Gasoline Ultra Fuel Efficient Vehicle Program Update

Directions in Engine-Efficiency and Emissions Research Conference 2012

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October 16, 2012

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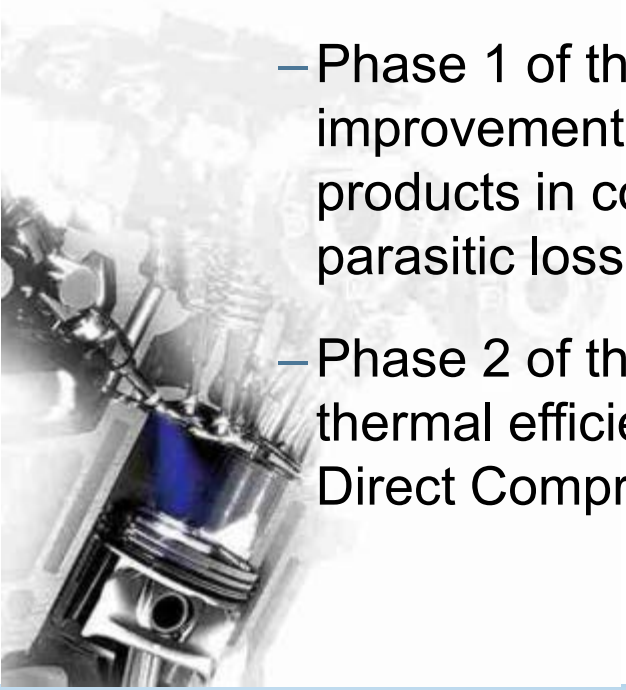
Ultra Fuel Efficient Vehicle (UFEV) Project

- **Project Background**
  - Awarded DE-FOA-0000079 Area of Interest 2: Advanced Technology Powertrains for Light Duty Vehicles.
  - 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

DELPHI

Project Lead

Henrietta, New York

Auburn Hills, Michigan

HYUNDAI

Hyundai America Technical Center, Inc.

Superior Township, Michigan

WERC

Wisconsin Engine Research Consultants

Madison, Wisconsin

Detroit, Michigan

WAYNE STATE UNIVERSITY

ENGINE RESEARCH CENTER
UNIVERSITY OF WISCONSIN - MADISON
est 1946

University of Wisconsin

Project Plan – With a Focus on Hardware

April 2010 | June 2012 | March 2014

Phase 1 Vehicle Demo

Phase 1

Phase 1 Loss Reduction Vehicle

Applicable Technologies

Phase 1 Electronics & Controls Vehicle

Phase 2 Vehicle Demo

Phase 2 Vehicle

Phase 2

GDCI SCE1

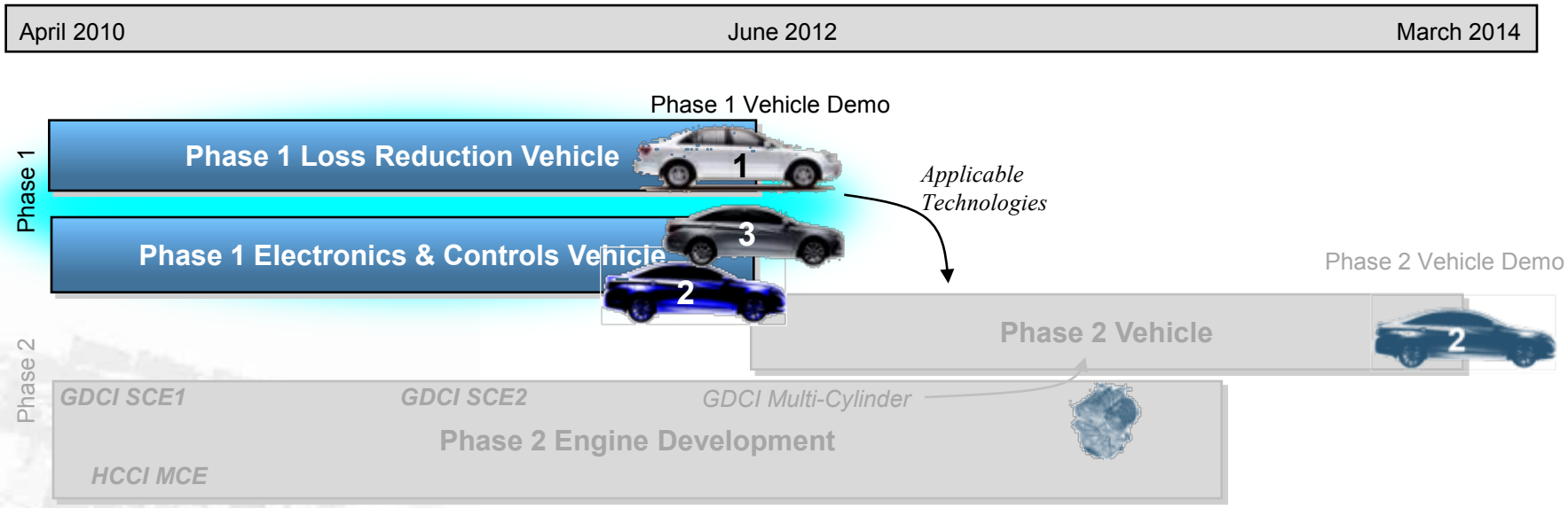
GDCI SCE2

GDCI Multi-Cylinder

Phase 2 Engine Development

HCCI MCE

Phase 1- Systems-Level Approach to Fuel Economy Improvement Technologies

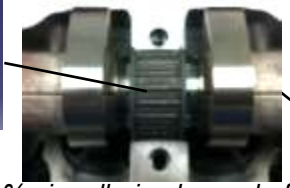


Phase 1, Vehicle 1 (Reduced Parasitic Loss)
Approach / Strategy

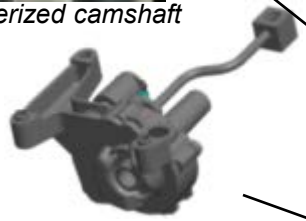
- 2011 Sonata 6MT, 2.4L GDi Theta II

- Technologies on Vehicle:

Camshaft Rollerization



~ 1% via rollerized camshaft



Optimized Oil Pump

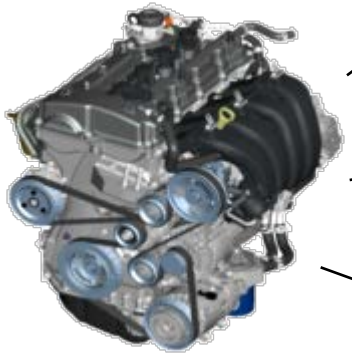
Crank Rollerization

~ 3% via Rollerized Cranktrain

Engine Downspeeding

- •5000 RPM
- •Revised cam shafts
- •Coated Piston Rings
- •Low Tension Oil Control Rings
- •Coated Piston Skirt

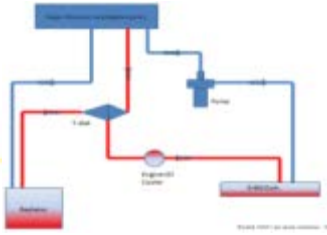
~3% via downspeeding and friction reduction



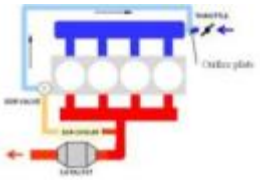
Demonstrated on Hyundai Theta GDi engine in a 2011 Sonata

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

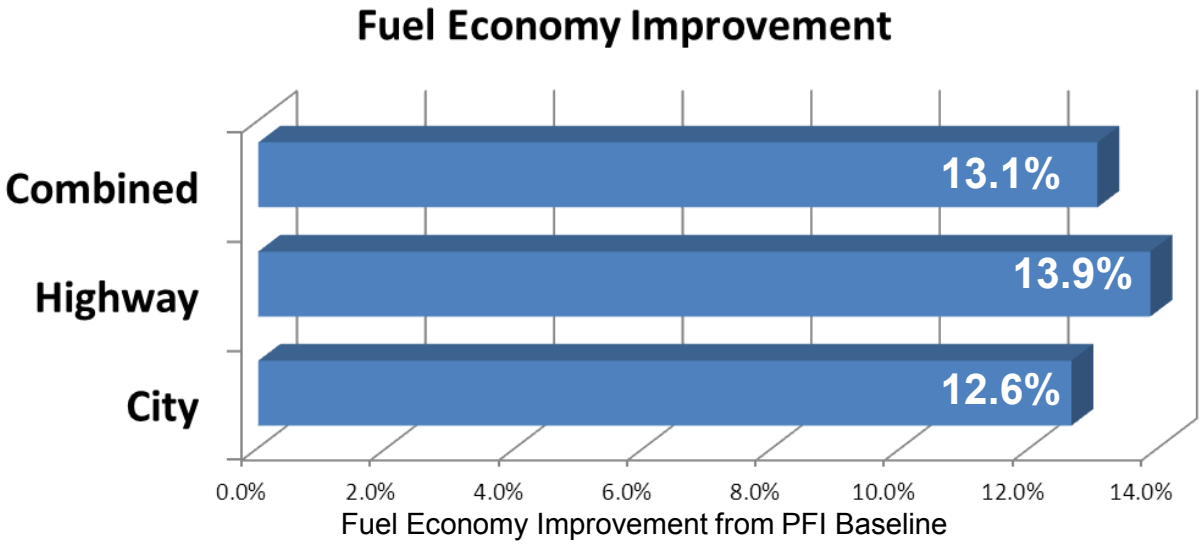
- **Vehicle Build and Integration of Technologies**
  - The Phase 1 Parasitic Loss Demonstration Vehicle completed build, calibration and test.

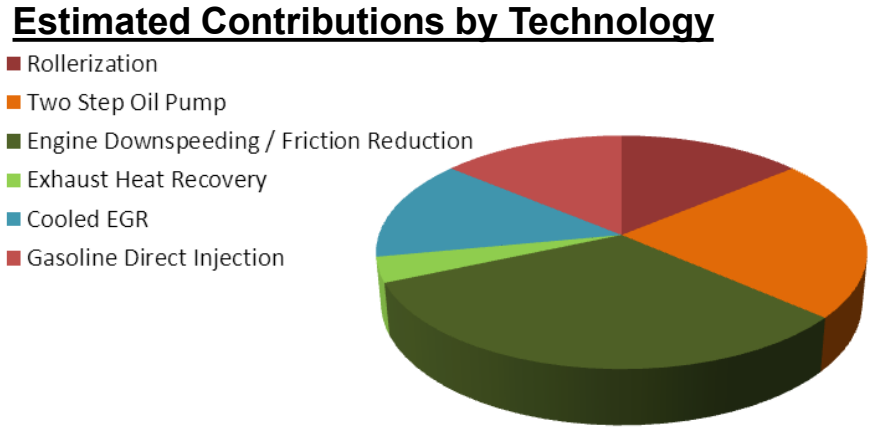
HATCI low friction technologies

HATCI heat recovery system

Delphi heat recovery and friction reduction controls

Phase 1, Vehicle 1 (Reduced Parasitic Loss)
Test Results

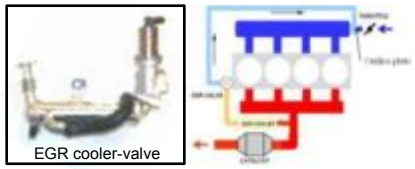




Phase 1, Vehicle 2 (Engine Management System)
Approach / Strategy

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

Cooled EGR



~ 3% via cooled EGR

Variable Valvetrain

~4% via advanced valvetrain

ePhaser

2 step valve lift

ePhaser Controls

GDi Fuel System

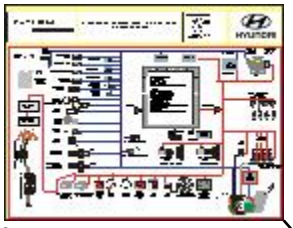
1-3% via fuel system

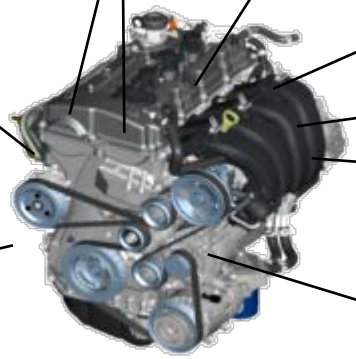
GDi Pump

GDi Injector

GDi Rail

EMS Control Algorithms





ECM
with integrated
GDi controls

Calibration

Demonstrated on Hyundai Theta
GDi engine in a 2011 Sonata

Stop / Start

•Stop / Start Controls

~3% via stop/start

**Targeted fuel economy improvement vs. PFI baseline vehicle shown in italics*

Phase 1, Vehicle 2 (Engine Management System)
Hardware and Testing

- **Vehicle Build and Integration of Technologies**
  - The second Phase 1 demonstration vehicle has been built and all calibration and testing completed.

Hyundai 2 step head

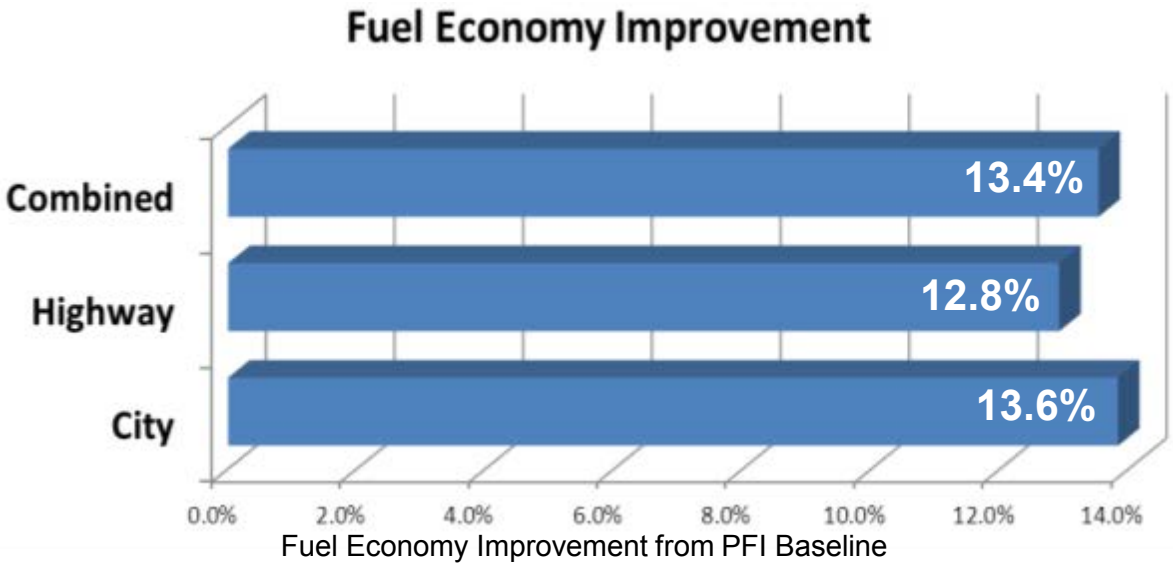
Delphi ePhasers

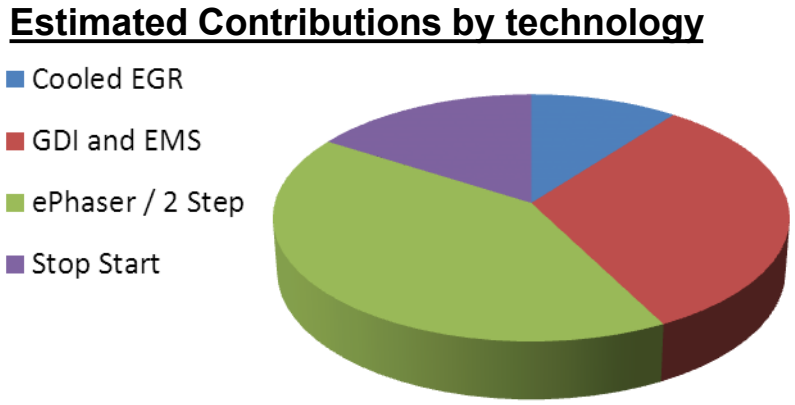
Delphi GDi fuel system

Delphi EMS

Delphi stop start system

Phase 1, Vehicle 2 (Engine Management System)
Test Results





Phase 1 Vehicles:
Summary

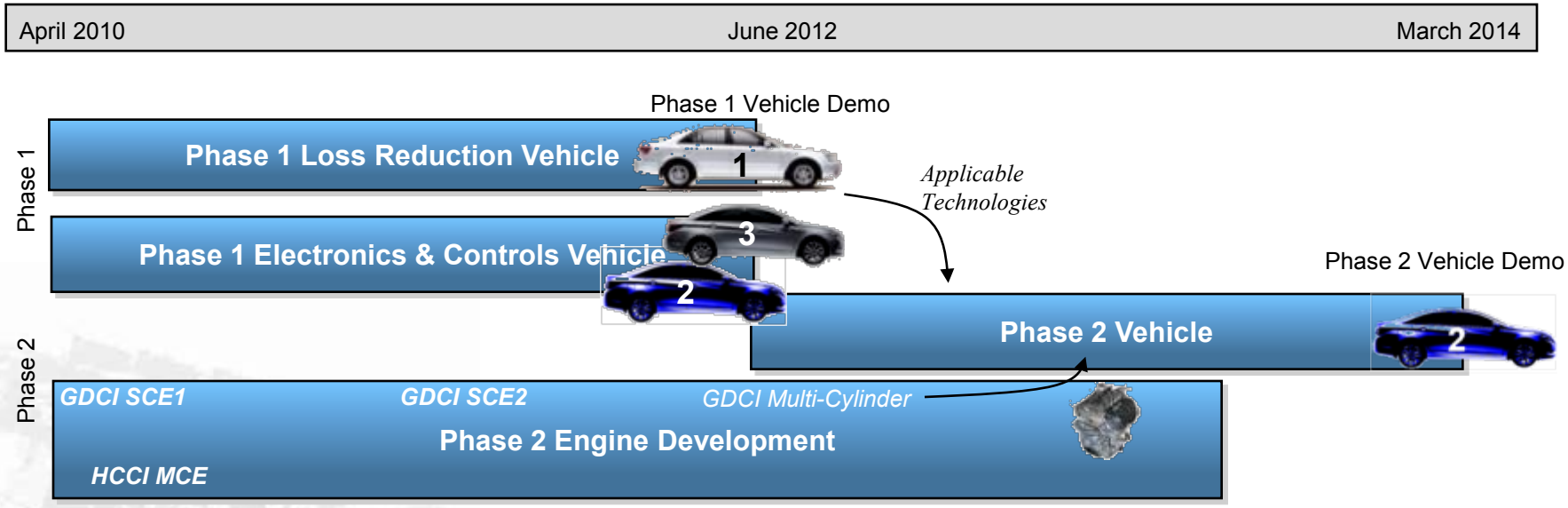
Technology Overlap

- Rollerization
- Two Step Oil Pump
- Down speed / Friction Reduction
- Exhaust Heat Recovery
- Cooled EGR
- Gasoline Direct Injection
- ePhaser / 2 Step Valve Lift
- Stop Start

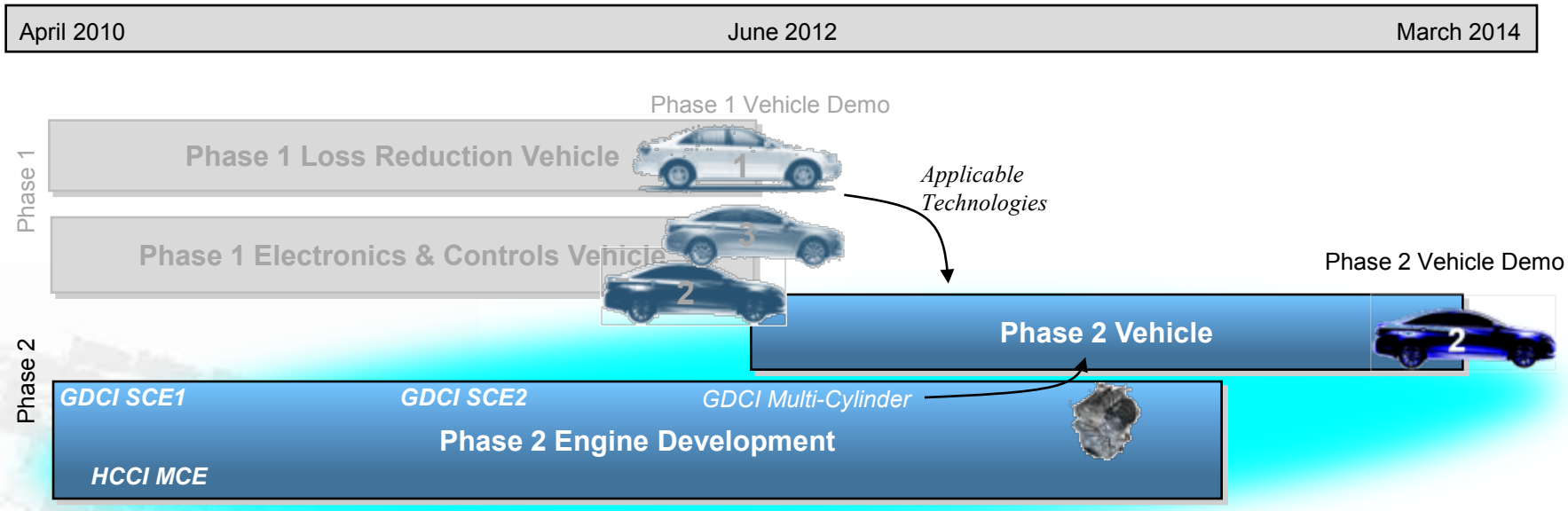
FE gain from PFI base	White Car (HATCI)	Black Car (Delphi)
City	12.6%	13.6%
Highway	13.9%	12.8%
Combined	13.1%	13.4%

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 2 - Gasoline Direct-Injection Compression-Ignition (GDCI)

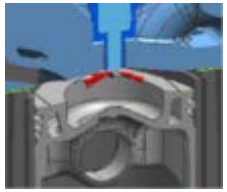


Phase 2 Vehicle (GDCI)
Approach / Strategy

- 2011 Sonata 6MT, 2.0L GDi Theta Turbo

- Technologies on Vehicle:

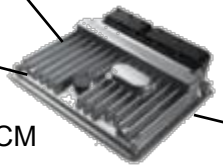
GDCI Low Temperature Combustion Process and Controls



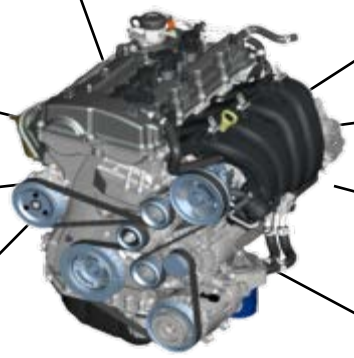
~25% targeted fuel economy improvement

EMS Control Algorithms

Calibration



ECM



Demonstrate on Hyundai Theta Turbo GDi engine in a 2011 Sonata

GDCI Optimized Valvetrain

GDi Pump

GDCI Optimized Injector

GDi Rail

Boosting Systems

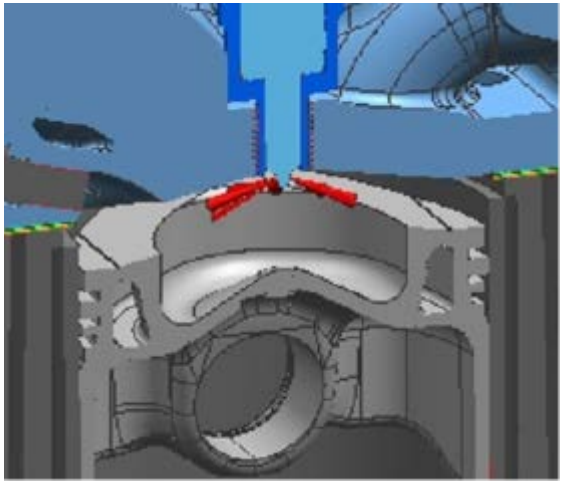
Charge Air Coolers

Parasitic loss reduction technologies from Phase 1 (where applicable)

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

Gen I GDCI Engine

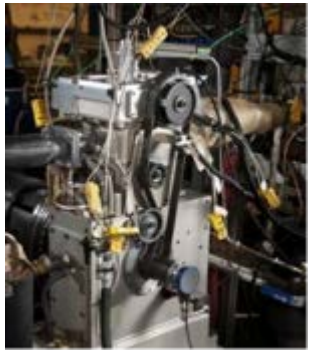


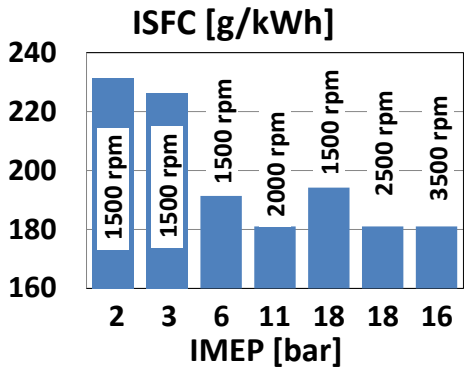
References:
Kalghatgi (Shell) 2005-2010
Manente & Johansson (Lund) 2007-2011
Dempsey & Reitz 2011, Ra & Reitz 2009-11, Hanson & Reitz 2009 (ERC)
Sellnau (Delphi) SAE 2012, SAE 2011, Aachen 2011 & 2012

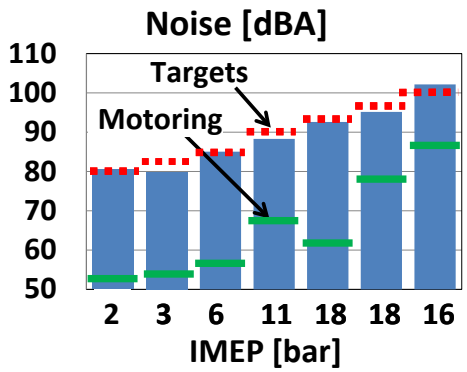
Phase 2 GDCI

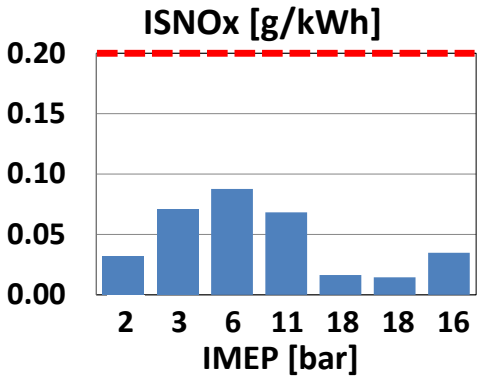
Hydra Single Cylinder Engine Tests with Diesel Piston

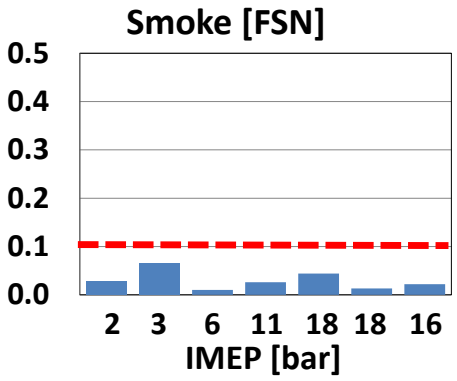
- Low ISFC achieved with very low NOx, low PM emissions and acceptable noise levels while maintaining exhaust temperatures

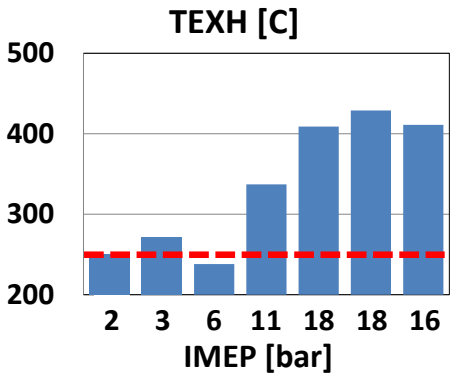










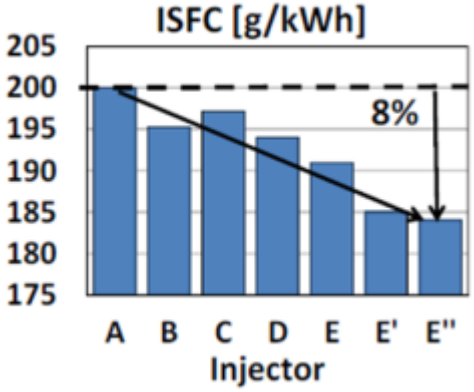


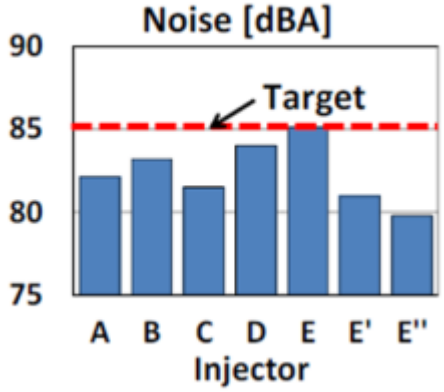
GDCI low-temperature combustion system enables very high efficiency and very low emissions over entire speed/load range.

Phase 2 GDCI

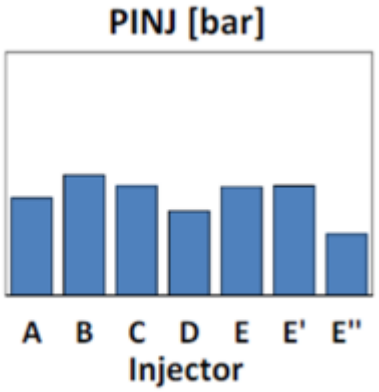
Injector Tests on Hydra Single Cylinder Engine (1500RPM-6bar)

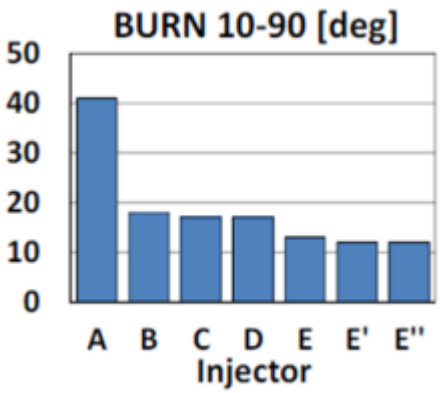
- Injectors A, B, C, D & E were tested with a diesel piston
- E' and E" were tested with a new GDCI-specific piston

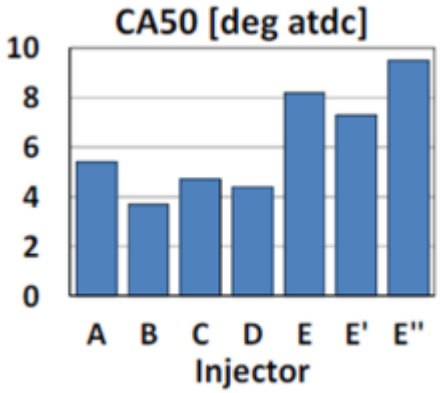




Constraints
Noise < 85 dB
Pinj < 500 bar
ISNOx< 0.2 g/kWh
Smoke < 0.1 FSN







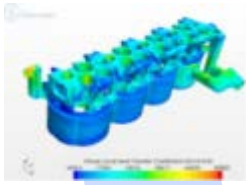
Phase 2 GDCI

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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Directions in Engine-Efficiency and Emissions Research Conference 2012

DELPHI

WERC

ENGINE RESEARCH CENTER UNIVERSITY OF WISCONSIN - MADISON est 1946

WAYNE STATE UNIVERSITY

HYUNDAI

Hyundai America Technical Center, Inc.

Thank-You

U.S. DEPARTMENT OF ENERGY

NETL

October 16, 2012

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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
- UFEV Project Merit Review Presentation, K. Confer, Merit Review, Washington DC, May 2012
- *“Combustion System for Full-time Gasoline Direct-Injection Compression-Ignition (GDCI)”* , M. Sellnau, et al., Aachen Colloquium Automobile and Engine Technology, October 2012