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# Effects of Catalysts on Emissions from Heavy-Duty Diesel Retrofits for PM and $NO_X$ Control

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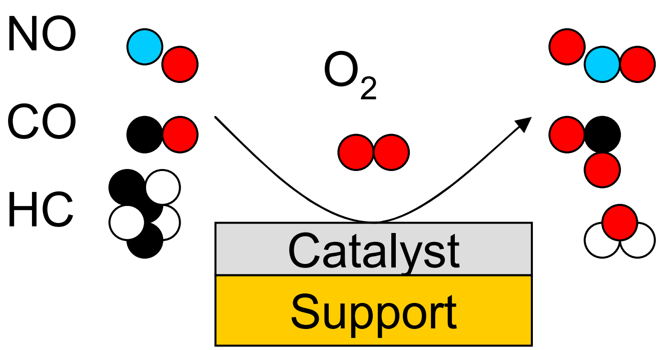


$NO + \frac{1}{2} O_2 \rightarrow NO_2$

$CO + \frac{1}{2} O_2 \rightarrow CO_2$

$[HC] + O_2 \rightarrow CO_2 + H_2O$

$2SO_2 + O_2 \rightarrow 2SO_3$

California Environmental Protection Agency
AIR RESOURCES BOARD

# CARB'S HEAVY-DUTY VEHICLE EMISSIONS LABORATORY

Collaborators, co-sponsors, and in-kind contributors

JM Johnson Matthey

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The University of Wisconsin Madison

UCLA

USC

South Coast AQMD

California Energy Commission

D.A.R.T. Downey Area Recycling & Transfer

California Department of Transportation

San Joaquin RTD

bp

UC Davis University of California

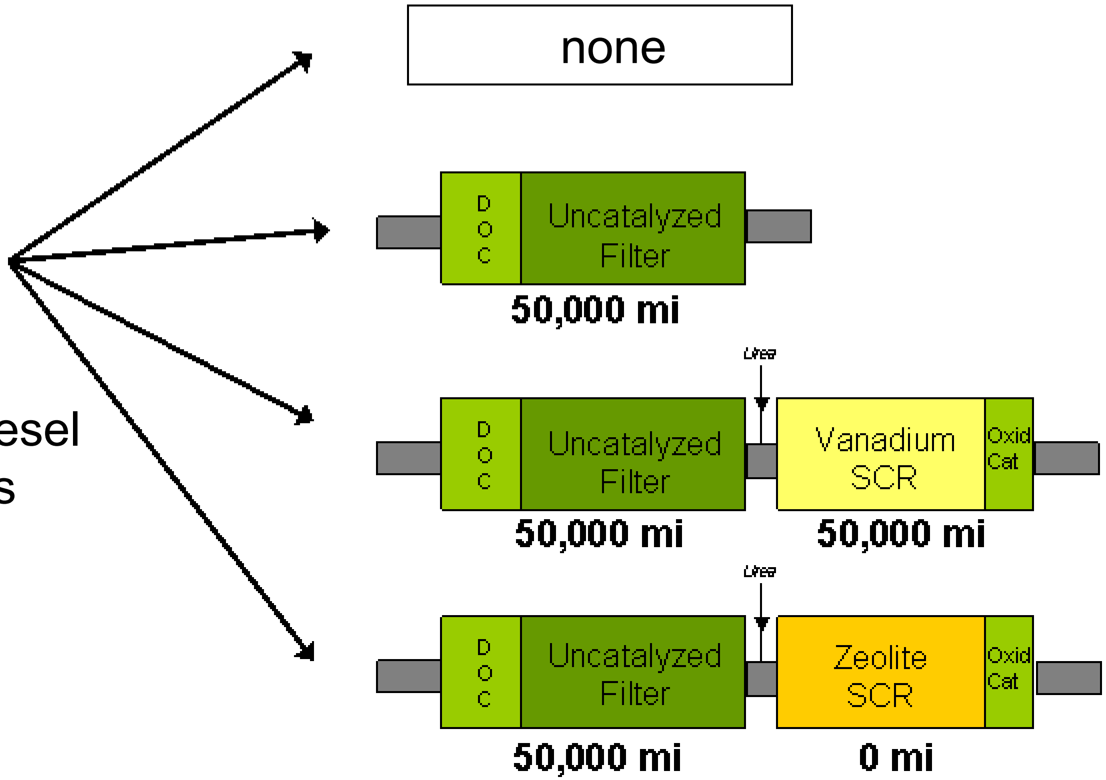
# RETROFIT DEVICE TEST MATRIX[2]

4 vehicles, 8 configurations, 3 driving cycles

**Vehicle** | **Aftertreatment** | **Abbreviation**

Veh#1

1998 Cummins Diesel
11L, 360,000 miles




**Baseline**

**Veh #1 CRT®**

**Veh #1 V-SCRT®***

**Veh #1 Z-SCRT®***

•**SCRT® systems used in this project are development prototypes not commercial units**.

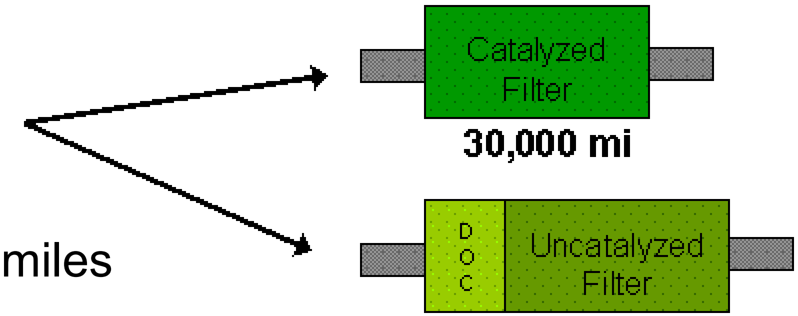
Ref: 2. Herner et al. 2007. Towards 2010 NOx and PM emission Levels: Overview of CARB's Investigation of Advanced Heavy-duty On-road Vehicle Retrofits and Other Technologies. 26th AAAR Annual Conference, September 24-28, 2007, Reno, NV

# TEST MATRIX (cont'd)[2]

## 4 vehicles, 8 configurations, 3 driving cycles

| Vehicle | Aftertreatment | Abbreviation |
|---|---|---|

Veh#2, 1999 International Diesel




30,000 mi

**Veh#2 DPX**

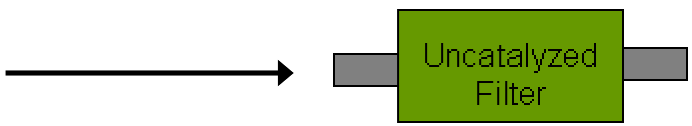
5,000 mi

Only tested for nucleation

**Veh#2 CRT2®**

7.6L, 40,000 miles

Veh#3 2003 Cummins Diesel,

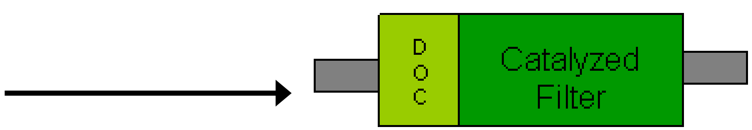



31,000 mi

**Veh#3 Horizon**

5.9L, 50,000 miles

Veh#4 2006 Cummins Diesel w/ Allison Hybrid drive

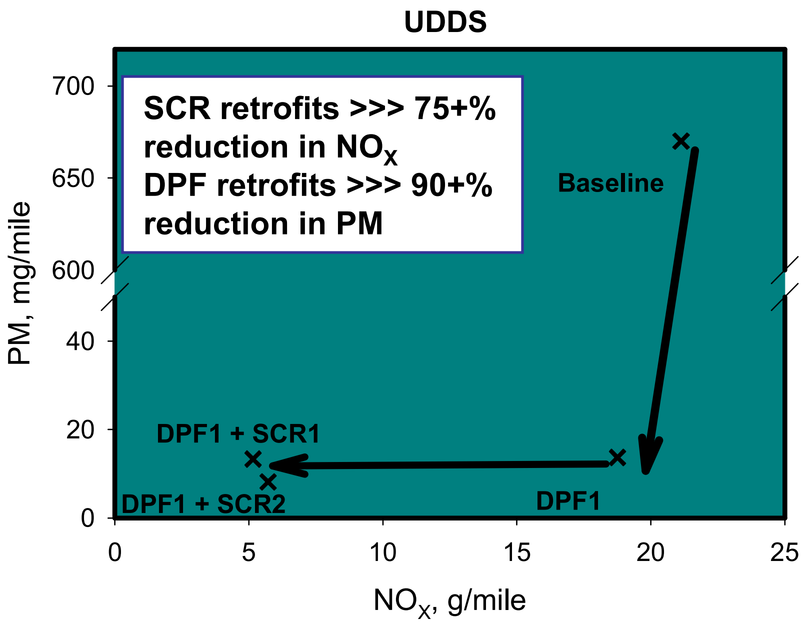


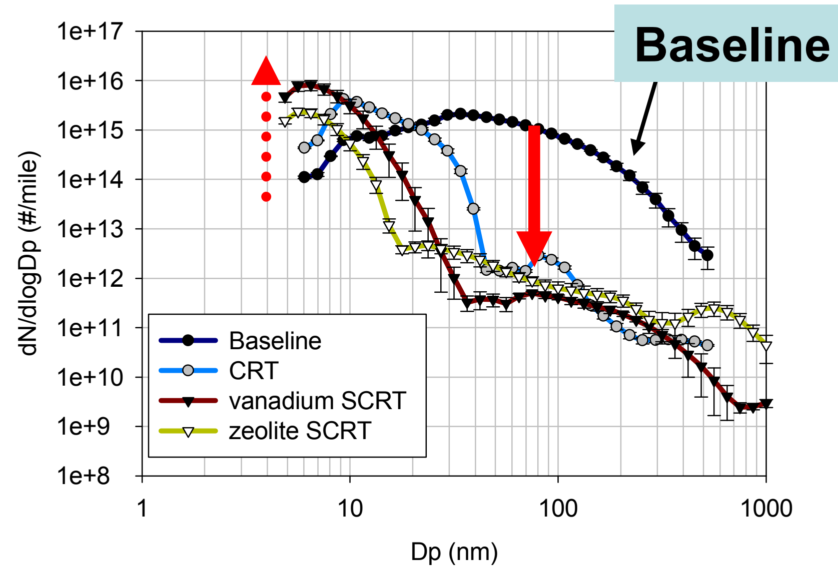

1,000 mi

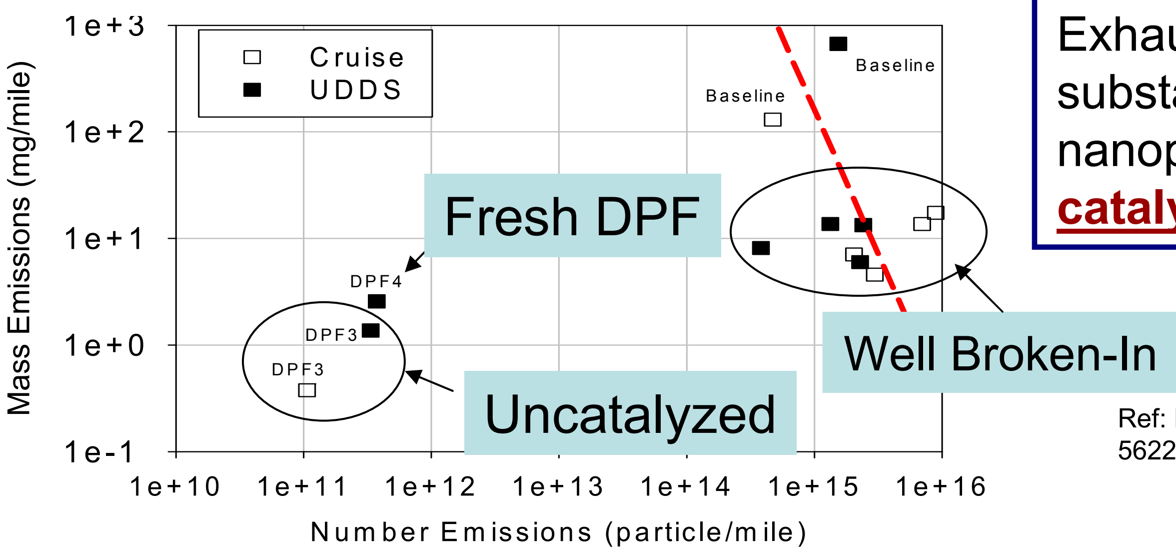
**Veh#4 CCRT®**

5.9L, 1,000 miles

# RETROFITS LEAD TO LOWER PARTICLE MASS, BUT SOMETIMES HIGHER ULTRAFINE PARTICLE NUMBER



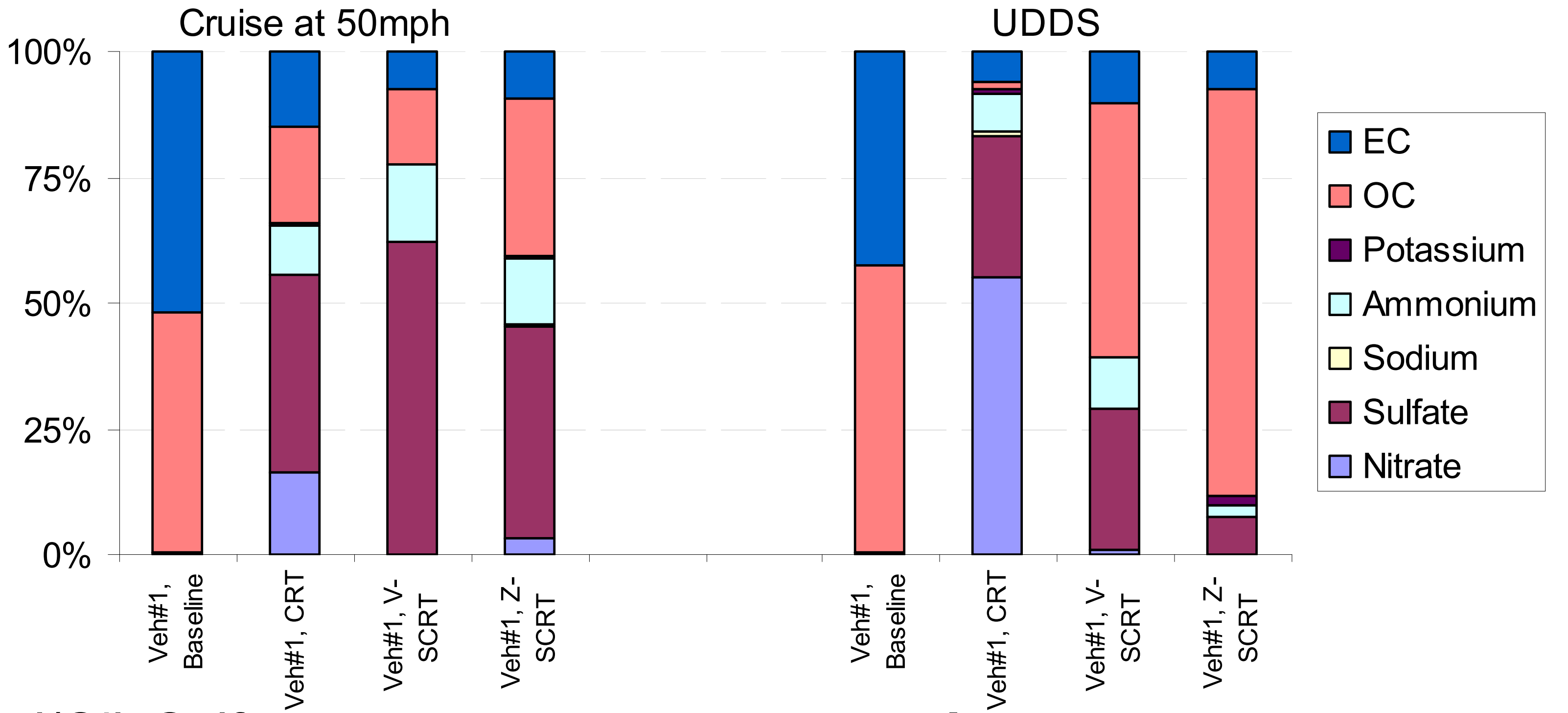



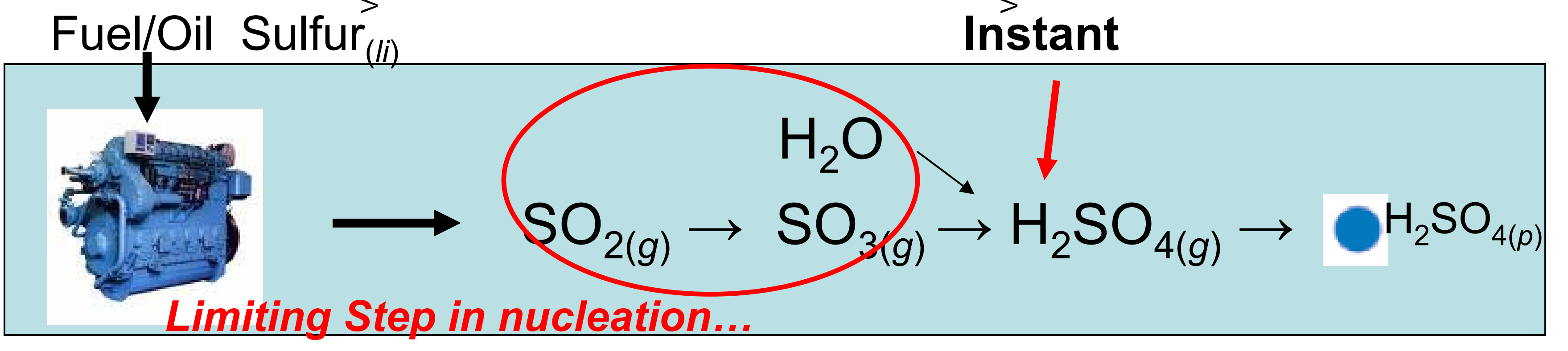




Exhaust **temperature** promotes substantial formation of nanoparticles for well-broken-in **catalytic** devices

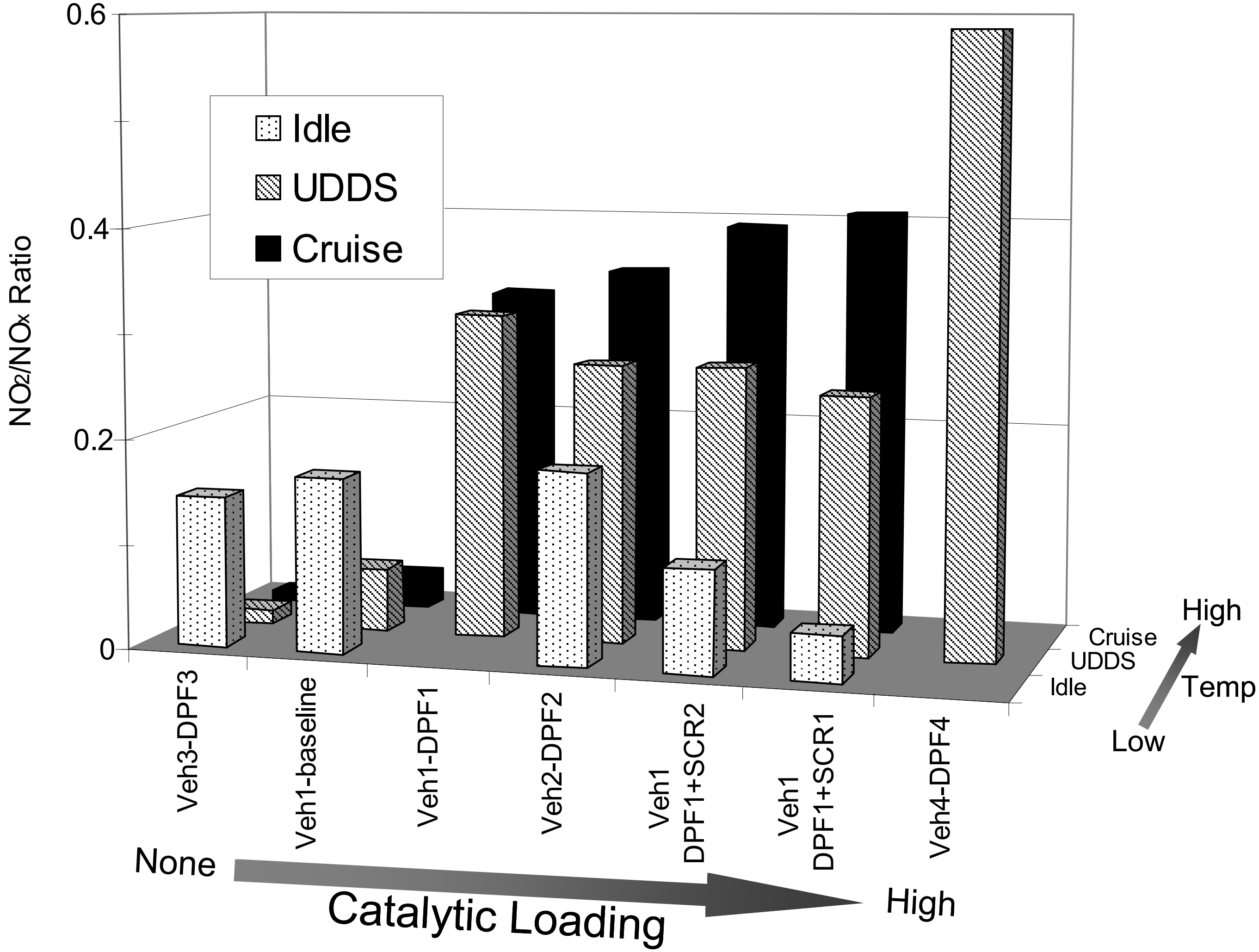
Ref: Biswas, S. et al., *Atmos. Environ.* **2008,** *42*, (22), 5622-5634.

# SULFATE DOMINATE COMPOSITION OF PARTICLE EMISSIONS FROM RETROFITS AT AGGRESSIVE CYCLE

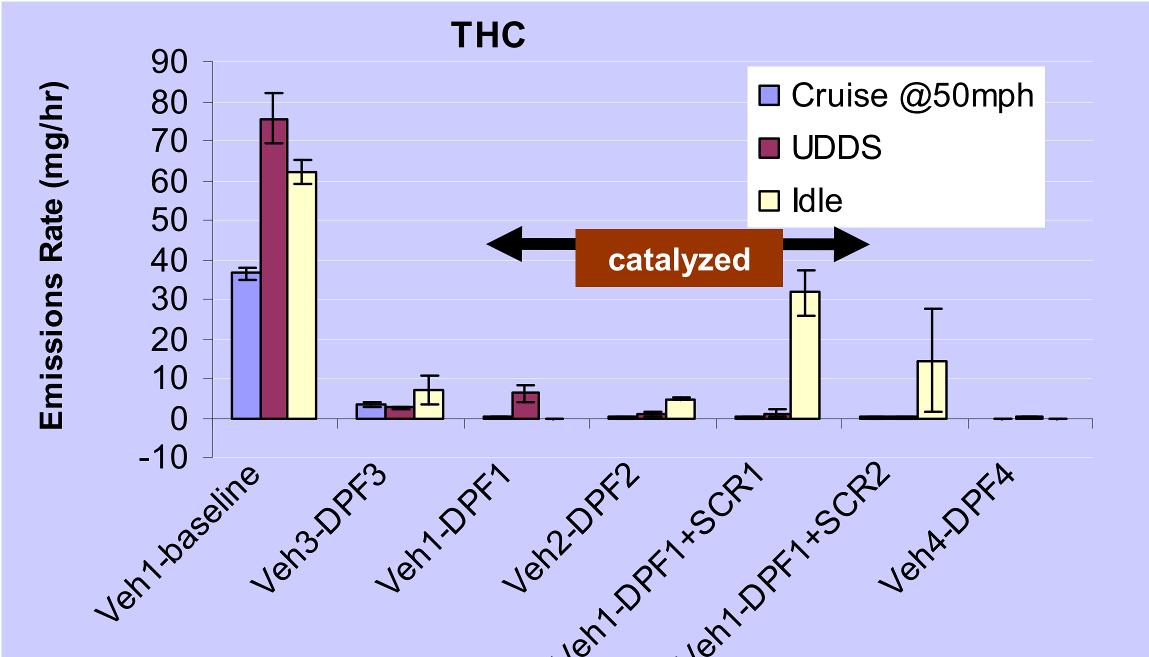


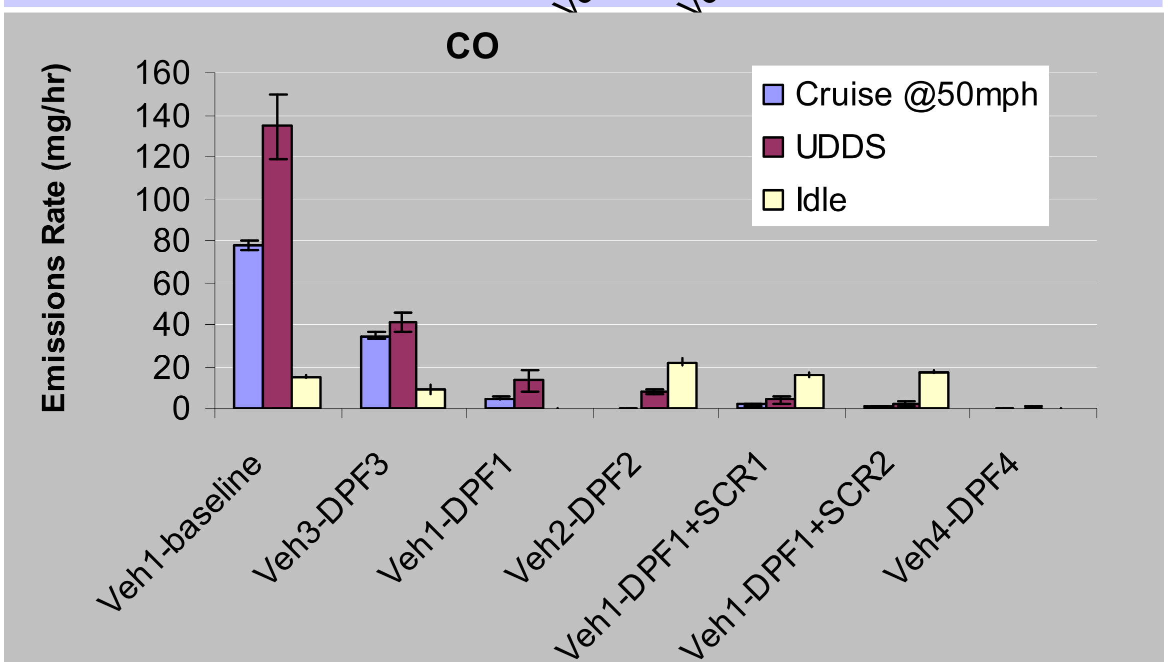



# $NO_2:NO_X$ RATIO AS A FUNCTION OF AFTERTREATMENT DEVICE AND DRIVING CYCLE



# THC AND CO EMISSIONS

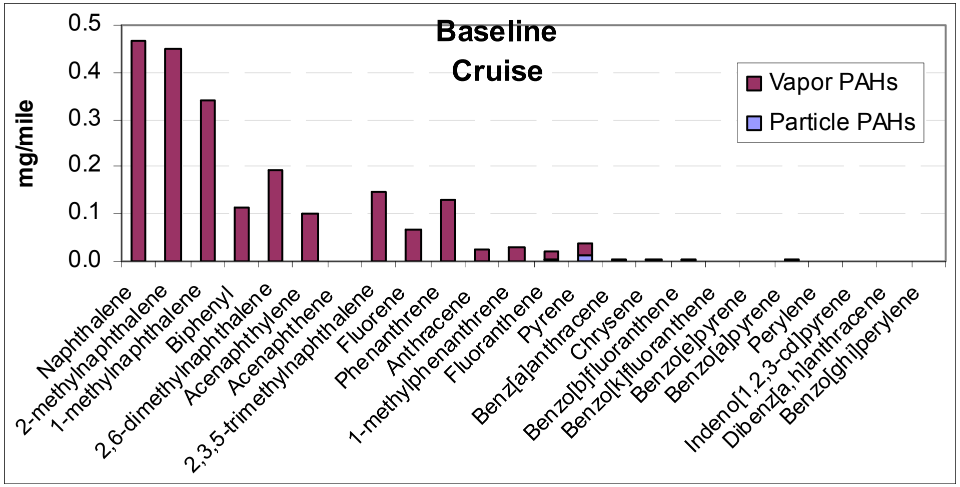


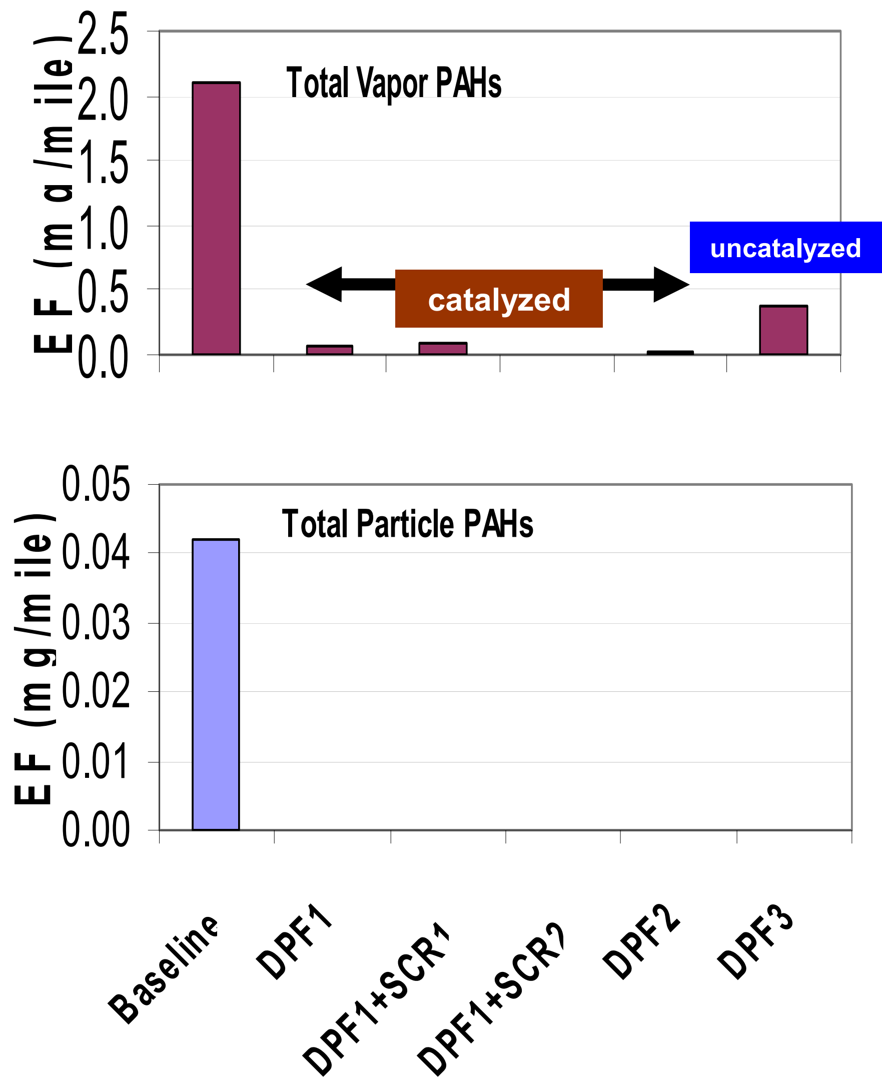




- They both are easily oxidized to the final complete combustion products, $H_2O$ and $CO_2$
- The emissions can be predictive by
  - Exhaust temperature and
  - the amount of catalyst in the aftertreatment.
- Because Its newer and smaller Engine, THC and CO emissions from the uncatalyzed Veh3-DPF3
  - LOWER than Veh1-baseline;

  BUT,
  - 1-2 orders of magnitude greater than catalyzed aftertreatment.

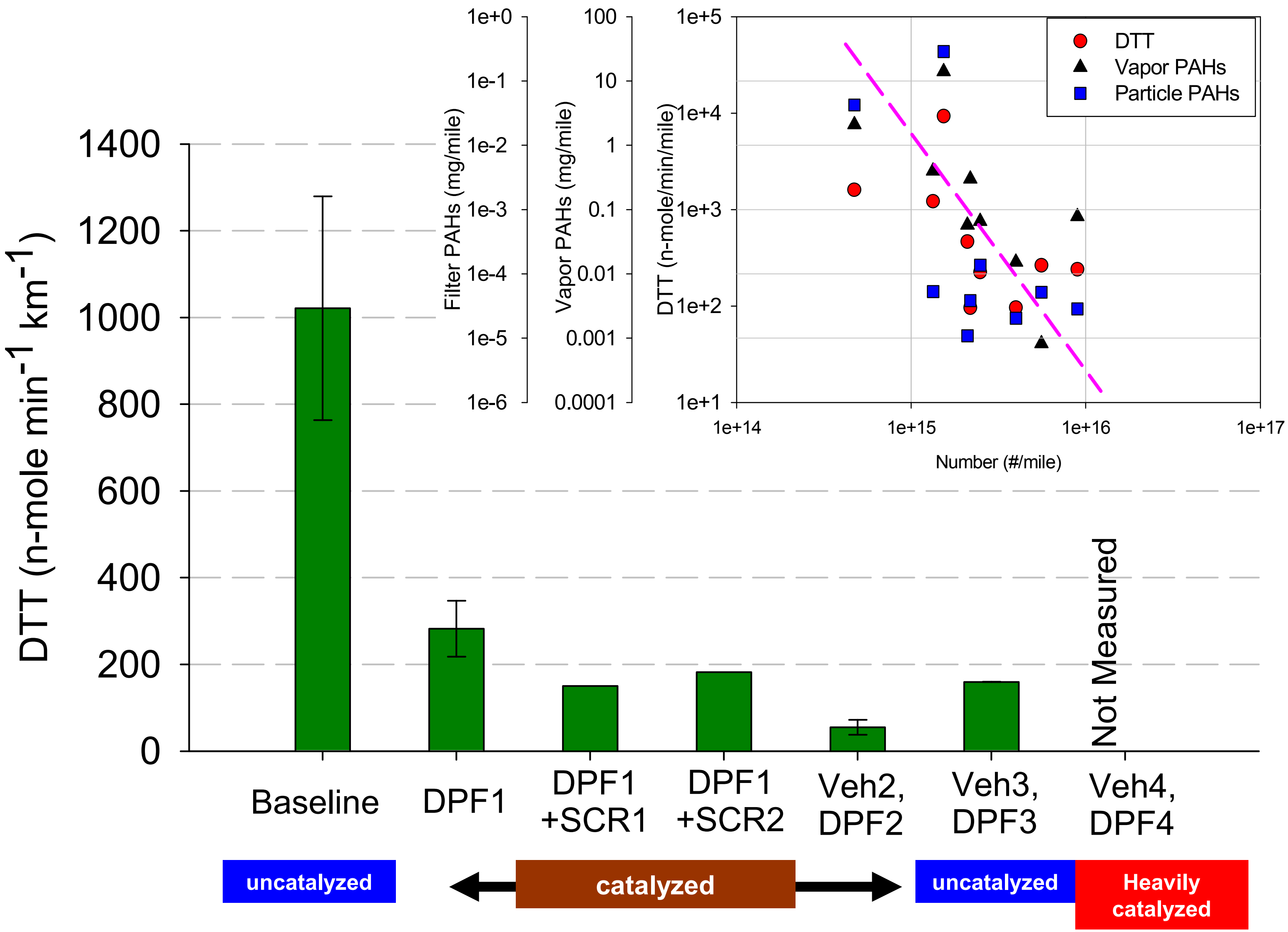
# PAHs ARE EFFECTIVELY REDUCED BY RETROFITS



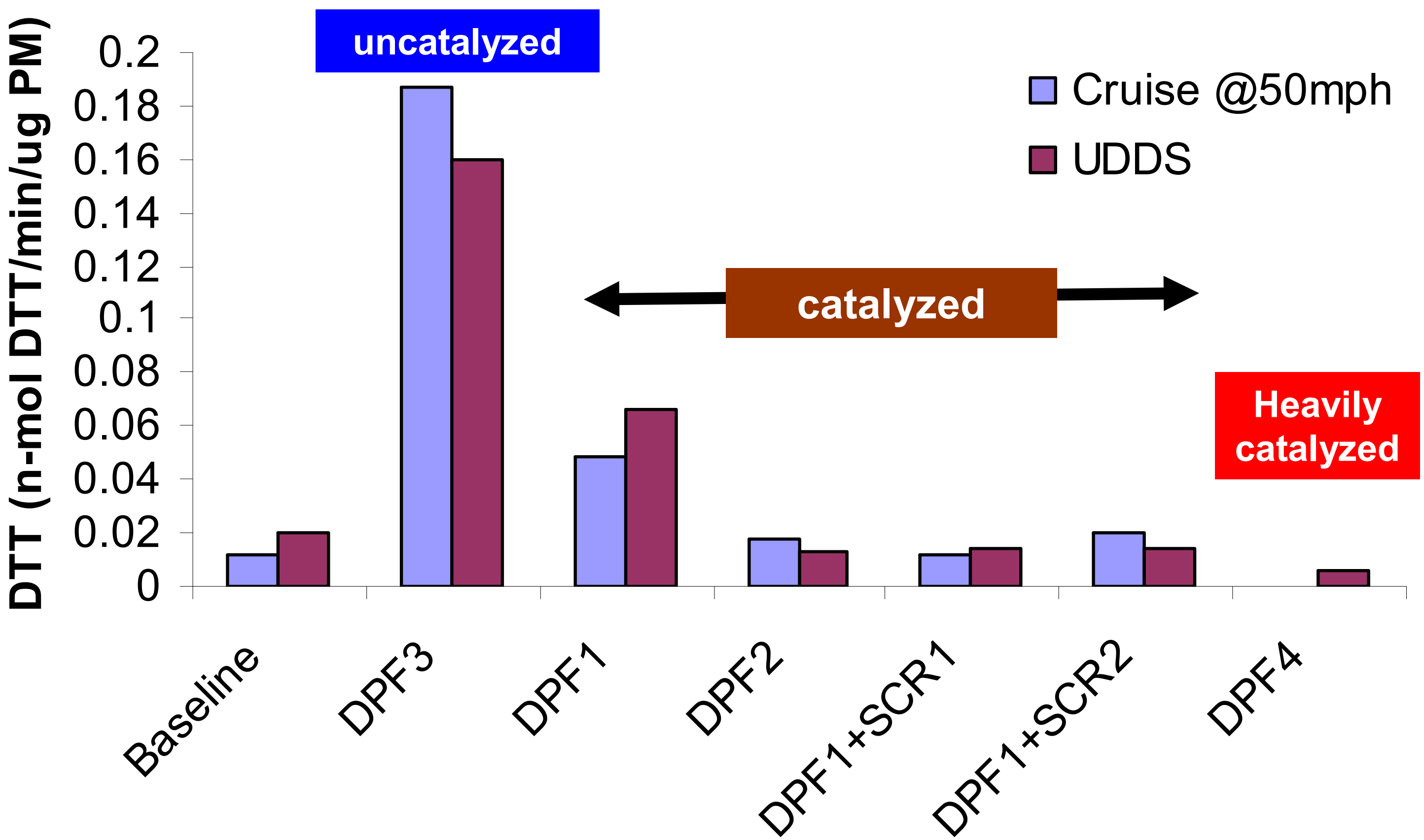




- Vapor phase PAHs dominate the total PAHs
- Light weight PAHs dominate
- Significant reduction of both Particle and Vapor PAHs
- Within retrofits, uncatalyzed DPF shows relative higher vapor PAHs
- No enhancement of nitro-PAHs from SCR (not shown)

# OXIDATIVE STRESS POTENTIAL OF TOTAL PM PER DISTANCE DRIVEN IS REDUCED BY ALL HD RETROFITS ($DTT$ - $C_4H_{10}O_2S_2$)



# OXIDATIVE STRESS POTENTIAL OF TOTAL PM PER PM MASS (DTT - $C_4H_{10}O_2S_2$)

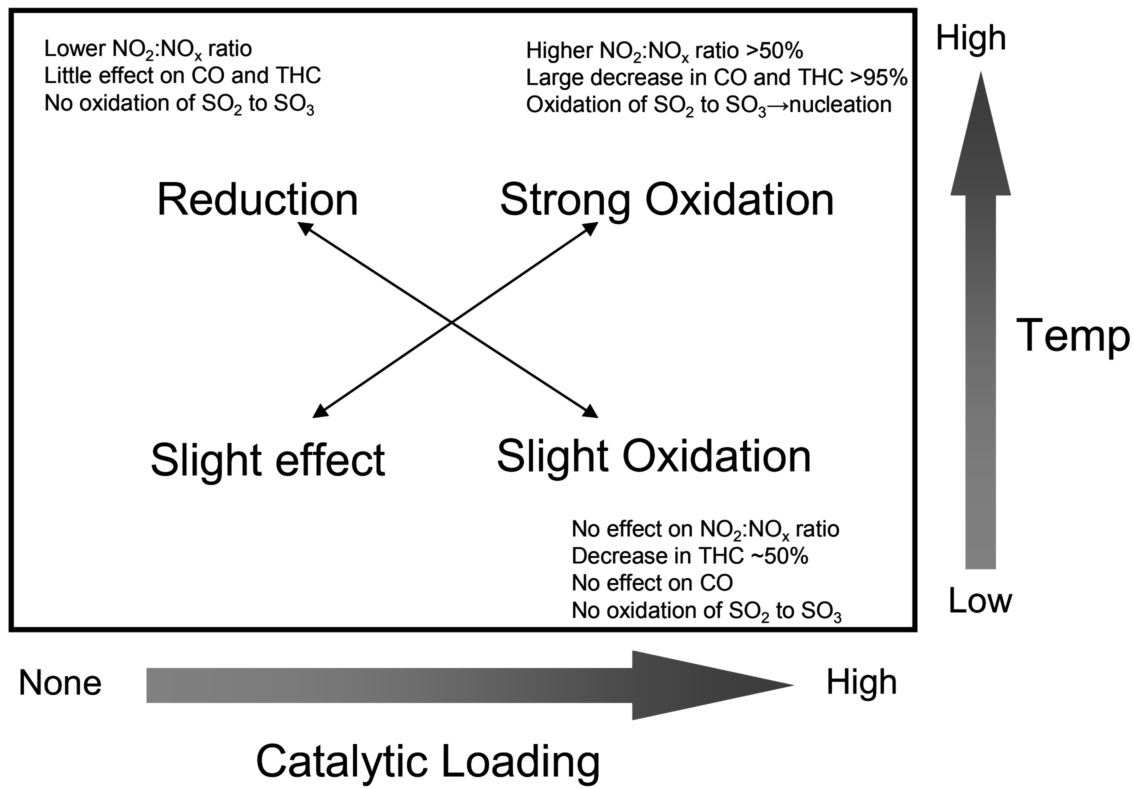



**DTT activity expressed per PM mass, was seen high activity for non-catalyzed substrate for PM control**

# CONCLUSIONS

- **TWO MAJOR FACTORS IN DPF CHEMISTRY – <u>CATALYTIC LOADING AND TEMPERATURE</u>**

Redox Chemistry in Diesel Aftertreatment




Ref: Herner, et al., *Environ Sci Technol* **2009,** *43*, (15), 5928-5933.

- The more heavily catalyzed and the hotter the exhaust temperature, the more strongly the aftertreatment will oxidize the exhaust.
- Uncatalyzed DPFs however, will have little effect on THC and CO, but will reduce $NO_2$ to NO, as the collected soot acts as a reductant.

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