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PARTICLE FILTERS FOR ALL INTERNAL COMBUSTION ENGINES

Successfully introduced
to eliminate the health risk from air pollution

Background and Facts
for the period 2000-2015
with an outlook to 2020

Contents

Preface

DPF (Diesel Particle Filters) with filtration efficiency > 95% for engine generated solid nanoparticles are technically available since 1979. The major manufacturers CORNING and NGK have sold these since 1982. The original design of fine cells (100-200 cpsi) extruded ceramic (mostly cordierite) wall-flow filters with pore size of 10-20 µm has prevailed and remained almost unchanged. These filters were even then ready for deployment. But the air quality authorities did not perceive the benefits. They decided the particle mass PM limit such that engine management was sufficient and exhaust-gas filtration avoided. Intentionally misleading was the deployment of DOC and open filters, thus ignoring the risk of increased NO_2 emission due to the use of precious metal coatings. This blunder only ended with the specification of the PN particle count criterion in the toxic size range 10-500 nm during the Swiss VERT Project (starting 1995). Consequently, only those DPF are eligible and are considered in this study that comply with the PN criterion, often exceeding 99% filtration.

1. Motivation – Health Effects and Benefit/Cost

Solid particles from engine combustion are certainly the most dangerous Toxic Air Contaminant TAC in urban exposure. European estimates are 450'000 premature deaths annually through heart attacks, brain strokes and cancer. The global estimate is close to 7 millions annually. Other diseases caused are Alzheimer and Parkinson. A Diesel car without DPF emits about 0.1 g/km. Thus during 10 year operation about 10 kg nanoparticles of soot and metal oxide particles are emitted. 1 kg of these particles cause about 2000 € external health costs, i.e. a vehicle causes health damage of about 20'000 €, which is comparable to the vehicle's purchase price. This enormous damage can be prevented by deploying the DPF, which including maintenance and replacement costs < 500 €.
→The **benefit/cost ratio** is **40:1** for modern cars with DPF**!**

Retrofitting is mostly done on utility vehicles that are estimated to emit 0.1 g/kWh during 1 million km. The total emission is thus about 100 kg and cause health damage of about 200'000 €, which is also comparable to the vehicle's purchase price. The retrofitted DPF including maintenance and replacement costs 10'000 €.
→The **benefit/cost ratio** is **20:1.**

Summary: DPF are the only the perfect method to eliminate the emission of carcinogenic combustion particles. The monetary health benefits are 10-40 times the costs.

2. Retrofitting of DPF

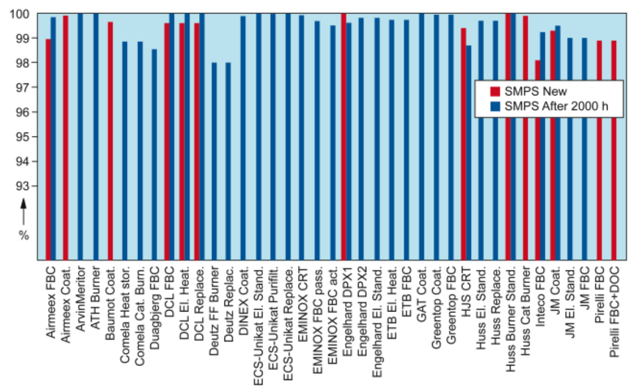
2.1 The Swiss VERT Project and its pilot impact

In 1993, Switzerland sought to eliminate the particle emission of construction machines in tunnel construction. Else the 57 km long transalpine high-speed rail tunnel system could not have been constructed. Rigorous retrofitting of Best Available Technology BAT filters ensured workplace air quality. Simultaneously, the medical and biological aspects of particle toxicity were researched, the particle count PN criterion was introduced, the necessary measurement instruments developed, and the VERT filter certification including suppression of secondary emissions was defined.

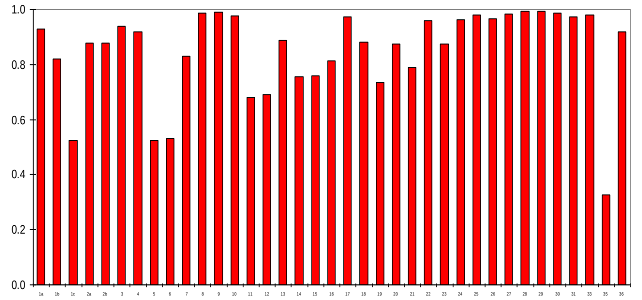
This complete package was the foundation for a sustainable filter policy for all Diesel engines powering Swiss construction machines, utility vehicles, locomotives and ships. Moreover it was the basis of European standards Euro 5b and Euro VI, the NRMM standard and the requirement of GPF and thus the prevalence of particle filters for all combustion engines. All technical findings of the VERT Project remain completely valid.

Year	Fuel Sulfur ppm	Retrofit total	Retro-Fitters	Failures % p.a.	VERT Certified	Comments
1988	2'000	100	2	>10	-	
1992	2'000	350	2	>10	-	
1995	500	500	3	>10	5	
1998	500	900	8	10	16	PN filtration > 95%
2000	350	2'500	12	8	23	15 DPF de-certified - insufficient reliability → endurance 2000 op.hrs test introduced
2002	50	4'900	7	3	8	
2003	50	6'500	11	2	22	
2005	10	11'500	21	2	30	PN filtration > 97%
2007	10	17'500	26	2	50	
2010	10	25'000	30	<2	71	
2012	10	35'000	30	<2	75	
2015	10	46'000	32	<2	80	PN filtration > 98%
2020	10	55'000	35	<1	85	Targets

Table 1: DPF Retrofit in Switzerland: construction machines (90%) public transport buses (100%), locomotives (>60%), stationary engines, industrial vehicles and ship engines



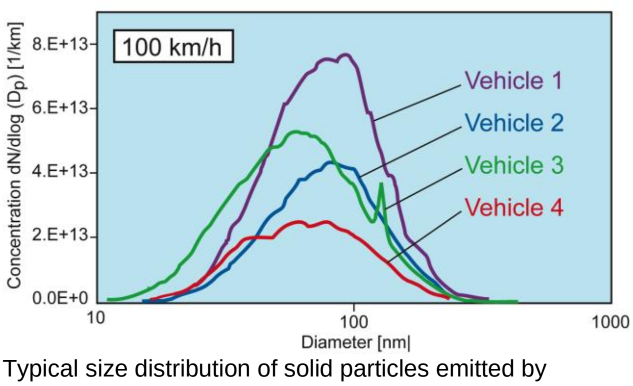
Filtration efficiency [%] as per particle count PN 10-500nm Before and after 2000 hours duration test (statistics 2006)



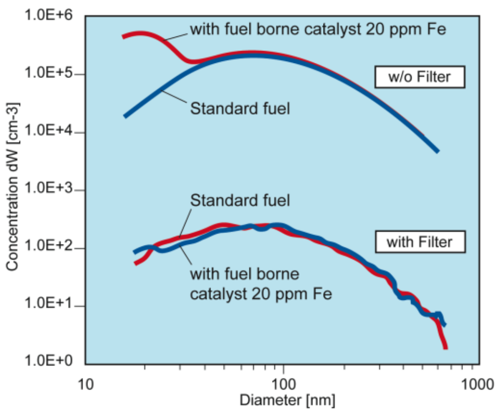
Reduction of Carcinogenic PAH deposited mass on the particles (statistics 2010) "1.0" means 100% reduction

Fig. 1: Filtration of solid articles 10-500 nm (left) and PAH reduction by catalytic coatings (right)

Consistent with the VERT principle of Best Available Technology, the requirements were continuously tightened as technology advanced. The left Fig.1 demonstrates the achievable filtration efficiency. The right Fig.1 shows that in addition to filtering the solid particles, other toxins are very effectively removed demonstrating that catalyzed particle filters are a detoxification technology for all engine-emitted toxic substances.



Typical size distribution of solid particles emitted by combustion engines



VERT-DPF are designed such that filtration efficiency covers the whole size range from 10 nm to 500 nm

Fig. 2 Solid particles of combustion engines are very small, smaller than natural particles. They must be perfectly filtered in the alveoli-penetrating size range of 10-500 nm

Filtration of these small particles is not by a “sieve” effect but by diffusion at low flow velocities – and diffusion becomes more active the smaller the particles are. This disproves the naive erroneous claim that the smallest (most toxic) particles cannot be filtered.

However, there are many DPF marketed even today that do not achieve this quality.

VERT certification ensures the best selection.

There were total 46‘000 retrofits in Switzerland in 2015. Subsequently there are less retrofits as a plateau is reached and all new vehicles are already delivered fitted with DPF.

2.2 Major retrofit projects worldwide (numbers in 1000; only full-flow filters)

Most countries first retrofit the public buses. Subsequently, some countries launched major projects. Examples are VERT tunneling in Switzerland, motorway tolls and LEZ (Low Emission Zones) in Germany, the 2 stage LEZ in London and greater London, and LEZ in Italian cities. Other big projects are in Seoul/Korea, in Japan and in Santiago de Chile.
Upcoming and very promising projects are now in Iran, Israel, China, Mexico, Chile and Colombia. Pertinent data is in Table 2 and Fig.3.

	Y2001-Y2005			Y2006-Y2010			Y2011-Y2015			Y2016-Y2020			Total
	Bus	Truck	NR	Bus	Truck	NR	Bus	Truck	NR	Bus	Truck	NR	x 1000
Switzerland	3	1	7	2	1	11	3	2	16	-	1	8	55
Germany	20			25	50		5	50				40	190
Italy	10			20			15						45
France	7			3			2					10	22
G.Britian	9	11			12			10	1			5	48
EU-Rest	15			15			15						45
EU Indoor			50			75			75			50	250
USA	20	10		12	22	2	20	28	7	10	20	10	161
Latin Amer.				3			1			10	40	10	64
Iran										8	35	2	45
Israel										4	5	2	11
Korea	10	20		20	130		20	80		20	70		370
Japan	30	30		30	30		30	30		-	-		180?
China				4	4		15	10	1	50	30	50	164?
Asia-Rest	15			15			15			25			70
Sum	139	72	57	149	249	88	141	210	100	127	201	187	
Total	268			486			451			515			
Total	1‘205 (Europe: 541)												1’720

Table 2: Retrofits worldwide (x 1000)

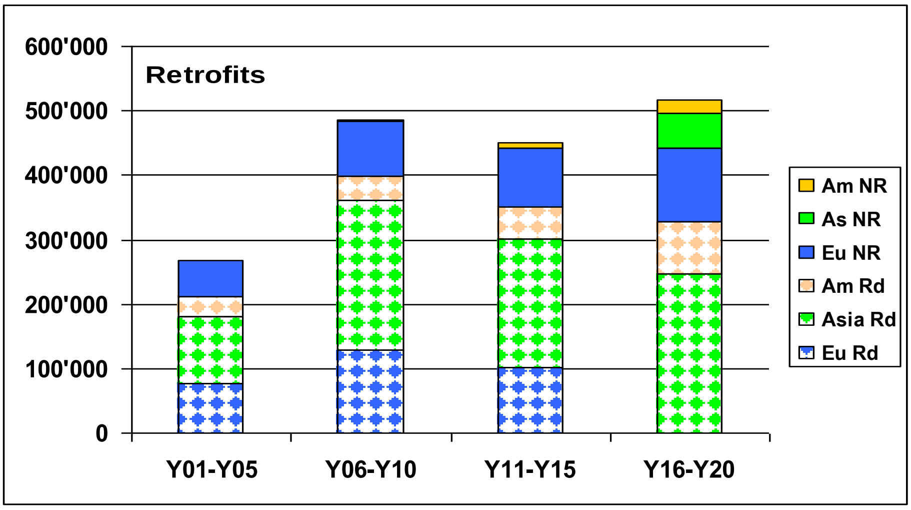


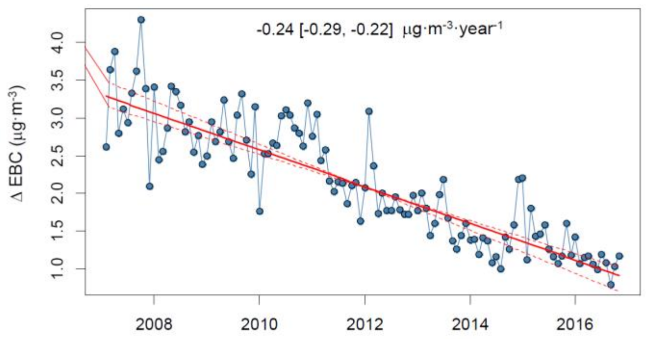
Fig. 3: Retrofits worldwide summarized from Table 2

“EU-Rest“ refers to the Scandinavian countries and BeNeLux. “Asia-Rest“ is Singapore, Taiwan and Hong Kong. “EU-Indoor“ refers to forklifts.

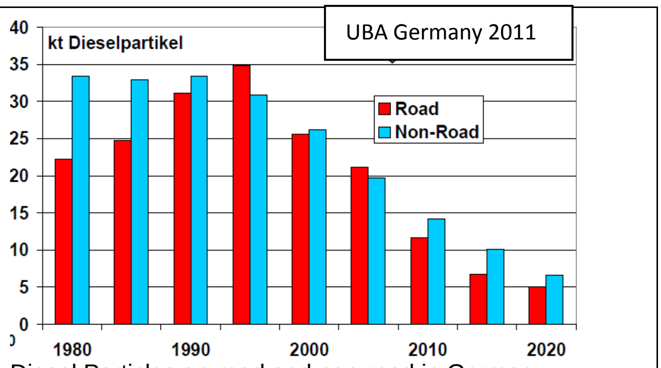
China had a project during the Olympics 2008 and now begins widespread deployment. The numbers are derived from numerous manufacturers’ sources. Only a few, such as Korea, USA, GB and Switzerland are from official statistics. The forecasts for Y2016 to Y2020 may be slightly optimistic. The EU would mandate retrofitting of construction machines in urban deployment. Large retrofit projects are anticipated in Asia and Latin America. The more uncertain forecasts are question marked.

2.3 Trends, gaps and new opportunities

The historic retrofitting trend is disappointingly slow and incomplete. Switzerland, London and Berlin succeeded through resolute retrofitting to lower the concentration of Black Carbon BC and the particle count PN to almost a third, within 15 years (left Fig.4). During that time period, PM10 remained almost unchanged. The data clearly indicates the powerful potential of DPF, which are highly advisable for the highly polluted megacities in Asia and Latin America.



Black Carbon at Swiss motorway junction Härkingen
Chr.Hüglin, EMPA, ETH-NPC 2017



Diesel Particles on-road and non-road in Germany
H.Jahn, UBA, 2011

Fig. 4: DPF reduces particle emission very efficiently as demonstrated by ambient air measurement (left). Non-road vehicles (urban construction) should be also DPF retrofitted

The right hand Fig.4 is data from the German Environmental Agency. The non-road urban machines, mainly construction machines, are emitting more particles than the road traffic. The urban environmental authorities appear helpless. Instead of discussing traffic restrictions, they should eliminate the emissions from non-road machines. That is easily done as proven in Switzerland since 1994.

2.4 The legislation – unfavorable historical trends outside Switzerland

The essential elements of developments in Switzerland were:

- The Swiss road regulators (Justice Department, later Roads Office ASTRA) issued a Directive in 1990. It permitted vehicle DPF retrofitting, provided that noise levels did not increase and no secondary toxins were emitted. Retrofitting had to be recorded in the vehicle registration document together with a test report that the retrofitter and operator prepared together. The operator was and still is responsible.

- Although the vehicle manufacturers cancelled all guarantees for retrofitted vehicles, their local dealers nevertheless honored the guarantees as a goodwill gesture.

- The emission limits were reformulated in 1997 and updated to the latest technology. The filtration was specified for PN 10-500 nm. Emissions were declared carcinogenic, to be minimized as best possible, and secondary emissions prohibited. This achieved maximum curtailment of emissions for all retrofits instead of prescribing general limits. Only VERT filters compliant with SN277206 were permitted. Every retrofit had to be tested and documented and required periodic retesting.

- The Swiss occupational health authority SUVA made DPF mandatory without exceptions (!) for all underground workplaces. The Air Quality Authorities extended the filter compulsion to all non-road engines, initially construction machines and subsequently locomotives, ships and public buses. These were legislated imperatives regardless of financing. Nevertheless some incentives were offered. Switzerland had EU treaty obligations to not discriminate against road vehicles that only complied with less stringent EU legislation. However public opinion (municipalities) often demanded the DPF option even for Euro III. Passenger cars, too, were often bought with DPF as soon as the Peugeot 2000 came with factory fitted DPF.

- The regional authorities (Swiss cantons) did spot checks of emission and imposed heavy penalties for transgressions. They also specified the particle count criterion.

Unlike Switzerland, the other European countries did not properly legislate for retrofit.

The following elements were particularly detrimental

- There was a patchwork of heterogeneous legislation because the EU did not insist on a standard procedure. This despite the consensus proposals that VERT had formulated with the EU's JRC Research Center in Italy in 2009 and presented in Brussels.

- All countries and cities continued to use the inappropriate metric of particle mass PM.

- All directives specified the tailpipe PM emissions. The filter efficiency was NOT specified. Instead the misleading criterion was the combination of engine and filter and this only limited the product of both but did not realize the best possible filtration in each case.

- This necessitated testing of every feasible combination of engine-families and filters.

- PM as false criterion resulted in misjudgment and poor filter quality, since PM-measurement at 52°C permitted condensation and did not detect ultrafine particles filtration deficiencies.

- The authorities at that time were satisfied with the PM level of Euro IV. Thus PM progress was negligible and no improvements made in curtailing PN

- Very often the emission limits were so lax that even DOC and open filters were deployed even in Germany and supported by tax payer's money

This lapse of the European air quality authorities reflects inadequate technical knowledge. They seriously damaged the reputation of retrofitting. The retrofit financing model was deficient and the quality assurance absent. The Authorities' unwillingness to learn stunted the retrofitting in Europe and also in USA.

The UN-ECE REC Project (2010-2014) reflected this blocked situation. PM unfortunately remained the metric. The certification procedure was very expensive and de facto ineffective. Only in a second edition in 2015 did they copy/paste the VERT criteria PN (10 years after VERT!) and limit secondary emissions. But they retained the scientifically meaningless measurement of combined engine and filter emissions at the tail pipe.

More hopeful are the newest EU emission limits. They recommend retrofitting vehicles in emission hotspots and make concessions in the financing (abandoning the de-minimis rule)

2.5 The evolution of the retrofit industry in a very difficult market

The retrofitters of the 1990s were all small and very entrepreneurial firms. Many failed: Pioneers without whose efforts this new technology of exhaust-gas filtration would not have established. The development was also inhibited because NGK and Corning held the patents for the extrusion of the ceramic substrate. Similarly Johnson Matthey held the patents for the elegant (but also emissions critical) NO_2 regeneration CRT procedure. Another hurdle was the high sulfur content of the fuel. However there was strong motivation to filter exhaust, e.g. the VERT project in Switzerland, the retrofit of bus fleets in big cities, and the workplace air quality in room interiors and underground construction.

These however, remained sporadic single projects that offered business opportunities for a few years. Then followed meager years. The breakthrough to widespread retrofitting did not happen because of the wavering Air Quality authorities, inadequate support from the medical physicians, and the irresponsibility of the politicians including the EU Commission: 450‘000 premature deaths were apparently not enough and the consequential costs were also ignored. Only a few firms mastered the DPF + DOC and SCR technologies. They made the filter substrate, did the catalytic coating and engineered the system controls. But none of them succeeded as large volume OEM vendors. Ibiden with the new SiC-technology became competitive with NGK and Corning – maybe only due to the PSA initiative.

The retrofit pioneers were significant contributors. VERT strongly supported them with technical advice and organized the international ETH Nanoparticle Conferences annually from 1997, which became the central event. VERT guided countless R&D projects at the Swiss Exhaust Test Center (University Biel), at the ETH / EMPA (Swiss Federal Institute of Technology, Zurich) and published the research results. These are the fundaments of the emission directives.

3. DPF in OEM new vehicles ex-factory “first fit”

3.1 The Peugeot Initiative in May 2000 and the background

Peugeot (PSA) was not reputed for engine innovation and in the 1990s lagged its peers. From 1997, the new management (M.Folz, from Rhone Poulenc) started a comprehensive upgrade of its Diesel engine family. This comprised high-pressure injection, common rail, electronic engine management and DPF. PSA’s DPF decision was bold and despite the automobile manufacturers rejecting DPF after the 1988 Mercedes disaster in California.

DPF were then not a regulatory requirement. PSA however understood that customers wanted environmentally friendly cars. PSA’s partners were Rhodia (earlier Rhone Poulenc with J.Lemaire, who contributed a Cerium based regeneration additive) and IBIDEN (Dr.Komori, who contributed the new segmented SiC-DPF). PSA Chief Engineer Dr.G.Belot, a frequent speaker at ETH-NPC was encouraged by the proven success of VERT.

The Peugeot 607 FAP (filtre à particules) roll out was May 2000. The German manufacturers reacted with protest and ridicule. Soon PSA began offering DPF also on their smaller cars with sales success. Ibiden built a factory near Paris in 2002 and delivered 1 million filters already by 2006!

The German Automobile Club ADAC (Dr.A.Friedrich, S.Rodt) started comparative testing of Peugeot vs. Mercedes and quarterly published the particle emission count. The Mercedes was each time emitting 1'000 times the PN of Peugeot 607. The buyers began to prefer Peugeot. The other car manufacturers began investigating options. To protect the reputation of German cars, Chancellor Gerhard Schröder convinced the German automobile manufacturers that all German brands must offer a DPF option starting 2008.

This was unique: emission curtailment without legislation. Prerequisites were the second AutoOil project lowering the fuel sulfur content to 10 ppm and suitable lube additives for the lubrication of injection pumps and camshafts.

3.2 The legislative progress for on-road and non-road

The essential aspects of the EU legislation that forced the DPF deployment were the following:

- PMP was a program for testing and approving a particle count measurement method for the type certification of new vehicles. This initiative started November 2000 in Switzerland together with a group of 5 EU member states and then continued under UN-ECE. This tedious process was only to confirm what Switzerland had 1998 implemented with the golden Instrument of Matter Engineering (M.Kasper). The UN procedure completed in 2007 and the UN published GRPE-54-08-Rev.1 (54th GRPE, 4-8 June 2007) UN Regulations 49 and 83. This paved the way for PN based emission legislation.

- The European Parliament and Council approved the Directive (EC) 715/2007 of 20th June 2007. The Directive specified a PN limit for cars and light commercial vehicles. It required, for the first time, that DPF with Best Available Technology shall be deployed to protect human health. The EU-Commission (Dr.N.Steininger) specified a PN limit value 6×10^{11} P/km according to the state of the art. This was seen feasible from existing DPF data. Note that this value is about 0.2 mg/kWh and thereby it is 50 times stricter than the previous gravimetric limit of 10 mg/km, which is now obsolete and superseded by Euro 5/6 legislation.

- The Directive (EC) 595/2009, for heavy-duty vehicles followed and specified a particle count limit 6×10^{11} P/kWh - Euro VI. This established the new concept of evaluating engine emissions based on the count of solid particles in the alveolar penetration range.

- The Commission Regulation (EU) 459/2012 of 29th May 2012 extended Euro 5/6 also to gasoline engines, unfortunately however only to direct injection.

- These new limits are mandatory for the type certification of
  - Diesel cars effective September 2011,
  - Diesel trucks effective January 2013
  - Gasoline cars effective September 2017
    (with a transitional limit of 6×10^{12} P/km from September 2014 till August 2017)

- The ongoing last phase is the NRMM guideline decision on Stage V. It covers many non-road vehicles and equipment requiring DPF. The pertinent European legislation is: CODEC of Parliament and council dated 8th July 2016 that annuls Guideline 97/68/EC and replaces it with the Directive (EU) 1024/2012 and 167/2013. These Directives would necessitate compulsory DPF fitting starting in 2018/19. The PN particle count is the specified metric. But at 10^{12} P/kWh is unnecessarily lax – using state of the art DPF it could be lowered to 10^{10}.

The OEM-DPF history becomes transparent by analyzing the Diesel engine production in the context of the emission legislation year by year – adding the initiatives of Peugeot and followers. For this we first present the number of Diesel vehicles LDV and HDV produced in Europe and the USA in the period Y2000-2016 and risk a forecast till Y2020:

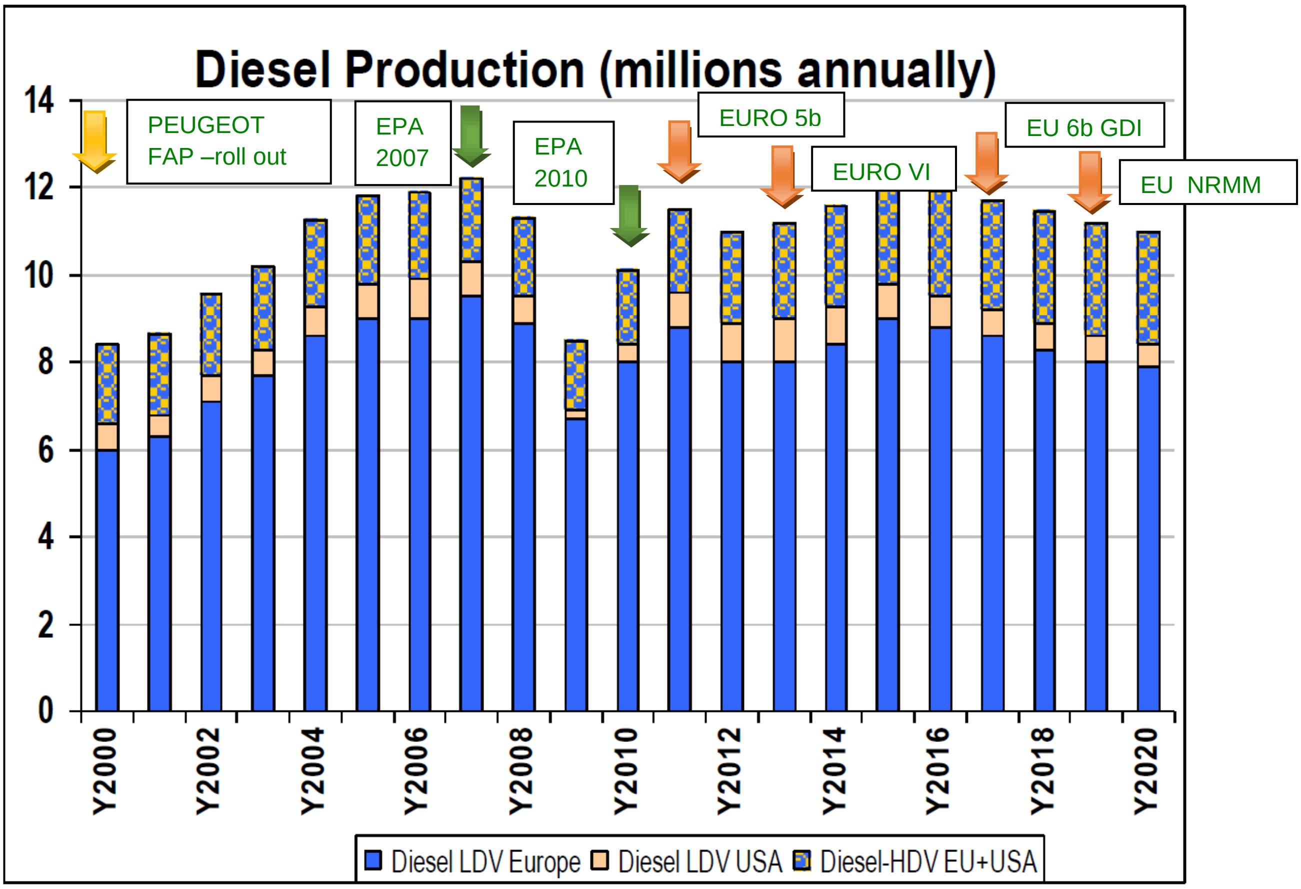


Fig 5 Diesel LDV and HDV production in EU and USA. Arrows show the emission legislation

From 2000, the Diesel market continuously increased because of the new technology with high-pressure common rail injection, supercharging, electronic engine control and catalytic after-treatment. The gasoline counterpart had to use catalysts and electronic control 20 years earlier. But the Diesel lagged behind until this became enforced by legislation.

Now Diesel has caught up and even expanded its traditional advantages like fuel economy. The VW-scandal apparently interrupted the trend.

The most significant European legislation step in this phase was the introduction of the PN criterion. Compliance was only possible using particle filters.

USA unfortunately until today has not yet adopted the scientifically compelling concept of a PN limit, despite the Californian CARB proposing it for ZEV (Zero Emission vehicle) in 2010.

Why are commercial vehicles nevertheless equipped with DPF in the USA since 2007? The simple explanation is that EPA 2007 did not approve SCR deployment, despite lowering the NOx and the PM limits. The manufacturers were forced to curtail NOx using exhaust-gas recirculation EGR with cooling. This inevitably increases engine PM emission considerably. The DPF was therefore essential. DPF continue to be fitted despite modern injection technology and EPA now permitting SCR.

Some vehicle manufacturers may stop fitting DPF since with new technology they can curtail PM without deploying DPF; a trend is already evident for non-road deployment.

3.3 DPF and GPF deployment trends: past, present and future

Fig.6 shows the number of Diesel filters substrate deployed in the EU and USA during the time period Y2000 to Y2015 and the further projection till Y2020.

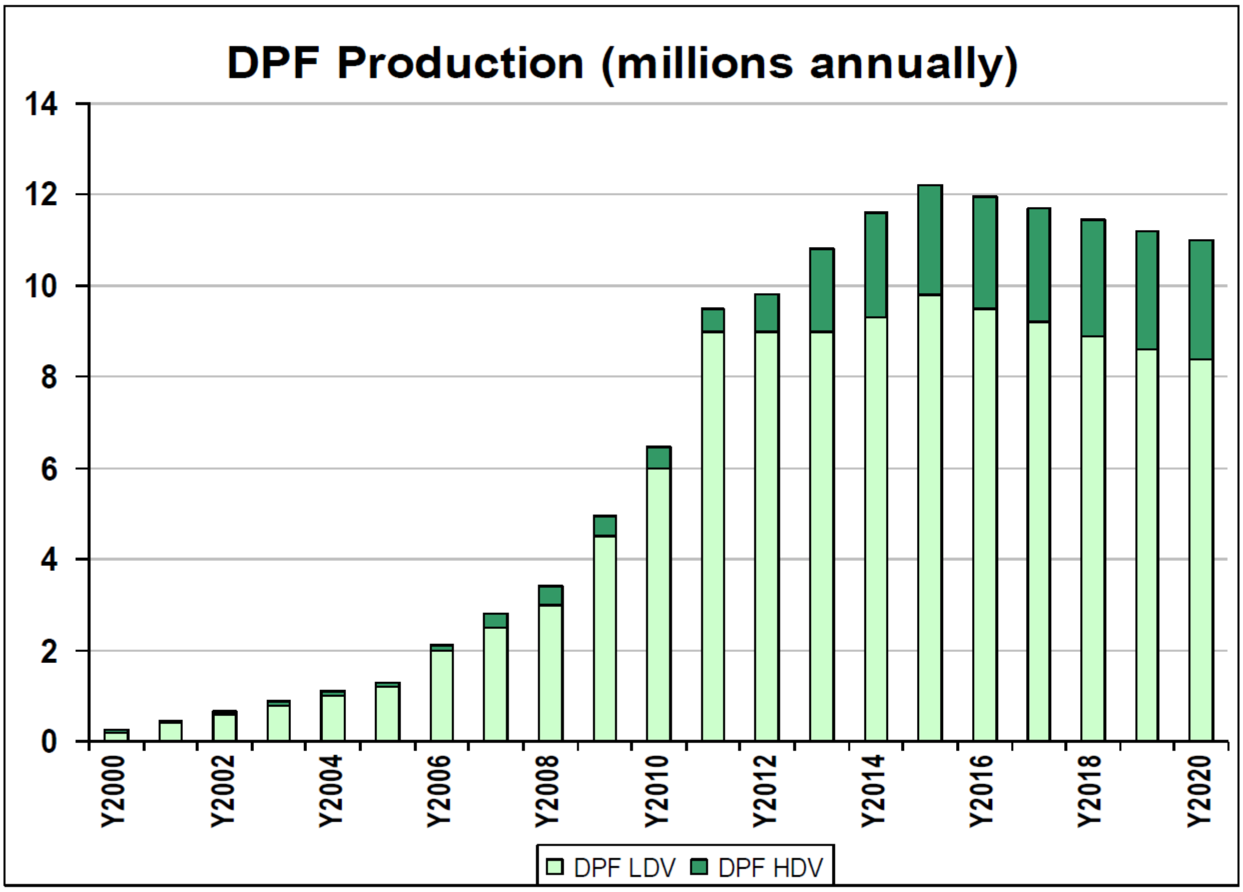


Fig. 6 DPF-Production annually for LDV and HDV – USA and Europe

Fig 6 shows the results of one data source, which we believe is a bit too conservative.
We estimate >100 million DPF have been manufactured till 2015.
The following two inputs substantiate our estimate:

- Leaders of the coating industry have confidentially indicated to us the total tonnage of substrate coated for LDV and HDV. Plausibly assuming the pertinent substrate weights, we deduce approximately 105 million DPF manufactured for Europe and 15 million for USA.
- A large substrate manufacturer has confidentially indicated to us its production statistics. Based on our estimates of its market share, we extrapolate the total substrate quantity manufactured till Y2015 of >130

But this is only Diesel.
After formulating the PN criterion, it was soon detected that gasoline engines also emit solid nanoparticles in large concentrations. This is particularly valid for gasoline direct injection DI-engines, which however will be needed to achieve the CO_2-limits. The forecast for Gasoline Particle Filters GPF for DI-engines is depicted in Fig.7.
It starts low, but as more and more manufacturers realize that they cannot achieve the Real Drive Emission RDE conformity limits nor the CO_2-limits this number is increasing and will double the total particle filter production soon.
But what about MPI, the port injected gasoline engines, which represent at least 50% of the total gasoline fleet. New data demonstrate that they, too, require particle filters.

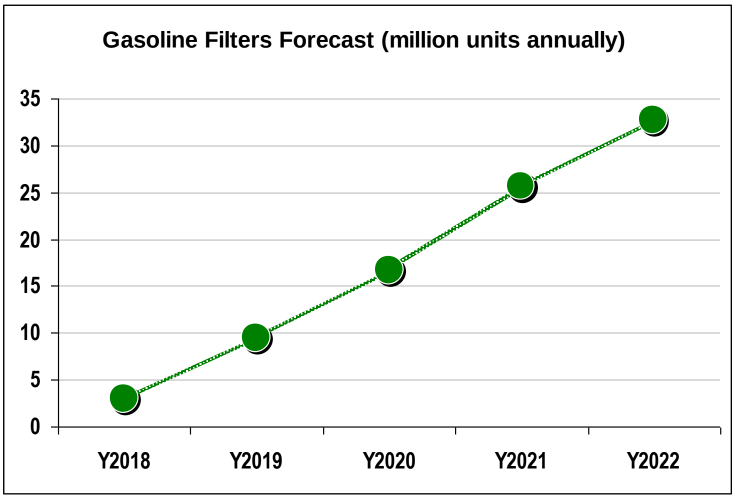


Fig.7 shows the anticipated manufacture of GPF - particle filters for gasoline engines during the next five years.

Moreover, non-road filter sales will increase due to compliance with NRMM so in total we will reach an anual manufacturing volume of > 25 million by 2020.

3.4 Quality assurance and replacement market

After implementing the European PN legislation, there are now more than 100 million in-use vehicles deployed with particle filters and soon there will be 200 million. The OEM filters are not substantially different from the retrofit filters. So cleaning from ash deposits will be required periodically and some repair and replacement might be needed. This technology is new. Failures are probable and may be high at the beginning.

The existing vehicle generations Euro 5 and Euro 6 were no longer compelled to periodic exhaust-gas measurement and inspection. Hence no official failure data is available. Fleet investigations in the Netherlands and Switzerland indicate failure rates in the range 7-11%. The failures are easily detected with a simple tailpipe measurement. Damaged filters emit impermissibly excessive emissions. When failure is detected, during the periodic exhaust-gas inspections PTI, then the filter must be replaced to restore functionality.

We estimate an annual replacement of about 10 million DPF for those deployed during the previous 10 years. This requirement will naturally decrease to about 1-2 million annually . The OEM will want to capture this replacement demand with original parts. The EU commission however, wants to support SME (Small and Medium Enterprises). The replacement market can be relatively large and lucrative for the SME that have gained expertise in retrofitting. The rules for filter replacement are the responsibility of the individual EU member states and are not established yet. The legislative process has commenced in Germany, in the BeNeLux countries and in Switzerland. The filter industry should get involved.

3.5 The structure of the supply chain

The automobile industry's OEM supply chain for exhaust-gas after-treatment equipment, both filters and catalytic converters, is split according to the production specialization. These are sequentially: manufacturing the substrate, catalytic coating and then canning the coated substrate. No single company manufactures the equipment alone in-house. Thus the OEM can better manage costs, particularly the expensive coating with precious metals. The supply chains exist and are nurtured ever since the deployment, over 35 years ago, of catalytic converter for gasoline engines.

The dominant substrate manufacturers are Corning, NGK and Ibiden. Their estimated market shares are shown

Fig.8. Market share estimate for filter substrate production in 2016

The European catalytic coating companies are mainly Umicore, Johnson Matthey, BASF and Delphi. They obtain the substrate and coat it, as required by the DPF manufacturers. The coated substrates are delivered to the canners: Tenneco, Eberspächer, Fauresia, Bosal and others.

This supply chain is a complex and carefully coordinated process. New market entrants cannot easily break into the OEM market. Some of the larger retrofitters tried and failed. They may have opportunities in the non-road market, which is a niche business requiring bespoke DPF in small quantities. Other opportunities may arise in after-sales replacements.

4. Sustained technology improvements and opportunities

The particle filter is now “State of the Art” the best available technology for all combustion engines. It is widely recognized that solid particles from combustion are highly toxic. Many ongoing investigations confirm the toxicity and come up with more and more nasty endpoints. The filter deployment will spread to all combustion engines (including gasoline and CNG, because of the highly toxic metal oxide nanoparticles from engine wear and lube oil packages) and all geographies. This will open new opportunities, e.g. marine and engine powered tools. The vehicle operators cannot escape their responsibilities and must ensure air quality improvements. Engine emissions must be continuously verified and, after the VW scandal, will not be delegated anymore to the engine manufacturers. Only particle filters can substantially eliminate toxic emissions and thus ensure the future of combustion engines – a success story as mentioned in the title, thanks to the retrofit pioneers, who deserve to be honored for outstanding innovation.

5. Sources of information

- Scientific papers and conference presentations
- Statistics collected from members of the VERT Association and the US-MECA.
- Official data of the environmental authorities in Korea, London, Berlin, Santiago de Chile, Israel and Iran.
- Inputs from European associations of public transport.
- Participation in working groups on legislation, standards, instrumentation, etc.
- Collaboration with many filter substrate manufacturers, coaters, canners and retrofitters.
- Contacts with engine and vehicle manufacturers.
- Market analyses from data providers, financial institutions, etc.
- Internet

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www.VERT-certification.eu

The VERT Association publishes on its web site information on the topic of particle filter retrofitting. The site also has a comprehensive database of already retrofitted vehicles and machines. The VERT Filter List documents the certified filter systems and their manufacturer: www.VERT-dpf.eu.

The PDF version of this publication can be downloaded at www.VERT-certification.eu.

Appendices

- Chronicle of DPF-Introduction
- VERT-Certification Process
- VERT-Certification Criteria
- VERT-Worldwide Recognition
- VERT-Filterlist Summary
- Plurality of DPF Technologies

Acronyms

ADAC	German Automobile Club https://www.adac.de
ASTRA	Swiss Federal Roads Office https://www.astra.admin.ch/astra/en/home.html
BAT	Best Available Technology https://en.wikipedia.org/wiki/Best_available_technology
BeNeLux	Belgium, Netherlands and Luxembourg https://en.wikipedia.org/wiki/Benelux
CNG	Compressed Natural Gas
CODEC	Co-Decision of the EU Parliament and the Council of Ministers
cpsi	Number of cells per square inch
DOC	Diesel Oxidation Catalyst https://en.wikipedia.org/wiki/Catalytic_converter#Diesel_Oxidation_Catalyst
DPF	Diesel Particle Filter https://en.wikipedia.org/wiki/Diesel_particulate_filter
EJPD	Swiss Department of Justice and Police https://www.ejpd.admin.ch/ejpd/en/home.html
ETH	Swiss Federal Institute of Technology (Zurich) https://www.ethz.ch/en.html
FAP	Filtre à Particules https://fr.wikipedia.org/wiki/Filtre_%C3%A0_particules
GDI	Gasoline direct injection https://en.wikipedia.org/wiki/Gasoline_direct_injection
GPF	Gasoline particle filter
GRPE	Working Party on Pollution and Energy https://www.unece.org/trans/main/wp29/meeting_docs_grpe.html
HDV	Heavy Duty Vehicle
JRC	Joint Research Center of the EU Commission https://ec.europa.eu/jrc/en/about/jrc-in-brief
LDV	Light Duty Vehicle
LEZ	Low Emission Zone https://en.wikipedia.org/wiki/Low-emission_zone
MECA	Manufacturer of Emission Control Association USA http://www.meca.org
MPI	Gasoline multiport fuel injection
NOx	Oxides of nitrogen NO + NO_2 https://en.wikipedia.org/wiki/NOx
NR	Non-Road
NRMM	EU Non-Road Mobile Machinery https://ec.europa.eu/growth/sectors/automotive/environment-protection/non-road-mobile-machinery_en
OEM	Original Equipment Manufacturer https://en.wikipedia.org/wiki/Original_equipment_manufacturer
NPC	Nanoparticle Conference at the ETH Zurich http://www.nanoparticles.ch
PM	Particle Mass (as defined in the legislation)
PMP	UN Particle Measurement Program https://wiki.unece.org/pages/viewpage.action?pageId=2523173
PN	Particle Number density https://en.wikipedia.org/wiki/Particle_number#In_air_quality
PSA	Peugeot Société Anonyme https://www.groupe-psa.com/en
SCR	Selective Catalytic Reduction https://en.wikipedia.org/wiki/Selective_catalytic_reduction
SiC	Silicon Carbide https://en.wikipedia.org/wiki/Silicon_carbide
SUVA	Swiss Occupational Health Agency https://en.wikipedia.org/wiki/Suva_(insurer)
UN-ECE	United Nations Economic Commission for Europe http://www.unece.org/trans/welcome.html
VDA	German Association of the Automotive Industry https://www.vda.de/en.html
VERT®	Association dedicated to the promotion of emission control BAT http://vert-certification.eu
ZEV	Zero Emission Vehicle https://en.wikipedia.org/wiki/Zero-emissions_vehicle