2011 DOE Vehicle Technologies Review

Gasoline Ultra Fuel Efficient Vehicle

DELPHI

KIA

WERC

ENGINE RESEARCH CENTER UNIVERSITY OF WISCONSIN - MADISON est 1946

WAYNE STATE UNIVERSITY

ACE064

Merit Review DE-EE0003258

Keith Confer

Project Principal Investigator

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U.S. DEPARTMENT OF ENERGY

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Ultra Fuel Efficient Vehicle (UFEV) Project Overview

Timeline

- Project start: 9/1/2010
- Project end: 8/31/2014
- Percent complete: 25%

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 MYPP 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

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

KIA

HATCI
HYUNDAI AMERICA TECHNICAL CENTER INC.

Superior Township, Michigan

Detroit, Michigan

WAYNE STATE UNIVERSITY

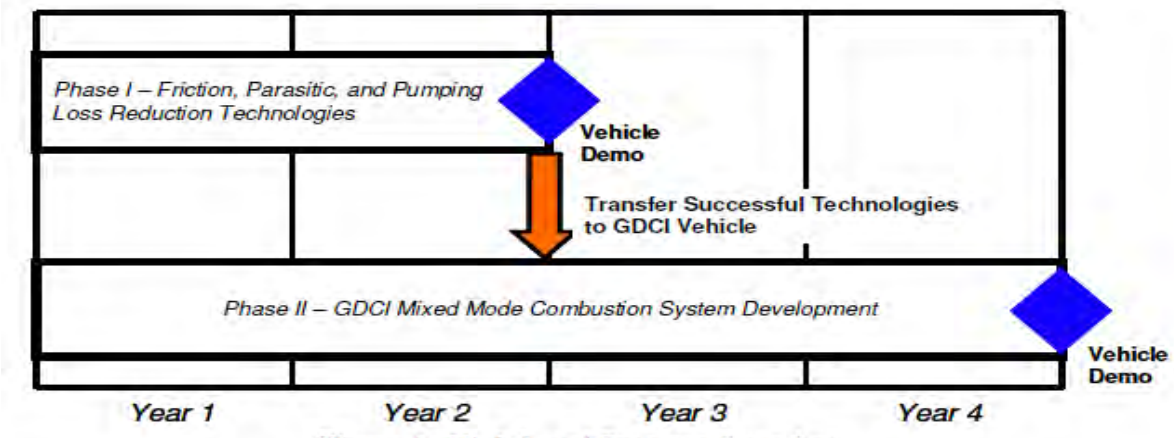
WERC
Wisconsin Engine
Research Consultants

Madison, Wisconsin

Ultra Fuel Efficient Vehicle (UFEV) Project Relevance

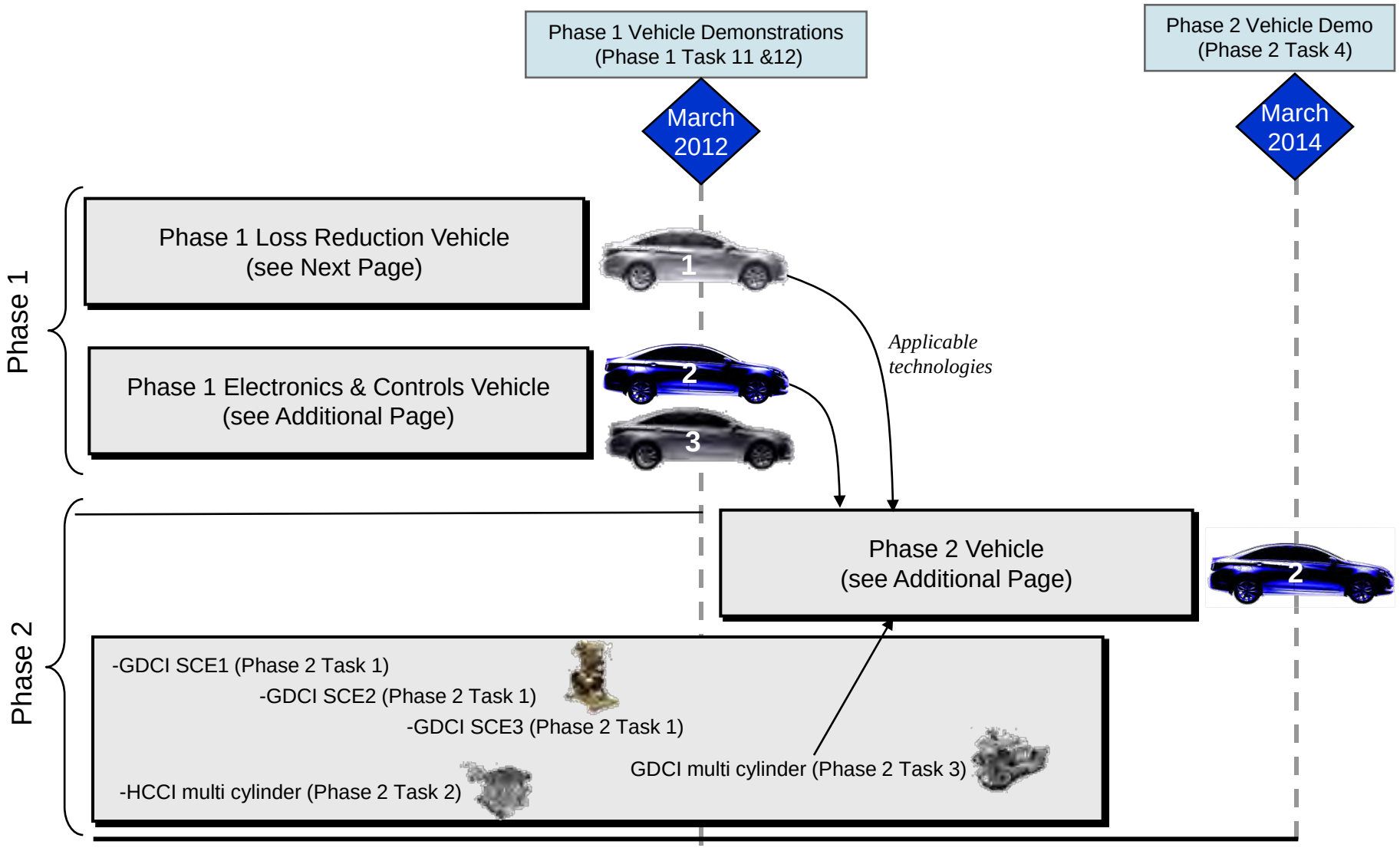
- **Objective**
  - Develop, implement and demonstrate fuel consumption reduction technologies with a partnership of universities, systems level OEM supplier and OEM.
  - Targeted fuel economy improvement of > 30% vs. PFI baseline.
  - Phase I of the project concentrates on fuel efficiency improvements 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



- March 2012: Vehicle Demo of Friction, Parasitic and Pumping Loss Reduction
- March 2012: Go / No Go Phase Review
- March 2013: Go / No Go Phase Review
- March 2014: GDCI Project Vehicle Demonstration

Approach / Strategy
Project Hardware Plan

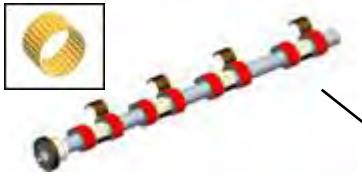


Approach / Strategy
Phase 1 Vehicle 1 (Parasitic Loss Reduction Vehicle)

- 2011 Sonata 6MT, 2.4L GDI Theta II

- Technologies on Vehicle:

Camshaft Rollerization



~ 1% for rollerized Camshaft

Optimized Oil Pump

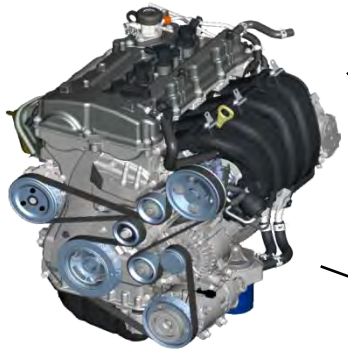
Crank Rollerization

~ 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



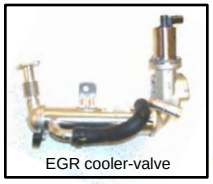
Demonstrated on Hyundai Theta GDi engine in a 2011 Sonata

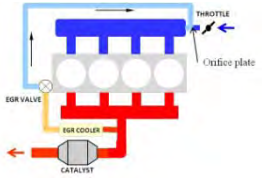
Exhaust Thermal Management

~1-2% exhaust heat recovery

Optimized Water Pump

Cooled EGR





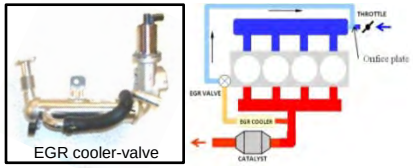
~ 3% cooled EGR

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

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

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

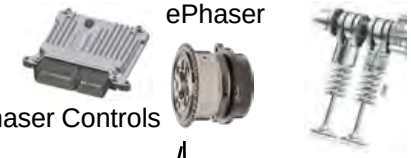
Cooled EGR



~ 3% cooled EGR

Variable Valvetrain

~4% improvement in vehicle level



ePhaser

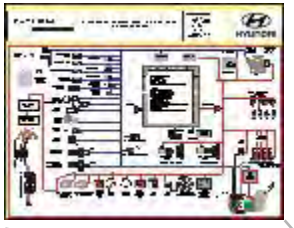
ePhaser Controls

GDi Fuel System

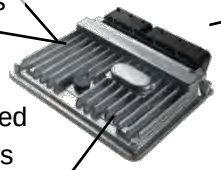
1-3% improvement

GDi pump

GDi injector

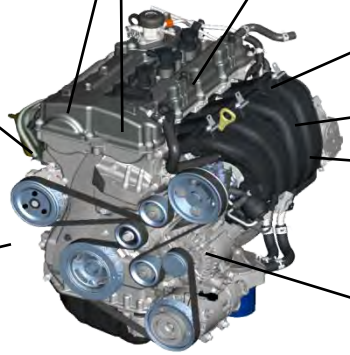


EMS Control Algorithms



ECM
With Integrated
GDi Controls

Calibration



Demonstrated on Hyundai Theta
GDi engine in a 2011 Sonata

GDi rail

Stop / Start

- Micro Hybrid Stop / Start Controls
- Modified FEAD

~3% improvement in vehicle level

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

Phase 1 Accomplishments: Project specific hardware and testing

- Start cart
  - Controls
  - GDI
  - Belt Alternator Starter – Stop / Start
  - Stop / Start Development
- Friction rig
  - Cylinder head friction
- Phase 1 dyno engines
  - Controls
  - GDI
  - Advanced Valvetrain
  - Calibration Design of Experiment
  - Thermal management
  - Rollerization
- HCCI dyno engine
  - HCCI Controls
  - Advanced valvetrain and fuel injection systems
- 2011 Sonata 2.4L Theta II vehicles
  - Controls
  - GDI
  - Belt Alternator Starter – Stop / Start
  - Advanced Valvetrain


Phase 1 Start Cart


Friction Rig


Thermal Management


HCCI dyno engine


Phase 1 Vehicle 1

Approach / Strategy
Phase 2 Demonstrator Vehicle (GDCI)

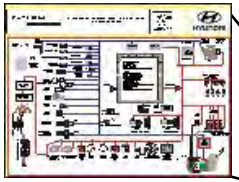
- 2011 Sonata 6MT, 2.0L GDI Theta Turbo

- Technologies on Vehicle:

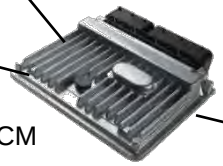
GDCI low temperature combustion process and controls

~25% targeted fuel economy improvement

EMS Control Algorithms



Calibration



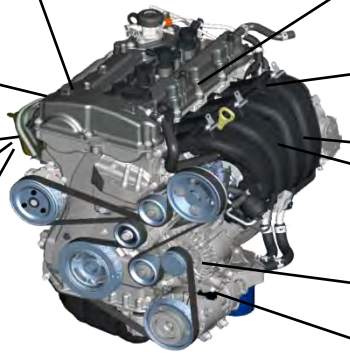
ECM

GDCI optimized valvetrain

GDi pump

GDCI optimized injector

Boosting System



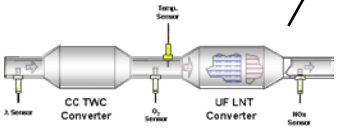
GDi rail

Charge Air Cooler

Stop / start

Demonstrated on Hyundai Theta Turbo GDi engine in a 2011 Sonata

Aftertreatment System



Parasitic loss reduction technologies from Phase 1 (where applicable)

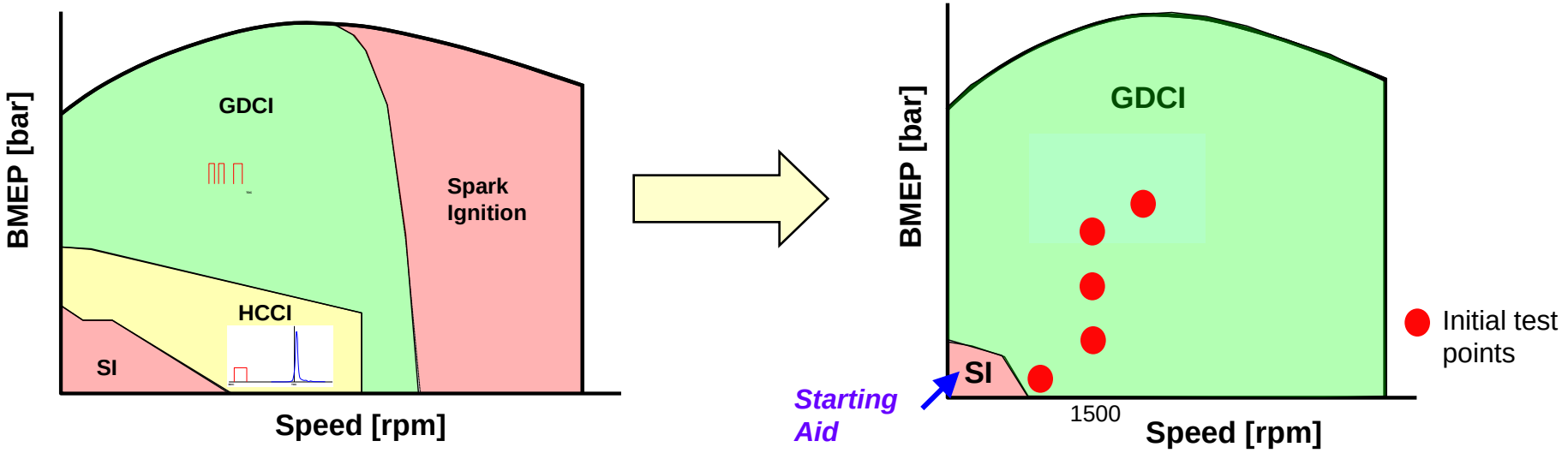
Approach / Strategy
Phase 2 Advanced Combustion

- Establish diesel-like efficiency and T2B5/B2 emissions using unleaded gasoline with low-moderate fuel pressure
- Develop combustion technology and practical engine systems for **Full-time** GDCI operation

Mixed Mode Combustion as submitted in project proposal

Goal

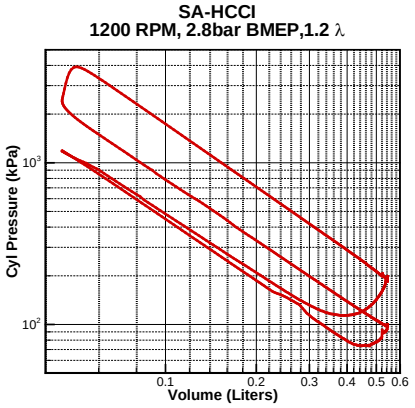
GDCI Full-time Down-speeded with Start Mode



Accomplishments
Phase 2 HCCI Project at Delphi CTCM

- HCCI engine constructed and testing begun
  - Cycle/cycle, cylinder independent, combustion feedback based controls
  - 12:1 Compression Ratio
    - » Modified pistons from production 9.2:1
  - GDi fuel injection (side mount)
  - Extended authority Delphi Hydraulic Cam Phasers
  - Delphi 2-Step valvetrain on intake & exhaust
    - » Modifications to enable fast evaluation of cams
    - » Enable transitions between SI and HCCI
  - Controls work is concentrating on expanding the usable speed load range of operation.

Project specific engine installed at Delphi

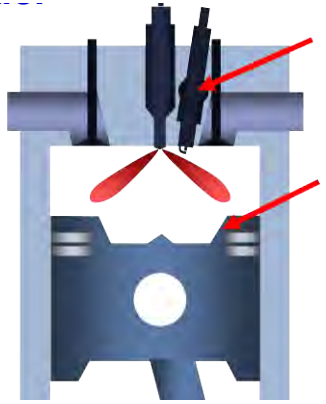


- Modifications to existing optical engine at WSU to run HCCI combustion has begun
  - Cooling jacket, Heated inlet, Access window, Improved optics/imaging
  - Observe combustion initiation of compression auto ignition and improve understanding of combustion initiation processes

Approach / Strategy
Phase 2 Gasoline Direct-injection Compression Ignition

- Gasoline premixed-compression-ignition combustion process
  - High CR and Lean for High Thermal Efficiency
  - Central Inj., GDi-like pressure; multi-late injection
  - No classic Knock limits or Pre-Ignition expected
  - Boosted and Down-speeded

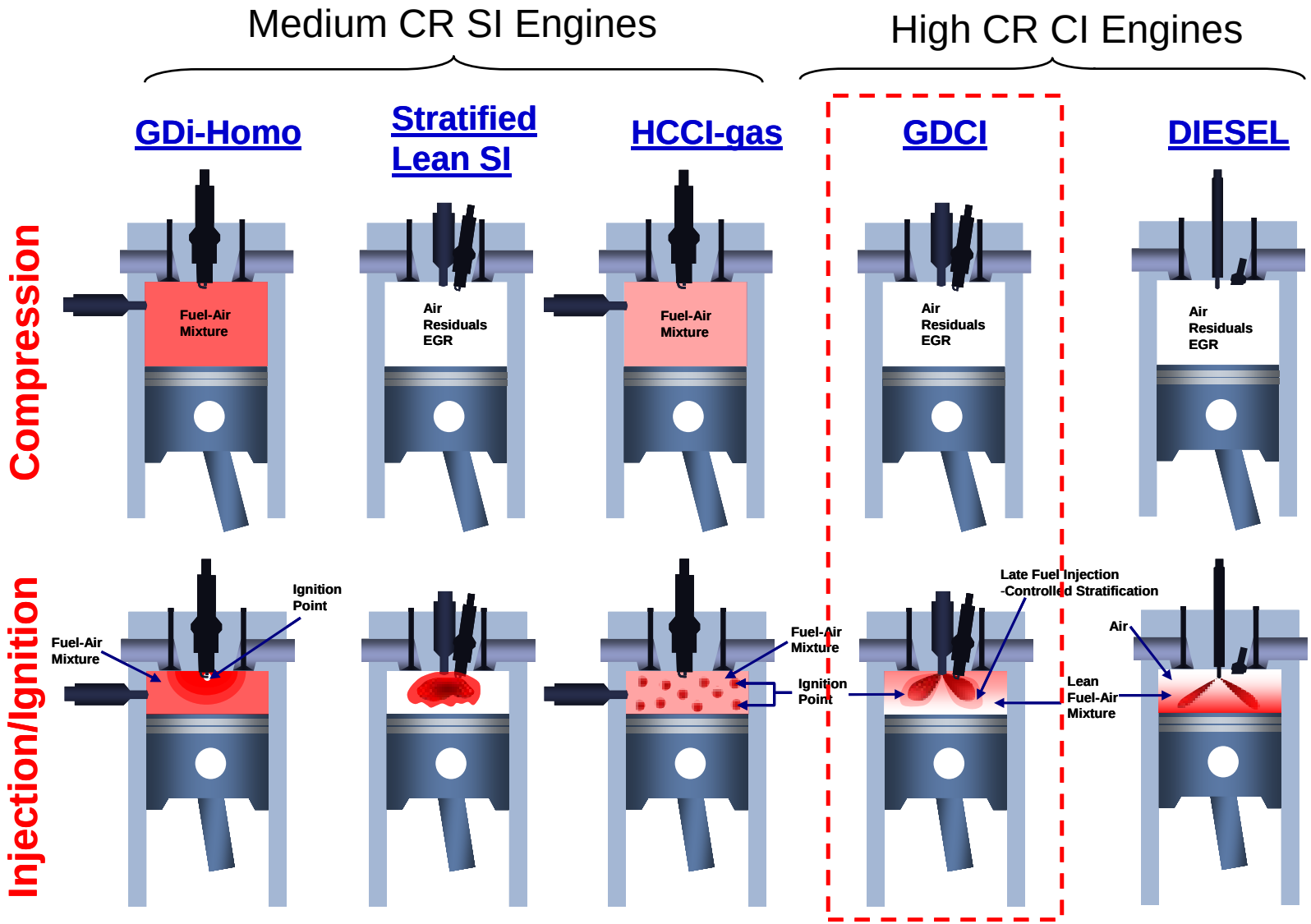
GDCI Preliminary Concept



- Gasoline has <u>superior fuel properties</u> for PCI comb. modes (Shell, U.Wisc, VW, Toyota, Lund)
  - <u>Volatility</u> aids rapid mixing (at low inj. Pressure)
  - <u>High octane</u> increases ign. delay (more mixing time)

- Low NOx & Soot via Low Temp Combustion (LTC)
  - Controlled stratification; lean with EGR

Approach / Strategy
Phase 2 Gasoline Direct-injection Compression Ignition



Accomplishments
Phase 2 Gasoline Direct-injection Compression Ignition

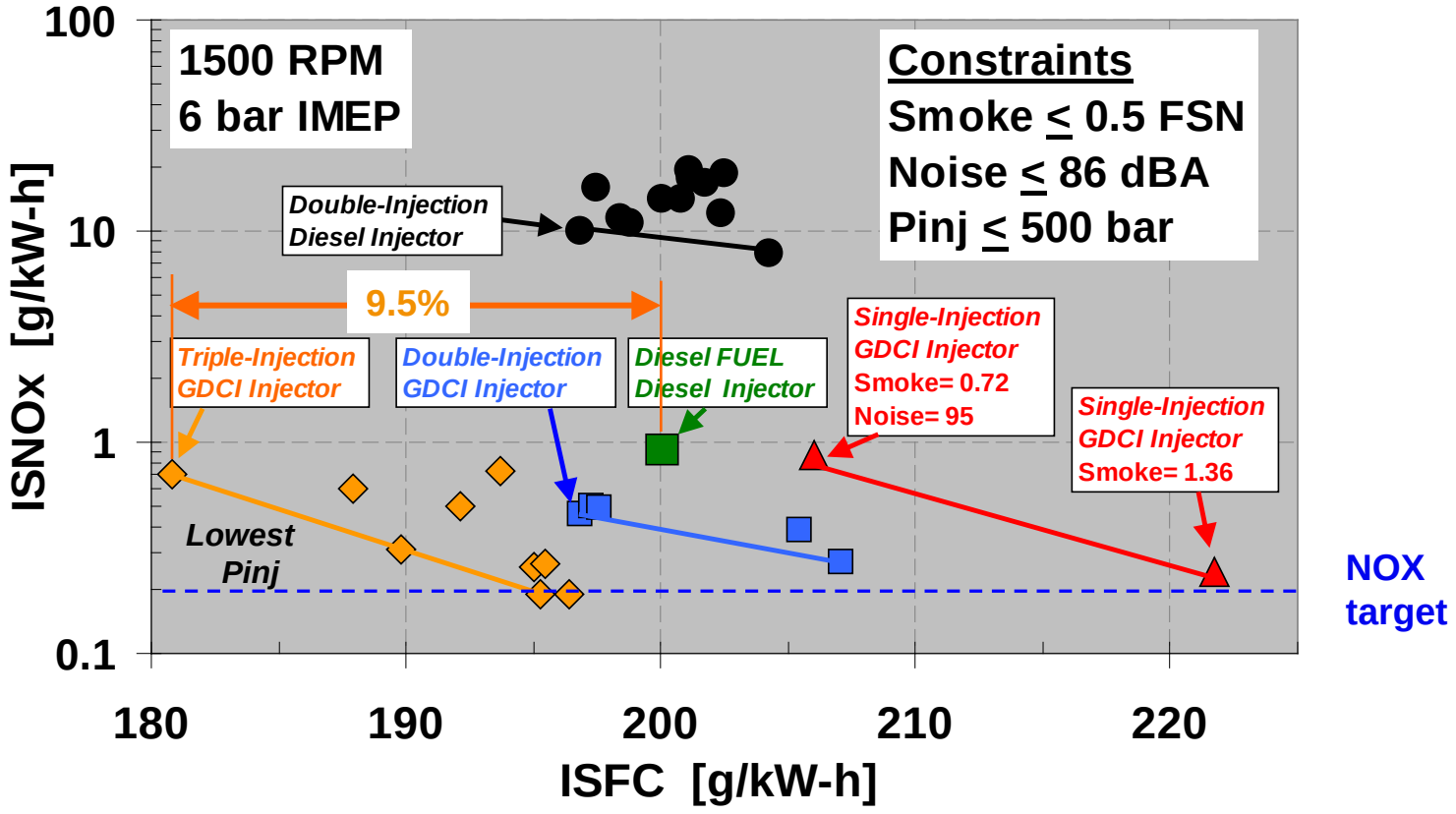
Single-Cyl Test Engine (Ricardo Hydra)

Engine Type	4-valve Comp. Ignition
Bore Stroke	84 90 mm
Displacement	499 cc
Compression Ratio	16.2 (adjustable)
Max. Cyl. Pressure	200 bar
Injection	Central mount – various injector types
Piston & Bowl	piston blanks & variants
DOHC Type II Valvetrain	Fixed cams (selectable)
Swirl ratio	Variable (0.5 ~ 3.0) PDA

Accomplishments
Phase 2 Gasoline Direct-injection Compression Ignition

Injection Strategy Results: Single, Double, Triple

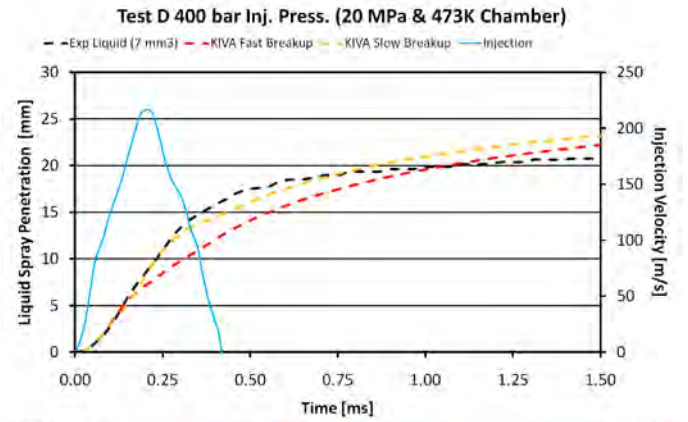
- A GDCI injector is under development for this work
- With Triple injection, GDCI injector was significantly better than a diesel injector with diesel fuel or gasoline



Accomplishments
Phase 2 Gasoline Direct-injection Compression Ignition

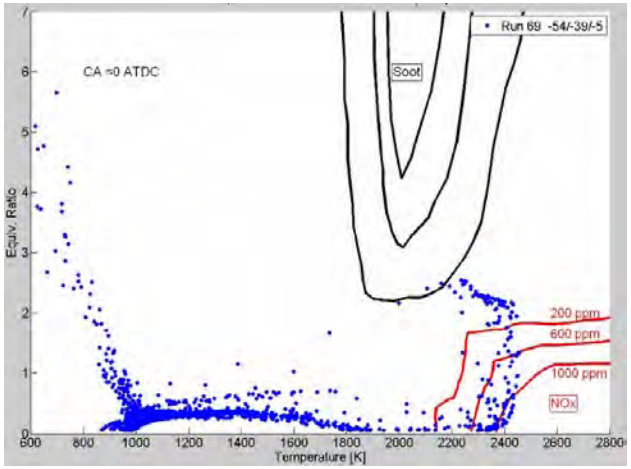
Spray Chamber

- Prelim. spray chamber tests completed for test injector with gasoline
- Backlit (liquid) and Schlieren (vapor)
- TSI PDPA (droplet size) system purchased & setup



KIVA Validation & First Results

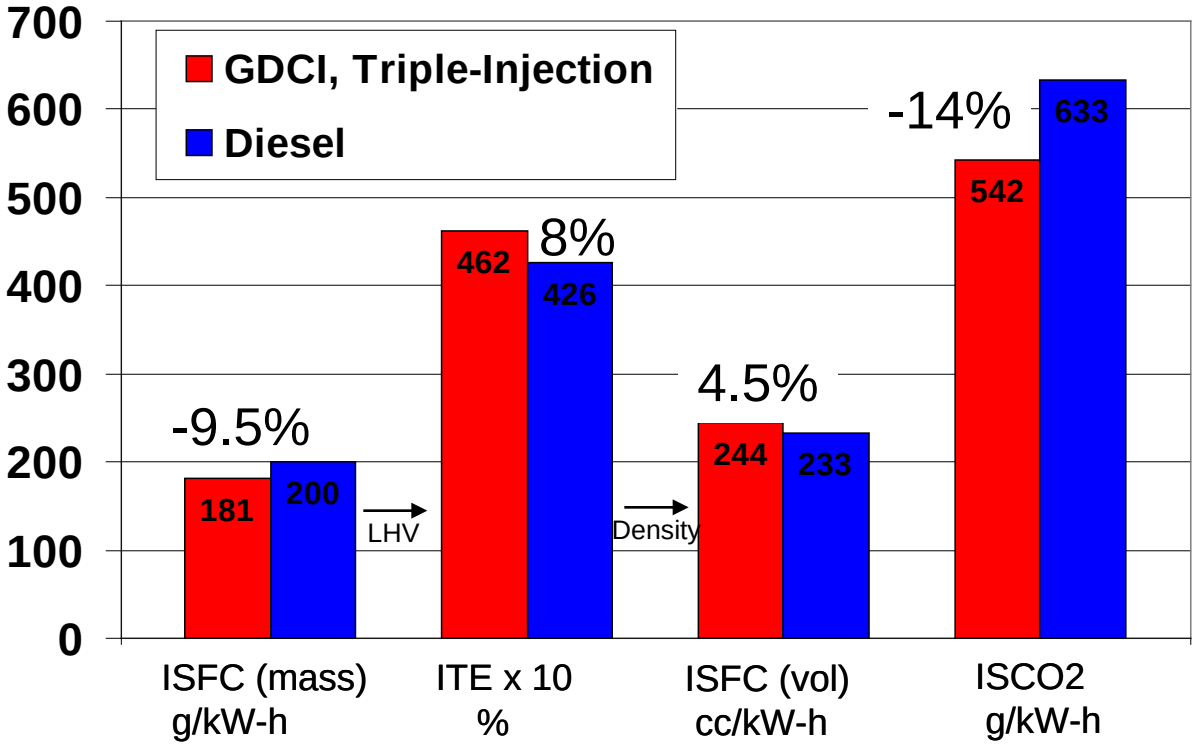
- KIVA spray penetration comparable to measurements for test injector
- KIVA correlation to engine test results for single, double, triple injection strategies
- “Phi-T plot” shows stratification control for triple injection strategy



Accomplishments
Phase 2 Gasoline Direct-injection Compression Ignition

Efficiency Comparison: GDCI & Diesel

- A-B tests on same engine; equally constrained for smoke & noise
- ISFC, ITE, and ISCO2 significantly improved over diesel
- ISFC (cc/kWh) worse than diesel (fuel energy density)



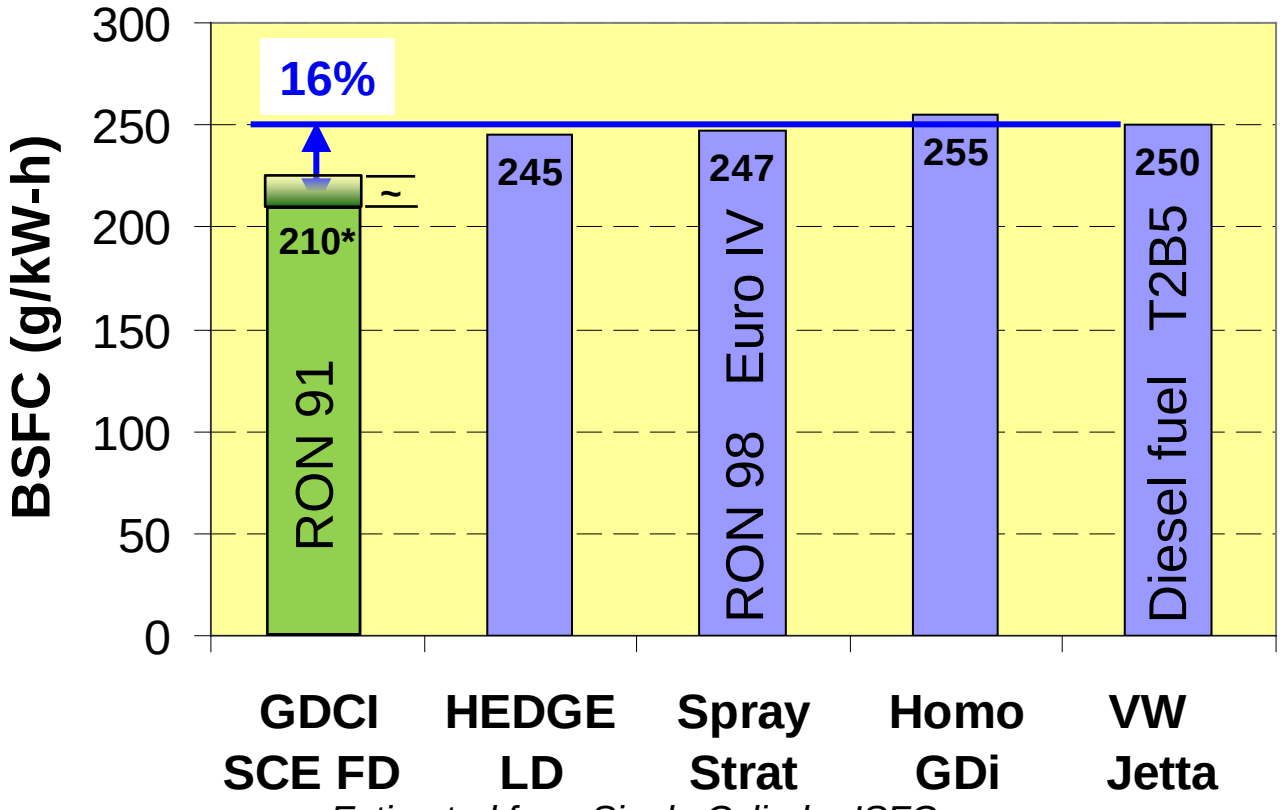
1500 rpm
6bar IMEP

	Gasoline	Diesel
Density (g/cc)	0.741	0.857
LHV (MJ/kg)	43.1	42.8
CO2 (g/MJ-HR)	73.6	74.44

Accomplishments
Phase 2 Gasoline Direct-injection Compression Ignition

Efficiency Comparison (1500 – 6bar IMEP)

- Preliminary GDCI estimates based on single-cylinder engine tests
- Other combustion types taken from published literature
- Summary: Favorable BSFC potential compared to leading engines



1500 rpm
6bar IMEP

∗ *Estimated from Single Cylinder ISFC*

Future Work
UFEV Project 2011-2012

- **Phase 1**
  - **Vehicle Build**: Demonstration vehicles will be retrofitted with project specific hardware
  - **Calibration**: Demonstration vehicles will be calibrated for fuel economy and emissions
  - **Vehicle Test**: Vehicle level testing and demonstration will be completed
- **Phase 2**
  - **SCE Testing**: Advanced injection and valvetrain strategies are being developed over the speed load range. Very aggressive fuel consumption, emissions, and noise targets.
  - **Simulation**: A variety of simulation tools for injection and spray development, combustion system, and valvetrain systems are being applied to achieve minimum NOx and PM emissions.
  - **Engine Design and Build**: All new cylinder head, piston, and block rated at high cylinder pressure and including GDCI enabling systems are being developed. Both single-cylinder and multi-cylinder engines are being fabricated.
  - **Begin MCE Testing**: An additional test cell is being prepared for GDCI MCE testing.

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.
  - The project is meeting budget targets.
- **Phase 1**
  - Demonstration vehicle content has been selected and is currently undergoing phases of design, construction and bench testing in preparation for installation in the demonstration vehicles.
- **Phase 2**
  - HCCI multi-cylinder engine has been built and is undergoing testing and controls refinement.
  - A GDCI combustion system is under development for low-to–moderate injection pressures using RON91 pump gasoline.
  - Based on preliminary single-cylinder test data, estimated BSFC is attractive relative to competitive powertrains.

Gasoline Ultra Fuel Efficient Vehicle

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Thank-You

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