Best Available Technology for all Engines in Use!

Urgent Need for a Fleet Turn-Around Challenge for the OEM

Andreas Mayer

F.Legerer, John J.Mooney
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• Mobility at any price?
• Loosing the battle at the hotspots
• Progress with new engines too slow
• Upgrade tools for in-use engines
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• Retrofit or OE-upgrade
• Introduction of upgrade engines
• Who to start?
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Society needs Mobility
Road Vehicle Emissions By Country

Particulate Matter

Base Case

Million Metric Tons

Source: Mike Walsh
Mortality correlates with PM2.5

6-Cities-Study
USA 1978-93
15'000 cases

Correlation with fine particles only

Source: D.Dockery NEJM 1993
The weakest size range of the Lungs is the strongest emission range of the Engines and the weakest size range of Filters

*The Lung is an open door for engine emitted particles*
WHO 12. Juni 2012

„Diesel Exhaust Carcinogen Class 1“

237 years after P. Pott

IARC: DIESEL ENGINE EXHAUST CARCINOGENIC

Lyons, France. June 12, 2012 -- After a week-long meeting of international experts, the International Agency for Research on Cancer (IARC), which is part of the World Health Organization (WHO), today classified diesel engine exhaust as carcinogenic to humans (Group 1), based on sufficient evidence that exposure is associated with an increased risk for lung cancer.
### Mortality and Health Cost global 2012
**due to Traffic Emissions [per year]**

<table>
<thead>
<tr>
<th></th>
<th>Inhabitants Mio</th>
<th>Mortality x1000</th>
<th>Cost Mia €</th>
<th>Mortality per 1 Mio</th>
<th>Cost €/Pers</th>
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</thead>
<tbody>
<tr>
<td>USA</td>
<td>313</td>
<td>200</td>
<td>?</td>
<td>638</td>
<td>?</td>
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<tr>
<td>Kalif.</td>
<td>38</td>
<td>9</td>
<td>?</td>
<td>236</td>
<td>?</td>
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<tr>
<td>London</td>
<td>8.1</td>
<td>4</td>
<td>23.4</td>
<td>493</td>
<td>2800</td>
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<tr>
<td>Schweiz</td>
<td>7.8</td>
<td>4.5</td>
<td>6.5</td>
<td>576</td>
<td>833</td>
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<tr>
<td>EU28</td>
<td>505</td>
<td>480</td>
<td>650</td>
<td>960</td>
<td>1390</td>
</tr>
<tr>
<td>World</td>
<td>7000</td>
<td><strong>7000</strong></td>
<td><strong>3'500</strong></td>
<td><strong>1000</strong></td>
<td><strong>500</strong></td>
</tr>
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*Like world war II*

12% of all death
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Claude Monet
1901
fascinated
„London-Smog“
London Smog 1952

6000 died within one week
6000 more within one month
8 month after replacing electric tram by Diesel buses
Electron microscopic analyses revealed the dominance of retained soot and a surfeit of other particle types. A variety of metal-bearing particle types were found in all compartments, but Pb, Zn, and SnZn types appeared the least biopersistent. The results support the acute toxicologic importance of ultrafine carbonaceous and metal PM. Key words: 1952 London smog, autopsy, lung.
Beijing December 2012
VERT - Retrofit Bus + Construction Machines

Beijing 20.12.2012 9:00
day before predicted apocalypse

DISCmini: 90'000 P/cm³
(60 nm $\rightarrow$ 20 $\mu$g/m³ BC)

PM2.5 official: 182 $\mu$g/m³
PM2.5 US: 320 $\mu$g/m³
(24h-mean value)
PM2.5 official
Bogotá 2013 VERT-Retrofit 12’000 buses

Foto tomada el 20 de abril de 2006 a las 8:30 a.m. (smog fotoquímico)

Foto: Juan Felipe Franco
Foto tomada el 3 de mayo de 2006 (segundo día para de transporte). 8:30 a.m.

Foto: Juan Felipe Franco
Teheran 2013 VERT-Retrofit 7’000 Buses
PM10 versus PM2.5 at inversion and dust event

- **Dust event**:
  - PM10: 435 µg/m³
  - PM2.5: 105 µg/m³
  - \( \frac{PM2.5}{PM10} = 24\% \)

- **Inversion**:
  - PM10: 150 µg/m³
  - PM2.5: 75 µg/m³
  - \( \frac{PM2.5}{PM10} = 50\% \)
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Emission Regulation PM

Übersicht der HD-Abgasgesetzgebung (USA & EU)
What happened to PNC while PM was reduced

Recent Test in Tel-Aviv – see paper in session 5
Coagulation

Brings PNC quickly to a saturation point while particle size is growing

Paper on Scavenging
Session 4B

\[ N(t) = \frac{N_0}{1 + N_0 K_0 x t} \]
\[ D(t) = D_0 x (1 + N_0 K_0 x t)^{1/df} \]

Source W.C.Hinds
Particle Emission of ICE

**Diesel**
- Sootpeak: 80 nm; $10^6$
- Ashpeak: 10 nm; $10^7$

**Petrol**
- Sootpeak: 30 nm; $10^5$
- Ashpeak: 10 nm; $10^7$

Soot and Ash Peaks
Source: M. Kasper
EU Strategy with Filters Euro-VI
EU Co-Decision (Art.12, Rec.15 - 2008)

• In order to achieve these environmental objectives it is appropriate to indicate that particle number limits are likely to reflect the highest level of performance with particle filters using best available technology

• .. the commission shall introduce particle number based limit values at a level appropriate to the technologies actually being used.
EU PNC-Regulation enforced the DPF but Only 2 % of the Population

- In Europe only onroad and only new, only Diesel
- US has no regulations which requires filters
- Asia and Latin America target Euro IV
- All activities are limited to new engines only
- We need a *turn-around* of the whole fleet
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Particle Filter für Diesel-Exhaust 1982
now over 40 Mio successful on the road

1982
Corning

1979
GM

1985
BBC
DB
65 Filter-Families VERT certified
Average 98.4 %, 25 % pass 99.8 %
Upgrade Tools

• High Efficiency Particle Filters for CI and SI
• Catalysis for Reduction of CO, HC, PAH, Soot
• DeNOx – however with a much lower priority
• Closed Crankcase to avoid Blow By HC-Emission
• Clean Fuels
• Low Ash Lubrication Oils (no regulation so far !)
• Nanoparticle Cabin Filters
• Engine Management upgrade Kits

and we must intensify inspection and maintenance
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Upgrade legally permitted?

- **Polluter Pays – Principle**
  The operator of a technical system is the polluter. He is legally responsible for all damages inclusive health effects due to operation. He may voluntarily upgrade his system to reduce cost and he can be forced to upgrade any time if upgrade is available. *Is a vehicle such a system? Of course.*

- **Road Vehicles lose Operation Permission if modified**
  by retrofitting you not only lose the permission to use a vehicle on public roads but you also lose the manufacturer guarantee

- **Governments can permit and require Retrofit (CH 1990)**
  you do not lose the permission to use a vehicle on public roads but you may lose the manufacturer guarantee

- **OEM can not upgrade a homologated Vehicle, unless**
  there is a regulation which permits or requires upgrade
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VERT 1993 -1998
Construction of the NEAT tunneling system
AQ-limit value 100 μg/m³ and carcinogenicity declared
PM defined by «solid particles 20-500 nm»
Air Quality in Swiss Tunnelling Sites
Filters obligatory for every Diesel Engine SUVA/H.Egli
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Table 1  Air pollution cost factors in EUR/ton of pollutant (€2008 values)

| Pollutant | PM$_{2.5}$ (exhaust) | PM$_{10}$ (non-exhaust) | NO$_x$ | NMVOC | SO$_2$
|-----------|----------------------|-------------------------|--------|--------|--------
| Region type | Metropolitan | Urban | Non-urban | Metropolitan | Urban | Non-urban | Metropolitan | Urban | Non-urban |
| Source | HEATCO | *UBA/HEATCO | HEATCO | *UBA/HEATCO | *UBA/HEATCO | *UBA/HEATCO | NEEDS | NEEDS | NEEDS |
| Country | | | | | | | | | |
| Austria | 482,200 | 155,900 | 80,700 | 192,900 | 62,400 | 32,300 | 13'600 | 1'600 | 10'000 |
| Belgium | 483,400 | 156,000 | 104,400 | 193,400 | 62,400 | 41,700 | 8'700 | 2'600 | 10'900 |
| Bulgaria | 70,500 | 22,700 | 18,100 | 28,200 | 9,100 | 7,200 | 7'100 | 400 | 6'200 |
| Czech Republic | 355,400 | 114,500 | 88,200 | 142,200 | 45,800 | 35,300 | 10'600 | 1'100 | 9'500 |
| Denmark | 436,400 | 140,700 | 51,300 | 174,500 | 56,300 | 20,500 | 5'300 | 1'200 | 5'700 |
| Estonia | 261,700 | 85,000 | 44,200 | 104,700 | 34,000 | 17,700 | 2'800 | 600 | 4'500 |
| Finland | 432,600 | 139,400 | 36,100 | 173,000 | 55,800 | 14,400 | 2'600 | 600 | 3'500 |
| France | 438,600 | 141,200 | 87,700 | 175,500 | 56,500 | 35,100 | 10'500 | 1'400 | 9'900 |
| Germany | 436,200 | 138,800 | 82,900 | 172,100 | 55,500 | 32,600 | 12'700 | 1'400 | 10'900 |
| Greece | | | | | | | | | |
| Hungary | 537,200 | 173,400 | 56,200 | 214,900 | 69,300 | 22,500 | 4'400 | 1'100 | 5'400 |
| Ireland | 397,400 | 128,400 | 72,300 | 159,000 | 51,400 | 28,900 | 9'500 | 1'100 | 8'700 |
| Latvia | 245,300 | 78,900 | 45,600 | 98,100 | 31,500 | 18,200 | 4'000 | 700 | 5'000 |
| Lithuania | 266,300 | 86,500 | 53,300 | 106,500 | 34,600 | 21,300 | 5'600 | 800 | 5'700 |
| Luxembourg | 877,100 | 282,400 | 125,000 | 350,800 | 112,900 | 50,000 | 12'700 | 2'400 | 10'300 |
| Switzerland | 498,700 | 160,500 | 82,400 | | | | 600 | 5'800 | |
| Poland | 248,900 | 79,900 | 74,700 | | | | 1'000 | 9'100 | |

Value chosen: 460 CHF/kg PM10
## Monetary Health Benefit

**DPF-Application on a Heavy Duty Truck**

<table>
<thead>
<tr>
<th>Specification</th>
<th>HDV+FFF</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PM-Emission (Euro III / 3)</strong></td>
<td>0.1 g/kWh</td>
</tr>
<tr>
<td>Mileage</td>
<td>1000 hrs/yr</td>
</tr>
<tr>
<td>Average Performance [kW]</td>
<td>100</td>
</tr>
<tr>
<td>PM Emission [kg/year]</td>
<td>10</td>
</tr>
<tr>
<td>Overall vehicle life [year]</td>
<td>15</td>
</tr>
<tr>
<td>Emission [kg/vehicle life]</td>
<td>150</td>
</tr>
<tr>
<td>Filter type</td>
<td>wall flow</td>
</tr>
<tr>
<td>Filter efficiency [%]</td>
<td>99.9</td>
</tr>
<tr>
<td>Health Cost [€/kg PM10]</td>
<td>460</td>
</tr>
<tr>
<td>Total prevented soot [kg/life]</td>
<td>150</td>
</tr>
<tr>
<td>Health Benefit [€]</td>
<td>69'000</td>
</tr>
</tbody>
</table>
Retrofit or OE-Upgrade?

• Retrofitters were the pioneers and continue to be the true pioneers in many areas but 50 small companies cannot solve this giant worldwide problem against the OE since retrofit is limited in volume and cost – strong limiting factors and here is the problem

we must involve the Engine OEM by Directives

• OEM know best how they can upgrade their own older generation engines at low cost and guaranteed quality. They know the clientele and applications, can use their sales and maintenance network and have the capacity

• and some have started to do so – some in cooperation with retrofitters (German Maut, Tunneling, LEZ)
Who to Start?

- EU must start and is best prepared: legally and technically
- BAT is required because of carcinogenicity
- Retrofit regulations are in place with UN-ECE-REC
- BAT catalysed filter aftertreatment is available in large volume for CI and SI
- Cost Effectiveness is proven
- EU-Incentive regulations are in place
- LEZ-regulations are in place
- Retrofit has demonstrated feasibility during 20 years
- Polluter Pays principle is valid
- **Regulation must require OEM to provide BAT emission upgrade for their older generations** – faced-in gradually
WIN - WIN - WIN

- Fleet-wide Application of catalysed UFP-filters will eliminate health effects by vehicle emissions
- A large new Market created for 15-25 years
- OEM can solve this with available, proven and cost effective technologies
- Health cost will be much reduced and will cover all investment with a 10:1 benefit/cost ratio
- Upgrading becomes excellent new business for OEM
- This can start immediately or who will take the responsibility to delay it?