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

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Project ID:ACE061

Changing the Climate
on Climate Change

Next Generation T2B2 Diesel Engine Overview

Timeline

Start: 10/1/2010

End: 9/31/2014

Complete: 80%

Budget

Total Project:
$15M DoE
$15M Cummins

Total Spend to date:
$13M DoE
$13M 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)

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.

Next Generation T2B2 Diesel Engine Objectives

	Baseline * vehicle data	DoE Program Target **	
FTP – 75 "city"	15.6	21.8	mpg
	570	462	g/mi CO_2
HFET "Highway"	24.5	34.3	mpg
	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

2013 Completed Milestones

	% Complete	2013 Milestones
Mar 2013	100	New engine torque curve demonstration
July 2013	100	T2B5 Demonstration on engine dynamometer
Aug 2013	100	T2B2 Development Engine start up
Dec 2013	100	T2B5 Vehicle demonstration

2014 Milestones

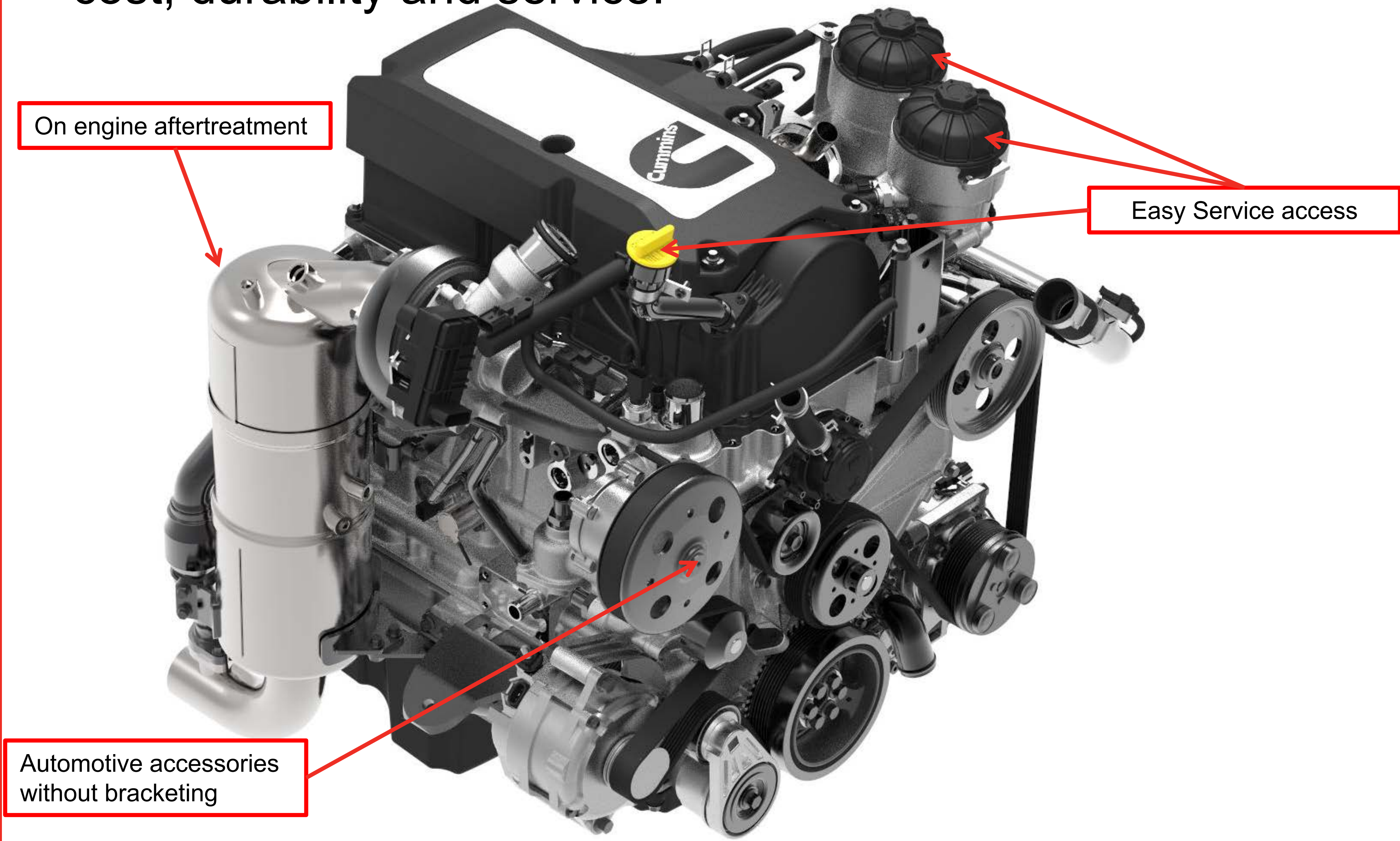
	% Complete	**2014 Milestones**
March 2014	100%	T2B2 Aftertreatment integrated in dynamometer environment
May 2014	50%	Convert Vehicle to T2B2 configuration
Aug 2014	20%	Demonstration of FTP on engine dyno at T2B2 tailpipe
Sept 2014	0%	Demonstration of FTP on chassis at T2B2

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

Technical Approach

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



Technical Approach

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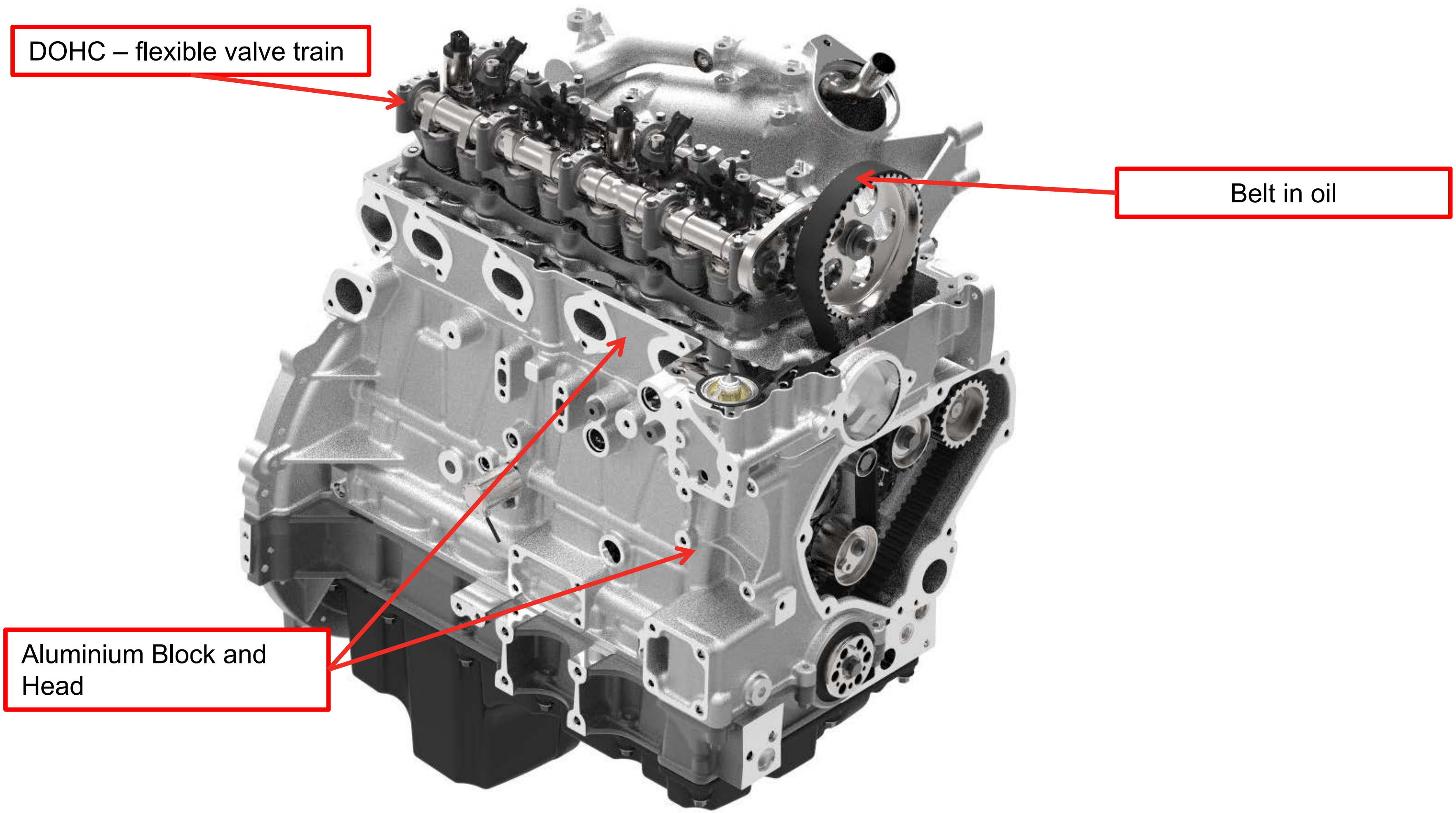
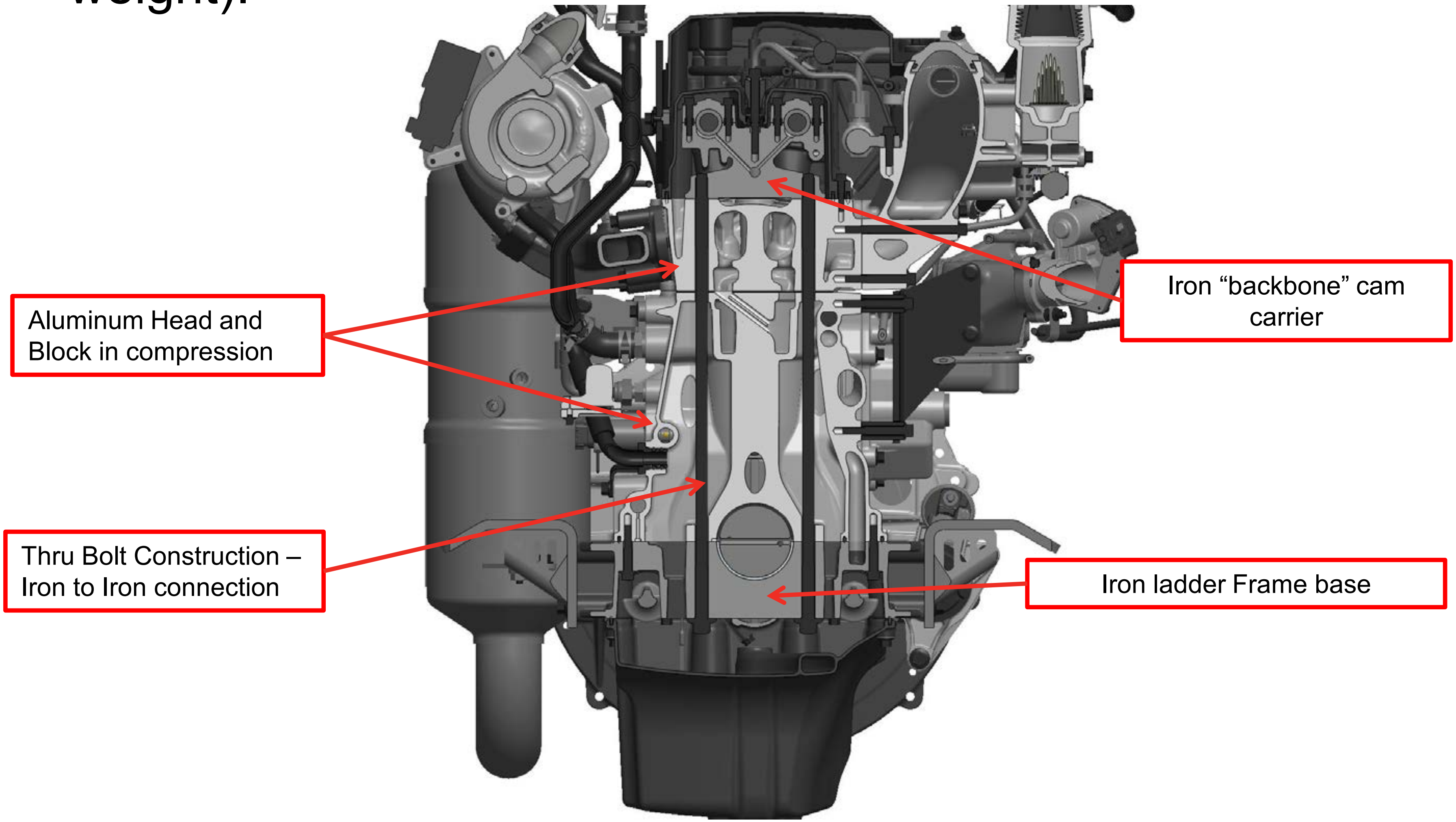


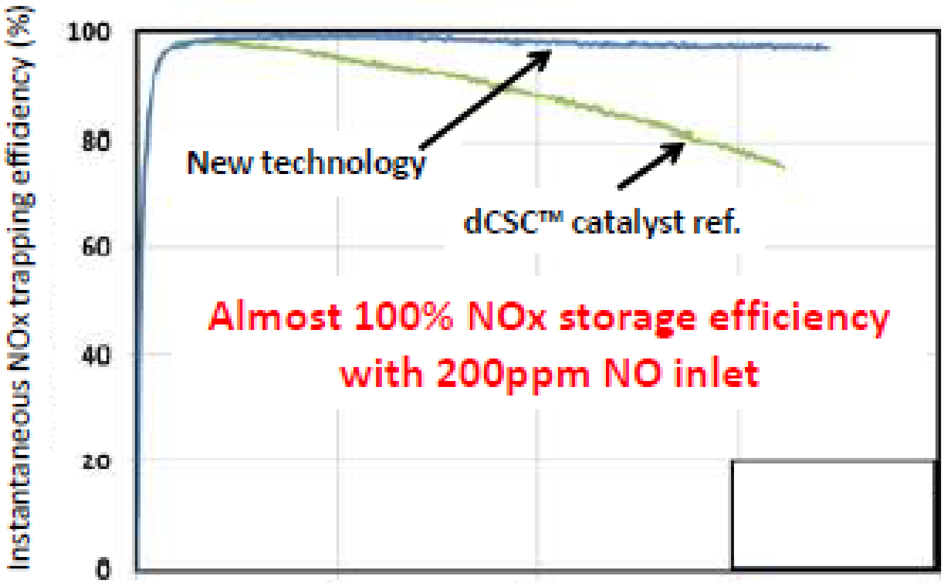
Technical Approach

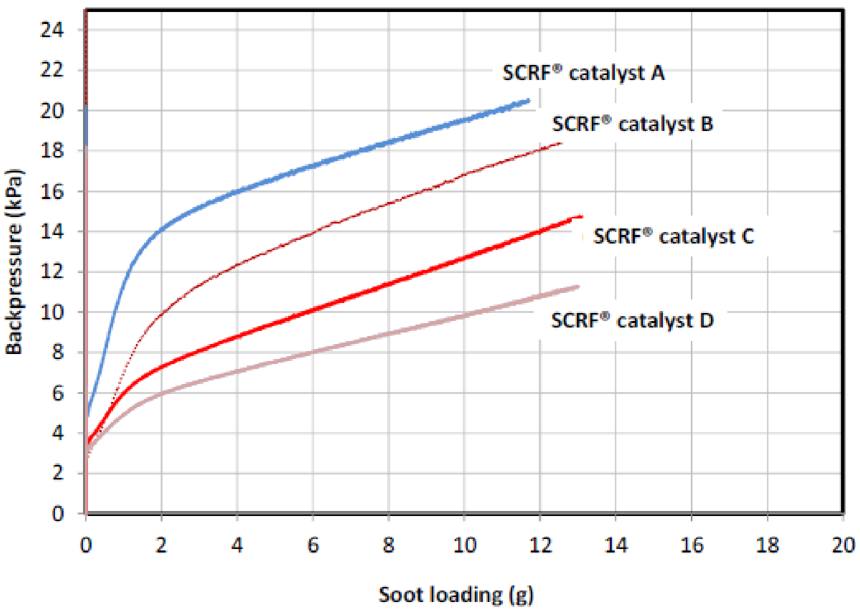
- Design element focused on automotive requirements (high power density, high cylinder pressure, light weight).



Technical Approach

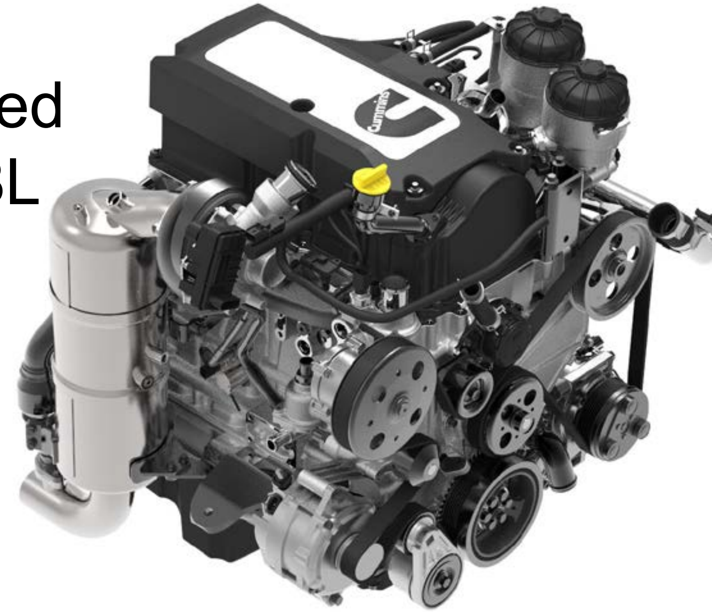
- Catalyst system for cold start emission control
  - dCSC™ for NOx storage during initial start (low temperature adsorbtion – release at higher temperature)
  - SCRF™ for rapid warm up to reach peak NOx conversion





Technical Accomplishments and Progress; New Engine

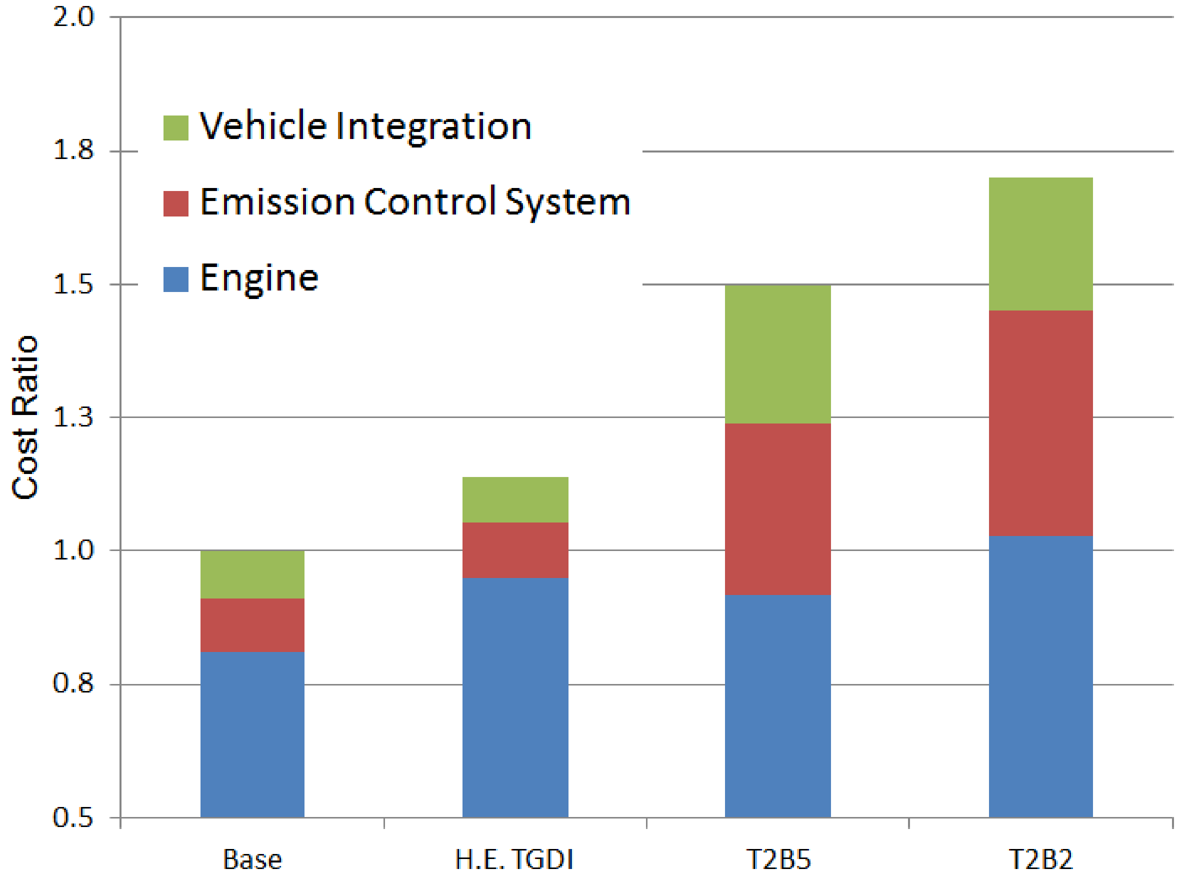
- Cummins has successfully designed and procured an all Aluminium 2.8L engine
  - 362 lb (production 2.8L = 480 lb)
- Gasoline engine w/ECS
  - 514 lb



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

Weight neutral goal achieved!!!

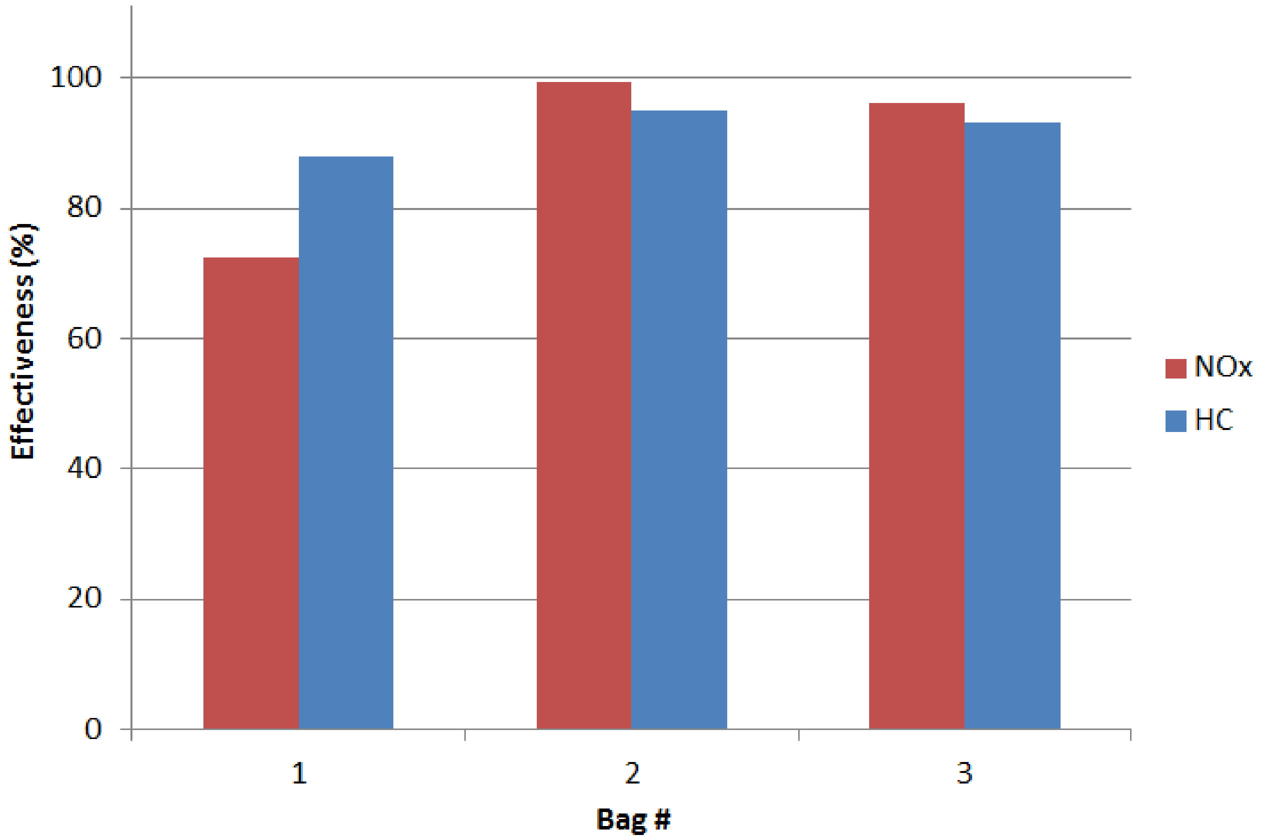
Technical Accomplishments and Progress; Cost Effective Solution



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

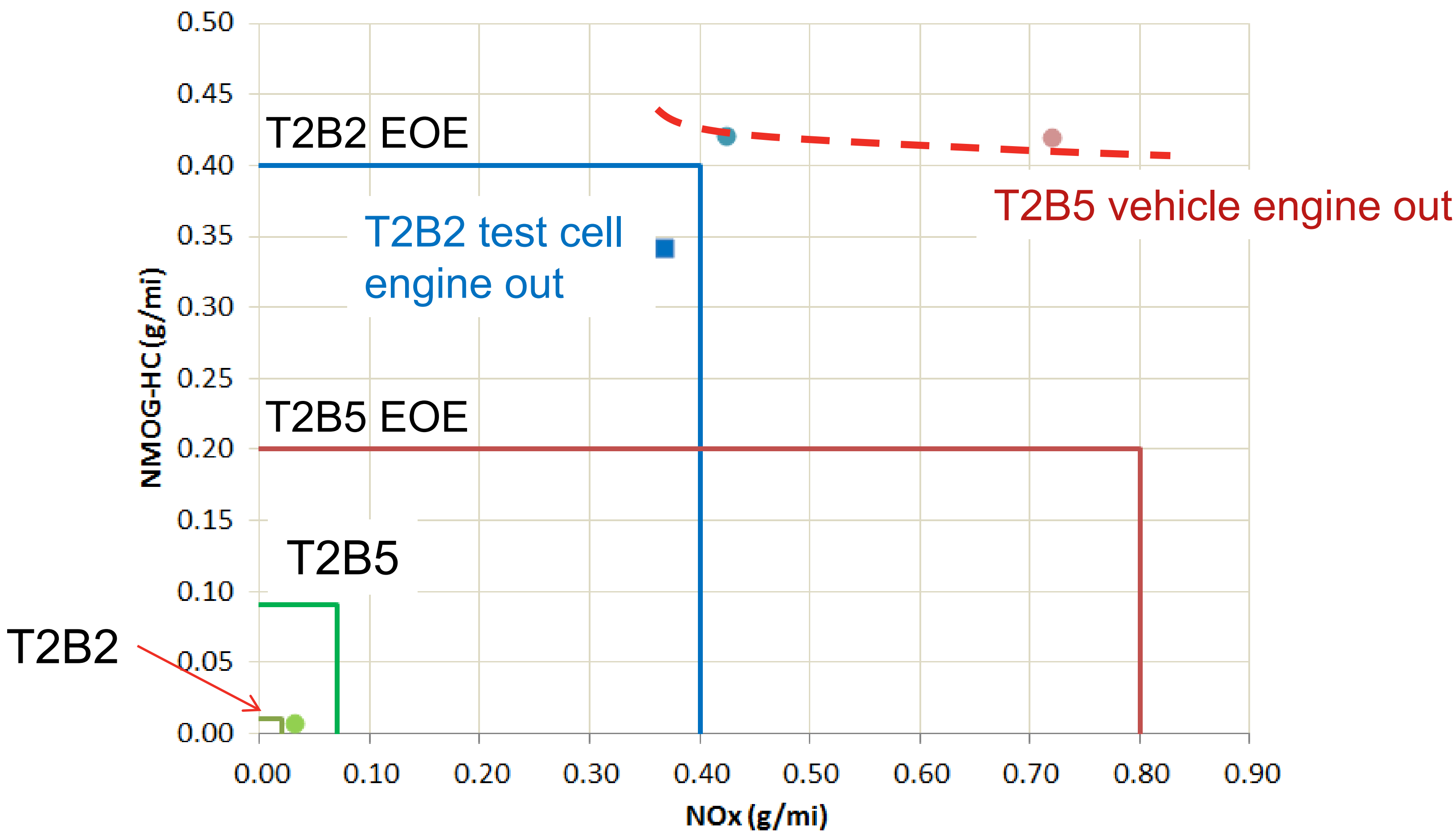
Technical Accomplishments and Progress; Aftertreatment

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



Technical Accomplishments and Progress; Vehicle Demonstration

- ATLAS engine achieving engine out targets

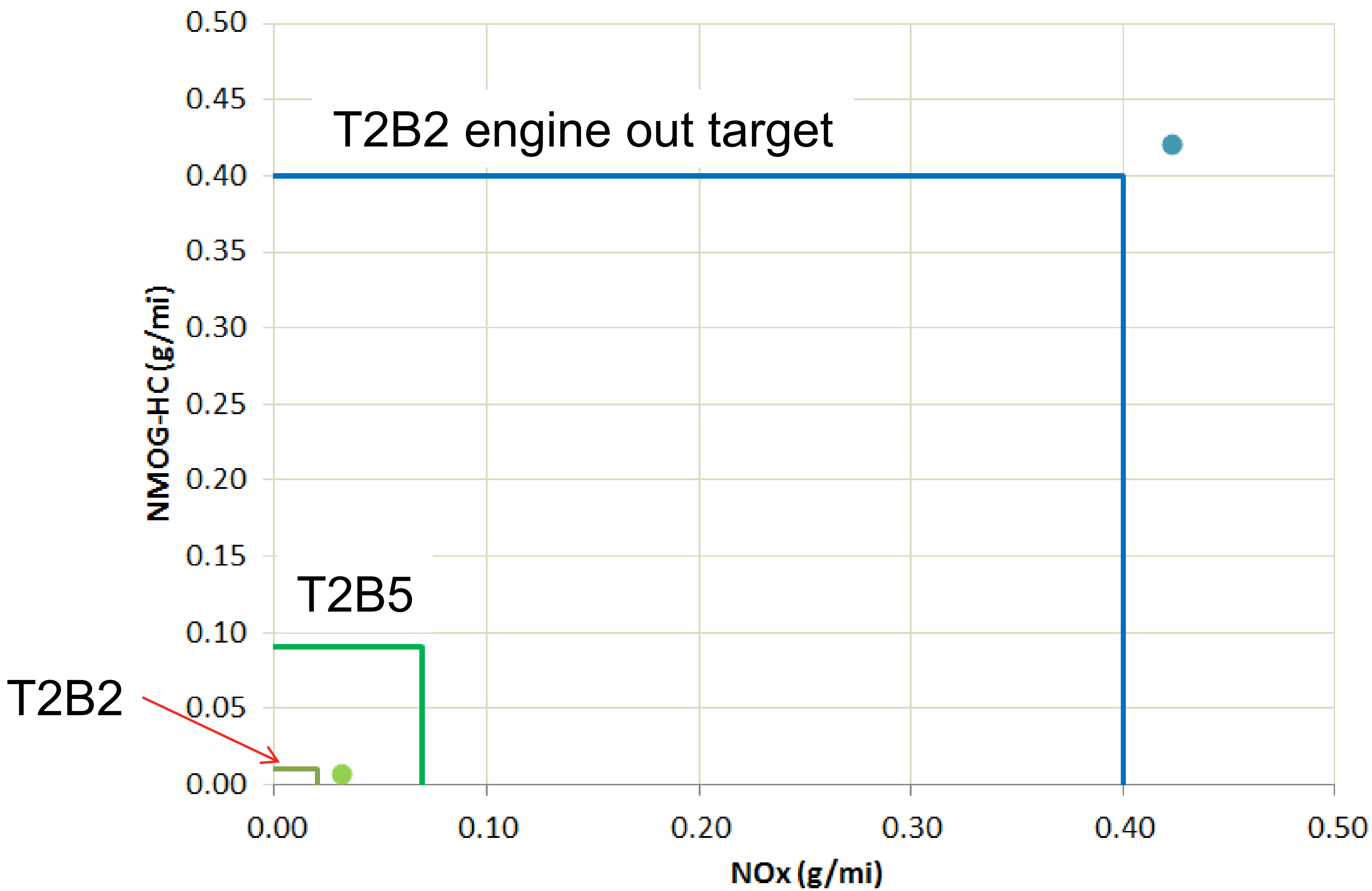


T2B5 = HP EGR only

T2B2 = Dual loop EGR

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>**!



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

Future Work

- 2014: Full ATLAS engine move to JMI for added test capacity
  - Continued refinement of the dCSC™ operation
  - Refinement of overall aftertreatment control strategy
- 2014: System measurements for model validation
  - Thermal survey (heat transfer, thermal durability)
  - Hemi-anechoic noise measurement (Aluminium structure)
- 2014: Work with Purdue on variable valve train options for warm up and HC control
  - Test and analysis of how ATLAS flexible overhead can be utilized to improve HC/NOx trade-off under warm up conditions.
- 2014: Complete the final T2B2 demonstration on a complete, street worthy, drive able vehicle

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Summary

- Cummins is on plan to deliver fuel economy 40% improved over that of the baseline gasoline power train while also meeting the requirements of Tier2Bin2 tail pipe emissions.
- Technical focus over the past year has been centered on new engine installation and performance assessments
- The new engine has achieved target engine out emissions, performance and fuel economy.
- Demonstrated catalyst performance has met or exceeded targeted conversion rates.
  - Increased allowance on engine out HC
- Cummins and our partners are developing technology to improve the overall engine package;
  - JM – Delivering materials for low temperature emission mitigation
  - Nissan – Guiding hardware updates to vehicle systems for up to date technology improvements and feedback on overall vehicle NVH and performance feel.

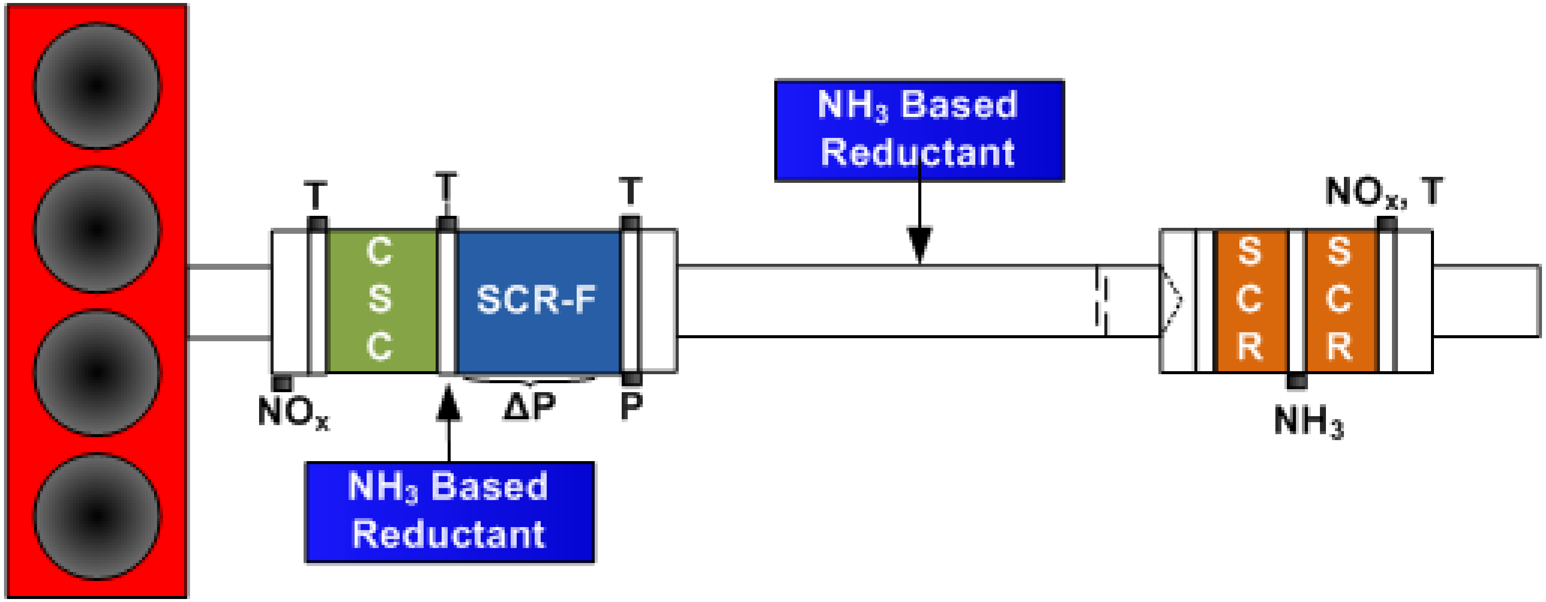
Technical Backup Slides (5 max)

Technical Approach – High Efficiency
Engine weight control via design features

<u>Goal: equivalent application weight as baseline engine</u>

- 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

Technical Approach - Exhaust System Configuration

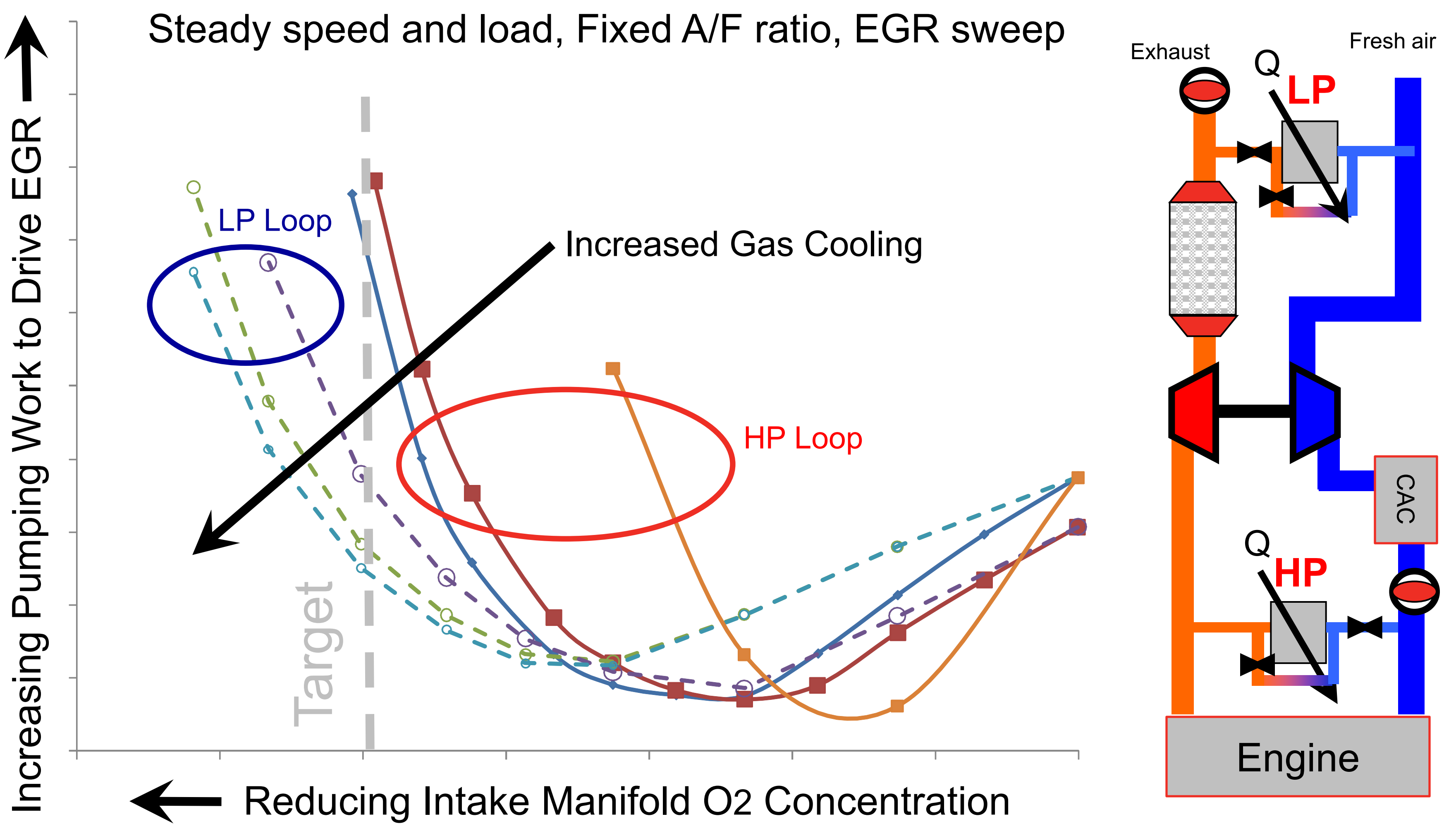


- Close coupled filter system to enable low pressure EGR
- SCR coated on filter (SCR-F) allows for close coupling of SCR function for fast light off
- Use of a direct ammonia delivery system (DADS) can further improve NOx conversion performance by reducing the time delay before NH_3 introduction after 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

Technical Approach – High Efficiency

Reduce FE penalty due to emission controls

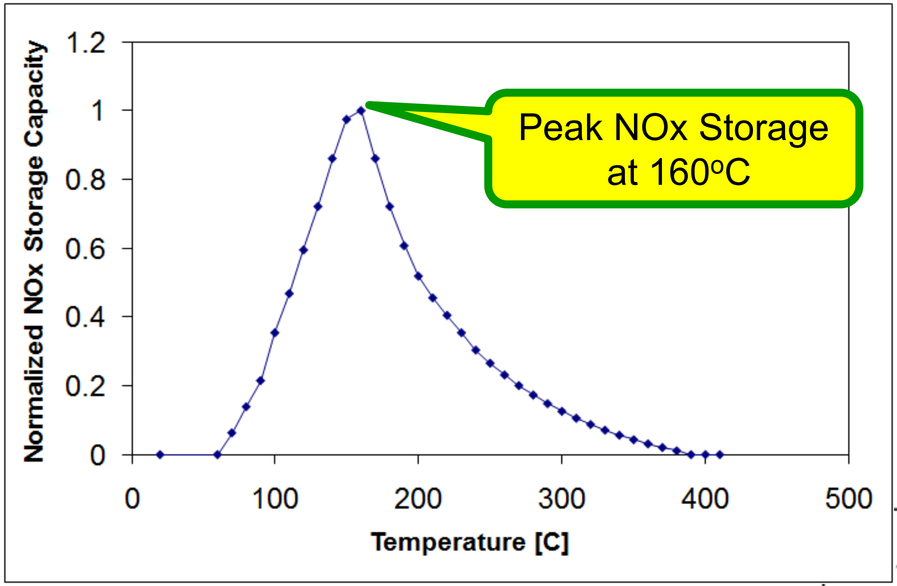
- Low pressure EGR to reduce pumping work



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