

Ultra Efficient Light Duty Powertrain with Gasoline Low Temperature Combustion

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Delphi Advanced Powertrain

2015 DOE Vehicle Technologies Review
June 11th, 2015

Project ID: ACE094
DE-EE0006839



ACE094 Project Overview

Timeline

- Project start: 10/1/2014
- Project end: 9/01/2018
- Percent complete: 18%

VT Programmatic Barrier

- Improve the efficiency of light-duty engines for passenger vehicles through advanced combustion and minimization of thermal and parasitic losses.
- Project primarily addresses VT Program Barriers:
 - A: Advanced engine combustion regimes
 - B: Emission controls
 - D: Effective engine controls

Budget

- Total project funding share
 - DOE : \$9,812,865 (40%)
 - Contractor: \$14,719,297 (60%)
- Budget Period Funding
 - BP1 2014-2015 : \$2,935,672
 - BP2 2015-2016 : \$3,442,329
 - BP3 2016-2017 : \$2,158,100
 - BP4 2017-2018 : \$1,276,763

Partners

- Delphi - Project Lead
- HATCI (Hyundai America Technical Center Inc.)
- University of Wisconsin - Madison
- Oak Ridge National Lab
- Umicore

Relevance and Project Objectives

- Relevance:

- The Advanced Combustion Engine R&D (ACE R&D) subprogram supports the mission of the Vehicle Technologies Program to develop more energy-efficient and environmentally friendly technologies for highway transportation vehicles.
- This project directly addresses two of the three primary ACE R&D directions:
 - Improve the efficiency of light-duty engines for passenger vehicles and heavy-duty engines for commercial vehicles through advanced combustion research and minimization of thermal and parasitic losses;
 - Develop aftertreatment technologies integrated with combustion strategies for emissions compliance and minimization of efficiency penalty

- Project Goal

- The project will develop, implement and demonstrate a low temperature combustion scheme called Gasoline Direct-injection Compression Ignition (GDCI). The project will demonstrate a 35% fuel economy improvement over the baseline vehicle while meeting Tier 3 emissions levels.



This Project supports the Vehicle Technologies Program's goal to improve the efficiency of light-duty engines for passenger vehicles through advanced combustion and minimization of thermal and parasitic losses.

Relevance and Project Objectives

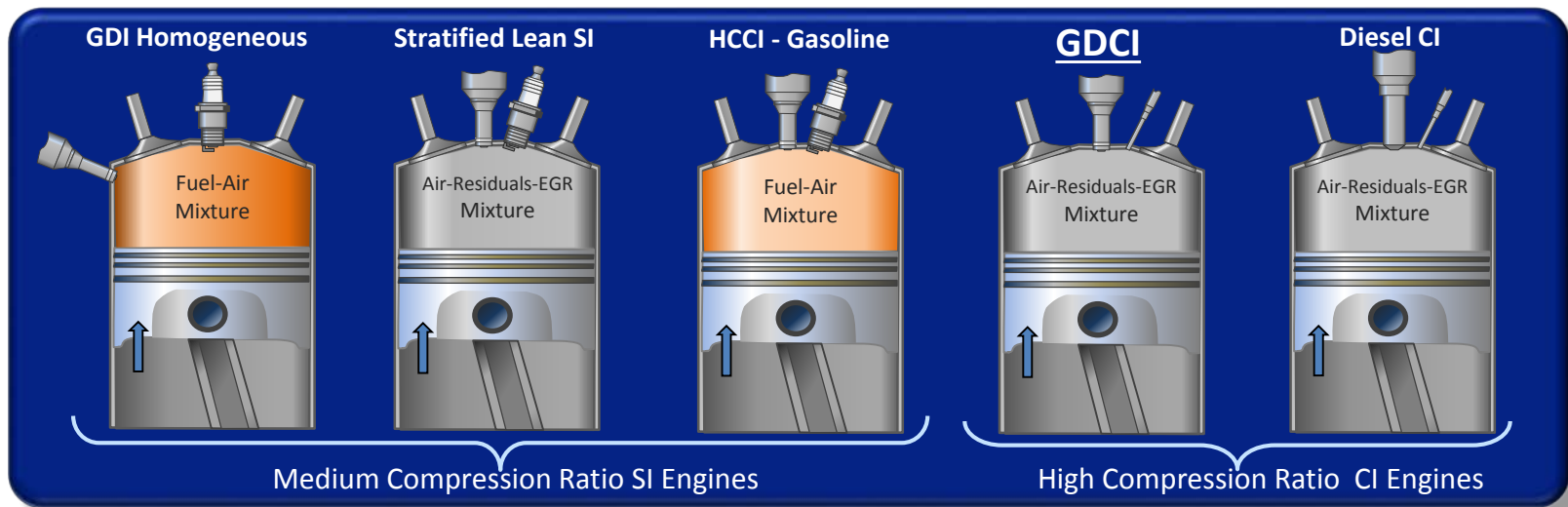
- Project Objective: Demonstrate the fuel consumption reduction capability of GDCI combustion at a vehicle level. The primary project focus is on a number of technical risks which must be overcome for a production-viable technology:
 - Development of an aftertreatment system that is effective in dealing with the low-temperature challenges of a highly efficient engine.
 - Further refinement of the GDCI combustion system to achieve near-ideal air/fuel mixture preparation for high efficiency and low HC and CO emissions
 - Demonstration of transient control with high EGR levels during real-world transient driving maneuvers and over a broader range of ambient conditions
- Objectives (October 2014 – March 2015)
 - Finalize and kick-off project teams
 - Evaluate and document GDCI baseline performance (Fuel Economy, Power and Emissions)
 - Complete first samples of Gen2 GDCI engine hardware and debug



This Project supports the Vehicle Technologies Program's goal to develop aftertreatment technologies integrated with combustion strategies for emissions compliance and minimization of efficiency penalty

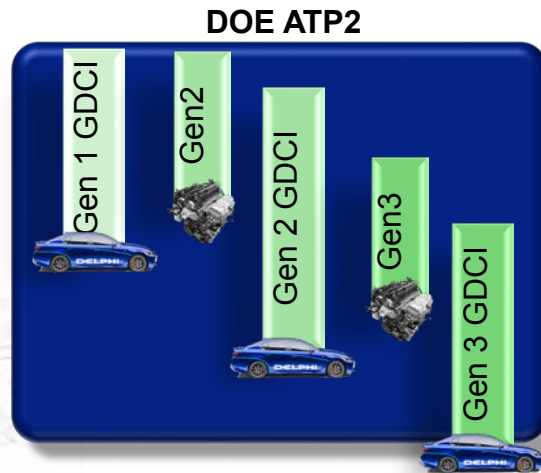
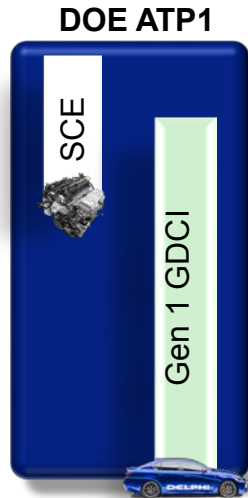
Approach / Strategy

- The project will employ a unique low temperature combustion scheme called Gasoline Direct-injection Compression Ignition (GDCI) to achieve the targeted fuel economy improvements.
 - High compression ratio with multiple late injections (similar to diesel)
 - Gasoline which vaporizes & mixes easily at low injection pressure
 - Low-temperature combustion process for Partially-Premixed Compression Ignition
- The project will develop an aftertreatment system approach that works with the low-temperature challenges of a highly efficient engine.
 - Address: system content, system architecture, combustion strategies and catalysts materials
 - Collaboration with Oak Ridge National Lab and Umicore Autocat USA



Approach / Strategy

Develop, implement and demonstrate the fuel consumption reduction capability of GDCI at a vehicle level.



2008

Is the concept viable?

2010

How to design an engine around the concept?

How to control the engine?

How to make a vehicle drivable?

2014

How to meet FE and emissions targets?

Engine design upgrades?

Engine control upgrades?

How to have the vehicle function under all operating conditions?

2018

How to meet all regulatory requirements?

How to have a production-level of performance?

Approach / Strategy: Milestones

- Milestones and go/no-go's for FY 2014 and FY 2015*
(note that project started in FY2015)

Project Decision Points				
Recipient:	Delphi			
Project:	Ultra Efficient Light Duty Powertrain with Gasoline Low Temperature Combustion			
Task Title	Milestone Type	Milestone Description	Anticipated Quarter	Status
Build Gen2 engines	Milestone	Gen2 GDCI engine assemblies built and ready for debug	Q1 2015	Complete
Engine and Vehicle Simulation	Milestone	GT Drive engine simulation completed for the Gen2 in the ATP1 vehicle	Q2 2015	Complete
ORNL characterize Gen 2 GDCI LTC emissions	Go/No-Go	Gen2 engine built and characterized - Go/No-Go for Gen2 vehicle build activities	Q3 2015	On Target
Develop and build aftertreatment for Gen2 GDCI	Milestone	High performance low temperature exhaust aftertreatment system designed and built for use on the Gen2 GDCI development vehicle.	Q3 2015	On Target

Discussed later in this presentation

GT Drive simulation complete and Gen1 GDCI engine run for true peak torque values

Gen2 engine running on dynamometer. ORNL and Delphi successfully characterized Gen1 vehicle using same tools required for this task.

Characterization of the vehicle emissions, with cold FTP, forms the basis for the projects exhaust aftertreatment work (key cornerstone of development work).

Technical Accomplishments and Progress: Background: Ultra Fuel Efficient Project EE0003258

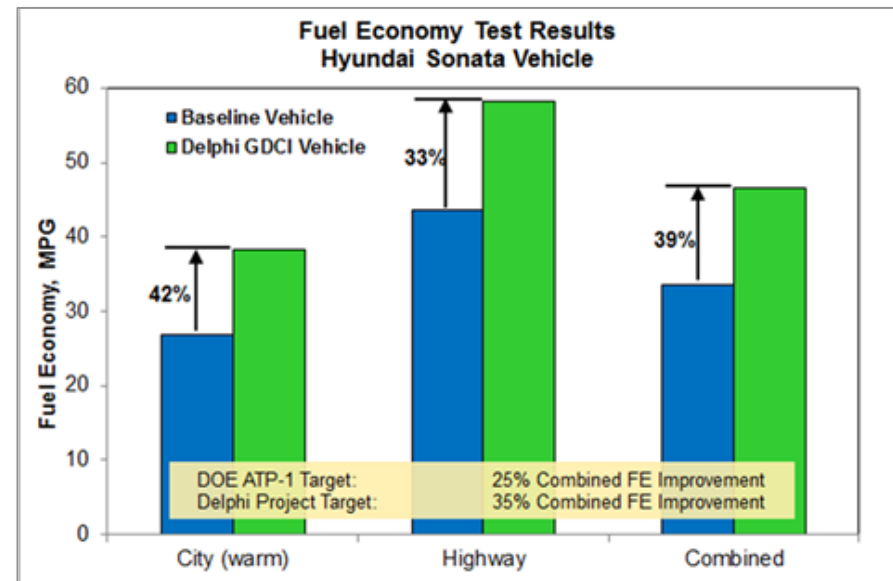
- Delphi and HATCI along with WERC demonstrated the potential of Gasoline Direct-injection Compression Ignition (GDCI) with the UFEV project which concluded in September 2014
- Project culminated in a vehicle level demonstration of 39% combined City+Highway fuel economy improvement with a warmed-up engine relative to a 2009 port fuel injected baseline vehicle (also run warm).
- While fuel economy targets were exceeded, the emissions performance target (Tier 2, Bin 2) was not met.



Gen1 GDCI engine



GDCI vehicle running FTP at Delphi



This work was supported by the US Department of Energy, Office of Vehicle Technology
Thank you to the DOE

Technical Accomplishments and Progress: Overview

- This project highly leverages the previous project's hardware allowing early progress
- Project management activities and establishment of new team required significant effort in these early stages of the project
- Primary areas of technical accomplishments since the start of the project in October 2014 include:
 - Controls development progress and testing using vehicle and engine from UFEV project.
 - Characterization of vehicle level emissions on FTP cycle
 - High load dynamometer testing of Gen1 GDCI engine from UFEV project
 - Build and debug of Gen2 GDCI single cylinder engine
 - Build and debug of Gen2 GDCI multi-cylinder engines



Technical Accomplishments and Progress: Vehicle Level Progress

- Delphi EMS controls progress using vehicle from UFEV project
 - FTP cycle run successfully from room temperature
 - Algorithms have been developed which automate the cold start and warm-up transition to closed loop control.

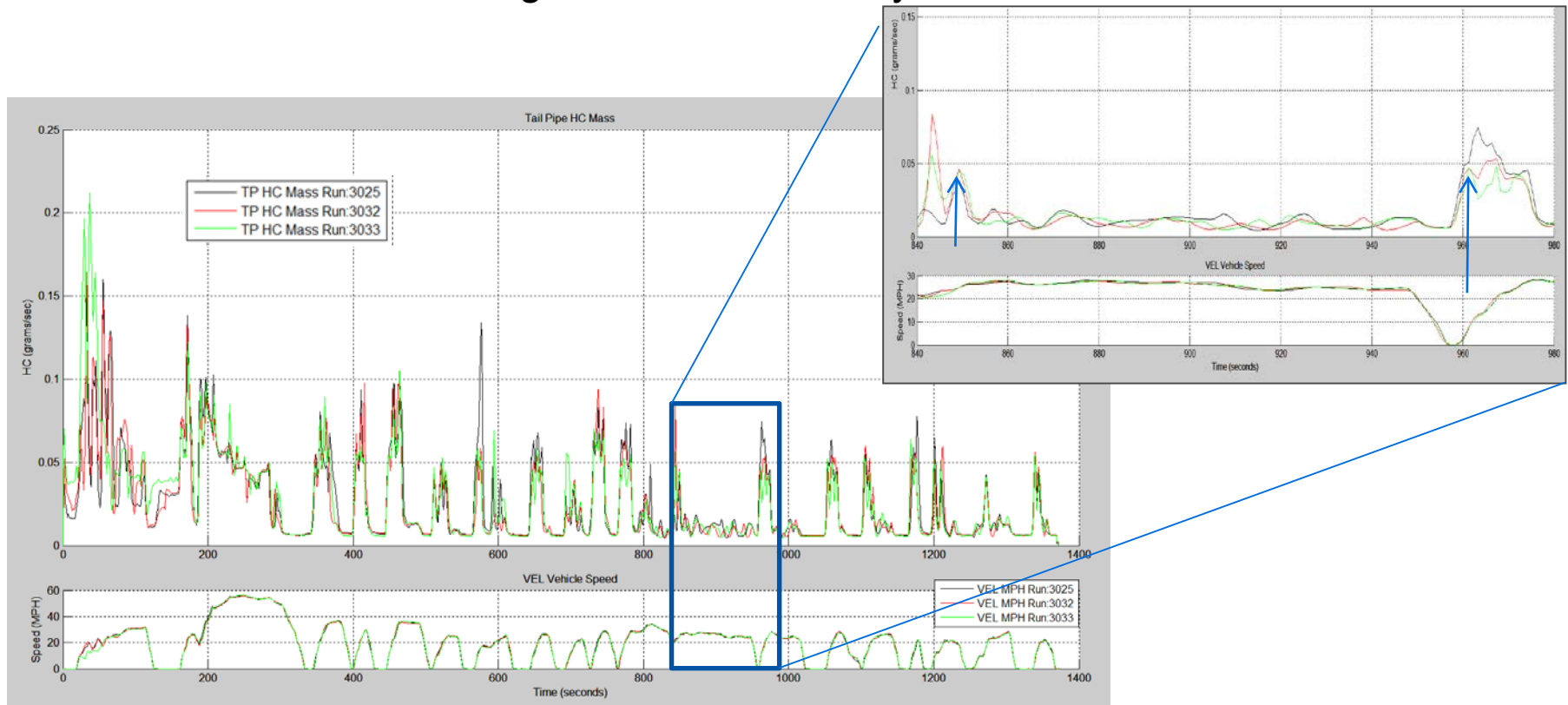


- ORNL & Delphi fully characterize emissions
 - Teams from Delphi and ORNL tested the Delphi Gen 1 GDCI vehicle under a variety of transient and steady-state conditions and made measurements of emissions. The objective of the testing was to characterize the vehicle-level engine-out transient emissions.



Technical Accomplishments and Progress: Vehicle Level Progress

- Vehicle emissions –
 - Emission data show transients as high contributors to emissions
 - Several new algorithms have been developed that improve transient control
 - Calibration of these algorithms is underway



Transient control of this new combustion process is one key to emissions reduction

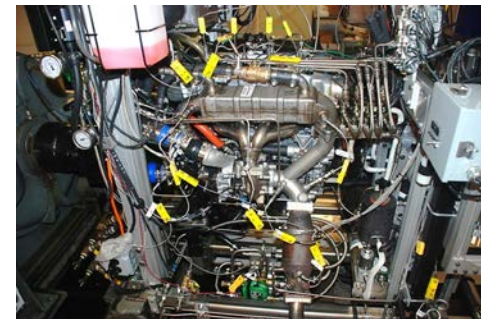
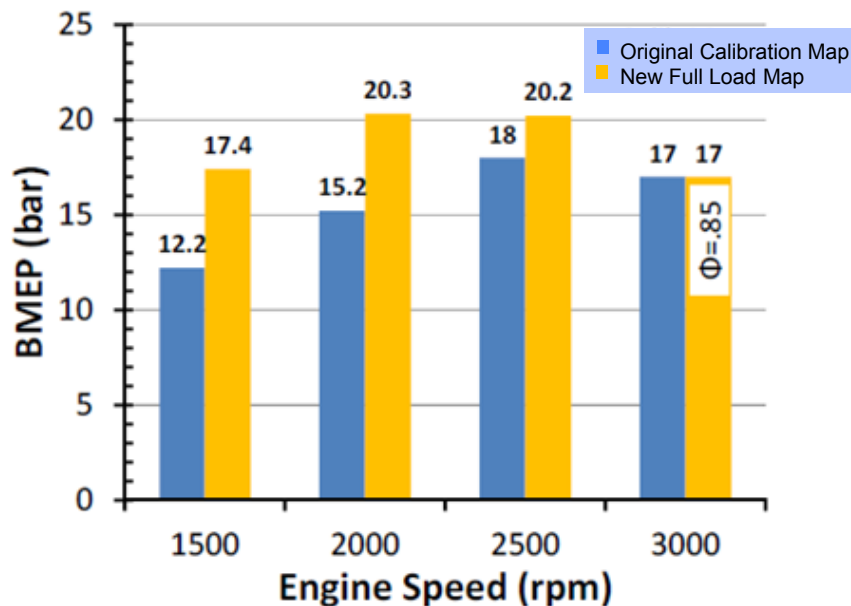
Technical Accomplishments and Progress: Hardware Build

- Build of Gen2 MCE engines
 - Gen2 GDCI engine was designed by Delphi and HATCI outside of Department of Energy funded projects.
 - First Gen2 engine was completed for the project. Updates include:
 - Increased Compression Ratio (15.5 vs 15.0 for Gen1)
 - New fuel system
 - New valvetrain
 - New thermal management system
 - New aftertreatment system
 - New piston and ring packs
 - Improved lubrication system
 - Reduced motoring and firing friction
 - Updated engine sensors and actuators



Technical Accomplishments and Progress: Dynamometer Testing

- Gen 1 GDCI Multi-cylinder Engine
 - The Gen 1 GDCI engine was run at high load to characterize the full-load performance of that design phase.
 - Evaluated Injection strategies, boost systems, thermal system, fuel injection system, and valvetrain system modifications during testing
 - Achieved torque needed for successful down-speeding & boost strategy

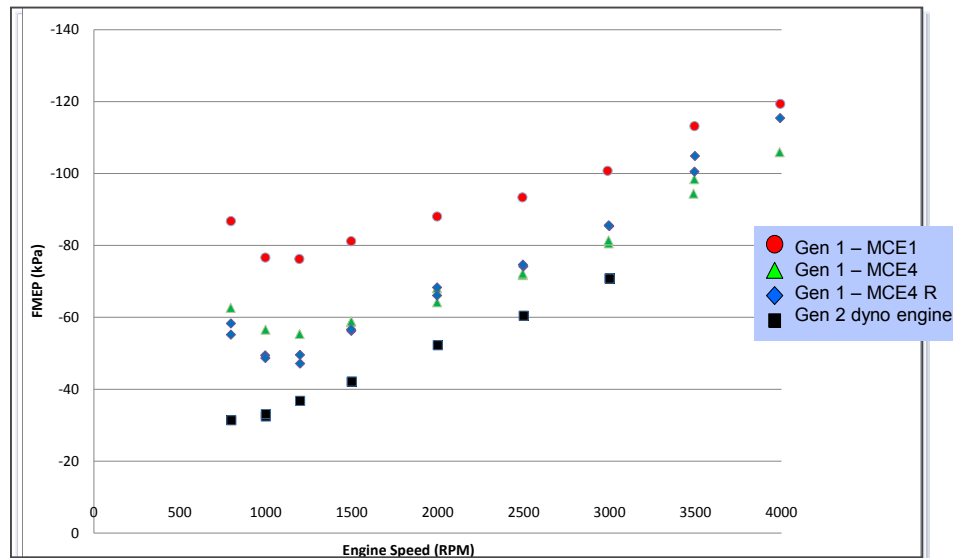


Gen1 GDCI engine on Dynamometer at Delphi

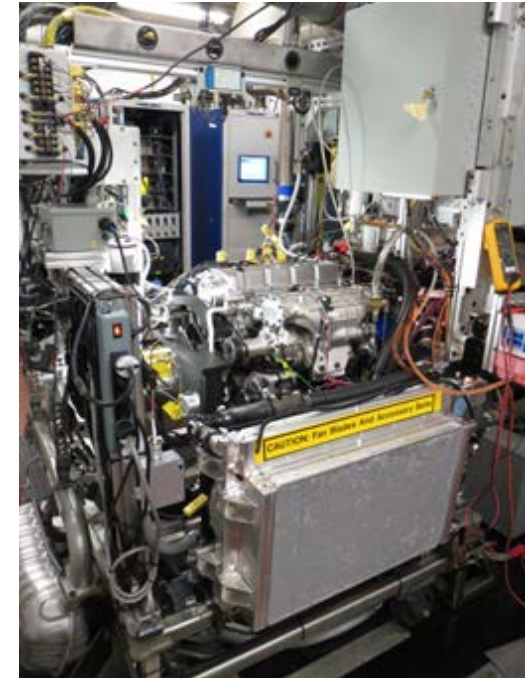
While additional full load development is needed, results for the first generation GDCI multi-cylinder engine met project expectations.

Technical Accomplishments and Progress: Dynamometer Testing

- Gen 2 GDCI Multi-cylinder Engine
 - The first Gen 2.0 GDCI engine was installed on the dynamometer & debugged
 - Includes a vehicle ready thermal management system, sensors, and actuators
 - Pre “break-in” motoring friction significantly reduced relative to Gen I engine



Friction Mean Effective Pressure (FMEP) of Gen 2 GDCI engine versus previous Gen 1 GDCI builds



Collaboration and Coordination with Other Institutions

Oak Ridge National Laboratory - National Lab

Analyze exhaust emissions samples after sample collection at the Delphi facility. (Collect, Analyze, Consult)



Hyundai America Technical Center, Inc. (HATCI), OEM

Engineering design and analysis as well as prototype fabrication and testing at component, engine and vehicle levels. (Support, Resources)



University of Wisconsin Madison - University

Characterization testing of gasoline fuel injectors. (Test)



Madison, WI

Umicore Autocat USA – Tier 1 Supplier

Prepare and test low temperature exhaust aftertreatment samples. (Analyze, Design, Formulate, Build, Consult)



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Remaining Challenges and Barriers

- Development of an aftertreatment system that is effective in dealing with the low-temperature challenges of a highly efficient engine.
- Further refinement of the GDCI combustion system to achieve near-ideal air/fuel mixture preparation for high efficiency and low HC and CO emissions
- Demonstration of transient control with high EGR levels during real-world transient driving maneuvers and over a broader range of ambient conditions



Proposed Future Work

Next Steps

- Characterize and map the Gen2 GDCI multi-cylinder dynamometer engine.
 - Refine combustion system to achieve near-ideal air/fuel mixture preparation and low engine out emissions
 - Optimize engine out temperature profiles for exhaust aftertreatment
- Develop low temperature exhaust aftertreatment system based on emissions data from ORNL and on the Gen2 temperature profiles
 - Delphi and ORNL working closely with Umicore
- Further develop and refine controls and calibration of GDCI for improved fuel economy and emissions with an emphasis on vehicle transient operation.



Summary

- Leveraging the previous projects hardware allowed early progress
- Project management activities and establishment of new team required significant effort in early stages of the project
- Primary areas of technical accomplishments since the start of the project in October 2014 include:
 - Controls development progress using vehicle and engine from UFEV project.
 - Characterization of vehicle level emissions on FTP cycle with ORNL
 - High load dynamometer testing of Gen1 GDCI engine
 - Build and debug of Gen2 GDCI single cylinder engine and multi-cylinder engine complete
- All Milestones were met on time
- Future Work for Calendar Year 2015 / 2016
 - Characterize Gen2 GDCI engine on dynamometer
 - Develop low temperature exhaust aftertreatment system based on emissions results from Gen1 vehicle and on Gen2 temperature profiles from dynamometer
 - Refine controls and calibration of GDCI for improved fuel economy and emissions with an emphasis on vehicle transient operation.

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Innovation for the Real World

Thank you to the Department of Energy for
supporting this project.

Responses to Previous Year Reviewers' Comments

- This project was not reviewed last year but we look forward to your feedback this year.



Technical Back-Up Slides

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Innovation for the Real World

Technical Back-Up Slide: Previous project results (UFEV Project EE0003258)

- On a warm-start, combined FTP cycle, the GDCI vehicle achieved 39% improvement in fuel economy relative to a baseline PFI vehicle, exceeding the DOE ATP target of 25% improvement and the project target of 35% improvement.

Delphi GDCI Vehicle Fuel Economy (mpg)				
Cycle	Run 1	Run 2	Run 3	Avg.
City - EPAIII (Warm, uncorrected E10 fuel)	38.19	38.47	38.44	38.37
Hwy (uncorrected E10 fuel)	57.04	57.86	59.54	58.15
CAFE method Combined FE (Warm, corrected to E0)	46.21	46.66	47.11	46.66
Percent Improvement over Baseline				
Combined FE comparison (Warm, corrected to E0)	38.0%	39.3%	40.7%	39.3%

- While fuel economy targets were exceeded the emissions performance target (Tier 2, Bin 2) was not met.

