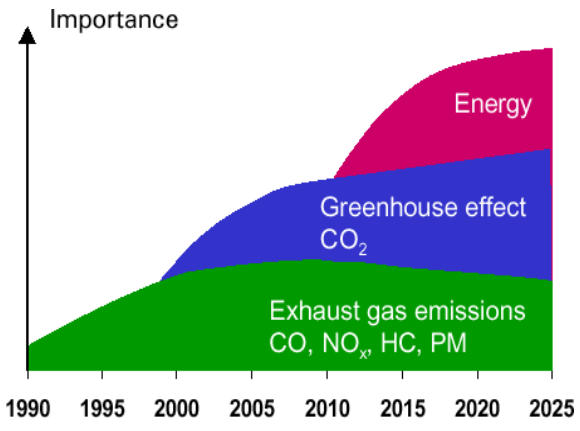
Diesel Particulate Filters: Regulations and Status of Technology

W. Addy Majewski
Ecopoint Inc.

Mining Diesel Emissions Conference
October 28-31, 2002
Markham, ON

www.DieselNet.com

Environmental drivers in vehicle development



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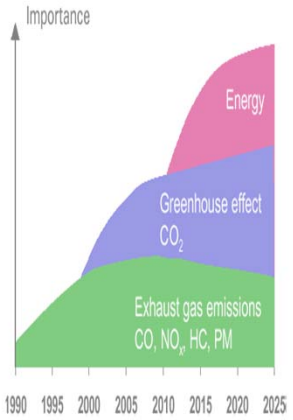
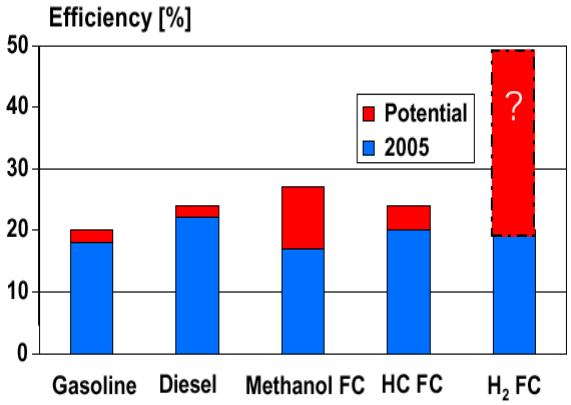
Environmental Effects of Diesel



- **No substitute for liquid HC fuels in short to mid-term**
- **Best energy efficiency**
- **Low greenhouse gases (CO_2, N_2O, CH_4)**
- **Air pollutants:**
  - low CO, HC
  - high **PM**
  - high **NOx**

Efficiency of Modern Propulsion Systems



Total "well-to-wheel" efficiency, including fuel production, distribution, and vehicle operation.

Passenger cars (VW)

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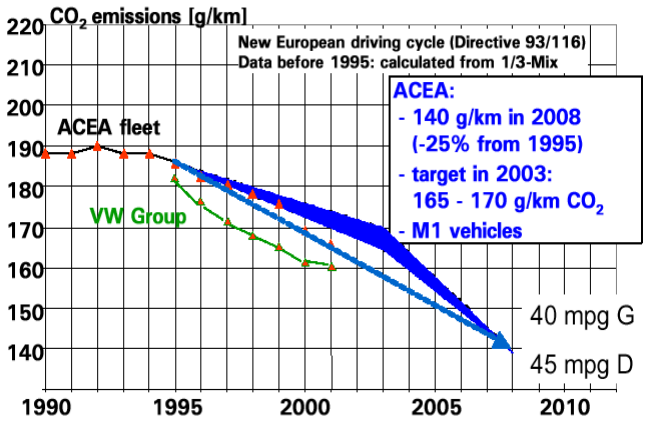
Carbon Dioxide Reduction in the EU



Voluntary agreement between ACEA and the European Commission

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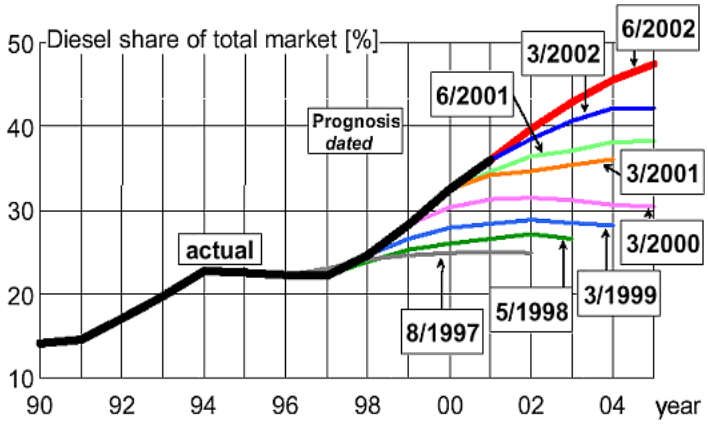
Diesel Market Share in the EU

Comparison of different prognosis



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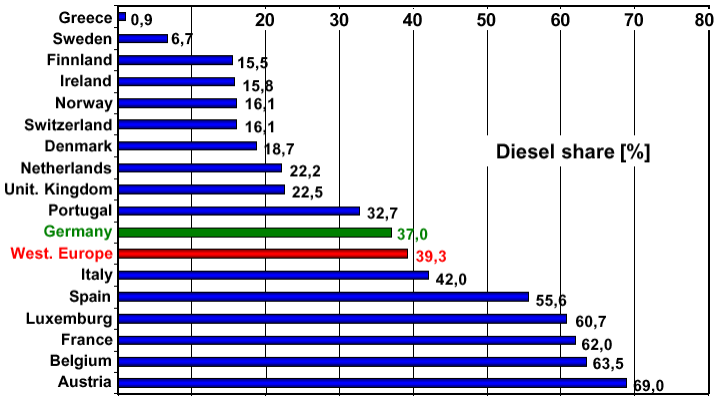
New Registrations of Diesel Passenger Cars

January – June 2002



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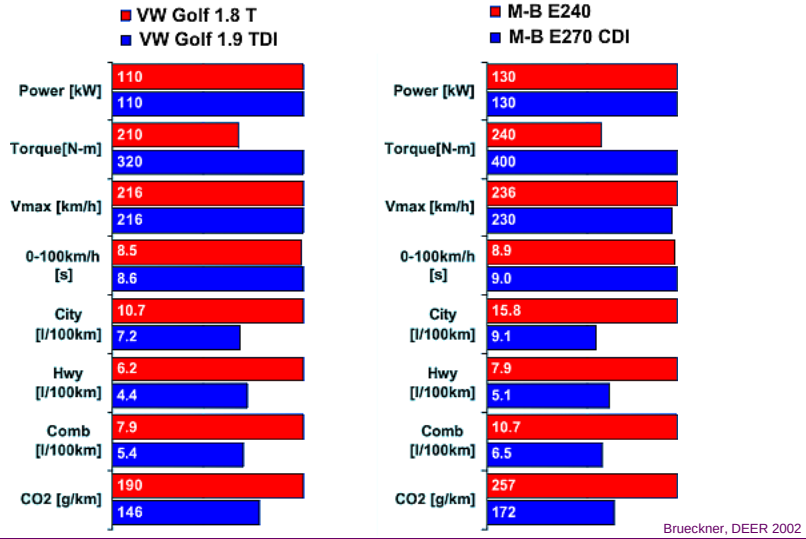
Diesel and Gasoline Car Performance

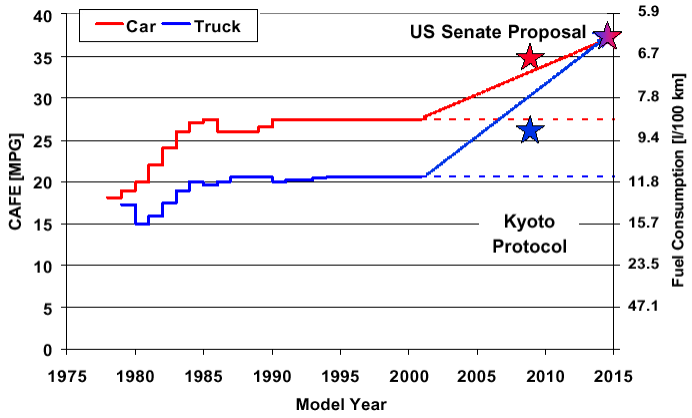


Brueckner, DEER 2002

Diesels in the U.S.

- **Diesels dominate the heavy-duty market**
  - No known substitute for diesel in long-haul trucking
  - Liquid H_2 FC not feasible – only 25% energy density compared to diesel
- **U.S. diesel sales top one million a year**
- **Greenhouse gases**
  - No federal CO_2 legislation yet
  - Greenhouse gases legislation adopted in California, other states likely to follow
- **Pressures to increase diesel share in light truck, SUV, minivan applications**
  - CAFE
  - CO_2

U.S. CAFE Standards



Brueckner, DEER 2002

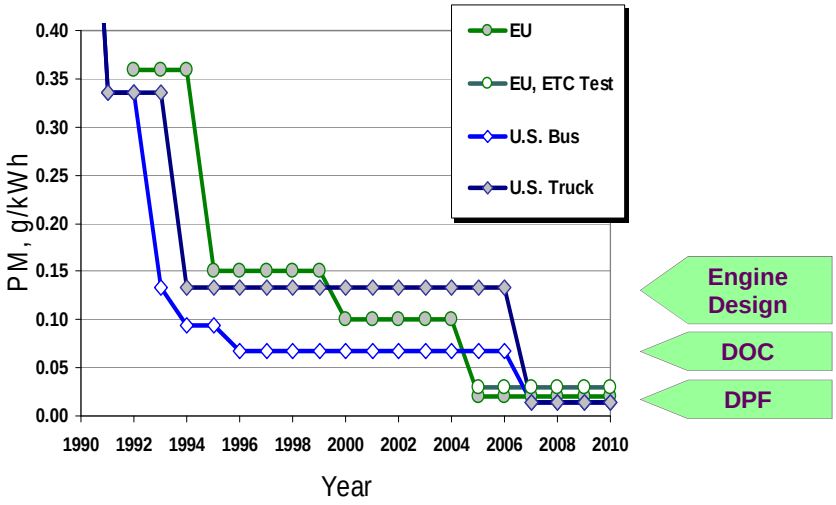
Impact on Air Quality

- **Increased population of diesels a concern about impacts on public health and environment due to PM and NOx**
  - US: Diesel trucks and buses contribute 28% NOx and 20% PM mobile source emissions nationwide
  - Higher contributions in areas with air quality problems
  - U.S. EPA: Diesel exhaust implicated in an increased risk of heart and respiratory disease, classified as a "likely human carcinogen"
- **The role of black carbon in global warming**
  - high climate forcing potential, counterproductive to the CO_2 benefit of diesel
  - new theory: can change precipitation patterns, causing flooding and droughts
  - short lifetime in the atmosphere (~weeks, CO_2 ~100 years)

"Aftertreatment-Forcing" Emission Standards

- **"Aftertreatment-forcing" emission standards for new highway diesel engines over 2005-2010**
  - Heavy-duty engines
    - Euro 4 (2005)
    - US 2007/2010
    - Euro 5 (2008)
  - Light-Duty vehicles
    - Euro 4 (2005)
    - US Tier 2 (2004 .. 2009)
    - Cal LEV 2 (2004 .. 2010)
- **System (vehicle&fuel) approach: ultra-low sulfur fuels**
  - US 15 ppm S, 2006 (80%)
  - EU 50 ppm S, 2005 | 10 ppm S, 2009 (?)

HD Diesel Truck & Bus PM Emission Standards



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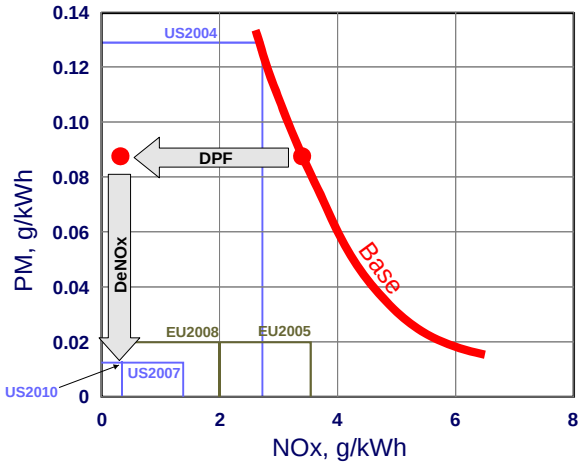
Future NOx and PM Control Strategies

Preferred by regulators,

envisioned at the time the regulations were adopted



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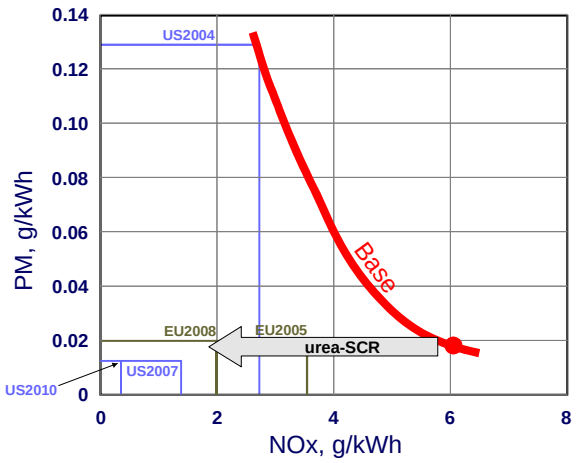
Euro 4/5 Strategies

Demonstrated feasibility

Preferred by manufacturers (no DPF)



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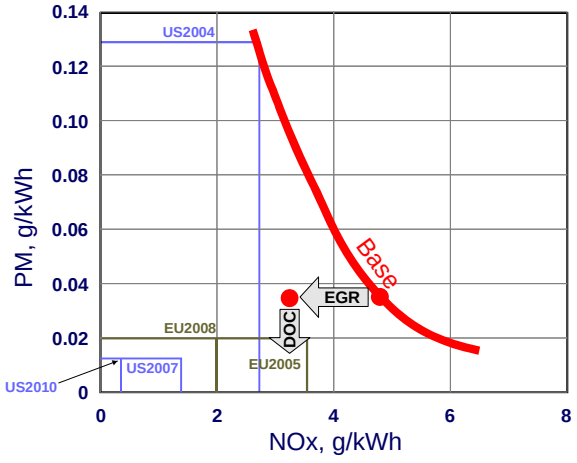
Euro 4 Strategies

Investigated

- **no DPF**
- **no NOx catalyst**



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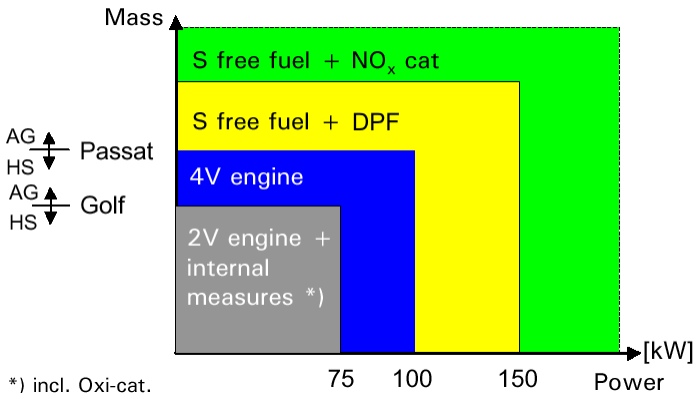
Euro 4 Light-Duty Strategies

- **DPF only on larger vehicles**



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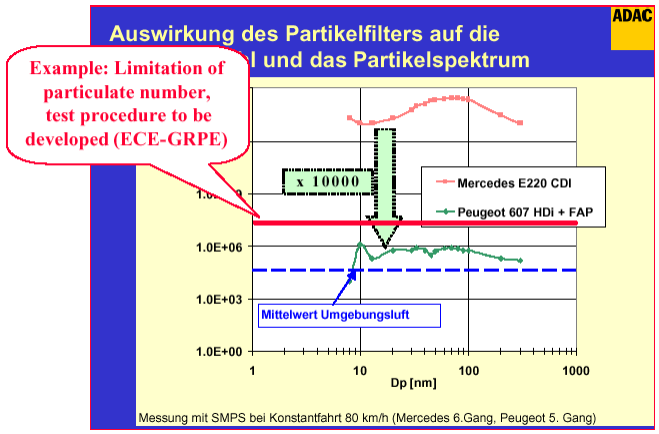
German Euro 5 Proposal

- **New proposal to be presented to the European Commission this Fall**
- **Adopted standards do not force DPF technology**
  - Introduce light-duty Euro 5 (2008)
  - Revise existing HD Euro 5 (2008)
- **New Euro 5 limits (mass) under consideration:**
  - Light-duty
    - NOx 0.08 g/km (Euro 4: 0.25 g/km)
    - PM 0.0025 g/km (Euro 4: 0.025 g/km)
  - Heavy-duty
    - NOx < 1 g/kWh (existing Euro 5: 2.0 g/kWh)
    - PM 0.002 g/kWh (existing Euro 5: 0.02 g/kWh)

German Euro 5 Proposal: Particle Number Limit



Particle Number limits for both LD and HD

Rationale:

- low mass limits difficult to measure
- small particles (below 100 nm) present only a small fraction of the total PM mass

Rodt, DEER 2002

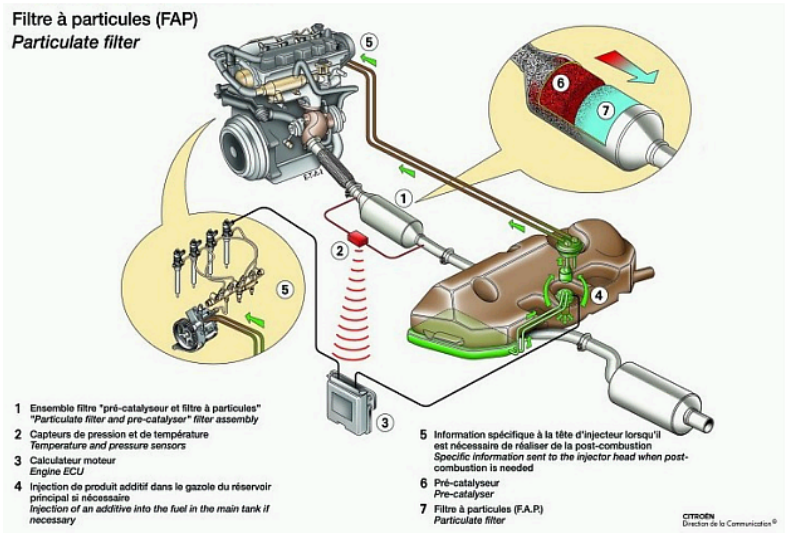
Commercial DPF Technologies

- **Voluntary character**
  - technology development towards future standards
  - competitive and political motivation
- **Active systems required in OEM applications**
- **Light-duty (cars)**
  - Peugeot system
    - commercial, started in 2000
  - Toyota DPNR system approaching commercialization
- **Heavy-duty (trucks and buses)**
  - Navistar 530, school bus in California
    - ~100 sold
    - reliability unknown
  - Hino to launch DPF-equipped truck in 2003

Peugeot DPF System

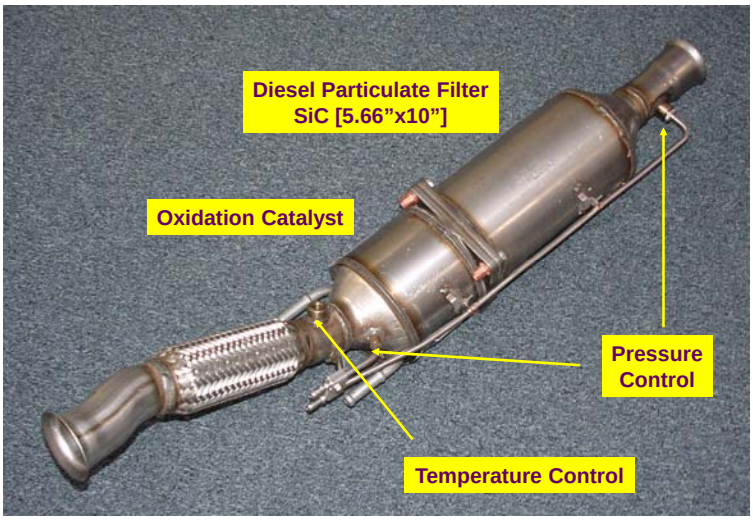
- **Commercial status**
  - Introduced on diesel Peugeot 607 in May 2000
  - 400,000 vehicles sold since market introduction
  - Used on Peugeot 807, 607, 406, 406 Coupé, 307 and RC (Sport Car), Citroën C8, C5, FIAT Ulysse and Lancia Phedra
  - New platforms will be DPF-equipped in 2003
  - Estimated 2005 sales of 1 million vehicles
- **Operation principle**
  - Regeneration:
    - Continuous: Ce additive (Eolys from Rhodia)
    - Assisted: Combustion management (post-injections) + catalyst temperature increase
  - Maintenance every 80,000 km
    - Replenish additive, wash filter from ash
  - Fuel economy penalty: 5%

Peugeot DPF System



Peugeot DPF System

APPLIED TO
- **Peugeot 406**
- **Citroën C5**



Source : Tenneco Automotive - Gillet

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DPF Retrofit Programs, Highway Engines

- **Environmental Zones (Sweden, 1996)**
  - ~5,000 DPFs, mostly CRT, 10 ppm S fuel
- **New York MTA**
  - Retrofit/repower the entire bus fleet of 3,500 by 2003
- **UK, mostly urban buses**
  - ~3,000 DPFs, passive systems, 30 ppm S fuel
- **California Diesel Risk Reduction Plan (09/2000)**
  - Retrofit 90% of the State's diesel population of >1,000,000
  - High DPF durability requirements, no verified DPF technology for many applications
- **Tokyo**
  - starting October 2003
  - DPF + DOC

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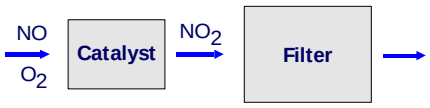
DPF Retrofit Programs, Occupational Health

- **U.S. MSHA**
  - TLV for diesel PM in non-coal mines
  - Engine emission limit in coal mines
  - DPF will have to be used, but technology unclear
  - NO_2 problems with Pt filters
- **Switzerland**
  - DPF mandatory on engines in tunnel construction (SUVA)
  - Extended on general construction engines at large construction sites (BUWAL, 1 September 2002)
  - Technology: electric regeneration (shore power, manual), CRT
- **Germany**
  - Exposure limit (TRK) of 0.1 mg/m^3 EC (0.3 mg/m^3 in non-coal mines)
  - DPFs used on indoor engines (diesel forklifts, …)

Retrofit DPF Technologies – Passive Filters

- **Catalytic DPF systems**

OC-DPF configuration (CRT)



Catalyzed DPF

- **Fuel additive systems**
- **Regeneration depends on temperature and duty cycle**
  - work well on hot engines
  - careful selection of application required
  - prone to failure on cold engines/duty cycles
  - NO_2 formed with Pt catalyst

Retrofit DPF Technologies – Active Filters

- **Commercially available**
  - Manually regenerated
    - Electric off-board, shore power, …, fuel burner w/ idle regen.
    - maintenance intensive, require operator's intervention
    - prone to failure if not regenerated on time
  - Fully automated fuel burner systems
    - limited commercial availability
    - complex, high cost
    - what is the reliability record?
- **Not commercially available**
  - On-board partial flow electric, partial flow burner, mechanical (air-blast), microwave,…

Electric Off-Board DPF System

- **Uses off-board regeneration device**
- **Requires frequent (daily) removal from vehicle for regeneration**
- **Operators often purchase two units for switching between operation and regeneration**

Electric Off-Board DPF System

- **Three units on a concrete mixer:**
  - 2 units serve the main engine
  - extra unit fitted on the mixer engine

Retrofits – Unproven Reliability Record

- **Retrofit applications more challenging than OEM**
- **Limited published data, but failure rates may be high**
- **There is a need for a robust, durable, and cost-effective DPF system for retrofits**

A fully integrated engine and aftertreatment system is required, where regeneration must occur regardless of machine duty cycle and without the need of intervention of the machine operator. This requires the development of active regeneration, automatic filter systems. No such systems exist today at a sufficiently mature level of technological development required for commercial viability

[from EMA/EUROMOT PM filter report, August 2002]

Summary

- **DPF technology on new diesel engines**
  - DPF technology expected to be widely introduced on new *highway engines* in the U.S., EU, Japan, likely in the 2007 – 2008 timeframe (unless new ultra-low-emission diesel combustion systems are developed)
  - DPF-forcing standards for *nonroad engines* expected to become effective in the U.S. in 2009 or later
  - Existing OEM systems appear to be reliable and work with acceptable engine performance penalty and acceptable amount of added maintenance
- **Retrofit DPF technology**
  - DPF retrofits become increasingly common to control emissions from existing engine fleets
  - Suitable DPF technologies exist to retrofit selected (mostly high temperature) engine applications
  - Many retrofit DPFs require extremely high maintenance effort
  - No convincing DPF reliability demonstrated in any of existing wide-scale retrofit programs worldwide
  - Robust DPF systems may be developed as sales volumes increase (e.g., California, Tokyo,…)