Light-Duty Diesel Market Potential in North America

Diesel Engine Emissions Reduction Conference
August 22, 2005
Chicago

Charles E. Freese, V
Executive Director, Diesel Engineering
General Motors Corporation
GM’s Long Term Vision

Remove the automobile from the energy & environmental equation
Advanced Propulsion Technology Strategy

- Reduced Vehicle Emissions and Increased Vehicle Fuel Economy

- Near-Term: Incremental Internal Combustion Engine and Transmission Improvements
- Mid-Term: Hybrid Electric Vehicles
- Long-Term: Hydrogen Fuel Cell

Hydrogen Infrastructure
Advanced Propulsion Technology Strategy

These technologies will exist simultaneously

- Reduced Vehicle Emissions and Increased Vehicle Fuel Economy
- Hydrogen Fuel Cell
- Hybrid Electric Vehicles
- Incremental Internal Combustion Engine and Transmission Improvements
- Hydrogen Infrastructure

Near-Term, Mid-Term, Long-Term
Advanced Propulsion Technology Strategy

Near-Term

Reduced Vehicle Emissions and Increased Vehicle Fuel Economy

Incremental Internal Combustion Engine and Transmission Improvements

Hydrogen Infrastructure
Diesel Market Overview

GM’s Perspective

• Diesel engines are a key strategic component of GM’s advanced propulsion strategy
• GM has capacity for over 1.3 million diesels per year
• Diesel powertrains satisfy unique vehicle requirements
  – Utility & large vehicles
  – Displacement limited passenger cars
• Significant technological challenges exist for long term light duty North American presence
  – NO\textsubscript{x} aftertreatment & fuel limitations
• GM is committed to developing global diesel solutions
Propulsion Application Map

- **Commercial (High Load)**
- **Consumer (Light Load)**
- **Stop-and-Go (City)**
- **Continuous (Highway)**

**Propulsion Types**
- **Hybridized**
- **Gas**
- **Diesel**
- **Conventional**
Propulsion Application Map

Commercial (High Load)

Consumer (Light load)

Stop-and-Go (City)

Continuous (Highway)

Duty Cycle

Drive Cycle

Diesel Hybrid Bus

(2023-03-15)
Duty Cycle

Commercial (High Load)

Stop-and-Go (City)

Continuous (Highway)

Drive Cycle

Consumer

Propulsion Application Map

Diesel Hybrid Bus

City Car (Gas Hybrid)

Non-towing Highway Gas Car & SUV
Propulsion Application Map

- Commercial (High Load)
- Consumer (Light load)
- Duty Cycle
- Drive Cycle
- Continuous (Highway)
- Stop-and-Go (City)
- Consumer (Light load)
- Over the Road Truck
- Diesel Hybrid Bus
- City Car (Gas Hybrid)
- Non-towing Highway Gas Car & SUV

GM
Propulsion Application Map

- **Stop-and-Go (City):**
  - Diesel Hybrid Bus
  - City Car (Gas Hybrid)

- **Drive Cycle:**
  - Heavy Duty Pickup Truck

- **Continuous (Highway):**
  - Over the Road Truck
  - Non-towing Highway Gas Car & SUV

- **Consumer (Light load):**
  - Gas Car & SUV
  - Diesel Hybrid
  - Bus
Propulsion Application Map

Commercial (High Load)

- Diesel Hybrid Bus
- Over the Road Truck

Drive Cycle

Continuous (Highway)

- City Car (Gas Hybrid)
- Commuter Car
- Non-towing Highway Gas Car & SUV

Stop-and-Go (City)

- Heavy Duty Pickup Truck
- Commuter Car
- City Car (Gas Hybrid)

- Over the Road Truck
- Commuter Car
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Propulsion Application Map

- **Commercial (High Load)**
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- **Stop-and-Go (City)**
  - City Car (Gas Hybrid)
  - Commuter Car

- **Continuous (Highway)**
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- **Drive Cycle**
  - Commercial (High Load)
  - Consumer (Light load)
Where to Use Diesels?

- European light duty vehicles (near 50%)
- Heavy duty Class 7 & 8 trucks for cargo hauling
- Heavy duty diesel hybrid buses
- Asia-Pacific
  - Korea, India, & potentially China are growing markets
  - Strong diesel bias in Korean SUV market (over 90% diesel)
- North America
  - First introduced diesel engines in larger vehicles
  - Consumer recovery of additional financial investment
  - Utility applications
  - Towing & hauling
European Diesel Passenger Car Market

Originally displacement driven

Now fun to drive & gasoline-like
North American Vehicle Sales Mix

Light Duty Truck & Sport Utility Vehicles (SUV) Gain Share

• U.S. vehicle market share:
  – Passenger car volumes have declined
  – Light duty trucks & SUVs gained relative market share
• Light truck share will remain high for foreseeable future
Heavy Duty Duramax Applications
North American Growth
North American Heavy Duty Pickup Truck Market (3/4 & 1 Ton)

3/4 and 1-ton Full Size Truck Volume by Manufacturer – Diesel Only

- Ford Diesel
- DCx Diesel
- GM Diesel
- Total Diesel Industry

Units Registered vs. Month of USA Registration
Why Use Diesels?

- Heavy duty towing & hauling (high load advantage is greater)
- Satisfy fuel economy improvement objectives
  - Positive influence on CO₂ & CAFE
  - Real world fuel economy improvement – a robust solution
- Improve vehicle performance with lower displacement engine
  - Fun to drive
- Achieve benefit of tax incentives in European markets
Economic Model – Fuel Price as an Influence
Comparison between U.S. & Europe

Fuel Price (Dollars/Gallon)

- Austria: 71%
- France: 67%
- Spain: 58%
- Italy: 47%
- Germany: 39%
- U.K.: 26%
- U.S.: 3%

Gasoline Base
Diesel Base
Gasoline Tax
Diesel Tax
Diesel Penetration

Source: U.S. Department of Energy Report, October 2003; Association of European Automobile Manufacturers, April 2003
Note: All Data Valid through December 2002
Correlation with fuel price: \( R^2 = 0.61 \)
**Economic Model**

Comparison between U.S. and Europe – Diesel Break-Even Point

**Vehicle Mileage Required to Recover Diesel Engine Cost**

**Chart Assumptions:**
- 20,000 Annual Vehicle Miles
- Diesel Efficiency Advantage:
  - Europe 30%, Bin 5 North America 25%
- 6% Annual Finance Rate Available

**Initial Purchase Price ($ U.S.)**

**Vehicle Mileage (miles)**

- North America: Gas = Diesel = $2.50/Gal
- Europe: Gas = $6/Gal, Diesel = $5/Gal
Diesel Engine Technology Trends – Europe

 Benchmark trends to help predict requirements

 Diesel Engines
 - Naturally Aspirated
 - Turbocharged (TC)
 - TC-Intercooled

 Turbo Charged SI Engines
 Future HSDI Diesel Engines

 4V-SI Engines

 Source: FEV Data
Diesel Growth
Western Europe & North America

Western Europe
Ricardo Forecast Diesel Passenger Car Sales & Market Penetration to 2006

Diesel Sales Volume
- Diesel Car Sales
- Diesel Penetration
- Forecast Diesel Car Sales

Diesel Penetration
North American PC Market Share
Introduction of DI technology
Introduction of Common Rail and VGT

Diesel Car Sales
Diesel Penetration
Forecast Diesel Car Sales

0%
10%
20%
30%
40%
50%
60%

0
1,000,000
2,000,000
3,000,000
4,000,000
5,000,000
6,000,000
7,000,000
8,000,000
9,000,000


GM
Diesel Growth
Western Europe & North America

Western Europe
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Introduction of true high performance diesel engines
Introduction of Common Rail and VGT
Introduction of DI technology
Global Recession
North American Class 2 Truck Market Share
North American PC Market Share
2nd Oil Crisis

Crude Oil Price (1995$/barrel)
- $22
- $57
- $44
- $37
- $24
- $20
- $15
- $25
- $70+?
Europe vs. U.S. Tier 2 FTP-75

Emissions

Light-Duty

<table>
<thead>
<tr>
<th>Standard</th>
<th>NOx (g/mile)</th>
<th>PM (g/mile)</th>
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</thead>
<tbody>
<tr>
<td>Bin 10</td>
<td>0.60</td>
<td>0.080</td>
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<tr>
<td>Bin 8</td>
<td>0.20</td>
<td>0.020</td>
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<tr>
<td>Bin 5</td>
<td>0.07</td>
<td>0.010</td>
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<tr>
<td>Bin 4</td>
<td>0.04</td>
<td>0.010</td>
</tr>
<tr>
<td>Euro 3</td>
<td>0.50</td>
<td>0.050</td>
</tr>
<tr>
<td>Euro 4</td>
<td>0.25</td>
<td>0.025</td>
</tr>
<tr>
<td>Euro 5</td>
<td>0.08-0.20</td>
<td>0.0025-0.010</td>
</tr>
</tbody>
</table>

Emission = Emission Index \times Fuel Consumption

\((g/mile) \times (g/kg \text{ fuel}) \times (kg \text{ fuel/mile})\)
Global Emissions (Europe vs. U.S. Applications)

Light-Duty

1.7L I-4

6.6L V-8

Opel Astra

Chevrolet Silverado
Offsetting Diesel NO\textsubscript{x} Emissions – Tier 2

Moving to a lower bin adds incremental cost to gasoline off-set vehicles.

Option 1 – Bin 4 offset

1 - Bin 8 Diesel
0.20g NO\textsubscript{x}/mile

Diesel penetration
19% of fleet

0.04 NO\textsubscript{x} Fleet
2008 MY +

4.33 – Bin 4 Gas to Offset

0.04 NO\textsubscript{x} 0.04 NO\textsubscript{x} 0.04 NO\textsubscript{x} 0.04 NO\textsubscript{x}
FTP-75 versus US-06 Drive Cycles

FTP–75 & NEDC are similar
- Produce similar emissions

Supplemental FTP (SFTP) includes:
- US-06
- SC-03 (accessory load)

USO6 is more challenging
- US-only
- Higher load
- Higher speed
- Higher NO\textsubscript{x}
- 50% to 150% more NO\textsubscript{x} than FTP-75

NEDC = New European Drive Cycle
### Light Duty Supplemental Emissions Test Cycles

#### US-06 Emissions Limits versus FTP-75

<table>
<thead>
<tr>
<th>Cycle</th>
<th>US-06 NMHC+NO\textsubscript{X}</th>
<th>FTP Bin 8 (@120K) NMHC+NO\textsubscript{X}</th>
<th>FTP Bin 5 (@120K) NMHC+NO\textsubscript{X}</th>
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<tbody>
<tr>
<td>PC/LDT1</td>
<td>0.140 g/mile</td>
<td>0.325</td>
<td>0.160</td>
</tr>
<tr>
<td>LDT2</td>
<td>0.250</td>
<td>0.325</td>
<td>0.160</td>
</tr>
<tr>
<td>LDT3</td>
<td>0.400</td>
<td>0.325</td>
<td>0.160</td>
</tr>
<tr>
<td>LDT4</td>
<td>0.600</td>
<td>0.325</td>
<td>0.160</td>
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</table>

More difficult US-06 test has lower standard than FTP.
Diesel Engine
Enabling Technology Development

- Enhanced EGR Cooling
- Advanced EGR Systems
- VVT / VVA
- Low Temp / Low soot Combustion
- DPF, SCR & LNT Aftertreatment
- Advanced Boost Configurations
- Reduced Compression Ratio
- PCCI Pre-Mixed Charge Comb.
- HCCI Homogeneous Combustion
PCCI Combustion
Diesel Engine
Enabling Technology Development

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Homogeneous Charge Compression Ignition
(convergence of gasoline and diesel technologies)
Diesel Engine
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Advanced Boosting
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Aftertreatment Systems
Balancing the requirements of FTP with US06

Typical Thermal Operating “Windows”

Light Duty Diesel FTP Catalyst Temps
Light Duty Diesel US06 Catalyst Temps

SCR Effective Range
LNT Effective Range

NOx Conversion Efficiency (%)

Catalyst Operating Temperature (degrees C)
European versus U.S. Tier 2 FTP-75 Emissions

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<tr>
<th>Test</th>
<th>NOx (g/mile)</th>
<th>PM (g/mile)</th>
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<tr>
<td>LNT Fresh</td>
<td>0.06</td>
<td>0.015</td>
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<tr>
<td>LNT Aged</td>
<td>0.10</td>
<td>0.020</td>
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<tr>
<td>LNT Aged, Seq.</td>
<td>0.35</td>
<td>0.020</td>
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<tr>
<td>SCR-Urea Fresh</td>
<td>0.04</td>
<td>0.009</td>
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Light-Duty Test

- NOx (g/km)
- PM (g/mile)

- Euro 3
- Euro 4
- Bin 8
- Bin 10

- SCR-Urea
- LNT Fresh
- LNT Aged
- LNT Aged, Sequential Tests
# Internal Combustion Engine (ICE) Technology Continuum

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<th>Combustion Strategy</th>
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*GM*
Summary

Advanced Propulsion Solutions

• Portfolio approach is required for advanced powertrain strategies
  – Market, vehicle, & customer requirements influence powertrain usage

• Diesel engines are critical to GM’s global product portfolio

• Emission regulations, fuel price, taxation based on engine displacement and fuel consumption largely dictate markets where diesels are popular today
  – Voluntary 140 g/km CO₂ commitment is a European driver

• Increased fuel prices may encourage additional diesel penetration
Summary
Technology Driven Trends

• Diesel technological advancements over past 15 years have radically changed public perception of diesels
  – High performance (torque)
  – Fun to drive
  – Refined
  – Significant penetration in European luxury vehicle segments

• Diesel & gasoline technologies are converging
  – boost, direct injection, controls, & HCCI

• Must retain fuel economy advantages while meeting new emissions standards

• Diesel must overcome cost disadvantages
Summary
Market Factors in North America

• GM continues to apply North American diesel engines where they maximize customer benefits:
  – Large vehicles
  – Towing & hauling utility applications
• U.S. market, with its larger vehicles, could benefit from diesel technology introduction
• Growing large truck diesel market share implies improved U.S. consumer acceptance of diesel engines
• Must address North American NO$_x$ standards (one sixth that of Europe) at an acceptable cost
Diesel Powertrain Technology

Advantages

• Improved high load fuel economy versus alternatives
• Improved low speed torque capacity
• Consistent performance
  – Robust fuel economy advantages are relatively insensitive to driving cycle
  – Consistent utility attributes (gradeability, altitude performance)
• Fun to drive (even with small displacement powertrains)
• Image powertrain for utility vehicles (customer willing to pay premium)
• Favorable taxation & fuel prices in specific markets
Diesel Powertrain Technology
Disadvantages

• Higher cost than gasoline alternatives

• Poor diesel fuel quality in some regions

• Emissions & NVH are more challenging than for gasoline applications