Diesel Exhaust Emission Control in Europe: The Regulatory Drivers, the Issue of Diesel Sulfur, Emerging Technological Solutions

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Overview of the Presentation

- Introduction
- Major health concerns from motor vehicle pollution in Europe
- EU regulations compared to USA
- EU current and future fuel sulfur requirements
- Current and future incentives to lower diesel sulfur
- One example of a commercial diesel passenger car with DPF : PSA Peugeot-Citroen
- Plans of other car and heavy truck manufacturers
- Conclusions

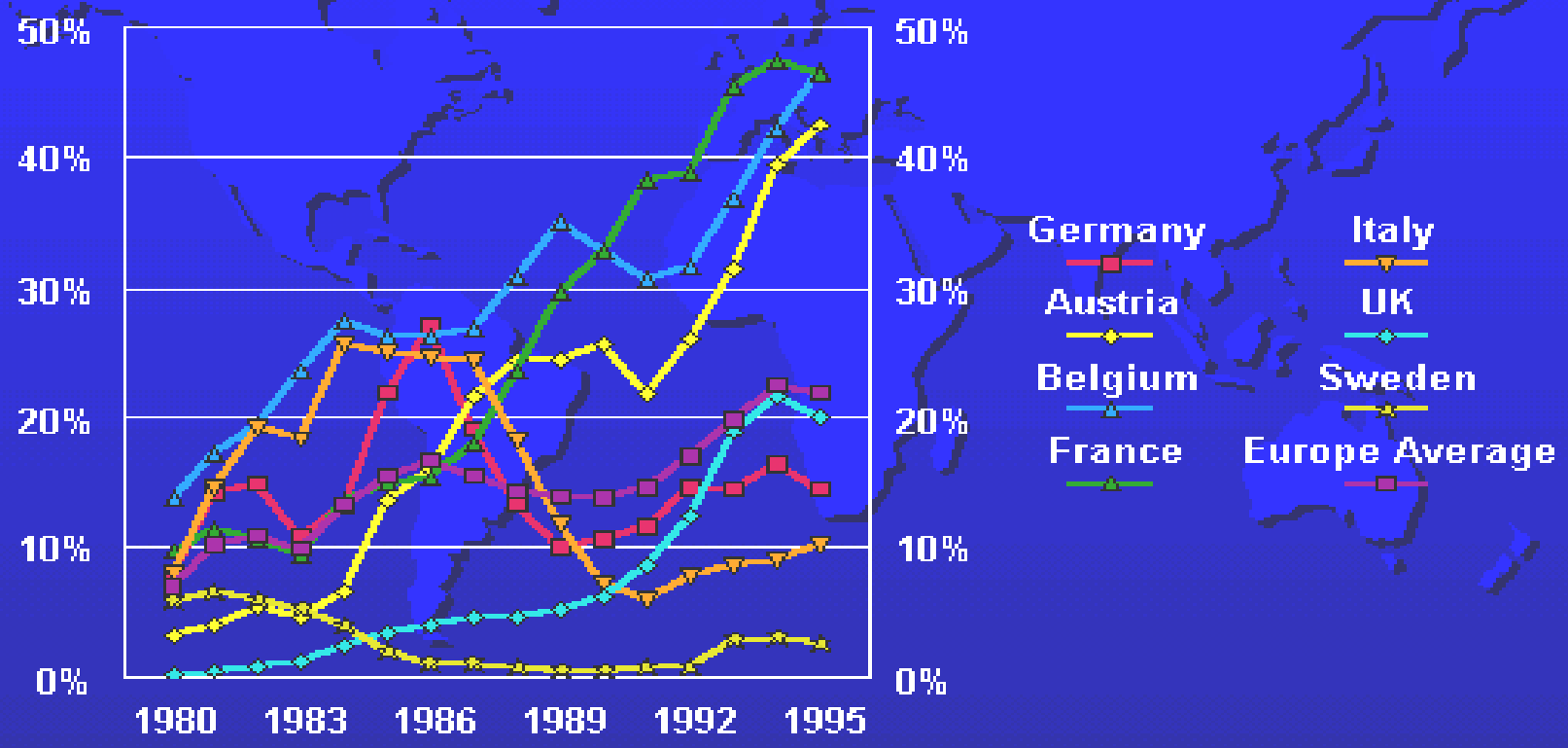
Introduction

- Diesel is a popular engine for cars and light-duty trucks
  - Favorable tax differential (France)
  - Fuel efficiency and drivability (Germany, Italy)
  - Durability
- European governments need to keep a part of the fleet powered by diesel engines to optimize any barrel of imported crude
- But the public is becoming increasingly concerned with diesel exhaust, especially particulates

Introduction
(continued)

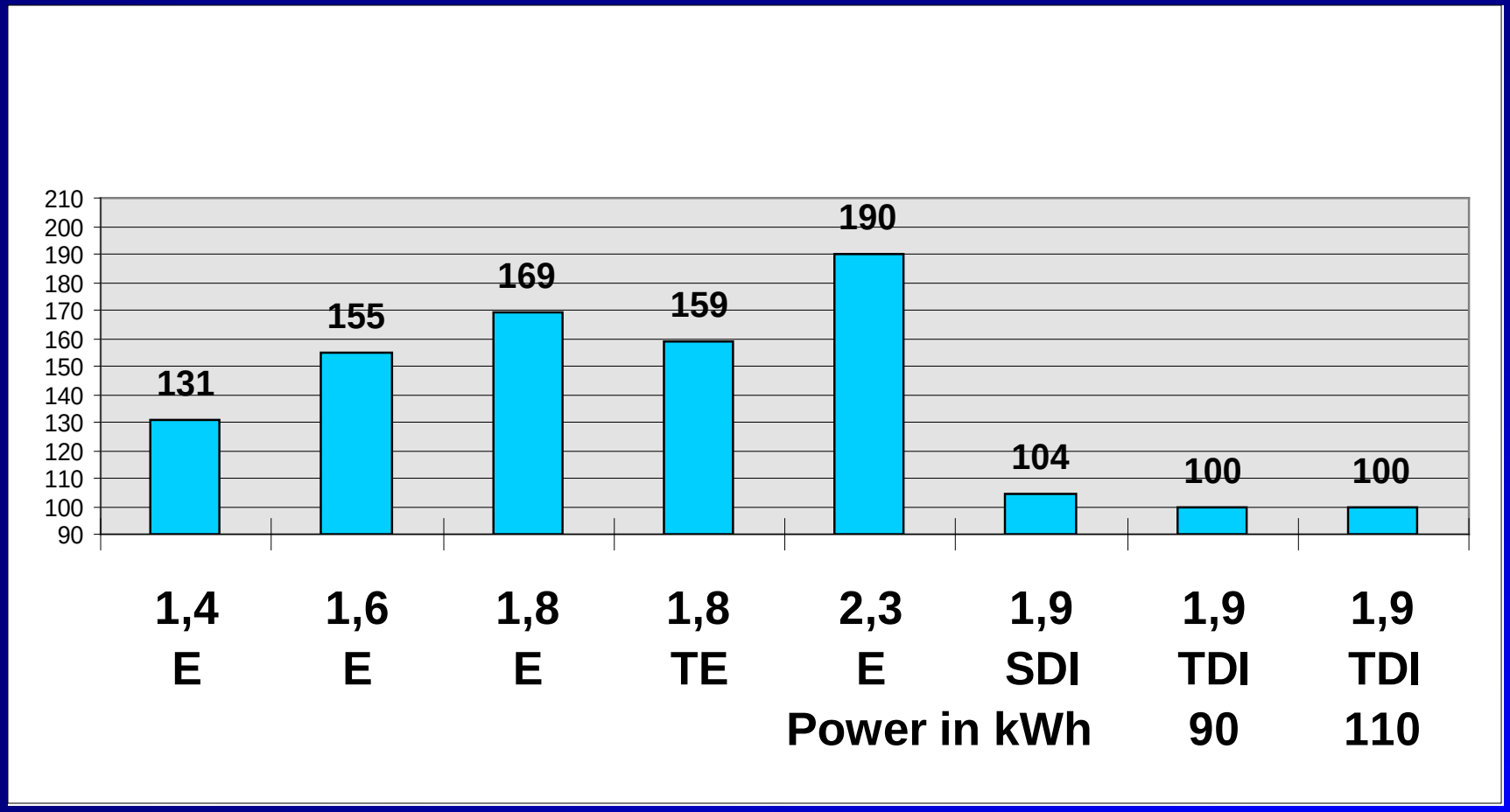
- To achieve a good balance between pollution control and fuel economy, the EU established unprecedented, ambitious emission standards, simultaneously regulating vehicle emissions and fuel quality in 2 stages : 2000 and 2005
- The Council of Ministers of the EU announced its determination to force the use of filters on all trucks by 2005

Penetration of Diesel Cars in Europe
(% of New Sales)



Courtesy of Michael Walsh

CO_2 Production with Different Engines on the VW GOLF 1997 Chassis



Origin : Volkswagen

Major Health Concerns from Motor Vehicle Pollution in Europe

- Ozone less of a public concern due to climatic conditions especially in northern Europe which has the highest ecological sensitivity
- With a large proportion of diesel light duty vehicles in the cities, the public and the media concentrate their criticism on diesel
  - Diesel has the image of being a dirty engine that emits offensive odors
  - Public perception is that PM emissions increase the asthma risk for young children and worsen existing asthma/bronchitis symptoms

Major Health Concerns
(continued)

- Major concerns of health officials
  - Potential lung cancer risk is not the primary health concern, for which the last cancer assessment was by IARC in 1988
  - Most of debates on PM emissions concern risks associated with short peak exposures for the persons at risk (children and senior) : asthma, chronicle bronchitis, cardiovascular-vascular crisis, blood pressure
  - Recent studies which have been consolidated at the EU Commission level show correlation between PM peaks and increased morbidity and mortality of persons at risk (increasing the concern of **non-drivers)**

Major Health Concerns
(continued)

- Trend in Europe is to focus on issue of particle size and number rather than mass emissions only
  - The British, German, Scandinavian and Swiss health communities recommend focusing on particle size/number
  - PM inventories in Great Britain and the Netherlands show diesel PM is the highest contributor to PM <1 micron and 0.1 micron
  - Fraunhofer Institute study prepared for German EPA (UBA) confirmed that the ultra fine solid PM are the most important parameter for evaluation of health risk
  - Fraunhofer study revisited the risk of cancer based on IARC and concluded that the risk associated with filtered diesel exhausts is equivalent to those of properly catalyzed gasoline cars or CNG buses
  - The British and German Governments are recommending that a PM reduction of at least 90% is a priority, especially for heavy-duty vehicles

US & EU Standards for Heavy Duty Engines

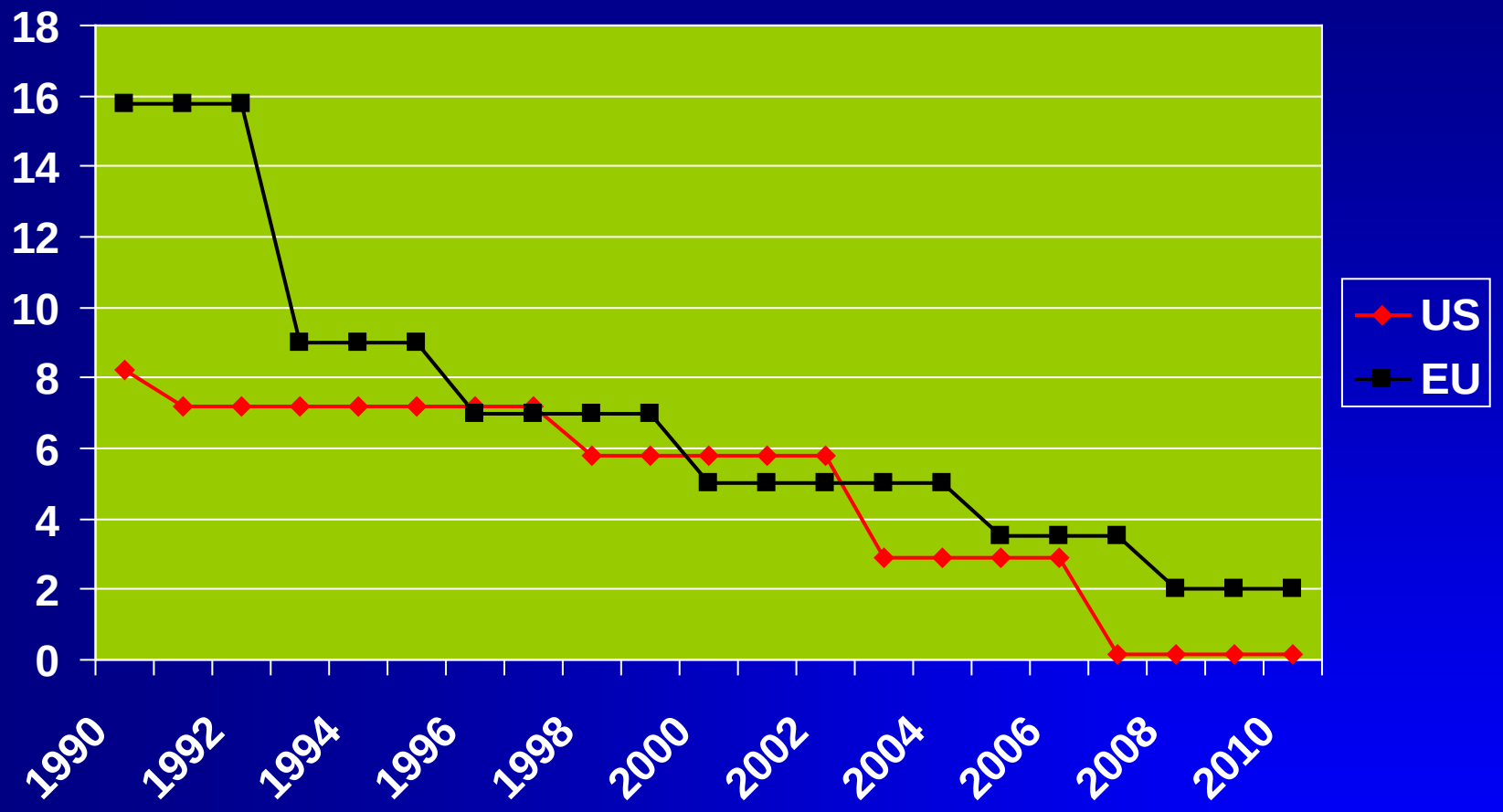
Model Year	US	EU
1990	8.2	15.8
1991	7.2	15.8
1992	7.2	15.8
1993	7.2	9
1994	7.2	9
1995	7.2	9
1996	7.2	7
1997	7.2	7
1998	5.8	7
1999	5.8	7
2000	5.8	5
2001	5.8	5
2002	5.8	5
2003	2.9	5
2004	2.9	5
2005	2.9	3.5
2006	2.9	3.5
2007	0.16	3.5
2008	0.16	2
2009	0.16	2
2010	0.16	2

NOx grams per kwh

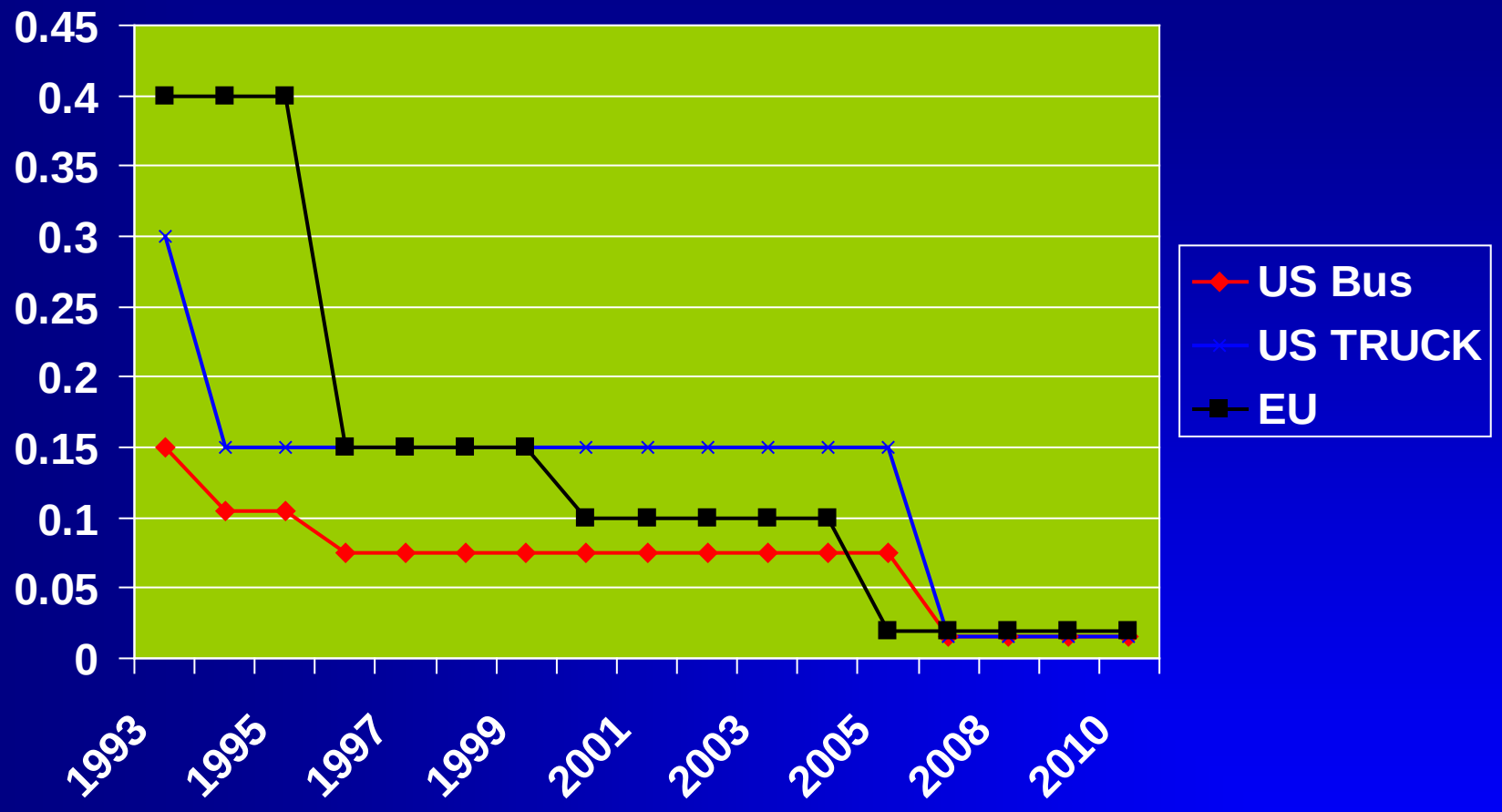
Model Year	US Trucks	US Buses	EU
1993	0.3	0.15	0.4
1994	0.15	0.105	0.4
1995	0.15	0.105	0.4
1996	0.15	0.075	0.15
1997	0.15	0.075	0.15
1998	0.15	0.075	0.15
1999	0.15	0.075	0.15
2000	0.15	0.075	0.1
2001	0.15	0.075	0.1
2002	0.15	0.075	0.1
2003	0.15	0.075	0.1
2004	0.15	0.075	0.1
2005	0.15	0.075	0.02
2006	0.15	0.075	0.02
2007	0.015	0.015	0.02
2008	0.015	0.015	0.02
2009	0.015	0.015	0.02
2010	0.015	0.015	0.02

PM grams per kwh

US and EU Heavy Duty NOx Standards (g/kwh)



US and EU Heavy Duty PM Standards (g/kwh)



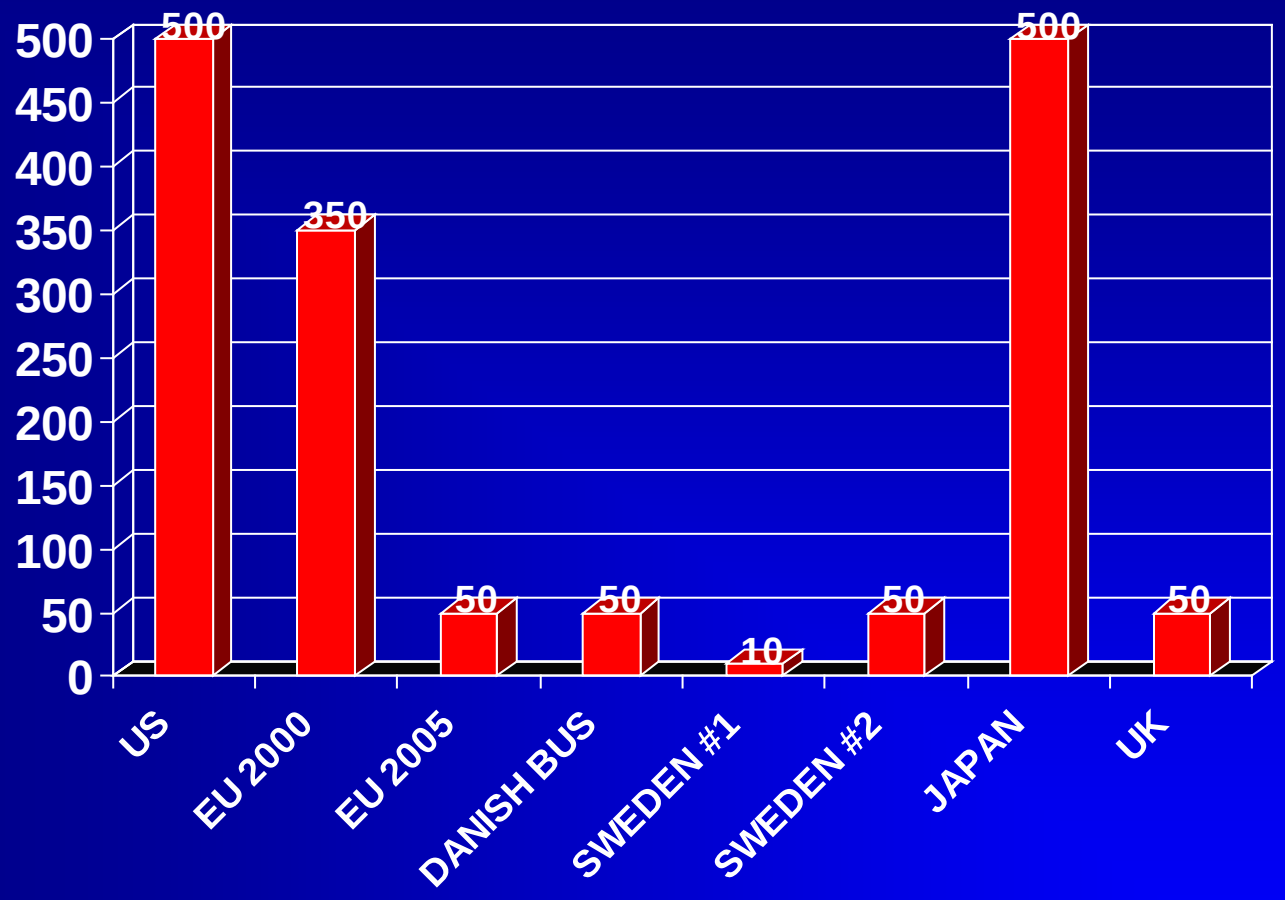
Current and future EU fuel specifications

Mandatory fuel specifications for gasoline and diesel in two stages - 2000 and 2005:

DIESEL	*2000*	*2005*
Cetane #	51	-
Density 15 oC	845	--
Distillation 95%	360	-
Polyaromatics	11	-
Sulfur (ppm)	350	50

PETROL	*2000*	*2005*
RVP Summer	60	-
Aromatic Content	42	35
Benzene	1	-
Olefins	18	-
Oxygen	2,7	-
Sulfur (ppm)	150	50

Diesel Fuel Sulfur Specifications (ppm)



Courtesy: Michael Walsh

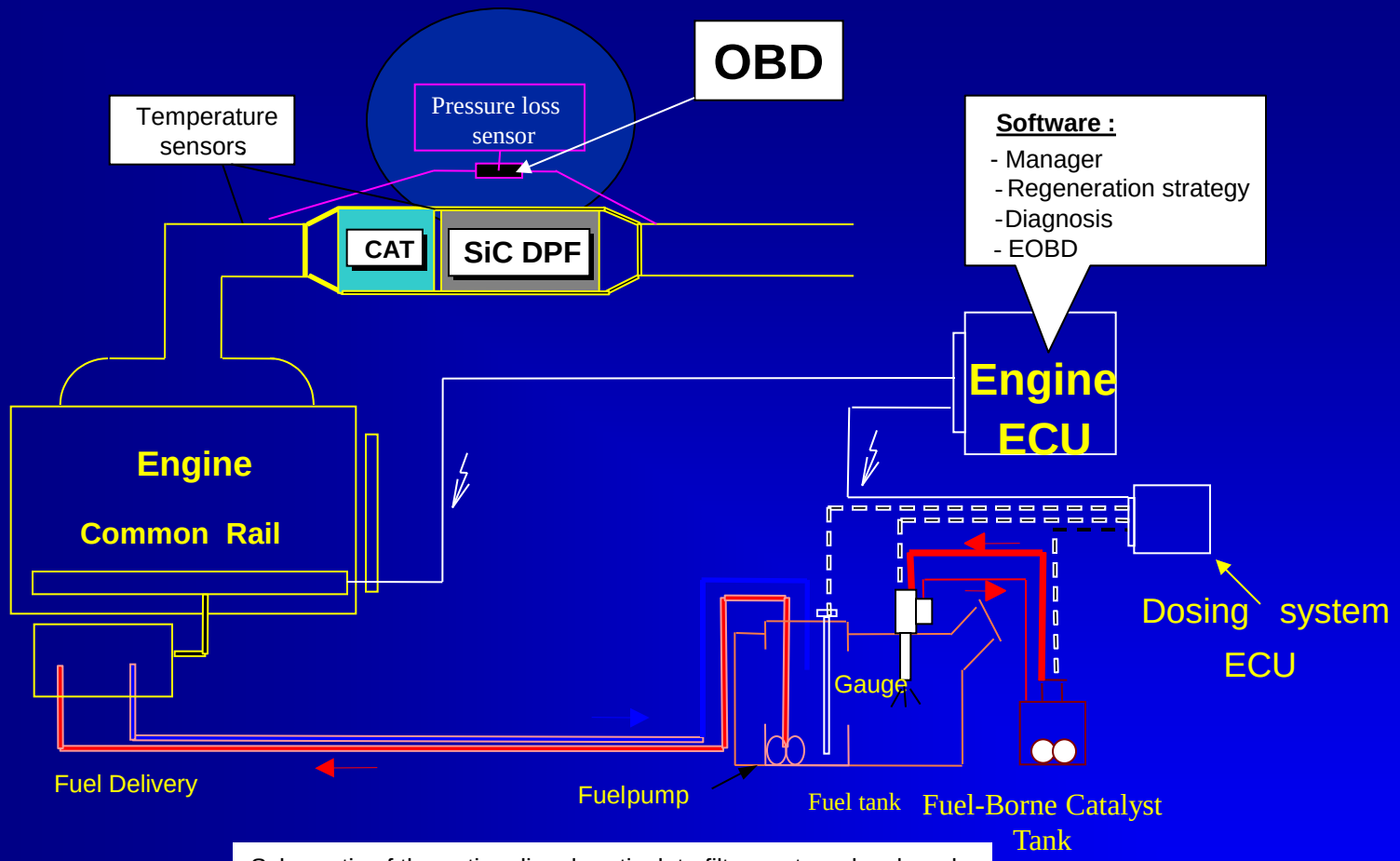
Incentives for Lower Sulfur Diesel Fuel in some European States

- Finland, Sweden and UK have tax differentials which favor low and ultra-low sulfur fuels. This tax differential is told to cover the extra refining cost.
- All UK diesel fuel sold today is < 50 ppm sulfur
- Germany plans to increase the tax on fuels with sulfur higher than 50 ppm beginning November 2001. The EU Commission has stated the extra tax is permissible
- Germany also proposed to move the threshold of this tax increase down to 10 ppm beginning January 2003. The EU Commission has not yet accepted the proposal
- Niche markets exist for low sulfur diesel for bus fleets in some countries

Series Production of DPF on a Commercial Passenger Car : PSA

- Beginning May 2000, the Peugeot 607 luxury sedan will be sold with a diesel particulate ceramic filter regenerated by a cerium based fuel-borne catalyst (FBC) combined with engine management.
- Other models of Peugeot and Citroen equipped with filters will be introduced in the near future.
- Regeneration is achieved by the FBC when the exhaust temperature is 400/450°C, assistance to the regeneration is provided by fuel post injection (common rail) and oxidation catalyst (upstream of trap) in critical conditions such as slow urban traffic.
- Levels of PM mass emissions as low as 0.002 - 0.004 g/km have been achieved in the NEDC (identical to the PM mass measured in the dilution air used in the dilution tunnel)
- When expressed in terms of the number of particulate, the filter efficiency is close to 100%

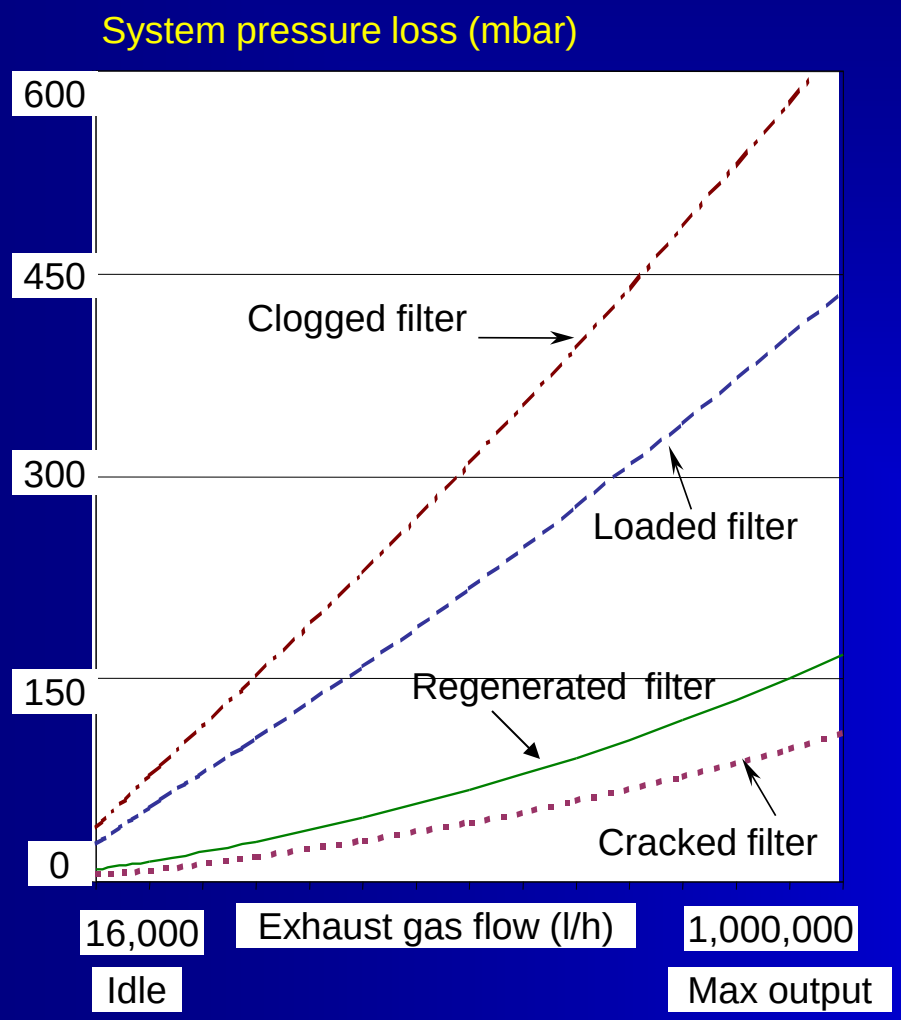
PSA PM Filter System for LDV



Schematic of the active diesel particulate filter system developed

Courtesy of PSA Peugeot-Citroen

Diesel PM Filter OBD

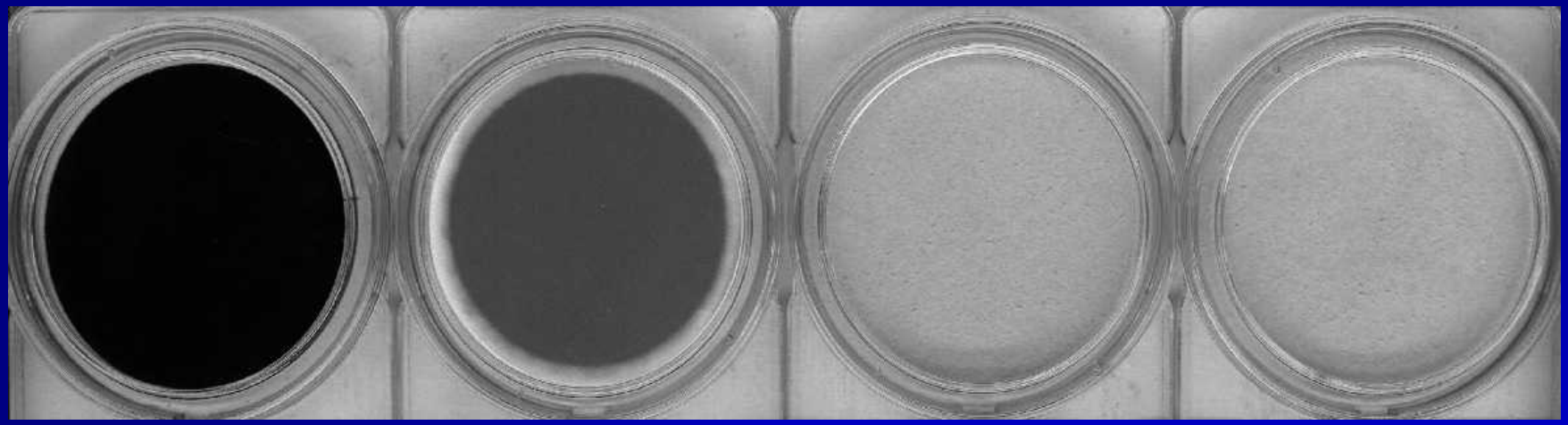


Pressure loss sensor acts as the DPF OBD monitor

- when pressure loss does not increase the DPF is cracked
- when pressure loss increases higher than the defined upper limit, DPF is clogged due to failure of regeneration process
- when pressure loss evolves normally, the regeneration process works properly
- when the filter is cracked, injection of fuel-borne catalyst is stopped

Courtesy of PSA

Emissions: PM Mass Identical in Exhaust and Tunnel Air Dilution

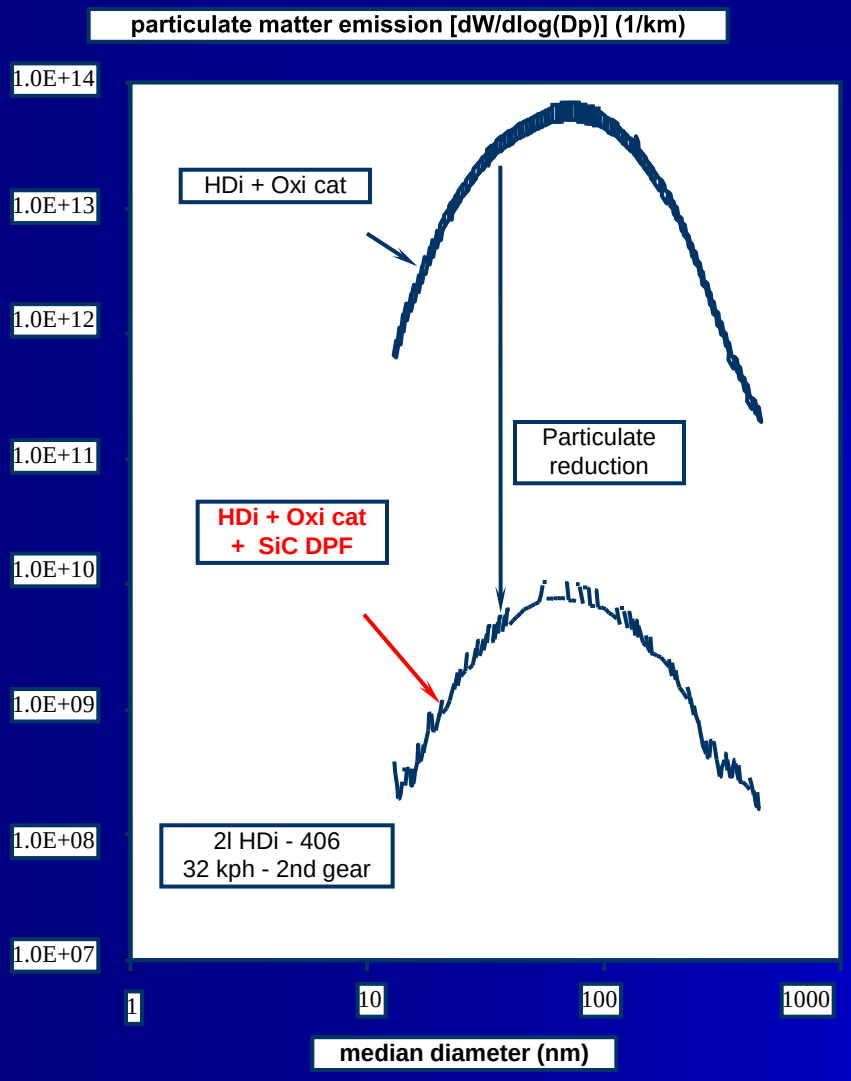


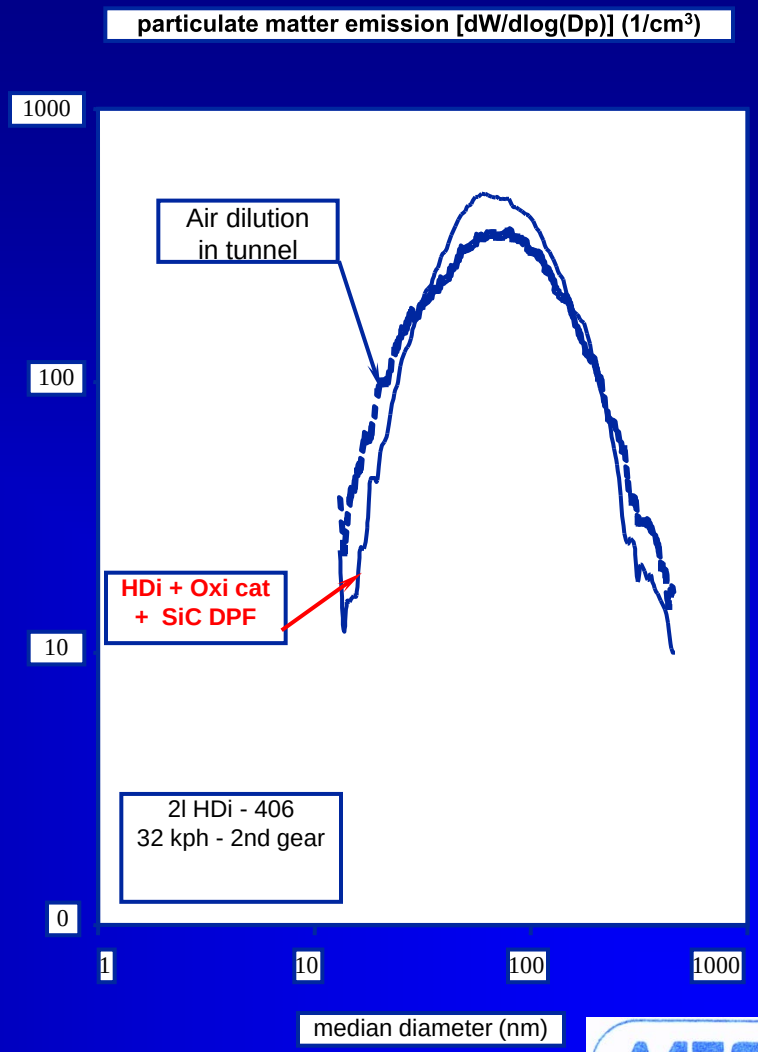
605 - DK5	605 - HDi	605 - HDi + DPF	Air Dilution
Particulates 0.1 g/km	**Particulates 0.035 g/km**	**Particulates 0.004 g/km**	**Particulates 0.004 g/km**

Particulate Matter Emissions in Mass (NEDC cycle)

Courtesy of PSA

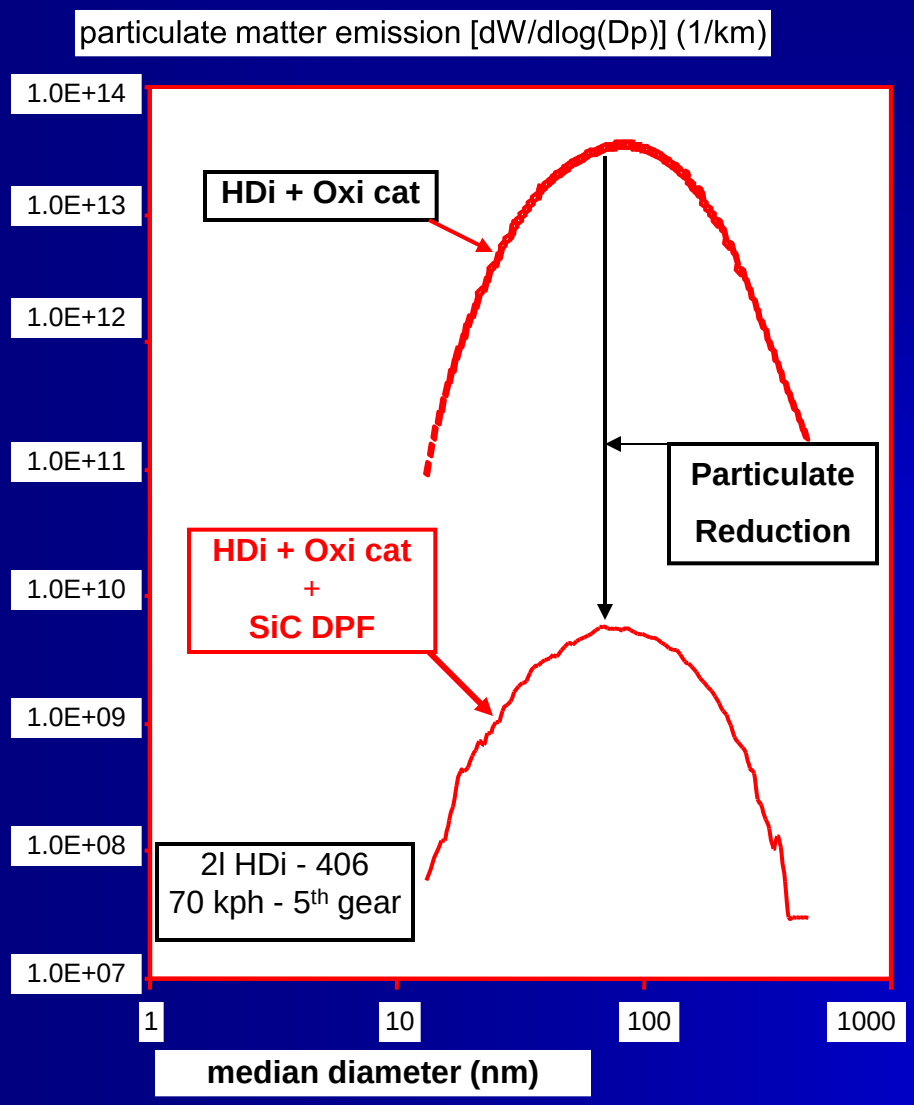
PSA Filter Efficiency in Numbers of PM at 20 mph, 2nd Gear

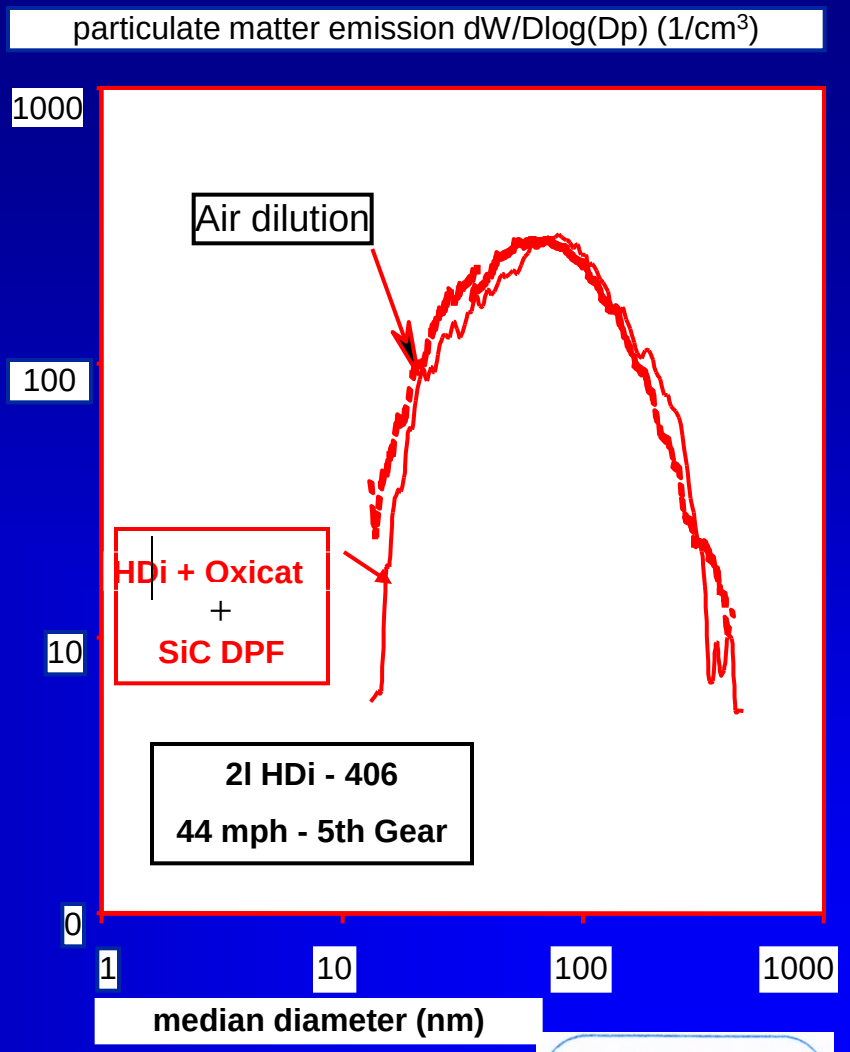




Courtesy of PSA

PSA Filter Efficiency in Numbers of PM at 44 mph, 5th Gear





Plans of Other LDV Producers in Europe

- Renault announced in November 1999 the introduction of a DPF on its new luxury sedan for the 2001 model year
- No other formal announcements, but presentations at technical conferences suggest that the DPF will be needed for the large sedans and SUV by nearly all the major producers
- Government pressure (e.g. German, UK, Swiss) to reduce PM number from diesels is causing manufacturers to consider DPF as the only medium term approach

Plans of HDE Manufacturers

- For NOx, major German and Swedish engine manufacturers are investigating the potential of SCR.
- The fact that heavy trucks operate in more than one country and may refuel in non EU countries is a problem for technologies requiring ultra low sulfur fuels.
- German and UK governments have taken the lead in calling for a 90 percent reduction in PM mass emissions as well as reductions in particle numbers and support requiring DPFs on all diesel vehicles.

Plans of HDE Manufacturers
(continued)

- Compliance with EU HDE 2005 limits will require only EGR + DPF or SCR + oxidation catalyst.
- Compliance with the EU HDE 2008 limits will probably require SCR + DPF.
- HDE engine manufacturers have not clearly expressed their strategies for meeting the future EU HDE standards

Conclusions

- For cars and light trucks, US and European emission standards are closer than ever, but with the implementation of LEV II and Tier 2 the US will be move ahead of the EU
- The EU 2005 standards (Step IV) is probably the last time diesel engines will be able to certify to standards less stringent than standards for gasoline-powered cars and light trucks
- New HDE test cycles are now comparable, but Europe is focusing more on PM, while US require more stringent NOx limits

Conclusions (continued)

- While the major European problem with PM is urban pollution, no specific standards for urban buses or retrofit initiatives are in place at either the EU level or at the individual country level
- DPFs are now in commercial application on commercial passenger cars
  - Measured control efficiency close to 100% for both mass and number of particles
  - Absolute zero PM could not be measured with a dilution tunnel as the air dilution already contains PM

Conclusions (continued)

- In 2005, the EU will be first region in the world to have a 50 ppm sulfur limit for on-road fuel
- Some countries have already introduced or are considering to introduce tax incentives or tax penalties in order to reach the 50 ppm sulfur limit earlier than 2005 (Austria, Denmark, Finland, Germany and UK)
- Sulfur lower than 50 ppm is being sought by ACEA (Engine Makers Association) and is supported by German Government (10 ppm is the target), but will face some strong opposition from the countries of southern Europe and the countries in the process of joining the EU