Lean Gasoline System Development for Fuel Efficient Small Car

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GM Powertrain

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Project ID: ACE063

Lean Gasoline System Development

Overview

Timeline

• Project start:	May 2010
• Project end:	Sept 2013
• Project duration:	3 yrs 4m
• Percent complete:	60%

Barriers

- Improve the efficiency of light-duty passenger vehicles through:
  - Engine Efficiency Improvement
  - Effective Engine Controls
  - Cost Effective Emission Control

Budget

• Total project funding:	$15,411,724
– DOE share:	$7,705,862
– GM share:	$7,705,862
– Funding in 2011	$4,426,336

Partners

- Ricardo (combustion)
- Bosch (fuel system)
- Umicore (aftertreatment)

Lean Gasoline System Development

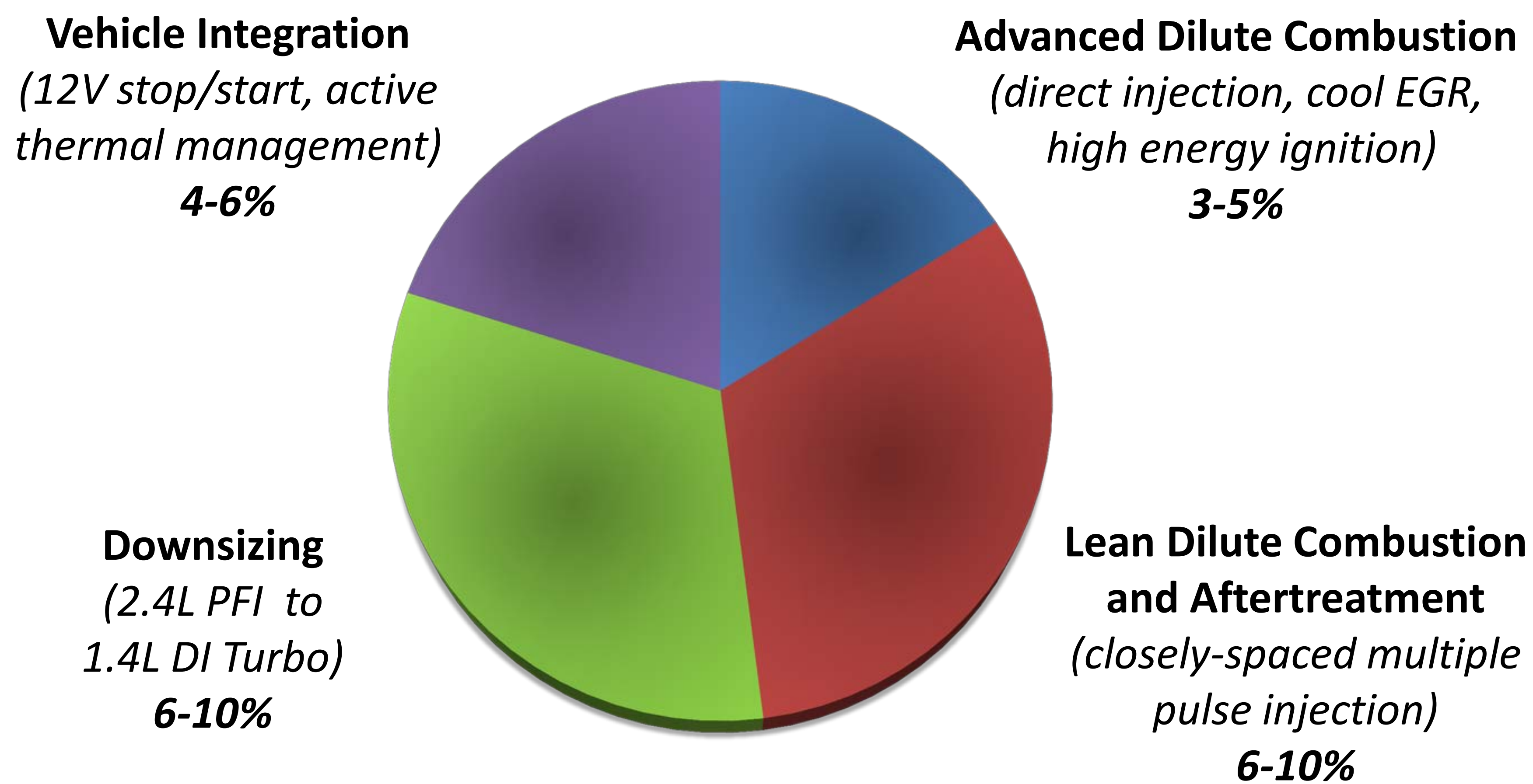
Relevance – Program Objective

Demonstrate a lean gasoline engine system that achieves 25% fuel economy improvement compared to a 4-cylinder PFI engine in a mid-size sedan, while meeting T2B2 emissions.

- Fundamental combustion analysis and experimental investigation to generate knowledge that would support implementation across engine families
- Novel Lean after-treatment hardware and strategy developed
- Engine and after-treatment controls development within production controls constraints

Lean Gasoline System Development

Approach / Strategy – Targeted Efficiency Improvement



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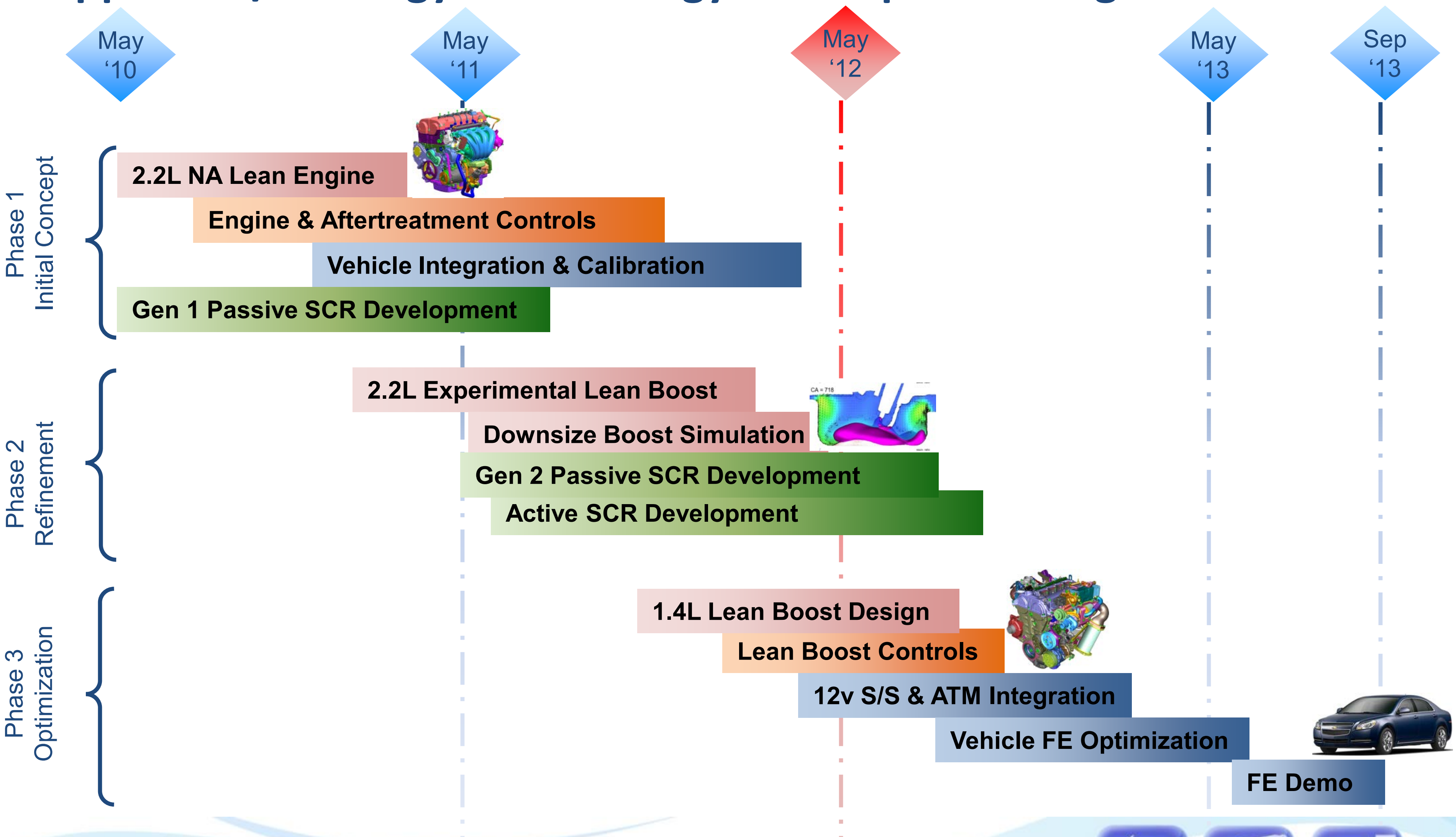
Approach / Strategy – Technology Development Progression



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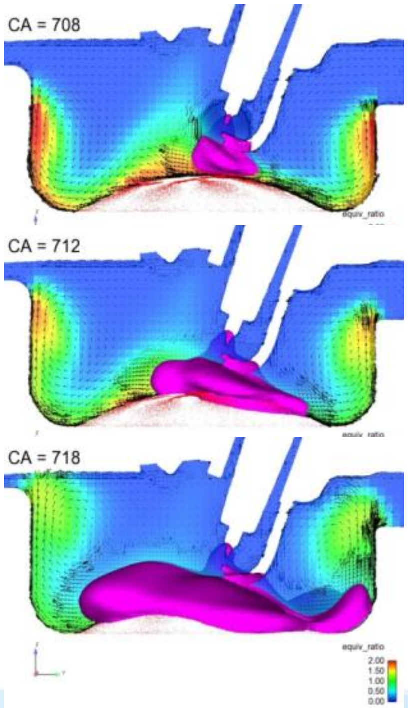
Approach / Strategy – Development Process

Combustion

Use CFD, spray lab and single cylinder dynamometer to define boosted lean combustion system prior to multi-cylinder engine design, procurement & development

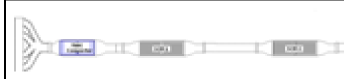
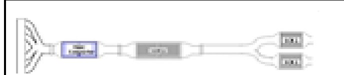
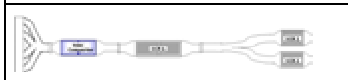
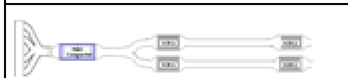


Intake Temp = 60 C

- Flame follows rich mixture and flow
- Rich mixture position varies w/ temp
- Flame motion f(heat release, flow)

Aftertreatment

Use system level engine and aftertreatment modeling techniques to drive refined exhaust architecture selection and aftertreatment emission control development

Configuration	Comments	Tailpipe NO_x	NH_3 breakthrough	Overall system backpressure
	Baseline (split 4L SCR catalysts in series)	—	—	—
	Reduce face velocity of rear SCR by half	↓	↑	↓
	Eliminate need for one NO_x sensor	↓	↑	↓
	Split exhaust after first SCR for thermal management	↑	↓	↓
	Dual exhaust line for thermal management	↑	↓	↓
	Reduce face velocity and space velocity of rear SCR by half	↓	↓	—

Various exhaust system architectures simulated to optimize PASS aftertreatment system

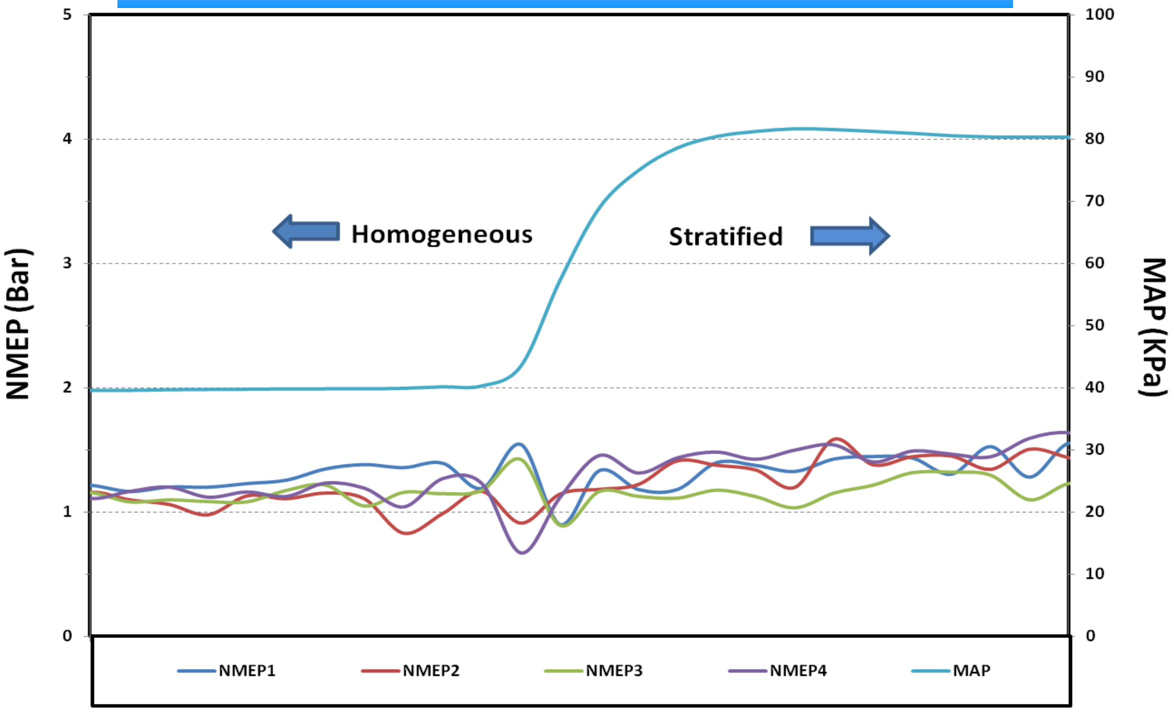
Lean Gasoline System Development

Accomplishments – Phase 1: Lean Combustion Controls

Lean stratified torque model integrated into production torque structure

- Hi Flow EGR control
- Fuel mode transitions
- Passive SCR NH3 generation control strategies
- Initial 12V Stop / Start controls for lean combustion

Homogeneous to Lean Stratified Transition



➔ Strategies for lean combustion and passive SCR implemented into production controls

➔ Transition from homogeneous to stratified without significant torque disturbance

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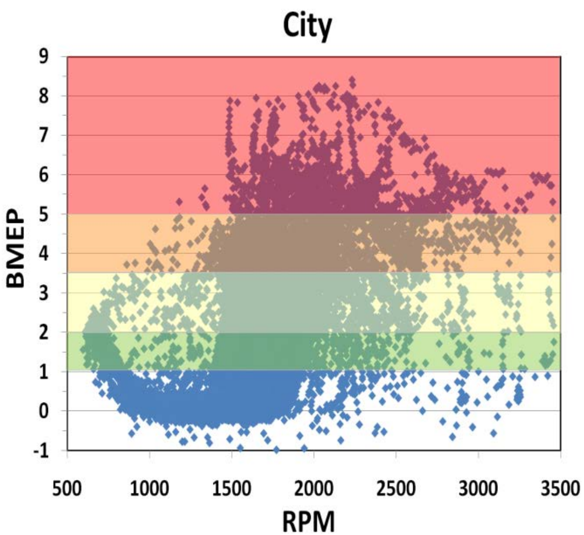
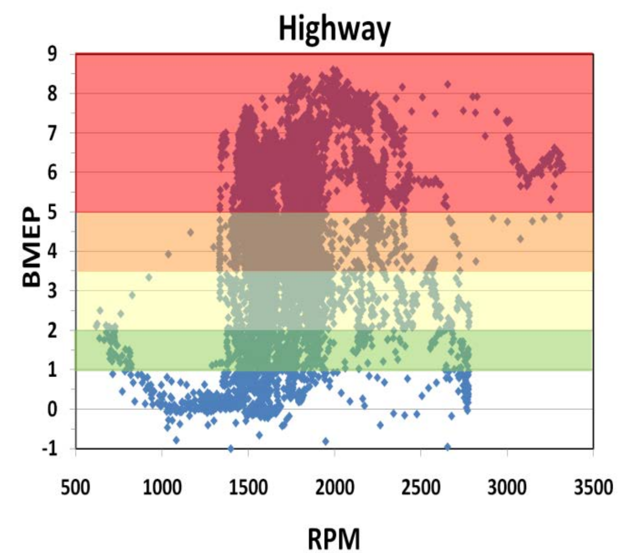
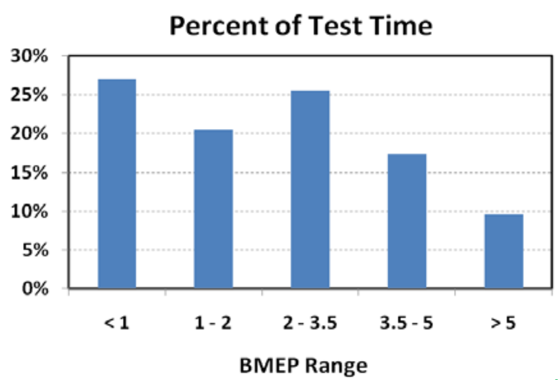
Accomplishments – Phase 1: Naturally Aspirated Fuel Economy

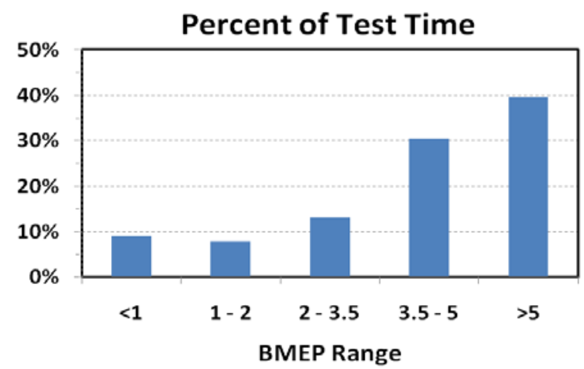


Improvement

- 0 to -2%
- 5%
- 10%
- 10 to 20%
- 20 to 30%







- ➔ Lean operation shows significant fuel economy improvement at light to medium loads
- ➔Need to extend the lean operating range to higher loads
- ➔ Lean combustion systems is not very efficient in stoichiometric homogenous mode

Lean Gasoline System Development

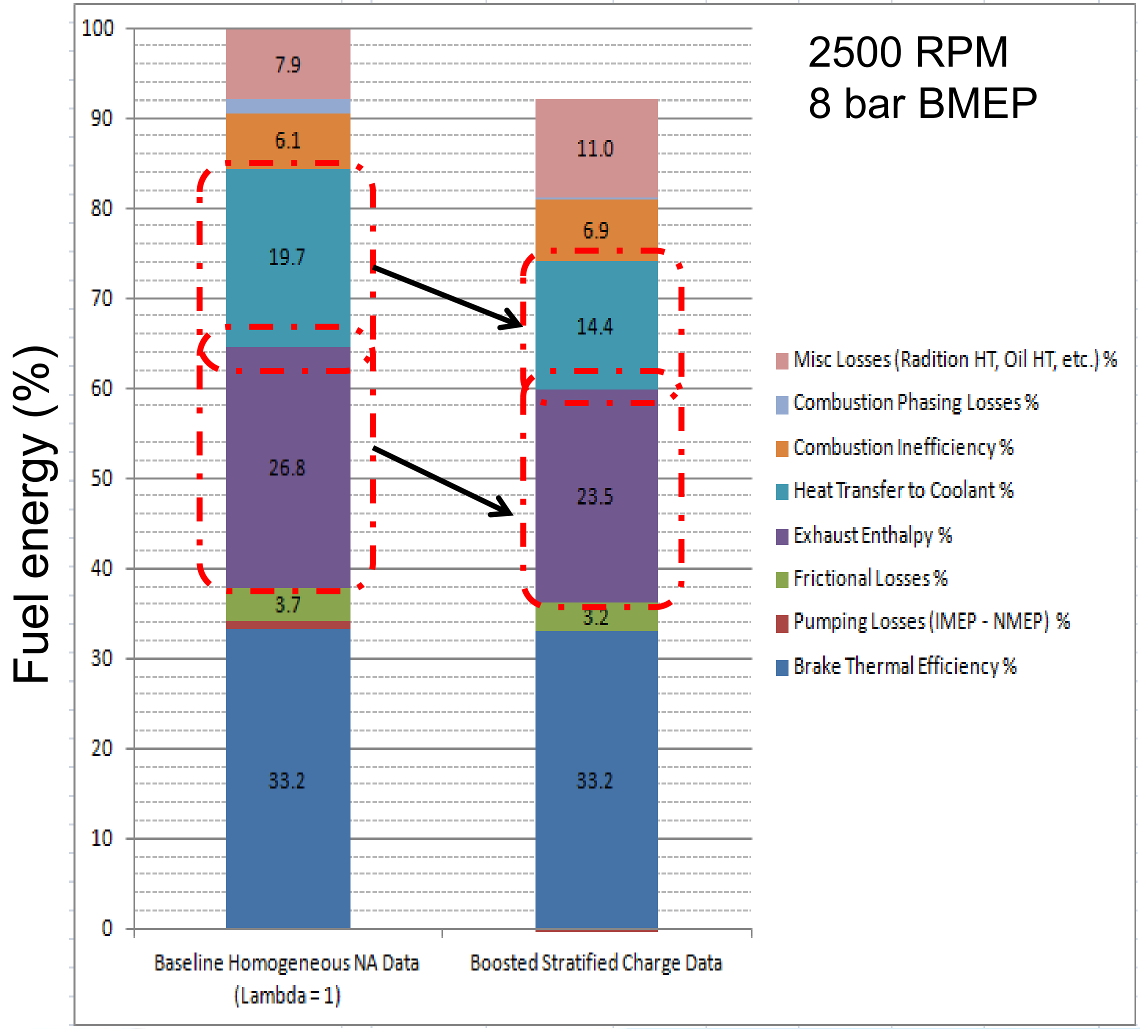
Accomplishments – Phase 2: Exploratory Boosted Lean Combustion

Boosted combustion enables leaner operation at higher loads through increased trapped air mass capacity while maintaining high EGR level for NOx emission control

Fuel economy improvement from:

- Lower heat transfer to coolant
- Lower exhaust gas

➔ Boost is key enabler to run lean at higher loads



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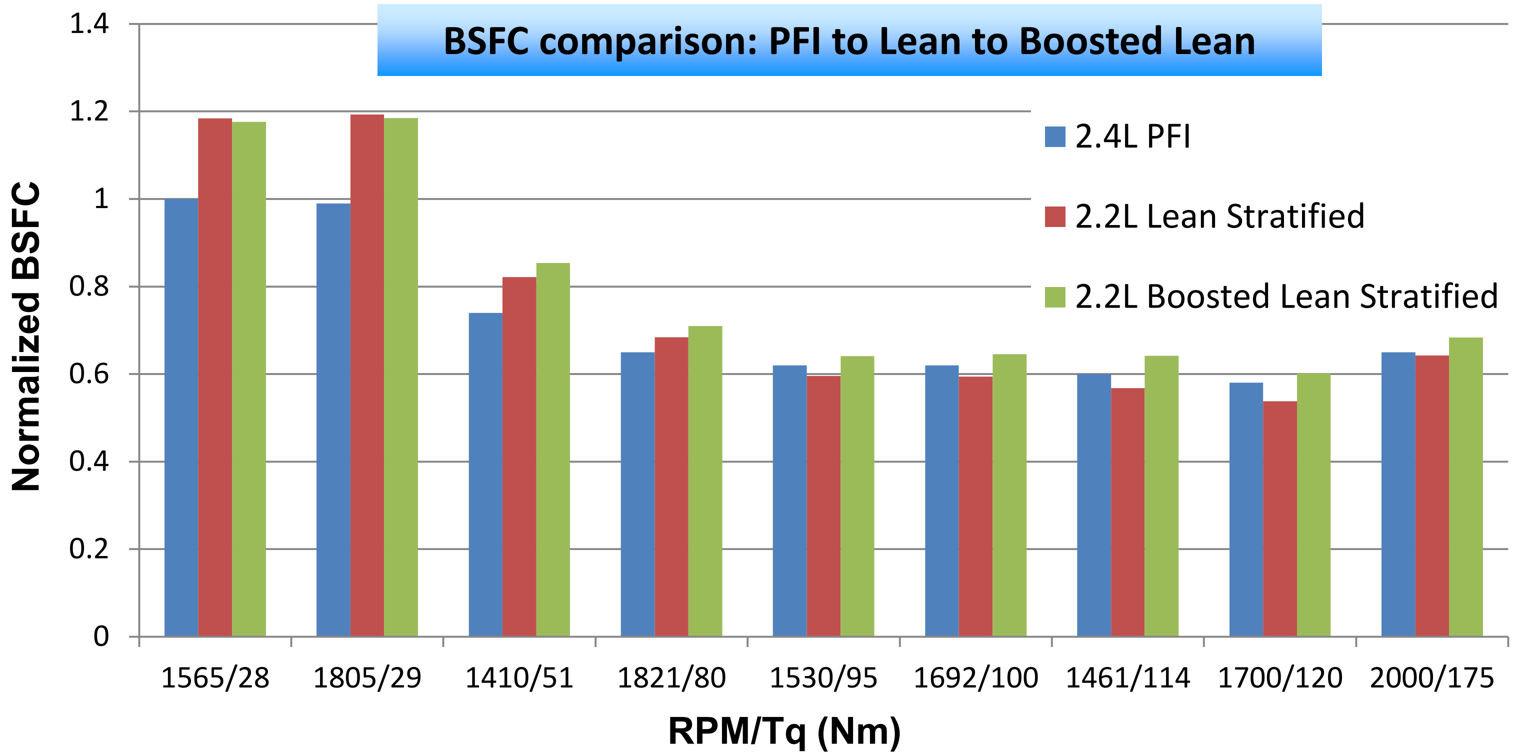
Accomplishments – Phase 2: Exploratory Boosted Lean Combustion



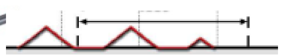
➔ The fuel economy improvement of the naturally aspirated lean stratified engine reduces from 20% to 10% as the load increases from 25 Nm to 50 Nm

➔ The highest naturally aspirated load that can be operated in lean stratified is ~85 Nm

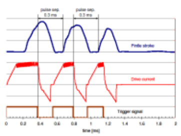
➔ Boosting the engine allows us to run lean up to 175 Nm

Lean Gasoline System Development

Accomplishments – Phase 2: Closely-Spaced Injection

Reference 2.0L Boosted Low-Tumble Multi-Pulse Bosch A-cone

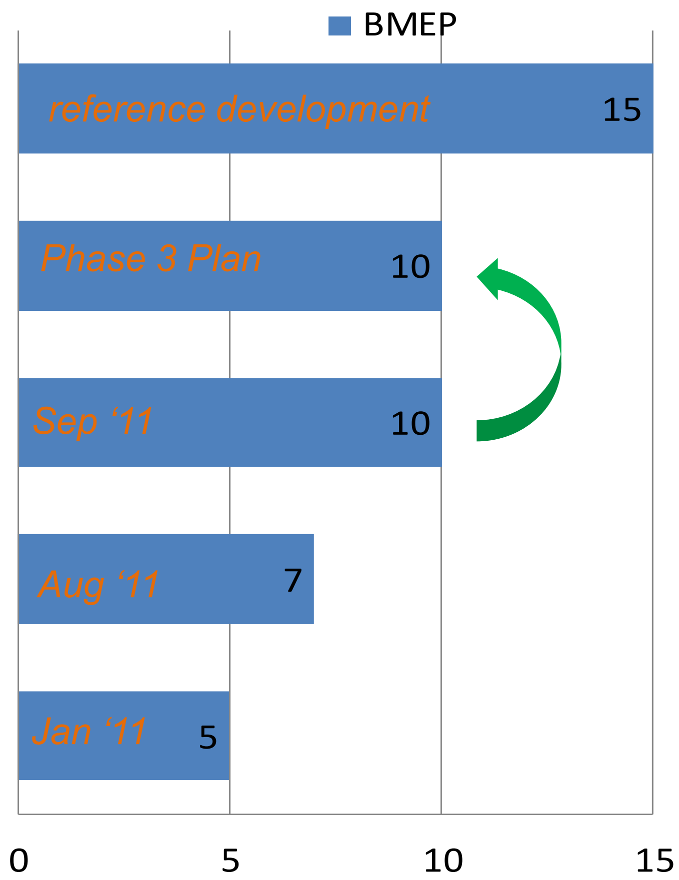



1.4 L 1st-stage Boosted Swirl SGE closely-spaced solenoid multi-hole

2.2L Boosted Swirl SG5 closely-spaced solenoid multi-hole

2.2L Boosted Swirl SG5 widely-spaced solenoid multi-hole

2.2L NA SG5 Swirl widely-spaced solenoid multi-hole



➔ Boosted combustion with closely-spaced solenoid injection enables 90% of FTP and Hwy cycles to be operated in lean stratified with 1.4L boosted engine

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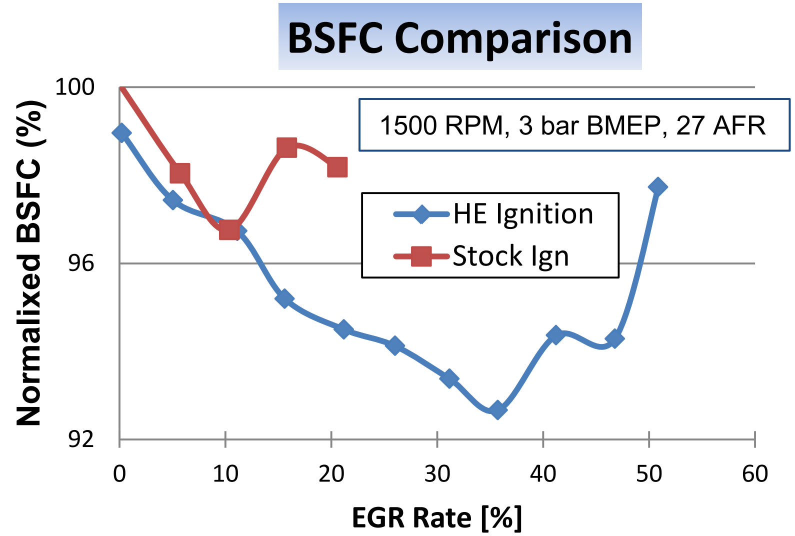
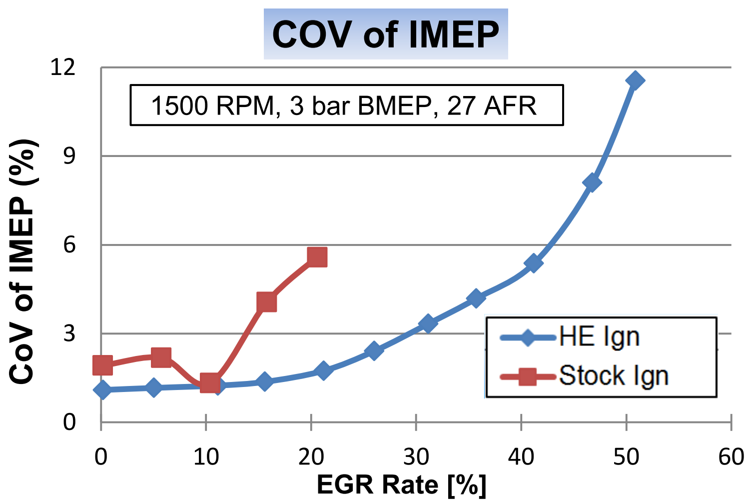
Accomplishments – Phase 2: High Energy Ignition

High energy ignition enables higher EGR tolerance at low and mid load

- EGR tolerance was increased from 15 to 35% with constant AFR
- 4% BSFC reduction can be achieved at lower load condition

➔ High energy ignition will enable improved fuel economy at the same engine out NOx levels





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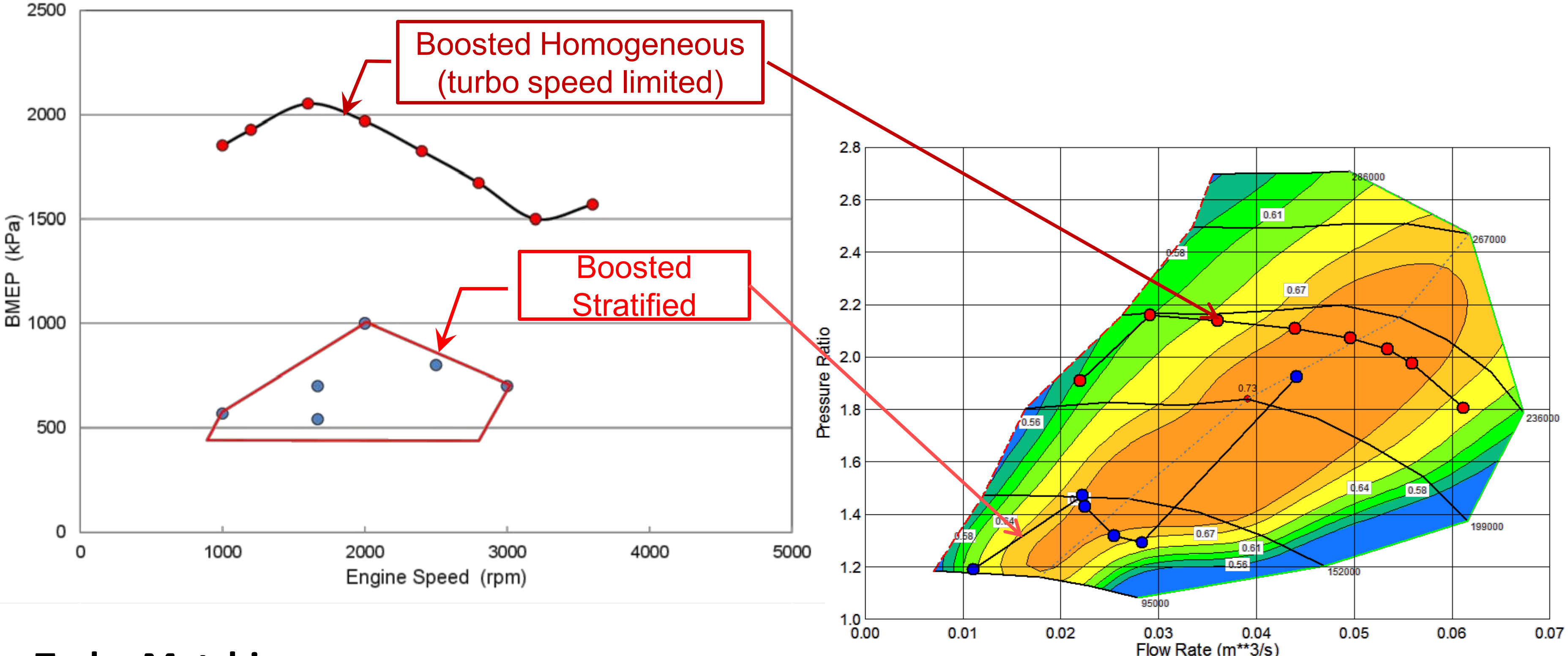
Accomplishments – Phase 2: Turbo Matching for Boosted Lean



Turbo Matching

- Restricted selection to single stage turbo, biased selection to meet low speed stratified rather than peak power charging requirements. System solution may eventually drive multi-stage charging.

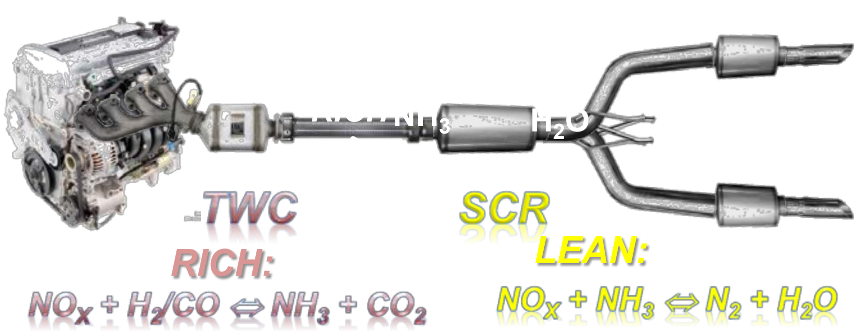
➔ Turbocharger is aggressively sized to provide the maximum potential efficiency gain while providing the large mass flow required to support lean operation

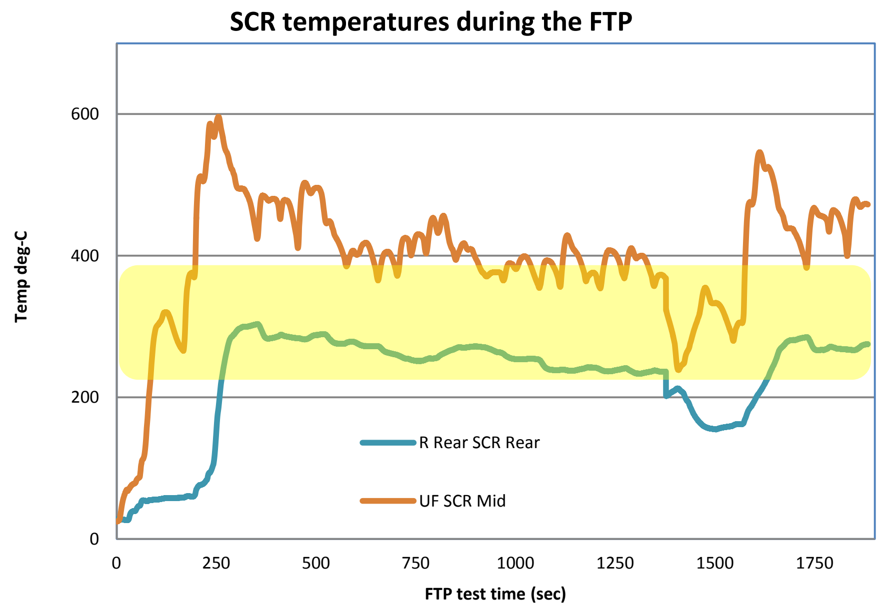
Lean Gasoline System Development

Accomplishments – Phase 1: Passive SCR Aftertreatment

Passive SCR – NH3 is generated across three way catalyst

- Passive SCR system installed and currently being calibrated
- Front SCR too hot to store NH3 effectively, may require exhaust thermal management
- Not able to meet target NOx efficiencies at high loads
- Need to be able to generate NH3 more efficiently at high loads (FE penalty increasing)





➔ Passive SCR currently has thermal limitations resulting in missing T2B2 emission target

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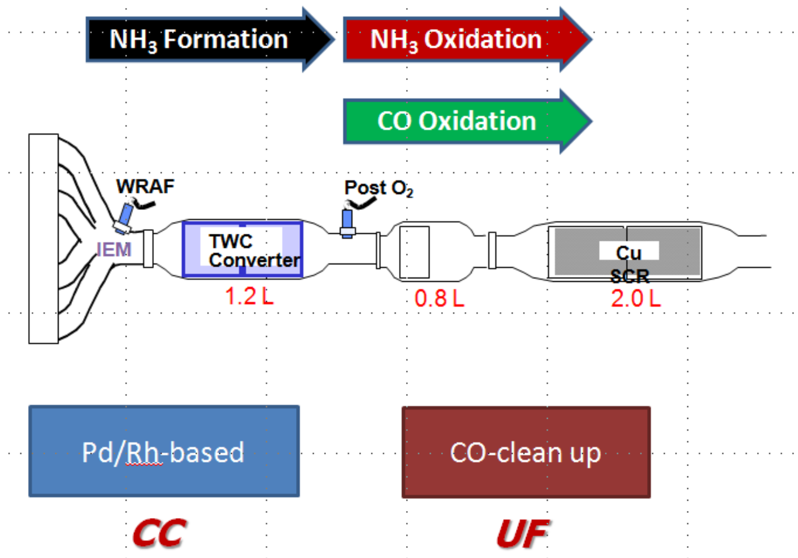
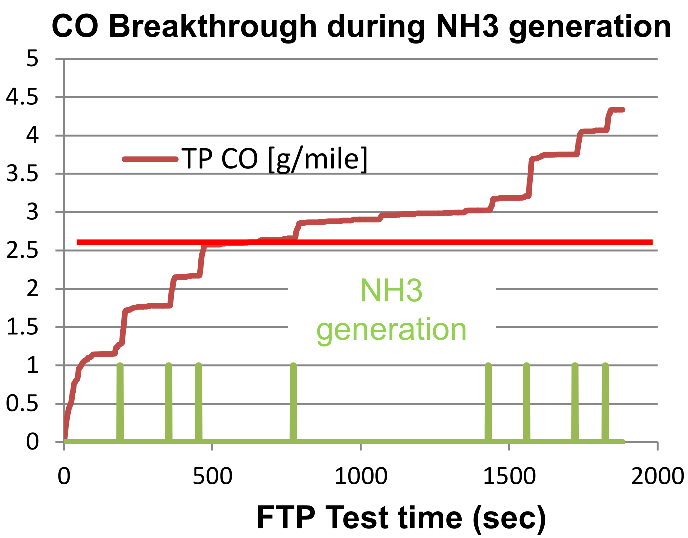
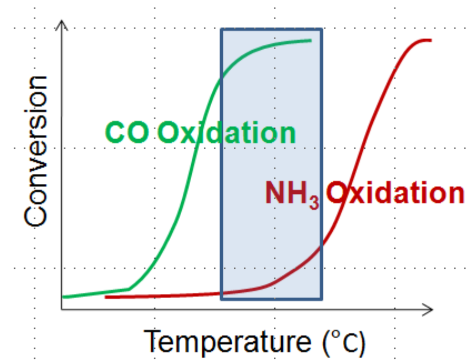
Accomplishments – Phase 1: Passive SCR CO reduction

Passive SCR system generates excess CO during NH3 generation event

- Continuing to investigate washcoat formulations to improve NH3/CO ratio
- Currently require additional CO clean-up catalyst downstream of TWC



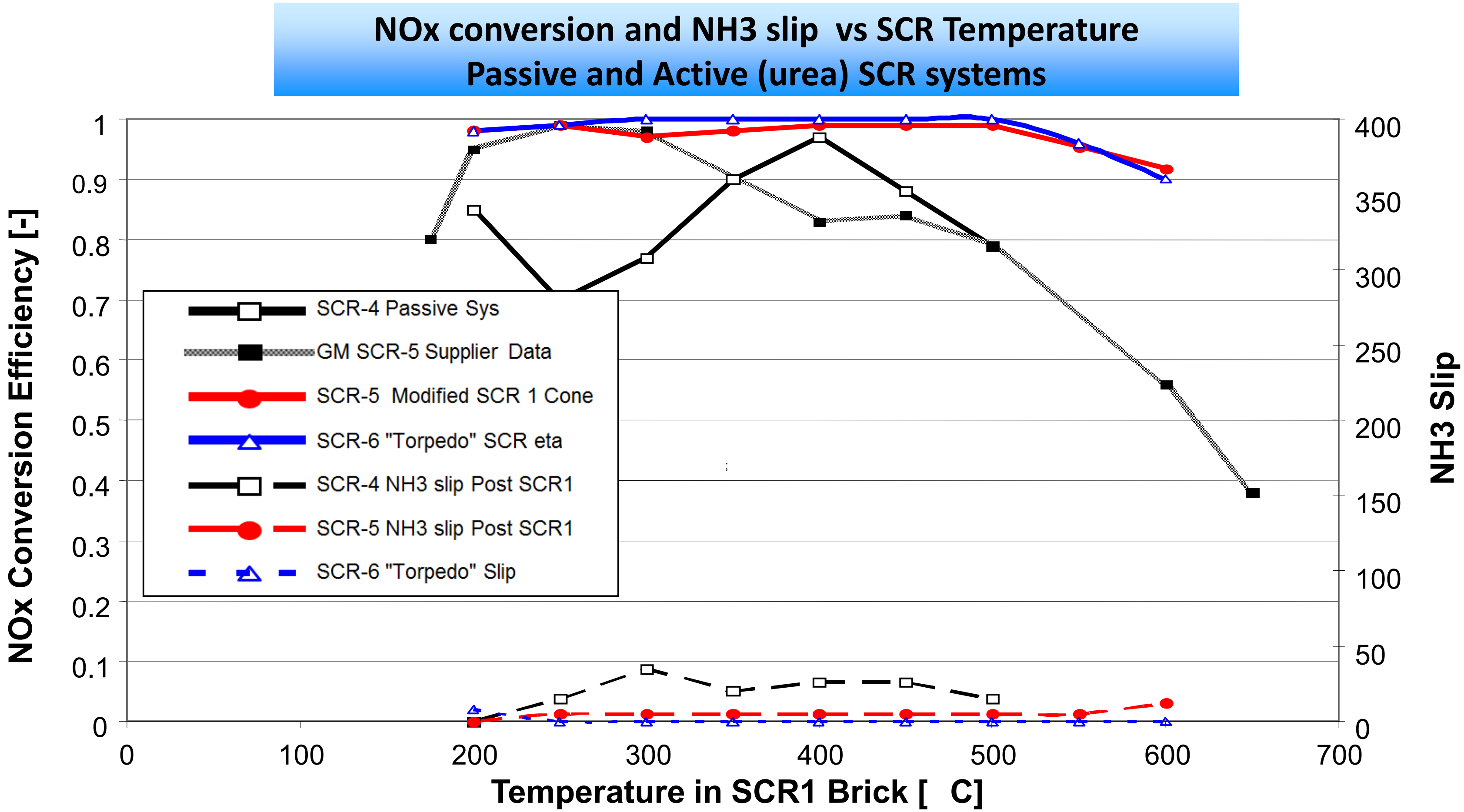




➔ Passive SCR currently generates excess CO resulting in missing T2B2 emission target

Lean Gasoline System Development

Accomplishments – Phase 2: Active SCR Aftertreatment

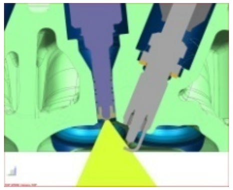


- ➔ Active SCR is more capable than passive and without fuel economy penalty
- ➔ Phase 2 will leverage passive SCR at light loads to reduce urea consumption

Lean Gasoline System Development

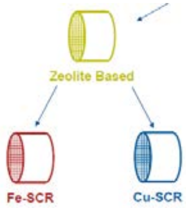
Collaboration – Key Supplier Involvement

The program is partnering with the following suppliers in order to develop a common understanding of the integration challenges to implement lean gasoline systems in to production



• **Ricardo** - Combustion knowledge and analysis techniques as well as a broad knowledge of lean combustion systems

• **Bosch** – Injector hardware including spray geometry and small closely-spaced pulse capability

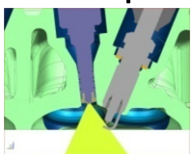


• **Umicore** – Aftertreatment knowledge for lean gasoline and diesel systems, analytical and production field experience

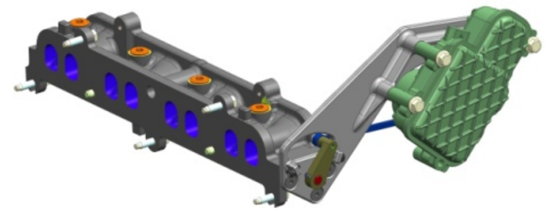
Lean Gasoline System Development

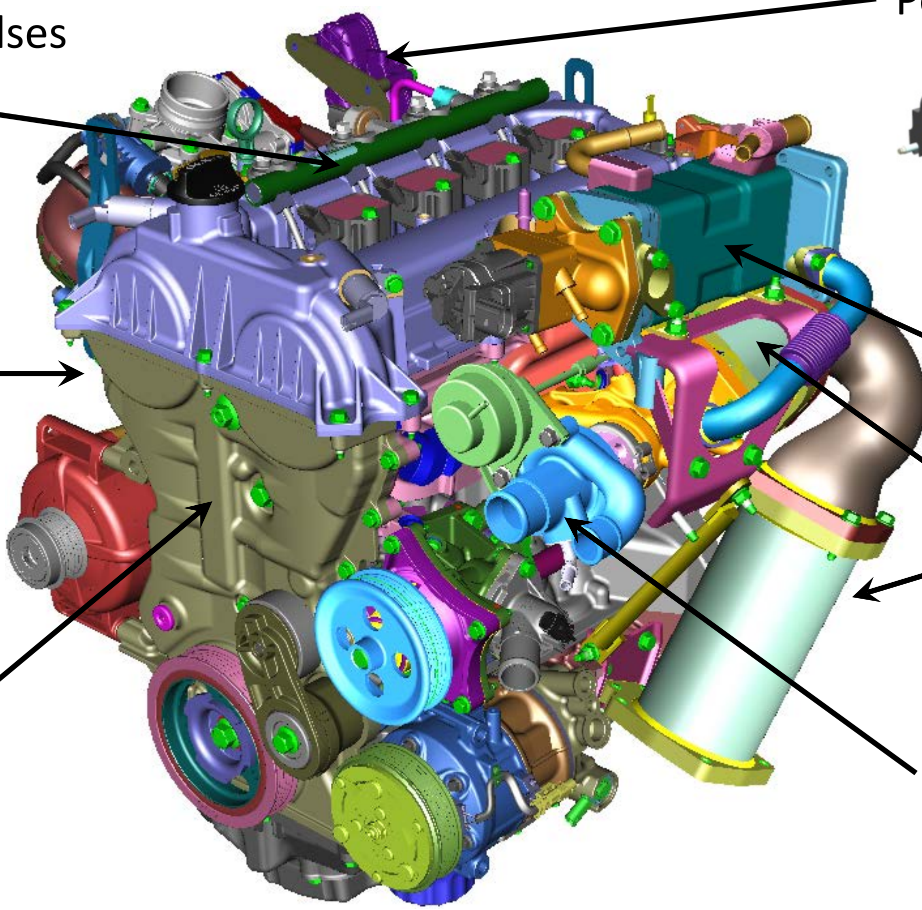
Future Activities – Phase 3: 1.4L Downsized Lean Boost Engine

Central Direct Injection
w/ Close-Spaced Pulses



Port De-Activation

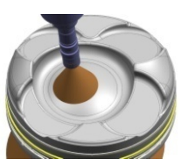




Split Port Swirl
Cylinder Head

Cooled High-Flow
EGR System

Closed Coupled
Catalyst Exhaust



Optimized Spray
Guided Pistons

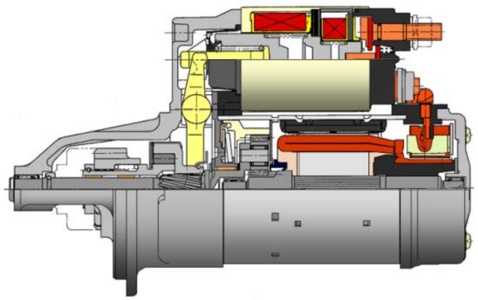
Compact Turbocharger
Assembly

Lean Gasoline System Development

Future Activities – Phase 3: Vehicle Integration and Aftertreatment

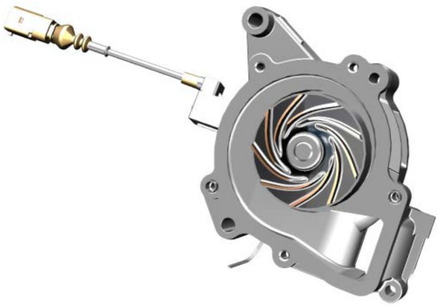
Vehicle Integration

- Integrate 12V stop/start into lean combustion system and controls
- Develop and calibrate lean boosted controls for refined drivability



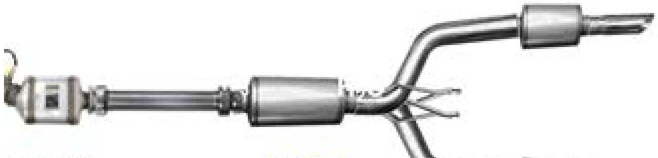
Thermal Management

- Integrate "controlled flow" water pump concept into 1.4L lean boost engine
- Develop and integrate the automatic transmission thermal system



Aftertreatment

- Integrate passive and active aftertreatment to optimize emission performance and minimized urea consumption



Lean Gasoline System Development
Summary

Phase 1 – Initial Development – FY10 to FY12

- Controls strategies for lean combustion and passive SCR are implemented on the naturally aspirated lean combustion engine and exhaust system
- Lean operation shows significant fuel consumption improvements at light to medium load, though did not meet target with naturally aspirated engine

Phase 2 – Experimental Refinement – FY11 to FY12

- Fundamental analysis and hardware experimentation undertaken to explore boosted lean combustion with substantial efficiency gains realized
- The passive SCR aftertreatment was refined to provide significant NH_3 production, though generates excessive CO and lacks sufficient thermal operating range
- The active SCR aftertreatment demonstrates a significant NO_x reduction

Phase 3 – Future Optimized System – FY12 to FY13

- Fuel economy optimization with a 1.4L downsized lean boost engine
- Lean combustion controls development for boosted operation
- Vehicle optimization with 12V stop/start and thermal management integration
- Aftertreatment optimization to achieve target of T2B2