Characteristics of PM from Modern Diesel Engines

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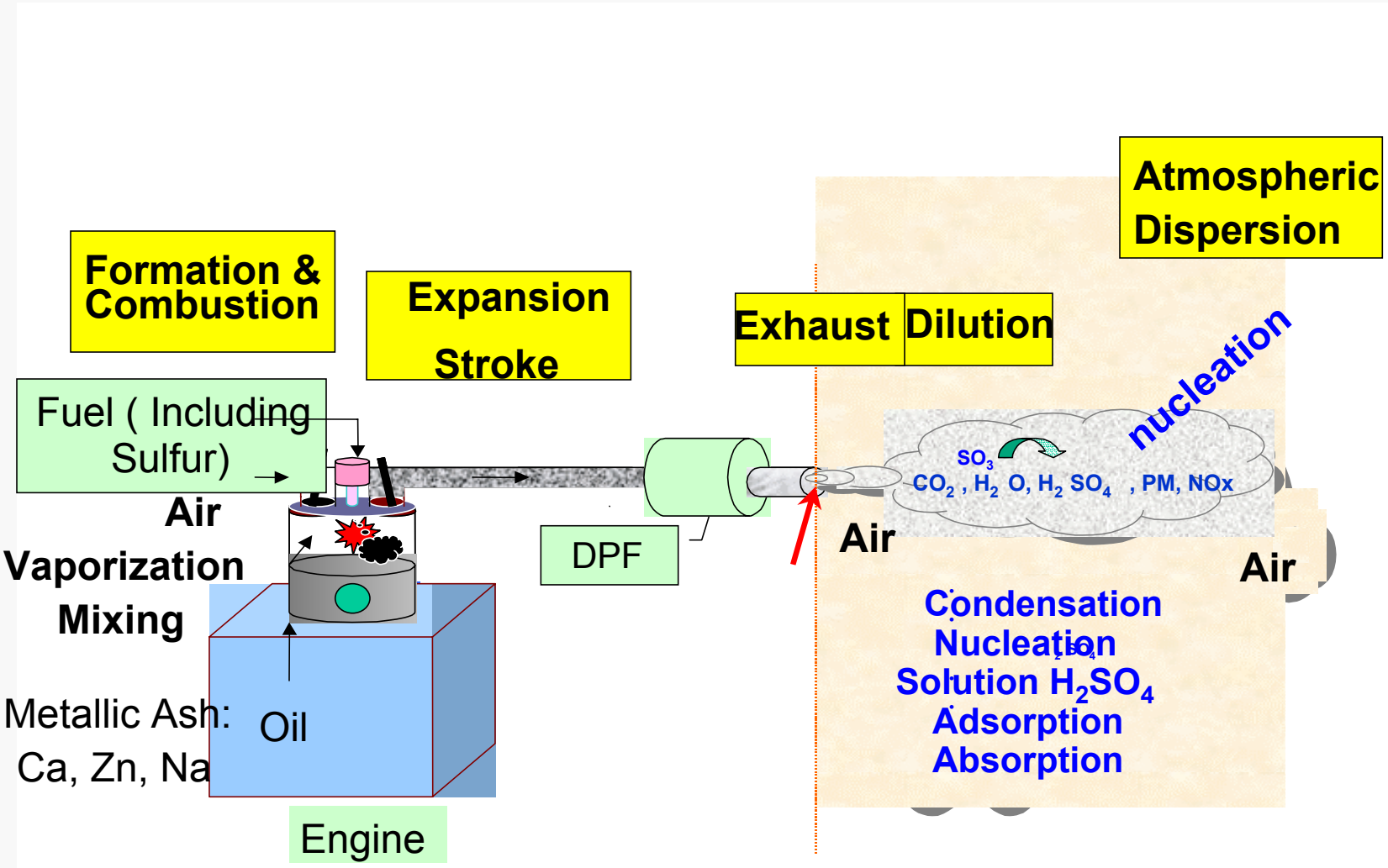
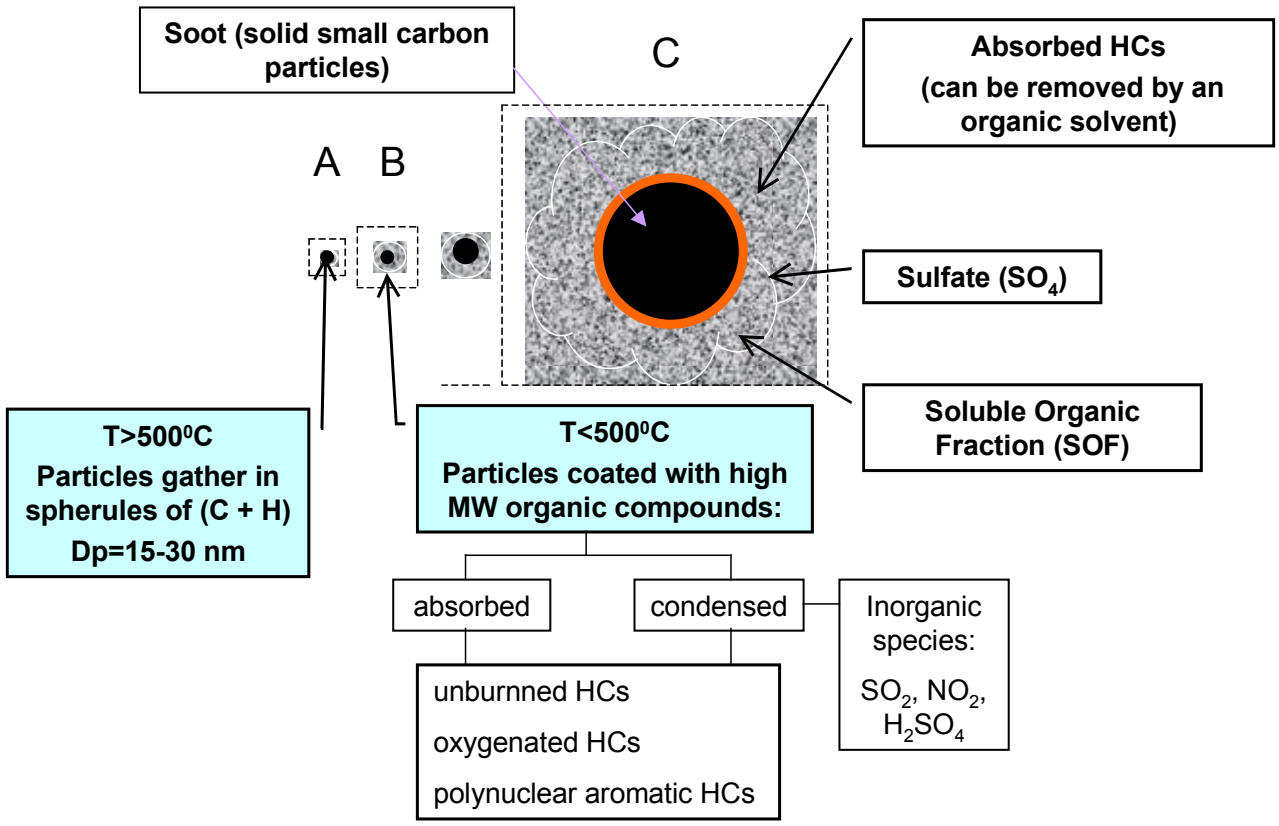
Dearborn, MI

October 18, 2001

What is Diesel Particulate Matter?

- Overview of what is known
  - Composition
  - Morphology
  - Size
- Challenges for modeling
- PM that DPFs emit
- Thoughts on other “stuff” that DPFs emit


Formation & Combustion
Expansion Stroke
Exhaust
Dilution
Atmospheric Dispersion
Fuel (Including Sulfur)
Air
Vaporization
Mixing
Metallic Ash:
Ca, Zn, Na
Oil
Engine
DPF
nucleation
SO_3
CO_2 , H_2 O, H_2 SO_4 , PM, NOx
Air
Air
Condensation
Nucleation
Solution H_2SO_4
Adsorption
Absorption



TPM = SOL + SOF + SULF where TPM: total particulate matter;
SOL: solid carbides or soot; SOF: soluble organic fraction; SULF: sulfate

Basic PM constituents are defined by test

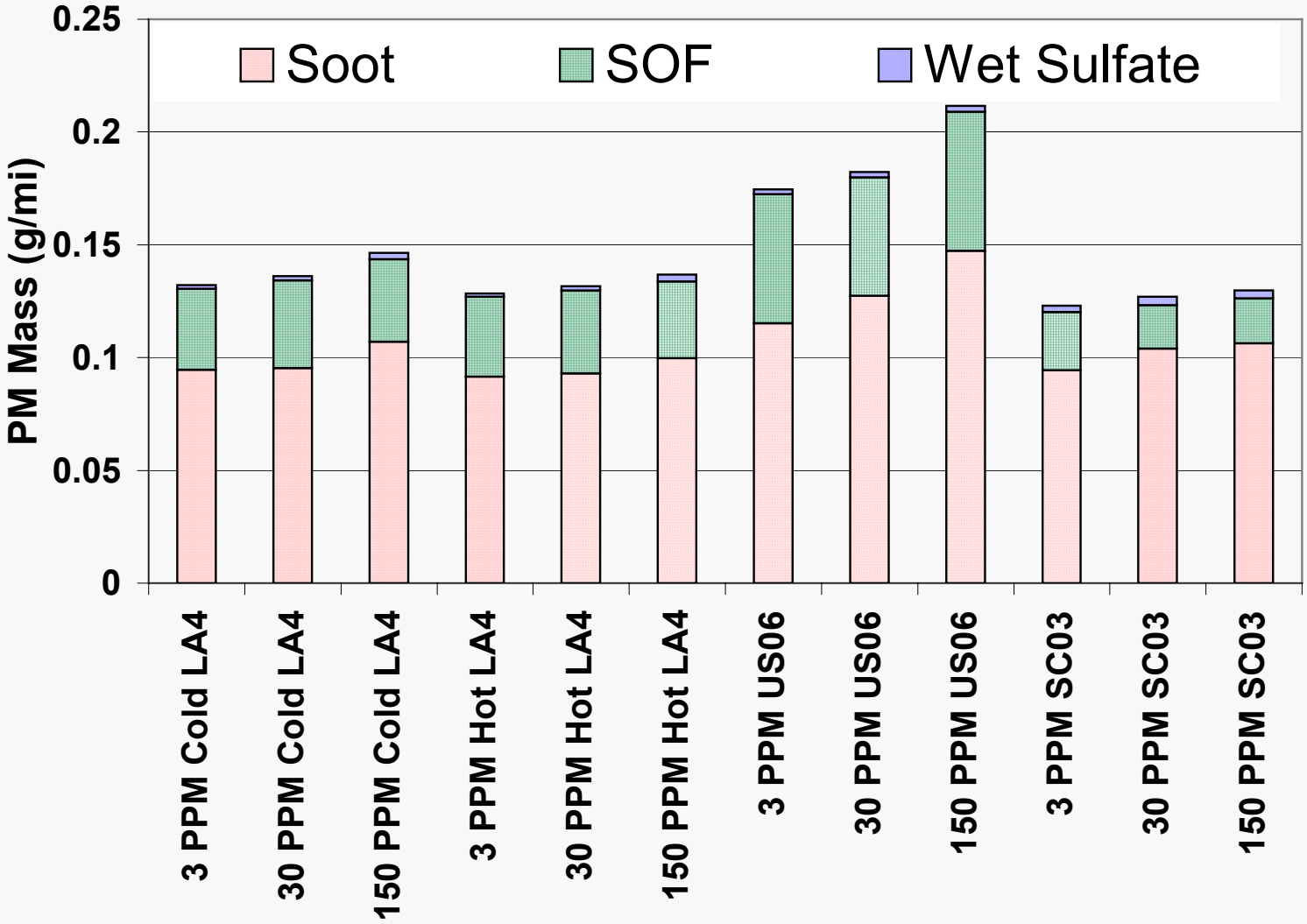
- SOF and soot are operationally defined
  - SOF is the Soluble Organic Fraction given a defined extraction process
  - Soot = Total PM – SOF – Sulfate (wet)
- OC/EC (organic and elemental carbon)
  - OC = what combusts below 650 °C
  - EC = what combusts above 650 °C – “char”
- Nanoparticles (<50 nm)
  - Not counted at all (no mass!)
  - Account for majority of particle numbers

What is in SOF and Soot?

- SOF is defined by the test – what is in SOF?
  - Fuel HCs and PAH
  - Polar organics – typically oxygenated fuel HCs and oxy-PAH
  - Other things: stay tuned

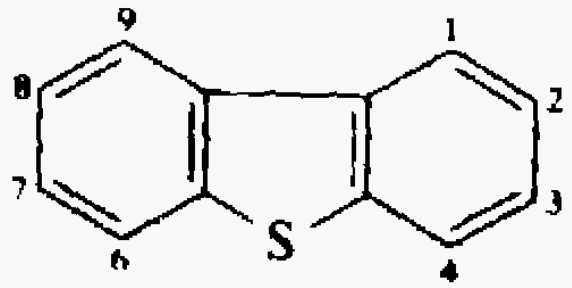
- Soot is also defined by test… what is leftover
  - Elemental carbon largely
  - Organics that are bound tightly
  - Ash

Soot Fraction Depends on S Level in Fuel

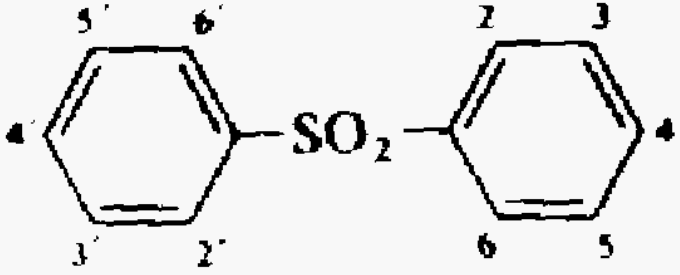


New extraction method identifies some fuel sulfur compounds do not completely combust in the engine, leading to increased PM soot fraction.

- **Method based on accelerated solvent extraction**
- **Previously unexplained insoluble emissions increases with increasing S in amount equal to 50% of dibenzthiophene added**
- **Found partial oxidation components of sulfur dopants in PM samples.**
- **Can no longer assume all fuel S goes to SO_2 in exhaust**



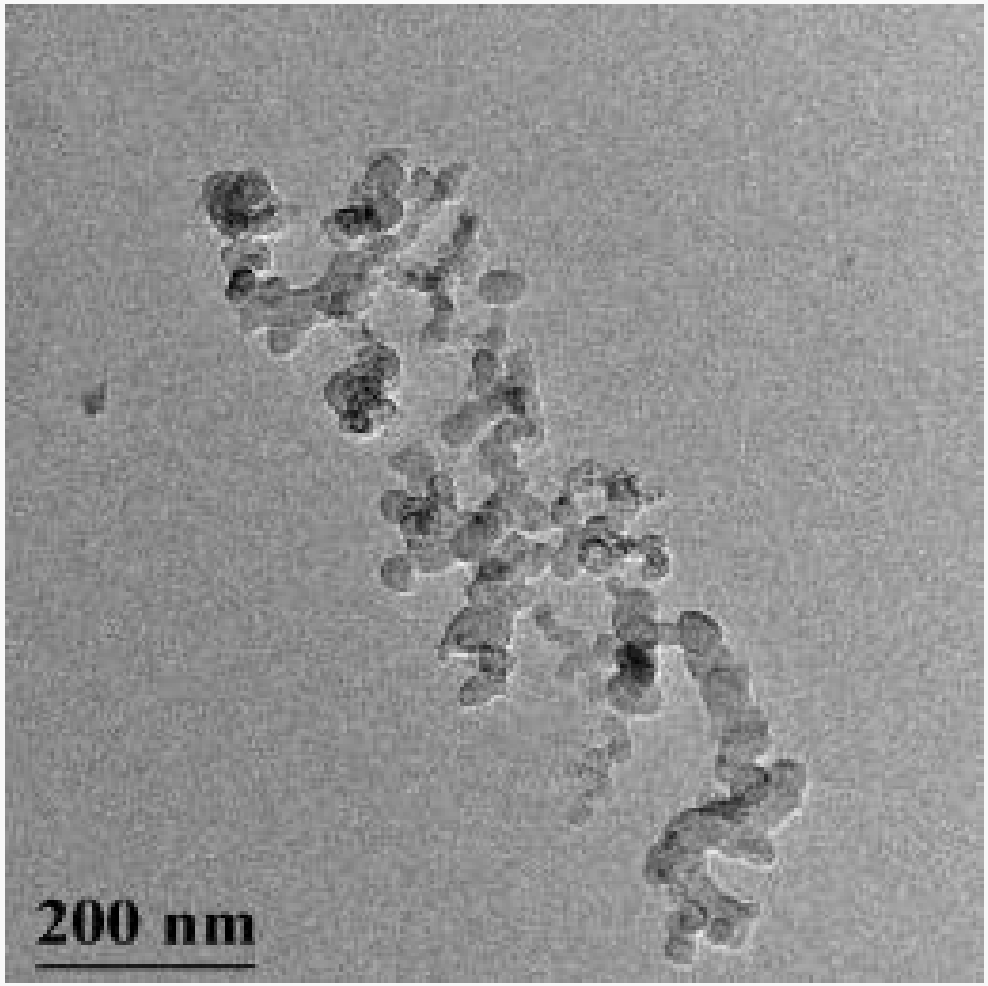
Dibenzothiophene (in fuel)



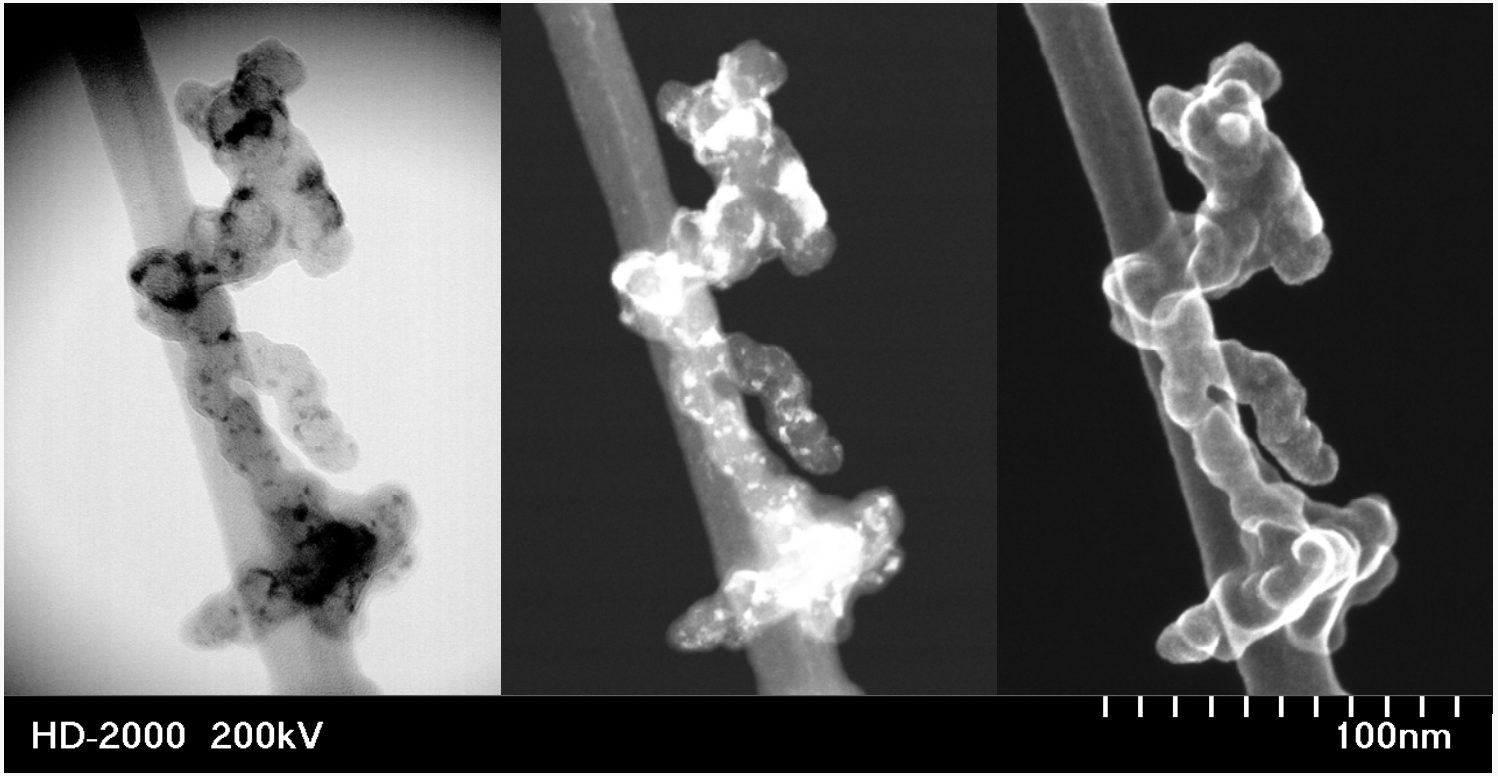
Diphenyl sulfone (in PM)

Morphology

PM from light-duty diesel with EGR



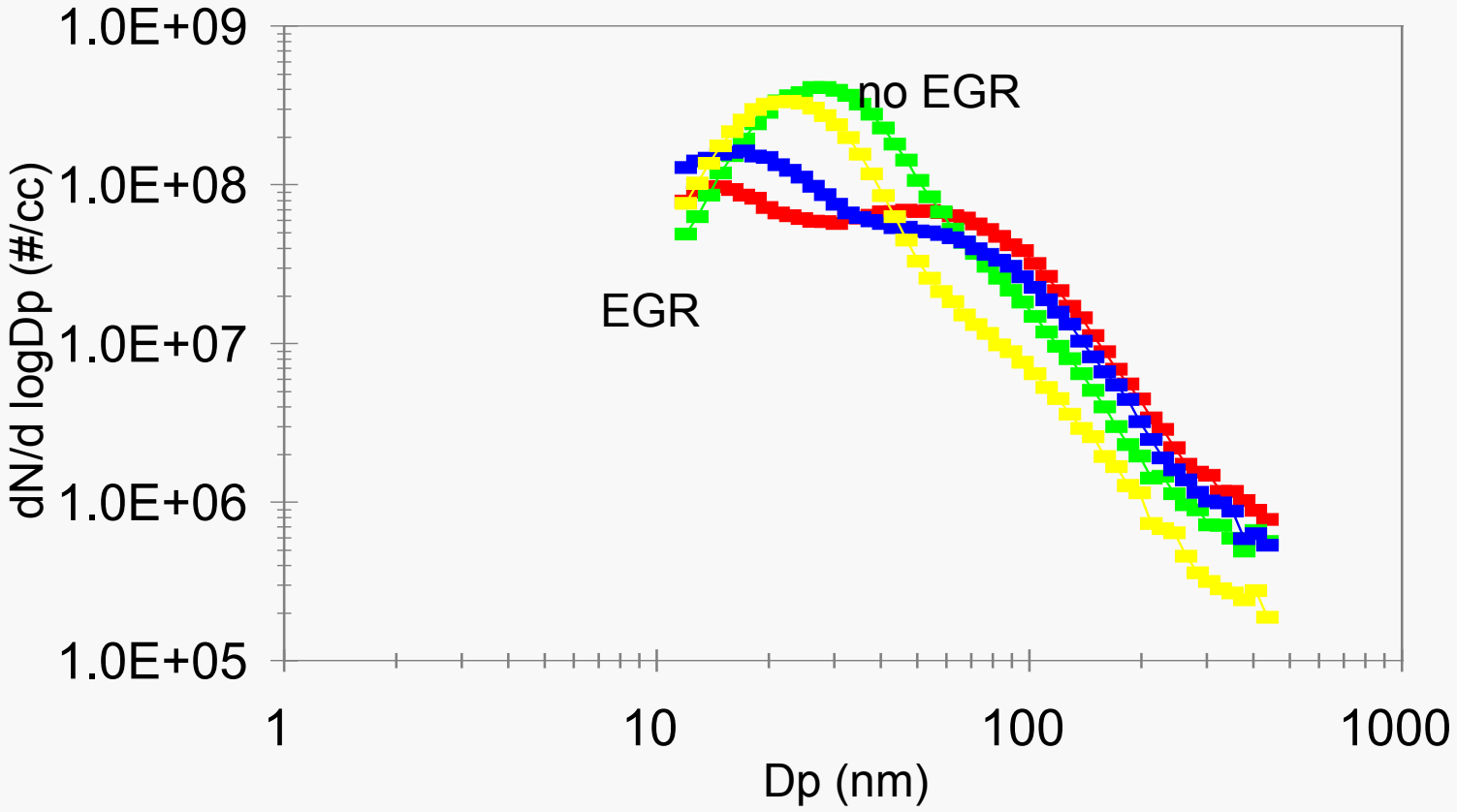
Soot particle from a high emitter shows metal content



Morphology determines surface area, packing

- The multiple chains of “primary” particles means the volume is largely air
- Primary particles have turbostratic structure
- Chains formed when layers interweave during initial soot formation in combustion chamber
- Lots of surface area means high burn rate

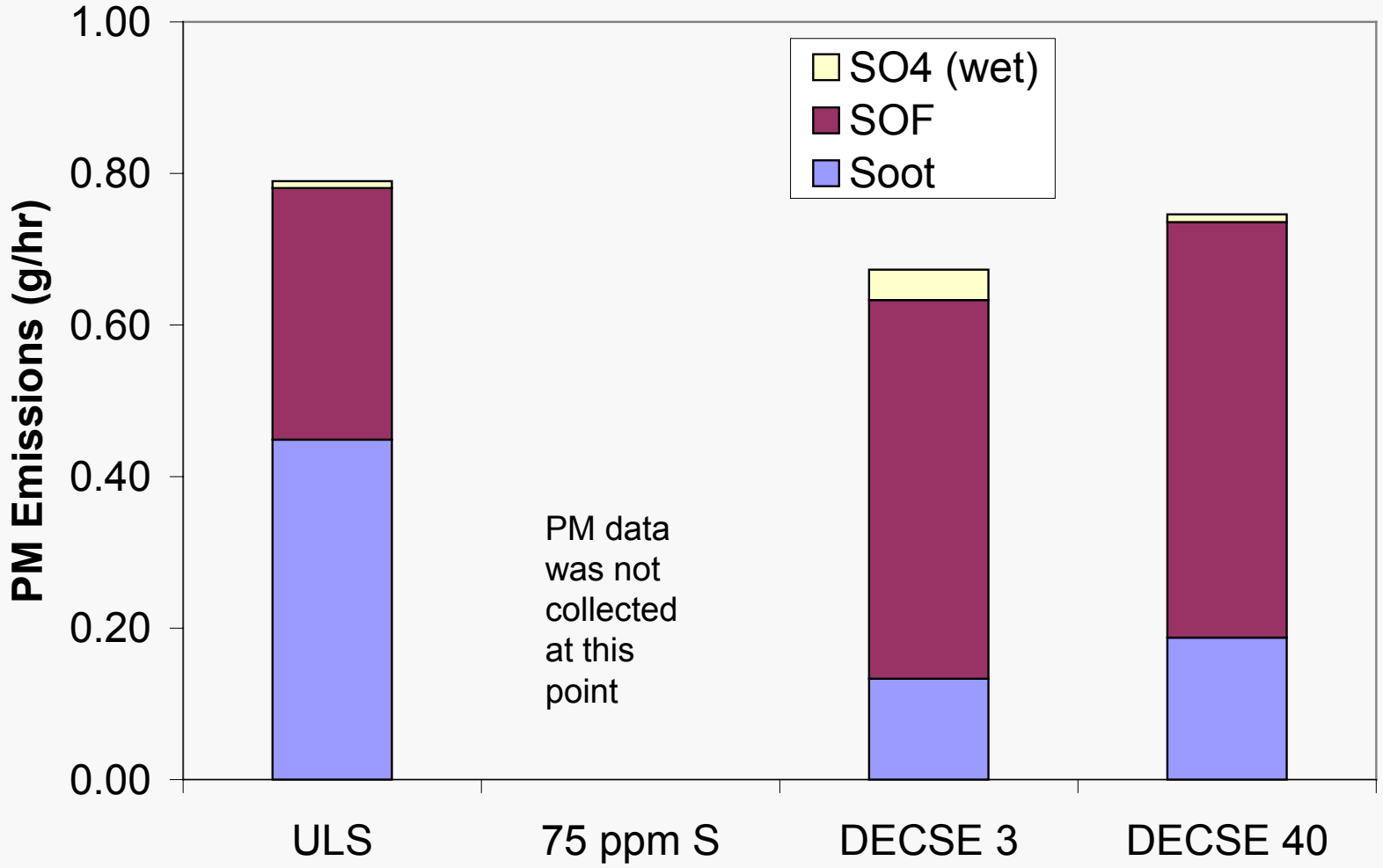
EGR increases size of particles…removes nanoPM



PM emitted from a DPF

- What happens to SOF on a DPF
  - During operation at high T, it is consumed
  - During regen, much is emitted
  - During idle, it goes through…
- Sulfur appears to be trapped on CDPF, oxidized on CR-DPF
- Soot remains trapped and is burned during regeneration

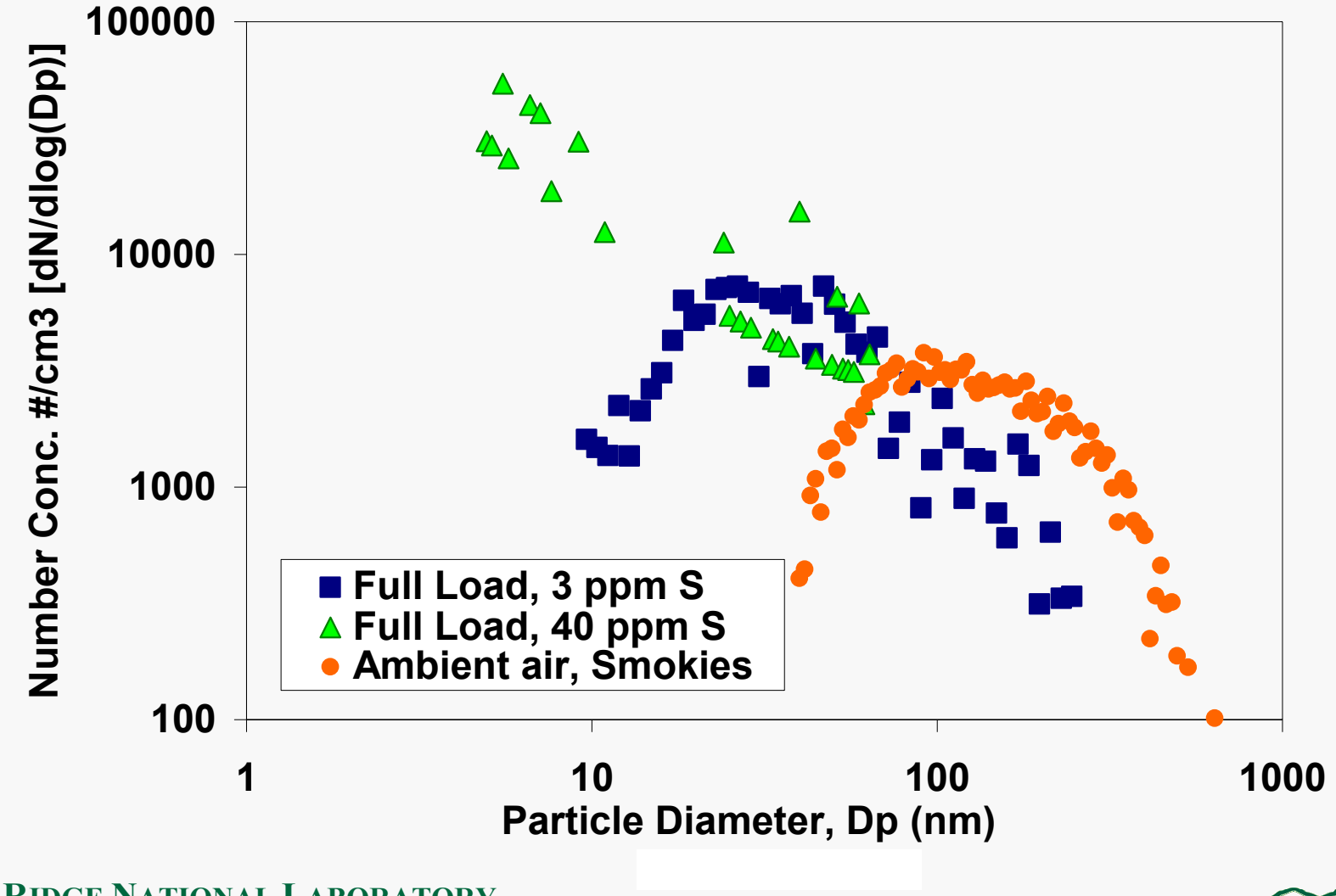
Idle PM out of the CDPF is mostly SOF



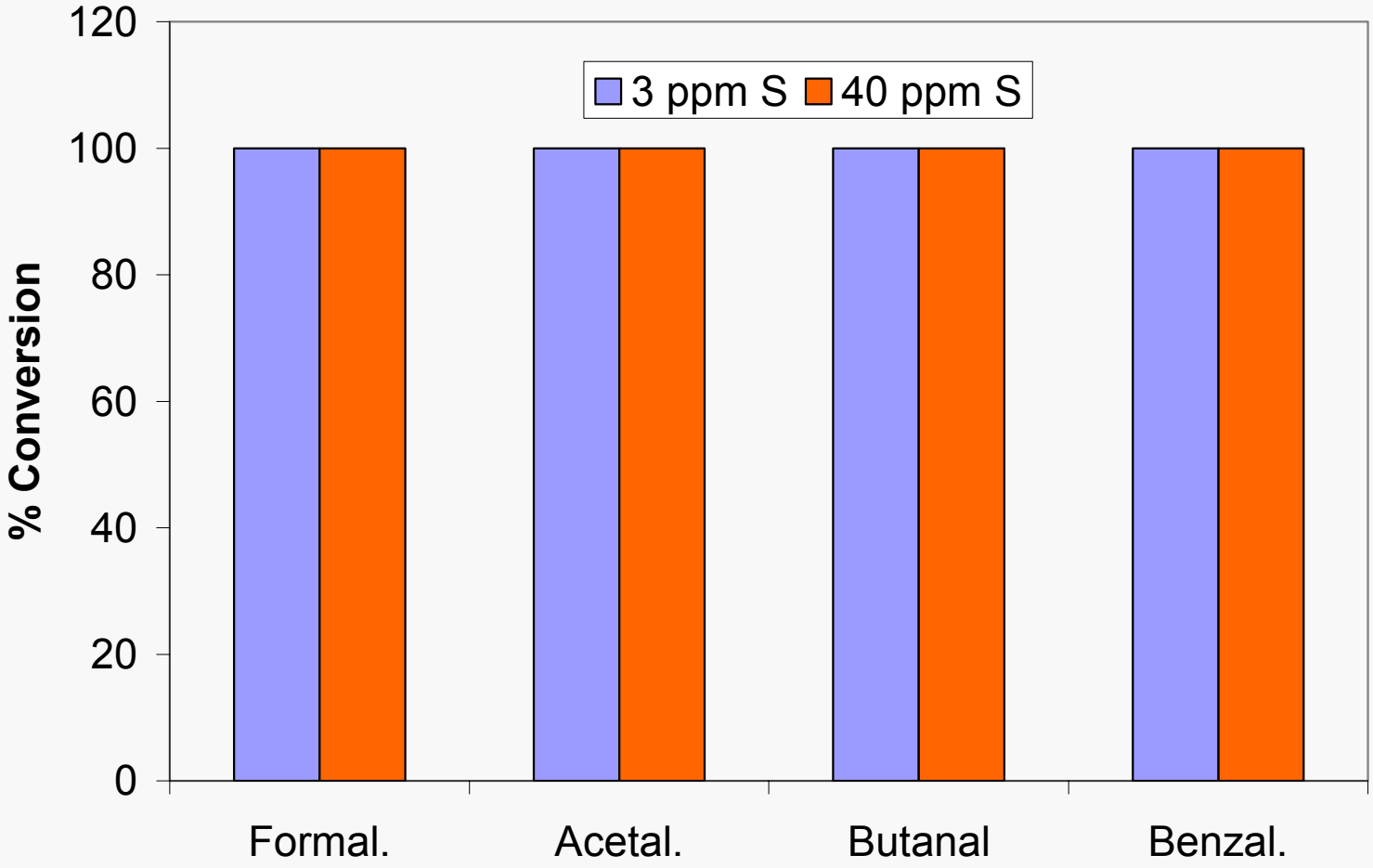
What happens to PM during DPF regeneration?

- **Stored SOF, sulfate are emitted**
- **Initial rise in temperature "boils" off SOF**
- **Much of *measured* PM during regen formed in dilution process**
  - **Condensation**
  - **Nucleation**

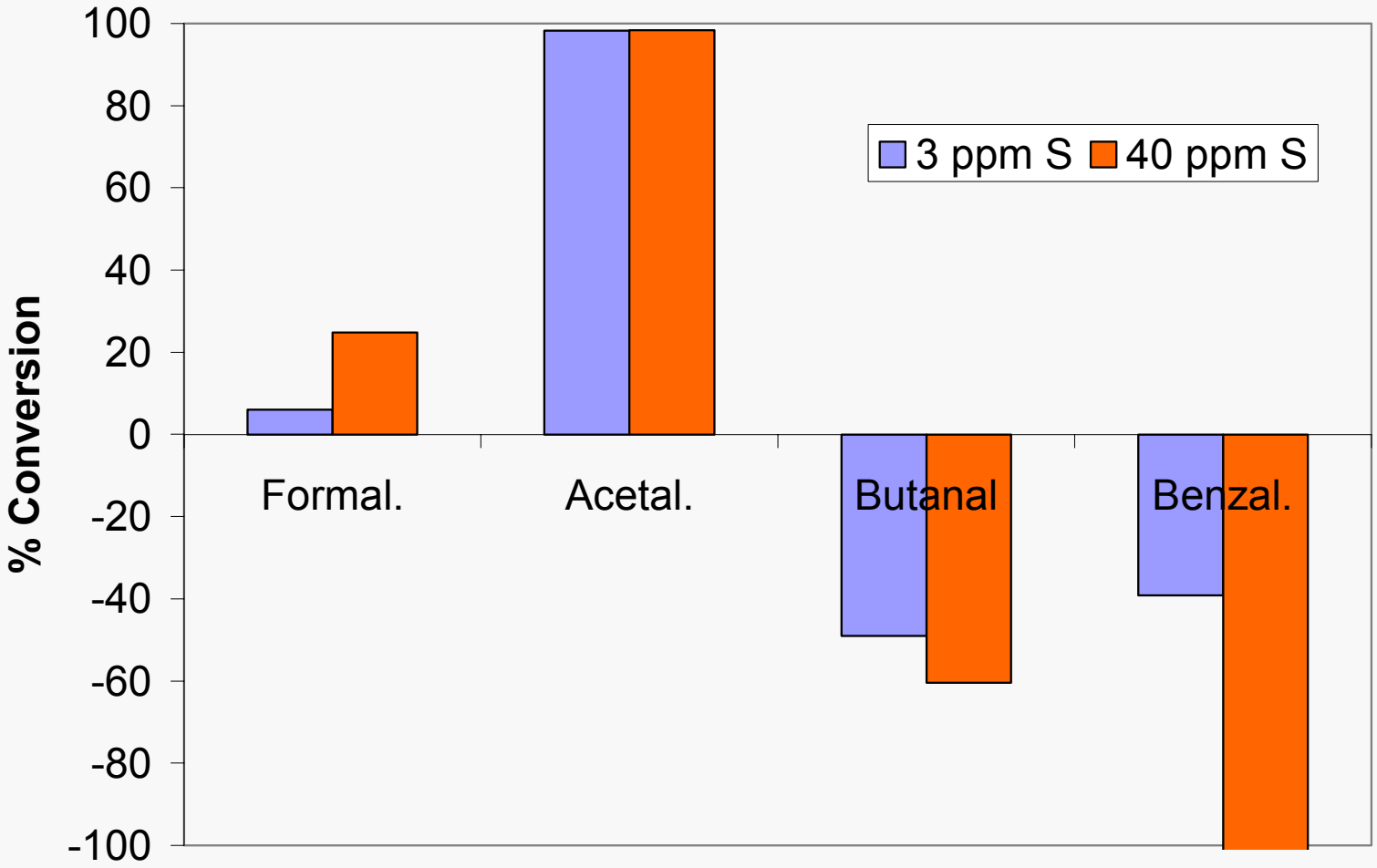
Sulfur in fuel creates nanoparticles after CDPF (Full load, rated speed)



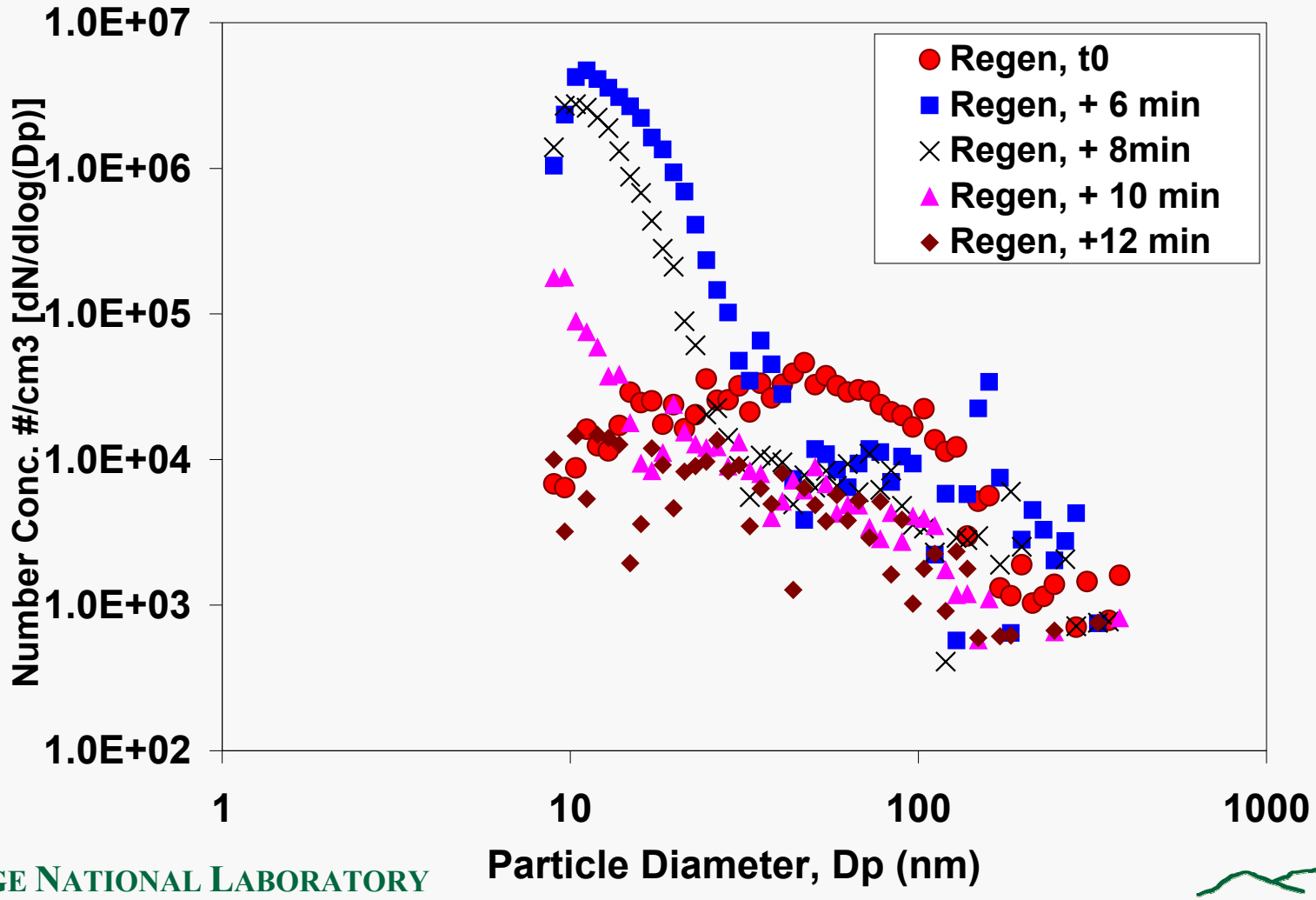
At rated speed, low T, CR-DPF converts all aldehydes



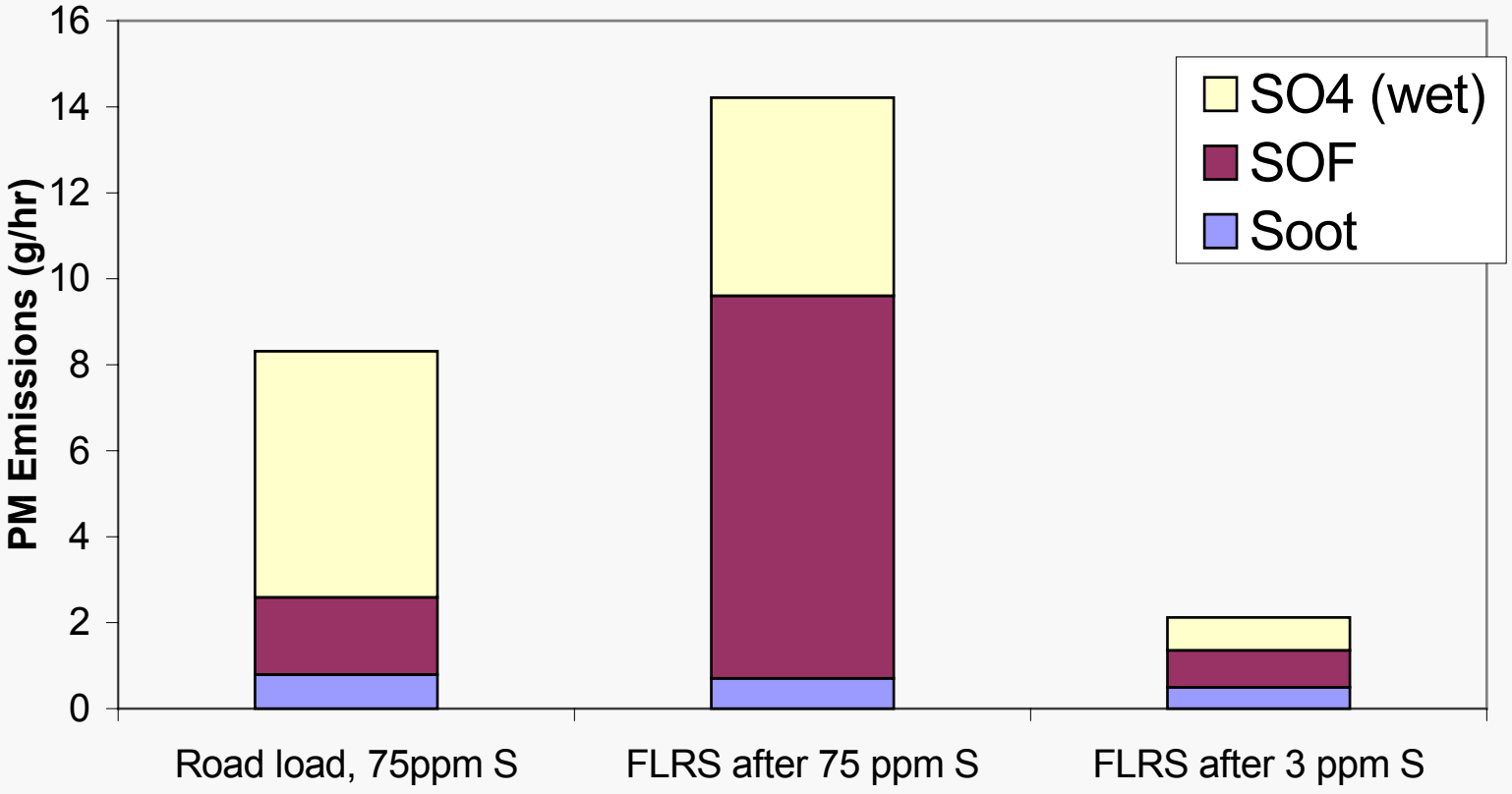
At idle, CR-DPF converts, creates aldehydes



Regen with low S fuel emits PM nuclei



Not much Soot PM is emitted during Regen



Challenges for CLEERS concerning PM characteristics

– **Modeling**

- **Accounting for complex composition of engine out PM**
  - **Oxidation characteristics**

- **Model PM as packed spheres, or other shape**

- **Accounting for what is *measured* as PM**

Challenges for CLEERS

– **Measurement**

- **Void volume, surface area of PM in loaded DPF**
- **NO_2 , O_2 concentrations near soot cake**
- **Nature of emission burst during regen**

Summary

- PM is a complex mixture
- DPF technology will influence PM characteristics