Gaseous Fuels in Transportation -- Prospects and Promise

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OHVT Mission
To conduct, in collaboration with our heavy vehicle industry partners and their suppliers, a customer-focused national program to research and develop technologies that will enable trucks and other heavy vehicles to be more energy efficient and able to use alternative fuels while simultaneously reducing emissions.
Gaseous Fuels in Transportation -- Prospects and Promise

Outline

- The Transportation Energy Situation
- Transportation Options for the 21st Century
- Future of Combustion Engines in Transportation
- Natural Gas As Alternative Fuel
- Two-Pronged Fuels Strategy
- Hydrogen As Alternative Fuel
- Summary
Rationale for a Heavy Vehicle Technologies R&D Program

Since the 1973 Oil Embargo All of the Increase in U.S. Surface Transportation Fuel Consumption has been due to Heavy Vehicles

Transportation Energy Data Book: Edition 20, DOE/ORNL-6959, October 2000
The Transportation Sector Is Almost Totally Dependent on Liquid Carbon-Based Fuels

Transportation Energy Consumption, 1997

- **Electricity**: 0.2%
- **Natural Gas**: 2.8%
- **Petroleum**: 97%

Creating Transportation Options for the 21st Century
History of “Promising” Alternatives

- **1960s**
  - Steam (Rankine cycle) engines

- **1970s**
  - Gas turbines
  - Stirling engines

- **1980s**
  - Adiabatic engines
  - Alternative fuels

- **1990s**
  - Hybrids
  - Fuel cells
Alternatives to Carbon-based Fuels

As a chemical storage system, we have no practical substitute for the C-C bond.
Energy Density of Fuels

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Thousand Btu per ft³</th>
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</thead>
<tbody>
<tr>
<td>Diesel Fuel</td>
<td>1058</td>
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<tr>
<td>F-T Diesel</td>
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<tr>
<td>Gasoline</td>
<td>922</td>
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<tr>
<td>Propane</td>
<td>683</td>
</tr>
<tr>
<td>LNG</td>
<td>635</td>
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<tr>
<td>Ethanol</td>
<td>594</td>
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<tr>
<td>Methanol</td>
<td>488</td>
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<tr>
<td>Liquid H₂ (3626 psi)</td>
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<tr>
<td>CNG (3626 psi)</td>
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<tr>
<td>Compressed Hydrogen (3626 psi)</td>
<td>68</td>
</tr>
<tr>
<td>NiMH Battery</td>
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</tbody>
</table>
Comparison of Energy Conversion Efficiencies

- Fuel Cell-Stored Hydrogen
- Fuel Cell-Methanol Reformer
- Heavy Duty Diesel Engine
- Compression-Ignition Direct-Injection ICE
- Gas Turbine
- Gasoline Direct Injection
- Conventional Spark Ignition ICE

Peak Thermal Efficiency (%)
Vehicle Range Limitation - Challenge To Be Overcome By Alternatives

- Diesel Engine-Conv. Diesel Fuel
- Diesel Engine-F-T Diesel
- Fuel Cell - Gasoline
- Direct Injection Engine- Gasoline
- Adv. NG Engine- CNG (3,600 psi)
- Fuel Cell-Hydrogen (3,600 psi)

Comparison of Miles Driven
(Same Volume of On-Board Fuel)
Combustion Engines Are Still the Most Viable for Future Heavy Vehicles
Diesel Engines Continue To Be The Most Viable Option for Heavy Vehicles

Heavy-Duty Diesel Engine Progress

Efficiency objective reached with DOE assisted R&D

Increasing Efficiency

Decreasing Emissions

Source: Caterpillar

Source: Cummins, modified by DOE

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Progress in Reducing Diesel Emissions

- Integrated systems approach
- Progress made in all 3 areas
- Partnerships with leading industry suppliers, truck/auto manufacturing, energy companies, and national labs
- Cross-cutting applications
Laboratory Demonstrated Diesel Emissions – Tier 2 Results

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Laboratory Setup:
• Stationary engine control system
• Stationary aftertreatment system
• Urban Dyno Drive Schedule (UDDS) – First 1,392 secs. of FTP
• Sulfur < 4 ppm, 48 Cetane
• NOx accuracy +/- 0.025 g/mi
• PM accuracy +/- 0.005 g/mi

Source: Cummins
Natural Gas Vehicles

Pros and Cons

- Current natural gas engines can have very low engine-out emissions compared to current model diesels.
- Customers are seeking better fuel economy, higher power ratings, and lower capital expenditures.
- Ultra-low NOx emissions (<0.2 g/bhp-hr) will be needed to meet future regulations and to compete with emerging clean diesel technology.
- Efficiency may continue to be a barrier along with on vehicle storage.
- Recent price increases for natural gas create uncertainty for vehicle operators.
- Use of natural gas for power generation competes with use for vehicles.
Natural Gas as Fuel for Heavy Vehicles

Technology Barriers

- Current natural gas engines operate at lower efficiency than conventional engines.
- On-board fuel storage for natural gas too expensive, too heavy and inconvenient for operators to refill.
- Natural gas transportation fuel facilities not widely available.
- Fueling facilities for natural gas are too expensive.
February 10, 2000 EPA adopted Tier 2 Emissions Standards which became effective April 10, 2000. (Includes reducing sulfur levels in gasoline to 30 ppm.)


January 18, 2001 EPA issued rule requiring 80 percent of all on-road diesel fuel to have less than 15 ppm sulfur starting in 2006.
EPA Emissions Standards

- **Tier 2 Regulations for Light-Duty Vehicles (LDVs):**
  - 0.07 g/mi NOx and 0.01 g/mi PM; represent 77 to 95% reduction from Tier 1 levels
  - Includes all LDVs under 10,000 lbs
  - Phased in 2004-2008

- **Heavy-Duty Diesel Engine Regulations:**
  - 0.2 g/bhp-hr NOx and 0.01 g/bhp-hr PM; represents about 90% reduction from 2004 regs
  - Phased in 2007-2010

- Heavy-duty regulations include ultra-low sulfur diesel fuel
Impact of EPA 2007 emissions standards

- 0.2 g/bhp-hr NOx will be difficult to achieve with natural gas as well as diesel
- Other regulated emissions also tough
- Progress in emissions control technologies R&D indicates diesel engines are likely to meet standards

Emissions advantage of natural gas is diminishing.
Homogeneous Charge Compression Ignition (HCCI) Engines

Potential of HCCI Engines
- High efficiency
- Very low NO$_x$
- Lower cost (possibly no need for high pressure injection system, 1/3rd of diesel engine cost)
- Low cycle-to-cycle variation
- Fuel flexibility
- Unthrottled operation

Technical challenges of HCCI
- Difficult to control
- Difficult to start
- High peak heat release and peak pressure
- High hydrocarbon and CO emissions

*Natural gas may be a good fuel choice for HCCI.*
On-Board Gas Storage –
The Subject of This Workshop
Challenges

- Current and projected pressures (3,600 psi to 10,000 psi) are inconvenient and potentially very hazardous.
- Heavy and strong tanks are required.
- Multistage compression is required and very expensive.
Breakthrough Enables Two-Pronged Fuels Strategy

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Liquid Fuels for All Heavy Vehicles

Gaseous Fuels for Light and Medium Trucks

Clean, High Efficiency Compression Ignition Engines (Diesel or Homogeneous Charge)
Hydrogen can be stored on board and supplied directly to the fuel cell: *Storage (volume, pressure, weight) and Infrastructure Issues*

- Hydrogen can be derived on-board from fuels such as ethanol, methanol, natural gas, gasoline or FT fuels: *Complexity, Cost, & Start-up Issues*
Hydrogen Infrastructure

Hydrogen Production
Las Vegas, NV Station - autothermal reformer/steam methane reformer
Palm Desert Station, CA - autothermal reformer
advanced cyclic reformer
electrolyzers
Chula Vista, CA Station – steam methane reformer

Storage
Pressurized Tanks – 5,000 to 10,000psi
Cryogas Tank - private auto company vehicle

Vehicles
30% Hydrogen/70% Natural Gas Mixture
Hydrogen Storage

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Today

Compressed Storage Tanks
Cryogenic Liquid Hydrogen

Tomorrow

Metal Hydrides and Carbon-nanotubes?
The transportation sector is almost totally dependent on liquid carbon-based fuels.

Combustion engines are still the most viable transportation energy conversion technologies for the near future despite a history of R&D on “promising” alternatives.

Vehicle range limitation is one challenge that needs to be overcome by alternatives, especially gaseous fuels.

EPA enacted emissions regulations that include ultra-low sulfur fuel requirements have diminished the emissions advantage of gaseous fuels burned in internal combustion engines.

Research results show that ultra-low sulfur fuel will enable diesel engines to meet stringent emissions standards.

Breakthroughs are needed in on-board storage and engine efficiency (e.g., HCCI) to improve prospects for gaseous fuels as alternatives to liquid carbon-based fuels for transportation.