



# 3-Cylinder Turbocharged Gasoline Direct Injection: A High Value Solution for Euro VI Emissions

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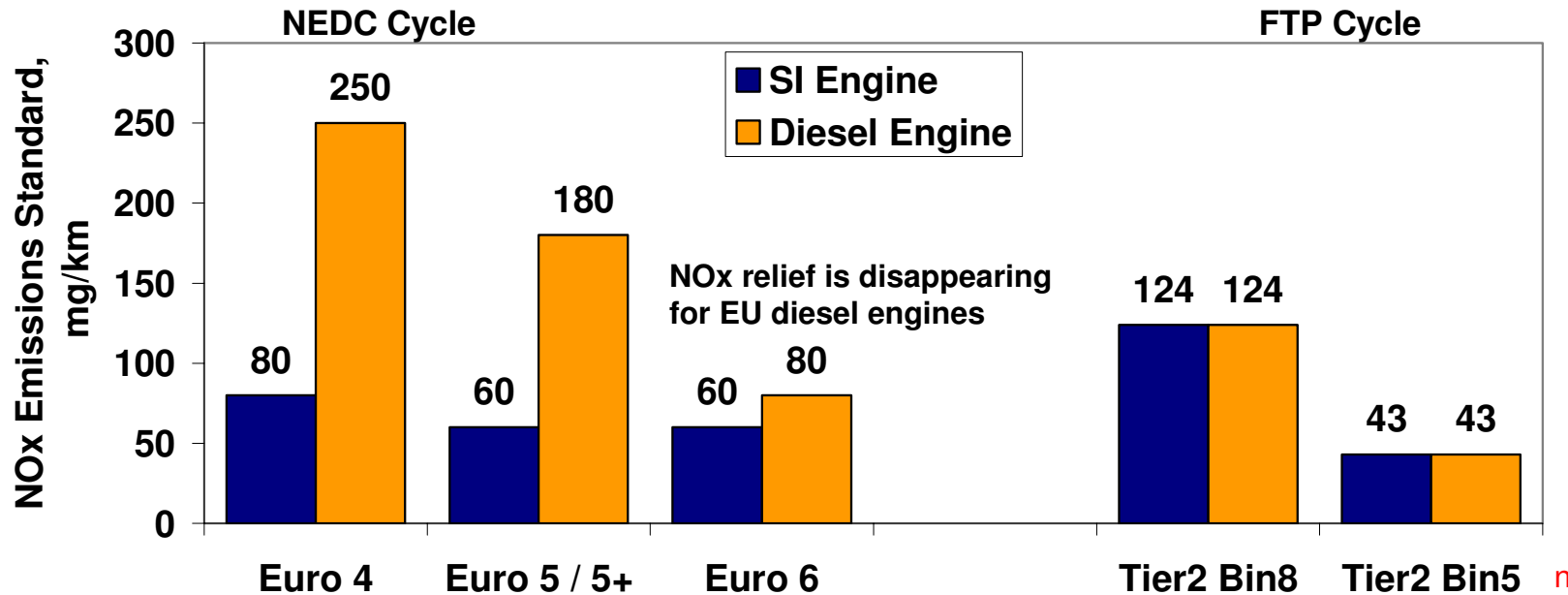
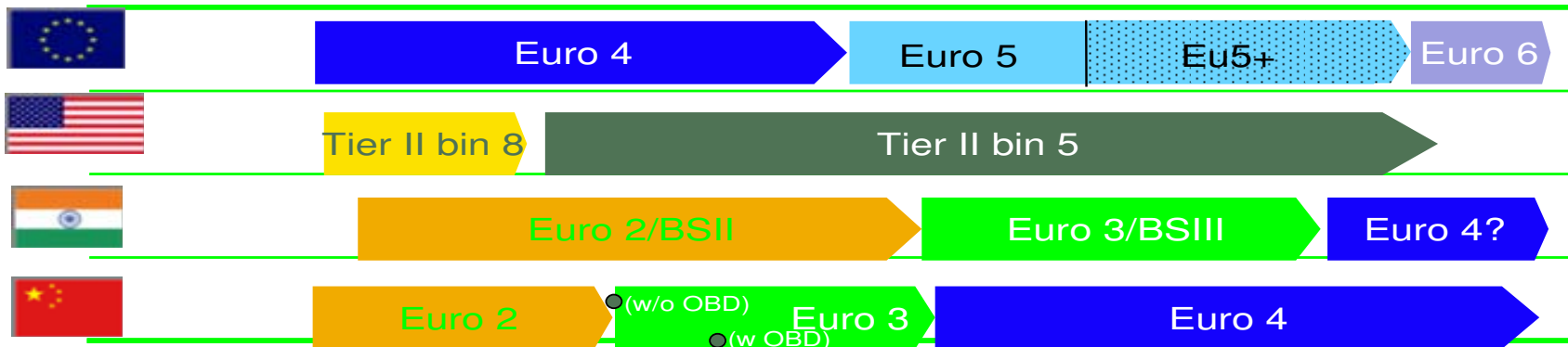
John E. Kirwan

Presented at DEER 2009 Conference  
August 5, 2009

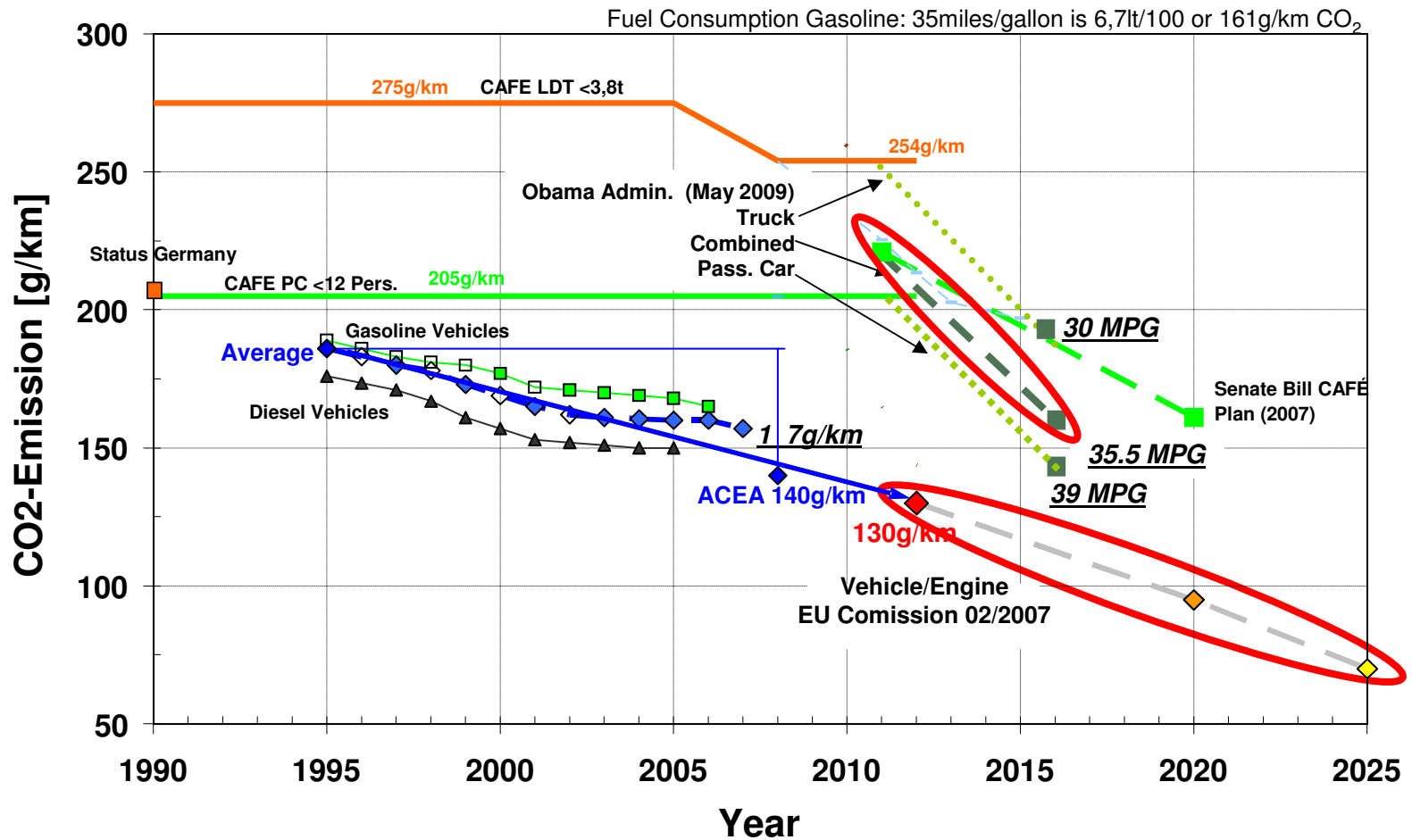
- ◆ Global Emissions and CO<sub>2</sub> Challenges
- ◆ Technology Overview for 3-Cyl Boosted GDi Engines
- ◆ Value Analysis
- ◆ Summary and Conclusions

## The Emission Legislation Global Drive

Global emission legislation are evolving toward fuel neutral standards, with emerging countries adopting European legislation.



## CO<sub>2</sub> Regulations Globally Introduced

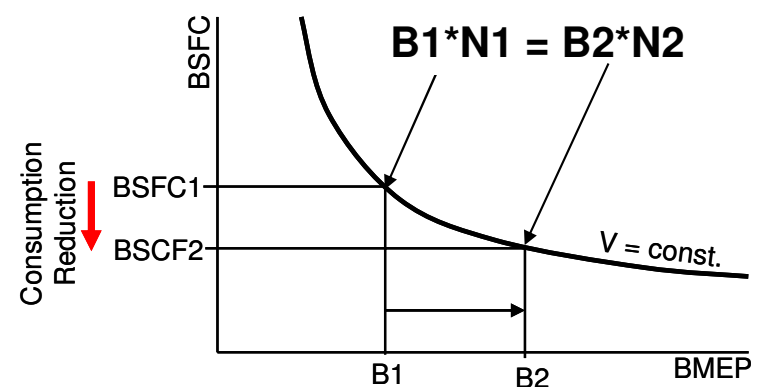
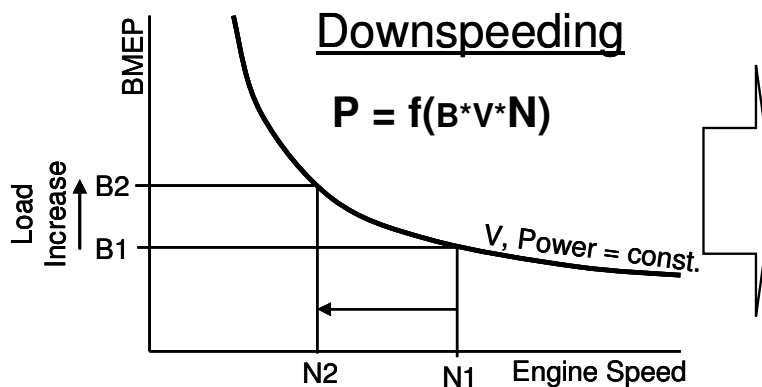
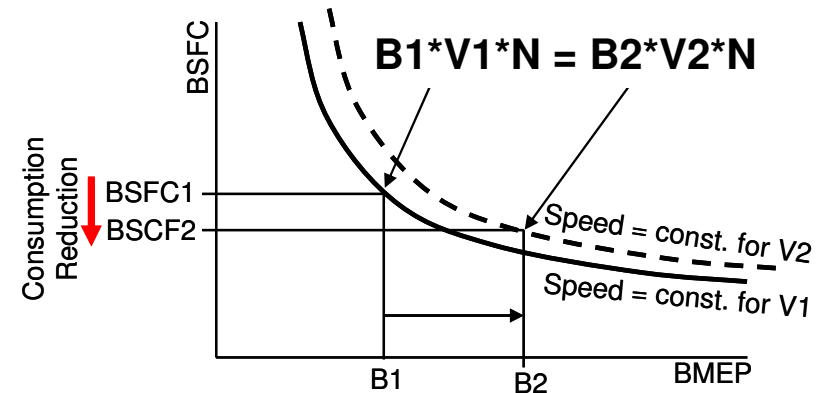
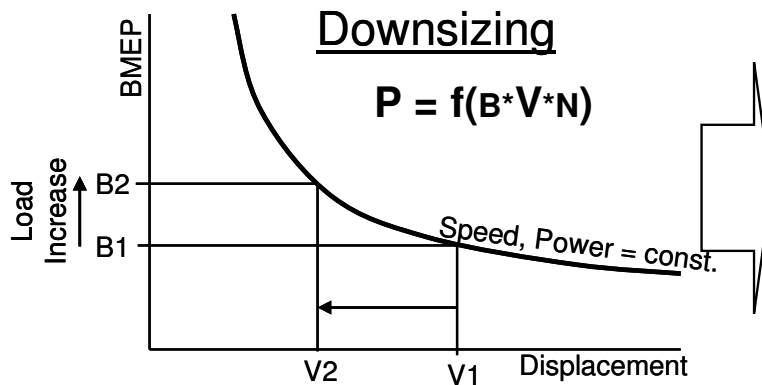


- Powertrain/Vehicles will change significantly:
- **Dramatic Downsize and Boost → 3-cyl. Turbo GDi**
  - **Hybrids/Electrification required to meet future targets**

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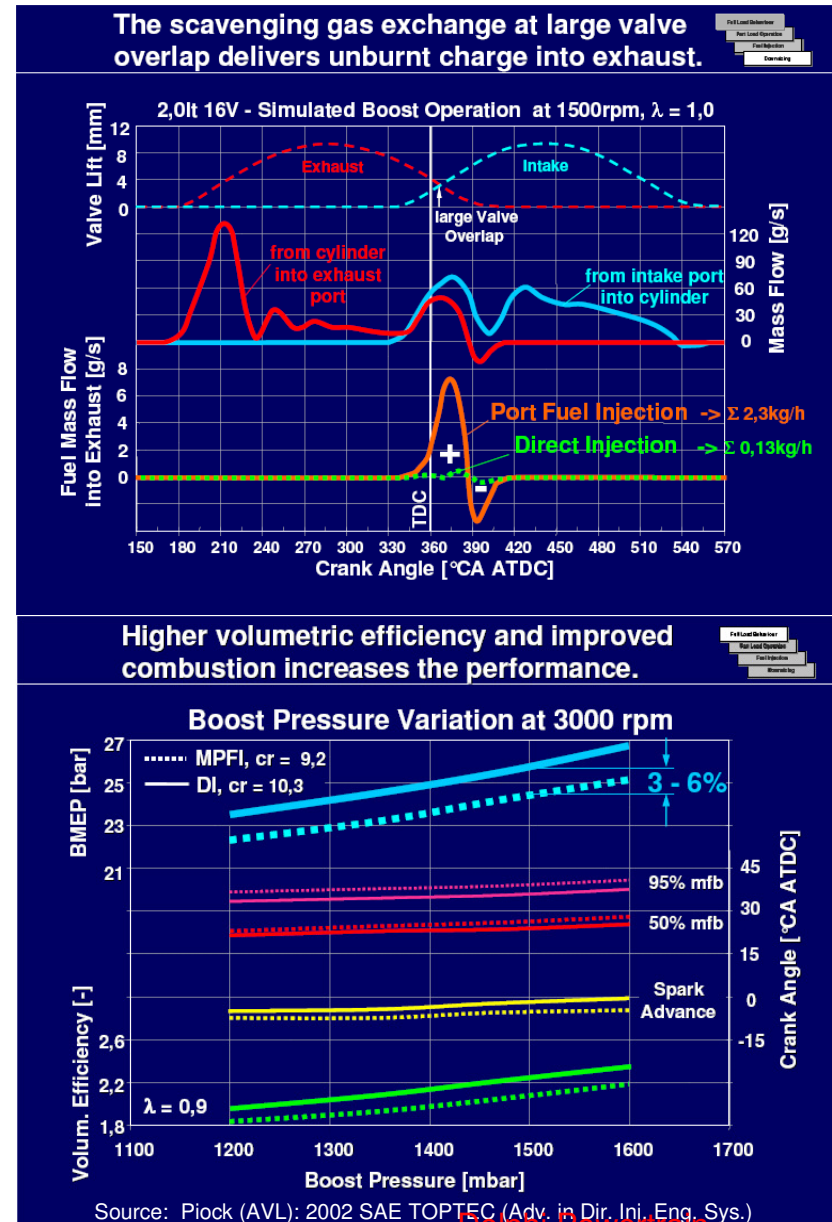
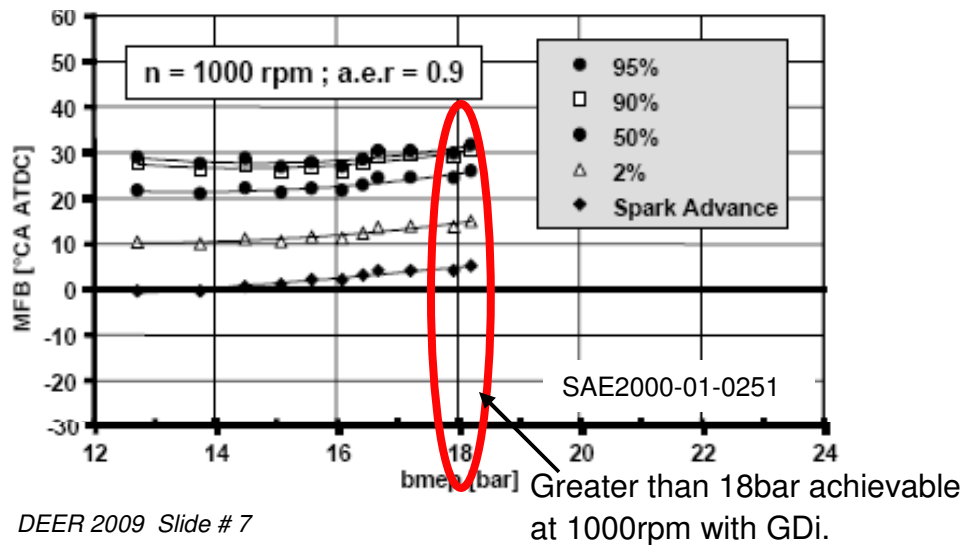
# DELPHI Fuel Economy Benefits from Engine Boosting Downsizing and Downspeeding

- ◆ Reduced Engine Displacement and Decreased Engine Speed Increase Engine Load for Reduce Fuel Consumption
  - Good low end torque is essential



◆ Gasoline Direct Injection is a Key Enabler to Improve Low End Torque in Boosted Engines

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

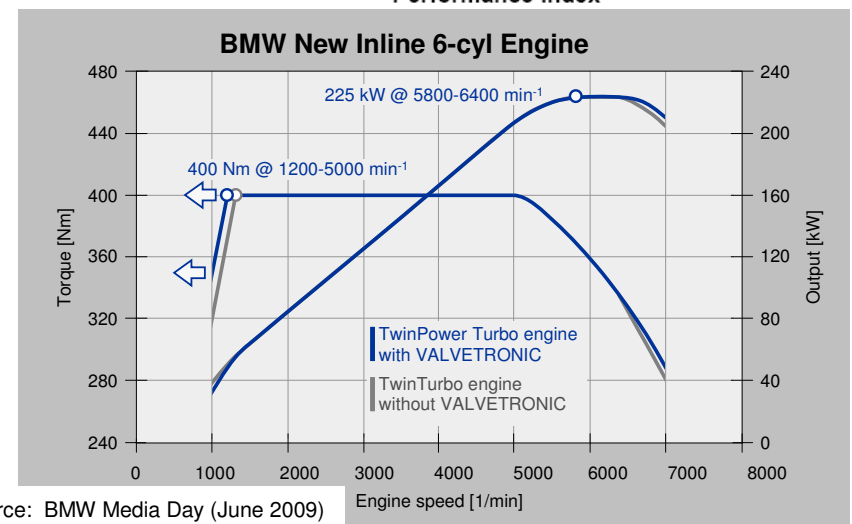
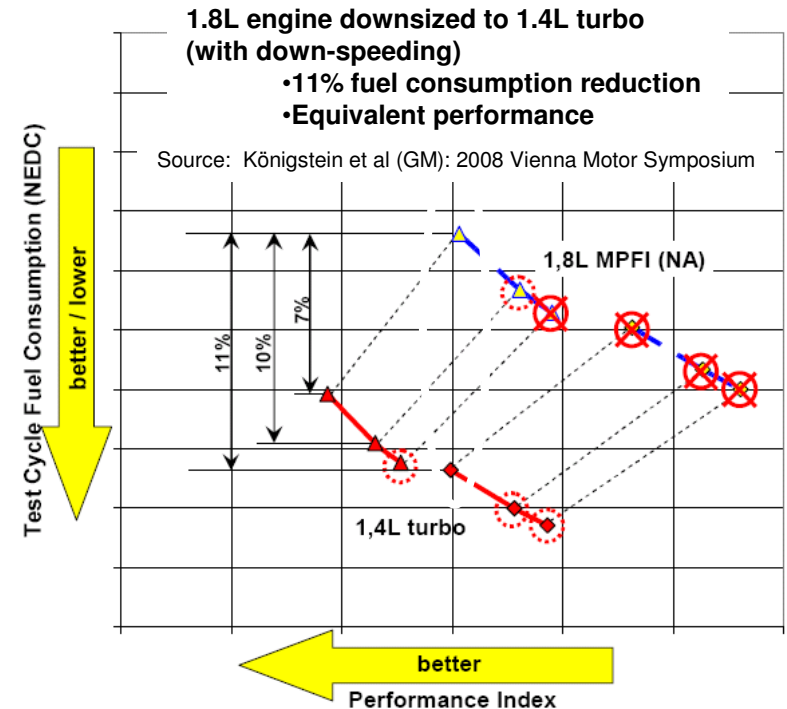


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### ◆ Benefits

- Fuel economy improvement
  - 9-15% for homogeneous systems
  - 15-21% for stratified systems
- Improved fuel control and rapid catalyst light-off with split-injection during cold start
- Increased power and responsiveness

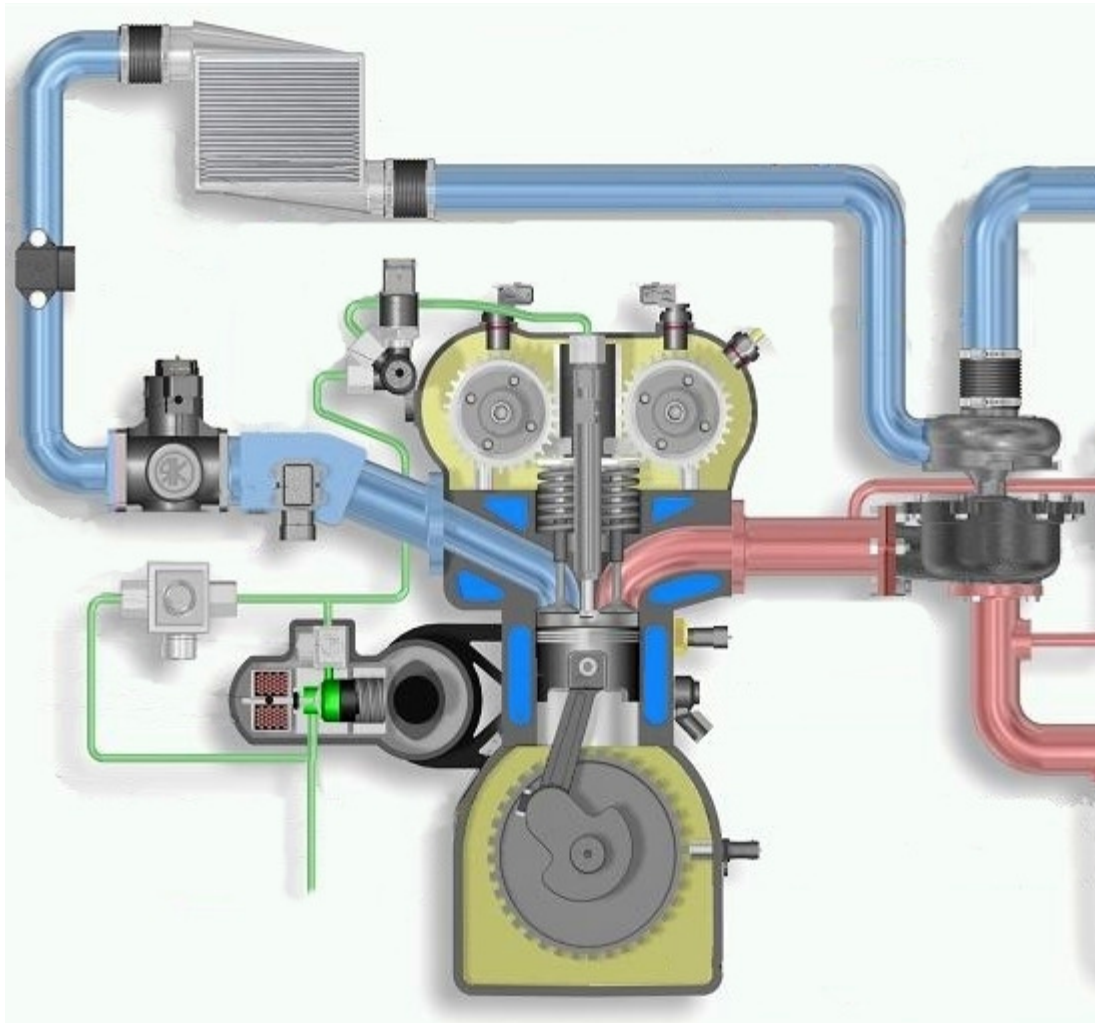


Source: BMW Media Day (June 2009)



**DELPHI**

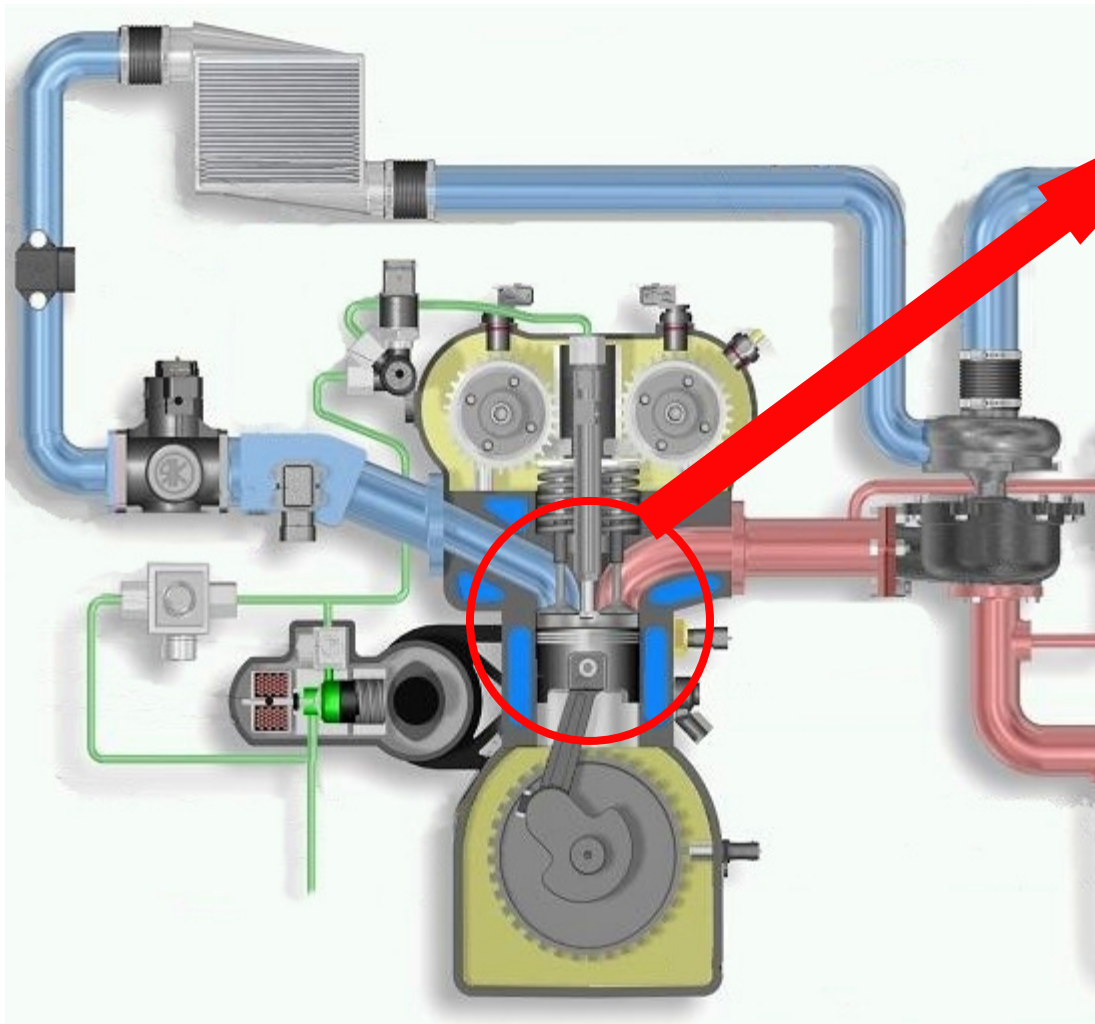
Gasoline Direct Injection  
Boosted Engine System Mechanization



Delphi Powertrain

# DELPHI

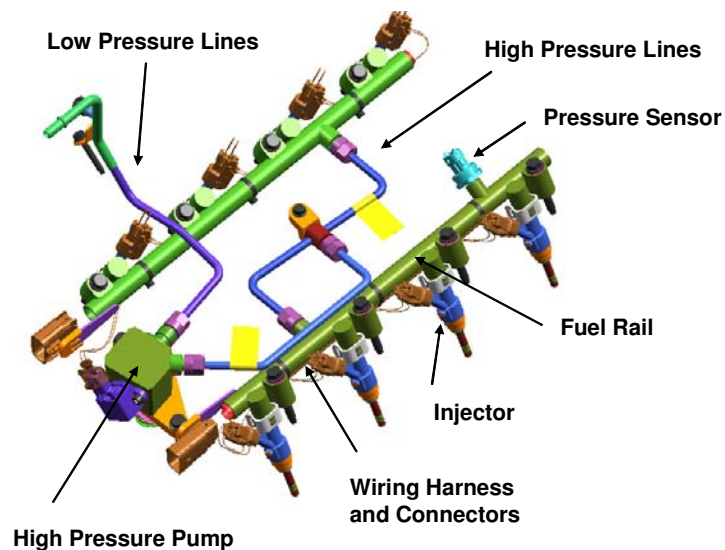
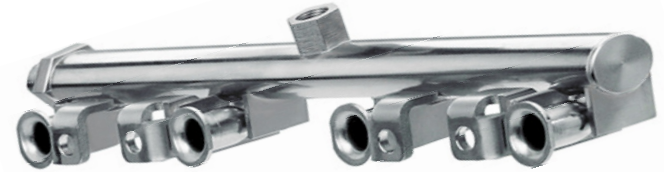
## Gasoline Direct Injection Boosted Engine System Mechanization



Delphi Powertrain

### ◆ System Features

- Inwardly-opening, multi-hole GDI Injectors, fuel rail and engine-driven high pressure fuel pump
- Injection during the intake stroke focused on complete vaporization and mixing of fuel and air
- Stoichiometric operation allows emissions control via traditional 3-way exhaust catalyst

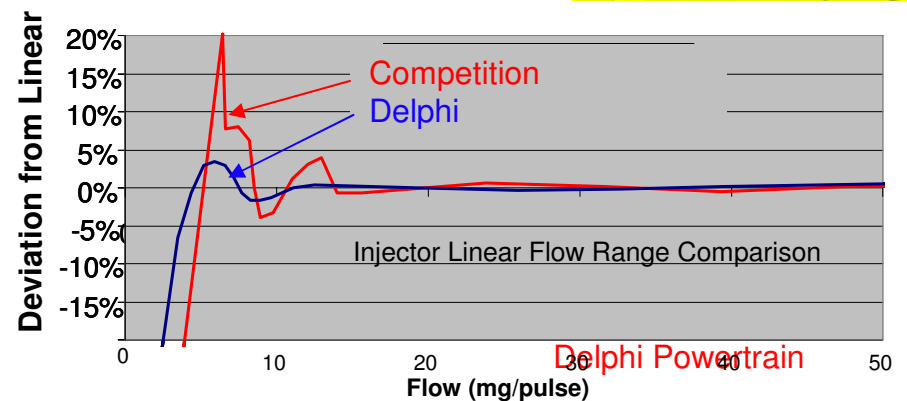
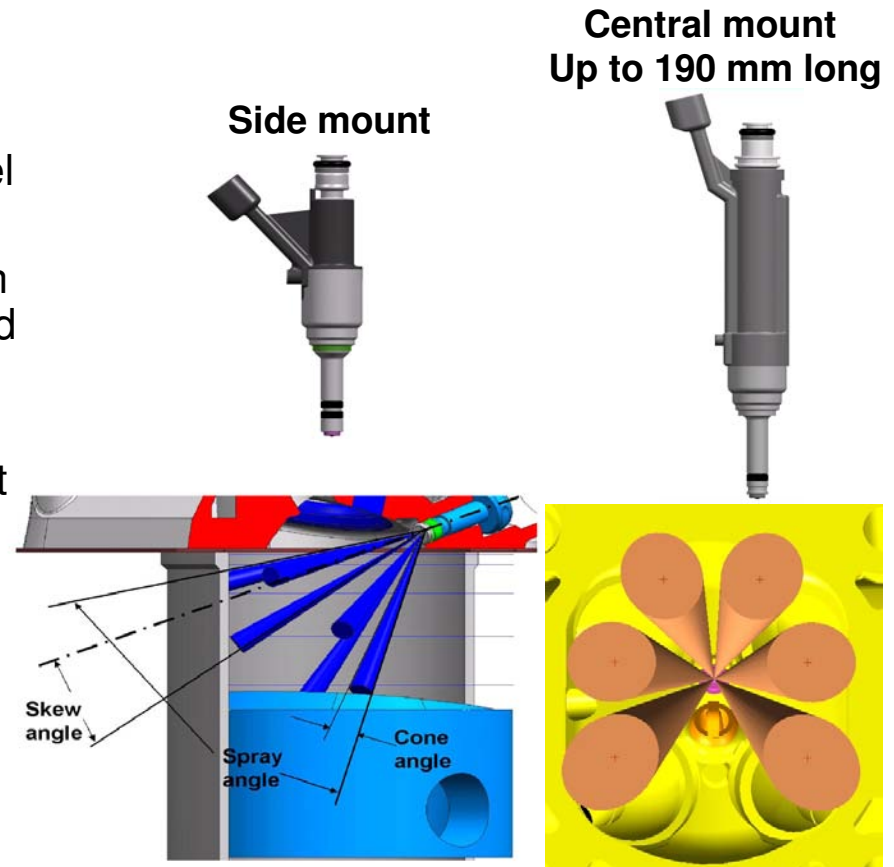


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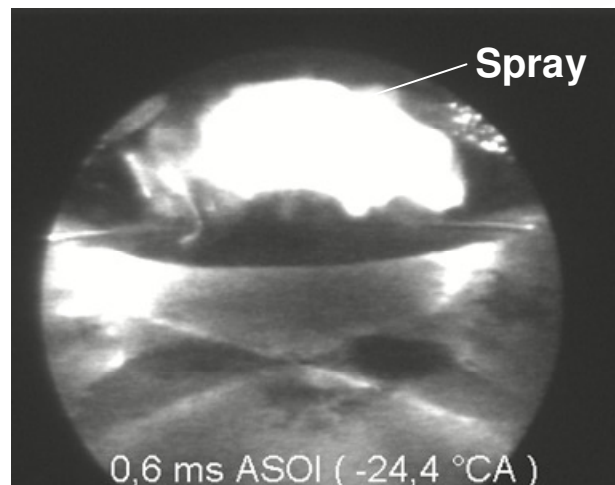
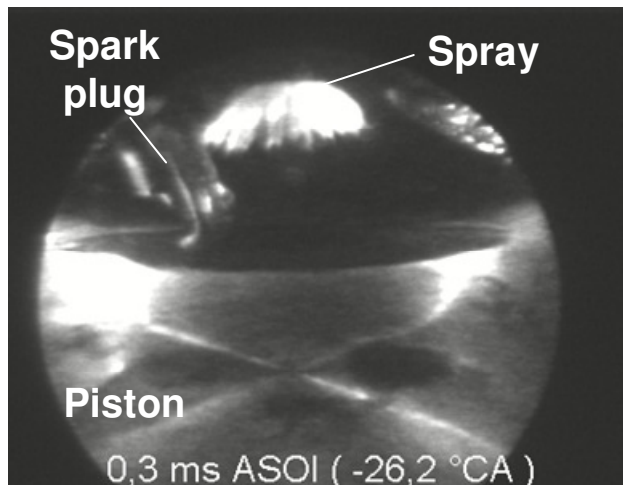
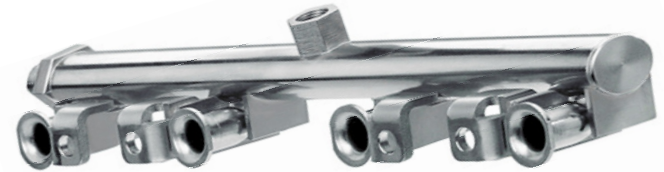
### ◆ Key Requirements

- Operation at fuel pressures up to 200 bar
- Injector packaging for cylinder side mount and central mount
- Spray generation for good vaporization and mixing without wetting in-cylinder surfaces
- Good linear flow range



### ◆ System Features

- Outwardly-opening, hollow-cone GDi Injectors, fuel rail and engine-driven high pressure fuel pump
- Central mount injector near spark plug
- Injection during the compression stroke for careful placement of fuel mixture in space and time



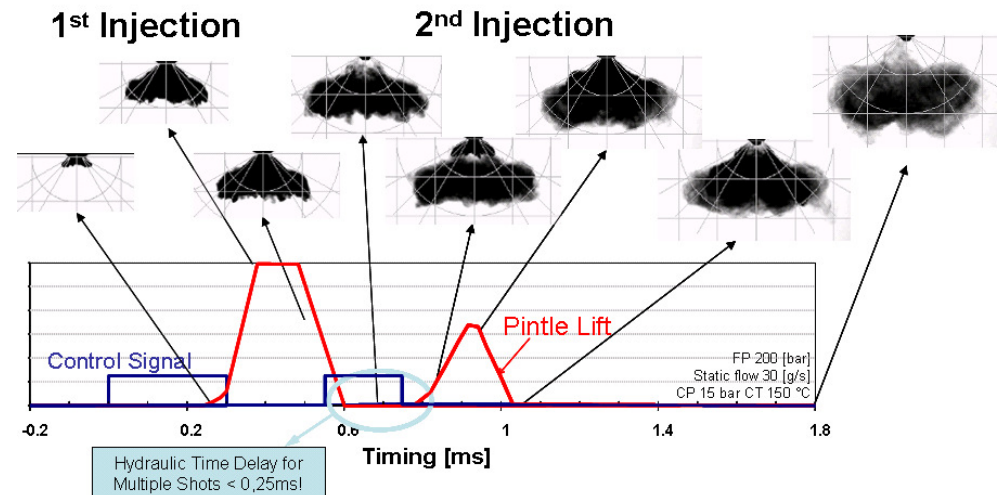
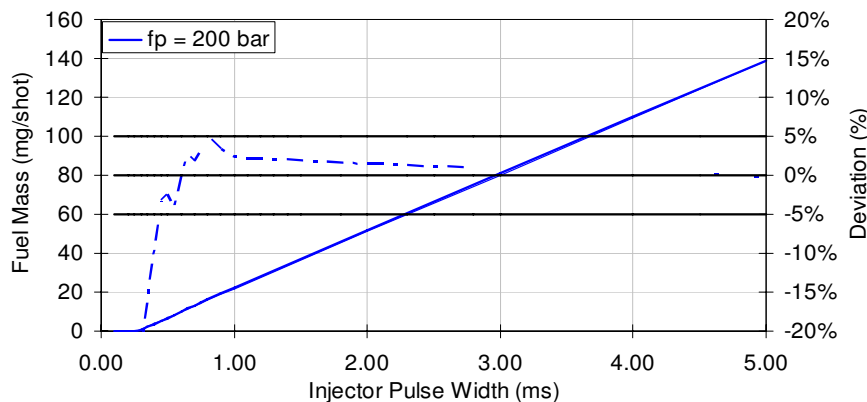
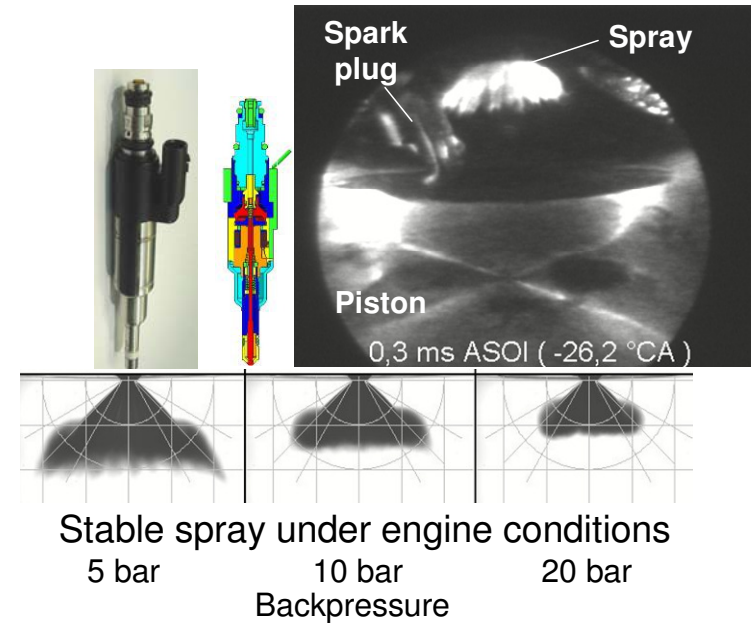


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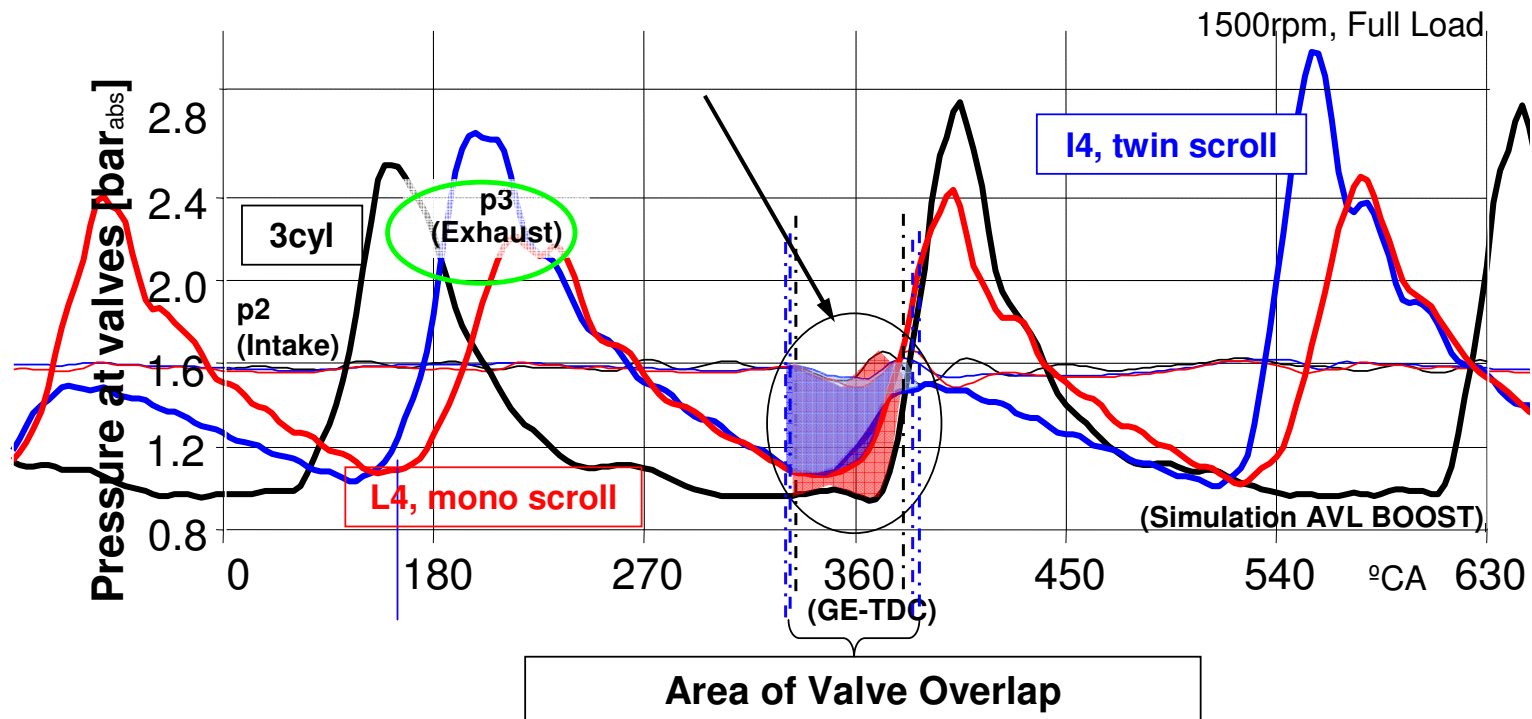
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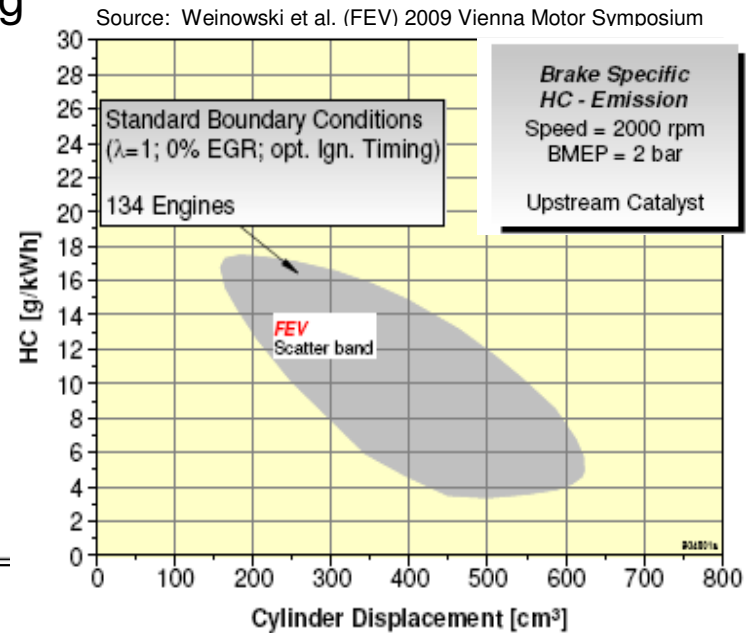
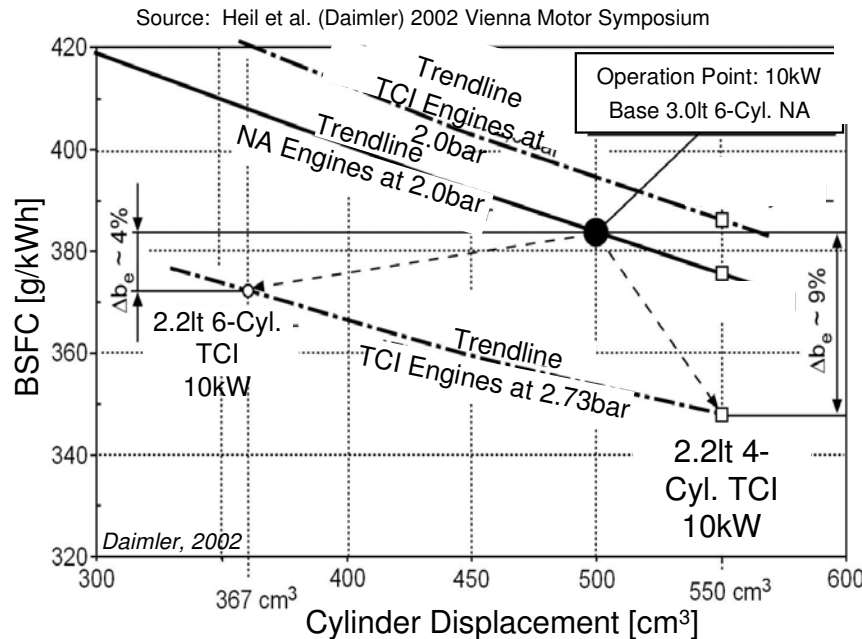
- Operation at fuel pressures up to 200 bar
- Well-atomized and well-placed stratified mixture under engine conditions
- Multiple injections to confine the fuel mixture
- High linear flow range



- ◆ 3 Cylinder Engine Offers Improved Engine Breathing at Full Load
  - Reduced firing frequency increases scavenging for improved full load torque



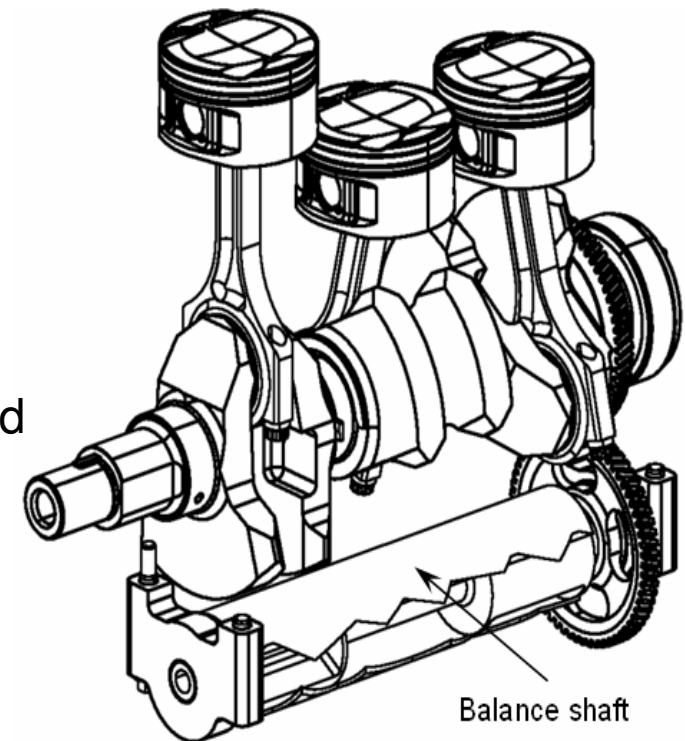
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- ◆ 3 Cylinder Engine Provides Reduced Fuel Consumption and Emissions
  - Reduced heat transfer surface area
  - Reduced quench layer and crevices
  - Lower friction



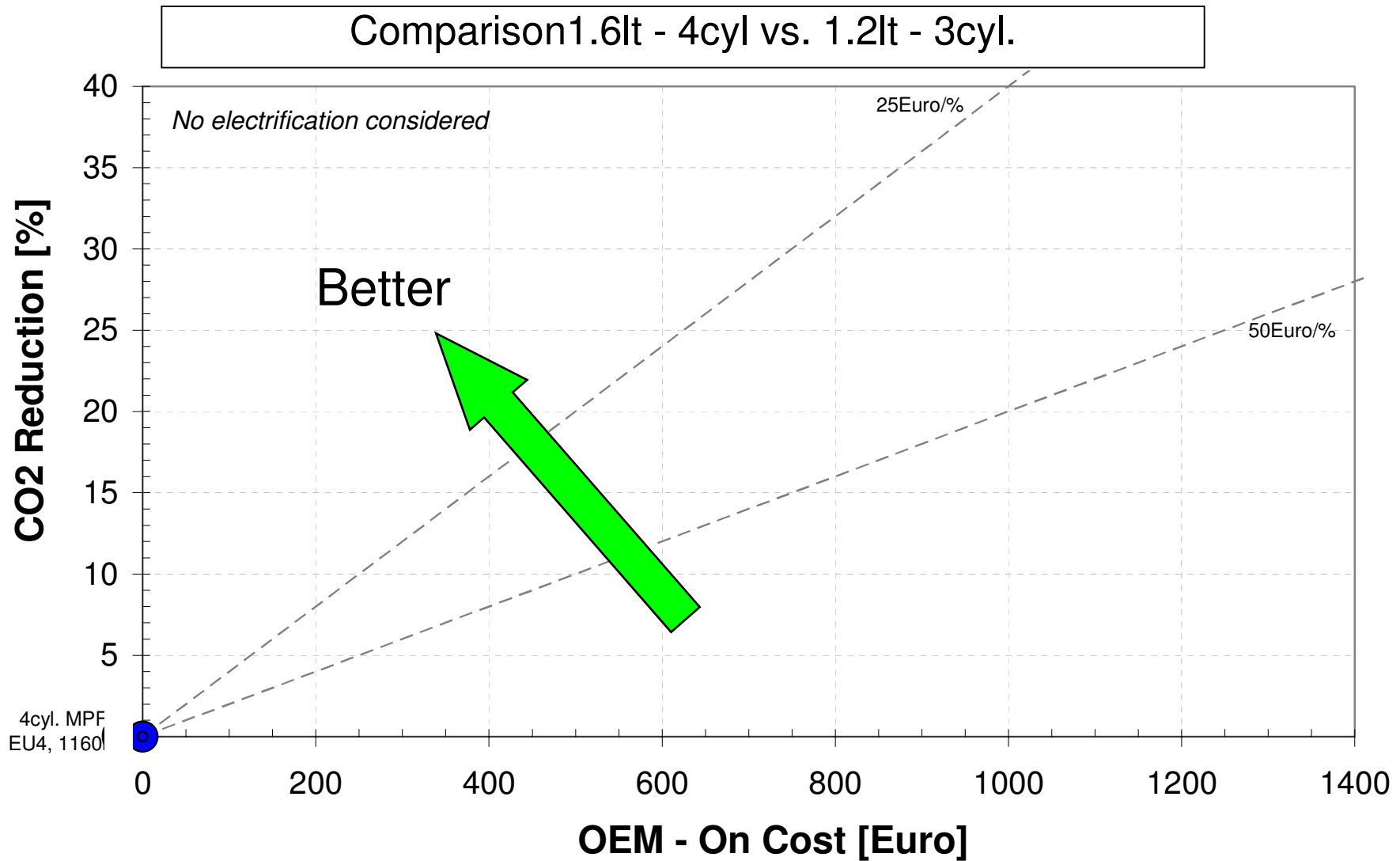


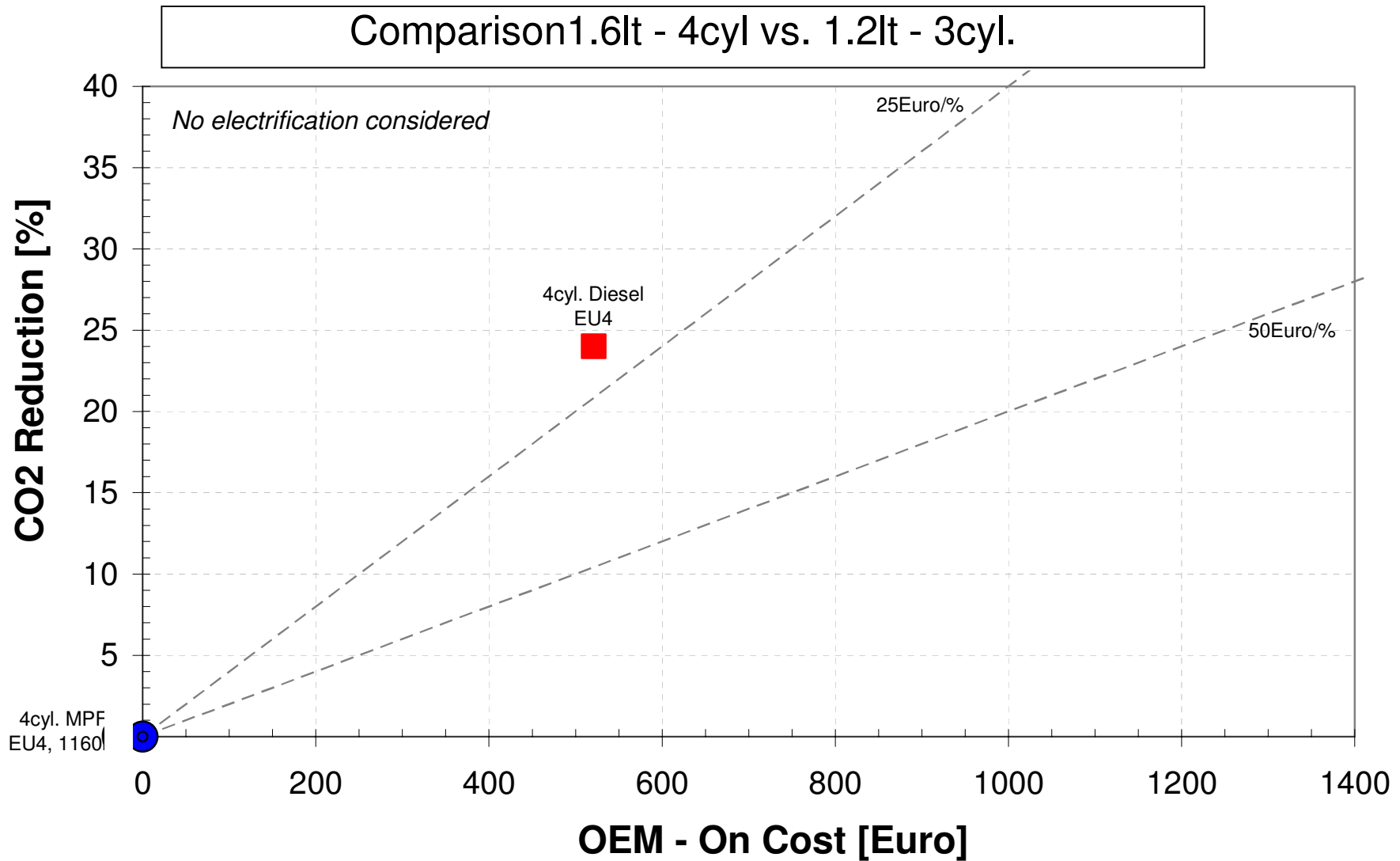
## 3 Cylinder Engine Analysis Comparison with 4 Cylinder

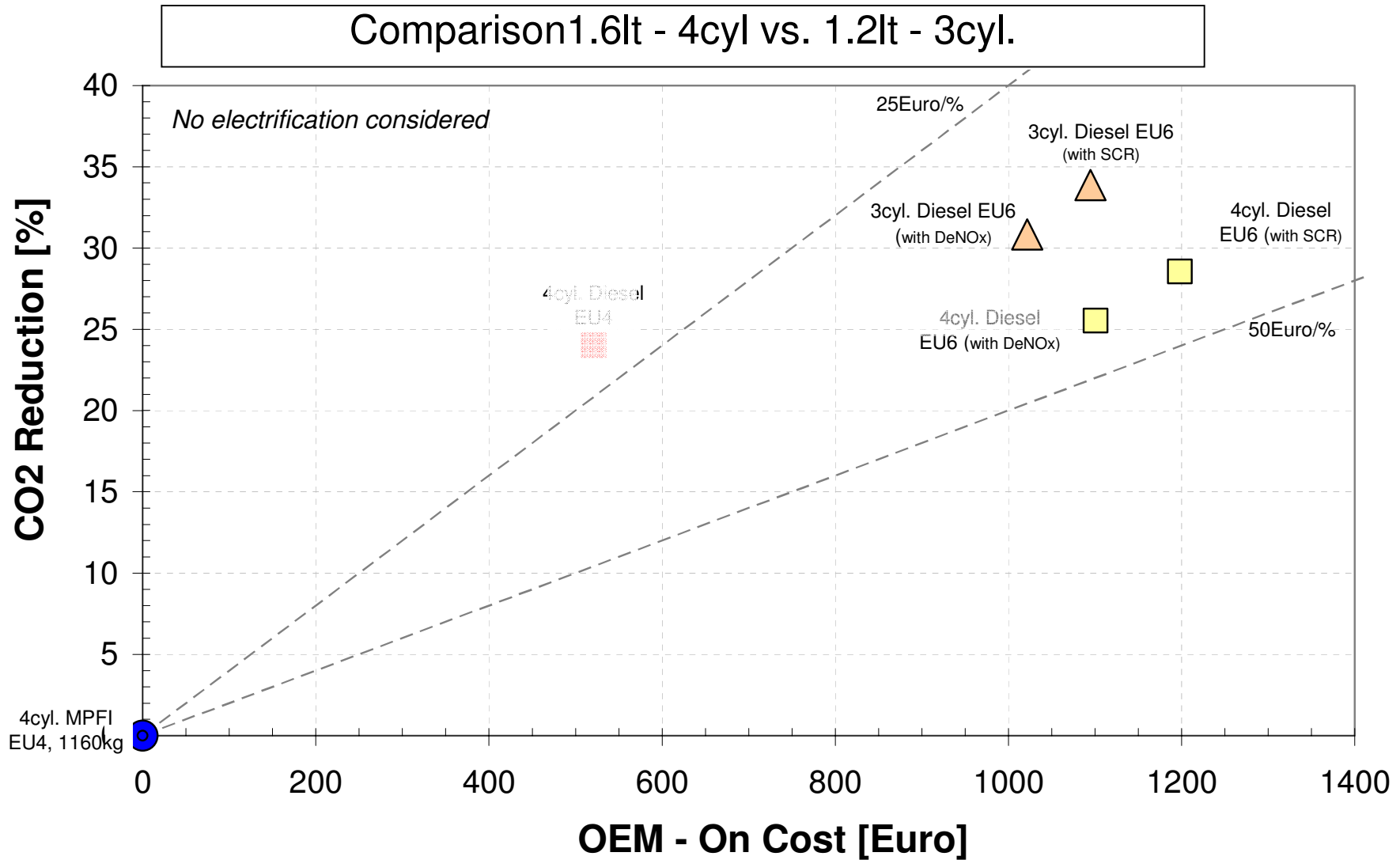
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- ◆ 3 Cylinder Engine Increases NVH
  - Unbalanced 1<sup>st</sup> and 2<sup>nd</sup> order torque pulses require counterbalancing
  - Results in slight friction increase
- ◆ Overall Conclusion: 3 Cylinder Engine is the Preferred Configuration for Displacements < 1.5L

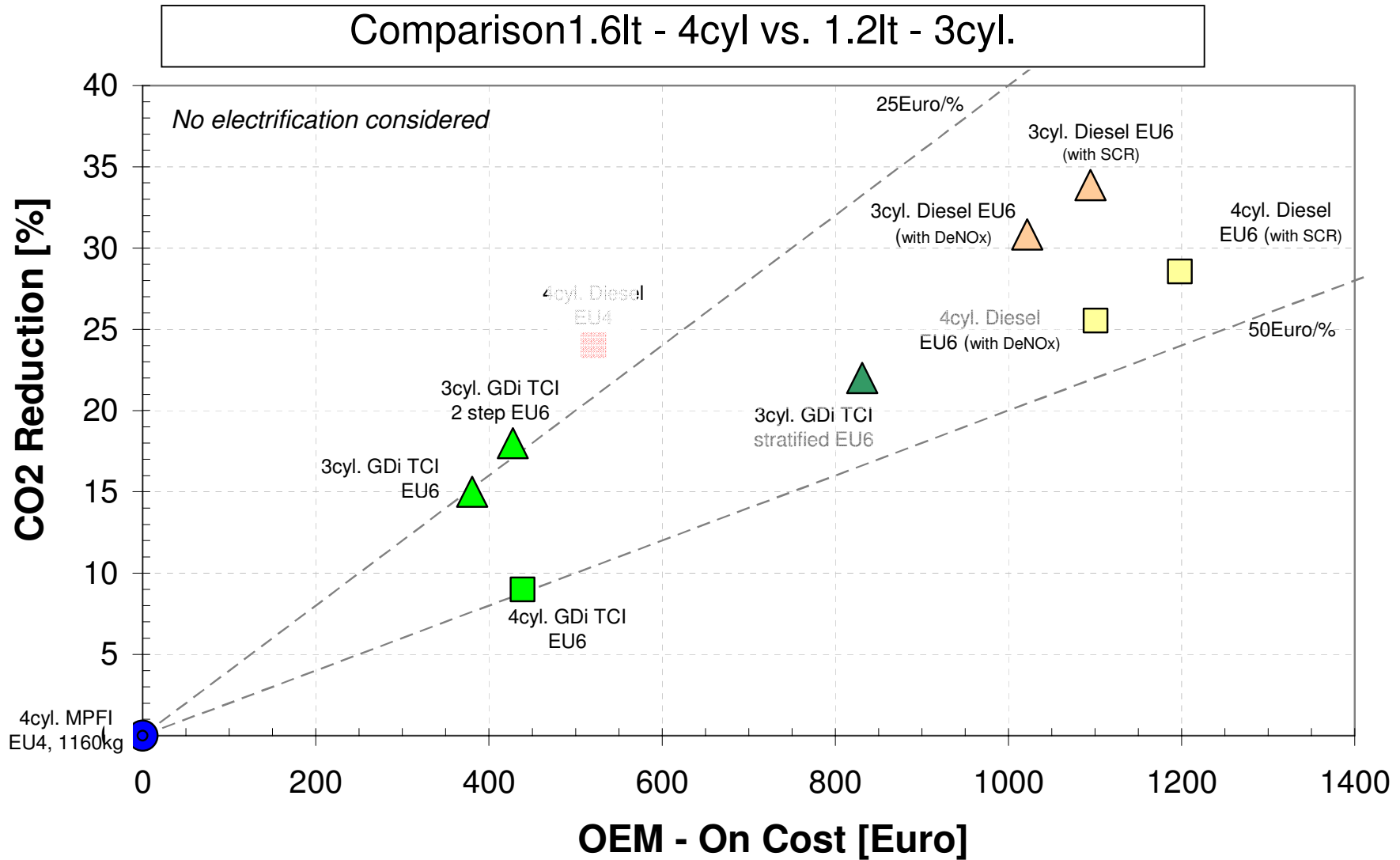


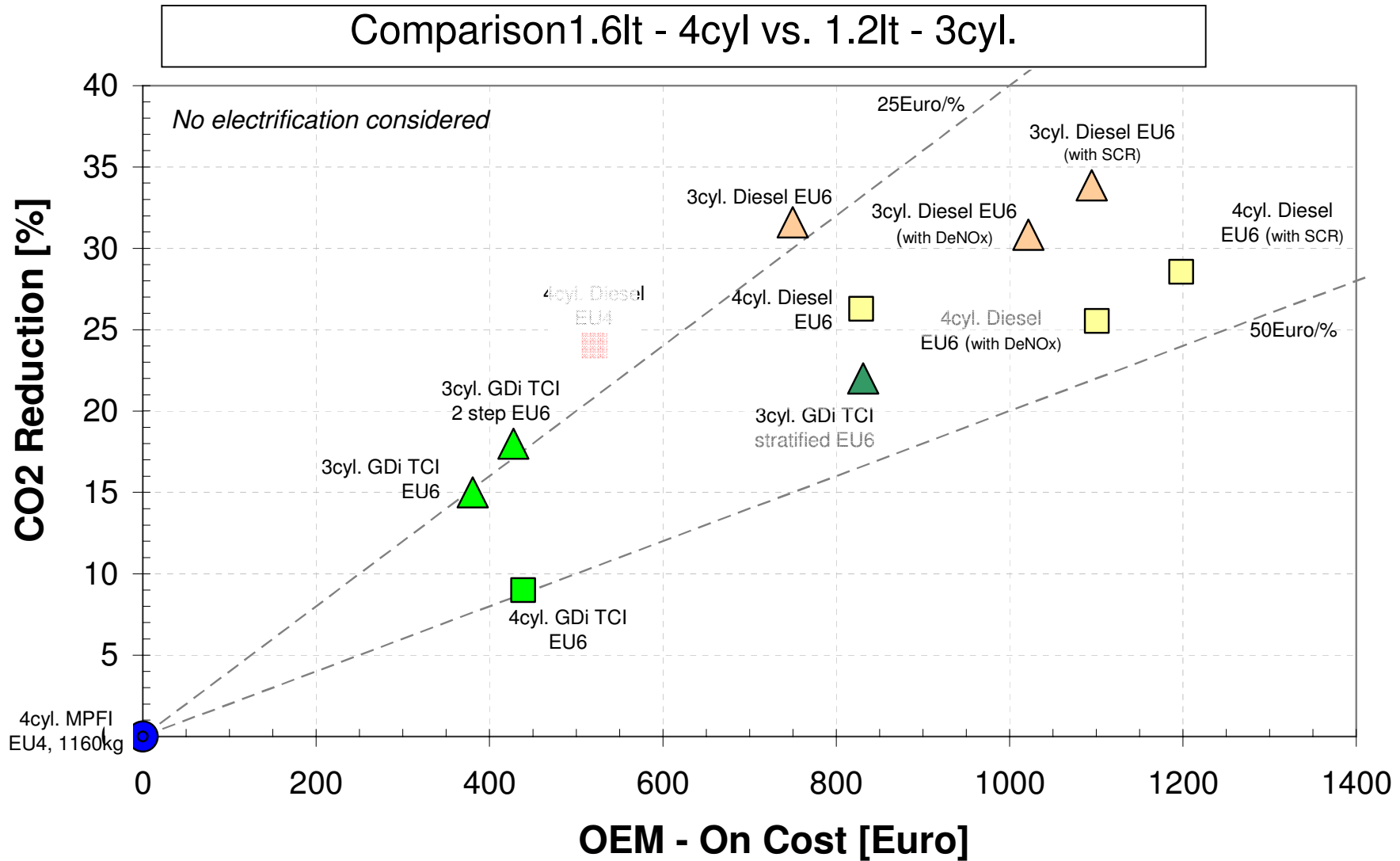
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- ◆ Global CO2 Regulations Will Require Substantial Engine Downsizing and Hybridization
- ◆ Significant Reduction in Euro 6 Standards Makes Diesel NOx Emissions Compliance More Challenging and Expensive
  - Global rollout expected and viable
- ◆ Gasoline Direct Injection Systems Enable Excellent Low End Torque and Responsiveness in Downsized, Boosted Engines
- ◆ 3-Cylinder Gasoline Direct Injection Engines Offer Similar Value in CO2 Reduction Capability (Euros / % CO2 Reduction) at a Significantly Lower On-Cost
  - Particularly Attractive for Compact / Sub-compact Vehicle Customers