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

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Cummins Inc

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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: 30%

Budget

Total Project:
$15M DoE
$15M Cummins

Total Spend to date:
$4.4M DoE
$4.4M Cummins

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

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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

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

2012 Milestones

	% Complete	2012 Milestones
Mar 2012	100	Steady state demo with engine out emissions at target level
April 2012	100	Demonstration of direct NH_3 gas delivery system
April 2012	100	Complete initial evaluation of Passive NOx Adsorber catalyst
May 2012	90	Mule engine dual loop EGR control system tuning
June 2012	70	Implement A/T control system for vehicle demonstration
July 2012	50	Engine out emissions demonstration in engine dyno cell
Sept 2012	30	Cold bag measurement in engine test cell
Sept 2012	15	New engine materials ready date
Dec 2012	0	New engine first fire date

Program Milestones

2012 - 2014	
Jul 2012	A/T system architecture is defined, include sensor plan and OBD plan
Oct 2012	New engine assembly complete
June 2013	Demonstration of FTP on engine dyno at T2B5 tailpipe
Nov 2013	New engine operational in vehicle with full A/T system
Dec 2013	Demonstration of FTP on chassis at T2B5
May 2014	Demonstration of FTP on engine dyno at T2B2 tailpipe
Sept 2014	Demonstration of FTP on chassis at T2B2

Technical Approach – High Efficiency

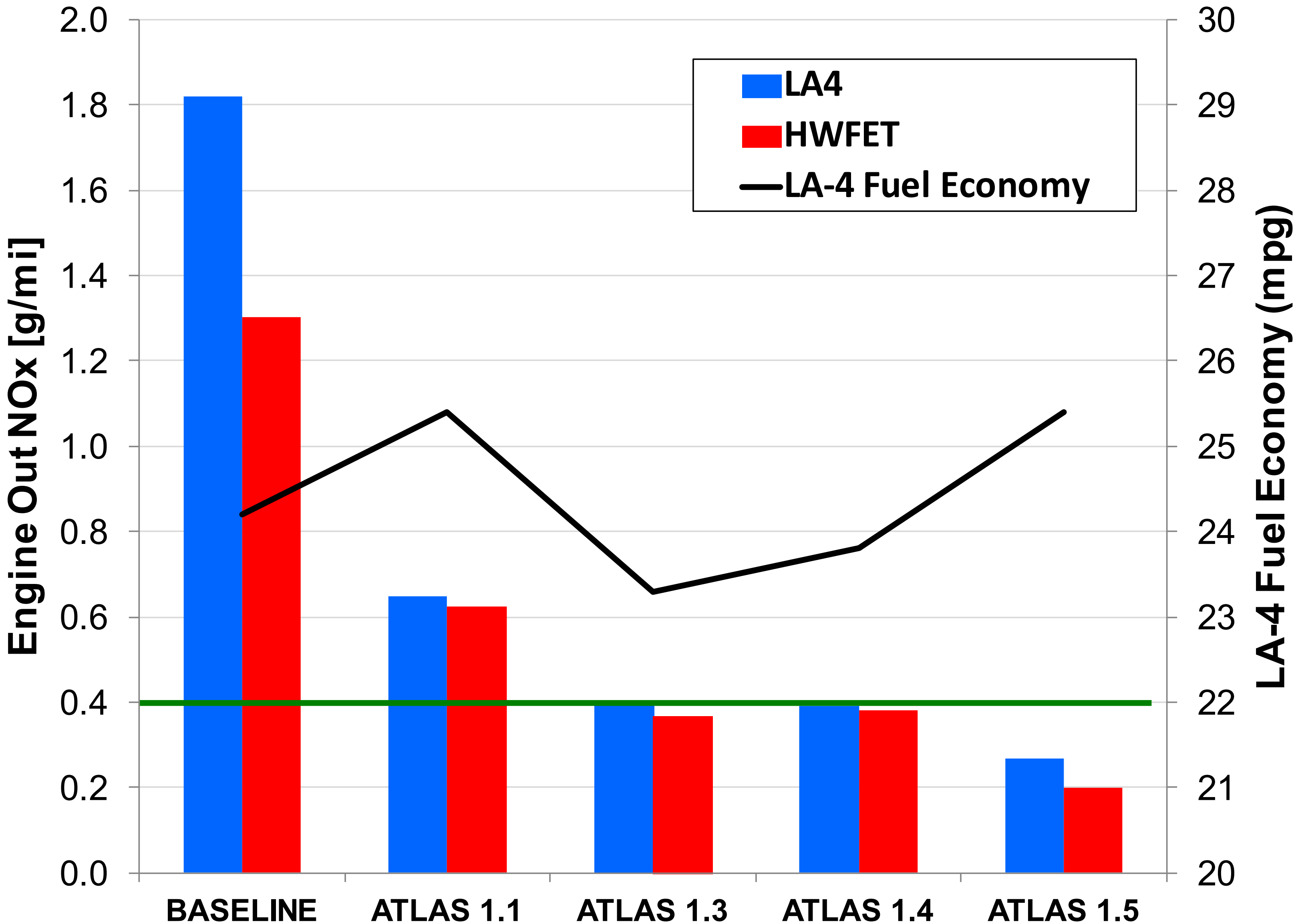
- Learning from LDECC program
  - High charge flow for extended PCCI operating range
  - High charge flow reduces energy available for A/T
- Appropriate sized engine
  - Down sized engine =>Increased power density => Maintain vehicle drivability & Improved FE
  - Down sized engine => increased loads => higher exhaust gas temperature => Improved A/T performance
- Reduce FE penalty due to emission controls
  - Low pressure EGR to reduce pumping work
  - Passive NOx Adsorber to control NOx under cold start w/o FE penalty
  - Direct Ammonia Delivery System (DADS) for immediate reductant delivery without need for thermal enhancement

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

Technical Accomplishments and Progress
Engine Out Emissions and Fuel Economy



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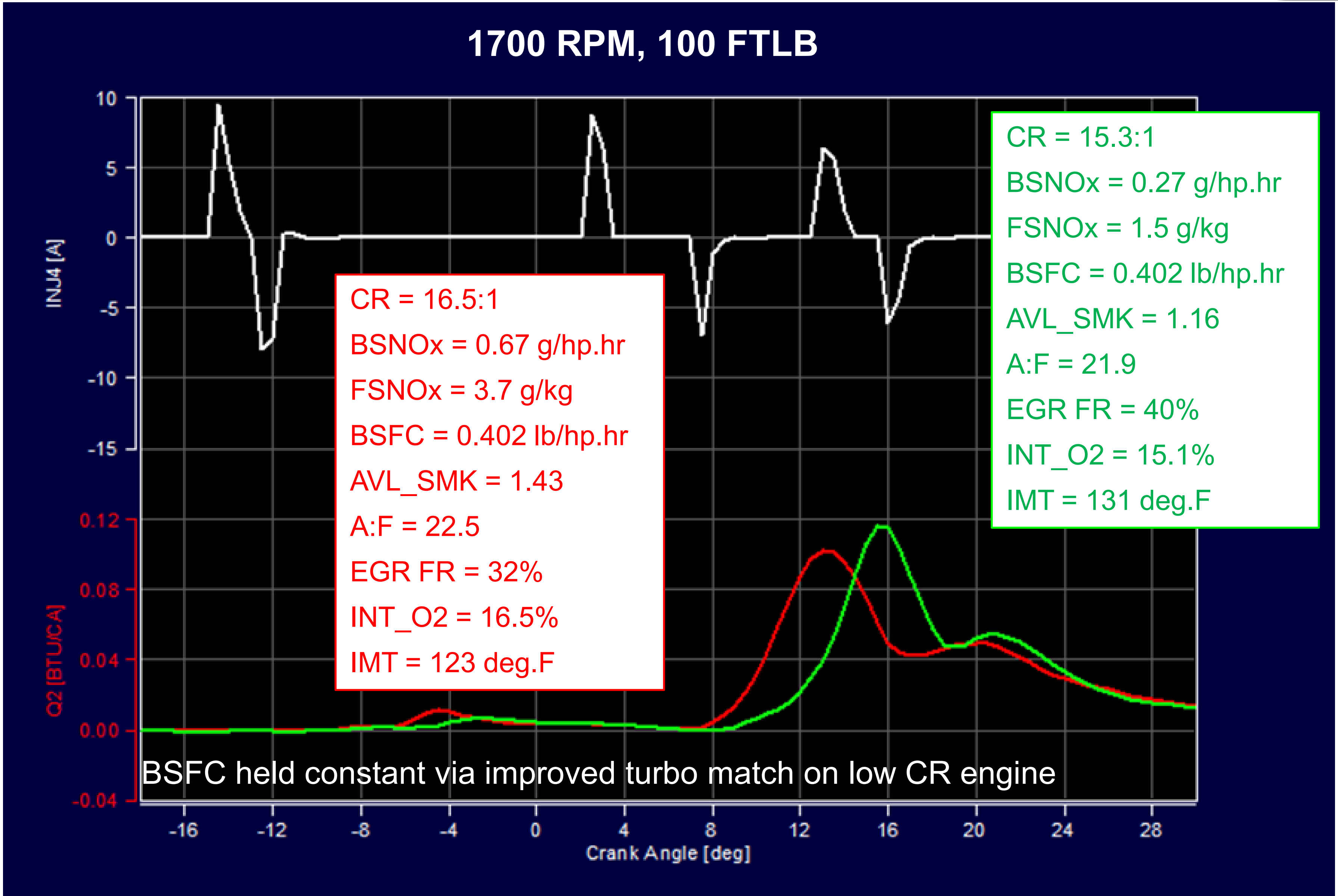
Technical Accomplishments and Progress
Engine Out Emissions and Fuel Economy



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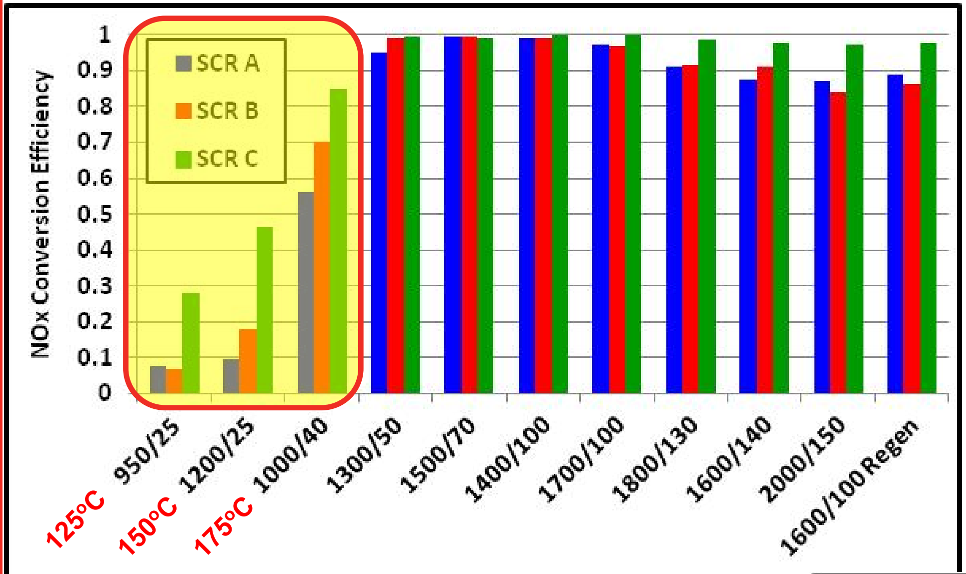
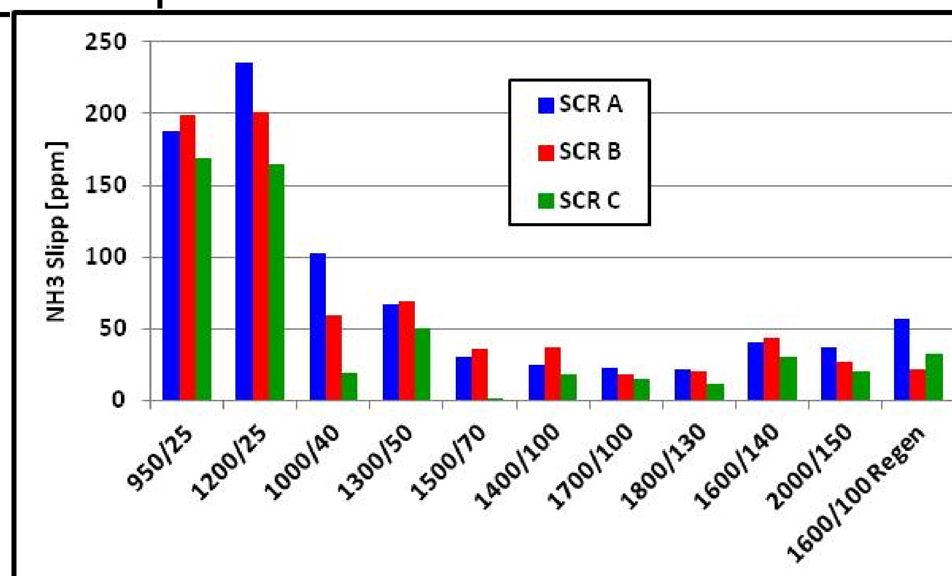
Technical Accomplishments and Progress
Aftertreatment System Development



- LT performance made possible by direct NH_3 dosing
- SCR-C shows improved NOx conversion over an expanded temperature window

- SCR-C has an overall reduction in NH_3 slip



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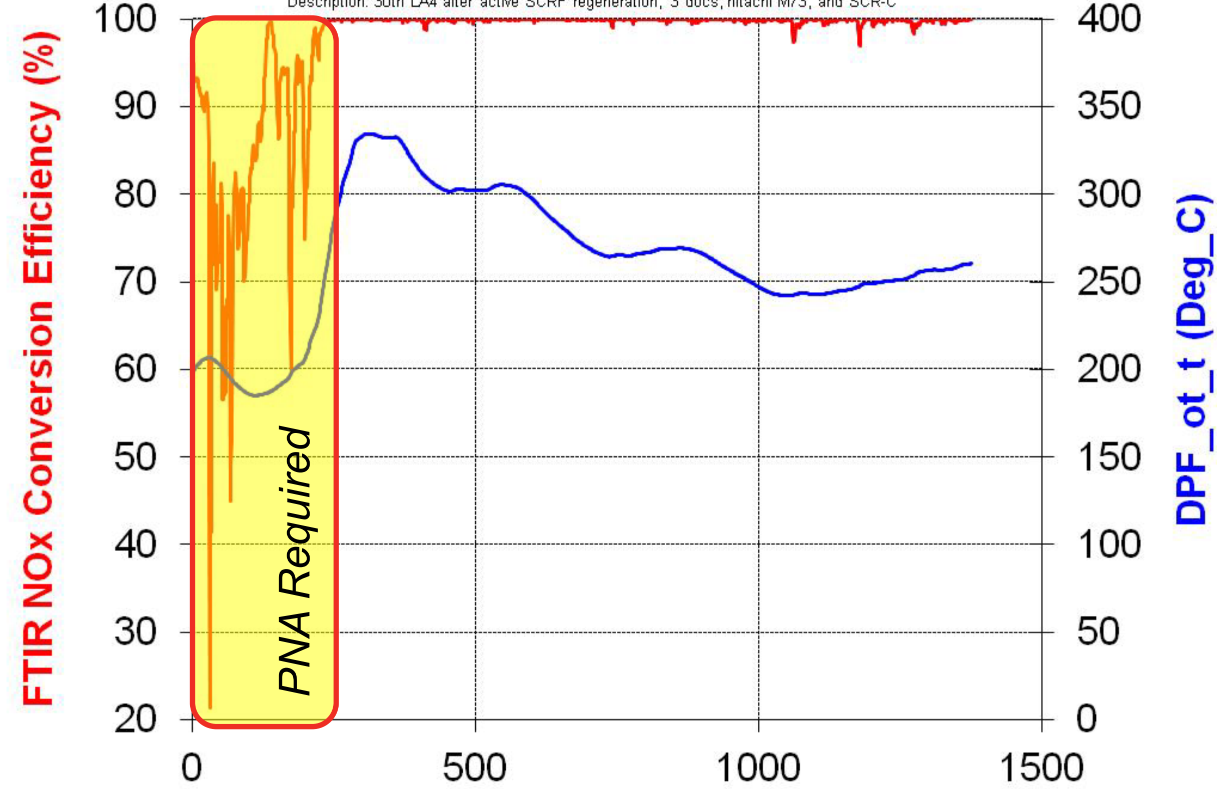
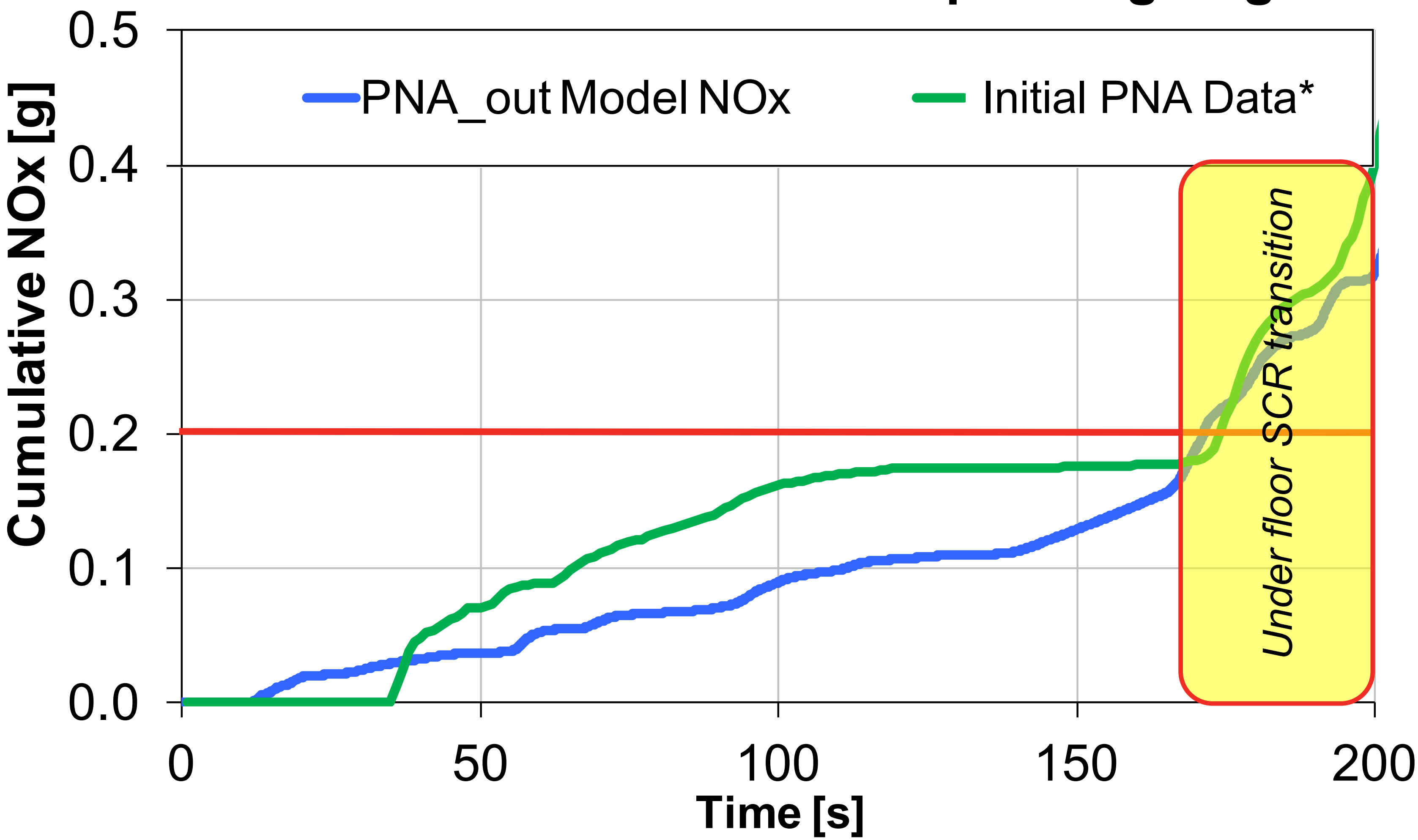
Technical Accomplishments and Progress
Aftertreatment System Development

Warm Cycle with DOC, SCRF and SCR Using Direct NH_3 Gas Delivery



Warm cycle average NOx conversion >97%

Initial Evaluation of PNA on Operating Engine



* Data adjusted for PNA size and NOx flux

Technical Accomplishments and Progress Vehicle Systems

- Mule vehicle build complete
  - Established vehicle communication network
  - Baseline for mule engine fuel economy and emission map
  - Development bed for NVH solutions
- Completed system map for FE accounting
  - Alternator, Vacuum pump, Oil viscosity, etc.

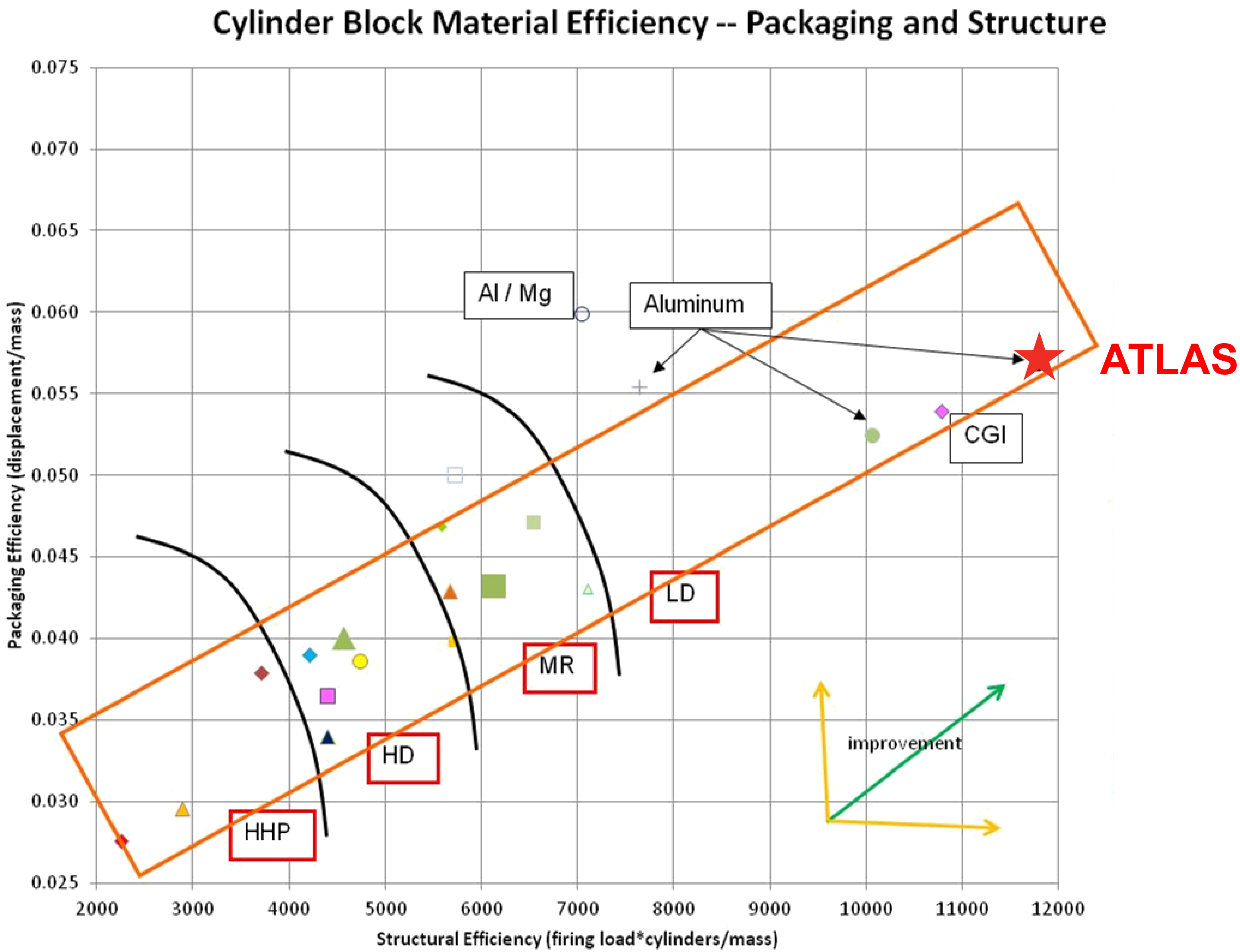
	Base 15W40 Mech Vac	15W40 Elec Vac	5W30 Mech Vac	15W40 Mech Vac No Alt load	
Fuel Economy LA-4	24.2	24.4	25.5	26.9	MPG
Fuel Economy HWFET	33.1	N/A	N/A	N/A	MPG

Technical Accomplishments and Progress
New Engine Design

	ATLAS 2.8L	Baseline 2.8L
Block Sys.	52.7	65.5
Misc. Hsgs.	0	27.1
Head Sys.	23.6	34.4
Rot&Recip	29.3	31.0
Valve Drive	1.2	5.3
Cam & Drive	7.4	5.9
Balance	6.1	14.6
Sum	120.4	183.7
Sum / L	43.0	65.6

ATLAS architecture is 63.3 kg (140 lbs) lighter than baseline with increased capability

Technical Accomplishments and Progress
New Engine Design



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Layout Overview

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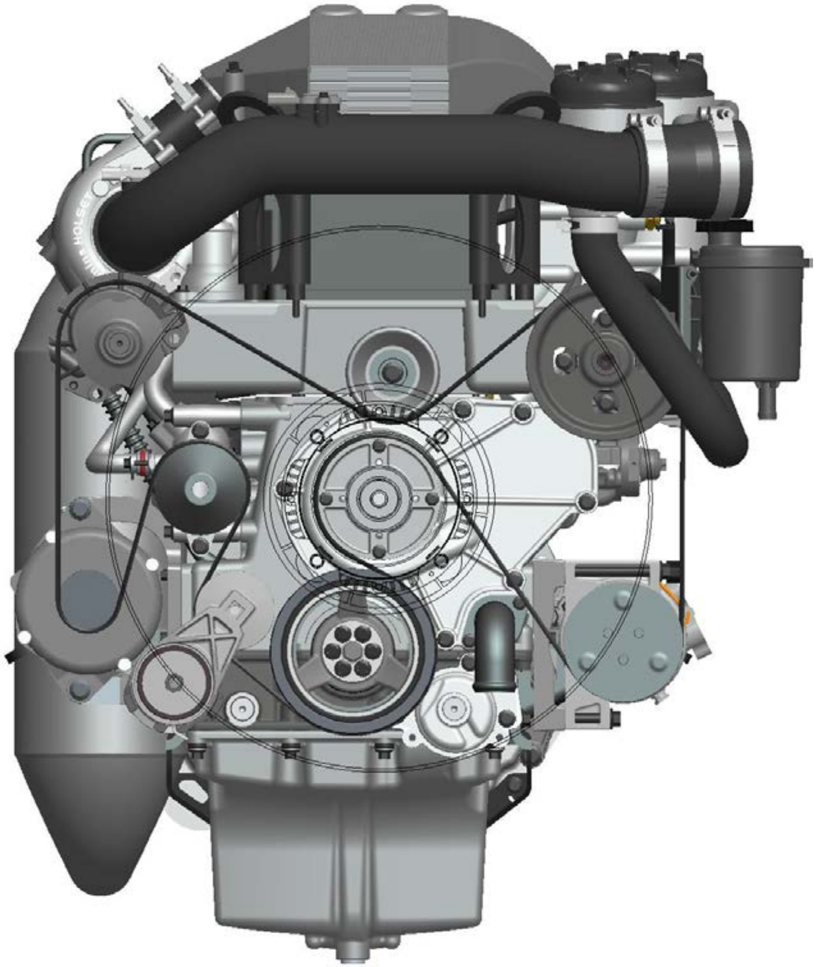

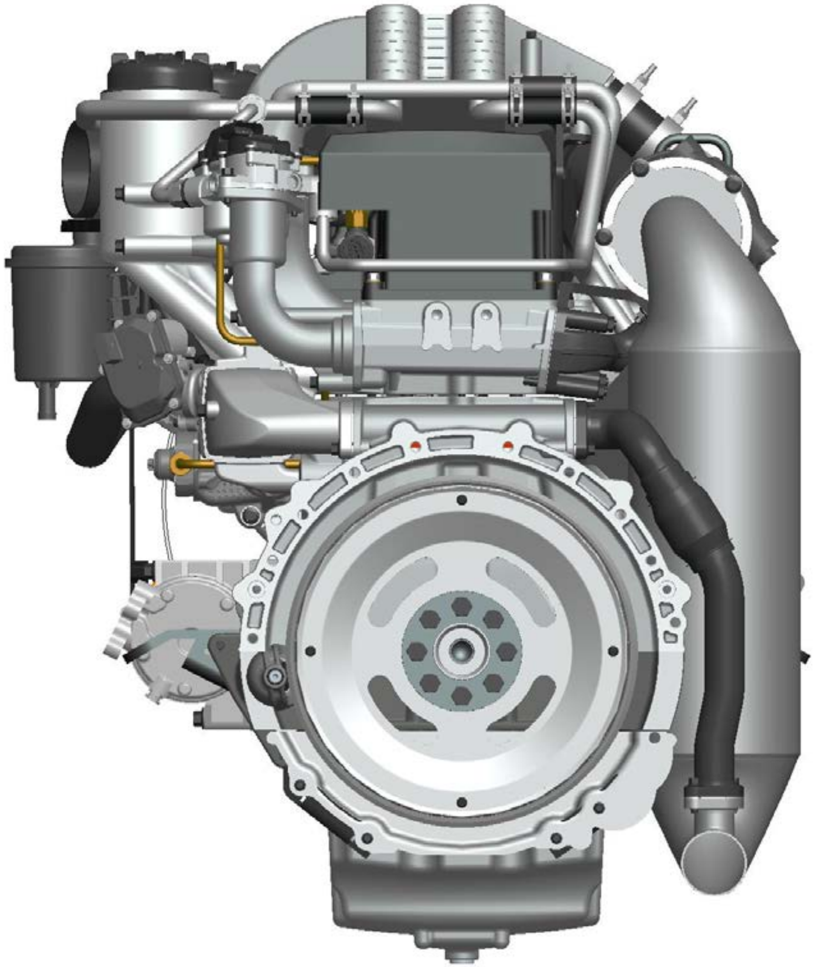

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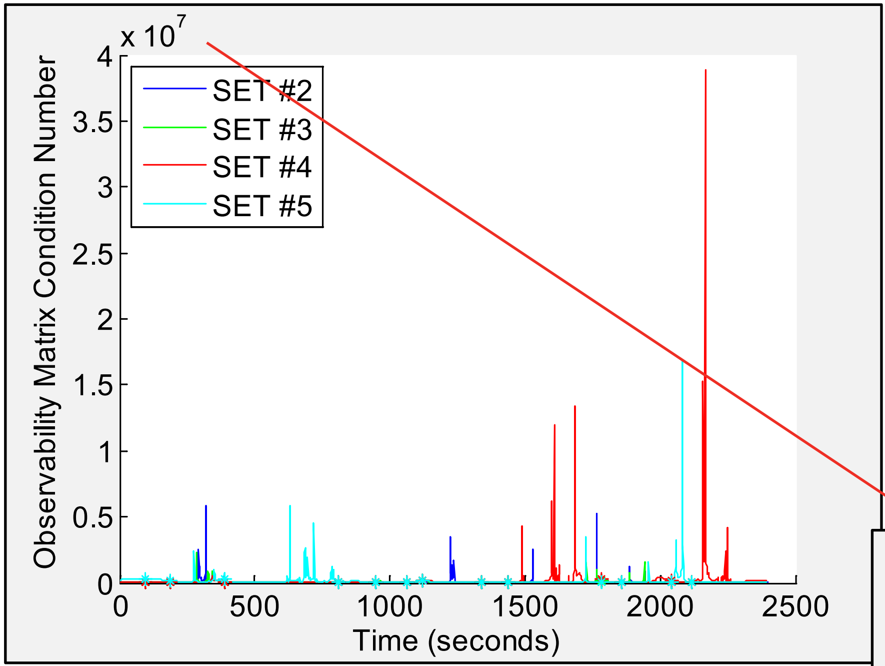
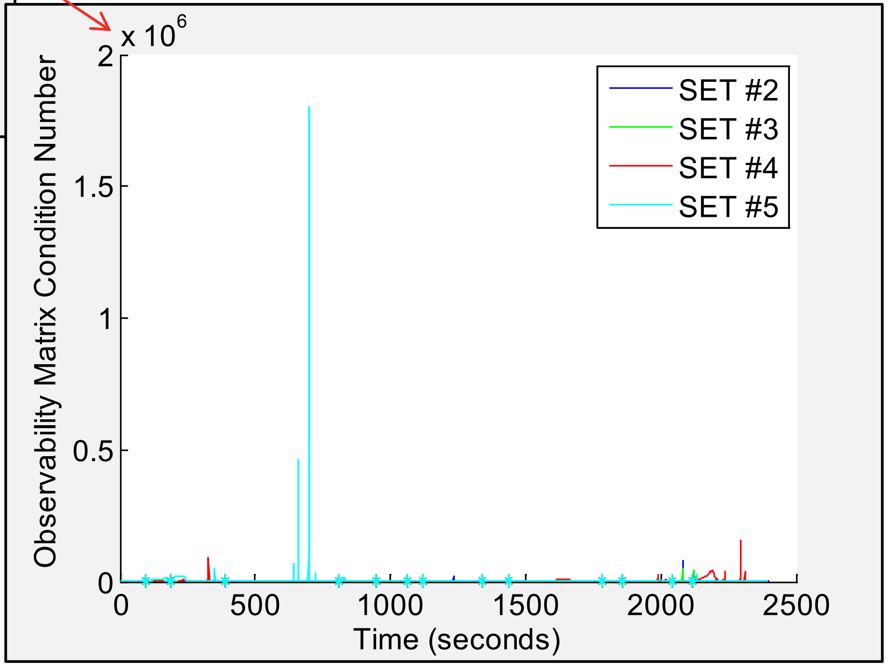
Technical Accomplishments and Progress NOx Sensor Observability - RHIT



- Observability condition numerical representation established
- Lower values indicate better observability



- Progress showing an order of magnitude reduction in condition number
- Looking forward; understand high value areas and transient performance

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Collaborations

- Partners
  - **Johnson-Matthey** –(industry, subcontractor) Advanced aftertreatment formulations and architecture
    - Passive NOx adsorbers for cold start NOx emission mitigation
    - Close coupled SCR on filter for improved cost and effectiveness
  - **Nissan** (industry, partner) – Vehicle integration and guidance on engine technical profile.

- Other involvement
  - **Rose-Hulman** – (institution, contract) Control system development to reduce sensor needs and improve robustness of controls
  - **ORNL** – (Nat'l Lab, association) working with light weight CRADA team to integrate advanced material process into base engine components

Future Work

- 2012: Complete the work required to integrate the Passive NOx adsorber and SCRF + SCR system;
  - Map out operational space of NOx capacity and NO/NO2 split vs temperature and space velocity using engine exhaust gas
  - Create controls to drive PNA to peak operating conditions for adsorption and release of NOx
- 2012: Complete upgrade to mule vehicle;
  - Include advanced fuel system, NH3 gas delivery system and modern transmission (8 speed automatic) integration
- 2012: Build up and initial test of new engine base hardware;
  - Base engine testing completed making engine available for emissions and performance in 2013
- 2013: Move development from mule to new engine
  - New engine will display mule hardware in test cells and vehicle

Summary

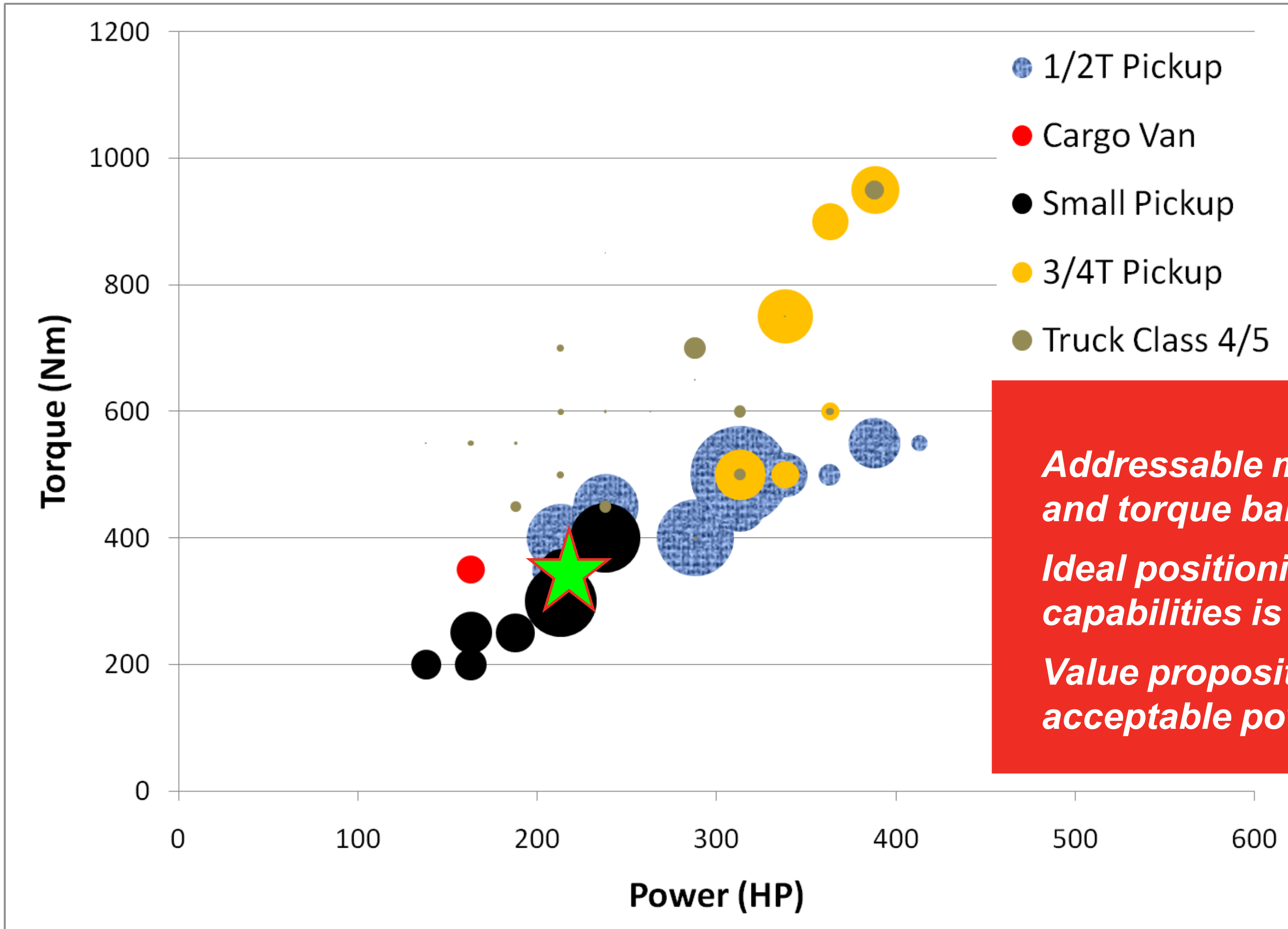
- Cummins is on plan to deliver fuel economy 40% improved over that of the baseline gasoline power train while also meeting the requirements of Tier2Bin2 tail pipe emissions.
- Technical accomplishments over the past year have shown potential for greater than 40% FE improvement at target engine out emission levels.
- The new engine design is exceeding original projections for weight, providing a weight margin compared to gasoline.
- Cummins and our partners are developing technology to improve the overall engine package;
  - RHIT – Improve robustness/eliminate aftertreatment sensors
  - JMI – Delivering materials for low temperature emission mitigation
  - ORNL – Leveraging materials and design for light weight engine
  - Nissan – Guiding hardware updates to vehicle systems for up to date technology improvements

Technical Backup Slides

Technical Approach – High Efficiency

Appropriate sized engine

- Down sized engine =>Increased power density => Maintain vehicle drivability & Improved FE



Addressable market based on power and torque band in base offerings.

Ideal positioning given current capabilities is shown with a 'star'.

Value proposition is 'high FE' with acceptable power/torque.

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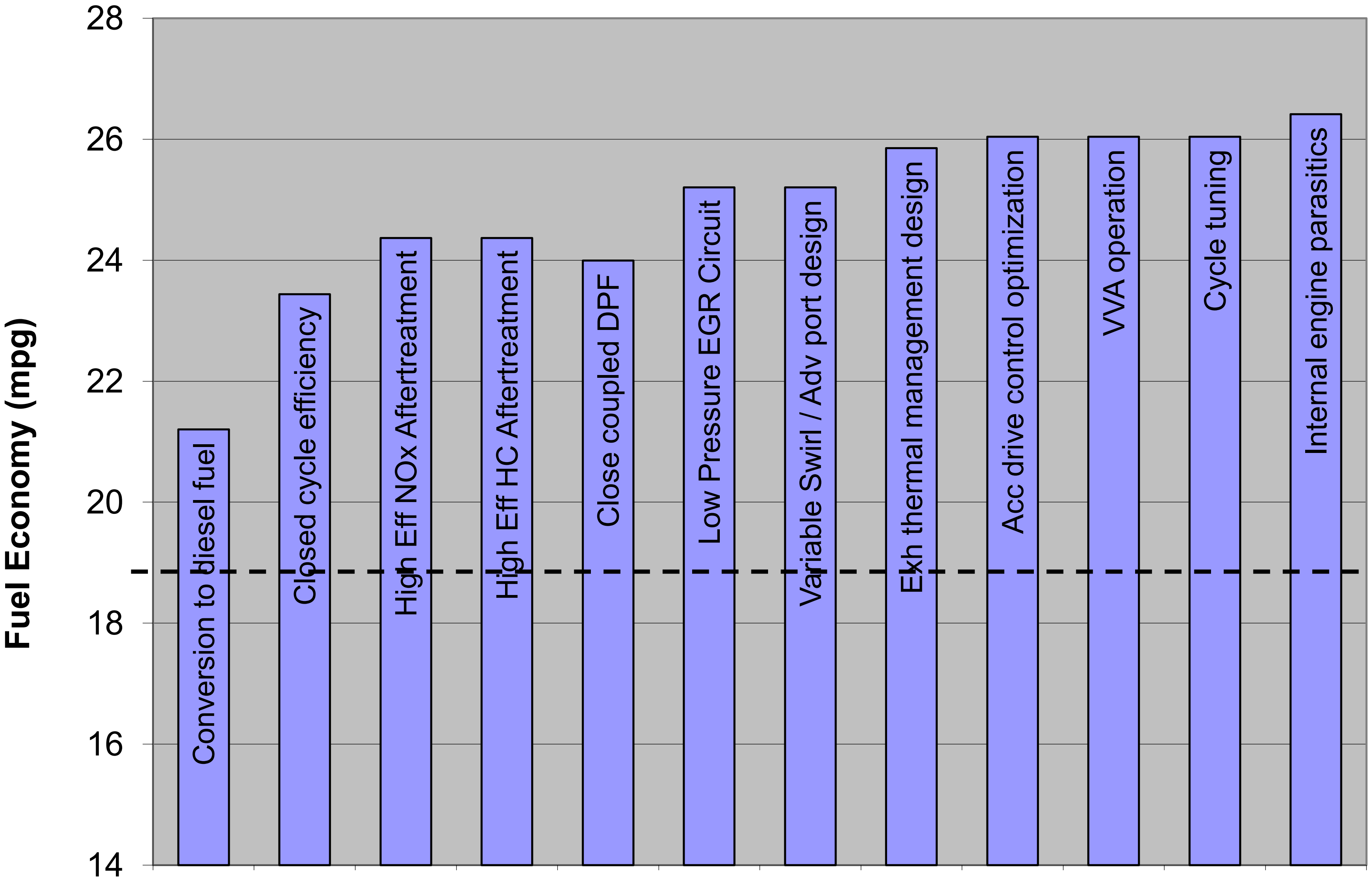
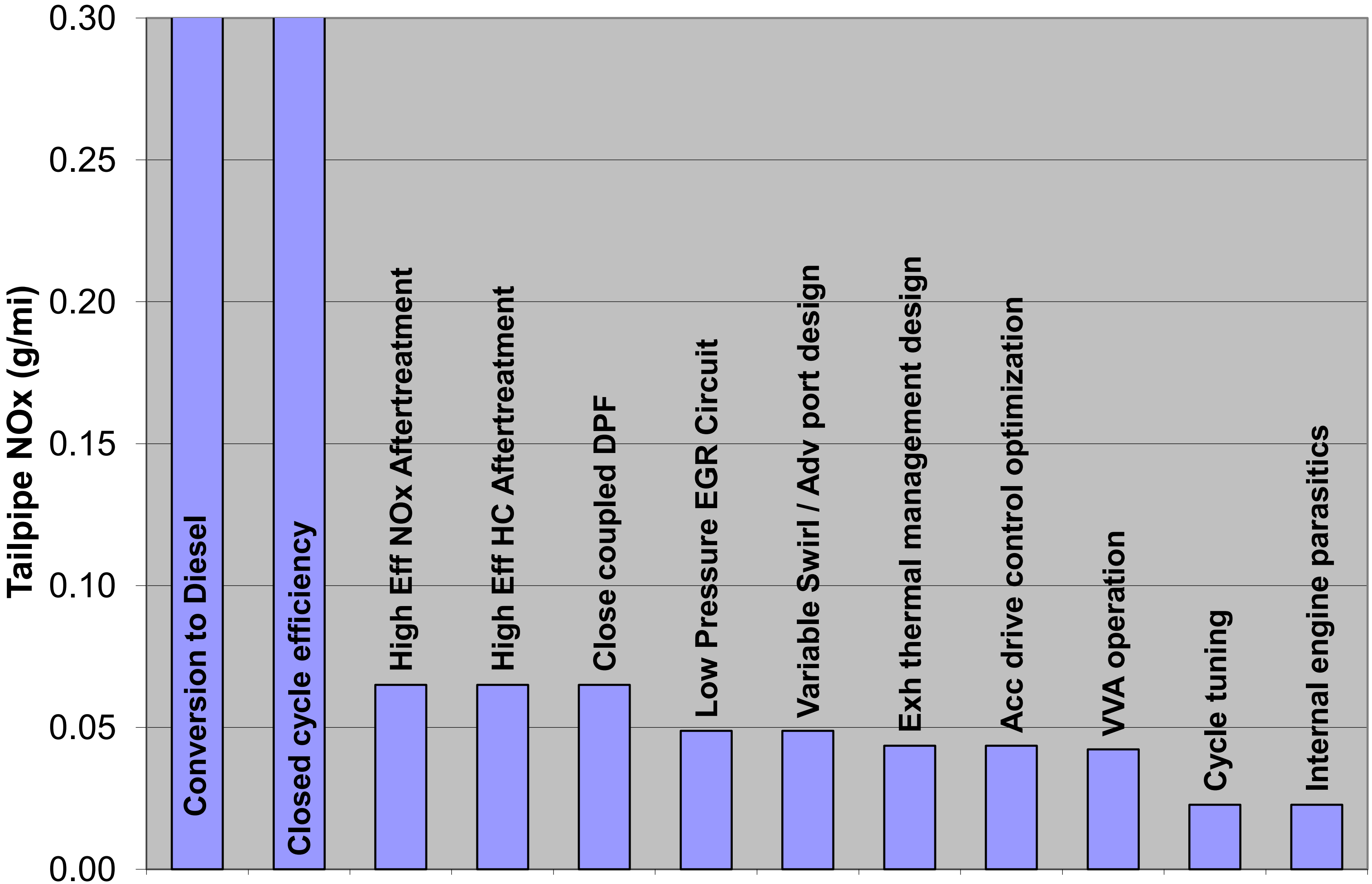
APT LD Fuel Economy Plan



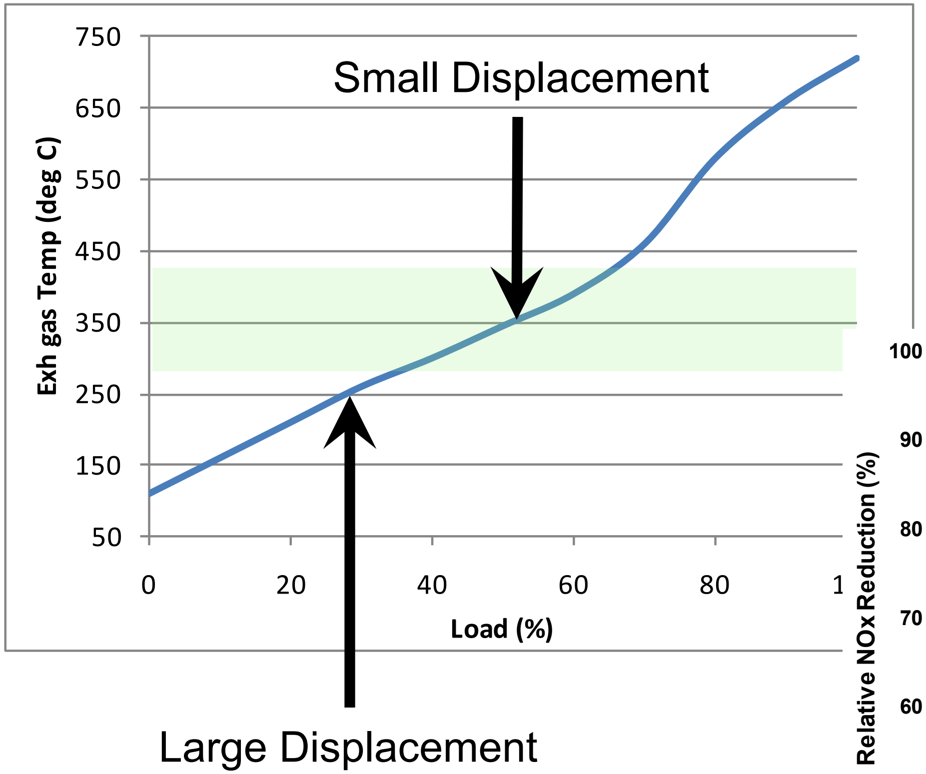
APT Light Duty Tailpipe NOx Strategy

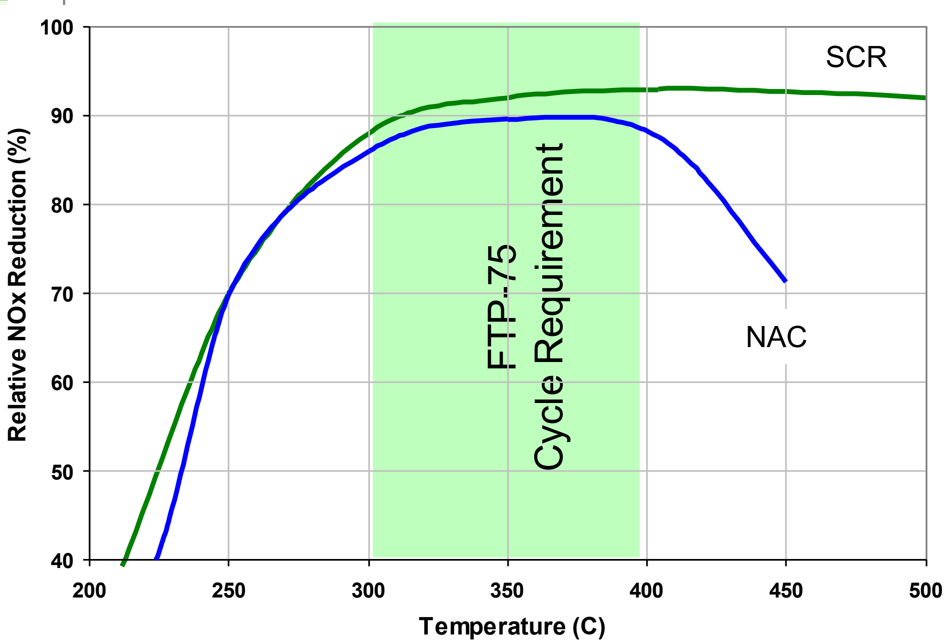


Technical Approach – High Efficiency

Appropriate sized engine

- Down sized engine => increased loads => higher exhaust gas temperature => Improved A/T performance





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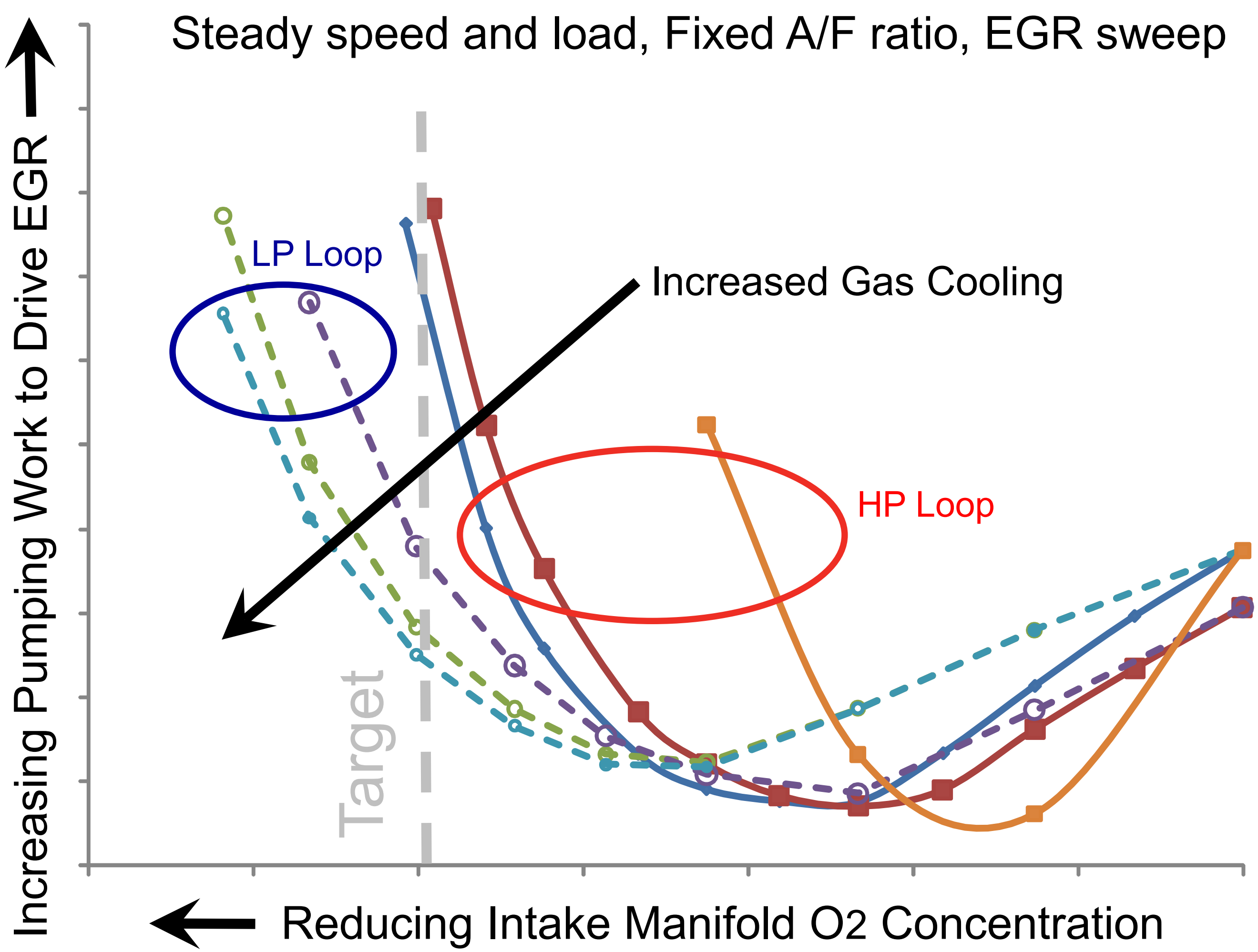
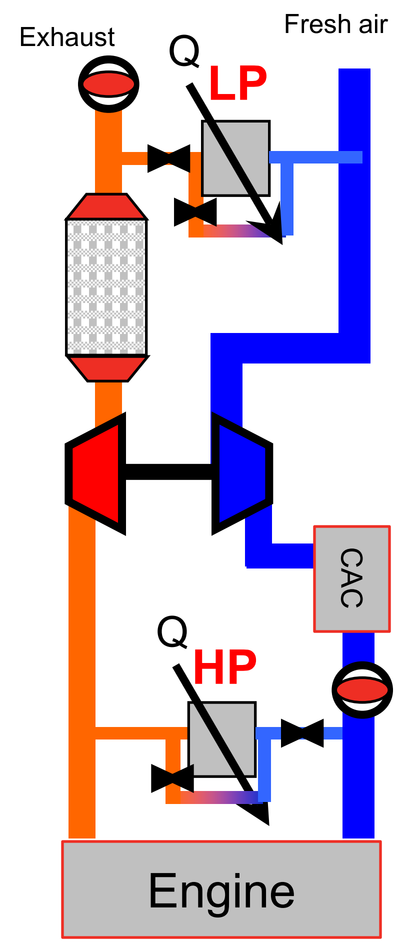
Technical Approach – High Efficiency

Reduce FE penalty due to emission controls

- Low pressure EGR to reduce pumping work

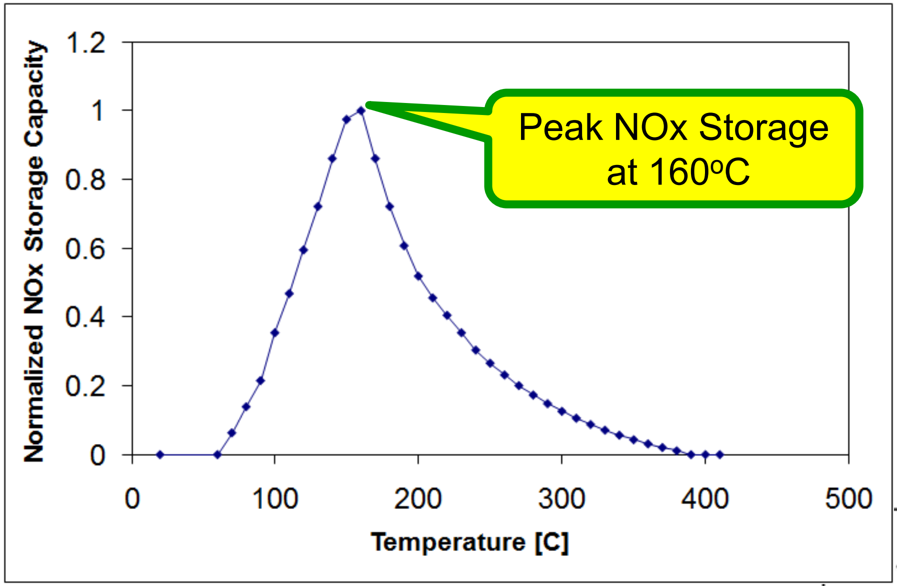




Technical Approach – High Efficiency

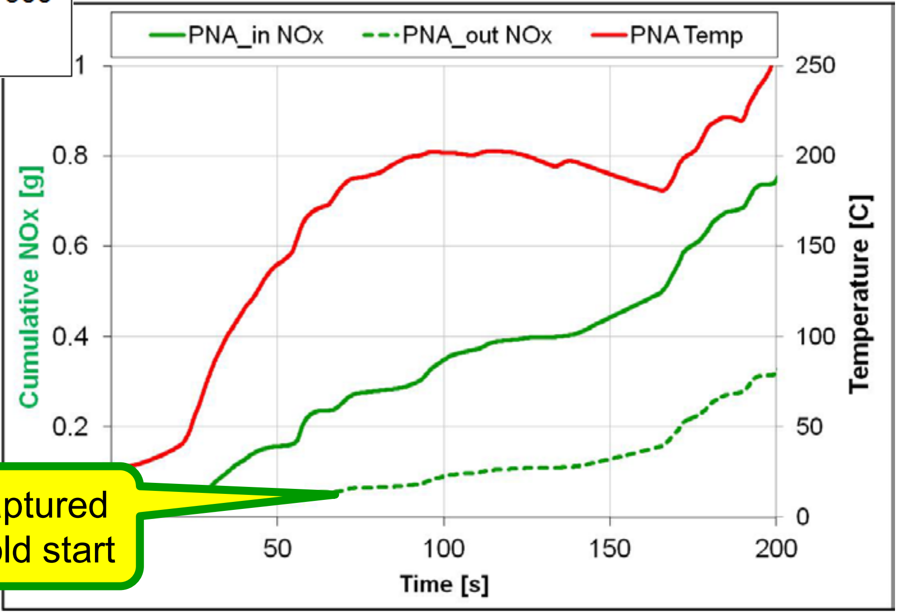
Reduce FE penalty due to emission controls

- 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

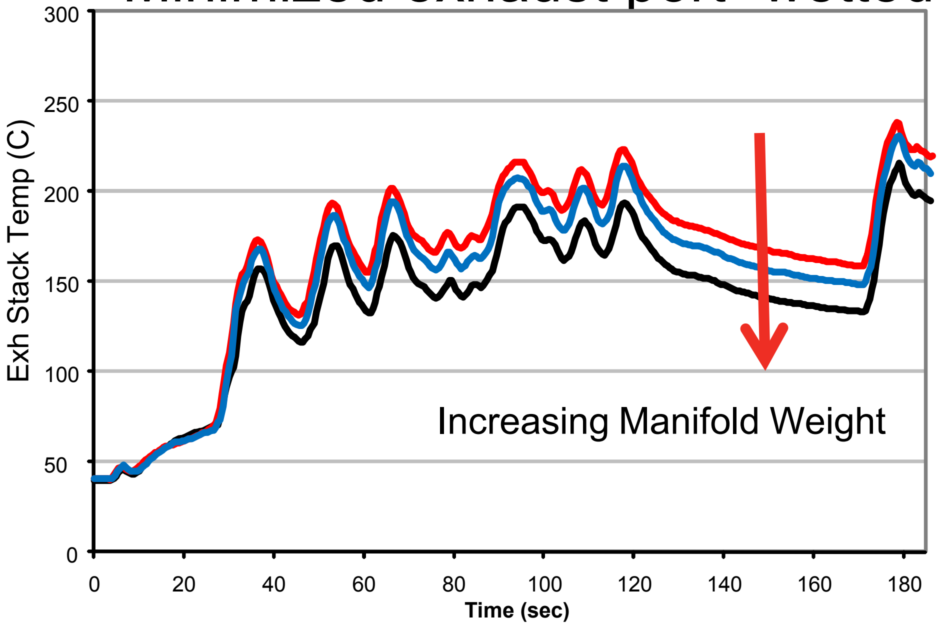


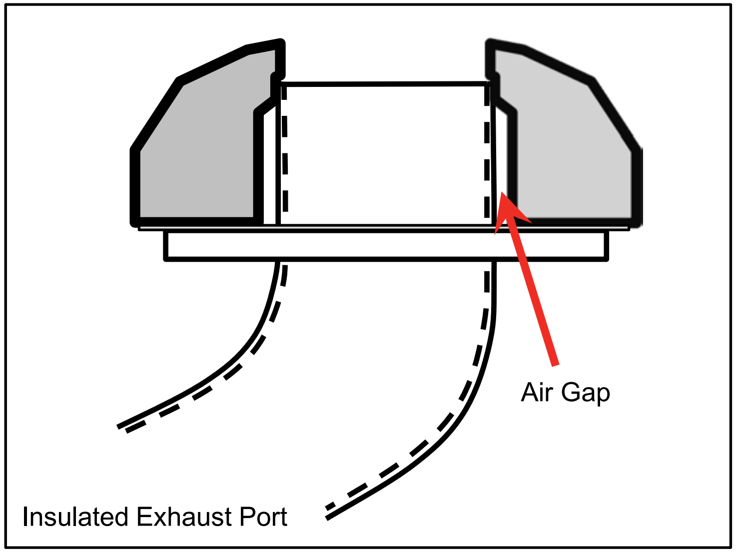
Technical Approach – High Efficiency

Reduce FE penalty due to emission controls

Design features for fast warm up

- Fabricated exhaust manifold instead of cast iron
- Close coupled aftertreatment
  - DOC/DPF assembled onto engine
  - Dual wall exhaust pipe work underbody
- Minimized exhaust port "wetted" area





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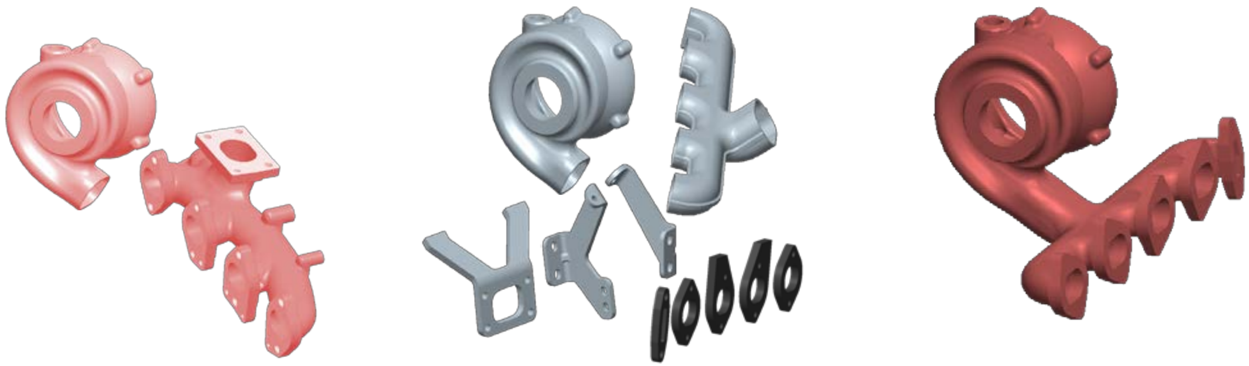
Technical Accomplishments and Progress
New Engine Design

Exhaust Manifold System Design – Selection Matrix

	Baseline	Fabrication	OPTIC
Light Weight	100	97	120
Low Thermal Mass	100	121	120
Cost	100	50	96
Structural Integrity	100	100	100
Score	100	92	**109**



OPTIC – One Piece Thin-wall Integrated Casting