Gasoline Ultra Fuel Efficient Vehicle Program Update
Directions in Engine-Efficiency and Emissions Research Conference 2012

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Ultra Fuel Efficient Vehicle (UFEV) Project

**Project Background**

- DE-EE0003258
- $14.9M total project funding
  - DOE share $7,480,582 (50%)
  - Contractor share: $7,480,582 (50%)
- Project officially began in September 2010.
- Project end date is March 31, 2014
Ultra Fuel Efficient Vehicle (UFEV) Project

**Project Objective**

- Develop, implement and demonstrate fuel consumption reduction technologies with a partnership of OEM, Tier 1 supplier, consultants and universities.

- Targeted fuel economy improvement of > 25% vs. PFI baseline.

- Phase 1 of the project concentrates on fuel efficiency improvements using EMS, GDi, and advanced valvetrain products in combination with technologies to reduce friction and parasitic losses.

- Phase 2 of the project will develop and demonstrate improved thermal efficiency from in-cylinder combustion with Gasoline Direct Compression Ignition (GDCI).
Ultra Fuel Efficient Vehicle (UFEV) Project Collaboration with Other Institutions

Project Lead

Auburn Hills, Michigan

Henrietta, New York

Superior Township, Michigan

Detroit, Michigan

Madison, Wisconsin

University of Wisconsin

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Project Plan – With a Focus on Hardware

<table>
<thead>
<tr>
<th>Phase 1</th>
<th>Phase 2</th>
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</thead>
<tbody>
<tr>
<td>April 2010</td>
<td>June 2012</td>
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</table>

**Phase 1 Loss Reduction Vehicle**
- GDCI SCE1
- GDCI SCE2
- GDCI Multi-Cylinder
- HCCI MCE

**Phase 1 Electronics & Controls Vehicle**
- Applicable Technologies

**Phase 2 Vehicle**
- Phase 1 Vehicle Demo
- Phase 2 Vehicle Demo

**Phase 2 Engine Development**
- April 2010
- March 2014
Phase 1- Systems-Level Approach to Fuel Economy Improvement Technologies

- Phase 1 Loss Reduction Vehicle
- Phase 1 Electronics & Controls Vehicle
- Phase 2 Vehicle Demo
- Phase 2 Vehicle

- GDCI SCE1
- GDCI SCE2
- GDCI Multi-Cylinder
- HCCI MCE

Timeline:
- April 2010
- June 2012
- March 2014
Phase 1, Vehicle 1 (Reduced Parasitic Loss)

**Approach / Strategy**

- 2011 Sonata 6MT, 2.4L GDi Theta II

**Technologies on Vehicle:**

- **Camshaft Rollerization**
  - ~1% via rollerized camshaft

- **Optimized Oil Pump**

- **Crank Rollerization**
  - ~3% via Rollerized Cranktrain

- **Engine Downsampling**
  - 5000 RPM
  - Revised cam shafts
  - Coated Piston Rings
  - Low Tension Oil Control Rings
  - Coated Piston Skirt
  - ~3% via downsampling and friction reduction

- **Exhaust Heat Recovery System**
  - ~1-2% via exhaust heat recovery

- **Cooled EGR**
  - ~3% via cooled EGR

*Targeted fuel economy improvement vs. PFI baseline vehicle shown in italics*
Phase 1, Vehicle 1 (Reduced Parasitic Loss)

Hardware and Testing

- Vehicle Build and Integration of Technologies
  - The Phase 1 Parasitic Loss Demonstration Vehicle completed build, calibration and test.

HATCI low friction technologies

Delphi heat recovery and friction reduction controls

HATCI heat recovery system
Phase 1, Vehicle 1 (Reduced Parasitic Loss) Test Results

Fuel Economy Improvement

<table>
<thead>
<tr>
<th>Category</th>
<th>Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combined</td>
<td>13.1%</td>
</tr>
<tr>
<td>Highway</td>
<td>13.9%</td>
</tr>
<tr>
<td>City</td>
<td>12.6%</td>
</tr>
</tbody>
</table>

Estimated Contributions by Technology

- Rollerization
- Two Step Oil Pump
- Engine Downspeeding / Friction Reduction
- Exhaust Heat Recovery
- Cooled EGR
- Gasoline Direct Injection
Phase 1, Vehicle 2 (Engine Management System) 
Approach / Strategy

- 2011 Sonata 6MT, 2.4L GDi Theta II
- Technologies on Vehicle:

  - Cooled EGR
  - Variable Valvetrain
  - EMS Control Algorithms
  - EGR cooler-valve
  - ePhaser Controls
  - GDi Pump
  - GDi Injector
  - GDi Rail
  - Stop / Start Controls
  - ECM with integrated GDi controls
  - Calibration
  - Demonstrated on Hyundai Theta GDi engine in a 2011 Sonata

*Targeted fuel economy improvement vs. PFI baseline vehicle shown in italics
**Vehicle Build and Integration of Technologies**

- The second Phase 1 demonstration vehicle has been built and all calibration and testing completed.
Phase 1, Vehicle 2 (Engine Management System) Test Results

Fuel Economy Improvement from PFI Baseline

Estimated Contributions by technology

- Cooled EGR
- GDI and EMS
- ePhaser / 2 Step
- Stop Start

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Minimal technology overlap between the two vehicles suggests that the technologies could be combined into a single vehicle which would benefit from the complementary technologies.
Project Plan – With a Focus on Hardware

Phase 1
- Phase 1 Loss Reduction Vehicle
- Phase 1 Electronics & Controls Vehicle

Phase 2
- Phase 2 Vehicle
- Phase 2 Engine Development
- Applicable Technologies

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GDCI SCE1  GDCI SCE2  GDCI Multi-Cylinder

HCCI MCE
Phase 2 - Gasoline Direct-Injection Compression-Ignition (GDCI)

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Phase 2 Engine Development

April 2010 to June 2012

Phase 1 Vehicle Demo

Applicable Technologies

Phase 2 Vehicle Demo

March 2014
Phase 2 Vehicle (GDCI) Approach / Strategy

- 2011 Sonata 6MT, 2.0L GDi Theta Turbo
- Technologies on Vehicle:

  - GDCI Low Temperature Combustion Process and Controls
  - Parasitic loss reduction technologies from Phase 1 (where applicable)
  - ~25% targeted fuel economy improvement
  - EMS Control Algorithms
  - Calibration
  - ECM
  - Boosting Systems
  - Charge Air Coolers
  - GDCI Optimized Valvetrain
  - GDi Pump
  - GDCI Optimized Injector
  - GDi Rail

Demonstrate on Hyundai Theta Turbo GDi engine in a 2011 Sonata.
Approach / Strategy  
GDCI Engine Concept

- Gasoline Partially-Premixed CI (PPCI)
- Fuel injection system
  - Central mounted injector
  - Multiple late Injections
  - GDi-like injection pressures
- Valvetrain – continuously-variable mechanical
- Advanced Engine Controls
- No classic SI knock or pre-ignition
- Boosted and down-speeded
- High CR & lean for high thermal efficiency

References:
Kalghatgi (Shell) 2005-2010
Manente & Johansson (Lund) 2007-2011
Dempsey & Reitz 2011, Ra & Reitz 2009-11, Hanson & Reitz 2009 (ERC)
Phase 2 GDCI

Hydra Single Cylinder Engine Tests with Diesel Piston

- Low ISFC achieved with very low NOx, low PM emissions and acceptable noise levels while maintaining exhaust temperatures

GDCI low-temperature combustion system enables very high efficiency and very low emissions over entire speed/load range.
Phase 2 GDCI

Injector Tests on Hydra Single Cylinder Engine (1500RPM-6bar)

- Injectors A, B, C, D & E were tested with a diesel piston
- E’ and E” were tested with a new GDCI-specific piston

Constraints
Noise < 85 dB
Pinj < 500 bar
ISNOx < 0.2 g/kWh
Smoke < 0.1 FSN
Phase 2 GDCI

Engine Design, Analysis, & Fabrication

**Strong Delphi & HATCI collaboration for first multi-cylinder GDCI engine**

- Cylinder Head Design & Packaging
- Structural Analysis & CFD
- Cylinder Head Fabrication
- Enhanced Block & Analysis
- Piston Design & Fab
Future Work
UFEV Project 2012-2013

Phase 1
- Phase 1 of the DOE project has been successfully completed

Phase 2
- **Single-Cylinder Engine Testing**: Advanced injection and valvetrain strategies will be refined over the speed load range using a project specific head.
- **Simulation**: A variety of simulation tools for injection and spray development, combustion system, and valvetrain system will be applied to achieve minimum NOx and PM emissions.
- **Multi-Cylinder Engine Testing**: MCE testing will continue throughout the project in support of powertrain integration, component refinement, controls development and calibration
- **Advanced Controls**: Advanced controls hardware and software will be developed using HIL Bench, simulation, and start cart, followed by transfer to the vehicle
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Thank-You

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Related Technical Papers

- "Development of Full-time Gasoline Direct-Injection Compression-Ignition (GDCI) for High Efficiency and Low CO2, NOx and PM", M. Sellnau et al., Aachen Colloquium Automobile and Engine Technology, October 2011

- “Gasoline Direct-Injection Compression-Ignition” M. Sellnau, SAE 2012 High Efficiency IC Engine Symposium, April 2012

- “Full-time Gasoline Direct-Injection Compression Ignition (GDCI) for High Efficiency and Low NOx and PM”, M. Sellnau et al., SAE 2012-01-0384 SAE World Congress April 2012
