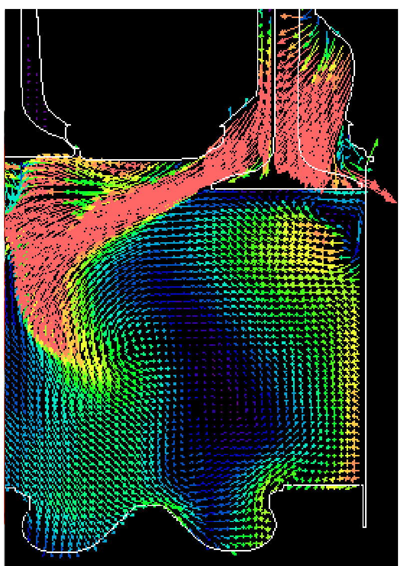
U.S. DEPARTMENT OF ENERGY
DEER 2011 DETROIT
DIRECTIONS IN ENGINE-EFFICIENCY AND EMISSIONS RESEARCH CONFERENCE

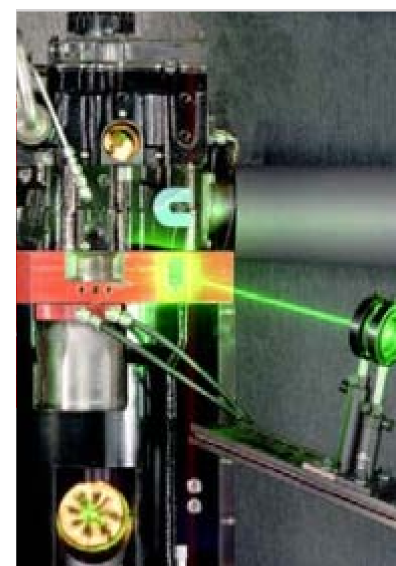
Cummins®

Cummins Next Generation Tier 2, Bin 2 Light Truck Diesel Engine

Michael Ruth
Principal Investigator

5 October 2011





Advanced
Technology
Light
Automotive
Systems

ATLAS

Changing the Climate on Climate Change

Cummins Next Generation
Tier 2, Bin 2
Light Truck Diesel Engine

Program

Timeline

Technical approach

Progress

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Changing the Climate on Climate Change

Program Goals

- ½ Ton Pick-up Truck application
- 40% Better miles per gallon
  - Compared to V8 gasoline powered equivalent
- US Tier 2, Bin 2 emissions levels
- Commercially Viable Solutions
  - High quality, Great Performance, Low Total Cost of Ownership

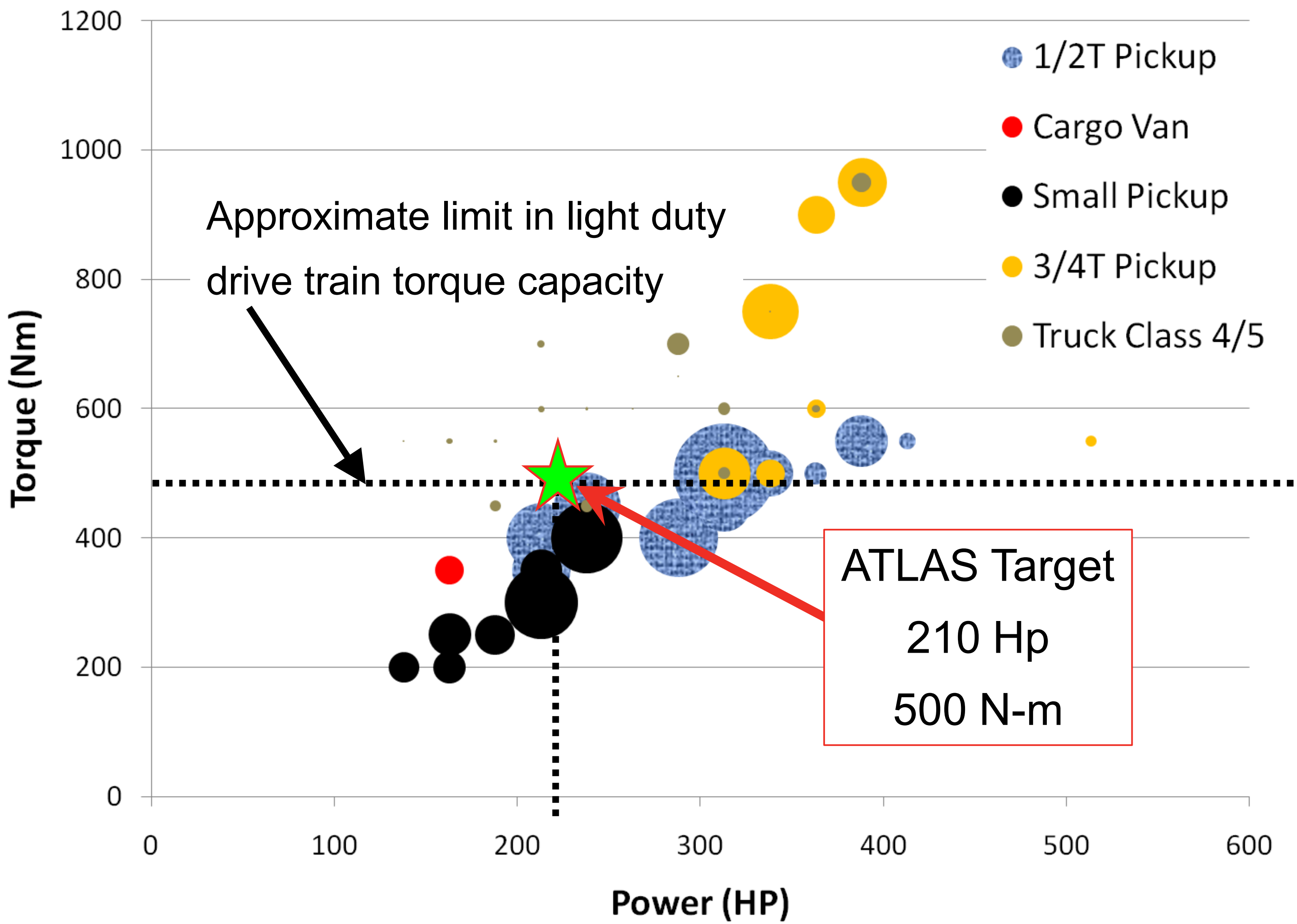
Scope

- Weight reduction in comparison to current diesel
- Aftertreatment effectiveness improvement
- Reduction in emission control fuel economy penalty
- Low impact vehicle integration for OEM application

Partners

- Johnson-Matthey
  - Catalyst technology
- Nissan Motors
  - Vehicle targets and integration support
- U.S. Department of Energy

Power & Torque for U.S. Light Truck Market



Bubble size represents relative market size

Baseline

2010 Nissan Titan

- 5.6L
  all aluminum V-8
- 317HP @ 5,200rpm
- 385ft-lb @ 3,400rpm
- 5 spd automatic transmission
- 5078lb curb / 8299lb GVWR / 15,100lb GCWR
- Tier2Bin5 (FED) / LEVII LEV (CA)

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Fuel Economy

5500 lb ETW

	Baseline vehicle data+	DoE Program at 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

***DoE Performance Metric**

+ **Data from EPA 2010 Certification database**

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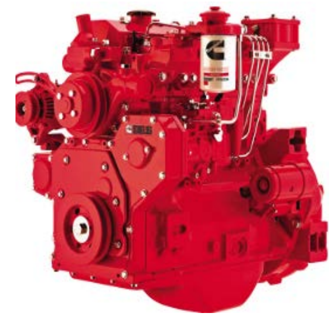
Program Timeline

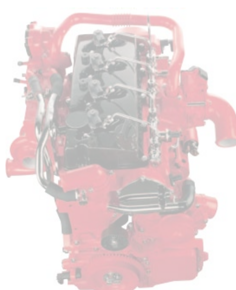
4 year program
October 2010 Kickoff

T2B5 Vehicle Demo
December 2013

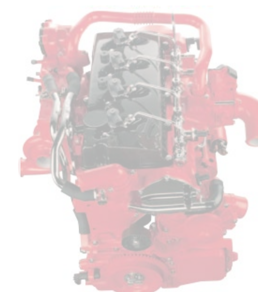


Engine Out at Target
July 2012

T2B2 Vehicle Demo
August 2014



T2B5 Eng Dyno Demo
June 2013



New Engine Available
December 2012

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Design Vision; Highly Integrated

- Engine package that will include close coupled aftertreatment and doser for fast light off and reduced burden on OEM assembly stations
- Weight neutral to baseline gasoline powertrain
- Elimination of “generic adaptation”
- Down sized, high power density, and minimized NVH

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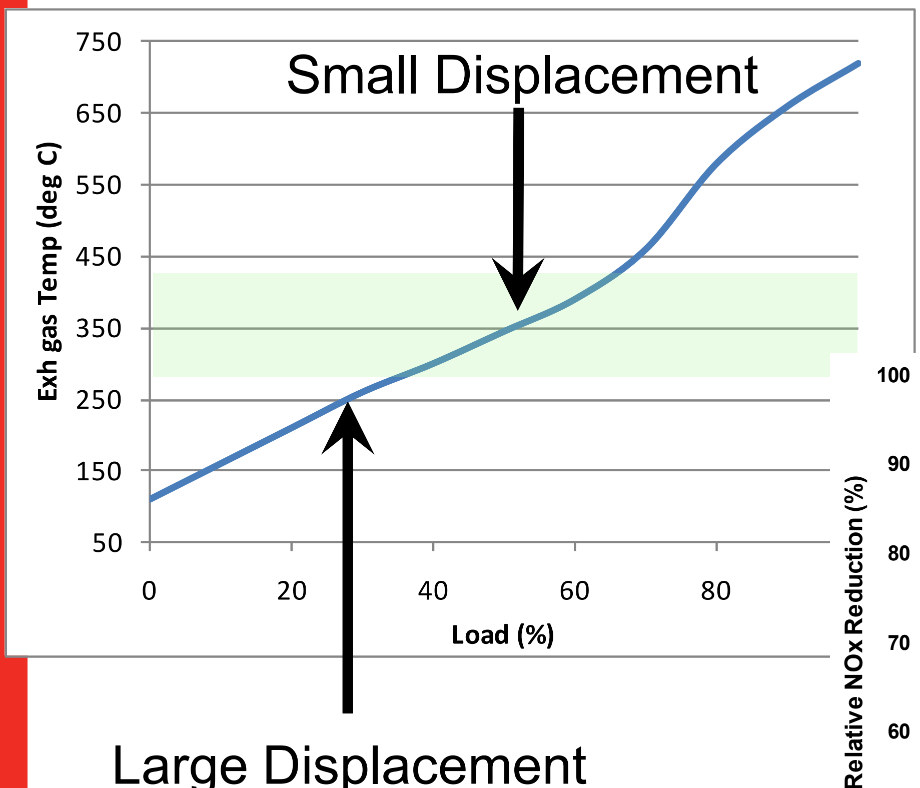
Technical Approach – F.E. & Emissions

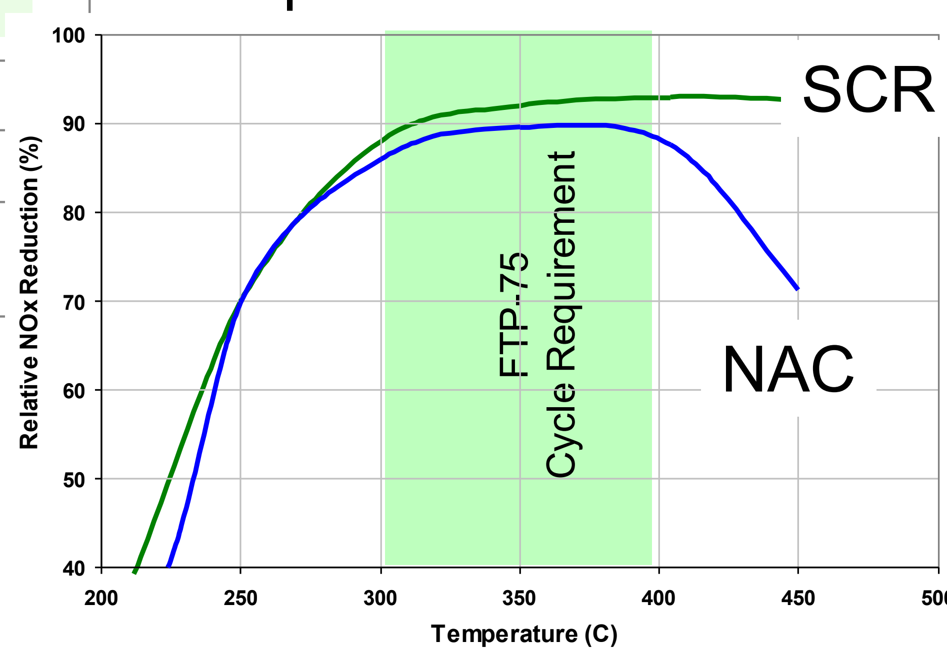
Down sized engine



increased loads

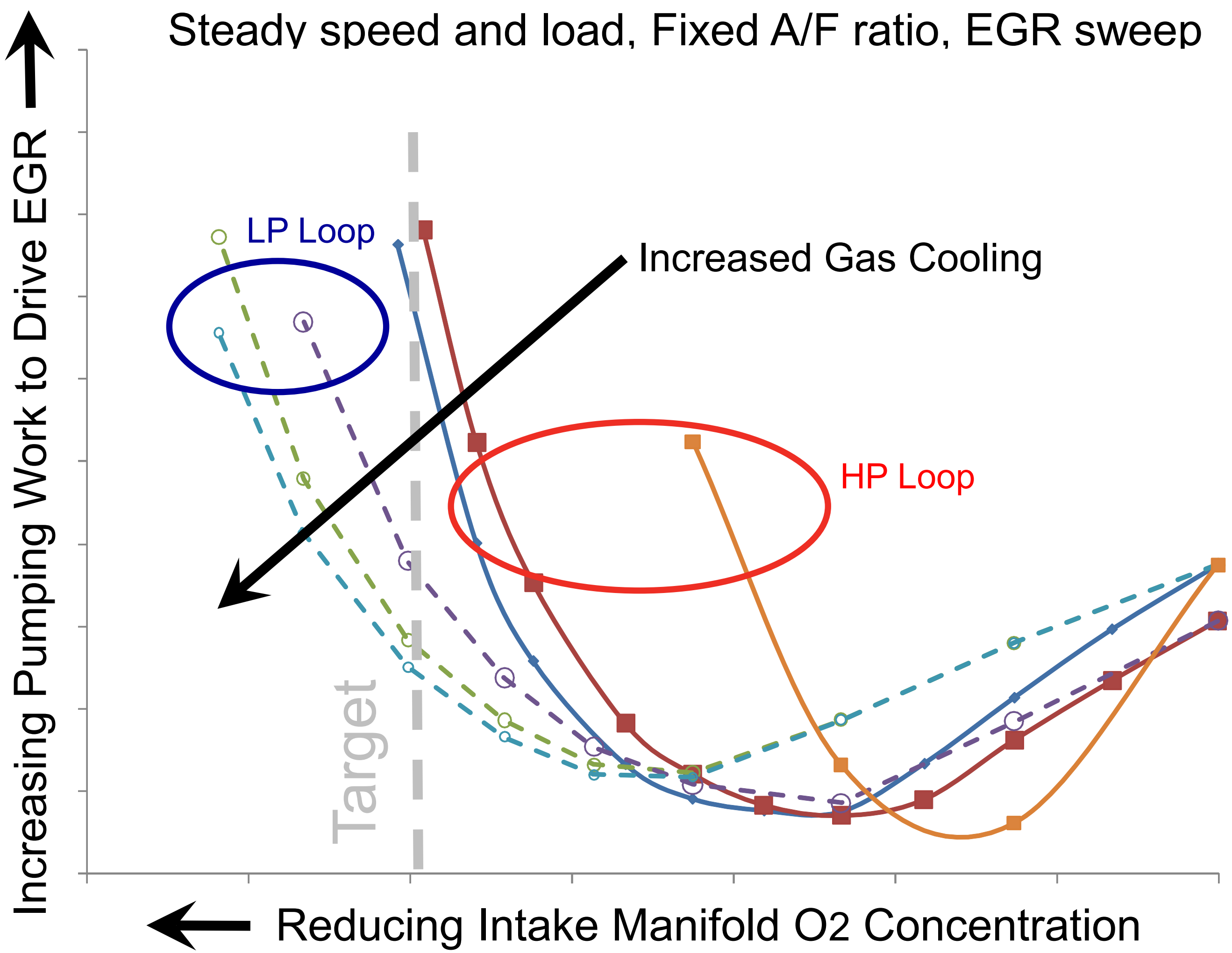
higher exhaust gas temperature

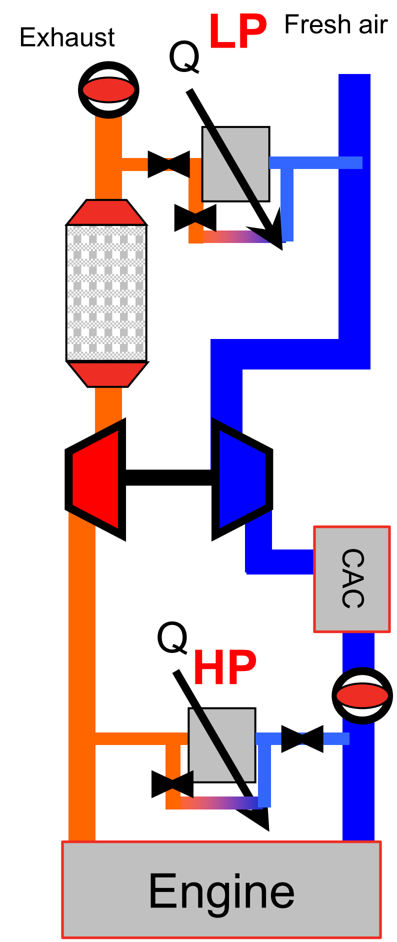
Improved A/T performance



Technical Approach – F.E. & Emissions

Low pressure EGR to reduce pumping work

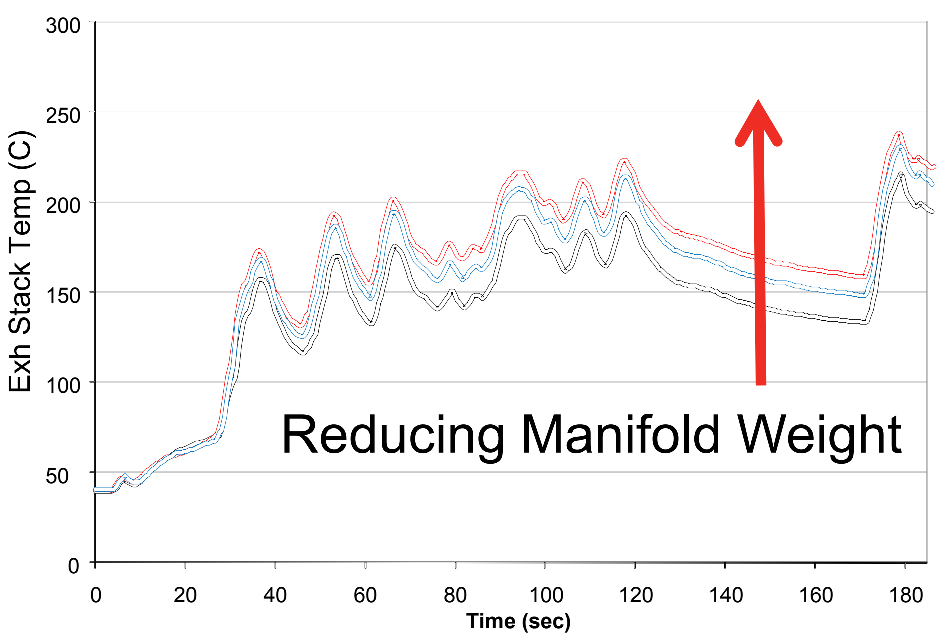


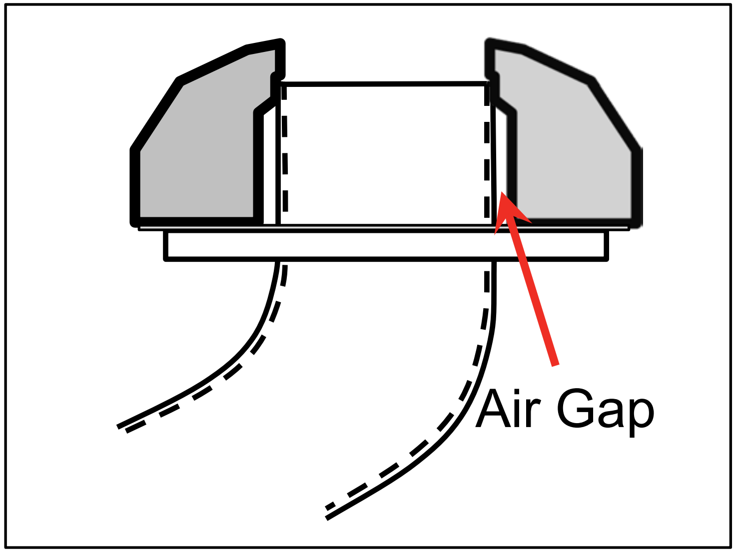


Technical Approach – F.E. & Emissions

Design features for fast warm up

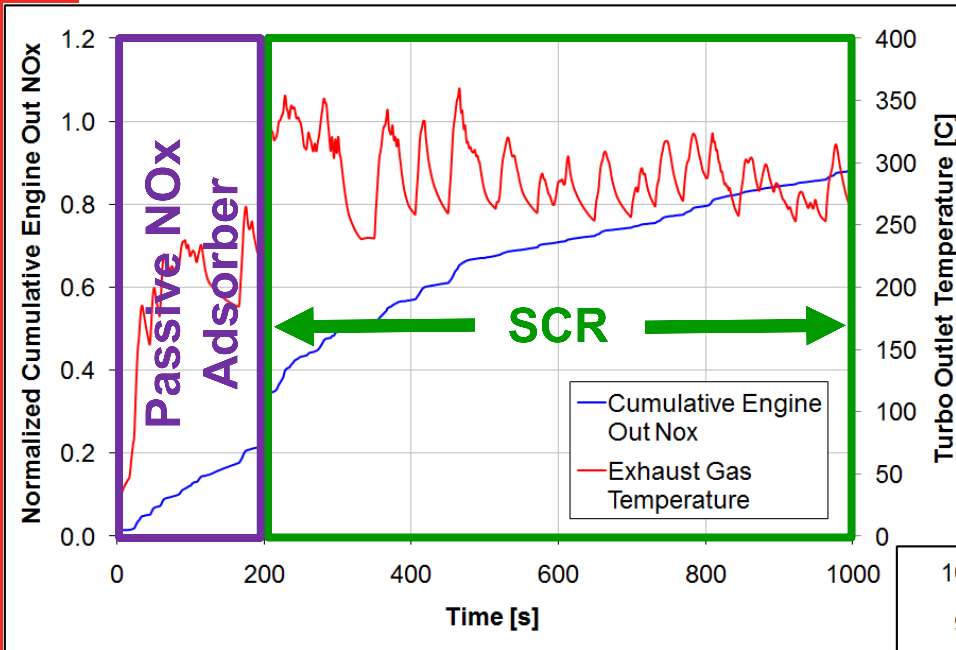
- Fabricated exhaust manifold instead of cast iron
- Close coupled aftertreatment
  - DOC/DPF assembled onto engine
  - Dual wall exhaust pipe work underbody
- Minimized exhaust port "wetted" area





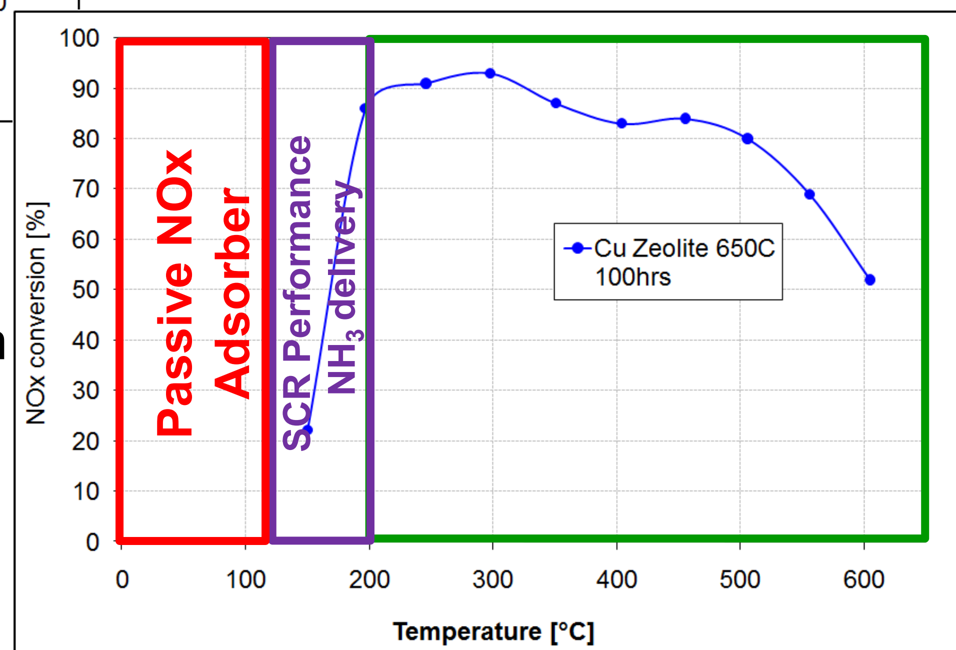
Insulated Exhaust Port

LT NOx Slip Control Strategies



- **Major focus areas**
  - Control engine out NOx in cold start
  - Limit NOx slip
  - Improve A/T warm up performance

- **SCR development focus**
  - Low temperature conversion
  - Reductant delivery



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Progress

- Mule Engine
  - Low viscosity engine oil evaluation
  - Variable swirl system testing
  - Generation 3 Piezo FIE applied to baseline engine
  - Design and procurement of HP/LP EGR system
    - Testing started 9/15
- Mule Vehicle
  - Build complete, first fire in April 2011
  - Development of shift strategy, acc load management, etc..

Low Viscosity Oil Testing (Engine Dyno Cycle)

- Engine dyno cycles were used to approximate vehicle cycle operation.

	Base 15W40	10W30	5W30	5W30 Low V	
Fuel Economy FTP-75	23.8	24.0	24.1	N/A	MPG
Fuel Economy Bag 1	23.1	23.6	23.7	N/A	MPG
Fuel Economy LA-4	24.6	24.6	25.0	25.9	MPG
Fuel Economy HWFET	29.6	30.0	30.0	30.4	MPG

- Low V 5W30 is a 2.9 cp HTHS rating, all others are 3.4 cp HTHS rating or greater.

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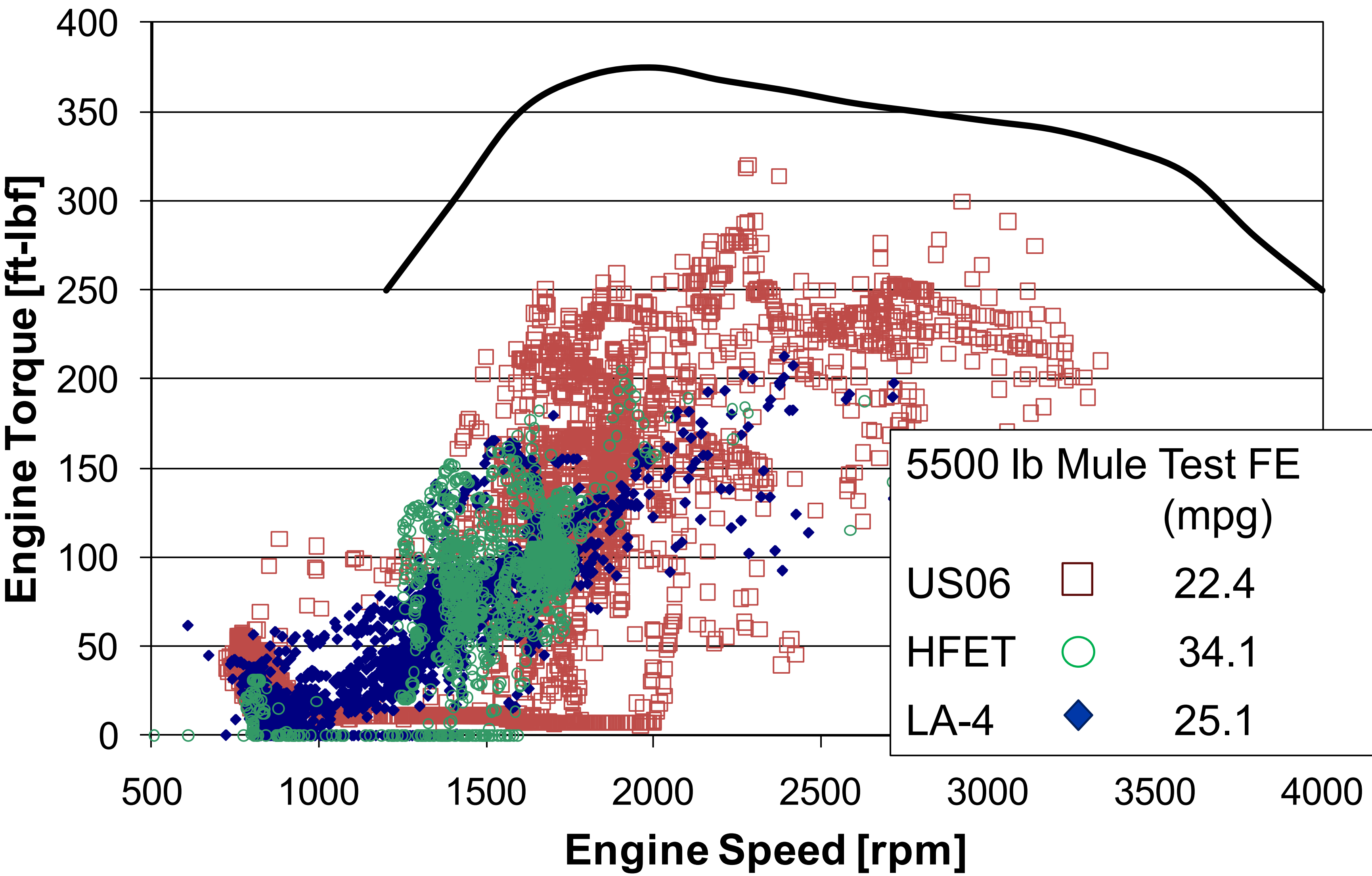
Mule Vehicle Test Results



Technical Accomplishments – New Engine

- Base engine design work
  - Analysis of crankshaft to design included low viscosity oil properties
  - Power cylinder designed for short compression height and high cylinder pressure requirements
- Control system
  - Coupled control system logic to GT simulation
- Aftertreatment modeling
  - New A/T technology first order model (PNA)
  - Full model for A/T options (SCR vs NAC)
  - Detailed model for target development of 0-180 sec
- Vehicle model
  - Integrated system model under development

Thank You!

- Partners
  - Johnson-Matthey Inc. Catalyst systems
  - Nissan Motors Light Truck – Vehicle development
- Contributors
  - Rose-Hulman Institute of Technology – Advanced control system analysis
- U.S. Department of Energy
- Cummins management and team members

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TITAN
Advanced Technology Light Automotive Systems