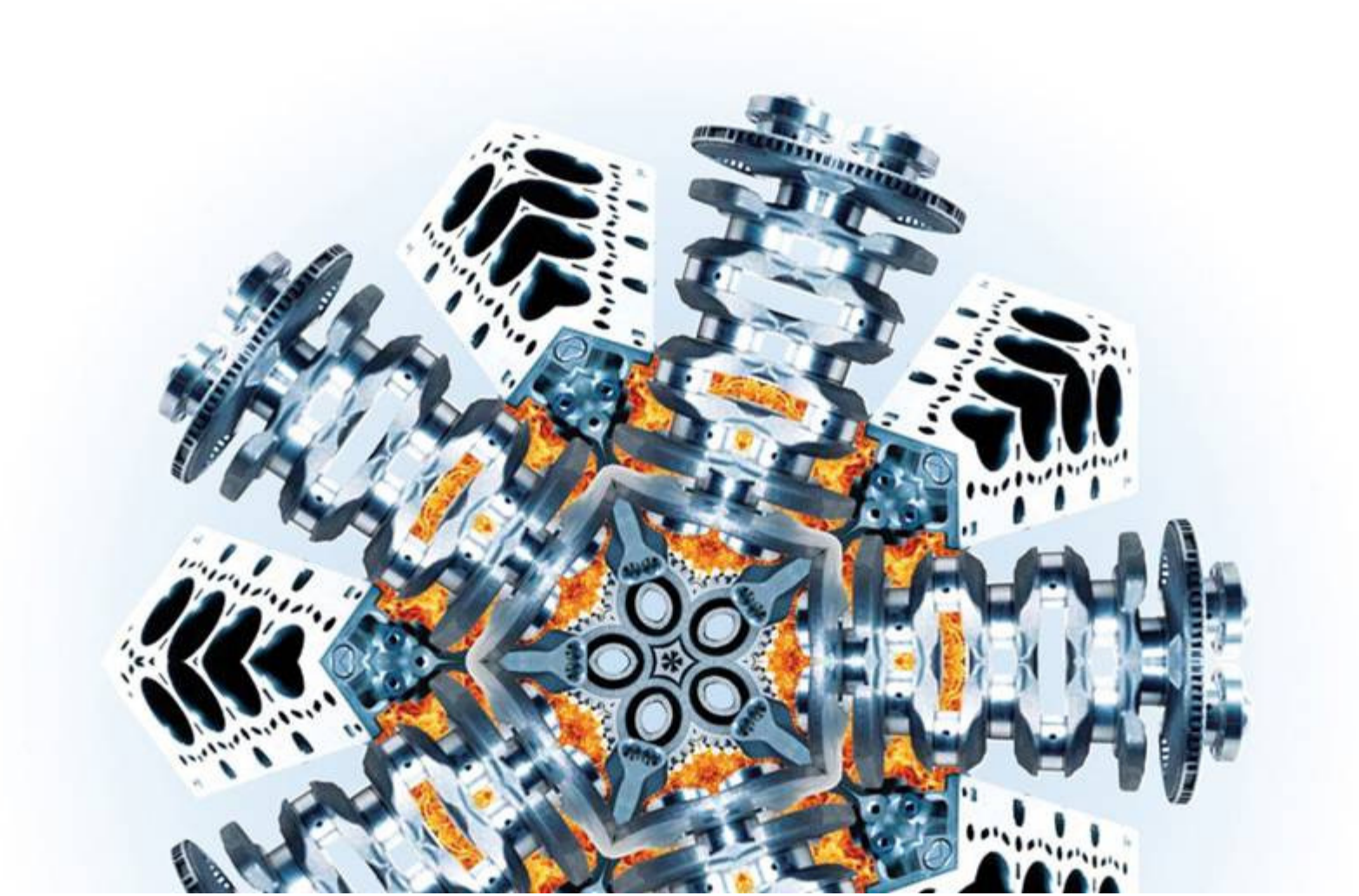
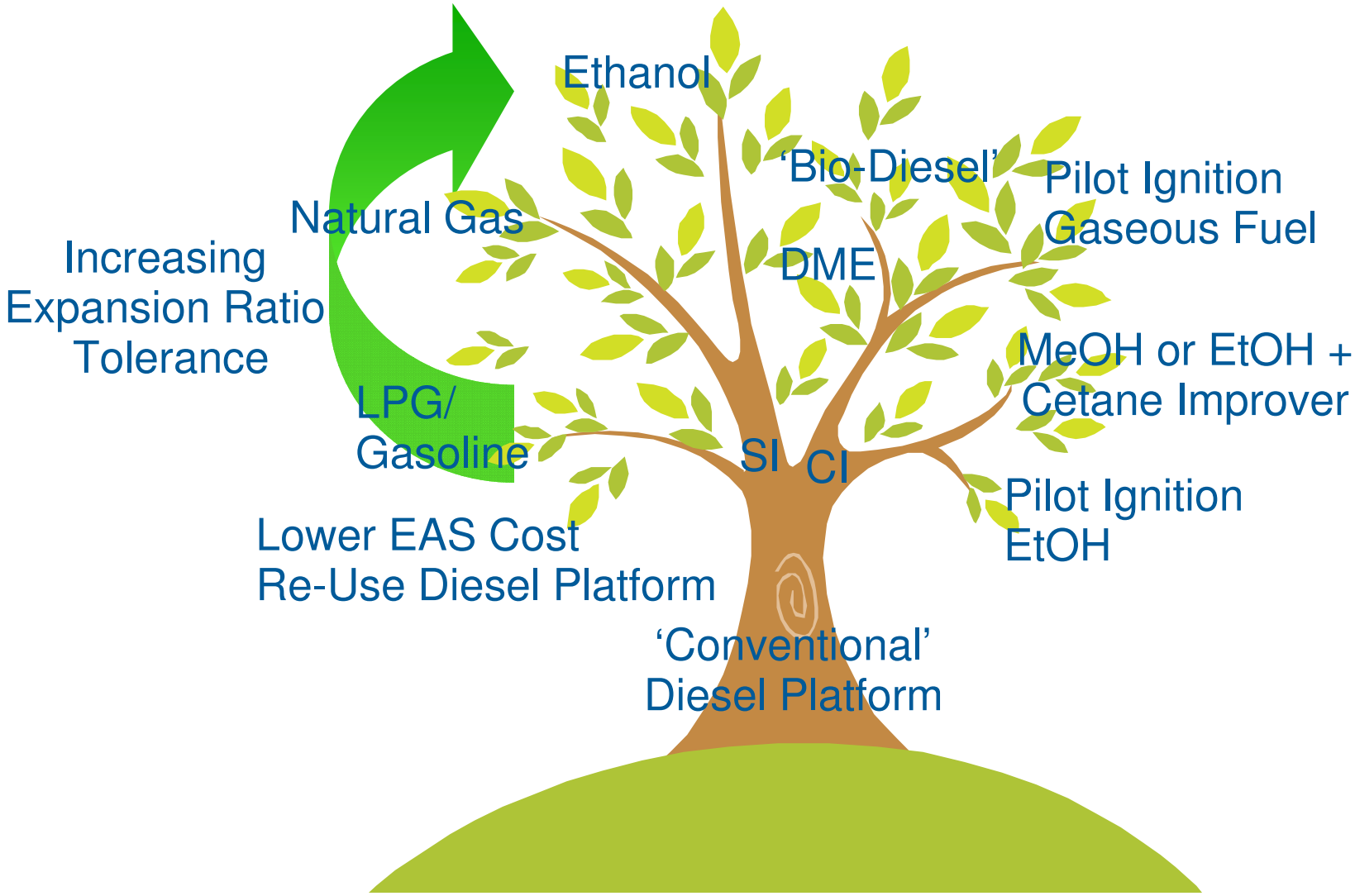
Efficiency Impacts of Alternative Fuels in ‘Current’ Engines

AVL Powertrain Inc.



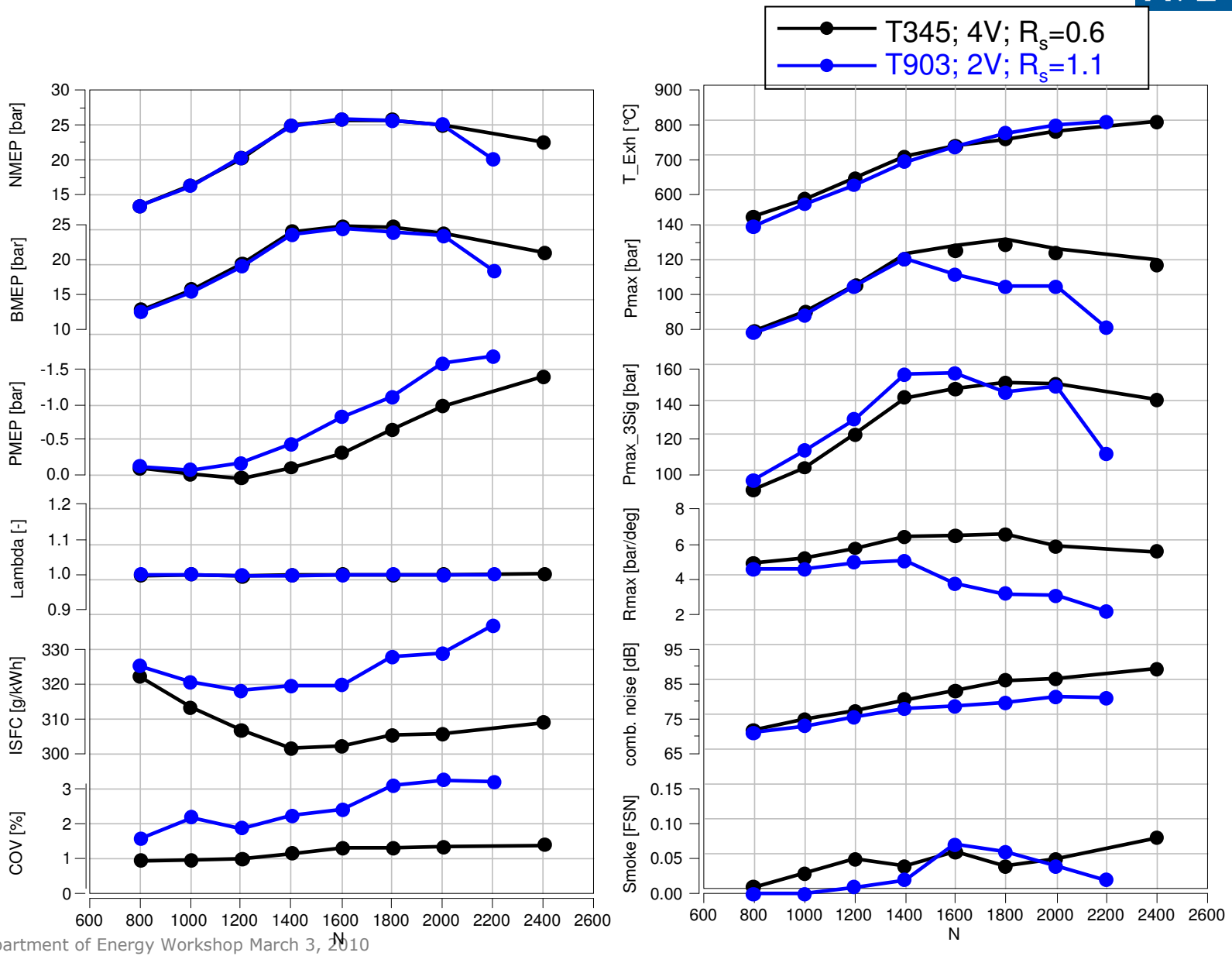
Commercial Engine Alternate Fuel Family Tree



MHD SI EtOH Program Background

- Investigate conversion of an existing diesel engine to EtOH TDI
- Be manufacturable with minimum change to base engine
- Departure from typical tumble based pent-roof combustion system
  - swirl based vertical valve bowl-in-piston combustion system
- Demonstrate the potential to meet/exceed existing MHD performance

E85 Full Load Curve – CR=~12:1
4-Valve Head vs 2-Valve Head



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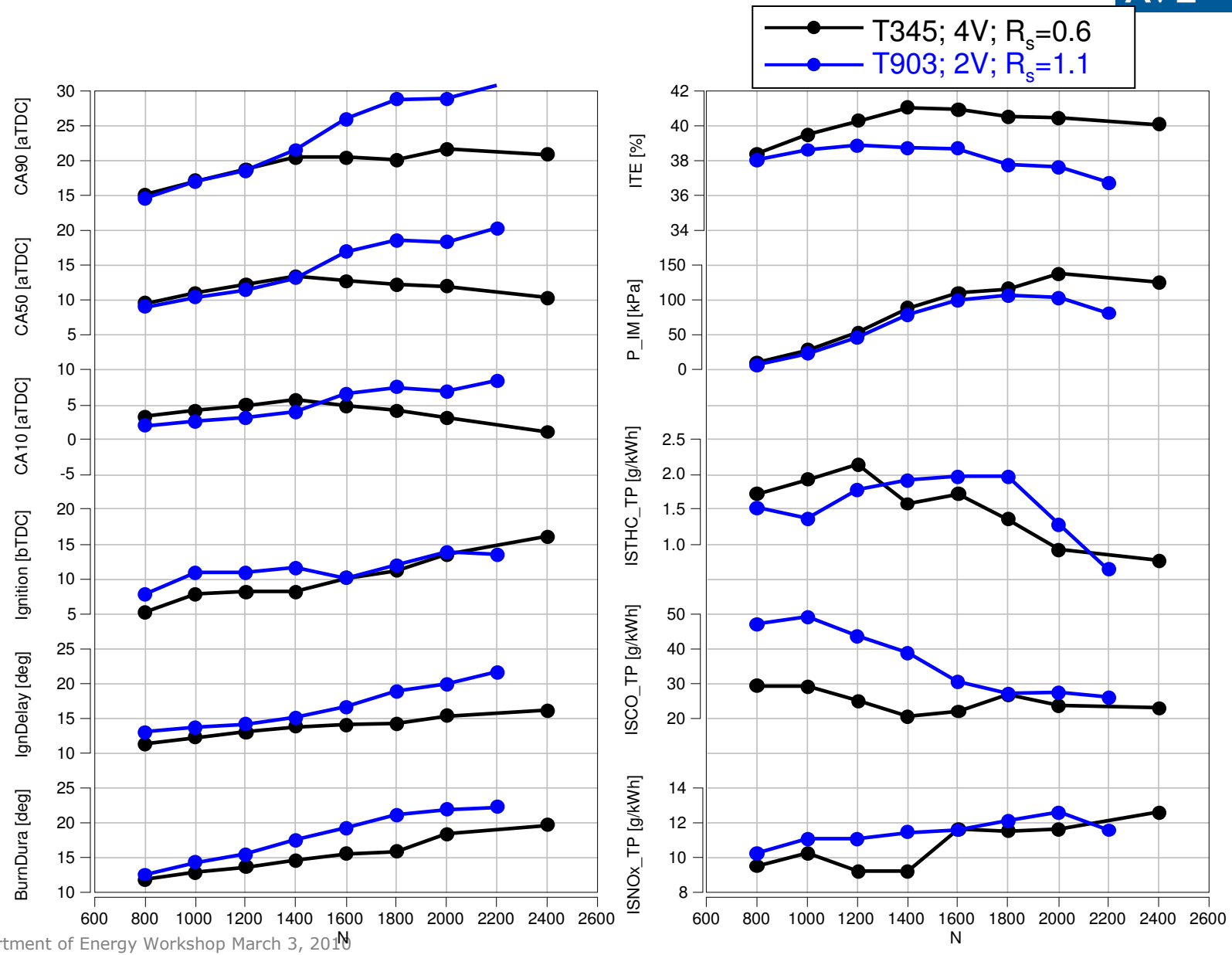
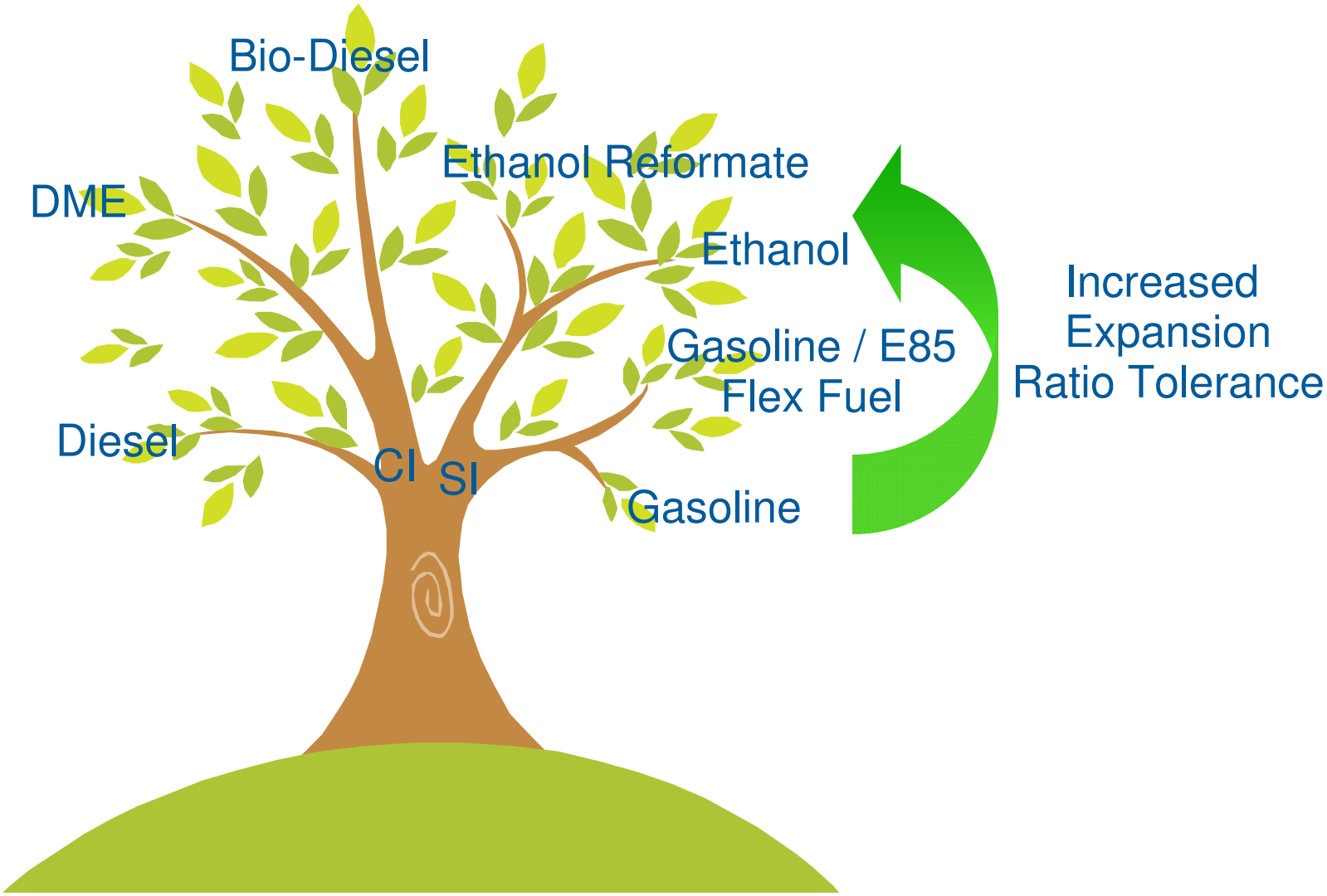


MHD Ethanol Engine Alternatives Overview

Ethanol Fuel System	Ignition	
	Diesel Micro-Pilot	Spark Ignition
Direct Injection	full diesel function flexibility package of two direct injectors **ethanol injector durability** CR too high for FL Ethanol highest cost	Optimal Ethanol Function Low Cost (TWC)
Port Fuel Injection	full diesel function flexibility CR too high for FL Ethanol durability task high cost	compromised function cold starting task durability task lowest cost (TWC)

Personal Transport Engine Alternate Fuel Family Tree

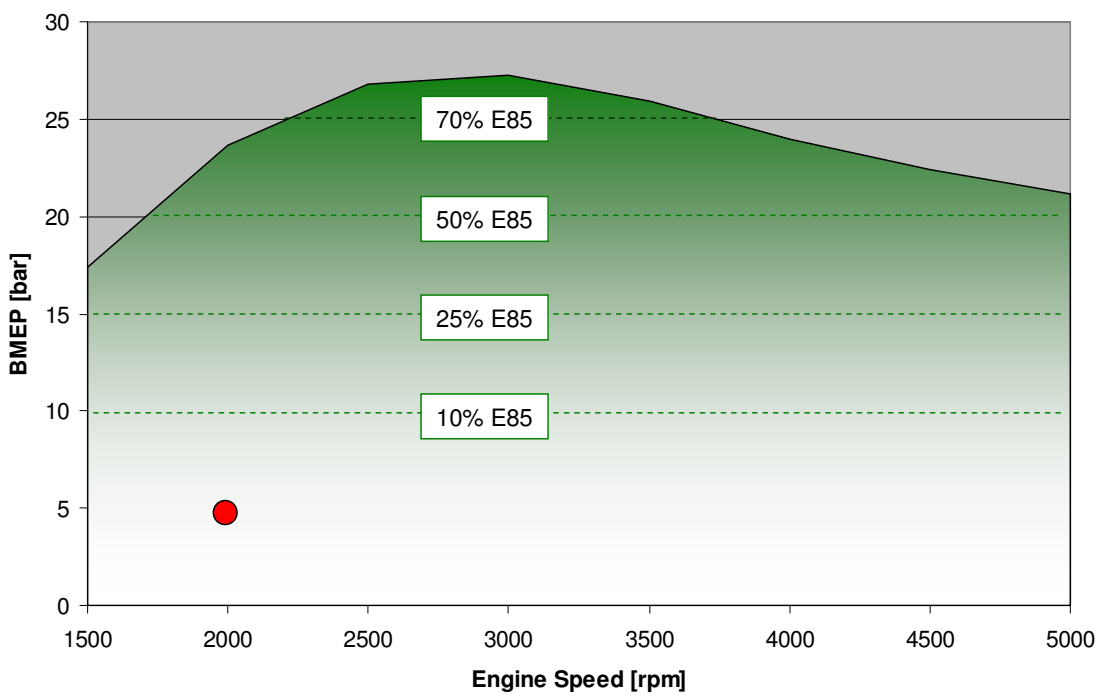


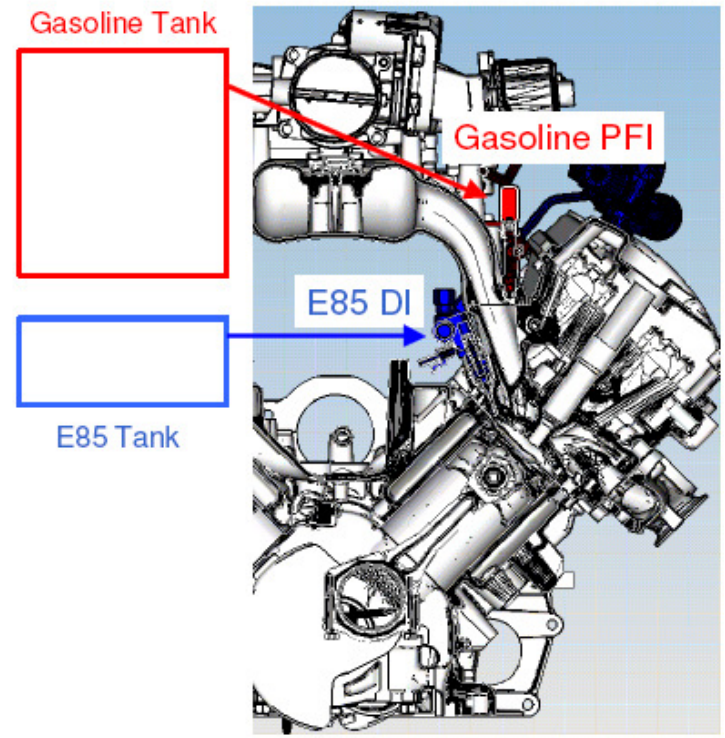
EBS Strategy

- E85 provides significant octane benefit with DI due to high latent heat of vaporization and high octane rating
- Allows knock-free operation at high CR and high BMEP with very high thermal efficiency

but…

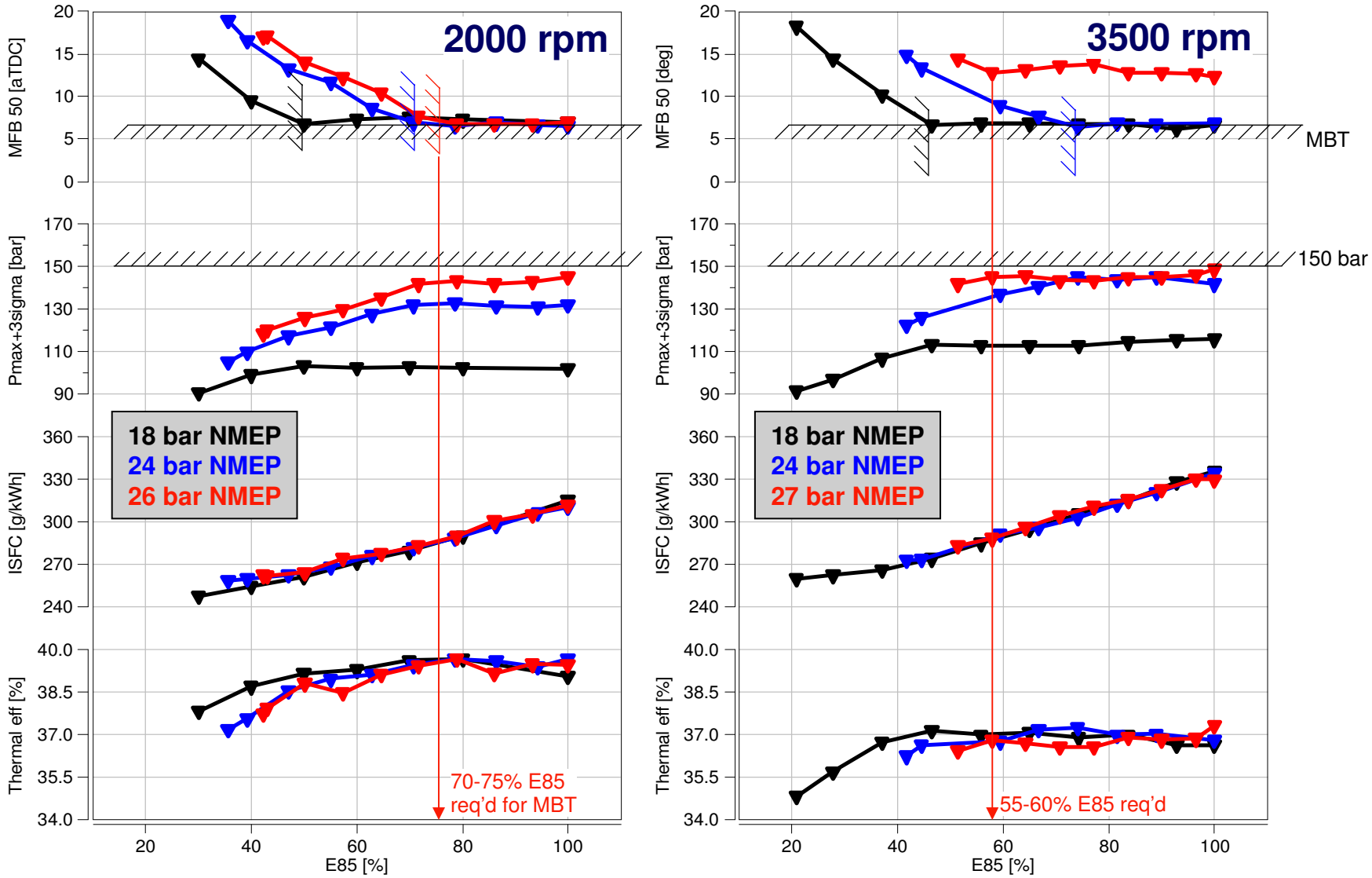
- Low E85 heating value is a disadvantage



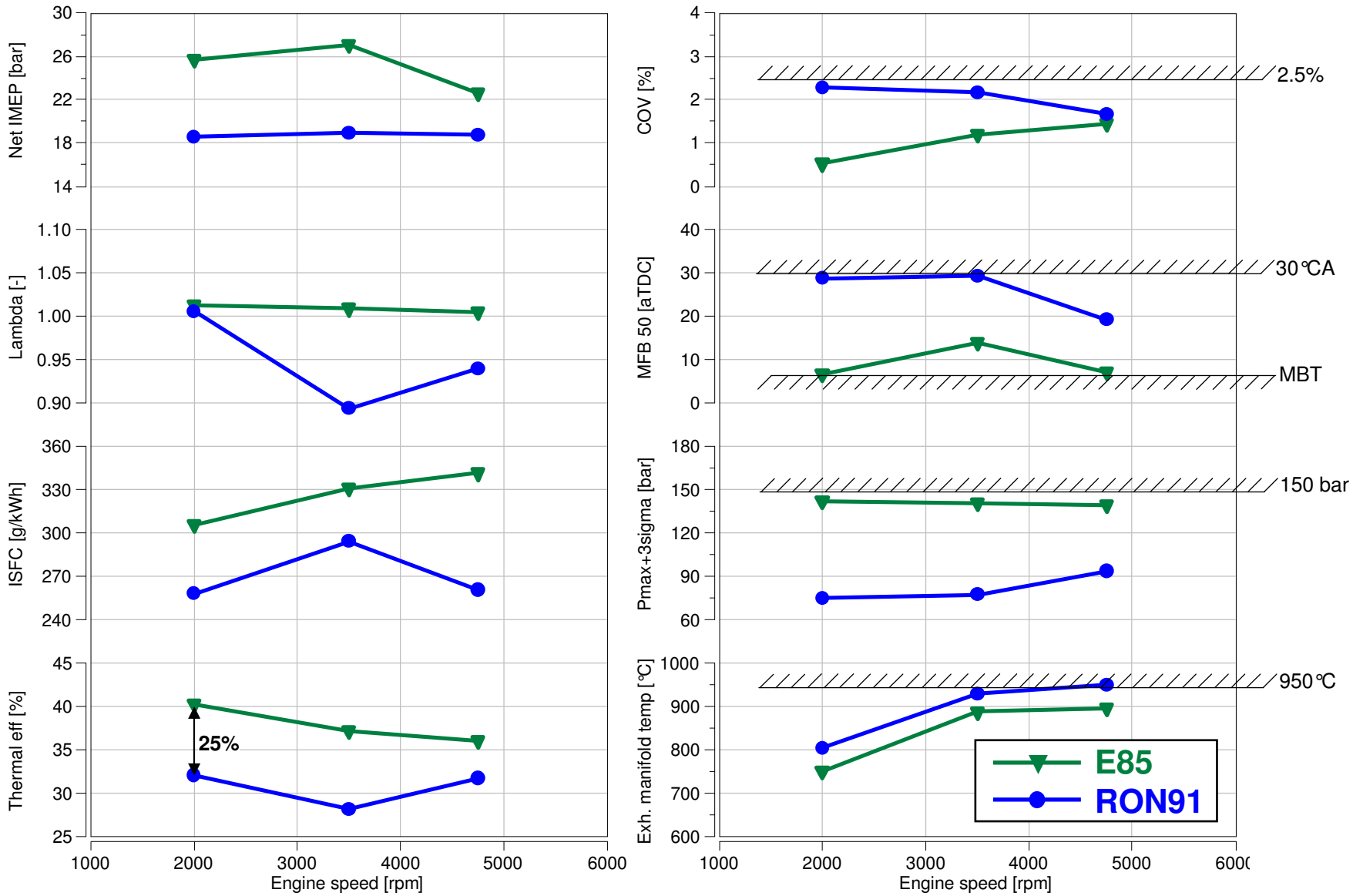


- Dual fuel strategy uses E85 DI only as required to eliminate knock in a high CR gasoline engine.
- Combines high load E85 octane benefit with part load gasoline heating value advantage
- Provides maximum leveraging of available ethanol

Dual Fuel E85 DI % sweep, Full Load, 9.3 CR



SI Ethanol DI Full Load Benefits - E85 vs. RON91(9.3:1)



Background of Ethanol Reformate

Monsanto has developed a catalytic reformer which uses exhaust heat to convert liquid ethanol into a gaseous fuel:

$$C_2H_5OH \rightarrow CO + H_2 + CH_4$$

Expected benefits of the gaseous reformate include:

- Extension of the dilute limit (lean or EGR) at part load due to the presence of $^1/_3$ hydrogen.
- Increased heating value via exhaust heat recovery.
  - ~ 7% relative to the input ethanol.
  - ~ 4% after taking into account the heat of vaporization of liquid ethanol.
- Excellent cold start characteristics.
- Reduced risk of pre-ignition compared to pure hydrogen.
- To be Published in SAE 2010-01-0621 'High Efficiency, Low Feedgas NOx, and Improved Cold Start Enabled by Low-Temperature Ethanol Reforming'

Lean A/F vs. Cooled EGR with Reformate 1500 rpm, 3.5 Bar NMEP

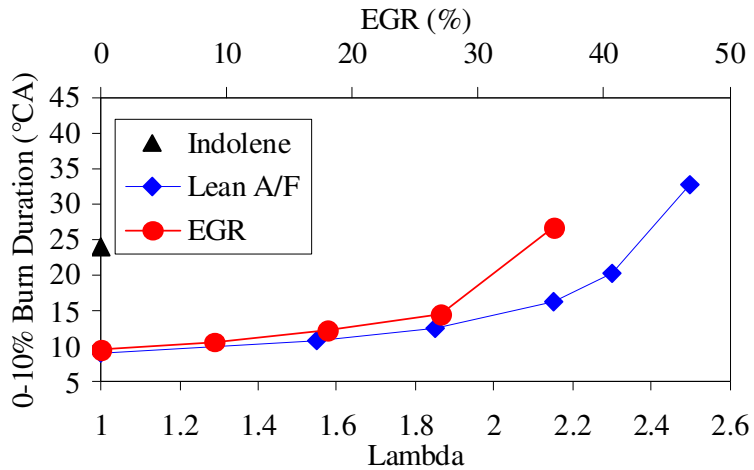
The 0-10% burn times decreased in comparison to Indolene.

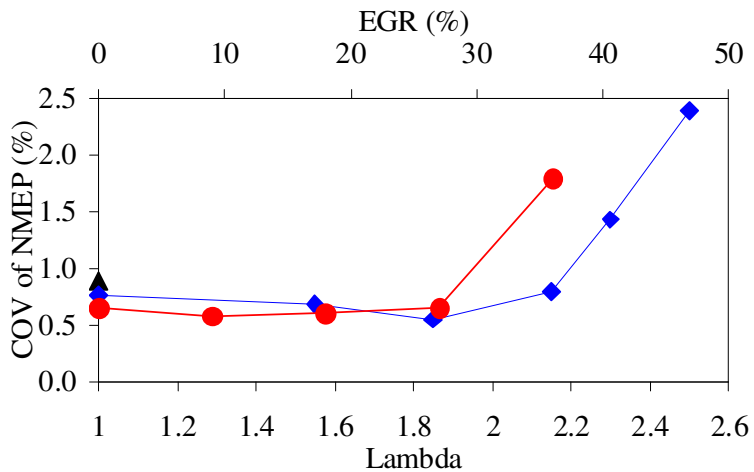
- Increased CR from 10:1 to 14:1.
- High swirl ratio of 2.6.
- Presence of hydrogen in reformate.

Burn times increased with the addition of dilution.

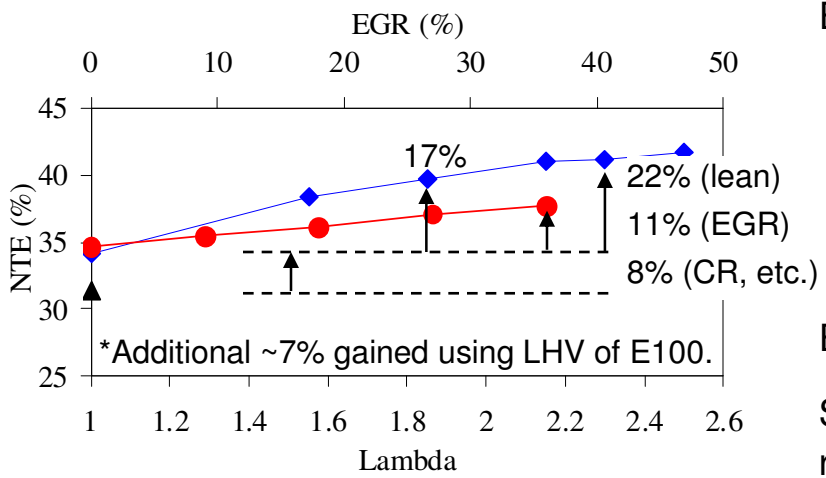
Increased burn times ultimately result in loss of engine stability (COV > 2%):

- Lambda = 2.3 or
- 36% EGR (equivalent to λ = 1.6)



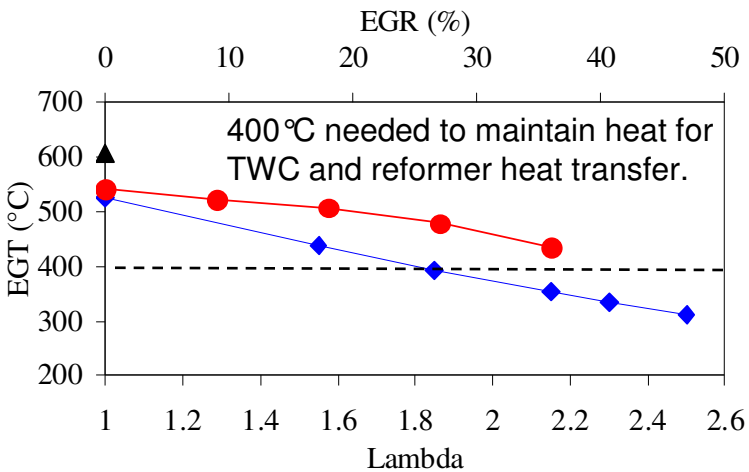
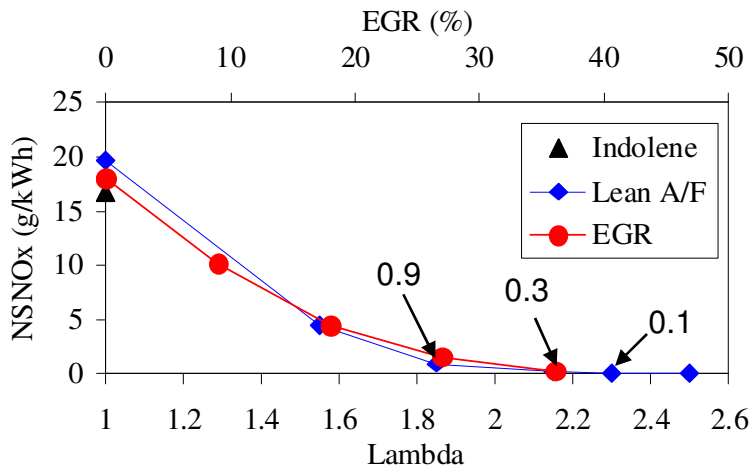


Lean A/F vs. Cooled EGR with Reformate
1500 rpm, 3.5 Bar NMEP



Exhaust temperature constraint of 400℃:

- Limits A/F to ~1.8 λ
- Reduces NTE benefit from 22% to 17%.
- Increases NOx, effectively decreasing NTE further via LNT regeneration requirement.

EGR was used for the rest of this study.

Strategy of combined Lean A/F, EGR and internal residual will be studied separately.