DEER Conference 2009
Dearborn, MI

A View from the Bridge

Gary W. Rogers
President and CEO, FEV Inc.
August 3, 2009
A View from the Bridge

Light-Duty Emission Regulations History

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**PM**

- EU 3
- EU 4
- TIER 2, Bin 5
- EU 5
- EU 6

**NOx**

- TIER 1
- EU 3
- EU 4
- EU 5
- EU 6

**CO**

- TIER 1
- TIER 2, Bin 5
- EU 3
- EU 4
- EU 5
- EU 6

**HC**

- TIER 1
- EU 3
- EU 4
- EU 5
- EU 6

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TIER 1 and TIER 2, Bin 5: 50,000 miles
Japan beyond Model Year 2011: proposed limits

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A View from the Bridge
Heavy-Duty Emission Regulations History
A View from the Bridge
Heavy-Duty Test Cycle History

Evolution of Test Procedures for On- and Off-Road Engines

1) NRSC mostly ISO 8178 C1 test. Other ISO 8178 test cycles are allowed for selected applications.
A View from the Bridge
U.S. Vehicle Sales and Fuel Price Development

Average Monthly Fuel Sales Price [$/gal]
Average Monthly Vehicle Sales [x100k]

- Average U.S. Gasoline Pump Price
- Average U.S. Diesel Pump Price
- U.S. Passenger Car Sales
- U.S. SUV & Light-Duty Truck Sales

Source: www.bts.gov; www.eia.doe.gov
www.automotivenews.com

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A View from the Bridge
Factors that Influence Fuel Price

Fuel prices depend on a variety of factors:

• Supply and demand
  • General increase in demand
  • Emerging markets

• Political issues/instabilities
  • War
  • Embargos
  • Terrorist Attacks

• Natural disasters

• Investors and speculators

• Alternative Options
  • Hydrogen
  • Ethanol
  • Biodiesel & biomethane
  • CNG & LNG
  • Electricity
Optimization of individual systems and a combination of many technologies will be necessary to meet future requirements.
A View from the Bridge
U.S. Light-Duty Diesel Applications

Customer Acceptance
- Noisy
- Smoky
- Smelly
- Costly
- Performance

North American LD-Diesel
- Engine (FIS)
- Aftertreatment
- Maintenance
- ROI

Emissions (Controls)
- Cost
- Complexity
- Durability
- Maintenance

Fuel
- Cost
- Smell
- Oily
- Availability

Cost
A View from the Bridge
U.S. Light-Duty Gasoline Applications

Vehicle Class

Small

1.0-2.0l (3-4 cyl.)
- NA, PFI
- NA, PFI, EGR or VVT (Int+Exh)
- NA, PFI/DI, EGR or VVT (Int+Exh)

PFI, NA

1.4-4.0l (4-8 cyl.)
- NA/TC 70kW/l PFI & DI \(\lambda_1\) (\(\lambda > 1\) low vol.)
- DI TC 80-100kW/l \(\lambda_1\) (\(\lambda > 1\) low volume), VVT Integrated, cooled manifold
- DI TC 110-120kW/l 2-stage TC/SC (VCR)

Direct Injection, Boosting

3.0-6.0l (6-12 cyl.)
- NA, PFI / DI VVT, CDA, \(\lambda_1\)
- NA/TC, DI VVT, CDA, \(\lambda_1\)
- NA/TC DI VVT+CDA, \(\lambda_1\)

2.0-5.0l (6-12 cyl.)

Luxury

Variable Valve Train

2008
2010
2012
A View from the Bridge
Emissions vs. Fuel Economy Trade-Off – FTP 75

Diesel Passenger Car

NOx [g/mi]

<table>
<thead>
<tr>
<th></th>
<th>EURO 4</th>
<th>Engine-out recalibration</th>
<th>T2B5 NAC</th>
<th>T2B5 SCR</th>
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</thead>
<tbody>
<tr>
<td>NOx</td>
<td>0.80</td>
<td>-56%</td>
<td>-95%</td>
<td>-95%</td>
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Fuel Economy [mpg]

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<tr>
<th></th>
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<th>Engine-out recalibration</th>
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<th>T2B5 SCR</th>
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A View from the Bridge
Emissions vs. Fuel Economy Trade-Off - HWFET

Diesel Passenger Car

<table>
<thead>
<tr>
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<th>T2B5 SCR</th>
</tr>
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<tbody>
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<td>0.5</td>
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<td>-30%</td>
<td>-90%</td>
<td>-96%</td>
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<table>
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<th>Fuel Economy [mpg]</th>
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<th>T2B5 SCR</th>
</tr>
</thead>
<tbody>
<tr>
<td>58</td>
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<td>-15%</td>
<td>-17%</td>
<td>-15%</td>
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</table>
A View from the Bridge
Alternative Aftertreatment Systems

Reactors
Dosing Valve
Oil Separator
Oil Valve
Inlet Heat Transfer Fluid From Pump Heater

SCR Catalyst
A View from the Bridge
Electronic Control Systems

Actuator Adaptation
Actuator Controls

Heat Management

Emission Management

Sensor Adaptation
Sensor Controls

Electronic Controls

Engine Controls

Fuel System Controls

Electric Motor Controls

Air System Controls
A View from the Bridge
Development Tools and Methodologies

System Capabilities

FEV-Apogee System

Thermal Imaging

Flow Visualization

Spark Advance 5°
A View from the Bridge
Development Tools and Methodologies

Fired Engine Test Results

22°BTDC
21°BTDC
20°BTDC
19°BTDC
18°BTDC
17°BTDC
A View from the Bridge
Development Tools and Methodologies

Combustion System Design and Optimization

Thermodynamics
- In Cylinder Charge Motion
- In Bowl Swirl Motion
- Mixture Formation

Design
- Intake Port Design
- Piston Bowl Design
- Injector Concept

Experiment
- Combustion /Emissions
- Asymmetric Soot

CFD
- Asymmetric Flow

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A View from the Bridge
Conclusions

- On- and off-highway heavy-duty engine and emission-control technologies will tend to converge in the future
- Fuel prices will remain unpredictable, but increasing demand will lead to higher prices in the future
- Availability of alternative fuels, combined with CO2 legislation will significantly influence technology options
- Demand for larger trucks and SUVs will continue
- Shift towards lighter, more efficient passenger cars
- Expected technology mix will continue to increase
- Timely identification of optimal technology compromises is crucial to minimize cost