2011 DOE Vehicle Technologies Review
Gasoline Ultra Fuel Efficient Vehicle

DELPHI

KIA

WERC

WAYNE STATE UNIVERSITY

ACE064
Merit Review DE-EE0003258

Keith Confer

Project Principal Investigator

18MY12

U.S. DEPARTMENT OF ENERGY

NETL

Ultra Fuel Efficient Vehicle (UFEV) Project Overview

Timeline

- Project start: 9/1/2010
- Project end: 3/31/2014
- Percent complete: 50%

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
  - D: Effective engine controls

Budget

- Total project funding
  - DOE share $7,480,582 (50%)
  - Contractor share: $7,480,582 (50%)
- BP1 2010-2011 Funding: $2,788,205
- BP2 2011-2012 Funding: $2,837,265
- BP3 2012-2013 Funding: $1,169,418
- BP4 2013-2014 Funding: $ 685,693

Partners

- Delphi - Project Lead
- HATCI (Hyundai America Technical Center Inc.)
- WERC (Wisconsin Engine Research Consultants)
- Wayne State University

Ultra Fuel Efficient Vehicle (UFEV) Project Collaboration with Other Institutions

DELPHI

Project Lead

Henrietta, New York

Auburn Hills, Michigan

HATCI
HYUNDAI AMERICA TECHNICAL CENTER INC.

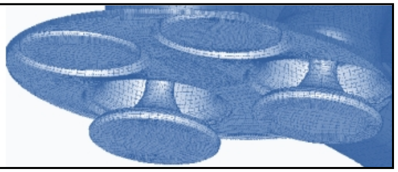
Superior Township, Michigan

Detroit, Michigan

WAYNE STATE UNIVERSITY

WERC

Wisconsin Engine Research Consultants



Madison, Wisconsin

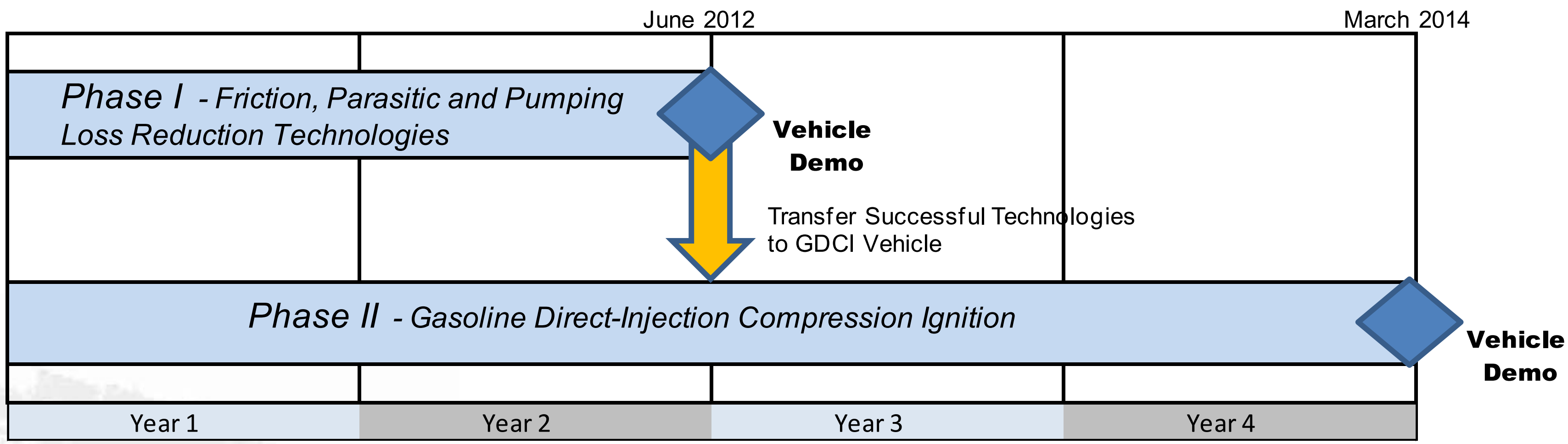
ENGINE RESEARCH CENTER
UNIVERSITY OF WISCONSIN - MADISON
est 1946

University of Wisconsin

Ultra Fuel Efficient Vehicle (UFEV) Project Relevance

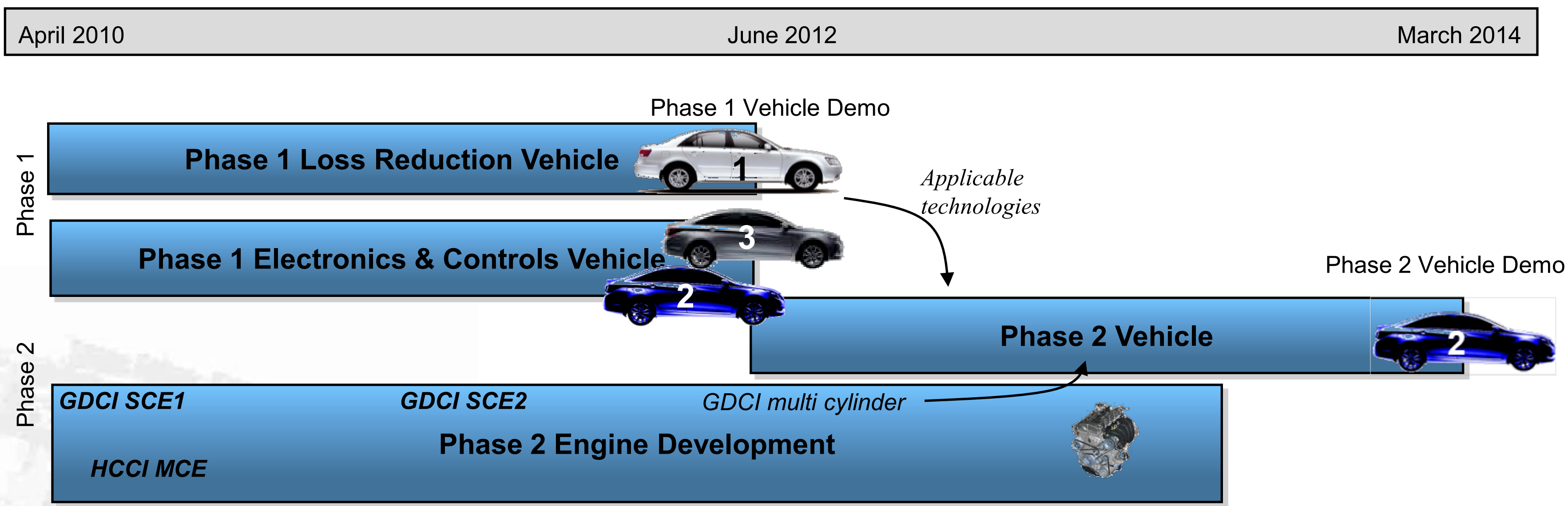
- **Objective**
  - Develop, implement and demonstrate fuel consumption reduction technologies with a partnership of universities, systems level OEM supplier and OEM.
  - Targeted fuel economy improvement of > 30% vs. PFI baseline.
    - Improved internal combustion engine efficiency reduces GHG and emissions by reducing petroleum consumption.
  - Phase I 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 Project Milestones



- June 2012: Vehicle Demo of Phase 1
- June 2012: Go / No Go Phase Review
- March 2013: Go / No Go Phase Review
- March 2014: GDCI Project Vehicle Demonstration

Approach / Strategy
Project Hardware Plan

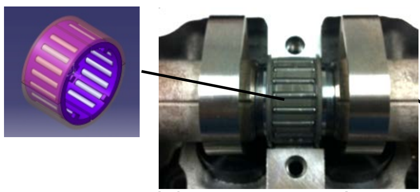


Approach / Strategy
Phase 1 Vehicle 1 (Parasitic Loss Reduction Vehicle)

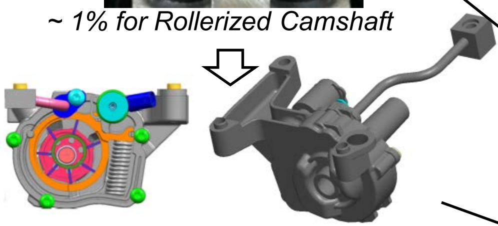
- 2011 Sonata 6MT, 2.4L GDI Theta II

- Technologies on Vehicle:

Camshaft Rollerization



~ 1% for Rollerized Camshaft

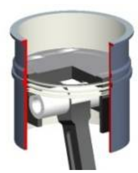


Optimized Oil Pump

Crank Rollerization

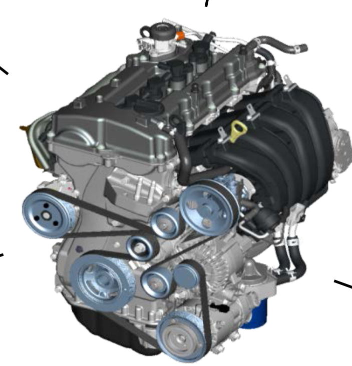
~ 3% for Rollerized Cranktrain

Engine Downspeeding



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

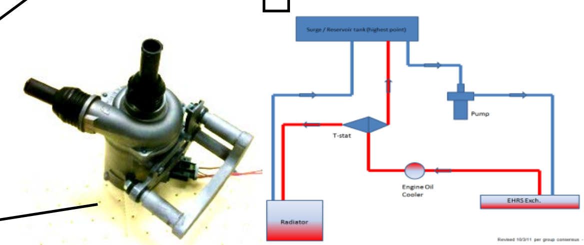
~3% improvement in vehicle level



Demonstrated on Hyundai Theta GDi engine in a 2011 Sonata

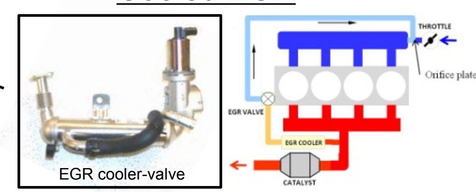
Exhaust Thermal Management

~1-2% exhaust heat recovery



Optimized eCoolant Pump

Cooled EGR

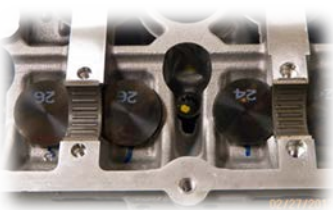


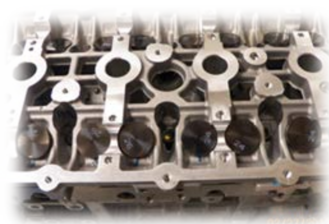
~ 3% cooled EGR

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

Phase 1 Accomplishments:
Project specific hardware and testing

- **Vehicle Build and Integration of Technologies**
  - The Phase 1 Parasitic loss demonstration vehicle has been assembled and is currently completing calibration and testing. The build at HATCI included; a new engine with roller bearing crank and cam shafts, cooled EGR, exhaust heat recovery system, down speeding (gear ratio, low tension oil control rings, reduced force chain tensioner, reduced flow oil pump…), low friction engine hardware (DLC coatings, roller chain, coated piston skirts…). Delphi also provided stand-alone controls for the exhaust heat recovery system and for the two step oil pump system.





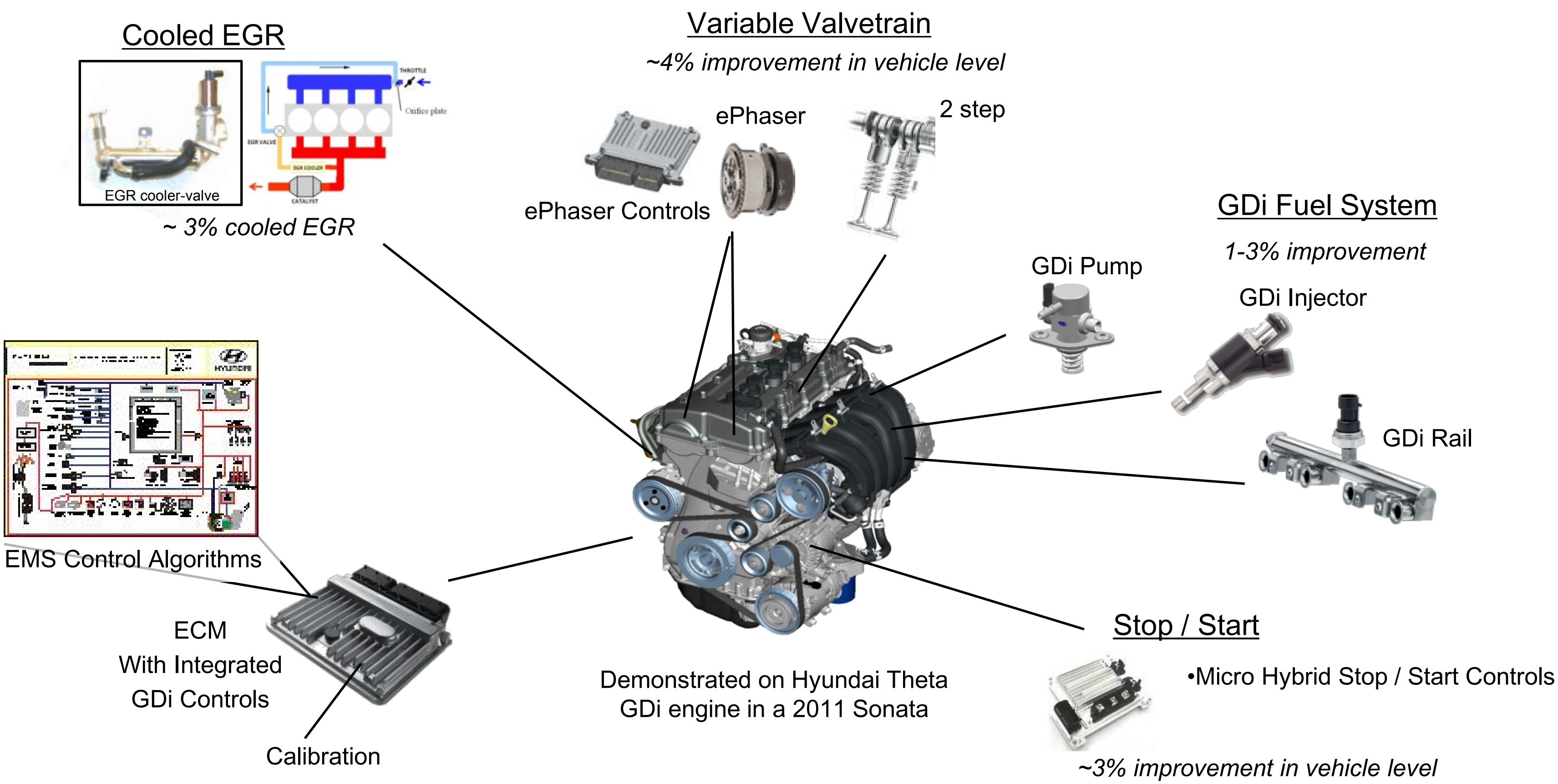
HATCI low friction technologies

Delphi Heat Recovery and Friction Reduction Controls

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

- 2011 Sonata 6MT, 2.4L GDI Theta II

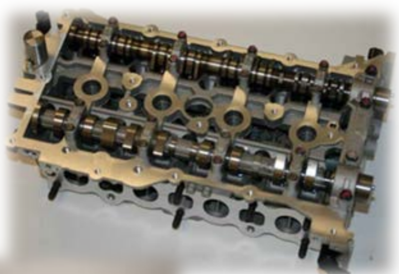
- Technologies on Vehicle:



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

Phase 1 Accomplishments:
Project Specific Hardware and Testing

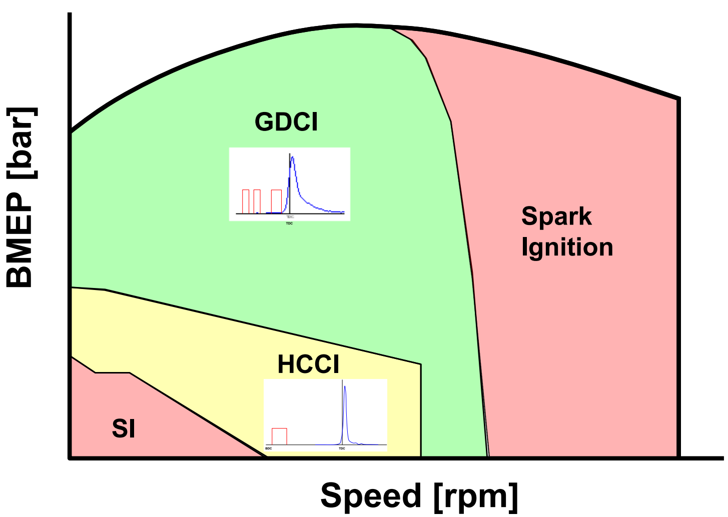
- **Vehicle Build and Integration of Technologies**
  - The Phase 1 demonstration vehicle has been completed and is currently being calibrated. The build included conversion from the production engine controller to a Delphi MT92 development engine controller, Delphi GDI fuel system, Delphi ePhasers, Delphi belt alternator starter system (BAS) and modifications to receive the HATCI 2-step head and cooled EGR.



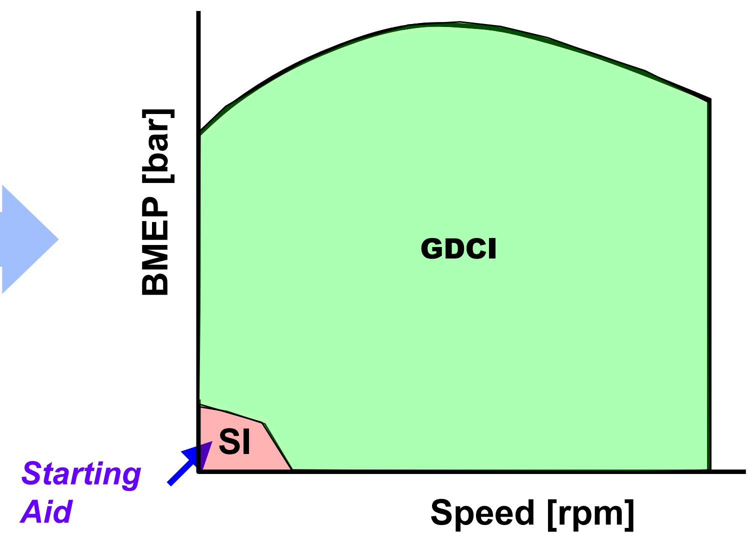
Approach / Strategy
Phase 2 Advanced Combustion

- The project was submitted with a mixed mode combustion strategy and evaluation of GDCI, HCCI and mode transition control were built into the project scope.
- Strategy: Work to develop combustion technology and practical engine systems that permit full-time GDCI operation.
- In SCE tests, GDCI combustion has demonstrated good performance across the speed-load range

Mixed Mode Combustion as submitted in project proposal



GDCI Full-time Down-speeded with Start Mode

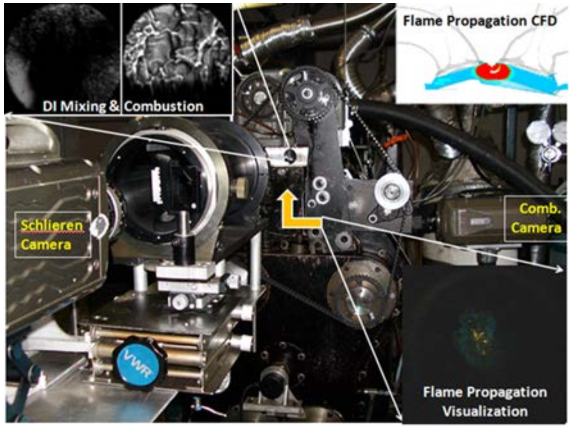


Accomplishments
Phase 2 HCCI Development at Delphi and WSU

- HCCI engine construction and testing
  - A project specific HCCI engine was constructed featuring advanced valvetrain, redesigned pistons, fuel injectors and controls systems.
  - Engine testing focused on optimizing injection and valvetrain strategies to extend the operating range of the HCCI operational envelope.
  - While HCCI has shown considerable benefits in terms of fuel consumption when compared to the baseline, GDCI technology has fuel consumption improvements plus superior emissions at loads and speeds that far exceed that of the HCCI domain.
  - Future work will focus on developing GDCI across a broad dynamic range and HCCI will not be explored further in this project.

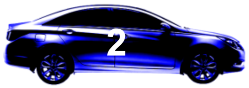
Project specific engine installed at Delphi

- Optical engine at Wayne State University - HCCI combustion
  - Observe combustion initiation of compression auto ignition and improve understanding of combustion initiation processes
  - HCCI work on this project has concluded

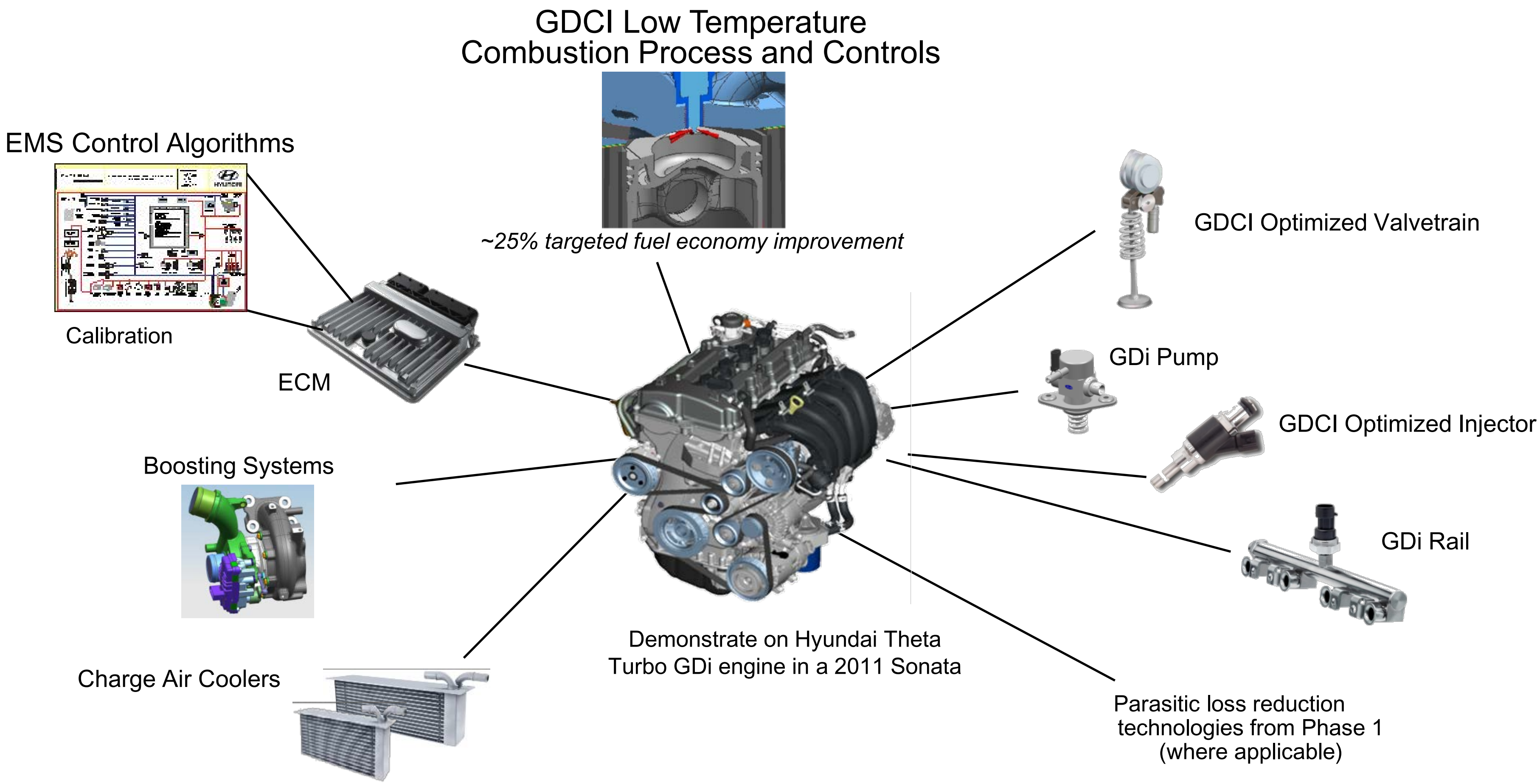


Project hardware installed at Wayne State University

Approach / Strategy
Phase 2 GDCI (Gasoline Direct injection Compression Ignition)

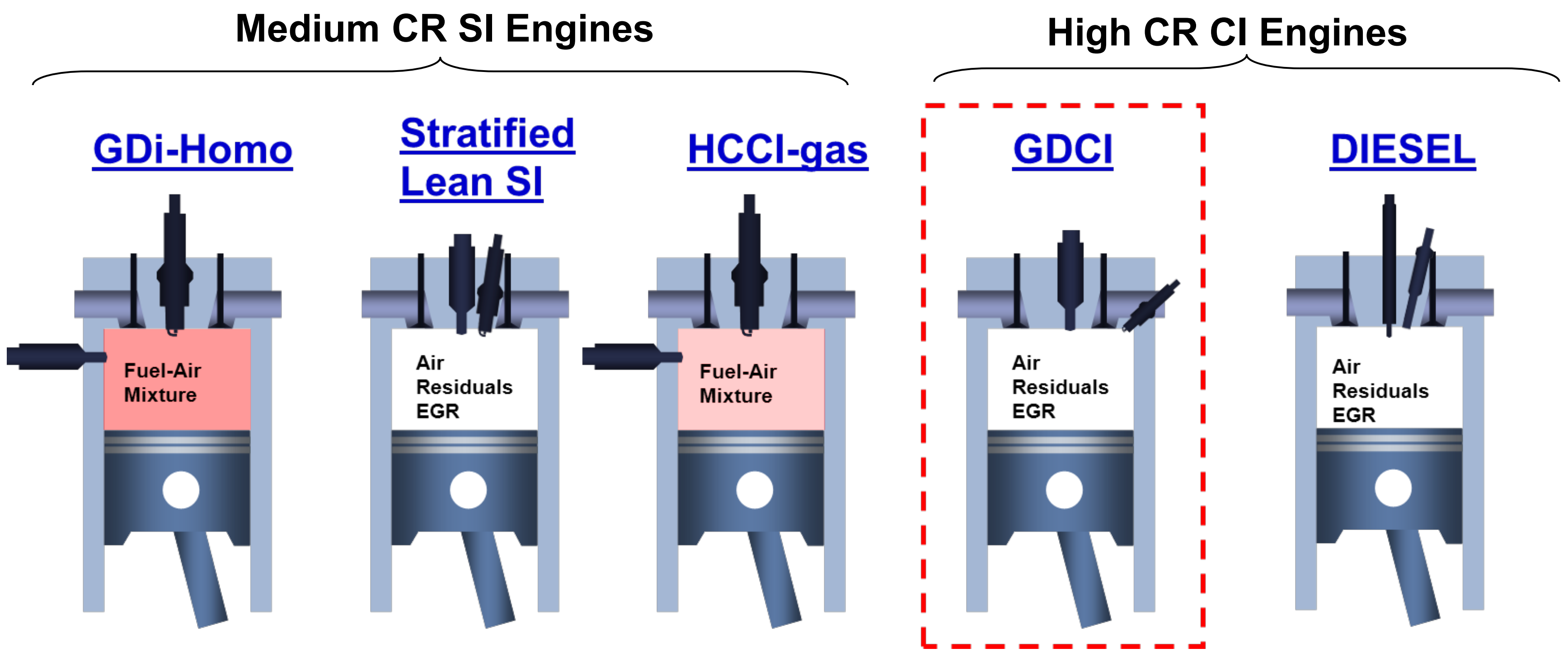
- 2011 Sonata 6MT, 2.0L GDI Theta Turbo 

- Technologies on Vehicle:



Approach / Strategy
GDCI Combines the Best of Diesel & SI Technology

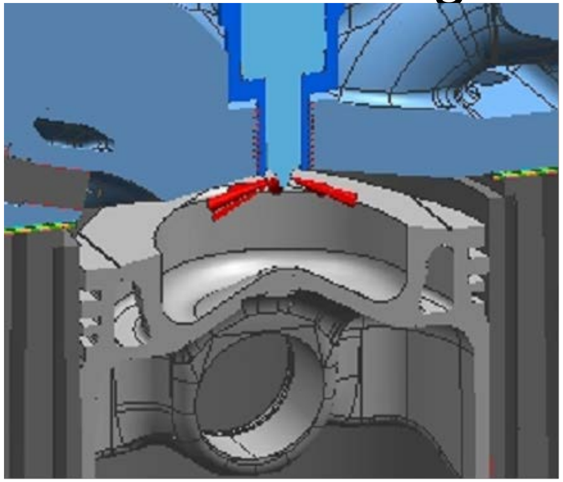
- High compression ratio (CR) with late multiple injections (similar to diesel)
- Gasoline that vaporizes & mixes easily at low injection pressure
- A new low-temp combustion process for partially-premixed CI
- High efficiency with low NOx & PM over full speed-load range



Approach / Strategy
GDCI Engine Concept

- Gasoline Partially-Premixed CI (PPCI)
- Fuel Injection
  - Central Mounted
  - 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

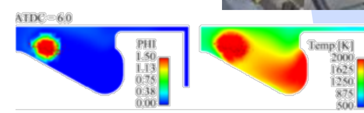
Manente & Johansson (Lund) 2007-2011

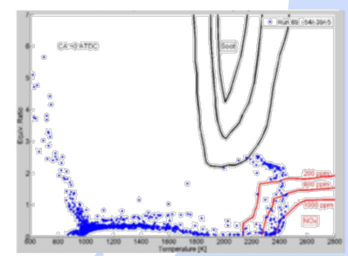
Dempsey & Reitz 2011, Ra & Reitz 2009-11, Hanson & Reitz 2009 (ERC)

Sellnau (Delphi) SAE 2012, SAE 2011, Aachen 2011, Deer 2010

Accomplishments
Phase 2 GDCI (Gasoline Direct injection Compression Ignition)

- Conducted extensive single cylinder engine tests with advanced injectors, valvetrain and piston designs
- Conducted extensive FIRE & KIVA simulations of spray, mixing and combustion processes (performed at WERC and Delphi)
- Designed and fabricated new GDCI engine
  - Cylinder heads and enhanced engine block
  - Valvetrain systems
  - Injection systems
  - Boost & air control system
- Running new single cylinder and multi-cylinder engines on dynamometers
- Initiated advanced controls work

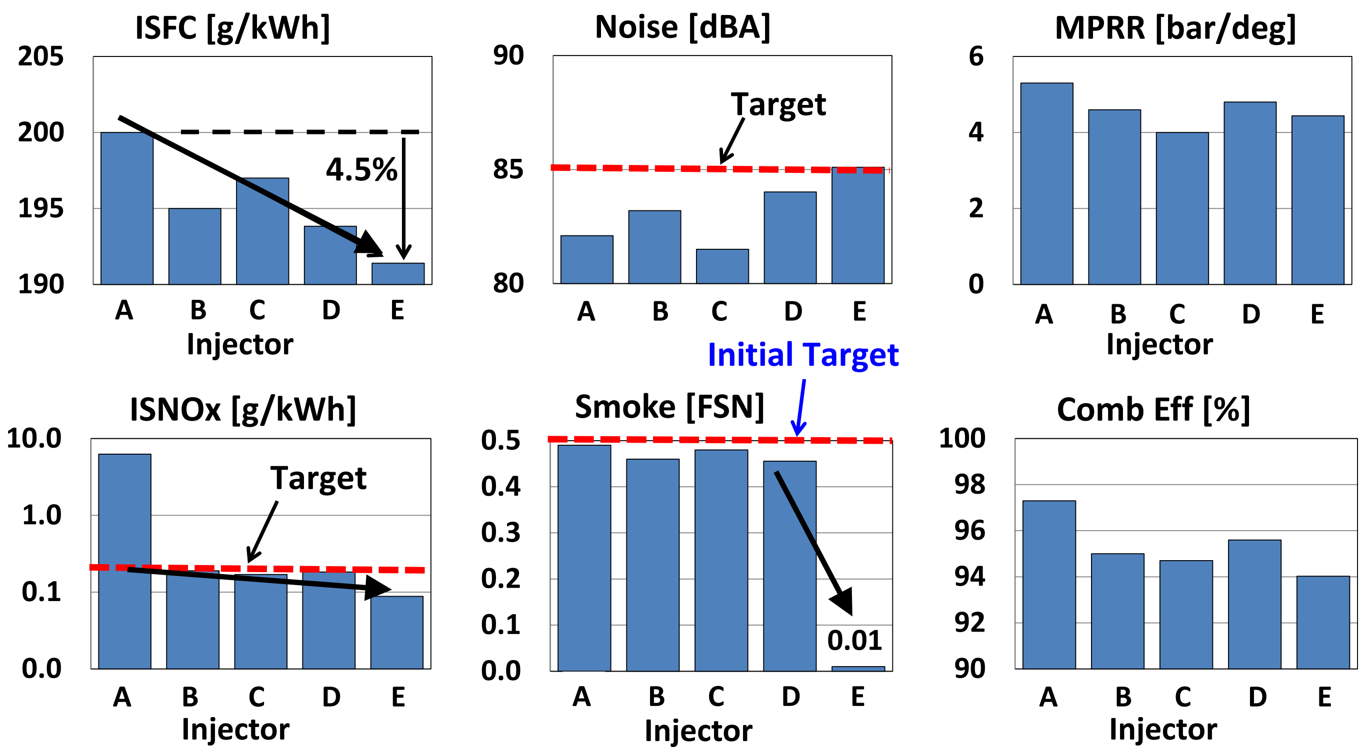




Accomplishments
Phase 2 GDCI (Gasoline Direct injection Compression Ignition)

Injector Tests on Hydra Engine (1500-6bar)

- Injectors A, B, C, D, E were tested on Hydra SCE with M57 bowl
- Injector E performed best
  - *FSN ~0.01 with 4.5% lower ISFC and no swirl*



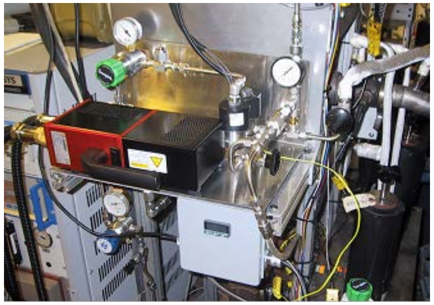
Constraints
Noise < 85 dB
Pinj < 500 bar
ISNOx< 0.2 g/kWh

Note:
- GCR=16.2 for INJ A-D
- GCR=14.5 for INJ E

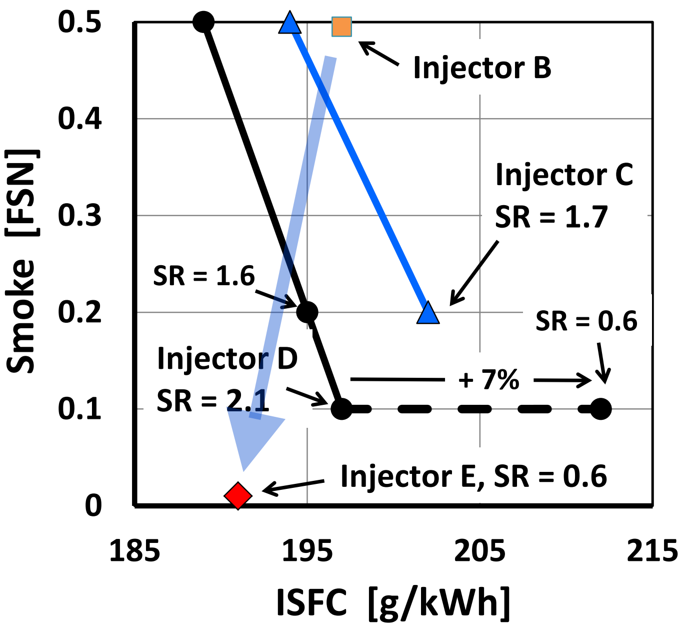
Accomplishments
Phase 2 GDCI (Gasoline Direct injection Compression Ignition)

Injector Tests on Hydra Engine (1500-6bar)

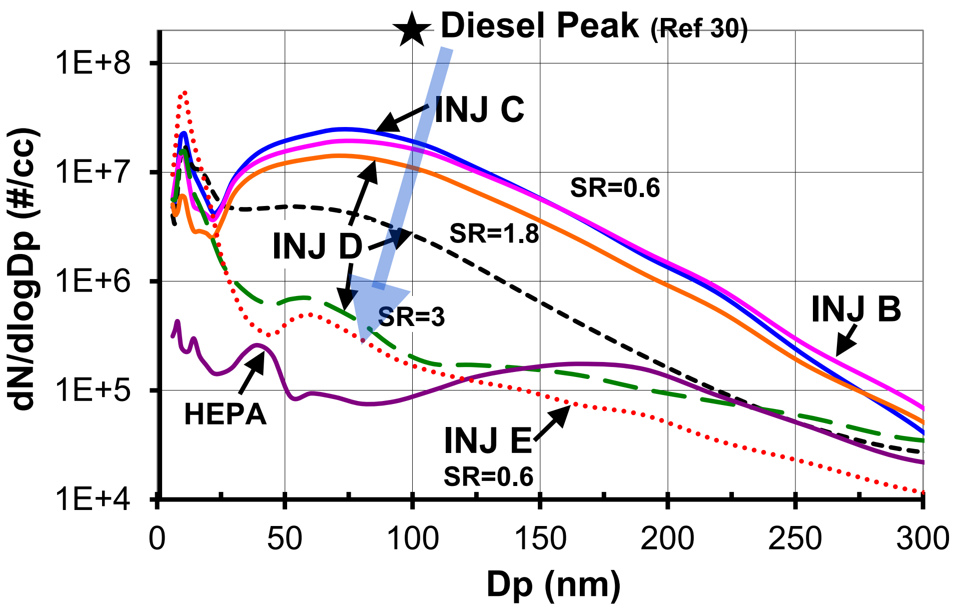
- Exhaust Particle Size Distribution measured with TSI EEPS
- EEPS data confirming very low particulate emissions for injector E without swirl



Smoke vs ISFC



Particle Size Distrib (EEPS)

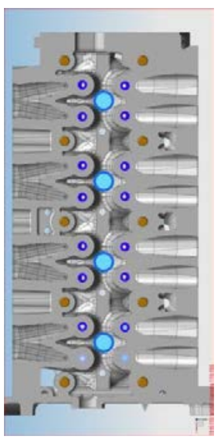


Accomplishments
Phase 2 GDCI (Gasoline Direct injection Compression Ignition)

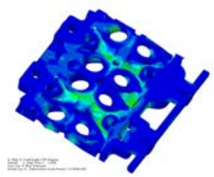
Engine Design, Analysis, & Fabrication

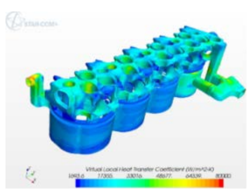
Strong Delphi & HATCI collaboration for First GDCI engine

Cylinder Head Design & Packaging

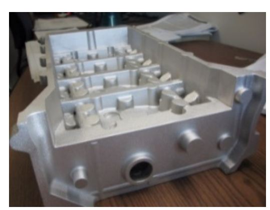


Structural Analysis & CFD

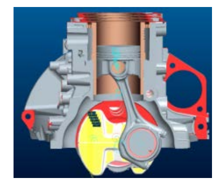


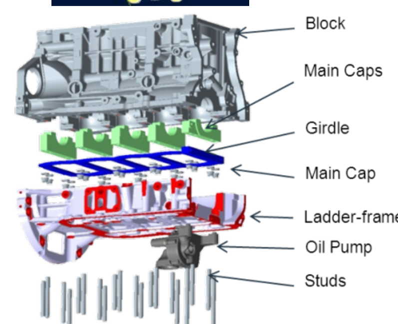


Cylinder Head Fabrication



Enhanced Block & Analysis





Piston Design & Fab

Future Work
UFEV Project 2012-2013

- **Phase 1**
  - **Calibration**: Demonstration vehicles will finish calibration for fuel economy and emissions
  - **Vehicle Test**: Vehicle level testing and demonstration will be completed
- **Phase 2**
  - **SCE 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 systems will be applied to achieve minimum NOx and PM emissions.
  - **MCE 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

Summary
Ultra Fuel Efficient Vehicle (UFEV) Project

- **Objective**
  - Develop, implement and demonstrate fuel consumption reduction technologies with a targeted fuel economy improvement of > 30% vs. PFI baseline.
- **Project**
  - The project team, with representation from universities, research, systems level automotive supplier and automotive OEM, has been assembled and tasked.
  - The project is on schedule and is meeting budget targets.
- **Phase 1**
  - Demonstration vehicle design and construction is complete. The demonstration vehicles are currently undergoing final calibration and testing.
- **Phase 2**
  - An HCCI multi-cylinder engine has been built and tested but HCCI combustion mode will not be required due to large operating range of GDCI.
  - SCE test results have demonstrated very low fuel consumption and emissions for GDCI, with the potential to not require lean NOx aftertreatment.
  - A new multi-cylinder GDCI engine has been designed and fabricated with new valvetrain and injection systems. Multiple test facilities are in use to integrate systems and calibrate ahead of vehicle demonstration