Passive Catalytic Approach to Low Temperature NOx Emission Abatement

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U.S. DEPARTMENT OF ENERGY

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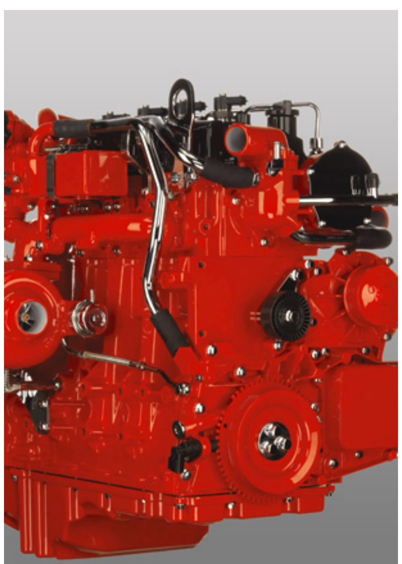
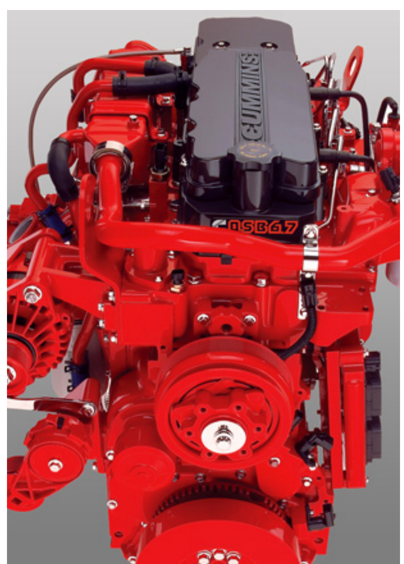
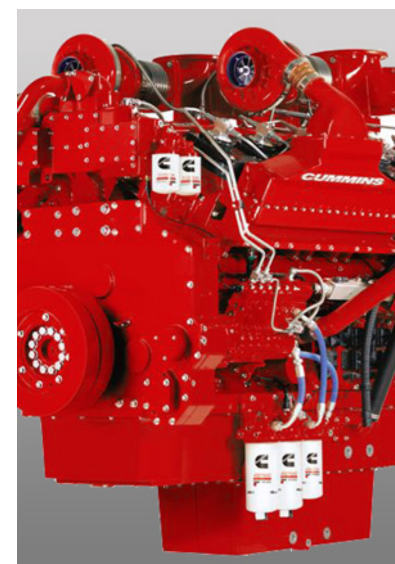
DETROIT

DIRECTIONS IN ENGINE-EFFICIENCY AND EMISSIONS RESEARCH CONFERENCE







ATLAS Program Goals

	Baseline vehicle data+	DoE Program Target	
FTP – 75 “city”	15.6 570	21.8 467	mpg CO_2 g/mi
HFET “hi-way”	24.5 363	34.3 297	mpg CO_2 g/mi
CAFE	18.6 476	26.1 390	mpg CO_2 g/mi

- 40% Fuel Economy 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, Inc

ATLAS Program Requirements

Bin#	Intermediate life (5 years / 50,000 mi)					Full useful life				
	NMOG*	CO	NOx	PM	HCHO	NMOG*	CO	NOx†	PM	HCHO
Permanent Bins										
ISF 2.8						0.194	6.7	2.01	0.29	-------
8[b]	0.100 0.125	3.4	0.14	-	0.015	0.125 0.156	4.2	0.20	0.02	0.018
5	0.075	3.4	0.05	-	0.015	0.090 53.6%	4.2 37.3%	0.07 92.3%	0.01 96.6%	0.018
2	-	-	-	-	-	0.010 94.8%	2.1 68.7%	0.02 99.0%	0.01 96.6%	0.004

* for diesel fueled vehicle, NMOG (non-methane organic gases) means NMHC (non-methane hydrocarbons)
† average manufacturer fleet NOx standard is 0.07 g/mi for Tier 2 vehicles
b - The higher temporary NMOG, CO and HCHO values apply only to HLDTs and MDPVs and expire after 2008

http://www.dieselnet.com/standards/us/ld_t2.php

- ISF 2.8 data from baseline Euro IV engine with no A/T during FTP-75 4 bag cycle
- PM mass emissions estimated based on test cell opacity measurements

Bag-Specific NOx and HC Emissions for LDECC

LDECC			
FTP-75	Eng Out NOx (g/mi)	TP NOx (g/mi)	NOx η (%)
Bag 1	0.80	0.24	70.0
Bag 2	0.43	0.01	97.7
Bag 3	0.60	0.05	91.7
Bag 4	0.47	0.01	97.9
Weighted Cycle	0.56	0.07	90.0

- LDECC was well within the certification limits for T2B2 applications during bags 2 and 4 of the FTP-75 drive cycle for NOx and NMHC emissions
- Bag 1 emissions for the FTP-75 cycle are an order of magnitude greater than T2B2 limits
- Meeting T2B2 emission levels during bags 2 and 4 required 97% NOx conversion, and allows zero margin for IRAF

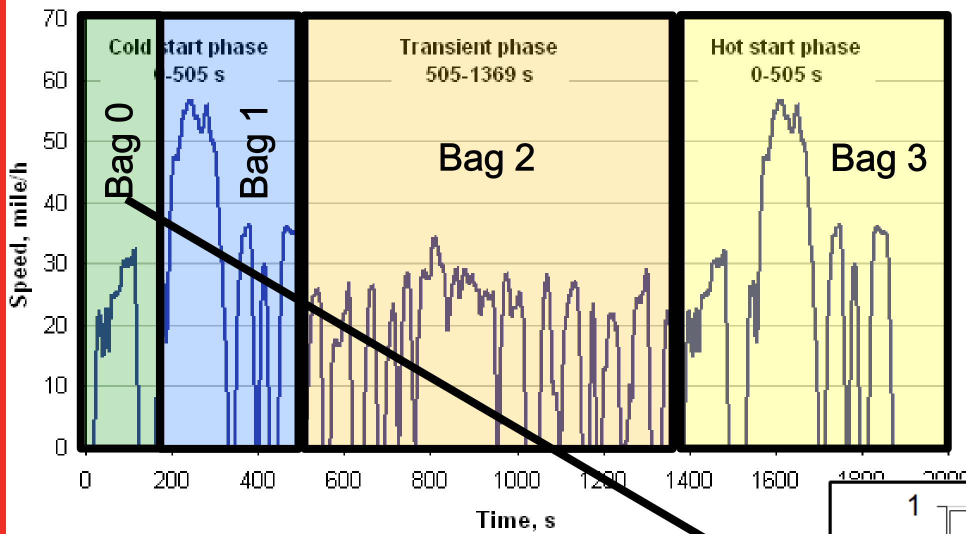
Bag-Specific NOx Emission Targets for ATLAS

ATLAS Predictions Assuming LDECC AT Performance					
		ISF 2.8 Baseline		[illegible]	
FTP-75	Predicted NOx η (%)	EO NOx (g/mi)	TP [illegible]	[illegible]	[illegible] (g/mi)
Bag 1	70.0	[illegible]	[illegible]	0.41	0.123
Bag 2	[illegible]	[illegible]	[illegible]038	0.39	0.008
Ba[illegible]	[illegible]	[illegible]	0.151	0.40	0.032
[illegible]	[illegible]	2.08	0.042	0.43	0.009
[illegible]ycle	83.3	1.92	0.332	0.40	0.068

Substantial (>75%) reduction in bag 0 TP emissions is the key enabler to meeting Tier 2 Bin 2 certification levels

- AT Performance predicted based on LDECC AT performance
- Current emissions of ISF 2.8 during FTP-75 are too high for current state of the art NOx A/T to meet T2B2 emission levels
- Reduction in engine out NOx emissions from 2 g/mi to 0.4 g/mi allows for T2B2 emissions levels during bags 2&4 with current state of the art NOx A/T
- Further improvements to the cold start behavior of A/T system is required to meet T2B2 emission levels during bags 1&3

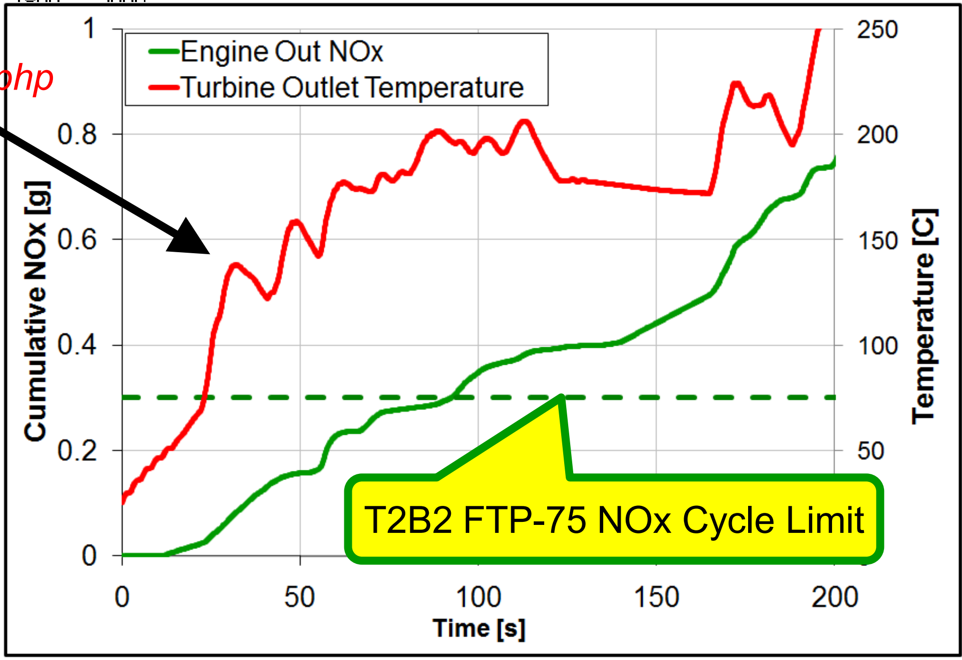
ATLAS Engine Out Emissions Targets



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

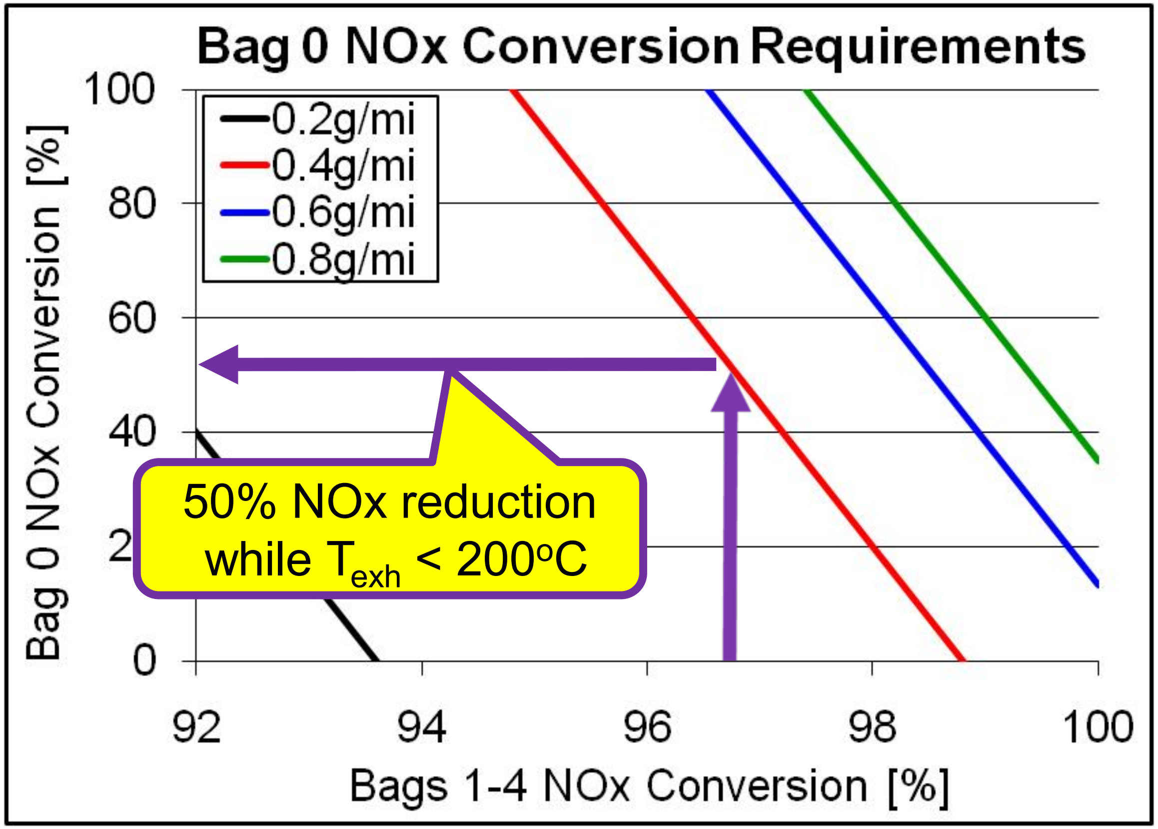
- For LD certification, cold FTP-75 cycle has increased weighting of 43% (compared to 17% for HD)
- Base 2.8L engine takes approximately 170s to reach and maintain exhaust temperature of 200°C

- ATLAS is referring to this portion of the FTP-75 cycle as “Bag 0”
- Current state-of-the-art Cu Zeolite catalysts do not efficiently reduce NOx at these temperatures
- Mitigation of NOx and HC at these low temperatures requires technological advancements in A/T design and control



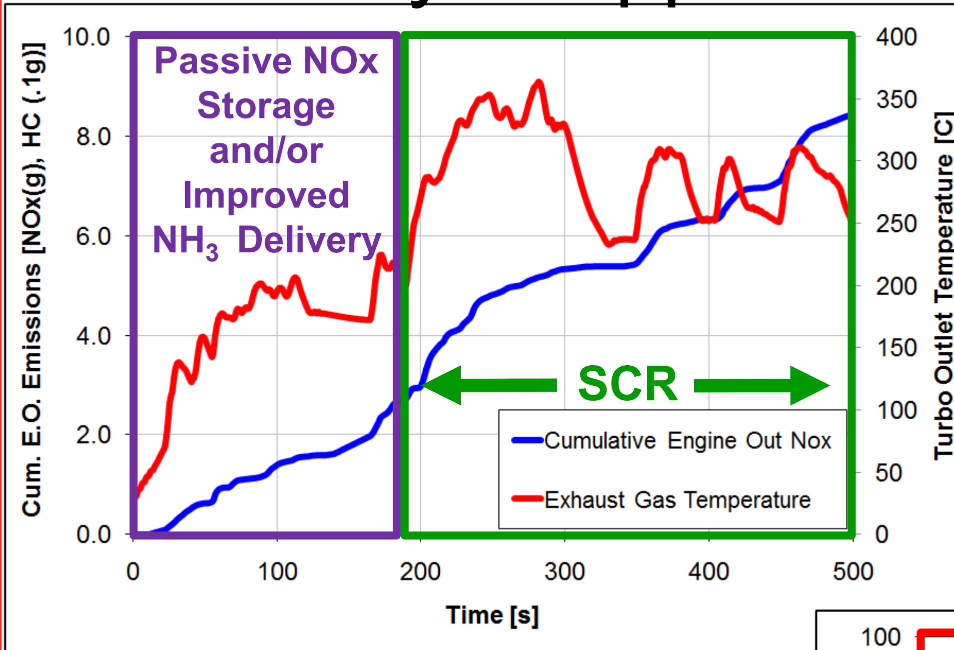
EO NOx = 0.4g/mi

NOx Conversion Performance Requirement for ATLAS



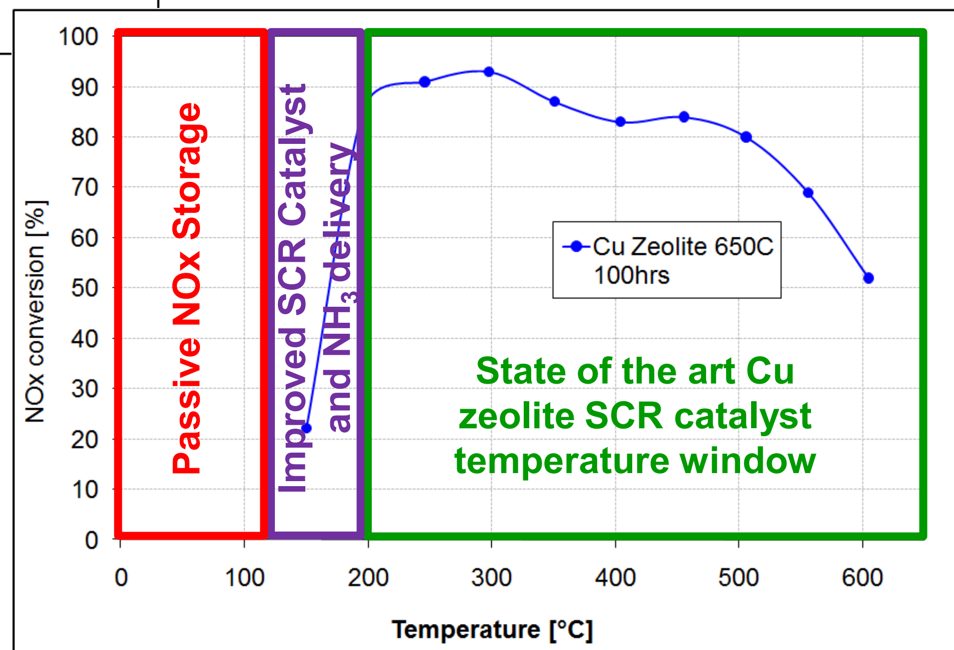
- To meet the T2B2 TP target for EO NOx of 0.4g/mi, NOx conversion efficiency during Bags 1-4 must be >96%
- In order to meet T2B2 emission levels with the current state of the art Cu Zeolite SCR formulations (~97% NOx conversion), tailpipe NOx during bag 0 must be reduced by ~50%

Catalytic Approaches to Bag 0 Emissions Mitigation

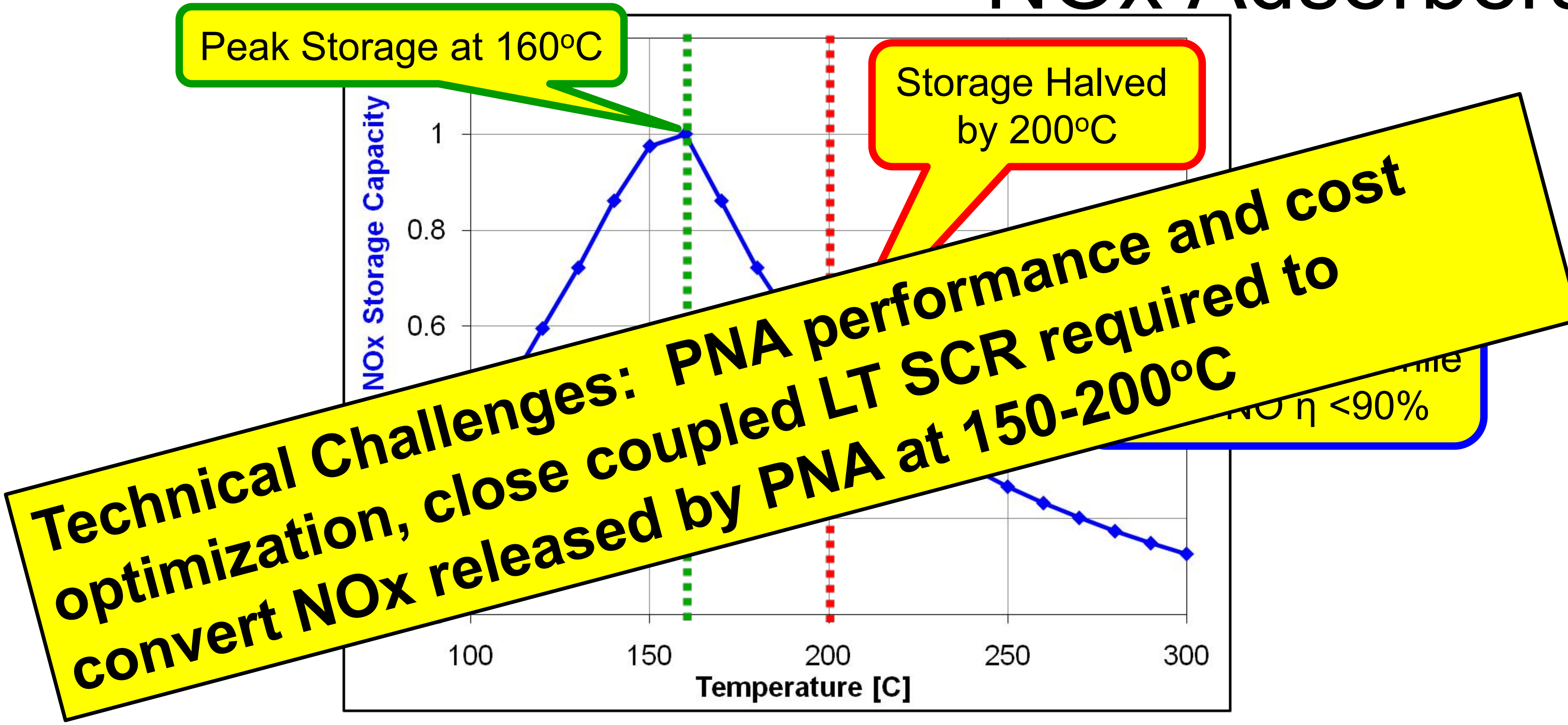


- Current state of the art Cu Zeolite formulations have a substantial drop in NOx conversion performance below 200°C
- In order to mitigate NOx emissions at the low temperatures experienced during cold starts, new advances in technology are required

- Improving current SCR formulations and NH_3 delivery may improve performance down to 150°C
- To prevent NOx slip at lower temperatures, novel technologies such as Passive NOx Adsorbers (PNA) show great potential



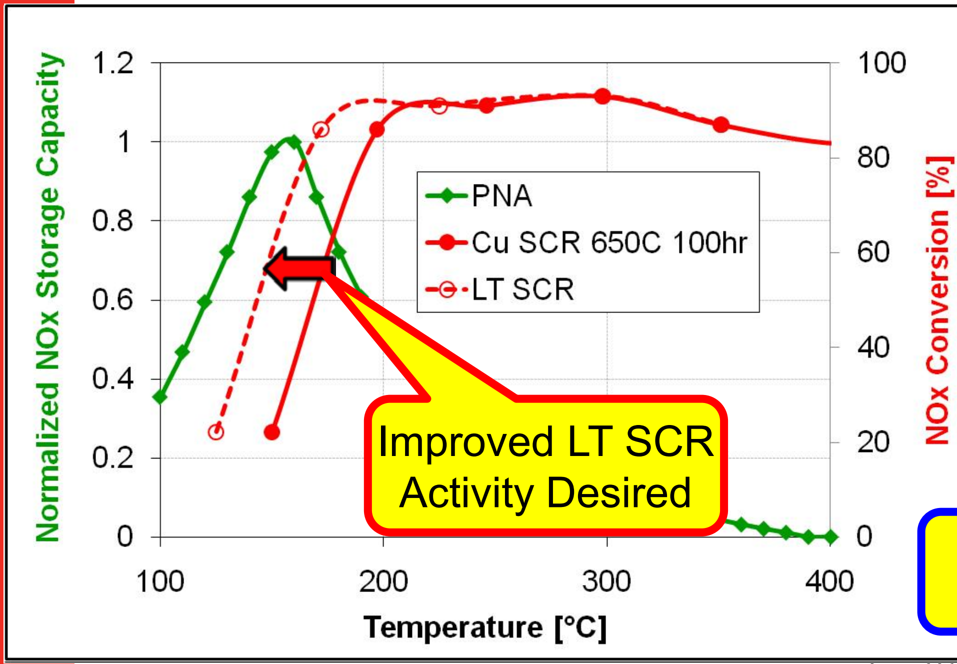
LT NOx Slip Reduction Using Passive NOx Adsorbers



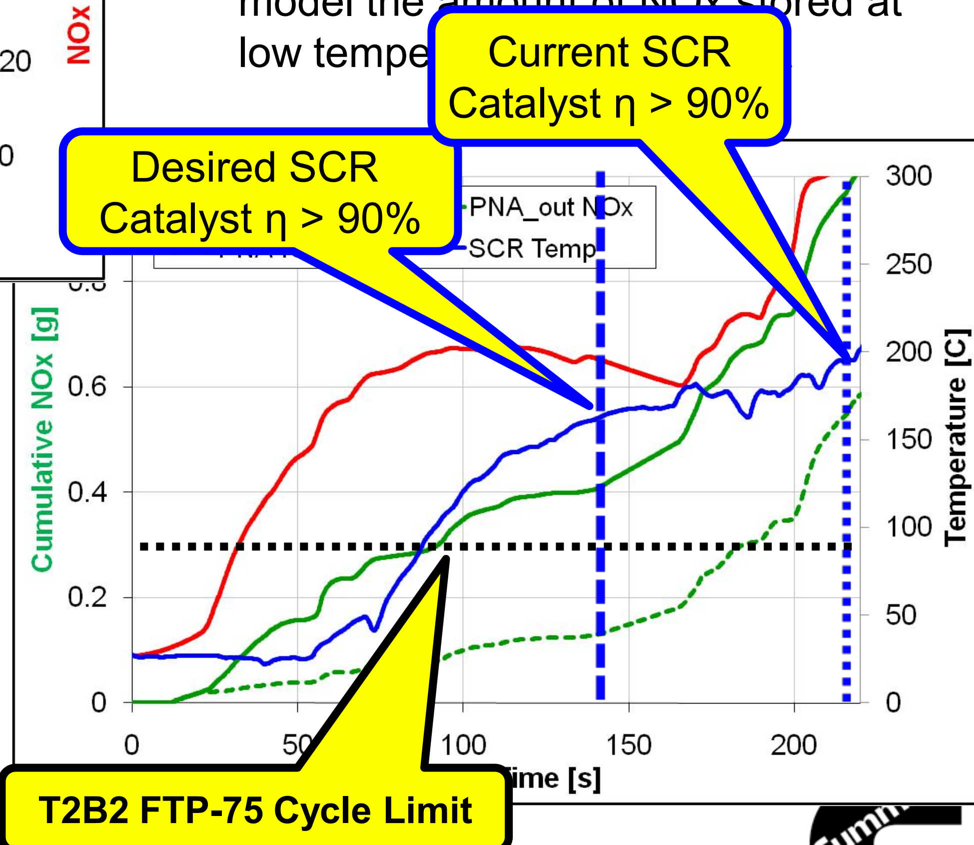
PNA storage data courtesy of Johnson Matthey, Inc

- PNAs store NOx at low temperature and release NOx as the catalyst temperature increases
- This stored NOx begins releasing from the PNA at 150°C
- **Due to the bulk release of NOx at these temperatures, a LT SCR catalyst must be close coupled to the PNA**

LT SCR Development for Improved PNA Utilization



- NOx storage data extrapolated from early JMI Dev B Formulation
- Using FTP data from the ISF 2.8, a very simplistic model was created to model the amount of NOx stored at low tempe



- Assuming a PNA volume of 0.9L with engine out NOx of 0.4 g/mi, PNA stores >65% of NOx emitted during bag 0
- This stored NOx is released around 170s when the PNA exceeds 200ºC
- Due to the bulk release of NOx near 200ºC, Dev B PNA may require SCR to be close coupled to PNA

PNA storage data courtesy of Johnson Matthey

Summary

- **Mitigation of NOx emissions during first 180s of FTP-75, is the key enabler for meeting T2B2 emissions levels**
  - Developmental PNA may be suitable for temporarily storing NOx during bag 0
    - Due to NOx release profile of PNA, SCR may need to be close-coupled to the PNA, and optimized for LT performance
- **Technical Challenges**
  - PNA Performance Optimization
    - Increased NOx release temp (~175^{o}C SOR), increased NOx storage efficiency >90% (27-150^{o}C)
  - LT CC-SCR Formulation
    - Improved LT NOx conversion efficiency (>90% @ 175^{o}C) for converting NOx released from PNA during cold start

Thank You!

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