ATP-LD; Cummins Next Generation Tier 2 Bin 2 Diesel Engine

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Cummins Inc

12 June 2015

Project ID:ACE061

Changing the Climate
on Climate Change

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Next Generation T2B2 Diesel Engine Overview

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Timeline

Start: 10/1/2010

End: 9/31/2014
(ext 3/30/2015)

Complete: 100%

Budget

Total Project:
$15M DoE
$15M Cummins

Total Spend to date:
~$15M DoE
~$15M Cummins and partners

Barriers

GHG Requirements of 28 MPG CAFE in ½ ton pickup truck

Low emission – Tier2 Bin2

Cost effective solution

Partners

Nissan Motors Light Truck

Johnson Matthey Inc

Cummins Inc (Project Lead)

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Relevance:
Next Generation T2B2 Diesel Engine Objectives

- Engine design and development program to achieve:
  - 40% Fuel Economy improvement over current gasoline V8 powered half-ton pickup truck
  - Tailpipe requirements: US T2B2 new vehicle standards

- FE increase in light trucks and SUVs of 40% would reduce US oil consumption by 1.5M bbl/day
  - Lower oil imports and trade deficits
  - GHG emissions reduction of 0.5 MMT/day
  - Enable OEM ability to continue to offer products as capable as those in commerce today.

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Next Generation T2B2 Diesel Engine Objectives

	Baseline * vehicle data	DoE Program Target **	
FTP – 75	15.6	21.8	mpg
"city"	570	462	g/mi CO_2
HFET	24.5	34.3	mpg
"Highway"	363	292	g/mi CO_2
CAFE	18.6	26.0 ***	mpg
	476	385	g/mi CO_2

* Baseline data from 2010 EPA database for new vehicle certification for Nissan Titan 2WD at 5500 lb test weight

** DoE program targets base on MPG values at 40% greater than base

*** 26 mpg CAFE does not meet 2015 GHG requirement of 28 mpg

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2014/15 Milestones

	% Complete	2014/15 Milestones
March 2014	100%	T2B2 Aftertreatment integrated in dynamometer environment
May 2014	100%	Convert Vehicle to T2B2 configuration (Sept 2014)
Aug 2014	100%	Demonstration of FTP on engine dyno at T2B2 tailpipe (Jan 2015)
Sept 2014	100%	Demonstration of FTP on chassis at T2B2 (Feb 2015)

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Technical Approach

- Replace **aluminium V8 gasoline engine** and emission control system with smaller diesel and its emission control system (ECS) **without a weight penalty**
- Extensive use of aluminium as well as space saving design features for new engine weight control
- Down Sized Engine with high power density
- Integration of learning from LTD and LDECC programs to utilize PCCI and high charge flow operation
- Reduce FE penalty due to emission controls
  - Low pressure EGR, Cold Start Concept (CSC™) catalyst for cold start NOx & HC mitigation, NH3 gas System for immediate reductant delivery, and a small engine running higher loads resulting in faster warm-up

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Technical Accomplishments

- Cummins has successfully designed, procured, and demonstrated an all new 2.8L highly efficient diesel engine designed specifically for automotive use.
  - 120 lbm weight reduction compared to the production 2.8L and weight neutral, including ECS, compared to an all aluminium gasoline V8 powertrain.
- Cummins has over 10K hours of test time on the new engine design, demonstrating capacity of 220 hp and over 500 ft-lb of torque in vehicle certification trim.
  - Includes intake and exhaust restriction and all necessary equipment to meet tailpipe emissions requirements.
- Cummins has demonstrated Tier 2, Bin 2 emissions compliance with margin, repeatedly on two vehicles.

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Technical Accomplishments

Test - EPA75

2010 Nissan Titan #3546

Auto Trans

5500 lbi Test Wt

	NOx (g/mi)	CO (g/mi)	NMHC (g/mi)	FE (mpg)
Phase 1	0.060	0.614	0.0213	24.37
Phase 2	0.002	0.028	0.0001	25.84
Phase 3	0.004	0.154	0.0007	27.75
Weighted Composite	(0.015) **0.01**	(0.154) **0.2**	(0.0046) **0.00**	**26.00**
Tier 2 Bin 2	0.02	2.1	0.01	-

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Technical Accomplishments – CAFE Performance; 60% Improvement!

	Baseline Gasoline V8*	DoE Program Targets**	ATLAS Demonstration	
FTP – 75 "City"	15.6	21.8	**26.0**	mpg
	570	462	**391**	g/mi CO_2
HFET "Highway"	24.5	34.3	**36.2**	mpg
	363	292	**281**	g/mi CO_2
CAFE	18.6	26.0***	**29.8**	mpg
	476	385	**341**	g/mi CO_2

* Baseline data from 2010 EPA database for new vehicle certification for Nissan Titan 2WD at 5500 lb test weight

** DoE program targets base on MPG values at 40% greater than base

*** 26 mpg CAFE does not meet 2015 GHG requirement of 28 mpg

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Technical Accomplishments – No FE Penalty due to Emission Control

Test – LA4 (warm)

2010 Nissan Titan #3546

Auto Trans

5500 lbi Test Wt

	NOx (g/mi)	NMHC (g/mi)	FE (mpg)
With EGR	0.30	0.43	26.3
Without EGR	3.68	0.42	26.0
% change	92	102	101

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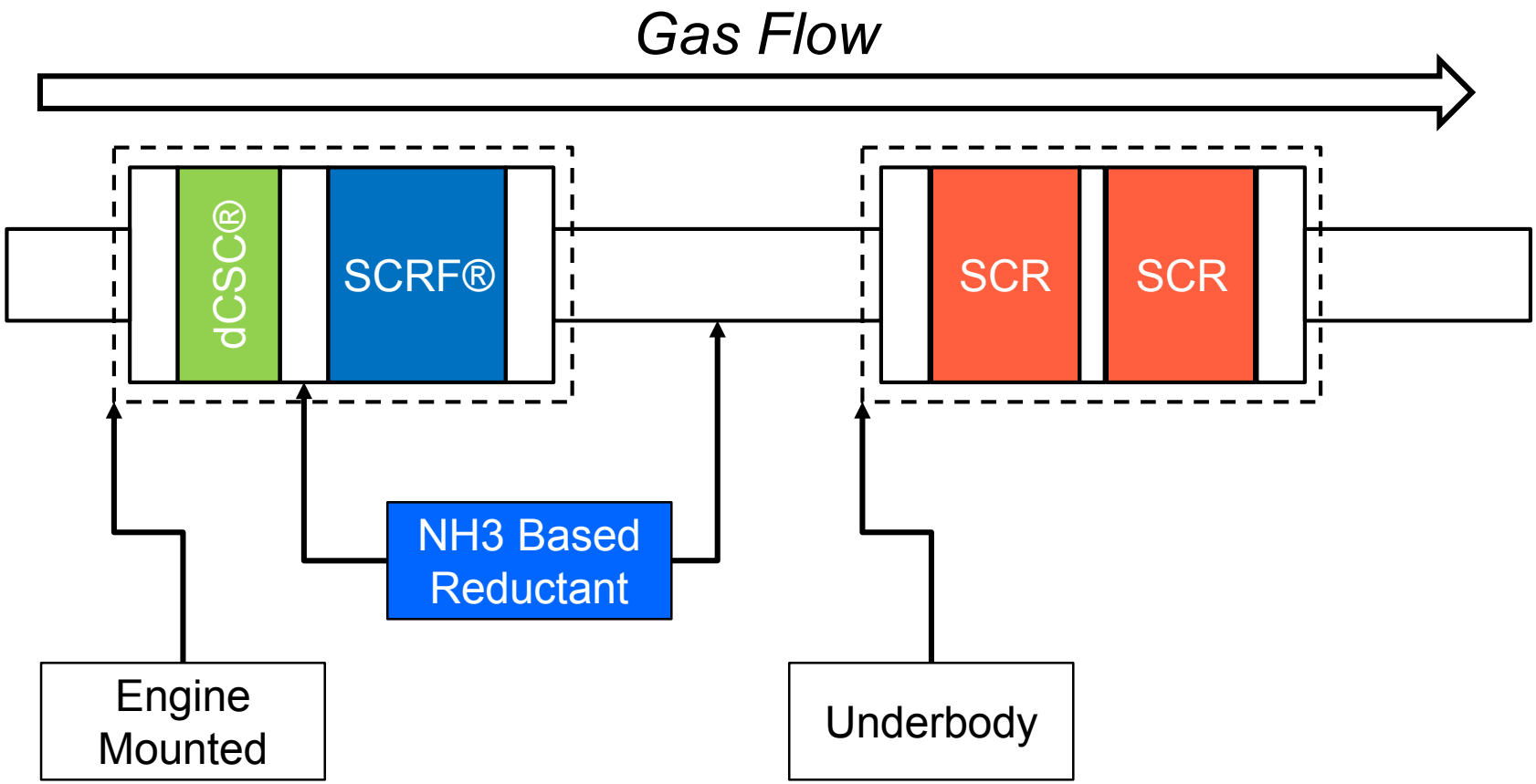
System description



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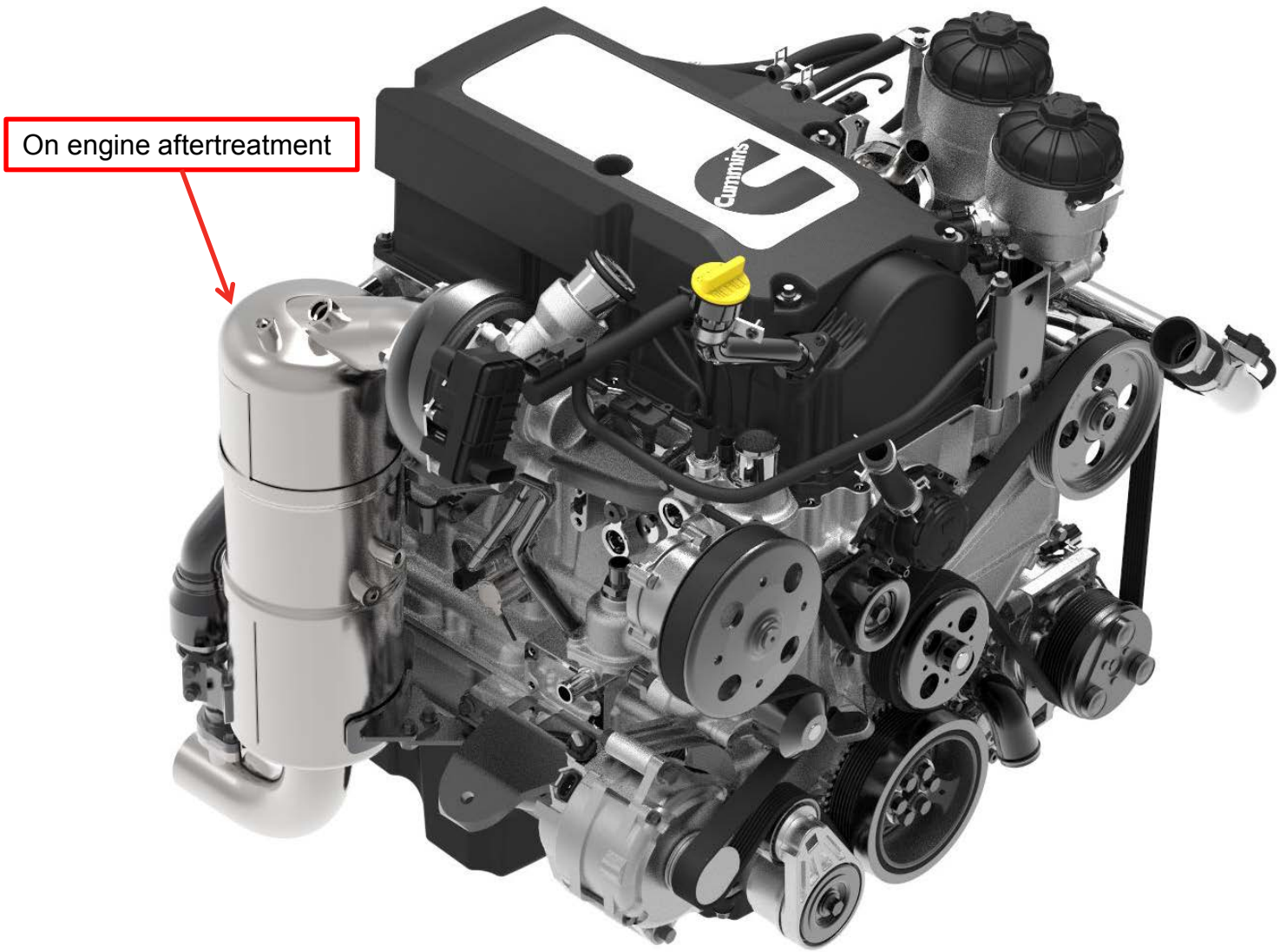

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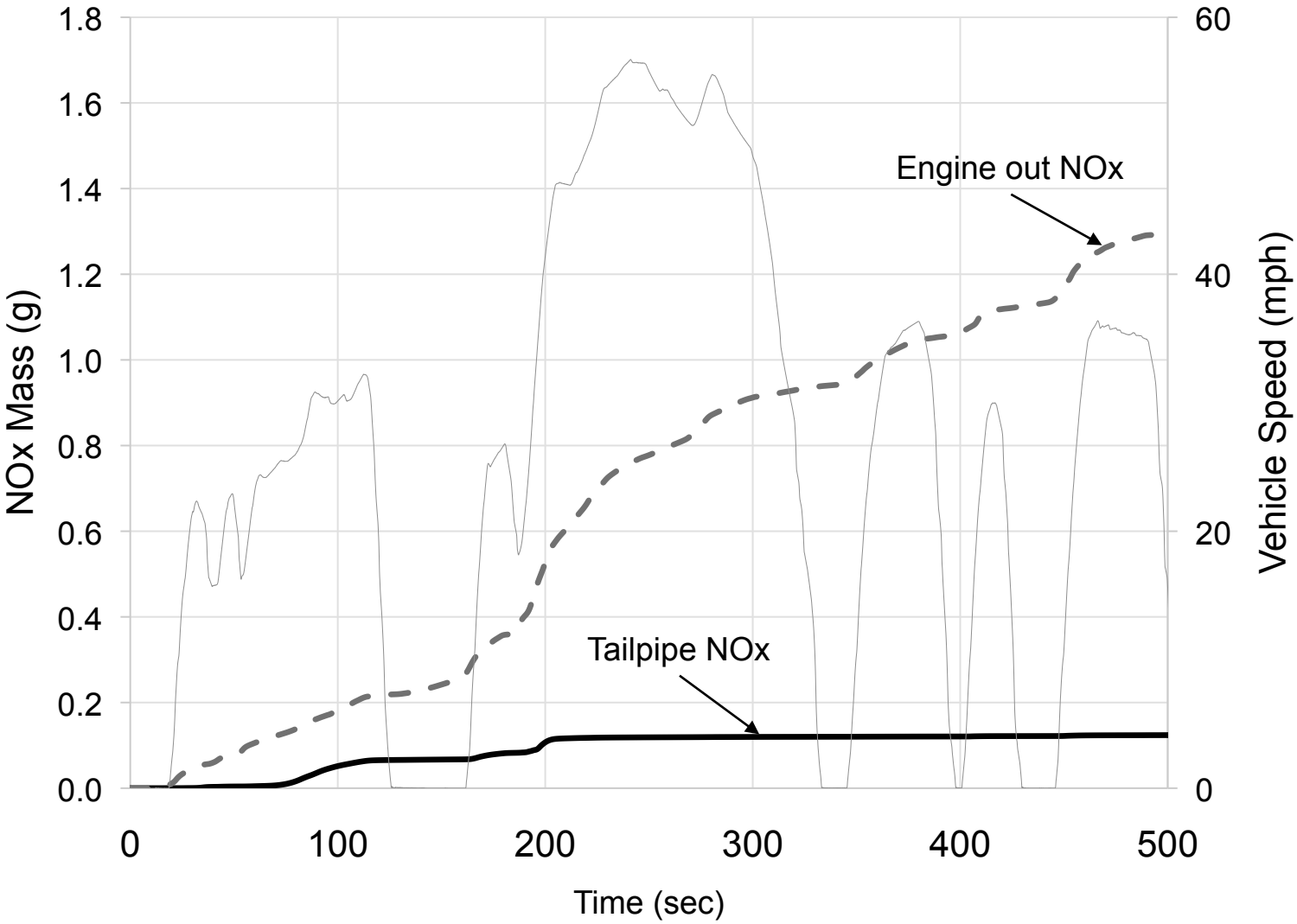
Technical Accomplishments Demonstration



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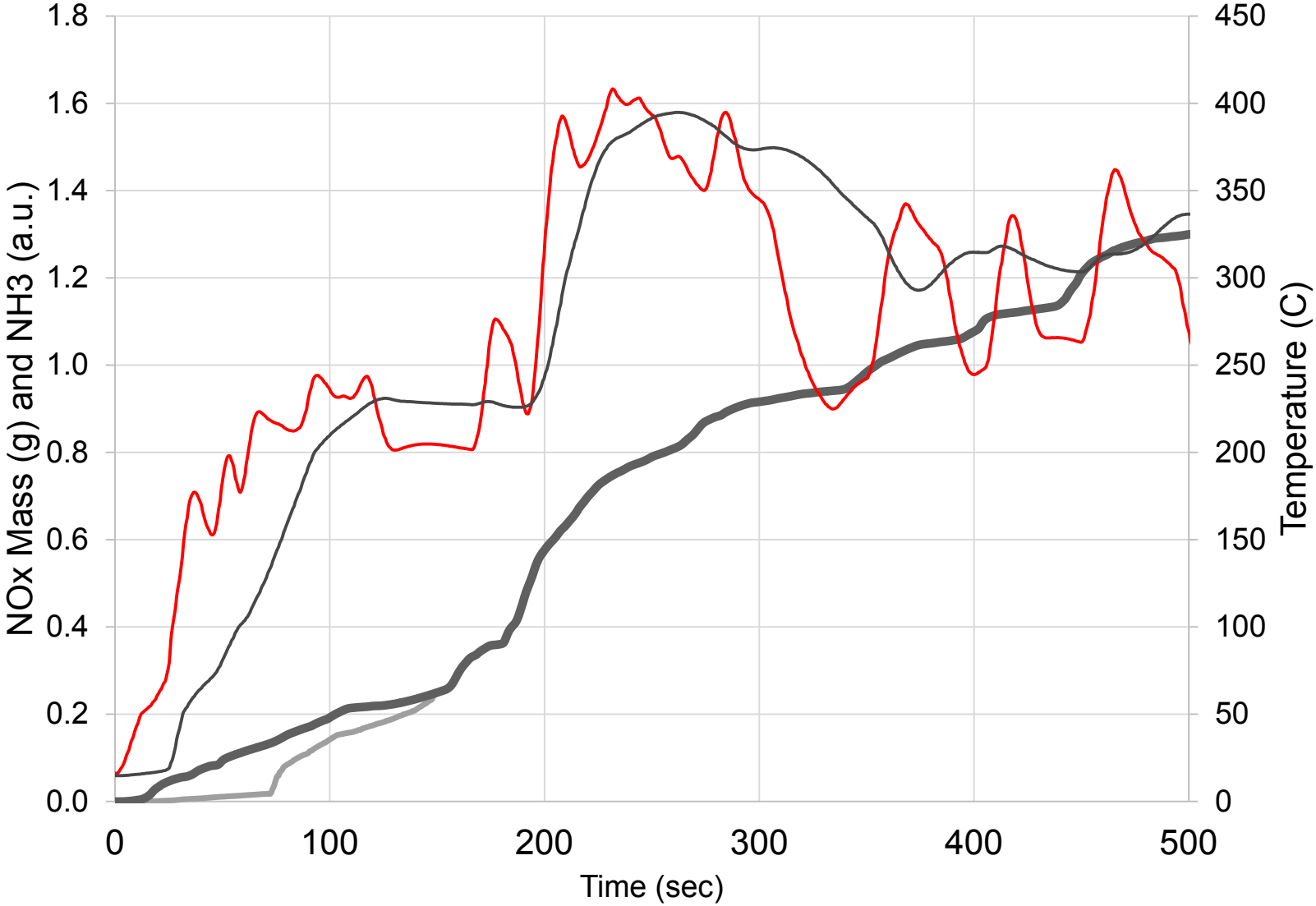
Technical Accomplishments
dCSC® Storage Performance



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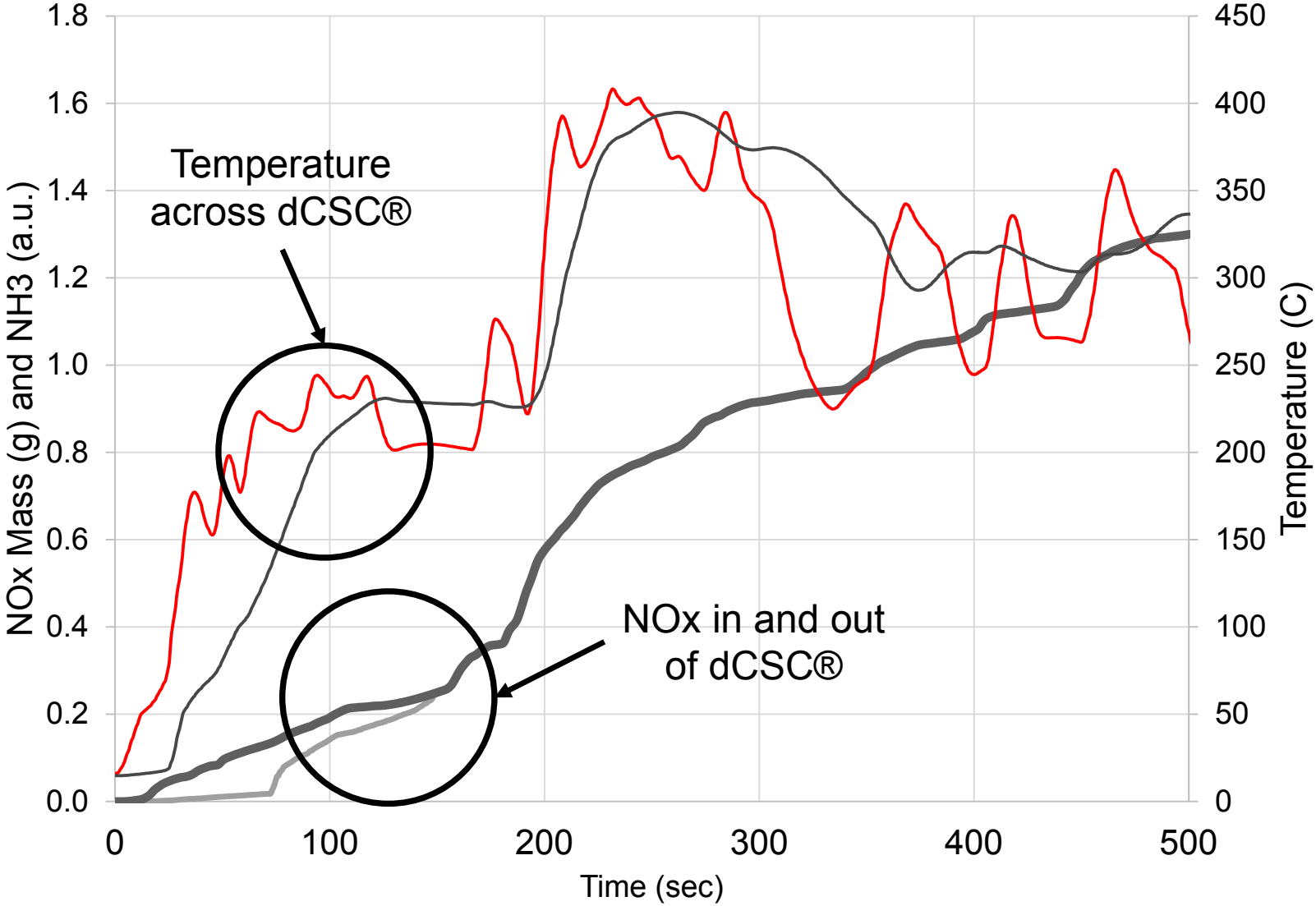
Technical Accomplishments
dCSC® Storage Performance



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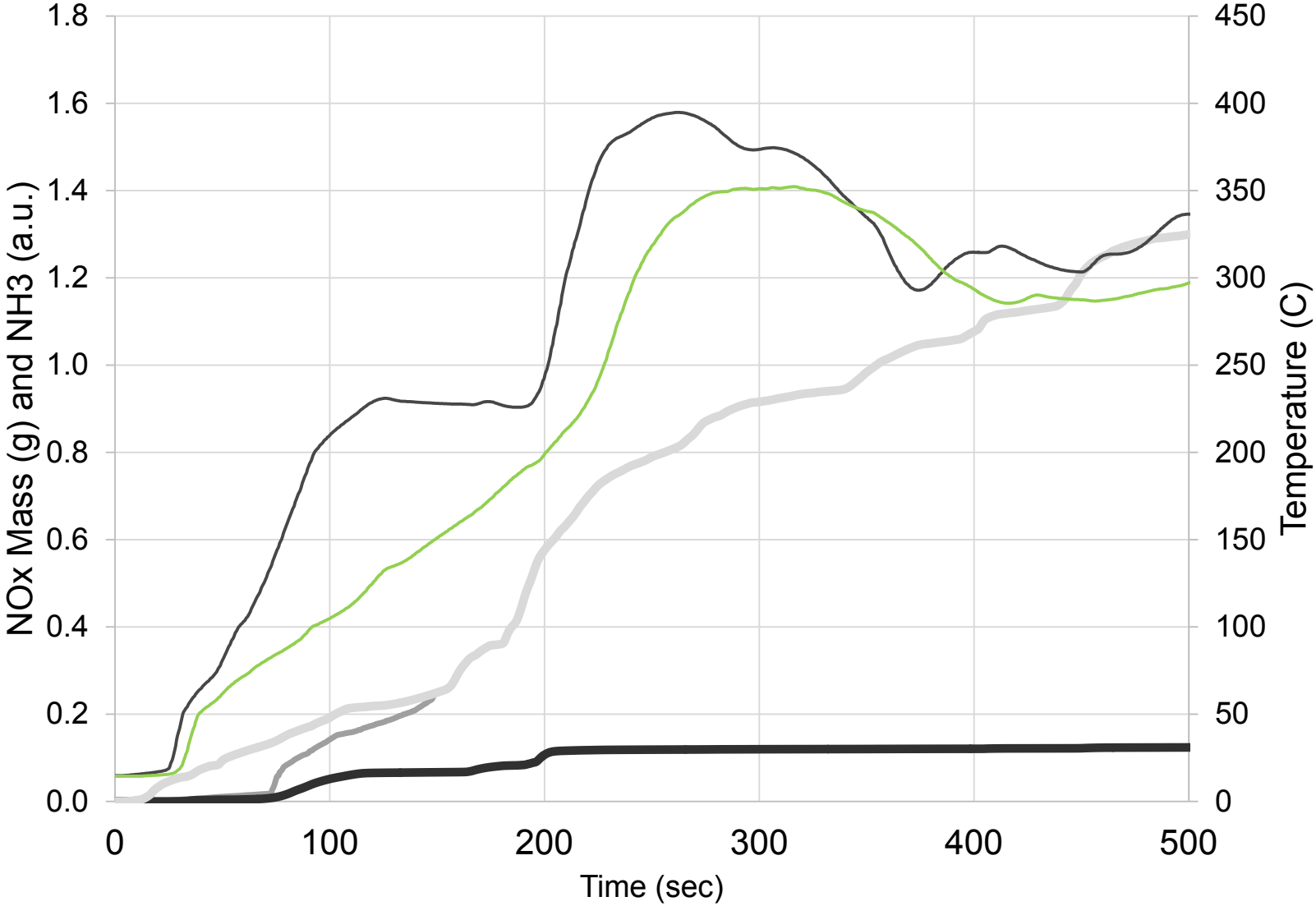
Technical Accomplishments
SCRF® Performance (Stored NH3)



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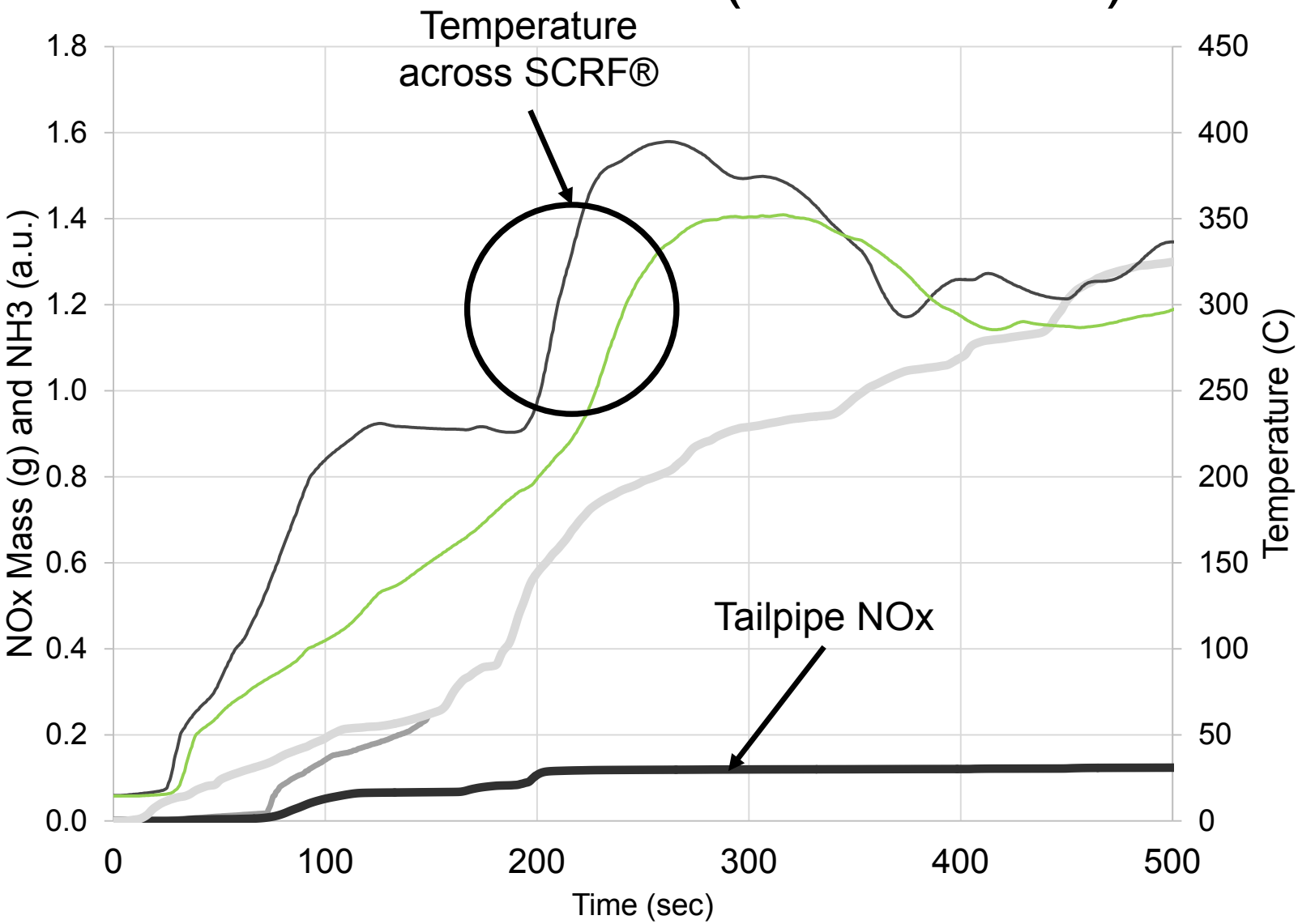
Technical Accomplishments
SCRF® Performance (Stored NH3)



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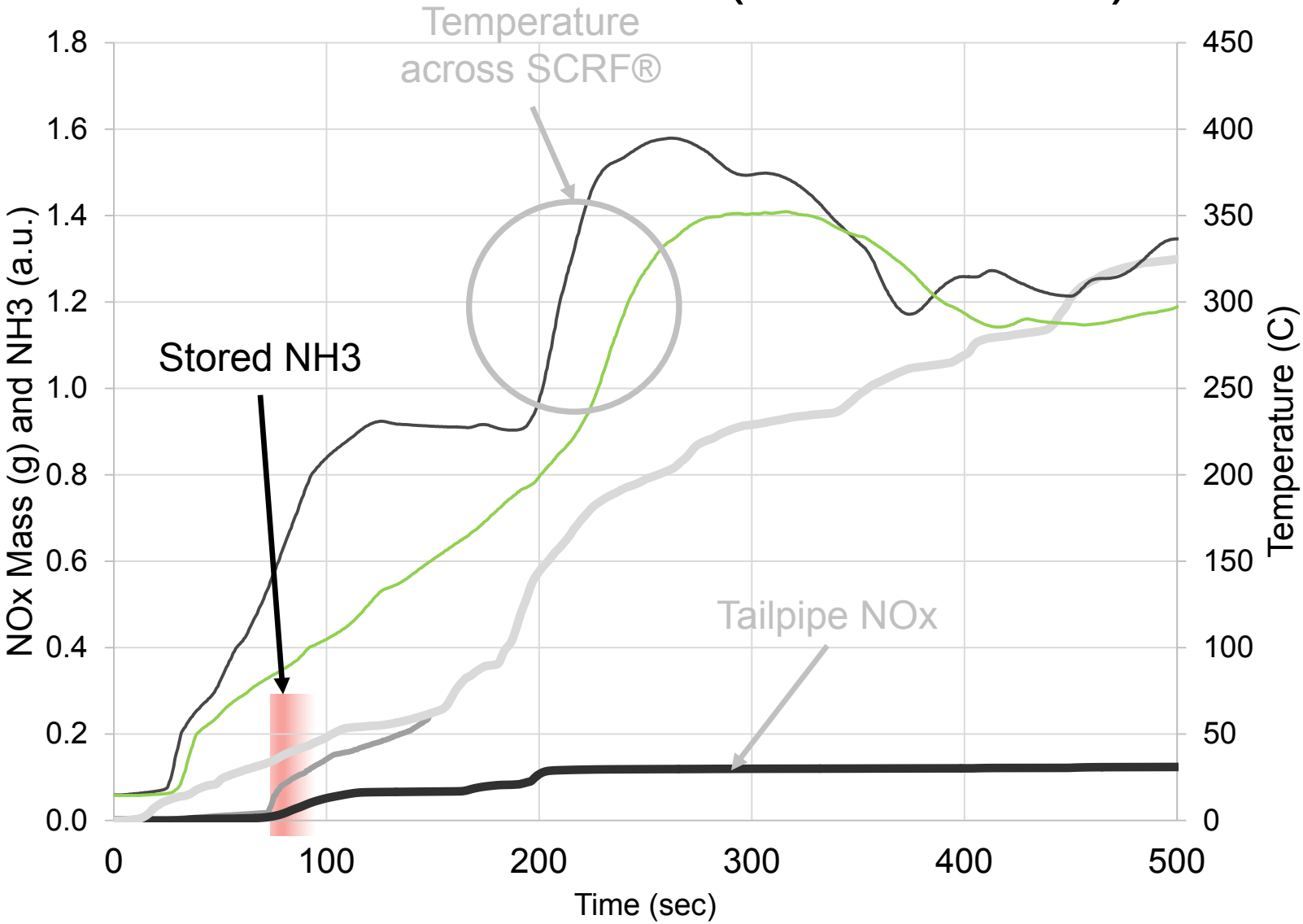
Technical Accomplishments
SCRF® Performance (Stored NH3)



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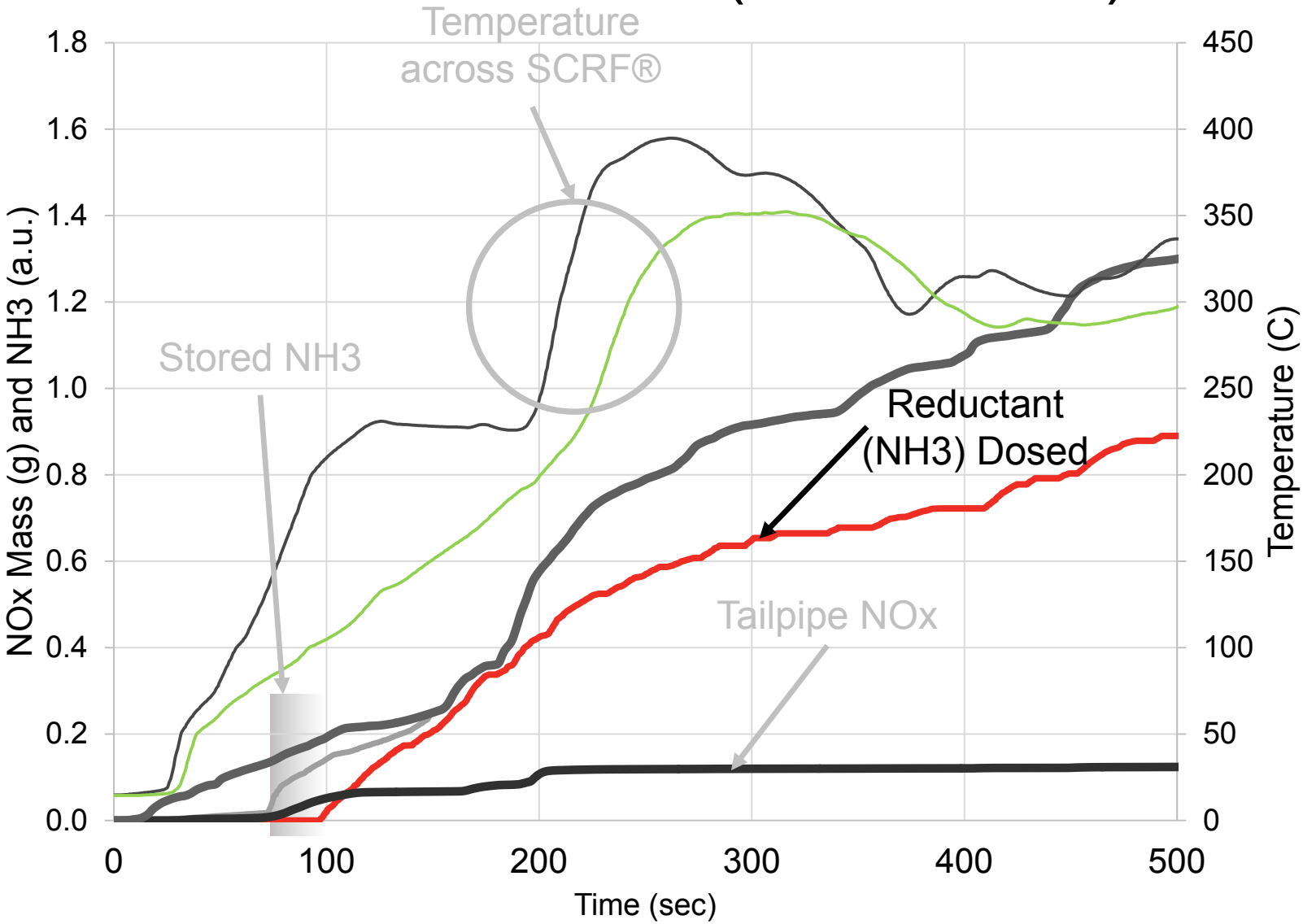
Technical Accomplishments
SCRF® Performance (Dosed NH3)



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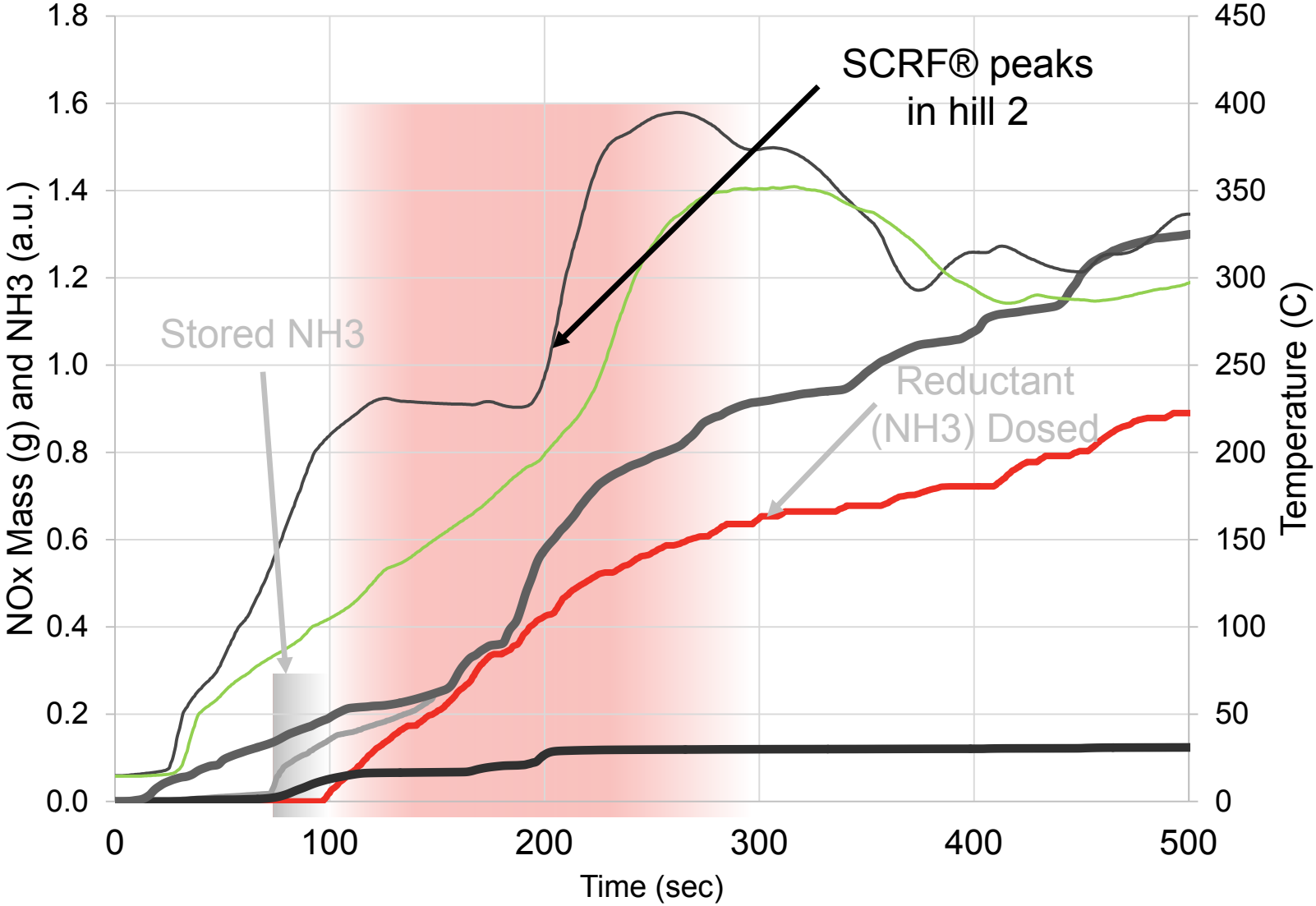
Technical Accomplishments
SCRF® Performance (Dosed NH3)



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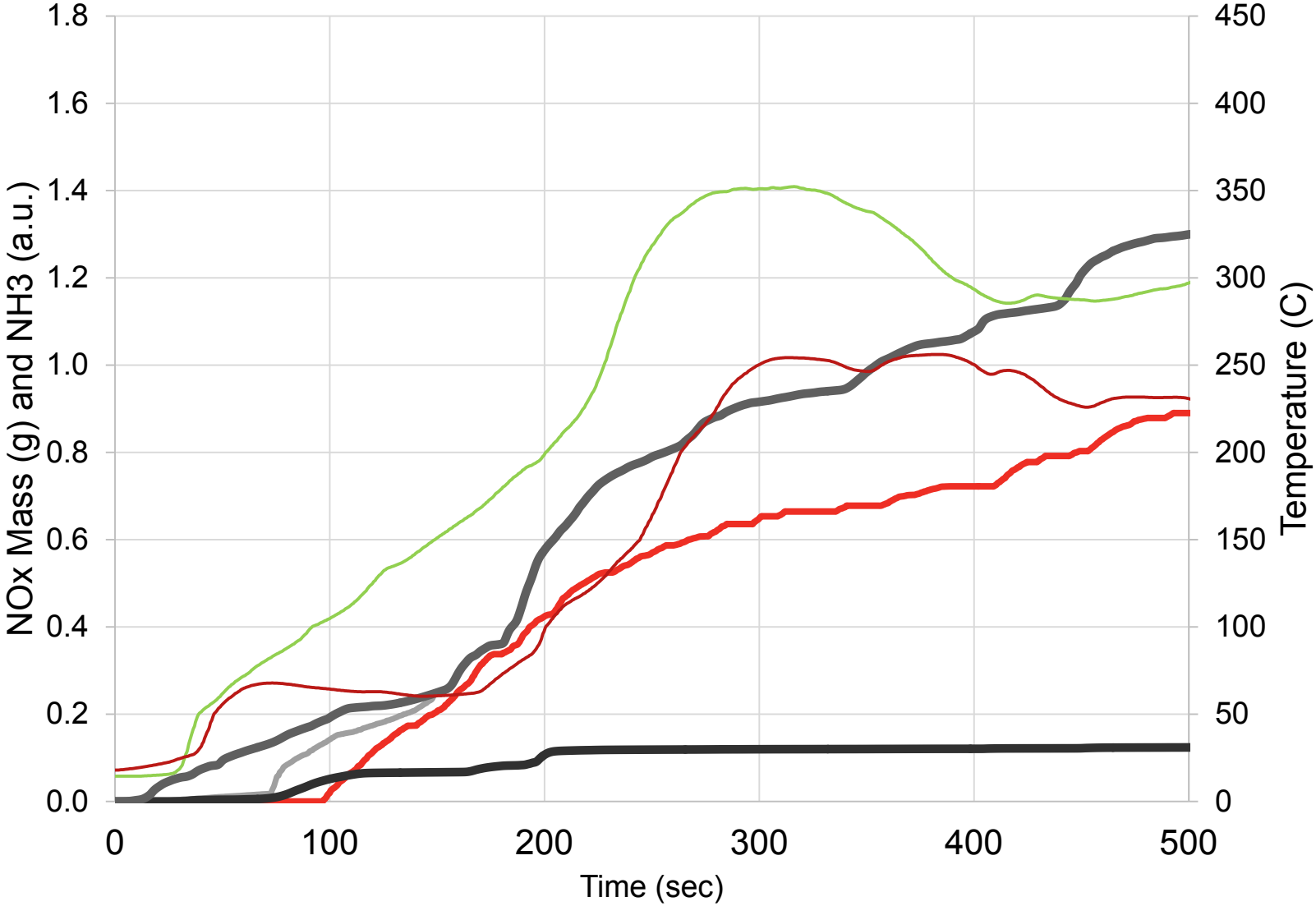
Technical Accomplishments
Underfloor SCR Performance



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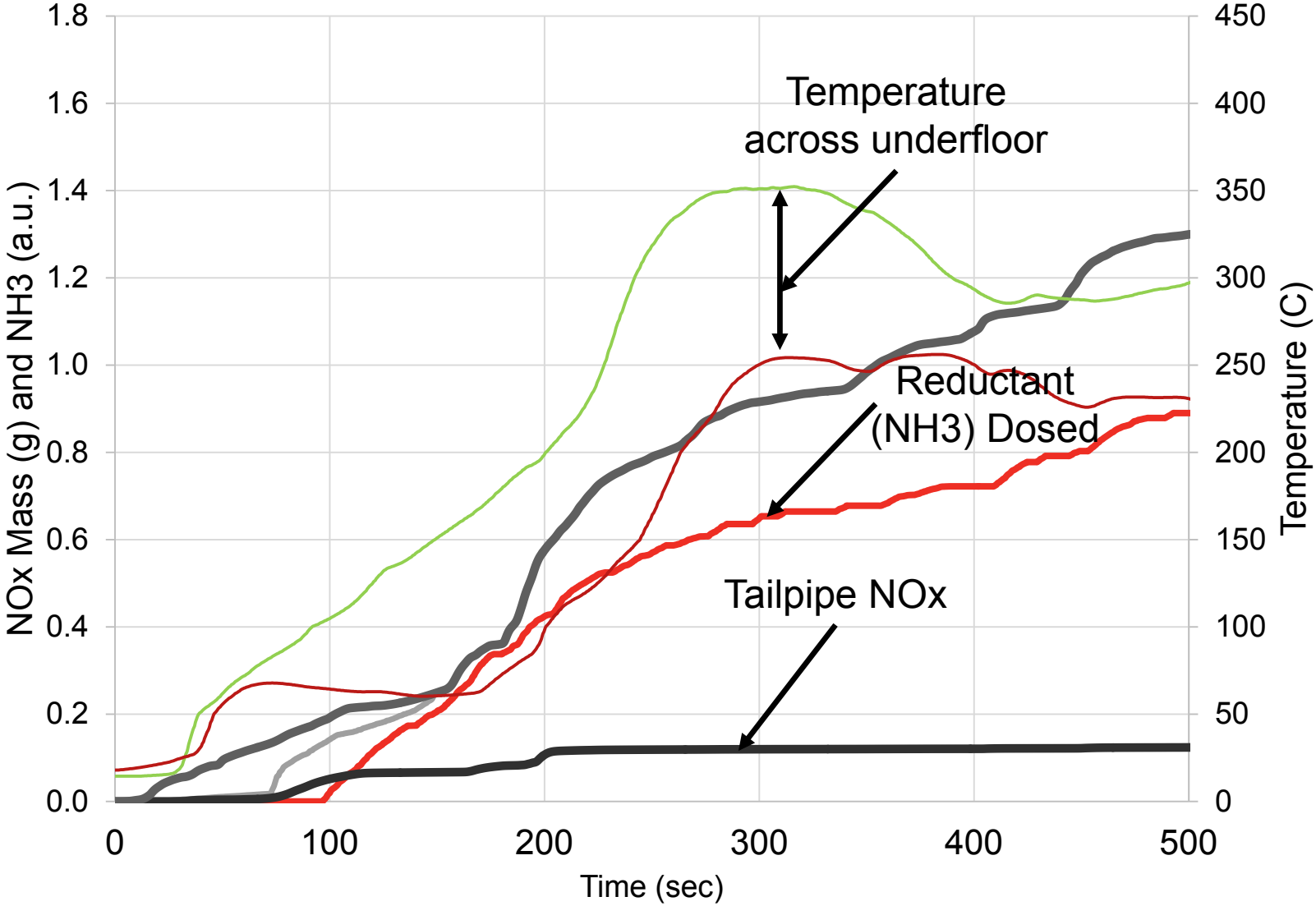
Technical Accomplishments
Underfloor SCR Performance



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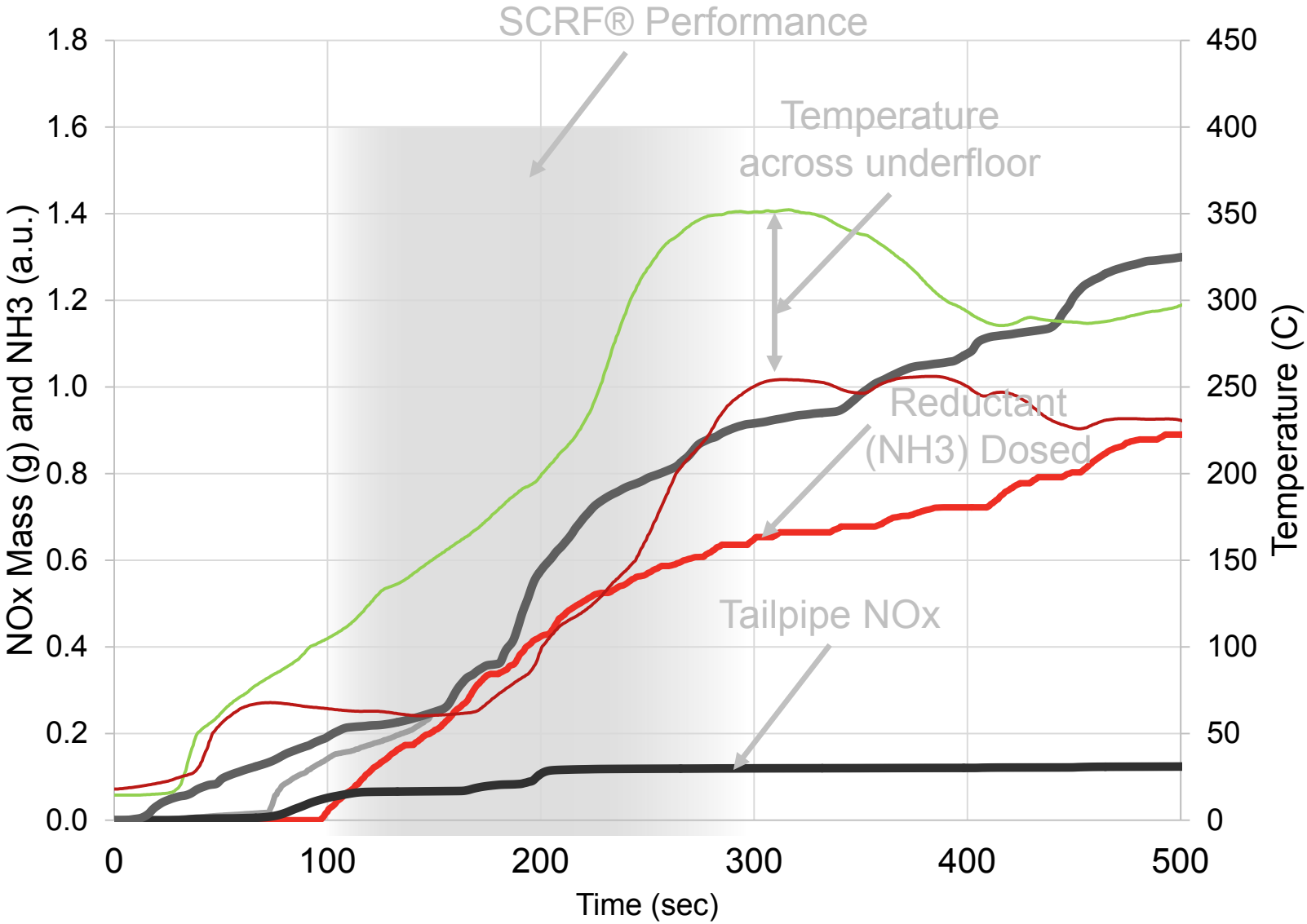
Technical Accomplishments
Underfloor SCR Performance



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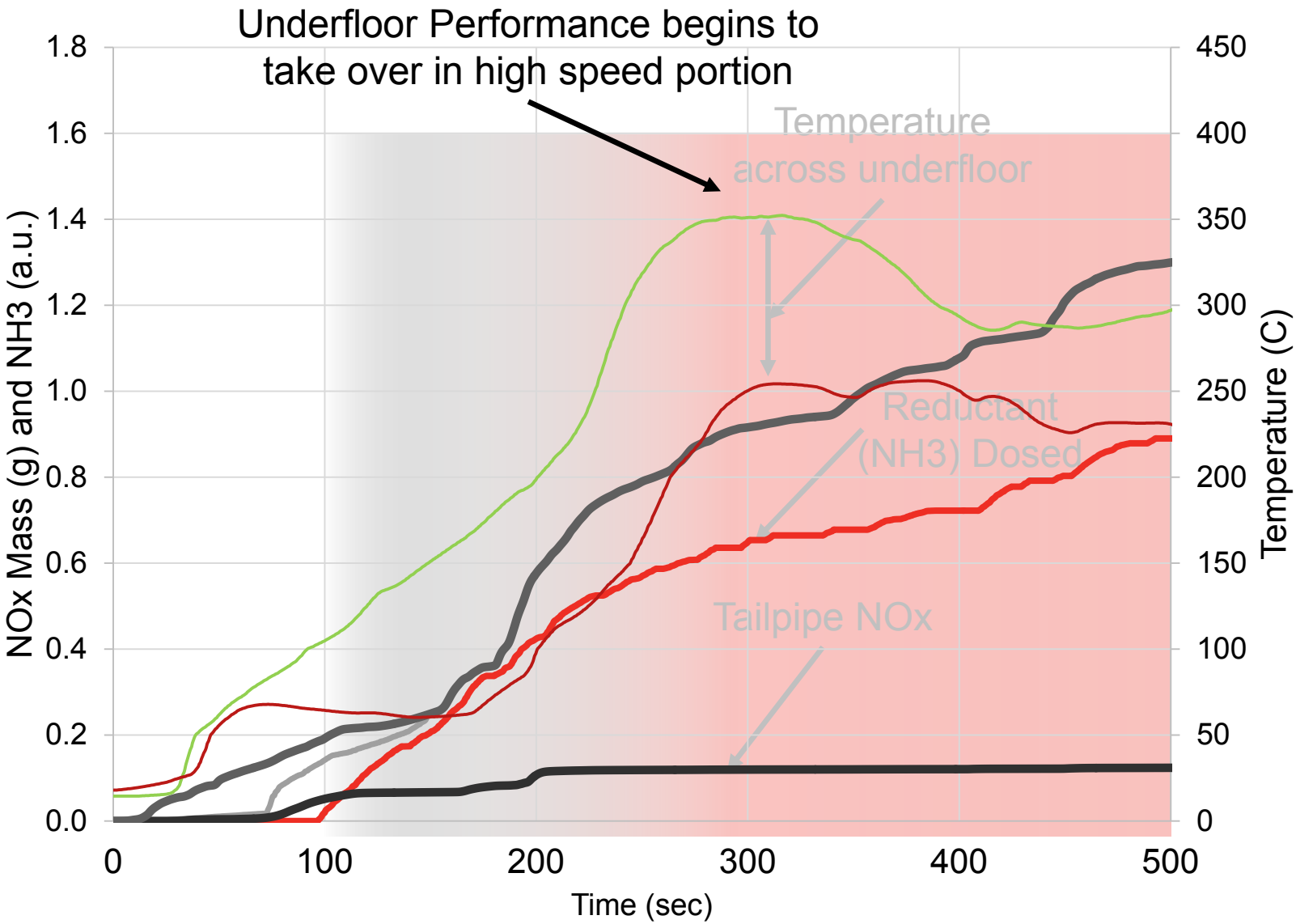
Underfloor SCR Performance



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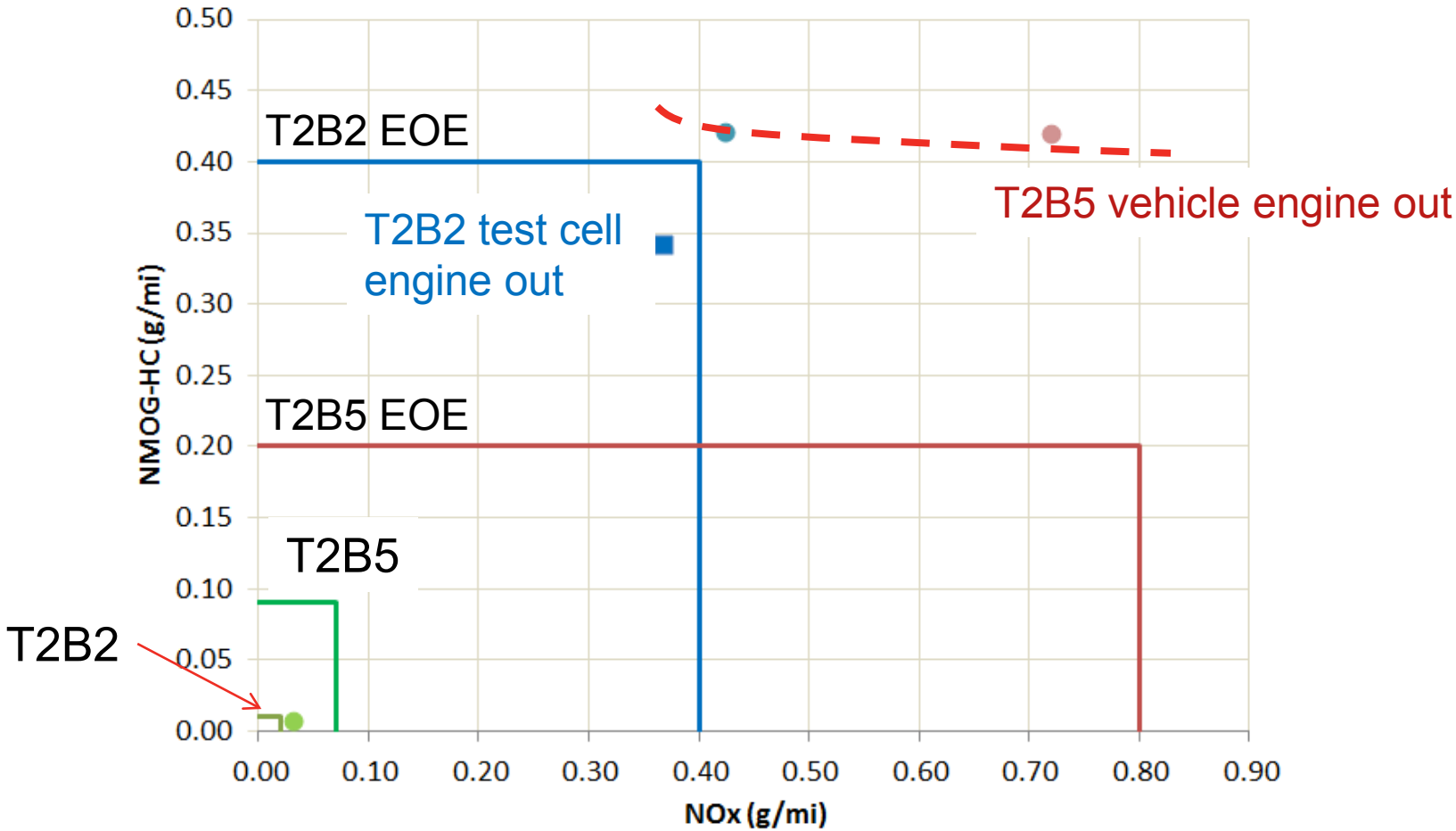
Technical Accomplishments and Progress; Vehicle Demonstration

- ATLAS engine achieving engine out targets



T2B5 = HP EGR only

T2B2 = Dual loop EGR

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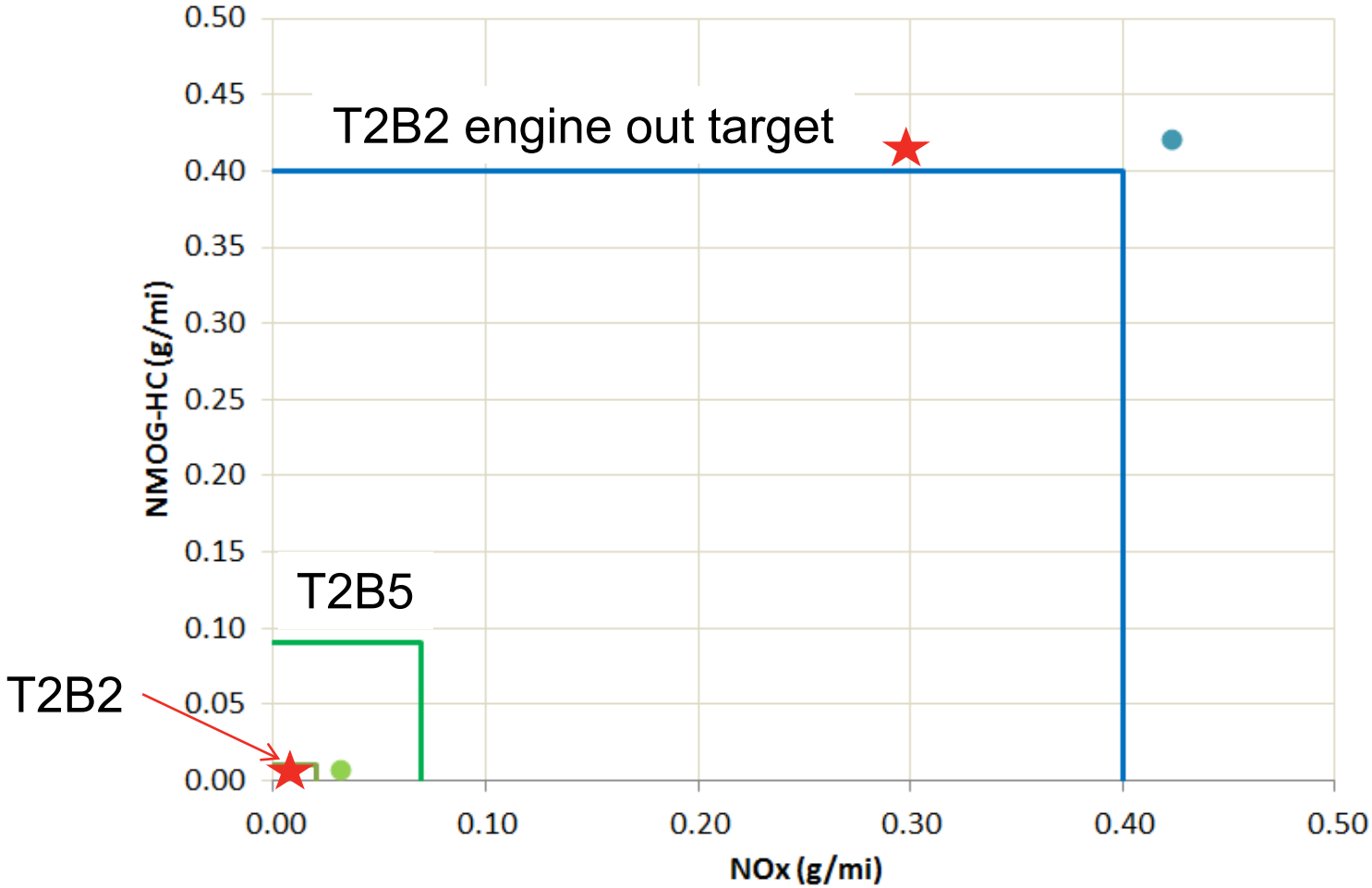
Technical Accomplishments and Progress; Vehicle Demonstration

- First demo vehicle demonstrated T2B5 with margin without the aid of full dCSC™ and LP EGR- **<u>while maintaining FE above target</u>**!



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Collaborations

- Partners
  - **Johnson Matthey** –(industry, subcontractor) Advanced aftertreatment formulations and architecture
    - CSC™ for cold start NOx and HC emission mitigation
    - Close coupled SCR on filter for improved cost and effectiveness
    - *T2B2 systems currently on test*
  - **Nissan** (industry, partner) – Vehicle integration and guidance on engine technical profile.
    - *Multiple vehicle evaluations over the past 6 months*
- Other involvement
  - **Purdue –** Utilization of "cam-less" engine to work on cold start improvement methods with the constraints of the current ATLAS overhead.
    - Work within the constraint of switching valve train to change intake or exhaust profile

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Summary

- Cummins has delivered fuel economy 60% improved over that of the baseline gasoline power train while also meeting the requirements of Tier2Bin2 tail pipe emissions.
- Cummins has designed a system that does not penalized fuel economy due to emission controls.
- Demonstrated catalyst performance has met or exceeded targeted conversion rates.
  - Increased allowance on engine out HC while meeting NOx performance
- Cummins has met the weight neutral goal for the system.
  - No increase in weight due to diesel engine application including all emission control systems
  - Power density of 80 hp/L (exceeding the target of 75 hp/L)

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Technical Backup Slides (5 max)

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Technical Approach – High Efficiency
Engine weight control via design features

Goal: equivalent application weight as baseline engine

- Light weight steel piston for reduced friction & compression height with increased power density
  - Reduce deck height=> reduced cylinder block weight
- Aluminum cylinder head and block
  - Reduced weight and physical size
  - Create a weight allowance for emission control devices
- Low thermal mass exhaust manifold for rapid warm up
  - Reduced mass & thermal load vs standard cast iron construction
- Forged crankshaft with smaller (than cast) journals and increased strength for power density
  - Smaller and lighter vs standard cast iron

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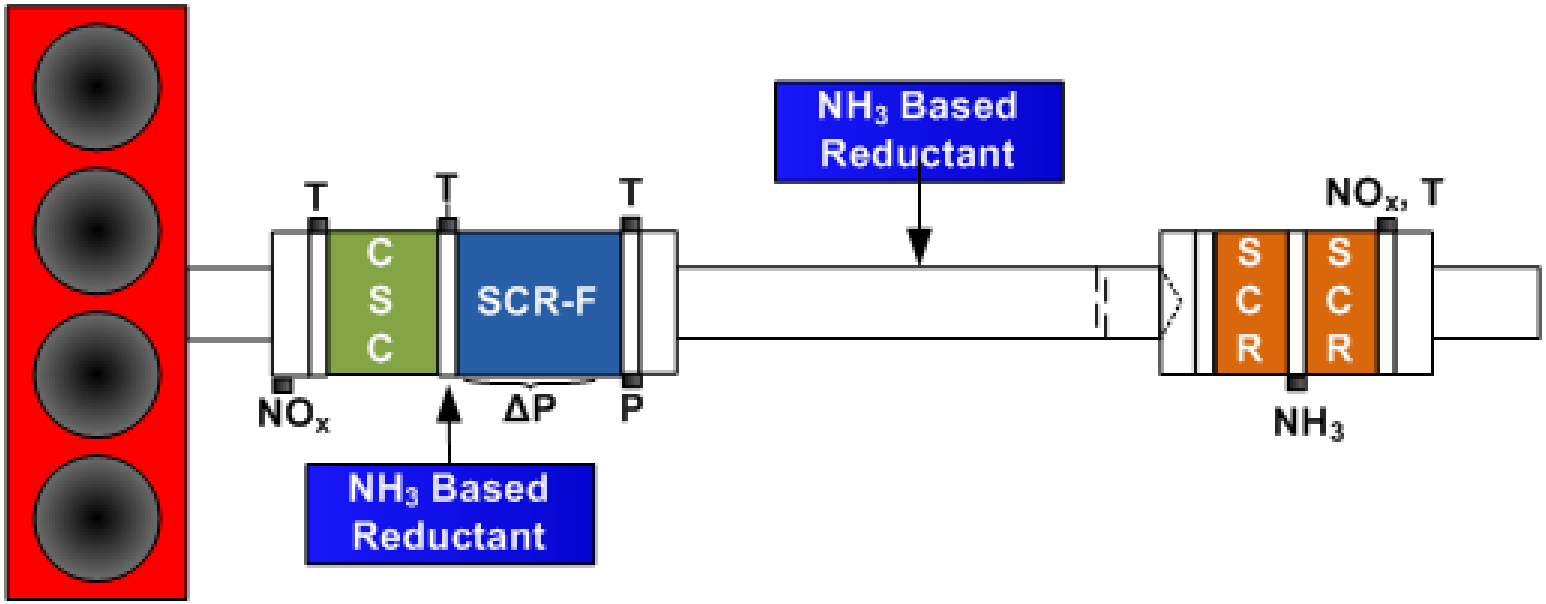
Technical Approach - Exhaust System Configuration



- Close coupled filter system to enable low pressure EGR
- SCR coated on filter (SCR-F) allows for close coupling of SCR function for fast light off
- Use of a direct ammonia delivery system (DADS) can further improve NOx conversion performance by reducing the time delay before NH_3 introduction after cold start
- DADS also allows for multiple NH_3 dosing locations, which allows for the integration of additional under-floor SCR elements to mitigate IRAF

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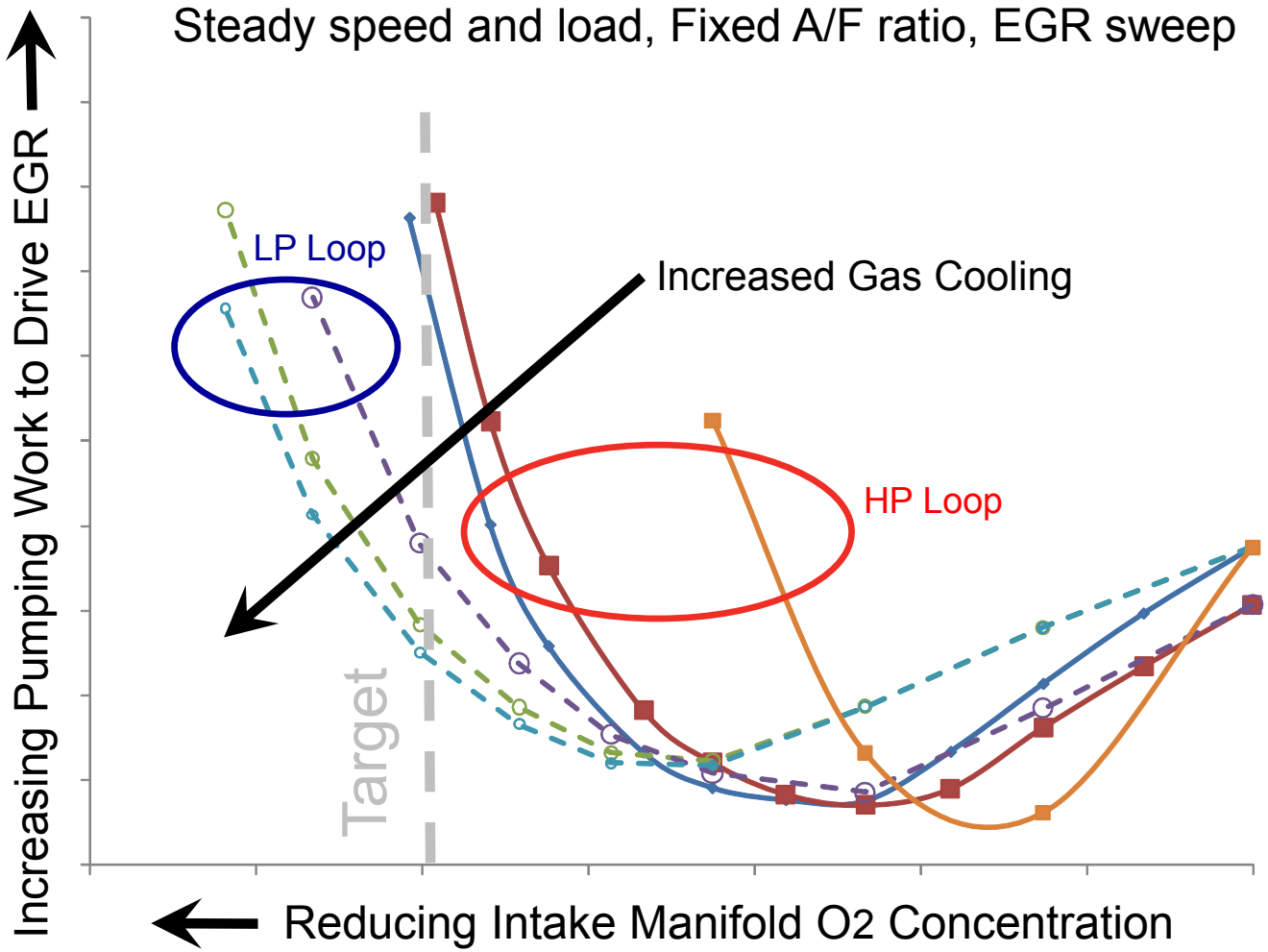
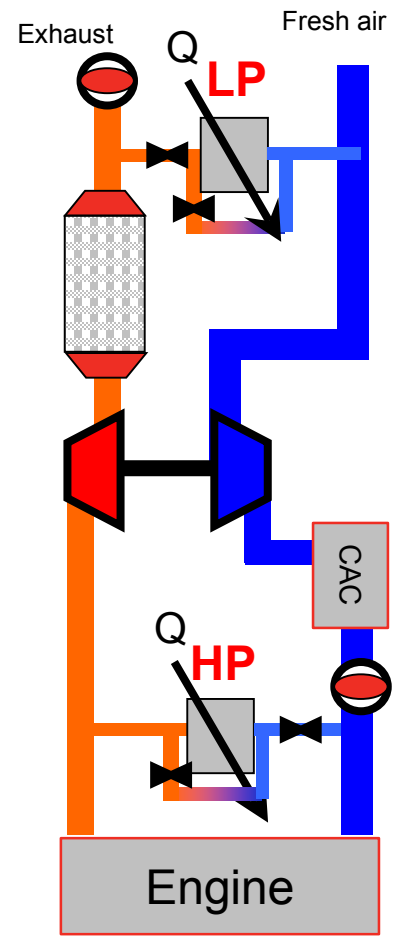
Technical Approach – High Efficiency

Reduce FE penalty due to emission controls

- Low pressure EGR to reduce pumping work





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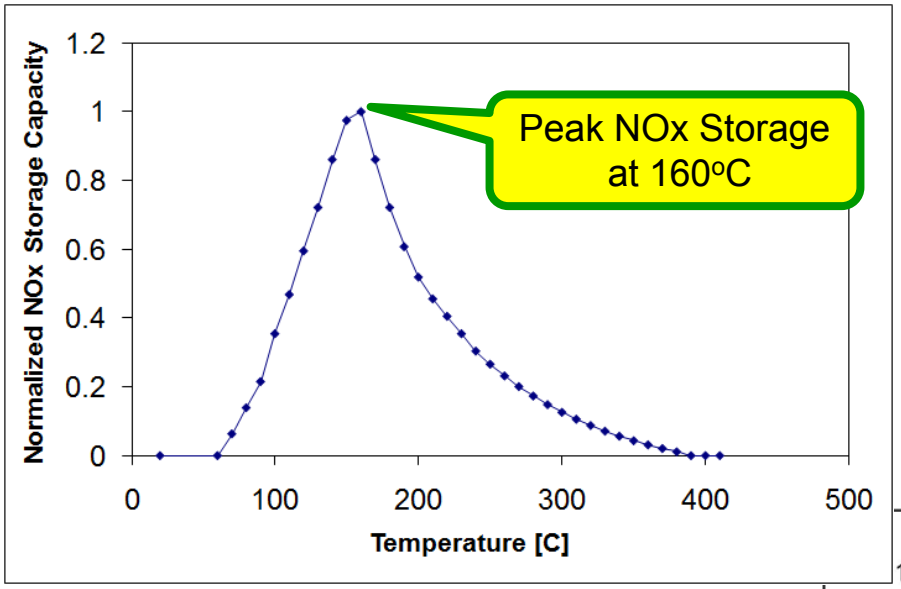
Technical Approach – High Efficiency

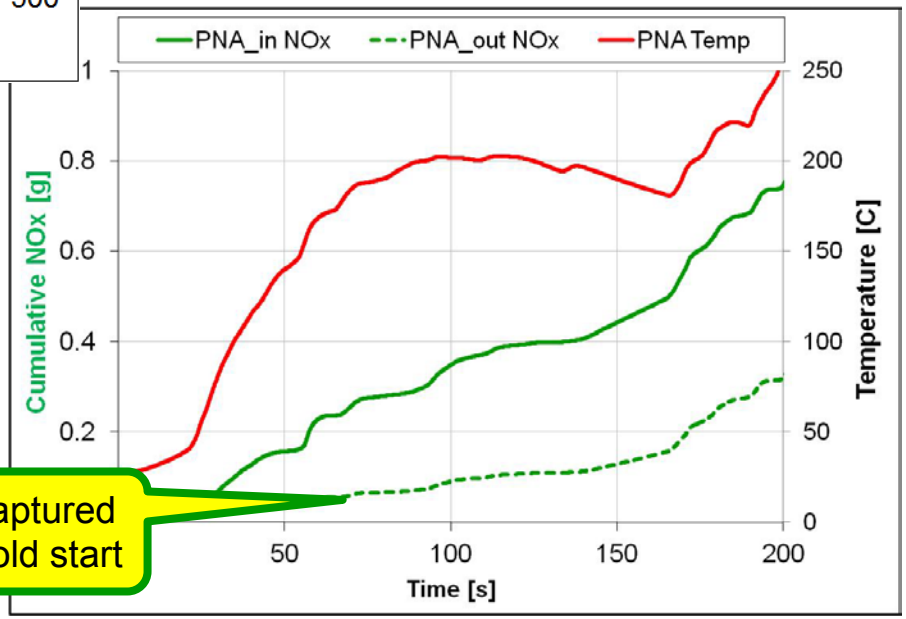
Reduce FE penalty due to emission controls

- PNA to control NOx under cold start w/o FE penalty



- A passive NOx Adsorber (PNA) stores NOx at low temperature and desorbs as the catalyst temperature increases
- With an optimal formulation release of NOx when the SCR reaches operating temperature

- PNA stores approximately 65% of the NOx released by the engine up to 180s into the cold FTP cycle
- This stored NOx is released around 180s when the exhaust temperature reaches 200°C



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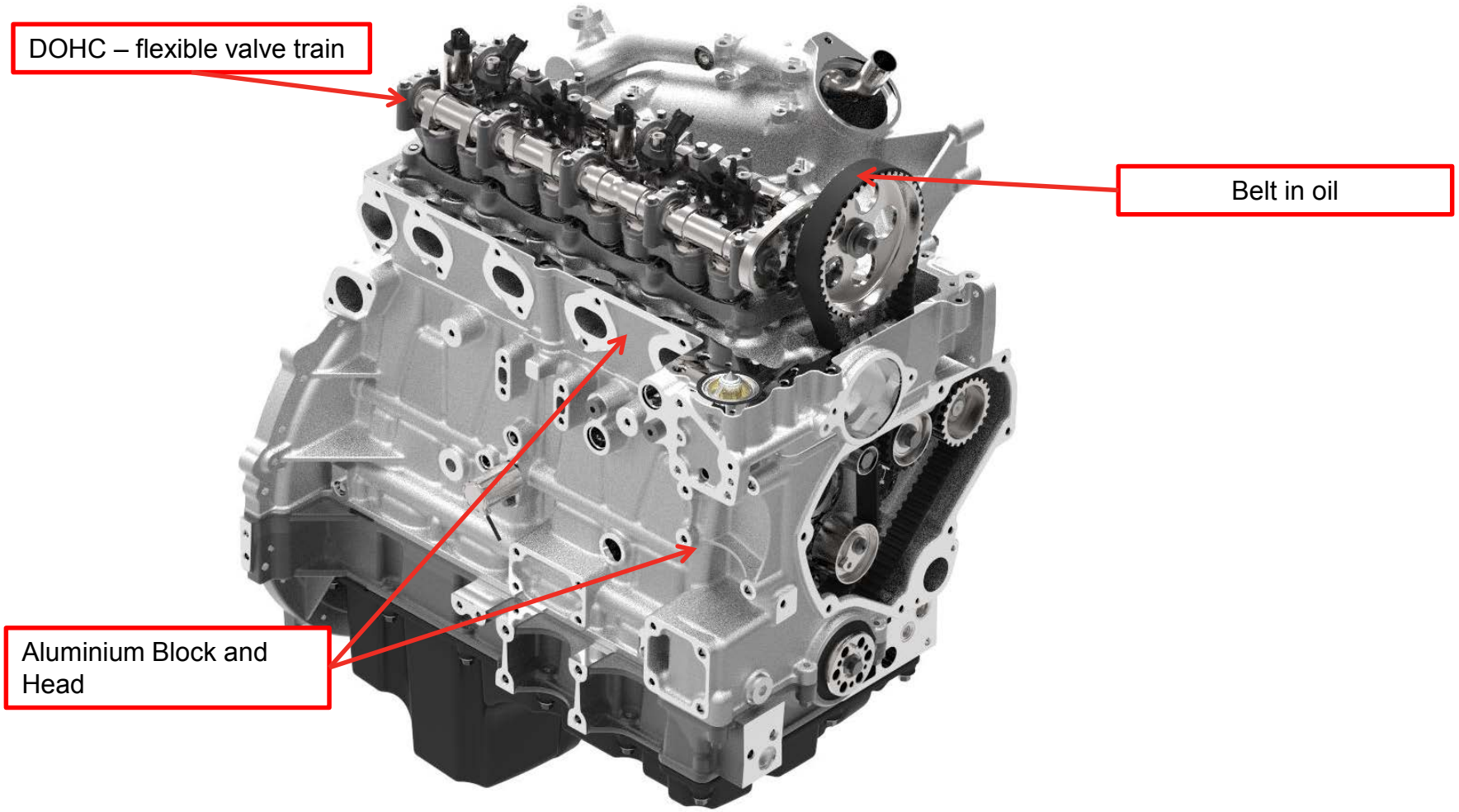
Technical Approach

- Design element focused on automotive expectations for cost, durability and service.



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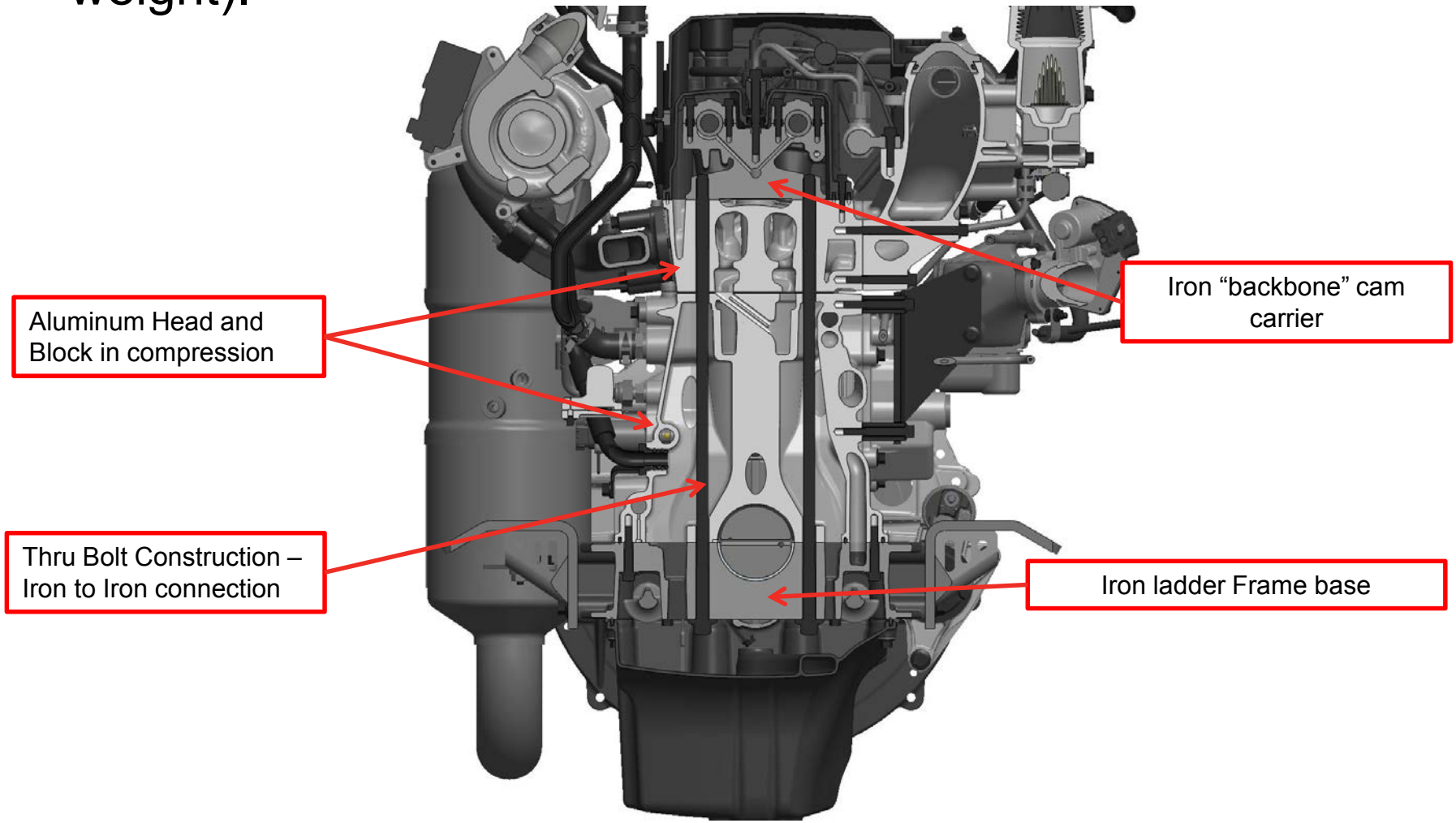
Technical Approach

- Design element focused on automotive requirements (high power density, high cylinder pressure, light weight).



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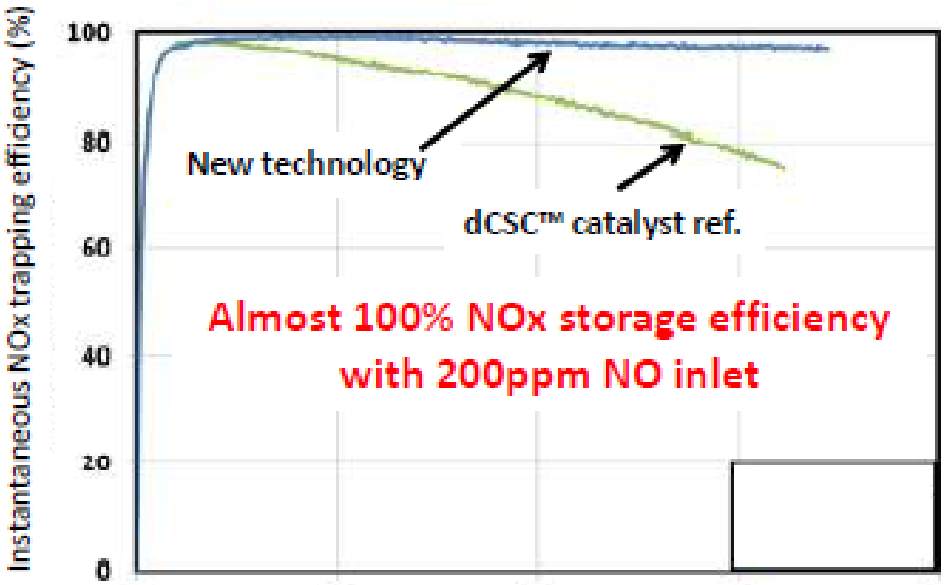
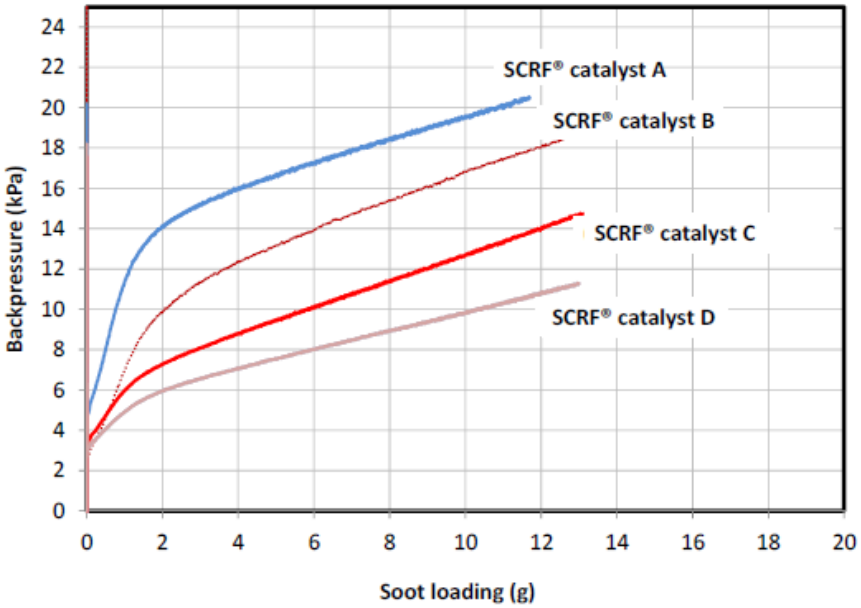
Technical Approach

- Catalyst system for cold start emission control
  - dCSC™ for NOx storage during initial start (low temperature adsorbtion – release at higher temperature)
  - SCRF™ for rapid warm up to reach peak NOx conversion





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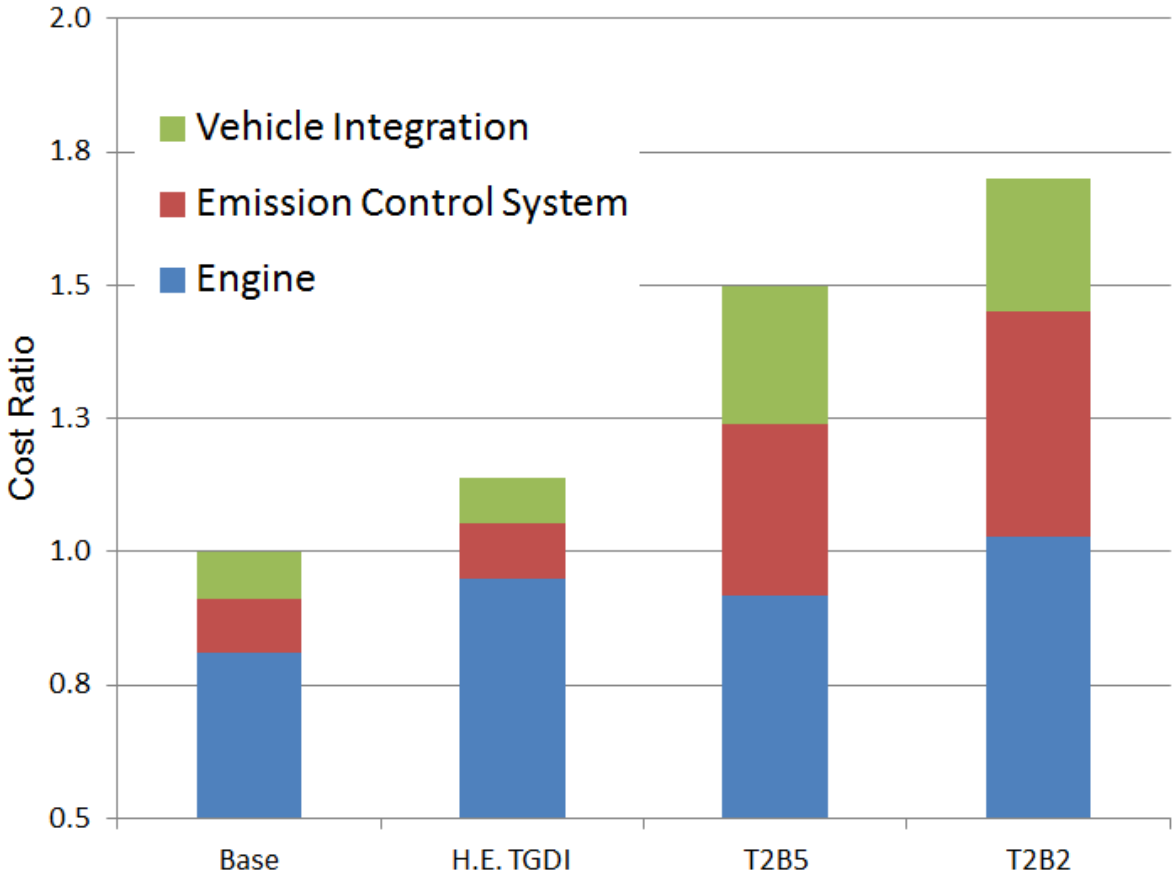
Technical Accomplishments and Progress; Cost Effective Solution



- Base = 4 cylinder turbocharged gasoline
- H.E.TGDI = High Efficiency, cooled EGR, Direct Injection
- T2B5, T2B2 = ATLAS construction

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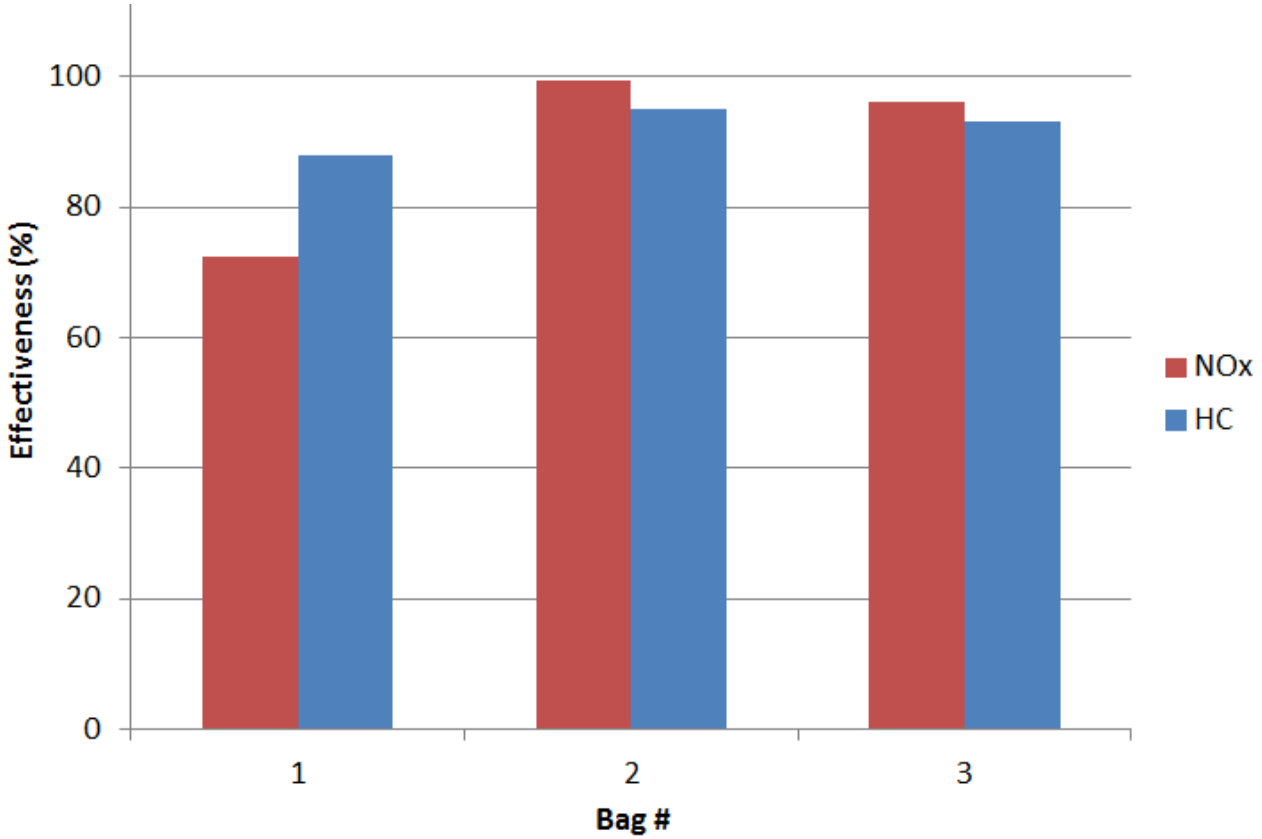
Technical Accomplishments and Progress; Aftertreatment

- Cold Start Concept (CSC™)* catalyst technology moved from lab scale to pilot plant scale
- SCR on filter formulation finalized for effectiveness



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Technical Accomplishments and Progress; New Engine

- Cummins has successfully designed and procured an all Aluminium 2.8L engine
  - 362 lb (production 2.8L = 480 lb)
- Gasoline engine w/ECS
  - 514 lb

- 152 lb weight allowance for diesel ECS and application
  - Exhaust (with catalysts)
  - Reductant and delivery system
  - Added cooling circuit

Weight neutral goal achieved!!!

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