

Developments in High Efficiency Engine Technologies

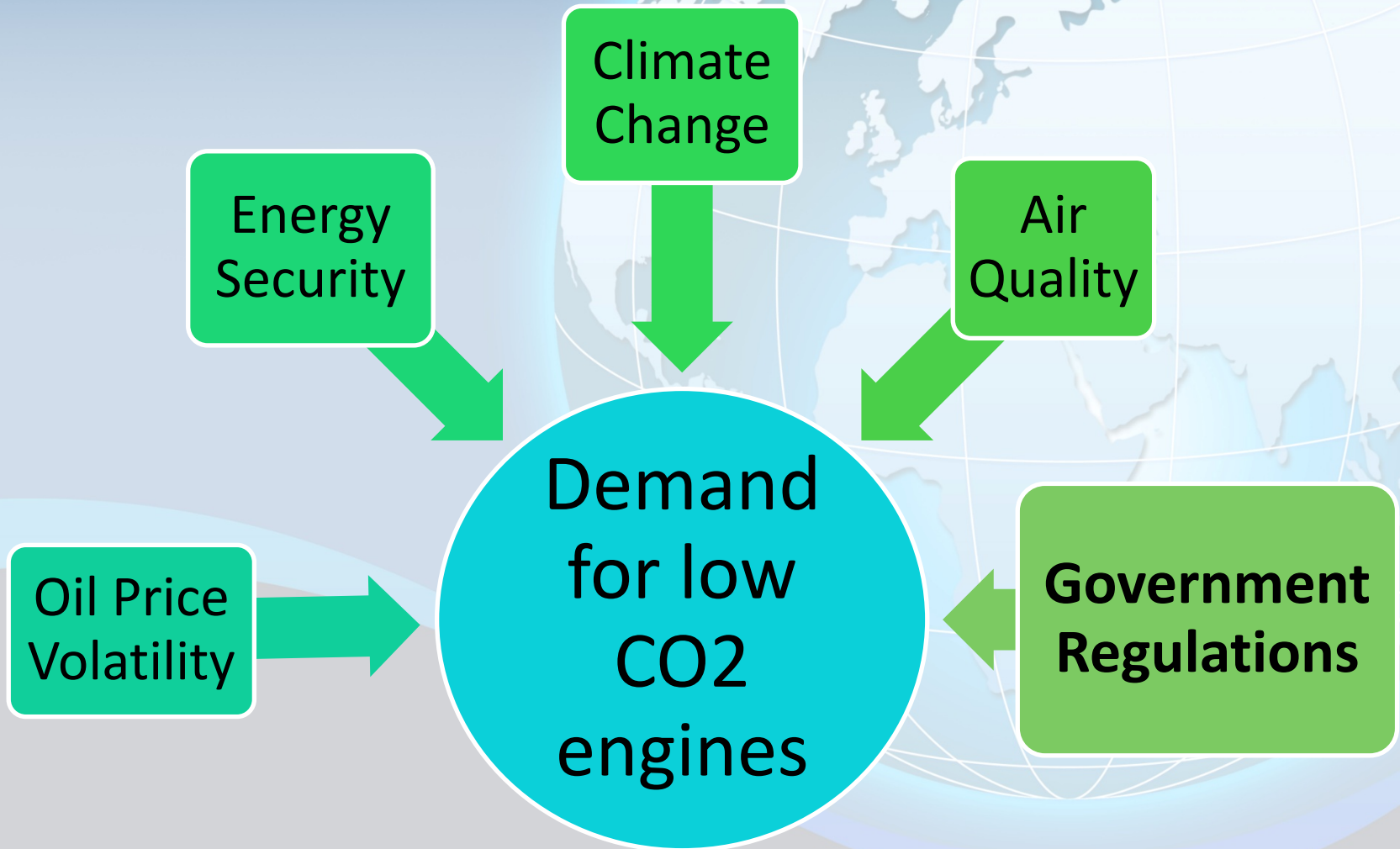
DEER 2012



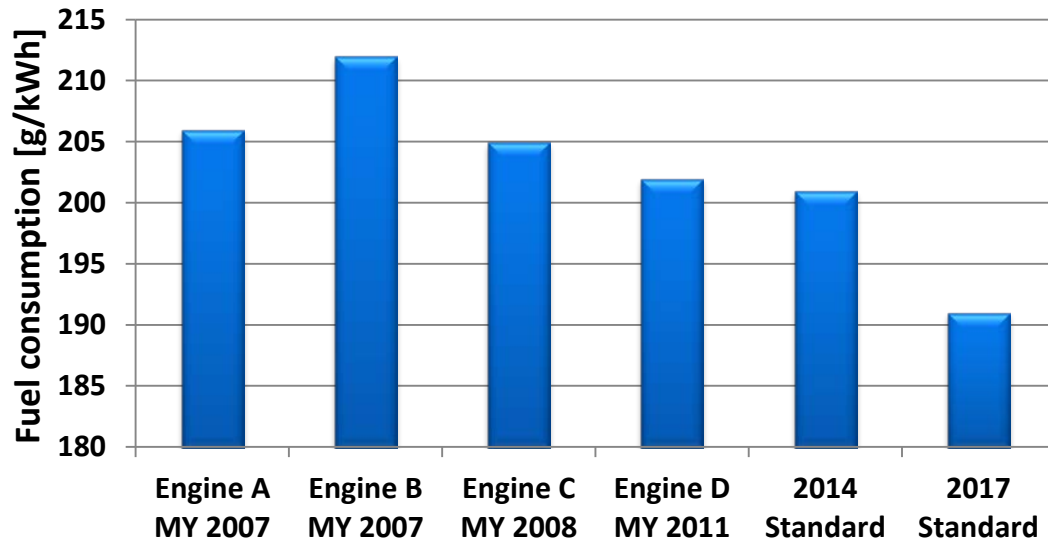
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San Antonio, Texas

Drivers for High Efficiency

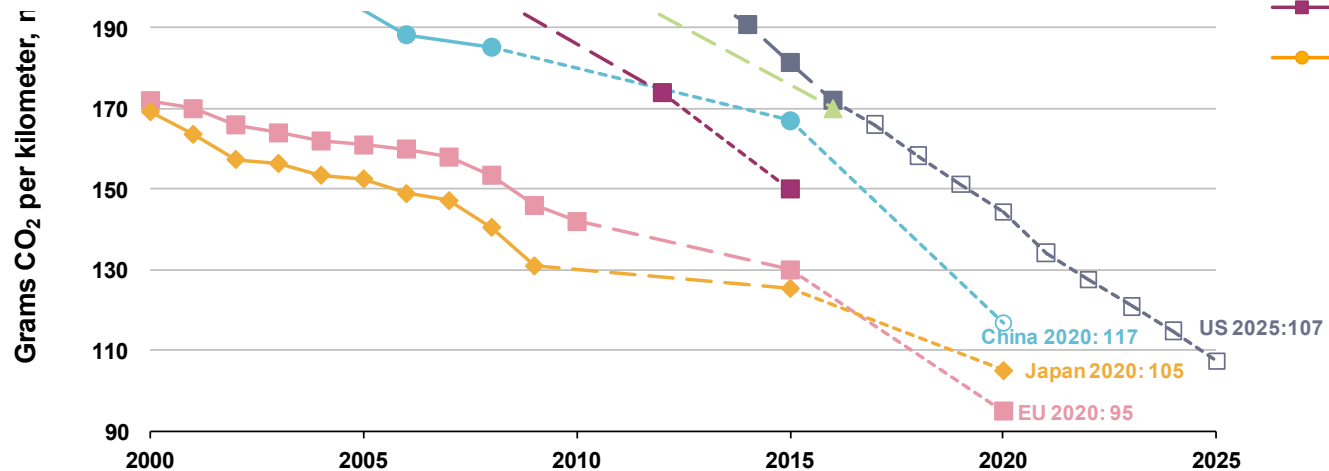


CAFE – not just for light duty anymore



and lines: historical performance
 and dashed lines: enacted targets
 and dotted lines: proposed targets
 and dotted lines: unannounced proposal

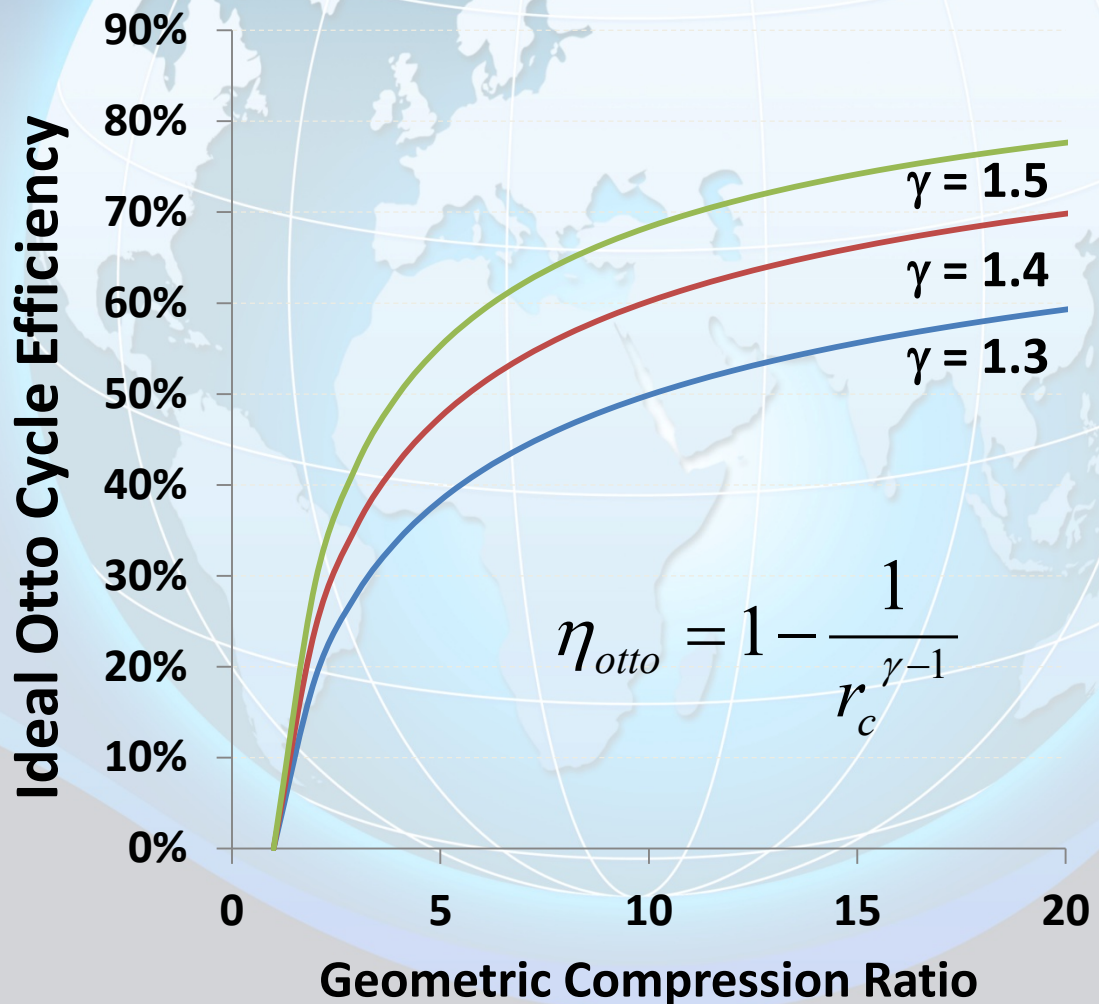
- US-LDV
- California-LDV
- ▲ Canada-LDV
- EU
- ◆ Japan
- China
- S. Korea
- Australia



[1] China's target reflects gasoline fleet scenario. If including other fuel types, the target will be lower.
 [2] US and Canada light-duty vehicles include light-commercial vehicles.

Fundamental Efficiency Drivers

- Sets the ceiling for the engine
- Gamma is a function of
 - Charge composition
 - Temperature
- In the real-world, high compression ratios have some unwanted side effects



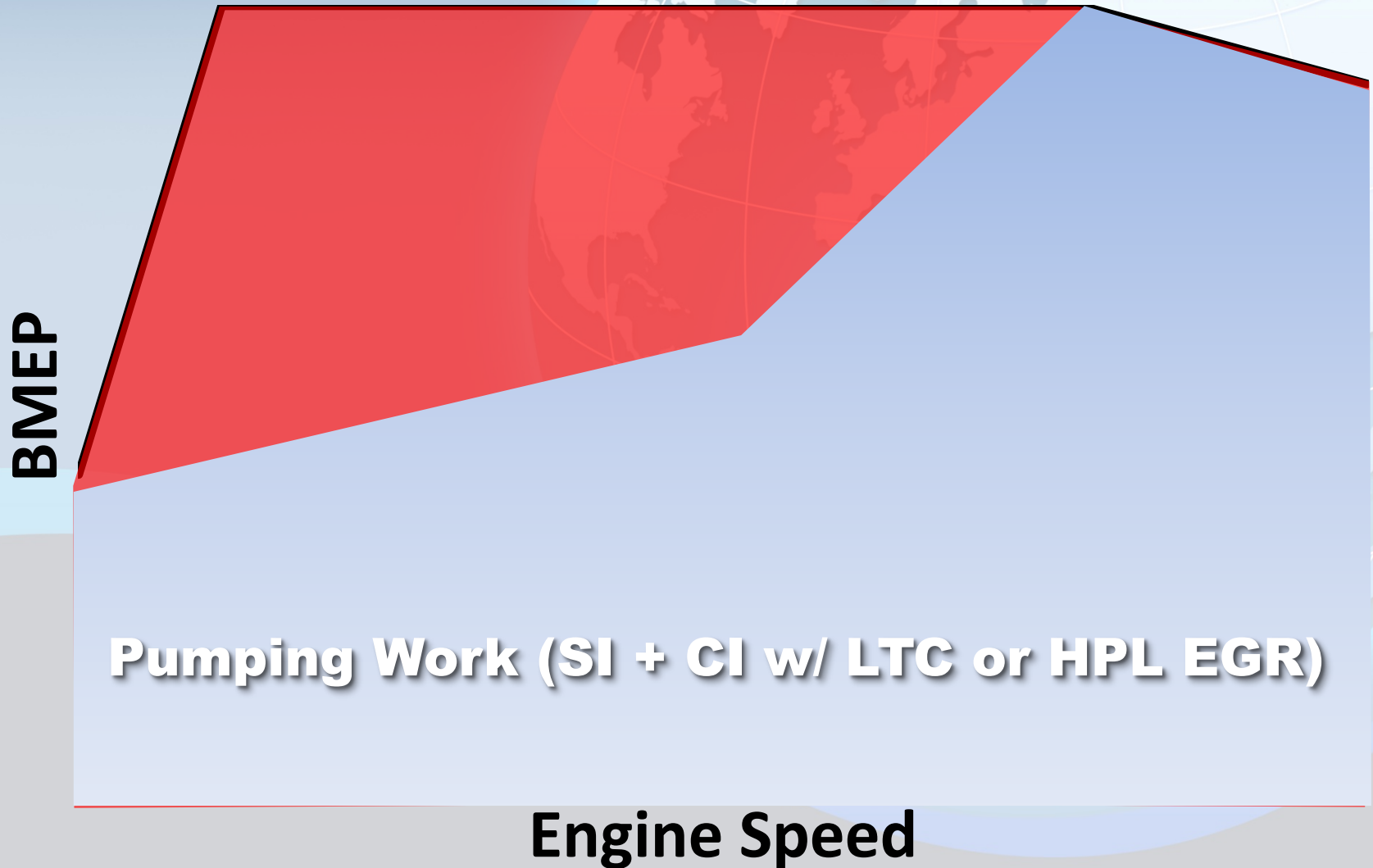
Sources of Real-World Losses in IC Engines

BMEP

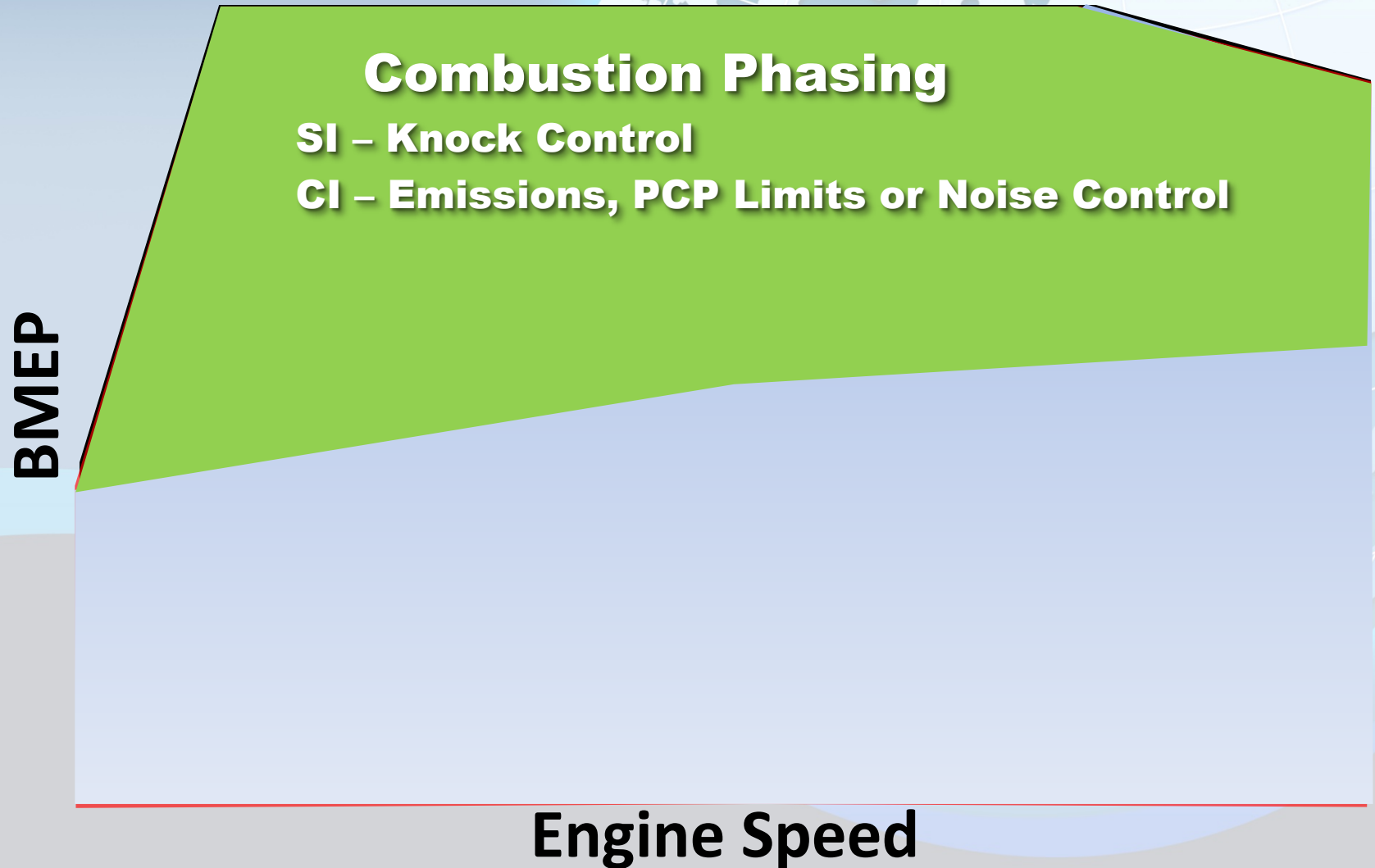
Heat Transfer
Friction
Combustion Efficiency
Cycle Efficiency / Charge Properties

Engine Speed

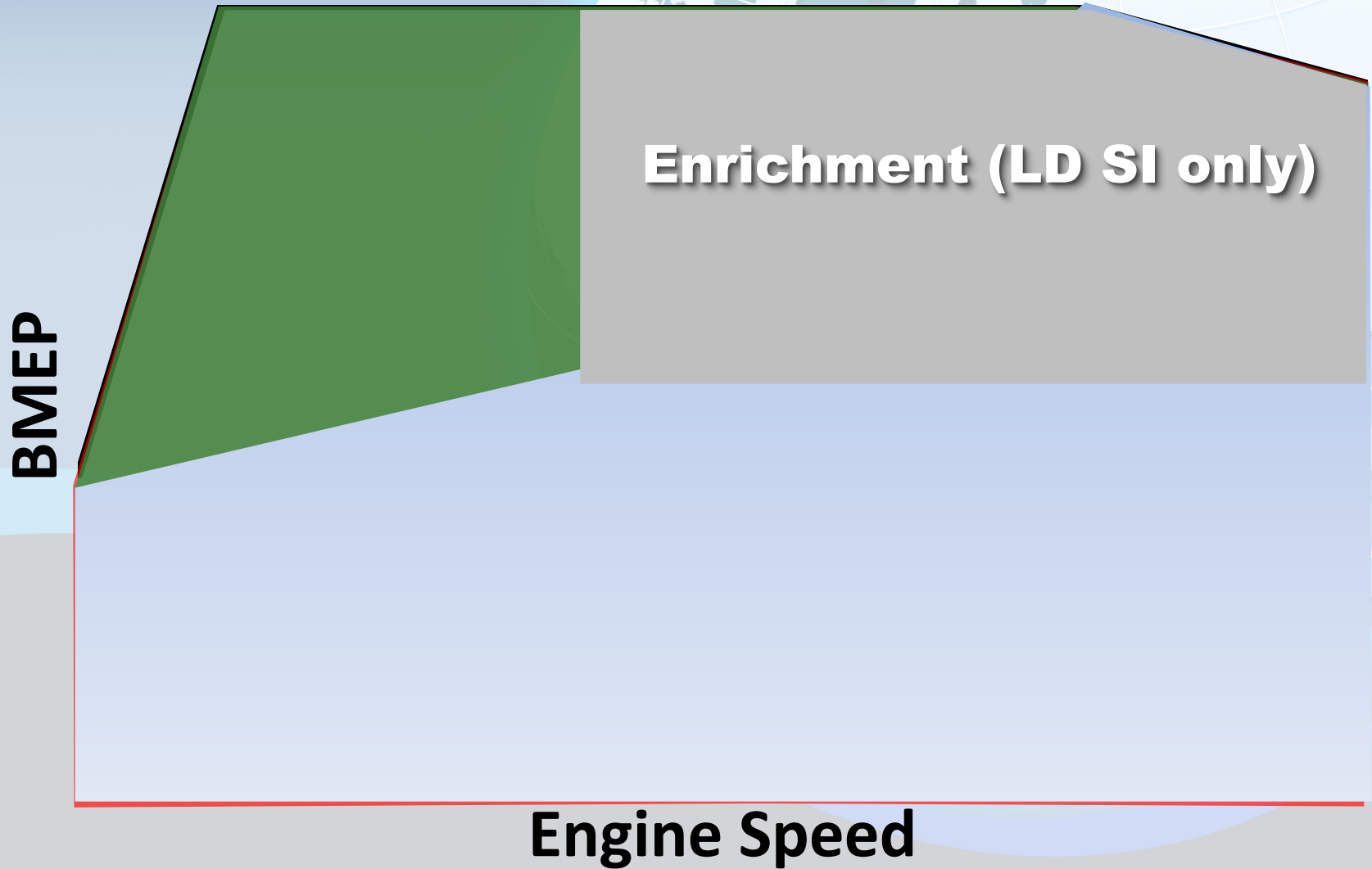
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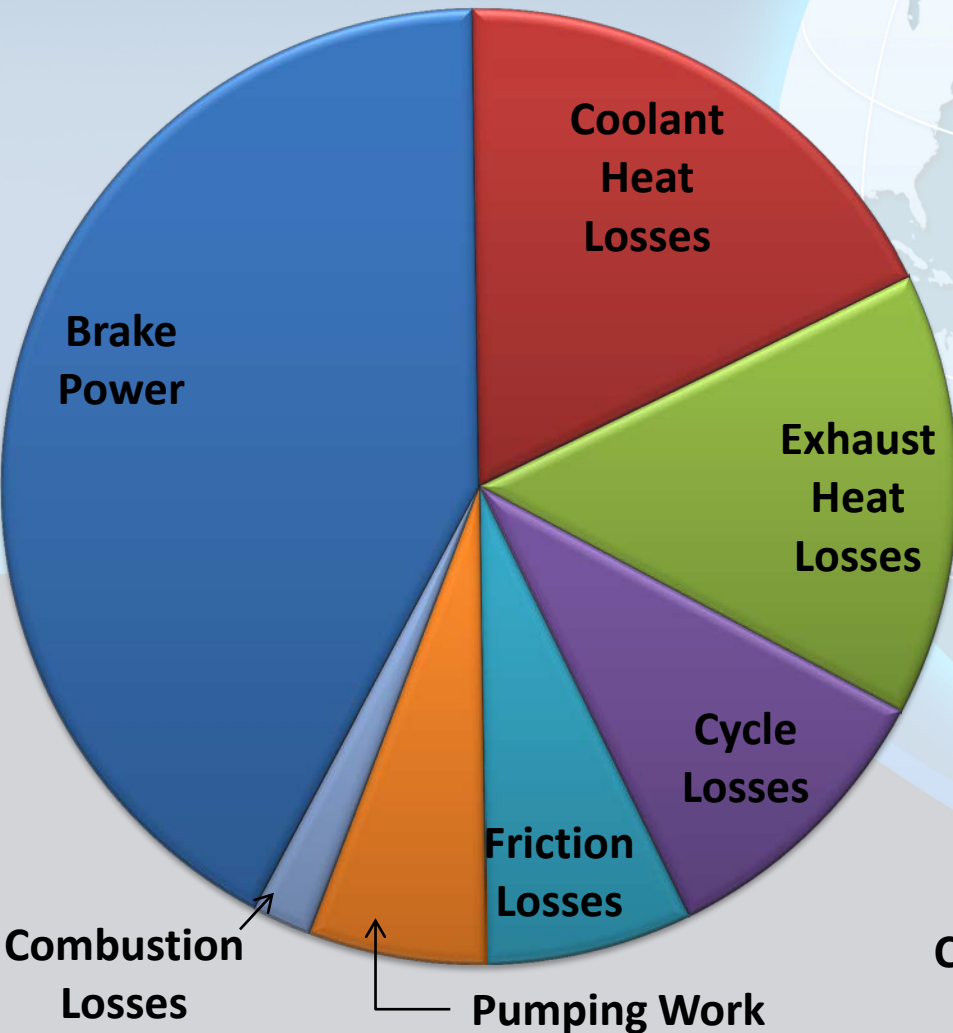


Sources of Real-World Losses in IC Engines

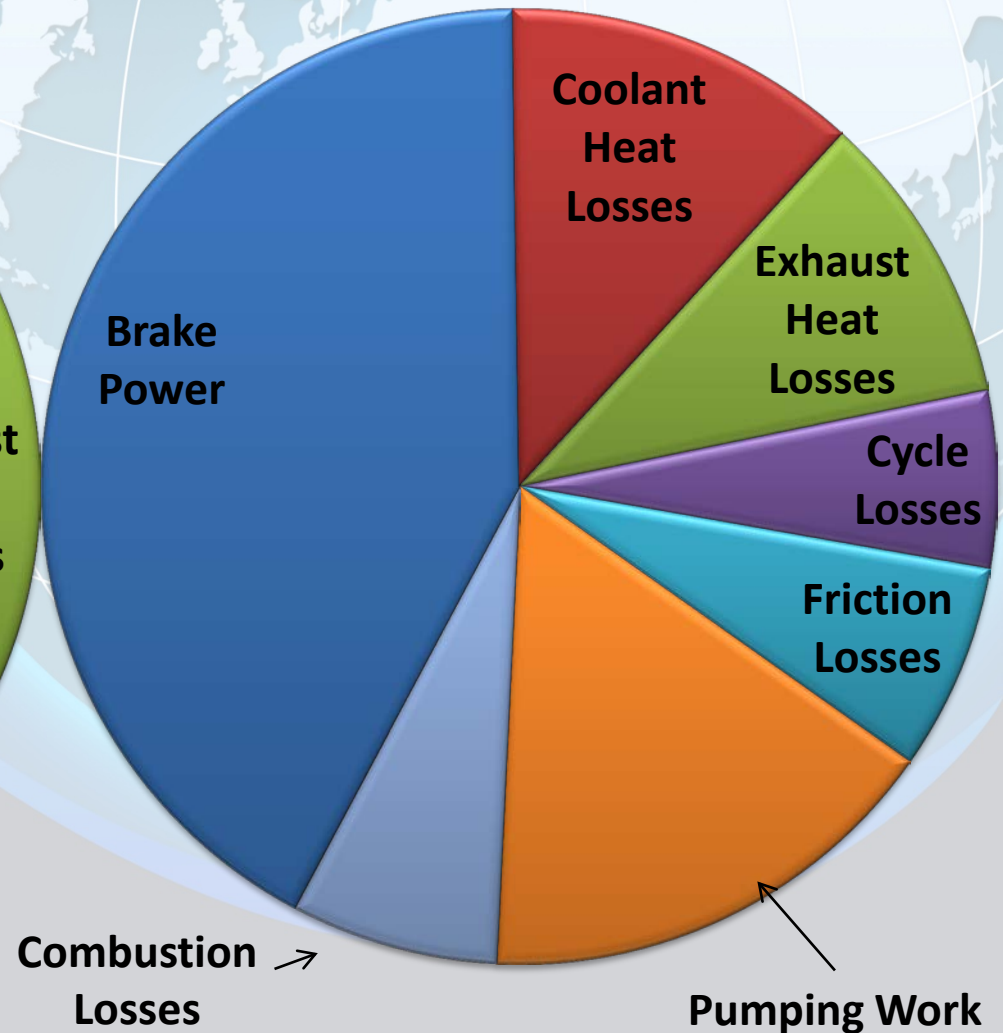


Two Paths to High Efficiency

Hot Combustion



Cold Combustion



Hot vs Cold Combustion

	Cold	Hot
Heat Transfer Losses	++	--
Combustion Phasing	+ (++ for SI)	0 (- - for SI)
Charge Properties	+	0
Emissions (engine-out)	+	-
Emissions (cycle or tailpipe)	0	+
Boosting	--	++
Engine Control	-	+
Hardware Requirements (e.g. PCP)	-	0
Waste Heat Recovery Potential	- (LPL EGR) + (HPL EGR)	+
Enrichment (SI only)	++	--

Path to High Efficiency May Depend on Application

General Engine Improvements

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graph LR; A[General Engine Improvements] --> B[Pre-Mixed Application]; A --> C[Diffusion Application]; B --> D[Cold Combustion]; C --> E[Hot Combustion]
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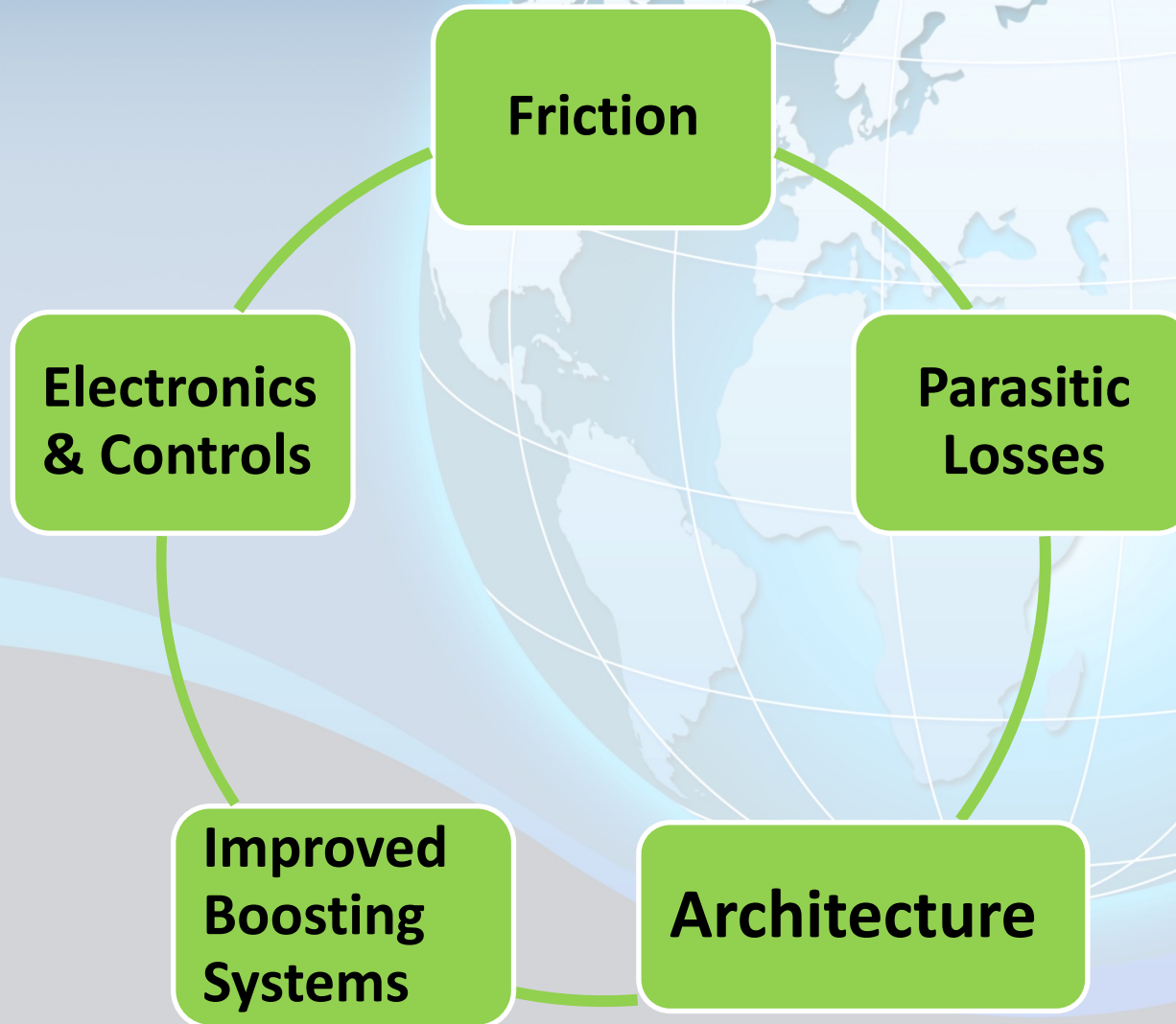
Pre-Mixed Application

Cold Combustion

Diffusion Application

Hot Combustion

General Engine Improvements



Research Goals and Topics for Pre-Mixed Combustion

Goal:

*High
Compression
Ratio
Downsizing and
Downspeeding*

Primary
Problem:
Knock

High Dilution

HEDGE[®]
RCCI
PPC
GDCI
HCCI

High Octane
Fuel

Alternative Architecture

Split-Cycle
VCR
Ethanol-Boost

Research Goals and Topics for Diffusion Combustion

Goal:

*High Efficiency
and Low
Emissions on
Highly Loaded
Duty Cycle*

Primary Problem:

Emissions

NO_x

PM

**Low Dilution
Diesel Engines**

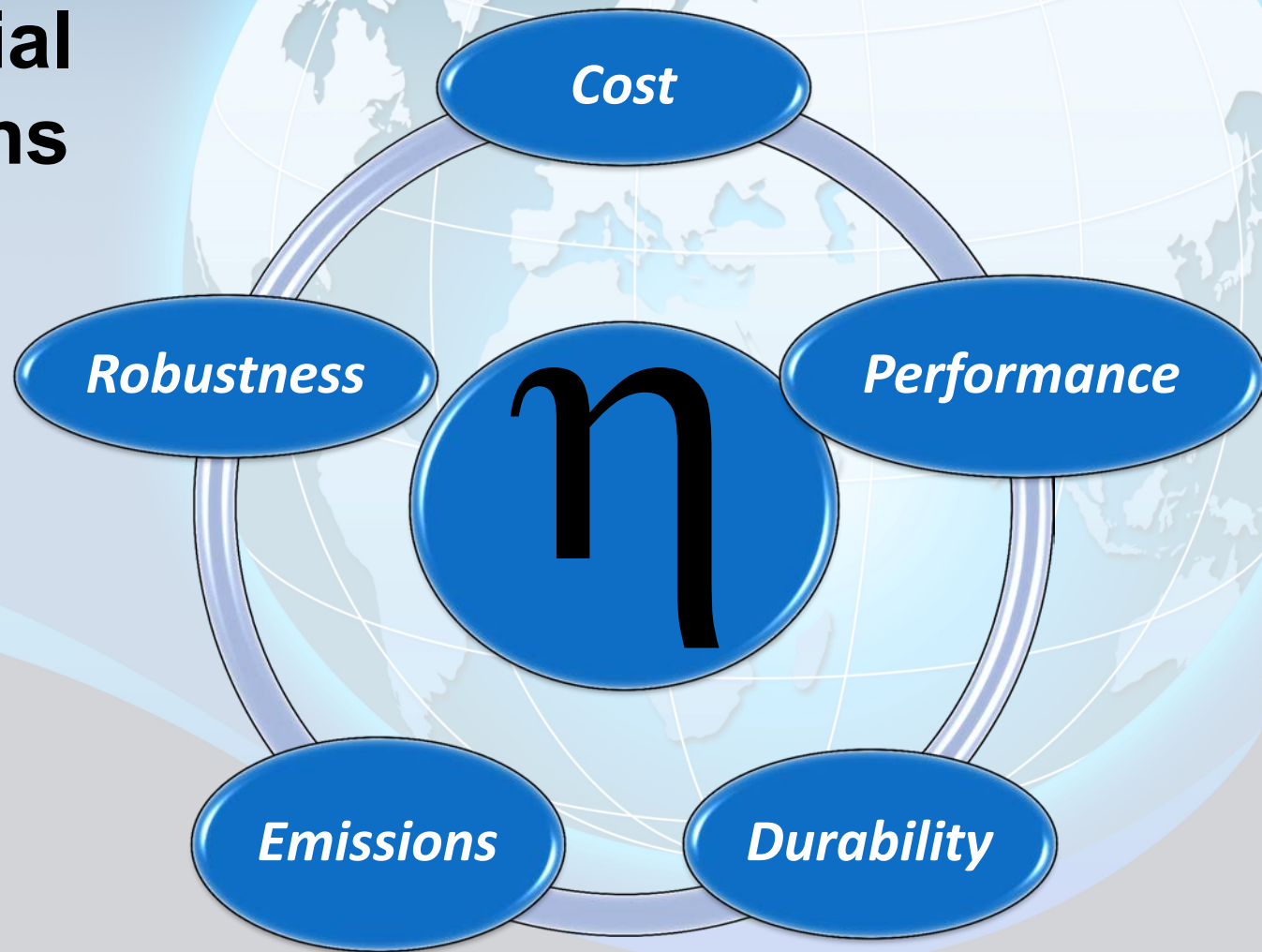
**Low Dilution Dual-
Fuel Applications**

**Waste Heat
Recovery**

**High Efficiency
Aftertreatment**

What's Next?

- Many potential configurations to address these challenges
- Industry assessment required



Introduction to SwRI's Dedicated EGR Concept

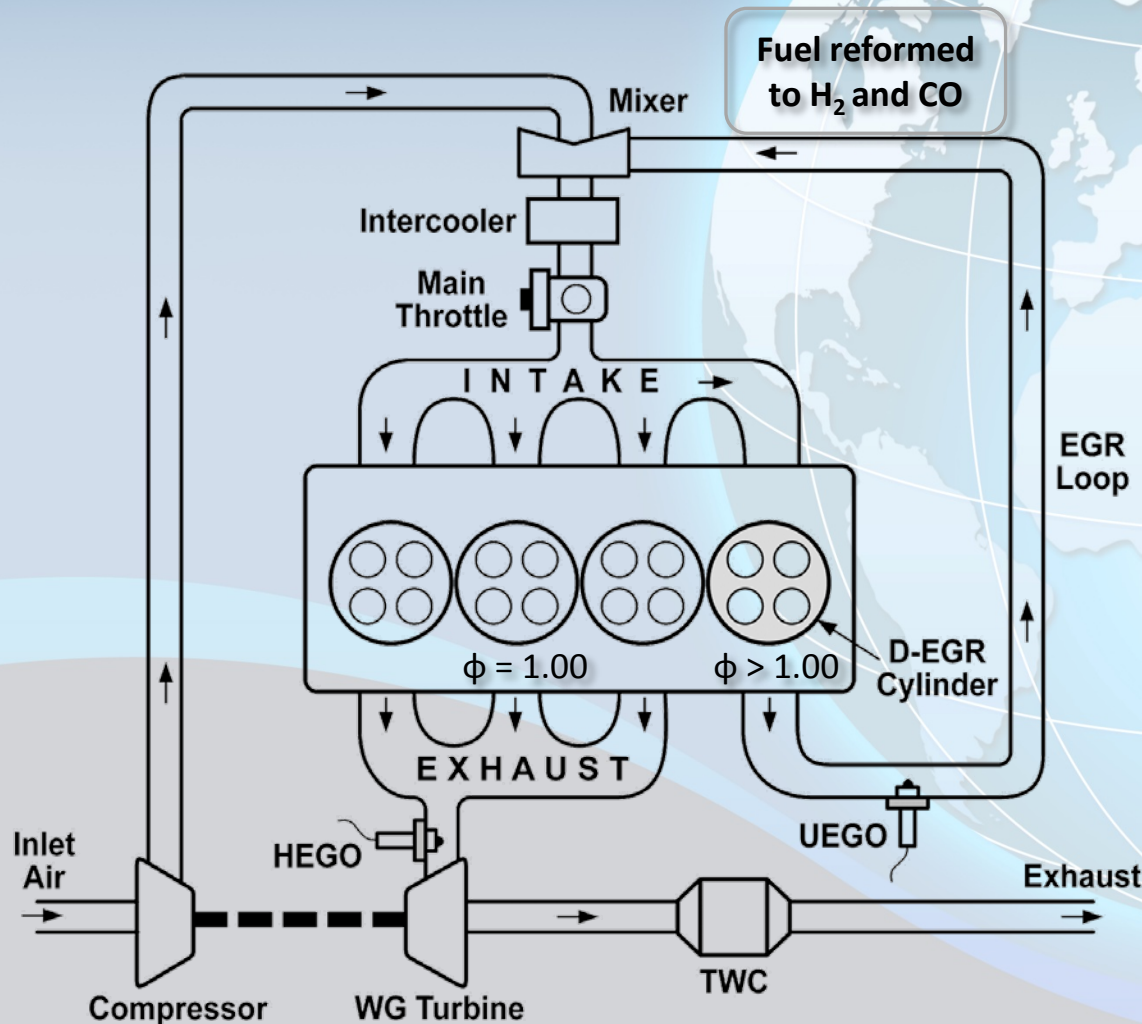
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What is Dedicated EGR (D-EGR)?

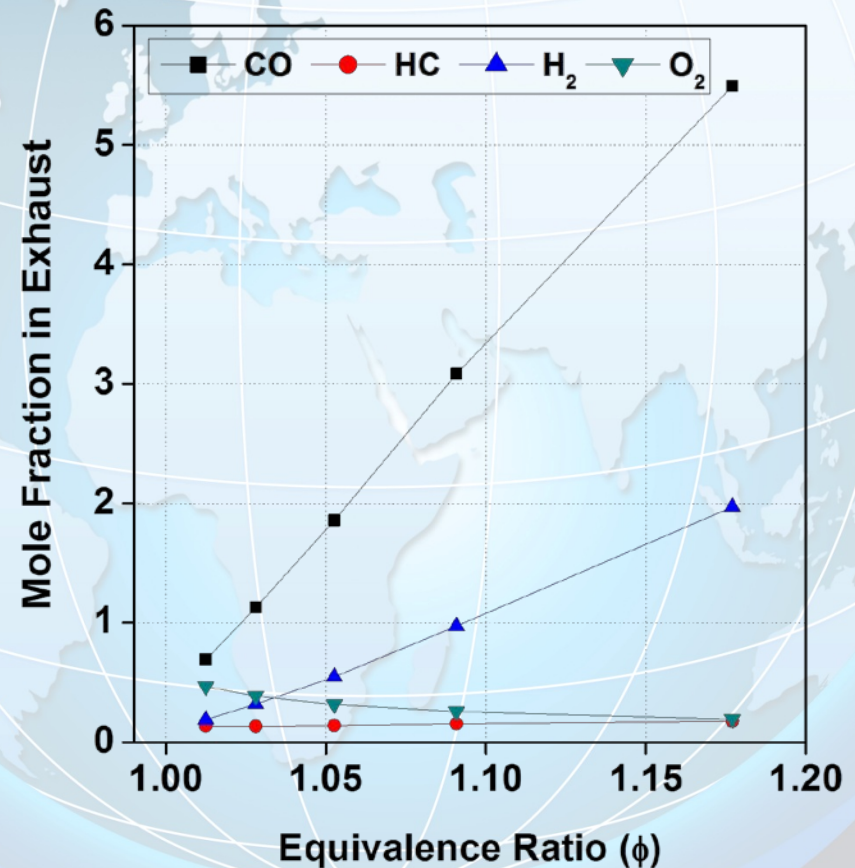


D-EGR combines **highly effective emissions control** technologies and **high efficiency potential** of gasoline reformat technologies

In-cylinder Reformation



- Rich combustion yields high levels of CO and H₂
- In-cylinder reformation may be more efficient than external reformation
 - Work still extracted from combustion
 - All effort occurs inside the engine block
 - Safer
 - More easily packaged
- Previous work (SAE paper 2007-01-0475) indicated that H₂ levels required for combustion optimization are not as high as previously thought

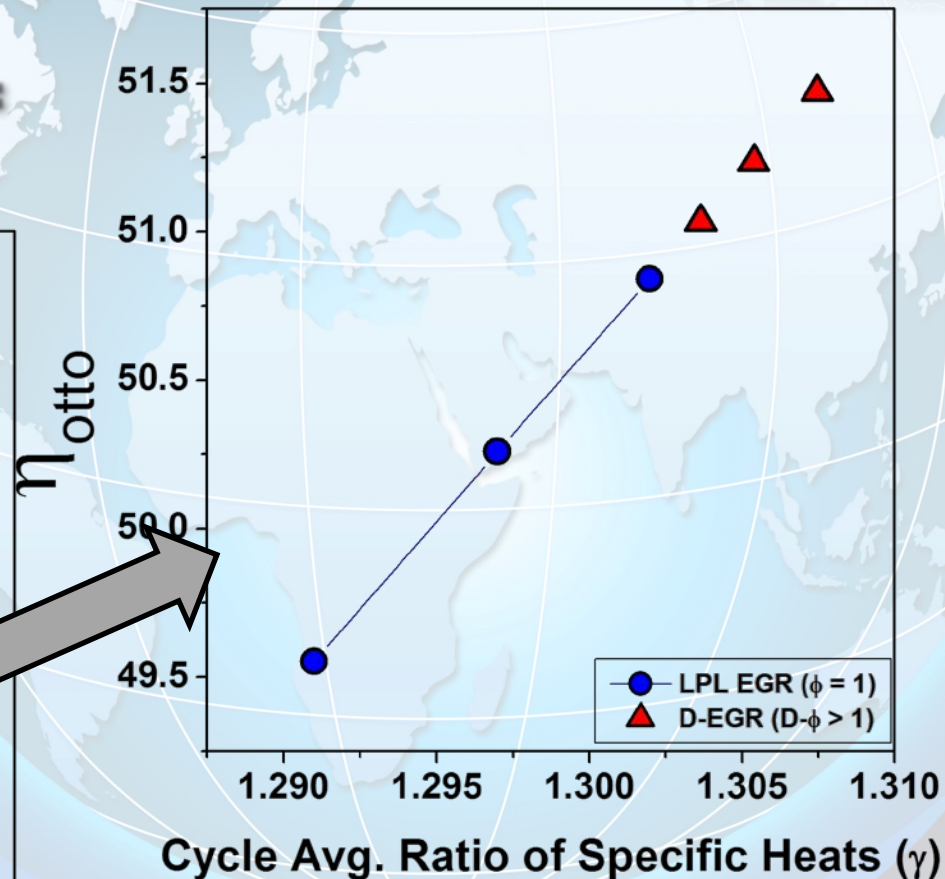
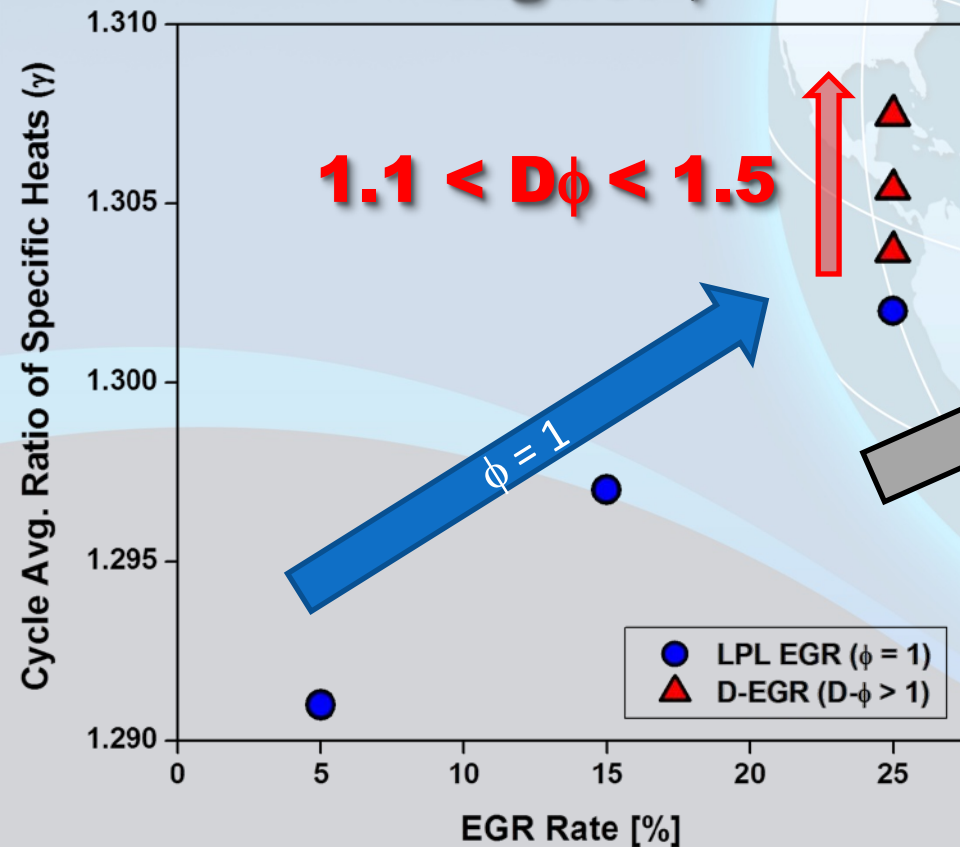


SAE Paper 2009-01-0694

Impacting the Working Fluid with D-EGR



Cool combustion + dilution + reformat = higher γ



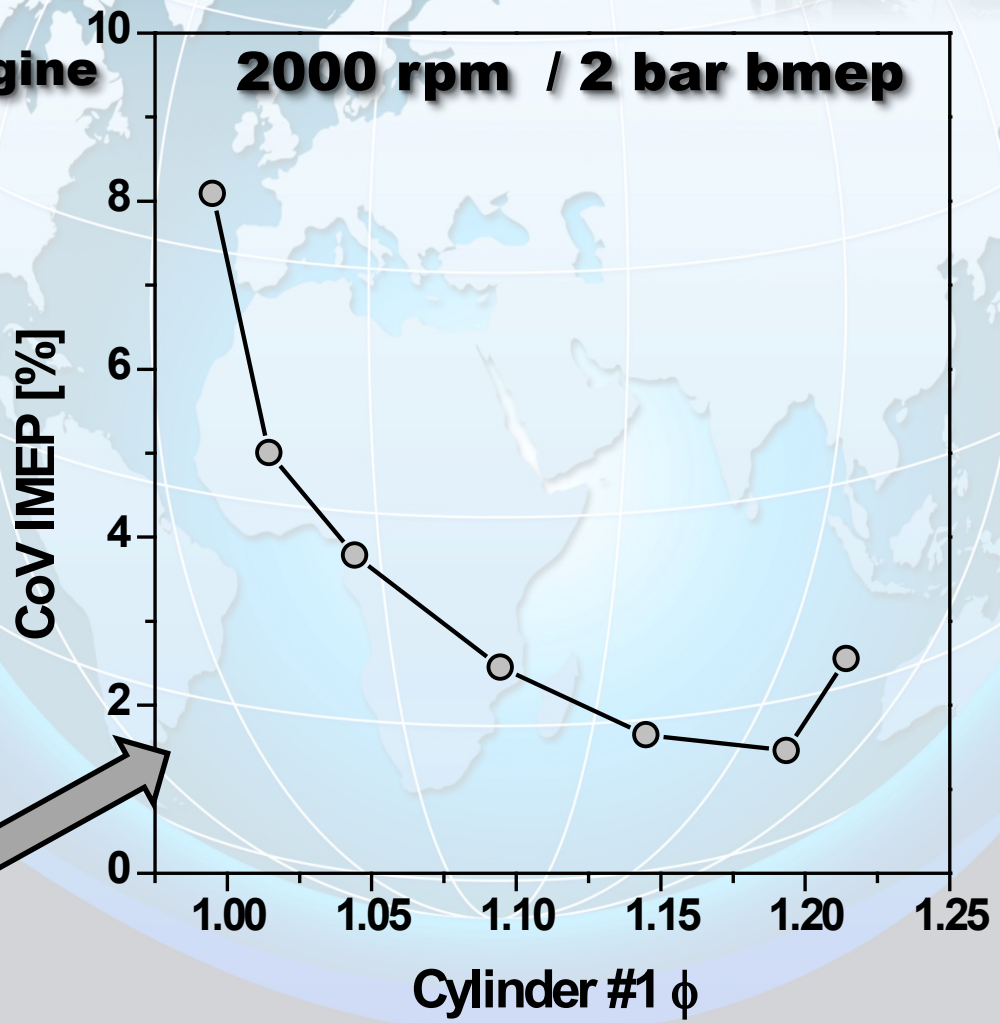
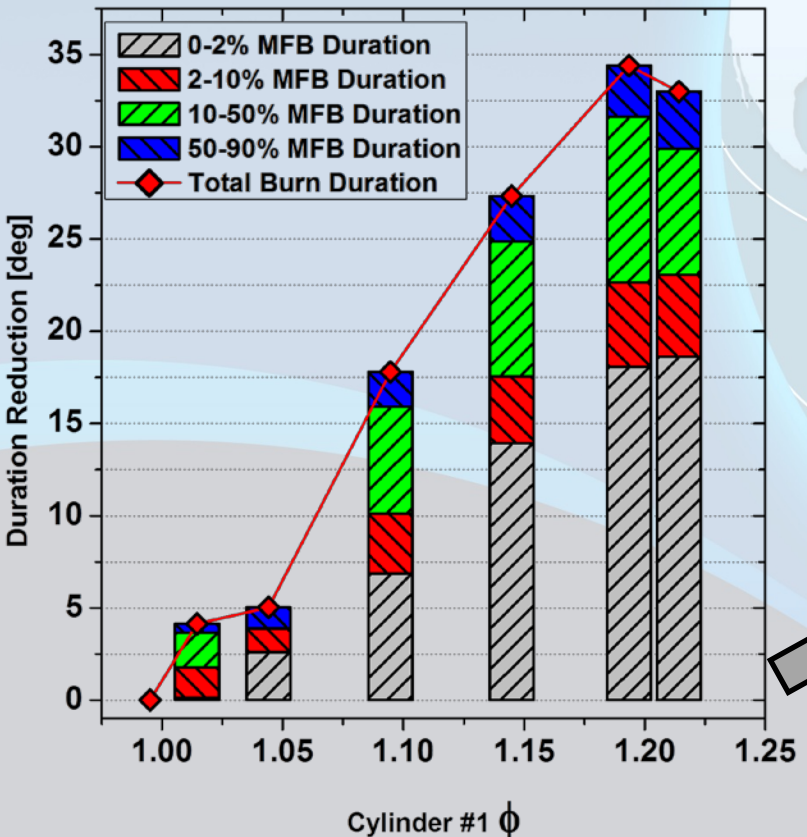
Higher γ = Improved η_{otto}



Enabling High EGR Tolerance

Test Platform

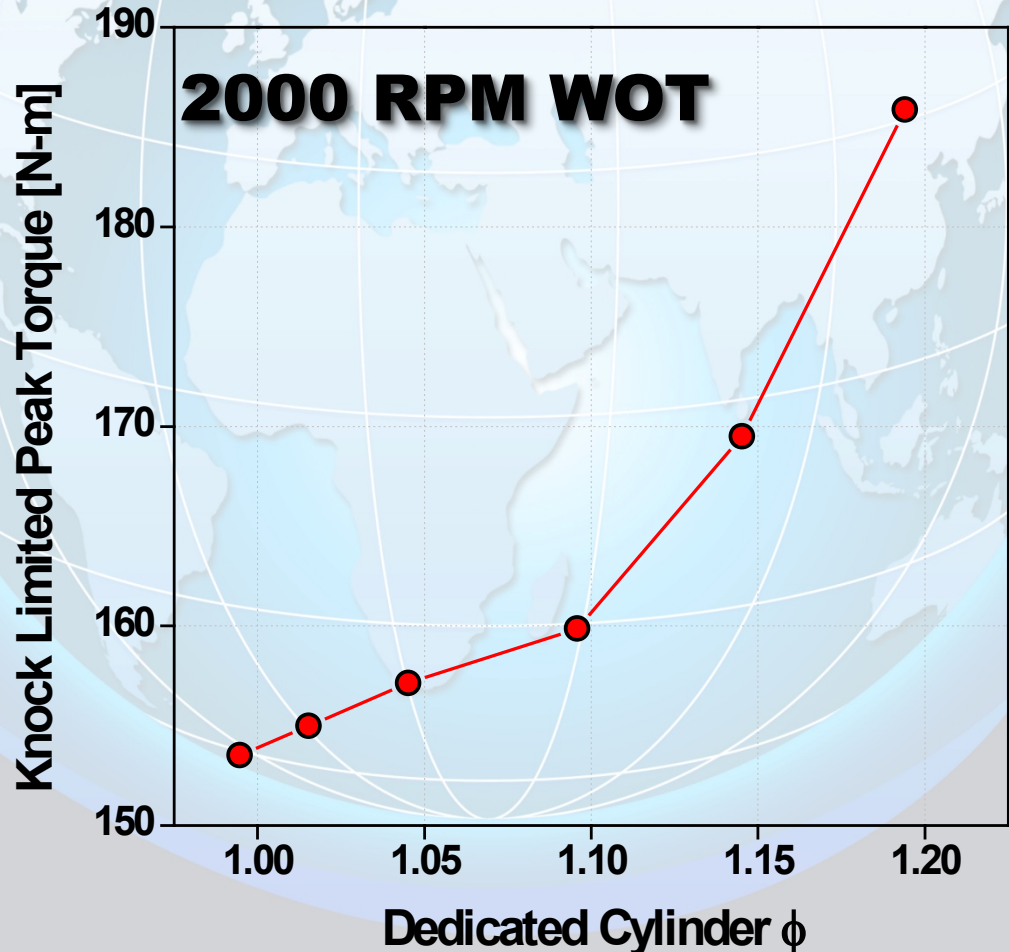
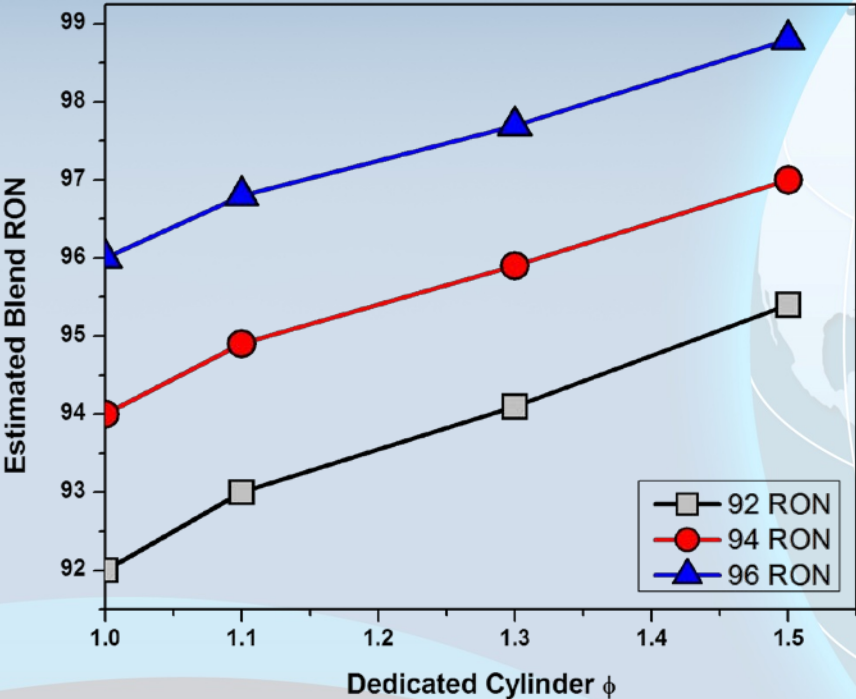
2006 MY 2.4 L Chrysler World Engine
14:1 CR



Faster combustion = Improved Stability at 25% EGR



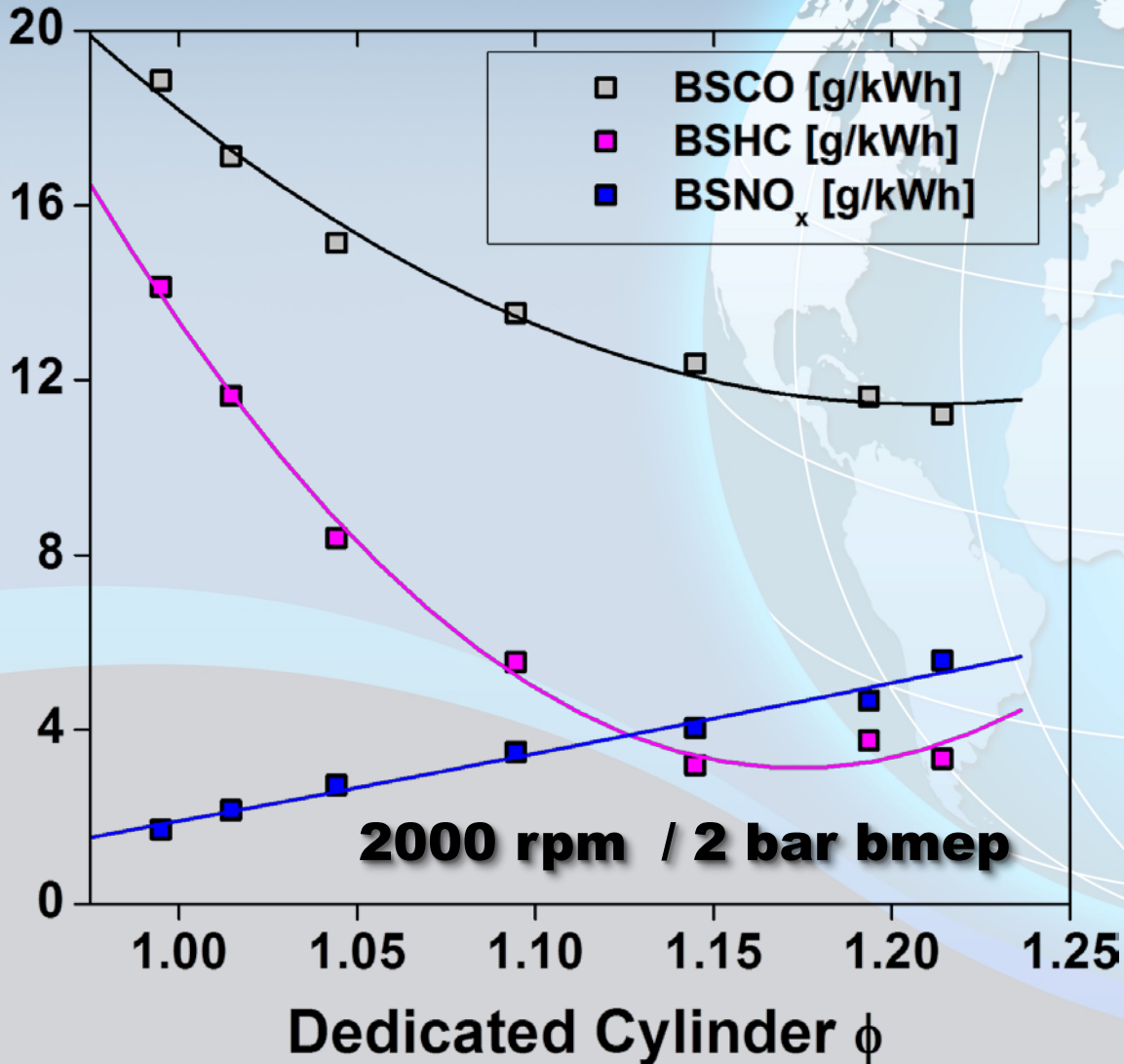
Increased Knock Resistance



Reformat Impact on Effective RON
+
Faster Burn Rates = Improved Knock Tolerance



Reduced Emissions

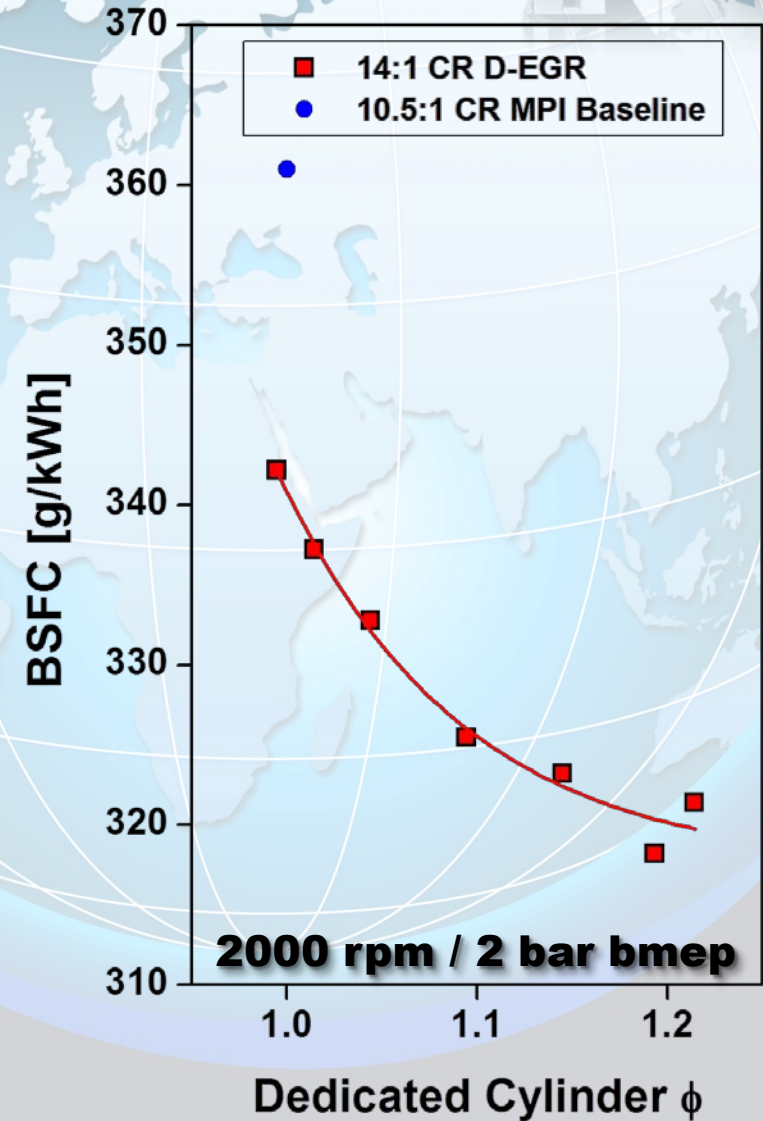
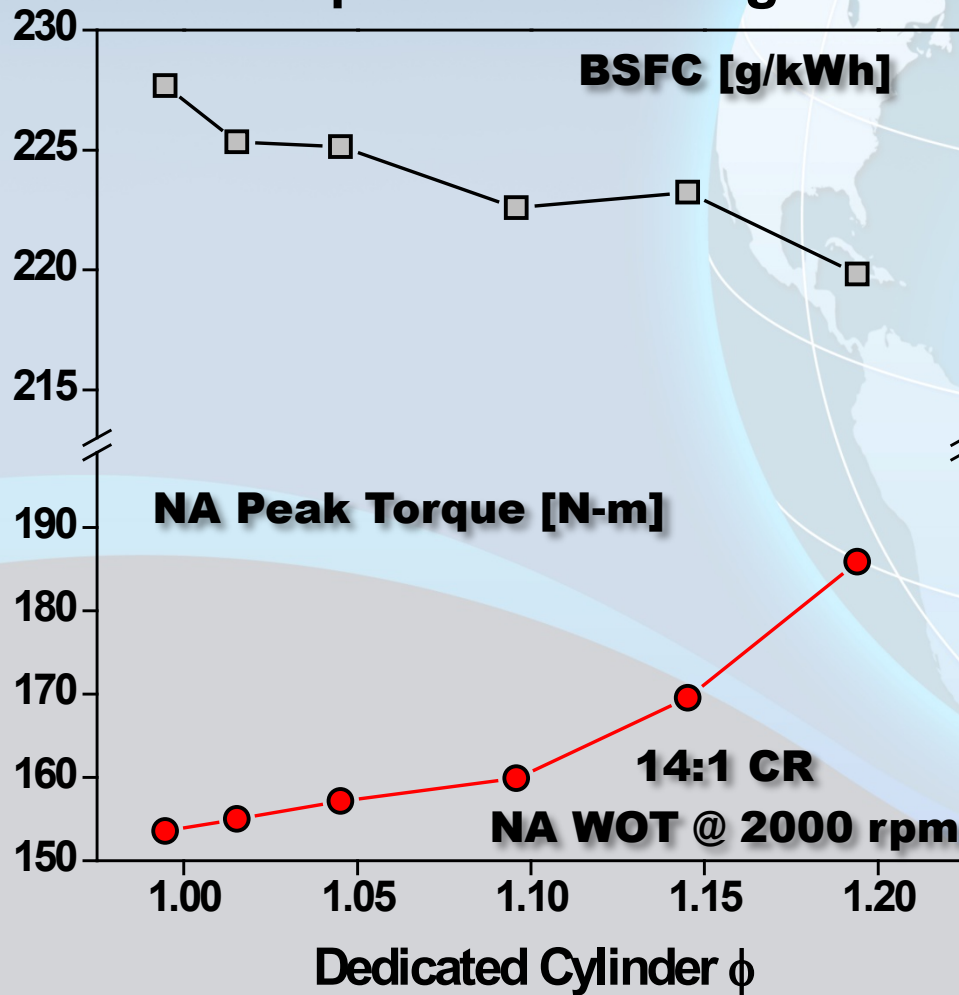


- **Combustion efficiency returns to nearly non-dilute levels**
- **Reformat improves HC and CO emissions**
- **NO_x emissions increase slightly**
 - Still ~ 1/4 of non-dilute case



Improved Fuel Consumption

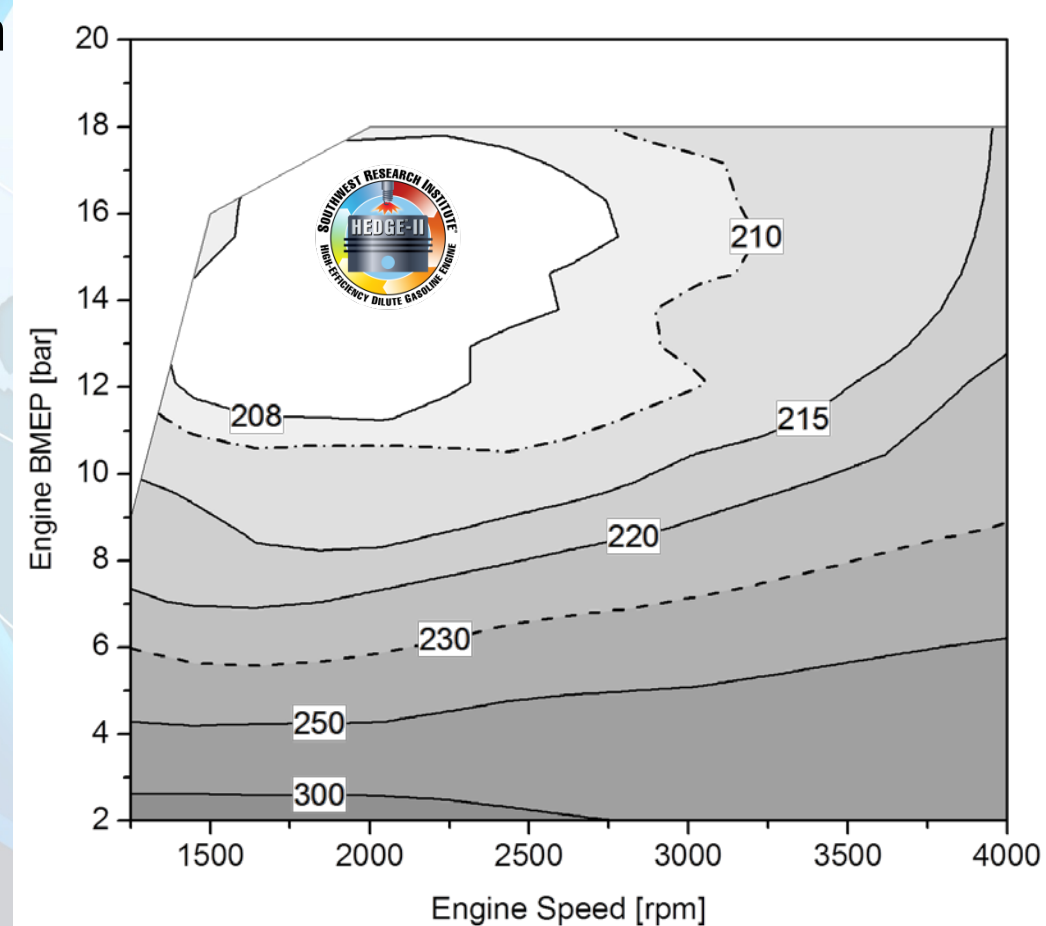
- BSFC improves considerably across speed / load range



Most Recent Results



- **2.0 L L4 TC MPI Application**
 - 12.5:1 CR
 - Advanced ignition system
 - Average D-EGR cylinder $\phi = 1.3$
- **Mean BSFC improvement : ~ 12-15%**
- **Best BTE to date : > 41%**
- **Best BSFC at 2000 rpm / 2 bar bmep : 315 g/kWh**
- ***Lower BSFC than a Tier II Bin 2 diesel with GDI performance and ultra-low emissions / no PM***



What is Next for D-EGR?

- **SwRI will be applying the D-EGR concept to new platforms in HEDGE III program**
 - **2.0 L TC GDI engine**
 - 25% D-EGR
 - **L6 MD CNG application**
 - 33% D-EGR
- **Internal funding has been received for demonstration of D-EGR concept on a 2012 MY Buick Regal**
 - **GOAL : 20% improvement in MPG over NA baseline**



Thank You



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