

The Dirty Tail of Modern Diesel Engines

MINING VEHICLE POWERTRAIN CONFERENCE · 6–8 October 2026

Robert Fraser - Purexhaust SA / VERT

Dr Andreas Mayer, Ralph Wilce - VERT Association

Victor Montt · Grupo SCAF



What is VERT?

Verification of Emission Reduction Technologies

40+

members

Including universities and research centres as associate partners

1

Non-profit international association

Filter, catalyst, instrument and engine manufacturers, universities and research associates

2

Particle filter testing and certification

Quality control and trademark for Best Available Technology (BAT)

3

Key role in PN emissions legislation

EU adopted VERT criteria in 2006 for Euro 6

4

Active on New PTI (NPTI) since 2016

New test method for DPF-equipped diesel vehicles, now used in 4 EU countries

5

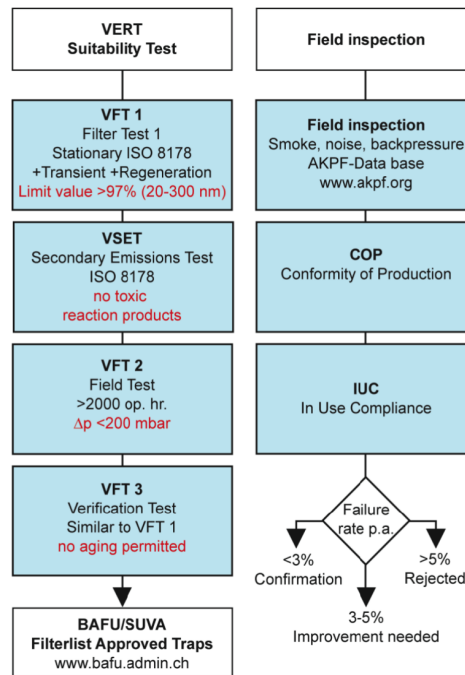
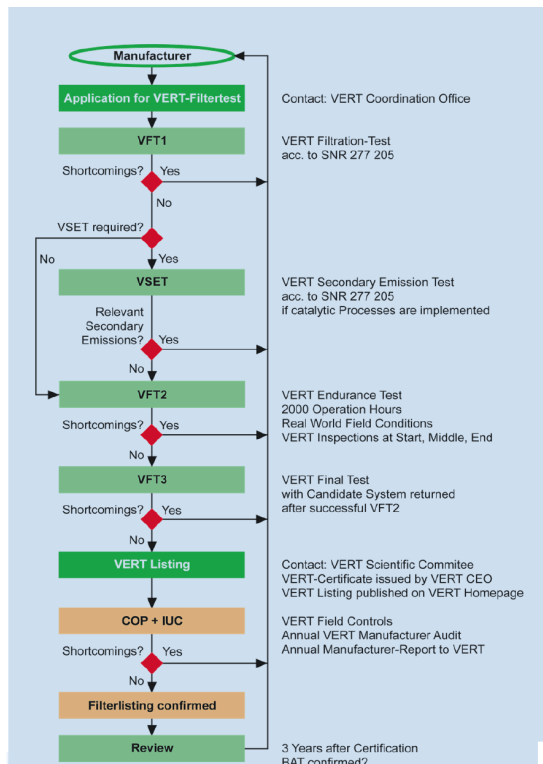
Filter testing procedures and global network

Retrofit programs with international partners and a worldwide scientific network

VERT Filter Testing Certification & Quality Control

Test protocol since 1997, codified by Swiss Technical Standard SN 277206

- The VERT® filter test protocol, in place since 1997, is codified by the **Swiss Technical Standard SN 277206**



VERT® testing of particle filter systems

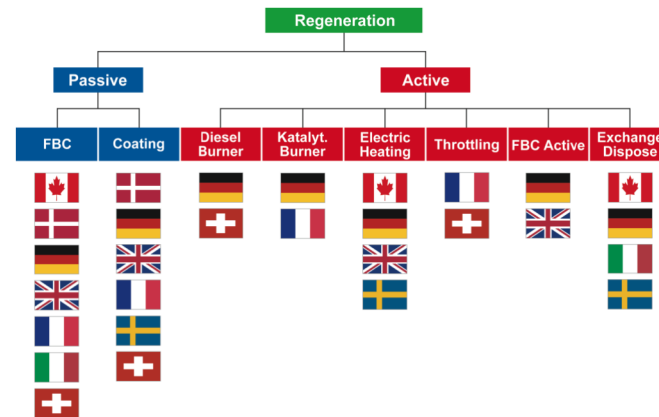
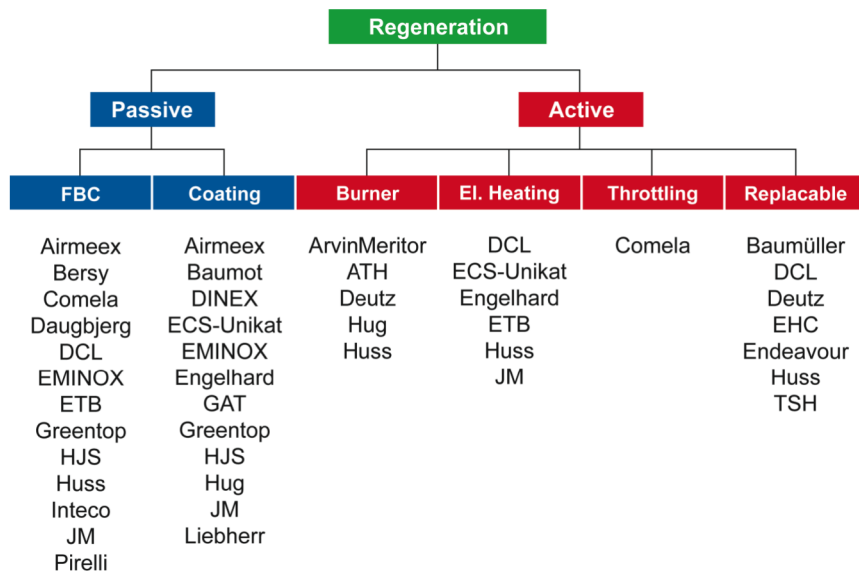


**VERT
Certified Filter List**



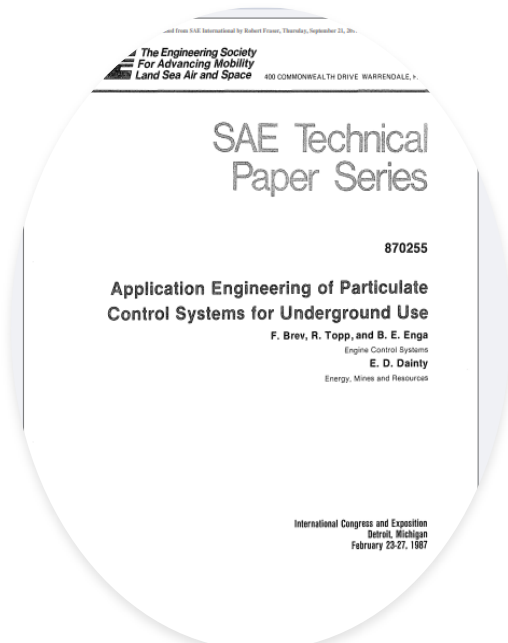
VERT-certified DPF Systems

Passive and active regeneration systems from certified manufacturers



DPFs for Underground: From 1985 to Stage V

Wall-flow diesel particulate filters have been engineered for underground use since the mid-1980s. Stage V makes them mandatory — with particle number as the metric.



SAE 870255 — First DPF systems engineered for underground mining

1985/87 First large scale underground DPF demonstration

Brev, Topp, Enga & Dainty (Engine Control Systems / Energy, Mines & Resources Canada) demonstrate wall-flow DPF for underground diesel vehicles. SAE 870255.

1986/87 Canadian ADHOC Diesel Committee

Formed to provide a venue for consultation among all segments of the mining industry and foster R&D progress in diesel emissions reduction. The forerunner of MDEC.

1990s–2000s VERT program and Swiss mandate

Switzerland mandates DPFs on all underground construction machinery. VERT certifies DPF systems — >98% filtration efficiency required.

2014 US EPA Tier 4 Final

PM mass limit of 0.02 g/kWh for off-road diesel >56 kW. Does not set a PN limit, but DPFs are typically included to meet the stringent PM mass standard.

2019 EU Stage V — the PN standard

First regulation to set a particle number limit: 1×10^{12} #/kWh for all off-road diesel 19–560 kW. Forces wall-flow DPF on every new construction and mining machine.

Homologation of Diesel Particulate Filters

VERT[®] certificate

CLASSIFIÉ



31. Jan. 2021

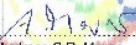
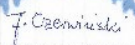
VERT[®]-Certificate

No	B322/02.12-1 VERT [®] -conformity extended to 31.January 2026
Product	EMT Particle Filter System: DPF 1/2; DPFN, DPFN+ Filter-Modul: Cordierite, 200 cps Regeneration: Catalytic Coating Filter Control: EDL-DT
Manufacturer	EMT automotive AG Vortaus 9 CH-6332 Rekingen

We herewith apply to be listed in the VERT[®] filter-list and we accept rules, conditions and self-commitments as being published on the VERT[®] filter-list.

Manufacturer	Date	Signature
EMT automotive AG	22.01.2021	

Certified by the VERT[®] Scientific Committee

 Andreas G.R. Mayer	 Prof. Dr. Jan Czerwinski	 Thomas W. Lutz
---	---	---

Why Act Now on Diesel Particles

Health science and European law have moved from particle mass to particle number

Group 1

Diesel exhaust classified as carcinogenic to humans by IARC (WHO) since 2012

< 100 nm

Ultrafine particles (UFPs): the size that reaches deepest into the lungs and bloodstream

1 EU Directive 2024/2881

First inclusion of UFPs: particle number (PN) and size distribution must be measured in urban areas and hotspots, in line with the latest WHO guidelines.

2 Right to compensation

Citizens gain the right to claim compensation for health damage caused by air pollution.

3 Working filters are the solution

A properly working DPF emits fewer particles at idle than the surrounding ambient air — relevant for idling vehicles and the school run.

4 Failed filters are the problem

Malfunctioning or tampered DPFs create high emitters. Follow the early adopters and EU recommendations to find and fix them.

5 Measure to know

Pair PN with particle mass to understand exposure, relative toxicity and health impact.

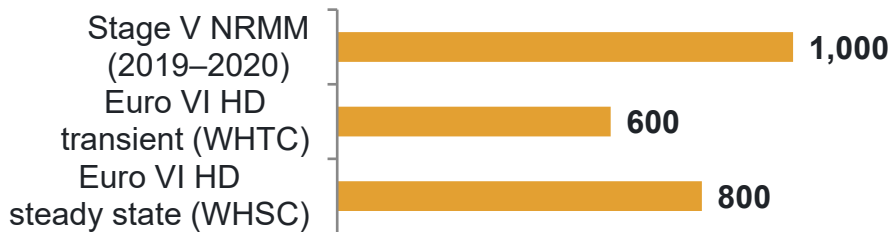
The Solution: DPFs and PN Standards

Wall-flow diesel particulate filters are the proven technology. Stage V and Euro VI mandate their use through particle number limits.

>99%

particle removal by number (wall-flow DPF). VERT-certified filters achieve 98.8% average filtration efficiency

PN Type-Approval Limits ($\times 10^9$ #/kWh)



Stage V (NRMM, 2019–2020)

PN limit: **1×10^{12} #/kWh** — applies to all off-road diesel 19–560 kW. Forces wall-flow DPF on every new construction and mining machine.

Euro VI (Heavy-Duty, 2013)

PN limit: **6×10^{11} #/kWh** (transient WHTC). Applied to trucks, buses, heavy equipment on-road. DPF required to comply.

DPFs work — but only if they remain intact. A cracked substrate, a removed filter, or a poor installation defeats the >99% efficiency. **How do you verify this in service?**

Latin America: Off-Road Diesel Standards

Only Chile requires Tier 4 Final / Stage V — Colombia at Stage IIIB (DPF required)

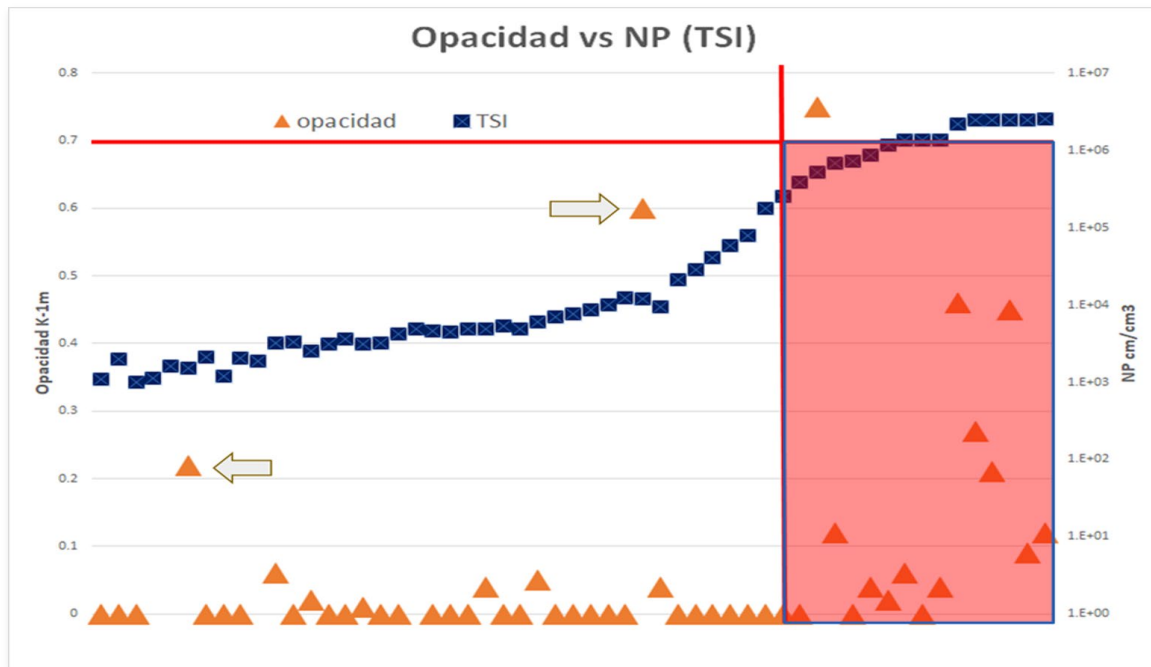
Country	Regulation	Tier / Stage (≥37 kW)	PM (g/kWh)	PN (#/kWh)	Effective	DPF?
Chile	DS 39/2020 (MMA)	Tier 4 Final Stage V	0.015–0.02	1×10^{12}	Oct 2023	Yes
Colombia	Res. 762/2022 (MinAmbiente)	Tier 4 Stage V		—	2026	Yes
Brazil	CONAMA 433/2011 (MAR-I)	Tier 3 Stage IIIA	0.2–0.6	—	2015–2019	No
Mexico	NOM-174 (SEMARNAT 2026)	Stage IIIA	~0.2–0.6	—	Nov 2026	No
Peru	—	Unregulated	—	—	—	No
Argentina	—	Unregulated	—	—	—	No

THE EVIDENCE

How do you know if the DPF is functioning?

Opacity vs. Particle Number: What Gets Missed

107 Swiss construction machines measured by opacity (triangles) and particle number with TSI CPC (squares). Machines ranked by PN emissions, rising left to right.



The pink zone

Machines in the shaded area exceed the PN limit ($>250,000 \text{ \#}/\text{cm}^3$) but most have **opacity near zero**. Opacity testing would pass these machines as clean.

22% fail PN

vs. only 3% fail opacity.

PN detects

7× more failures — broken DPFs that opacity simply cannot see.

Reference

AFHB B485a (2017): "PN and Opacity Measurements on 107 Swiss Construction Machines." Applied Sciences, University of Applied Sciences, Biel.

Why Particle Number?

The 2015 Dieselgate scandal exposed that vehicles could pass type-approval tests but emit far more in real driving. This drove development of the Nanoparticle Technical Inspection (NPTI) — a simple, 1-minute PN check at idle.

Belgium · July 2022

First country. Limit: 1,000,000 $\#/\text{cm}^3$. Euro 5b–6 diesels.

Netherlands · January 2023

Limit: 1,000,000 $\#/\text{cm}^3$. All diesels with wall-flow DPF.

Germany · January 2023

Strictest limit: 250,000 $\#/\text{cm}^3$. Euro 6 LD + Euro VI HD.

Switzerland · January 2023

Limit: 250,000 $\#/\text{cm}^3$ at high idle (or 100,000 at low idle).

Chile · In progress (2026)

First in South America. DS 4/1994 MTT revision adds PN to PTI.

Why Dieselgate changed everything

Type-approval PN limits (Stage V, Euro VI) only test new engines. Once in service, a DPF can crack, clog, or be removed — and **opacity testing cannot detect it**. NPTI fills this gap with a 1-minute idle PN check.

UNECE recognition

UNECE approved the PTI-PN procedure (entered force June 2024). Countries now considering adoption: South Korea, Japan, Israel, Colombia, Mexico — and Chile.

For mining and construction:

Stage V ensures new machines have DPFs. But the installed fleet — and any machine whose DPF degrades in harsh underground conditions — needs periodic PN verification. The same PN measurement technology (CPC and DC instruments) applies.

Technology & Equipment

**1**

Technology neutrality

DC or CPC instruments.

2

Robustness

For a high-throughput PTI environment.

3

Fraud prevention

Full data encryption from device to server.

4

Verification

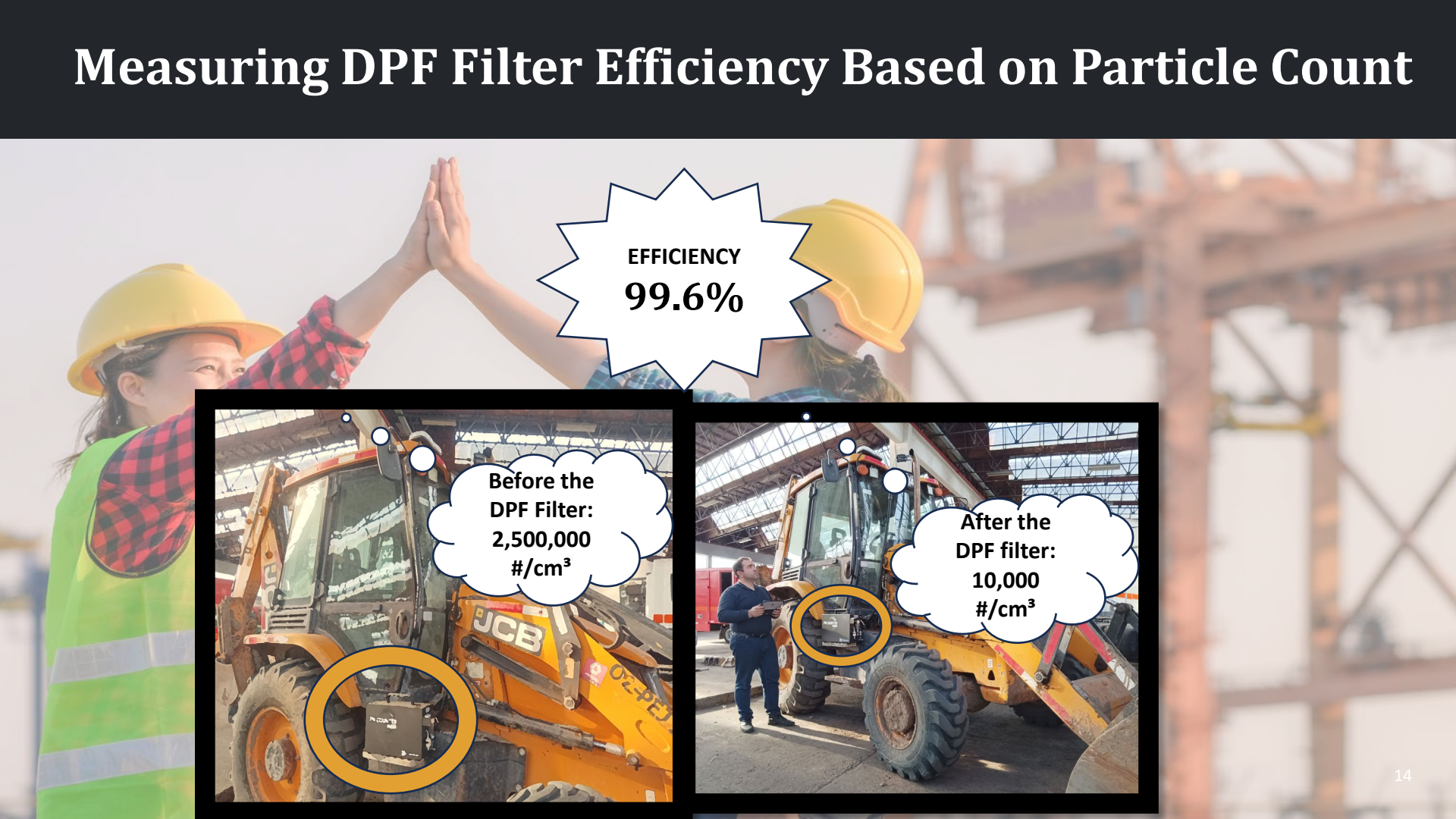
Use of miniCAST / bigCAST soot generators.

Homologated PN Instruments for PTI

18 instruments certified for periodic technical inspection — both CPC and DC technologies. Data as of November 2023.

#	Brand	Manufacturer	Type	DC/CPC	Year	Range [# /cm ³]
1	TSI	TSI	3795 (NPET-I)	CPC	2015	5,000–5,000,000
2	TSI	TSI	3795 (NPET-h)	CPC	2016	50,000–50,000,000
3	TEN	TEN	AEM	DC	2020	5,000–5,000,000
4	VLT	TEN	E9700	DC	2020	5,000–5,000,000
5	Saarloos	TEN	DPC	DC	2021	5,000–5,000,000
6	Capelec	Capelec	CAP3070	DC	2021	5,000–5,000,000
7	AVL-DiTest	AVL-DiTest	Counter	DC	2021	1,000–10,000,000
8	Continental	Capelec	DX 280 DC	DC	2022	5,000–5,000,001
9	Saxon Junkalor	Saxon Junkalor	Nanolyt M	DC	2022	5,000–5,000,000
10	TEXA	TEXA	NP 01	DC	2022	5,000–5,000,000
11	Mahle	Mahle	PMU 400	CPC	2022	5,000–50,000,000
12	Brainbee	Mahle	PMU-400	CPC	2022	5,000–50,000,000
13	MAHA	AVL-DiTest	MET	DC	2021	1,000–10,000,000
14	Bosch	Bosch	BEA 090	CPC	tbd	?
15	Assemblad	Assemblad	PRT 121	DC	2023	5,000–5,000,000
16	Hella Gutmann	?	HG4-PCK	DC	tbd	5,000–5,000,000
17	WOW	TEN	WPA	DC	tbd	?
18	Bartec Auto ID	Bartec Auto ID	nEC	DC	tbd	5,000–15,000,000

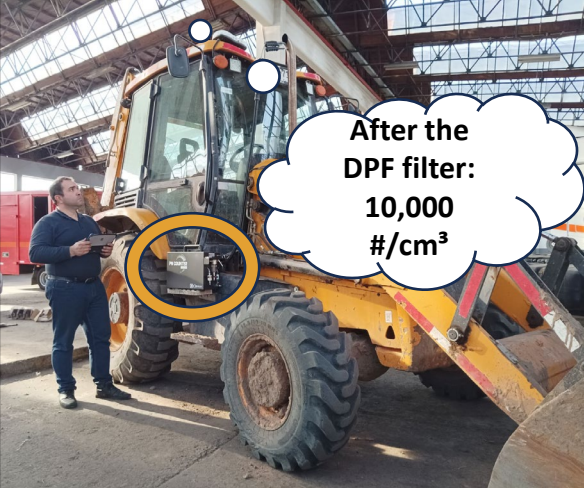
Measuring DPF Filter Efficiency Based on Particle Count



EFFICIENCY
99.6%



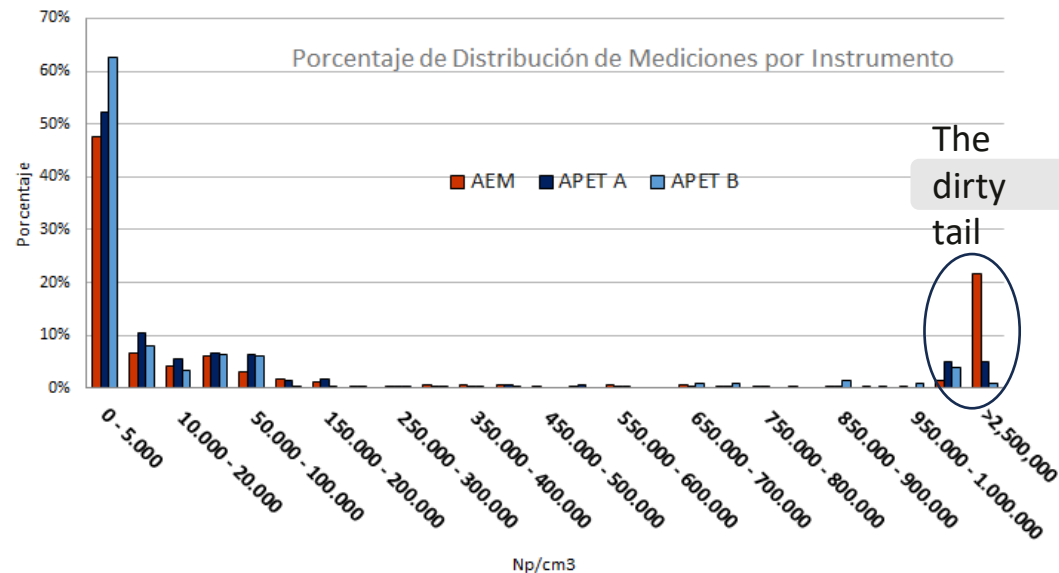
Before the
DPF Filter:
2,500,000
#/cm³



After the
DPF filter:
10,000
#/cm³

Working vs. Failed DPFs: A Clear Separation

Distribution of PN measurements on a sample of 1,000 vehicles, by three independent instruments. Nearly 30% of vehicles measured above 250,000 $\#/cm^3$.



Working DPFs

Most vehicles measure below 5,000 $\#/cm^3$ across all three instruments. A functioning wall-flow DPF produces near-zero particle counts.

Failed DPFs

Many vehicles with failed filters measure above 2,500,000 $\#/cm^3$ — orders of magnitude above the limit. Cracked substrates, removed filters, or installation defects.

The gap: 3 orders of magnitude

Working DPFs: mostly below 5,000 $\#/cm^3$.
Failed DPFs: many above 2,500,000 $\#/cm^3$. No grey zone — PN counting gives a clear, binary pass/fail.

DPF Failure Rates: Off-Highway Fleet Reality

BAFU / AFHB 2017 — PN failures by DPF type and emission stage ($\geq 250,000 \text{ \#/cm}^3$)

Overall Failure Rate (NPET standard)

Retrofit



25.7%

18 of 70

OEM



16.2%

6 of 37

Idle PN Test (NPET idle)

Retrofit: 7 of 33 failed (21%)

OEM: 0 of 23 failed (0%)

A simple idle test flags the worst retrofit DPFs

PN Failure Rate by Emission Stage

Stage I



60%

3/5

Stage II



27%

3/11

0%

0/1

Stage IIIA



27%

9/33

0%

0/3

Stage IIIB



20%

3/15



14%

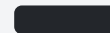
2/14

Stage IV



0%

0/2



22%

4/18

Even Stage IV OEM DPFs show 22% failure — periodic PN checks essential at every tier



Retrofit



OEM

Off-Highway DPF Verification: PN vs Opacity

BAFU / AFHB 2017 — 107 DPF-equipped construction machines, Switzerland

24

of 107 machines tested
exceeded PN limit

(> 250,000 #/cm³)

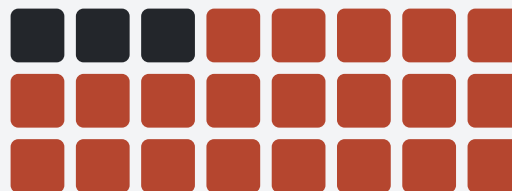
8×

3

of 107 machines tested
exceeded opacity limit

(> 0.24 m⁻¹)

The "Dirty Tail" on Construction Equipment



Black Caught by PN AND opacity (3)

Red Caught by PN ONLY — invisible to opacity (21)

Opacity missed 88% of DPF failures

Zero machines had high opacity but low PN — PN has no false positives vs opacity

One Failed Filter Can Ruin a Shift

UNDERGROUND RISK

Why opacity testing cannot protect miners from ultrafine particles

1 = 200

One failed filter emits as much as 200 machines with working filters

1,000×

More sensitive than opacity testing

< 1 min

To detect a broken, cracked or tampered filter on a vehicle or NRMM

The TWA risk

One cracked or malfunctioning DPF on a mining machine can flood a drift with enough soot to break the 8-hour exposure limit for every worker in that sector.

Modern diesels emit ultrafine particles that only PN counting can detect, and they are highly toxic to the lungs. DPFs can fail for various reasons. Ventilation alone cannot dilute a gross emitter fast enough.

8-hour TWA exposure limits for underground mines

EU

0.05 mg/m³ EC

European Parliament & Council · Directive (EU) 2019/130 (mining from Feb 2026)

Ontario

0.12 mg/m³ EC

Ontario Ministry of Labour (MLITSD) · O. Reg. 854 (since Sept 2023)

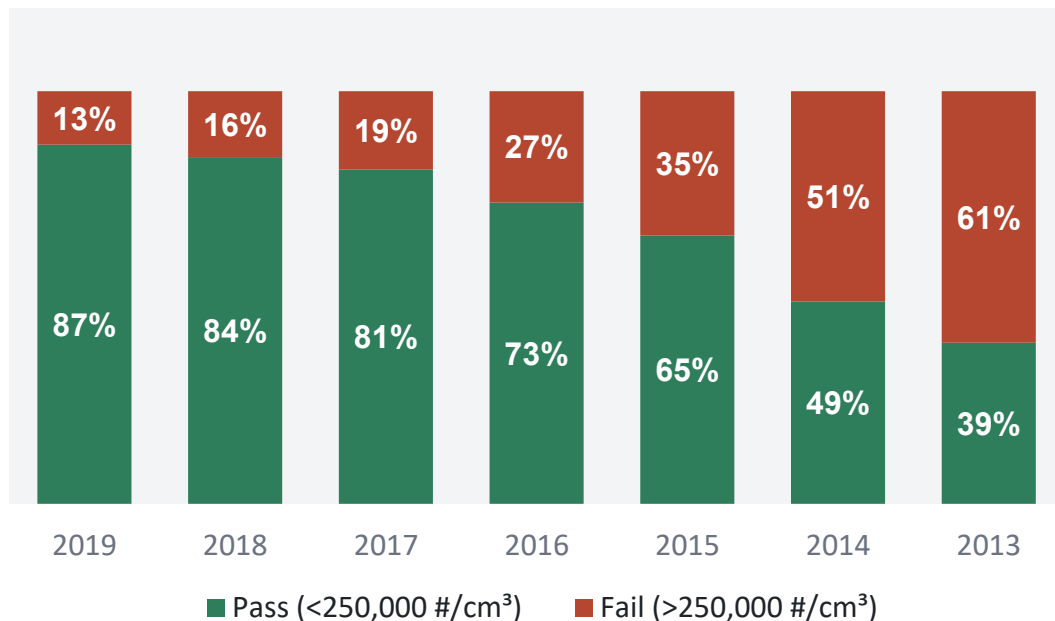
USA

0.16 mg/m³ TC

Mine Safety and Health Administration (MSHA) · 30 CFR 57.5060 (M/NM)

In-Service PN Testing: Failure Rate Rises with Age

Pass / fail rates by vehicle model year · TEN AEM instrument, 250,000 #/cm³ limit · Tests conducted: 2021



61% failure rate

on 2013 model-year vehicles. By 2019, only 13% fail — but that still means **1 in 8 near-new machines** has a compromised DPF.

Clear age trend

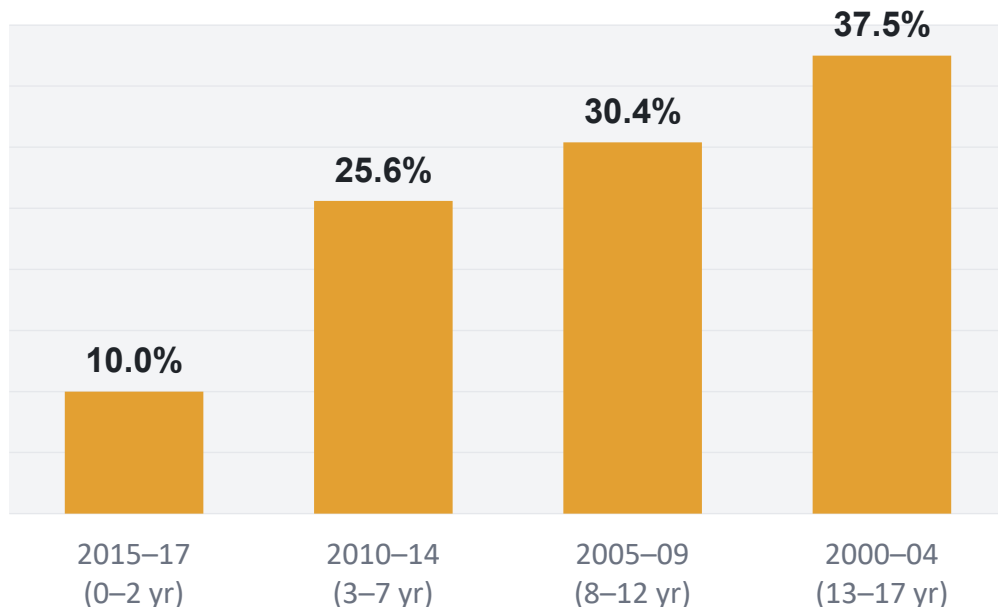
DPF integrity degrades steadily with age. Vehicles older than 5 years show >27% failure — periodic PN checks are essential, not optional.

Implication for mining:

Underground fleets with mixed-age equipment need annual PN verification — not just at commissioning.

DPF Failures by Machine Age: Not Just Old Equipment

B485 Study, Switzerland — measured 2017 — PN failure rate by production year bracket (NPET $\geq 250,000$ #/cm³)



Key finding

DPF failures are **due to engine problems**. Even the newest group (0–2 years) has a 10% failure rate — and mid-age machines (3–12 years) average 28%.

Fleet composition

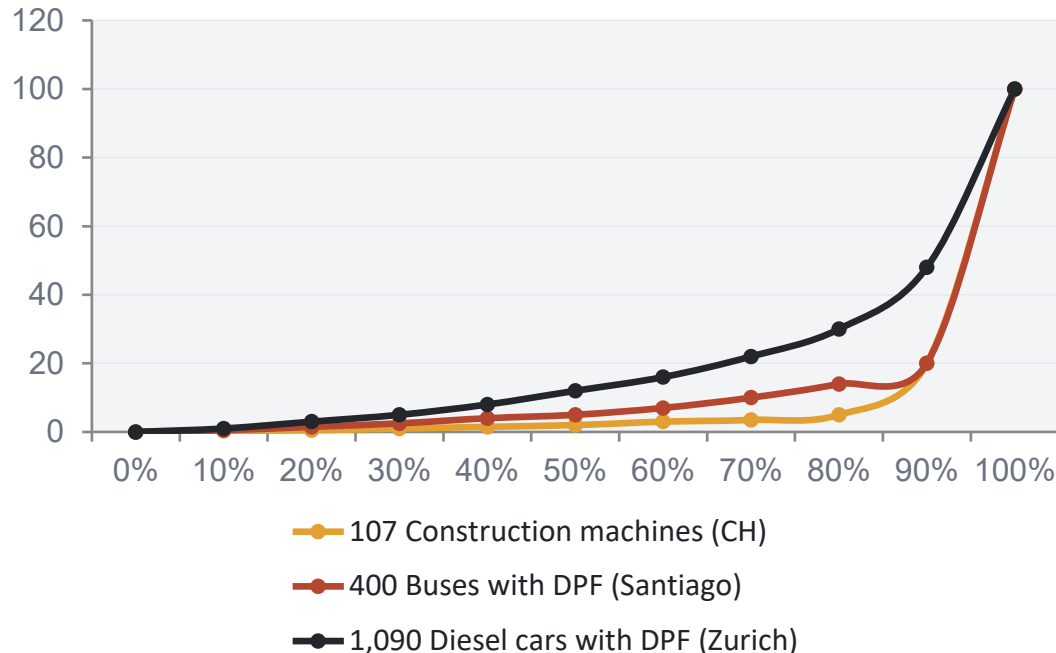
n = 107 machines
Retrofit DPFs: 70 (65%)
OEM DPFs: 37 (35%)
Measured 2017, Switzerland

Implication: periodic PN checks needed at every age — not just for ageing fleets

The Dirty Tail: A Few Machines Dominate Emissions

UNCLASSIFIED - NON CLASSIFIÉ

When vehicles are ranked by PN emissions, a small fraction — the "dirty tail" — produces most of the total particle output. This pattern is consistent across every diesel fleet studied.



80%

of all PN emissions
from just 10%
of machines

95%

of all PN emissions
from just 20%
of machines

22%

of construction
machines detected
by PN counting

3%

detected with
opacity (7× less
sensitive)

How PN-PTI Protects Miners

ALARP (As Low As Reasonably Practicable): keep cutting emissions unless the cost is grossly disproportionate

1 Catch gross emitters instantly

A 1-minute tailpipe check finds the machine with a failed filter. Pulling it out prevents spikes in underground air pollution.

2 Verify every DPF

Confirms that filters on diesel equipment actually perform to Tier 4 Final and Stage V.

3 Targeted maintenance

Weekly tests flag rising particle counts so machines are serviced before they pollute. Budgets go to the machines causing the most risk — optimising the fleet instead of replacing it.

4 More effective ventilation

Low tailpipe emissions mean ventilation works less hard to keep air safe, reducing the toxic load in confined zones.

A preventive compliance engine

PN-PTI does not measure the 8-hour ambient TWA directly.

It removes the diesel equipment causing high exposure, keeping mine air below exposure limits (EU 0.05 mg/m³ EC).

The same instruments can monitor ambient UFPs, focusing on the most toxic fraction: non-volatile solid particle number (nvSPN).

Conclusions

Particle number counting enables two transformative outcomes for underground diesel fleets

1 Improved Occupational Health of Exposed Miners

- Ultrafine particles (<100 nm) penetrate deep into the lungs and enter the bloodstream — the health risk opacity cannot measure
- PN counting is 100% reliable, compared to opacity, which only detects the visible emissions
- A 1-minute idle check identifies machines emitting orders of magnitude above safe limits
- Removing the "dirty tail" (20% of machines, 80–95% of emissions) dramatically cuts miner exposure to ultrafine particles
- 4 European countries now mandate PN-PTI; Chile is the first in Latin America

2 Preventative Maintenance of Diesel Machinery

- DPFs can deteriorate with age if engines not properly maintained
- Early detection of engine problems can prevent a filter failure
- A simple periodic check enables data-driven maintenance scheduling across the entire fleet
- Over 20 million tests completed in Europe demonstrate the reliability of the new approach to filter maintenance.

Join VERT



Be part of the network that sets the standard for clean diesel — from filter certification to particle-number inspection

Technology exchange

with filter, engine and instrument makers

Research library

200+ members-only publications

BAT recognition

VERT® trademark and website listing

A voice with regulators

worldwide legislation and retrofit programs

Become a member

office@vert-certification.eu · www.vert-dpf.eu

Robert@purexhaust.com
r.fraser@vert-dpf.eu

SAVE THE DATE

VERT Forum & Focus Day

March 2027

Switzerland

Dates and venue to be announced

Industry, research and regulators meet on emissions control and NPTI