Urea SCR and DPF System for Tier 2 Diesel Light-Duty Trucks

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Presentation Overview

1. Department of Energy Program Overview
2. Final System Durability and Results
3. Post Mortem Phase
4. On-going Catalyst Development
5. Conclusions

1. DOE Program Overview

Tier 2 Emission Standards

- Tier 2 Bin 5 / LEVII standards represent 90-95% NOx and PM reduction from Tier 1 standards for diesels.

Standard	NOx (g/mi)	PM (g/mi)
Tier 1 (100k mi)	1.25	0.10
Tier 2 Bin 5 (120k mi)	0.07	0.01

- NOx and PM control remain a challenge for diesels.

Program Objectives (2001)

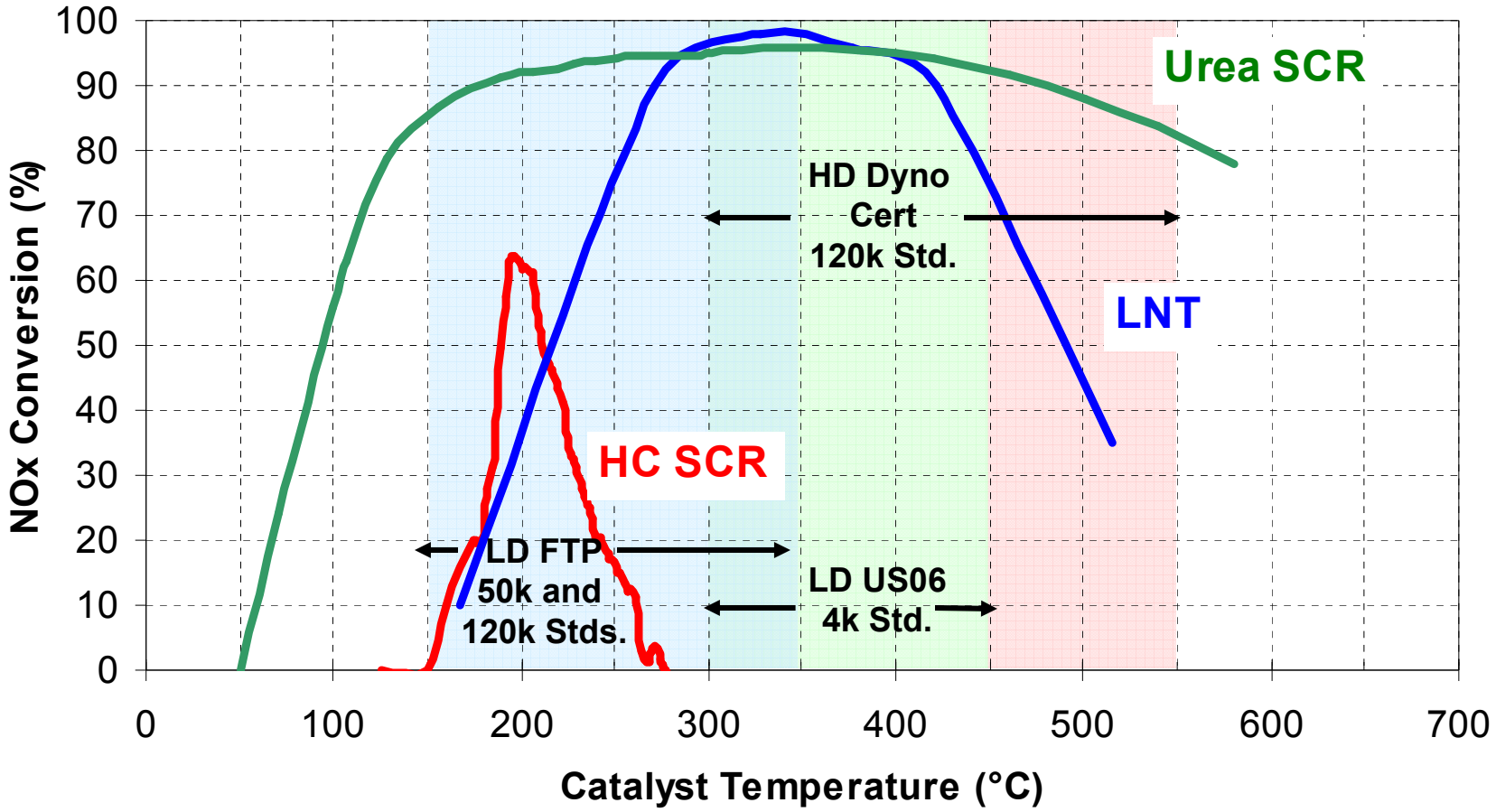
- 0.07 g/mi NOx
- 0.01 g/mi PM
- 120,000 miles of durability

Aftertreatment Selection

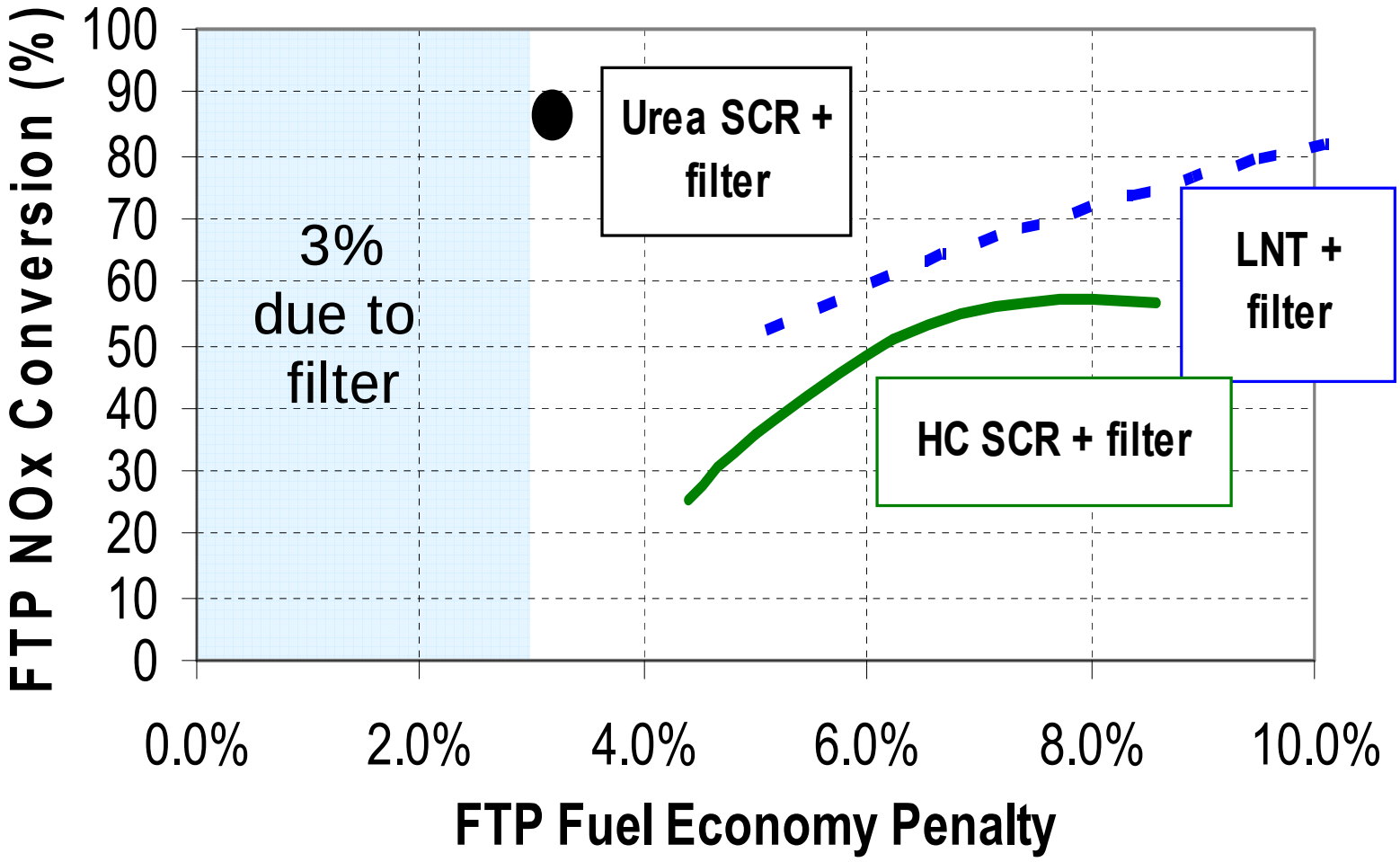
- Particulate Control – catalyzed DPF (CDPF)
- NOx Control 1 – HC SCR using diesel fuel
- NOx Control 2 – Lean NOx Trap (LNT)
- NOx Control 3 – SCR with ammonia-based reductant

(SCR = Selective Catalytic Reduction)

Typical Performance Curves of Slightly Aged Catalysts

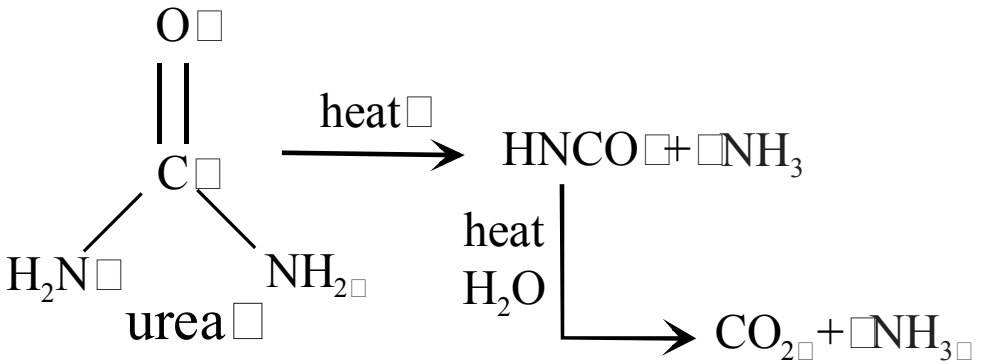


Simulated FTP NOx Conversion vs. FTP-75 Fuel Economy Penalty



Urea SCR Chemistry

urea decomposition:



NO_x reduction:

$$4NO + 4NH_3 + O_2 \longrightarrow 4N_2 + 6H_2O$$

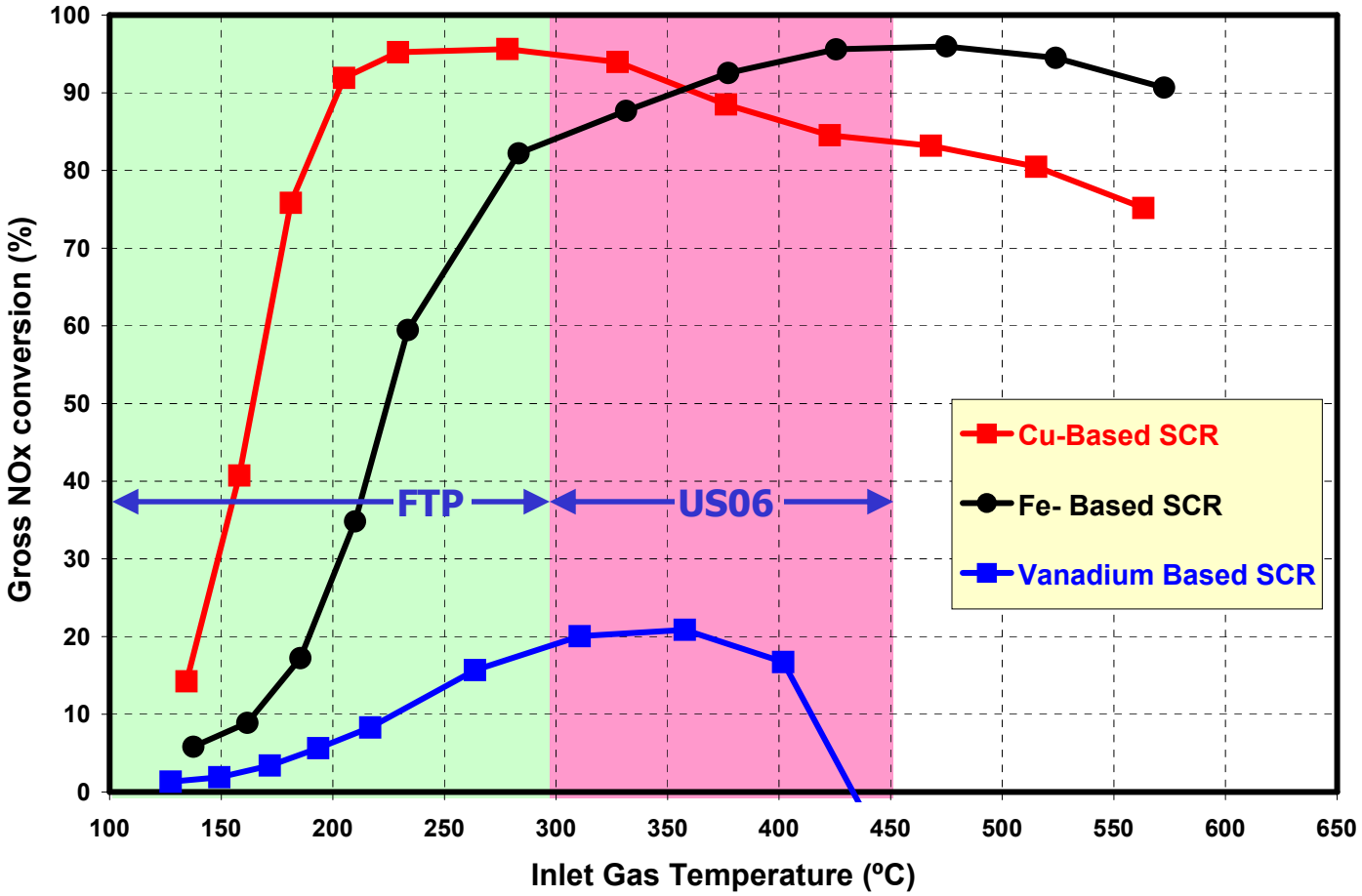
$$6NO_2 + 8NH_3 \longrightarrow 7N_2 + 12H_2O$$

$$2NH_3 + NO + NO_2 \longrightarrow 2N_2 + 3H_2O$$ **"fast SCR"**

SCR Catalyst Types: 1) vanadia and 2) base metal/zeolite

NOx Activity Profiles for Cu, Fe, and V Based SCR Formulations

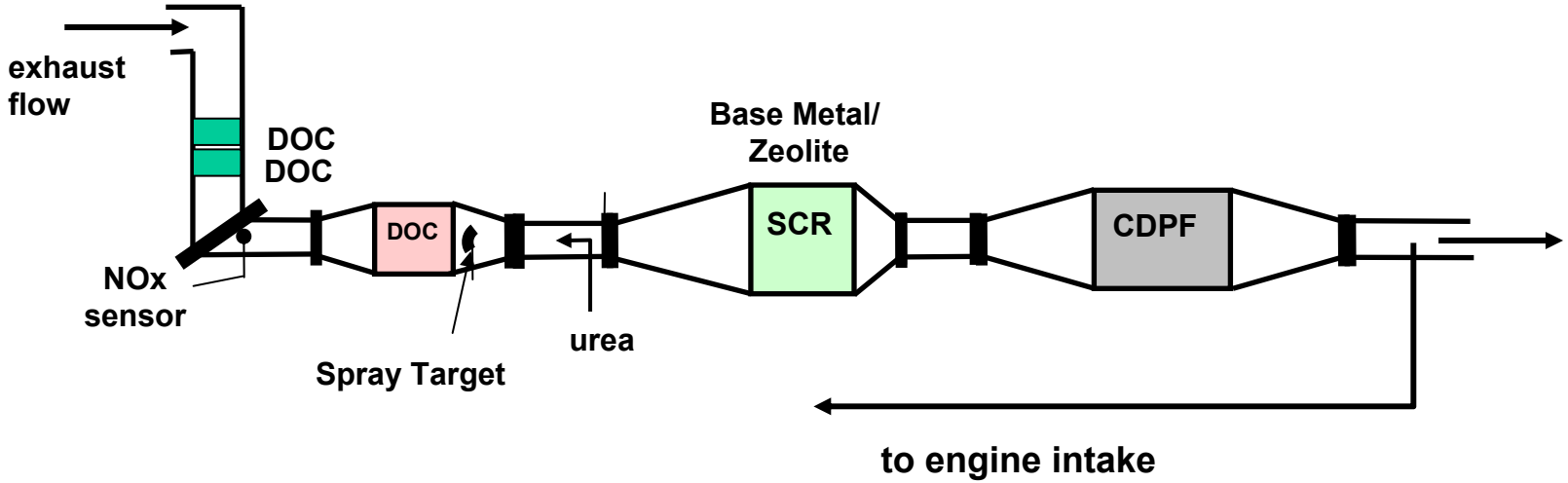
HTA 64hrs @ 670°C, 30,000/h



- Cu/zeolites are best at low temperatures
- Fe/zeolites perform well at high temperatures
- Vanadium based SCRs are not appropriate for North America

LDT Exhaust System (NOx)

90% FTP NOx conversion, 0.07 g/mi TP NOx



- Engine-out NOx lowered by 40% with increased EGR
- Low tailpipe NOx achieved with rapid warm-up strategy
  - lower thermal mass upstream of catalyst system
  - engine calibration changes during cold start (post injection & inc. idle speed)

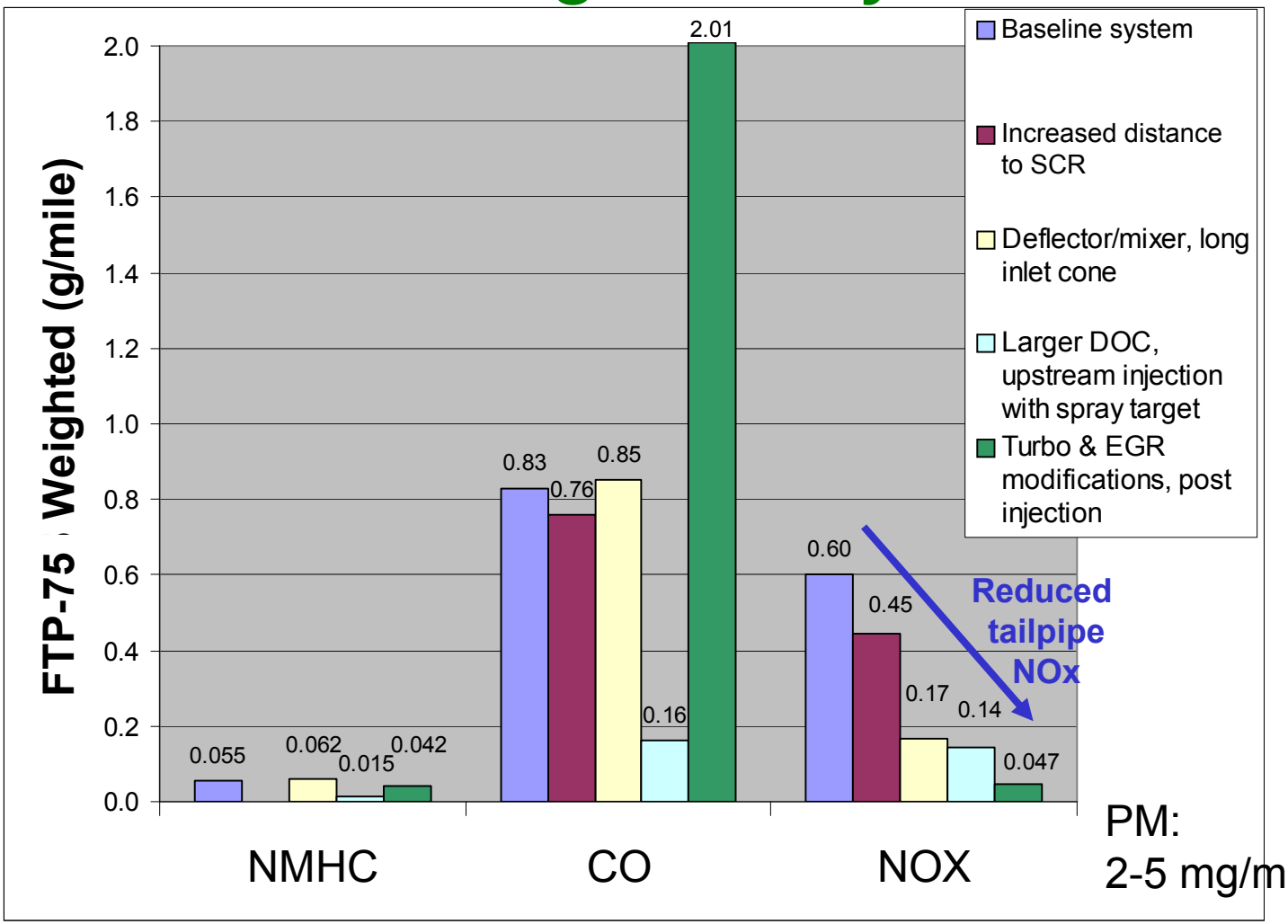
Diesel Fuel Properties

- **ExxonMobil blended 14,000 gallon batch to represent typical 2007 ULSD**

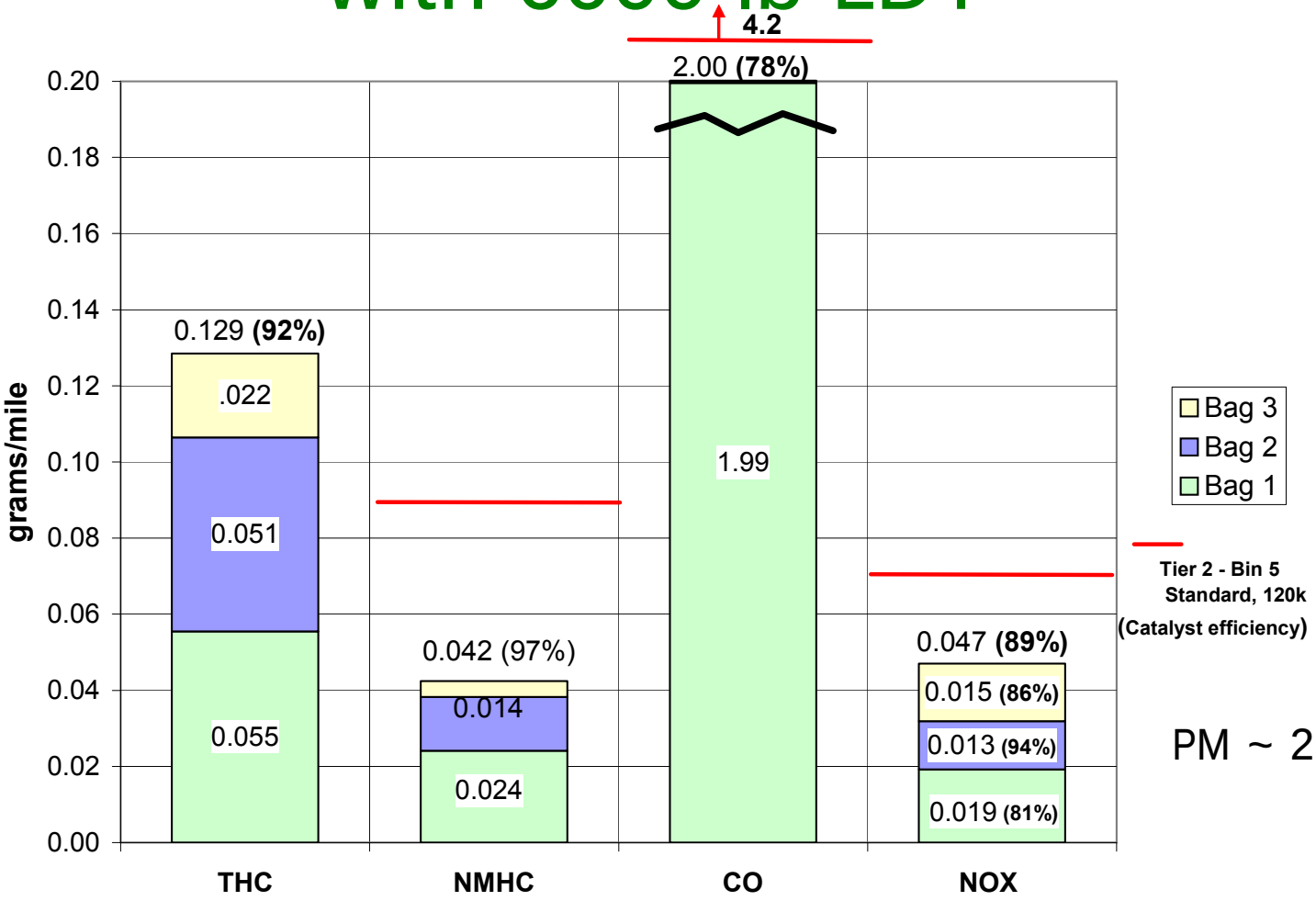
Fuel Property	Est. Avg. '06 Diesel Properties	Proposed DOE Prog. Min/Max	Program Fuel Delivered	Proposed 2007 Cert. Fuel
Sulfur, ppm	15*	10 / 15	**12.5**	7 / 15
Density, kg/m³	850	820 / 850	**841.1**	839 / 865
Aromatics, vol. %	32	25 / 32	**29.5**	27 min
Polyaromatics, wt. %	10	6 / 11	**11.0**	no spec
Cetane number	46	44 / 48	**44.9**	40 / 50
T50, C	267	250 / 280	**249**	243 / 282
T90, C	306	300 / 320	**307**	293 / 332

* As delivered to the vehicle

Weighted Tailpipe Emissions with Low-mileage Catalysts on LDT



Low-mileage FTP-75 Emissions with 6000 lb LDT



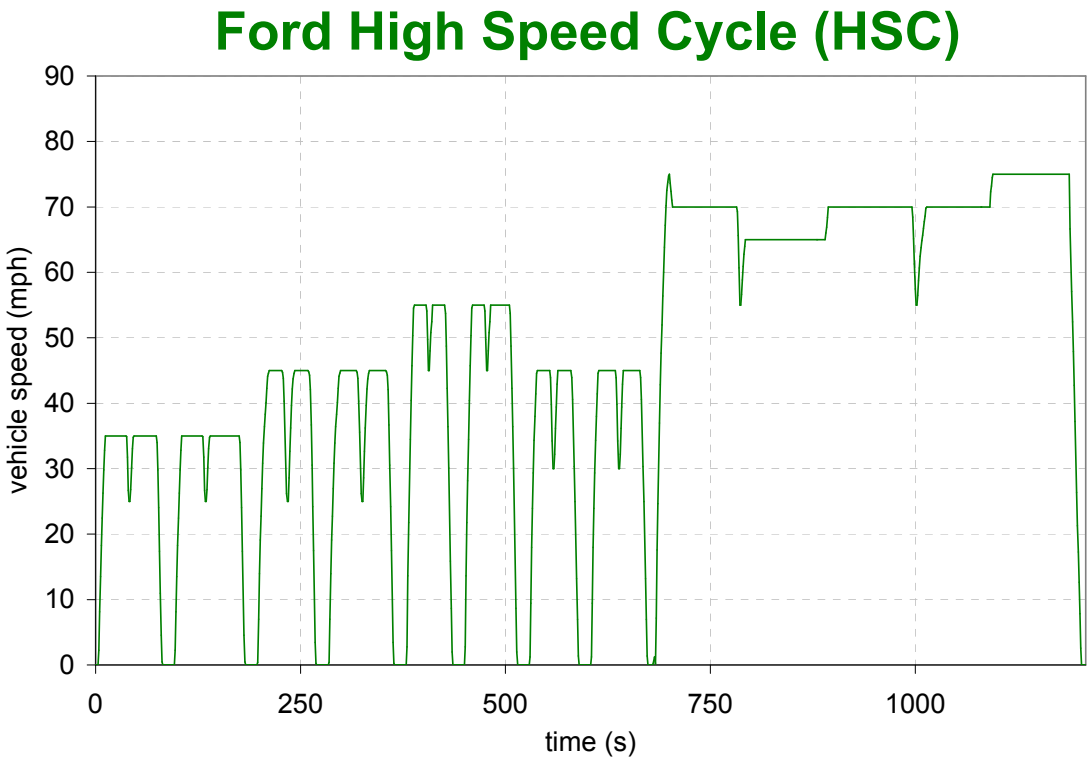
PM ~ 2 mg/mi

- Emissions were below 120k mi Tier 2 Bin 5 standards

2. Final System Durability and Results

Durability Test Definition (Dyno Aging)

- Full-size Urea SCR – CDPF system was aged for 120k mi on engine dyno with a total of 643 CDPF regenerations.



- Typical time at high temperature in SCR

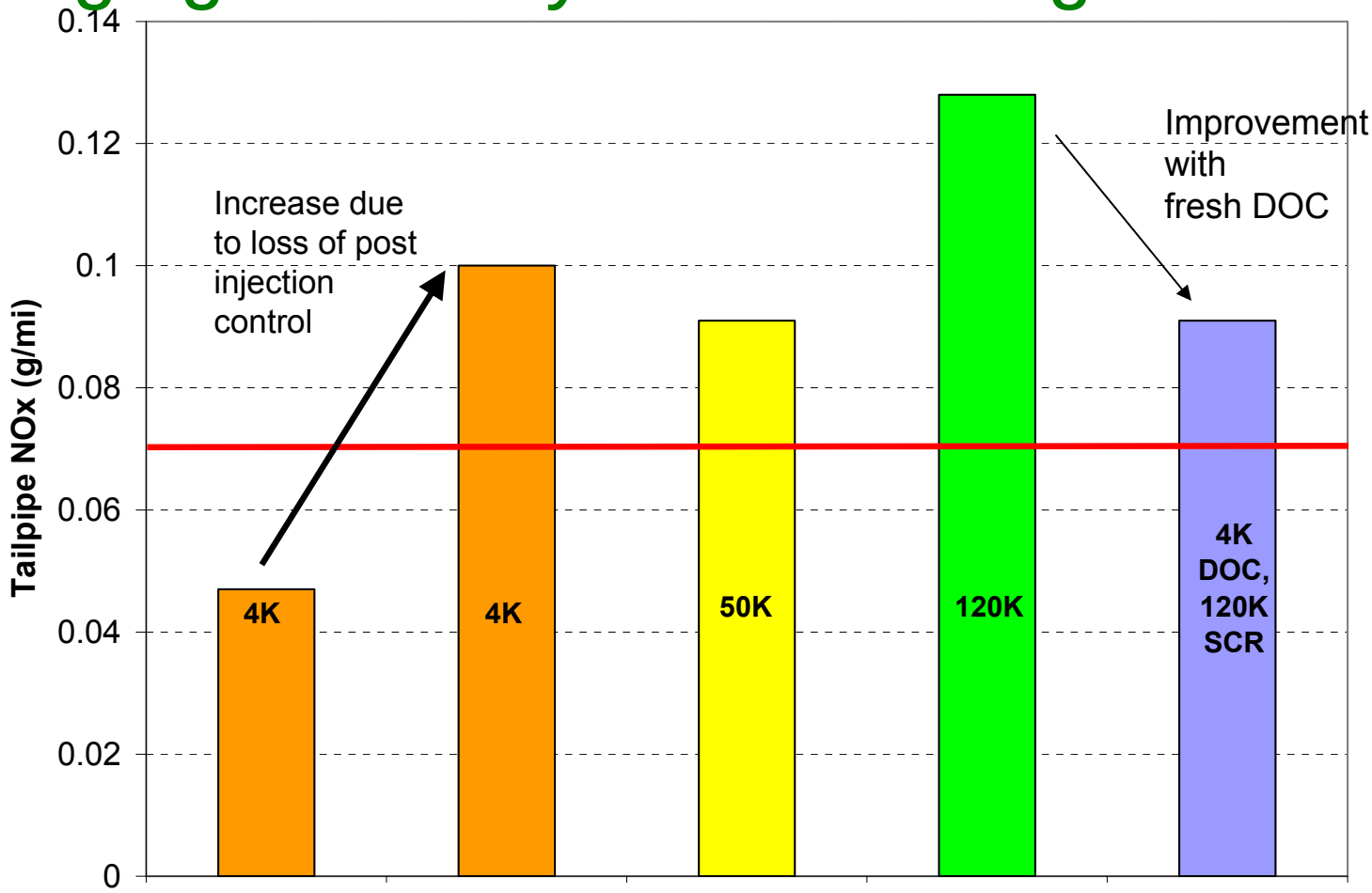
  ~ 6 min per regen

- 643 regens x

  6 min/regen x

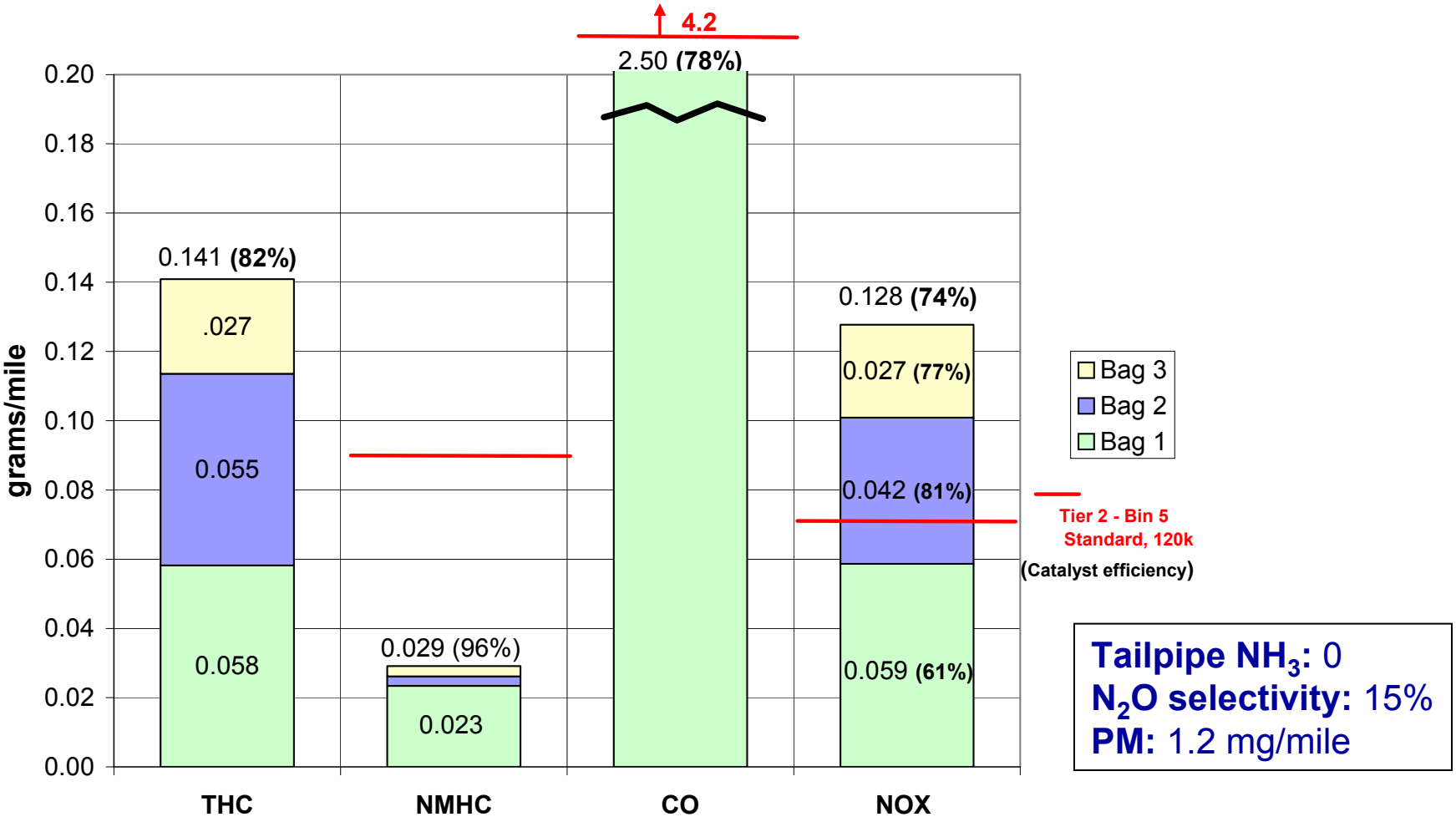
  h/60min = 64 h

Aging Summary: FTP-75 Weighted NOx



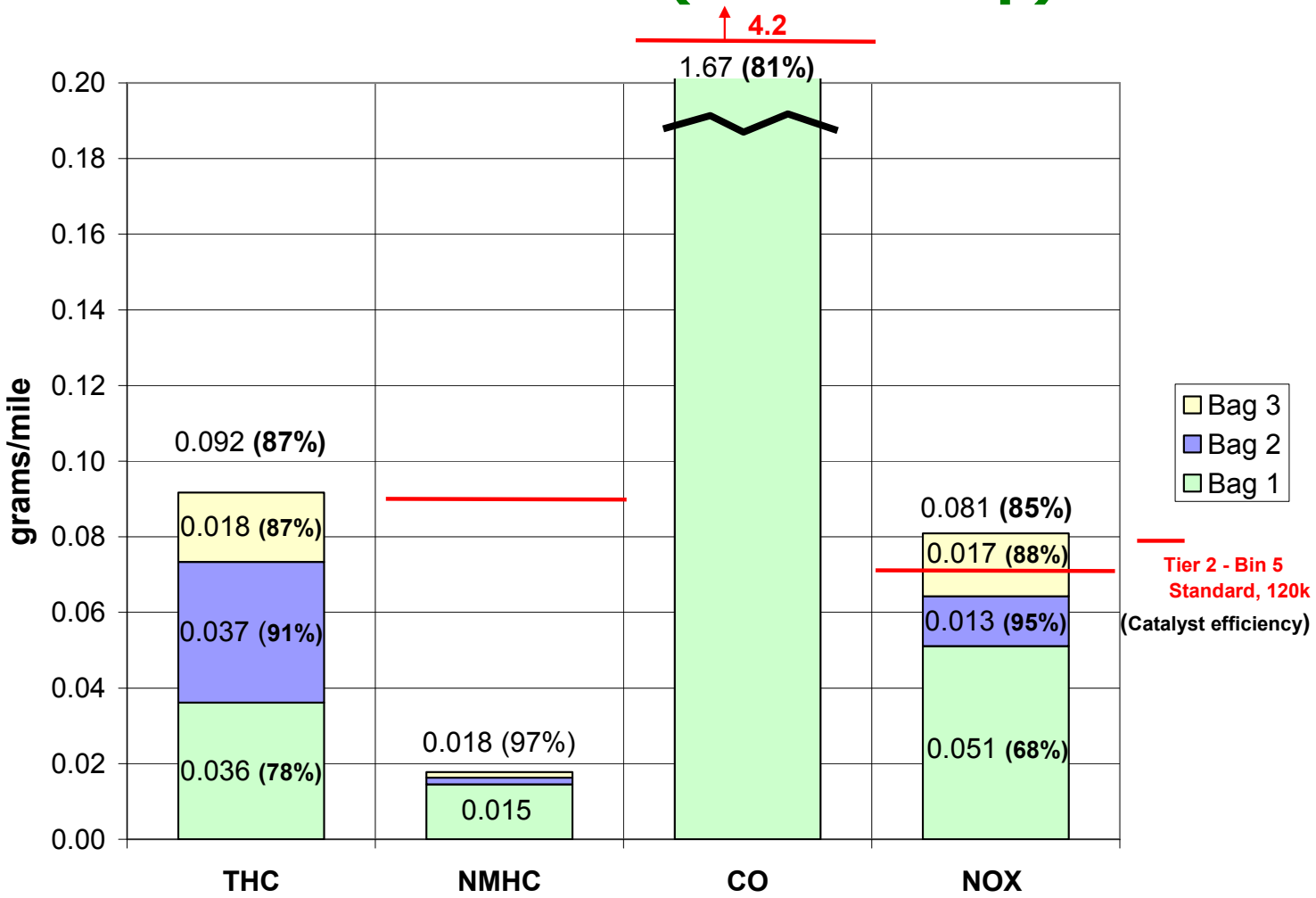
- Loss of DOC activity resulted in higher NOx emissions at 120k mi

Emissions With 120k mi Catalysts on 6000 lb LDT (No Warmup)



- Emissions were below 120k mi Tier 2 Bin 5 standards except for NOx

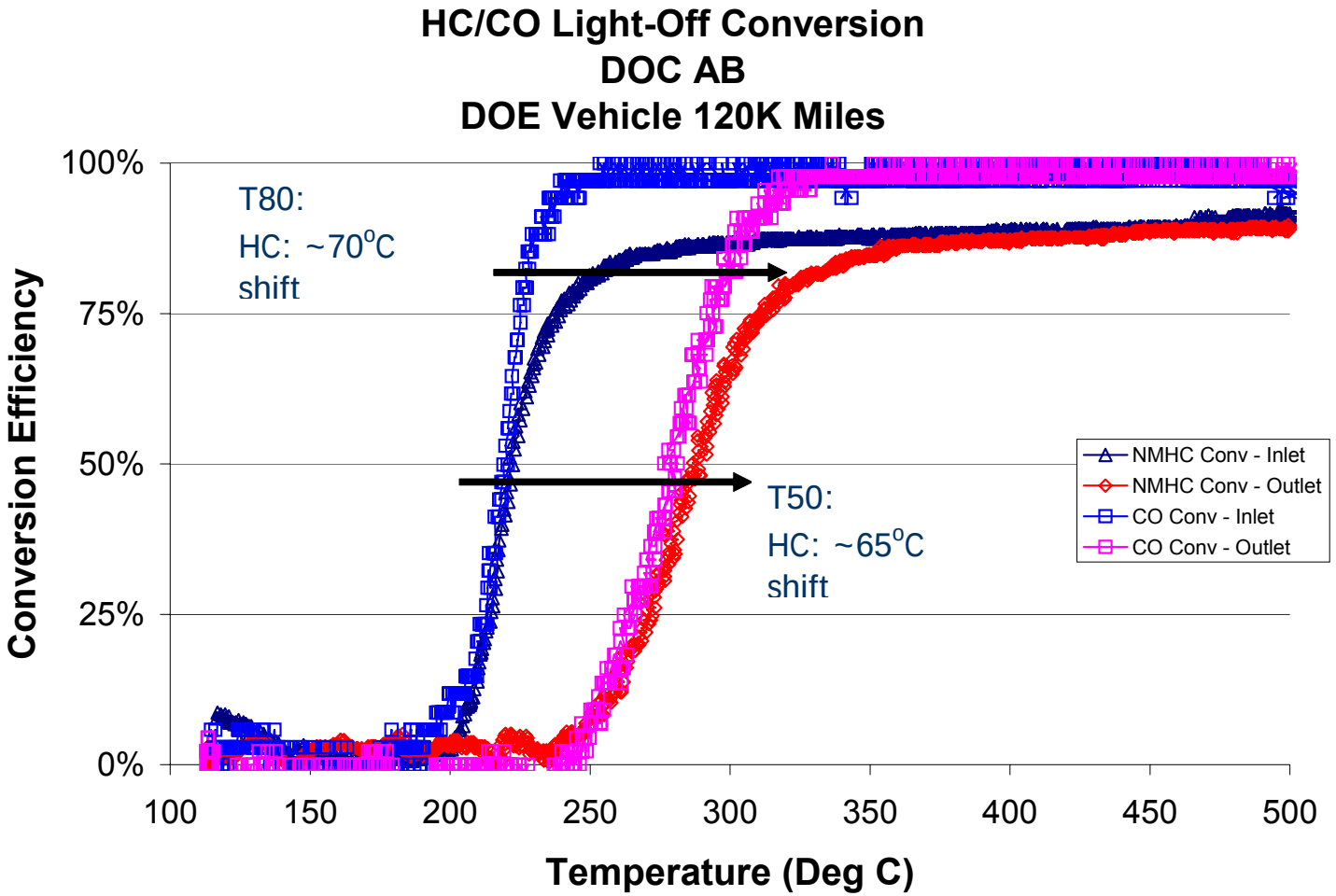
Emissions With 120k mi DOC and Lab Aged Improved SCR on 6000 lb LDT (No Warmup)



- Improved SCR catalyst was less sensitive to NO_2/NOx ratio

3. Post Mortem Phase

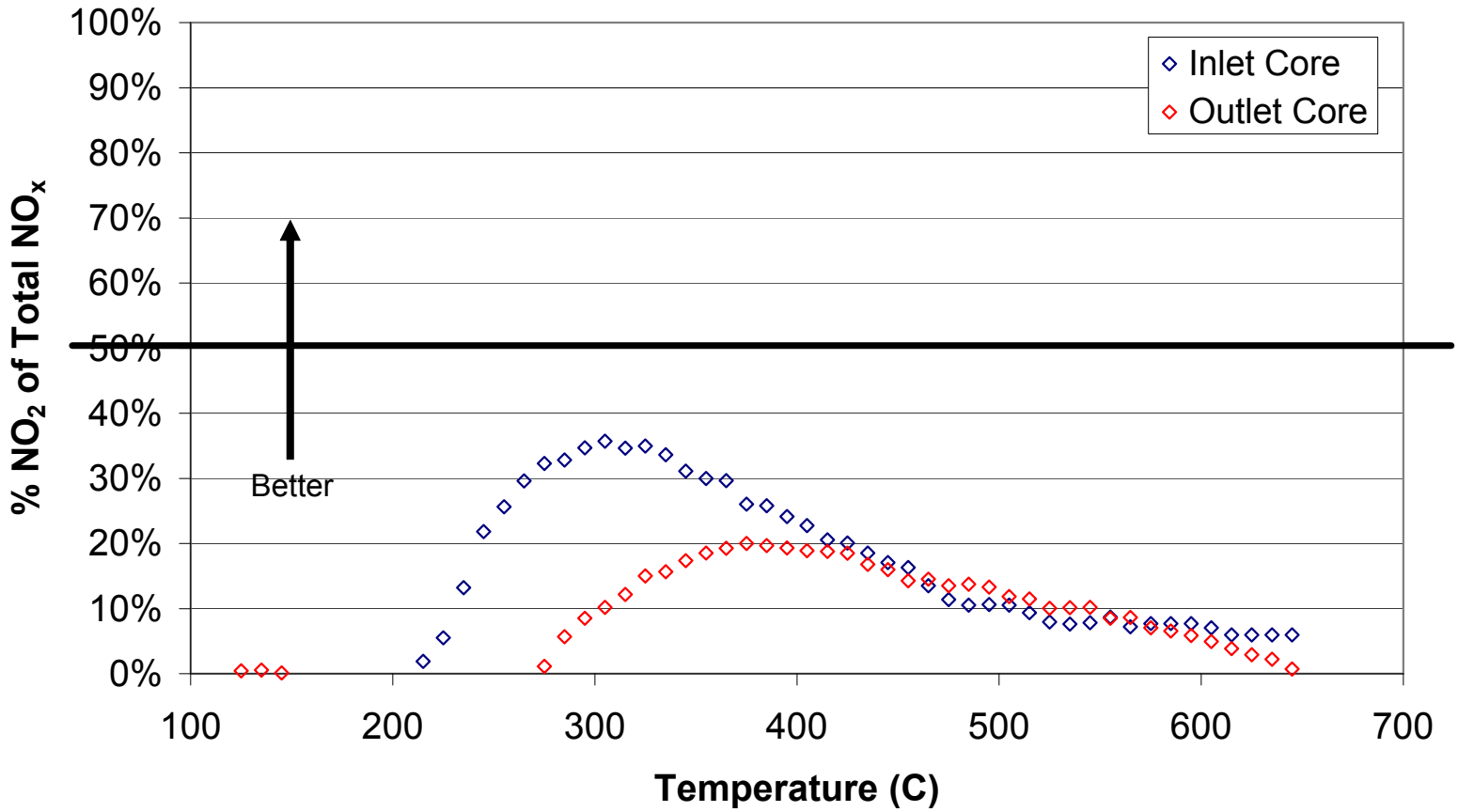
DOC HC and CO Oxidation



- **Key deactivation of inlet is chemical poisoning due to phosphorous deposition.**
- **Key deactivation of outlet is due to fuel combustion required for DPF regen.**

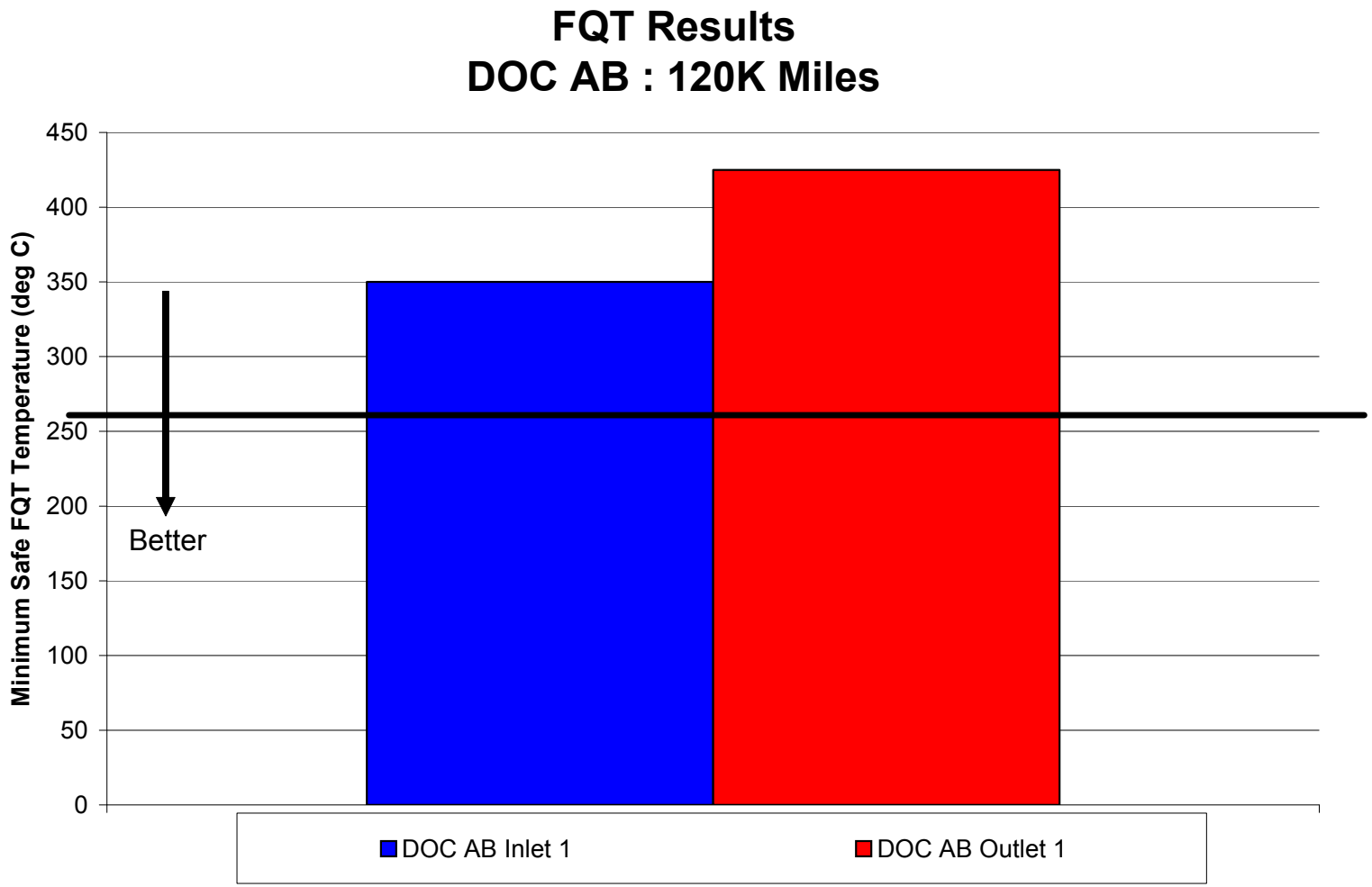
DOC NO Oxidation

NO_2:NO_x
DOC AB : 120K Miles



- **NO oxidation is more deactivated at the outlet of the 120k mi engine aged DOC**

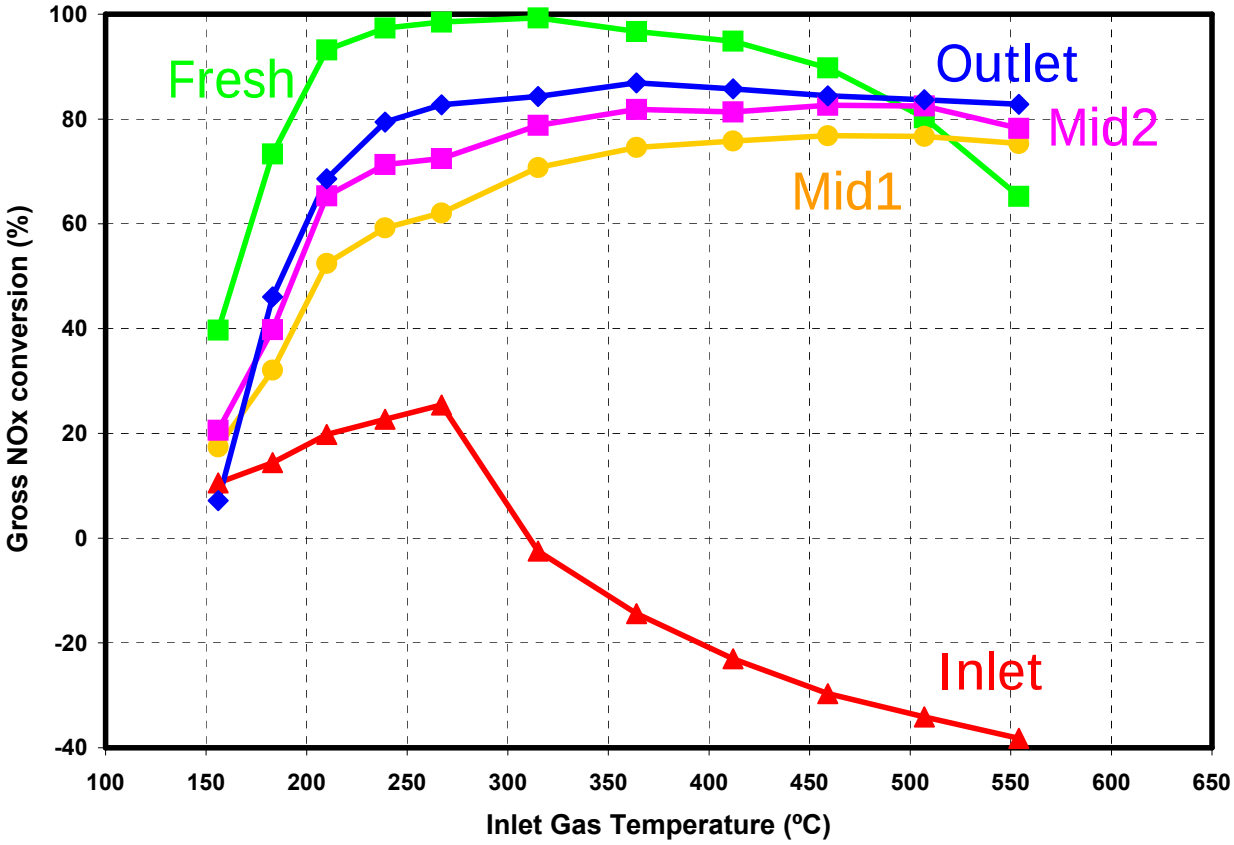
DOC Fuel Quench Temperature



- **DOC outlet requires an inlet of 425°C to maintain DPF regeneration conditions.**

Post Mortem of 120k mi SCR – Core#1

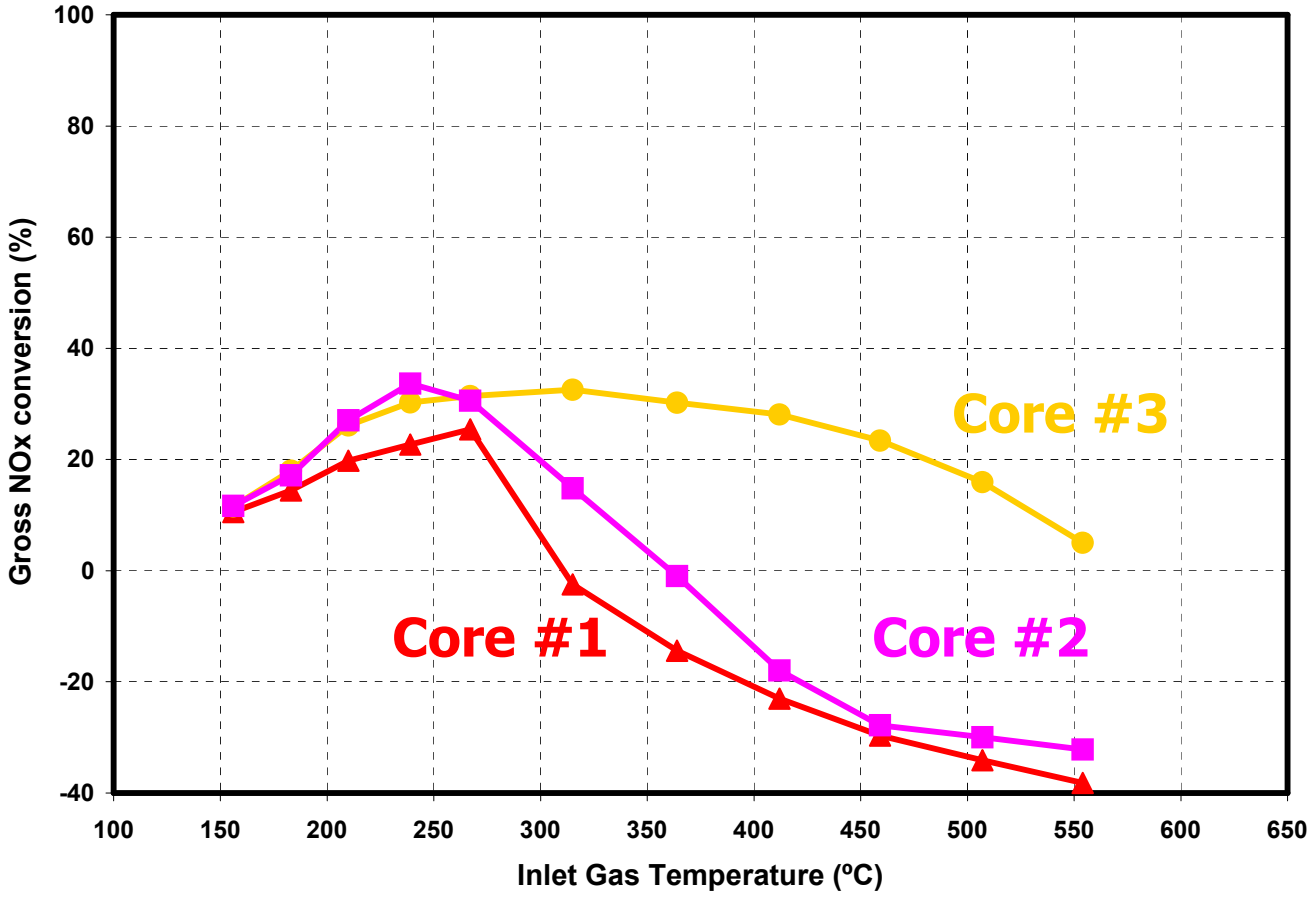
NO only and SV=30,000/hr



- **120k mi engine aging of SCR catalyst upstream of filter was non-uniform**
- **Outlet of engine aged SCR correlates well to the 64hr/670°C hydrothermal aging**
- **Inlet was most severely aged – work ongoing to understand**

Deactivation of Inlet of 120k mi SCR

NO only and SV=30,000/hr



- **Severe deactivation is observed at inlet and across the radius**

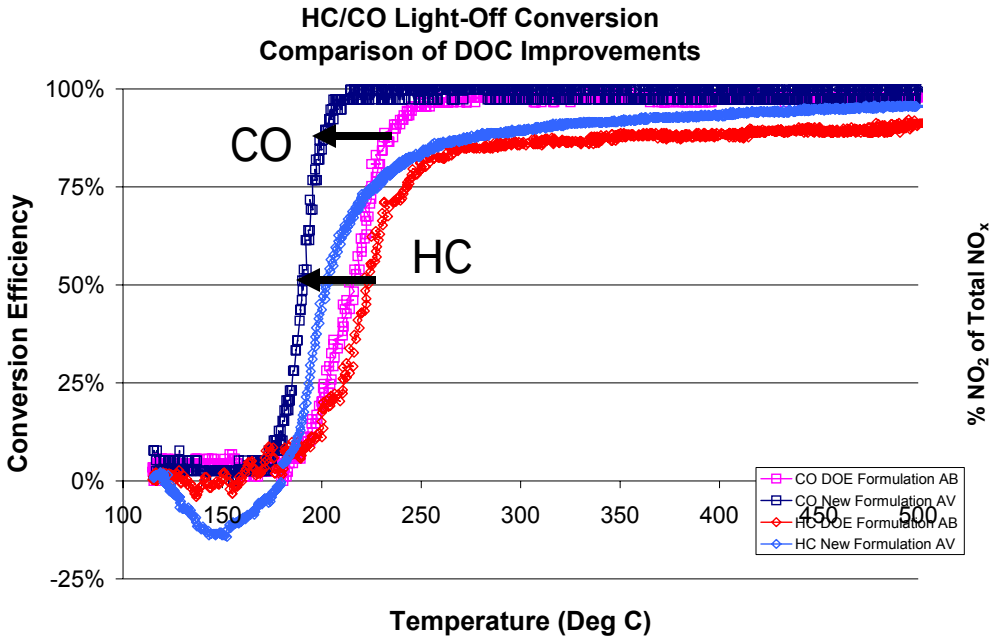
Next Steps for DOC and SCR Post Mortem

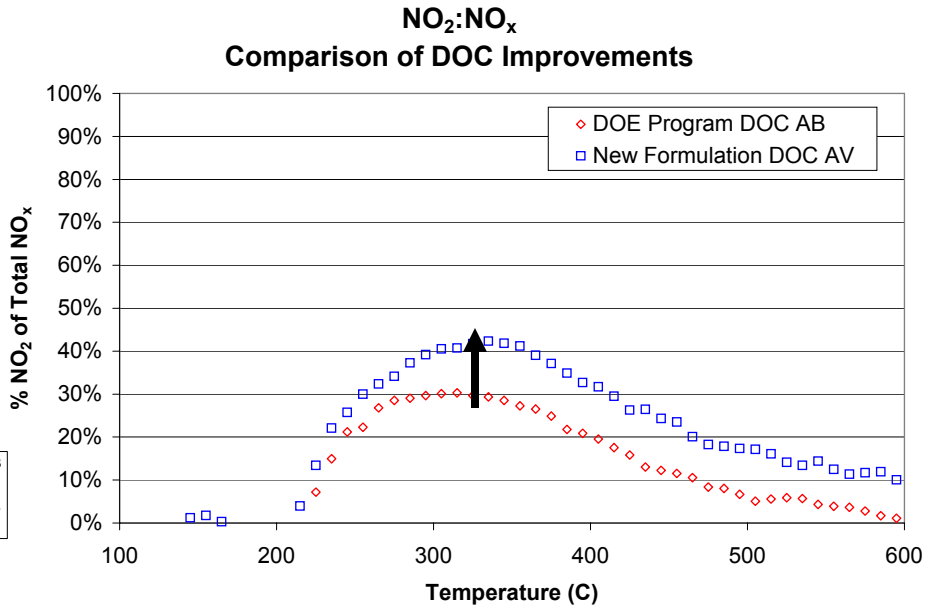
- Investigate possible deactivation mechanisms:
  - Thermal deactivation due to DPF regeneration events
  - Chemical poisoning from oil contamination
  - Washcoat adhesion
  - Contamination from urea by-products (SCR only)

- Develop new formulations that are more robust

4. On-going Catalyst Development

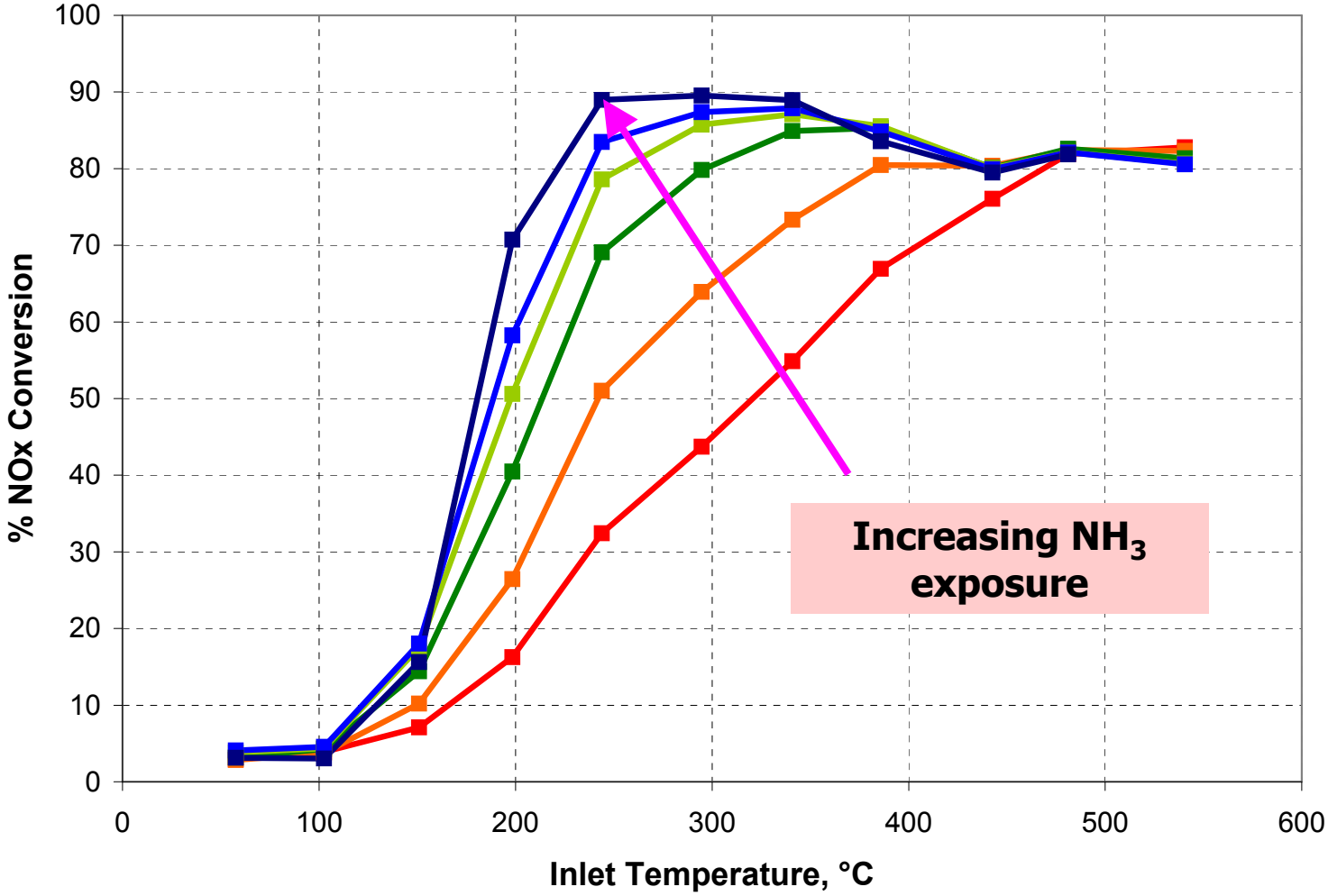
DOC Development





- HC and CO light-off has improved by ~ 20°C
- NO_2 generation has improved by ~10%.

SCR Development: Importance of NH_3 Storage



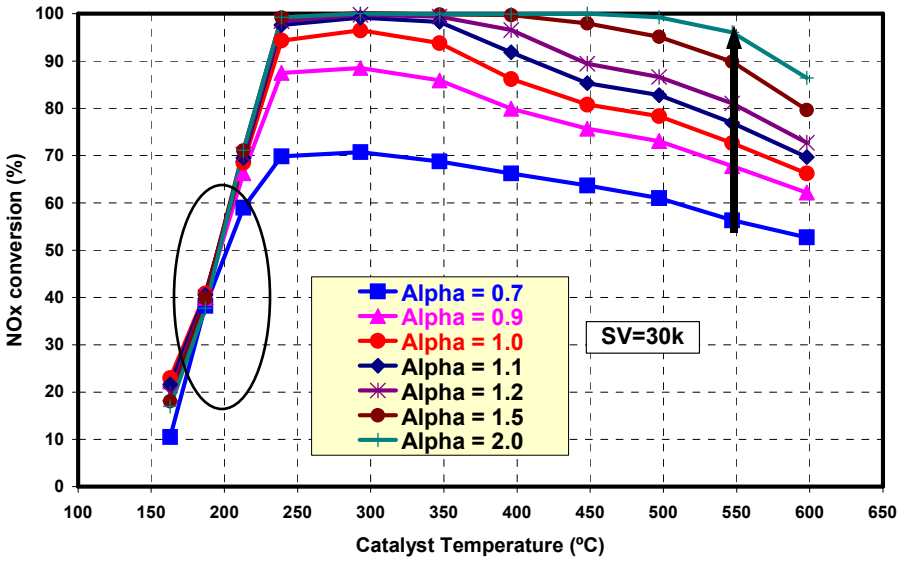
- NOx Conversion of SCRs is strongly related to NH_3 storage

SCR Development: Benefits of Over-Dosing NH_3 at High Temperature Low Temperature SCR

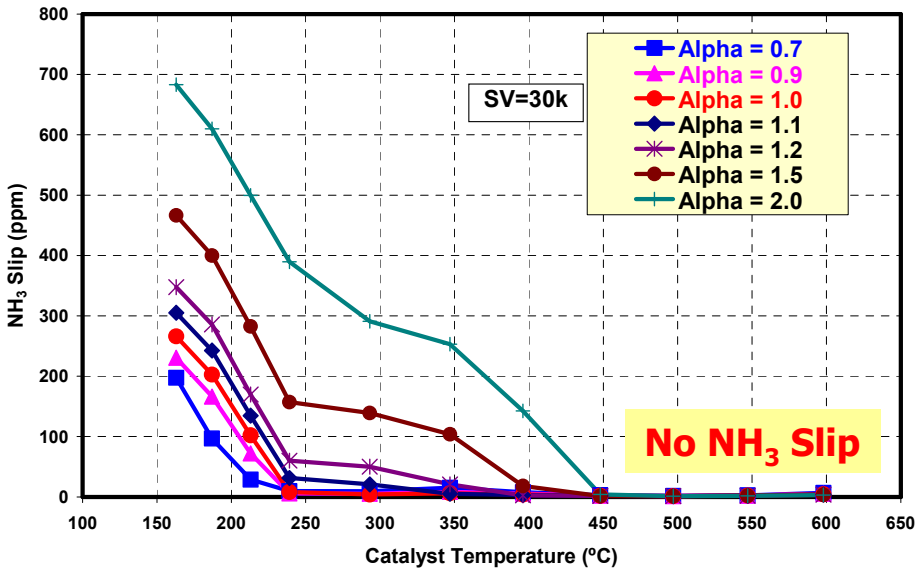
Steady State Performance

Aged 64hrs@ 670°C, SV=30,000/hr, NO only

NOx Conversion

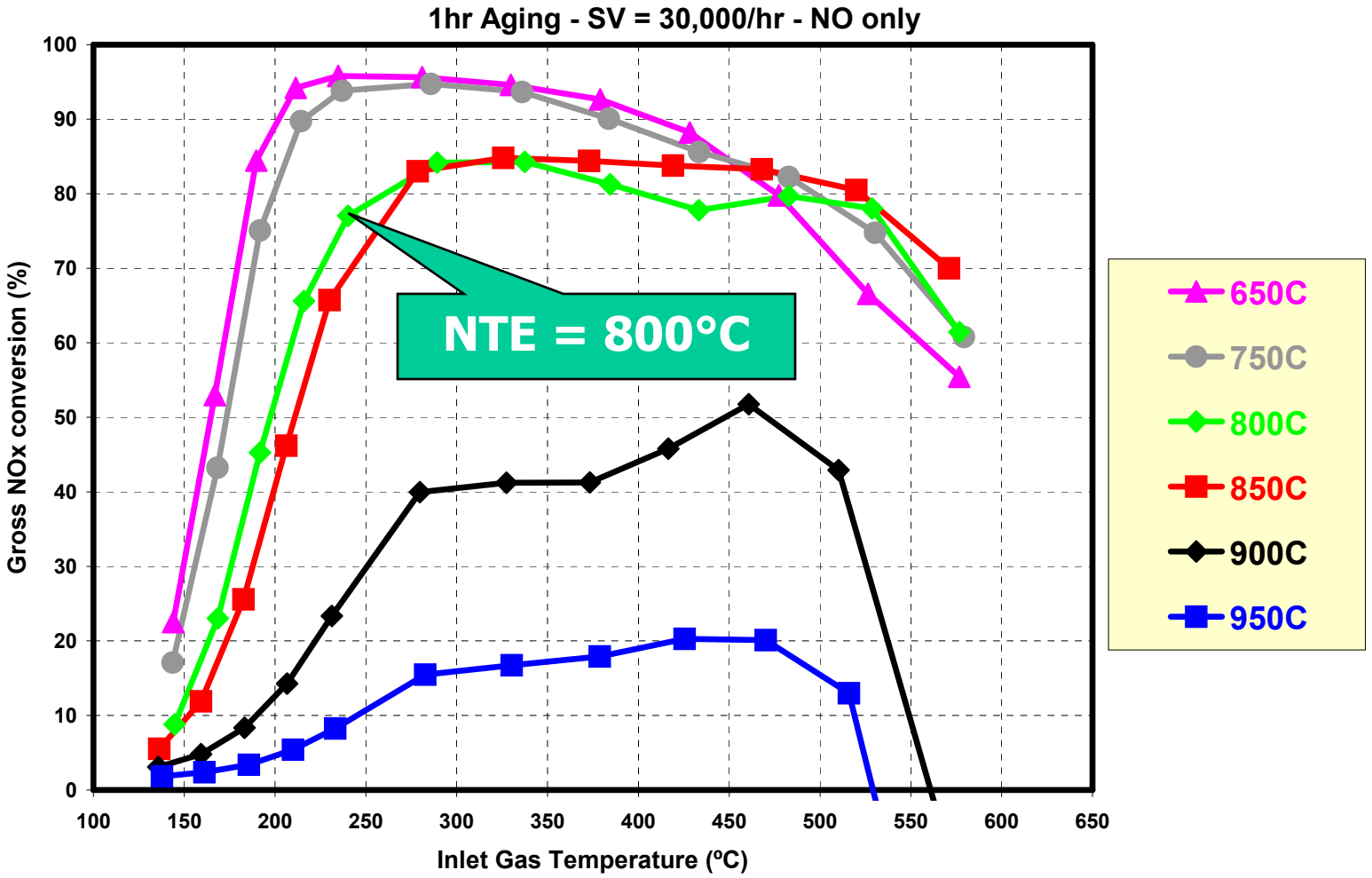


NH_3 Slip



- Excess gas phase NH_3 helps high temperature but no improvement is possible below 200°C
- NH_3 slip is controlled when over-dosing above 450°C

SCR Development - Never-to-Exceed Temperature



- Robustness to occasional high temperatures during DPF regeneration is required

Conclusions

- Urea SCR has most potential to reach Tier 2 for light-duty trucks. Base metal zeolites are superior to vanadia for NA applications.
- After 120k mi of engine aging, a DOC-SCR-DPF system met Tier 2 standards except for NOx. A new SCR formulation that was less sensitive to inlet NO_2/NOx ratio resulted in tailpipe NOx that approached the standard.
- Post-mortem testing of the 120k mi catalysts revealed non-uniform activity. The outlet of the DOC and inlet of SCR were most severely deactivated.
- Improvements were made in DOC formulation for HC, CO and NO oxidation.
- Pre-stored NH_3 and overdosing of NH_3 increased overall activity of base metal/zeolite SCR catalysts.
- Base metal/zeolites are robust enough to handle DPF regeneration temperatures.

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