Role of Low Sulfur Diesel Fuel in Future Clean Transport Policy

Dr. James J. Eberhardt, Director
Office of Heavy Vehicle Technologies
U.S. Department of Energy

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A Policy Overview: Low Sulfur Diesel Fuel, Fleet Rules, and Engine Retrofits
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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.
Role of Low Sulfur Diesel Fuel in Future Clean Transport Policy

Outline

- Transportation and Urban Air Quality
- EPA Emissions Standards
- Diesel Engine Emissions Control Strategy
- Low Sulfur Diesel Fuel Rule
- Alternatives to Carbon-Based Fuels
- DOE Advanced Petroleum-Based Program
- Fuels Progress
- EC-Diesel Program and Results
- Catalyzed Diesel Particulate Filter
- Diesel versus Gasoline Emissions
- Summary
Population and miles traveled continue to increase resulting in increasing congestion and air pollution.

As a result, over 100 million people live in areas not meeting National Ambient Air Quality Standards (EPA, Oct. 1995).
EPA Emissions Standards

- **Tier 2 Regulations for Light-Duty Vehicles (LDVs):**
  - 0.07 g/mi NOx and 0.01 g/mi PM; represents 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
Three-pronged systems approach appears necessary to meet very low emissions without sacrificing engine efficiency.
Outlook on Mobile Emissions

Environmental Groups
(UCS, NRDC, etc.)

Government
(DOE, EPA, CARB, SCAQMD)

Industry
(Vehicle/Engine Manufacturers, Fuel Providers, API)

What Can Be Accomplished By Working Together
Low Sulfur Diesel Fuel Rule - Background

- EPA rule issued January 18, 2001 requiring 80% of all on-road diesel fuel to have less than 15ppm sulfur starting in 2006
  - after significant debate within Administration and in regulated communities (refiners, autos, fuel distributors and sellers).
- DOE worked with EPA on this rulemaking for over a year,
  - filed detailed public comments on the proposal and worked with affected parties to try to reach consensus.
- DOE supported the requirement for an ultra-clean fuel (less than 10ppm on average) and the market introduction in 2006.
DOE did not support the 80 percent, over-production, mandate that EPA adopted

- argued for phase-in of the clean fuel to assure retail availability to the new diesel cars, light trucks and heavy-duty vehicles that needed the ultra-low sulfur to protect their emission control systems.

- DOE, and other agencies view within the Administration supporting this position, did not prevail within the interagency review/negotiation process in November and December of 2000.
The Department’s primary concerns:

- Availability of diesel fuel clean enough for new diesel vehicles (light and heavy-duty) to meet extremely tight EPA emission standards in 2006 time period (in the 10ppm sulfur range similar to what the EPA rules require).
- Assuring that fuel requirement implementation does not threaten US refinery viability or diesel fuel supply.
- Limiting the cost impact of this rule on consumers and the US economy. DOE proposed phase-in would save US diesel fuel consumers over $10 billion, compared to the EPA rule, while providing the same environmental benefits.
New Administration in process of reviewing Rule with goal of achieving implementation approach that reduces the impact on refiners and reduces consumer costs.

A key element of achieving a successful phase-in (over a 5 to 7 year time period) is a policy that focuses on assuring retail availability, rather than the approach in the issued rule mandating refinery over-production.

The review of the rule is reconsidering alternative policy approaches, including incentives for retail availability, that were not considered in the rule issued.
As a chemical storage system, we have no practical substitute for the C-C bond.
Energy Density of Fuels

<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>Energy Density (Thousand Btu per ft³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel Fuel</td>
<td>1058</td>
</tr>
<tr>
<td>F-T Diesel</td>
<td>990</td>
</tr>
<tr>
<td>Gasoline</td>
<td>922</td>
</tr>
<tr>
<td>LNG</td>
<td>635</td>
</tr>
<tr>
<td>Ethanol</td>
<td>594</td>
</tr>
<tr>
<td>Methanol</td>
<td>488</td>
</tr>
<tr>
<td>Liquid H₂ (@ 3626 psi)</td>
<td>270</td>
</tr>
<tr>
<td>CNG ((@ 3626 psi)</td>
<td>266</td>
</tr>
<tr>
<td>Compressed Hydrogen</td>
<td>68</td>
</tr>
<tr>
<td>NiMH Battery</td>
<td>14</td>
</tr>
</tbody>
</table>

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Comparison of Energy Conversion Efficiencies

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<table>
<thead>
<tr>
<th>Type</th>
<th>Peak Thermal Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel Cell-Stored Hydrogen</td>
<td>60%</td>
</tr>
<tr>
<td>Fuel Cell-Methanol Reformer</td>
<td>50%</td>
</tr>
<tr>
<td>Heavy Duty Diesel Engine</td>
<td>50%</td>
</tr>
<tr>
<td>Compression-Ignition ICE</td>
<td>40%</td>
</tr>
<tr>
<td>Direct-Injection ICE</td>
<td>40%</td>
</tr>
<tr>
<td>Gas Turbine</td>
<td>30%</td>
</tr>
<tr>
<td>Gasoline Direct Injection</td>
<td>30%</td>
</tr>
<tr>
<td>Conventional Spark Ignition</td>
<td>20%</td>
</tr>
</tbody>
</table>

- **Today's Capability**
- **Projected Capability (2004)**
Vehicle Range Limitation - Challenge To Be Overcome By Alternatives

Comparison of Miles Driven (Same Volume of On-Board Fuel)

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

- Fischer-Tropsch and Oxygenated Diesel Fuels Significantly Reduce PM

- Fischer-Tropsch and Oxygenated Diesel Fuels Dramatically Reduce Polycyclic Aromatic Hydrocarbon Emissions

Source: DOE APBFP Ad Hoc Auto/Energy Working Group
Mercedes A170 FTP NOx Emissions Using NOx Adsorber and Various Fuel Sulfur Levels

FTP NOx Emissions (g/mi)

- 3 ppm
- 30 ppm
- 150 ppm

Engine Out

NOx Adsorber

After 3000 mile equivalent aging with 30 ppm fuel

Tier 2 Fleet Average NOx

Source: ORNL; using laboratory reductant system
Low Sulfur Fuel Enables Heavy-Duty Engine PM Control Devices to Meet EPA Proposed Standards

Source: DOE APBFP DECSE Program
A government-industry working group established to objectively evaluate EC-Diesel fuel and catalyzed particle filters in fleet vehicles

- widely recognized that ultra-low sulfur diesel fuels will enable many diesel emission control technologies
- BP/ARCO Products introducing ultra-low sulfur diesel fuel in southern California

Participants: International, Detroit Diesel, Cummins, BP, Engelhard, Johnson-Matthey, DOE, NREL, CARB, SCAQMD, CEC
EC-Diesel Program

Vehicle Retrofits Engelhard DPX and Johnson Matthey CRT catalyzed particle filters (passive devices) - installed in place of the existing muffler system without any modification to the engines.

Seven fleets operating in Southern California are participating in the program.
EC-Diesel Program - Vehicle Emissions Testing

City-Suburban Heavy Vehicle Route (CSHVR)

Grocery Truck Testing on the West Virginia University Transportable Chassis Dynamometer

Retrofitted vehicles are fueled exclusively with EC-Diesel using segregated storage tanks.
Emissions with and without Particulate Filters

Average Grocery Truck Emissions, CSHVR(1&2)

- **Control Vehicles, CARB Fuel (150ppmS)**
- **Test Vehicles, ECD Fuel (<10ppm S)**
- **Test Vehicles, ECD Fuel & DPX Filter**
- **Test Vehicles, ECD Fuel & CRT Filter**

<table>
<thead>
<tr>
<th>Emissions, g/mile</th>
<th>CO/10</th>
<th>NOx/100</th>
<th>HC</th>
<th>PM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Below Detection Limit</td>
<td>0.03</td>
<td>0.32</td>
<td>0.35</td>
<td>Below Detection Limit</td>
</tr>
<tr>
<td>Below Detection Limit</td>
<td>0.01</td>
<td>0.003</td>
<td>0.003</td>
<td>0.003</td>
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</tbody>
</table>
Emissions with and without Particulate Filters

**Average School Bus Emissions**

<table>
<thead>
<tr>
<th>Emissions, g/mile</th>
<th>Control Vehicles, CARB Fuel (150ppm S)</th>
<th>Test Vehicles, CARB Fuel</th>
<th>Test Vehicles, ECD Fuel (&lt;10 ppm S)</th>
<th>Test Vehicles, ECD Fuel &amp; DPX Filter</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO</td>
<td>0.15</td>
<td>0.5</td>
<td>Below Detection Limit</td>
<td>Below Detection Limit</td>
</tr>
<tr>
<td>NOx/10</td>
<td>1.62</td>
<td>1.0</td>
<td>Below Detection Limit</td>
<td>Below Detection Limit</td>
</tr>
<tr>
<td>HC</td>
<td>Below Detection Limit</td>
<td>Below Detection Limit</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PM</td>
<td>Below Detection Limit</td>
<td>Below Detection Limit</td>
<td></td>
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</tr>
</tbody>
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Lower Sulfur Fuel Reduces PM Emissions from Current Heavy-Duty Diesel Engines

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Tanker Truck Emissions

Engine Out

PM, g/mile

Sulfur Level, ppm

**100 gasoline cars (equivalent work to a tanker truck) each one complying with EPA Tier 2**

*Source: NREL, Evaluation of ARCO EC-Diesel in California Buses and Trucks*
Progress made in all 3 areas
Integrated systems approach
Partnerships with leading industry suppliers, truck/auto manufacturing, energy companies, and national labs
Cross-cutting applications

Auto → Light Truck → Heavy Truck
Schematic of Catalyzed Diesel Particulate Filter

 ENGINE-OUT EXHAUST FLOW

 INLET

 EXHAUST

 STEEL CANISTER

 INSULATION

 CROSS SECTION X-X
A Catalyst Layer of Precious Metals and Base Metal Oxides Is Formed on/Within the Diesel Particulate Wall Flow Filter (DPF)

Particulate Matter (PM) Is Filtered From the Exhaust – Spontaneous Combustion of Collected PM Occurs Either Continuously and Periodically Depending on Exhaust Temp

90%+ PM Reduction

80%+ Carbon Monoxide and Hydrocarbon Reductions Including Toxic HCs

Slight NOx Reductions

Sulfur – Originally Designed for 0.05% S and US FTP Transient Cycle – CSF Performs Better With Lower Sulfur Diesel Fuel

Clean ‘Green’ Diesel Engine Meeting Strict Emissions Standards Under All Engine Operating Modes – Requires Ultra-Low Sulfur Fuel
Congestion and emissions of criteria pollutants remain national concerns.

Future EPA emissions regulations include requirements for ultra-low sulfur diesel fuel.

DOE’s three-pronged diesel engine emissions control strategy had always advocated fuel formulation/quality as being necessary to meet very low emissions without sacrificing engine efficiency.

DOE work on advanced petroleum-based fuels shows that low sulfur diesel fuel is critical to the commercial viability of advanced emission control technologies.

Advanced emission control technologies are critical components of a clean transportation policy.