Fuels and Propulsion Systems for the Future

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GM Sees a Change Coming

Drivers for Change

- World population and global vehicle parc
- Transportation “Well-to-Wheels” CO2 emissions
- Energy security
  - Demand for country or region-specific solutions
Transportation is a growth industry!

Sources: U.S. Census Bureau International Population Database, GM Global Market & Industry Analysis
Transportation “Well-to-Wheels CO2 Emissions”

Hypothetical potential of individual technologies to lower road transport Well-To-Wheels CO2 emissions

Gigatonnes CO₂-Equivalent GHGs

Source: World Business Council for Sustainable Development

Note: Each curve represents the effects of individual technology penetrations to near 100% without regard to feasibility.
Global Energy Demand – 2030

Source: DOE-EIA 2006
So What’s the Solution?

In GM’s view we must

- Increase fuel efficiency of conventional propulsion vehicles in response to market demands
- Displace a portion of petroleum fuel usage
- Diversify energy sources for use in transportation applications
- Reduce net emissions of carbon dioxide
GM Advanced Propulsion Technology Strategy

Improved Vehicle Fuel Economy & Emissions

Reduced Petroleum Consumption

Hydrogen Fuel Cell Vehicles

Battery Electric Vehicles

Hybrid Electric Vehicles (incl. Plug-In HEV)

IC Engine and Transmission Improvements

Near-Term  Mid-Term  Long-Term

Petroleum (Conventional and Alternative Sources)

Bio Fuels (Ethanol E85, Bio-diesel)

Electricity (Conventional & Alternative Sources)

Hydrogen

Fuel Infrastructure
GM Advanced Propulsion Technology Strategy

- Improved Vehicle Fuel Economy & Emissions
- Reduced Petroleum Consumption
- Hydrogen Fuel Cell Vehicles
- Battery Electric Vehicles
- Hybrid Electric Vehicles (incl. Plug-In HEV)
- IC Engine and Transmission Improvements

Fuel Infrastructure:
- Near-Term: Petroleum (Conventional and Alternative Sources)
- Mid-Term: Bio Fuels (Ethanol E85, Bio-diesel)
- Long-Term: Electricity (Conventional & Alternative Sources), Hydrogen
Conventional Propulsion Systems

Gasoline

- Active Fuel Management
- Variable Valve Timing (VVT)
- Direct Injection
- Turbocharging
- Lean Combustion: HCCI / Stratified

Diesel

- Low-Temperature Combustion
- Advanced Air Handling
- Model-Based & Closed-Loop Control
- Efficient NOx aftertreatment

**Improve fuel efficiency:**

**Improve Emissions:**
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

Near-Term: Petroleum (Conventional and Alternative Sources)
Mid-Term: Bio Fuels (Ethanol E85, Bio-diesel)
Long-Term: Electricity (Conventional & Alternative Sources), Hydrogen

Fuel Infrastructure
GM Hybrid Portfolio

- 2001: GM/Allison Hybrid Bus
- 2002: Chevy Silverado/GMC Sierra
- 2003: Saturn VUE
- 2004: Saturn AURA/Chevy Malibu
- 2005: Tahoe/Yukon
- 2006: Escalade
- 2007: Silverado/Sierra
- 2008: Saturn VUE
- 2009: Saturn VUE (timing not announced)
Chevy Volt Concept

Electric Drive Motor
- 120 kW / 320Nm (peak)

Li Ion Battery Pack
- 136 kW peak power
- 16 kWh energy

53 kW Generator
- Internal Combustion Engine
- 1.0L 3-cylinder turbo
Advanced Battery Technology

Much improvement over time

- Focused on “power” for hybrids, NOT “energy” for plug-ins and pure electric vehicles
- Lithium-ion chemistry can provide both power and energy

Greatest hurdle: Develop large, high-volume lithium-ion battery packs

- Individual cells that meet requirements exist
- Cost ($/kWh)
- Requires intensive development with battery sources
GM Advanced Propulsion Technology Strategy

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- IC Engine and Transmission Improvements

**Fuel Infrastructure**

- Near-Term: Petroleum (Conventional and Alternative Sources)
- Near-Term: Bio Fuels (Ethanol E85, Bio-diesel)
- Near-Term: Electricity (Conventional & Alternative Sources)
- Long-Term: Hydrogen
GM’s Newest Fuel Cell Stack

**Power:**
- 73kW continuous
- 110kW peak
- Power density: 1.6kW/liter

**4th generation fuel cell stack**
- 372 single fuel cells
Project Driveway - 100 Vehicle Fleet

- World’s largest fuel cell vehicle fleet
- With customers later this year
- 4th-generation fuel cell propulsion
- Engineered for 50,000 miles of life
- Able to start and operate in sub-freezing temperatures.
GM Advanced Propulsion Technology Strategy

- Improved Vehicle Fuel Economy & Emissions
- Reduced Petroleum Consumption
- Hydrogen Fuel Cell Vehicles
- Battery Electric Vehicles
- Hybrid Electric Vehicles (incl. Plug-In HEV)
- IC Engine and Transmission Improvements

What about Energy Source Diversification?

Near-Term
- Petroleum (Conventional and Alternative Sources)
- Bio Fuels (Ethanol E85, Bio-diesel)

Mid-Term
- Electricity (Conventional & Alternative Sources)

Long-Term
- Hydrogen
**Alternate Resources – A Blending Strategy**

*Electricity / Hydrogen as the In-Vehicle Energy Carriers*

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**1st and 2nd Generation Biofuels**

- Methanol or Fischer Tropsch
- Syngas CO, H₂

**Critical Dependency on Battery Technology**

- Electrification

**Critical Energy Resources**

- Petroleum Fuels
- Liquid Fuels / Electricity / Hydrogen as the In-Vehicle Energy Carriers
- Fuel-Cell Electric

**Critical Energy Carriers**

- Methanol
- Fischer Tropsch
- Syngas CO, H₂
- Heat

**Renewables**

- Solar
- Wind
- Hydro

**Nuclear**

- Critical Energy Resources

**Electricity**

- Critical Energy Carriers

**Propulsion System**

- Conventional ICE: Gasoline / Diesel
- ICE Hybrid
- Plug-In Hybrid ICE
- Electric Vehicle
- Fuel-Cell Electric
Electricity: Energy Diversity Exemplified

- Diverse energy sources are used for electricity generation – based on local resources
- Existing, global infrastructure with clearly-defined standards
- Efficient transmission system
- Spare generation capacity exists: US “valley filling” up to 43% of light-duty fleet *
- Energy from Renewables (17%)
  - High growth (~52%) but just keeping up with overall demand growth
  - Hydropower already maximixed

* PNNL Report 2007; 33miles/day commute
BIOFUELS are part of the solution.
The GM U.S. “FlexFuel Club”
17 models for 2007 MY!

GMC Sierra

Chevy Impala

GMC Yukon & Yukon XL

Chevy Silverado

Chevy Uplander

Chevy Monte Carlo

Chevy Avalanche, Suburban & Tahoe

GMC Savana
Global Renewable Fuels

In U.S., GM has 2 million FlexFuel E85-capable vehicles on the road. Building >400,000 more every year.

In Brazil, FlexPower is now available in every passenger car model. FlexPower models account for 90% of sales.

In Sweden, Saab leads the environment-friendly car segment with 9-5 BioPower, accounting for 85% of Saab 9-5 sales.
Biofuels will play a key role

Achieving the maximum potential of biofuels will require continued innovation

- Plants with high yields and low resource inputs
- Low cost cellulosic conversion technologies
- Improved systems for resource and fuel logistics
- Propulsion technologies that maximize “Field-to-Wheels” fuel efficiency
But what about COAL?
World Coal Reserves

Three expected largest automobile markets have much coal, but little oil

Source: Businessweek 2006
Multiple Options for Coal

Energy Resource: Coal

Conversion:
- Syngas: CO, H₂
- Heat
- Shift Reaction

Energy Carrier:
- Electricity
- Hydrogen
- XTL or Methanol

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

Critical Dependency on Battery Technology

Electrification
How will Coal be Used?

- **Coal to liquids**
  - Fischer Tropsch liquids compatible with oil infrastructure
  - Methanol and dimethyl ether lower manufacturing investment
  - China is the place to watch

- **Electricity**
  - Much progress still needed in battery cost and performance

- **Hydrogen**
  - Storage technology and infrastructure

Affordable CO$_2$ sequestration will be the key to large scale use of coal
Fuels and Propulsion are a System

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

Conversion
- Petroleum Fuels
- 1st and 2nd Generation Biofuels
- Syngas CO, H₂
- Heat
- Shift Reaction

Energy Carrier
- Liquid Fuels
- Hydrogen

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

Critical Dependency on Battery Technology

Electrification
Characteristics of best fuels/propulsion system

- On a well to wheels basis, maximizes the distance driven per
  - Unit resource (barrel, ton, or acre)
  - Ton of CO$_2$ or other emissions
  - Dollar

- Minimizes negative impacts on society

- Flexible to permit regions to use resources they have available
Key Research Required

- Low cost battery technology
- Low cost, high density hydrogen storage
- Cost effective logistics and distribution systems for alternative fuels
- Low CO$_2$ biofuels, such as cellulosic ethanol
- Affordable CO$_2$ sequestration, especially for coal-derived fuels
Summary

General Motors is Committed to

- Implement Advanced Propulsion Technologies to optimize fuel efficiency and minimize emissions
- Accelerate the utilization of biomass with E85 and Bio Diesel capable propulsion systems
- Drive the electrification of the vehicle
- Reinvent the automobile with a viable automotive fuel cell system
- Work closely with all stakeholders make sure we have the best fuels/propulsion system