

Why China Needs Low Sulfur Fuels

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Overview

- Why Low Sulfur Fuels
- Worldwide Trends and Tendencies
- International Experience Regarding The Benefits and Costs of Reducing Sulfur
- Comments on ExxonMobil Presentation



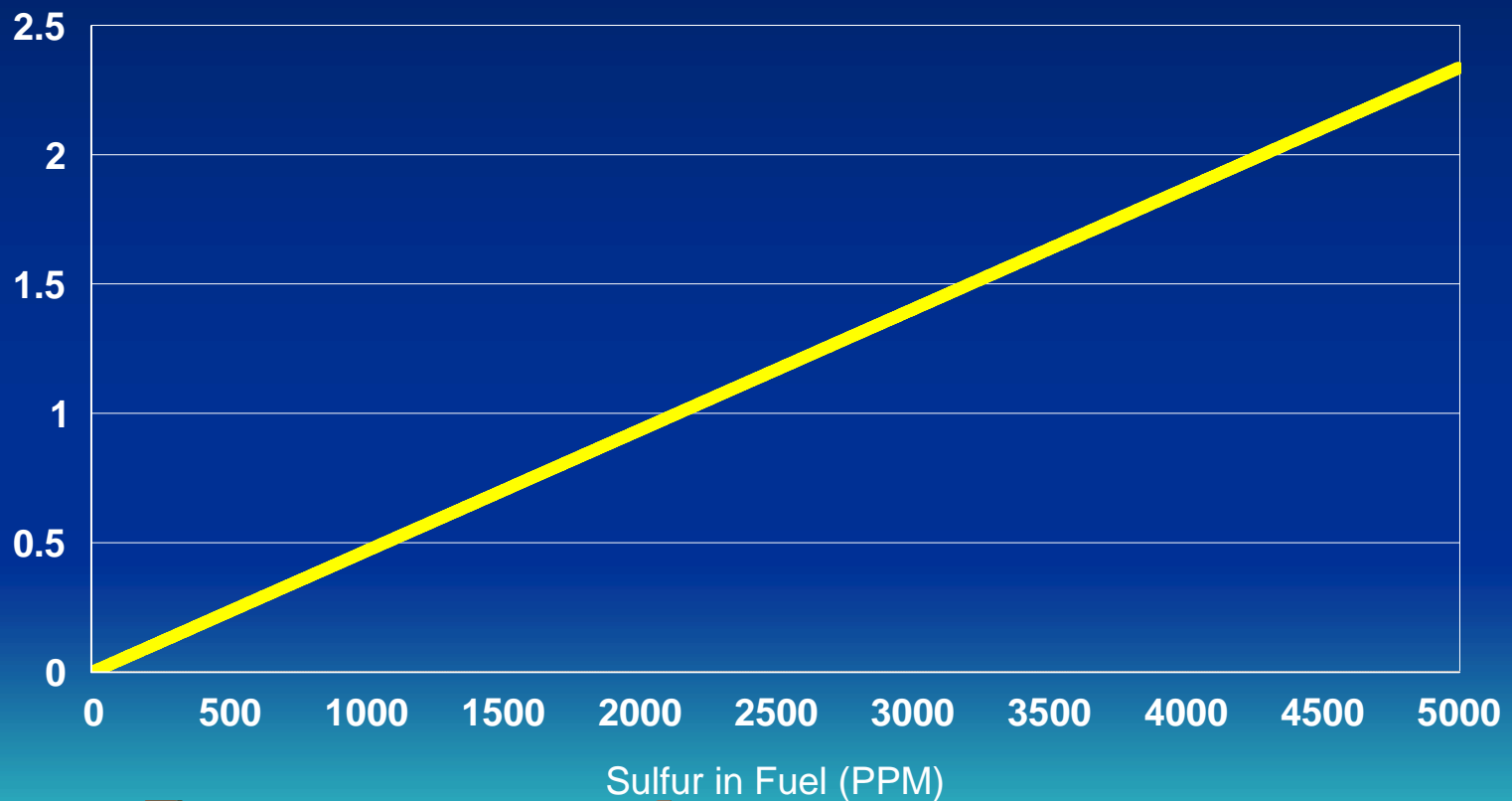
Why Low Sulfur Fuel?

- 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



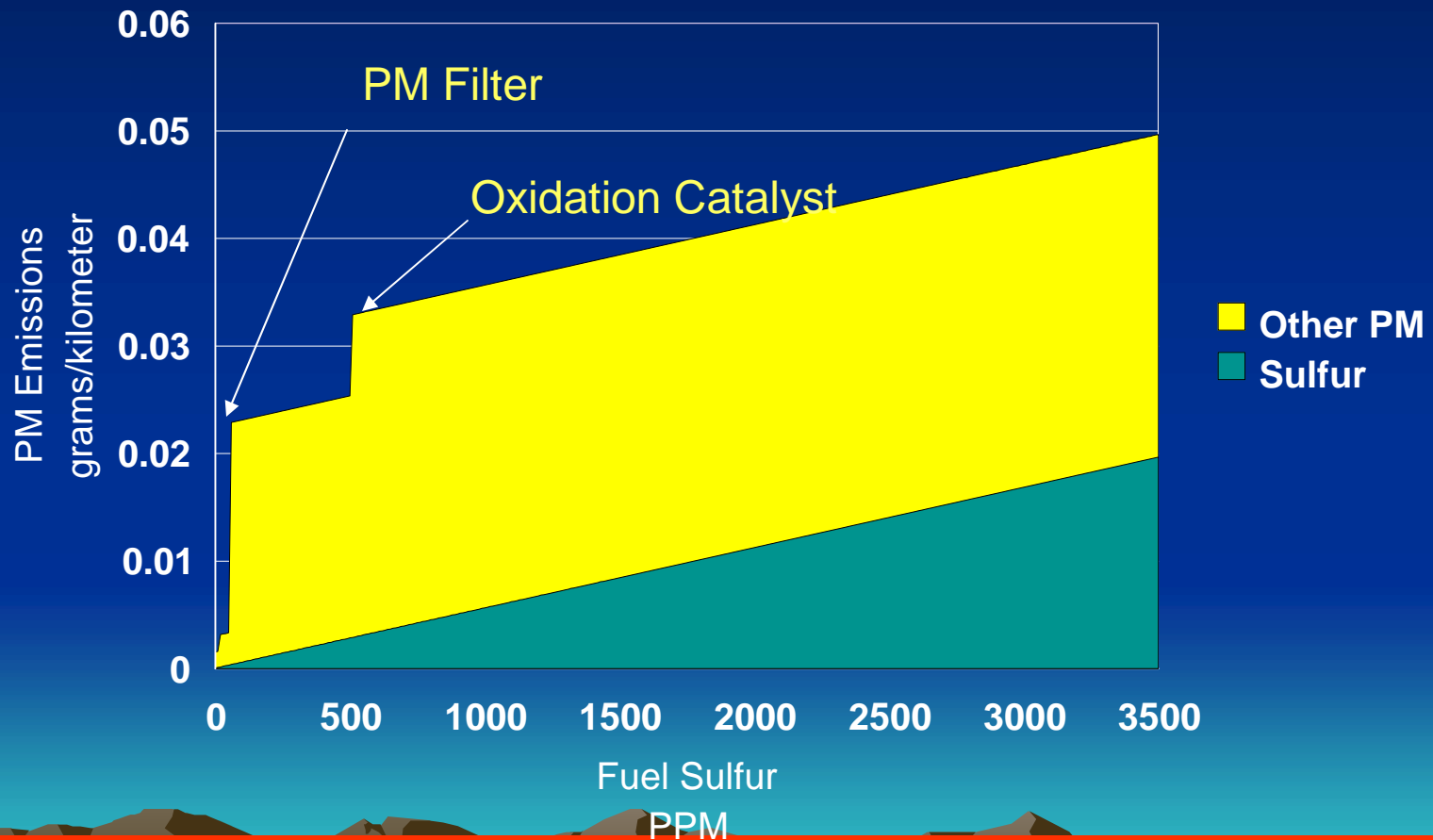
Tons of Directly Emitted PM From Diesel Fuels Sulfur

Tons Per Million Gallons

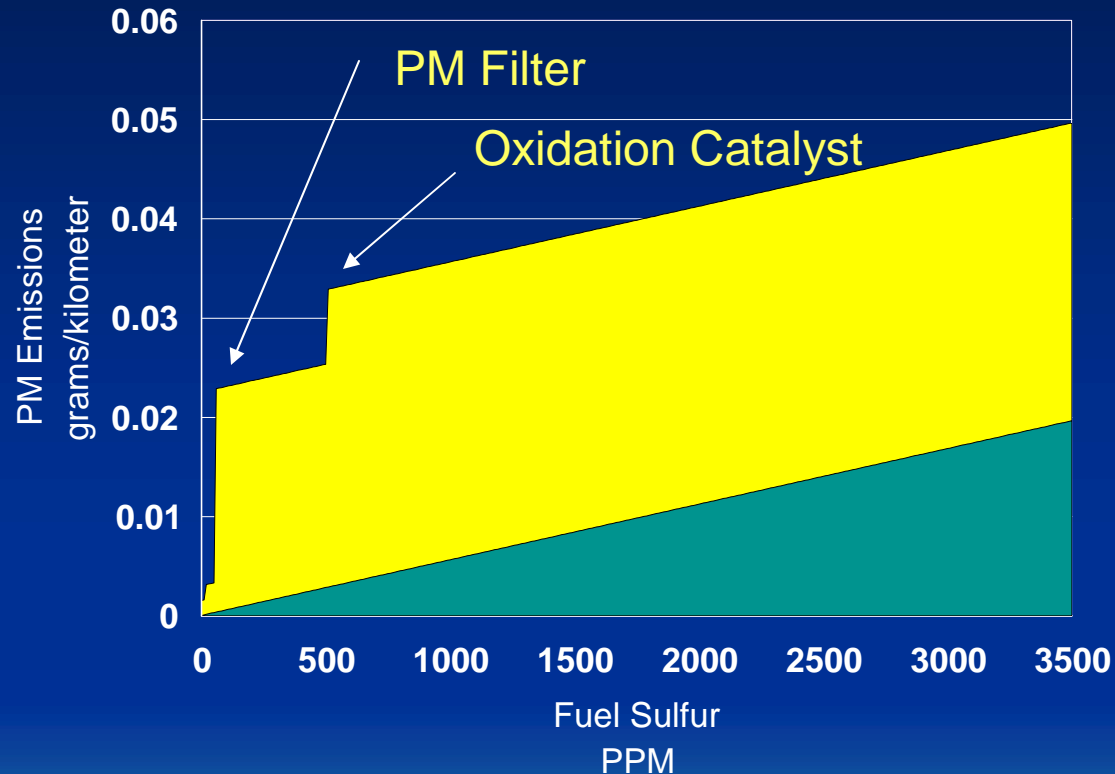


Derived From US EPA Data

Linkage Between Fuel Sulfur and PM Emissions



Linkage Between Fuel Sulfur and PM Emissions



■ Other PM
■ Sulfur

500 PPM Sulfur
Ox Cat Retrofit Viable

50 PPM Sulfur
Reasonable PM Filter Feasible
~85% PM Reduction

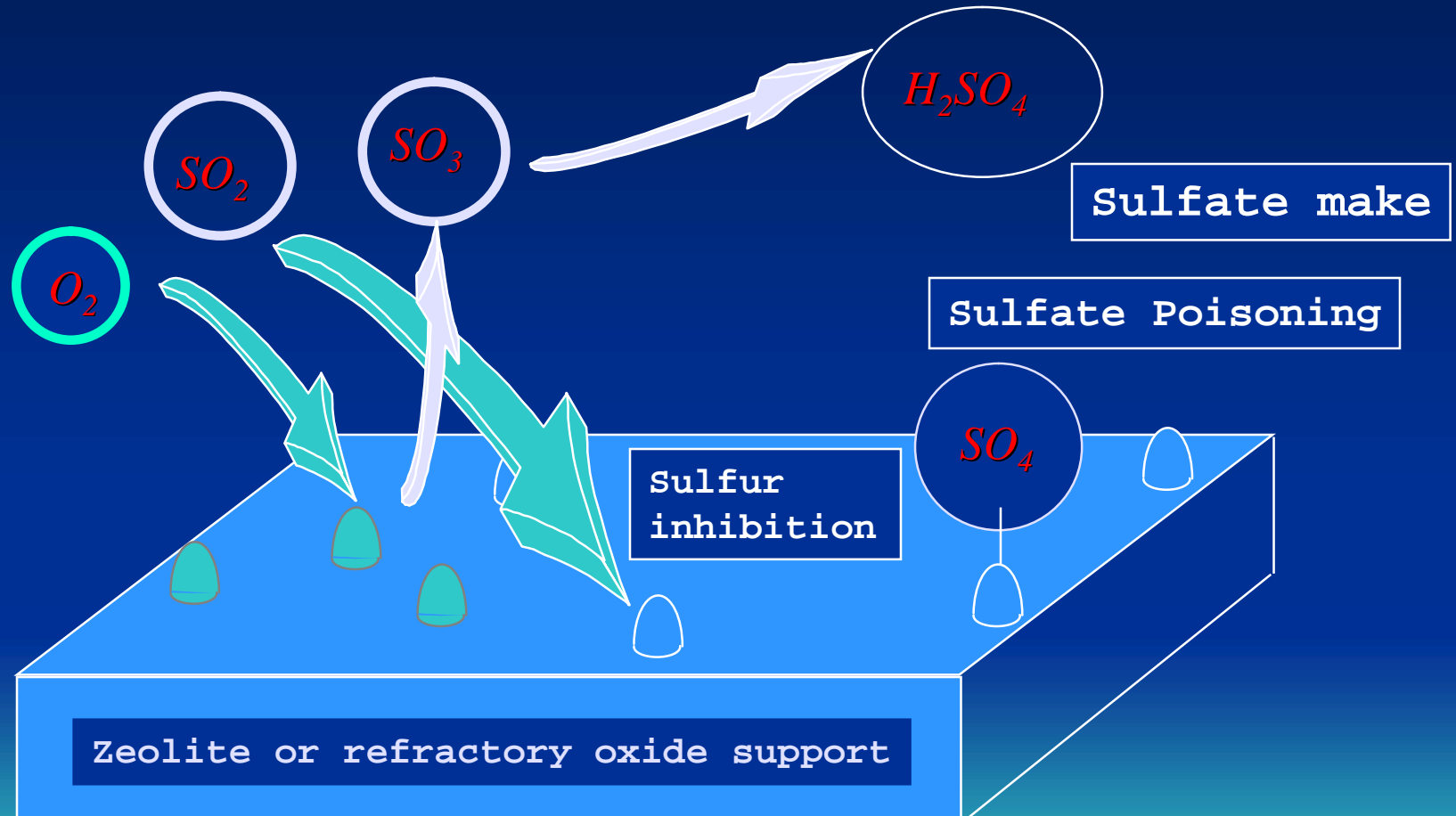
10/15 PPM Sulfur
Strong PM Filter Feasible
~95-99% PM Reduction

Fuel Sulfur Negatively Affects All Catalyst-Based Emission Control Technology

- Impacts of Sulfur
 - SO_2 Sticks to Catalyst Sites (Chemisorption)
 - Inhibits Gaseous Catalytic Reactions
 - Catalytic Oxidation of SO_2 to SO_3
 - SO_3 Adds to Tailpipe PM Emissions – Up to 40 to 50% of SO_2 Can Be Oxidized to SO_3
 - SO_3 Reacts with Catalyst Base Metal Oxides to Form Metal Sulfate which reduces catalytic activity
 - For Catalyst-Based Diesel Particulate Filters, Sulfur Adversely Effects the Regeneration of the Filter
 - For NO_x Adsorbers, Sulfate Clogs Up and Shuts Down the NO_x Storage Mechanism



Sulfur Effects



Summary of Influence of Fuel Sulfur on Diesel Exhaust Emission Control Devices

- **Control Technology**

- Oxidation Catalyst
- Lean NO_x Catalyst
- SCR with Urea
- Catalytic Filters

- NO_x Adsorbers

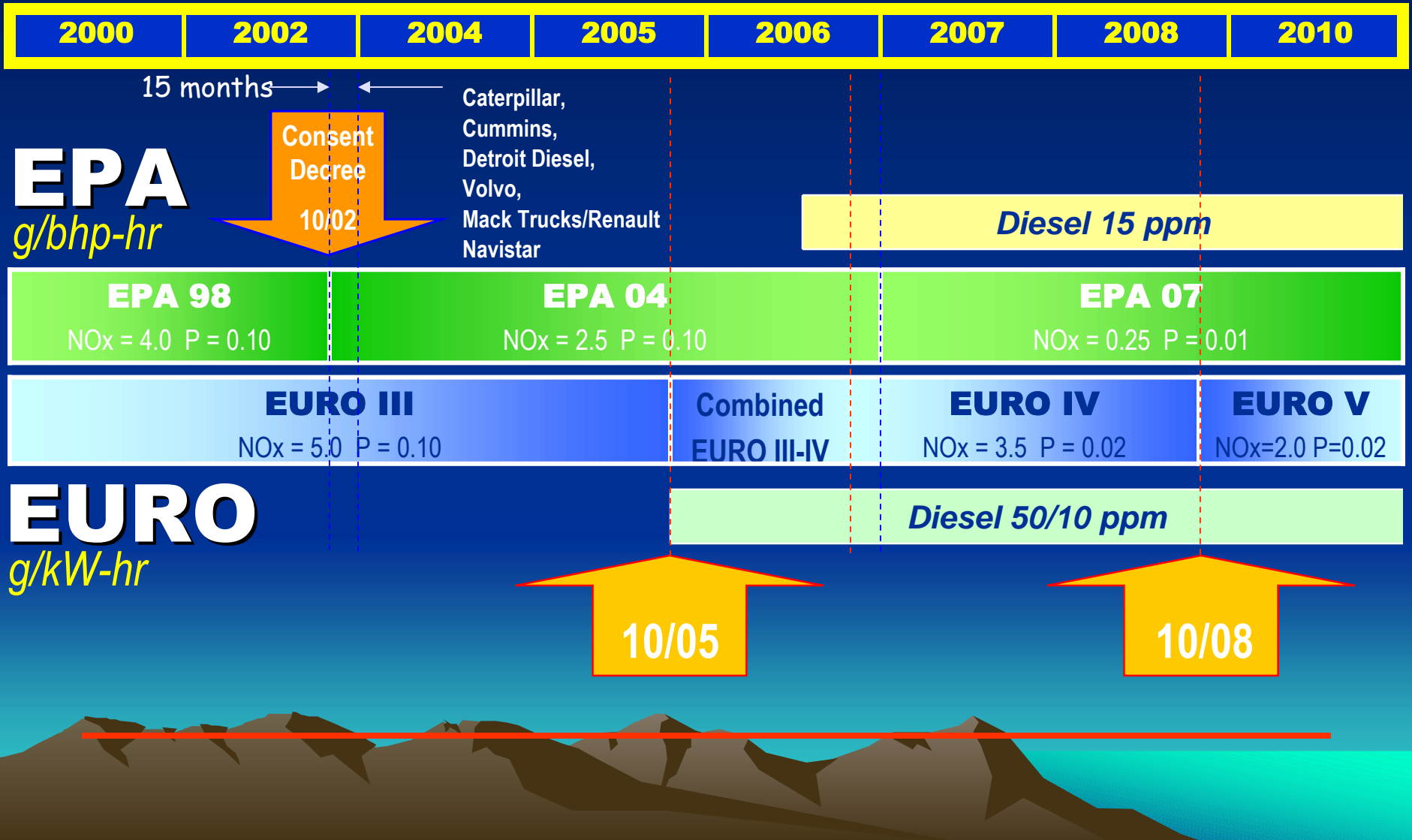
- **Sulfur Effects**

- Inhibition, form SO₃ PM
- Inhibition, form SO₃ PM
- Inhibition, form SO₃ PM
- Inhibition, form SO₃ and Affects Regeneration
- Clogging, form SO₃ and store as sulfate – requires periodic removal

All Catalyst Technologies

Adversely Affected

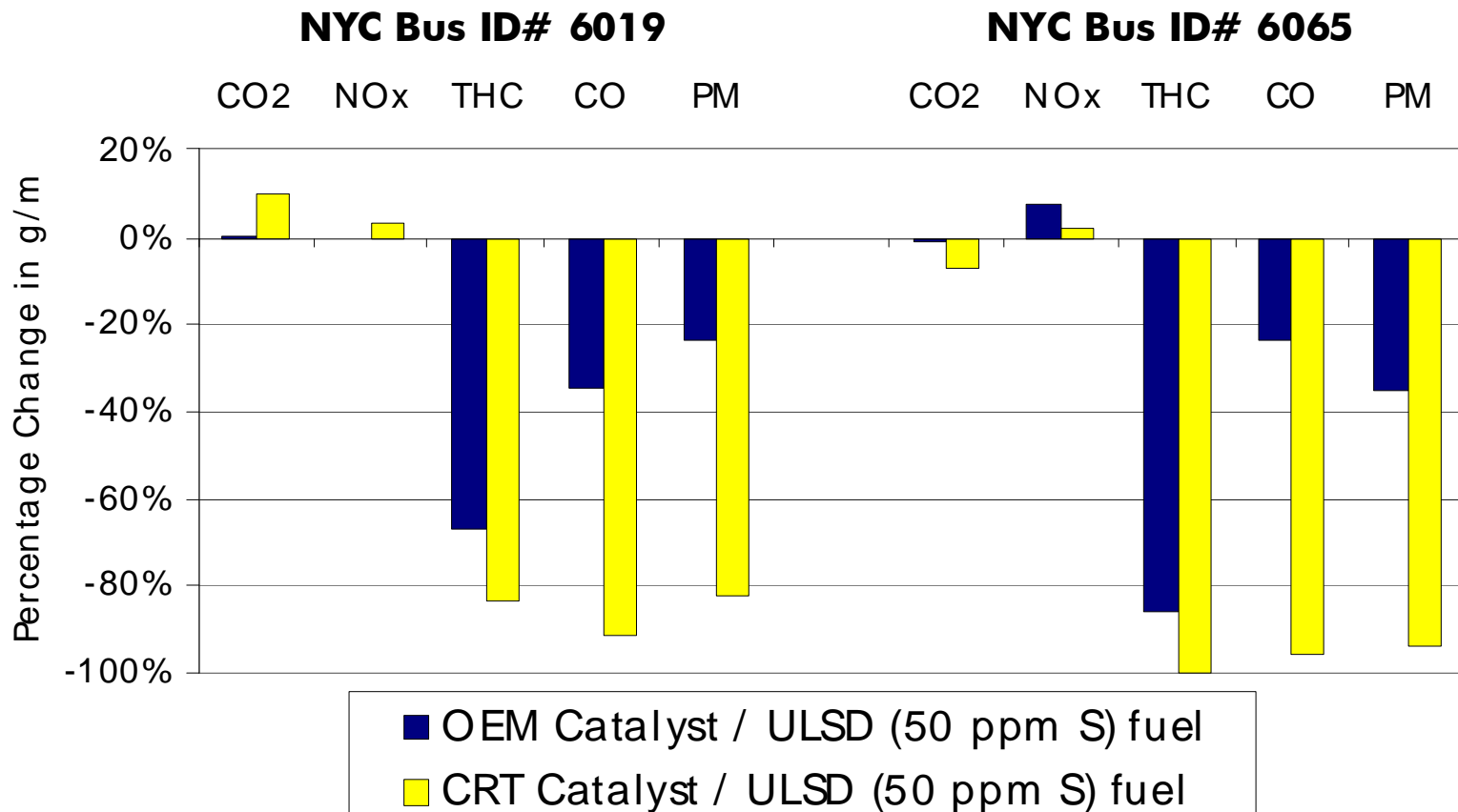
Close Linkage Between Vehicle Emissions Standards and Fuel Sulfur Levels



CONCAWE Study On Advanced Diesels

- “Fuel effects on PM and NOx emissions were also observed. However, ... DPFs were used ... the impact of changing fuel properties OTHER THAN SULFUR became negligible.”
- “In the heavy duty engines, the 300 ppm sulfur fuels were not considered relevant to test in the Euro 4 or Euro 5 engines.”
- In the [light duty] Euro 3 engine, lower sulfur content reduced PM emissions.

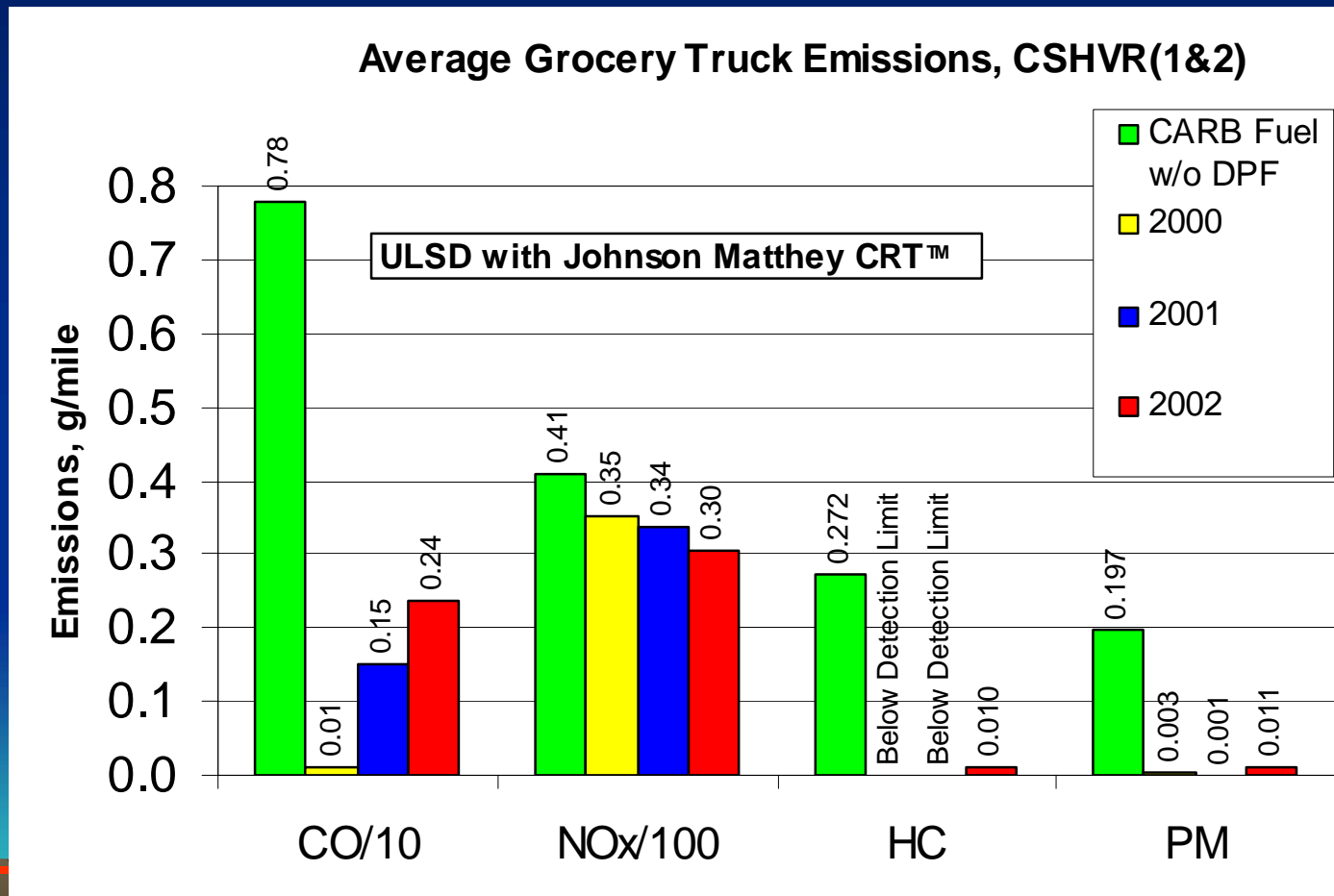
New York City Retrofit Experience



Durability & Reliability



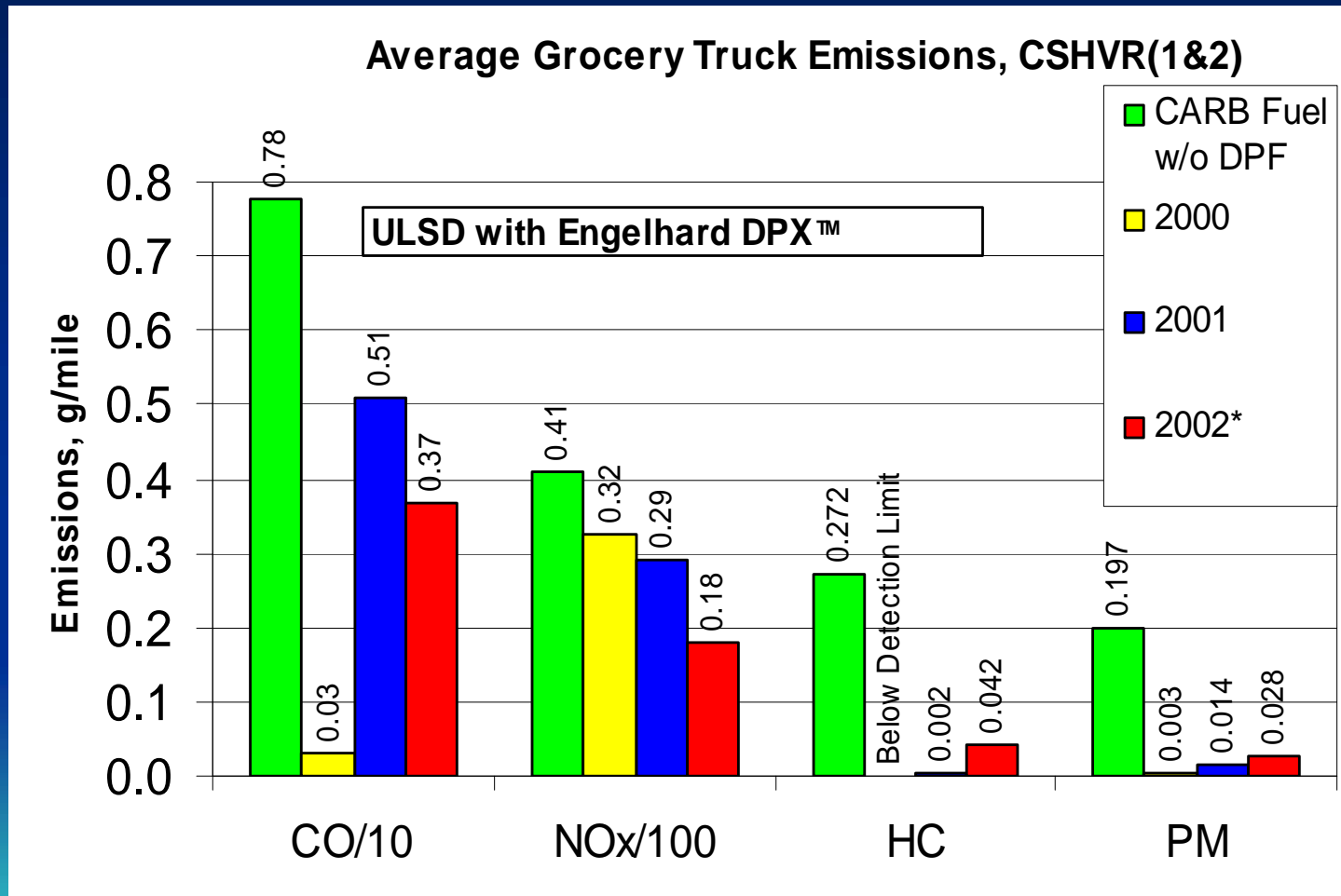
Ralphs Grocery Trucks



Durability & Reliability



Ralphs Grocery Trucks

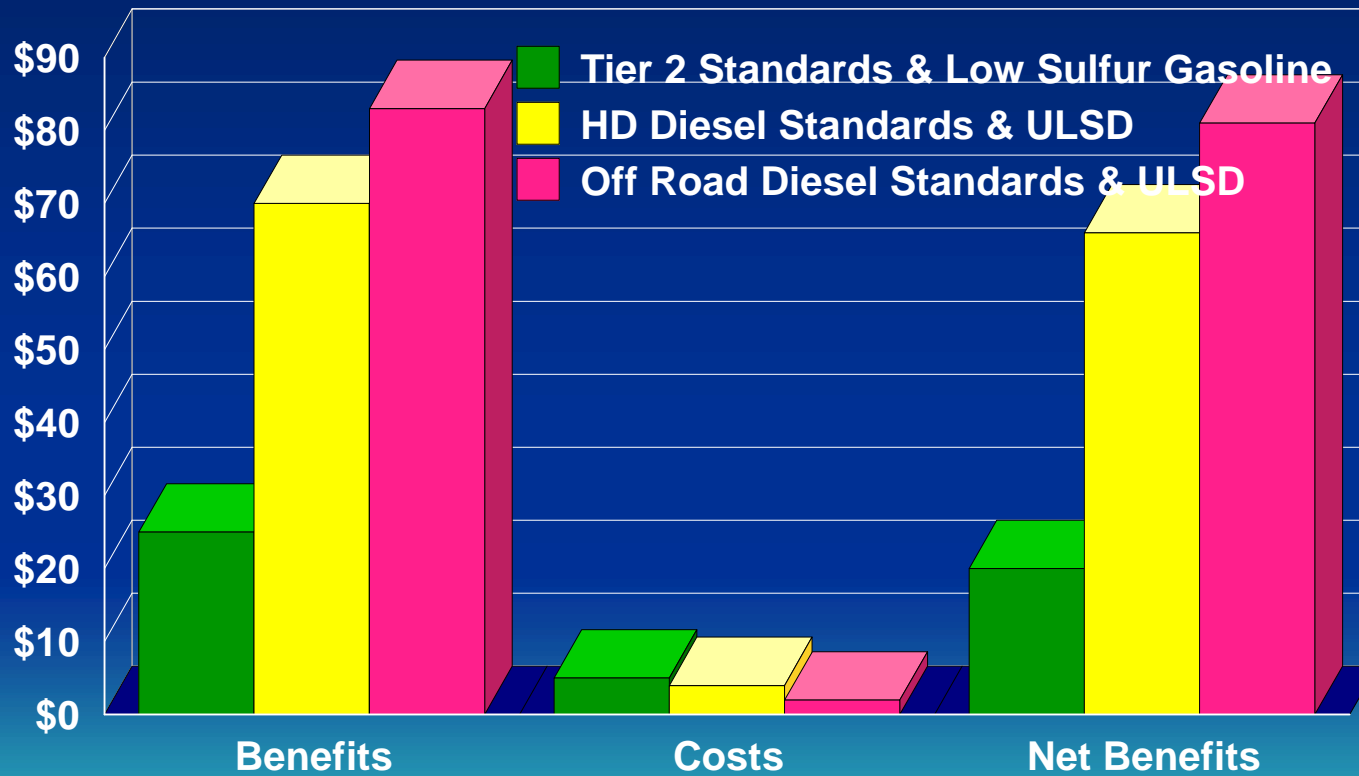


The Costs and Benefits of Shifting To Lower Sulfur Fuels International Experience



Results of Three Major US Rules

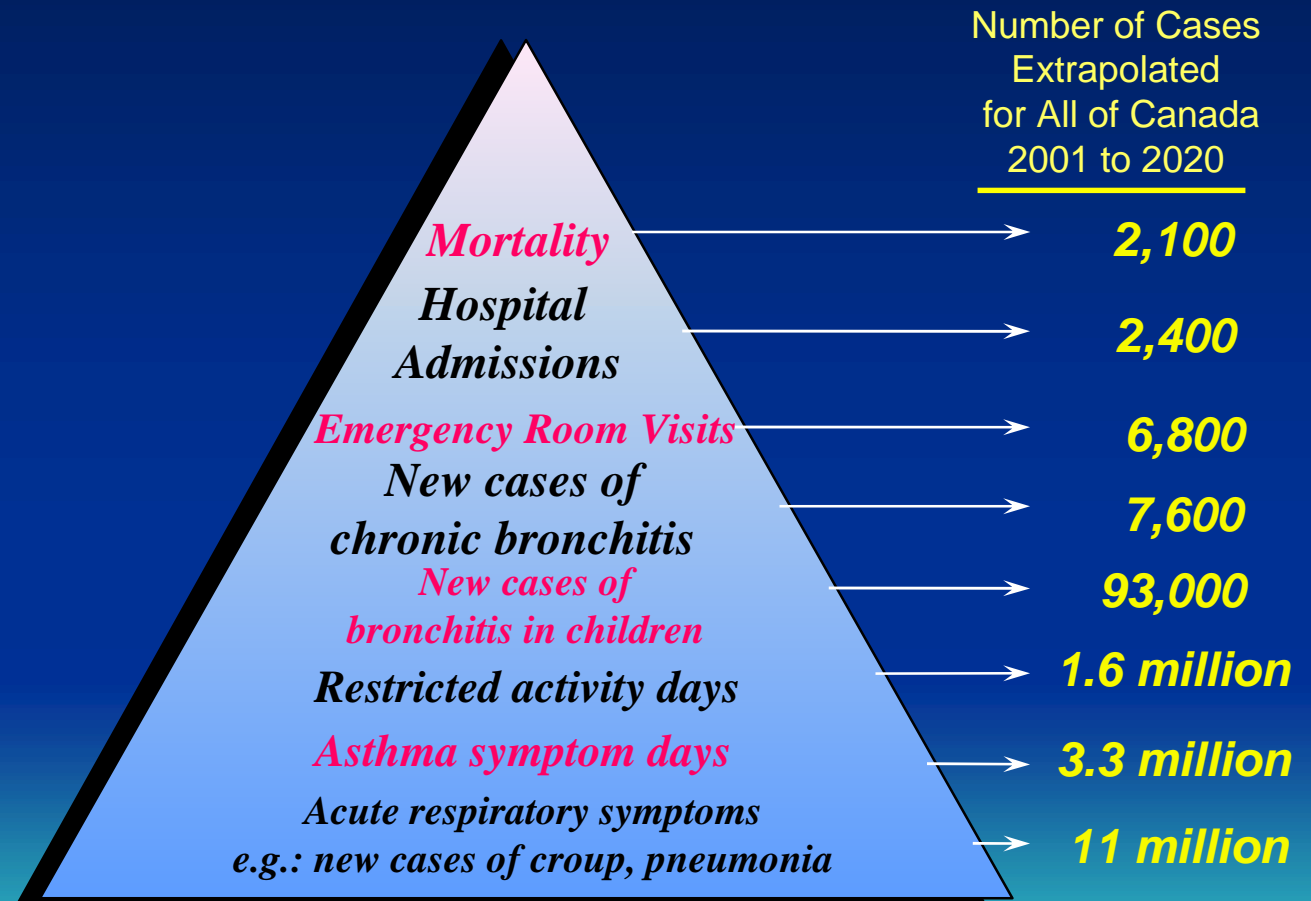
Billions



Canada Health Effects Consensus Findings (Independent Expert Panel)

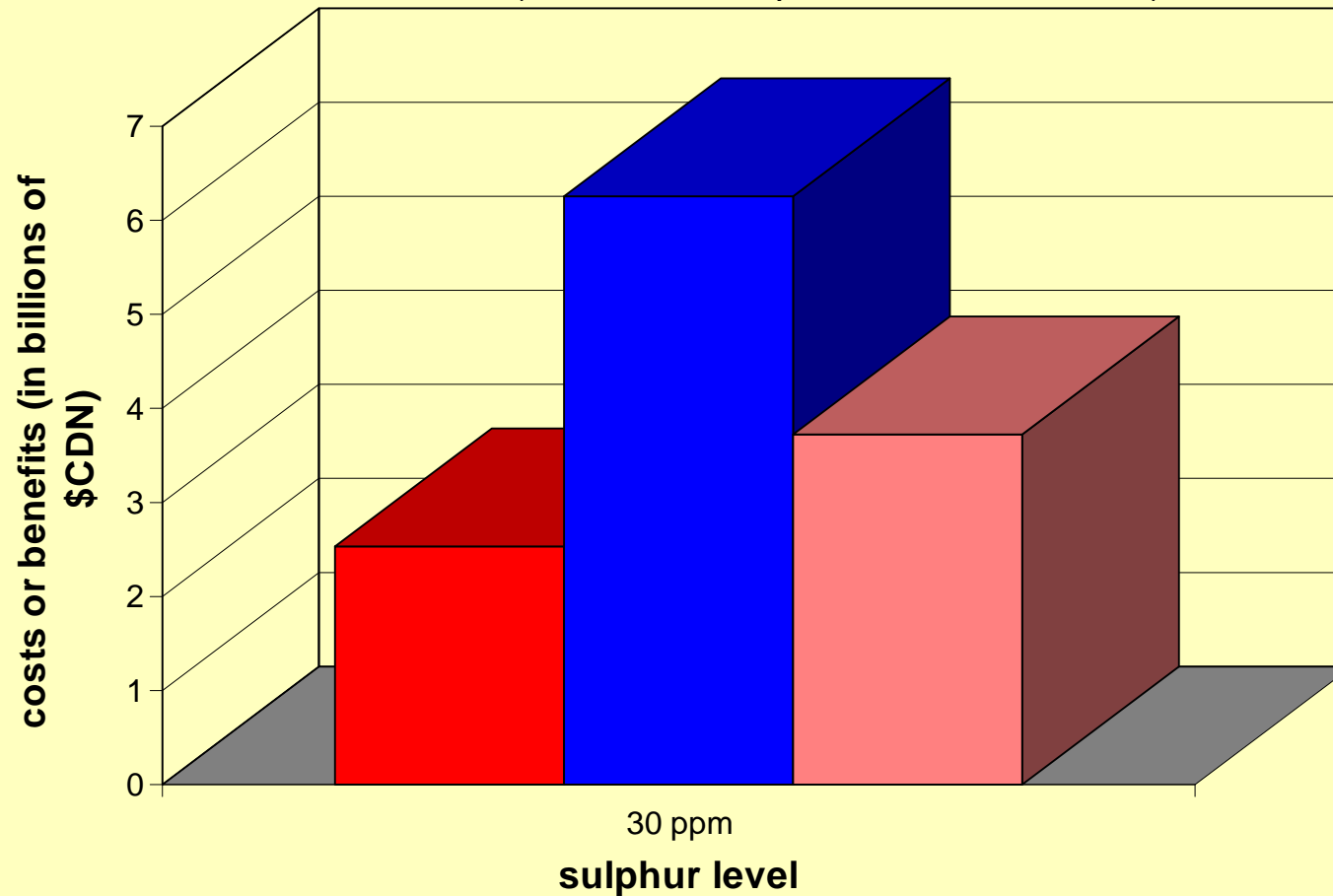
Reducing sulphur to 30 ppm improves the health of Canadians

**Health Effects
of Pollution
Mixture May
Be Much
Greater than
Particles Alone**



Costs and benefits of reduced-sulphur gasoline¹

(in terms of *net present value* ; 1994\$)



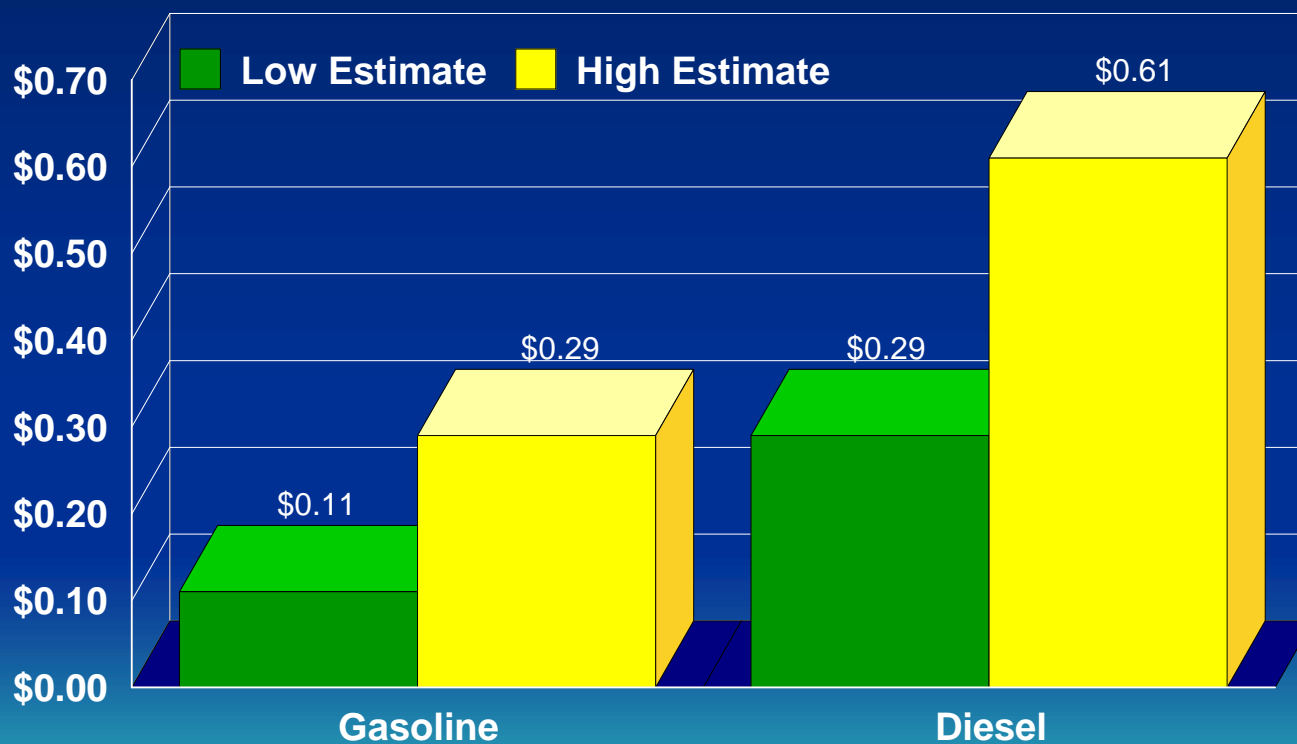
¹ costs and benefits calculated for the years 2001 - 2020.

Costs calculated country wide; benefits for seven cities including TORONTO, MONTREAL, VANCOUVER, HALIFAX, WINNIPEG, ST. JOHN, AND EDMONTON

- Costs
- Benefits
- Net benefits

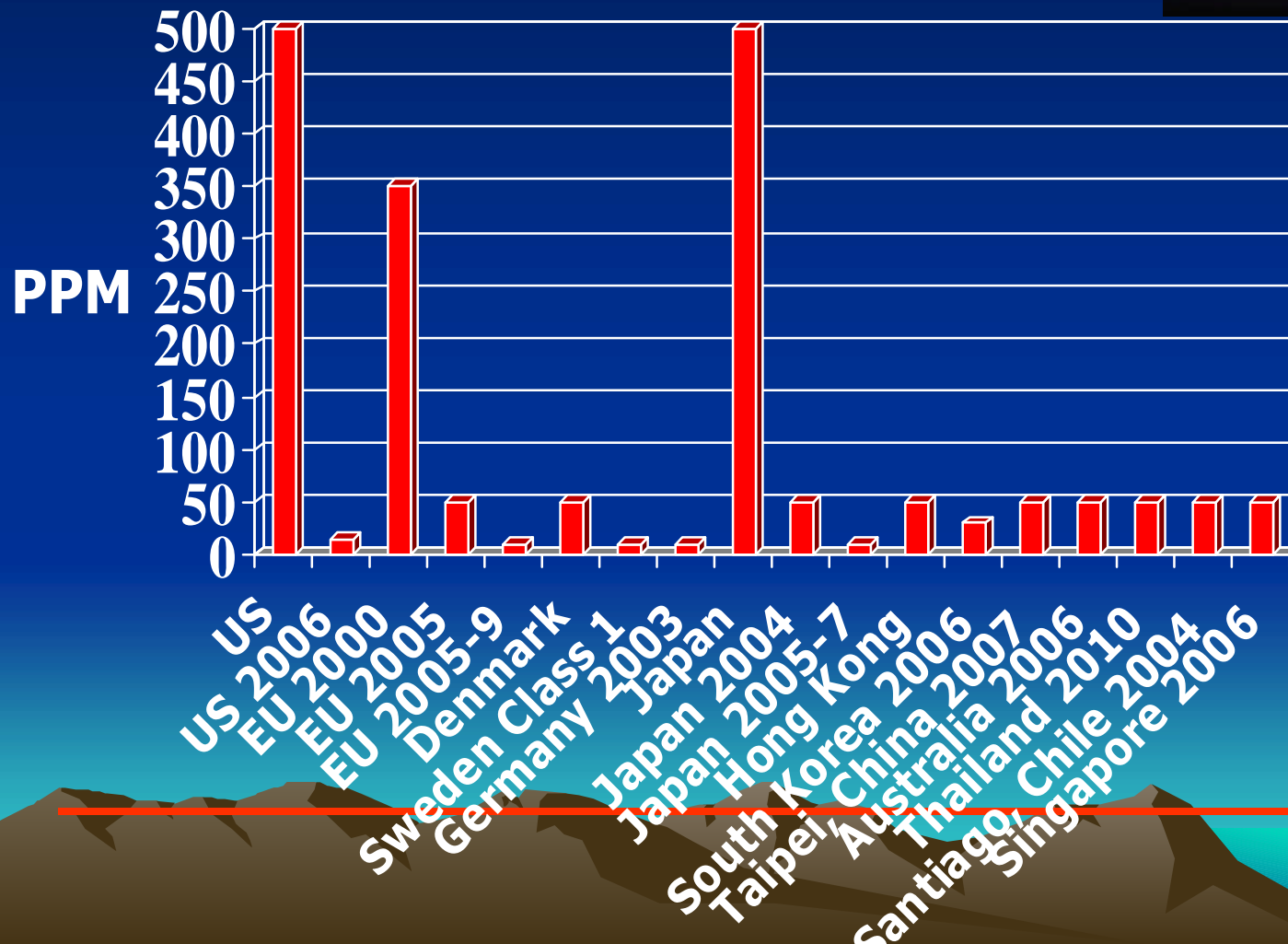
EU Estimate of Costs to Reduce Sulfur From 50 ppm to 10 ppm

Cents per Liter

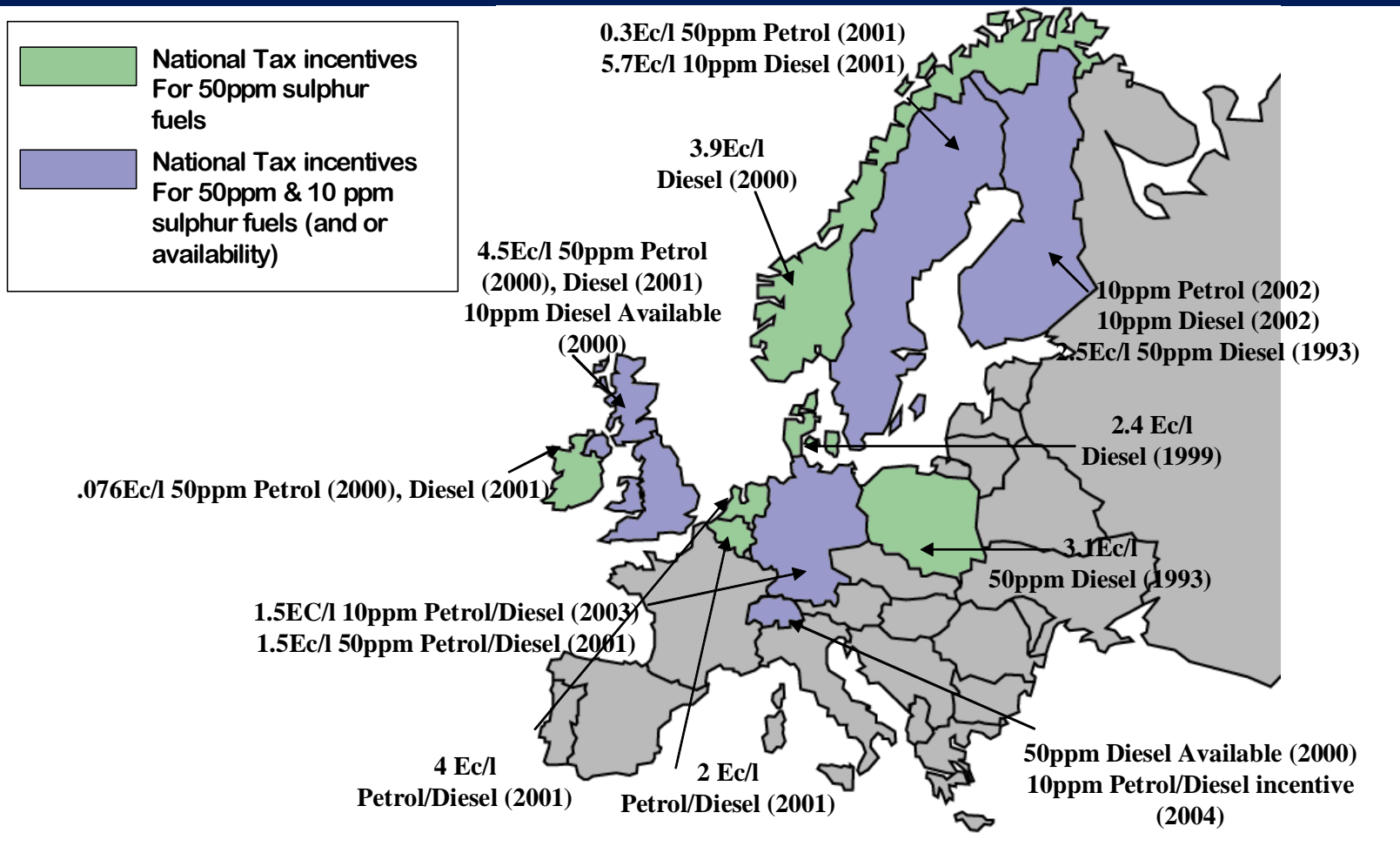


Benefits Exceeded Costs By Factor of 2 to 3 Times

Ultra Low Sulfur Diesel Fuel Is Spreading



European Tax Incentives Schemes To Encourage Low Sulfur Fuels



Conclusion

- 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



*Fuel Sulfur Content:
The Lower, the Better*

Conclusion (continued)

- 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



Comments on
ExxonMobil
Presentation On
Fuels Developments
and Specifications



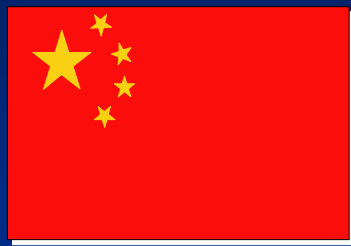
Analyze Vehicles and Fuels as a Single System



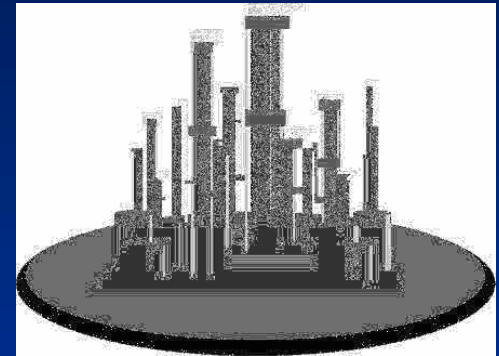
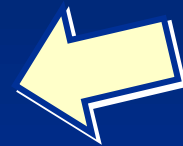
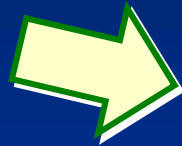
Vehicle technology can bring large emission reductions.
Fuels must be suitable for the vehicles to perform well.

I Agree!

All Parties Can Contribute to an Effective Regulatory Development Process



Government



Fuel Suppliers

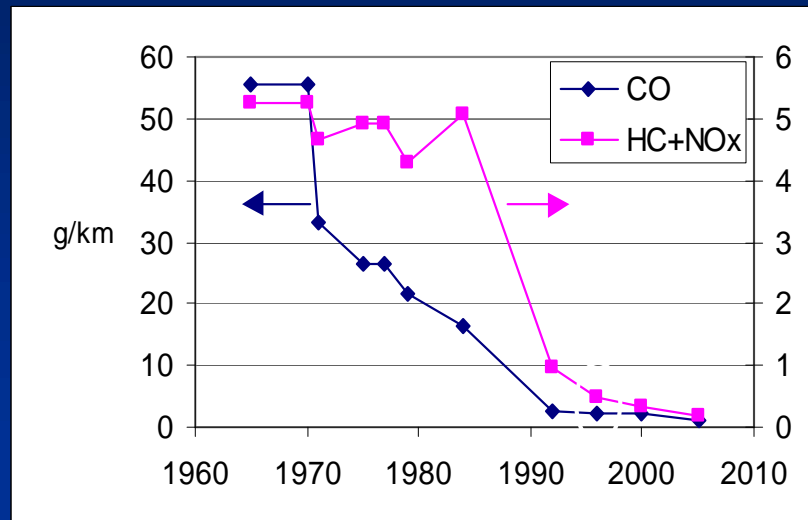


Vehicle Producers

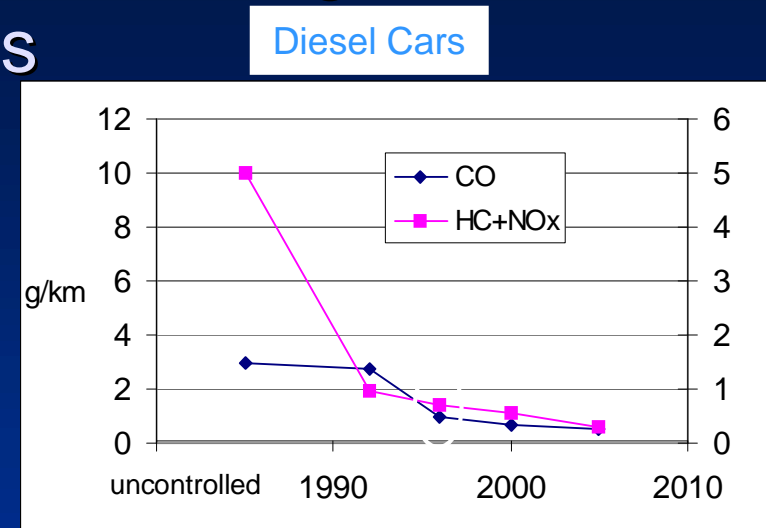
I Agree!

Vehicle Emission Standards Give Significant Reductions

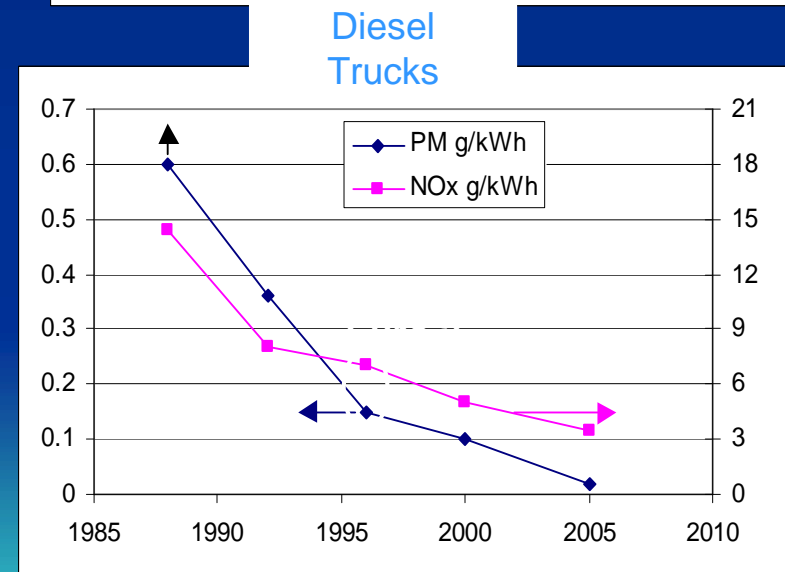
- European experience:



Gasoline Cars



Diesel Cars



Diesel Trucks

I Agree!

Diesel Cars and Trucks

China's Future Fuel Specifications

- Fuels must be appropriate for the vehicle technology
- Utilize Experiences From Other Regions But Incorporate Local Situation

Chinese Situation

Fuel sulfur levels higher than regional average. China processing more imported crudes with higher sulfur content

Considerations

1. Continue to look at all sources, including power plants, to identify the most cost-effective emission reduction steps
2. Reduce fuel sulfur levels consistent with vehicle equipment, air quality goals and cost-effectiveness of other available steps
3. THIS IS WHAT YOU ARE DOING!

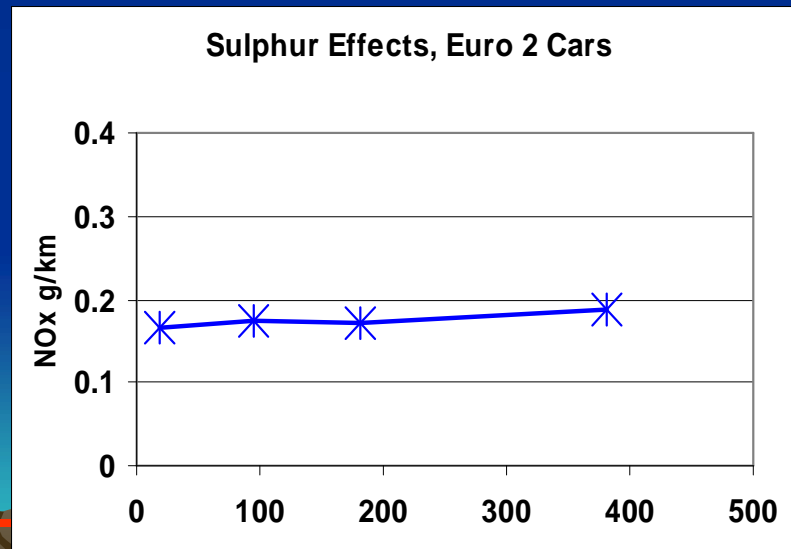
GASOLINE: DEFINING THE FUEL SPECIFICATIONS



Lead and Sulphur are Most Important Fuel Parameters **I AGREE!**

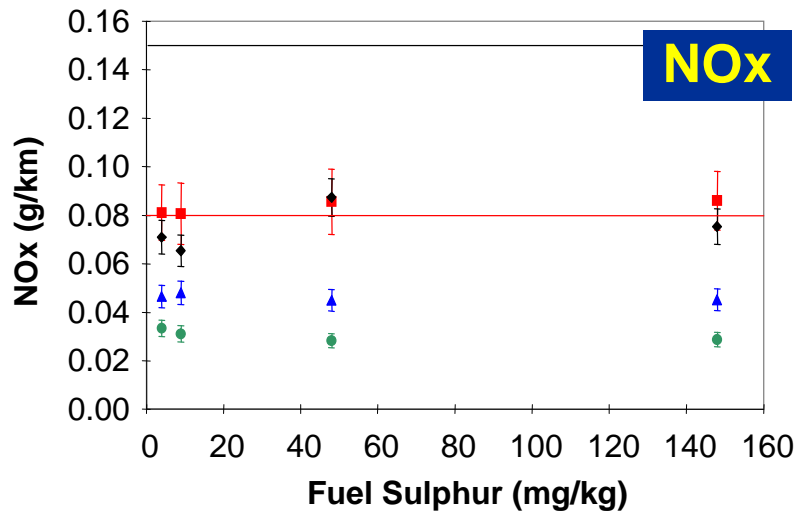
- Exhaust catalysts are much more sensitive to the fuel than the engine itself (**I AGREE!**)
- Most important fuel change is lead-free gasoline
 - Allows use of Three-Way Catalyst (**I AGREE!**)
- Fuel Sulphur affects catalyst performance
 - But very low levels not needed for Euro 2/3 emission limits

European
Auto-Oil
data,
gasoline cars

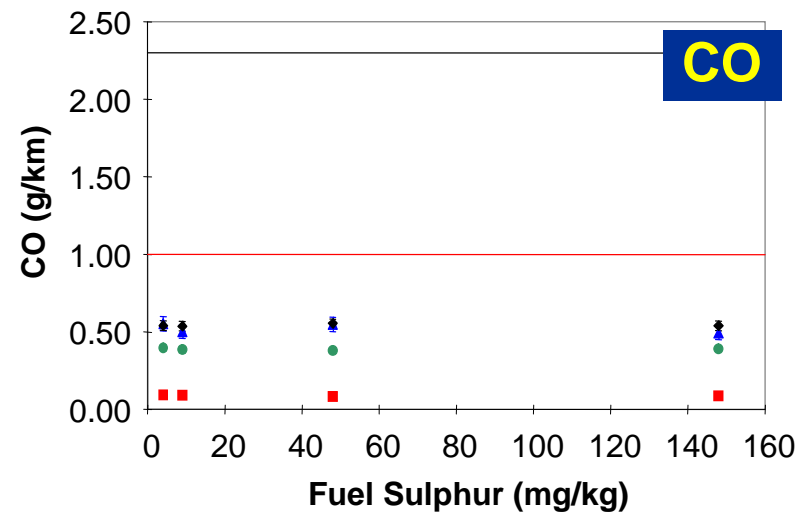
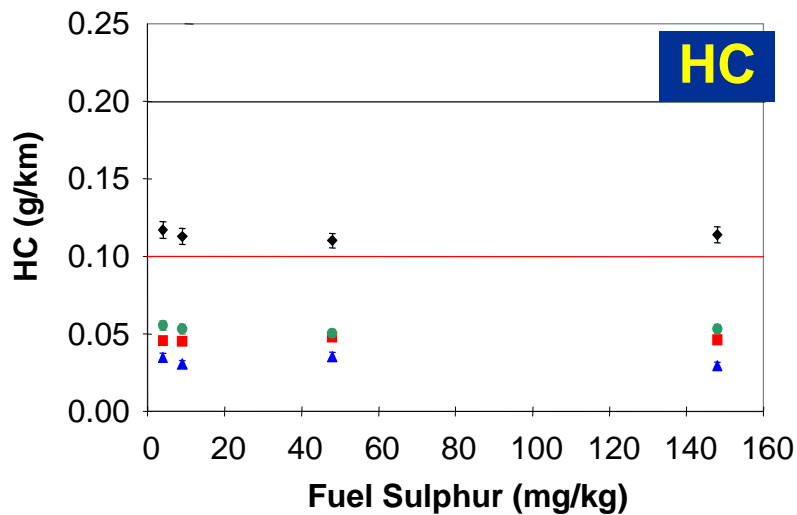
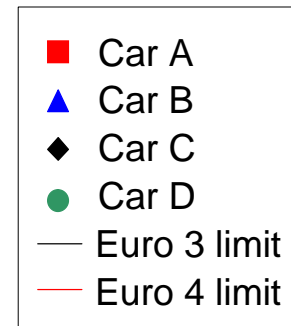


**Bangkok Real World
Experience Indicates
Euro 2 & Euro 3 Cars
Are Cleaner with Low Sulphu
Gasoline**

Sulphur Effects Small for Modern Vehicles

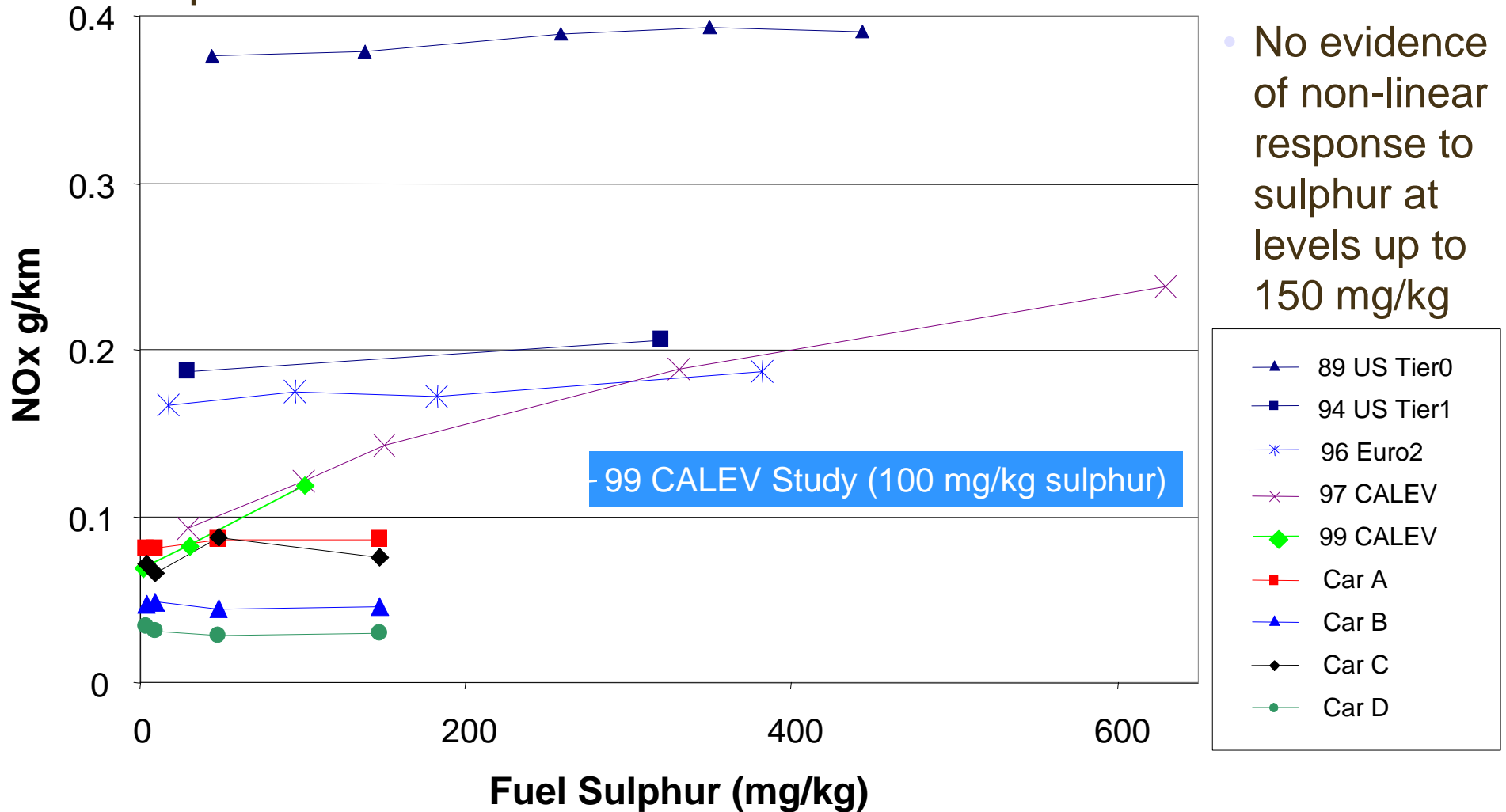


- No significant effect of sulphur on four advanced European gasoline cars



Sulphur Effects – US Study Comparison

- Strong sulphur effects seen in early Calif LEVs not repeated in other studies



Concawe Test Programme

- Fuels effects studied in more detail by CONCAWE
- Tested four modern European gasoline vehicles on European driving cycle
 - Car A – Euro 3 2.0 litre Stoich. DI TWC
 - Car B – Euro 4 1.8 litre VVA – MPI TWC
 - Car C – Euro 3 2.0 litre Lean DI TWC + NOx trap
 - Car D – Euro 4 1.6 litre Lean DI TWC + NOx trap



Methodology

- Test Design
 - Fuels tested in blocks – 1 test per fuel per block
 - Different randomised test orders for each block in each vehicle
 - Phase 1 (sulphur) minimum 4 tests / fuel
 - Extra tests if variability thresholds exceeded
- Additional Conditioning – Vehicle Specific
 - Phase 1: Sulphur purge within conditioning for each test
 - Phase 2: Sulphur purge for NOx trap vehicles before each block

OF COURSE YOU WOULD NOT EXPECT TO SEE ANY SULFUR EFFECT:

- Sulfur was purged before every test
- The durability of the catalyst exposed to the different sulfur levels was not monitored

Sulfur Purging Procedure

- Three Way Catalysts
 1. 90 km/hr for 5 minutes
 2. 50 km/hr for 1 minute
 3. Wide Open Throttle Acceleration for at least 5 seconds to at least 115 km/hr; hold speed for 15 seconds; decelerate to 50 km/hr
 4. Maintain 50 km/hr for 1 minute
 5. Repeat steps 3 & 4 for 4 additional cycles
- NOx Storage Catalysts
 1. Followed manufacturer guidelines



Limit Value of Gasoline-powered Vehicles (2009) (Draft)

		PM	NOx、NMHC、CO	Achivement periods
Passenger car		0.005	N.C.	2009
t r u c k s	Light-weight (GVW1.7t or less)	0.005		
	Middle-weight (GVW over 1.7t ~ 3.5t or less)	0.007		
	Heavy-weight (GVW over 3.5t)	0.01		

※1 Unit : Heavy-weight :g/kWh

Except Heavy-weight :g/km

※2 GVW : Gross weight Vehicle

NMHC: Non-methane hydrocarbons

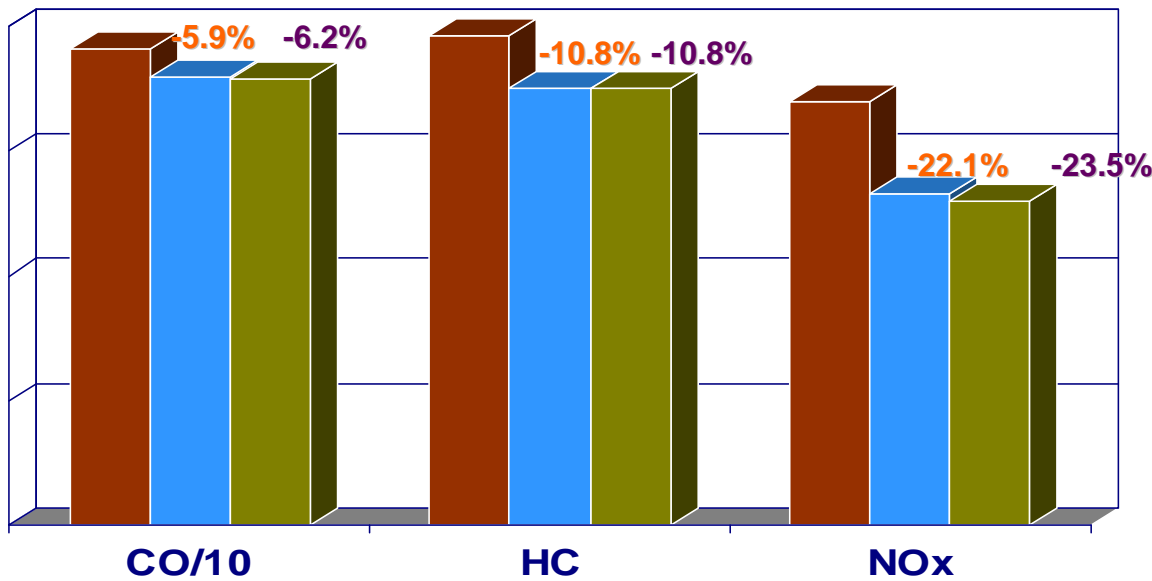
note) Target values of particulate matter are applied only to lean-burn, direct-injection vehicles mounted with storing-type NOx reduction catalyst.

Sulfur in Gasoline

- **Highly efficient catalysts are much more sensitive to sulfur** (if a catalyst is 99% efficient, a 1% decrease in efficiency will double emission)
- **Advanced technologies such as lean NOx traps and NOx reduction catalysts require < 5 ppm sulfur to operate**

Real World Experience From Bangkok- Dr. Supat Wangwongwatana

Impact of Sulfur On Exhaust Emissions from Gasoline Vehicles



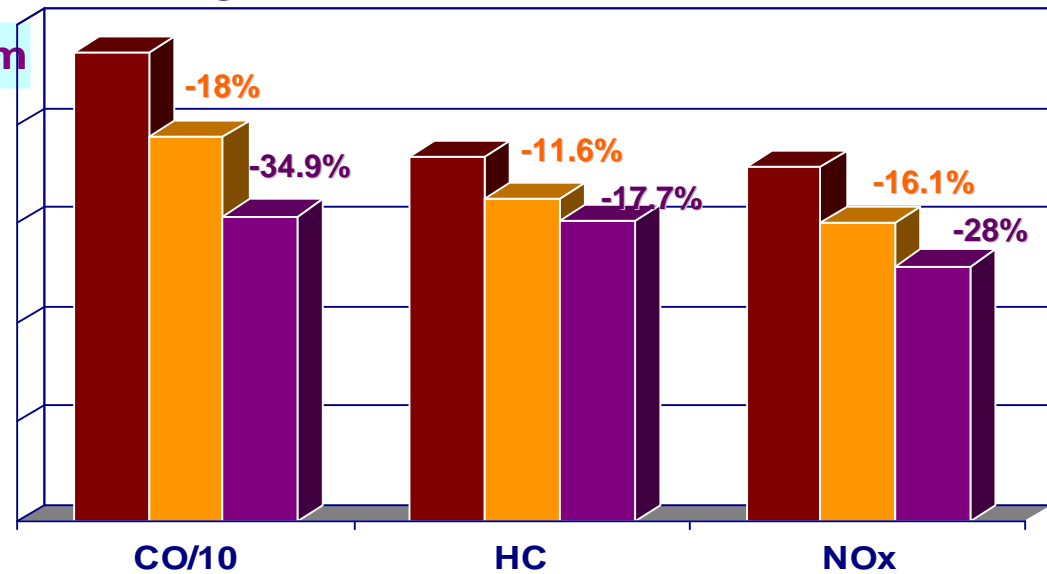
← **EURO 2**

■ 800 ppm ■ 500 ppm ■ 150 ppm

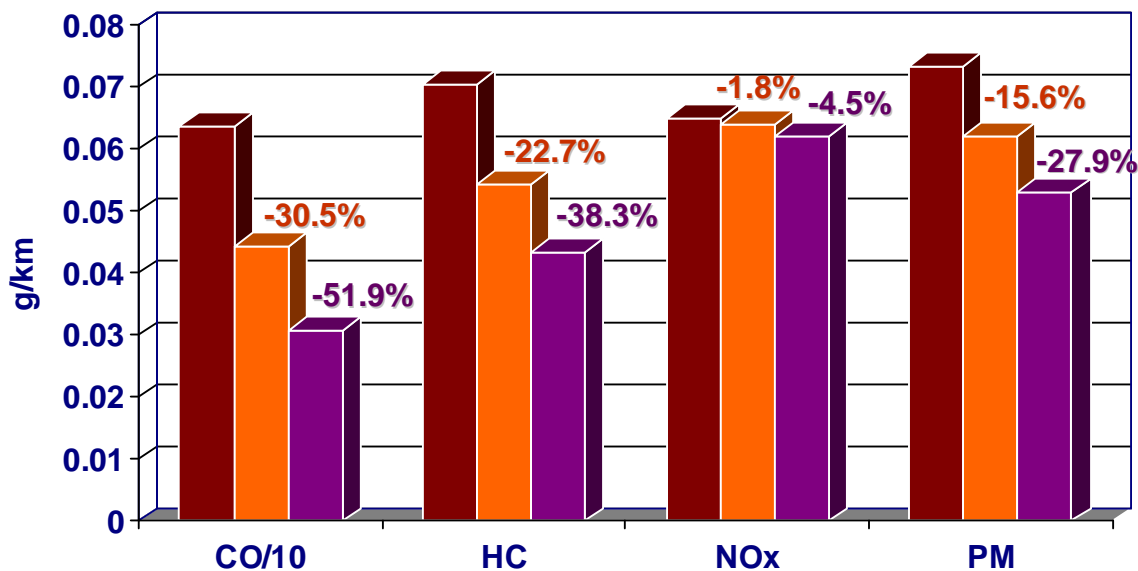
EURO 3



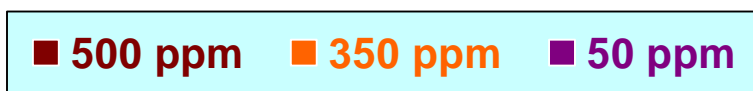
Real World Experience From Bangkok
- Dr. Supat Wangwongwatana



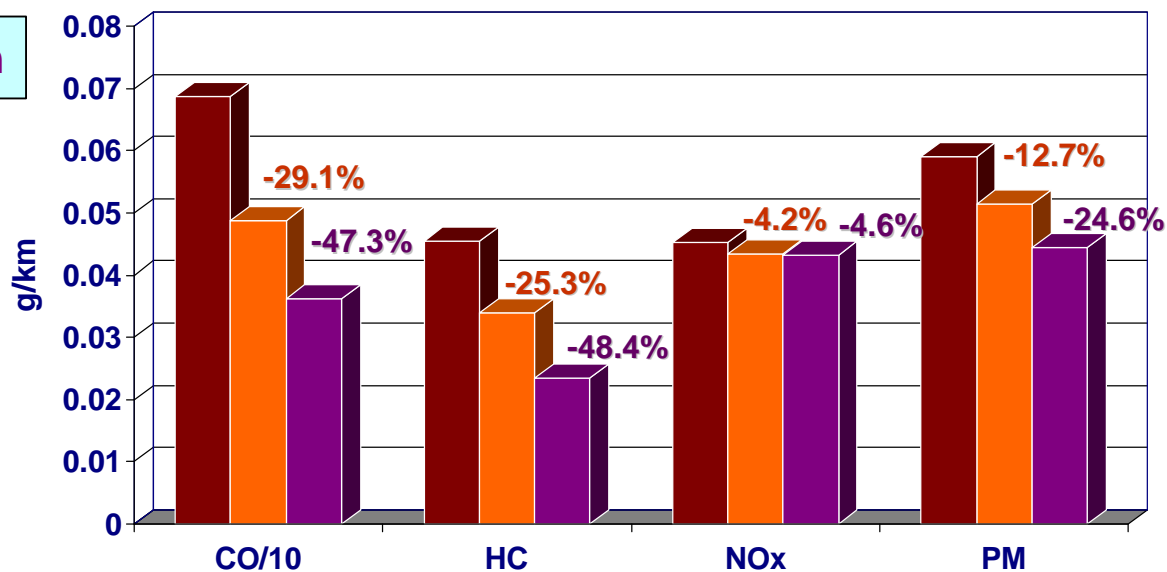
Impact of Sulfur On Diesel Vehicles



← **EURO 2**



EURO 3 →



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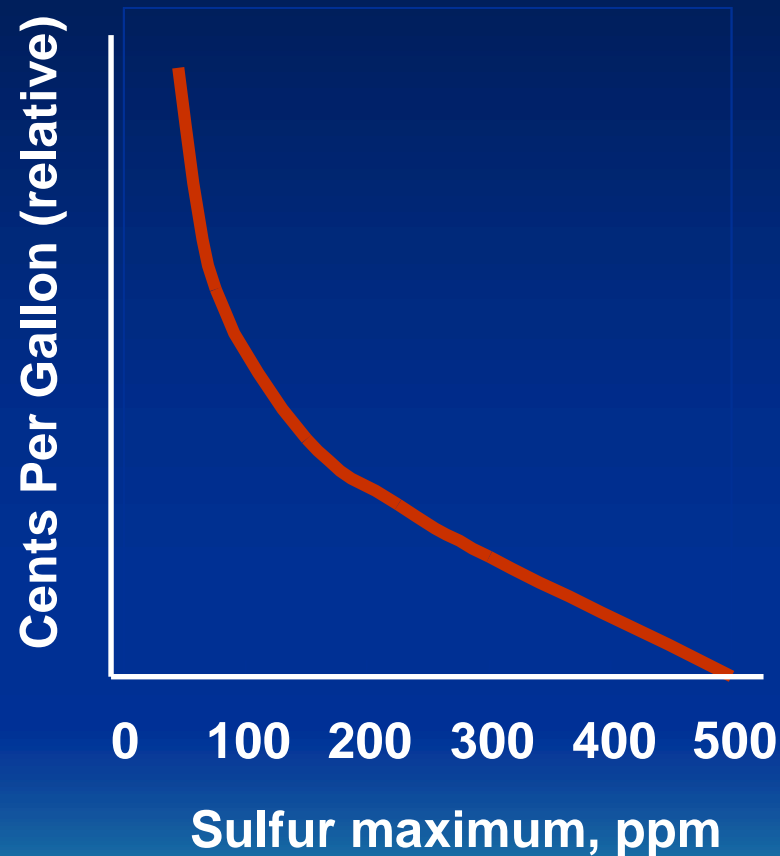
Napa Statement

International Council on Clean Transportation

4-6 May 2003, Napa, CA, USA

- “Sulfur” is the “Lead” of the new century
- Reducing fuel sulfur content in gasoline and diesel is crucial to any serious effort to reduce air pollution from existing and new vehicles.
- Reducing sulfur in all transportation fuels (including non-road machines) provides immediate air quality and public health benefits. Benefits include reduced PM emissions from all vehicles as well as reduced acidification. For vehicles equipped with any type of catalyst technology, sulfur reductions also reduce emissions of CO, HC, NO_x, and secondary PM.
- Near-zero sulfur fuels (10 ppm or less) are required for advanced vehicle technologies.

Conceptual Cost Analysis

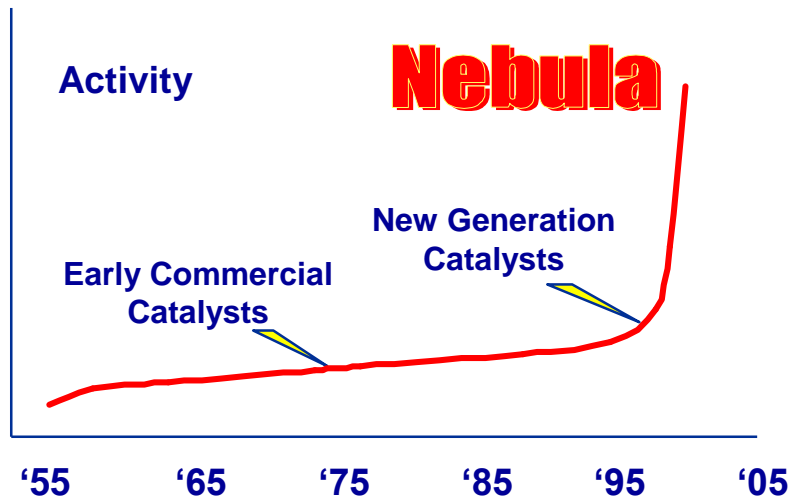


- As gasoline sulphur is reduced
 - Costs rise rapidly
 - Benefits decrease
- As technology improves
 - Costs decrease, but shape of curve stays the same
- Euro 2/3 gasoline vehicles need sulphur in range 150-500ppm
- Further reductions increase cost without benefit

Costs Rise As Levels Go Down
But The Benefits Far Outweigh
Costs

Technology Solutions - New Catalyst Development

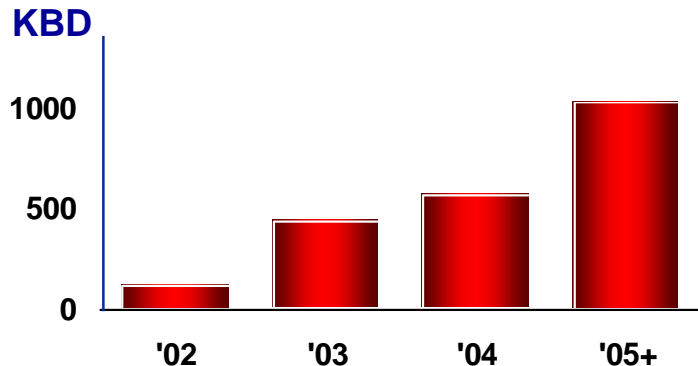
Nebula-20™ for Diesel



- Increasing ultra-low sulfur diesel producibility
 - Proprietary catalyst technology
 - Activity level tripled
 - Rapid development / deployment

SCANfining™ for Gasoline

Cumulative On-Line Capacity



And Refinery Catalysts Are Improving!

- Meeting gasoline sulfur specifications with minimal octane loss
 - Proprietary catalyst technology
 - Clear octane advantage
 - Lower operating cost
 - Retrofit capability
 - Over 1 Mbd committed capacity

Summary

- Addressing vehicles and fuels as a single system can significantly improve the cost-effectiveness of future regulations -- benefiting consumers and society
- Government and industry should work together to develop effective regulations to improve air quality
- China can benefit from experience in other regions -- but should develop regulations appropriate for the Chinese situation
- For Euro I,II,III vehicles and engines, sulphur is the most important fuel parameter (emphasis added!)

I AGREE WITH THESE CONCLUSIONS BUT WOULD ADD
THAT EURO FUEL SULFUR LEVELS SHOULD BE MATCHED
WITH VEHICLE STANDARDS