# Advanced Technology Light Duty Diesel Aftertreatment System

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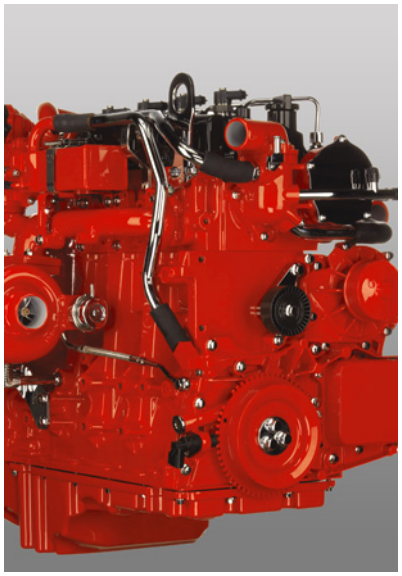
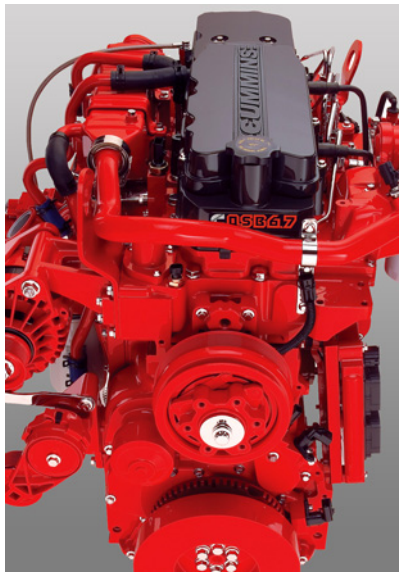
Johnson Matthey

U.S. DEPARTMENT OF ENERGY

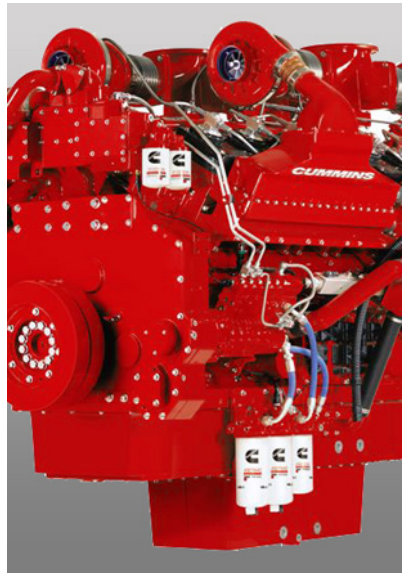
DEER 2012 DEARBORN

DIRECTIONS IN ENGINE-EFFICIENCY AND EMISSIONS RESEARCH CONFERENCE







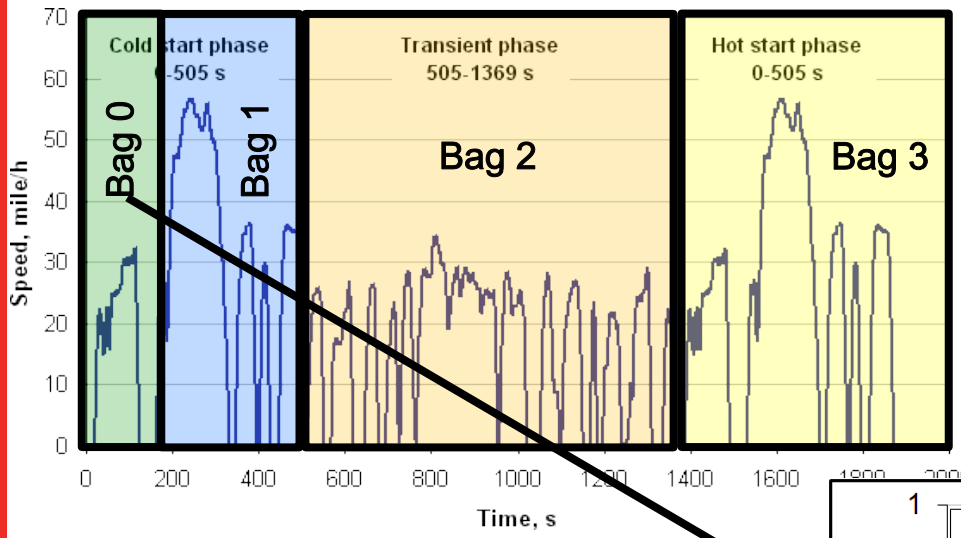


# ATLAS Program Goals

| | Baseline vehicle data | DoE Program Target | |
|---|---|---|---|
| FTP – 75 | 15.6 | 21.8 | mpg |
| "city" | 570 | 467 | CO2 g/mi |
| HFET | 24.5 | 34.3 | mpg |
| "highway" | 363 | 297 | CO2 g/mi |
| CAFE | 18.6 | 26.1 | mpg |
| | 476 | 390 | CO2 g/mi |

- 40% mpg improvement over current gasoline V8 powered half-ton pickup truck
- Initial demonstration of T2B5 TP emissions (6/2013), followed by T2B2 (6/2014)
- Catalyst development partnership with Johnson Matthey

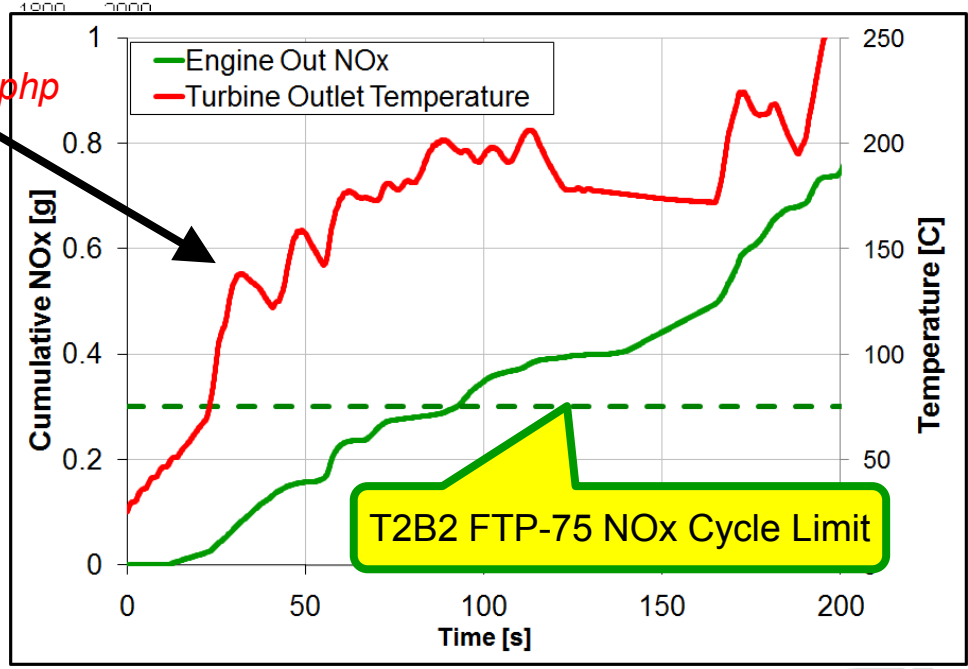
# ATLAS Engine Out Emissions Targets




http://www.dieselnet.com/standards/cycles/ftp75.php

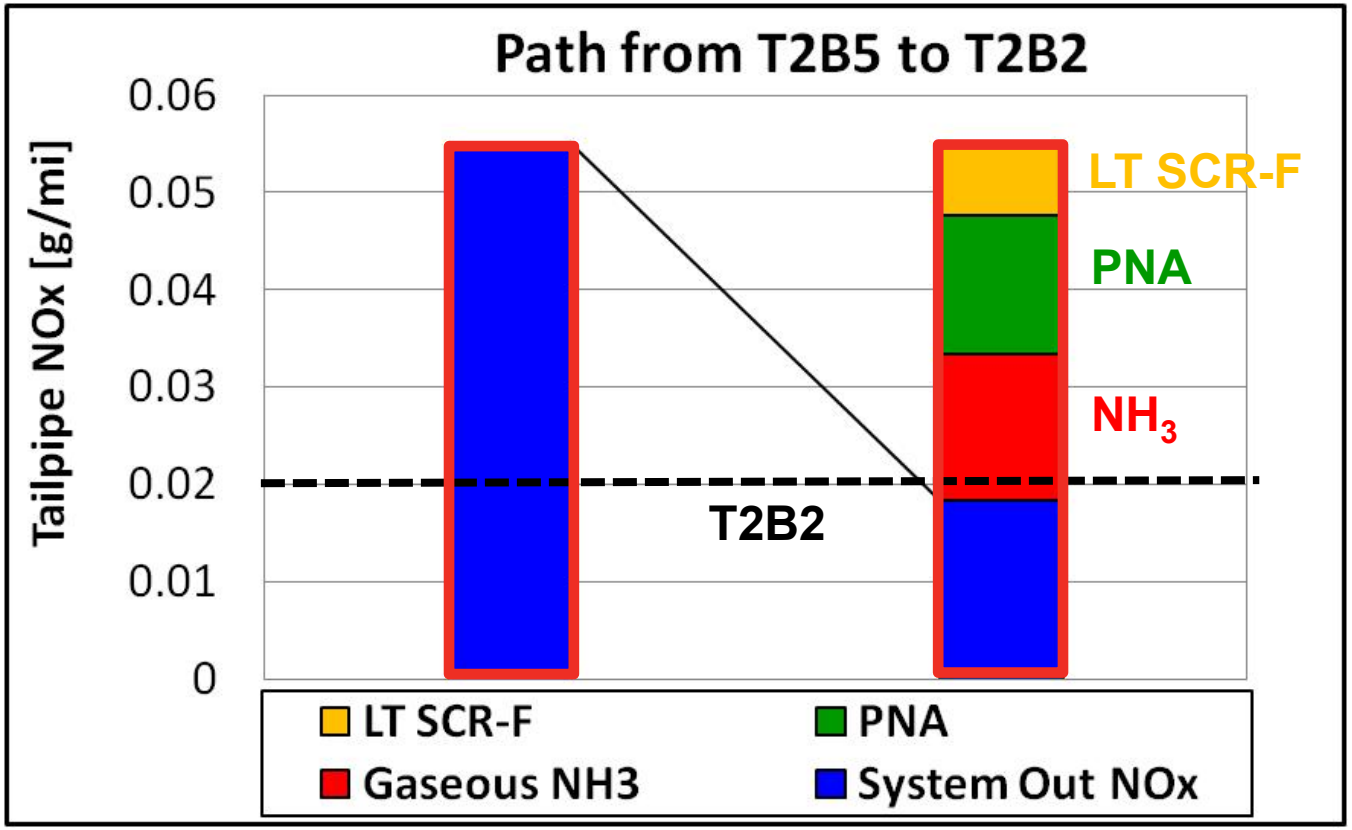
- Chassis cert cold FTP-75 cycle has increased weighting of 43%
- Engine takes approximately 170s to reach exhaust temperature of 200°C

- Time to 200°C is referred to as "Bag 0"
- Current state-of-the-art SCR catalysts have low NOx conversion at these temps
- Mitigation of NOx and HC at these low temperatures requires technological advancements in A/T design and control



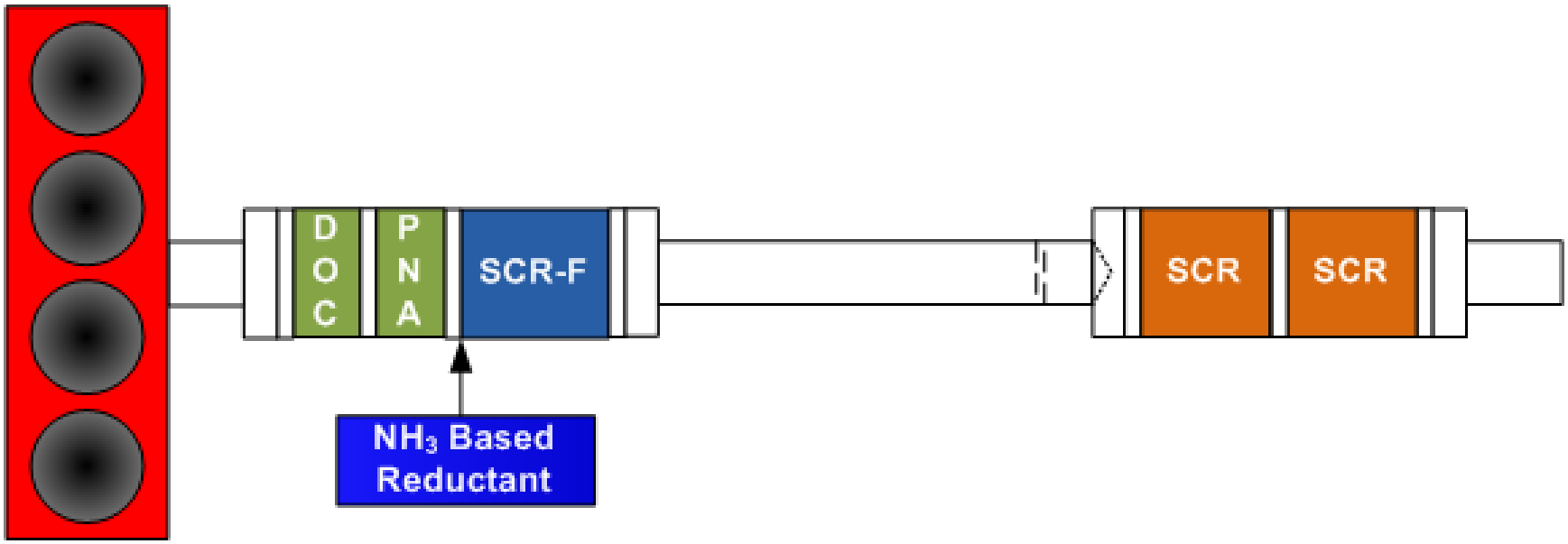

**EO NOx = 0.4g/mi**

# ATLAS T2B2 AT Strategy Summary



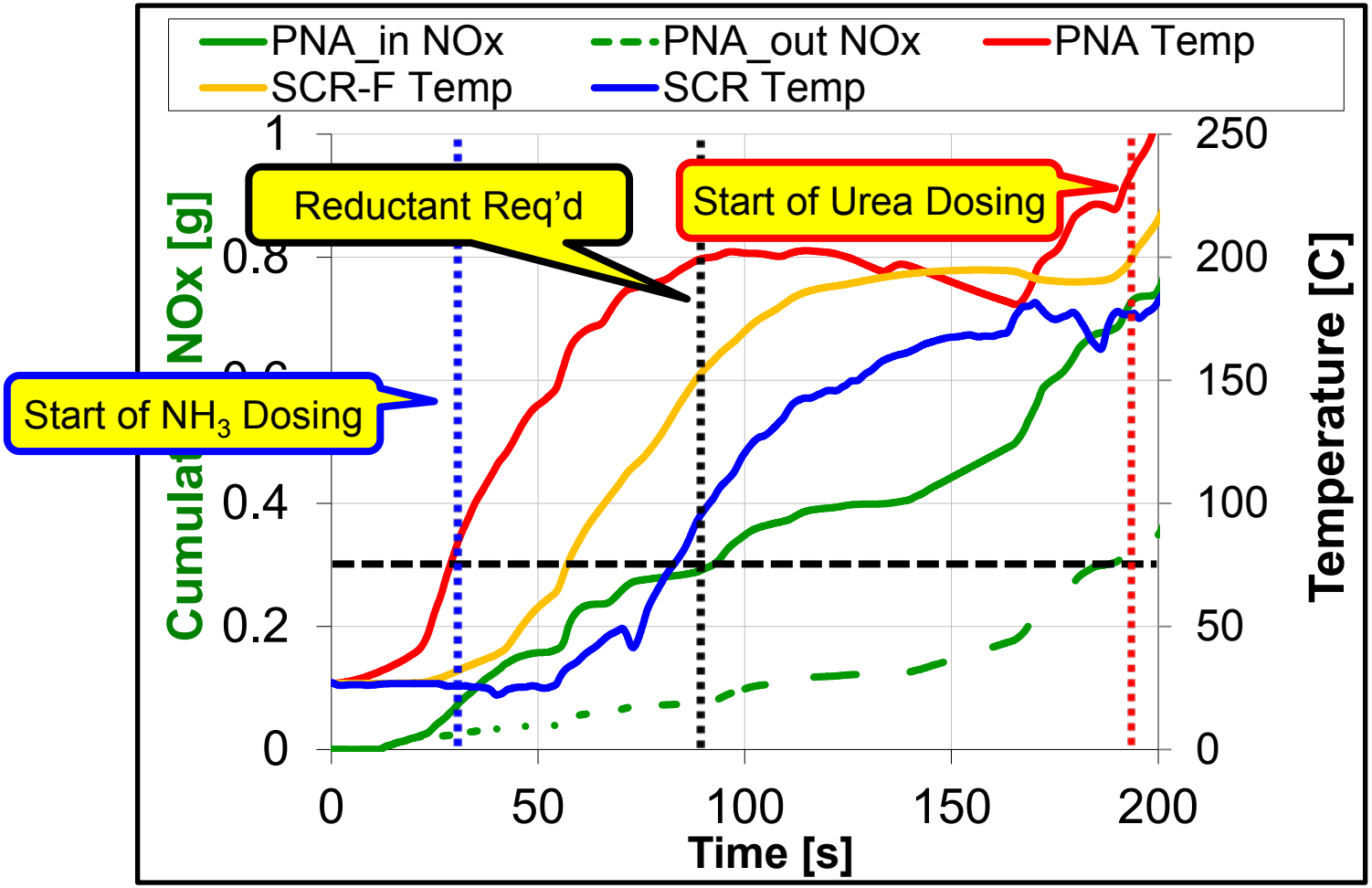

- NOx reduction values assume .4g/mi EO NOx
- DOC-DPF-SCR type AT ~0.055g/mi TP NOx
- DOC-PNA-LTSCR-F-SCR type AT ~0.018g/mi

# ATLAS Proposed T2B2 AT Architecture



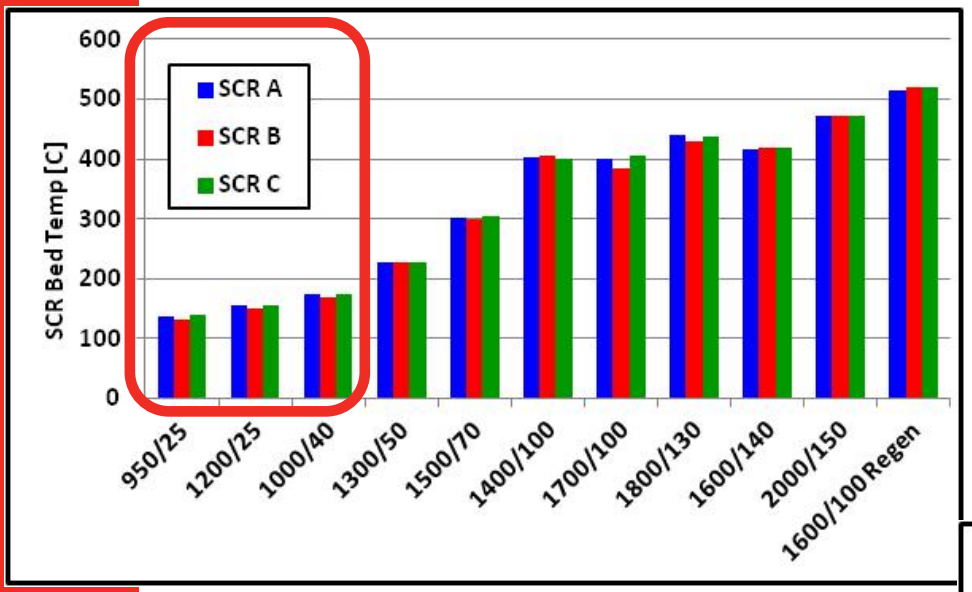

- **DOC, PNA and SCR-F are close coupled to engine**
- **Gaseous $NH_3$ delivery enables close coupling of SCR-F to DOC**
- **Close-coupling of SCR-F enables high conversion of NOx released by PNA**

# Case for Direct $NH_3$ Delivery

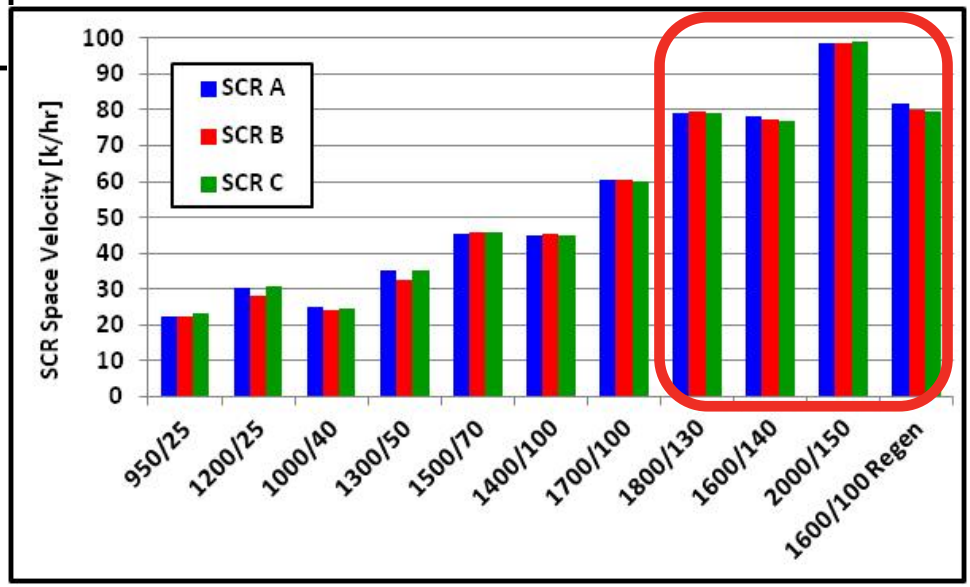



- Gaseous $NH_3$ enables close coupling of SCR device
- NOx release profile requires reductant delivery at SCR-F temp of 150°C
- Urea dosing cannot begin until exhaust temp >200°C

# Under-Floor SCR Performance Evaluation

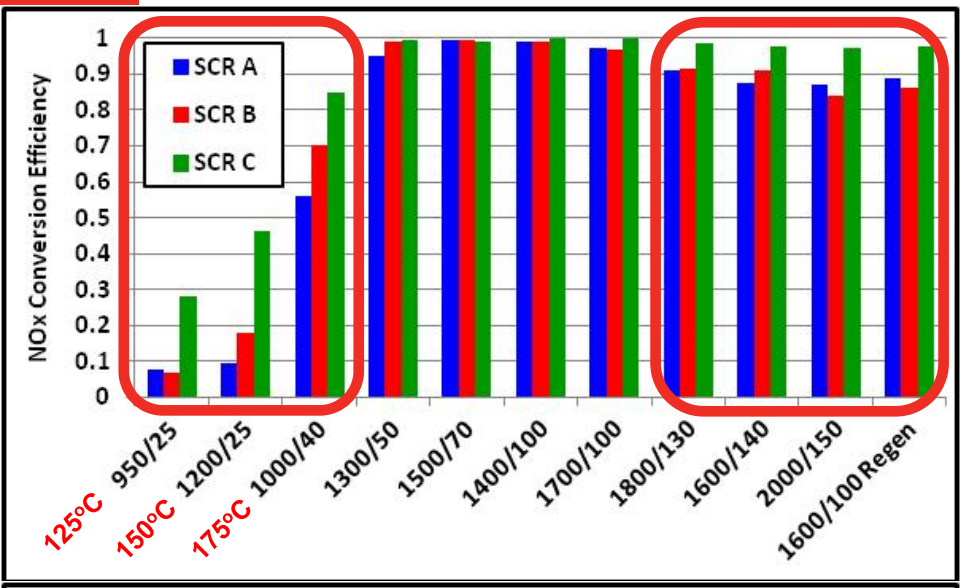


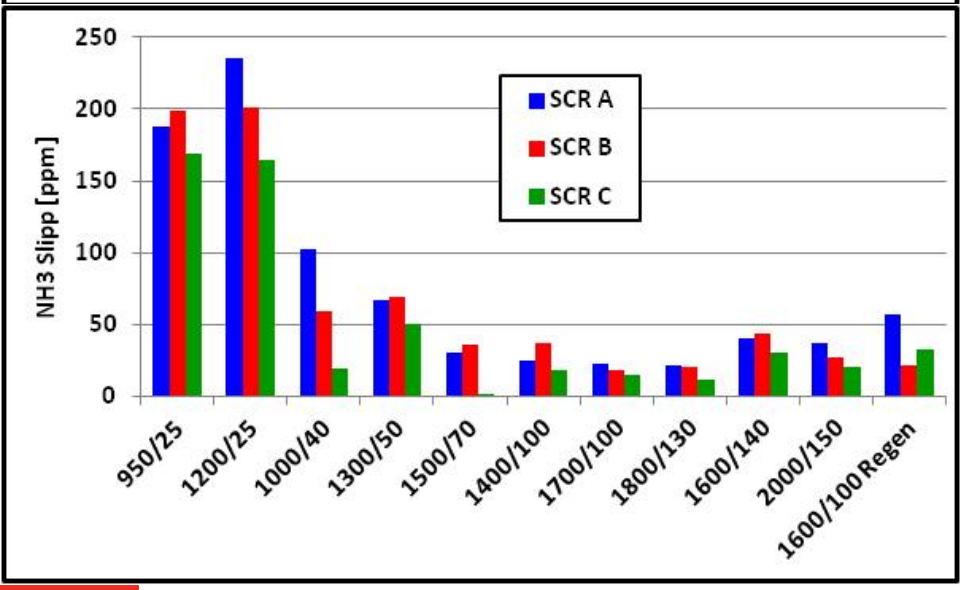

- LT performance measurement made possible by direct $NH_3$ dosing
- SCR catalyst performance is evaluated for entire temperature operating range
- Catalyst performance is evaluated at space velocities of 20-100khr$^{-1}$




- Performance evaluated for near idle condition as well as active regeneration
- High temp/SV conditions are intended to challenge catalysts
- Operating conditions are repeatable for all formulations

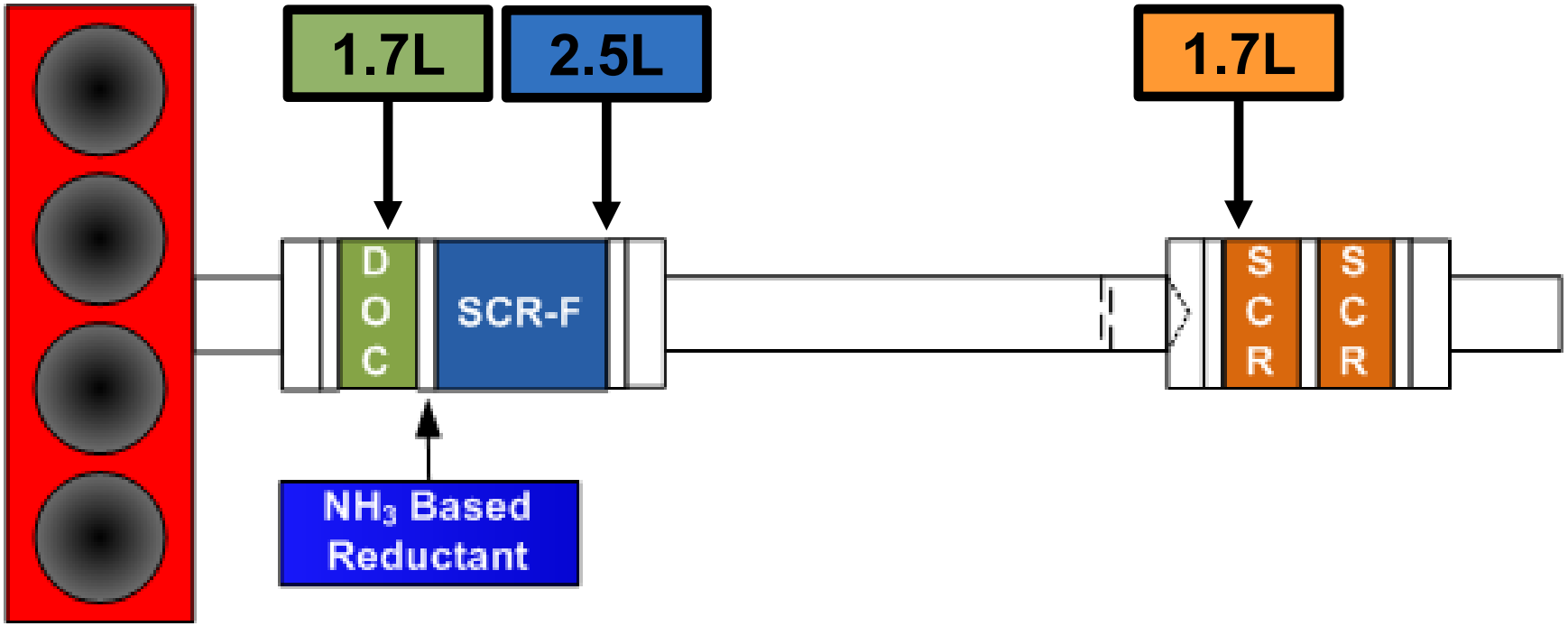
# Under-Floor SCR Performance Evaluation



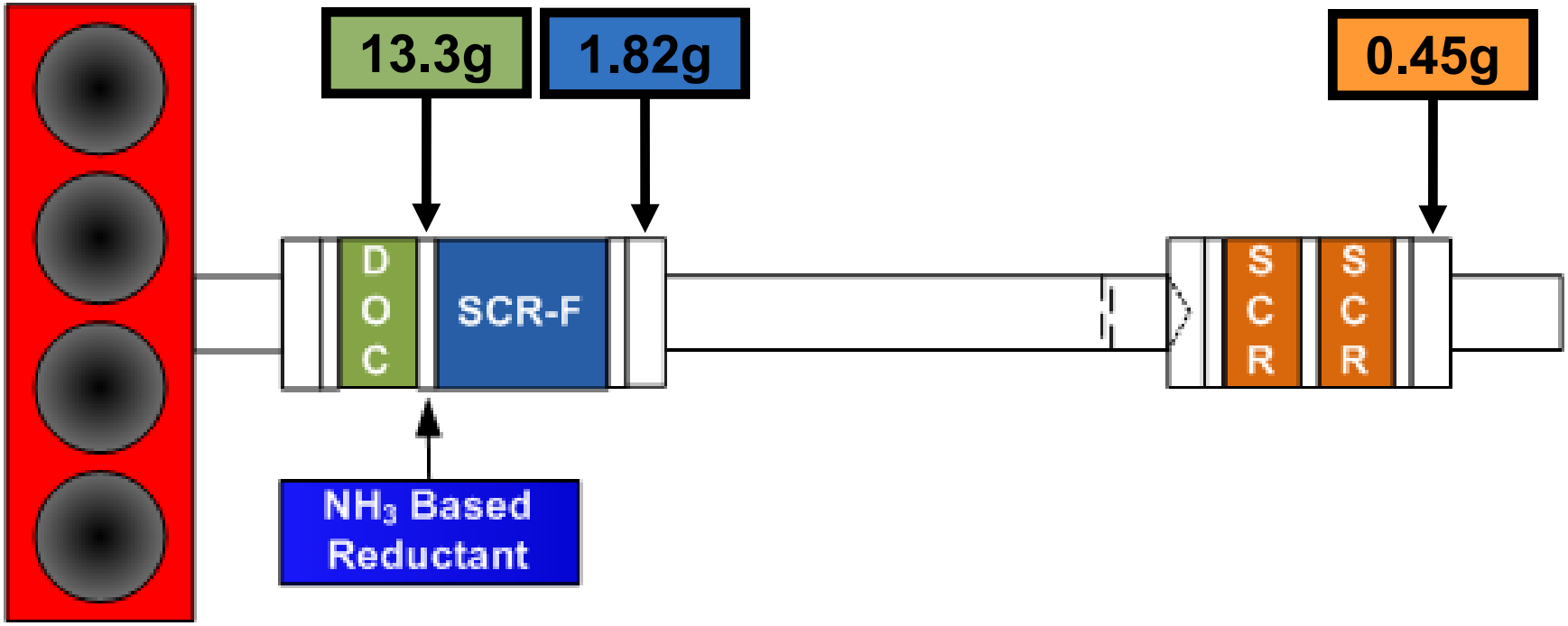

- Increased LT NOx conversion of SCR C maximizes benefit of gaseous $NH_3$
- >95% NOx conversion at ANR=1.5 during active regen
- $NH_3$ slip is also reduced for SCR C

# ATLAS Evaluated T2B5 AT Architecture



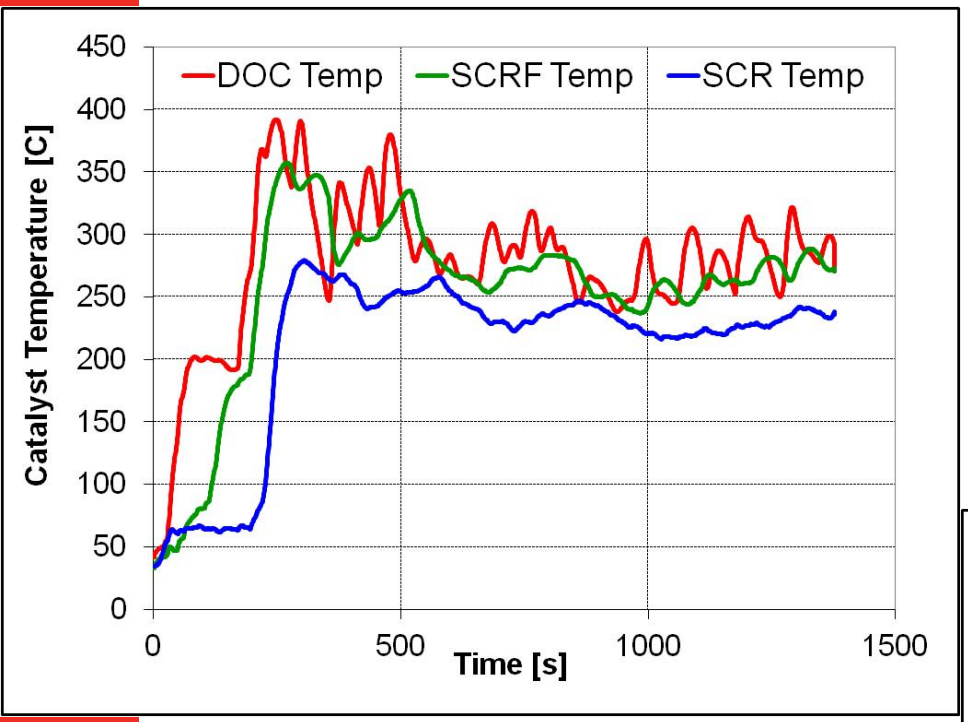

- **DOC and SCR-F are close coupled to engine**
- **Gaseous NH3 is delivered in 3” space between DOC and SCR-F**
- **Additional under-floor SCR catalyst enables high NOx conversion efficiency across operating range**

# LA4 NOx Reduction Across AT System

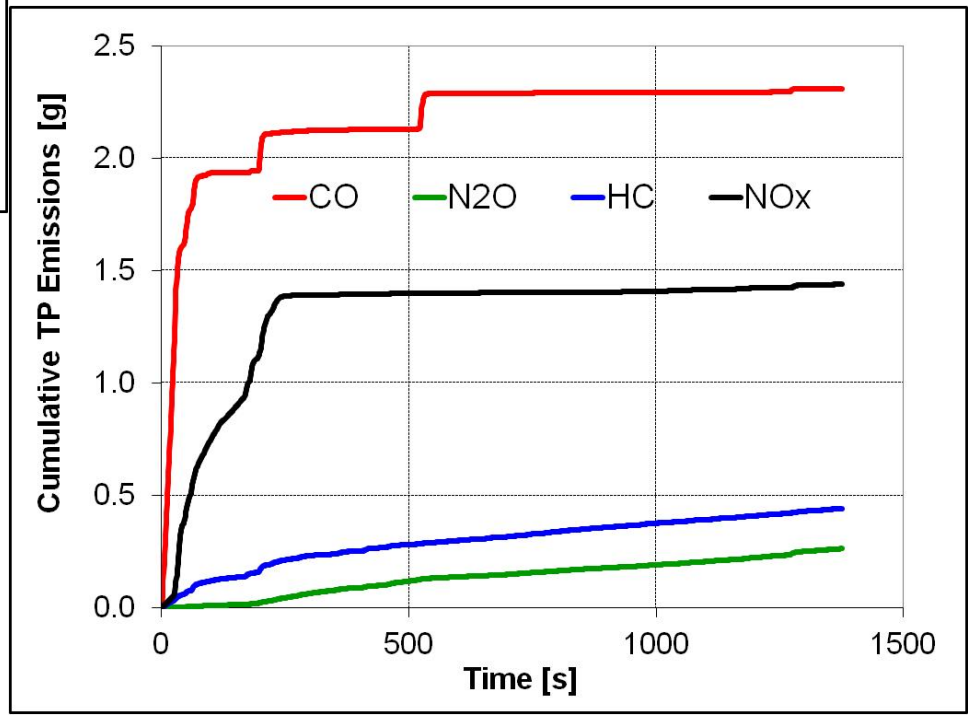



- NOx reduction quantified for hot LA4 cycle
- ~97% DOC outlet NOx reduced over SCR-F and SCR elements
  - ~87% SCR-F inlet NOx reduced over SCR-F
  - ~75% SCR inlet NOx reduced over SCR

# FTP-75 Cold Bag Performance Results

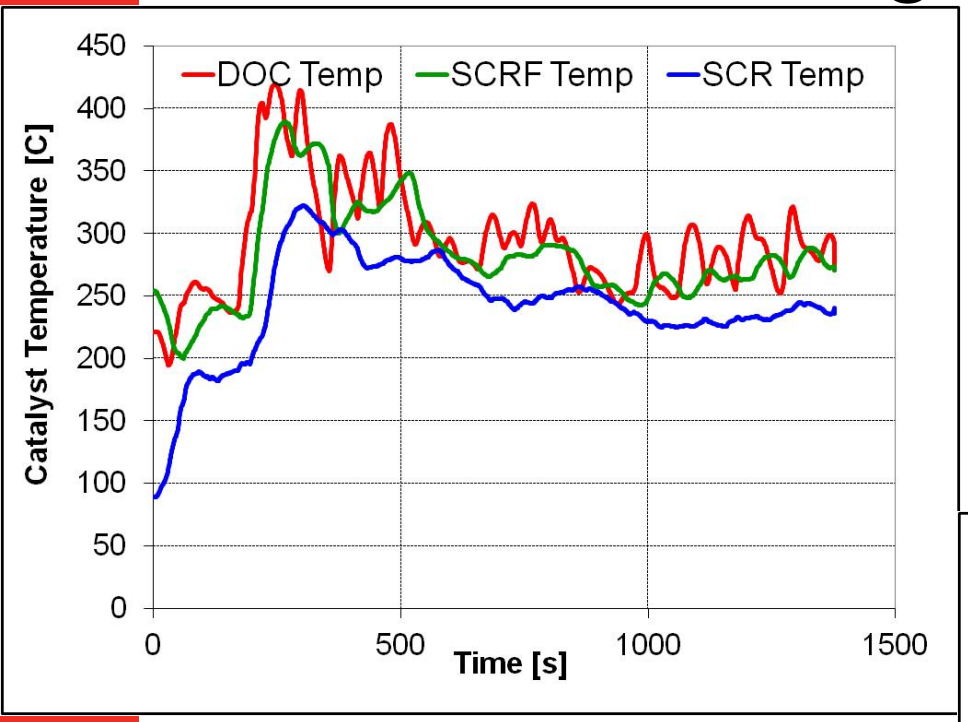



- Close coupling of SCR-F improves warm-up time
- SCR-F and SCR temperatures are above 200°C during entire transient phase

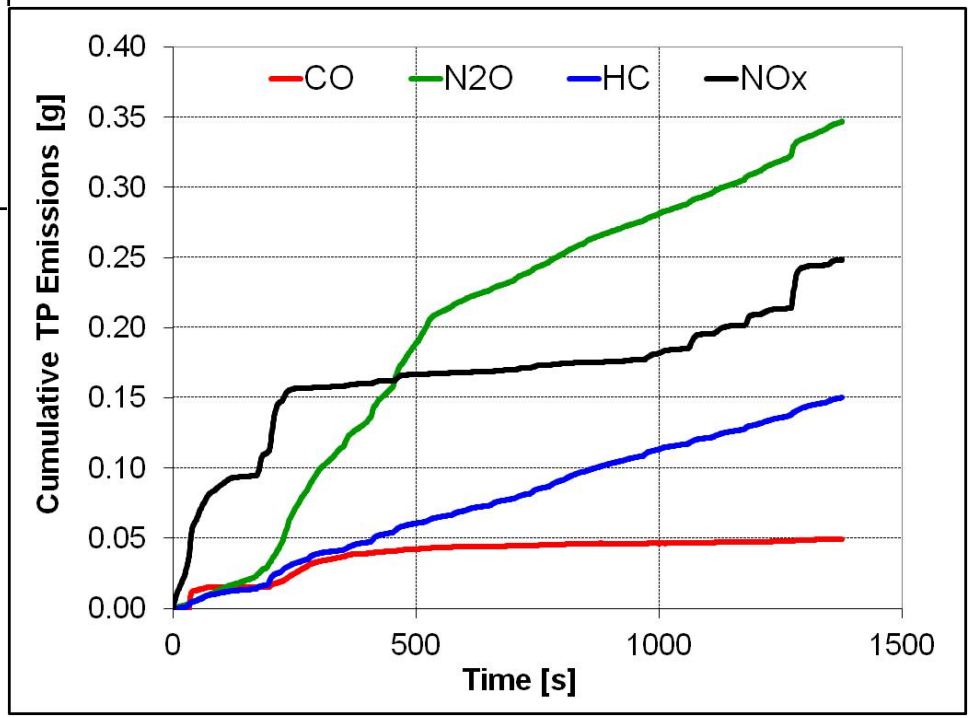



- TP CO ~0.31 g/mi
- TP $N_2O$ ~0.03g/mi
- TP HC ~0.06g/mi
- TP NOx ~0.19 g/mi
- Cold FTP NOx Conversion ~86%

# FTP-75 Hot Bag Performance Results




- Close coupling of SCR-F improves catalyst temperatures during cycle
- SCR-F and SCR temperatures are above 200°C during entire transient phase



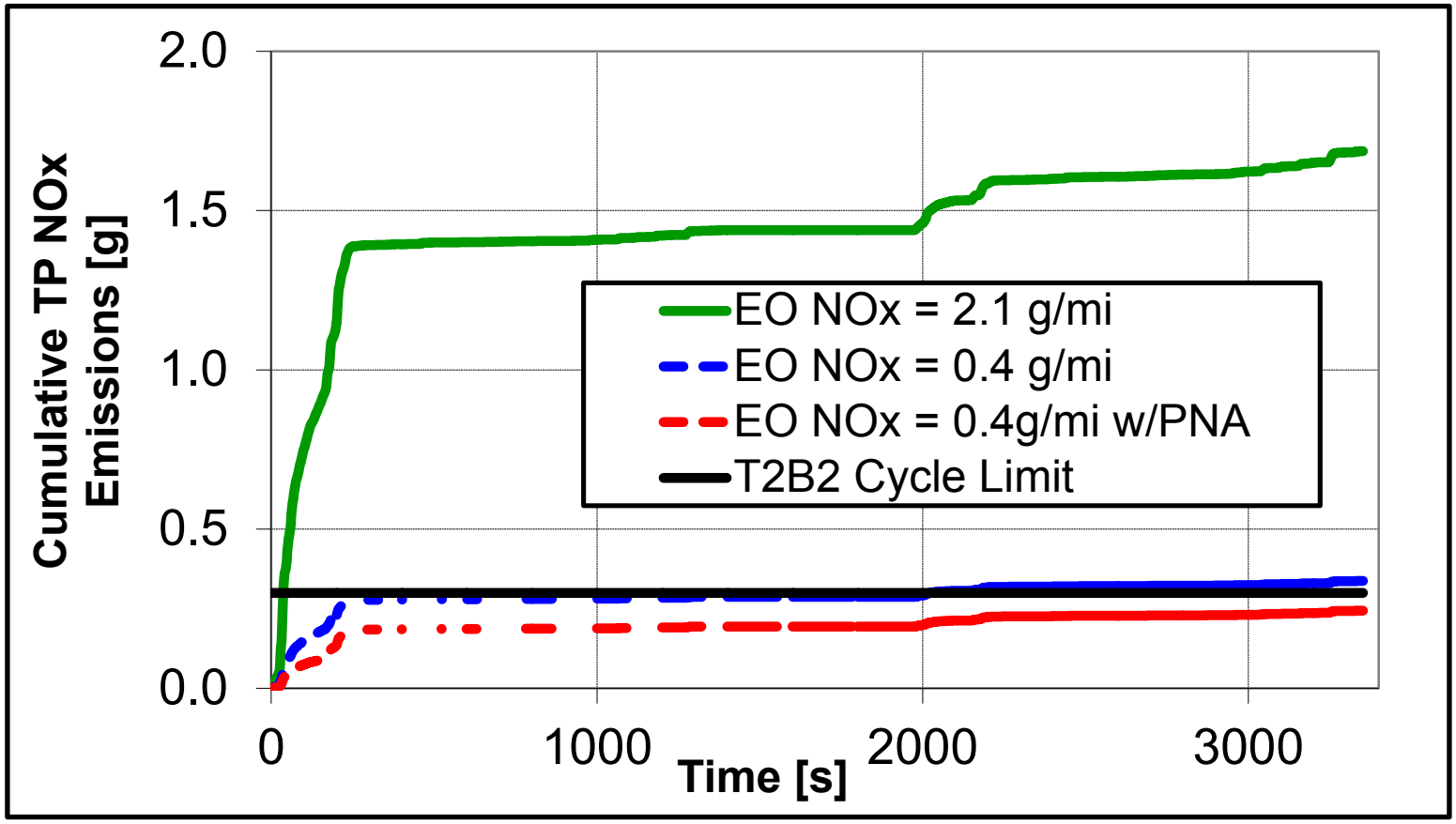

- TP CO ~0.01 g/mi
- TP $N_2O$ ~0.05g/mi
- TP HC ~0.02g/mi
- TP NOx ~0.03 g/mi
- Hot FTP NOx Conversion ~98%

# DOC-SCR-F-SCR FTP-75 Cycle NOx Emissions

| NOx Emissions | | | | | | |
|---|---|---|---|---|---|---|
| Run | Bag 1 [g] | Bag 2 [g] | Bag 3 [g] | Bag 4 [g] | Total [g/mi] | NOx η [%] |
| | | | | | | |
| A | 1.48 | 0.27 | 0.24 | 0.12 | 0.127 | 94.0 |
| B | 1.57 | 0.20 | 0.22 | 0.11 | 0.126 | 94.0 |
| C | 1.30 | 0.12 | 0.23 | 0.10 | 0.106 | 95.0 |
| D | 1.71 | 0.20 | 0.28 | 0.11 | 0.139 | 93.4 |
| E | 1.19 | 0.07 | 0.19 | 0.11 | 0.094 | 95.5 |
| F | 1.40 | 0.04 | 0.17 | 0.08 | 0.101 | 95.2 |

- Closed loop controller provided repeatable NOx conversion over drive cycles
- Average conversion efficiency of 94% reduces TP NOx by 65% from current chassis cert applications
- >80% of NOx released during bag 0

# Effect of EO NOx and PNA




- TP NOx for 2.1 g/mi EO NOx = 0.11g/mi
- TP NOx for 0.4 g/mi EO NOx estimated to be 0.022g/mi
- TP NOx for 0.4 g/mi EO NOx ***with PNA*** estimated to be 0.016g/mi

# Summary

- **Multi-pronged approach to reduce cold start emissions has been proposed in order to enable Tier 2 Bin 2 emission levels**
  - PNA stores NOx during cold operation and releases NOx as exhaust temperature increases
  - Gaseous $NH_3$ injection enables close coupling of SCR-F, and is able to provide reductant in advance of NOx release from PNA
  - Close-coupled SCR-F decreases warm-up time and increases overall aftertreatment temperatures

- **DOC-SCR-F-SCR system has been evaluated for FTP-75 NOx conversion performance**
  - Aftertreatment system was capable of ~94% NOx conversion efficiency on 2.1g/mi engine
  - >80% of tail pipe NOx is released during bag 1
  - Addition of PNA is expected to increase cycle NOx conversion efficiency to 96%

# Thank You!



- U.S. Department of Energy
  - Ken Howden, Carl Maronde, Roland Gravel, and Gurpreet Singh