Gasoline Powertrain Technologies: Developing Solutions for the Global Market

John Kirwan
Chief Scientist,
Gasoline Engine Management Systems
Outline

- Global Powertrain Market Drivers

- Delphi Gasoline Engine Management Systems Engineering Footprint with Examples of Regionally-Focused Activities

- CO₂ Reduction Technologies for Worldwide Application

- Summary and Conclusions
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- Summary and Conclusions
Committed to the Kind of Innovation that Will Keep Our Planet Green and Its Occupants Safer and More Connected

MEGATRENDS

◆ People Megatrends
  - Natural Growth
  - People Live Longer
  - Generations X & Y
  - Increased Concern about Safety, Security and Privacy
  - Health Care
  - 8/5 > 12/6 > 24/7

◆ World Megatrends
  - World Turmoil
  - Globalization
  - Higher Cost of Natural Resources
  - Increasing Environmental Awareness/Regulations

◆ Technological Megatrends
  - Information Explosion
  - Wireless World

◆ Safe
  - Traffic congestion in major metro areas around the world becomes worse; more accidents; longer commute; higher stress level

◆ Green
  - Fast growing economies: more fuel for mobile platforms
  - Demand for electrical energy and related conventional resources far exceeds current capabilities

◆ Connected
  - Global demand for broadband access will continue to grow
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Powertrain Global Market Drivers:
• Low tailpipe emissions and CO₂ reduction with fun-to-drive performance
Global emissions legislation is evolving toward fuel neutral standards, with emerging countries adopting European legislation.

**Powertrain Market Drivers:** CO₂ Reduction with Low Tailpipe Emissions

NOx relief is disappearing for EU diesel engines.
Powertrain Market Drivers: CO₂ Reduction with Low Tailpipe Emissions

Global CO₂ / Fuel Economy Legislation Creates a Significant Challenge
Powertrain Market Drivers: CO₂ Reduction with Low Tailpipe Emissions

Global CO₂ / Fuel Economy Legislation Creates a Significant Challenge


- LD Truck
- United States CAFE Pass. Car
- China Fleet Avg.
- Europe Fleet Avg.
- EU / ACEA Agreement
- EU Comission Phase-in
- 95 g/km EU Target
- 54.5 MPG Car + Truck
- 65%
- 100%

- Substantial innovation will be required to reduce CO₂ while delivering features and performance expected by today’s demanding customers
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Delphi Gasoline Engine Management Systems
Global Engineering Employees by Region

- Asia Pacific
- United States
- Mexico
- Europe
- South America

Includes DEG. As of Jul 2012.
Delphi Gasoline Engine Management Systems
Global Technical Centers

- Auburn Hills, MI, USA
- Rochester, NY, USA
- Krakow, Poland
- Beijing, China
- Kokomo, IN, USA
- Bascharage, Luxembourg
- Seoul, Korea
- Shanghai, China
- Juarez, Mexico
- Piracicaba, Brazil
- Bangalore, India
- Singapore, Singapore
European-Focused Activity: Gasoline Direct Injection (GDi) Engine Particulate Number Emissions Reduction
GDi Engine Particulate Number Emissions Reduction

Vehicle test data by Delphi

References:
SAE 2012-01-1212;
GDi Engine Particulate Number Emissions Reduction

Euro 6 Particulate Regulation

(Compliant)

(Non-Compliant)

6E11#/km
4.5 mg/km

Vehicle test data by Delphi

References:
SAE 2012-01-1212;
South American Focused Activity: Heated Tip Fuel Injector for Ethanol-Fueled (E100) Engine Cold Starting

Piracicaba, Brazil
Heated Tip Fuel Injector for Ethanol-Fueled (E100) Engine Cold Starting

- Fuel injector with electrically heated tip improves wintertime starting with E100-fueled vehicles in Brazil
  - Increases fuel vaporization for low volatility E100 fuel
  - Gasoline injector based design leverages vast experience and proven product robustness

- Eliminates secondary gasoline cold start systems

- Offers reduced complexity, faster starting and lower energy consumption compared to competing heated fuel rail systems

References:
SAE 2012-01-0418; SAE 2010-01-1265; SAE 2010-01-1264; SAE 2009-01-0615

E100 Cold Start Comparison:
1.6L production engine with heated fuel rail vs.
1.8L development engine with heated tip injectors
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Turbocharged Gasoline Direct Injection
Gasoline Direct Injection is a Key Enabler to Improve Low-end Torque in Boosted Engines

- Improved volumetric efficiency and reduced knock propensity
  - Direct injection with cam phasing allows scavenging with fresh air to reduce residual gas fraction
  - In-cylinder fuel vaporization reduces charge temperature
- Improved combustion phasing
  - Charge motion increases burn rate

Benefits
- Fuel economy improvement: 8 – 15%
- Increased power and responsiveness
- Stoichiometric engine operation allows emissions control via traditional 3-way exhaust catalyst
CO$_2$ Reduction Technologies for Gasoline Engines
Turbocharged Gasoline Direct Injection Engines

- **Homogeneous GDi fuel system features**
  - Inwardly-opening, multi-hole GDi Injectors, fuel rail and engine-driven high pressure fuel pump
  - Mixture preparation focused on complete vaporization and mixing of the fuel and air
  - Improved fuel control and split-injection during cold start for rapid catalyst light-off

- **Key requirements**
  - Operation at fuel pressures up to 200 bar
  - Spray generation for good vaporization and mixing without wetting in-cylinder surfaces
  - High linear flow range, no pintle bounce and low noise

![Diagram of GDi fuel system features and requirements](image-url)
CO₂ Reduction Technologies for Gasoline Engines

Turbocharged Gasoline Direct Injection Engines

Comparison: 1.6L 4-cylinder MPFI versus 1.2L 3-cylinder Turbo GDi and Turbo Diesel

- 3-cyl Boosted Engine
  - Value Analysis

No electrification considered

Reference: SAE 2010-01-0590
CO₂ Reduction Technologies for Gasoline Engines

Turbocharged Gasoline Direct Injection Engines

Comparison: 1.6L 4-cylinder MPFI versus 1.2L 3-cylinder Turbo GDi and Turbo Diesel

3-cyl Boosted Engine
Value Analysis

Turbo GDi and Turbo Diesel engine comparison shows similar
On Cost / % CO₂ reduction

No electrification considered

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Turbocharged Gasoline Direct Injection Engines

Comparison: 1.6L 4-cylinder MPFI versus 1.2L 3-cylinder Turbo GDi and Turbo Diesel

- **No electrification considered**

- **3-cyl Boosted Engine Value Analysis**

- Turbo GDi and Turbo Diesel engine comparison shows similar On Cost / % CO₂ reduction

- Lean NOx aftertreatment (if necessary) is a significant cost driver

Reference: SAE 2010-01-0590
Variable Valve Lift
CO₂ Reduction Technologies for Gasoline Engines

2-Step Variable Valve Lift and Timing

- 2-Step mechanization with cam phasing varies intake valve lift, duration and timing as a function of engine load
  - 3-lobe cam provides two intake valve lift profiles
  - Cam follower switches between high and low lift profiles
  - Oil control valve hydraulically actuates switching

- Enables separate optimization of low load and high load intake events
  - Optimized low load profile with early intake valve closing (EIVC) substantially reduces pumping work losses for improved fuel economy (3%-6%)
  - Optimized high load phasing improves low-speed torque (2%-3%) and peak power (2%-4%)

References:
SAE 2011-01-0900; SAE 2011-01-1221;
SAE 2007-01-1285; SAE 2006-01-0400;
SAE 2003-01-0029
2-Step Variable Valve Lift and Timing

- 2-Step mechanization with cam phasing varies intake valve lift, duration and timing as a function of engine load.
- 3-lobe cam provides two intake valve lift profiles.
- Cam follower switches between high and low lift profiles.
- Oil pressure regulating valve controls switching.

Animation of 2-step Operation
CO₂ Reduction Technologies for Gasoline Engines
2-Step Variable Valve Lift and Timing

Comparison: 1.6L 4-cylinder MPFI versus 1.2L 3-cylinder Turbo GDi and Turbo Diesel

No electrification considered

3-cyl Boosted Engine Value Analysis

Estimated 3% incremental benefit with 2-Step VVL

Reference: SAE 2010-01-0590
Advanced Low Temperature Gasoline Combustion
Objective

- Develop, implement and demonstrate fuel consumption reduction technologies in a gasoline-fueled vehicle
- Key emphasis on reduction-to-practice
- Targeted fuel economy improvement of > 25% versus PFI baseline.
- Phase 1 focus: EMS, GDi, and advanced valvetrain products in combination with technologies to reduce friction and parasitic losses.
- Phase 2 focus: develop and demonstrate improved thermal efficiency from advanced low temperature combustion with gasoline direct injection compression ignition (GDCI).

CO₂ Reduction Technologies for Gasoline Engines
Ultra Fuel Efficient Vehicle (UFEV) Project

1Q 2014
**Combustion strategy**

- High compression ratio (~15:1) and lean (with boost) for high thermal efficiency
- Central-mount, GDi-like injection pressure, multi-late injection strategy for partially pre-mixed combustion
- Gasoline has excellent fuel properties versus Diesel fuel for this combustion mode
  - Higher volatility enables rapid vaporization
  - Higher octane number increases ignition delay to increase mixing time
- Low temperature combustion (lean with EGR) enables low engine out NOx and soot
CO₂ Reduction Technologies for Gasoline Engines

Advanced Combustion: Gasoline Direct-injection Compression Ignition (GDCI)

Key Points:

- Representative Single Cylinder Engine Results
  - GDCI versus Diesel on the same engine
    - A-B tests equally constrained for smoke and noise
  - Efficiency evaluation
    - ISFC (vol.) worse than Diesel due to higher Diesel fuel density
    - ISFC (mass), thermal efficiency and CO₂ significantly improved over Diesel

### ISFC: Indicated specific fuel consumption

### ITE: Indicated thermal efficiency

### ISCO₂: Indicated specific CO₂ emissions

### Table: Fuel Properties

<table>
<thead>
<tr>
<th></th>
<th>Gasoline</th>
<th>Diesel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (g/cc)</td>
<td>0.741</td>
<td>0.857</td>
</tr>
<tr>
<td>LHV (MJ/kg)</td>
<td>43.1</td>
<td>42.8</td>
</tr>
<tr>
<td>CO₂ (g/MJ-HR)</td>
<td>73.6</td>
<td>74.44</td>
</tr>
</tbody>
</table>

### Graphs:

- **GDCI, Triple Injection** vs. Diesel
- **GDCI 10% better** vs. Diesel
- **GDCI 8% better** vs. Diesel
- **GDCI 4.5% worse** vs. Diesel

**1500 rpm 6bar IMEP**

ISFC: Indicated specific fuel consumption

ITE: Indicated thermal efficiency

ISCO₂: Indicated specific CO₂ emissions

### References:

- SAE 2012-01-0384;
- SAE 2011-01-1386;
- 20th Aachen Colloquium on Automobile and Engine Technology, October, 2011

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**DELPHI**
Summary and Conclusions

- Global emissions and CO$_2$ mandates are driving substantial powertrain innovations to meet legislative requirements in fun-to-drive vehicles.

- A worldwide engineering footprint is essential to develop region-specific solutions and meet the overall expectations of our global OEM customers.

- Turbocharged GDi engines and 2-step variable valvetrain systems offer high value CO$_2$ reduction strategies for worldwide application in gasoline-fueled vehicles.

- Low temperature GDCI combustion appears promising as a longer term CO$_2$ reduction strategy for Diesel-like fuel efficiency in gasoline-fueled engines.
Thank You for Your Attention

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