The Drive for Energy Diversity and Sustainability:
The Impact on Transportation Fuels and Propulsion System Portfolios

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13th Diesel Engine-Efficiency and Emissions Research (DEER) Conference, August 2007
SULEV Requirement!

HC: 99.8%
NOx: 99.5%
GM’s leadership in enabling the Federal Clean Air Act

- 1960s Development of Catalytic Converter at GM
- 1970 Ed Cole announces emissions control program – driving unleaded gasoline nationwide in US
- 1974: GM introduces the catalytic converter on all 1975 models sold in US and Canada
- 1970: GM introduces no lead tolerant engines on all 1971 models in US & Canada

Source: GM Public Policy Center
Transportation is a growth industry!

World Population Global Vehicle Parc

![Graph showing the growth of world population and global vehicle parc from 1980 to 2020.]

Sources: U.S. Census Bureau International Population Database, GM Global Market & Industry Analysis
Automotive Growth Opportunity

70% of growth from 10 emerging markets

China, South Korea, India, Mexico, Brazil, Poland, Russia, Turkey, South Africa, Thailand
Industry Challenges

- Energy
- Environment
- Safety
- Congestion
- Affordability
Global Energy Demand – 2030

- Global: 2.0%/yr
- 70% over 2003

**Source:** DOE-EIA 2006
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

WHERE WE NEED TO GO (Bold Moves)
GM Strategy: Energy DIVERSITY to Displace Petroleum
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)
- Syngas CO, H₂
- Fischer Tropsch
- Heat
- Shift Reaction

Energy Carrier:
- Liquid Fuels
- Gasous 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
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Critical to the future of transportation.
EXTRA-HEAVY OIL/OIL SANDS

Location: Venezuela/Canada
Quantity: Venezuela - 1.36 Tbbl resource, 270 Bbbl recoverable
         Canada - 2.5 Tbbl resource, 315 Bbbl recoverable
Source: AEO2006 EIA
(Note: Saudi Arabia - 270Bbbl recoverable)

Production: 5.3 - 8.5 Mbbl/day by 2030, depending on crude price
            source: AEO2006 EIA
            1.2 Mbbl/day in 2005 Geological Survey of Canada 2005

Issues:
Investment requires sustained high crude prices (> $30/bbl), inherently more expensive than Middle East crude
Water/process energy availability, GHG emissions
Can slow, not eliminate, falloff in world crude production
SHALE OIL

Location: Worldwide (U.S. resource - Utah, Wyoming, Colorado)

Quantity: Worldwide - 2.9 Tbbl recoverable
         U.S. West - 750 Bbbl recoverable
source: AEO2006 EIA

Production: 0.43 Mbbl/day by 2030, depending on crude price
source: AEO2006 EIA

Issues:
Investment requires sustained very high crude prices ($55-$70 bbl conventional mining, estimated $35-$48 bbl by 2030)

Water/process energy availability, GHG emissions
Coal-to-Liquids (CTL) Growth

**USA**
- Sasol: 80,000 bpd (Wyoming)
- DKRW: 5,000 bpd (Wyoming)
- Rentech: 10 bpd (Illinois)
- WMPI: 10,000 bpd (Wyoming)
- Headwaters: 50,000 bpd (Arizona)

**Germany**
- Syntroleum: 3,000 bpd

**India**
- Headwaters: 11,000 bpd [DCL]
- Sasol: 80,000 bpd [DCL]
- Shell: 60,000 bpd [ICL]
- Yankuang: 20,000 bpd
- Others: < 10,000 bpd

**Philippines**
- Headwaters: 11,000 bpd [DCL]

**South Africa**
- Sasol: 160,000 bpd
- Sasol: 80,000 bpd

**Source:** Global Insight
Alternate fossil fuel resources

- Very large reserves to produce liquid fuel from unconventional oil & coal
- Issues: Cost, CO₂ emissions and large energy required to extract
BIOFUELS
Biomass Production and Potential

Global Production

US Production

Renewable Fuels Standard
7.5B gal by 2012

US Biomass Potential:
1.3B Tons Per Year by 2030 (DOE)
= ~100B gallons ethanol
( ~65B gallons gas equivalent)
= 46% of actual usage in 2006
= 34% of projected usage in 2030
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 maximized

* PNNL Report 2007; 33miles/day commute
Nuclear Energy

- 16% of global electricity generated (2005; 16 trillion kWh)
  - 442 reactors
  - 370 GW capacity

- Current projections indicate significant additional capacity approved / being constructed
  - 80 reactors
  - 80 GW capacity

- Proposed capacity additions:
  - 152 reactors
  - 107 GW capacity

- China has 10 reactors, with 18 under construction / approved and 50 more proposed
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Electrification
**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**

- **Petroleum** (Conventional and Alternative Sources)
- **Bio Fuels** (Ethanol E85, Bio-diesel)
- **Electricity** (Conventional & Alternative Sources)
- **Hydrogen**
GM Advanced Propulsion Technology Strategy

- Improved Vehicle Fuel Economy & Emissions
- Reduced Petroleum Consumption

- Near-Term
  - IC Engine and Transmission Improvements

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

- Long-Term
  - Battery Electric Vehicles
  - Hydrogen Fuel Cell Vehicles

Fuel Infrastructure

- Petroleum (Conventional and Alternative Sources)
- Bio Fuels (Ethanol E85, Bio-diesel)
- Electricity (Conventional & Alternative Sources)
- Hydrogen
Achieving the Upper Potential of Gasoline Engines

- Cam Phasing
- Spark Ignition Direction Injection
- Port Deactivation
- 2-Step VVA
- Homogenous Charge Compression Ignition
Diesel Particulate Filter

Advanced Boosting

Cylinder Pressure Sensing

NOx Aftertreatment

PCCI Combustion

HCCI Homogeneous Combustion

PCCI Pre-Mixed Charge Comb.
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

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)
Global Renewable Fuels

In U.S., GM has over 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.
GM Advanced Propulsion Technology Strategy

- Improved Vehicle Fuel Economy & Emissions
- Reduced Petroleum Consumption

- Hybrid Electric Vehicles (incl. Plug-In HEV)
- Battery Electric Vehicles
- Hydrogen Fuel Cell Vehicles

- IC Engine and Transmission Improvements

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

- **2001**: Saturn VUE (timing not announced)
- **2002**: Saturn AURA/Chevy Malibu

- **2003**: Tahoe/Yukon, Silverado/Sierra
- **2004**: Saturn VUE

- **2005**: Saturn AURA/Chevy Malibu, Tahoe/Yukon

- **2006**: Silverado/Sierra, Escalade

- **2007**: Saturn VUE (timing not announced)

- **2008**: Saturn VUE

- **2009**: Saturn VUE

- **2010**: Saturn VUE
- 288V NiMH Battery
- 2-Mode Operation
- 2 X 60KW Motor/generators
2-Mode Hybrid - Joining Hybrid Forces

GM-DC MoU, 13.12.2004

GM joins DaimlerChrysler, GM in hybrid car project
FRANKFURT (Reuters) — German luxury carmaker BMW has joined DaimlerChrysler and General Motors in an alliance to develop hybrid vehicle technology, DaimlerChrysler and GM said Wednesday.

Bloomberg.com

BMW Joins GM, DaimlerChrysler to Develop Gas-Electric Engines

BMF joins DaimlerChrysler/GM hybrid project
By Michael Shields, European Automotive Correspondent
Reuters
Wednesday, September 7, 2005: 9:04 AM

sueddeutsche.de

BMW schließt sich Hybrid-Allianz von GM und DaimlerChrysler an

DC-GM-BMW MoU, 12.09.2005
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PLUG IN HYBRID (PHEV)
November 2006: Production Plans Announced (LA Auto Show)

CONTINUING THE PATH
January 2007: E-Flex Vehicle Architecture Announced (NAIAS)
- VOLT Concept Vehicle
- 40 miles All Electric Range (AER)

Critical Dependency on Battery Technology
Electrification

Energy Resource: Oil (Conventional)
Conversion: Petroleum Fuels
Energy Carrier: Liquid Fuels
Propulsion System:
- Conventional ICE: Gasoline / Diesel
- ICE Hybrid
- Plug-In Hybrid ICE
- Range-Extended EV (ICE/Fuel-Cell)
- Electric Vehicle
- Fuel-Cell Electric
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
Range-Extended EV
Range-Extended EV
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
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Reduced Petroleum Consumption

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Battery Electric Vehicles
Hybrid Electric Vehicles (incl. Plug-In HEV)
IC Engine and Transmission Improvements

Fuel Infrastructure

Near-Term
Mid-Term
Long-Term

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

4th generation fuel cell stack
- 372 single fuel cells

Power:
- 73kW continuous
- 110kW peak
- Power density: 1.6kW/liter
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.
Well-to-Wheels Analysis

Well-to-Tank

Tank-to-Wheels
Based on 2006 EUCAR/CONCAWE and GM 2005 WTW
In Summary

Demand

- 85MBD = 1,000 barrels / second!
- 70% growth through 2030
- US petroleum usage:
  140B gallons growing to 190B gallons (2030)

Supply

- Energy diversification required (reduce petroleum)
- Blending energy carrier strategy:
  coexistence of liquid fuels, electricity & hydrogen
  as the on-vehicle fuels
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- Oil (Conventional)
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- Coal
- Natural Gas
- Renewables (Solar, Wind, Hydro)
- Nuclear

Conversion
- Petroleum Fuels
- Liquid Fuels
- Synthetic Fuels (XTL)
- Regional Niche Gaseous Fuels

Energy Carrier
- Liquid Fuels
- Syngas CO, H₂
- Heat
- Electricity
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Propulsion System
- Conventional ICE: Gasoline / Diesel
- ICE Hybrid
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Electrification
GM’s Commitment

Promote & execute a “Blending Energy Carrier Strategy”

- **Efficiency**: Implement Advanced Propulsion Technologies to optimize fuel efficiency and minimize emissions
- **Biomass**: Accelerate the utilization of biomass with E85 and Bio Diesel capable propulsion systems
- **Electrification**: Drive the electrification of the vehicle
  - Hybrid vehicles & plug in hybrids
  - State of the art “Electric Drive” systems
- **Hydrogen**: Reinvent the automobile through the design, development and validation of a production viable automotive fuel cell system
March to Zero: Removing the Automobile from the Environmental Debate

Noxious Emissions:
Key Enabler: Catalytic Converter

Tailpipe CO2:
Key Enablers: Efficiency Improvements, Alternative Fuels, Electrification of the Vehicle

LEADERSHIP AND COLLABORATION
Auto Industry
Energy Industry
Governments
Thank You for your Attention.
Most Affordable

Hybrid SUV

on Market

- Delivers 20% improved fuel economy
- Best highway fuel economy
- Priced less than $23,000

Saturn VUE Green Line
GM Hybrid System for Saturn VUE Green Line

- Advanced 36V Nickel Metal Hydride Battery Pack
- Engine Control Module with Hybrid Supervisory Software
- Modified 4T45E Automatic Transmission with Auxiliary Pump
- Power Electronics with Inverter and DC/DC Converter
- 2.4 L 4-cyl Ecotec Engine, 170 HP @ 6600 RPM
- Dual Tensioner Assembly and Aramid Cord Belt
- 4KW Motor/Generator
- Modified 4T45E Automatic Transmission with Auxiliary Pump
Hybrid Version in 2007

Saturn Aura

Chevrolet Malibu
The GM U.S. “FlexFuel Club”
17 models for 2007 MY!

- GMC Sierra
- Chevy Impala
- GMC Yukon & Yukon XL
- Chevy Silverado
- Chevy Monte Carlo
- Chevy Uplander
- Chevy Avalanche, Suburban & Tahoe
Powertrain Technology Global Highlights

2007 MY

- Active Fuel Management: 9 engine variants in 15 models available
- Variable Valve Timing: 26 engine variants in 66 car and truck models
- SIDI: Globally, 2 engine variants in 9 models
- Port De-Activation: 6 engine variants in 16 models
- Turbocharged Gasoline Engines: 14 engine variants in 18 models
- Six-speed Transmissions
  - AT: 7 new variants in 41 global models
  - MT: 7 variants in 21 global models
- Diesel Engines
  - 17 engine variants available in 45 vehicle lines
  - More than one million diesel engines annually
A Healthy New Pipeline of CTL Projects are in Planning Stages Worldwide and in China

DKRW proposed two projects in Wyoming and Montana with a combined capacity of 33,000 bpd

WMPI to build a $612 M, 5000 bpd CTL demonstration facility in PA scheduled for 2009

Researchers from South Africa’s University of Witwatersrand participating in a $10 million pilot CTL plant in coal rich Shanxi province

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Rentech / Peabody to build two CTL plants in Montana and Illinois / Indiana / Kentucky with a combined capacity of 20,000 – 60,000 bpd

Synthroleum and Sustec (purchased by Siemens) to develop a 20,000 bpd project

3 companies including Headwater Energy Services formed American Lignite Energy to pursue development of a 32,000 bpd CTL facility in North Dakota

Oil India Ltd. To build a second pilot CTL plant to convert Assam coal to diesel

L&M Lignite of New Zealand proposed a 50,000 bpd CTL facility in South or Central Otago

Shenhua Group has partnered with Sasol to build a 3 million m.t./year CTL project

Shenhua Group has started construction on a 1 million m.t./year demonstration project for direct CTL

Shenhua Group and Shell formed a joint venture for a 70,000 bpd CTL project

Bumi announced plans in 2006 to build a 80,000 bpd CTL facility in South Sumatra

Source: Industry Reports, Booz Allen Analysis