Clean Fuels and Vehicles: A Comprehensive, Integrated Approach

International Specialty Conference

Leapfrogging Opportunities for Air Quality Improvement

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Outline

• Transportation and air pollution in the U.S.
• Major US Emission and Fuel Standards
• Compliance Monitoring / Enforcement
• Appendix: Diesel Retrofit Program
Fuels and Vehicles in the U.S.

• Transportation in the U.S.
  – About 68% of U.S. petroleum use
  – About 30-80% of urban air pollution (CO, NO\textsubscript{x}, HC, PM)
  – About 25% of energy use
  – About 25% and greenhouse gas emissions (e.g., CO\textsubscript{2})
  – Greater growth than other major economic sectors

• Light duty vehicle use in the U.S.
  – About 85% of passenger vehicle miles traveled
  – About 75% of road transport energy and GHG
  – About 60% of all transport energy and GHG
The “Systems Approach”

- Treat vehicles and fuels as one system
- Regulate fuel sulfur and vehicle emissions at same time.
- Sulfur reduction necessary for the most advanced emission controls
  - Diesel Particulate Filters and Lean NOx traps
  - Advanced catalysts for spark ignition engines
- Sulfur reduction yields immediate benefit from entire fleet
- US -- Gasoline  30 ppm average; 80 ppm maximum
- US -- Diesel    15 ppm maximum
US Major Mobile Source Rules

Tier 2 Light-Duty
final rule 1999
fully phased in 2009
Diesels held to same stringent standards as gasoline vehicles
GAS 30 PPM; DIESEL 15 PPM

Heavy-Duty Highway
sales 800,000 / yr
40B gallons / yr
final rule 2000
fully phased in 2010
DIESEL 15 PPM

Nonroad Diesel
sales over 650,000 / yr
12B gallons / yr
final rule 2004
fully phased in 2015
DIESEL 15 PPM

Locomotive/Marine
sales 40,000 marine engines, 1,000 locomotives / yr
final rule 2008
fully phased in 2017
DIESEL 15 PPM

Ocean Going Vessels
Final EPA Rule Dec 2009
IMO MARPOL Annex VI
ECA Controls
- Fuel Based 2015 1000 PPM
- SCR Catalyst Based 2016

Note: sales and diesel fuel usage vary year-to-year; these figures are for comparison purposes only.
U.S. Systems Approach: Clean Fuels and Vehicles: progress since 2006

• Clean Cars and Passenger Trucks
  – 2009: Tier 2 Standards fully implemented (Tier 2/Bin 5)
  – 77-95% lower light-duty vehicle standards (beginning in 2004)
  – Same standards for light trucks and cars; gasoline and diesel

• Clean Heavy-Duty Trucks and Buses
  – Heavy-Duty 2007 Standards are being implemented
  – 90% lower heavy-duty gasoline & diesel vehicle standards
  – PM filter forcing standards, NOx catalyst based standards

• Clean Nonroad Diesel Engines and Equipment
  – Some PM limits began in 2008; will be fully implemented over next
  – 90-95% lower emission standards for NOx and PM - based on high

• Locomotive and Marine Diesel Standards
  – Final rule issued in 2008
  – 90% cut in PM emissions; 80% cut in NOx emissions

• Oceangoing vessels (2009)
  – Starting in 2011, a 15-25% reduction in NOx emissions
  – Starting in 2016, about 80% reduction in NOx emissions
## Forecast of Vehicle Populations in China

<table>
<thead>
<tr>
<th>Population (millions)</th>
<th>2005</th>
<th>2008</th>
<th>2015</th>
<th>2025</th>
<th>2035</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-wheelers</td>
<td>55.3</td>
<td>78.1</td>
<td>146.7</td>
<td>193.2</td>
<td>130.4</td>
</tr>
<tr>
<td>3-wheelers</td>
<td>2</td>
<td>1.5</td>
<td>1.7</td>
<td>0.3</td>
<td>0</td>
</tr>
<tr>
<td>HD commercial</td>
<td>10.4</td>
<td>13.9</td>
<td>19.9</td>
<td>29.3</td>
<td>37.5</td>
</tr>
<tr>
<td>LD commercial</td>
<td>9.4</td>
<td>13.1</td>
<td>22.8</td>
<td>37.7</td>
<td>52.9</td>
</tr>
<tr>
<td>Car, SUV</td>
<td>12.9</td>
<td>23.4</td>
<td>56.8</td>
<td>115.8</td>
<td>192.7</td>
</tr>
<tr>
<td>Grand Total</td>
<td>90</td>
<td>130</td>
<td>248</td>
<td>376</td>
<td>413</td>
</tr>
</tbody>
</table>

This growth will lead to enormous increase in use of gasoline and diesel

Source: CAI Asia/ADB, 2008
Diesel Fuel Yesterday, Today, and Tomorrow in the U.S.

All Diesel ~3000 ppm

10/93

Highway Diesel 500ppm

<20% 500 ppm

6/06

>80% 15 ppm

6/10

All Highway 15 ppm

1/10

<20% 500 ppm

6/12

All Off-Highway Diesel ~3000 ppm

6/07

L&M 500 ppm

6/14

NR 15 ppm

6/10

Small & Credit 500 ppm

6/12

NR, L&M Diesel 500 ppm

L&M 15ppm

Small 15 ppm

Small & Credit ~3000

HHF ~3000ppm

* This figure is intended to illustrate the timeline for the final highway and nonroad diesel fuel sulfur control programs. It is not drawn to exact scale. Refer to 40 CFR Part 80 for specific program dates.
Nitrogen Oxide (NOx) Emissions

with and without controls

Year

Million tons

Millions of tons

With Regulations and Technology Advances

Without Regulations and Technology Advances

Nitrogen Oxide (NOx) Emissions with and without controls

1970 2000 2020
PM Reductions from DPF-based Standards in the U.S.
Mobile Source Program Impacts in 2030: Examples

**NOx**
- Light Duty Tier 2
- Heavy-Duty Highway
- Nonroad Diesel
- Locomotive / Marine

**PM**
- Light Duty Tier 2
- Heavy-Duty Highway
- Nonroad Diesel
- Locomotive / Marine

**Cost**
- Light Duty Tier 2
- Heavy-Duty Highway
- Nonroad Diesel
- Locomotive / Marine

**Benefits**
- Benefit to cost ratio
  - Light Duty Tier 2: 5:1
  - Heavy-Duty Highway: 17:1
  - Nonroad Diesel: 40:1
  - Locomotive / Marine: 15:1

**Thousands of tons reduced**
- 0
- 500
- 1000
- 1500
- 2000
- 2500
- 3000

**$Billion / year**
- 0
- 1
- 2
- 3
- 4
- 5
- 6
EU and US Light Duty Gasoline and Diesel Vehicle Standards

Graves/Km

May/Will Include A Number Based PM Standard
EU and U.S. Heavy-Duty Engine Transient Cycle Emission Standards

- **Euro IV**
  - 2005: 3.5 g/kWh
  - 2008: 3.0 g/kWh

- **Euro V**
  - 2008: 2.0 g/kWh
  - 2013/14: 1.0 g/kWh

- **Euro VI**
  - 2013/14: 0.4 g/kWh

- **U.S. 2007**
  - NOx: 1.5 g/kWh
  - PM: 1.3 g/kWh

- **U.S. 2010 (max NOx)**
  - NOx: 0.65 g/kWh
  - PM: 1.3 g/kWh

- **U.S. 2010 (std.)**
  - NOx: 0.26 g/kWh
  - PM: 1.3 g/kWh

Euro VI to include particle number limit
Compliance Monitoring Key Feature in all EPA Standards

- Certification alone is **never** enough
- Must have monitoring and enforcement to ensure real-world emission reductions are achieved
- Meet standards for “useful life”
- Production line testing and in-use testing
- Put testing responsibility on manufacturers
- Lab testing or PEMS testing
- Data reporting requirement
- EPA spot check testing
- Recalls or penalties for failure to comply
- Results feed back into development
Xie xie!

• More info:

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Appendix:
Cleaning Up Existing Diesel Vehicles

- The tightest new standards can not clean up existing fleet.
- Goal in U.S.: *reduce emissions from the legacy fleet of 11 million diesel engines*
Ways to reduce PM emissions

• Oxidize organic gas-phase components (i.e., oxidize HCs)
  – Diesel Oxidation Catalyst (DOC)
• Filter out solid components (soot and ash)
  – Diesel Particulate Filter (DPF)
• Reduce sulfur content (reduce sulfate/SOx)
  – Primarily in diesel fuel but, also in diesel engine oil
  – Lowers both directly emitted PM and secondary PM
• Recirculate crankcase vapor to combustion chamber; Closed crankcase ventilation
• Upgrade engine to cleaner standards
## Main PM Retrofit Technologies

<table>
<thead>
<tr>
<th>TECHNOLOGY</th>
<th>PM REDUCTION</th>
<th>COST on a Truck</th>
<th>FUEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel Oxidation Catalyst (DOC)</td>
<td>20-40%</td>
<td>$1000 - $2000</td>
<td>Best on ULSD</td>
</tr>
<tr>
<td>Partial Flow Filter</td>
<td>50%</td>
<td>$5000</td>
<td>Best on ULSD</td>
</tr>
<tr>
<td>Wall Flow Filter (DPF)</td>
<td>&gt;90%</td>
<td>$6000 - $10,000</td>
<td>ULSD</td>
</tr>
<tr>
<td>Closed Crankcase</td>
<td>10-20%</td>
<td>$500 --$1500</td>
<td>Any</td>
</tr>
</tbody>
</table>
Retrofitted Diesel Particulate Filters
Diesel Particulate Filter Technology

- **Trapped Soot**
- **Exhaust In** (Soot, CO, HC) Enter
- **Cell Plug**
- **Cell Plugs**
- **Exhaust out** (CO₂, H₂O)

- *Removes 90+% PM also HC and CO.*
- *Requires ULSD*
Wall Flow Filters / Diesel Particulate Filters

- Trap almost all PM
  - Including ultrafines and black carbon
  - Eliminate all black smoke
- Active or Passive
- Usually catalyzed
- Nearly eliminate HCs, CO and diesel smell
- Must have ULSD !!!!
- Present on all 2007 and later road diesels in US
Wall Flow Filters / Diesel Particulate Filters (2)

• Require occasional cleaning for ash
• Require monitoring of temperature and backpressure
• Must be very carefully matched to the vehicle and engine by vendor
• Generally not suitable for old, dirty engines (best on Euro 2 or later)
• Engine and vehicle maintenance critical
• Relatively expensive option
Wall Flow Filters / Diesel Particulate Filters (3)

- Uncatalyzed active filters offer options for vehicles in poor condition or where ULSD not available.
  - Electrically regenerated
  - Burner equipped
  - Add complexity and cost but in some cases may be a good option
- More than 8,200 have been installed on trucks and buses in Beijing
Electrically Regenerated DPF