SwRI's HEDGE™ Concept

High Efficiency Dilute Gasoline Engines

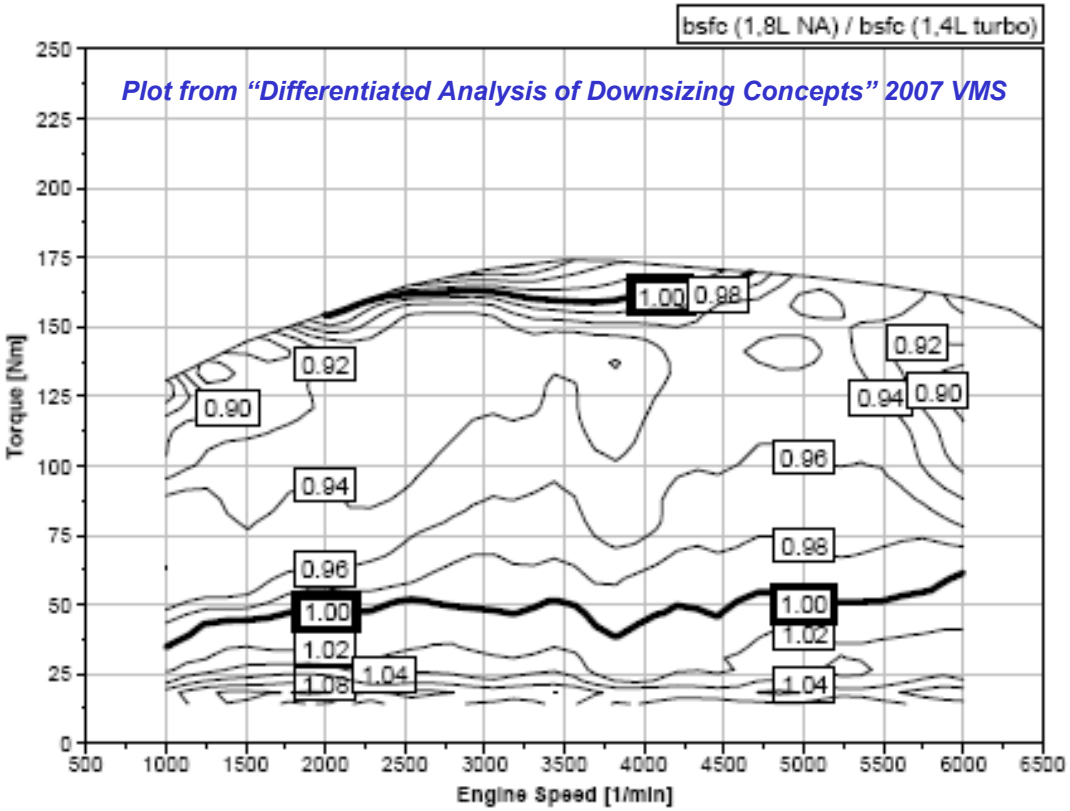
Dr. Terry Alger

2-3 March 2010

© South West Research Institute® 2009

Challenges to LD Engine OEMs

- **Lean burn engines require expensive and bulky NO_x and PM aftertreatment**
  - **Reduces system efficiencies**
  - **Difficult to package**
  - **May not be efficient enough**
- **Boosted engines (MPI or GDI) suffer from:**
  - **Knock**
    - Reduced CR
    - Retarded combustion
  - **Excessive exhaust temperatures**
    - Overfuelling
  - **Low-Speed Pre-Ignition**
    - Engine damage
    - NVH

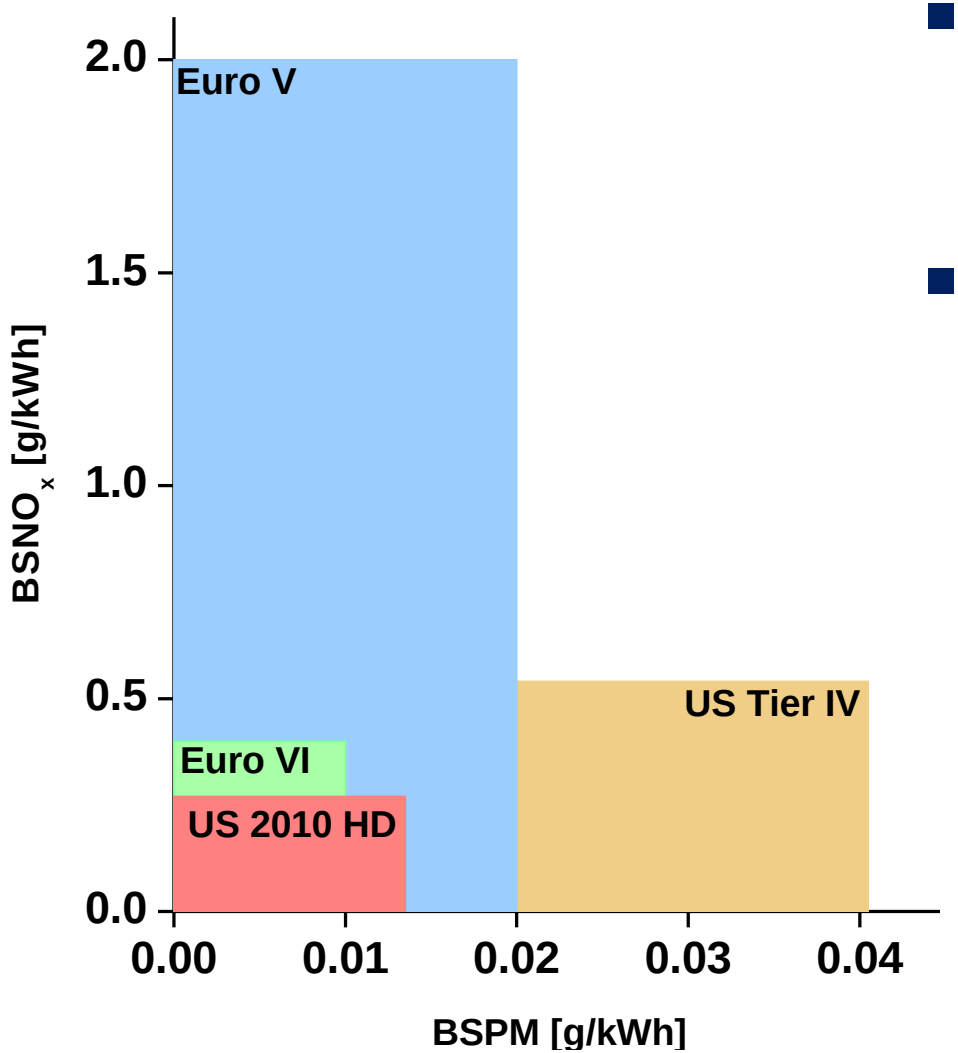


Real-world fuel economy is not matching test cycle results**

*** Car and Driver, June 2009*

© South West Research Institute® 2009

Challenges in the Medium / Heavy Duty and Off-Road Market



- **Emissions regulations are getting more strict**
  - **US 2010 HD and Tier 4 Interim / Final**
- **Aftertreatment solutions for diesels are bulky and expensive**
  - **Packaging challenges**
  - **Aftertreatment cost ~ engine cost**
    - SCR engine = +$9,600 retail
  - **Trying to achieve standards without aftertreatment = much worse BSFC**

© South West Research Institute® 2009

λ = 1 Gasoline Engines : A Low-Cost Solution to Efficiency and Emissions Challenges?

λ = 1 operation with three-way catalyst

- **Low Cost**
- Proven **ultra-low emissions** potential

SI gasoline technology

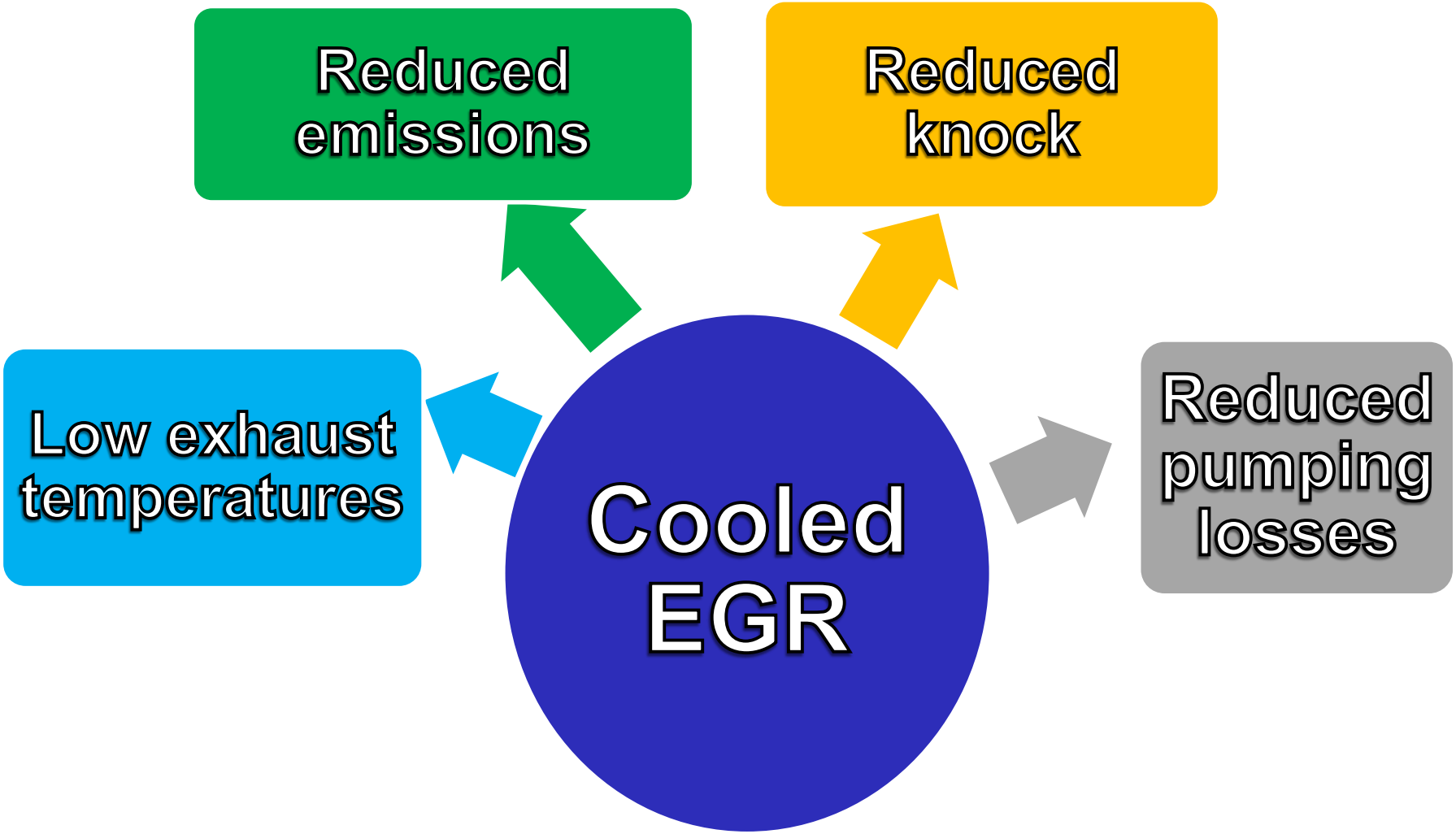
- **Lower cost** compared to DI diesel
- Robust operation
- Boosted operation yields good power density
- Reduced packaging constraints

Efficiency – **COST EFFECTIVE SOLUTION REQUIRED**

- Traditional gasoline engines have reduced efficiency
  - Knock
  - Overfuelling
  - Pumping losses

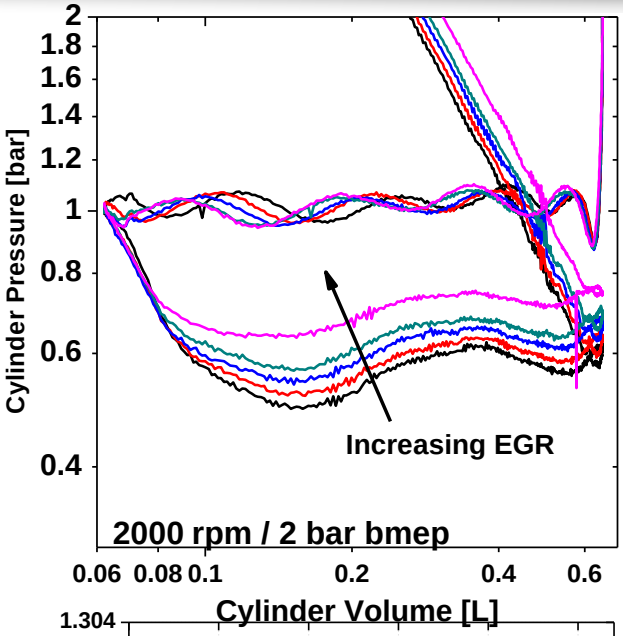
© South West Research Institute® 2009

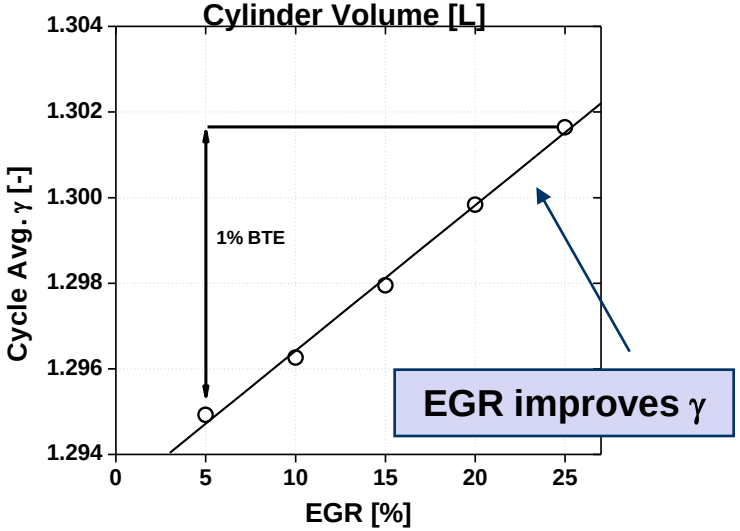
High Dilution with EGR
A Solution for High Efficiency Gasoline Engines

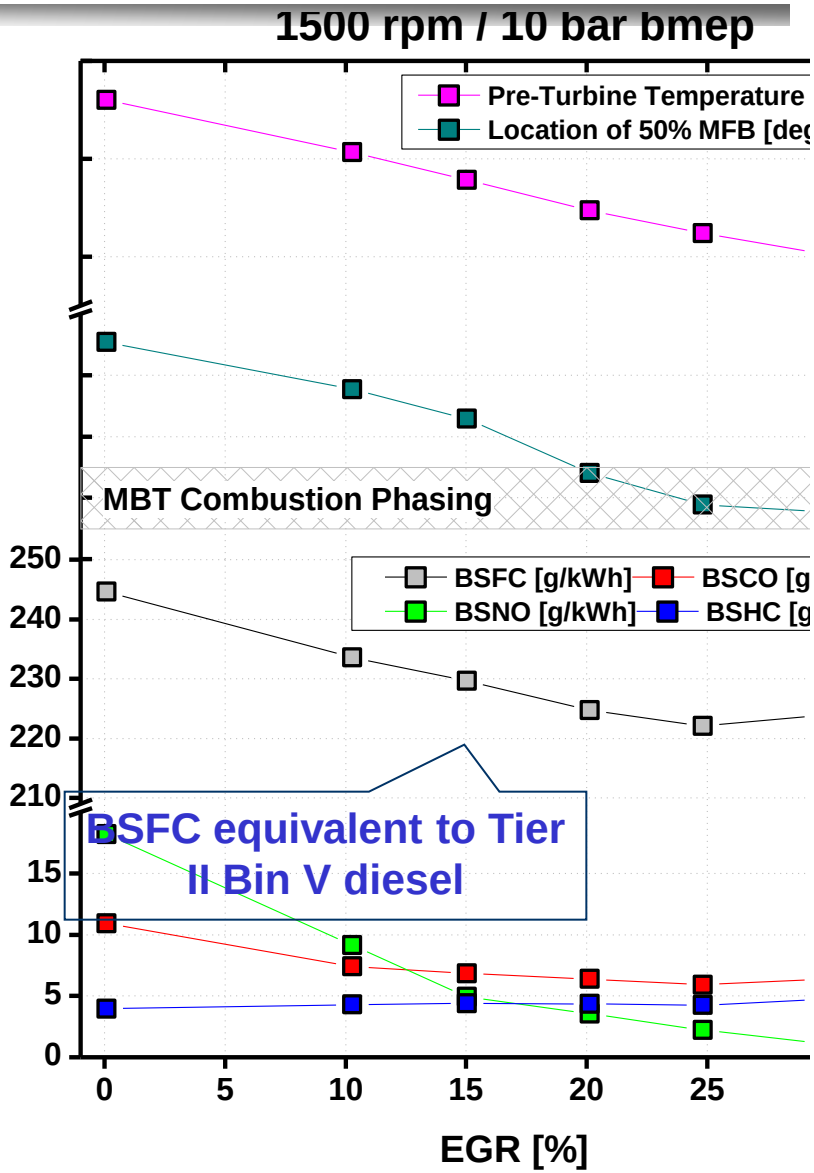


© South West Research Institute® 2009

Example of Improvement Using EGR







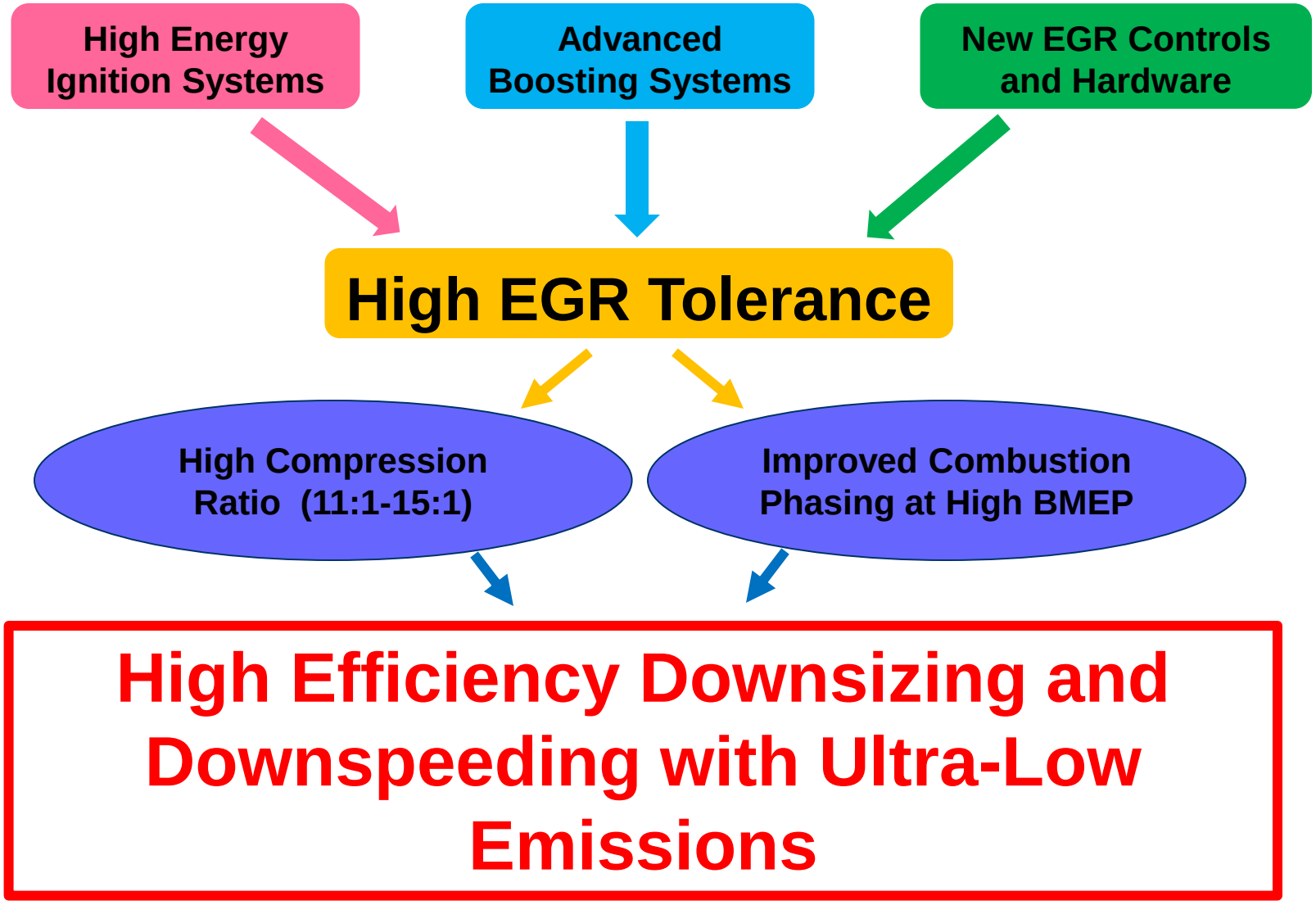
© South West Research Institute® 2009

EGR Challenges

- **High levels of EGR present some unique challenges**
  - **Misfire / partial burn**
    - EGR is difficult to ignite
    - Burn rates decrease
  - **Boosting**
    - Low exhaust temperatures
    - Increased mass flows and pressure ratios
    - Boost system can consume significant portion of efficiency improvement if not managed properly
  - **EGR control**
    - SwRI recommends at low load and cooled LPL EGR at high load
    - System design important to enable optimal control

© South West Research Institute® 2009

SwRI HEDGE™ Concept

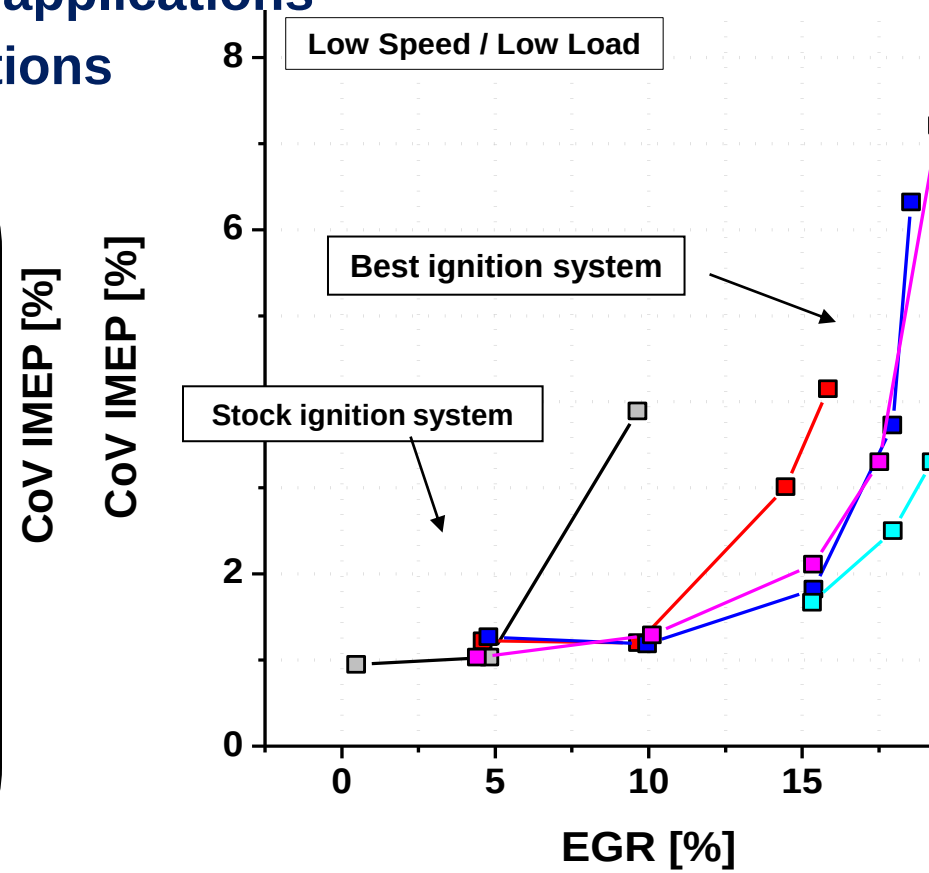


© South West Research Institute® 2009

Advanced Ignition Systems: Electrical Ignition

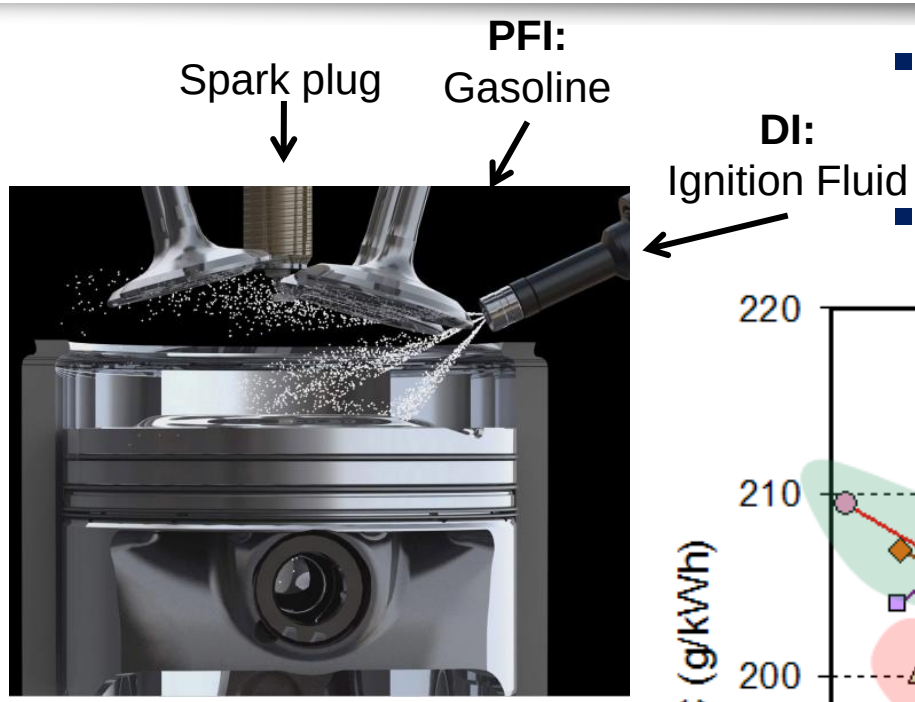
- High EGR mixtures are difficult to ignite
  - EGR rate limited by combustion instability
- SwRI uses advanced ignition systems to maximize EGR tolerance
- Sole source of ignition in gasoline applications
- Used in SI mode for diesel applications

- Characteristics of an ideal ignition system
  - High secondary currents
  - Long duration discharge
  - High energy levels
  - Results in improved initial flame kernel formation, burn rates and stability
  - Energy usage can be tailored to operating conditions



© South West Research Institute® 2009

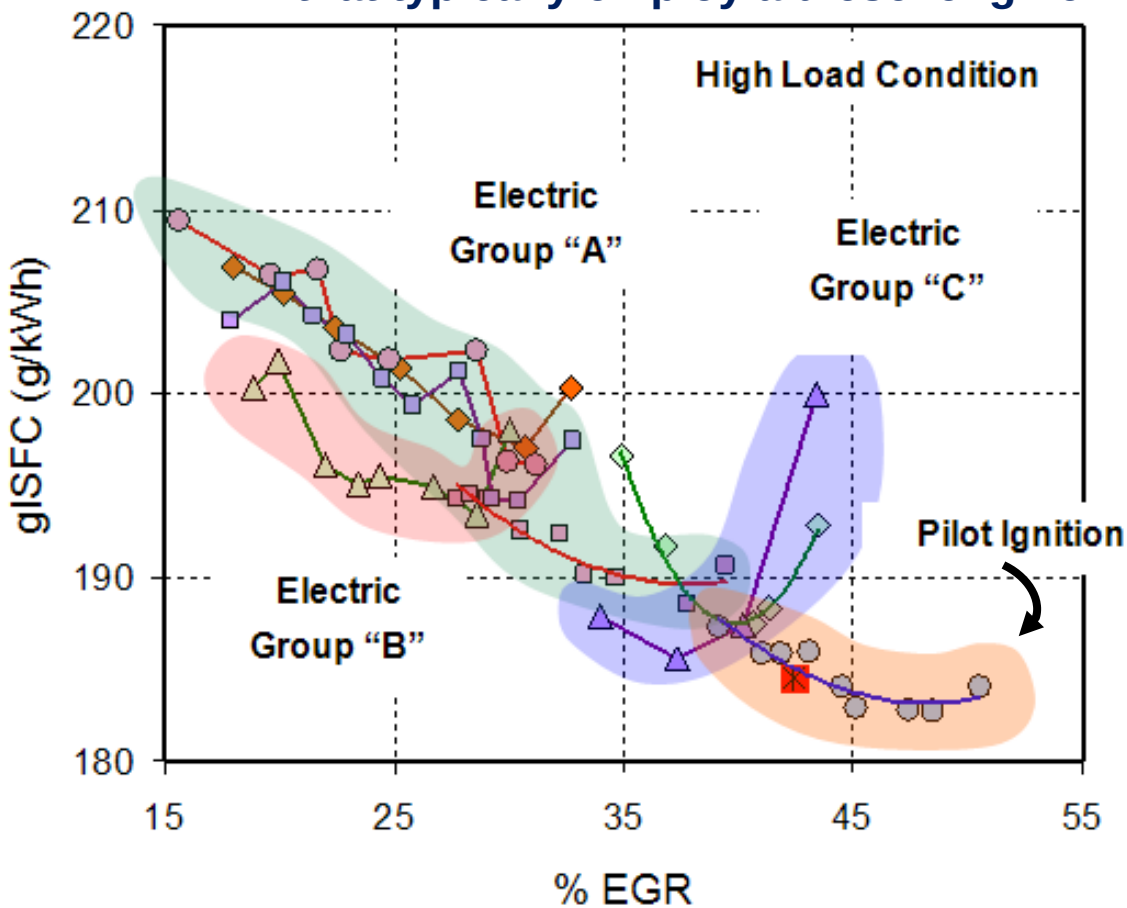
Advanced Ignition Systems: Pilot Ignition for CI Operation



SwRI Dual-Fuel Multi-Mode Concept

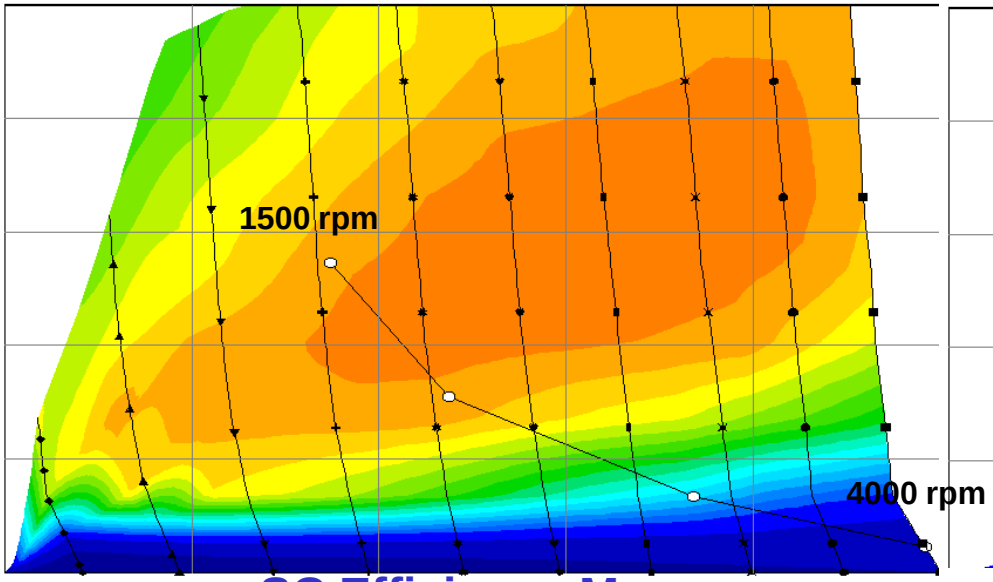
- **Typical fuel fractions:**
  - 85-95% gasoline
  - 15-5% diesel fuel
- **High pressure not required**

- **For best efficiency, use pilot ignition**
  - Ignition fluid is a "chemical spark plug"
- **Particularly useful in applications that typically employ a diesel engine**

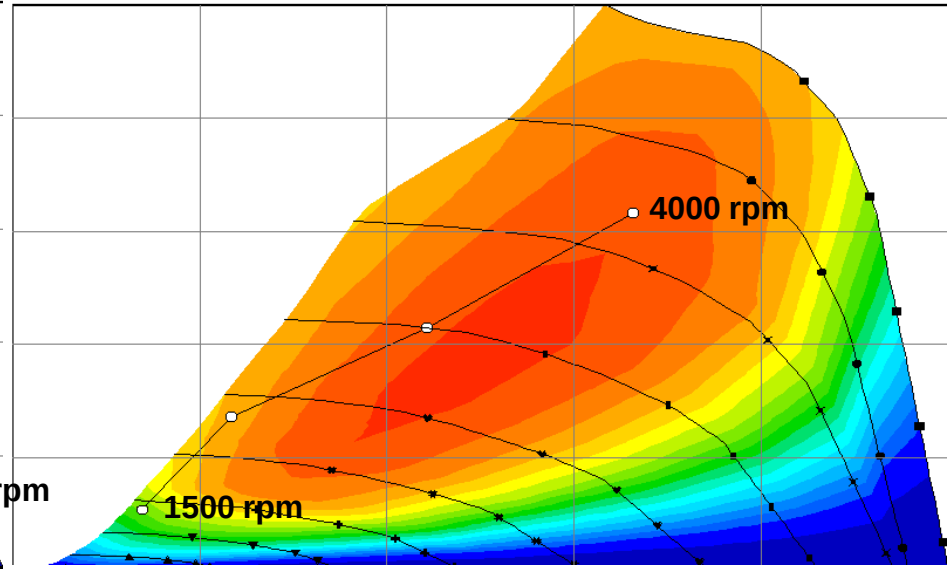


© South West Research Institute® 2009

Advanced Boosting System



SC Efficiency Map



TC Compressor Efficiency Map

Boost system layout for a 1.6L engine with 25% EGR

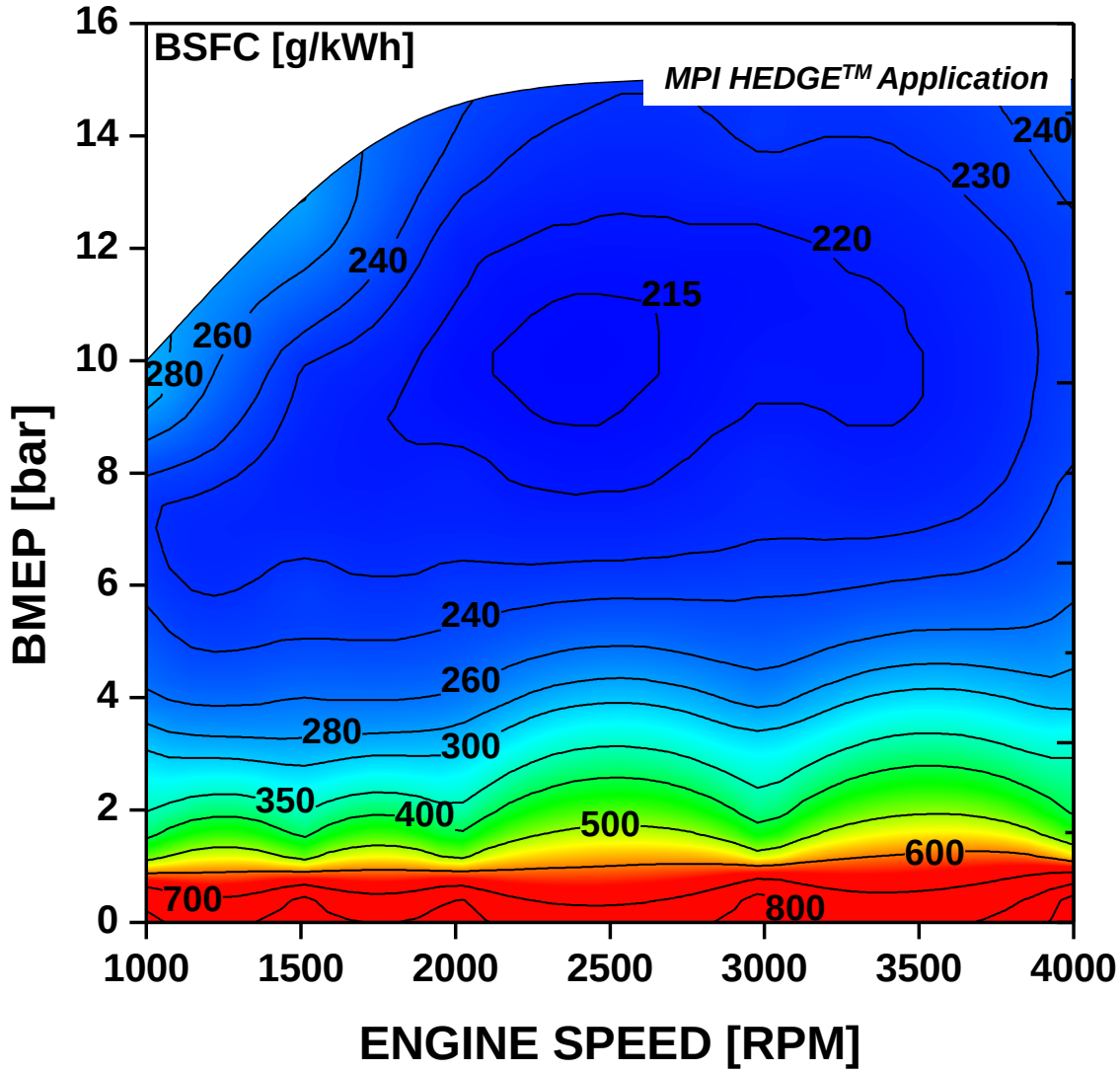
BMEP target : 20 bar bmep @ 1500-4000 rpm

- **Significant challenges to boosting highly dilute engines**
  - Reduced exhaust temperatures
  - Increased mass flow rates and pressure ratios
- **EGR rates > 25% may require 2-stage boosting**
- **Stoichiometric AFR relieves some of the boosting requirements**

© South West Research Institute® 2009

MPI Application Results

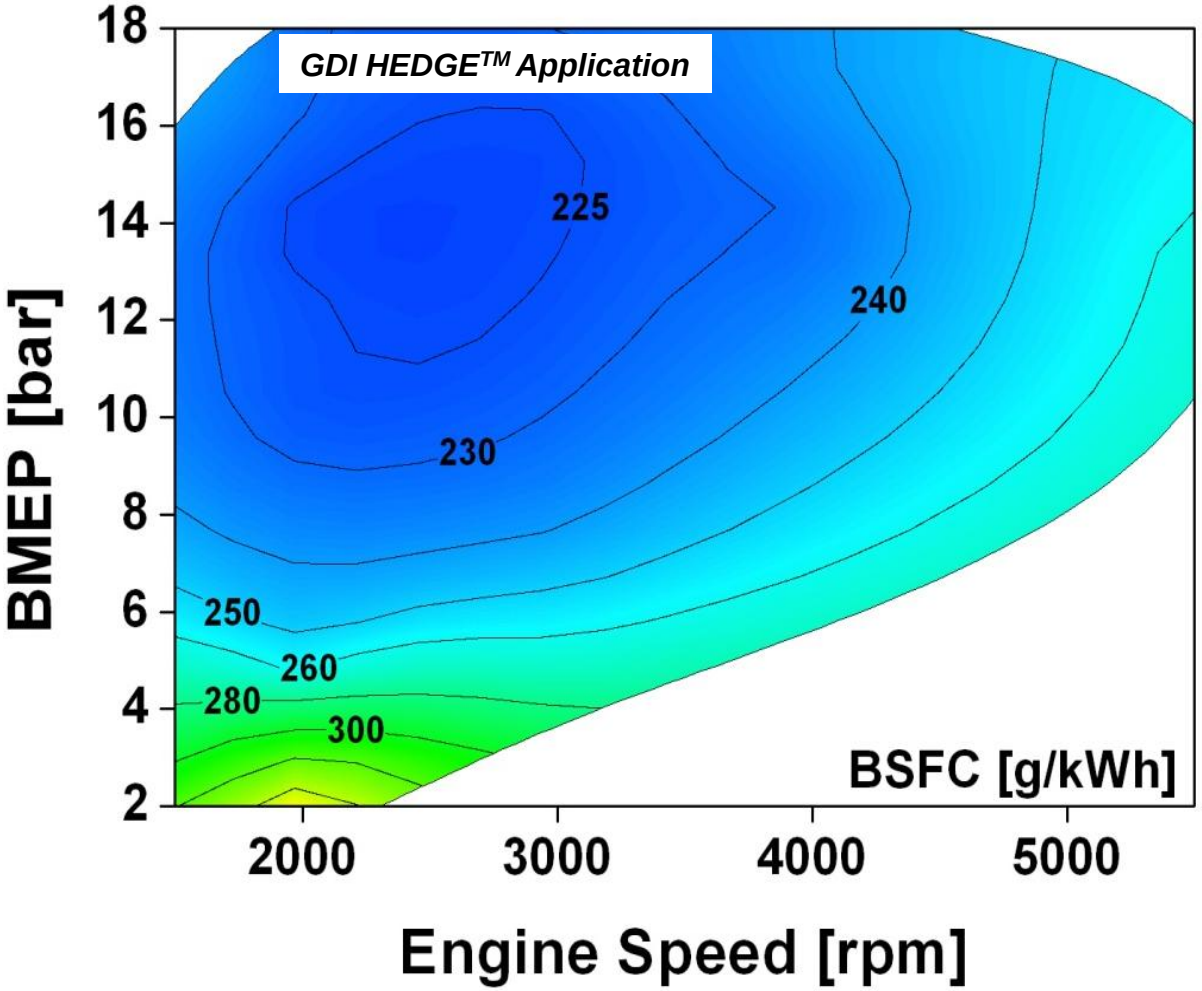
- **Large displacement I4**
  - High CR (> 11:1)
  - Limited boost
  - Restricted speed range
- **Improved efficiency**
  - 10% reduction at low to mid loads
  - 10%-30% reduction at high loads
- **Low BSFC at high loads = more efficient downsizing / downspeeding**
- **Vehicle FE improvement potential of up to 50%**



© South West Research Institute® 2009

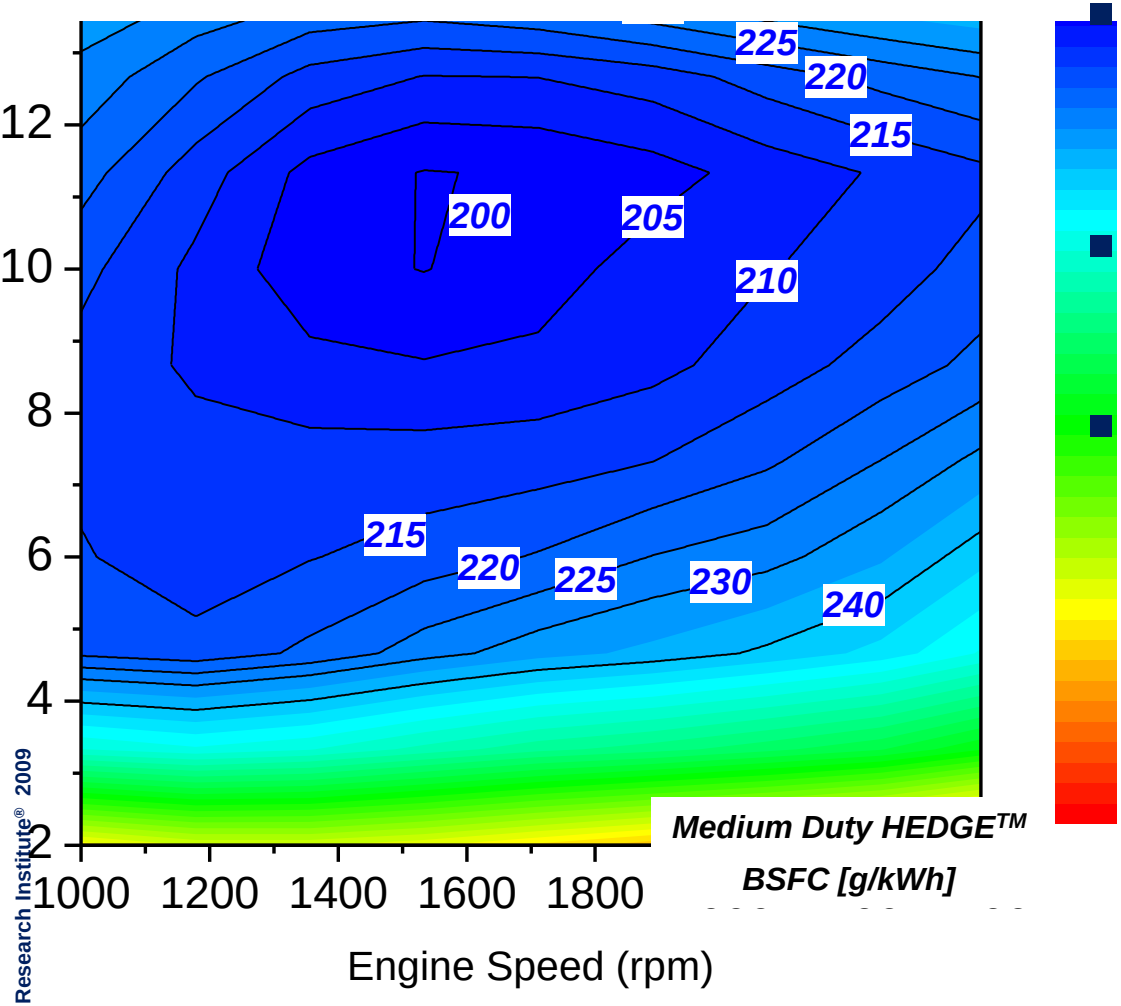
GDI Application Results

- **Initial results 5-30% BSFC improvement**
- **Recent results show increased FE benefits and higher BMEP operation**
  - **> 20 bar bmep with BSFC < 240 g/kWh demonstrated across speed range**
- **Unresolved question : Is GDI necessary for high BMEP when EGR is employed?**

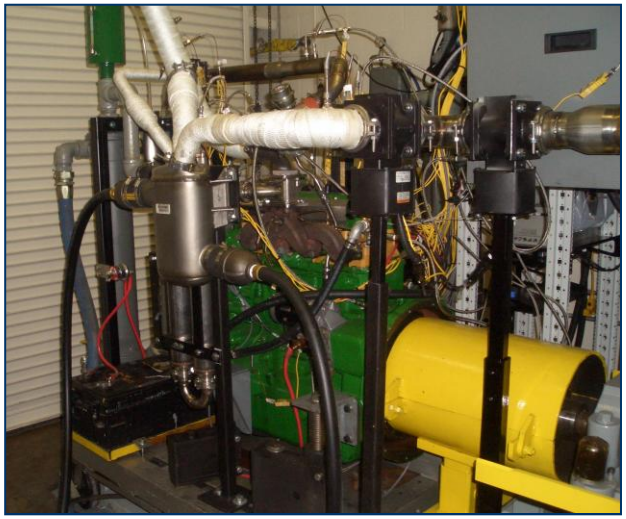


© South West Research Institute® 2009

MD Application Performance Results

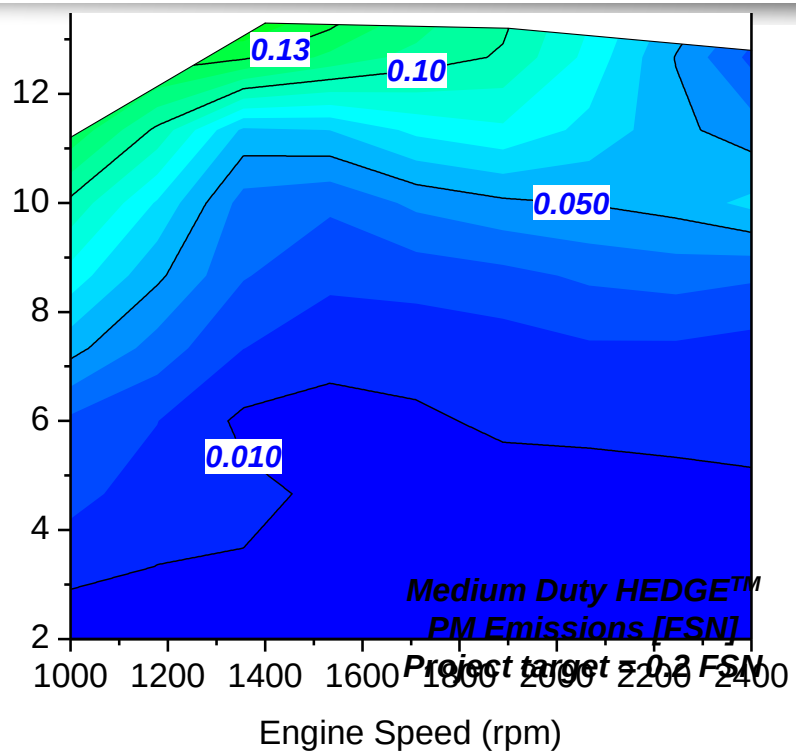


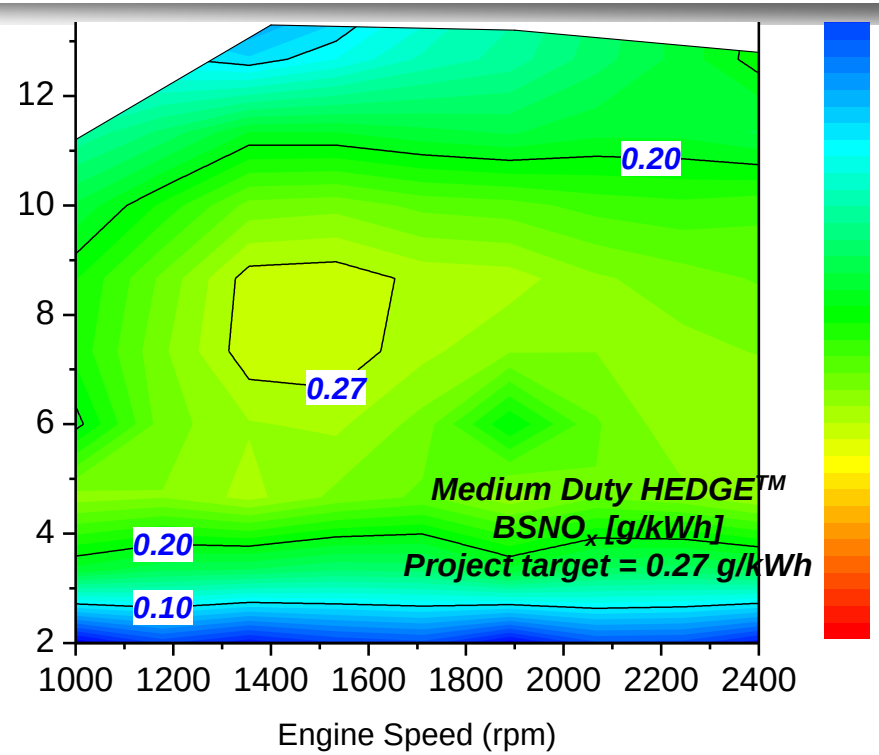
- **Achieves near diesel torque curve**
  - Limit is PCP of 180 bar
  - 2-Stage Boosting (SC+TC)
- **Diesel-like BSFC**
  - ~ 42% BTE
  - 14.3:1 CR
- **Dual-fuel / dual-mode operation**
  - Diesel + Gasoline
  - SI + CI



© South West Research Institute® 2009

MD Application Emissions Results





- **Dual-fuel / multi-mode operation yields ultra-low emissions**
- **Engine-out NOx and PM are less than US 2010 HD standard**
  - **Potential still exists for TWC operation**

© South West Research Institute® 2009

Summary

- High efficiency engines that provide acceptable emissions and performance are a challenge
  - Cost / benefit tradeoff curve not favorable for traditional engines
- High EGR, λ=1 engines offer advantages
  - No enrichment
  - High efficiency at both low and high loads
  - Low emissions
  - Feasible alternative to diesel in LD / MD / off-road market
- Challenges remain
  - Ignition
  - *Boosting*
  - *PCP limits*
- SwRI is developing solutions to these challenges and others in its HEDGE II consortium

© South West Research Institute® 2009

Potential Applications of HEDGE Technology

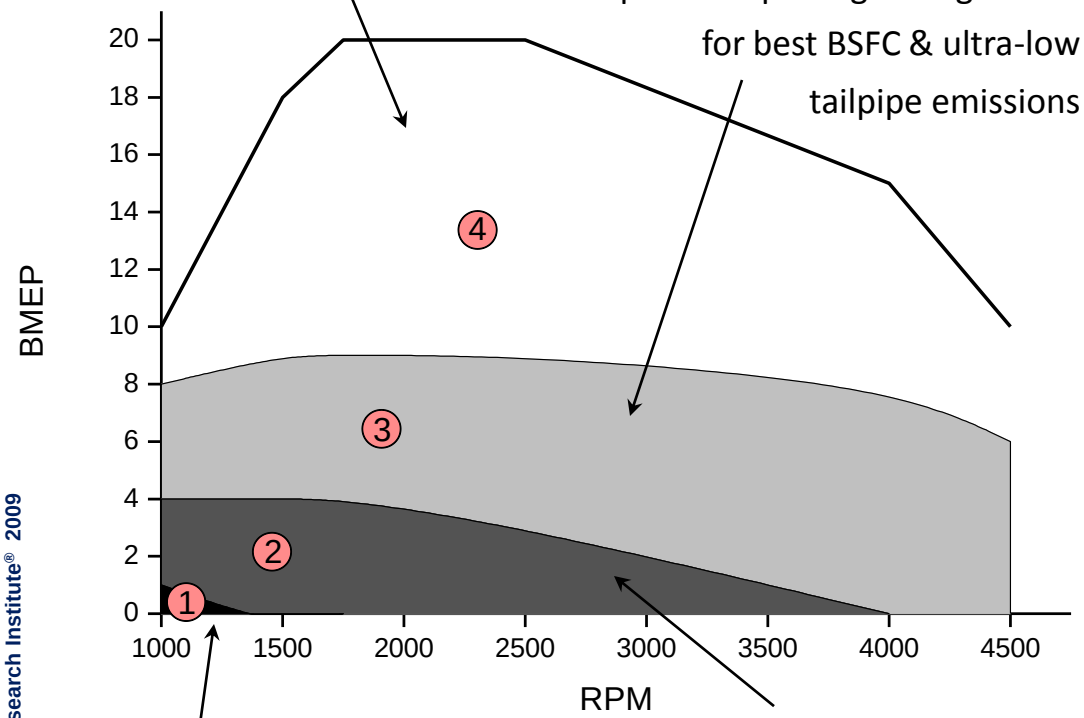
- Spark-ignition, high-EGR operation
  - Gasoline style base combustion system
  - Gasoline only
  - Limited EGR (< 30%)
  - Short timeline to production
- Longer Timeline Concepts
  - Dual Fuel
  - Dual Fuel / Multi-Mode

© South West Research Institute® 2009

SwRI Dual Fuel HEDGE™ Concept For Tier II Bin 2 Emissions

λ1 pilot-ignited gasoline for max efficiency and ultra-low tailpipe emissions

λ1 spark and pilot-ignited gasoline for best BSFC & ultra-low tailpipe emissions



λ1 SI gasoline for Bin 2 cold start and catalyst temperature maintenance

λ1 SI gasoline with EGR for ultra-low tailpipe emissions and minimal throttling losses

Combustion Zones

1: λ=1 Spark ignition, light EGR
2: λ=1 Spark ignition, high EGR
3: λ=1 Spark and pilot ignition, high EGR
4: λ=1 Pilot ignition,high EGR

Engine Hardware

- Base EU5 Diesel engine with lower CR
- Rematched turbocharger
- Add spark plug in place of glow plug
- Add gasoline port fuel injection system
- Replace HPL EGR system with LPL EGR

Aftertreatment

- TWC

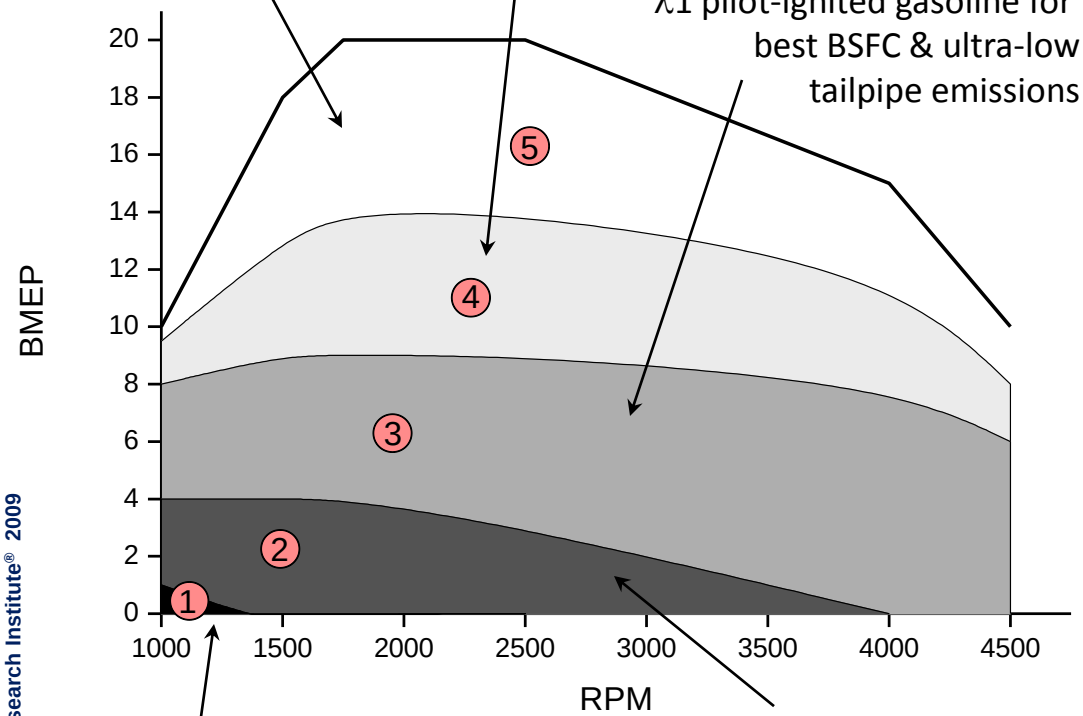
© South West Research Institute® 2009

SwRI's Dual-Fuel / Multi-Mode HEDGE Concept for Tier II Bin 2 Operation

Conventional Diesel combustion at high load

Diesel-to-gasoline transition region

λ1 pilot-ignited gasoline for best BSFC & ultra-low tailpipe emissions



λ1 SI gasoline for Bin 2 cold start and catalyst temperature maintenance

λ1 SI gasoline with EGR for ultra-low tailpipe emissions and minimal throttling losses

Combustion Zones

1: λ=1 SI gasoline, light EGR
2: λ=1 SI gasoline, high EGR
3: λ=1 Gasoline w/Diesel pilot ignition, high EGR
4: λ≥1 Diesel combustion w/gasoline support, moderate EGR
5: λ≥1 Diesel combustion only, light EGR

Engine Hardware

- Base EU5 Diesel engine
- Base Diesel turbocharger
- Add spark plug in place of glow plug
- Add gasoline port fuel injection system
- Potentially add LPL EGR system

Aftertreatment

- DPF
- DOC
- LNT / TWC

© South West Research Institute® 2009

Thank You

Dr. Terry Alger
Southwest Research Institute
talger@swri.org
210-522-5505

© South West Research Institute® 2009