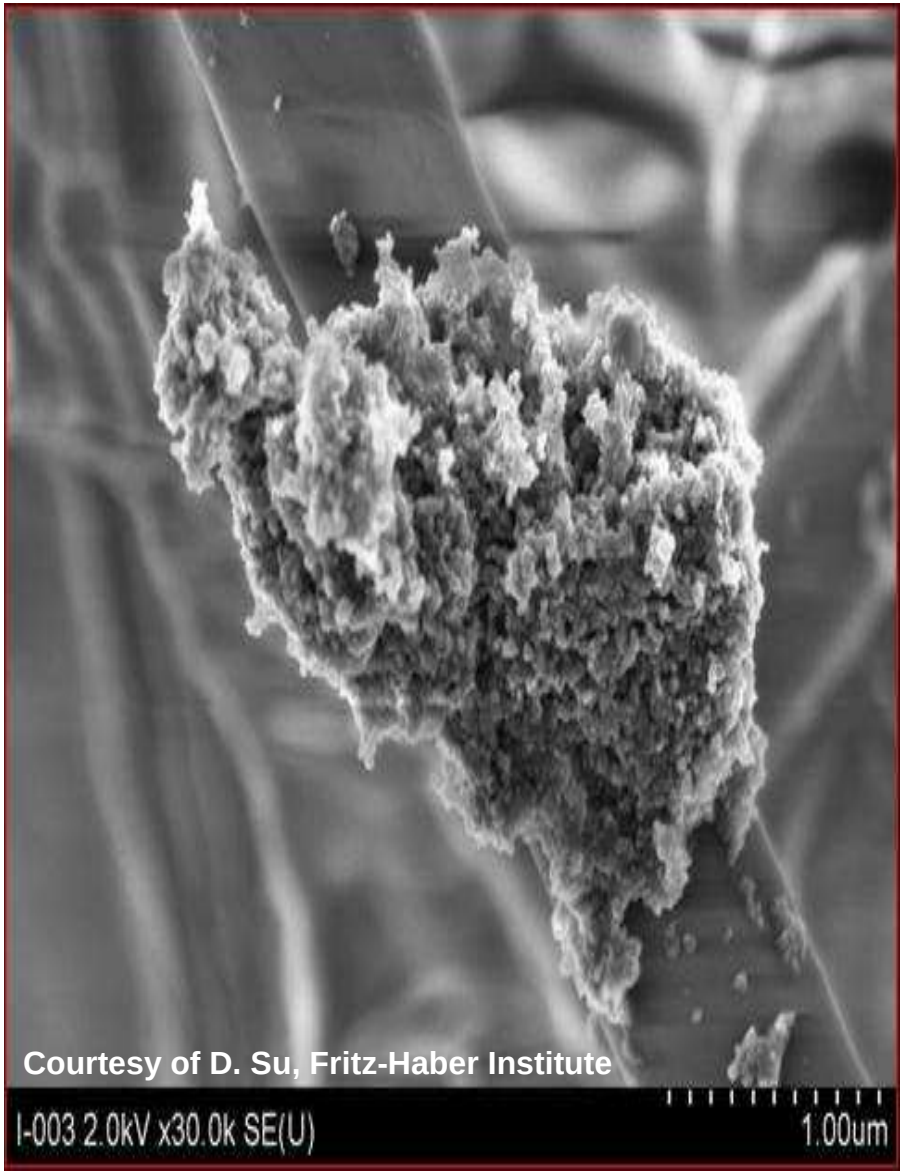


CRC Mobile Source Air Toxics Workshop
Dec 1-3, 2008, Phoenix, Arizona

Emissions from HD Diesel Retrofits for PM and NO_X Control

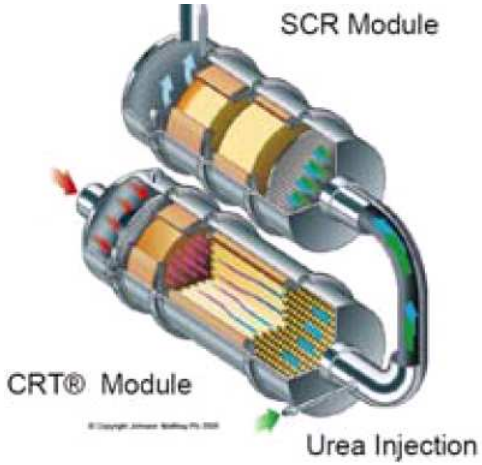
Shaohua Hu, Jorn Herner, William Robertson, M.-C. Oliver Chang, Tao Huai, John Collins, and Alberto Ayala

California Environmental Protection Agency
AIR RESOURCES BOARD

CARB's Heavy-duty Vehicle Emissions Laboratory

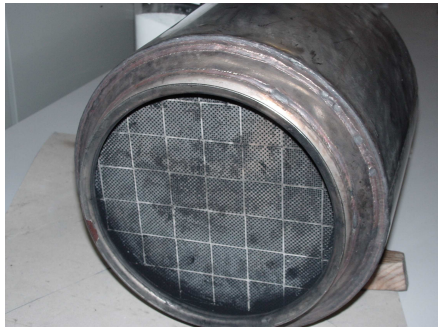
Collaborators, co-sponsors, and in-kind contributors

CARB's Diesel Retrofit Emissions Research Study



Baseline **SCRT 1** **SCRT 2** **CRT 1**

CRT 2 **DPX**



Cleaire's Horizon

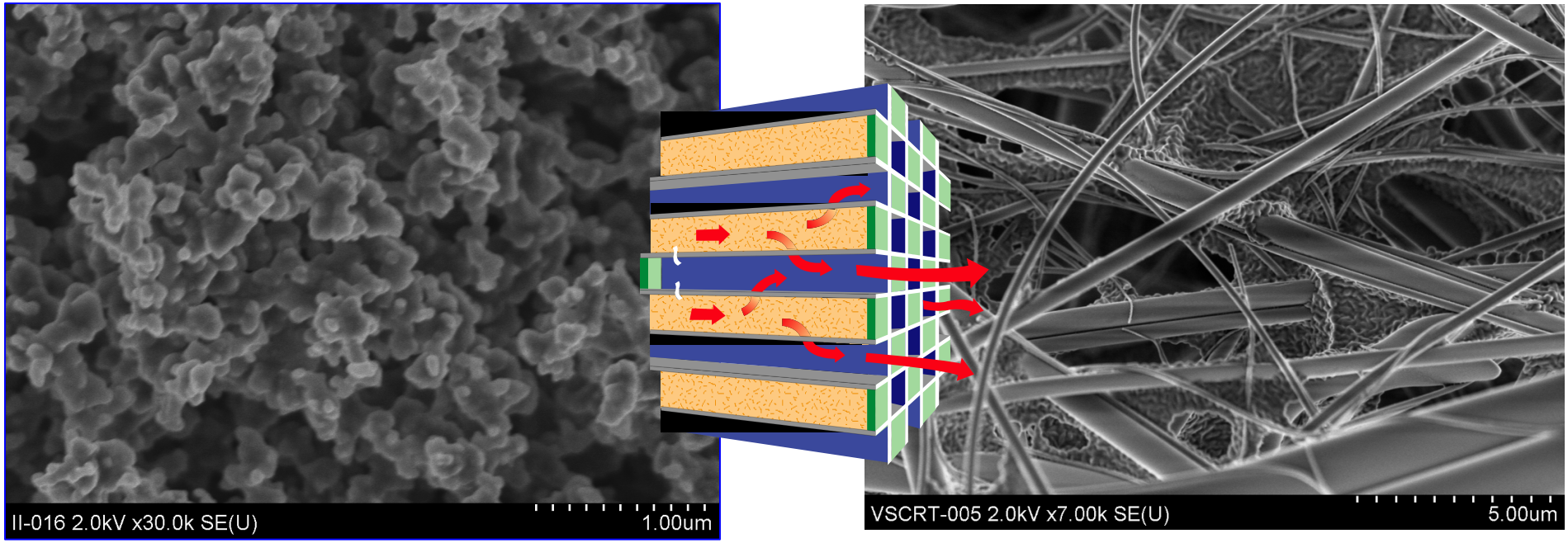
(electrical heater DPF)

Diesel electric hybrid (CCRT)

Snapshot of some results

- Mass emissions of PM, ions, and carbon
- NO_X and NO_2
- Metals
- Ultrafine particle emissions

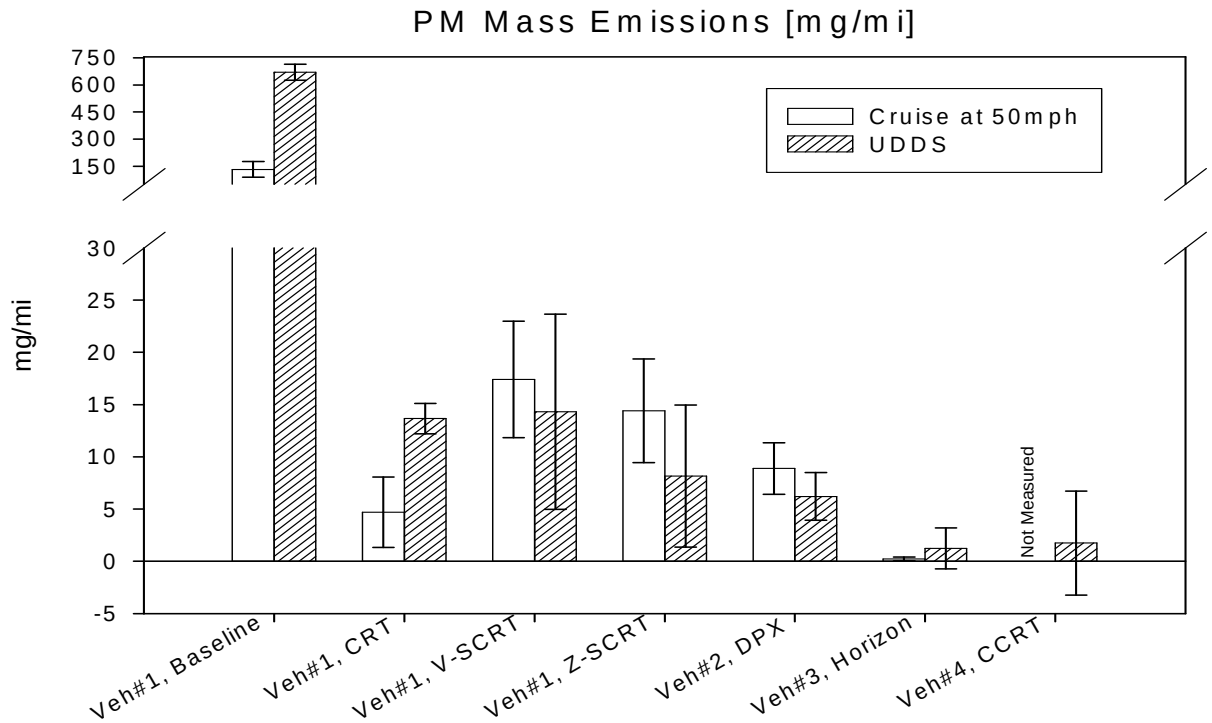
High filtration efficiency of wall-flow type DPF



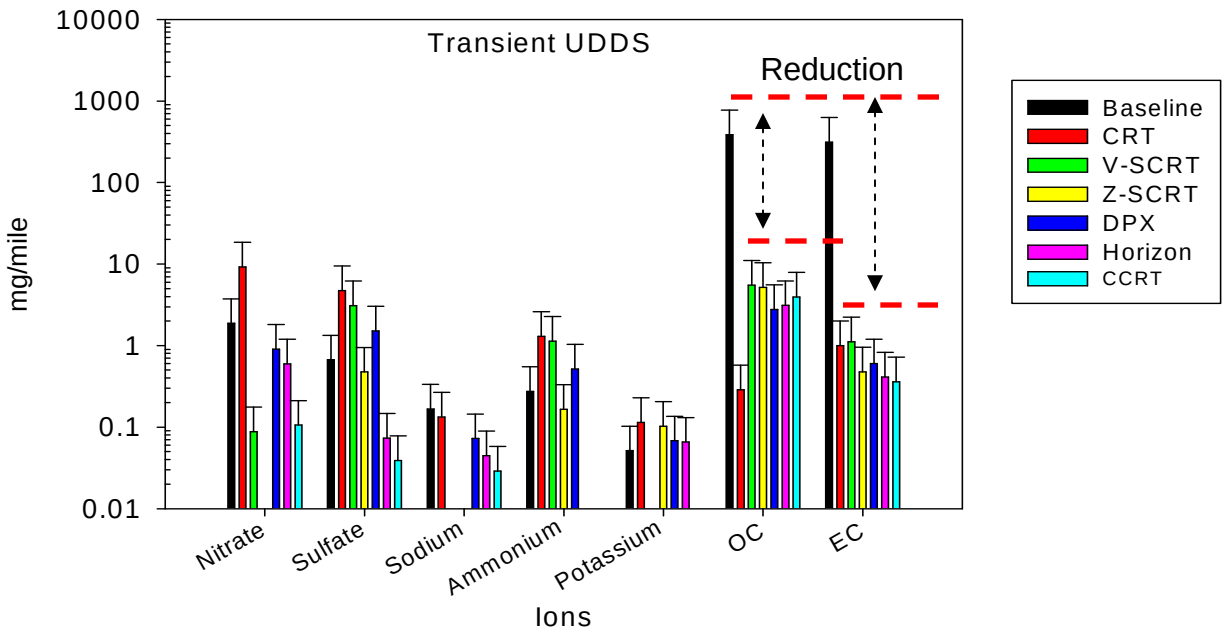
Baseline Diesel Sample
Agglomerates

DPF+SCR Sample
Clean as Blank

SEM images courtesy of Dr. D. Su, Fritz-Haber Institute

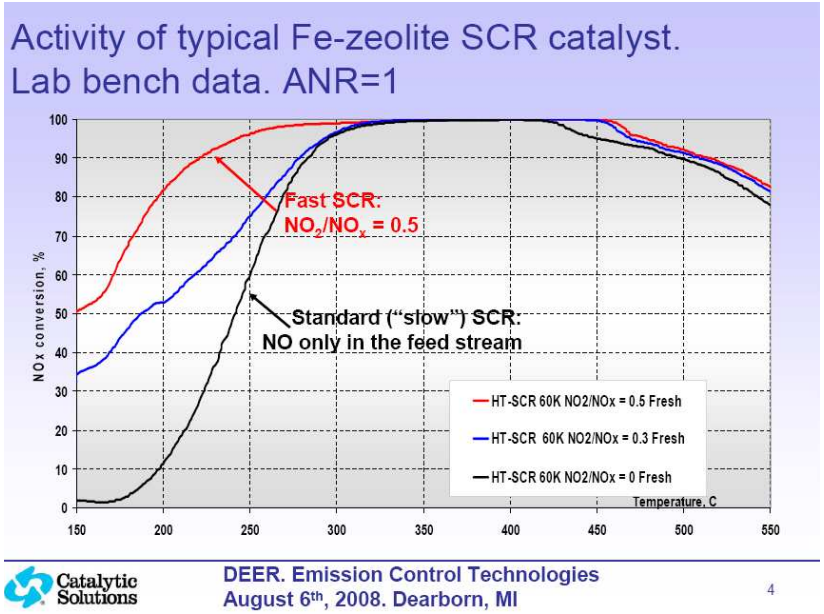


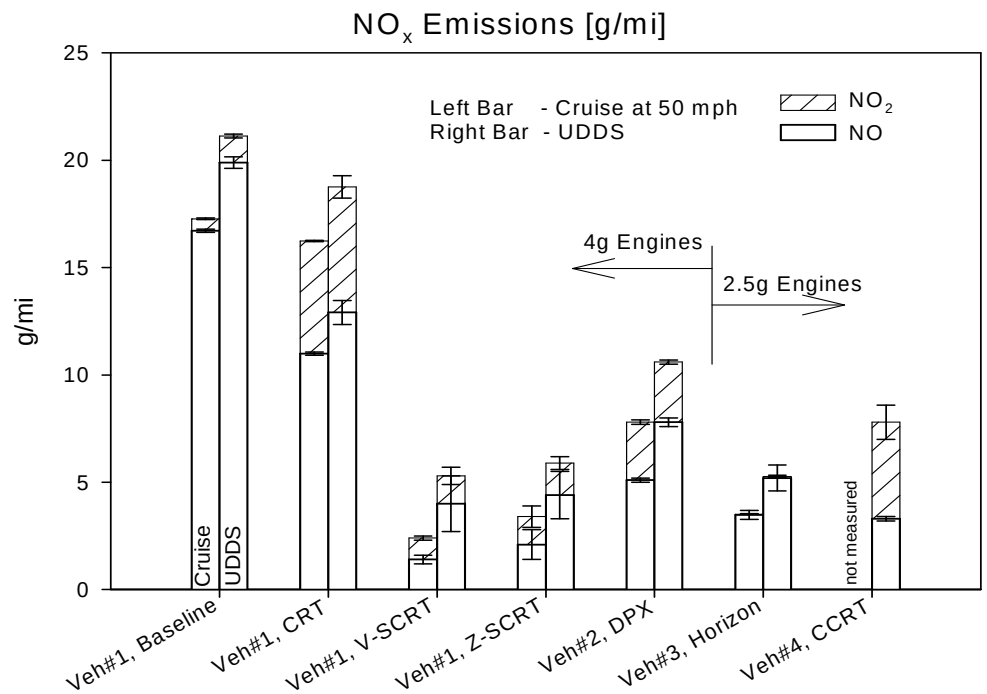
DPF retrofits yield 90+ % reduction in PM mass emissions

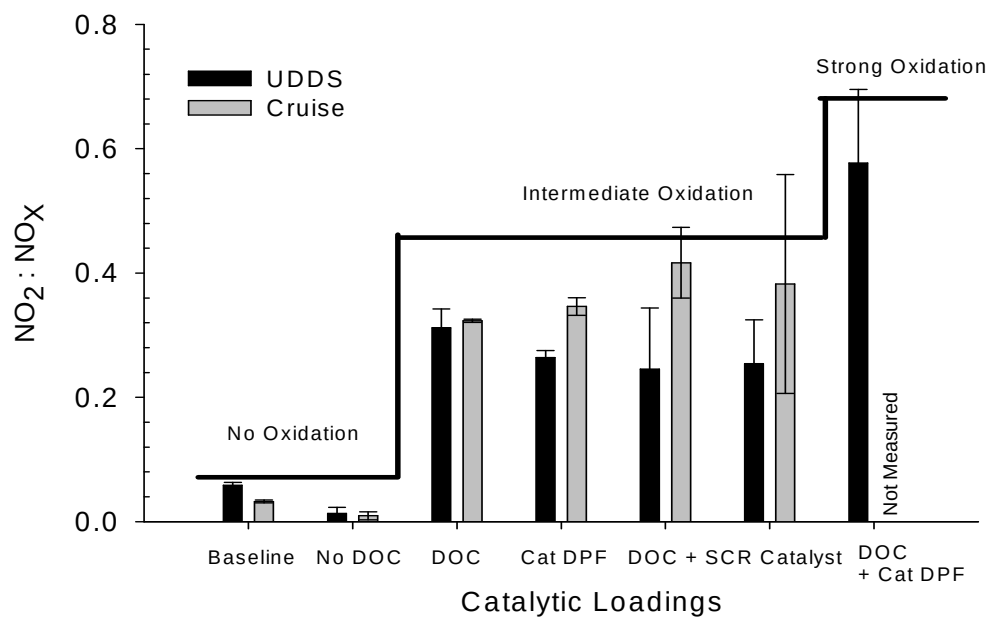


Ions and Carbon Emissions

Oxidation of engine-out NO to NO_2 to aid retrofits



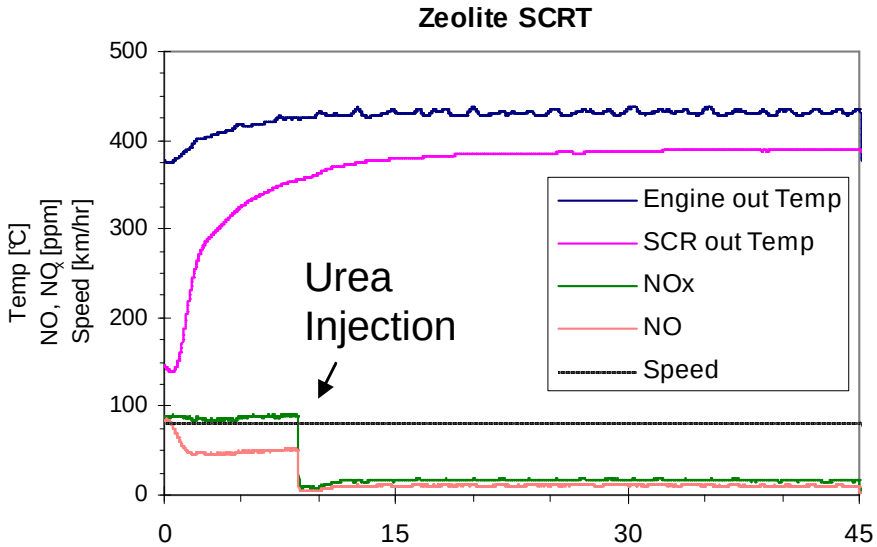




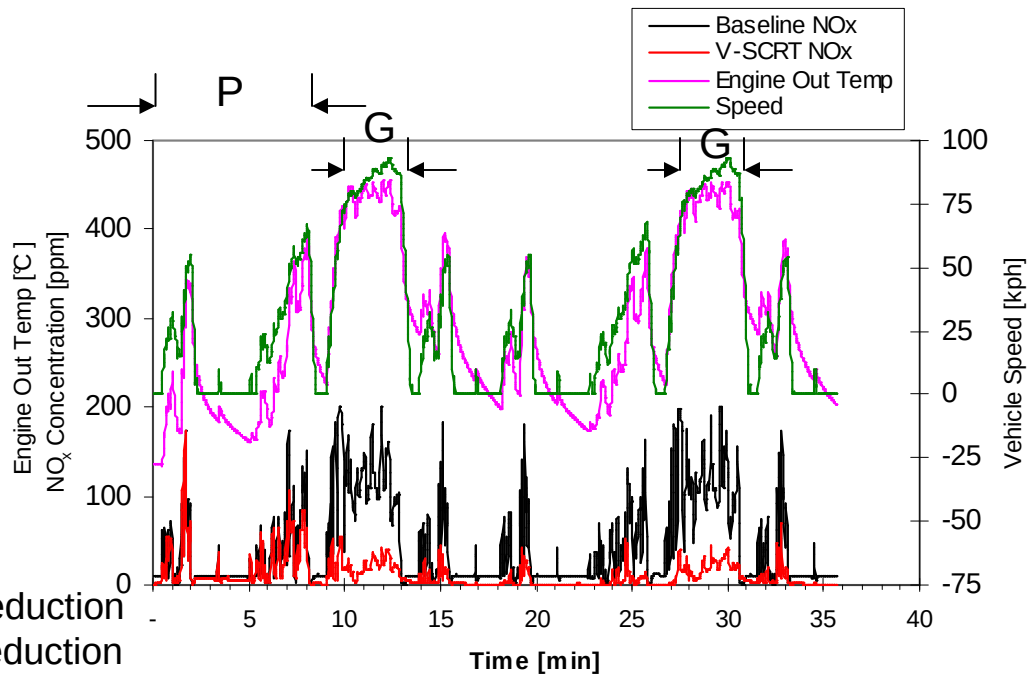
Iretskaya et al., "Two SCR Catalyst Formulation – One Solution for NO_X Aftertreatment Systems," DEER Conference, Dearborn, Aug. 2008.

Realtime NO_x Concentrations

a) Cruise 50mph



b) UDDS

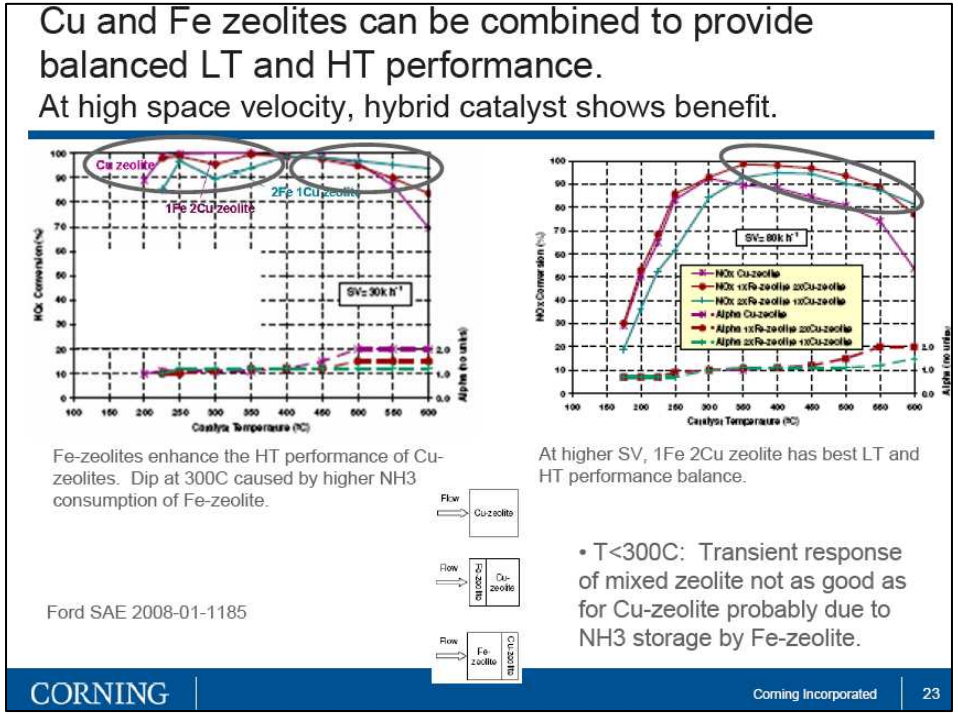


Conway et al., (2005)* and others have reported low NOX conversion during activity that yields low exhaust temperatures (i.e., stop-and-go driving)

* Conway et al., "Combined SCR and DPF Technology for Heavy Duty Diesel Retrofit," SAE Tech. Paper 2005-01-1862

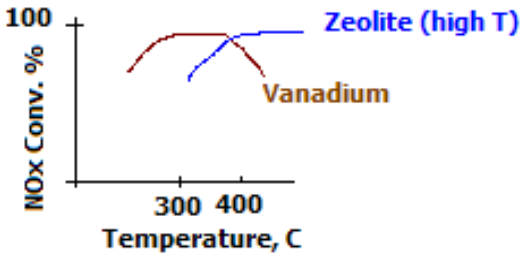
G: good NOx reduction
P: poor NOx reduction

Metal-based zeolite SCR



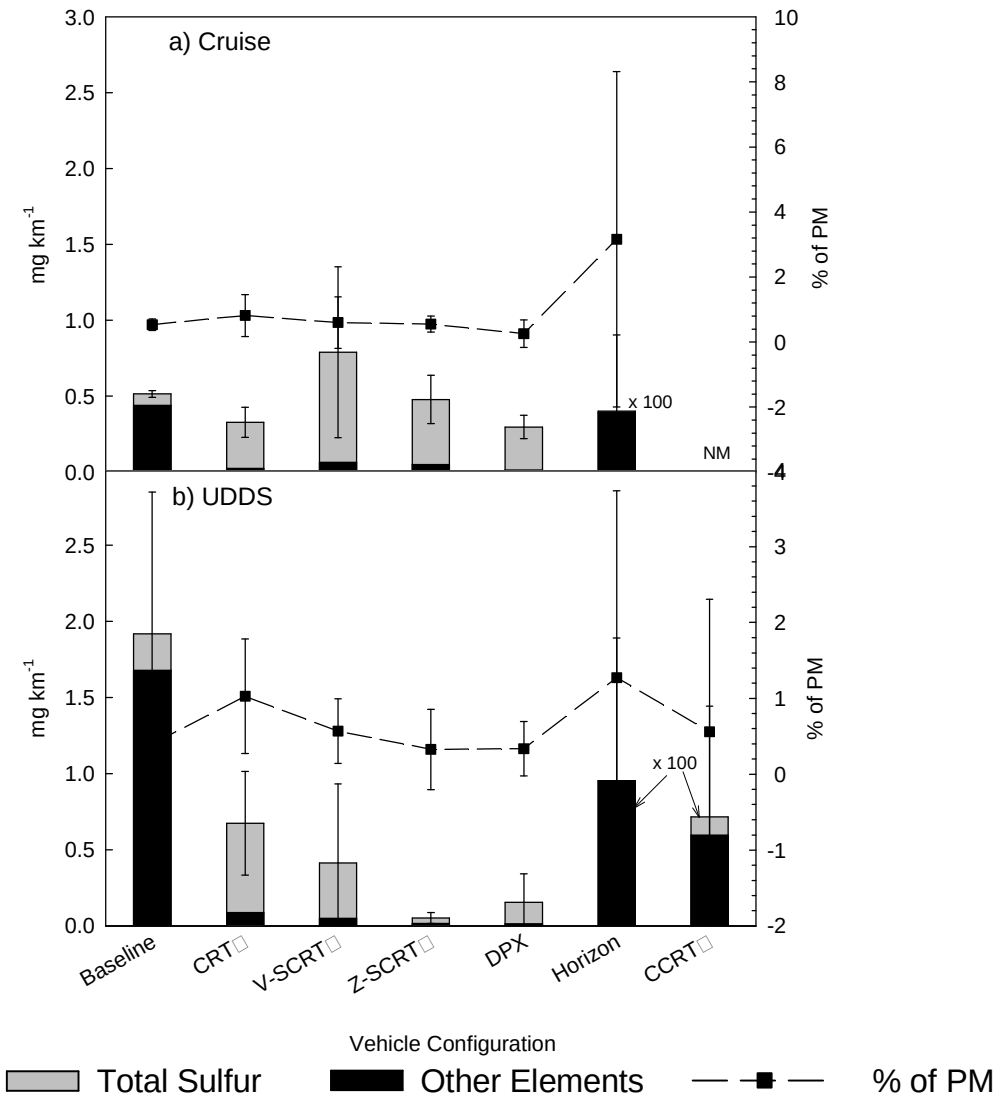
Tim Johnson, "Diesel Emission Control Technology in Review, DEER Conference, Dearborn, Aug. 2008.

Girard et al., "Combined Fe-Cu SCR Systems with Optimized Ammonia to NOX Ratio for Diesel NOX Control," SAE Tech. Paper 2008-01-1185

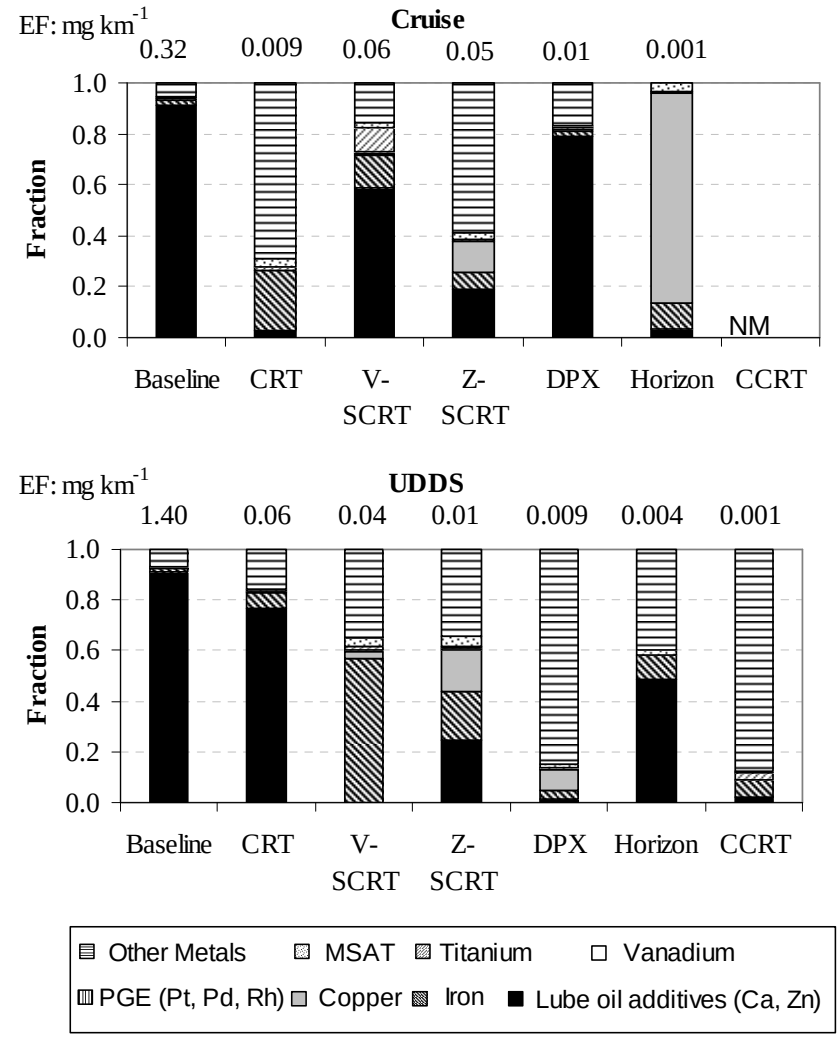


- **Cu-zeolite SCR catalysts favored for lower exhaust gas temperature applications (< 450oC)**
- **Fe-zeolite SCR catalysts preferred for higher temperature applications**
- **Ford exploring combination of Fe-Cu**
- **Fe-Cu SCR can wide operating temperature range**
- **Transient results are also being explored**

Emission rates of total elements

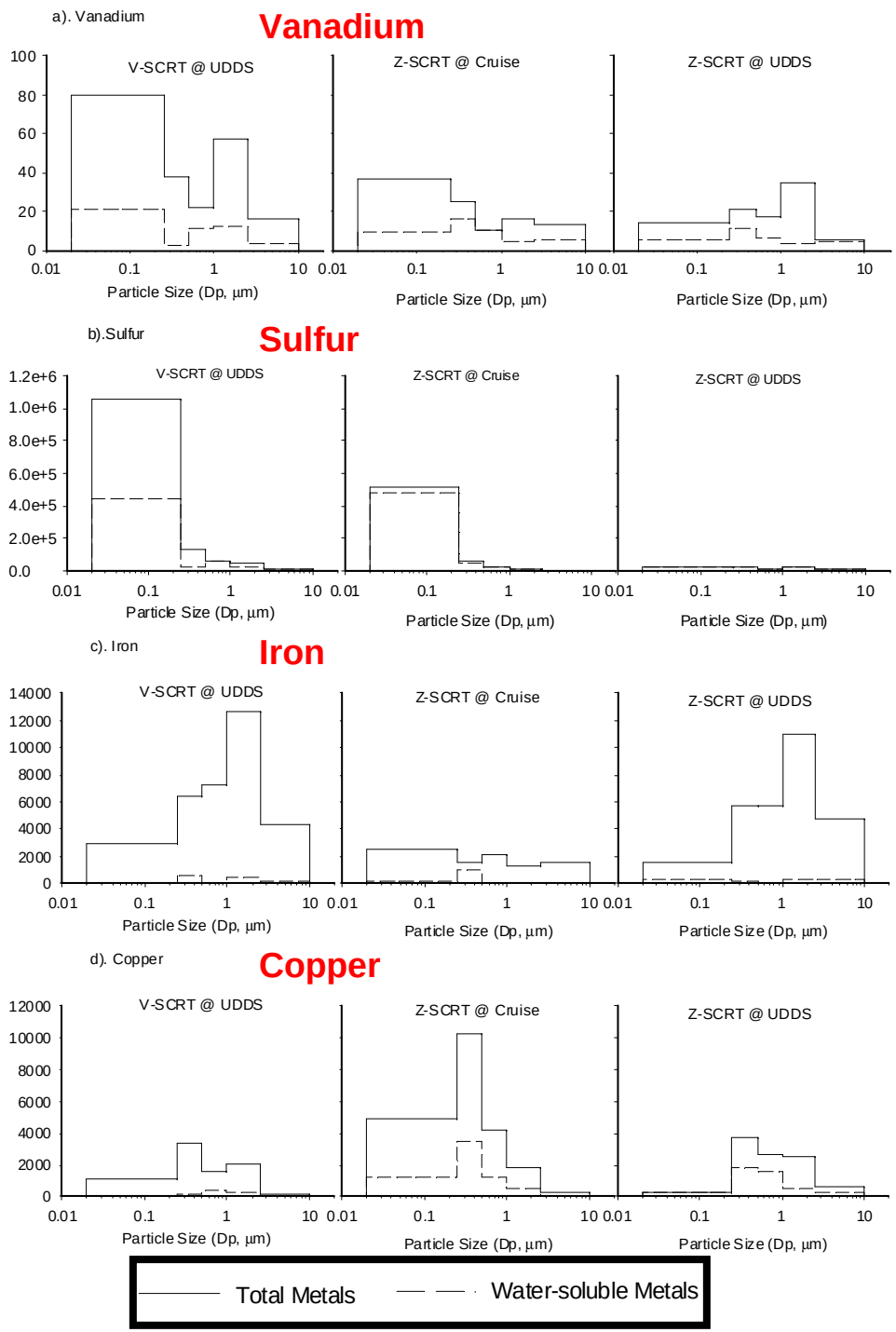


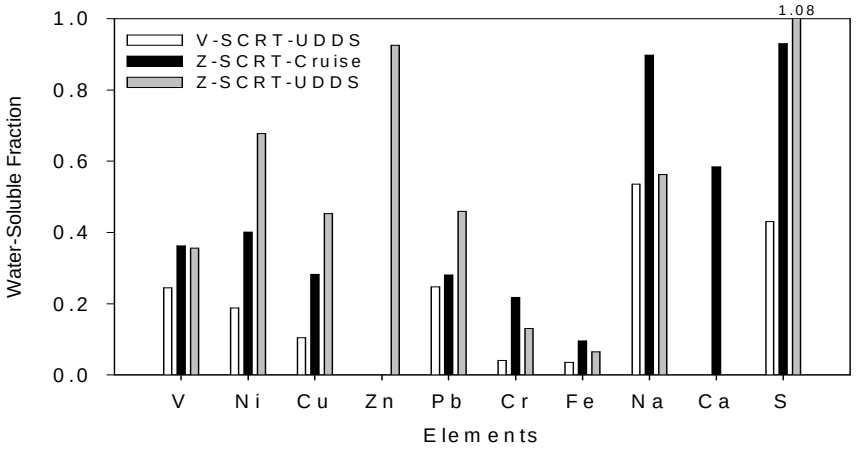
Hu et. al.,"Elements emitted from heavy-duty diesel vehicles equipped with advanced PM and NOx emission controls," In review at *Atmos.Env.*.Oct. **2008**.



Herner et. al., Metals from Heavy–duty Diesel Vehicles Equipped with Advanced PM and NOx Emission Controls, American Association for Aerosol Research Conference, Oct. **2008**, Orlando

SCRT Size-resolved Total and Water-soluble Metals

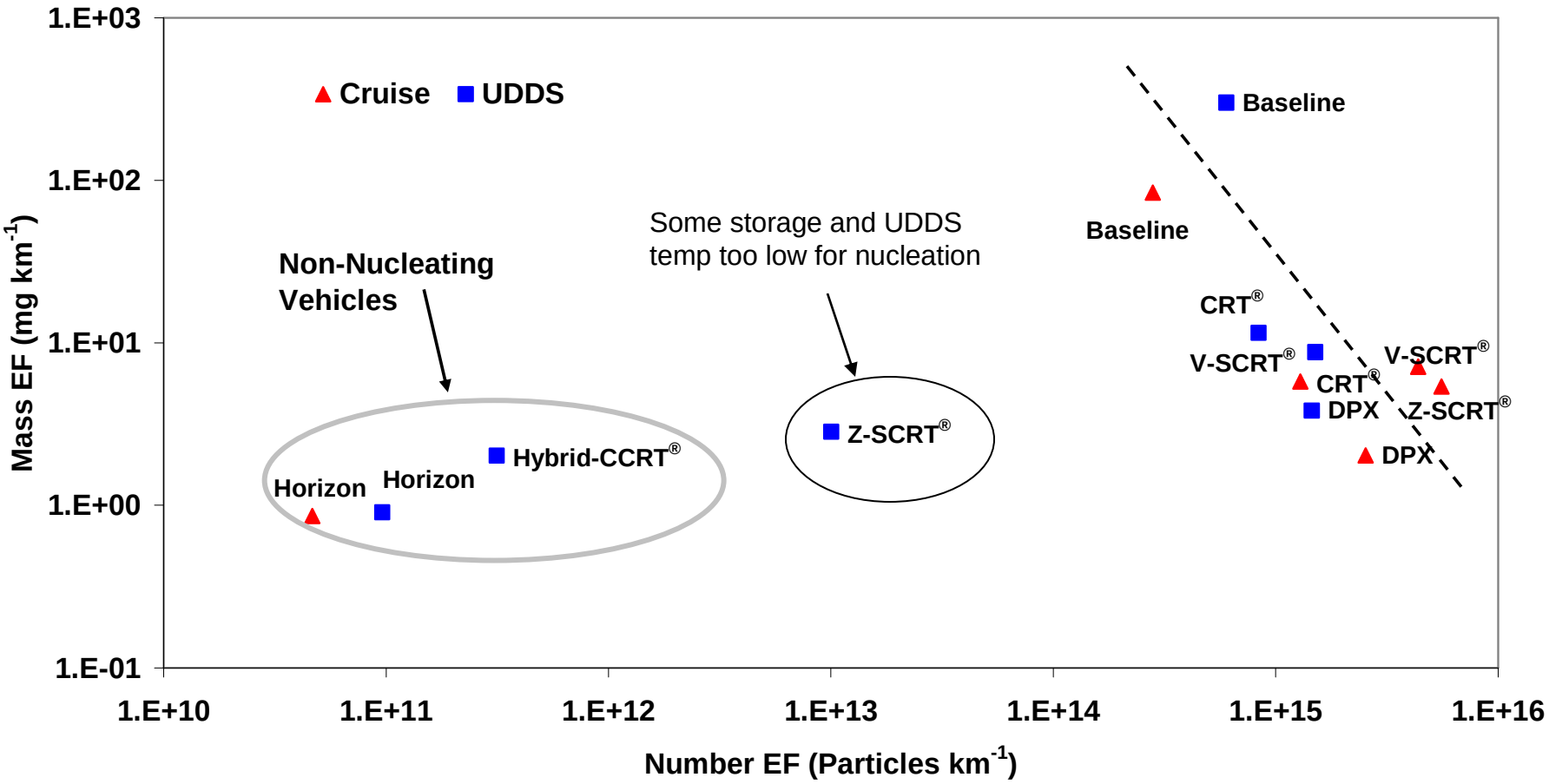




Water-soluble Fraction of Metals

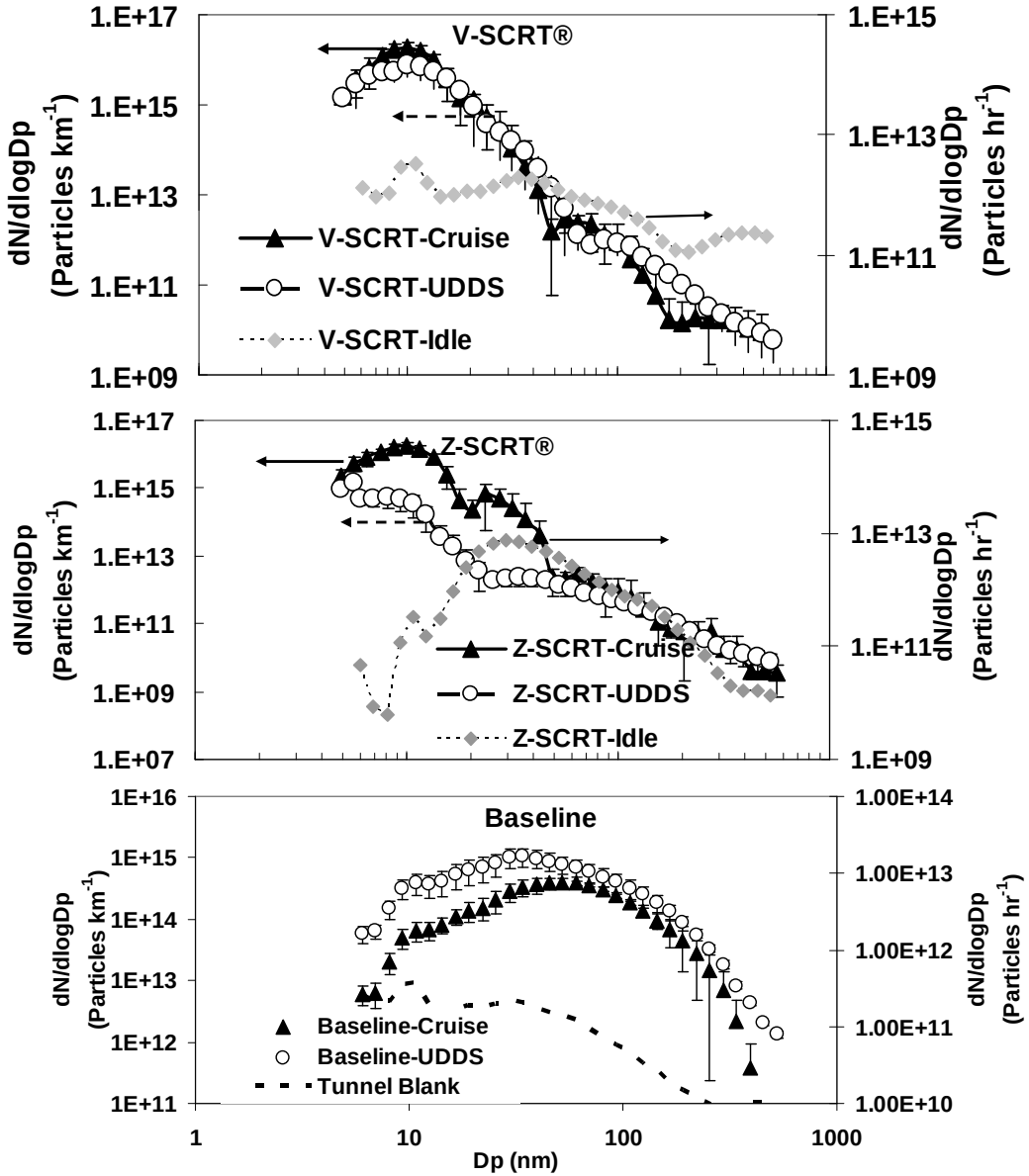
Herner et. al., Metals from Heavy–duty Diesel Vehicles Equipped with Advanced PM and NOx Emission Controls, American Association for Aerosol Research Conference, Oct. **2008**, Orlando

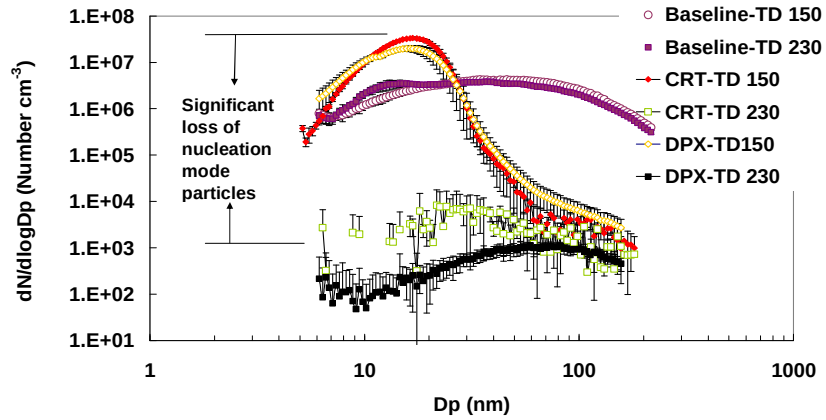
Particle Number versus Particle Mass



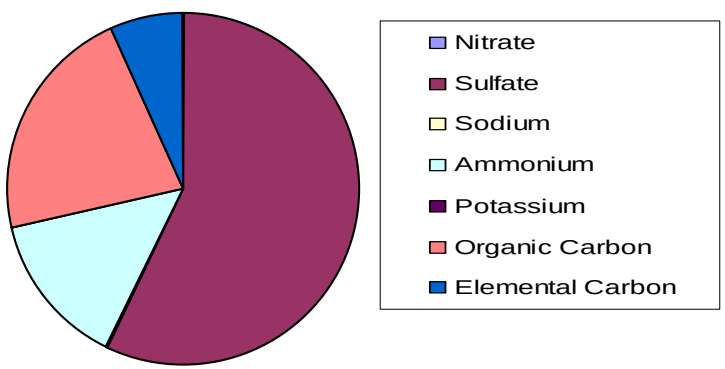
Ref: Biswas et al., Atmos. Env., 2008 42:5622-5634

Size distribution and volatility of particle emissions





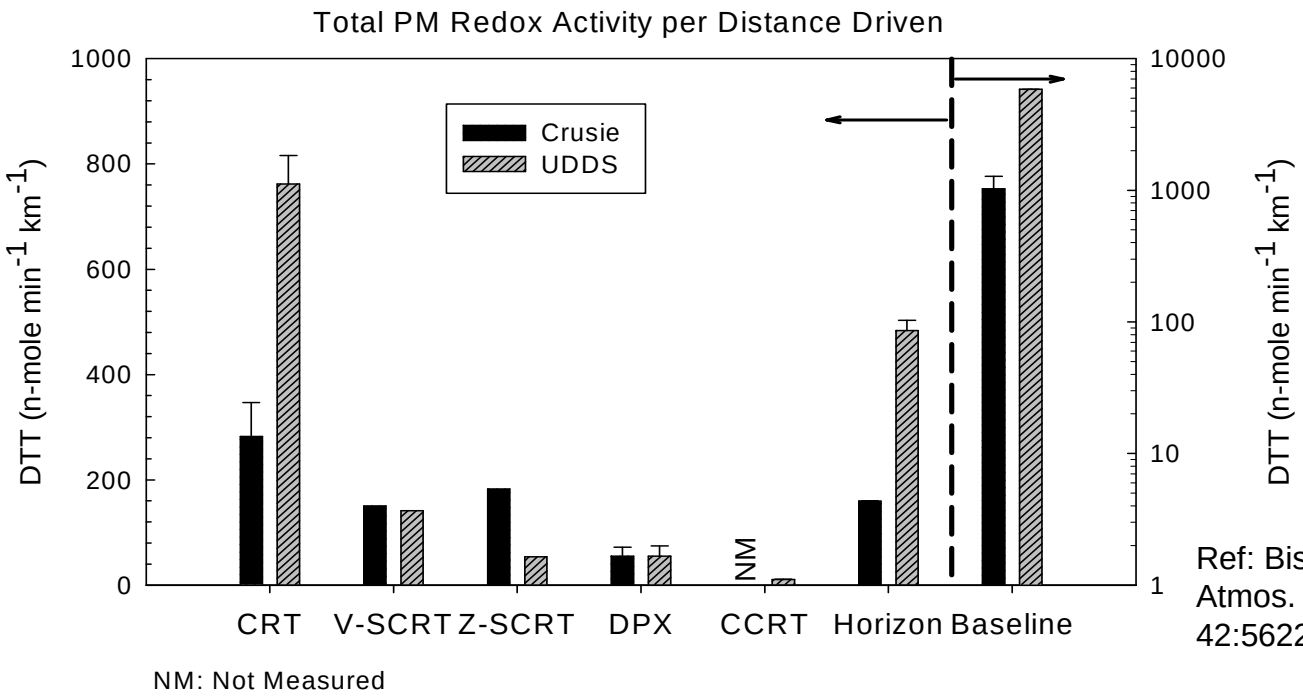
SCRT Retrofit



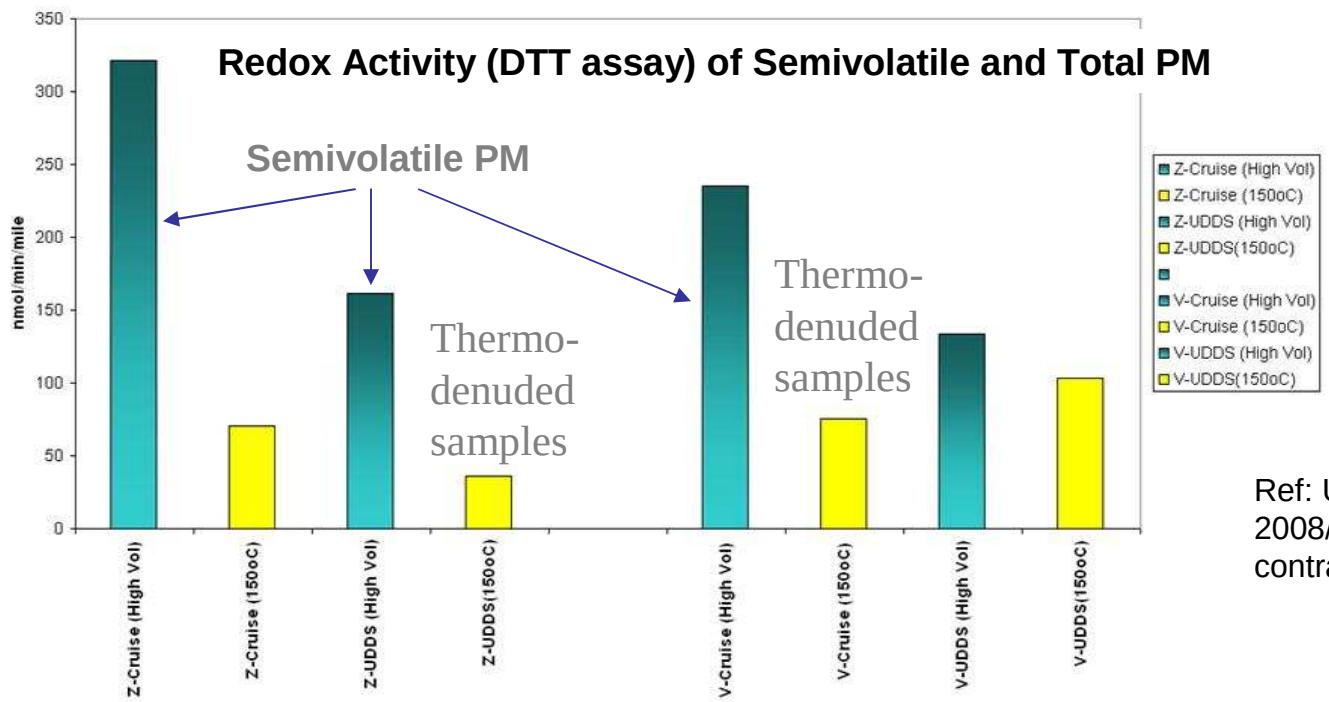
Herner et al., "Nucleation Mode Particle Emissions from In-use Heavy Duty Vehicles Equipped with DPF and SCR Retrofits," American Association for Aerosol Research, Reno, Sept. 2007

Biswas et.al., "Physical Properties of Particulate Matter from Newer Heavy-Duty Diesel Vehicles Operating with Advanced Emission Control Technologies," *Atmospheric Environment*, 42 (**2008**) 5622-5634.

Toxicity-Oxidative Potential of Emission Samples



Ref: Biswas et al., Atmos. Env., 2008 42:5622-5634



Ref: USC/AAAR 2008/Orlando – under contract to CARB

Some observations from research presented

- Retrofits performing as designed. They yield significant emission reductions (PM, NO_X, EC/OC, elements, toxicity, etc.)
- Some retrofits are prototypes. Optimization of production-ready systems expected.
- Oxidation of NO to NO_2 is evident in all catalyst-based systems.
- Significant production of ultrafine particles for some systems during some operation.
- Most ultrafine particles are volatile. And elevated sulfate and ammonium correspond to high ultrafine particle formation.
- Oxidative potential (in chemical assay) associated with volatile fraction of emissions. Water soluble metals may have role

Still to come

- nitro-PAH analysis by DRI
- LDV (E85, CNG, biodiesel, diesel, gasoline (normal and high emitter)
- HD CNG testing w/ WVU

What is beyond this project?

- dioxins
- testing for “production-intent” engine systems