Combined SCR/DPF System for Tier 2 LDT

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DOE Ultra-Clean Fuels Program

Outline of Ford's program to achieve Tier 2 emission standards for 2007 using low sulfur diesel fuel as an enabler for a high efficiency aftertreatment system.

Primary Contractor

Ford Research and Advanced Engineering

Subcontractors

ExxonMobil Research and Engineering

FEV

Catalyst Suppliers

Engelhard

Johnson Matthey

umicore

Phase I - Initial build/test phase (July01-July02)
- Establish baseline emission control system
- Deliver engine dynamometer NOx and PM test results
- Deliver prototype vehicle NOx and PM test results
- Deliver urea delivery (infrastructure) prototype

Phase II - System/component optimization phase (July02-July04)
- Define final system hardware components
- Deliver NOx and PM performance data from fresh system

Phase III - Durability phase (July04-Dec05)
- **Definition of durability test procedure**
- **Final NOx and PM emission levels**
- **Final report for the completed program**

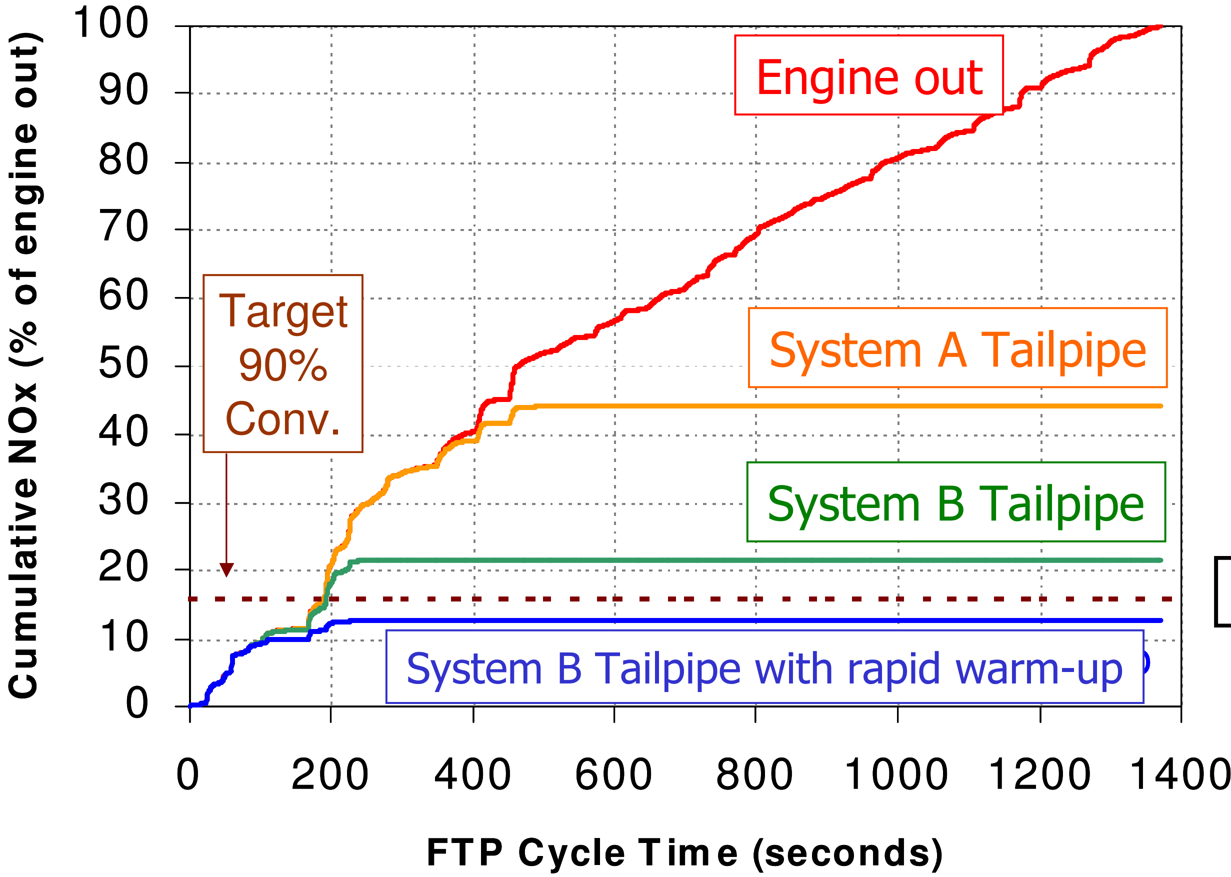
Program Objectives (2001)

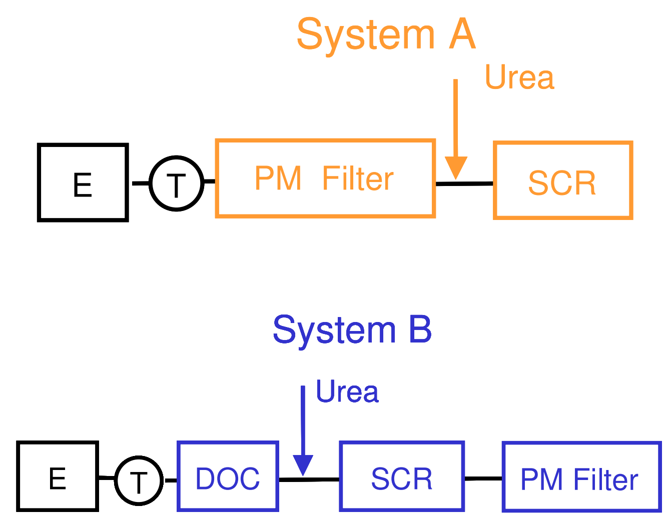
- 0.07 g/mi NOx
- 0.01 g/mi PM
- 120,000 miles of durability

Use of Modeling for Improved SCR Function

- Predict system performance
  - Predict NOx conversion levels
  - Predict fuel economy impact
  - Provide direction for system design
- Evaluate system performance
  - Diagnose problems with system hardware/strategy
  - Provide direction for future system testing

Example: Prediction of FTP-75 Performance

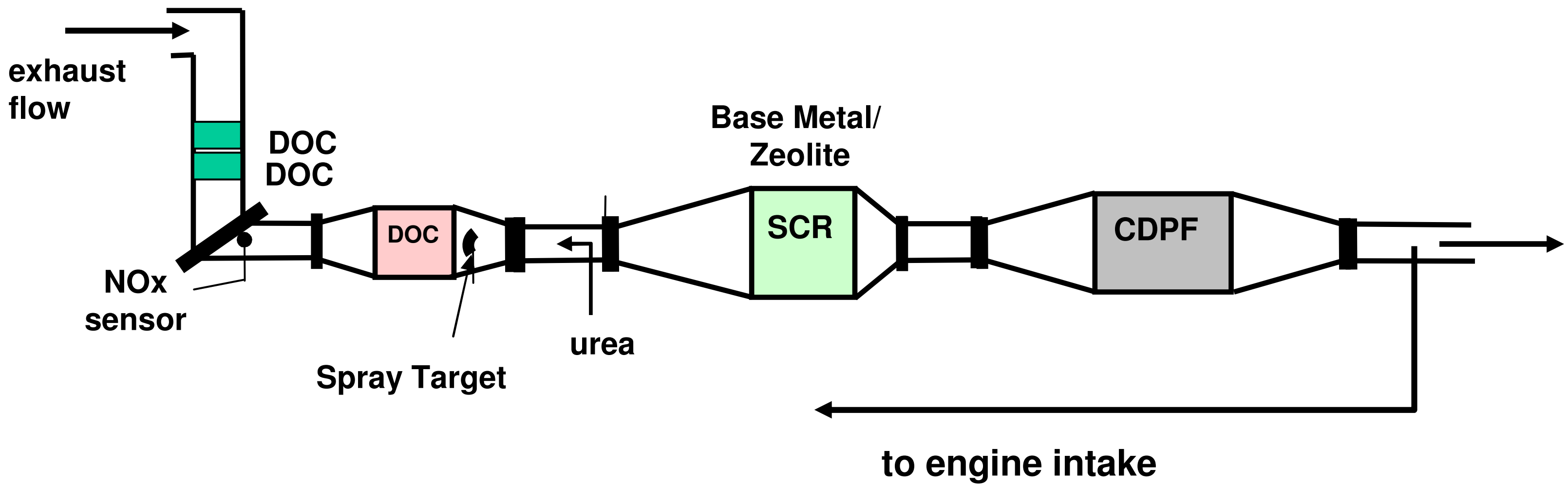




Rapid warm-up = extra 50°C ramped in over first 30s of test.

LDT Exhaust System (NOx)

>90% FTP NOx conversion, 0.05 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)

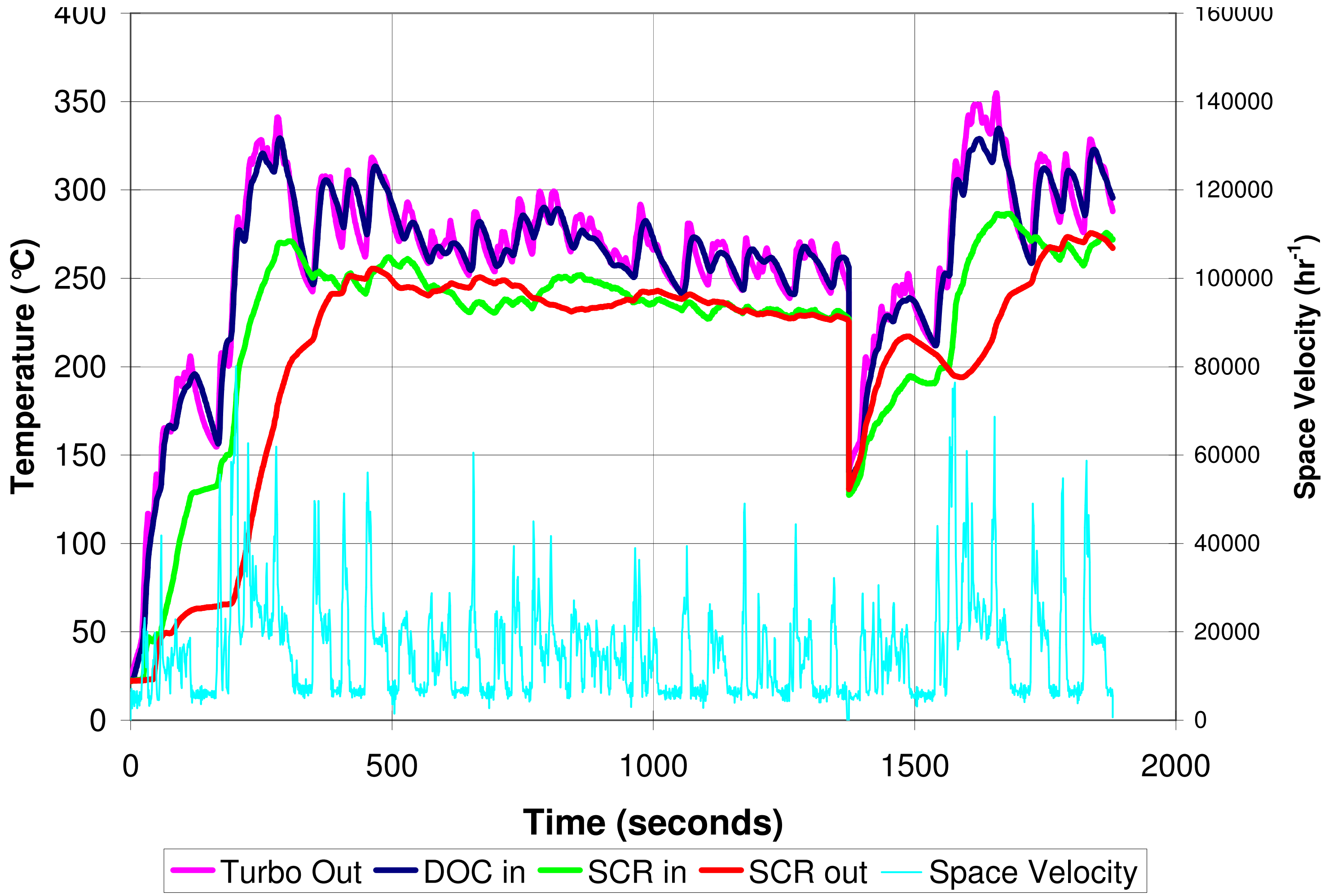
Diesel Fuel Properties

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

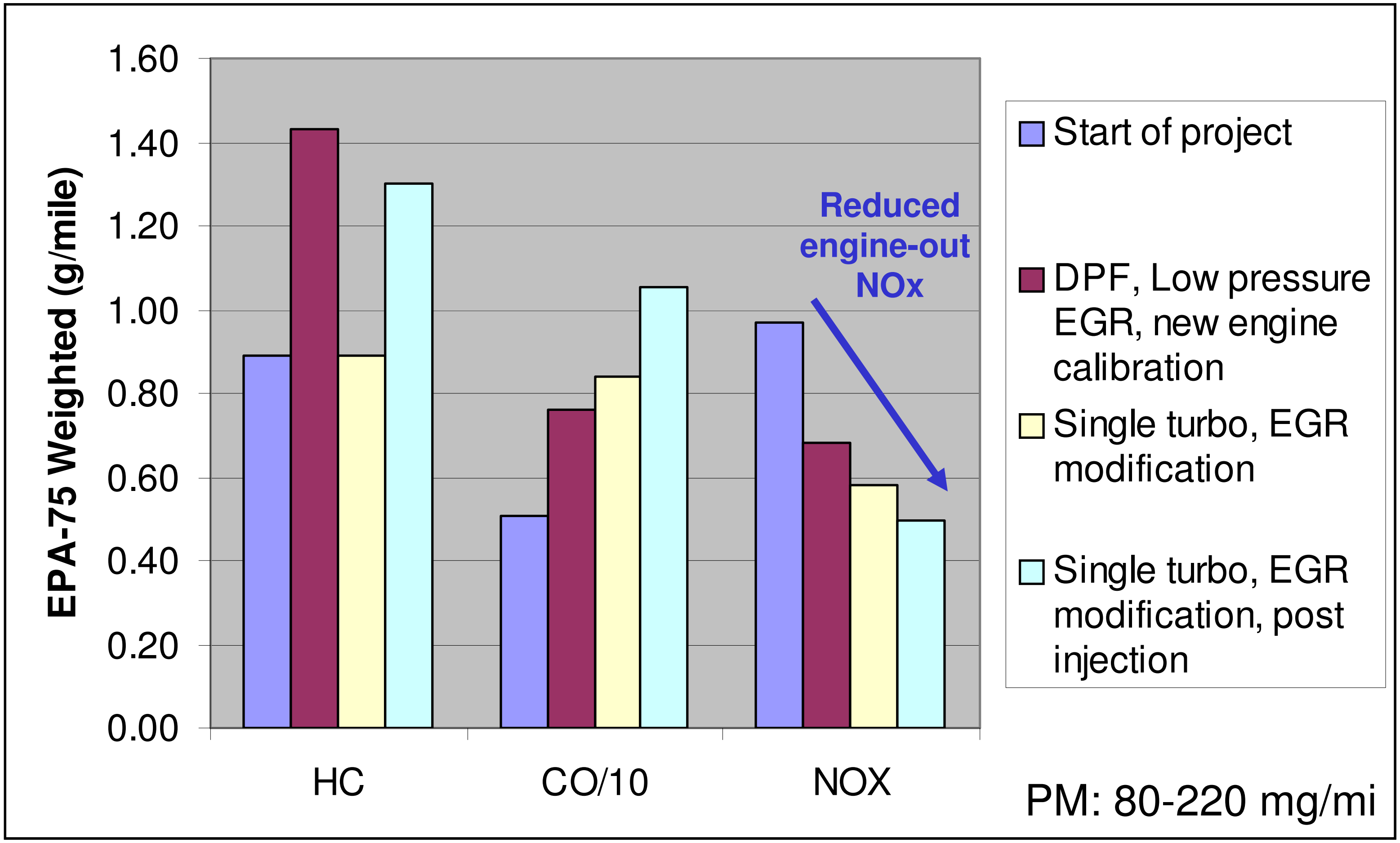
Fuel Property	Est. Avg. '06 Diesel Properties	Proposed DOE Prog. Min/Max	Program Fuel Delivered	Proposed 2007 Cert. Fuel
Sulfur, ppm	15*	10 / 15	**12.5**	7 / 15
Density, kg/m^3	850	820 / 850	**841.1**	839 / 865
Aromatics, vol. %	32	25 / 32	**29.5**	27 min
Polyaromatics, wt. %	10	6 / 11	**11.0**	no spec
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

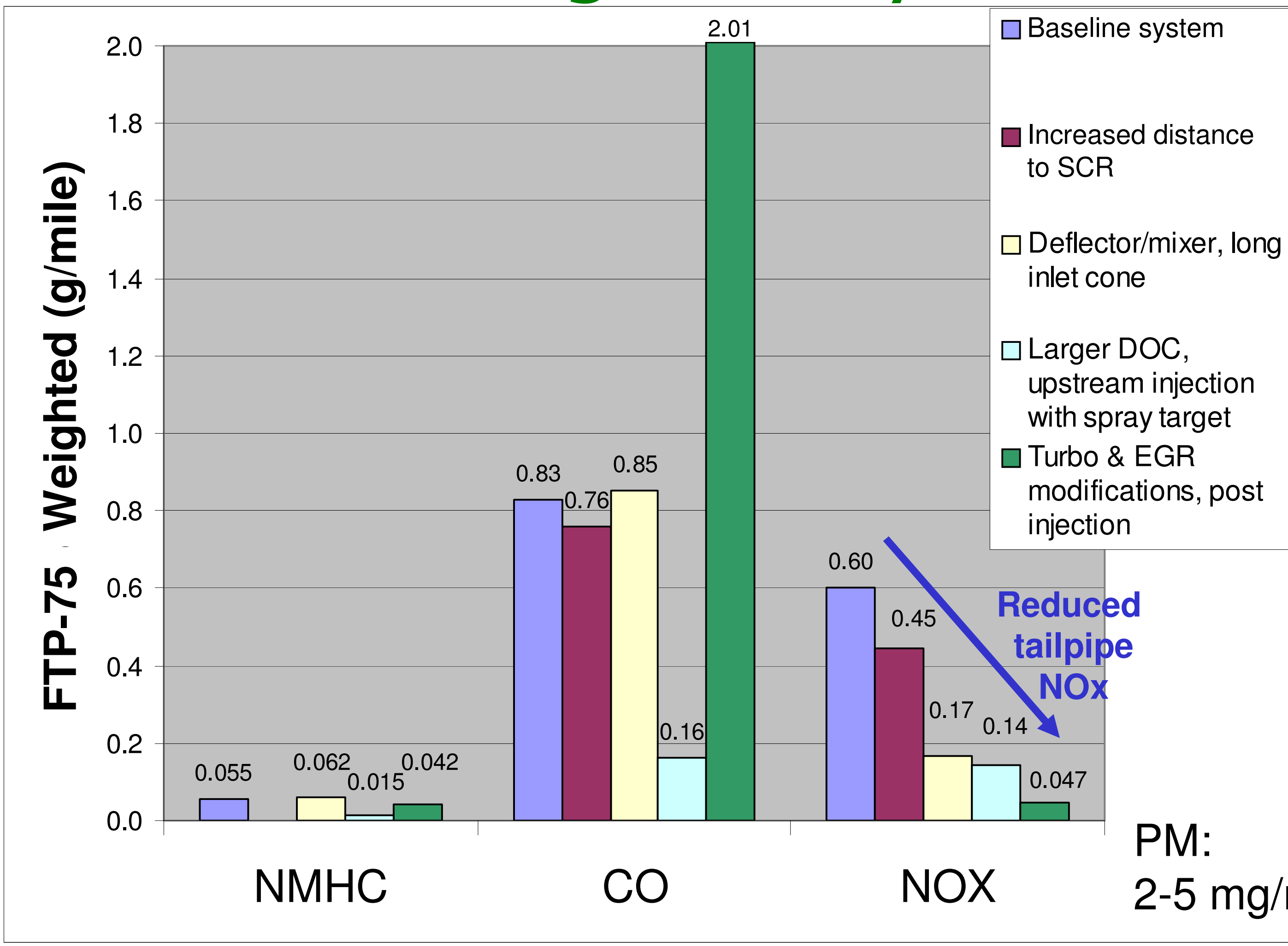
LDT Temperatures and Space Velocity on FTP-75
(without rapid warm-up strategy)



LDT Engine-Out Emissions at 6000 lbs

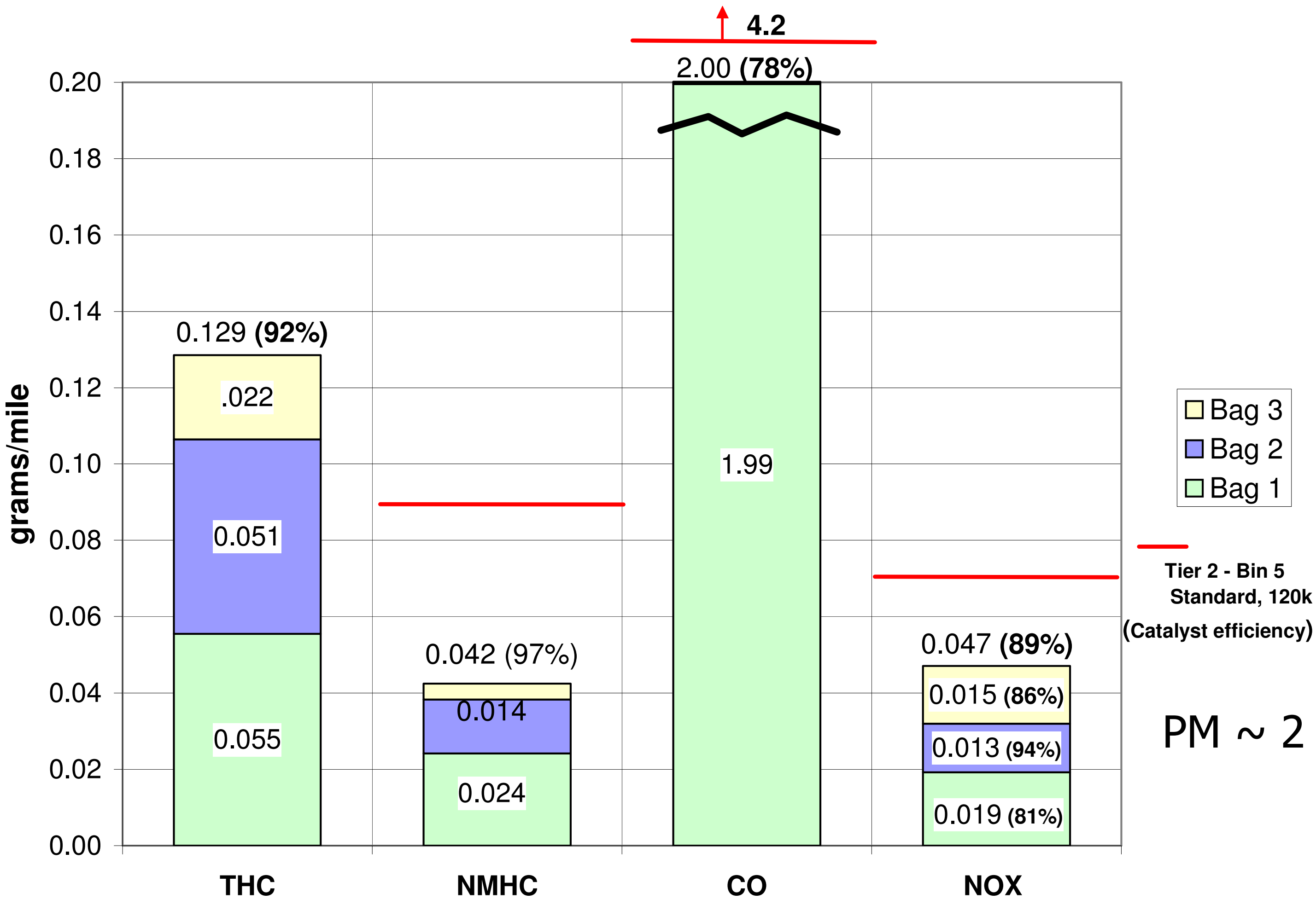


Weighted Tailpipe Emissions with Low-mileage Catalysts on LDT



PM:
2-5 mg/mi

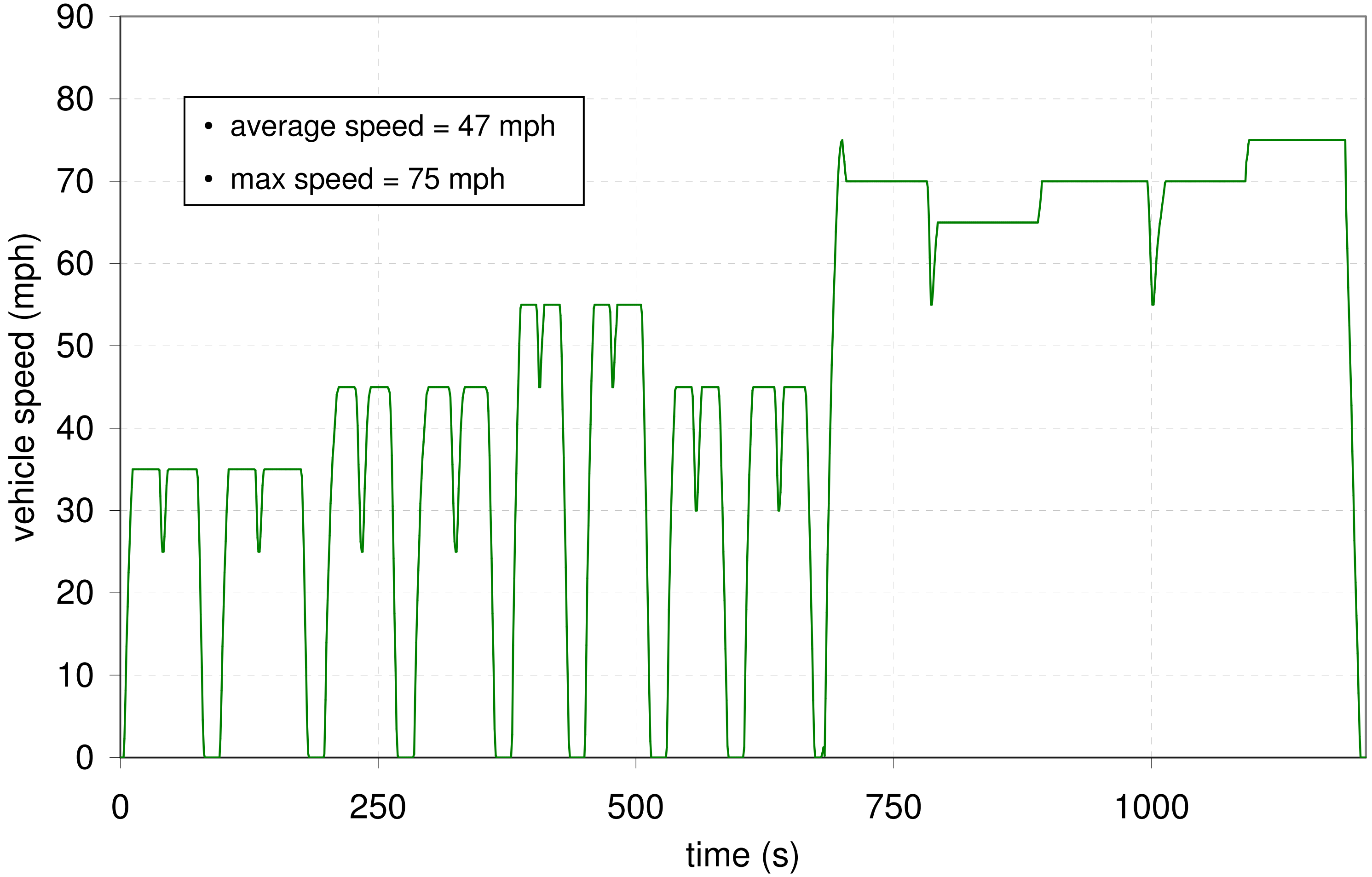
Low-mileage FTP-75 Emissions with 6000 lb LDT



PM ~ 2 mg/mi

Durability Test Definition (Dyno Aging)

Ford High Speed Cycle (HSC)

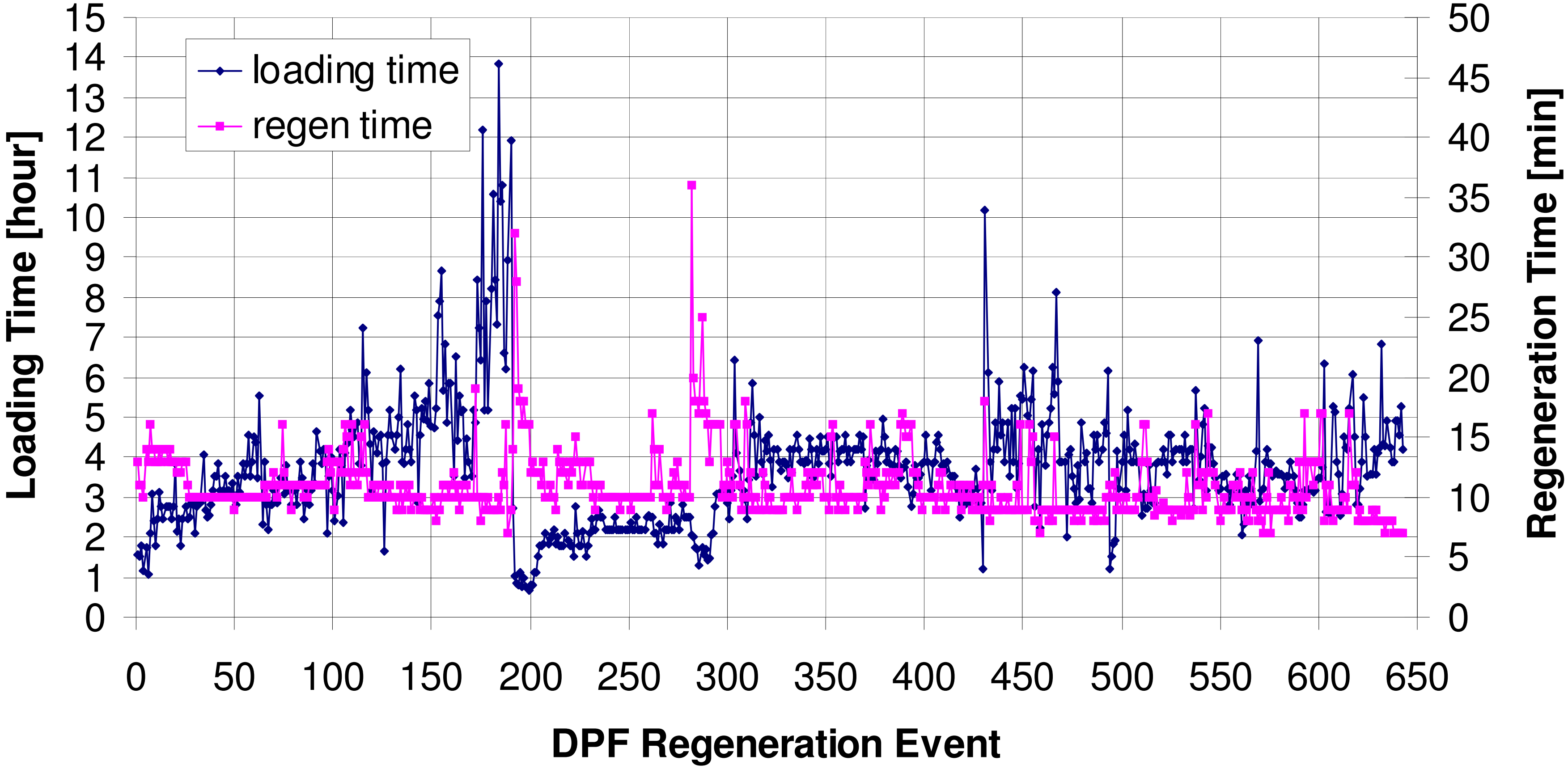


120,000 Mile Dyno Aging Summary

- Engine hours = 2554
- Accumulated mileage = 120,000
- Number of DPF regenerations = 643

- Typical Regeneration Time ~ 10 min *(includes T ramp up)*
- Typical time at high Temperature in SCR ~ 6 min per regen
- 643 regens x 6 min/regen x h/60min = 64 h

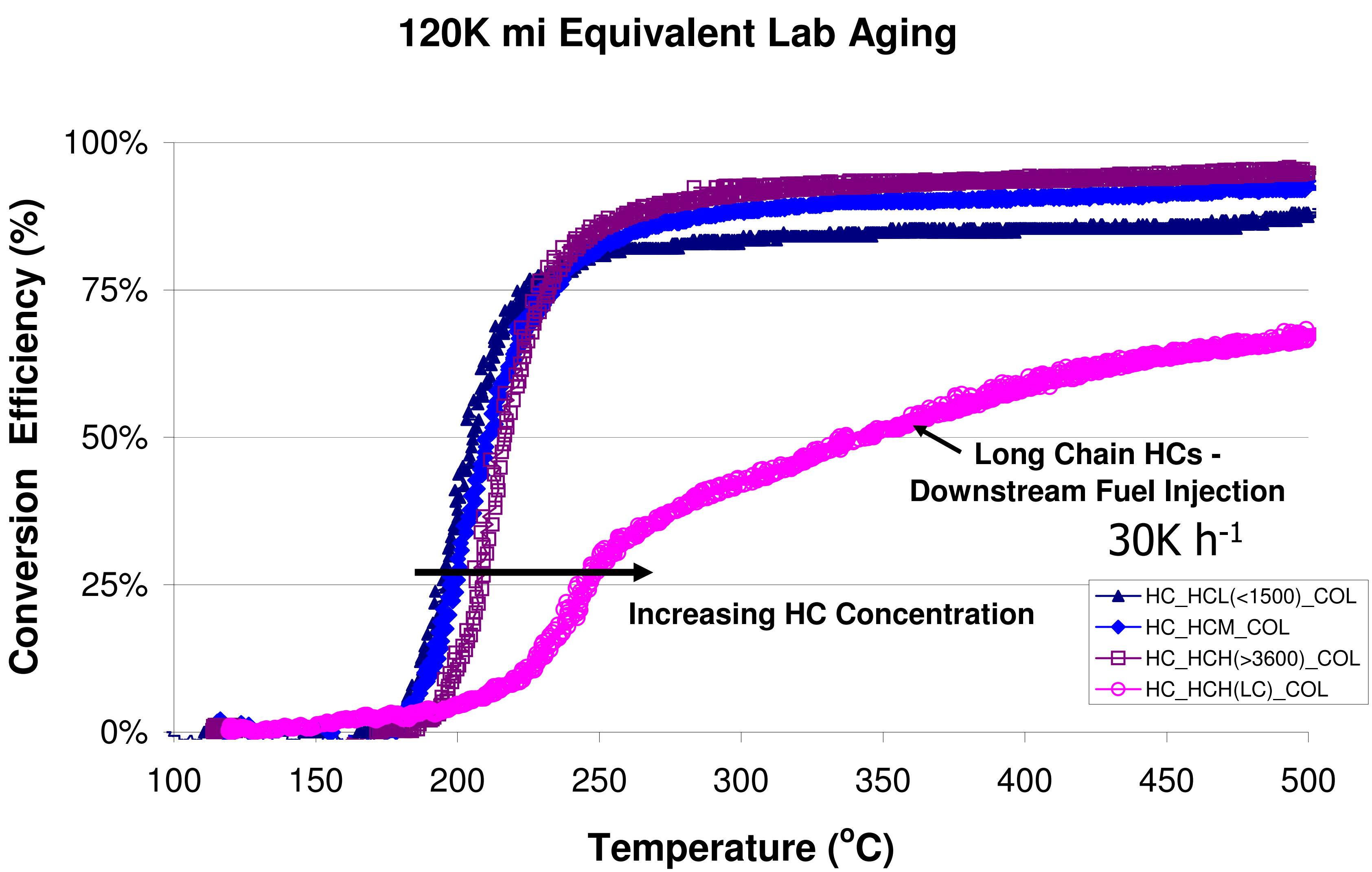
DPF Regeneration History Over 120,000 Mile Aging Procedure On Engine Dyno



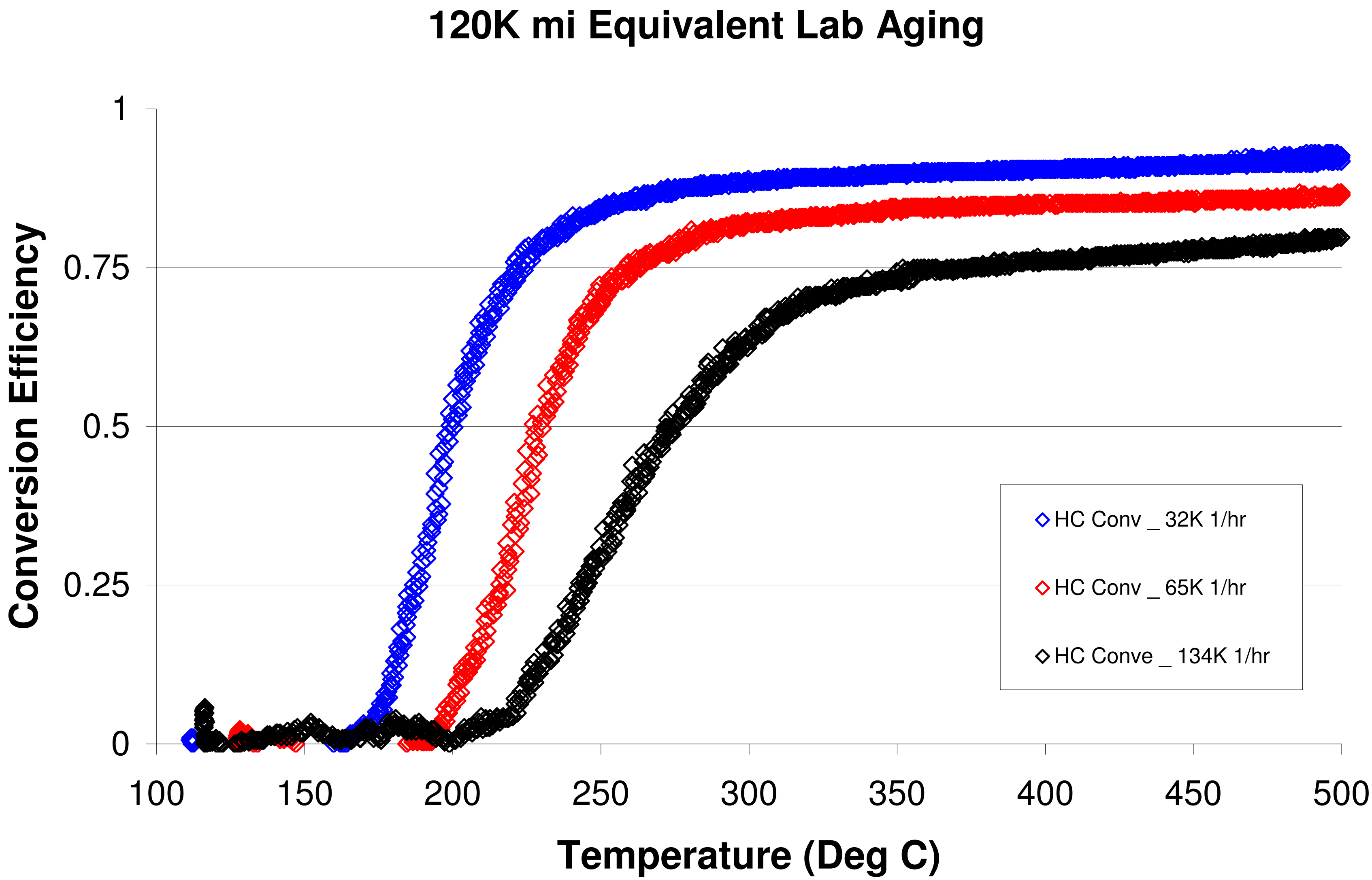
DOC Evaluation – FTP-75

	4k	50k	120k
NO Oxidation	40%	14% single test	5%-30% inconsistent results
HC Oxidation during warmup (with downstream injection)	83%	not tested	47%

DOC Performance Evaluation: HC Light-off

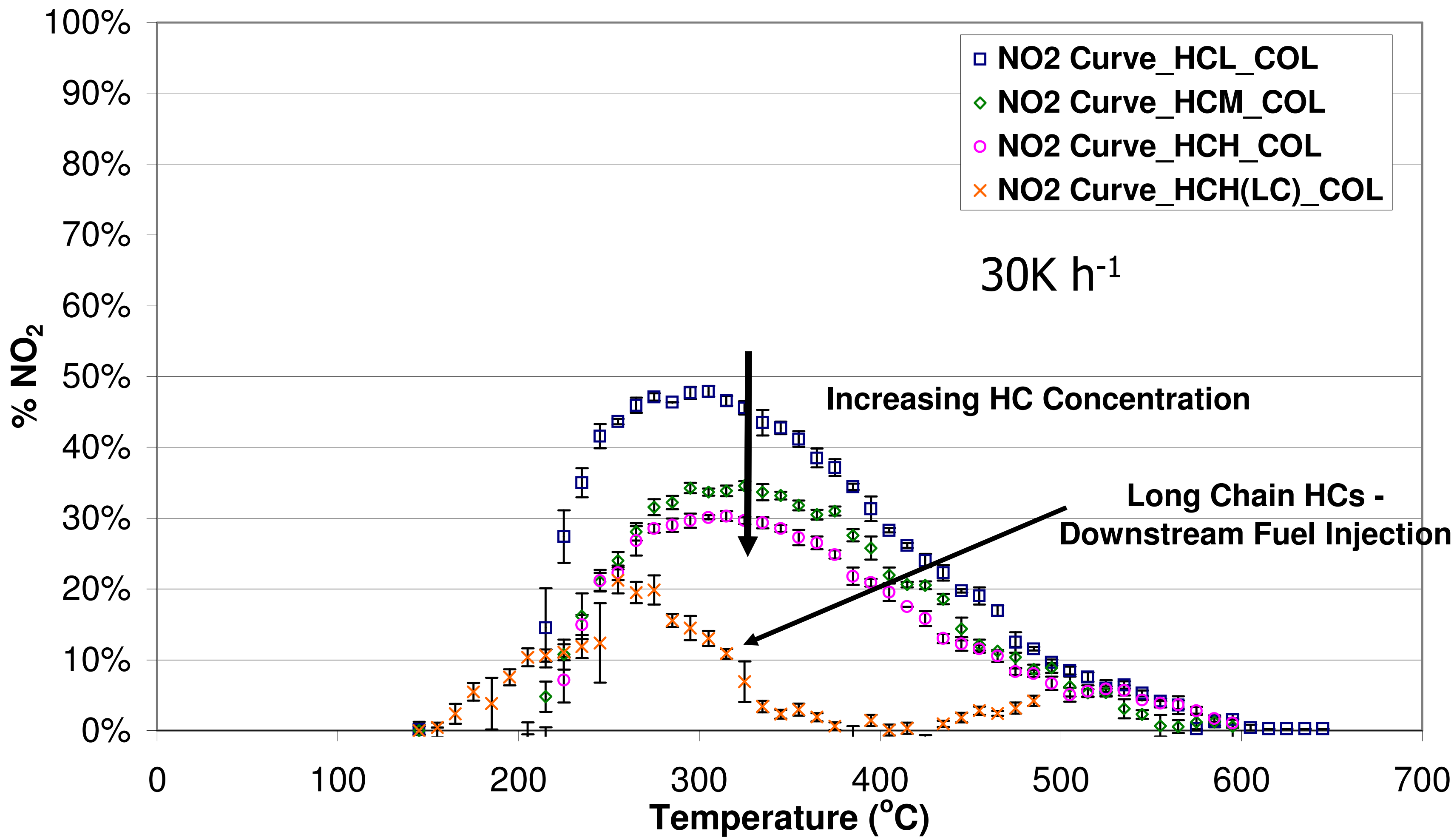


DOC Performance Evaluation: HC Light-off

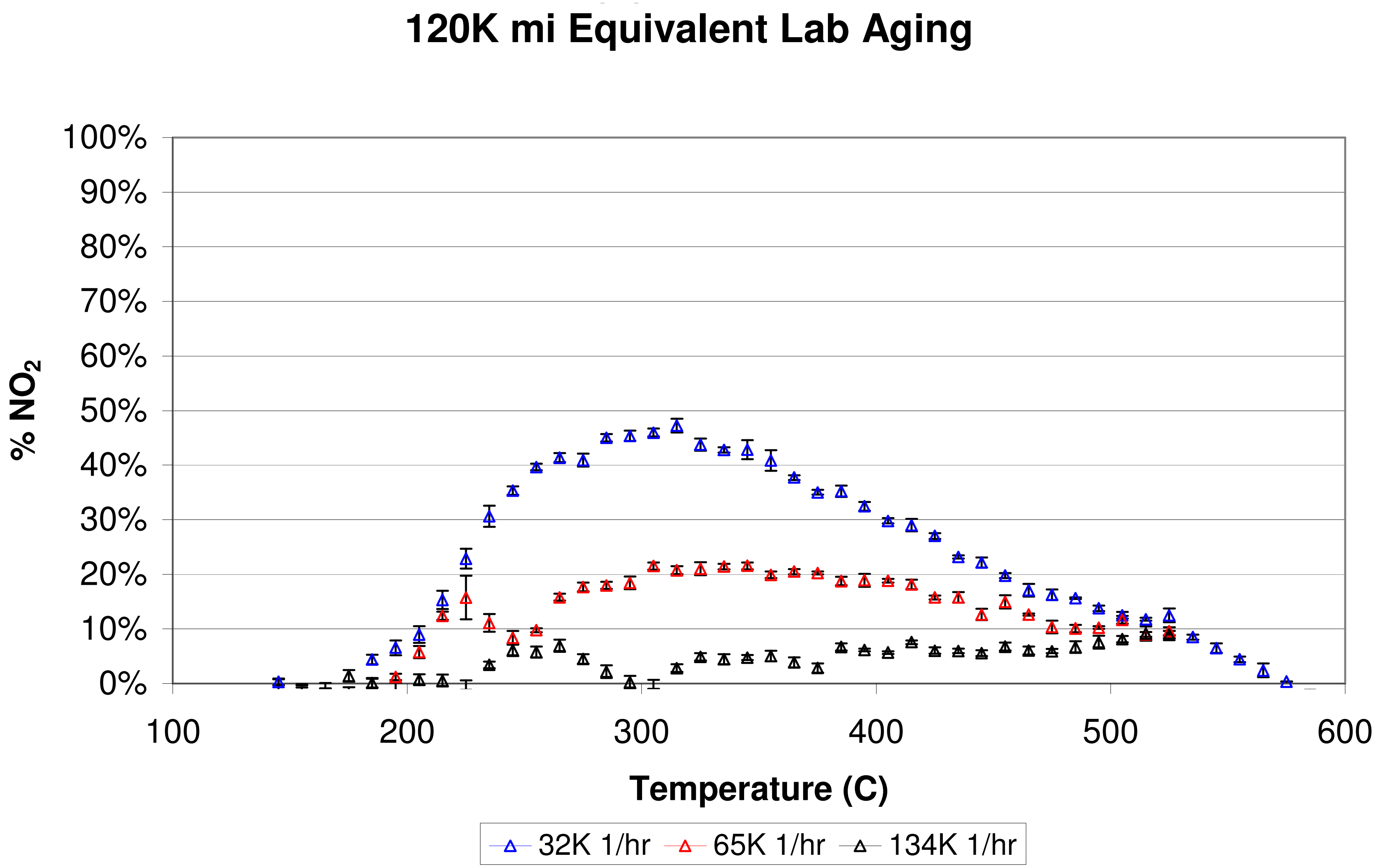


DOC Performance Evaluation: NO Oxidation

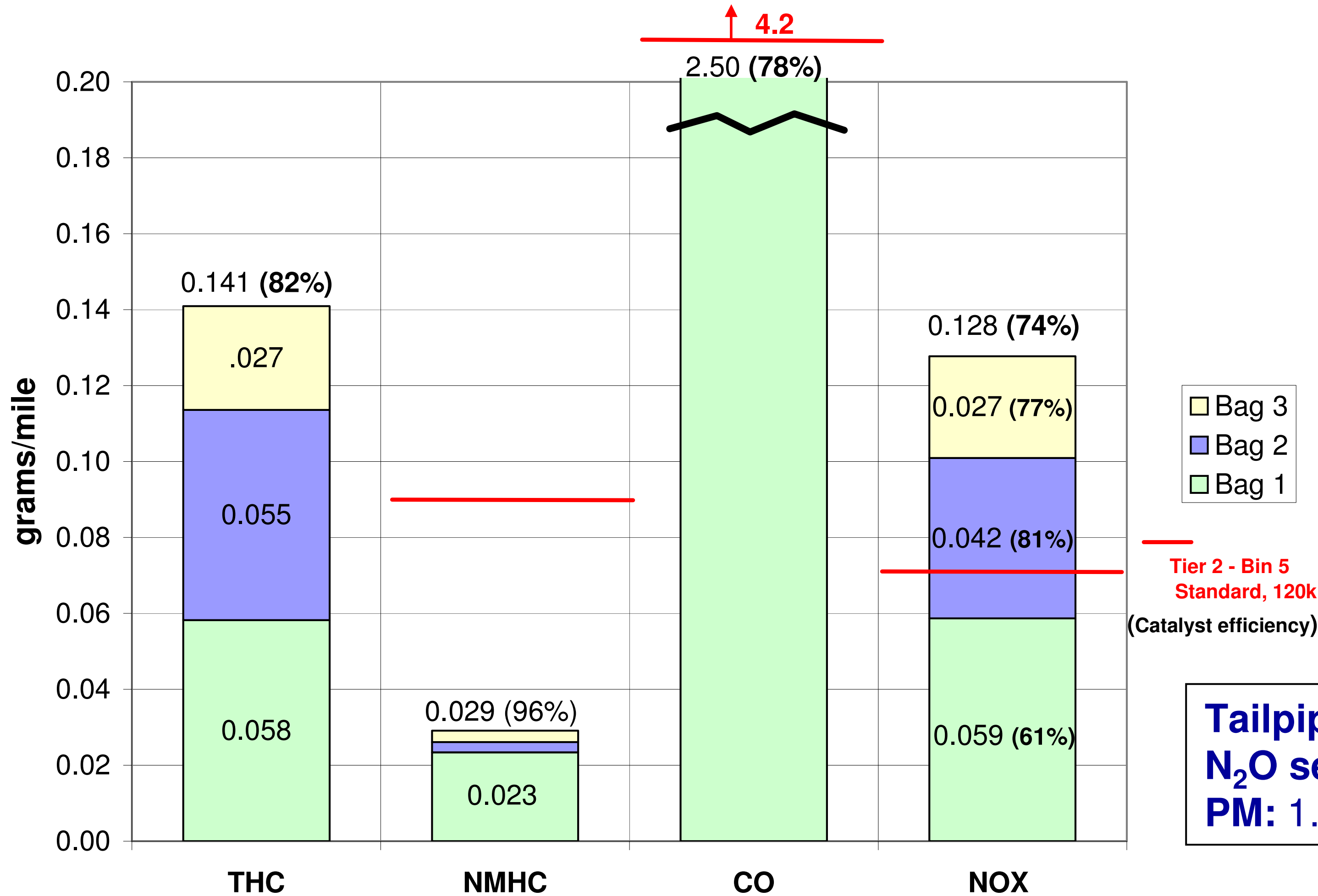
120K mi Equivalent Lab Aging



DOC Performance Evaluation: NO Oxidation



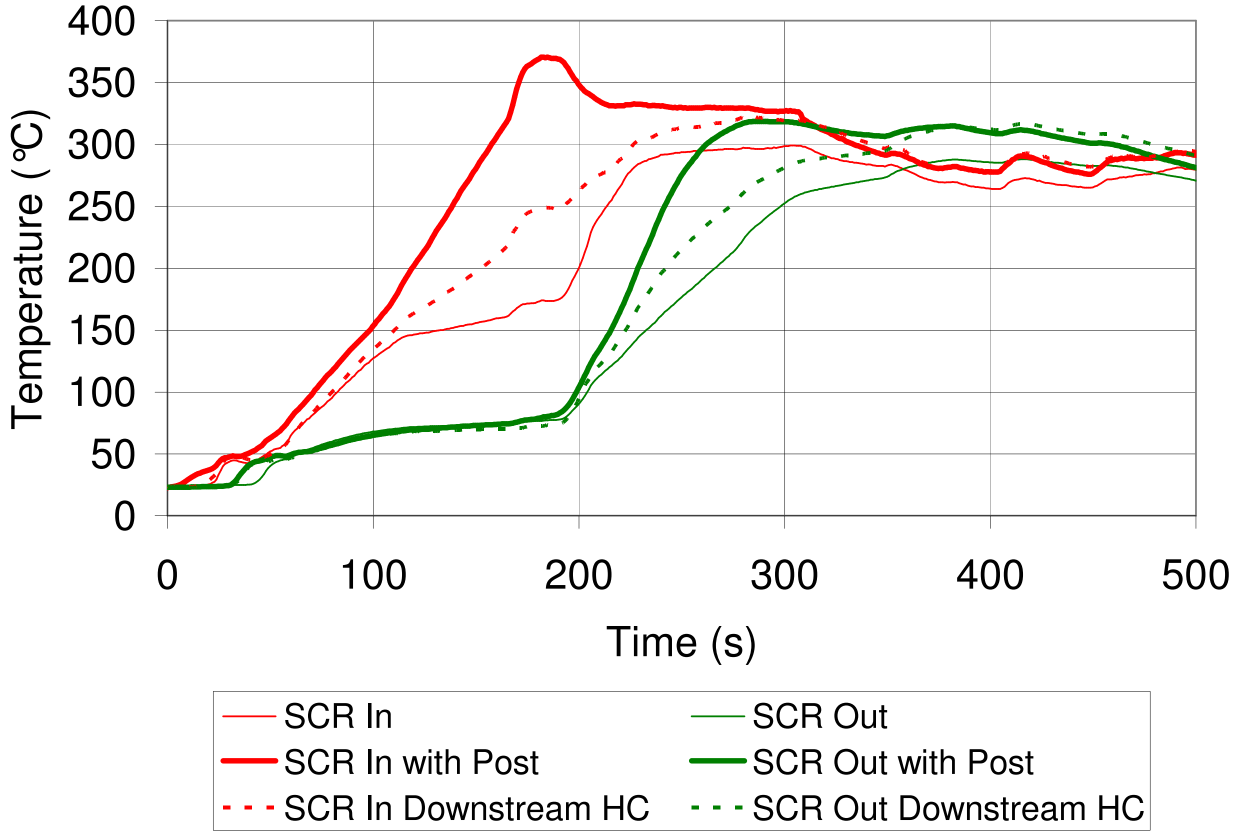
Emissions With 120k mi Catalysts on 6000 lb LDT (No Warmup)



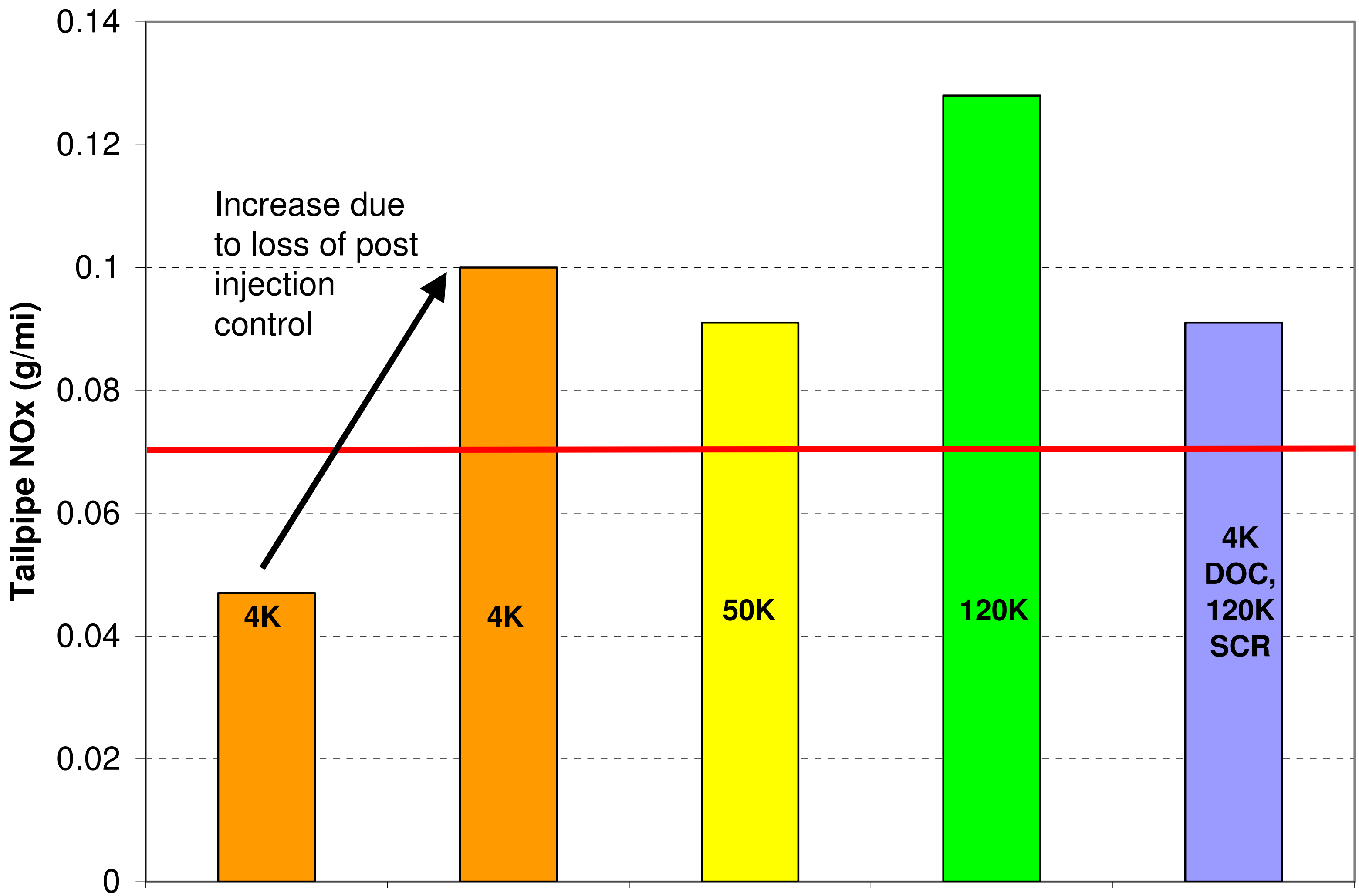
Tailpipe NH_3: 0
N_2O selectivity: 15%
PM: 1.2 mg/mile

SCR Catalyst Warm-up

- Downstream injection heats the catalyst less effectively than post injection.
- Downstream injection did not reduce Bag 1 NOx.

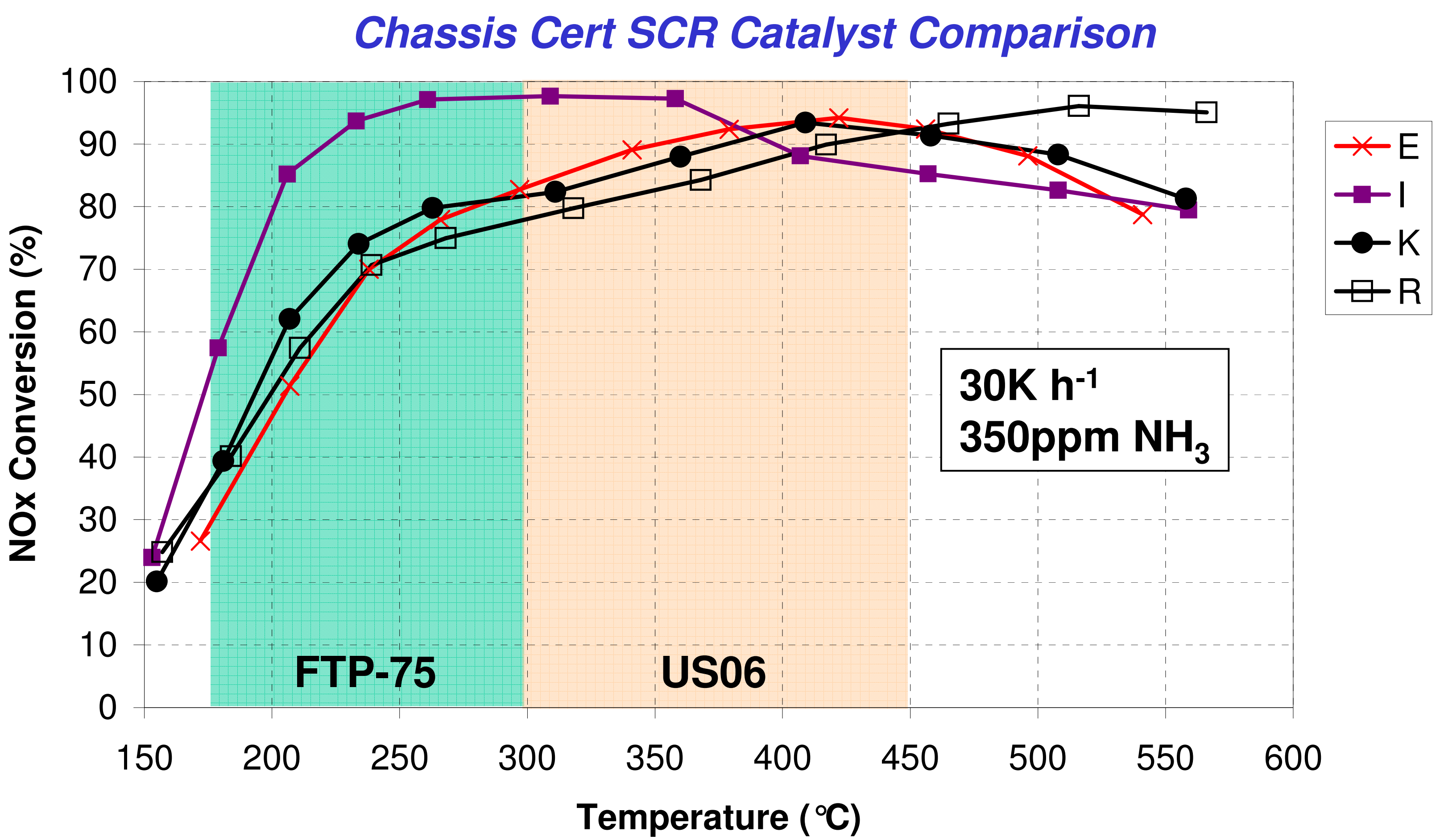


Aging Summary: FTP-75 Weighted NOx

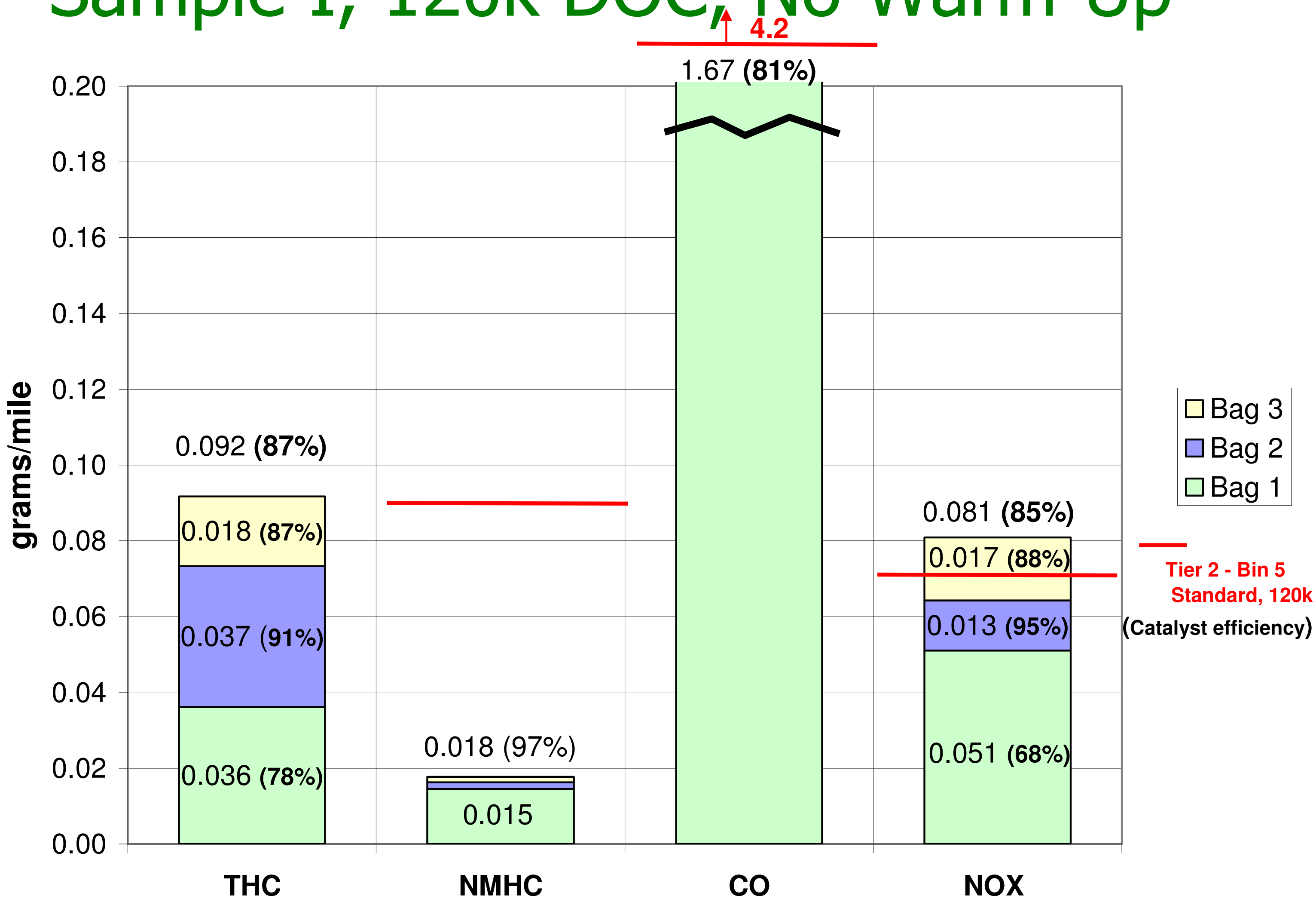


Comparison of Hydrothermally Aged SCR Catalysts

Comparison of Aged SCR Catalysts
64 hrs at 670℃, NO only



Emissions With Hydrothermally Aged SCR Sample I, 120k DOC, No Warm-Up



Vehicle Testing with 120K mi ECS Conclusions

- Emissions with 120K mi aged parts meet all emission limits except for NOx
- Deterioration of DOC was largest contributor to deterioration of NOx performance of SCR
- An improved SCR formulation shows promise to meet NOx target

Summary of Important Parameters for Urea SCR Systems

- mixing of reductant in exhaust gas
- rapid warm-up vs HC slip to SCR catalyst
- thermal durability of SCR catalyst
- NO_2/NOx ratio entering SCR catalyst
- effect of sulfur on SCR catalyst
- NH_3/NOx ratio
- Space Velocity
- O_2 concentration

Next Steps

- Post-mortem of 120K mi aged system
- Continue to develop improved DOC and SCR formulations
- Continue to update A/T models with data

Acknowledgements

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Ford

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FEV

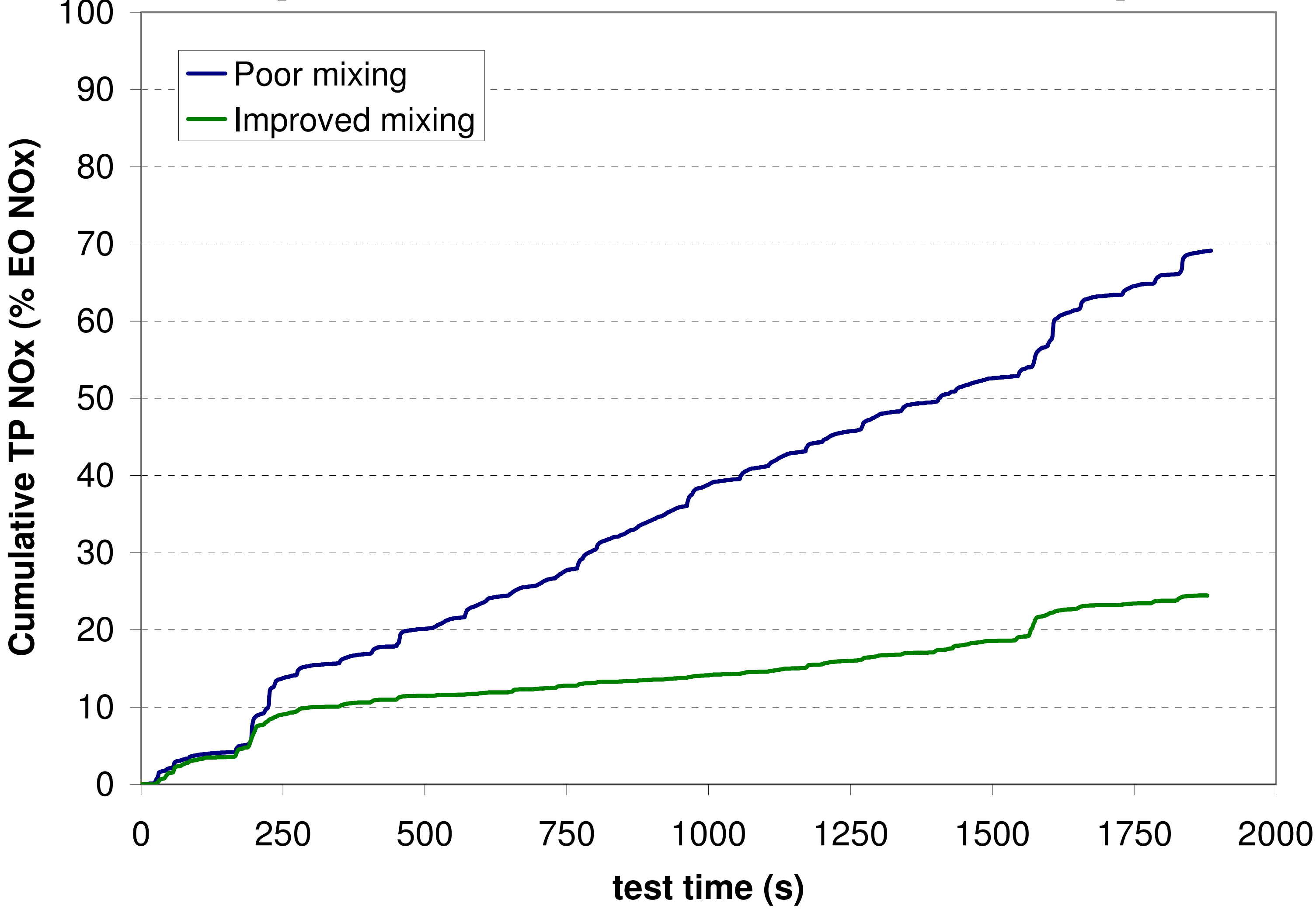
Erik Koehler, Dean Tomazic

Exxon Mobil

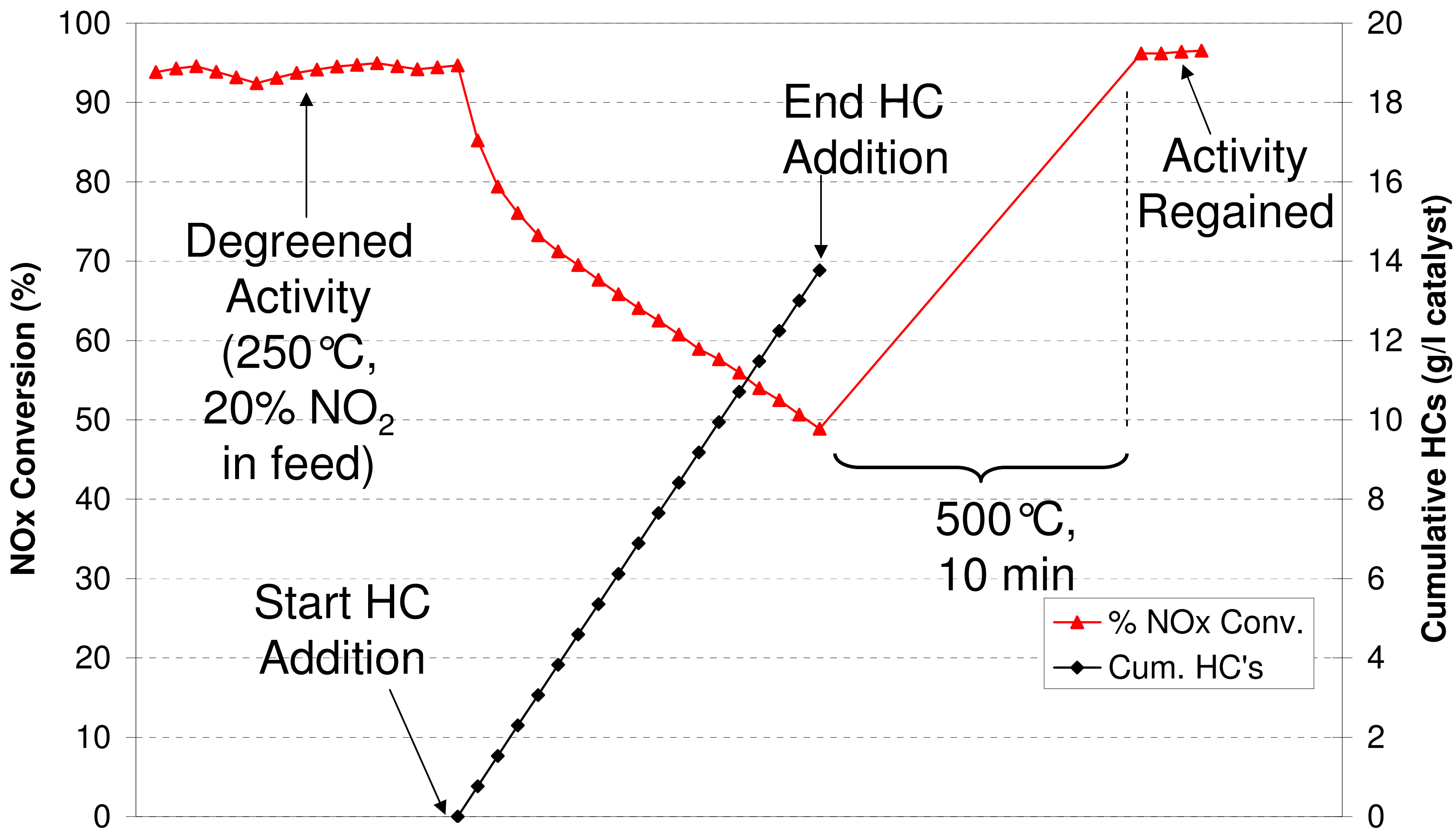
Rich Grosser, Marcus Moore, Mike Noorman, Charlie Schleyer

Backup Slides

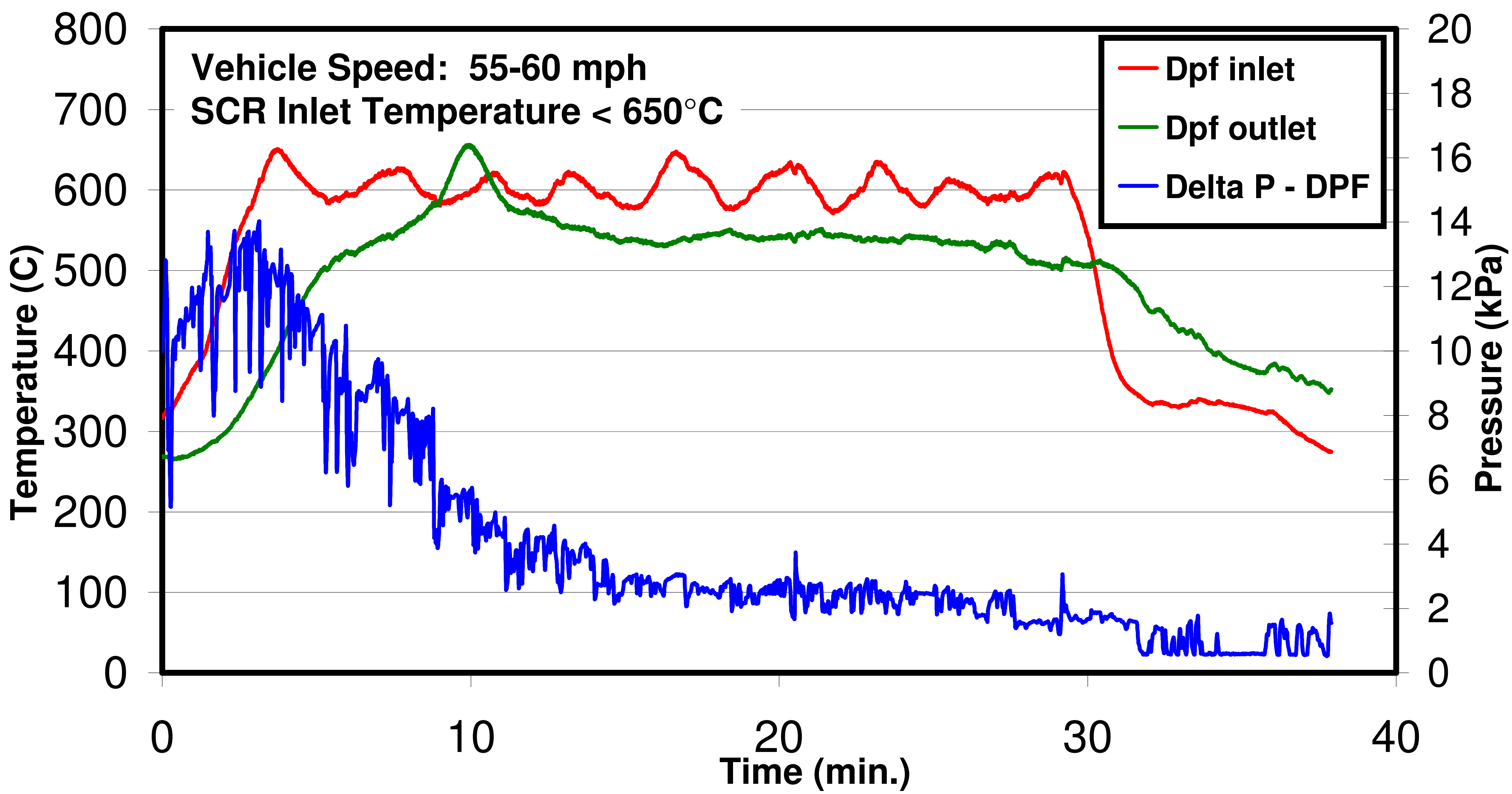
Importance of Urea Mixing (Transient Vehicle Results)



Impact of HC on SCR performance

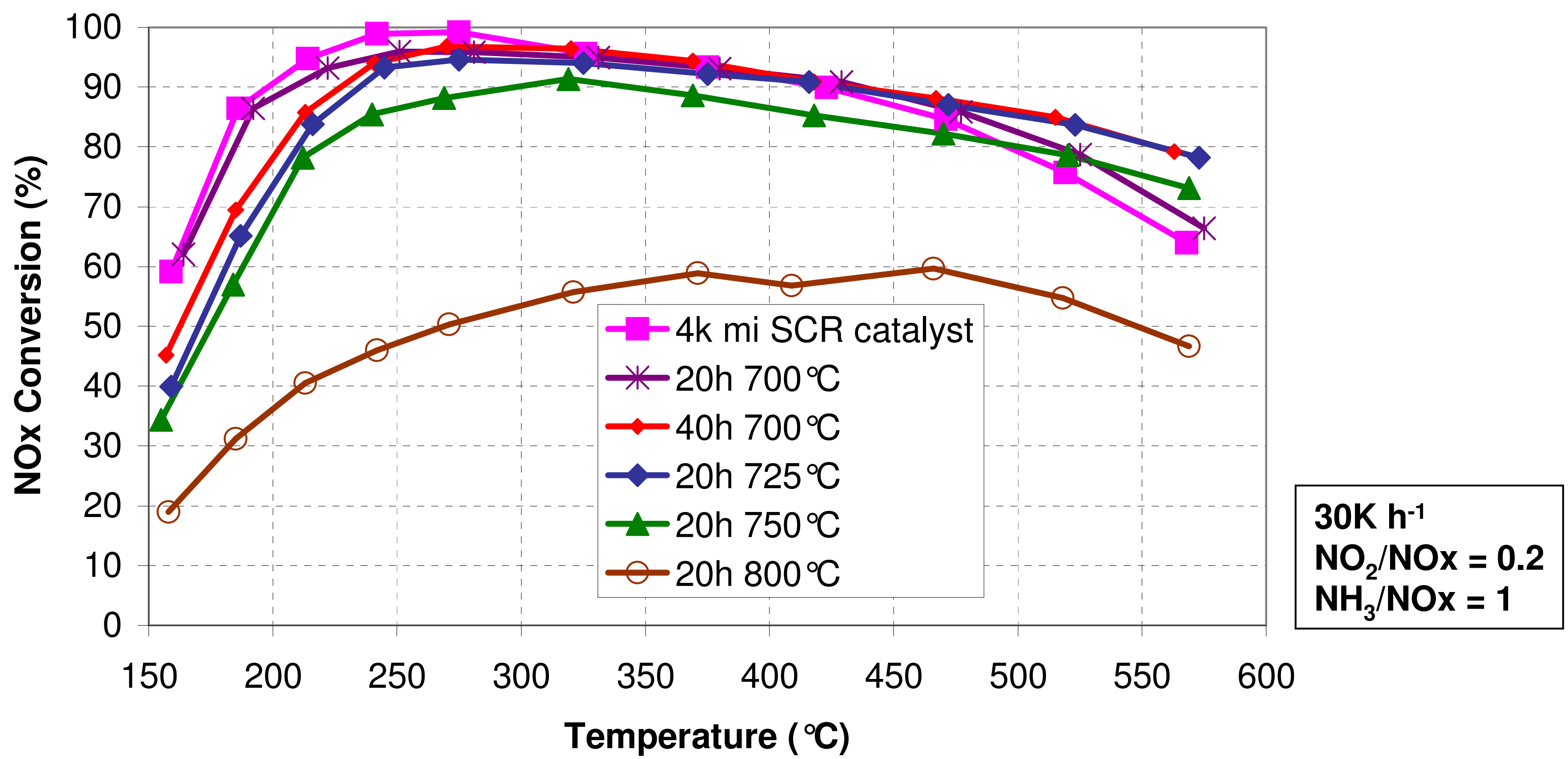


SCR Catalyst Durability: LDT CDPF Regeneration



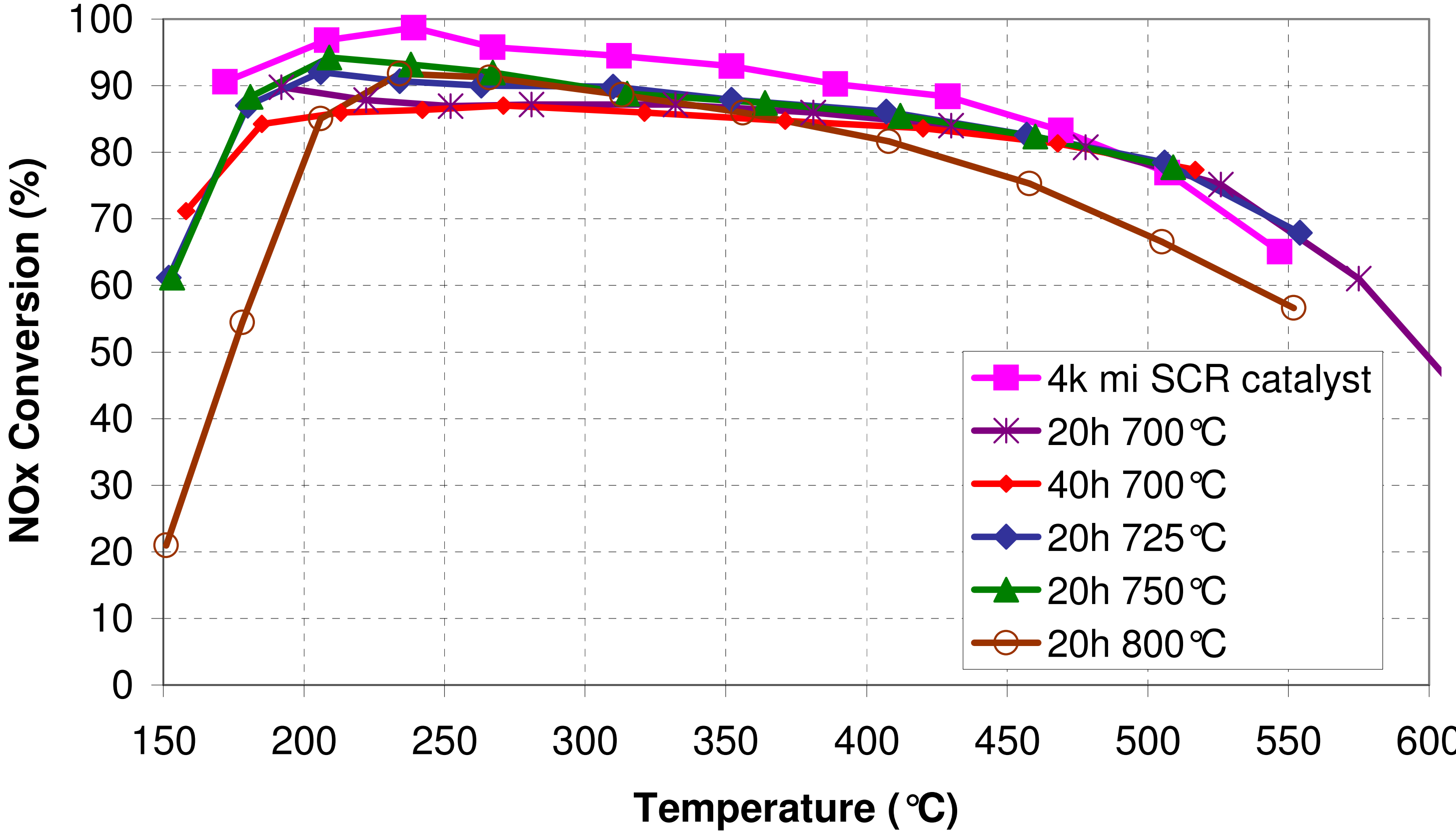
- SCR activity was identical before and after regeneration

SCR Catalyst Durability: High Temperature



- With 20% NO_2/NOx feed, the catalyst is durable to 750°C

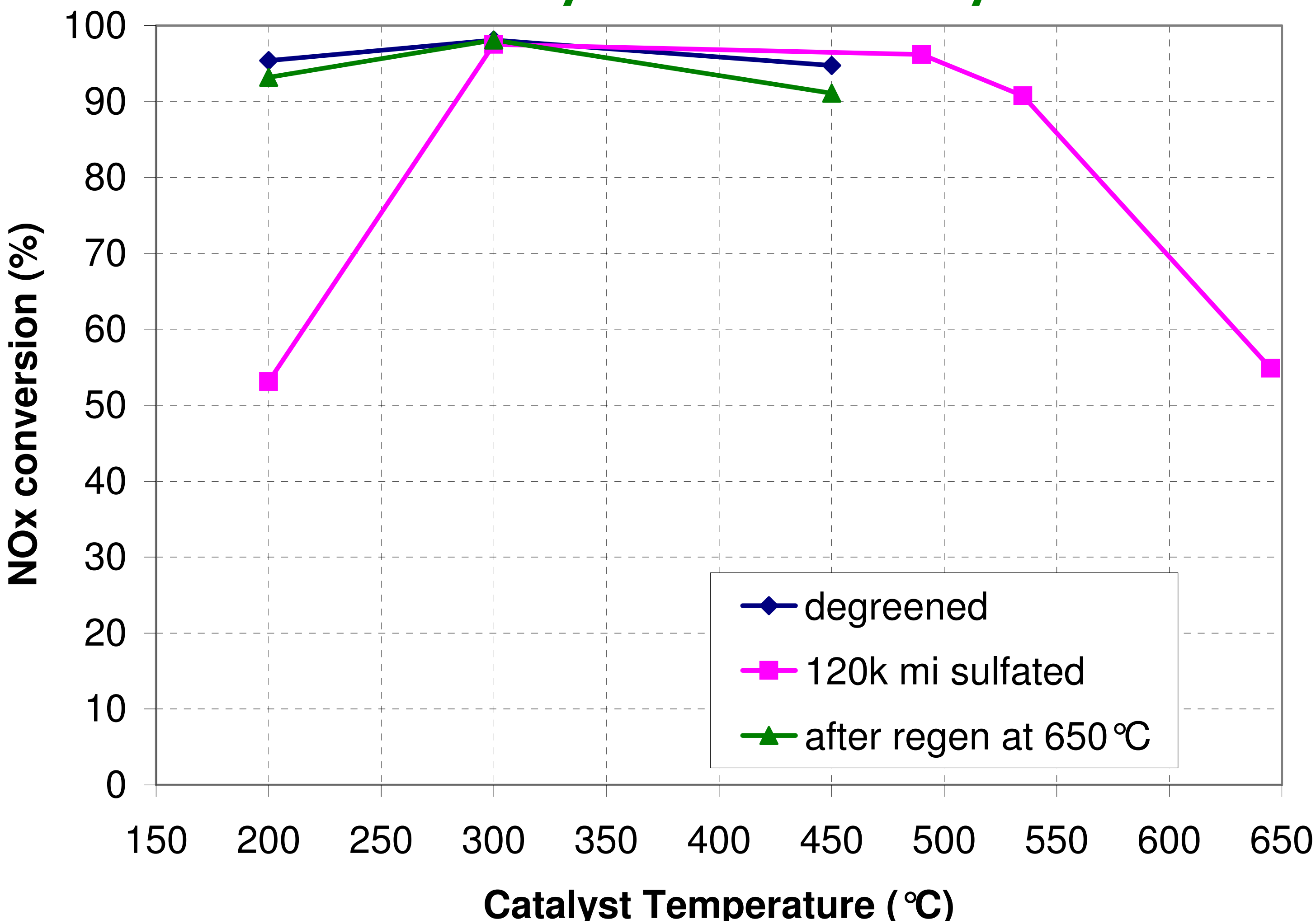
SCR Catalyst Durability: High Temperature



30K h⁻¹
NO_2/NOx = 0.8
NH_3/NOx = 1

- With 80% NO_2/NOx feed, the catalyst is durable to 800°C

SCR Catalyst Durability: Sulfur



- Sulfur poisoning is reversible after 650℃, lean