E85 Optimized Engine

Ford Motor Company
Subcontractors:
AVL
Ethanol Boosting Systems

A. Agarwal, Principal Investigator
R. Stein, Presenter

2008 DOE Merit Review
February 27, 2008

Outline

- Purpose of work
- Approach
- Barriers
- Performance Measures and Accomplishments
- Technology Transfer
- Plans for Next Fiscal Year
- Summary

Purpose of Work

- For a F-series truck with a spark ignition engine optimized for E85, demonstrate an improvement of energy consumption of 15 - 20% on typical drive cycles compared to a production gasoline engine.
- Meet at least ULEV II / Tier II Bin 5 emissions.
- Develop and assess the Ethanol Boosting Systems (EBS) engine concept for on-demand direct injection of ethanol.

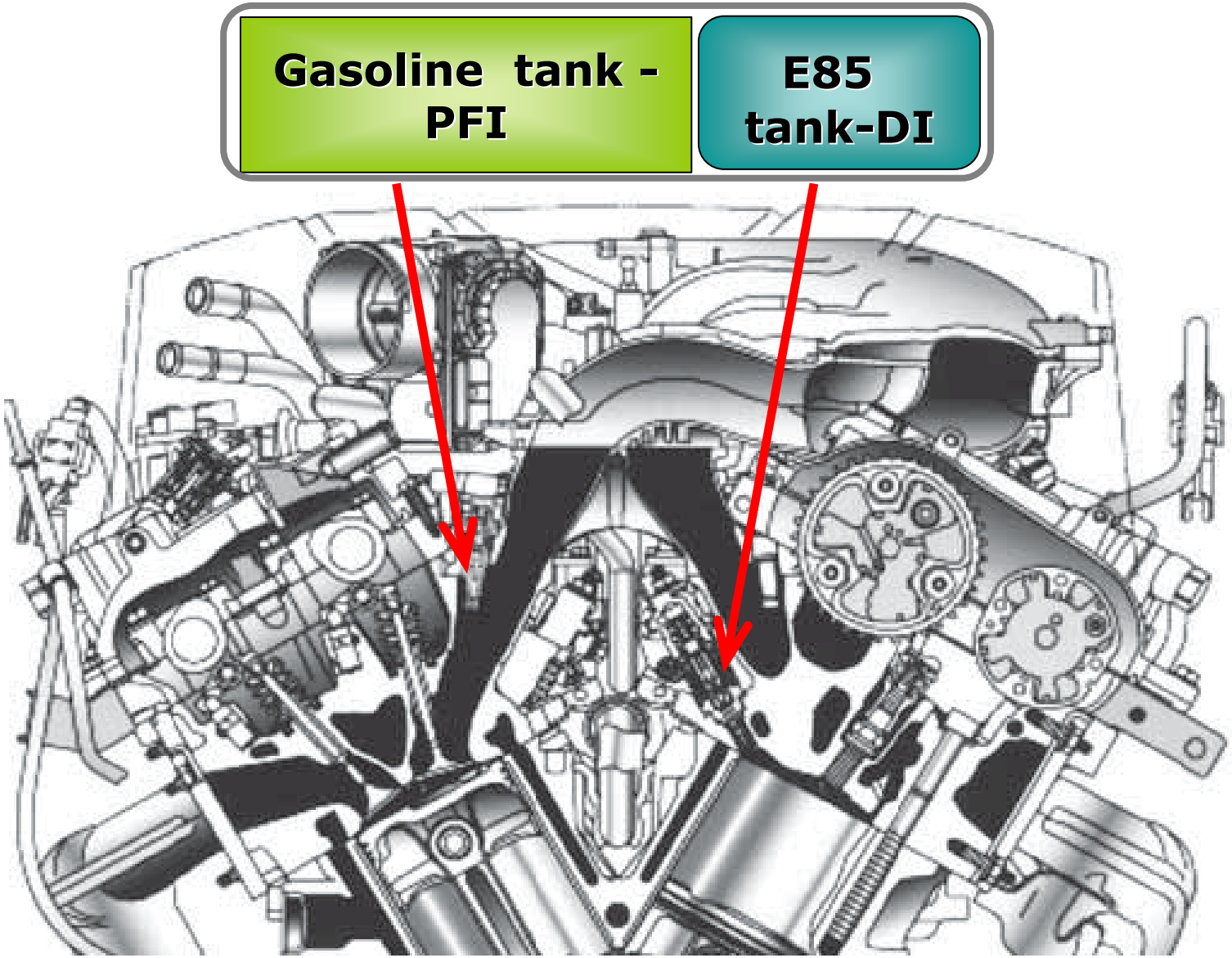
Approach - Overall

- Ethanol is a superb fuel for highly turbocharged engines due to its high octane and high heat of vaporization.

- Approach for reducing fuel consumption with ethanol:
  - Downsized, turbocharged, high compression ratio V8 engine with high low-end and mid-range torque.
  - Combine with optimized transmission drive ratios (down-speeding).

- Scope of work includes an overlay of the Ethanol Boosting Systems (EBS) concept.

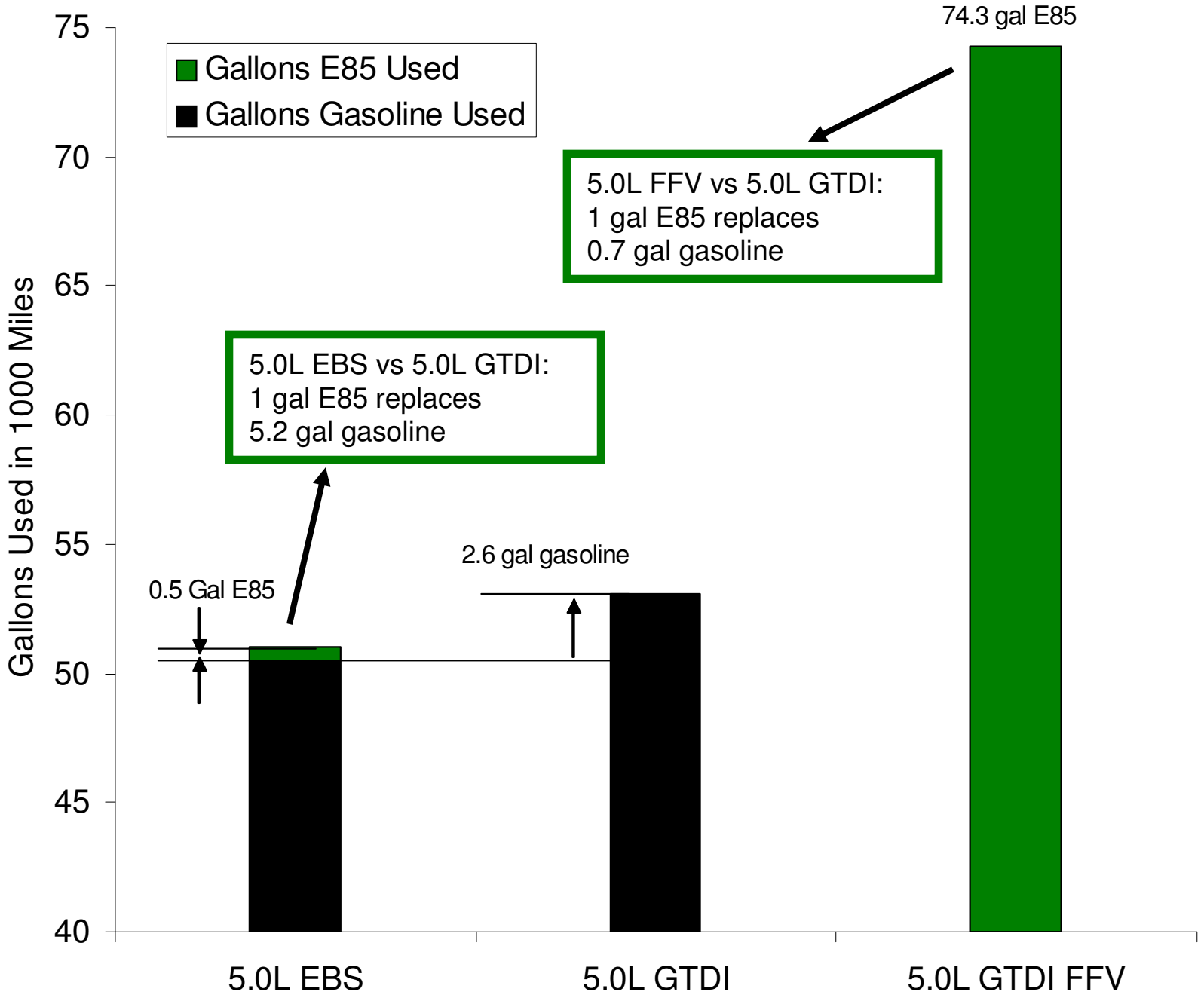
EBS: Gasoline Port Fuel Injection and E85 Direct Injection in the Same Engine



EBS Concept
Potential Environmental Impact

- E85 is only used as required at high loads to avoid knock.
  - Allows the beneficial impact of using the available E85 to be applied over a much broader number of vehicles.
- Efficiency of using gasoline is improved by using a high compression ratio downsized engine.
  - Leverages the effect of the available ethanol in reducing gasoline consumption.

Leveraging of E85 Use with EBS Concept on M-H Cycle



Barriers

Barriers:

- **Performance with gasoline:** Maintaining good functionality on gasoline with an engine optimized for operation on ethanol.
- **Boost system design:** Optimization of turbocharger function on the V8 engine with its uneven firing order on each bank.
- **Emissions:** Achievement of emission levels on E85 with turbochargers.
- **Engine structure:** Design of an engine structure capable of the high peak cylinder pressures required for an engine optimized for ethanol.
- **Packaging:** Packaging of turbochargers on a V8 engine in the vehicle.

Non-technical barriers:

- Availability of E85.
- For EBS, customer acceptance of filling two fuel tanks.

Approach – Engine Design and Optimization

- **Cam and turbocharger selection:** 1-Dimensional engine modeling (GT-Power) to determine initial cam timings and turbocharger matching.
- **Combustion system optimization:** 3-Dimensional CFD modeling, optical engine testing, and conventional single cylinder engine testing to optimize fuel spray, piston bowl geometry, and in-cylinder charge motion.
- **Multi-cylinder engine development:** Development of cam event durations, variable cam timing strategy, compression ratio, turbocharger matching, cooled EGR system, air induction system, etc. on multi-cylinder engines.
- **Vehicle projections:** Engine mapping to develop vehicle level projections of performance and fuel economy for various driving cycles.

Performance Measures/Technical Accomplishments/ Progress/Results

Budget Period 1 Milestones

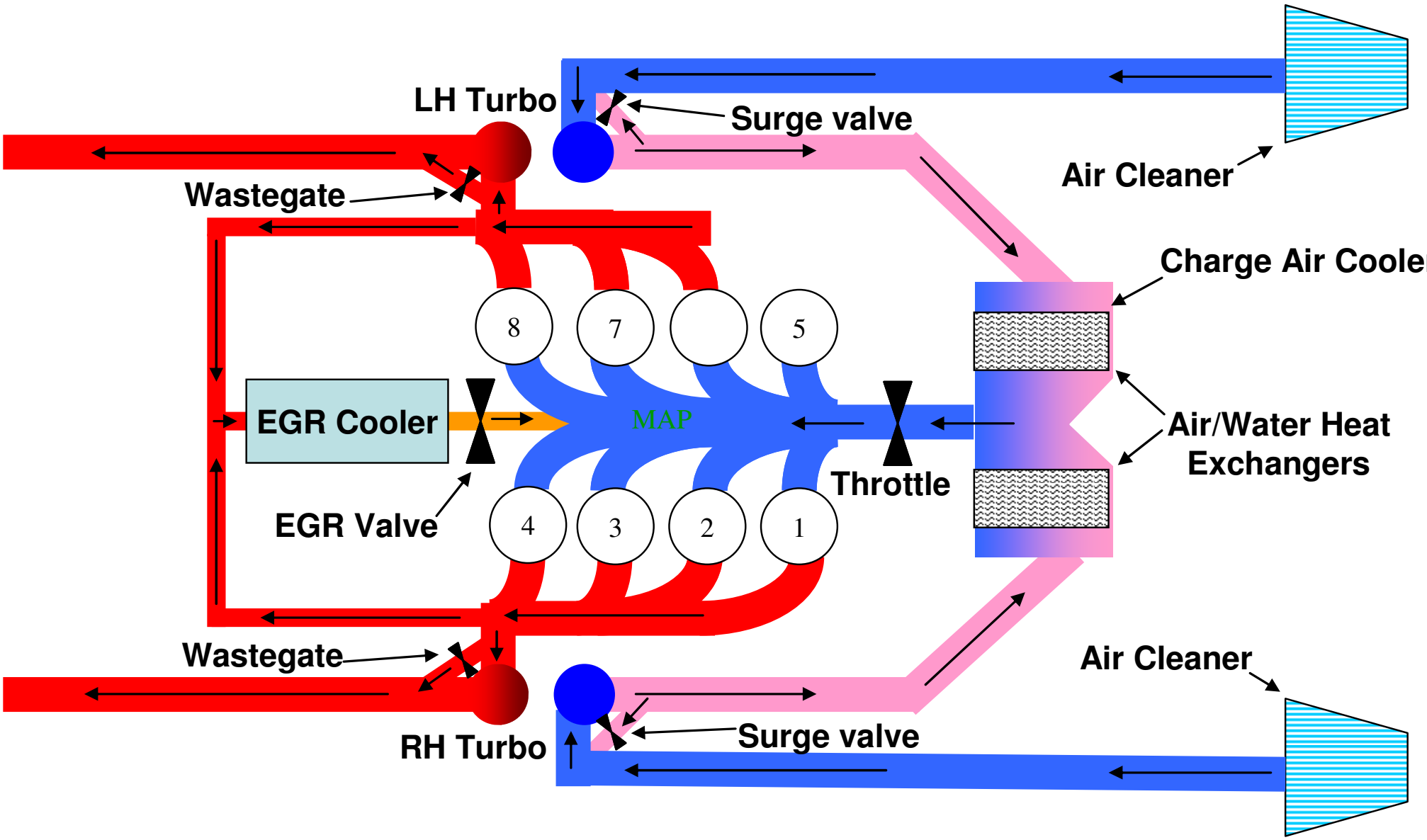
Phase 1: Oct 1, 2007 to Dec 31, 2007

- Engine system definition, including:
  - Cylinder head architecture
  - Boost system configuration
  - Fuel injection system
  - Engine structure
- Analytical predictions of engine full load performance and vehicle fuel efficiency for E85 optimized FFV and EBS engines.
- Component design for transparent and conventional single cylinder engines.

E85 Optimized Engine Definition

- Cylinder head architecture
  - Side direct injector location
  - Roller finger follower valvetrain
  - Twin independent variable cam timing
- Boost system configuration
  - Twin turbochargers with wastegates
- Fuel injection system
  - Two high pressure pumps driven by intake camshafts
  - PFI to enable EBS concept
- Engine structure
  - 150 bar peak cylinder pressure capable
    - Compacted graphite iron block
    - Oil gallery cooled pistons
    - Increased bolt diameters

Air System Layout



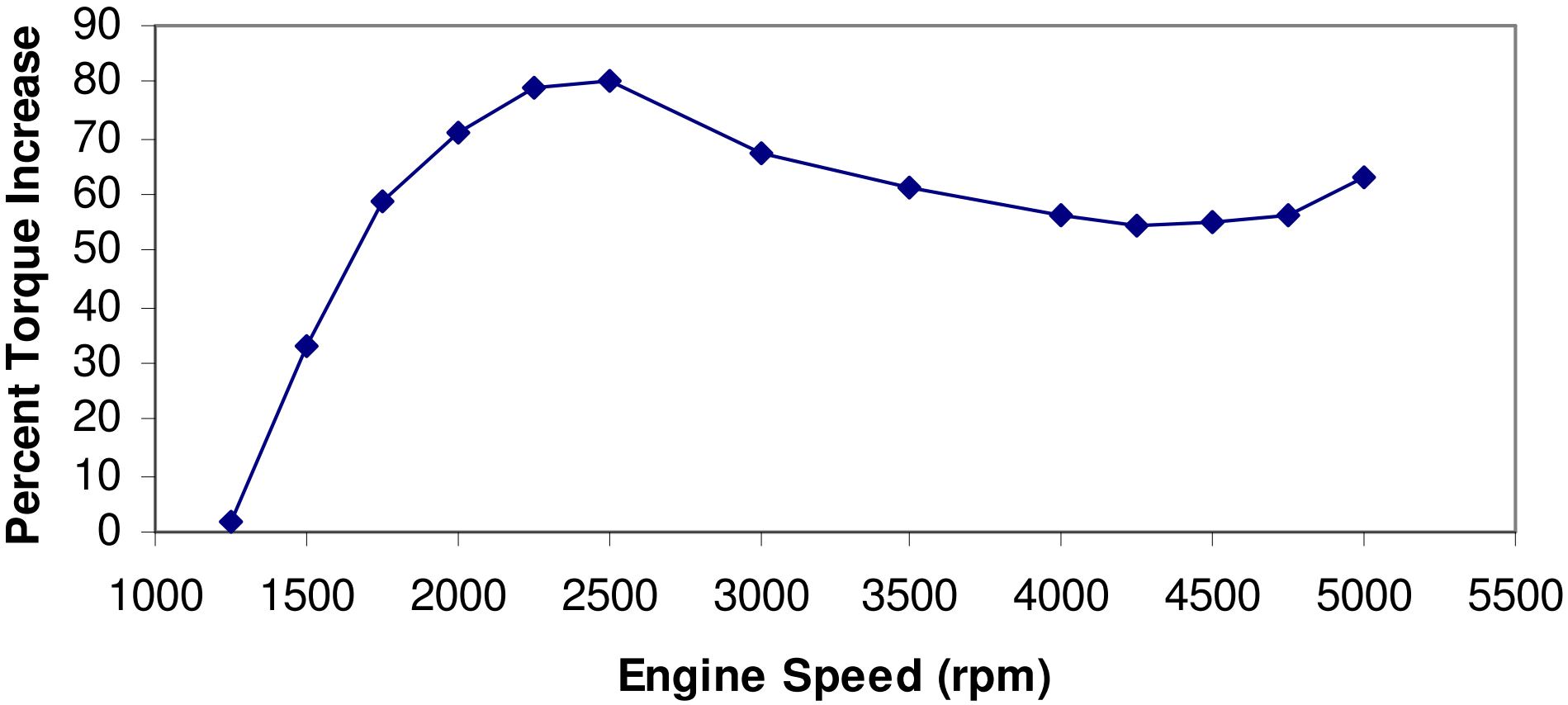
Performance Measures/Technical Accomplishments/ Progress/Results

- 1-Dimensional modeling (GT-Power) of boost system to determine initial cam durations and turbocharger match completed.
- Projections of vehicle fuel efficiency and full load performance completed. Compared to production gasoline engines:
  - Fuel efficiency is ~15 – 20% improved for various drive cycles.
  - Full load performance is significantly improved, and comparable to production diesel engines.
- 3-Dimensional CFD modeling of fuel spray, piston bowl, and in-cylinder charge motion interaction completed.
- Design of optical engine and conventional single cylinder components completed.
- Design of multi-cylinder components in progress.

Full Load Engine Performance Comparison

E85 Optimized Engine

E85 Optimized Engine vs Production Gasoline Engine

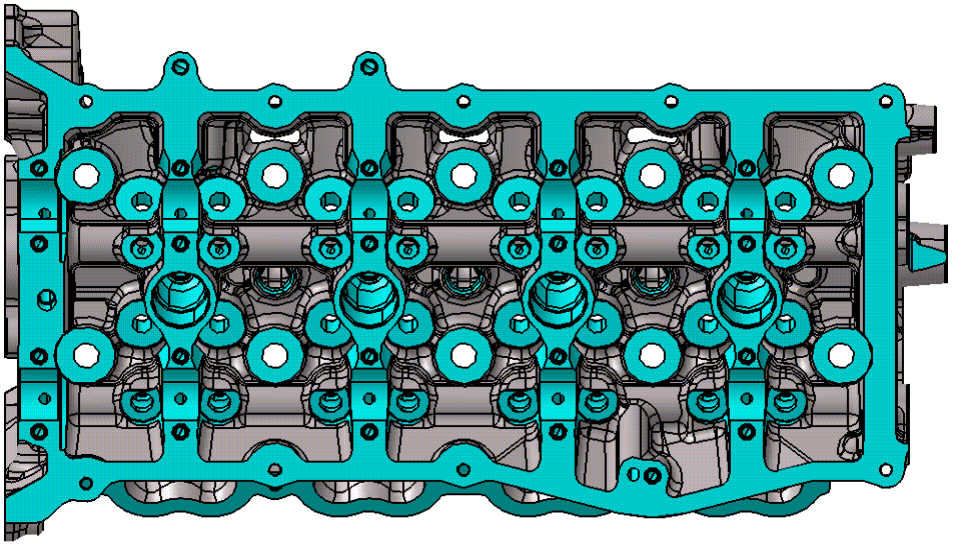


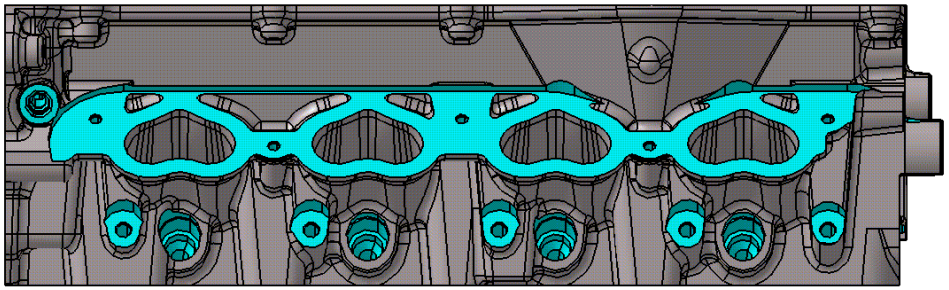
Single Cylinder Engine on Dynamometer

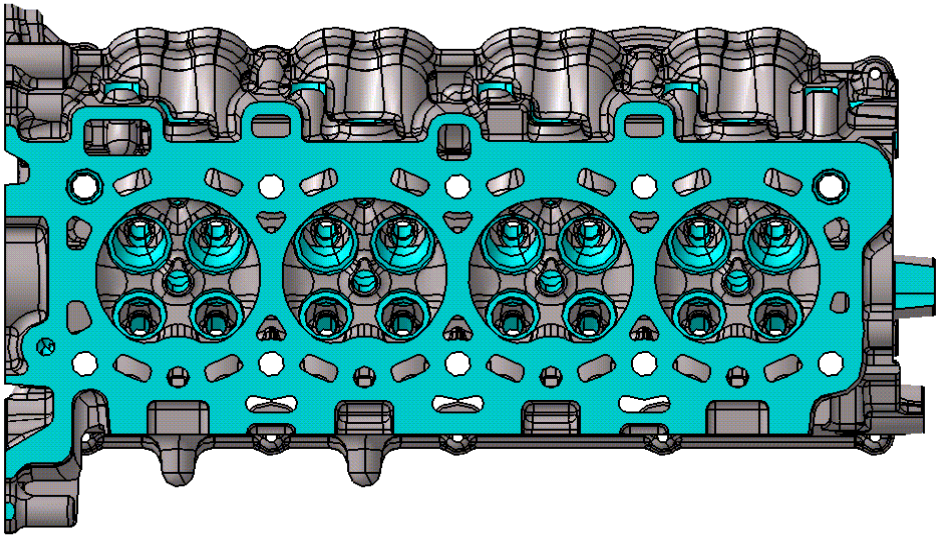
E85 Optimized Engine

Cylinder Head

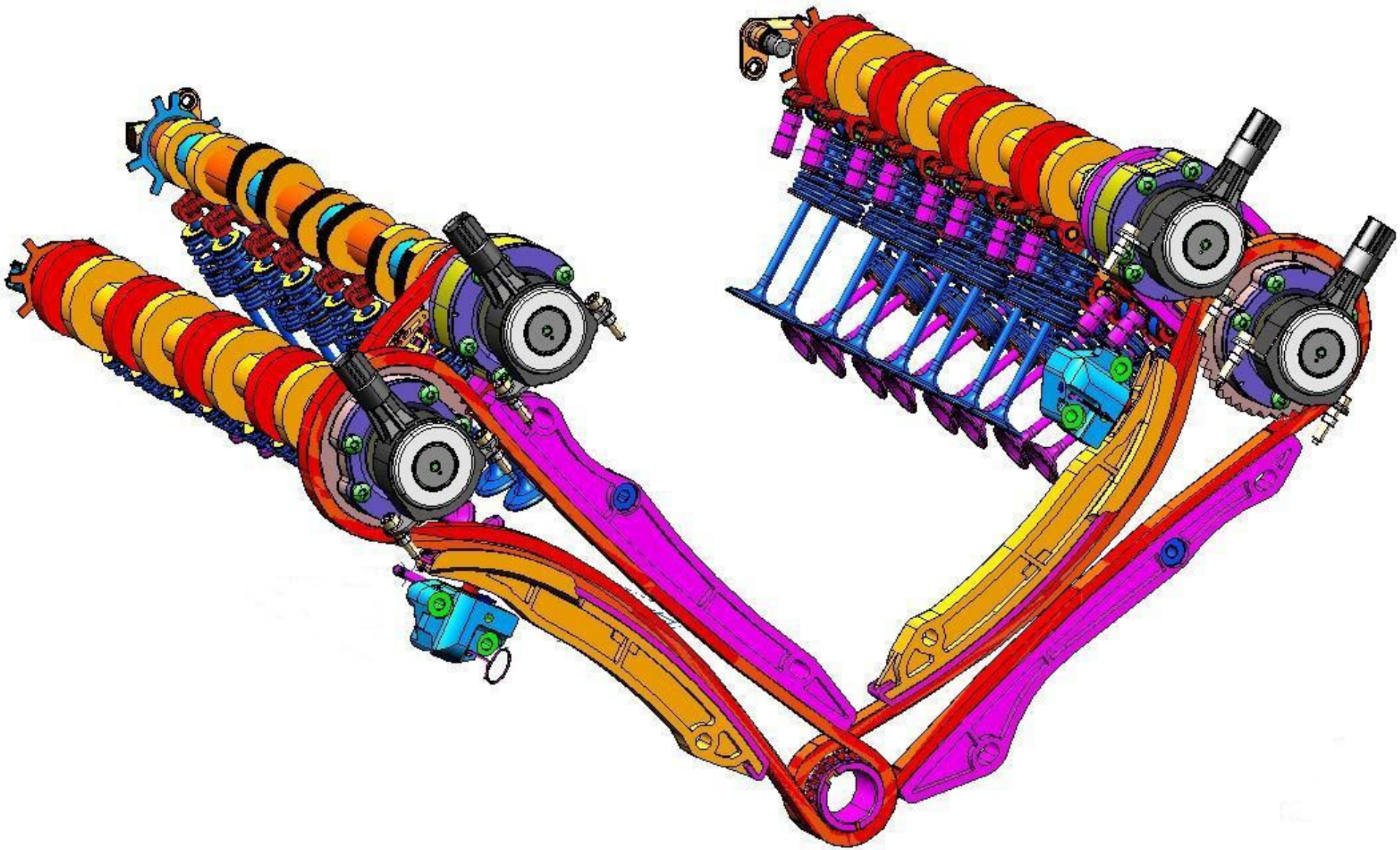
E85 Optimized Engine







Valvetrain and Cam Drive



Technology Transfer

- The E85 Optimized Engine technology being developed is a logical extension of Ford's announced "EcoBoost" engine technology strategy.

- The EBS technology overlay being developed can be viewed as a further extension of the "EcoBoost" strategy. The EBS technology results in significant leveraging of using the available E85 in reducing gasoline consumption.

Activities for Next Fiscal Year

Budget Period 1 Milestones

Phase 2: Jan 1, 2008 to Mar 31, 2008

Combustion system optimization for operation on E85 based on optical and conventional single cylinder tests.

- Intake port design (in-cylinder charge motion)
- Injector fuel spray
- Piston bowl
- Intake valve masking

Activities for Next Fiscal Year

Budget Period 2 Milestones
Phase 3: 4/1/2008 to 12/31/2008

- Design and analysis of multi-cylinder engine components.
- Multi-cylinder engine parts procured and engines built.
- Base engine optimization completed based on multi-cylinder engine dynamometer development and modeling studies.
  - Cam timing and variable cam timing strategy
  - Compression ratio
  - Turbocharger matching
  - Minimize ethanol consumption for EBS concept

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 EBS concept overlay provides a significant leveraging effect of using the available ethanol in reducing gasoline consumption.
- 3-Dimensional CFD engine modeling is being used in conjunction with optical and single cylinder engine testing to optimize combustion parameters.
- 1-Dimensional engine modeling is being used in conjunction with multi-cylinder engine testing to optimize valve timing, variable cam timing strategy, compression ratio, turbocharger matching, etc.

Summary (continued)

- The project is on track technically and all deliverables for Phase I have been completed.
- The E85 optimized engine and the EBS concept are logical extensions of Ford's "EcoBoost" strategic technology.
- Plans for 2008 include design of multi-cylinder components; and optical single cylinder, conventional single cylinder, and multi-cylinder engine development.