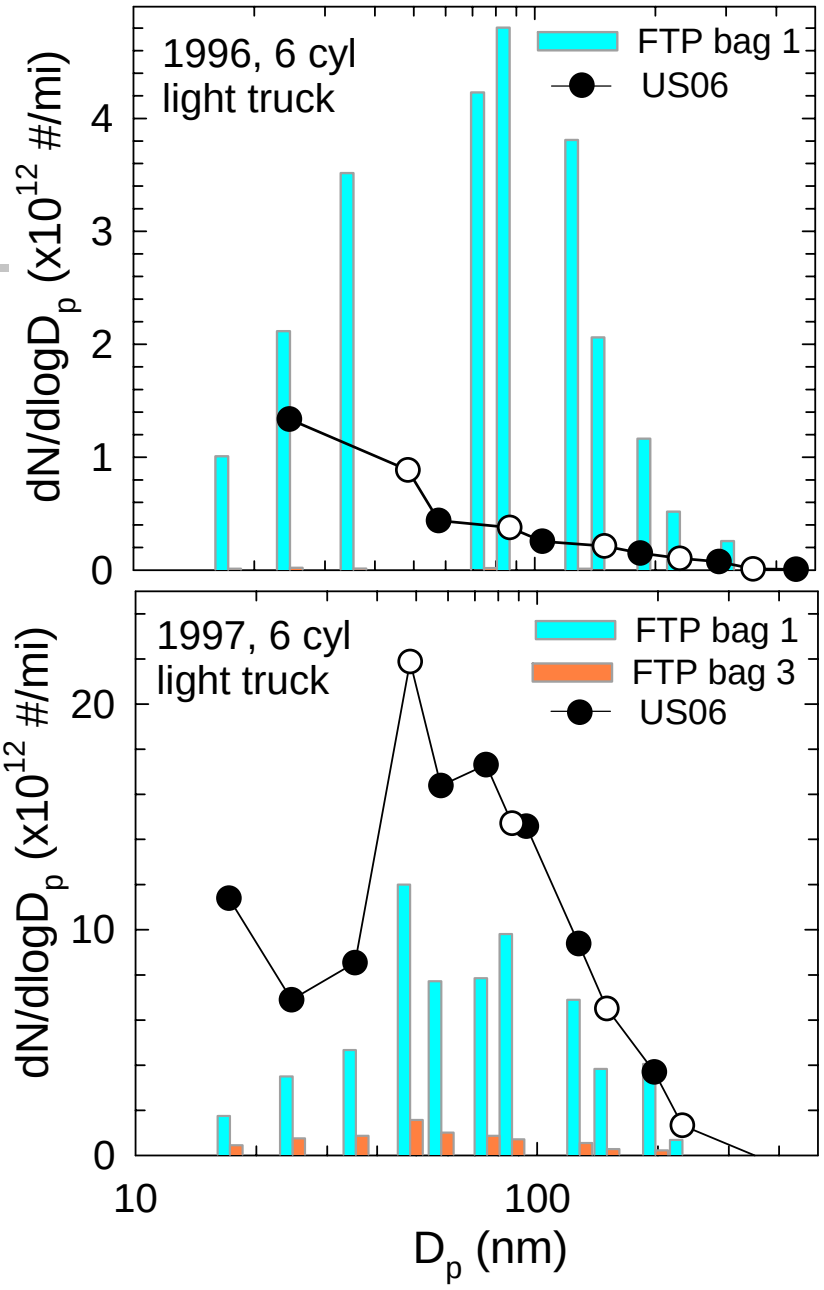
PM formation: gasoline vs diesel

- Diesel engines
  - Combustion occurs at air – fuel interface
  - Soot ~proportional to fuel (other factors include EGR)
  - ~90% soot oxidizes during post flame mixing with air
- Gasoline engines
  - Premixed combustion
  - Stochiometric A/F → almost no soot
  - Main source is transients, e.g. liquid fuel, loss of A/F



Size distributions for gasoline vehicle PM

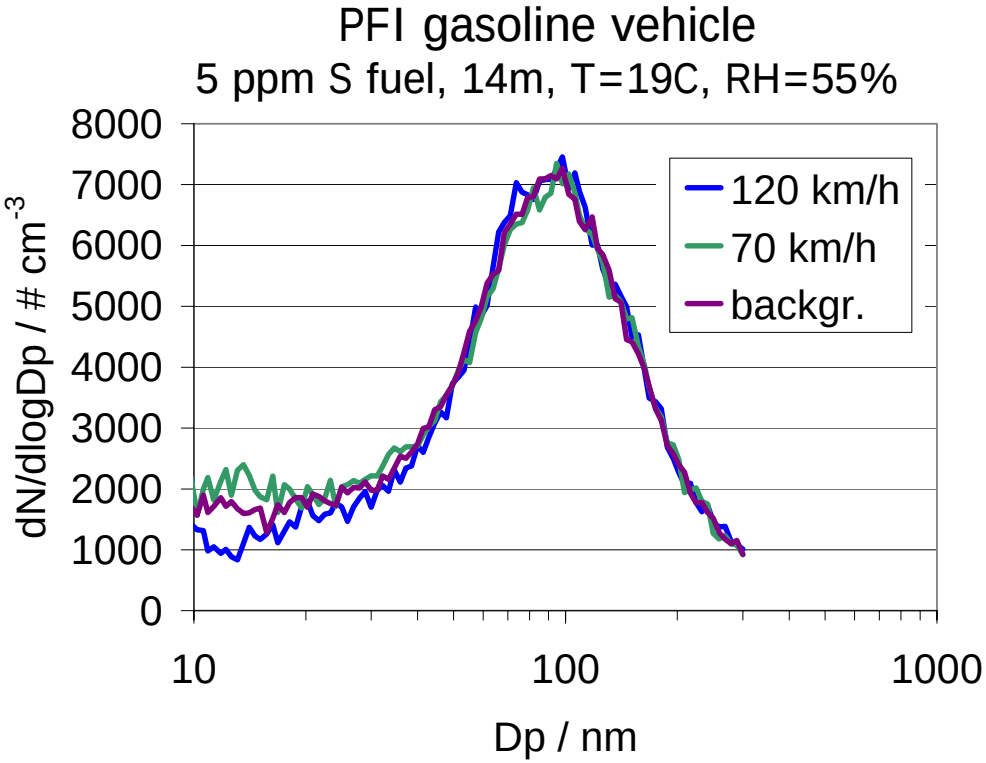
- Size distributions are for transient PM emissions.
- They are constructed from FTP and USO6 drive cycles.
- Emissions fall into the PM0.5 size range.
- No clear demarcation at either 100 nm (ultrafine) or 50 nm (nanoparticle)



“Real world” gasoline PM

Real world chasing of gasoline vehicle

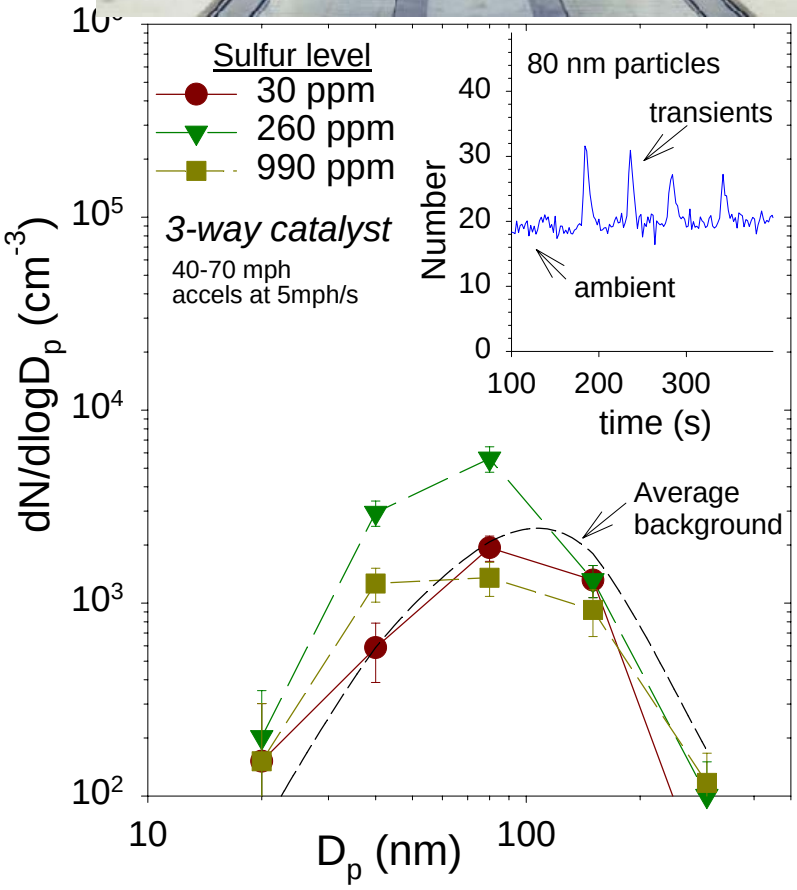
- Measurements made on test track away from other vehicles.
- At 70 & 120 km/h neither soot nor nucleation mode is detected above background level.
- PM emissions during step accelerations also remain below background.



Courtesy of V.Scheer and R. Vogt
Ford Forschungszentrum Aachen GmbH

Wind tunnel tests

- Current gasoline vehicle PM near ambient. Inset shows transients above ambient.
- Distinct nuclei mode not observed, even at high sulfur levels.
- Degradation of catalyst efficiency observed with high sulfur fuel.



Gasoline Direct Injection

Port fuel injection (PFI) – Fuel & air mix in intake port and are drawn into the engine cylinder during intake stroke.

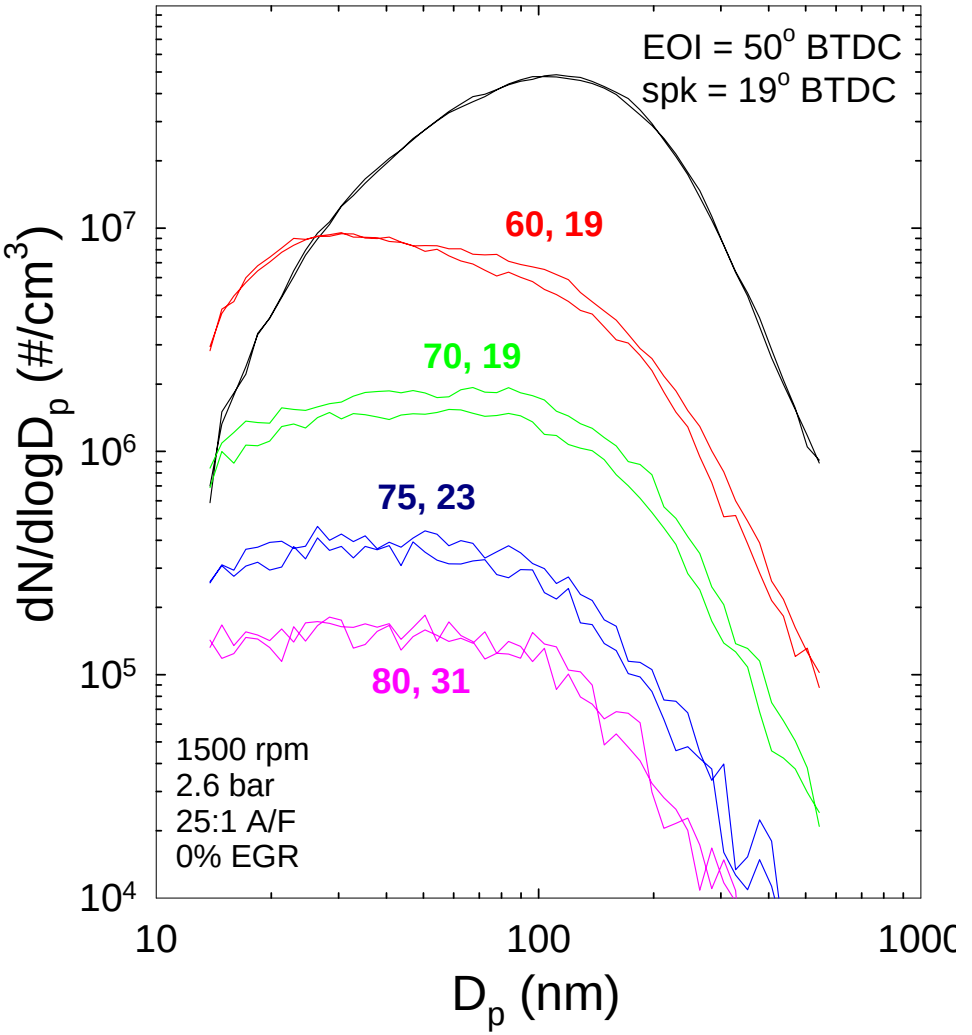
GDI – Air drawn into cylinder during intake stroke. Fuel is injected separately either during intake or compression stroke.

GDI engine PM emissions

Two modes of operation

- Stratified
  - Late fuel injection
  - Lean operation
  - Lower pumping losses
  - Fuel impingement, lack of mixing → higher PM
- Homogeneous
  - Early fuel injection
  - Stoichiometric A/F
  - Reduced emissions

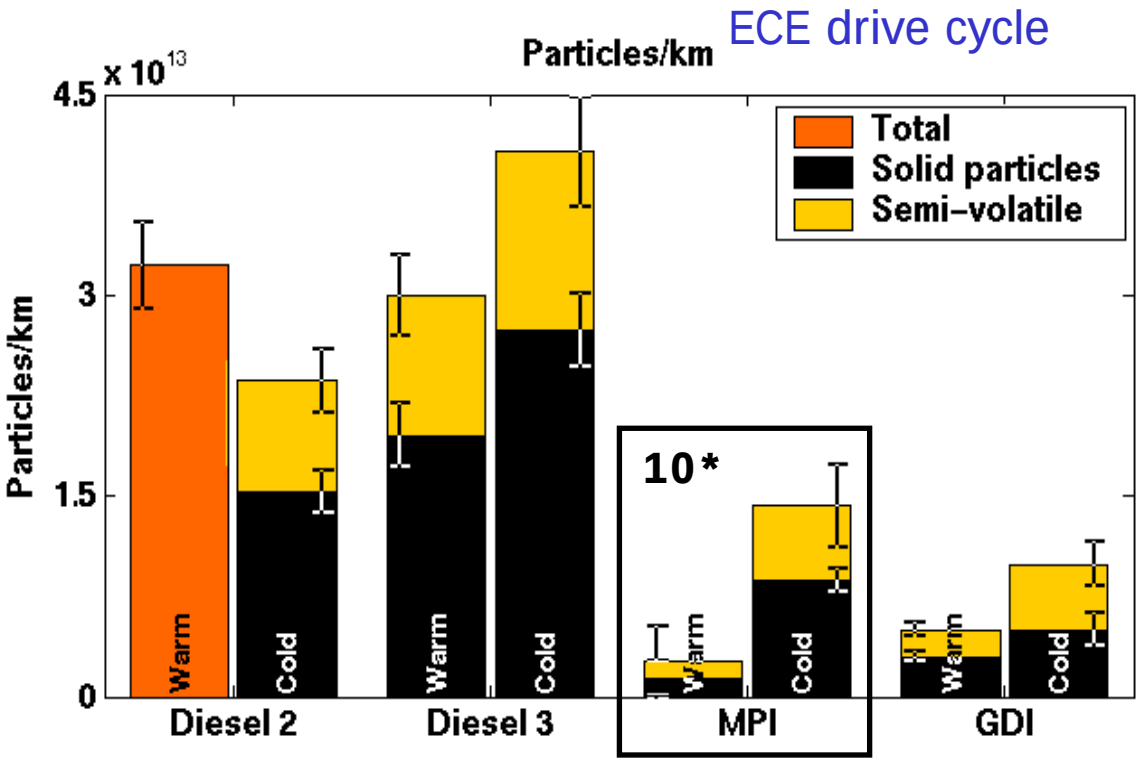
GDI engine: PM vs injection timing



Gasoline vehicle PM at cold temperatures (-7 C)

Gasoline PM at cold temperatures

- Temperature decrease from 25C to -7C → relatively large increase in gasoline (MPI) particle #
- Both solid and semi volatile # increase
- On absolute scale gasoline PM remains < 1/20 of diesel PM



Ristimäki et al.
Environ. Sci. Technol. **2005**, 39, 9424

Summary

- PM characteristics of modern PFI gasoline engines
  - Close A/F control → very low PM (often < 1 mg/mi)
  - PM predominantly a transient phenomenon
  - Particle # level tracks PM mass level relative to other engine technologies → no inordinate nucleation mode
  - Cold increases particle number, but from ~2% to 5% relative to light duty diesel
- PM characteristics of GDI
  - Stratified operation improves fuel economy, increases PM
  - PM during homogeneous operation is comparable to PFI gasoline vehicles
  - Most current development takes homogeneous approach

So, how to reconcile vehicle PM vs roadside?

- Data presented here are from modern, properly functioning, vehicles. The tight A/F control means that even small malfunctions could cause high relative increases in PM.
  - Oil leakage → heavy hydrocarbons that could nucleate
  - Faulty oxygen sensor → rich operation → higher soot formation
- Degraded catalyst performance – higher hydrocarbons could lead to increased nucleation
- Driving conditions with high use of transients, e.g., freeway entrance, could exacerbate PM emissions
- Dilution in test cell is with clean, low humidity air. Perhaps at the roadway there are synergistic nucleation opportunities, e.g., emissions from one vehicle exacerbating nucleation from the next.