Overview

- GM’s Energy & Propulsion Strategy
- The Diesel Engine’s Role in Propulsion Strategy
  - Regional Contrast between Europe & United States
- Diesel Challenges & Technologies

Answer Question:

Why not put a diesel engine into every vehicle?
GM’s Long Term Vision

Remove the automobile from the energy & environmental equation
Transportation is a growth industry!

Sources: U.S. Census Bureau International Population Database, GM Global Market & Industry Analysis
Global Energy Consumption to 2030

- **Oil**
  - 2006: 85MBD
  - 1,000 barrels/second!
  - 2030: 120 MBD projected
  - 50% used for transportation
  - Transportation is 98% dependent on petroleum

Source: DOE-EIA 2006
Fossil Fuel Resource Alternatives

- Very large reserves from unconventional oil & coal
- Issues: Cost, CO$_2$ emissions & large energy required to extract

Source: Global Insight 2006
BIOFUELS
Alternate Resources – A Blending Strategy
Liquid Fuels / Electricity / Hydrogen as the In-Vehicle Energy Carriers

Energy Resource
- Oil (Conventional)
- Oil (Non-Conventional)
- Biomass
- Coal
- Natural Gas
- Renewables (Solar, Wind, Hydro)
- Nuclear

Conversion
- Petroleum Fuels
- 1st and 2nd Generation Biofuels
- Synthetic Fuels (XTL)
- Fischer Tropsch
- Syngas \( \text{CO}, \text{H}_2 \)
- Heat
- Shift Reaction

Energy Carrier
- Liquid Fuels
- Regional Niche
- Gaseous Fuels
- Electricity
- Hydrogen

Propulsion System
- Conventional ICE: Gasoline / Diesel
- ICE Hybrid
- Plug-In Hybrid ICE
- Electric Vehicle
- Fuel-Cell Electric

Critical Dependency on Battery Technology
Electrification
Alternate Resources – A Blending Strategy

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  - Conventional ICE: Gasoline / Diesel
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  - Plug-In Hybrid ICE
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Critical Dependency on Battery Technology

Electrification
GM Advanced Propulsion Technology Strategy

These technologies will exist simultaneously

- Improved Vehicle Fuel Economy & Emissions
- Reduced Petroleum Consumption

In the Near-Term:
- IC Engine and Transmission Improvements

In the Mid-Term:
- Hybrid Electric Vehicles (incl. Plug-In HEV)
- Battery Electric Vehicles

In the Long-Term:
- Hydrogen Fuel Cell Vehicles

Fuel Infrastructure:
- Petroleum (Conventional and Alternative Sources)
- Bio Fuels (Ethanol E85, Bio-diesel)
- Electricity (Conventional & Alternative Sources)
- Hydrogen
Propulsion Application Map

Duty Duty Cycle
Propulsion Application Map

Commercial (High Load)

Diesel Engine Applications

Stop-and-Go (City)

Heavy Duty Pickup Truck

Drive Cycle

Continuous (Highway)

Over the Road Truck

Diesel Engine Applications

City Car (Gas Hybrid)

Commuter Car

Consumer (Light load)

Non-towing Highway Gas Car & SUV

Commuter Car (Gas Hybrid)
GM Advanced Propulsion Technology Strategy

- Improved Vehicle Fuel Economy & Emissions
- Reduced Petroleum Consumption

IC Engine and Transmission Improvements

Hybrid Electric Vehicles (incl. Plug-In HEV)

Battery Electric Vehicles

Hydrogen Fuel Cell Vehicles

Petroleum (Conventional and Alternative Sources)

Bio Fuels (Ethanol E85, Bio-diesel)

Electricity (Conventional & Alternative Sources)

Hydrogen

Near-Term

Mid-Term

Long-Term
Conventional Propulsion Systems

Gasoline

Improve fuel efficiency:
- Port Deactivation
- Variable Valve Timing (VVT)
- Direct Injection
- Turbocharging
- Lean Combustion: HCCI / Stratified

Improve Emissions:
- Low-Temperature Combustion
- Advanced Air Handling
- Model-Based & Closed-Loop Control
- Efficient NO\textsubscript{x} aftertreatment

Diesel
GM’s Diesel Portfolio

Market Perspective

- GM is committed to developing global diesel solutions
- Capacity for over 1.3 million diesels per year
- Support world markets with products ranging from 1.3L 4-cylinder diesel engine in Opel Astra to 6.6L V8 Duramax diesel in the U.S. Silverado/Sierra
- Diesel powertrains satisfy unique vehicle requirements
  - Utility & large vehicles
  - Diminishing returns when applied to smaller U.S. vehicles
- Significant technological challenges exist for long term light duty North American presence
  - NOₓ aftertreatment & fuel limitations
- GM is development technologies to address challenges
GMPT Global Portfolio Diesel Engines

1.3L I-4 CDTi
90 hp / 200 Nm (148 lb-ft)

1.7L I-4 CDTi
125 hp / 280 Nm (207 lb-ft)

1.9L I-4 CDTi
150 hp / 320 Nm (236 lb-ft)

2.0L I-4
150 hp / 310 Nm (229 lb-ft)

NEW IN 2009 – Europe

1.3L I-4 CDTi
90 hp / 200 Nm (148 lb-ft)

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150 hp / 320 Nm (236 lb-ft)

2.0L I-4
150 hp / 310 Nm (229 lb-ft)

NEW IN 2009

3.0L V-6 CDTi
180 hp / 420 Nm (310 lb-ft)

Duramax 6.6L V-8
365 hp / 895 Nm (660 lb-ft)
GMPT Global Portfolio Diesel Engines

1.3L I-4 CDTi
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2.0L I-4
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NEW IN 2009 – Europe

2.9L V-6
250 hp / 550 Nm (406 lb-ft)

3.0L V-6 CDTi
180 hp / 420 Nm (310 lb-ft)

NEW IN 2009

Duramax 4.5L V-8
310 hp / 704 Nm (520 lb-ft)

Duramax 6.6L V-8
365 hp / 895 Nm (660 lb-ft)
The All-New 2008 CTS
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 and 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
Global Diesel Sales
Growth Projections

Diesel Vehicle Sales

Calendar Year

Global Insight
J.D. Power Forecast
CSM Forecast

Global Diesel Sales Growth Projections
Why Use Diesels?

- Heavy duty towing & hauling
  - Improved utility & towing capabilities
  - Increased durability
- Satisfy fuel economy improvement objectives
  - Positive influence on CO₂ & CAFE
  - Real world fuel economy improvement – a robust solution
  - Fuel economy advantage is greater under high load
- Improve vehicle performance with less displacement
  - Fun to drive
- Tax incentives in European markets
**Economic Model**

**Comparison between U.S. & Europe – Diesel Break-Even**

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

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

- **Initial Purchase Price ($ U.S.)**
- **Vehicle Mileage (miles)**

- **Gas=Diesel=$2.50/Gal**
- **Gas = $6/Gal**
- **Diesel = $5/Gal**

- **MPG Options:**
  - 35 MPG
  - 30 MPG
  - 25 MPG
  - 20 MPG
  - 15 MPG

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**Notes:**
- Gas=15 MPG
- Gas=35 MPG
U.S. Heavy Duty Emissions Standards

PM (g/hp-hr)

2007

2004 (NOX+NMHC)

2010

1998

NOX (g/hp-hr)
2007 Duramax 6.6L V8 LMM Engine
Base Engine Modifications for Emissions

Major emissions related changes include:

- Structural improvements
- High pressure fuel system updates
- Intake throttle
- Higher capacity EGR cooler
- Revised cooler circuitry
- Extensive engine software and calibration changes
- Diesel Particulate Filter (DPF)
- Post injection to support DPF regeneration
- Updated internal turbocharger upgrades
Diesel Particulate Filter (DPF) Function

Trapped Diesel Particulate Matter

Porous Cell Wall

Alternate Cell Plugging Pattern
Global Emissions (Europe vs. U.S. Applications)

Light Duty

<table>
<thead>
<tr>
<th>Engine Type</th>
<th>Emission Calculation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.7L I-4</td>
<td>Emission = Emission Index X Fuel Consumption (g/mile) (g/kg fuel) (kg fuel/mile)</td>
</tr>
<tr>
<td>6.6L V-8</td>
<td></td>
</tr>
</tbody>
</table>

Opel Astra vs. Chevrolet Silverado
Diesel Advanced Combustion Technology

Path to Engine-Out NO$_x$/PM Reduction

Temperature [K]

Equivalence Ratio [-]

Mixing

Combustion

Expansion

NO$_x$

CO

SOOT
Tier 2 Bin 5 and Production Dispersion

Particulate Matter (g/mi)

- Base Engine & Aftertreatment
- Production Dispersion

NOX (g/mi)

T2 B5
Technologies to Reduce Engine-out Emissions
Closed Loop Diesel Combustion Control

ECU
EGR
Turbo
Fuel Injectors

Cylinder Pressure Sensor

6.6L V-8

GM
Technologies to Reduce Engine-out Emissions
Closed Loop Diesel Combustion Control

Fuel Dispersion Control: Injection Quantity

Closed-Loop Control
Open Loop Control

Target Fueling
Over
Under

Control Off
Control On

Time (s)
Combustion Stability

Example, measured at 1500 rpm, 4 bar BMEP
Closed Loop Combustion

Stable Premixed combustion
(with closed loop control)

Example, measured at 1500 rpm, 4 bar BMEP

Crank Angle

Variable injection timing

In-cylinder pressure (bar)
**NOx Reduction in MVEG Cycle**

- **Conventional Combustion**
- **Premixed combustion (PCCI)**

- **Emission** vs. **Vehicle Speed (km/h)** vs. **Time**

The diagram illustrates the comparison between Conventional and Premixed combustion in terms of NOx emission over the ECE Cycle (warm). The graph shows a reduction in NOx emissions with Premixed combustion compared to Conventional combustion.
Typical Operating “Windows”

Aged Catalyst

- LDD FTP Catalyst Temps
- US06 & HDD Catalyst Temps
- SCR Effective Range
- LNT Range
- DPF/DeSOx Regen Catalyst Temps

Requirements of FTP, US06 & DPF Regeneration

NOx Conversion Efficiency (%) vs Catalyst Operating Temperature (degrees C)
Then, Now & The Future...
Emissions Reduction Technologies versus Cost
Summary
Fuels & Advanced Propulsion Strategy

- Transportation is a growth industry
- Vehicle production is increasing globally
- Transportation Sector is highly dependent upon fossil fuels
- A diverse energy strategy is required for both energy security & competitive reasons
- There is no single silver bullet technology
- Successful Energy & Advanced Propulsion Strategies must be tightly integrated
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
  - Moving toward 120 g/km CO₂ requirement
Summary
Technology Driven Trends

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

- Must retain fuel economy advantages while meeting new emissions standards

- Diesel must overcome cost disadvantages
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, will 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\textsubscript{X} standards (one sixth that of Europe) at an acceptable cost.