Emissions Control Options For In-Use Diesel Vehicles

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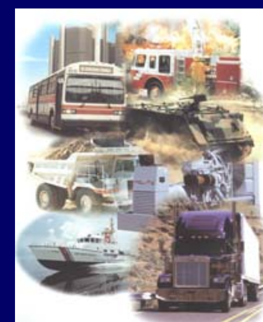
Diesel Engines: Air Quality Challenges

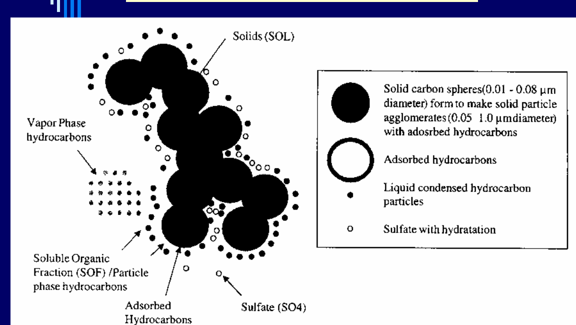
- NOx emissions
- PM emissions
  - Ultra-fine particles
  - Personal breathing space
  - Local & regional impacts
  - Global warming impacts
- Toxic HC emissions
- Sulfate Emissions
- Smoke
- Range of applications



Health Effects From Diesel Emissions Beyond Dispute

- WHO Concludes ~ 800,000 Premature Deaths Each Year From Urban PM; Diesels One Major Source
  - Numerous Studies in Europe & US Consistently Link PM With Premature Deaths, Hospital Admissions, Asthma Attacks, Etc.
  - No Evidence of a Threshold
- Ozone Also A Serious Health Concern

Diesel Particulate Matter

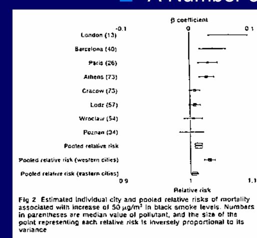


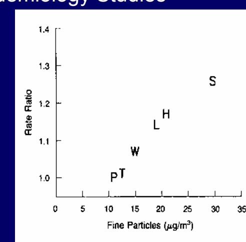
PM Health Effects

- High levels of PM (e.g. 500 μ/m³) known to cause premature death for many years
  - e.g. London 1952
- Recent studies in US, Europe, Asia, South America have found association of PM with premature death at much lower levels
  - no evidence of a “threshold” (safe level)

PM - The Epidemiology Studies

- A Number of Epidemiology Studies





- Europe Studies

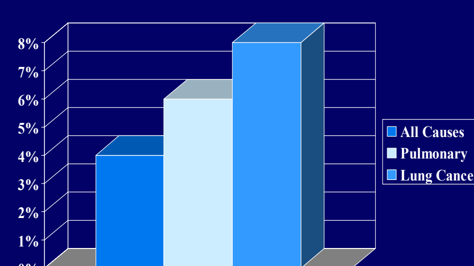
Harvard 6 Cities Study

PM_{10} Study in Europe

(Lancet Medical Journal – September 2, 2000)

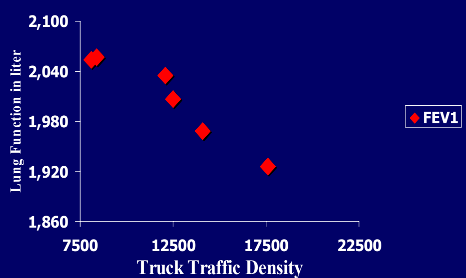
- ~6% of all deaths from PM_{10}
- ~40,000 deaths per year in Austria, France, Switzerland; 2 times traffic fatalities
- Motor Vehicles Responsible For ~50%
- People in Cities Die ~18Months Earlier Than They Otherwise Would
- Over 300,000 cases of chronic bronchitis; 500,000 asthma attacks; 16 million lost person days of activity
- Health Costs From Traffic Pollution ~1.7% of total GDP

Increased Risk of Premature Mortality Due To 10μg/m³ $PM_{2.5}$

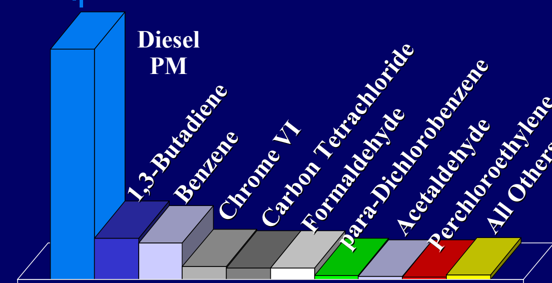


Journal of American Medical Association, March 2002

Dutch Study Links Proximity To Truck Traffic With Lung Function in Children

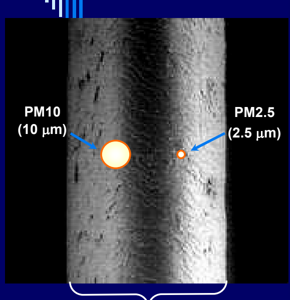


Relative Cancer Risks From Air Pollutants in Los Angeles

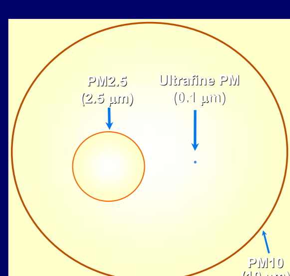


Based on ARB monitoring data 1995 - 1997

Comparison of PM10, PM2.5, and Ultrafine PM

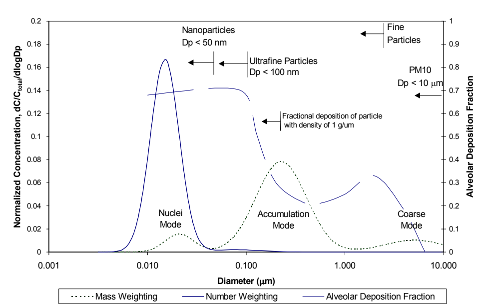


Human Hair (60 μm diameter)



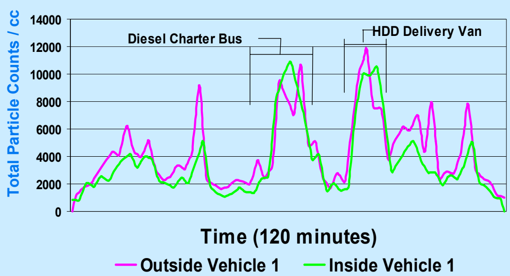
Relative size of particles

Typical engine exhaust mass and number weighted size distributions shown with alveolar deposition



ARB In-Vehicle Study
Real-Time Fine Particle Counts

(L.A. Freeway, AM Rush Hour, Vent Open)

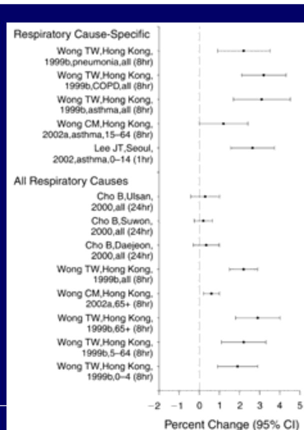


First Ever "Meta analysis" of Asian Studies of Acute Effects: *Results*

- 28 studies of daily changes in air pollution and health ("time series") studied in depth
- Studies more recent, of higher quality
- Studies find effects of air pollution on rate of death, illness
  - ~0.5% increase per 10 µg/m^3 of PM10
  - With high levels of air pollution in Asian cities (>100 µg/m^3), this could mean a substantial public health impact
- *Limitations exist:*
  - Small number of cities studied
  - Not geographically representative (areas with high pollution, high poverty less well studied)
  - Future studies needed to address

<u>**Ozone**</u>

Ozone and Respiratory Hospital Admissions

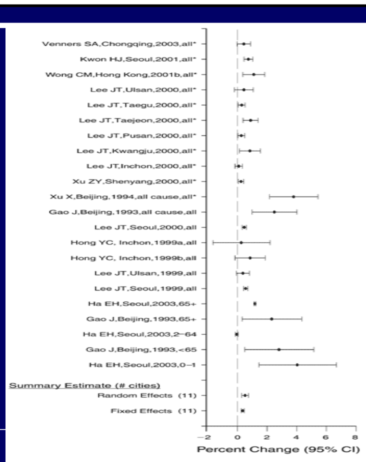


Ozone Health Effects

- Known to cause inflammation in respiratory tract
- reduces ability to breathe (lung function) for some people
- Increases hospitalization for asthma, other lung diseases
- Effects have been demonstrated for short term, long term effects are less certain
- LA Children's Health Study Indicates structural lung damage with lifetime impairment

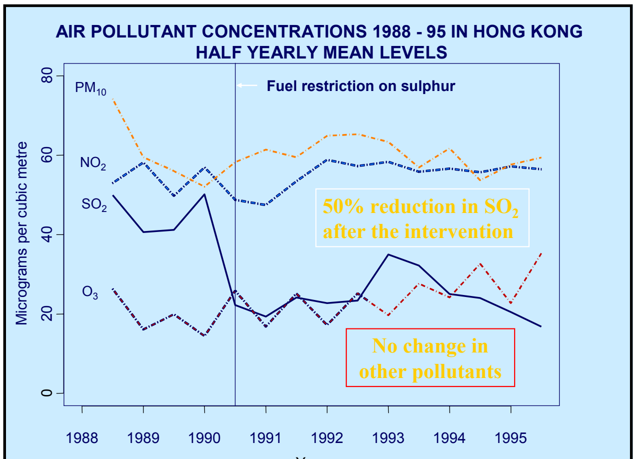
Sulfur Dioxide

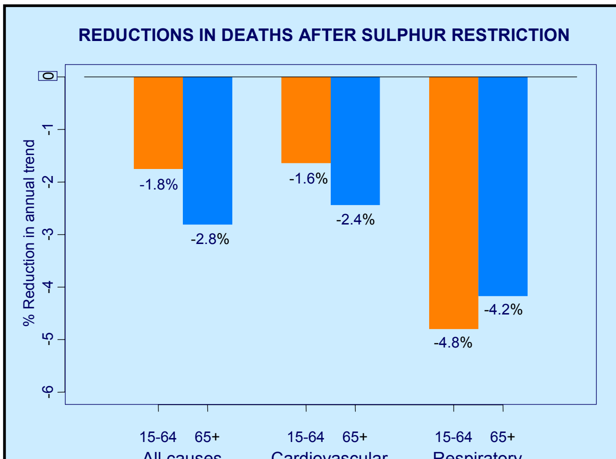
SO2 and All Cause Mortality



Sulfur Dioxide

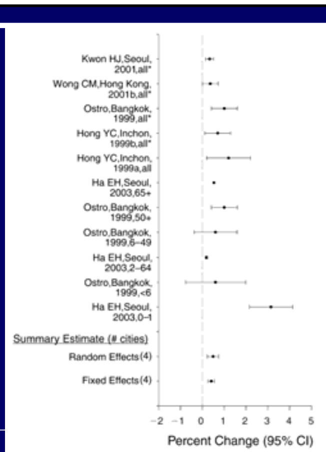
- Emitted from fossil fuel combustion
  - especially from coal burning facilities, high sulfur fuels
- Can impair breathing in asthmatic children and adults
- Has been associated, along with PM, with
  - increased aggravation of heart and lung disease
  - premature mortality
- Recent study in Hong Kong (Lancet 2002) has found:
  - substantial reductions in SO2 emissions can result in measurable improvements in mortality and illness



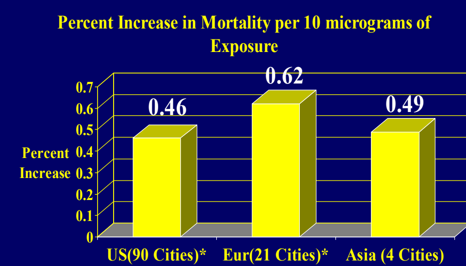


Particulates

PM10 and All Cause Mortality



Initial Results:
Asian Risk Estimates Similar to West



* Estimates Using Pre-GAM Results (without revision)

Conclusions

- Exposure to air pollution has been linked with increased death and illness
  - Most studies have been done in Europe and North America
- Asia faces significant air pollution problems today
  - Problem will grow with economic expansion
- The PAPA program is building a better base of Asian health and air pollution science
  - Review of the Asian literature found nearly 140 existing studies – partial basis for policy action
  - For small number of cities studied, effects appear to be similar to those in West

Options For Cleaning Up In Use Diesel Vehicles

- Improved Maintenance
- Improved Conventional Fuels
- Alternative Fuels with New Engines
- Retrofitting
- Engine Replacement or Repowering

Improved Maintenance

Improved Maintenance

Maintenance and Emissions

- Bus fleets follow a maintenance schedule prescribed by the bus manufacturer as part of the contract. Generally followed by the fleet operators in order for warranty to apply.
- Presumably, maintenance frequency and practices, at least with regard to the emission performance of vehicles, degrade as the fleet grows older. This may be even more true for taxis and refuse trucks.
- Emissions from diesel vehicles with no aftertreatment systems should be expected to significantly deteriorate only with respect to PM. Combustion inefficiency reduces NOx.
- Main diesel malfunctions involve faulty injectors and pump components and may increase PM from a few percentage units up to an order of magnitude higher than the emission standard.
- Pumps and injectors are the most expensive parts of the diesel engine. The mean repair cost is in the range of 1000 € for busses and 90-500 € for smaller vehicles.

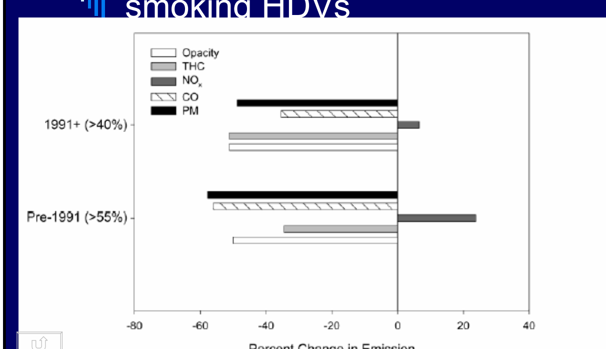
Improved Maintenance

Maintenance Enforcement

- Badly maintained busses may be ideally identified by an independent inspection.
- Most inspection regimes only look at smoke emissions (opacity) and do not differentiate between different diesel technologies.
- Smoke and PM are roughly correlated (one-way correlation), especially as technology improves and engines become smokeless.

Improved Maintenance

Effect of Maintenance on 26 smoking HDVs

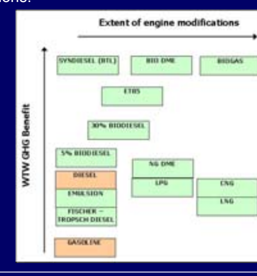


Refueling

Refuelling

Definition

- Refueling should be seen in two major directions:
  - Replacement or blending of fuels on existing engines
  - Introduction of new fuels for new engines
- Classification/Evaluation criteria
  - Engine/vehicle modifications
  - Blending
  - AQ improvement
  - WTW GHG
  - **Experience in use**
  - Costs
  - Availability / Infrastructure
  - **Feedstock**



Example only. Positions may change depending on assumptions.

Refueling (Existing Diesel Engines)

Refuelling (Existing Diesel Engines)

Emulsions – 1 (2)

- **Definition**: Emulsions are water in diesel systems (~83% diesel, ~14% water, ~3% additives).
- **Feedstock**: Crude oil (diesel) and water
- **Engine**: Diesel with no modifications
- **AQ potential**:
  - Based on information of their manufacturers, emulsions may achieve reductions of 30-80% in smoke, 10-40% in PM and 5-30% in NOx
  - Independent studies indicate reductions but lower in magnitude and engine and operation mode specific
- **WTW GHG**: Similar to diesel (slight efficiency improvement, slight upstream energy increase)
- **Experience**: A few thousand busses operate on emulsified fuels in Europe (Italy, France, Germany, UK, Switzerland)
- **Costs**: Depending on the taxation of water
- **Availability**: Similar to conventional diesel

Emulsions - 2

- **Issues**:
  - Suitable for old – high PM engines
  - Compatibility / effects on new engines (EGR optimised)
  - Increased noise
  - Increased fuel consumption / lower range
  - Water separation, freezing

Gas-to-Liquid from Natural Gas

- **Feedstock**: Natural Gas
- **Engine**: Diesel (Fischer-Tropsch), Converted Diesel (DME, Methanol)
- **AQ potential**:
  - Cleaner combustion (simple chemical structure)
  - No sulphur
  - Oxygenated (DME, Methanol) -> Low PM
- **WTW GHG**: More energy demanding than diesel, hence higher GHG emissions
- **Experience**: Limited
- **Costs**: Much higher than conventional diesel (energy intensive)
- **Availability**: Better than crude oil
- **Issues**:
  - Production processes may still be optimised
  - Cost is the major obstacle today
  - Not much experience of their use and AQ benefits in new engine technologies

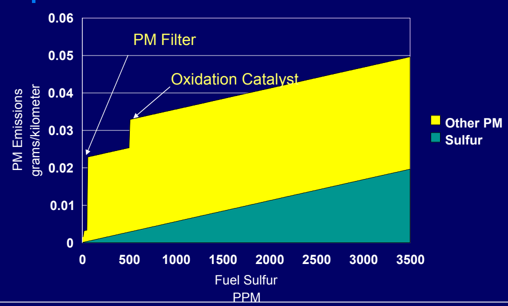
Biofuels: Biodiesel

- **Feedstock**: Biomass (Rapeseed, sunflower, cooking oil)
- **Engine**: Diesel (5% blend) or few modifications to diesel (30% blend)
- **AQ potential**:
  - Depending on blending proportion, increase of NOx, decrease of sulfate and carbon PM, increase of organic PM
  - Lower PAHs (simpler structure) and smoke
- **WTW GHG**: Decreasing with its increasing blend in the fuel (is N_2O from agriculture an issue?)
- **Experience**: Widely available in several countries (Germany, France, Austria, …) as a 5% blend. Pure biodiesel in pilot programs (Austria)
- **Costs**: Higher than conventional diesel
- **Availability**: Depending on the cost of the procedure
- **Issues**:
  - No major AQ benefits
  - Cost and GHG benefits depend on the procedure

Effect of biodiesel on diesel engine emissions

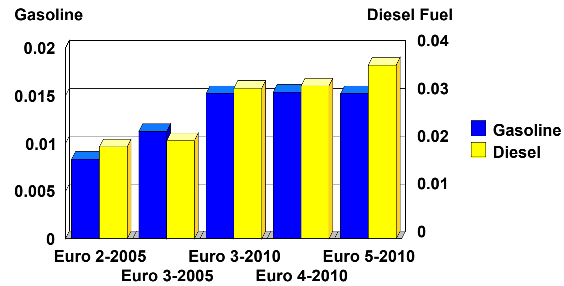
EMISSION	TREND	Biodiesel/Petrodiesel
Carbon monoxide	decrease	0.75 - 0.8
Hydrocarbons	decrease	0.2 - 0.8
Nitrogen oxides (NO_x)	increase	1.1 - 1.2
Total Particulate Matter (PM)	Change depends on SOF ratio	0.6 - 1.2
Organic fraction of particulates (SOF)	increase	
Sulphate fraction of particulates	decrease	
Carbon fraction of particulates	decrease	
Visible smoke	decrease	
PAH	decrease	
Aldehydes	increase	

Linkage Between Fuel Sulfur and PM Emissions

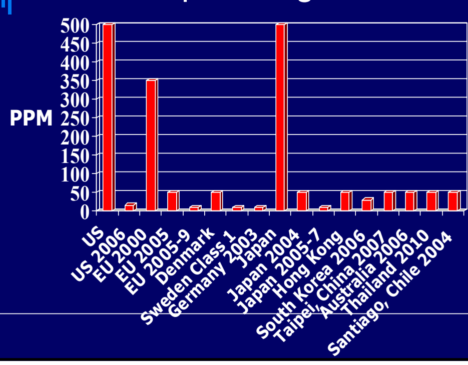


Cost of Providing Low Sulfur Fuels in China

US Cents per Gallon



Ultra Low Sulfur Diesel Fuel Is Spreading



Alternative Fuels (Alternative Engines)

Alternative Fuels (Alternative Engines)

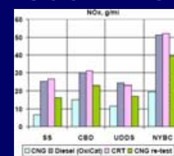
Natural Gas (CNG, LNG)

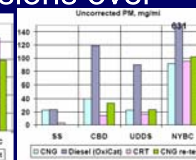
- **Feedstock**: Natural Gas as a fuel requires only a moderate purification compared to natural gas feedstock
- **Engine**: Dedicated NG with spark ignition (or bi-fuel). Stoichiometric or lean-burn
- **AQ potential**:
  - Depending on technology and aftertreatment but lower PM and NOx than diesel. Hydrocarbons (methane) are an issue
- **WTW GHG**: Worse than diesel (15-20%), better than gasoline (10%), improvements are expected
- **Experience**: A few thousand CNG busses all over Europe (France, Greece, …) and US
- **Costs**: Bus cost +35-40 k€ over diesel equivalent, NG cheaper than diesel per energy unit
- **Availability**: Depending on city infrastructure. NG reserves good for 65 years

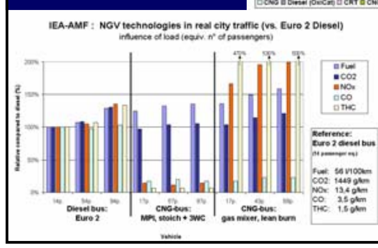
Alternative Fuels (Alternative Engines)

Natural Gas Emissions over Diesel

Typical emission behaviour of lean-burn CNG and diesel busses (CARB data)







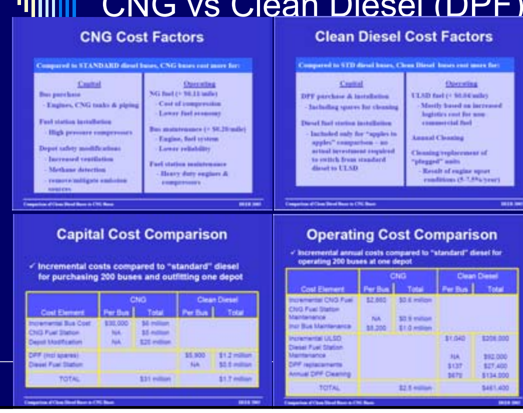
Comparison of CNG technologies over a Euro 2 diesel bus (VITO Data)

CONCLUSIONS

- On average, CNG delivers better emission performance than CRT equipped diesel
- Exhaust from advanced CNG vehicles was found less toxic than exhaust from CRT diesel
- Total numbers of particles and nanoparticles with CNG are similar to CRT diesel

Retrofitting / Refuelling

CNG vs Clean Diesel (DPF)



Alternative Fuels (Alternative Engines)

Biofuels: Biogas

- **Feedstock**: Biomass (Wastewater treatment, animal manure, …)
- **Engine**: Natural gas
- **AQ potential**: Natural gas
- **WTW GHG**: Low
- **Experience**: 500 dual-fuel municipal cars in Stockholm, 130 busses in Lille, 68 busses and 150 cars in Linköping, etc…
- **Costs**: High
- **Availability**: Limited
- **Issues**: A field for demonstration studies

Alternative Fuels (Alternative Engines)

LPG

- **Feedstock**: Crude Oil
- **Engine**: Dedicated LPG with spark ignition (or bi-fuel).
- **AQ potential**:
  - Depending on technology, but similar to gasoline for regulated pollutants
  - Lower PAHs (simpler structure)
- **WTW GHG**: Close to diesel
- **Experience**: Several thousand vehicles around the world, both busses and light cars. Large manufacturers produce LPG vehicles
- **Costs**: Cost of gasoline car conversion ~1000 €, cost of diesel bus conversion 25-40 k€, cost of fuel 50-60% of petrol/diesel
- **Availability**: Small due to limited production
- **Issues**:
  - Small availability (production and fuel stations)
  - Cost of diesel bus conversion / maintenance (depot, frequency)
  - Not much experience of its use in new engine technologies

Alternative Fuels (Alternative Engines)

Biofuels: Ethanol / Methanol

- **Feedstock**: Biomass (Sugar beet, wheat, corn, sugar cane, …) NG (Methanol)
- **Engine**: Petrol (blend – ET10) or dedicated engine (pure, ET85)
- **AQ potential**: Depending on the technology, lower PM and NOx than diesel (similar to gasoline)
- **WTW GHG**: Lower than diesel, depending on the process
- **Experience**: A fleet of ~250 urban busses operate in Stockholm. Ethanol in gasoline (up to 100%) used in Brazil
- **Costs**: Much higher than diesel, depending on the process
- **Availability**: Rather limited and depending on the cost of the procedure
- **Issues**:
  - Production cost / process
  - GHG-driven rather than AQ-driven

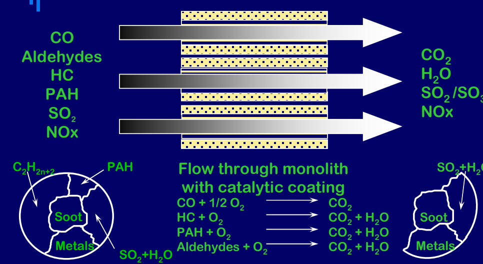
Retrofitting

Retrofitting

Diesel Oxidation Catalyst

- **Description**: Open channel devices installed in exhaust line
- **AQ Effect**:
  - PM: Oxidize the organic fraction and reduce PM by 10-50%
  - NOx: No effect on total NOx but NO_2/NO may be an issue
  - Non-regulated: Inconsistent effect
- **Costs**:
  - Passenger cars: 300 - 500 €
  - Busses: 1500 €
- **Experience**:
  - Large retrofitting activities throughout the world
  - Used in all Euro III diesel passenger cars
- **Issues**
  - No reduction of soot
  - NO_2 production by Pt-based catalysts

Diesel Oxidation Catalyst



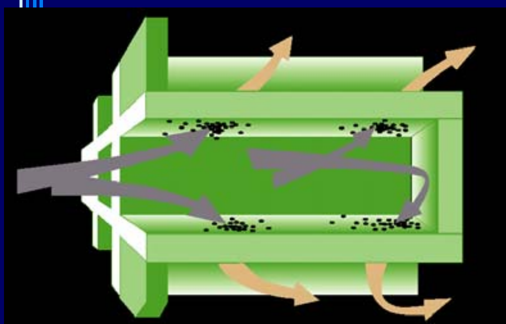
Retrofitting

Continuous Regeneration Diesel Particle Filters (CRDPF)

- **Description**: Wall flow devices installed in the exhaust line combined with a DOC to enable NO_2-based regeneration
- **AQ Effect**:
  - PM: Over 99% filtration of soot particles, oxidation of organic fraction, overall efficiency as high as 95%
  - NO_x: No effect on total NO_x but NO_2/NO may be an issue
  - Non-regulated: Large reductions of PAHs, nitro-PAHs, carbonyls
- **Costs**:
  - Not available for PCs (low NO_2/PM ratios, low exhaust temperature)
  - Busses: 4.5-9.5 k€ (+0.02-0.05 €/bus km maintenance cost)
- **Experience**:
  - Retrofitting activities throughout the world
  - Appears as a candidate technology for (future) heavy duty vehicles
- **Issues**
  - Applicability for different vehicle technologies and duty cycles
  - NO2 production by Pt-based catalysts
  - Reliability, maintenance

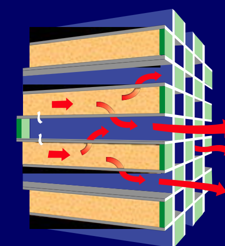
Filter System Retrofitted to a Refuse Truck

Diesel Particulate Filter

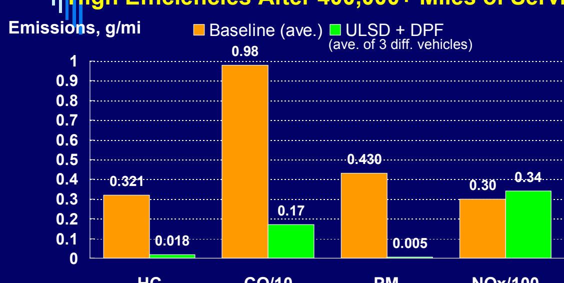


Diesel Particulate Filters (DPF)

- 175,000+ retrofits worldwide
- Many regions are mandating their use
- Variety of technologies for a variety of applications
- Not universally applicable, but expanded applications and technologies developing

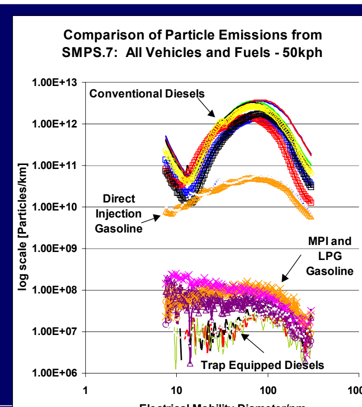


DPFs + 15 ppm S Diesel Fuel Demonstrate High Efficiencies After 400,000+ Miles of Service



Grocery Delivery Trucks with 12.7 L Engines
Emissions Measured Using City-Suburban Heavy Vehicle Route

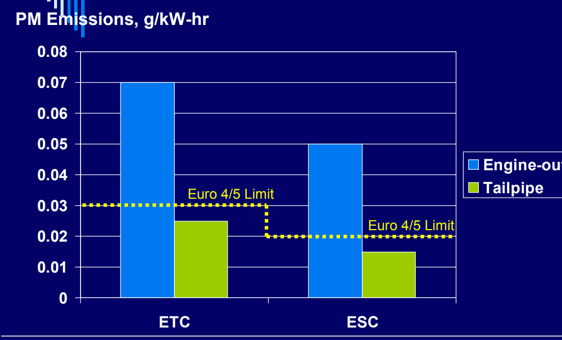
Reference: SAE 2004-01-0079



"Flow-Thru" or "Partial" Filter Technologies Emerging for Diesel Retrofits

- Potential for 50-70% PM reduction (Level 2, one technology already verified)
- Can be catalyzed or used with a DOC
- May have applicability on older engines
- Filtering achieved with sintered metal sheets or wire meshes
- Resistant to plugging

Euro 4 Application with Flow-Thru Filter Demonstrates 60-70% PM Reduction



Source: MAN

Retrofitting

Fuel-Borne Catalyst Diesel Particle Filters (FBDPF)

- **Description**: Wall flow devices installed in the exhaust line. Require a fuel-borne catalyst to facilitate soot combustion
- **AQ Effect**:
  - PM: Over 99% filtration of soot particles, lower oxidation of organic fraction than CRDPF
  - NO_x: No effect on total NO_x
  - Non-regulated: Reductions of PAHs, nitro-PAHs on PM.
- **Costs**:
  - Just available for passenger car retrofitting in Germany (600-700 €)
  - No commercial system for busses
- **Experience**:
  - Demonstration studies of busses and passenger cars in France, UK, Germany, …
- **Issues**
  - Infrastructure for FB catalyst delivery required
  - Regeneration strategy
  - Reliability, maintenance

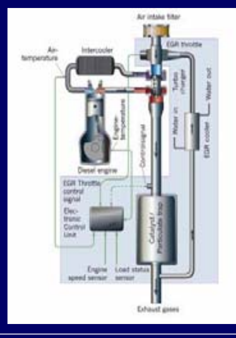
Retrofitting

Exhaust Gas Recirculation

- **Description**: Recycling of exhaust gas in the cylinder to reduce flame temperature and thus NO production
- **AQ Effect**:
  - PM: Low effect expected (reductions when combined with DPF)
  - NO_x: Up to 40% (retrofitting manufacturer's data)
  - Non-regulated: Depending on DPF application
- **Costs**:
  - Just available for bus retrofitting in Sweden, combined with CRDPF (14 k€)
- **Experience**:
  - Used in new engines
  - Limited experience with retrofitting
- **Issues**
  - Field for demonstration studies

Low Pressure Exhaust Gas Recirculation (EGR)

- Replaces inlet air with clean exhaust gas by recirculation through a CB-DPF
- Decreases the combustion temperature, thus lowering the NOx production
- Calibrated for minimum affect on power and fuel consumption
- For trucks, buses, and on-highway vehicles
- > 40% NOx efficiency with > 90% PM efficiency
- > 1500 systems operating worldwide including several U.S. programs



EGR Installation on Vacuum Truck in Texas

Lean NOx Catalyst Technology

- Flow-Through Catalyst Technology Not Unlike a DOC, But It Is Formulated for NOx Control
  - Typically use diesel fuel injection ahead of the catalyst to serve as NOx reductant
- Lean NOx Can Achieve a 10 to >40 percent NOx Reduction
- Combined DPF/Lean NOx Catalyst System Verified in CA for > 85% PM Efficiency and 25% NOx Efficiency

DPF/Lean NOx Catalyst – Urban Bus

Retrofitting

Selective Catalytic Reduction

- **Description**: Open channel devices with urea injection for the reduction of NOx to nitrogen and water
- **AQ Effect**:
  - PM: Low effect expected (reductions when combined with DPF)
  - NOx: Up to 80% (retrofitting manufacturer's data)
  - Non-regulated: Depending on DPF application
- **Costs**:
  - Commercial systems (presented in 2004) in the order of 20-25 k€ (+DPF). Urea consumption 0.005-0.01 €/bus-km
- **Experience**:
  - Considered as a technology for future HDV emission standards
  - Limited for retrofitting
- **Issues**
  - System complexity / reliability / applicability
  - Need for urea infrastructure

SCR Is Very Successful Worldwide on Stationary Sources and Now Applied to On-Road Engines

- SCR Control Performance (w/ Integral Oxidation Function)
  - PM - 20-50% reduction of organic PM
  - CO and HC - up to 90%
  - Toxic HCs - up to 70%
  - NOx - 50 to 90%
- SCR Operating Experience
  - HD truck demonstration in Europe since 1995 with mileage exceeding 400,000 miles
  - Expected to be used to meet the HDE Euro 4 standards in 2005
  - Some use on locomotives and marine vessels

SCR Applications

Retrofitting

Demonstrations / Approaches: USEPA/CARB

- Voluntary Diesel Retrofit Program (EPA)
  - Approval / Verification procedure for retrofit devices / systems (e.g. biodiesel is also included)
  - Assessment of environmental benefits (as part of the verification but also in-use)
  - Financial support by EPA grants, tax credits, court settlements
  - Other initiatives (e.g. Clean School Bus)
- Diesel Risk Reduction Plan (CARB)
  - Verification procedure to classify PM control measures, depending on reduction potential
  - Reciprocity of verifications with EPA

Retrofitting

Examples of EPA Supported Activities

- Clean School Bus Program
  - 21 Projects running
  - 5000 busses in 30 states (DOCs and CRDPFs)
- NY State Clean Diesel Air Quality Demonstration Program
  - Some 500 busses retrofitted with CRDPFs
  - 92% reductions in THC, 94% in CO, 88% in PM, 99% carbonyls, 78% in PAHs, 79% nitro-PAHs (no effect on NOx)
  - According to studies from this project "8 *months of operation on 25 buses without a failure or any significant increase in fuel economy indicates that the CRDPF has no adverse effect on the operation, reliability or maintainability of the vehicles thus retrofitted* "
  - Also evaluated CNG/CRDPF options and found an incremental cost of M$2.3 for CNG and M$ 0.34 for CRDPF (200 busses)

Retrofitting

Examples of Practices in Europe – 1(2)

- VERT Project and follow-ups (Switzerland)
  - Started with DPF retrofitting of diesel machinery in tunneling
  - Developed a protocol for durability evaluation and emission performance of different DPFs
  - This is supported and revised by SAEFL (indicative, not required)
  - Some 6500 DPF retrofits in on- and off-road applications.
  - Failure rates in the order of 2% (6% for earlier systems)
- Swedish Environmental Zones Program (EZP)
  - Since January 2002, the 4 largest Swedish cities introduced EZP
  - All HDVs entering EZP no more than 8 years old
  - Vehicles 9-15 years need to be retrofitted to achieve 80% PM and HC reductions (1st step) and 35% NOx (2nd step).
  - List of approved aftertreatment devices published
  - Effectiveness of the program was estimated 20% PM, 8% NOx

Retrofitting

Examples of Practices in Europe – 2

- Bus Retrofitting in La Rochelle (France)
  - 47 Euro 1 and Euro 2 busses retrofitted with FBDPFs
  - Fuel (30% biodiesel) is additized in the pump by an electronic dosage pump. The same fuel pump also used for non retrofitted busses (electronic recognition)
  - Filter ash cleaning every 18000 km
  - Builds upon earlier experience from Athens pilot study, Paris RATP retrofitting, Lyon experiment.
- Black Cabs retrofitting in London (UK)
  - "Taxi Emissions Strategy" requires all cabs to meet Euro 3 by 2007.
  - Special flat fare (20 p. per trip) to cover the cost of upgrading
  - Three options for taxi owners
    - A new cab
    - Retrofit SCRT system (?)
    - Convert to LPG

Retrofitting

Examples of Practices in Asia

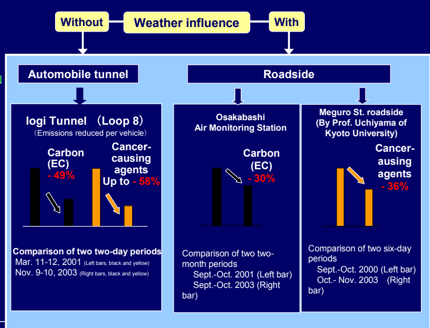
- Tokyo Metropolitan Government initiative
  - Ban of diesel trucks and busses (older than 8 years) if not equipped with aftertreatment (200 thousand vehicles)
  - Two PM reduction classes (60% old vehicles, 30% more recent vehicles)
  - Verification list for DPFs (~20 models) and DOCs (~30 models)
  - Financial support up to (DPF) ~3k€/veh. and (DOC) ~1.5k€/veh.
  - Problems are cost of retrofitting, failure rates, falsified data, etc.
- Hong-Kong Activities
  - Reduction of PM by 80% and NOx by 30% in 2005
  - Diesel taxi fleet replaced with LPG (18,000 vehicles)
  - Incentives to replace diesel light busses with LPG ones (3/4 of new registered light busses are LPG)
  - Mandatory retrofit of pre-Euro diesel vehicles

Metropolitan Tokyo in-Use Diesel Program

Measurement results indicate that Diesel PM levels have been significantly reduced.

(By the Research Institute for Environmental Protection)

Tokyo Metropolitan Research Institute for Environmental Protection



(With cooperation from the Bureau of Construction)

Mandatory Diesel Retrofit Programs in US

- Very few adopted thus far
- CA leading the way (per Diesel Risk Reduction Plan—75% less diesel PM by 2010; 85% by 2020)—
  - **Existing—**
    - **Urban Bus Rule (2000, 2002)**
    - **Waste Collection Vehicle Rule (2003)**
    - Stationary diesel engines (2004); portable diesel engines (2004); transport refrigeration units (2004)
  - Planned—
    - Public highway fleets—2005—will cover municipal and utility fleets not covered by urban bus rule
    - Private highway fleets—2006+?—early stages—will cover fuel delivery trucks and other HDE fleets
    - Harborcraft—2005?
    - Port and intermodal facilities cargo handling equipment—2005?
    - General land-based nonroad equipment—2005+?
    - Locomotives—2006+?
  - Fuel—ULSD (15 ppm) required for on-road and nonroad by 2006-2007

Mandatory Diesel Retrofit Programs (continued)

- Existing CA regulations
  - Urban Bus Rule
    - Choice of 2 compliance paths (alt. fuel, diesel), covering urban bus fleets—both new and old buses
    - PM retrofits—fleet–wide req'ts: 0.1 g/bhp-hr avg or phased in reduction from 2002 baseline to 85% in 2009
    - Rule also includes:
      - fleet-wide avg NOx req't of 4.8 g/bhp-hr;
      - new bus standards phased in to 2007—0.2g/bhp-hr NOx, 0.01g/bhp-hr PM
      - ULSD fuel in 2002
  - Waste Collection Vehicle Rule
    - PM BACT (retrofit, repower or replace) req'ts for existing trucks phased in from 2004-2010
    - CARB projects 81% PM fleet reduction by 2010, 85% by 2015 (from 2000 levels)

Mandatory Diesel Retrofit Programs (continued)

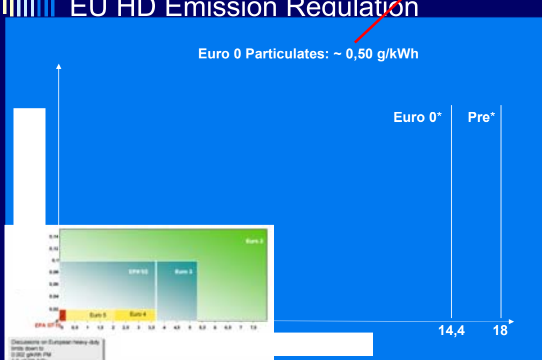
- NYC
  - Local Law 77 requires city to use ULSD fuel and best available technology in all of its non-road vehicles and construction contracts
  - Recent NY State law (Coordinated Construction Act for Lower Manhattan) has similar req'ts for state-controlled lower Manhattan construction projects, including WTC project

Voluntary Diesel Retrofit Programs

- CA Carl Moyer Program—
  - Grants for voluntary (i.e., better than required by regulation) NOx emissions reductions from HDE engines
  - During 1st 5 years—
    - State grants totaled ~ $149 million, with local matching funds of ~$34 million
    - Results— ~4950 cleaner engines
    - Focus on NOx, but some PM co-benefits
  - in 2004, expanded to include PM and HC reductions, (and to projects with light and medium-duty engines)
  - Until now, most on-road projects involved purchase of alternative fuel engines rather than diesel retrofits; that will likely change now that PM reductions qualify

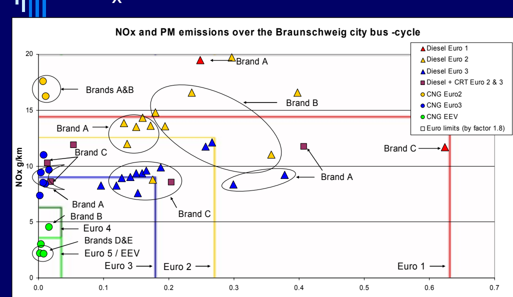
Replacing Engine (Repowering)

Repowering
EU HD Emission Regulation



*Pre Euro: 1980 tech, Euro 0: 1990 tech

NO_x Vs. Pm For Total Bus Matrix



NYC Transit Urban Bus Project

- NYC Transit program to clean up all of its 4500 transit buses
- Program is technology neutral, and includes CNG buses, hybrid buses, and "clean" (new and retrofitted) diesel buses
- CNG—
  - phased in since 1995; ~500 buses in service
  - Slightly less reliable and less energy efficient, and significantly more expensive, than urban diesel buses
- Hybrid Diesel-Electric—
  - ~125 in service
  - 2nd generation hybrids 30-40% more fuel efficient, with similar performance and reliability, but significantly greater cost than diesel buses

NYC Transit Project— "Clean Diesel" Approaches

- Retire older uncontrolled diesel engines—repowered 600+ older buses and purchased over 2900 new buses
- Use ULSD– have used fuel with less that 30 ppm sulfur since 2000 (US-wide—15 ppm in 2006)
- Retrofit all existing diesel buses with diesel particulate filters—to be completed this year, with 3300 DPFs; with new buses included, over 4100 buses will have DPFs

NYCT Project— "Clean Diesel" Costs

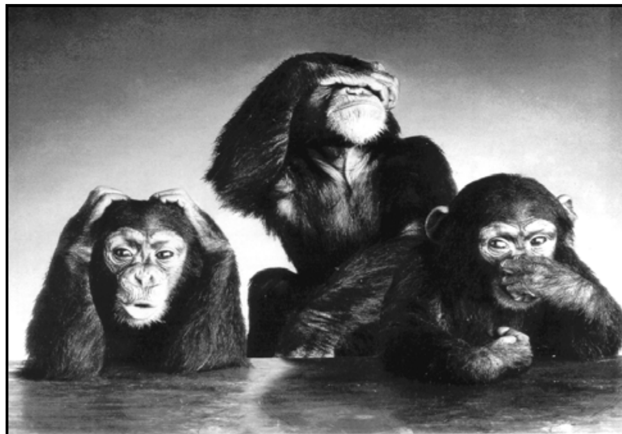
	Additional Costs Compared to Diesel Buses
Annual Maintenance	$150 to clean filter + 3 hrs R&R, 5% "plugging" rate
Fuel	+$0.03—0.10/gallon for ULSD
DPF Purchase	+$4000--$7000 per bus
Fuel Station	Nothing additional required
Depot Modifications	Nothing additional required

NYCT Diesel Experience— Lessons Learned

- Urban bus fleet replacement with modern diesel engines is effective and cost-effective in reducing emissions
- DPFs are durable on modern (Euro II-III) engines; probably not effective for older, non-electronically controlled, engines
- DPF retrofits are also effective and cost-effective in reducing PM emissions, including hard (black) carbon fraction

NYCT Diesel Experience—Lessons Learned (continued)

- ~5% per year "plugging" rate with DPFs due to engine upsets; most plugged filters can be cleaned, but some must be replaced
- Greater plugging problems with 2.5g/bhp-hr NOx EGR engines
- Plugging problems can be reduced with:
  - More pro-active maintenance to reduce upsets
  - Back-pressure monitoring systems (included now with most new DPFs)
  - Active filter regeneration systems (will likely be included with new 2007+ new US on-road engine DPFs)
- DPFs mask appearance of engine problems manifested by increased smoke—again, more pro-active engine maintenance is required



Hear no diesel. See no diesel. Smell no diesel.