E85 Optimized Engine

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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)**

- ✔ Overall engine system definition including cylinder head architecture, boost system configuration, fuel injection system and engine structure
- ✔ Analytical predictions of engine full load performance and vehicle fuel efficiency for FFV and E85 optimized dual fuel engines
- ✔ 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)**

- ✔ Completion of design and analysis of multi-cylinder engine components
- ✔ 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
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.
The optical engine is used to optimize mixture preparation, eliminate wall wetting and optimize catalyst heating and cold start.
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.
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!
Less than 100% E85 DI required to hold MBT ignition at high BMEP – minimizes E85 consumption increasing E85 range. Reduced E85 requirement when $P_{\text{max}}$ limited at higher speeds.
Cycle Simulation Results
Dual Fuel Optimized E85 Engine vs. Competitors – F-Series Preliminary Results Based on Estimated Fuel Maps

Metro Highway Fuel Economy Improvement (%)

Max Grade in 6th Gear at 65 mph (%)

-3 Compression Ratio Increase, Advanced Combustion Phasing Benefits
Gasoline Displaced By E85 At High Load

Heating Value Disadvantage

Downsizing/Downspeeding Benefit

5.0l GTDI 91 RON
5.0l GTDI FFV E85
5.0l Dual Fuel (gasoline mpg only)
NA Gasoline Baseline 91 RON
Diesel Target

+ 530 mpg E85
+ 860 mpg Urea
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
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.