Financing Refinery Upgrades To Reduce Sulfur in Gasoline and Diesel Fuel

Overview

• Why Low Sulfur Fuels
• How Sulfur Levels Can Be Reduced
• What Does It Cost
• What Benefits Result

Why Low Sulfur Fuel?

• Lowers Emissions From Existing Vehicles
  – SO₂ From All Vehicles
  – PM From Diesel Vehicles
  – CO, HC, NOx, Toxics From All Catalyst Vehicles
• Enables Advanced Technologies & Tight Standards For New Vehicles
• Enables Retrofit Technologies To Clean Up Existing Vehicles

Linkage Between Fuel Sulfur and PM Emissions
Close Linkage Between Vehicle Emissions Standards and Fuel Sulfur Levels

<table>
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<tr>
<th>Year</th>
<th>EPA 07</th>
<th>EPA 04</th>
<th>EPA 02</th>
<th>EPA 01</th>
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<tr>
<td>2008</td>
<td>NOx = 0.25</td>
<td>P = 0.01</td>
<td>Diesel 15 ppm</td>
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<td>NOx = 2.5</td>
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<td>EURO IV NOx = 3.5 P = 0.02</td>
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<td>2002</td>
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<td>Diesel 15 ppm</td>
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Increase in In-Use Vehicle Emissions in Bangkok Due To Sulfur in Fuel

- ** GASOLINE **
  - Percent Increase Compared to 150 PPM Sulfur
  - CO: 33% 47%
  - HC: 10% 14%
  - NOx: 26% 30%

- ** DIESEL **
  - Percent Increase Compared to 500 PPM Sulfur
  - CO: 350 ppm 33%
  - HC: 10% 16%
  - NOx: 50% 33%
  - PM: 0% 10%

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Measurement results indicate that Diesel PM levels have been significantly reduced. (By the Research Institute for Environmental Protection)
What a refinery does:
• Converts crude oil to usable products
• Adjusts yields to match product demand
• Adjusts qualities to meet product specifications.

Types of Refinery Processes
• Physical Separation Processes
  – Distillation/Fractionation
  – Extraction
• Chemical Processes
  – Cracking/Conversion
  – Combination/Reformulation
  – Hydrotreating

Refinery Configuration Overview
• Topping – Simple crude separation, no ability to change yield and quality
• Hydroskimming – Simple crude separation, no ability to adjust yield. Can increase octane, lower sulfur
• Conversion – Yield adjustment capability and quality improvement
• Deep Conversion – Large yield/quality flexibility, fuel oil minimization.

Conversion Refinery
Catalytic Cracking (FCC)
Deep Conversion Refinery
Catalytic Cracking, Coking & Hydrocracking

Diesel Hydrodesulfurization (HDS)

- Standard Diesel HDS:
  - Sulfur is catalytically removed in the presence of hydrogen
- Deep HDS
  - Higher activity catalyst and catalyst volume
  - More hydrogen consumed
  - High severity, high pressure operation
  - Loss of diesel yield

Fluid Catalytic Cracking (FCC)

- Vacuum and coker gasoil feeds
- Makes gasoline out of vacuum gasoil (a stream heavier than diesel)
- Using intense heat (about 1,000 deg F), low pressure and a powdered catalyst, the cat cracker converts heavy fractions into smaller gasoline molecules
- Product streams typically have high sulfur content

Hydrocracking

- Similar and preferably lighter feeds than cat cracking
- More flexible. Can optionally maximize gasoline, jet or diesel
- Uses a different catalyst, much greater pressure than FCC and a lot of hydrogen
- Products have minimal sulfur
Clean Gasoline Quality Changes
Severe sulfur reduction

- Hydrotreat naphthas and FCC gasoline
  - Higher capital expenditure. Some octane loss.

- Desulfurize FCC feed
  - Higher capital cost.

Cost of Reducing Sulfur in Diesel Fuel in Asia
(High Sulfur Crude)

Source: Enstrat International

Gasoline and Diesel Reformulation Costs in China by Scenario

Source: Dr. Yamaguchi
Costs for China

- Costs ranged from 2.8 to 3.2 c/g inclusive in 2005, 4.04 c/g in 2008, 4.7 c/g in 2010 except for EURO5 5.2 c/g.
- Diesel costs were roughly twice gasoline costs.
- Costs are well within acceptable parameters by US and European standards.
- Benefits may include emissions, fleet maintenance, fuel harmonization, ability to export.

EU Estimate of Costs to Reduce Sulfur From 50 ppm to 10 ppm

Benefits Exceeded Cost By Factor of 2 to 3 Times

Canada's Experience
Benefits of Clean Fuel and Vehicle Programs in USA

- premature deaths
- chronic bronchitis
- hospital admissions
- lost work days

Benefits of Clean Fuel and Vehicle Programs in USA

- Over 3 million

Costs & Benefits of Clean Fuels and Vehicles

- Tier 2 Light-duty highway: cost $11 billion, benefit $175 billion
- Tier 4 nonroad: cost $11 billion, benefit $175 billion

Ultra Low Sulfur Diesel Fuel is Spreading

- Fuel Quality is an Integral Part of a Complete Emission Control System for Both Gasoline- and Diesel-Powered Vehicles
- Fuel Sulfur Adversely Effects All Catalyst-Based Emission Control Technology and Needs to Be Reduced
- Using a Systems Approach with Ultra-Low Sulfur Fuel, Combined with Advanced Engine Designs and Advanced Emission Control Technology, Cars, Trucks, and Buses Will Emit 99% Less Pollution As Compared to Vehicles in the 1960s

Conclusion
• Introducing Low Sulfur Gasoline Fuel Will Immediately Improve the Emission Control Performance of Existing Catalyst-Equipped Vehicles
• Introducing Low Sulfur Diesel Fuel Will Enable Existing Engines to be Retrofitted with Advanced Control Technology

• Refinery Technology To Produce Low Sulfur Fuel is Well Understood and Advancing
• Cost are a few cents per gallon To go to Near Zero Sulfur Levels
• Every Available Study Indicates Benefits Will Far Outweigh Costs