Workshop on Ultrafine Particulate Emissions from Transportation
George Ignatieff Theatre. University of Toronto
September 18, 2019

UFPs from Transportation: Sources and Trends

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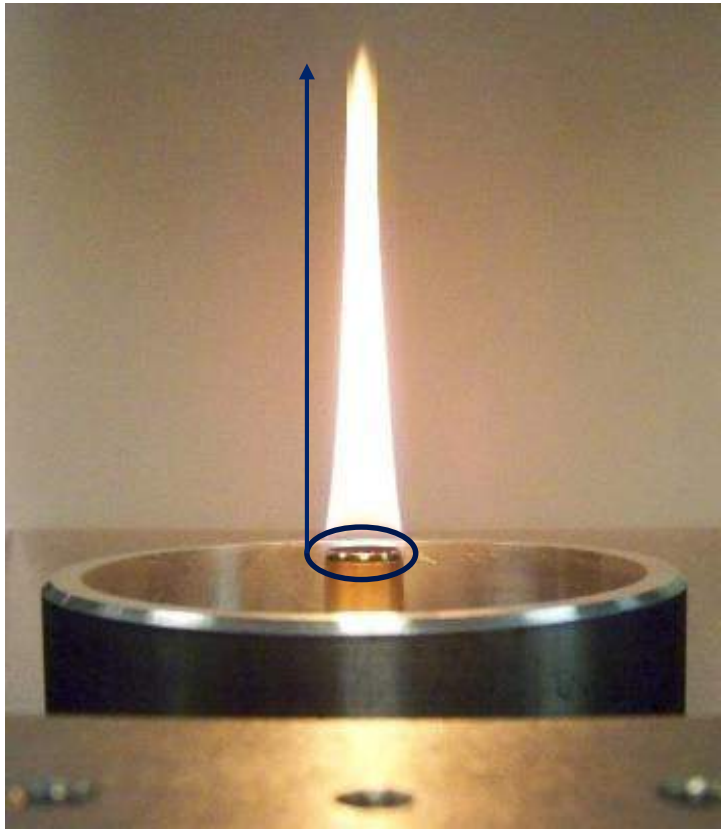
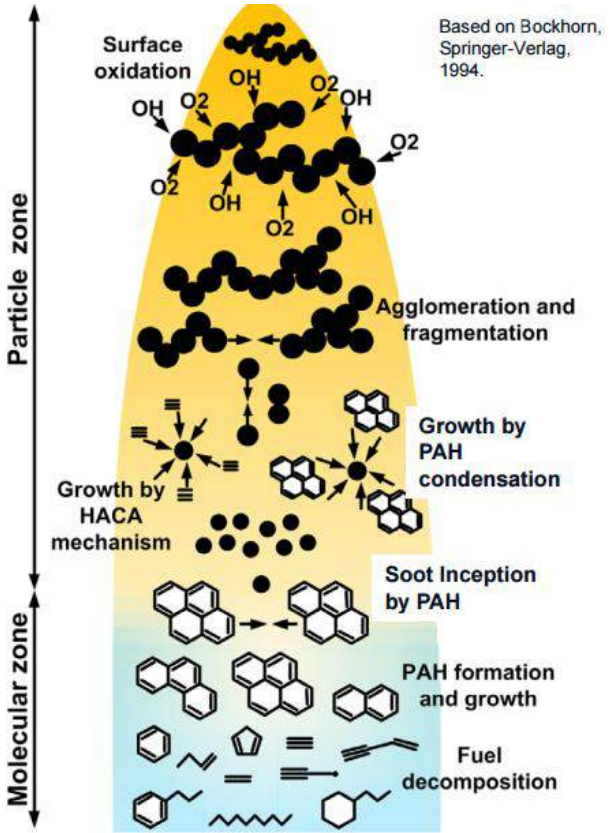
Combustion generated particles
Diffusion (mixing controlled) combustion

Co-flow diffusion flame



[http://combustion.mie.utoronto.ca/wp-content/uploads/2014/06/Santoro-diffusion-flame.jpg]

Soot formation



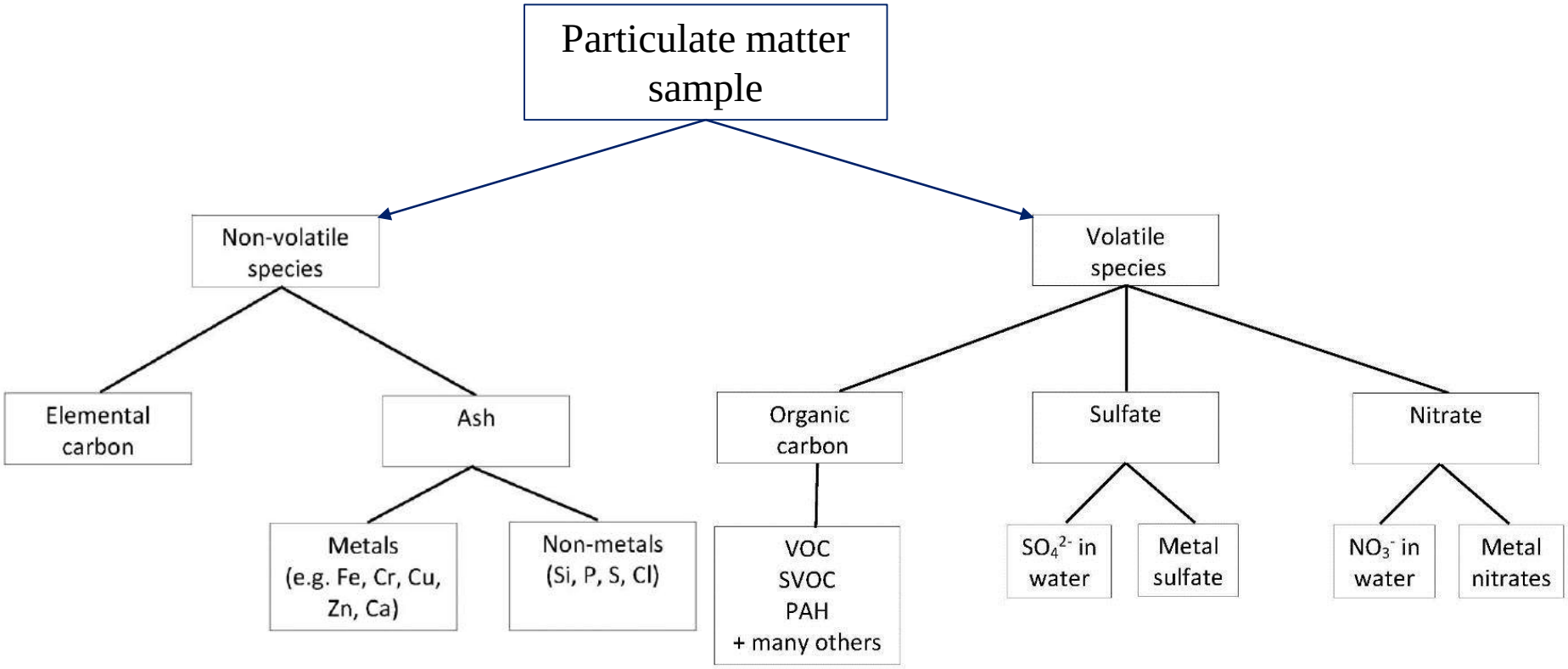
Soot Formation in a Diffusion Flame (Thomson, 2018)

Diffusion combustion examples

Smoking candle

Direct Injection Diesel Engine

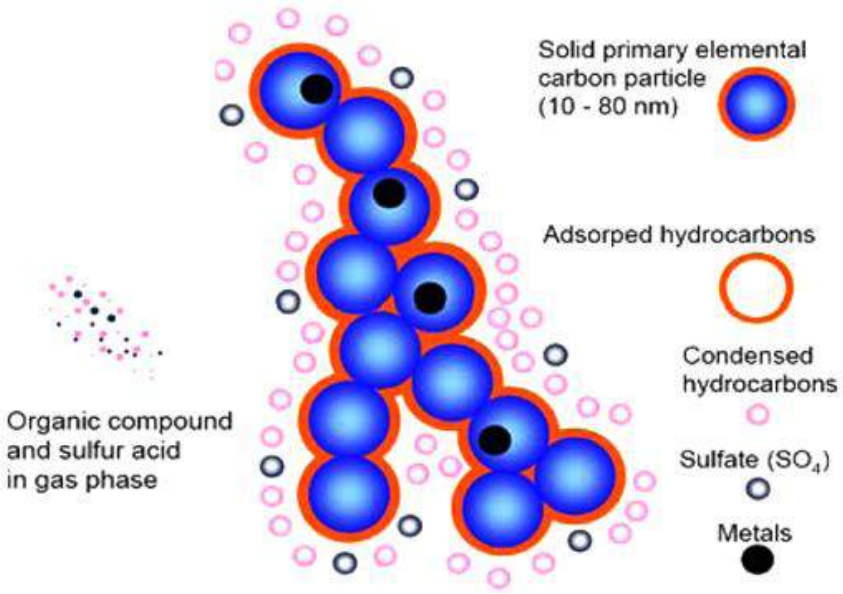
Conceptual model of PM composition



[after Raza et al., 2018]

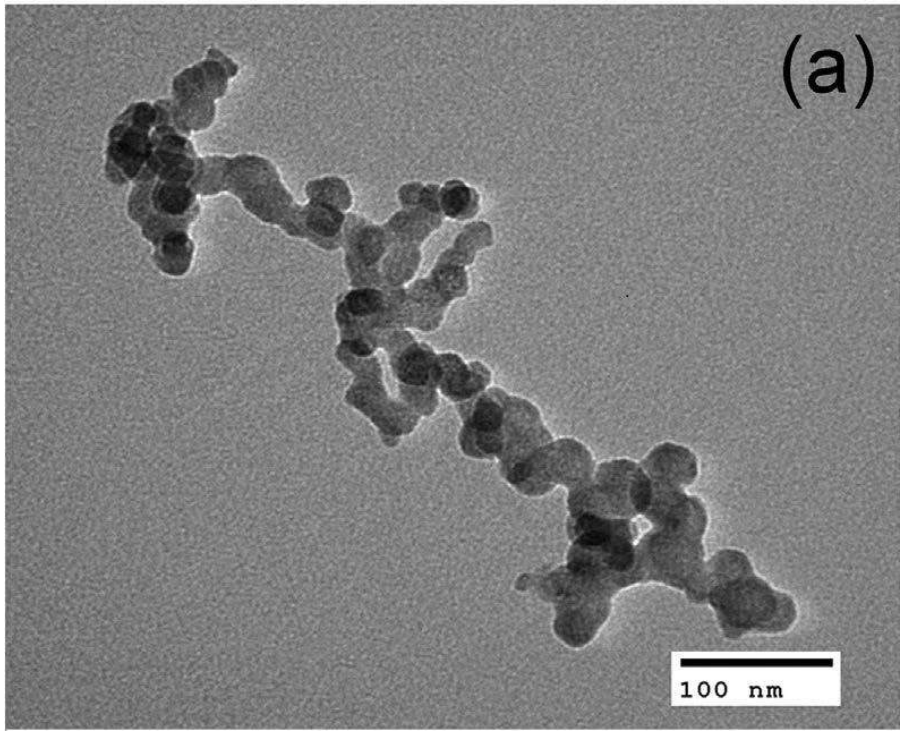
Particle structure

Agglomerated diesel particle



[Myung and Park, 2017]

Soot image (TEM)

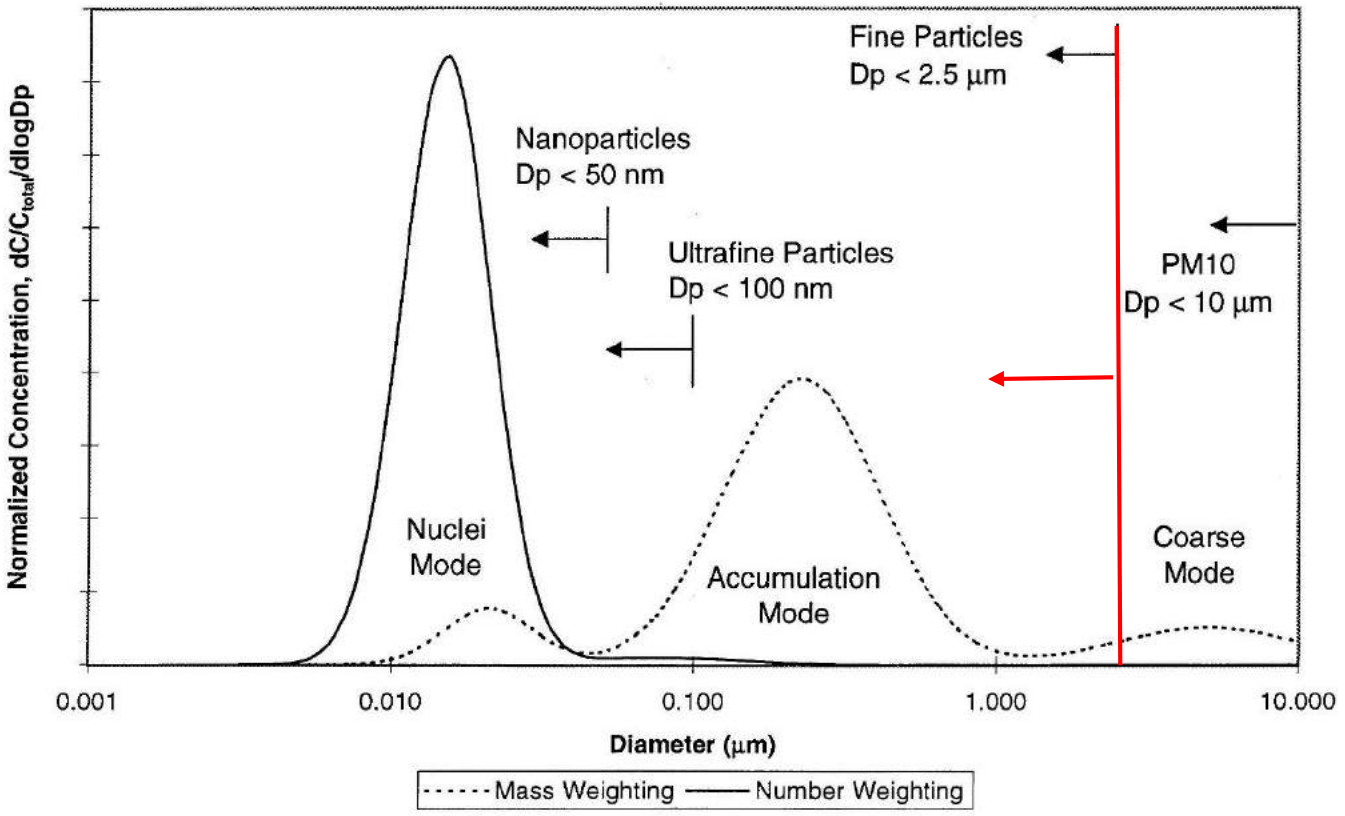


[Dastanour et al., 2016]

Particulate matter characterization

- Gravimetric measurement - Total mass of particles emitted during a sampling period
  - Vehicle mass emissions over a driving cycle (light duty)
  - Engine mass emissions over a test cycle (heavy duty)
- Particle number emissions – total number of particles emitted over a test cycle
  - Euro 6c: 6.0×10^{11} #/km for GDI vehicles on the Worldwide harmonized Light vehicles Test Cycle (WLTC)
- Particle size distribution
  - Characterizes number of particles in each size bin

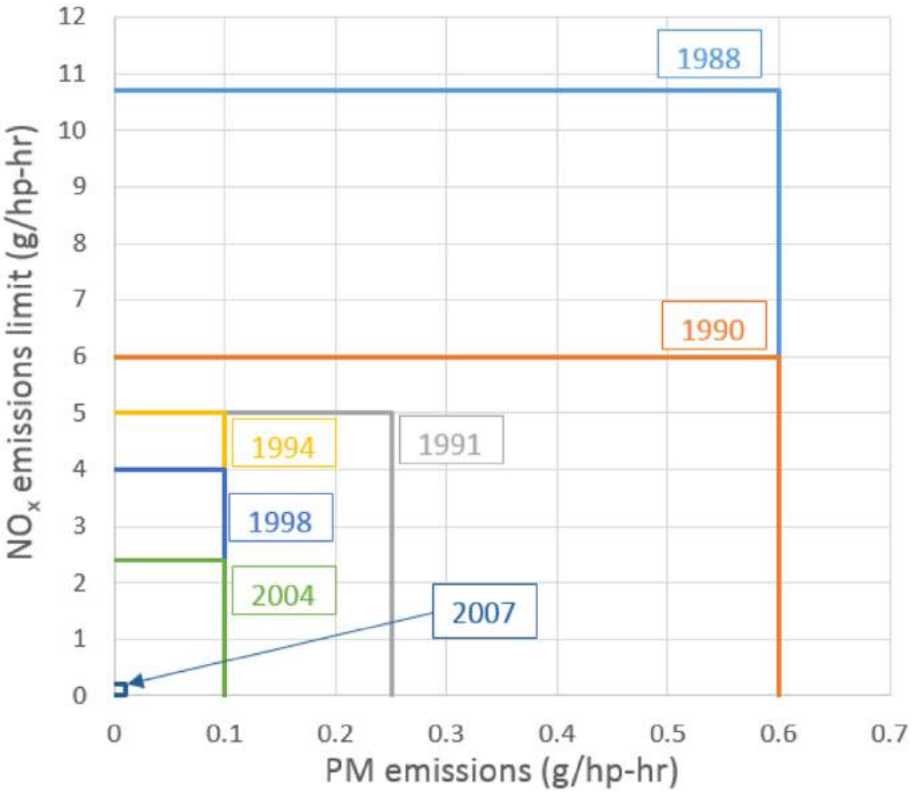
Representative exhaust size distribution



[Kittleson, 1998]

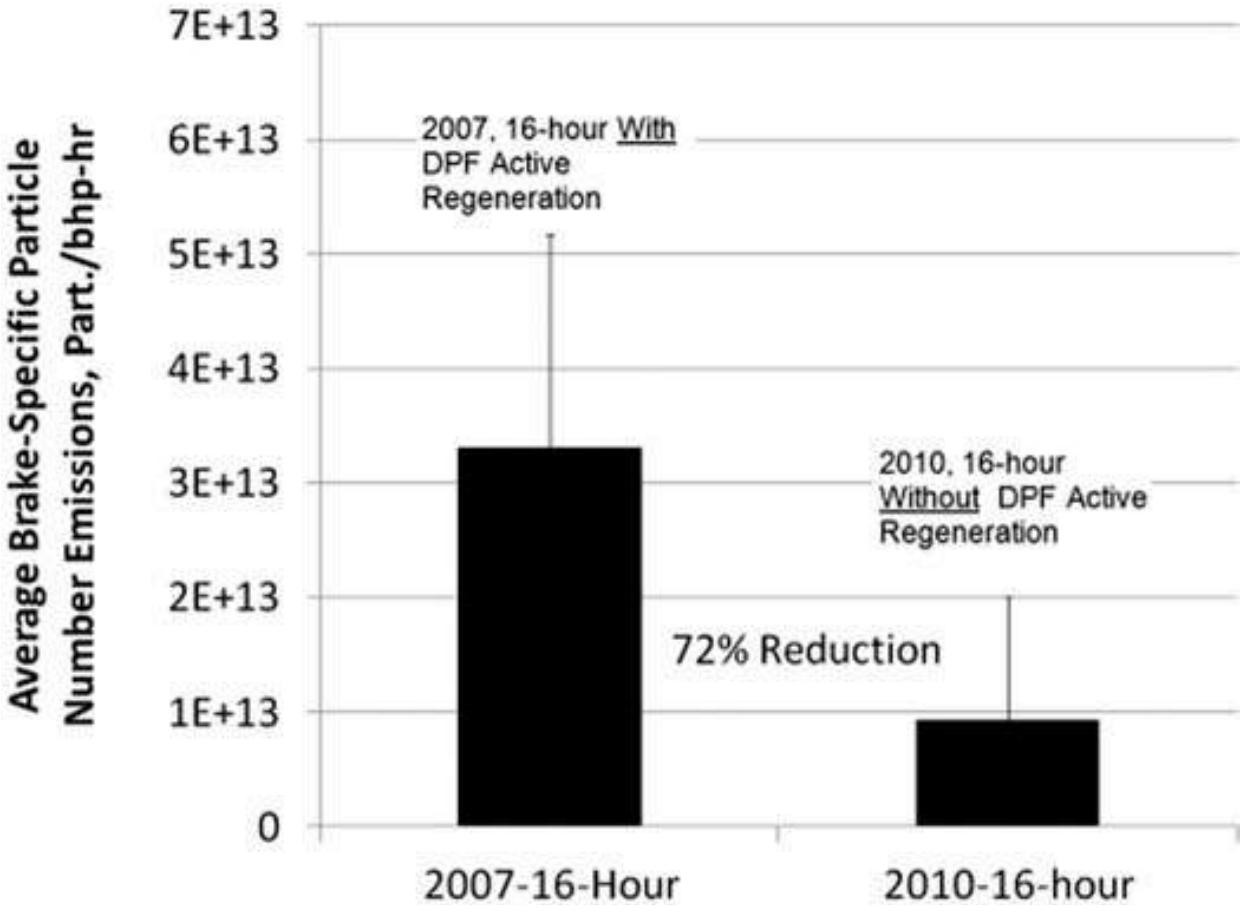
- Nucleation mode (<50nm)
- Accumulation mode (50nm-1000nm)
- Coarse (>1000nm)
- 2.5 µm cutoff on sampling system

Heavy Duty Engine Emissions



- Combustion system development
- Aftertreatment
  - Oxidation catalyst (DOC)
  - Diesel particulate filter (PDF)
  - Selective Catalytic Reduction (SCR)
- Improved fuel (ULSD)
- Improved lube oil (CJ4)

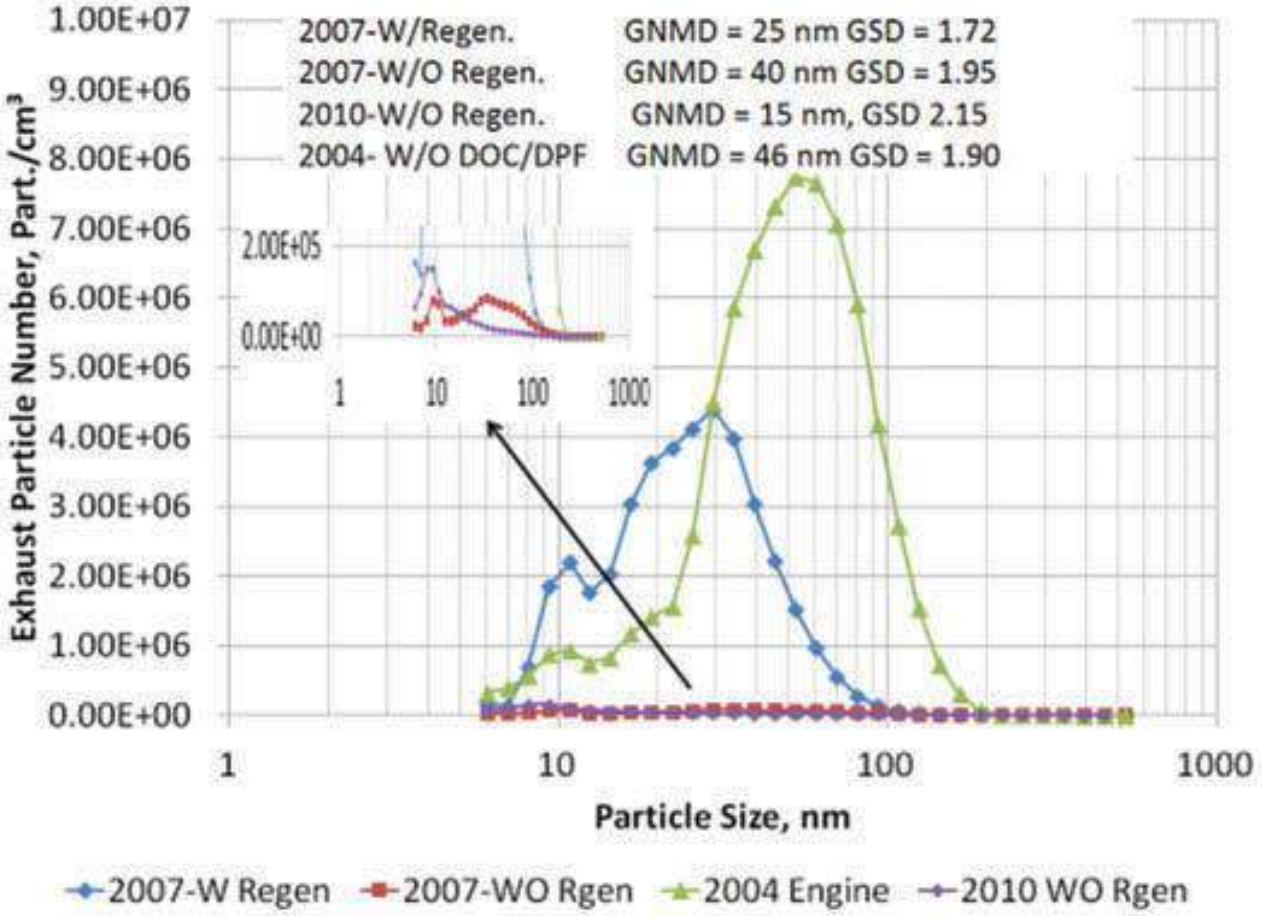
Averaged results for 3 HD engines
16 hour transient test



[Khalek et al, 2016]

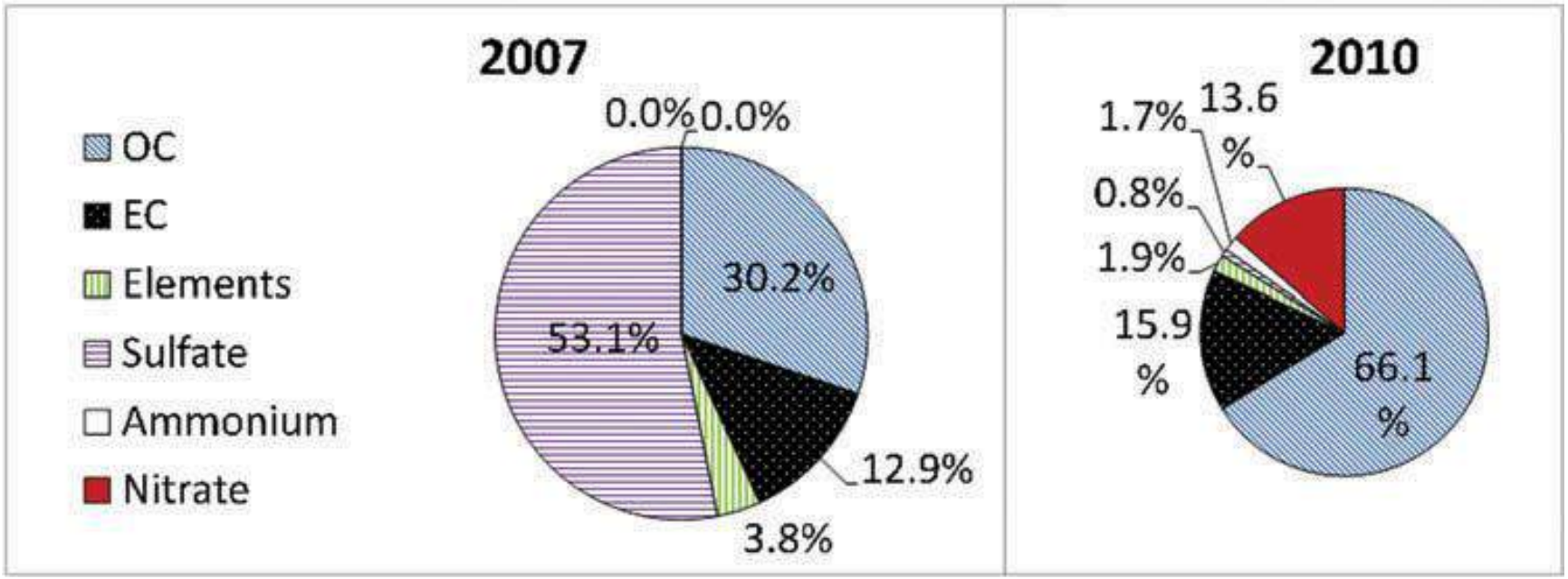
Averaged results for 3 HD engines

16 hour transient test



[Khalek et al, 2016]

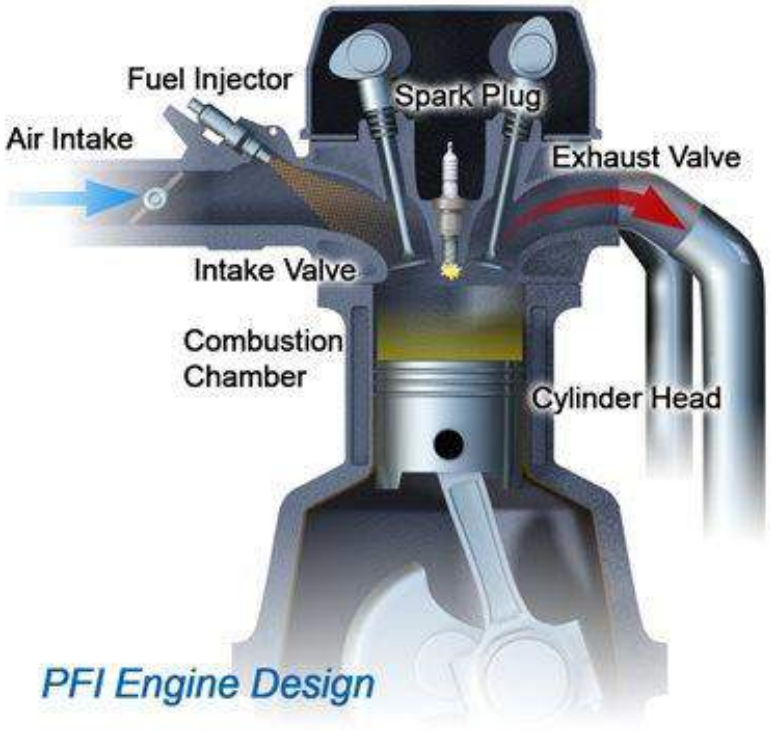
Average diesel composition data



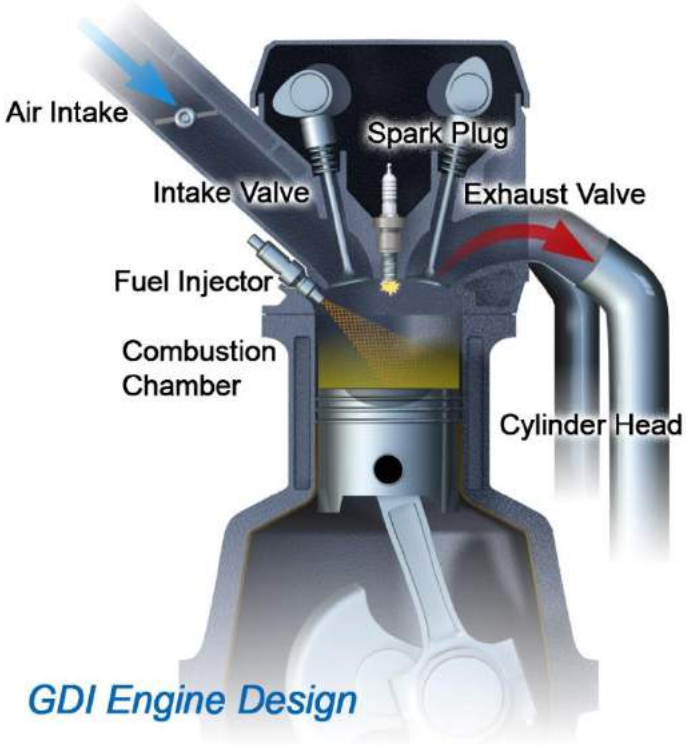
[Khalek et al, 2016]

Gasoline fuel injection technology

Port fuel injection



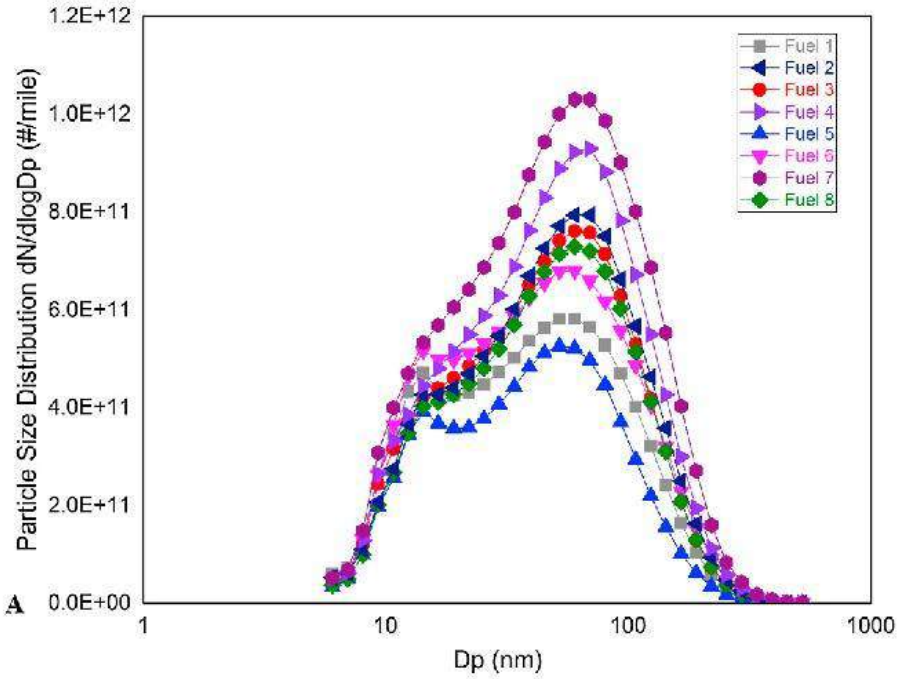
Gasoline direct injection



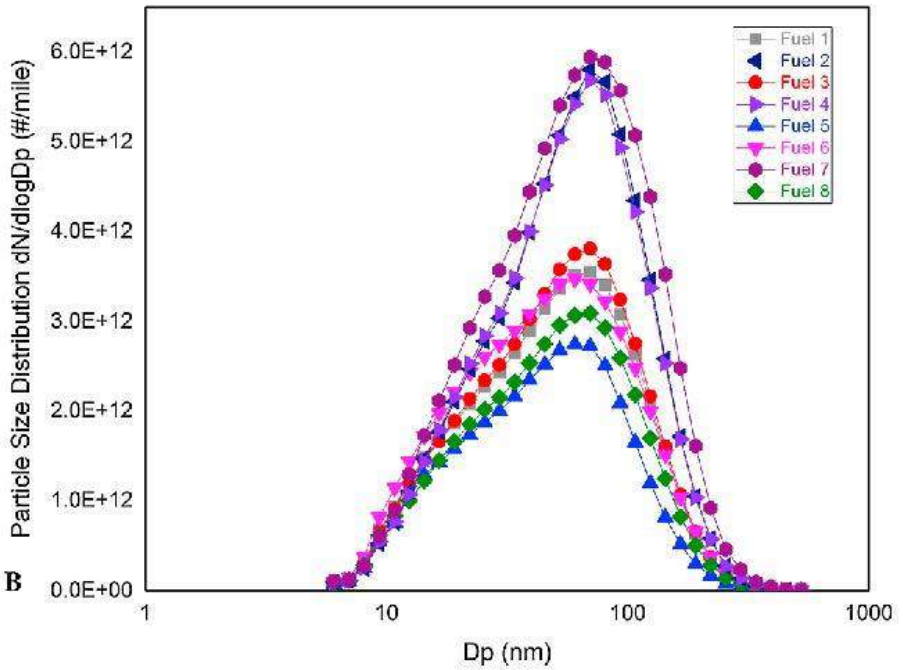
https://www.aftonchemical.com/Generic/PFI-vs-GDI#

Average particle size distributions for five GDI vehicles and 8 test fuels

Entire LA92 cycle

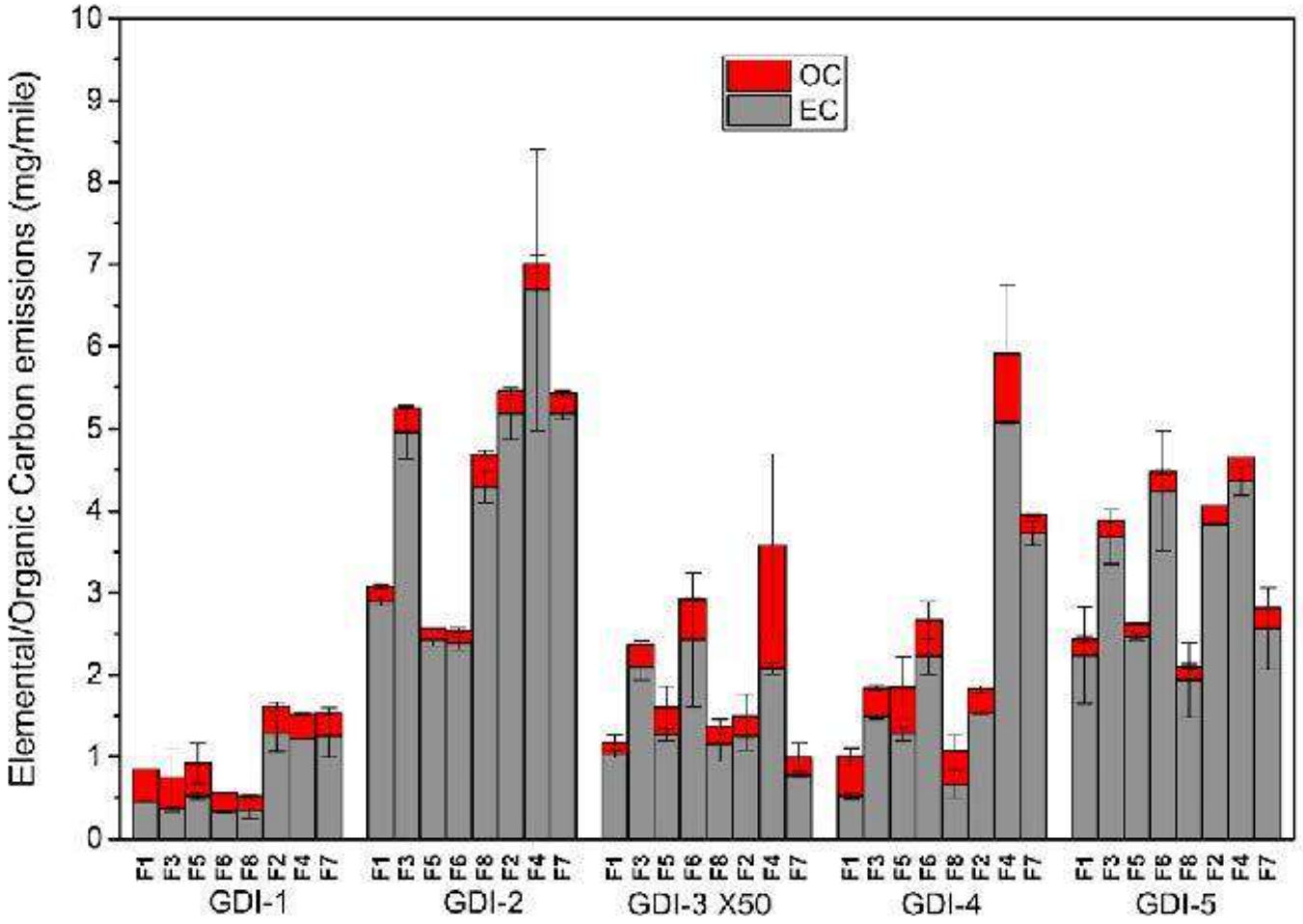


Cold start phase of LA92 cycle



[Yang et al., 2019]

GDI particle composition



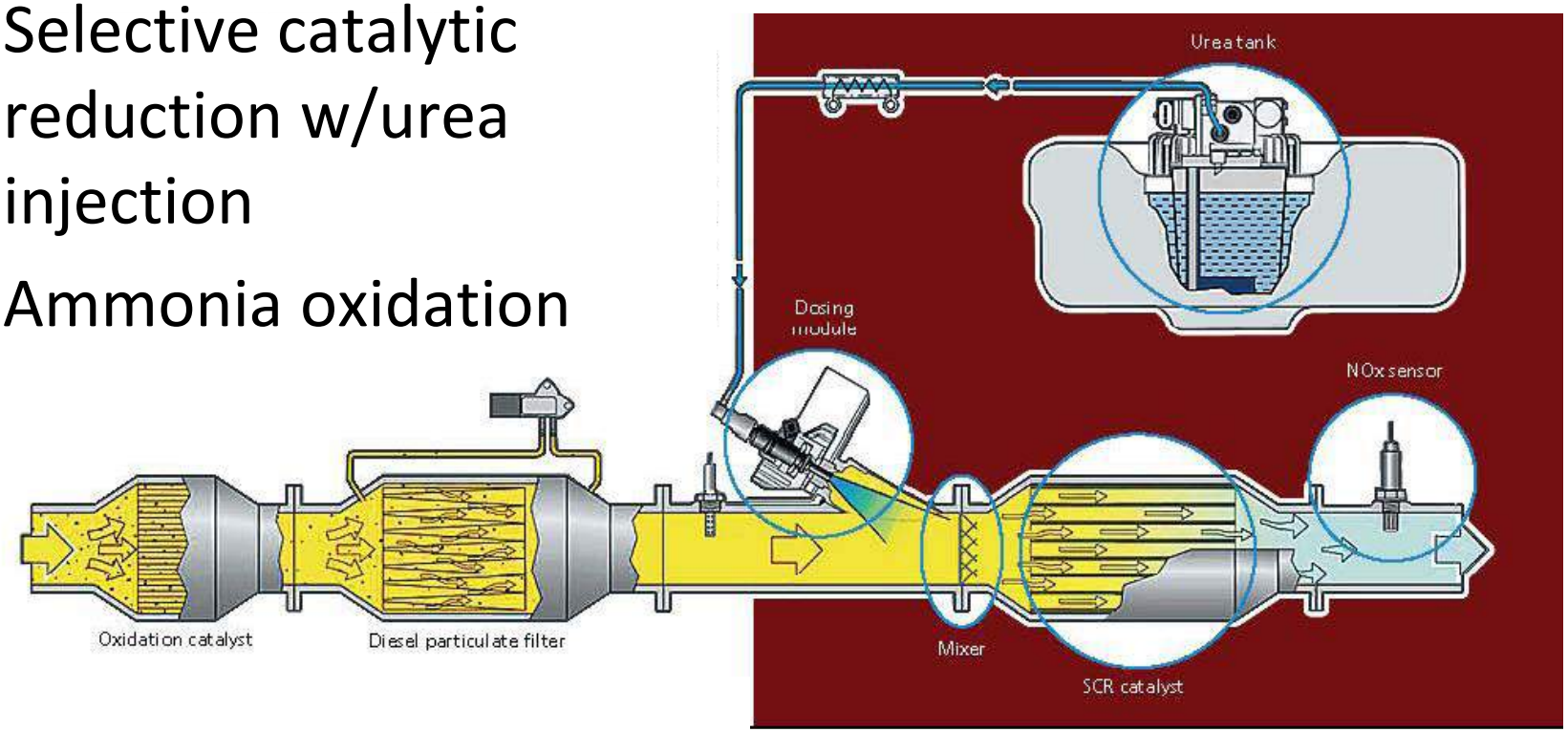
[Yang et al., 2019]

Summary

- New diesel engines meeting 2010 emission standards have made remarkable progress in reducing the number of particles emitted when operated under conditions that do not trigger active regeneration.
  - ? Field experience
- GDI engines emit significant numbers of ultra fine particles but the technology is still evolving, as is our understanding of factors that contribute to particle formation.
  - Technology, fuels, and operating conditions all have an effect

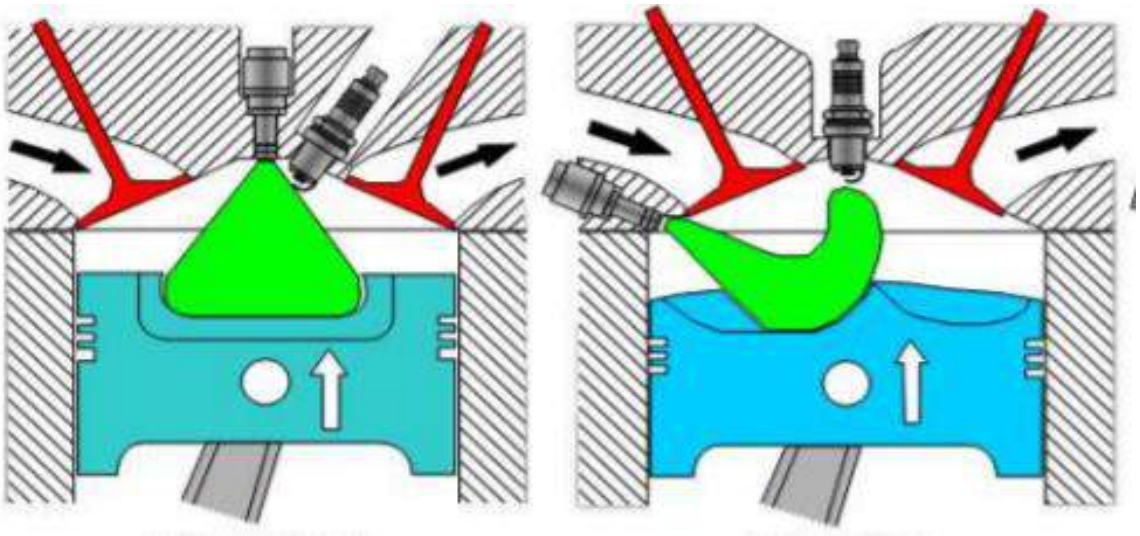
Diesel Exhaust Aftertreatment Components

- Diesel oxidation catalyst
- Diesel particulate filter
- Selective catalytic reduction w/urea injection
- Ammonia oxidation



GDI Engine Systems – (II)

Comparison of Injection Strategies
(Celik & Ozdalyan 2010)



Spray Guided

- Fuel Plumes Individually Directed into Cylinder
- Reduction of piston crown/ wall interaction
- Generates mostly Organic Carbon

Wall Guided

- Fuel Injected at Piston Crown
- Geometry Enhances Tumble Motion
- Generates Mostly Elemental Carbon