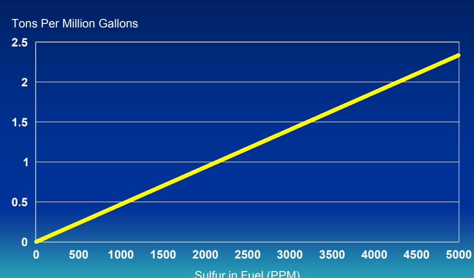
Technology And Cost Of Sulfur Reduction In Transportation Fuels

Central America Regional Workshop
Fuel Quality
Michael P. Walsh

Overview

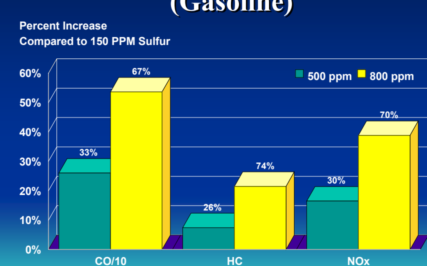
- Why Low Sulfur Fuels
- How To Reduce Sulfur in Both Gasoline and Diesel
- International Experience Regarding The Benefits and Costs of Reducing Sulfur

Tons of Directly Emitted PM From Diesel Fuels Sulfur



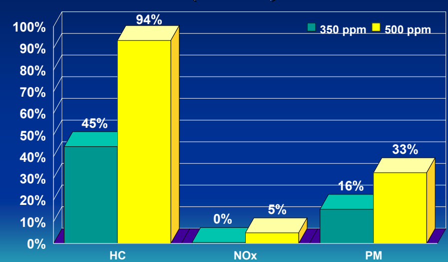
Derived From US EPA Data

Increase in In-Use Vehicle Emissions in Bangkok Due To Sulfur in Fuel (Gasoline)



Impact on Vehicles Meeting EURO 3 Standards

Increase in In-Use Vehicle Emissions in Bangkok Due To Sulfur in Fuel (Diesel)



Impact on Vehicles Meeting EURO 3 Standards

Other Benefits from Sulfur Control

- Sulfur reduction reduces SO2 emissions.
  - Less sulfate formation in the atmosphere (about 1/3 of SO2 reacts to sulfate)
  - Reduced acid rain.
- Sulfur reduction reduces engine wear.
  - Reduction from 2500 ppm to 500 ppm reduces engine wear 10 - 20%; about 33% if starting out at 5000 ppm.
  - Greater engine wear with infrequent oil change.
- Allows More Advanced Vehicle Technologies
- Retrofit Opportunities

What a refinery does:

- Converts crude oil to usable products
- Adjusts yields to match product demand
- Adjusts qualities to meet product specifications.

Typical Refinery Products

- Liquefied Petroleum Gas (LPG)
- Naphtha (for petrochemical feed)
- Motor Gasoline
- Distillates (Jet, Diesel, Heating Oil)
- Lubricants, Waxes
- Fuel Oil
- Asphalt

Crude Oil Characteristics –Sulfur

Sweet vs Sour Crude

Product	Sweet Crude (PPM Sulfur)	Sour Crude (PPM Sulfur)
Naphtha	100	400
Jet/Kerosene	500	4000
Distillate	2000	10000
Fuel Oil	6500	30000

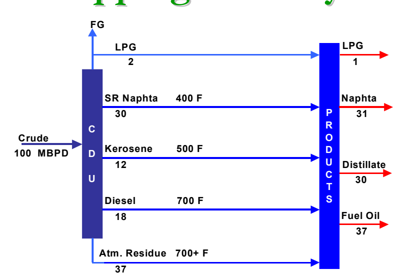
Types of Refinery Processes

- Physical Separation Processes
  - Distillation/Fractionation
  - Extraction
- Chemical Processes
  - Cracking/Conversion
  - Combination/Reformulation
  - Hydrotreating

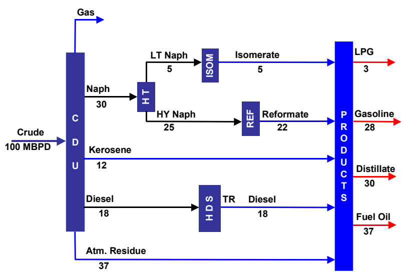
Refinery Configuration Overview

- **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.

Topping Refinery



Hydroskimming Refinery



Reformer

- SR Naphtha is hydrotreated and split.
- Heavy part (Heavy Naphtha) is catalytically processed and reformed to a highly aromatic stream called Reformate.

  Advantages: - High octane product

  - Hydrogen also a product

  Disadvantages: Aromatics are toxic and are limited in clean fuel specs.

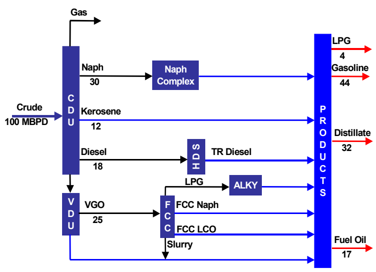
C5C6 Isomerization

- Straight chain paraffins are catalytically converted to their chain counterparts.
- Advantages: - 10 to 12 numbers octane gain
  - Elimination of toxic benzene
- Disadvantage: Product has higher RVP

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

Conversion Refinery
Catalytic Cracking (FCC)



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

Alkylation

- Combines FCC gas (propylenes/butylenes) with isobutane to produce a high octane stream called alkylate.
- Catalyst is sulfuric or hydrofluoric acid
- Alkylate is an excellent diluent for other gasoline blending components.

Diesel HDS and Aromatic Saturation

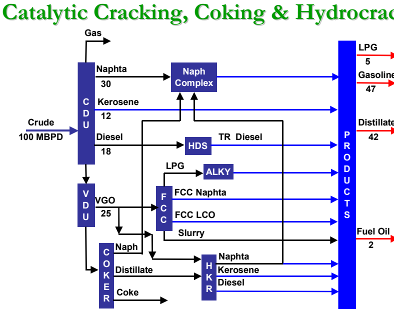
- Necessary for FCC LCO treatment
- 1st stage - requires Diesel HDS
- 2nd stage – aromatic saturation with noble catalysts
  - Process consumes hydrogen
  - Gains of 17 to 23 cetane numbers are possible

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

Deep Conversion Refinery

Catalytic Cracking, Coking & Hydrocracking



Visbreaking

- Also vacuum residue feed
- Mild form of thermal cracking. Reduces viscosity of residue
- Produces small quantity of diesel.

Coking

- Vacuum residue feed
- Thermal cracking process. No catalyst involved.
- Use heat and moderate pressure to turn heavy residues to lighter products and coke (a hard coal-like substance used as an industrial fuel).

Blending

- Blending is the physical mixture of a number of refinery streams to a finished product.
- Options include:
  - **Batch blending via manifolds into a tank**
  - **In-line blending via injection of proportionate components into a main stream**
- Additives/Improvers such as octane enhancers, detergents etc. are added before or after blending

Gasoline Blending Component Qualities

	Light Naphtha	Isomerate	Reformate	FCC Gasoline	C4 Alkyalte	MTBE
Sulfur, PPM	200	0	0	1200	5	2
Research Octane	72	82	92 - 98	93	96	118
Benzene, vol%	1.2	0.2	5.5	.5	0	0
Aromatics, vol%	2	0.2	65	26	0	0
RVP, psi	12	14	5	7.4	7	8

Clean Gasoline Quality Changes
Moderate sulfur reduction

- **Run crudes with lower sulfur content**
  - Pricier. Not always possible
- **Distillation tailoring/undercutting**
  - Loss of gasoline volume
- **Dilute sulfur with alcohol blending**
  - Pricy. Availability issues

Clean Gasoline Quality Changes
Severe sulfur reduction

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

Gasoline Sulfur Reduction Example

Blend Stream	Vol Base	PPM S	Octane	Vol Low S	PPM S	Octane
Lt Naphtha	6	120	66	2	120	66
Reformate	21	0	93	21	0	94
FCC Gasoline	16	600	86.5	2	600	86.5
Trt FCC Gasoline				14	50	81
Isomerate				4	0	81
Other	5	10	93	5	10	93
Total	48	215	87.5	48	46	87.5

Distillate Blending Component Qualities

Quality	SR Diesel	HKR Diesel	Thermal Diesel	FCC LCO
Sulfur, wppm:	1,000 - 5,000	30 – 50	10,000,-20,000	1,000 -20,000
Gravity, API:	34	44	29	16
Aromatics, vol%	20	10	45	78
PNAs, wt%	10	2	25	53
Distillation, 95% F:	690	690	660	670

Diesel Sulfur Reduction Example

Base, Low Sulfur, Fractionate

Blend Stream	Vol Base	PPM S	Vol LS Crude	PPM S	Vol Frac.	PPM S
Kerosene	15	2000	15	500	15	2000
Distillate	15	5500	15	2000	13	5300
FCC LCO	3	17500	3	6000	1	13000
Trt Dist.						
Trt Dist. (Severe)						
Total	33	5000	33	1680	29	3860

Diesel Sulfur Reduction Example

HDS, Full HDS, Severe HDS

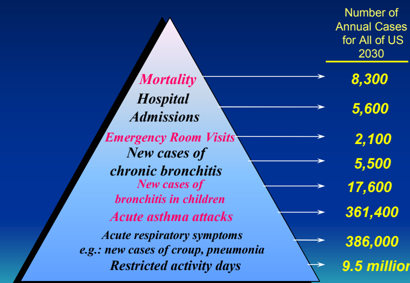
Blend Stream	Vol	PPM S	Vol	PPM S	Vol	PPM S
Kerosene	15	2000	0	2000	0	2000
Distillate	7	5500	0	5500	0	5500
FCC LCO	0	17500	0	17500	0	17500
Trt Dist.	11	870	32	500	0	500
Trt Dist. (Severe)					31	20
Total	33	2360	32	500	31	20

The Costs and Benefits of Shifting To Lower Sulfur Fuels International Experience

- US
- Canada
- European Union
- Asia Countries
- China

Estimates of benefits

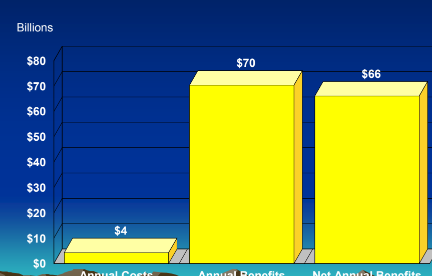
(Source: US EPA RIA, 2000)

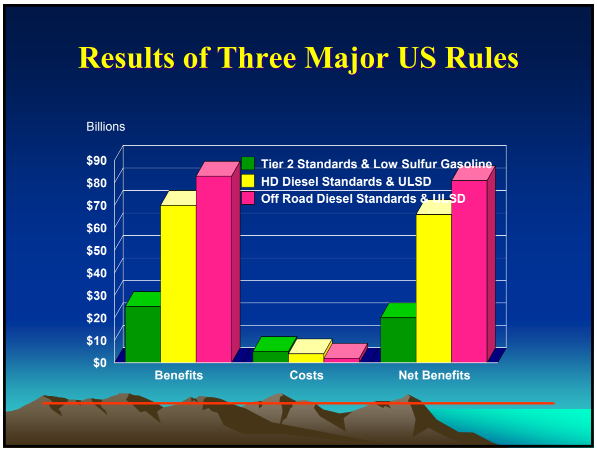


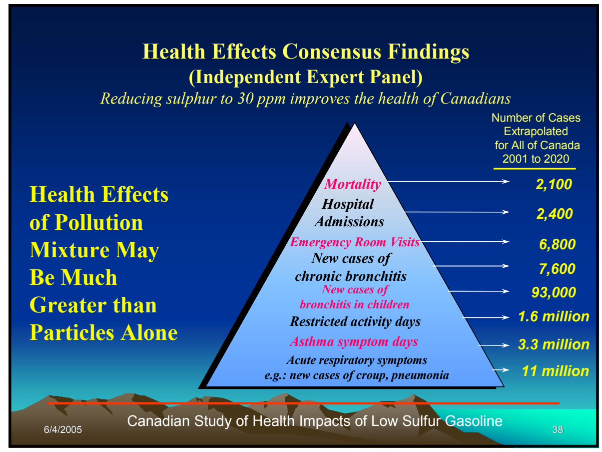
Assessing Health Benefits of US Diesel Fuel and Technology Rules

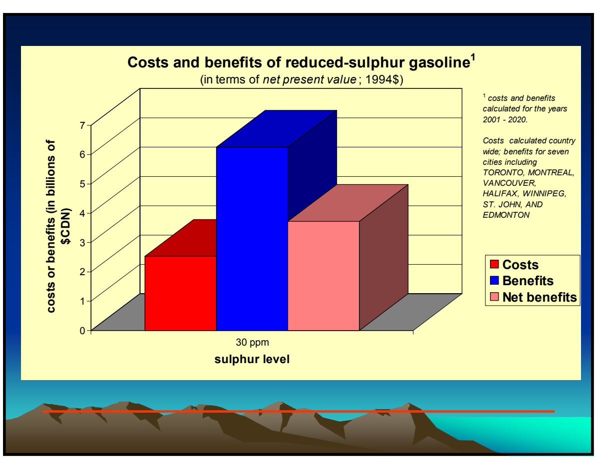
- New US EPA rules to reduce diesel fuel sulfur and engine emissions
  - Fuel sulfur from 500 ppm to 15 ppm in 2006
  - Reduced PM and NOx emissions in 2007, 2010
- EPA conducted extensive Regulatory Impact Analyses (2000)
- Accepted by US Office of Management and Budget

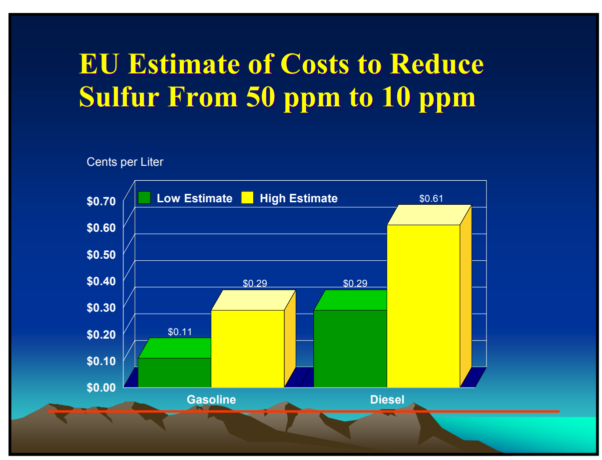
Costs and Benefits of Low Sulfur Diesel Fuel (<15 PPM) and Very Stringent Heavy Duty Engine Standards in the US




Results of Three Major US Rules
Billions
$90
$80
$70
$60
$50
$40
$30
$20
$10
$0
Tier 2 Standards & Low Sulfur Gasoline
HD Diesel Standards & ULSD
Off Road Diesel Standards & ULSD
Benefits
Costs
Net Benefits

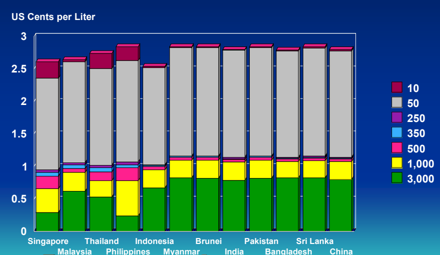

Health Effects Consensus Findings
(Independent Expert Panel)
Reducing sulphur to 30 ppm improves the health of Canadians
Number of Cases Extrapolated for All of Canada 2001 to 2020
Health Effects of Pollution Mixture May Be Much Greater than Particles Alone
Mortality
2,100
Hospital Admissions
2,400
Emergency Room Visits
6,800
New cases of chronic bronchitis
7,600
New cases of bronchitis in children
93,000
Restricted activity days
1.6 million
Asthma symptom days
3.3 million
Acute respiratory symptoms e.g.: new cases of croup, pneumonia
11 million
6/4/2005
Canadian Study of Health Impacts of Low Sulfur Gasoline
38


Costs and benefits of reduced-sulphur gasoline[1]
(in terms of net present value; 1994$)
costs or benefits (in billions of $CDN)
7
6
5
4
3
2
1
0
30 ppm
sulphur level
[1] costs and benefits calculated for the years 2001 - 2020.
Costs calculated country wide; benefits for seven cities including TORONTO, MONTREAL, VANCOUVER, HALIFAX, WINNIPEG, ST. JOHN, AND EDMONTON
Costs
Benefits
Net benefits


EU Estimate of Costs to Reduce Sulfur From 50 ppm to 10 ppm
Cents per Liter
$0.70
$0.60
$0.50
$0.40
$0.30
$0.20
$0.10
$0.00
Low Estimate
High Estimate
$0.11
$0.29
$0.29
$0.61
Gasoline
Diesel

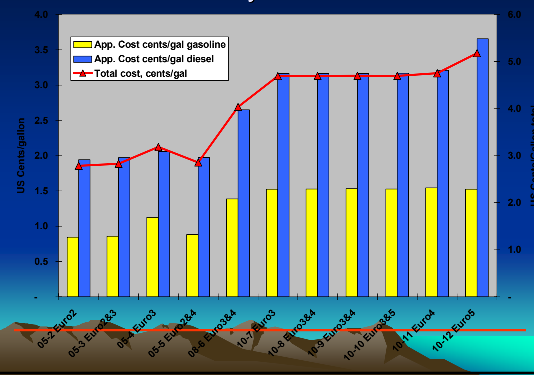
Cost of Reducing Sulfur in Diesel Fuel in Asia

(High Sulfur Crude)



Source: Enstrat International

Gasoline and Diesel Reformulation Costs in China by Scenario



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

Conclusions

- Low Sulfur Fuel Reduces Emissions
- Refinery Processes For Reducing Sulfur From Both Gasoline and Diesel Are Well Known and Improving
- Costs Are Quite Reasonable
- Benefits Far Outweigh The Costs