The GDI Revolution
World-Wide Powertrain Sales Forecast

Vehicle sales PC incl. LCV<6\(^1\)

<table>
<thead>
<tr>
<th>Year</th>
<th>EV</th>
<th>PHEV</th>
<th>HEV</th>
<th>CNG</th>
<th>GDI</th>
<th>PFI</th>
<th>Diesel</th>
<th>HEV</th>
<th>Pure ICE</th>
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<tbody>
<tr>
<td>2015</td>
<td>0.6</td>
<td>20.9</td>
<td>48.9</td>
<td>18.2</td>
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<td>2020</td>
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<td>35.8</td>
<td>86.7</td>
<td>19.1</td>
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<tr>
<td>2025</td>
<td>1.3</td>
<td>39.0</td>
<td>87.5</td>
<td>19.6</td>
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</tbody>
</table>

1) Estimation Bosch
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Why GDI?  Why Now?

**Turbo Charging**

Around since the 1960’s. Recuperates exhaust gas energy to boost intake air pressure, resulting in increased power. Remained a niche technology through 2010 primarily due to turbo lag.

**Variable Valve Timing**

Became common equipment in the mid-90’s. Allows precise control of airflow in/out of the cylinder.

**Gasoline Direct Injection**

First applied by Bosch in the 1950’s, industrialized from 2000 onwards. Allows precision injection of gasoline directly into the cylinder and optimization of the combustion process.

**SCAVENGING**

Air is swept through the combustion chamber to spool up the turbo charger even at low RPMs.
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Why GDI? Why Now?

Turbo Charging

Variable Valve Timing

Gasoline Direct Injection

SCAVENGING

Downsizing

More power from a smaller package…

- Fewer cylinders
- Less friction
- Less loss at idle
- Lower engine weight
- Lower vehicle weight

Fuel Economy

Fuel economy improves despite…

- More CUVs/SUVs/Pick-ups
- Larger footprint
- Increased horsepower

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Picking up the Pace of ICE Technology

Powertrain Technology Milestones:

- GDI
- CVT
- GTDI
- 8 Speed AT
- 10 Speed AT
- CVO
- 2nd Gen GTDI
- PFDI
- 350 Bar
- Cooled EGR?
- Water Injection?

GDI Engine Production in NA

Source: Bosch Internal Estimate (AMPI 2016)
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**Optimizing the Powertrain**

**Background:**
- Overall goal is to operate engine at high fuel efficiency regions as frequently as possible. Best fuel efficiency normally at high load/low engine speed conditions.
- Traditional PFI engines generally operated at higher engine speeds and lower loads.

**Powertrain Optimization:**
- GTDI enables **downsizing**, which moves the operating point into the higher load area.
- High speed transmissions enable **downspeeding**, which keeps the engine speed low.

**Fuel Economy Strategy:**
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CO2 Reduction Roadmap

Engine Measures

Powertrain Measures

Simulation for FTP75 test cycle
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Next Steps in GDI – Meeting the Emissions Challenge

Sources of Particles

1. Piston surface wetting
2. Combustion chamber roof wetting
3. Injector tip fuel deposits
4. Droplets in combustion zone

Diffusion Combustion:

Inhomogeneous Mixture:

1. Fuel vapor phase (l<1)
2. HC in crevices (l<1)

System Approaches to Increase Efficiency and Reduce Particulates

Increased Pressure:

Advanced Combustion:
Optimized Calibration, CVO, & Multi-Injection:

Spray Targeting:

Laser Drilling:

Reduced penetration
Thank you for your attention!

Questions?