# E85 Optimized Engine

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Project ID#: ft_12_agarwal

# Overview

## Timeline

- Project start date – Oct 2007
- Project end date – Dec 2009
- Percent complete – 65%

## Budget

- Total project funding
  - DOE share - $3.2 million
  - Ford share - $3.2 million
- Funding received in FY08
  - $1,217,847.80
- Funding received in FY09
  - $918,253.23 (invoiced)
- Funding for FY10
  - None

## Barriers

- Ethanol availability
- Engine structure requirements
- Emissions with E85

## Targets

- 15-20% better FE for F-Series trucks
- Meet 2012 HDGE emissions with stretch target of ULEVII/Tier 2 Bin 5

## Partners

- AVL Powertrain Engineering Inc
- Ethanol Boosting Systems LLC
- Ford Motor Company (project lead)

# Objectives

## Since Last Year's Merit Review

- Develop and assess a dual fuel concept for on-demand direct injection of E85
- Complete single and multi-cylinder engine design
  - Cylinder heads, valvetrain, pistons, fuel system, air system
  - Combustion system including ports, injectors, piston crown and combustion chamber
  - Support with 1D performance simulation
- Develop and verify combustion system using optical and single cylinder engine
- Develop base models for vehicle performance and fuel economy prediction
- Procure and build multi-cylinder hardware
- Commence multi-cylinder development

# Milestones

## Budget Period 1 (Oct 1, 2007 to Aug 31, 2008)

- [x] Overall engine system definition including cylinder head architecture, boost system configuration, fuel injection system and engine structure
- [x] Analytical predictions of engine full load performance and vehicle fuel efficiency for FFV and E85 optimized dual fuel engines
- [x] Combustion system optimization for operation on E85 based on optical and conventional single cylinder testing

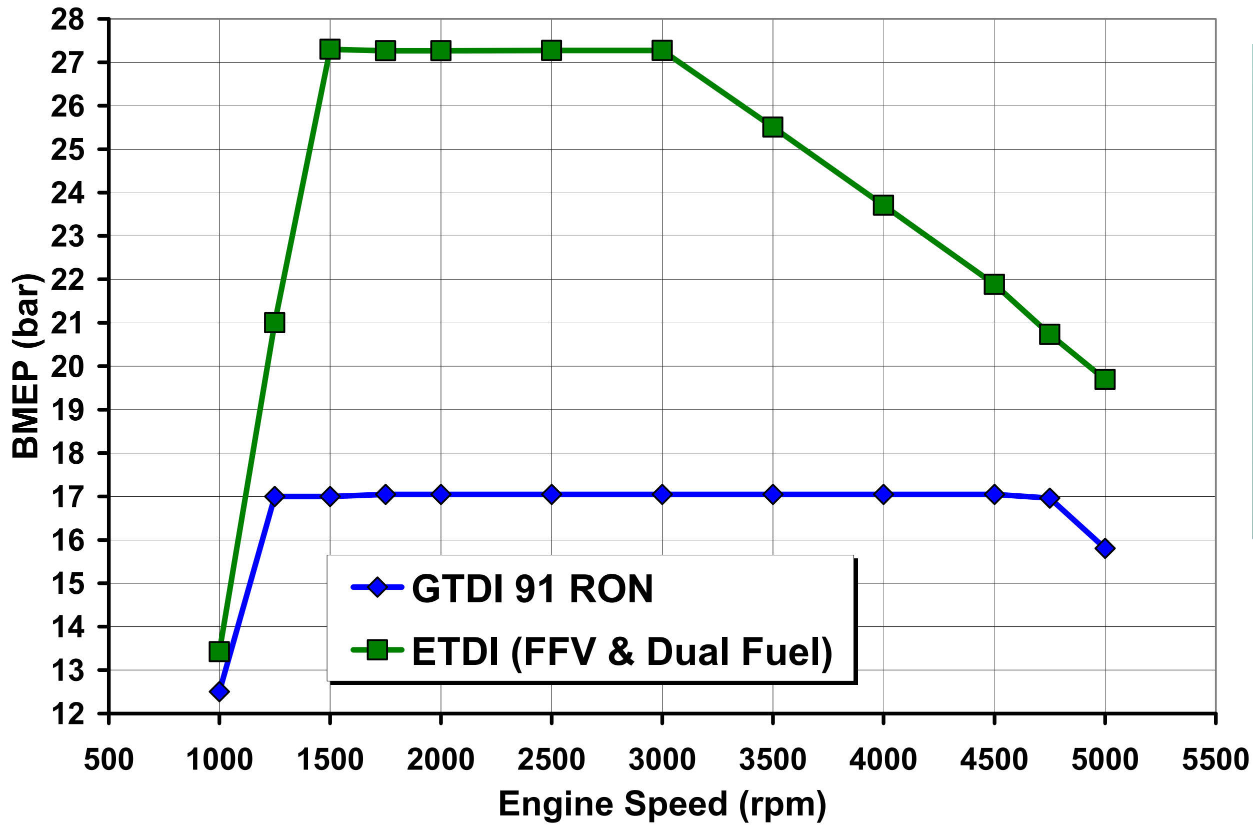
## Budget Period 2 (Sep 1, 2008 to May 31, 2009)

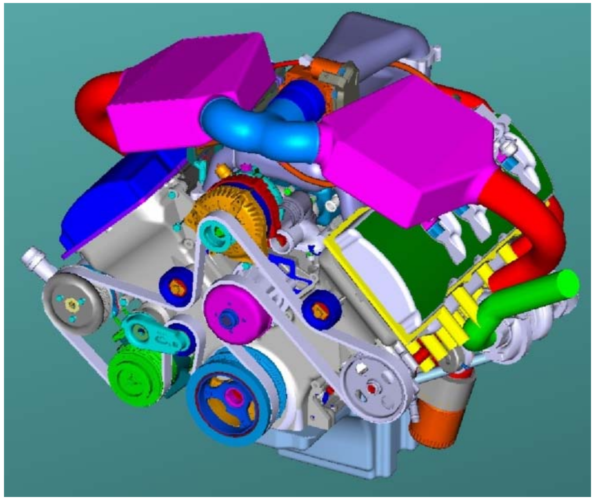
- [x] Completion of design and analysis of multi-cylinder engine components
- [x] Procurement and build of multi-cylinder engines
- [ ] Base engine optimization based on multi-cylinder engine dynamometer development and modeling studies
  - Demonstrate full load torque capability and fuel efficiency at vehicle mapping points

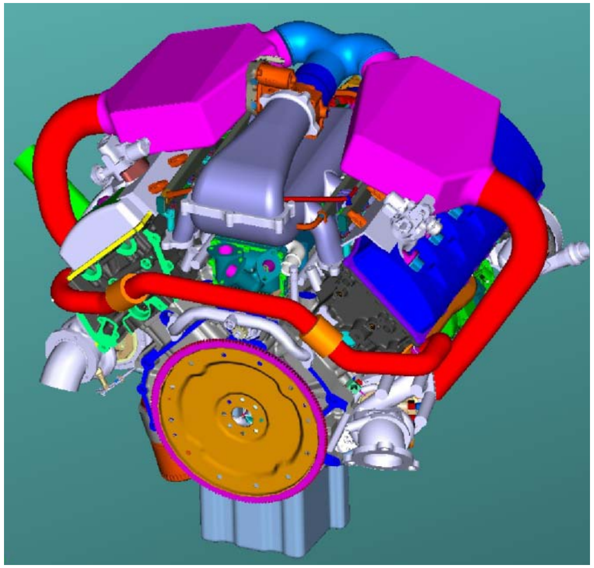
## Budget Period 3 (Jun 1, 2009 to Dec 31, 2009)

- [ ] Conduct base engine mapping and calibration optimization for fuel efficiency
- [ ] Optimize cold starting strategy
- [ ] Demonstrate overall program objectives at a vehicle level using vehicle simulation

# Combustion System Targets





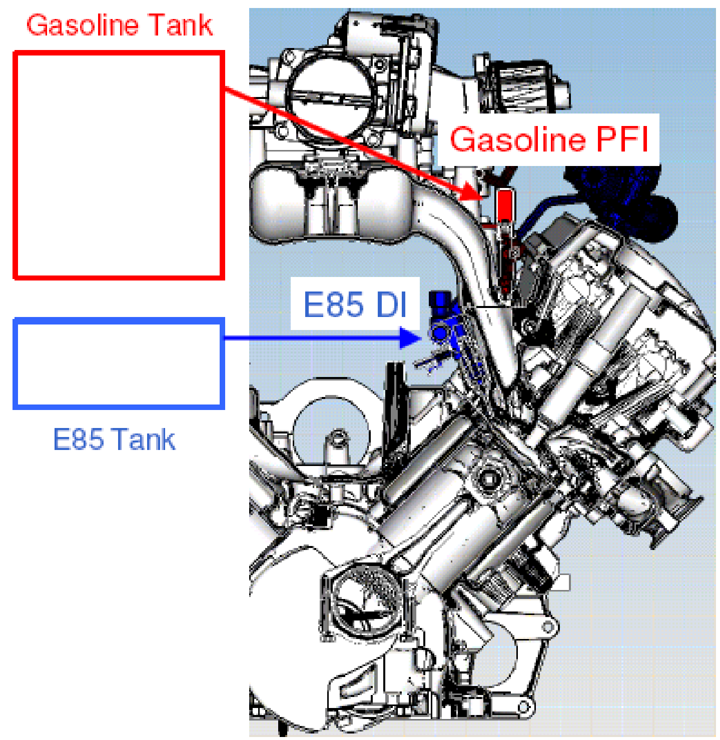
- Support flex and dual fuel operation
  - Address V8 residual imbalance issues
  - Minimize gasoline fuel enrichment at full load
  - Minimize cylinder wall wetting with fuel
  - Maximize low end torque with scavenging
  - Develop rapid catalyst heating strategies

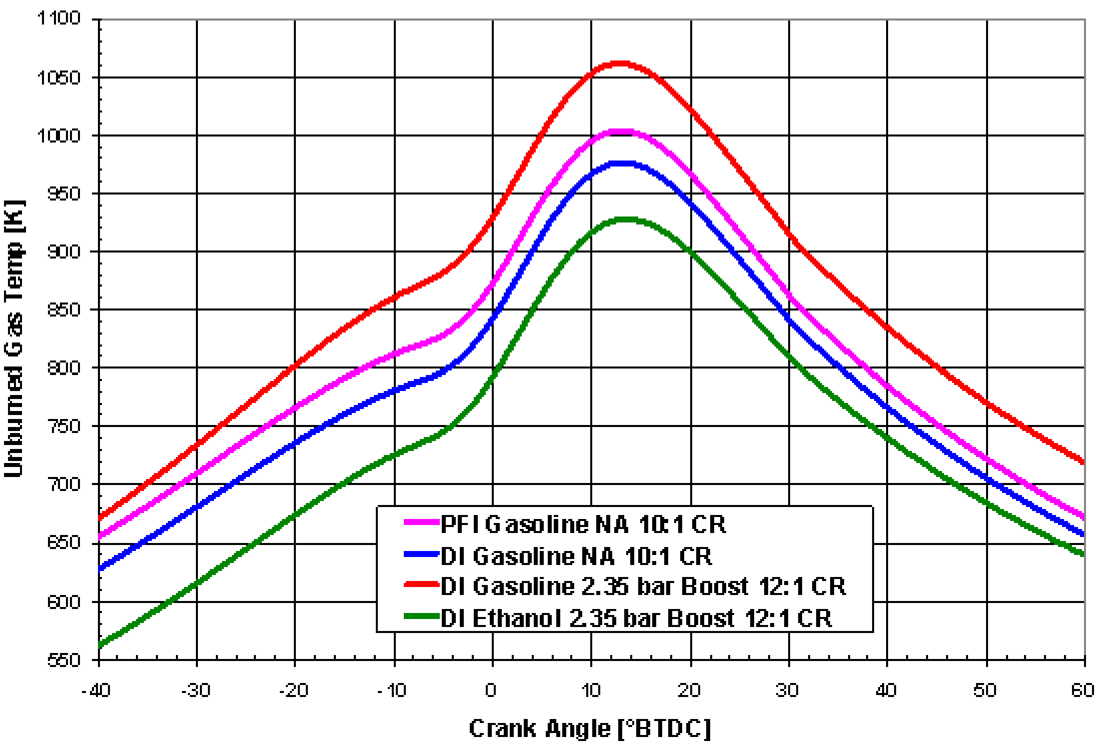
# Dual Fuel Strategy

- 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…

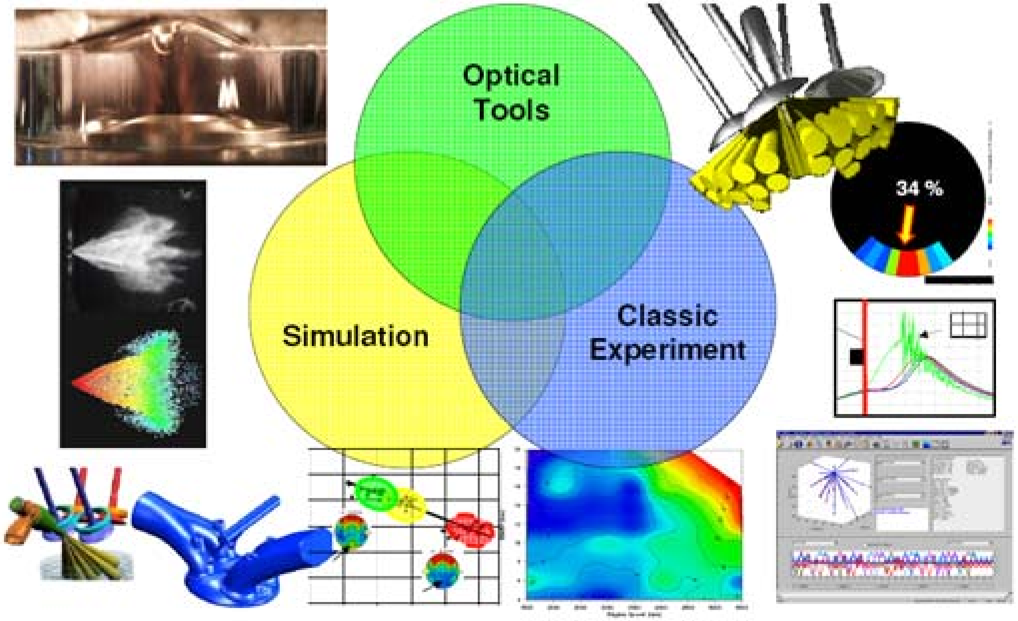
- Low E85 heating value is a disadvantage




- 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

# Approach

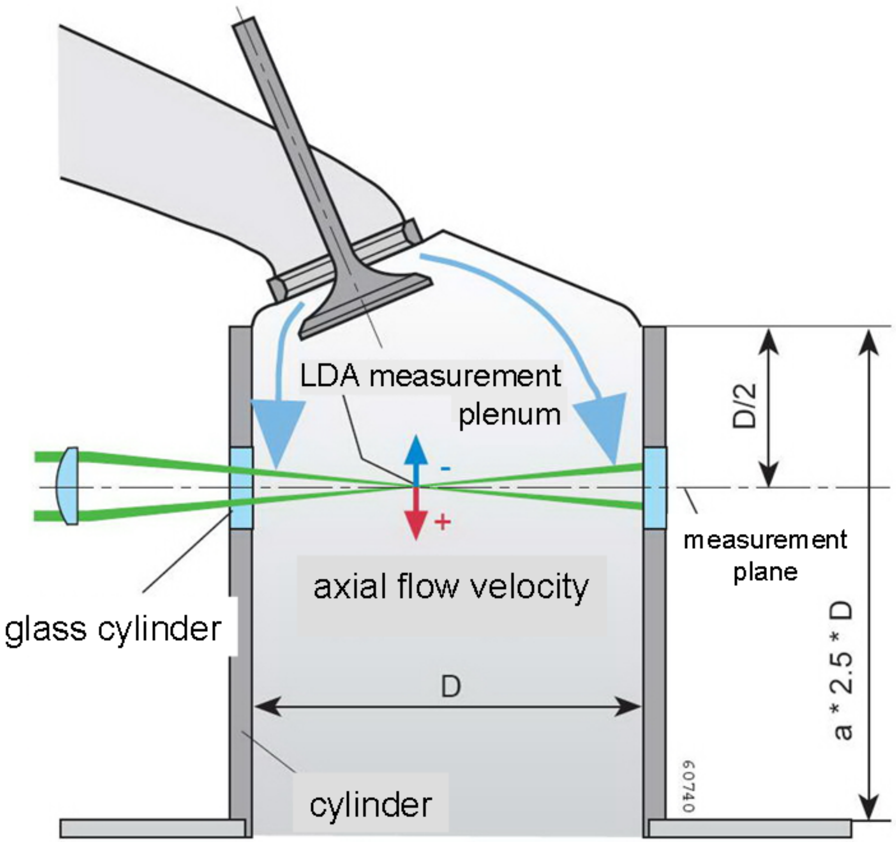


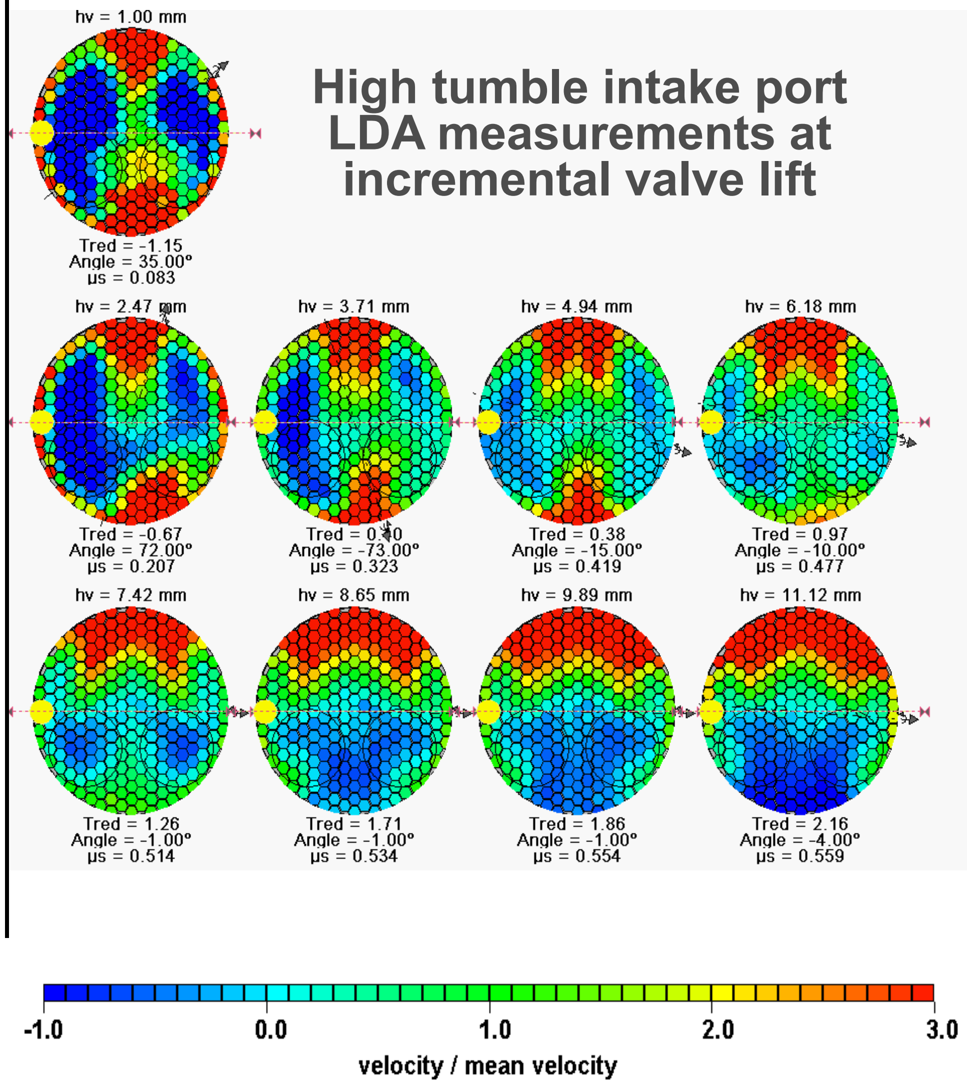

- Simultaneous use of detailed numerical simulations, optical, single and multi-cylinder engine investigations makes this a unique approach
  - 1-D modeling (GT-Power) used to determine initial cam timings and turbocharger match.
  - 3-D CFD modeling, optical engine testing, and conventional single cylinder engine testing used to optimize fuel spray, piston bowl geometry, and in-cylinder charge motion.
  - Use of multi-cylinder engine to develop cam event durations, variable cam timing strategy, compression ratio, turbocharger matching, cooled EGR system and air induction system.
  - Engine mapping used to develop vehicle level projections of performance and fuel economy for various driving cycles.

# FY08 Technical Accomplishments

- Completed optical and single cylinder investigations of fuel spray pattern, piston bowl geometry and in-cylinder charge motion
- Completed design, procurement and build of multi-cylinder turbocharged dual fuel engines capable of 150 bar peak pressure
- Installed and started testing a multi-cylinder engine in a dynamometer test cell
- Completed preliminary vehicle level simulations of fuel economy and performance of single and E85 optimized dual fuel engines

# High Tumble Port Development - LDA Rig




**High tumble improves mixture preparation and provides combustion efficiency improvements**

**LDA measurement helps ensure tumble field is centered for symmetric flame propagation**

# Optical Engine
## Optical Investigation Techniques

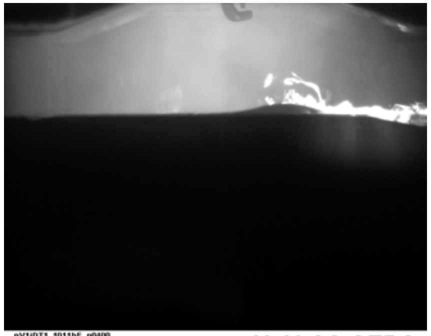
Planar Double Sided LIF Image

Flame Image

Pictures from Combustion Chamber after Measurement
1000rpm WOT, injector DT1, piston v1

Raw Image

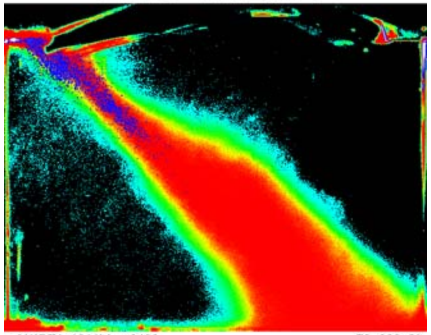
240.0° CA BTDC



40.0° CA ATDC

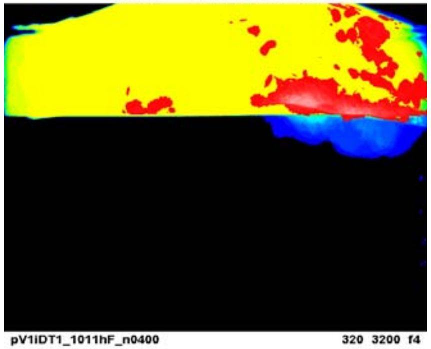
Statistical Image Evaluation

240.0° CA BTDC



pV1iDT1_1011hL_v2400 72 200 f4

40.0° CA ATDC



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Piston Top

Glass liner

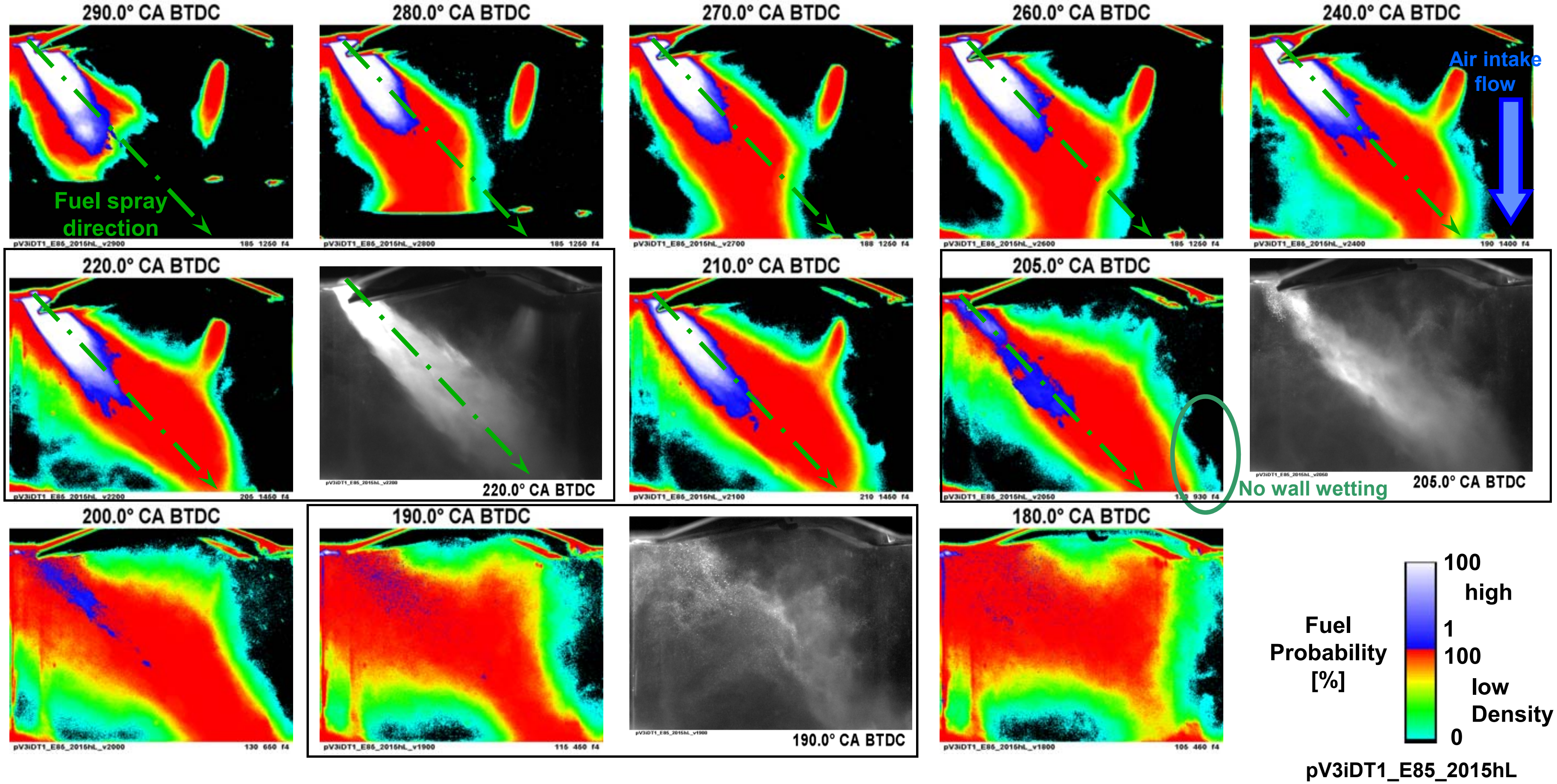
Glass liner framing

**The optical engine is used to optimize mixture preparation, eliminate wall wetting and optimize catalyst heating and cold start**

# Optical Engine

## 2000 rpm Full Load, Ethanol, LIF Images

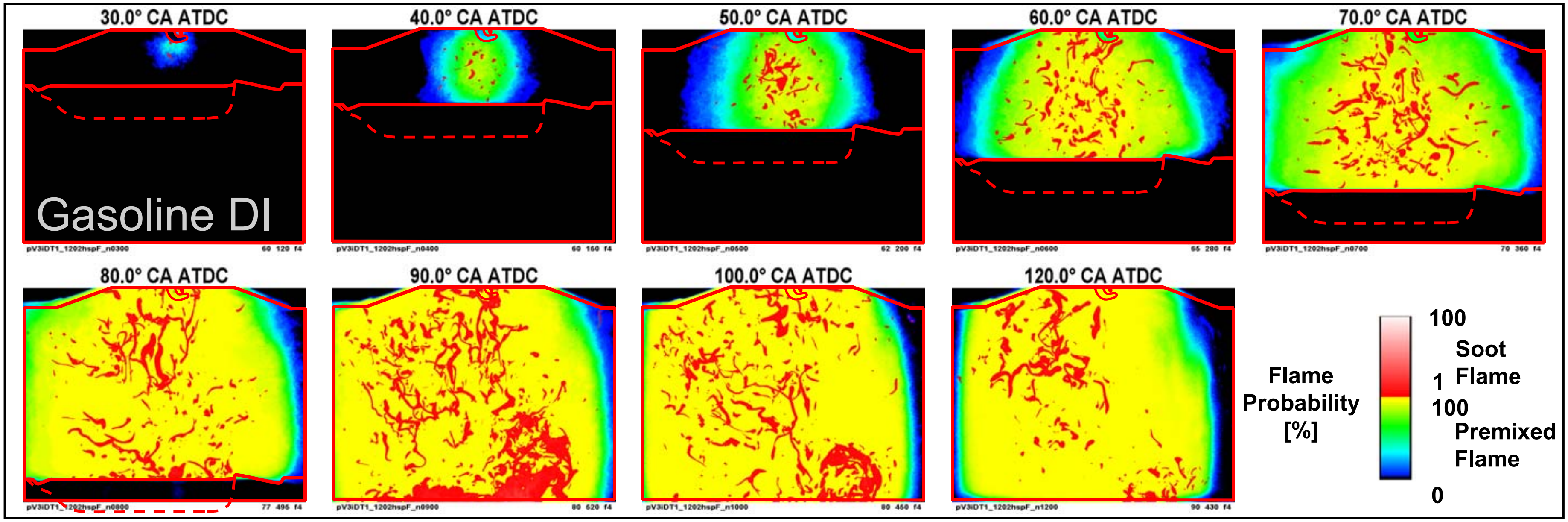
Satisfactory full load mixture preparation even with increased E85 flow rates. Significant beneficial fuel spray/air motion interaction even at low speed where air motion is low leading to no wall wetting issues.

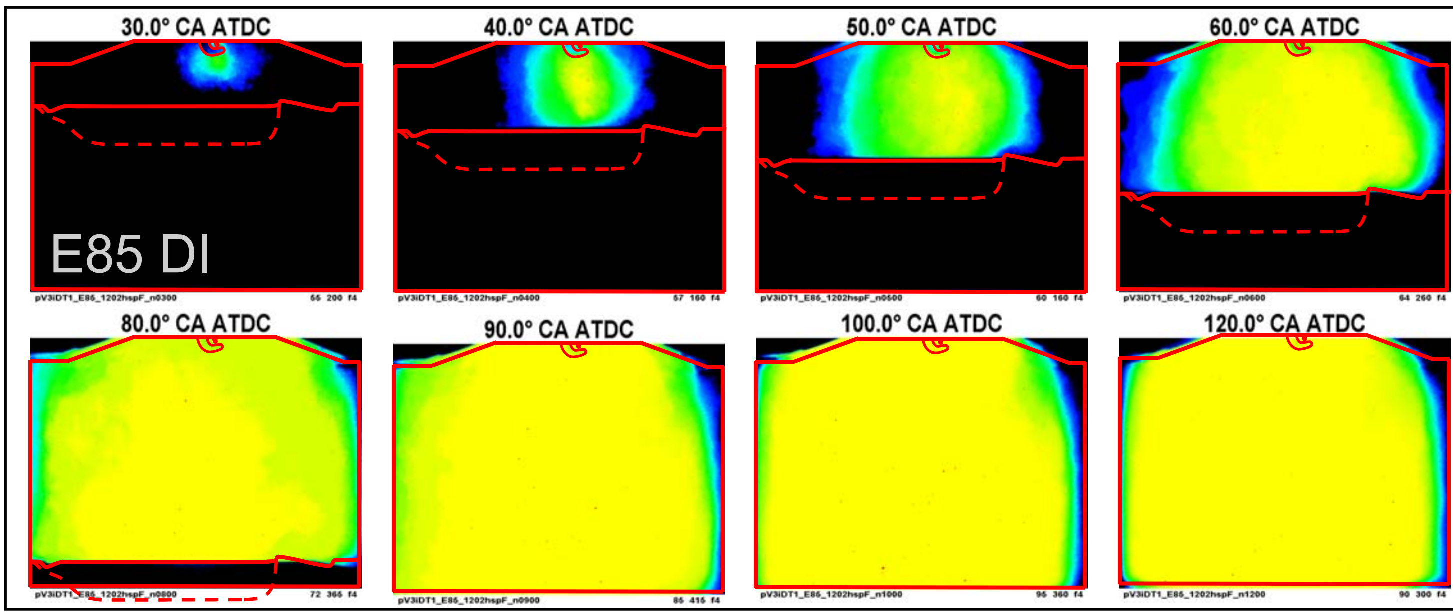



| Injector | Piston | Speed [rpm] | Mode | Valve Timing Exh. | Valve Timing Int. | AIP [kPa] | FRP [MPa] | SOI1 [BTDC] | DOI1 [ms] | EOI2 [BTDC] | DOI2 [ms] | SA [BTDC] | IMEP [MPa] | StD [kPa] | CO [% vol] | Optical Method |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DT1 | V 3 | 2000 | FL EtOH | 20 | -10 | 180 | 15 | 300 | 7.0 | - | - | -3 | 1.5 | 59 | 1.4 | LIF |

# Optical Engine - Split Injection for Catalyst Heating

## Comparison of Gasoline & E85 Flame Images

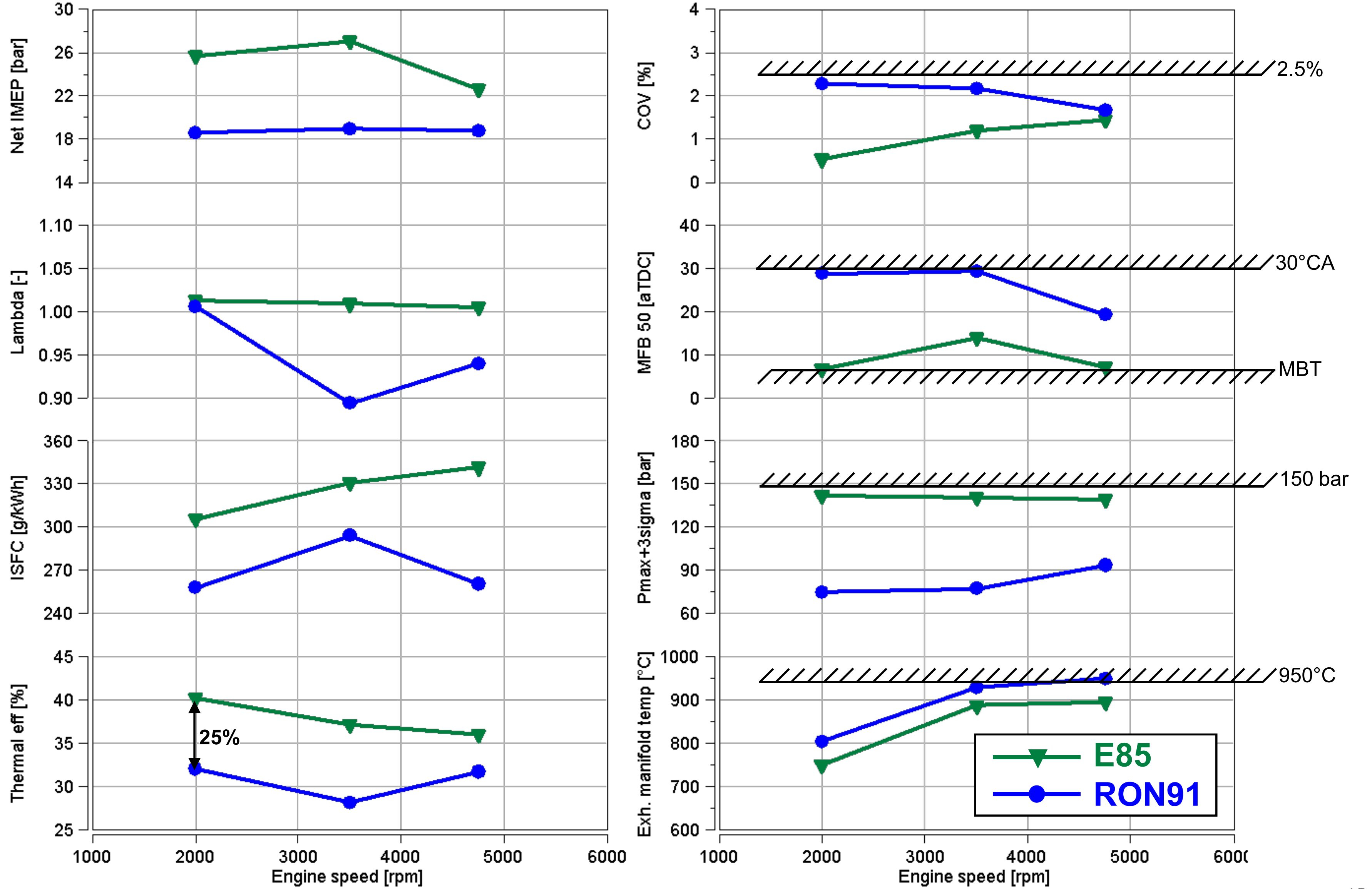



Significantly reduced smoke with E85 (oxygenated fuel) more calibration freedom, increased efficiency

# Single Cylinder Engine
## Ethanol Full Load Benefits - E85 vs. RON91

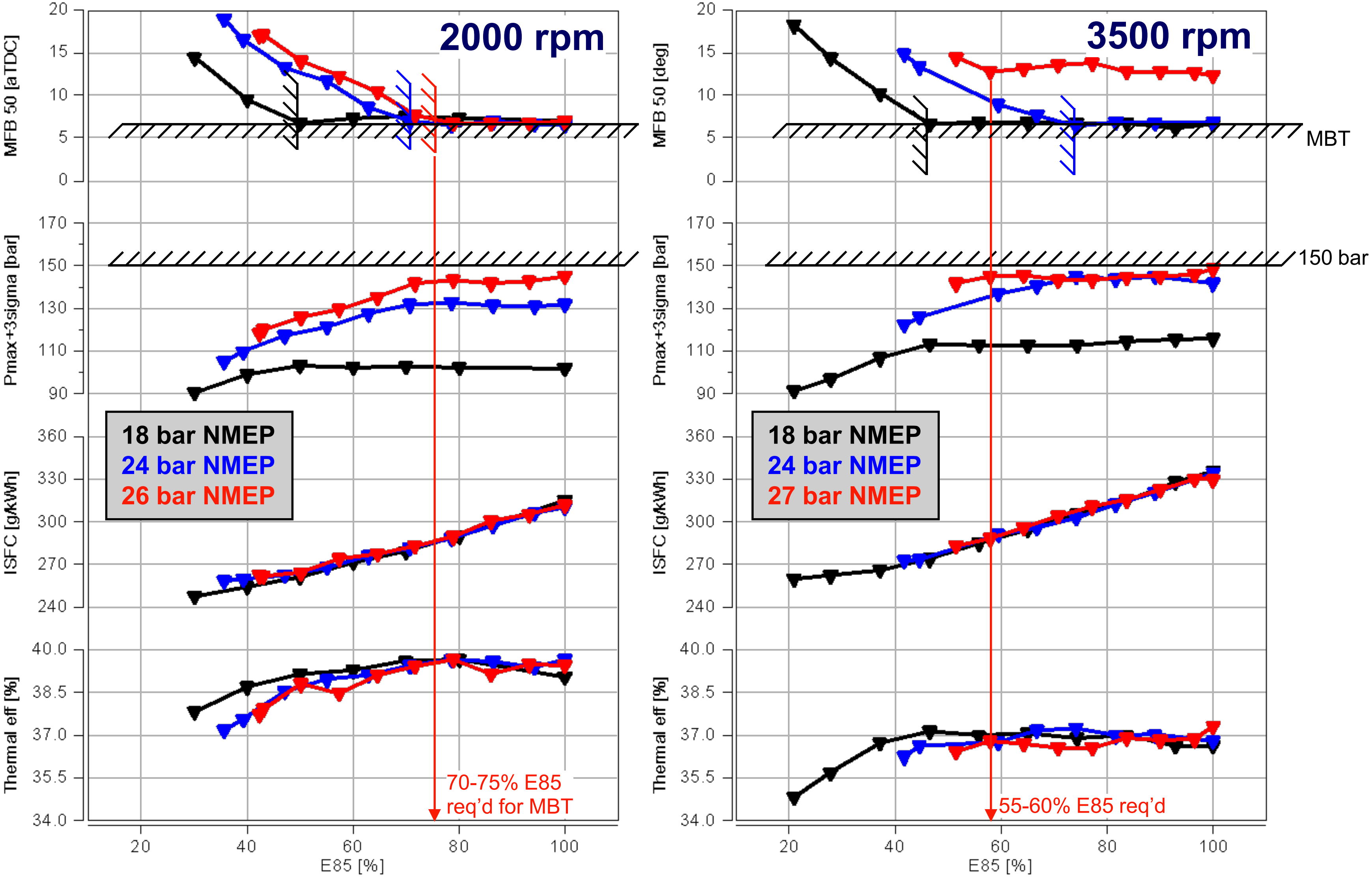
**DI E85 operation permits MBT ignition (where not peak pressure limited) without requiring fuel enrichment even at much higher loads than gasoline. This leads to significant efficiency increase!**



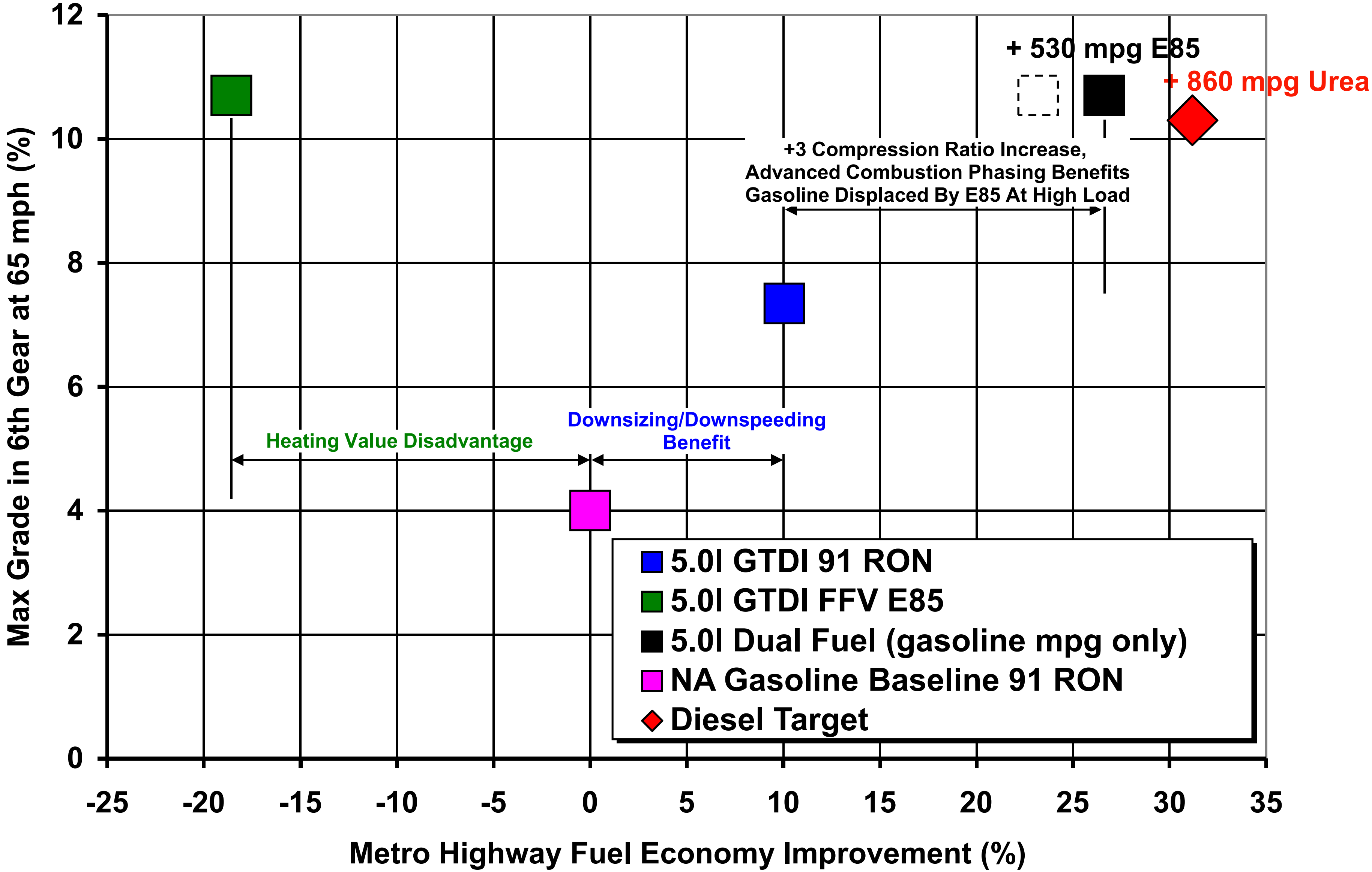
# Single Cylinder Engine

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

**Less than 100% E85 DI required to hold MBT ignition at high BMEP – minimizes E85 consumption increasing E85 range. Reduced E85 requirement when $P_{max}$ limited at higher speeds.**



# Cycle Simulation Results
## Dual Fuel Optimized E85 Engine vs. Competitors –
## F-Series Preliminary Results Based on Estimated Fuel Maps



# Future Work

- Cam timing and turbocharger matching optimization by completing multi-cylinder engine dynamometer development for both FFV and dual fuel engines
- Multi-cylinder full load performance and fuel efficiency at vehicle mapping points for FFV and E85 optimized dual fuel engines
  - Dual fuel evaluation at 12:1 compression ratio
- Cold starting strategy for E85 optimized dual fuel engine
- Mapping the FFV and E85 optimized dual fuel engines
- Evaluation of vehicle level attributes for the FFV and E85 optimized dual fuel engines

# Summary

- The E85 optimized engine provides improved efficiency via higher compression ratio and increased BMEP which allows greater levels of down-sizing and down-speeding.
- The dual fuel concept significantly leverages the use of available ethanol in reducing gasoline consumption.
- The project is on track technically. All deliverables for BP1 have been completed and those for BP2 will be completed by May 31.
- The E85 optimized engine and the dual fuel concept are logical extensions of Ford’s “EcoBoost” strategy.
- Plans for 2009 include completion of multi-cylinder engine development and projection of vehicle level fuel economy and performance.