Empa
Materials Science and Technology

Can diesel solve its emission problem in time?

7th VERT Forum: Efficient filter and deNOx-technologies

Dübendorf, March 18, 2016

Can diesel solve its NO and NO_2 problem in time?

GDCh/DECHEMA-Sonderkolloquium, “Stickoxide: Ist der Diesel noch zu retten?”

Frankfurt, 14. Januar 2016

7th VERT Forum: Efficient filter and deNOx-technologies

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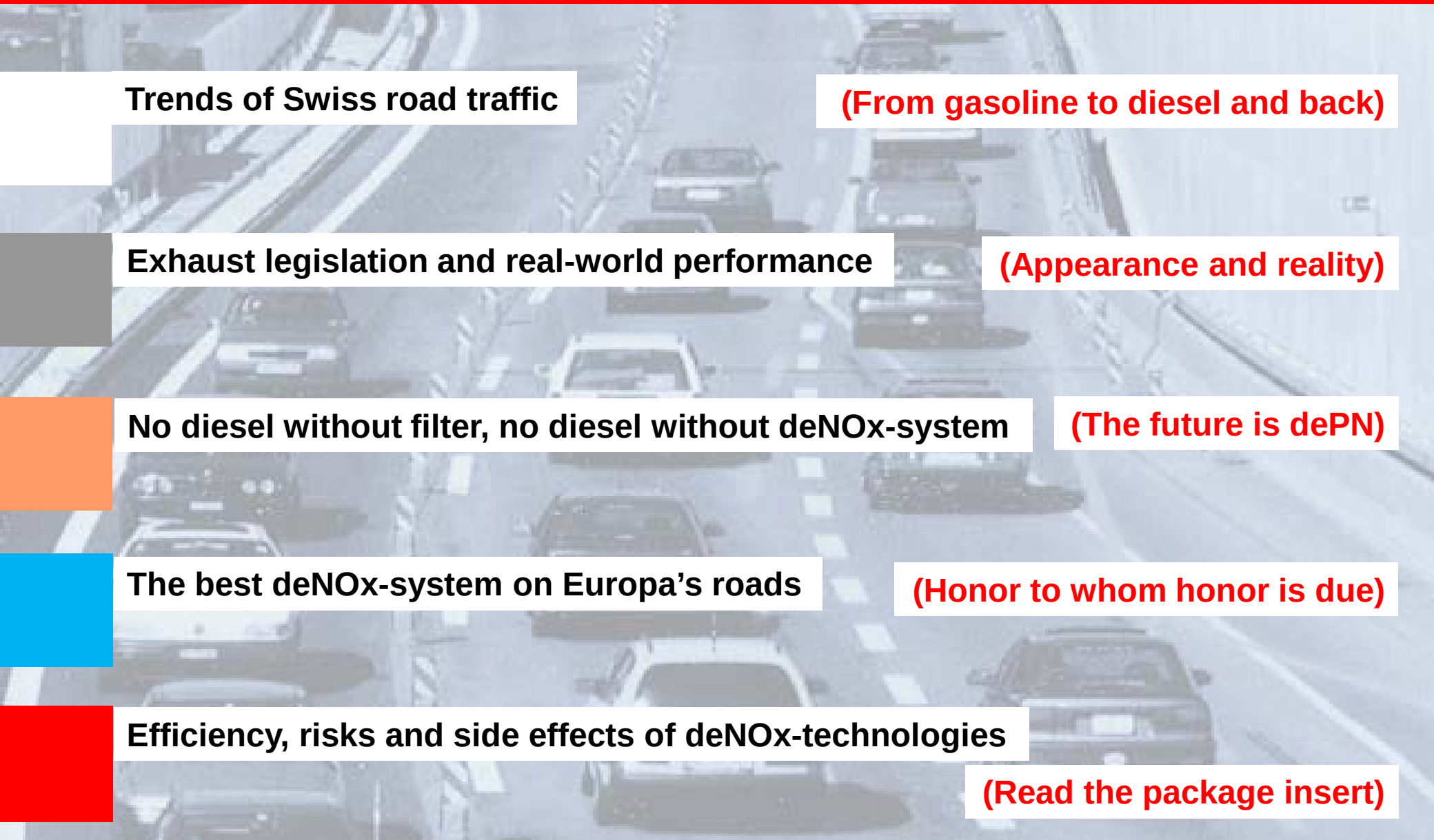
Europa's NOx problem – a consequence of poor legislation and inefficient deNOx-catalysts



Trends of Swiss road traffic

(From gasoline to diesel and back)

Exhaust legislation and real-world performance

(Appearance and reality)

No diesel without filter, no diesel without deNOx-system

(The future is dePN)

The best deNOx-system on Europa's roads

(Honor to whom honor is due)

Efficiency, risks and side effects of deNOx-technologies

(Read the package insert)

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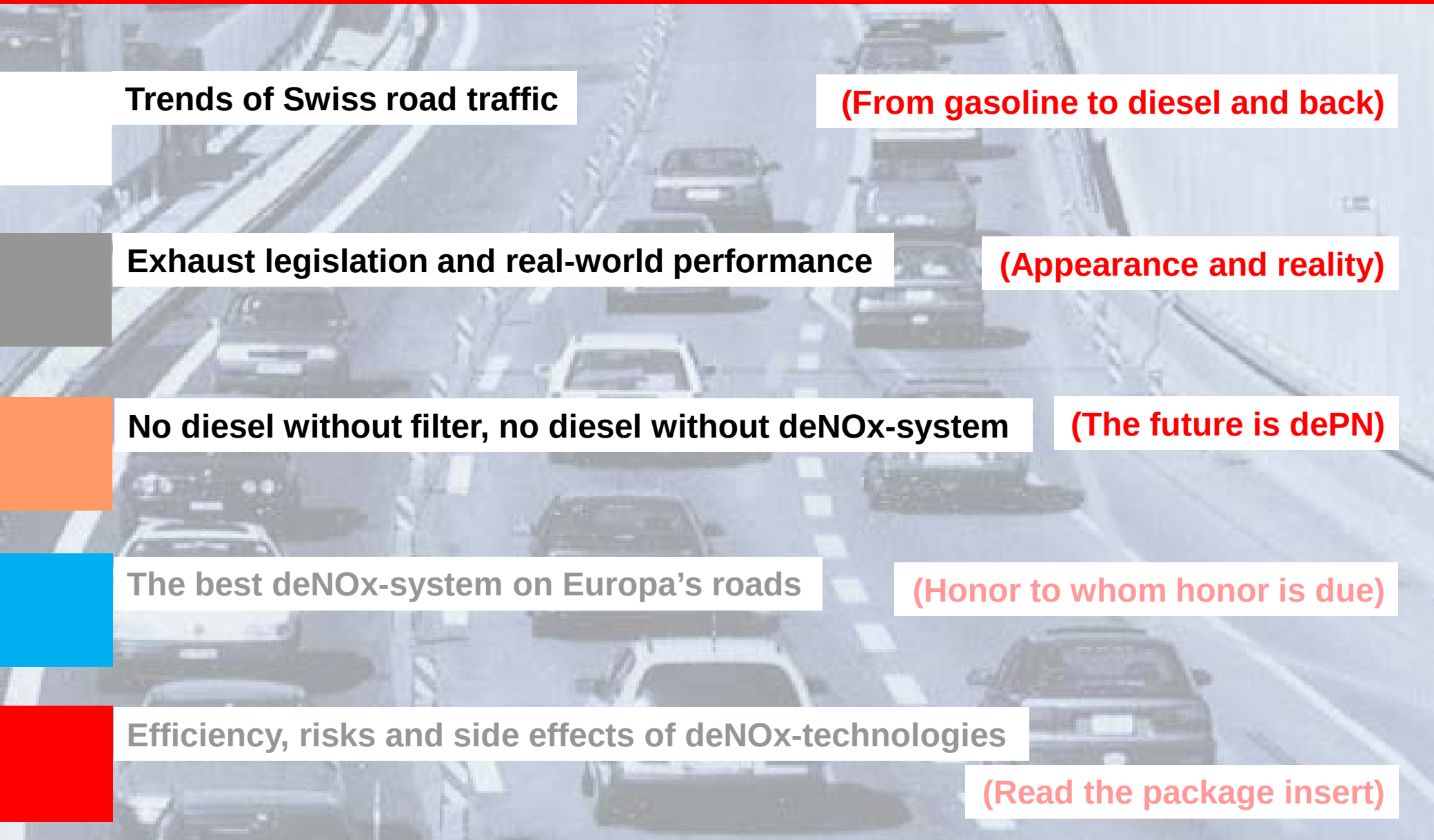

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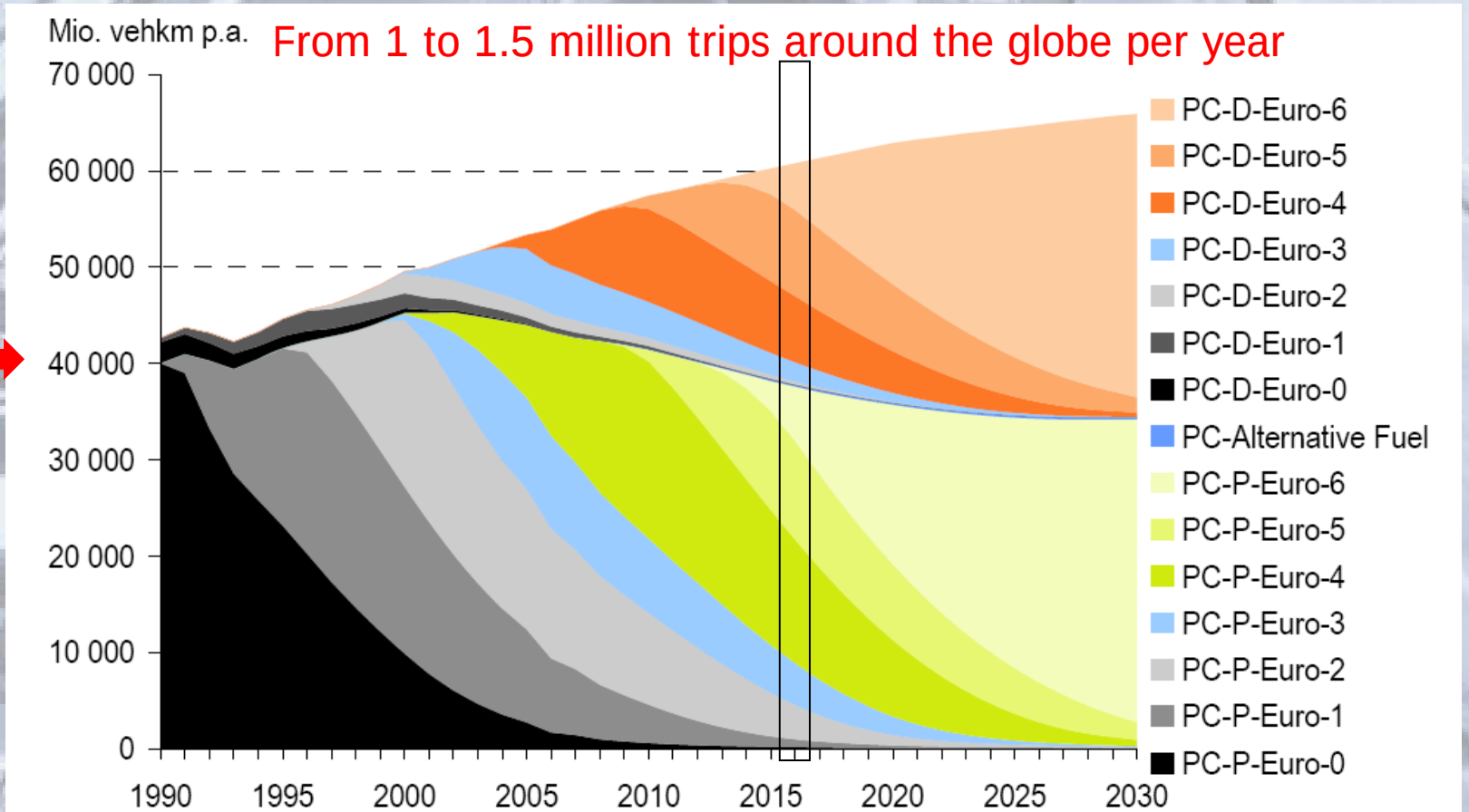
From 3% diesel pc in 1990 to 40% in 2016: diesel on the rise, alternative <1%!

Driving distance per vehicle class (million km/y)



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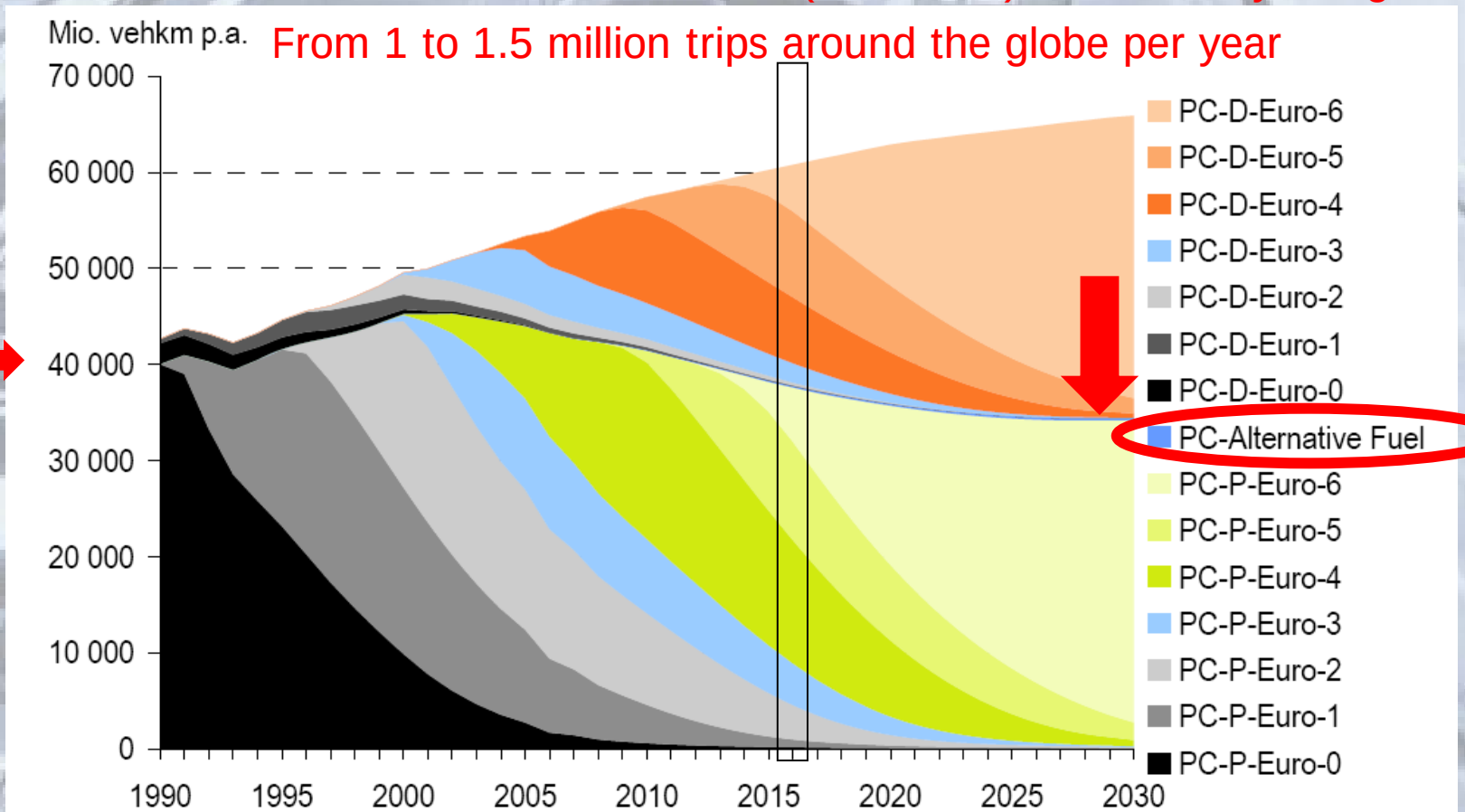
Not much low carbon fuels (CH4 & H2) or e-mobility in sight

From 1 to 1.5 million trips around the globe per year



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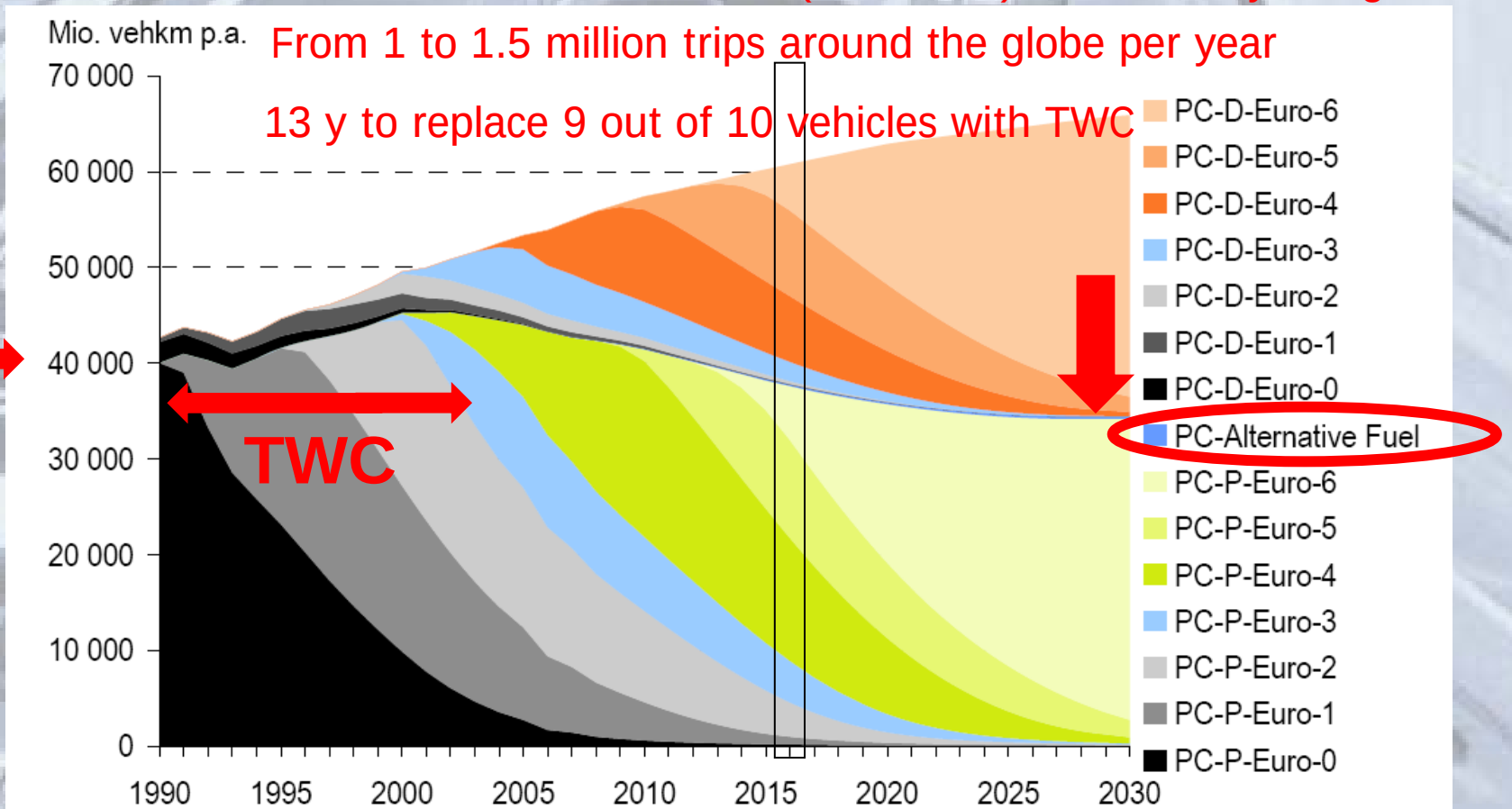

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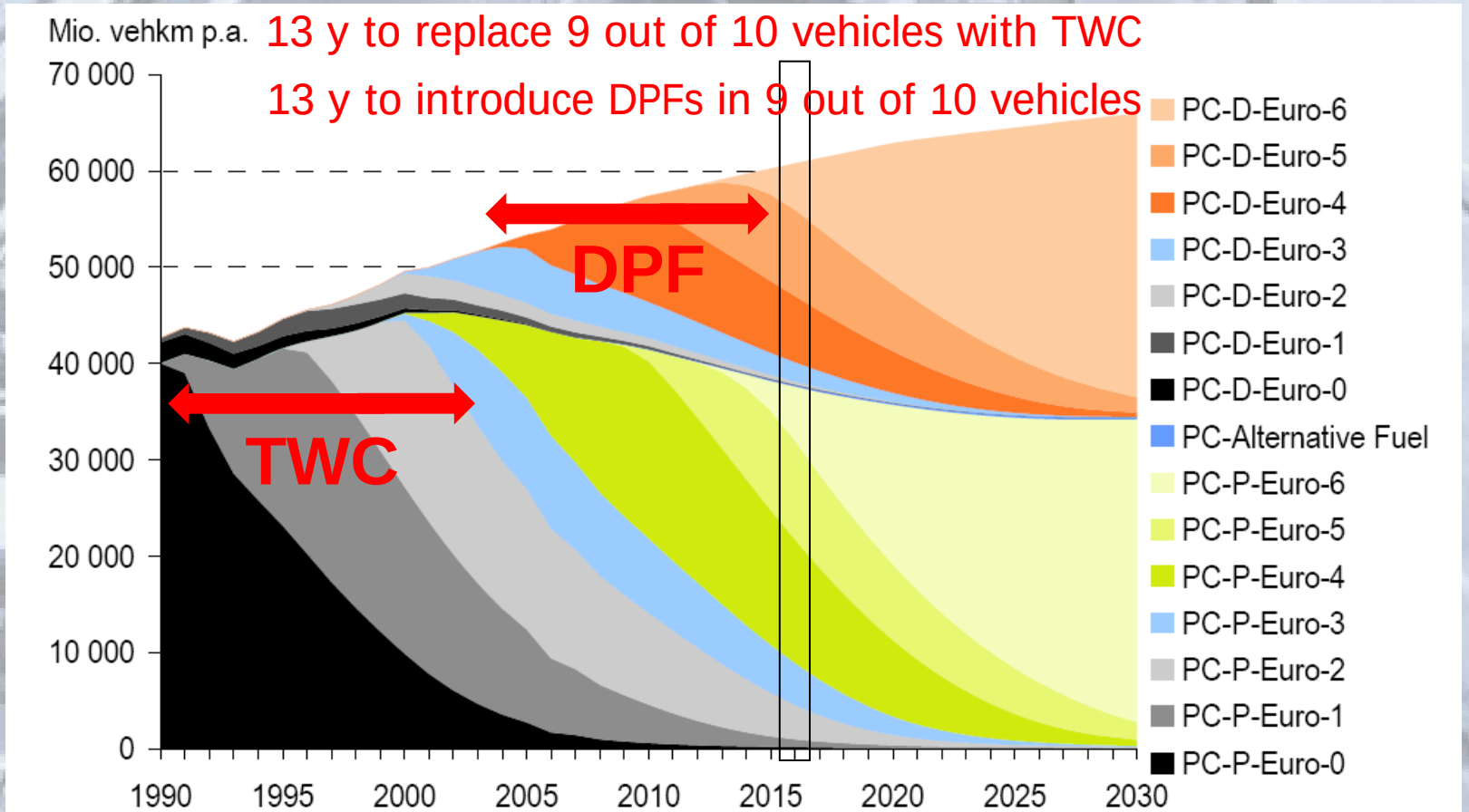

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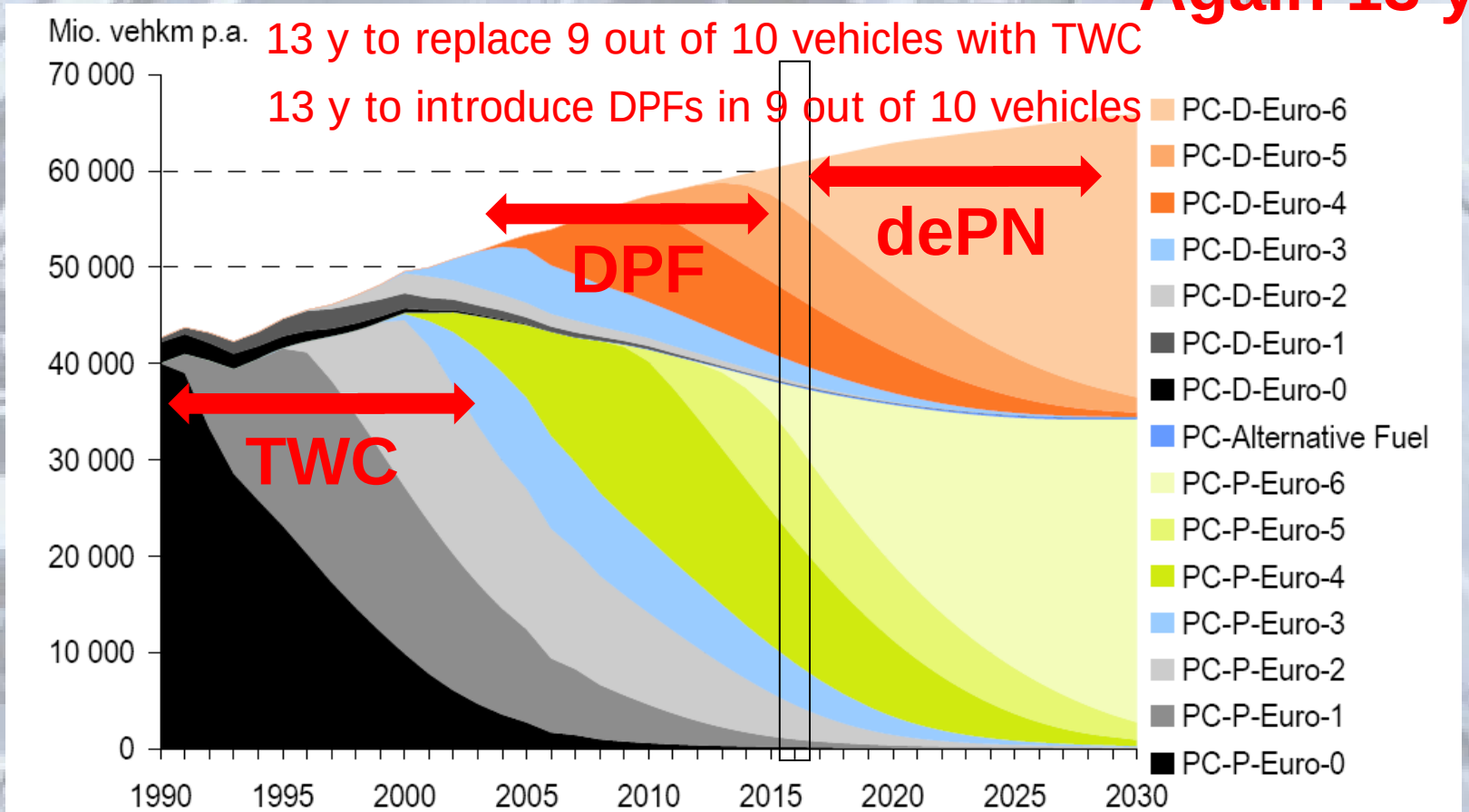

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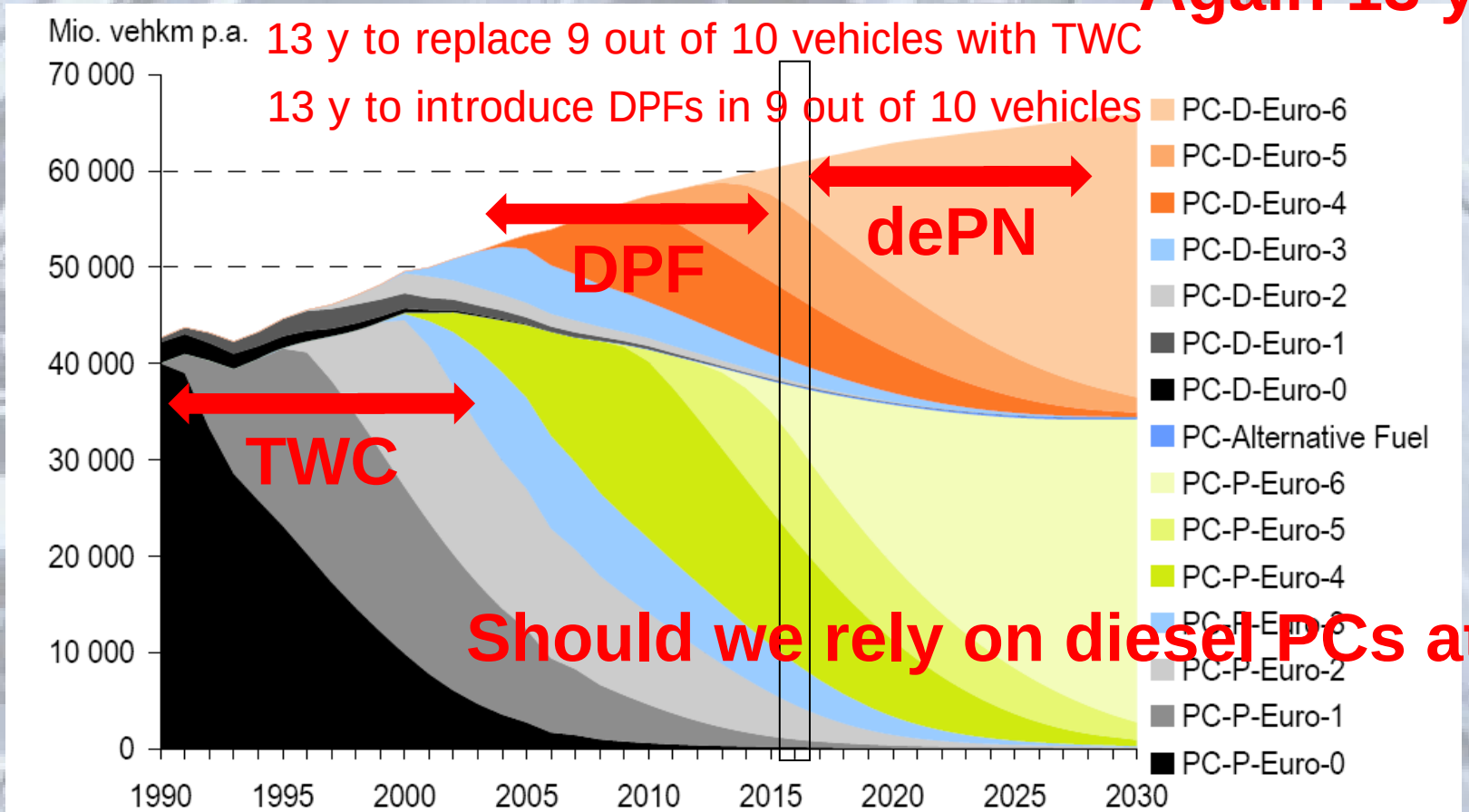
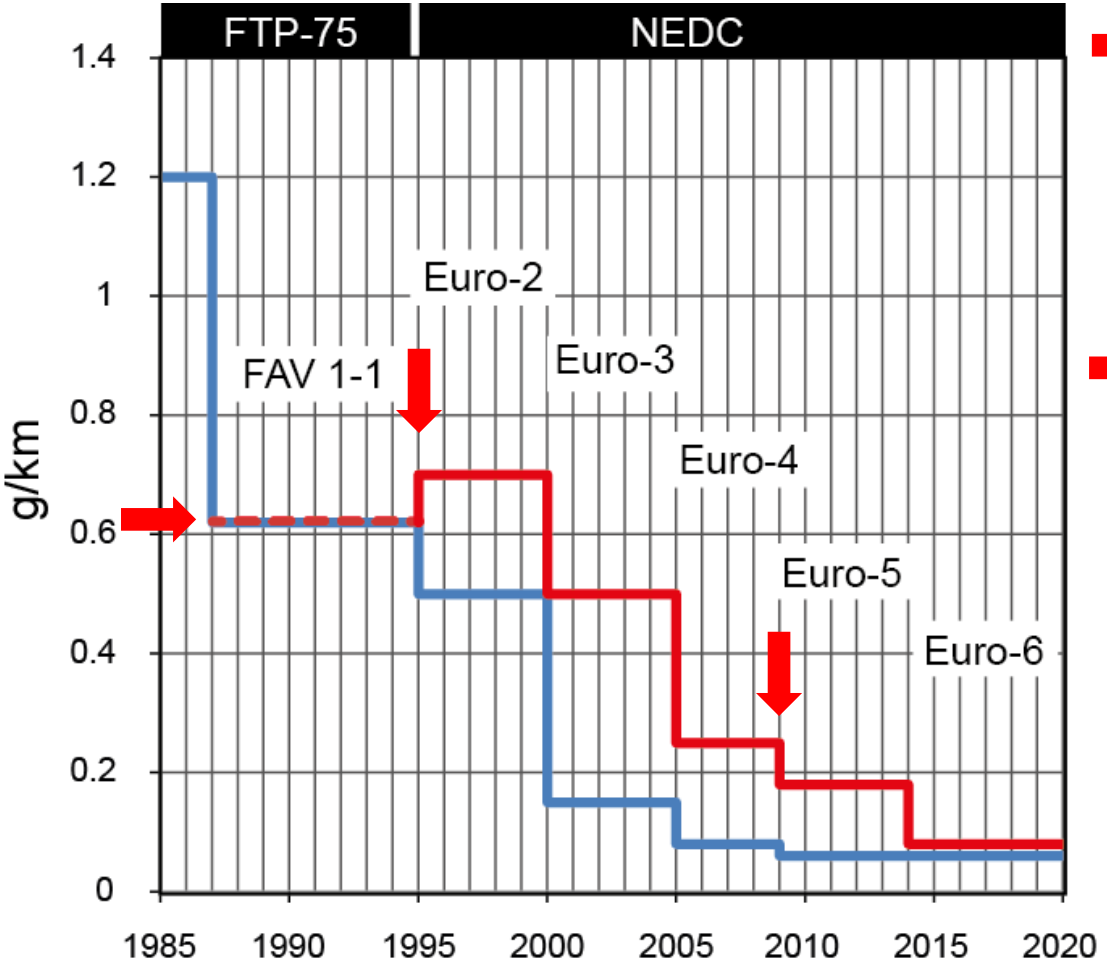


Should we rely on diesel PCs at all?

Legislation and reality

Since 1995 NOx limits in CH and Europe are based on EDC!



Before 1995 CH and US

- NOx limit technology independent

(0.65 g/km both for diesel & gasoline)

- transient cycle (FTP75)

After 1995 Europe favored diesel

- Higher NOx limits for diesel

- Static cycle (EDC)

- PN limit in 2009 (Euro-5)

(6x10e11 #/km, ca. 1 Billion #/km)

More diesel cars in Europe's cities

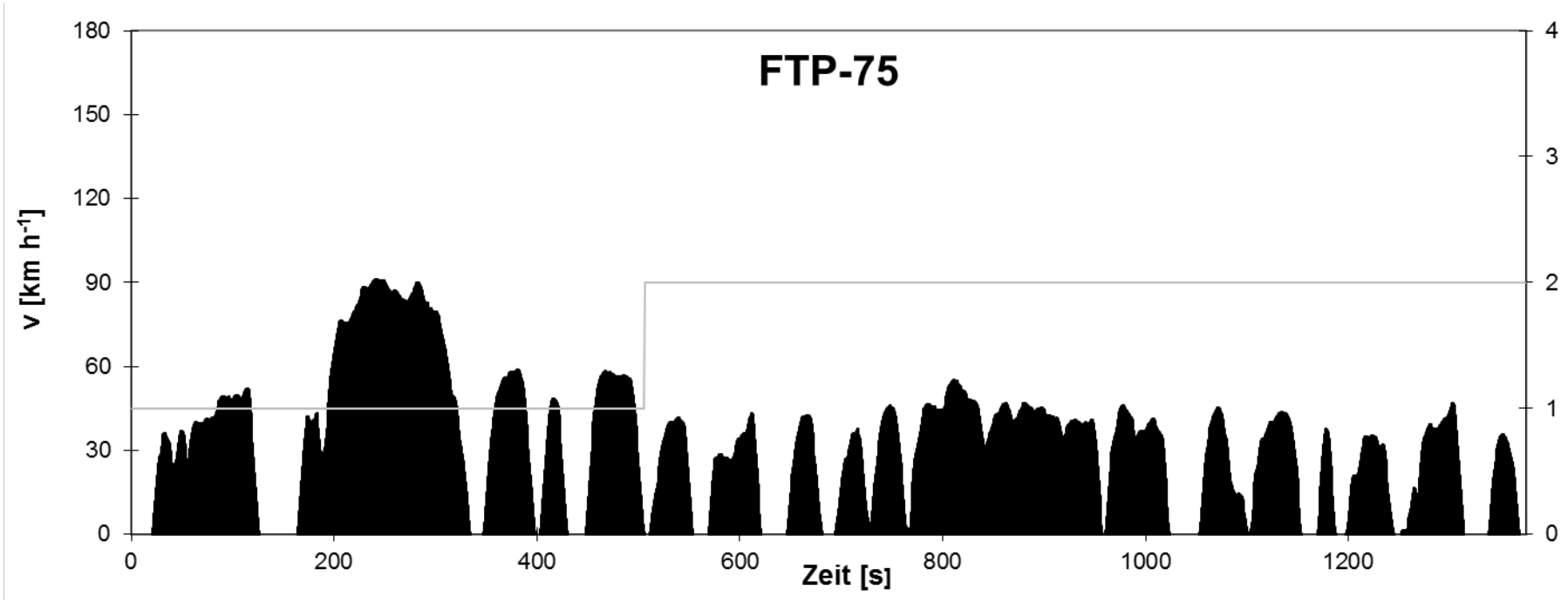
- Increased NO_2 emissions

- Increase of PN emissions

Useful and other driving cycles

Transient urban driving with cold start and stop-&-go

The US FTP-75, valid also in CH until 1995



Real-world driving cycle, realistic driving pattern

Consequence: Converter technologies are tested under road-like conditions

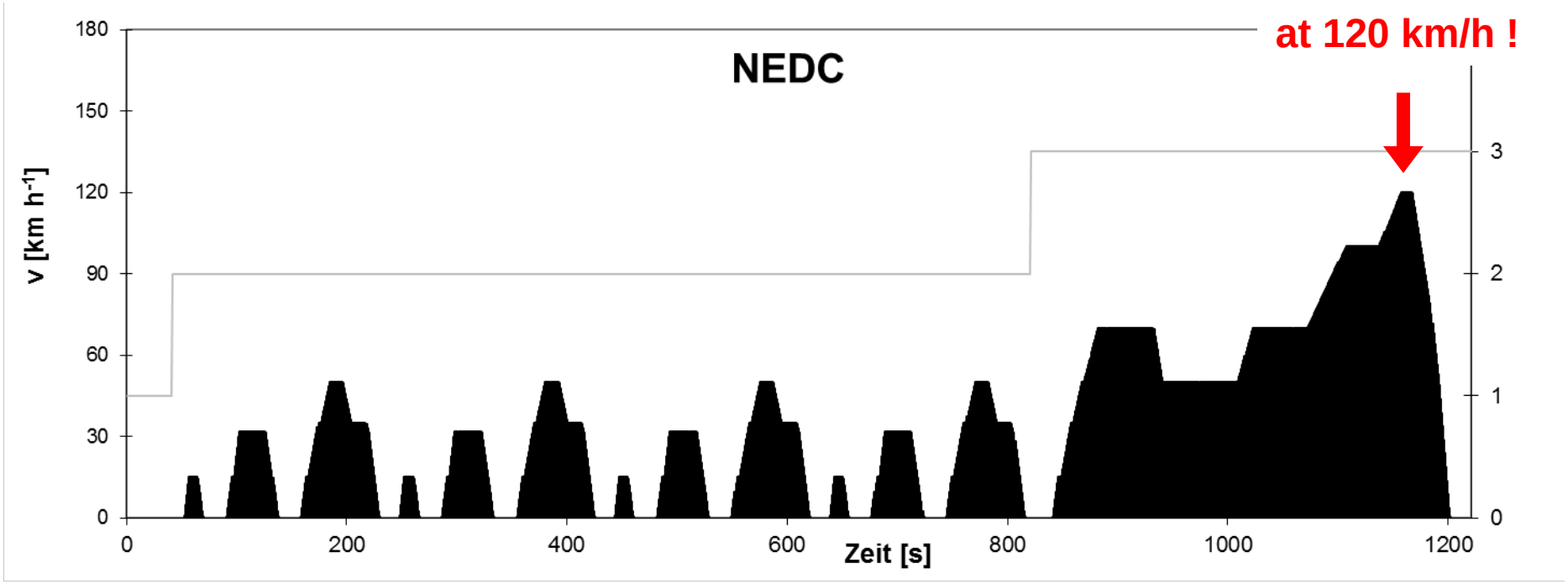
Useful and other driving cycles

Low engine load, fewer load changes, moderate acceleration, even without cold start

The EDC, valid in CH from 1995

5 seconds

at 120 km/h !



The outcome of a bureaucrat?

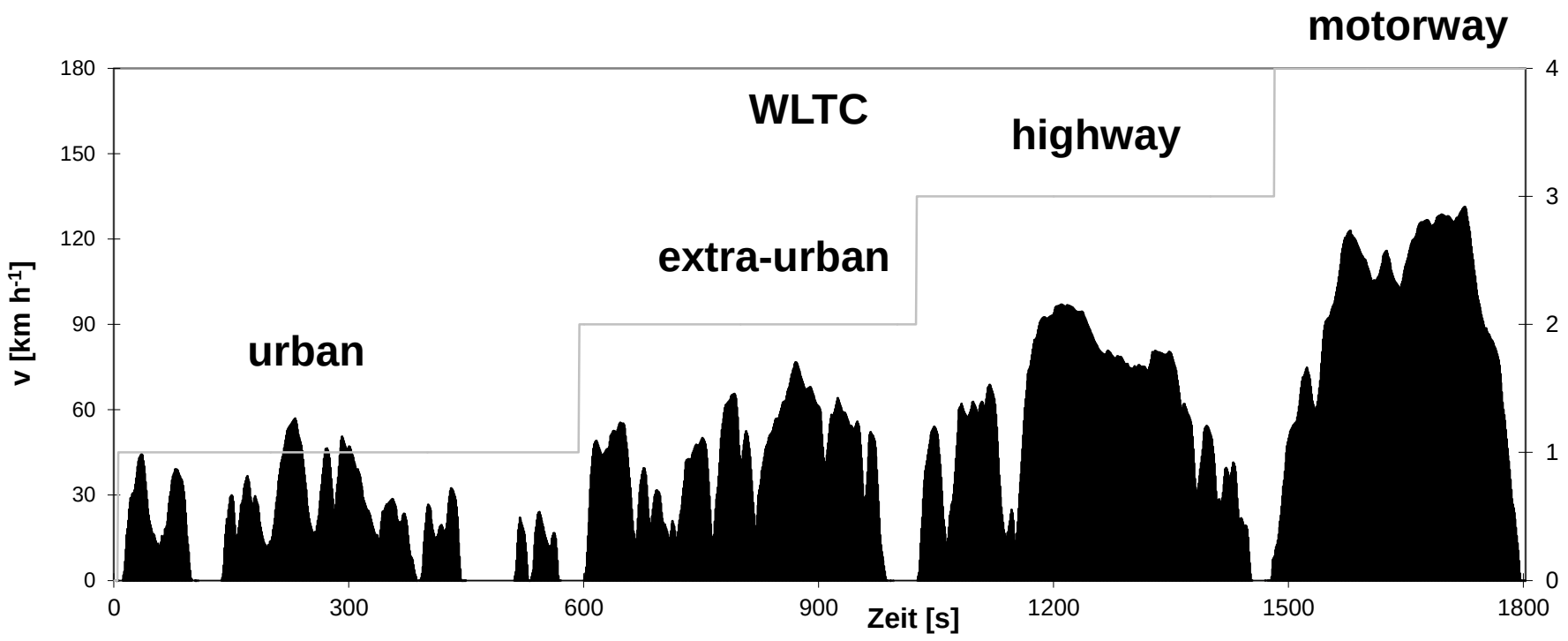
Consequence: Converter technologies are tested at low loads, quasi-stationary

Useful and other driving cycles

Lots of transients, with cold start, motorway and some stop-&-go

The WLTC, from 2017 on

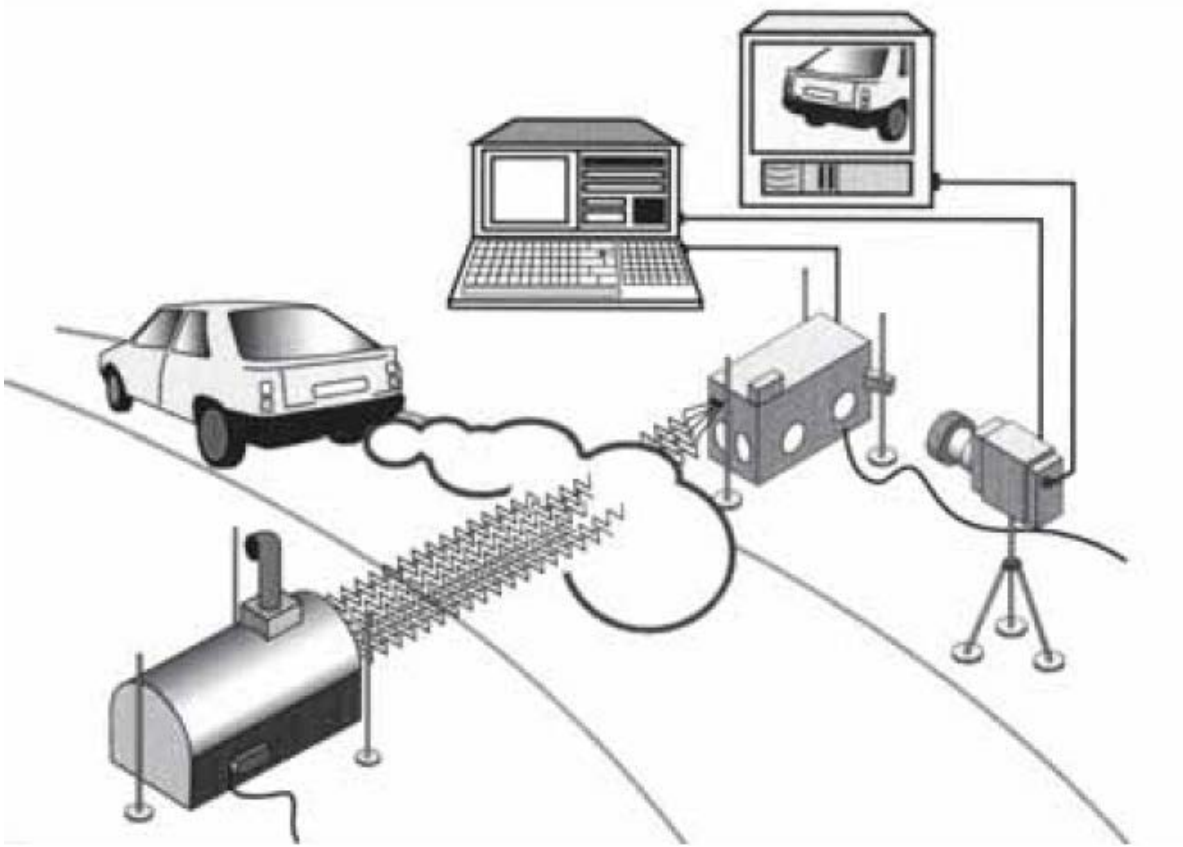
>100 s >120 km/h !



There's hope, that 40 years after the FTP-75 Europa is getting a transient cycle too!

From chassis dynamometers to on-road measurements

For example with an FT-IR at the curbside



- Remote Sensing

- Emissions of individual vehicles

- NO, CO, HC, CO_2

- 15 years, 500’000 vehicles

- Licence plate recognition

- Technology assignment

- Detection of high emitters

- Field inspection and control

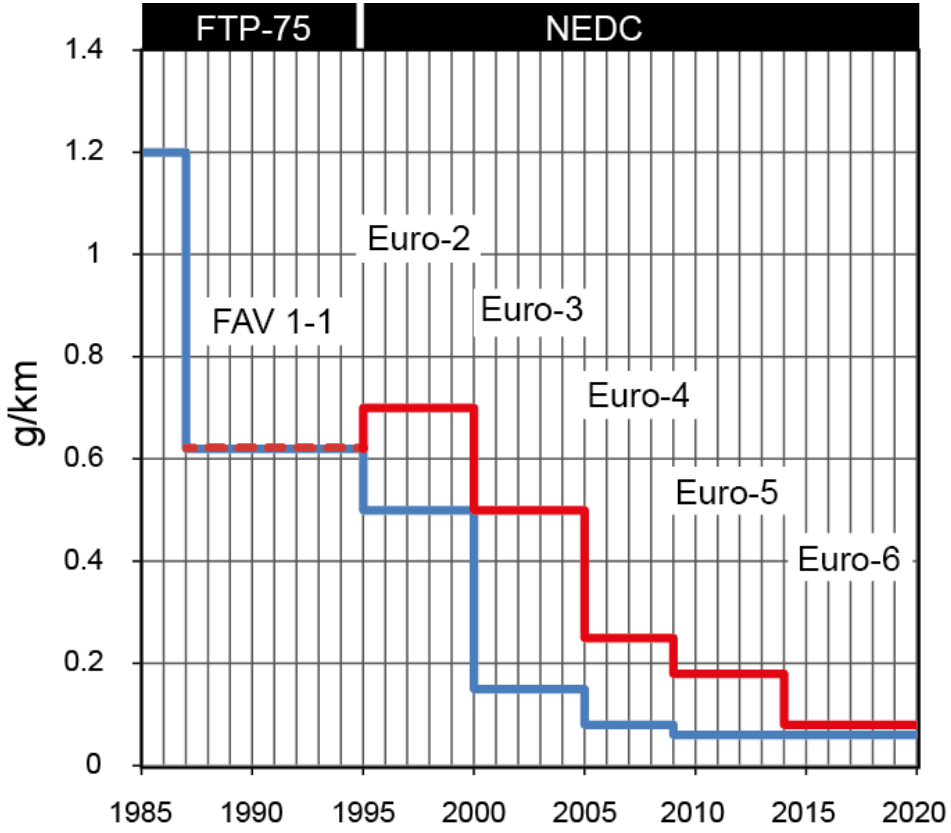
Gian-Marco Alt, Michael Götsch, Valentin Delb, AWEL, Zürich

Chen & Borken-Kleefeld Atm. Env. **2014**, 88, 157-164

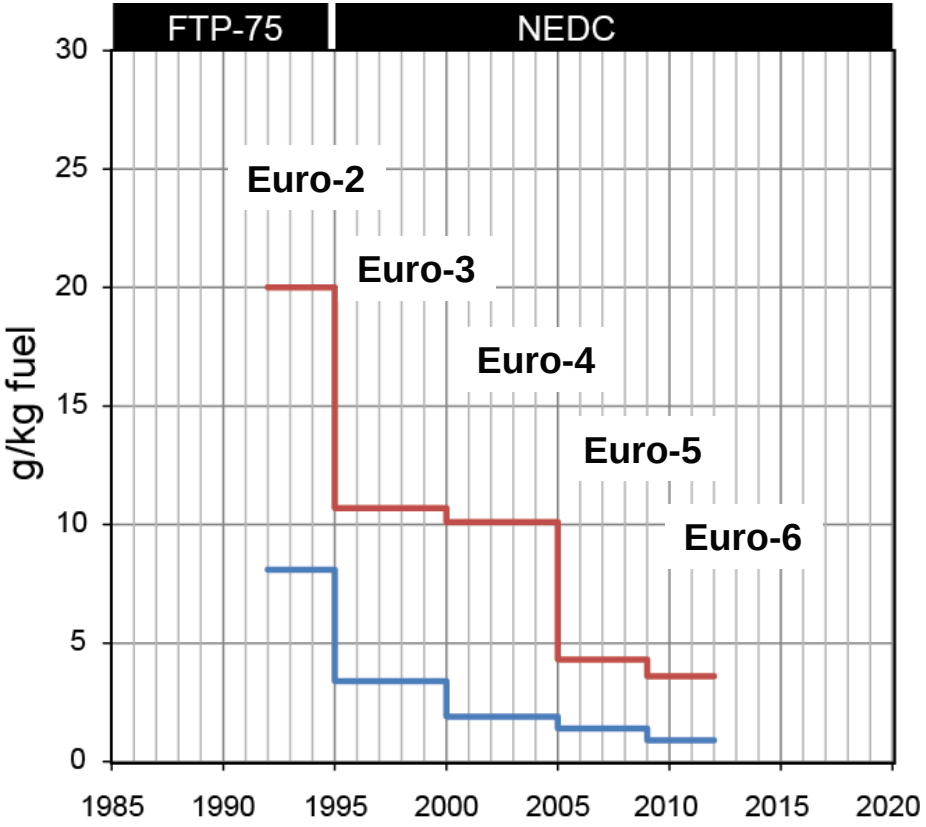
Exhaust regulation and reality

NOx emission limits in CH and Europe

Related to distance (g NOx/km)



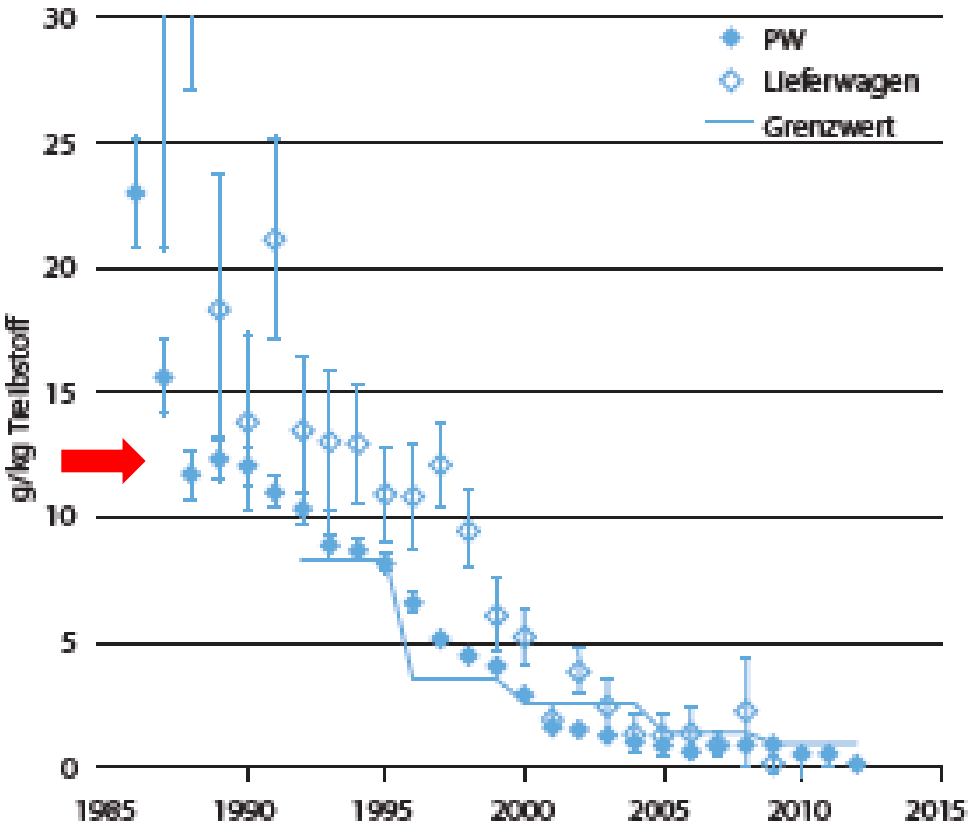
Consumption-related (g NOx/kg fuel)

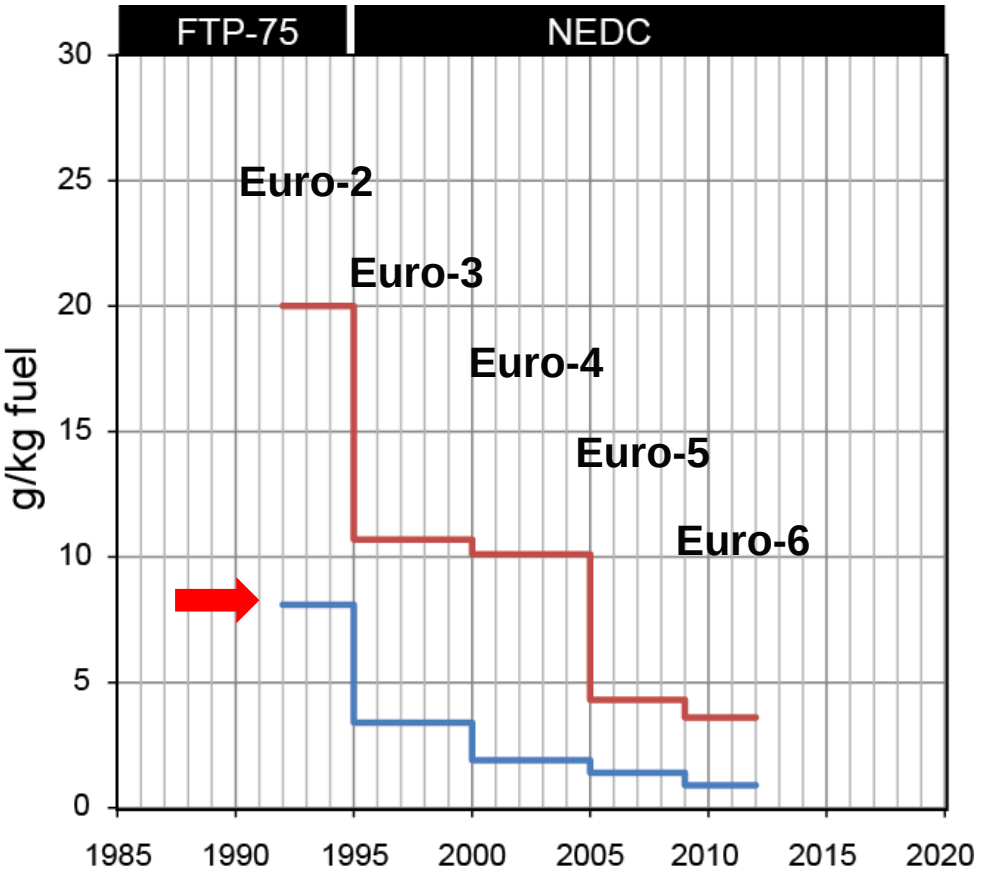


From chassis dynamometers to on-road measurements

NOx-emissions followed the prescribed limits (from 11 to <1 g/kg in 20 y)

NOx-emissions of gasoline cars





DeNOx-technologies of gasoline vehicles (TWCs) are active, also on roads

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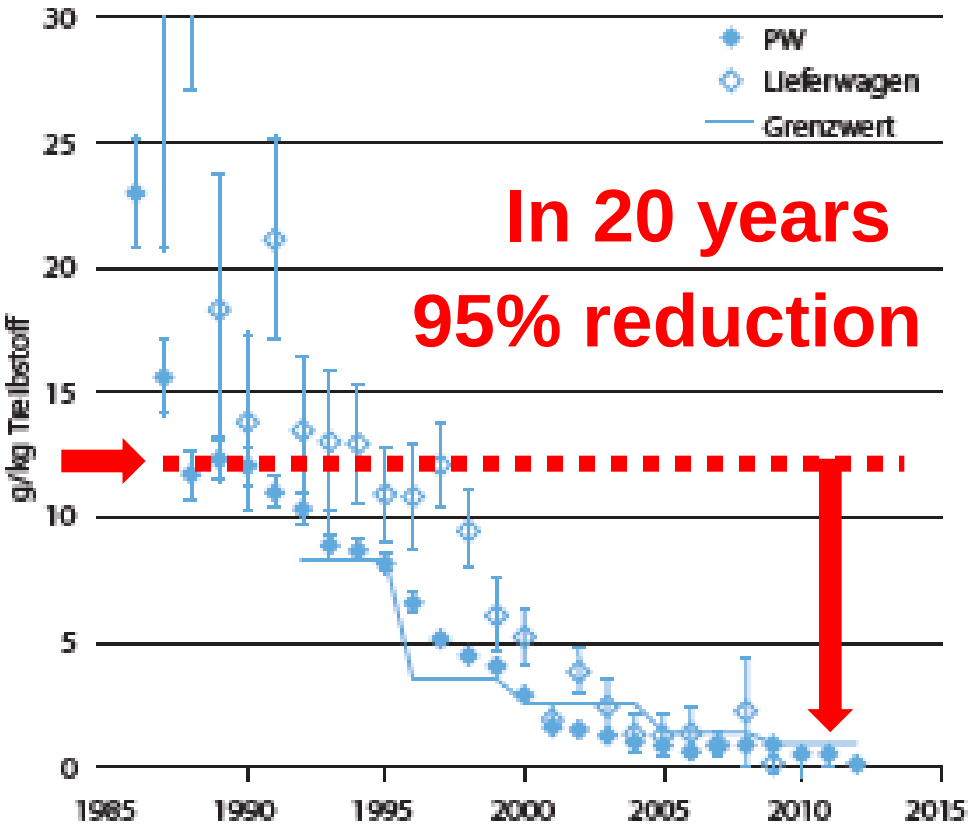

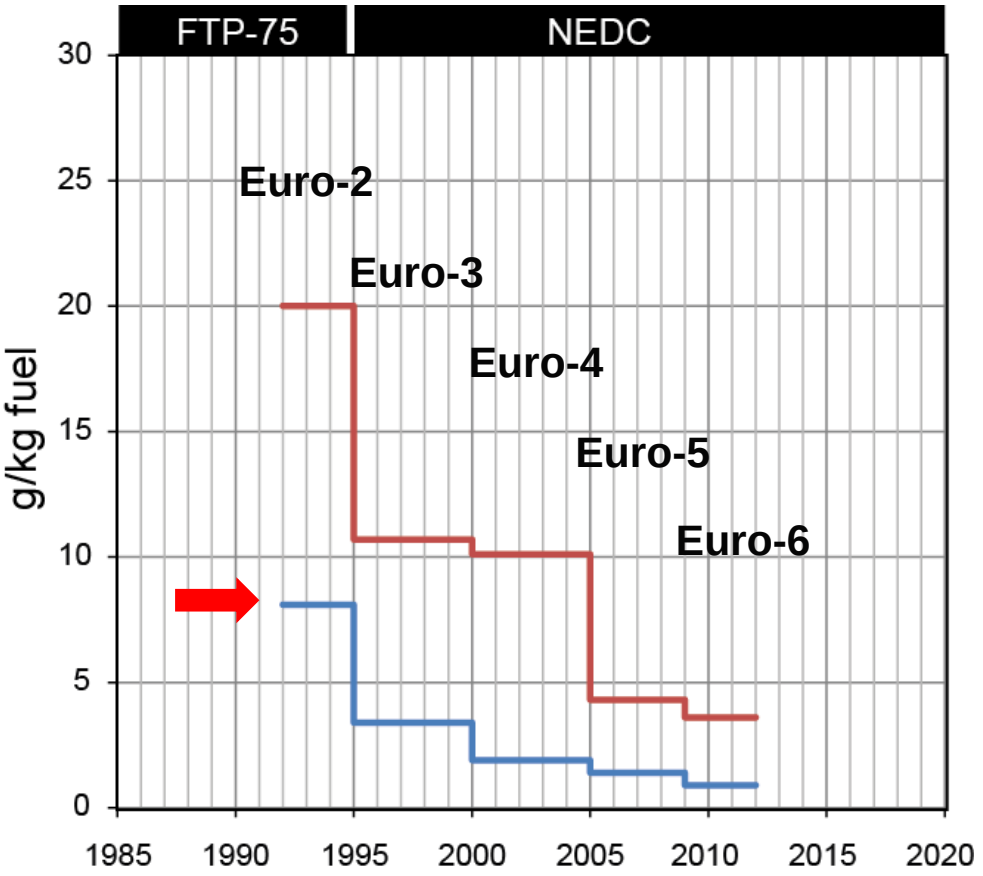

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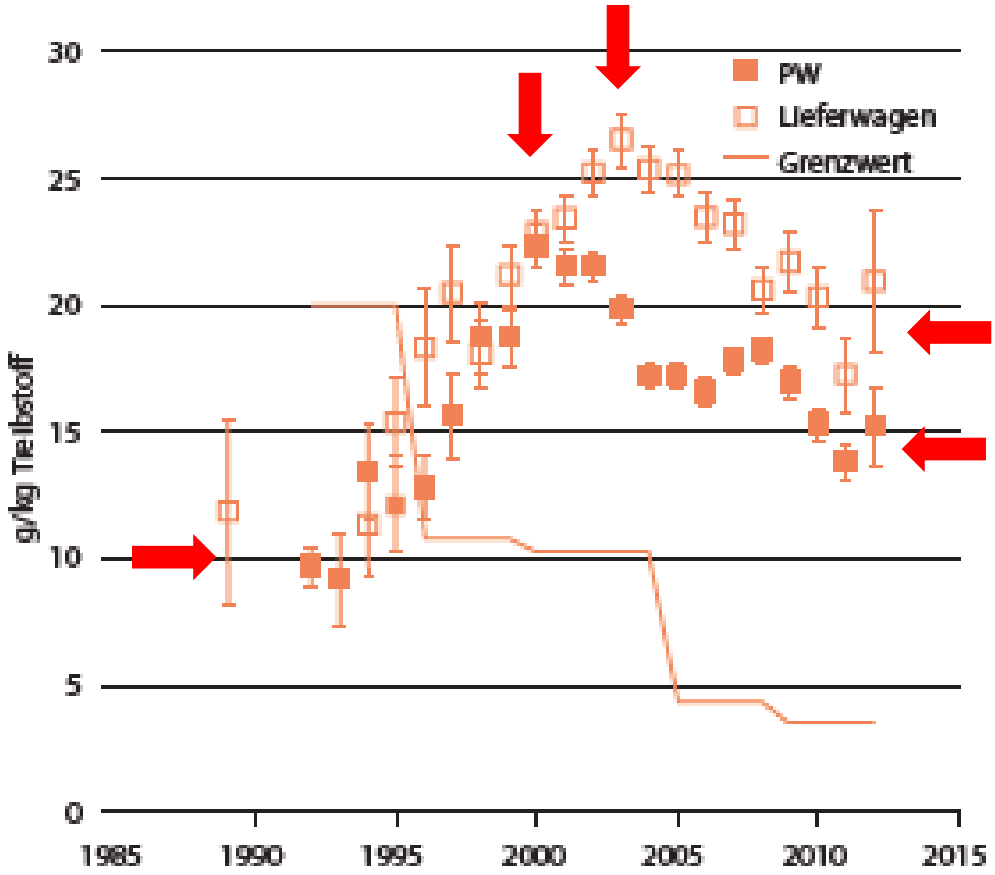
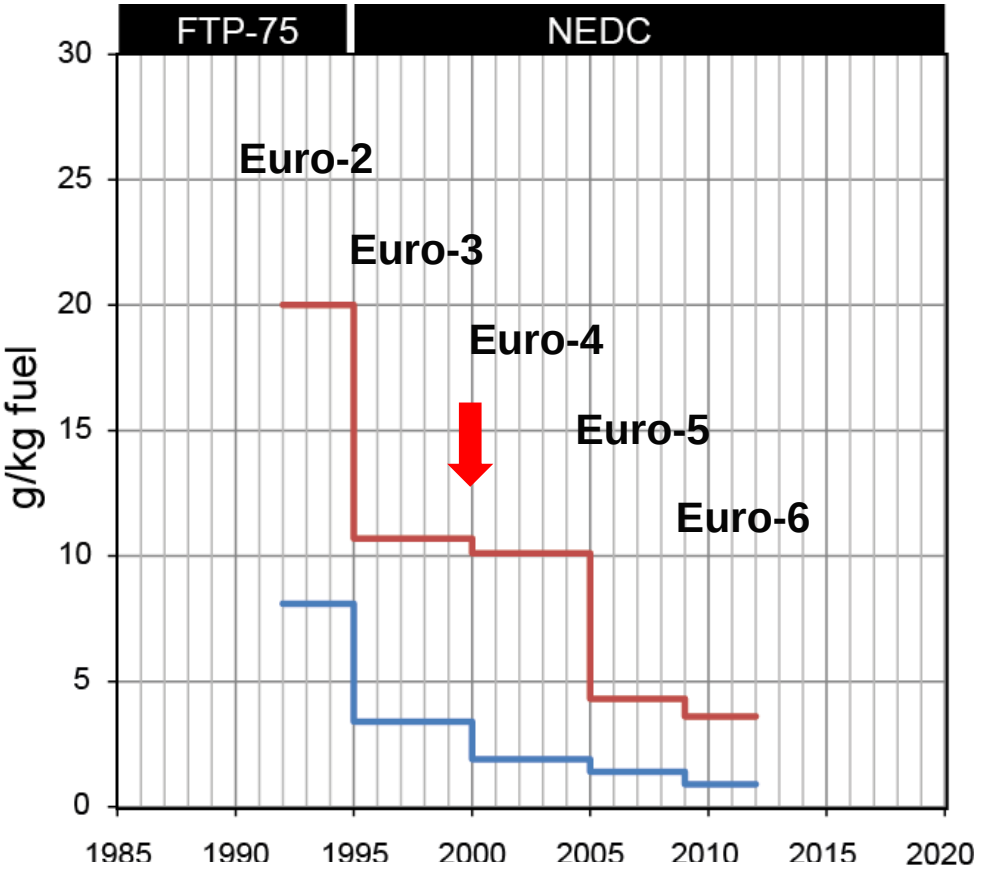
NOx-emissions of diesel-vehicles





DeNOx-technologies for diesel vehicles were introduced too late and are inefficient

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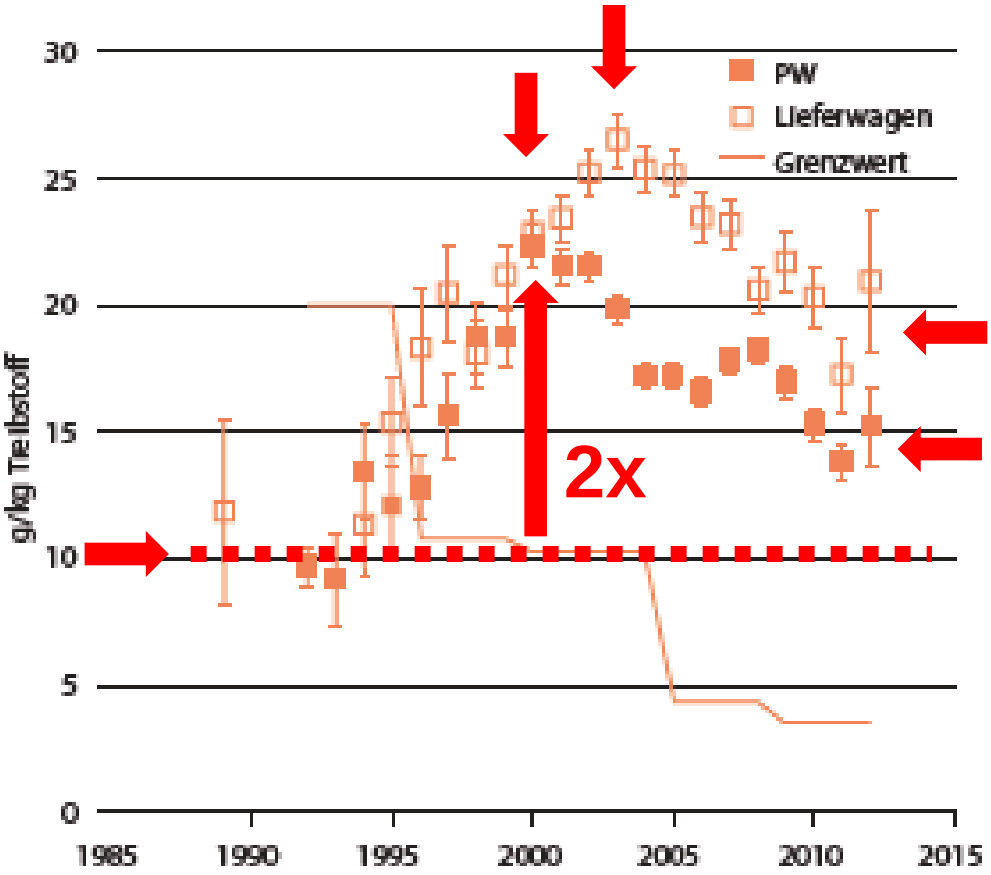

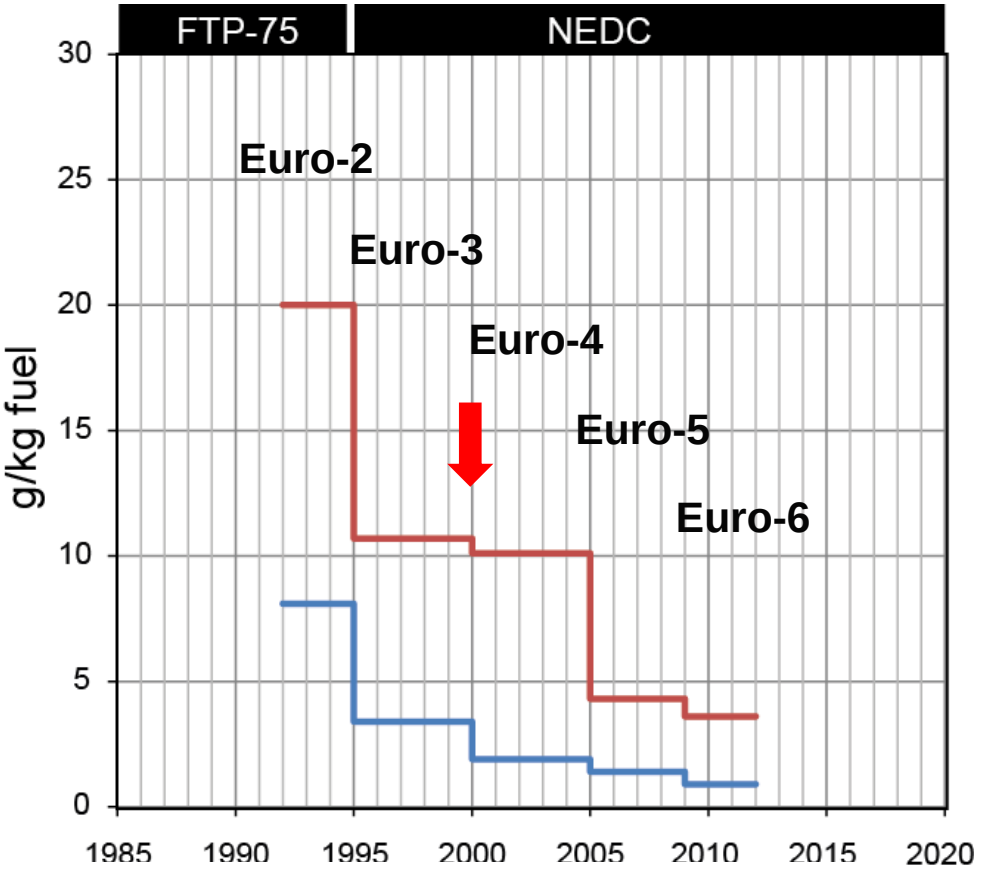

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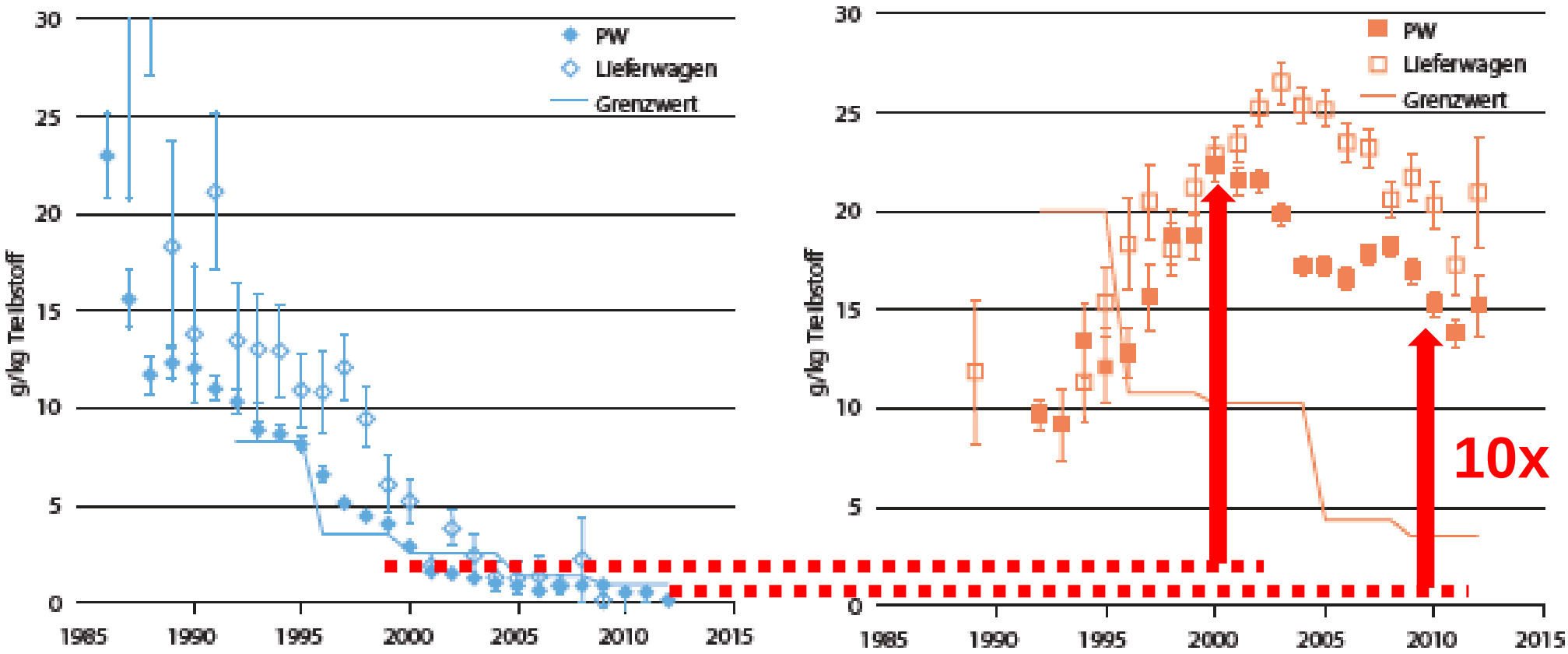
Appearance and reality are far apart! Diesel NOx 10x higher than gasoline vehicles

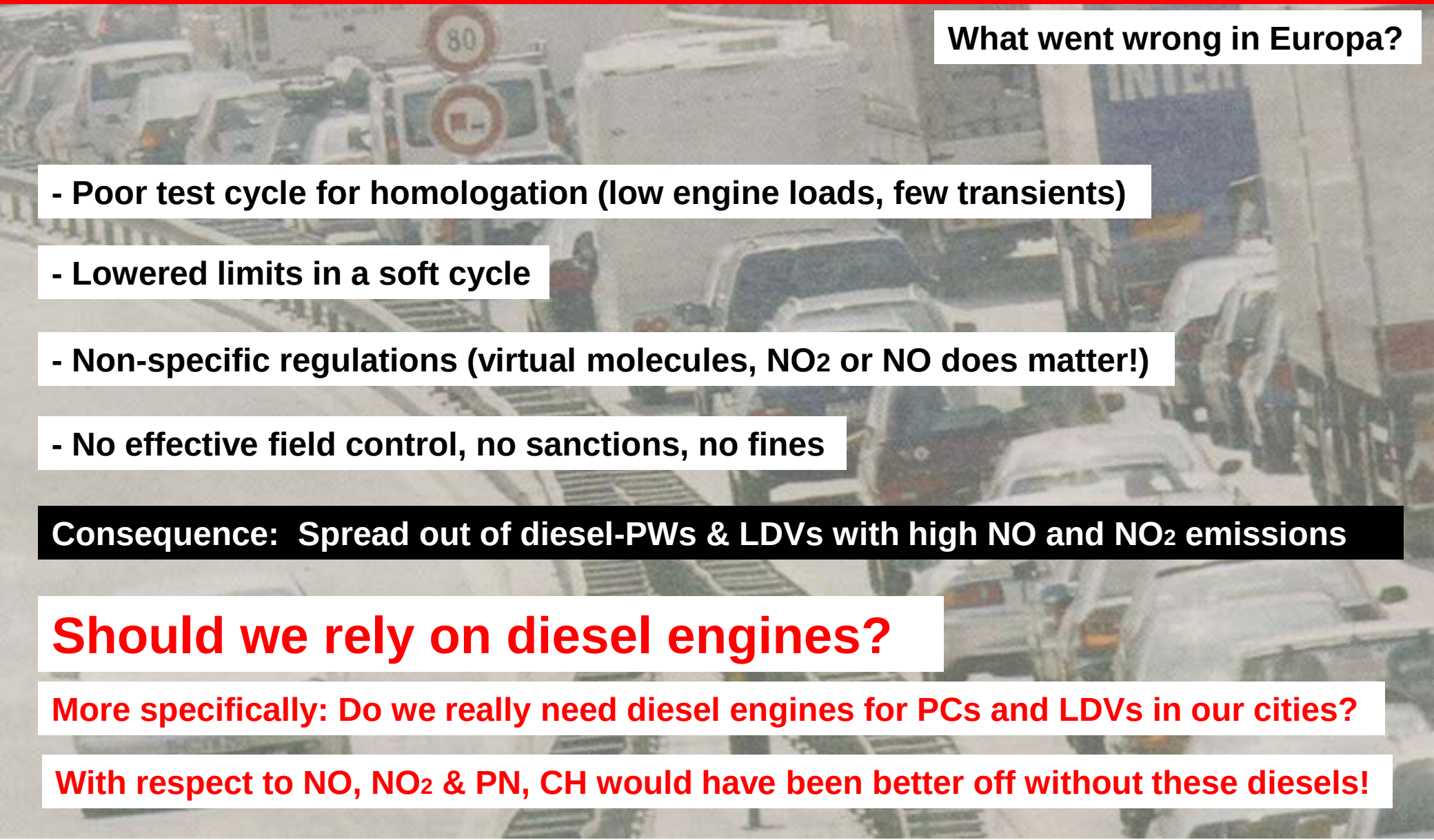
NOx-emissions of gasoline- & diesel-vehicles

The NOx-problem of diesel-PCs & LDVs is 20 years old – that's the scandal



Chen & Borken-Kleefeld Atm. Env. **2014**, 88, 157-164

Exhaust regulation and reality



What went wrong in Europa?

- Poor test cycle for homologation (low engine loads, few transients)
- Lowered limits in a soft cycle
- Non-specific regulations (virtual molecules, NO_2 or NO does matter!)
- No effective field control, no sanctions, no fines

Consequence: Spread out of diesel-PWs & LDVs with high NO and NO_2 emissions

Should we rely on diesel engines?

More specifically: Do we really need diesel engines for PCs and LDVs in our cities?

With respect to NO, NO_2 & PN, CH would have been better off without these diesels!

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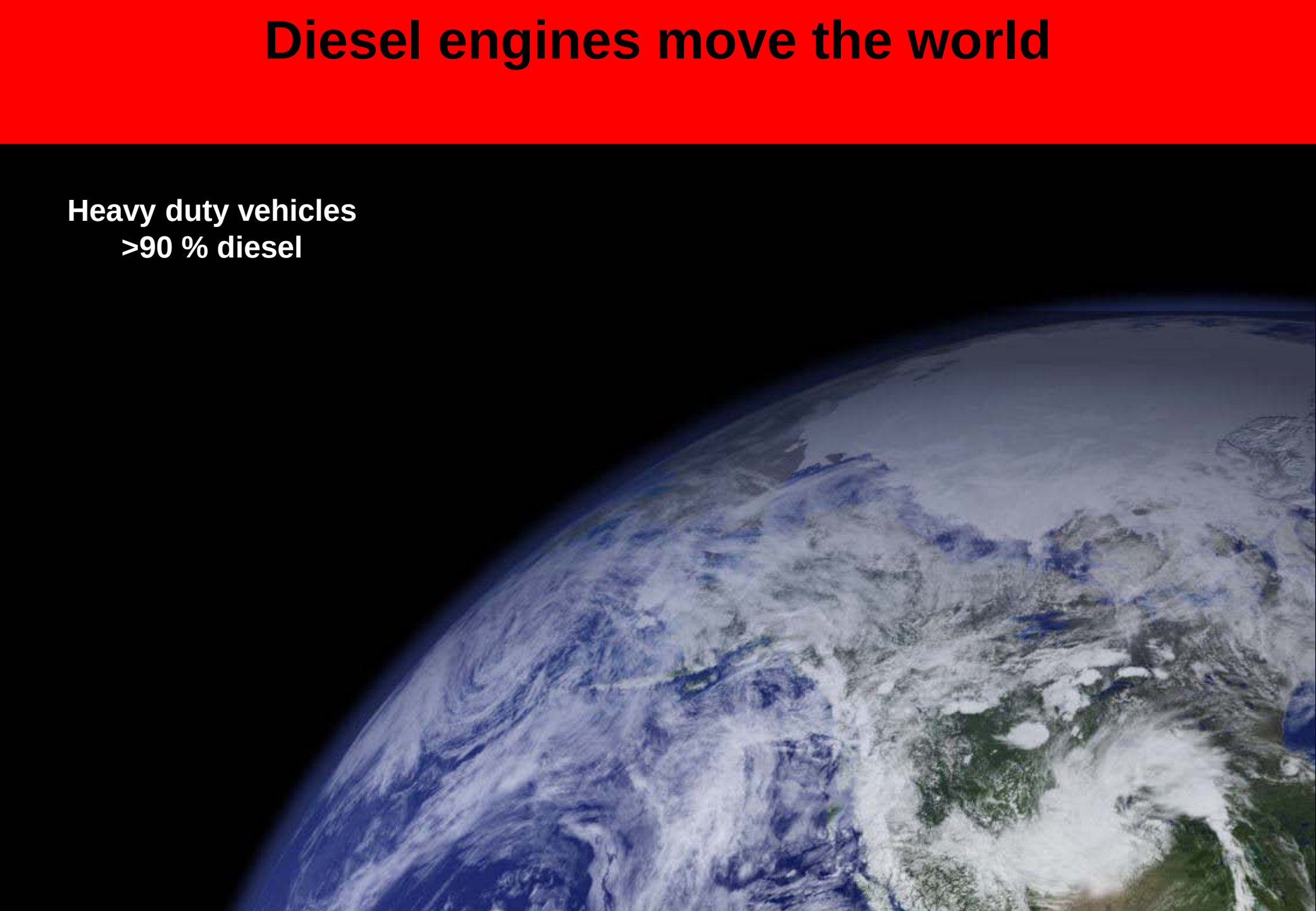
Heavy duty vehicles
>90 % diesel



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EU: ~42 % diesel
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We have to, they are all around us!

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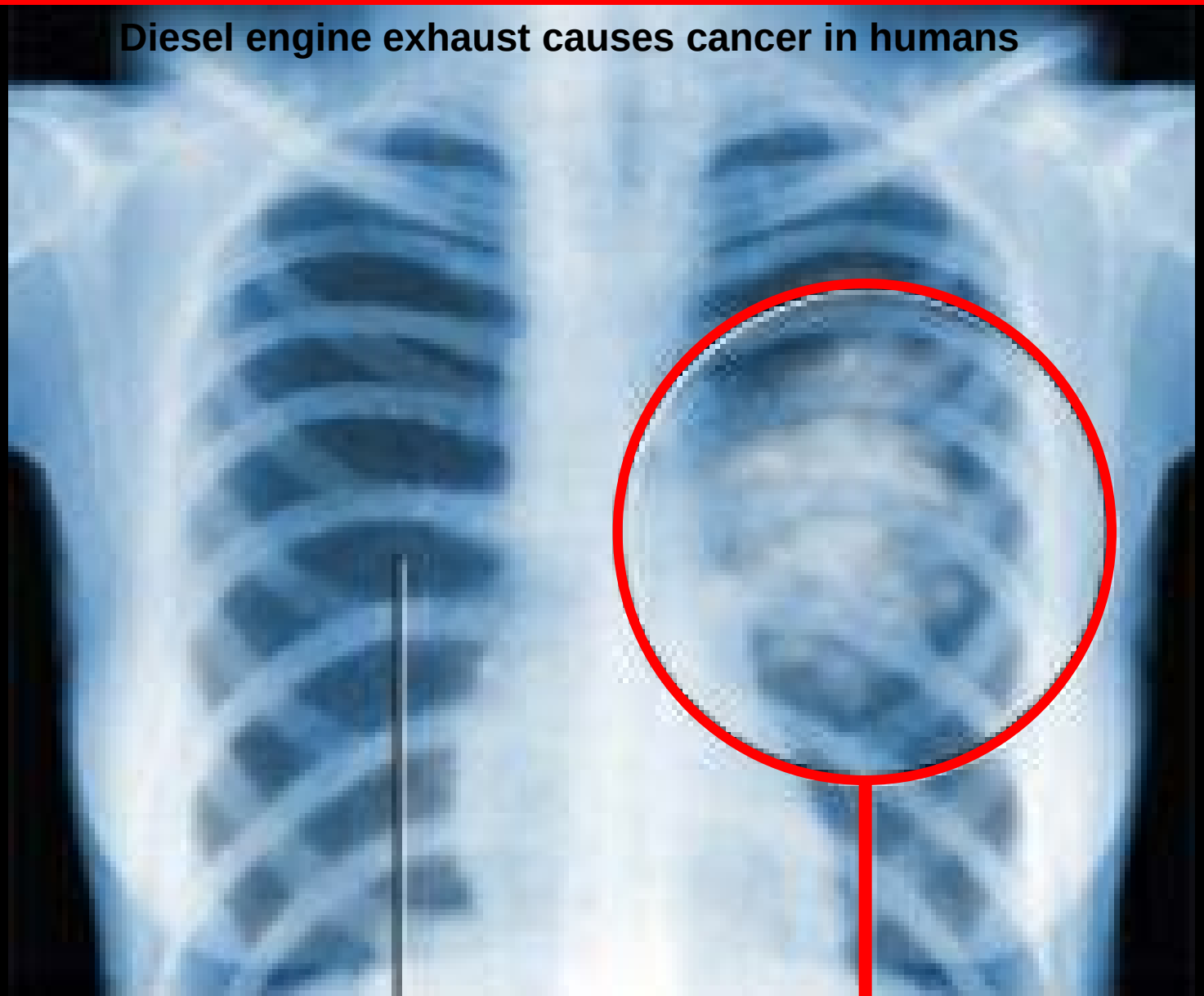
World Health Organization, IARC
Diesel engine exhaust: A group 1 carcinogen

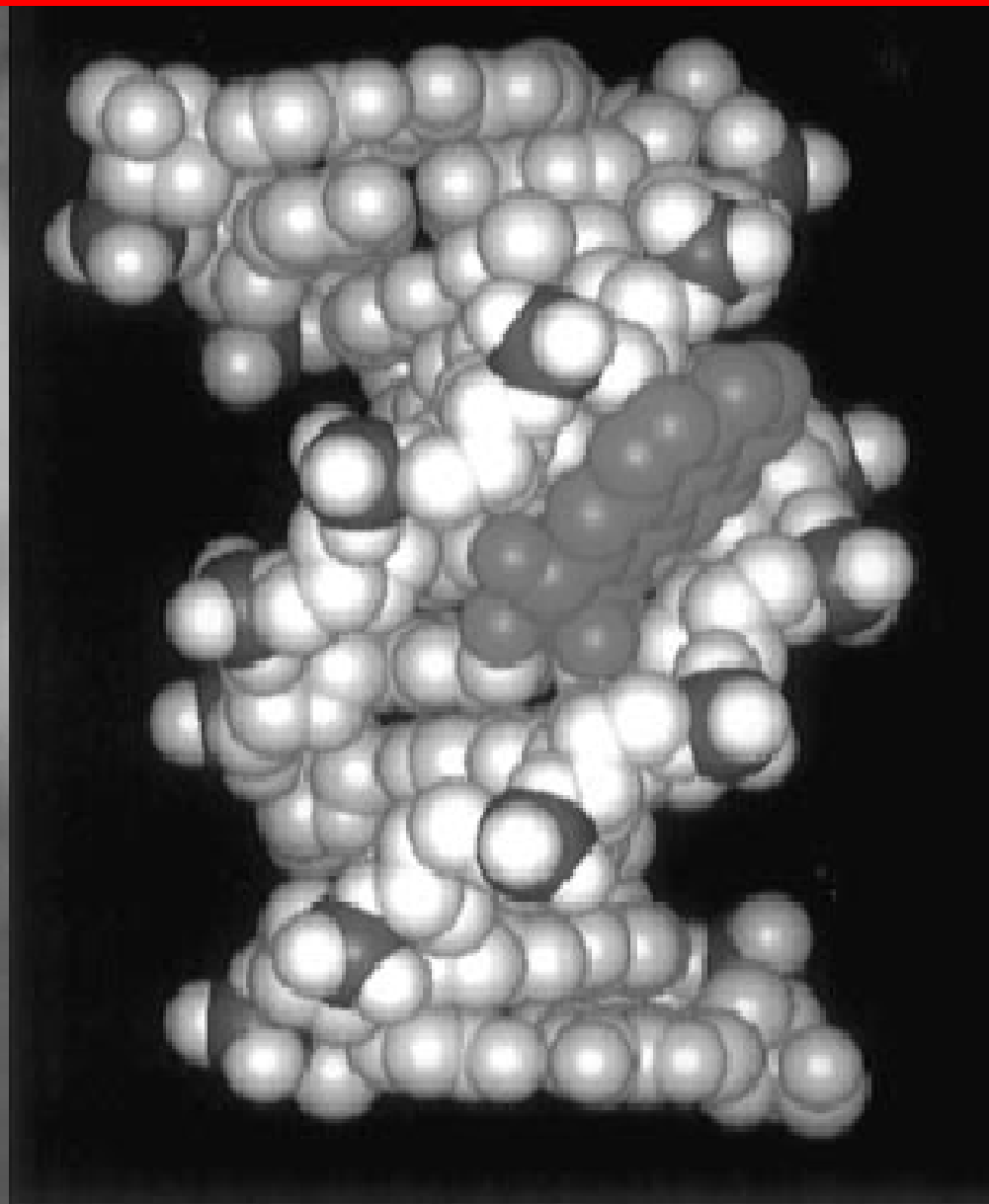


Adverse health effects of diesel exhaust

How about genotoxic compounds?

Problem 1: Genotoxicity

- Diesel exhaust is genotoxic (it contains mutagenic and carcinogenic compounds)



Adverse health effects of diesel exhaust

Problem 2: Trojan horse effect

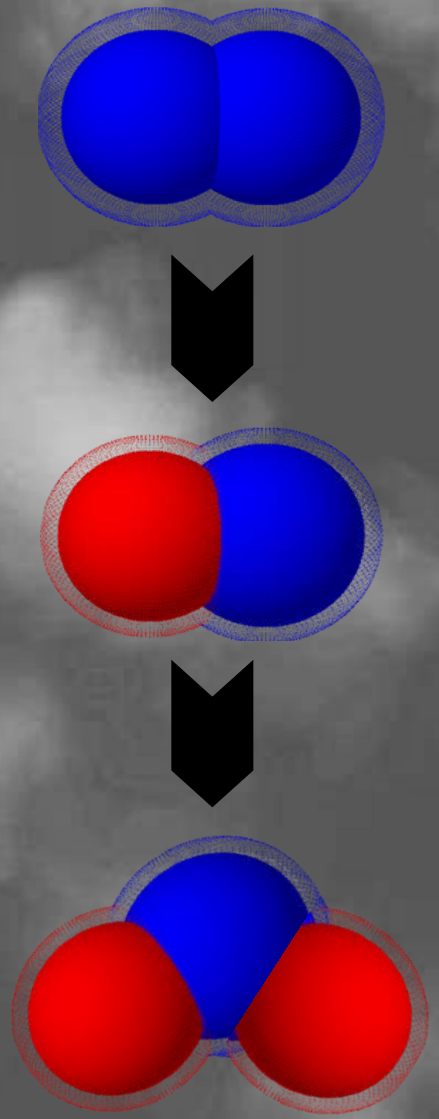
- Nanoparticles penetrate cell membranes (alveoli, placenta, blood cells) acting like a Trojan horse transporting toxic compounds into cells

Trojan horse, Harbour of Canakkale, Turkey

Adverse health effects of diesel exhaust

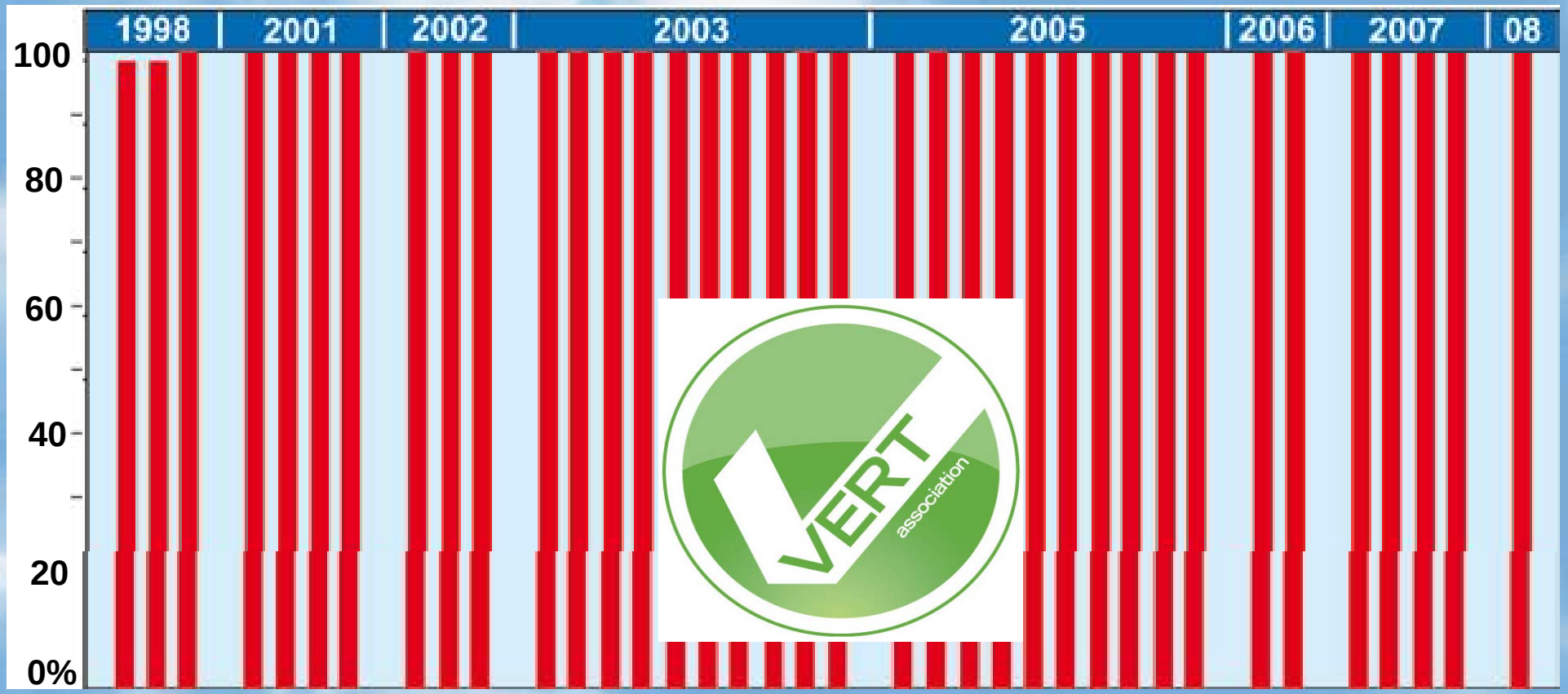
Problem 3: Reactive nitrogen compounds

- NO_2 highly toxic (acute and chronic) (induces oxidative stress, inflammation chronic obstructive pulmonary disease)
- Diesel vehicles with DOCs and hox-DPFs substantially increased NO_2 emissions
- **We have to tackle the NO and NO_2 problem!**



Catalytic DPFs, BAT since 1998

more than 50 VERT-tested DPFs are on the market (ready to be used).



Mayer et al. MTZ, **2009**, 70, 72-79

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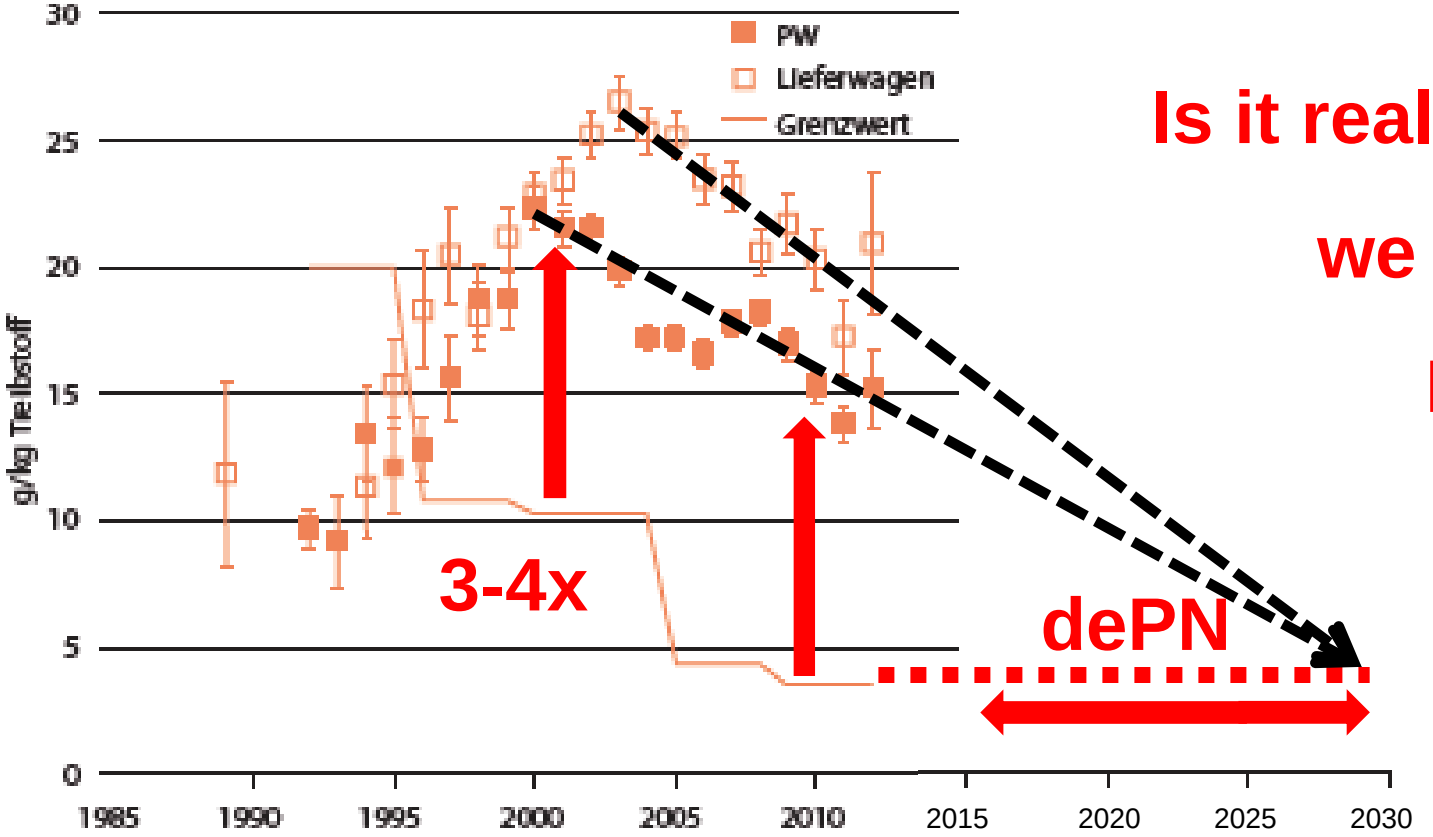
Can diesel solve its NO and NO_2 emission problem in time?

Appearance and reality are far apart! Another 15 years to wait?

NOx-emissions of diesel-vehicles

The NOx-problem of diesel-PCs & LDVs is 20 years old – that's the scandal



Is it really 2030 when we finally reach Euro-6 level?

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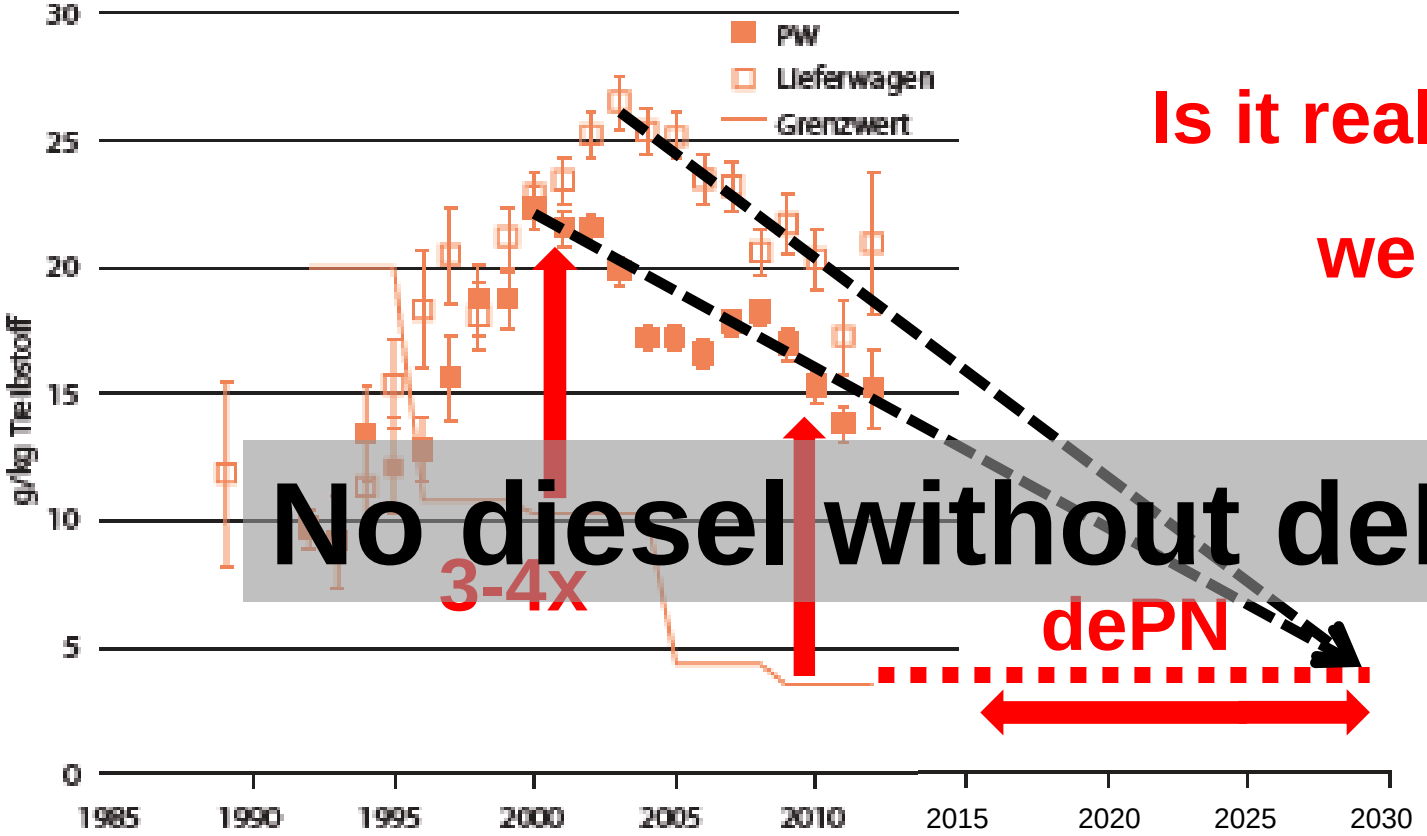

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No diesel without deNOx

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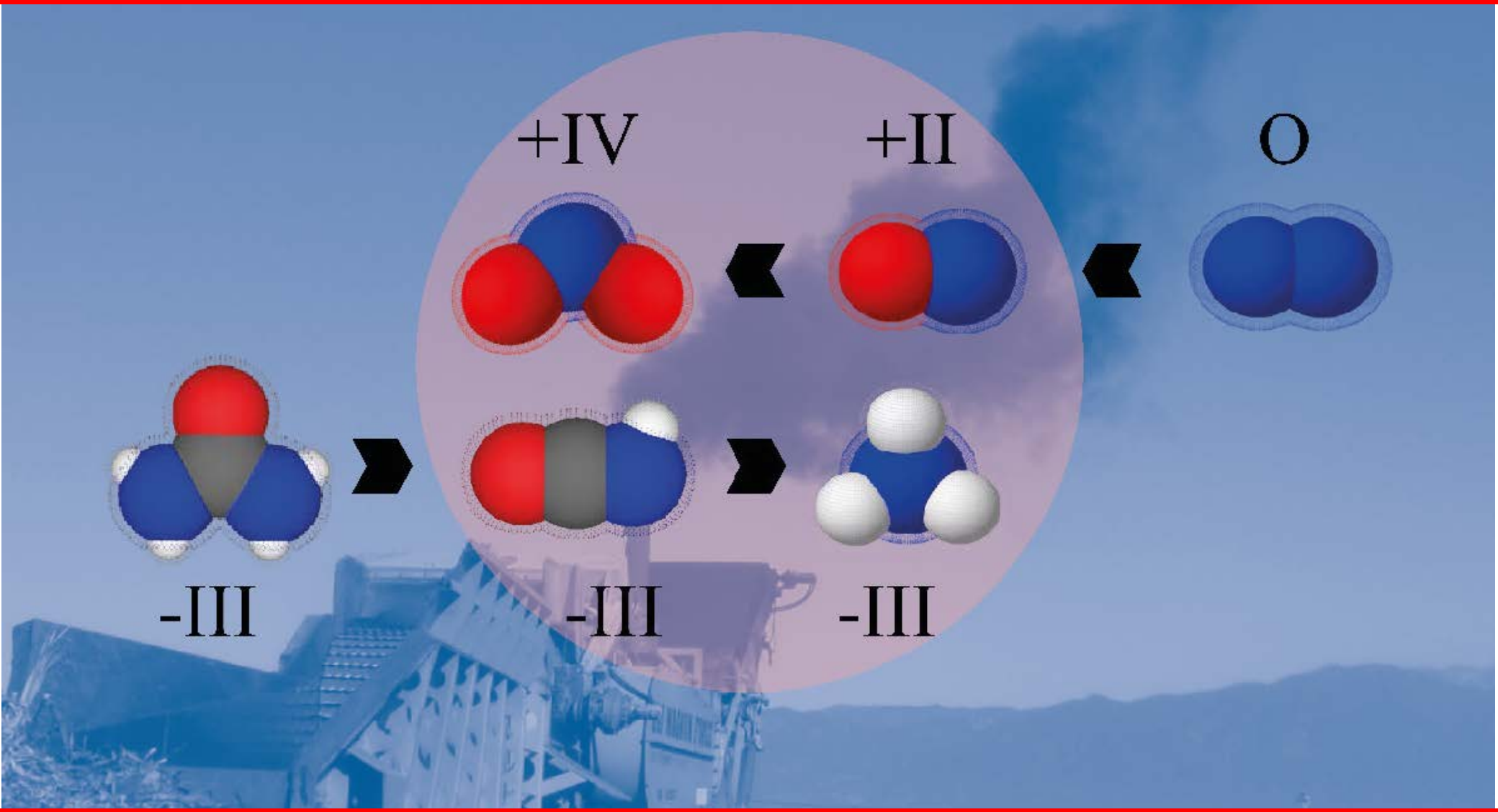
Urea-based SCR



Currently the most efficient deNOx system for diesel engines

The DePN - a chemical factory!

If we need the diesel, we need highly efficient deNOx and filters!

The DePN - a chemical factory!

In other words:
if we can not deliver deNOx technologies that are active in real world, diesel vehicles will not be tolerated in our cities even though they are equipped with highly efficient filters!

If we need the diesel, we need highly efficient deNOx and filters!

Can diesel solve its NO and NO_2 emission problem in time?

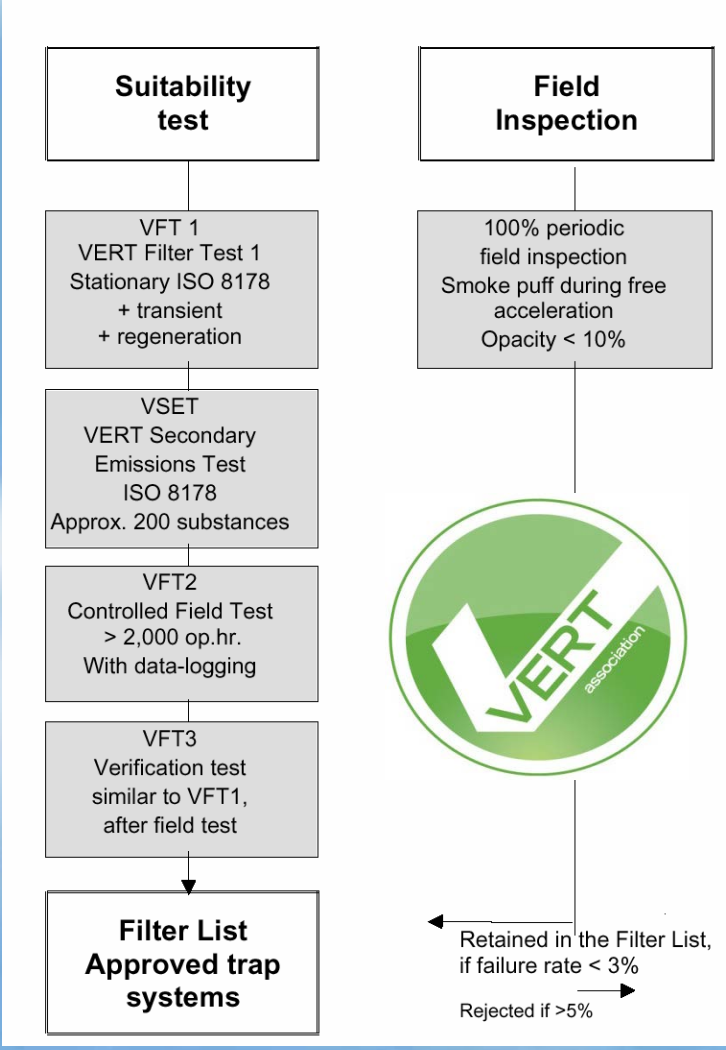
VERT should proceed and recommend the use of high quality dePN systems?

Requirements for VERT approved systems

Approved dePN systems should:

- lower genotoxic compounds (a.m.a.p.)
- reduce PM- & PN-emissions (>98%)
- reduce NO and NO_2 emissions (not defined yet)
- have low risks of secondary emissions
- not increase metal emissions (e.g. catalysts)

we need >90%



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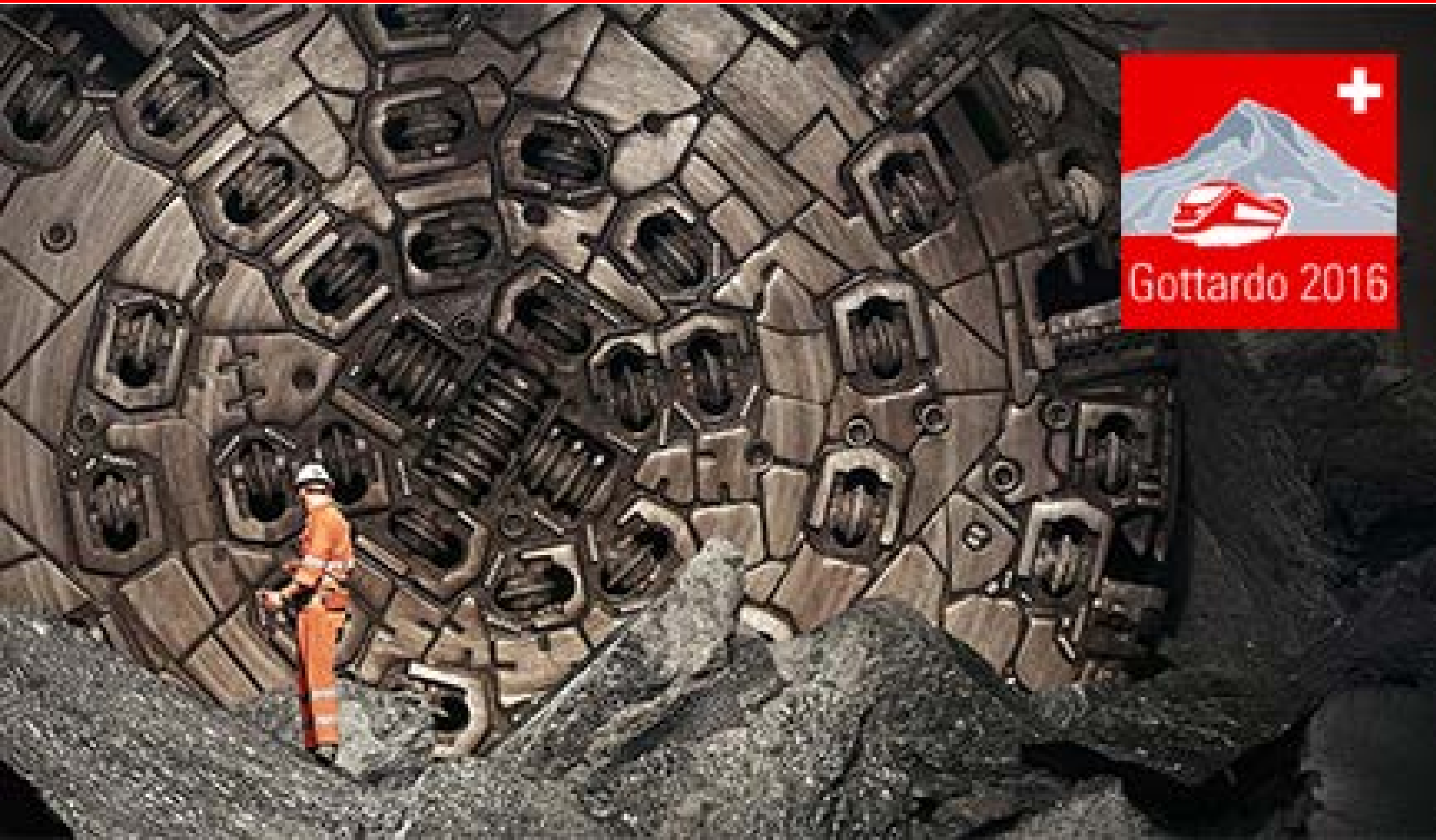
NEAT – the longest railway tunnel of the world built with VERT-approved DPFs



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Europa's NOx Problem – Eine Folge ineffizienter deNOx-Katalysatoren und schlechter Abgasgesetzgebung

A combined effort with many important contributions

Thanks:

- **VERT team:** Andreas Mayer, TTM, Niederrohrdorf
  Jan Czerwinski, Sandro Napoli, Tobias Neubert, Thomas Hilfiker, Samuel Bürki,
  Jean-Luc Petermann, Yan Zimmerli, Hervé Nauroy Uni. Appl. Sci., Biel.
  Markus Kasper, Adrian Hess, Thomas Mosimann, Matter Aerosols, Wohlen
  Hans Jaeckle, Urs Debrunner, Oliver Schumm, Intertek Caleb Brett, Schlieren.
- **Empa colleagues:** Brigitte Buchmann, Thomas Bührer, Lukas Emmenegger, Anna-Maria Forss, Urs Gfeller, Maria Guecheva, Peter Graf, Roland Graf, Erika Guyer, Regula Haag, Peter Honnegger, Judith Kobler, Martin Kohler, Peter Lienemann, Alfred Mack, Peter Mattrel, Martin Mohr, Joachim Mohn, Christof Moor, Andreas Paul, Peter Schmid, Cornelia Seiler, Andrea Ulrich, Heinz Vonmont, Thomas Walter, Max Wolfensberger, Daniela Wenger, Adrian Wichser, Markus Zennegg, Kerstin Zeyer.
- **Governement**: Philipp Hallauer, Giovanni D'Urbano, Felix Reutimann, Max Wyser, Gerhard Leutert, Martin Schiess, Swiss Fed. Office for Environment, Bern
  Thomas Gasser, Heinz Berger, Gerhard Stucki, Swiss Federal Road Office
- **Filter- & catalyst manufacturers**: >50 diesel particle filters, 4 deNOx-Systems

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SCHWEIZ. CHEMISCHE GESELLSCHAFT SCG
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Traugott Sandmeyer (1854-1922)

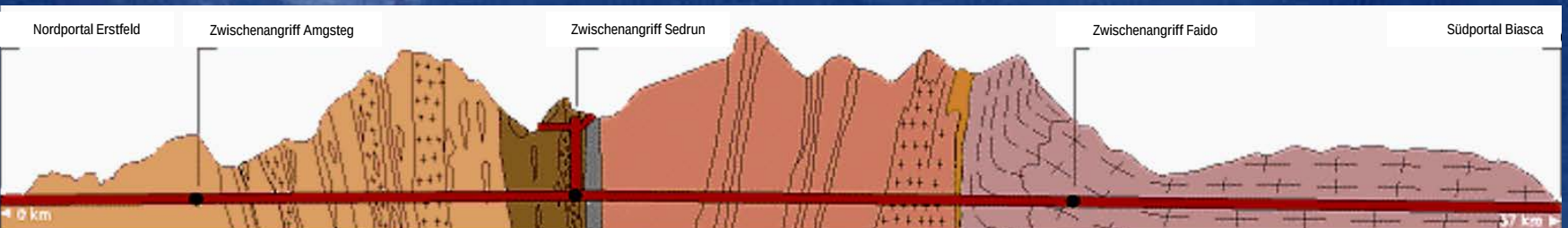
NEAT – der längste Eisenbahn-Tunnel der Welt

Visionäre Entscheide vor 20 Jahren!

- 2 Umweltpolitische Volksabstimmungen
  - Bau der Eisenbahn-Alpentransversale, 21.9.92
  - Alpenschutzinitiative, 20.2.94

- 2 Röhren à 57 km, 153 km Schächte & Tunnels
  - Kosten über 20 Milliarden SFr
  - Bauzeit von 1993-2016

Filterobligatorium für Baumaschinen, seit 1998 im Tunnel, in CH de facto seit 2010



NEAT – Wenn der DPF im Tunnel funktioniert tut er’s auch auf der Strasse

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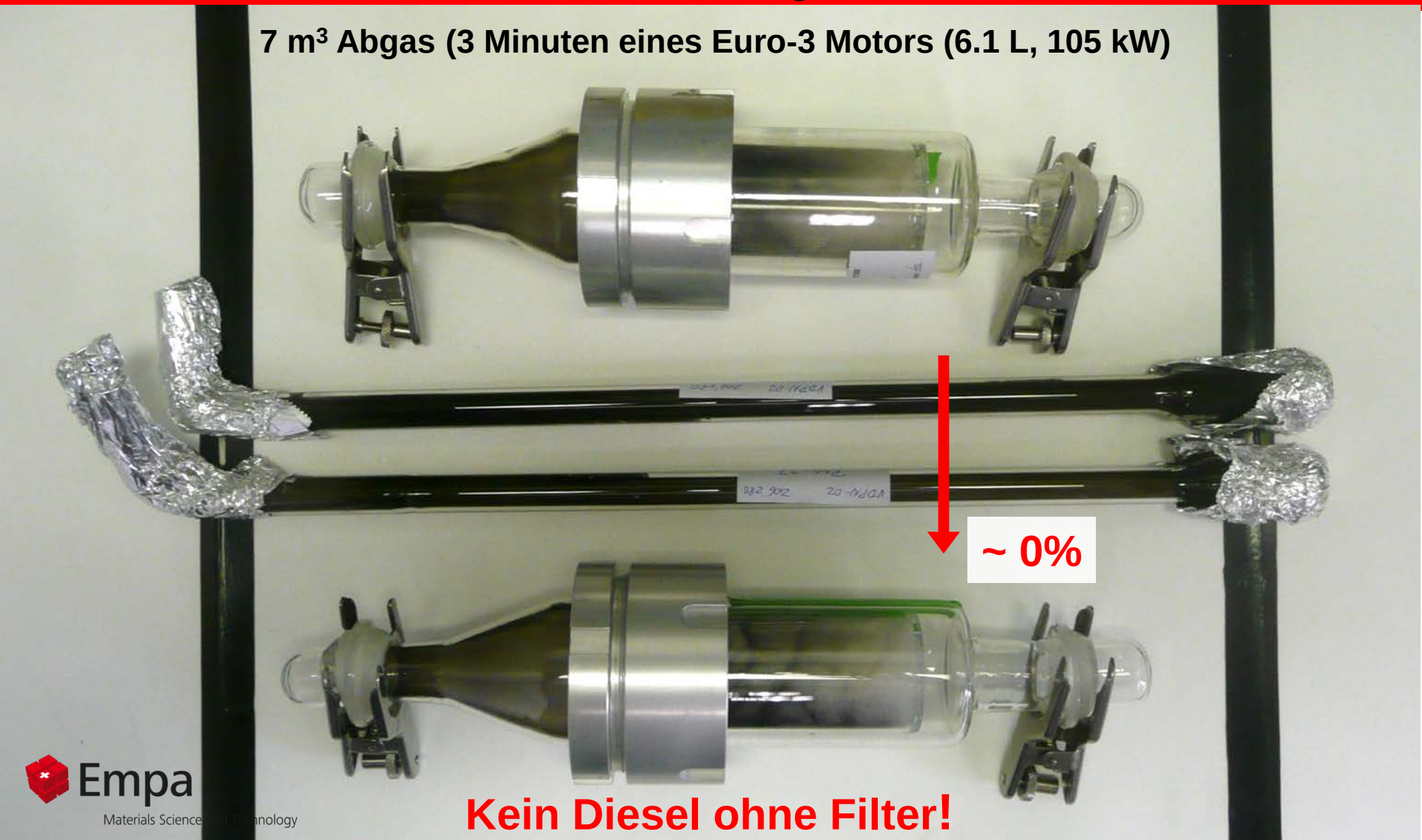
NEAT Eröffungsfeier
am 2. Juni 2016

The visible effect of an SCR-system



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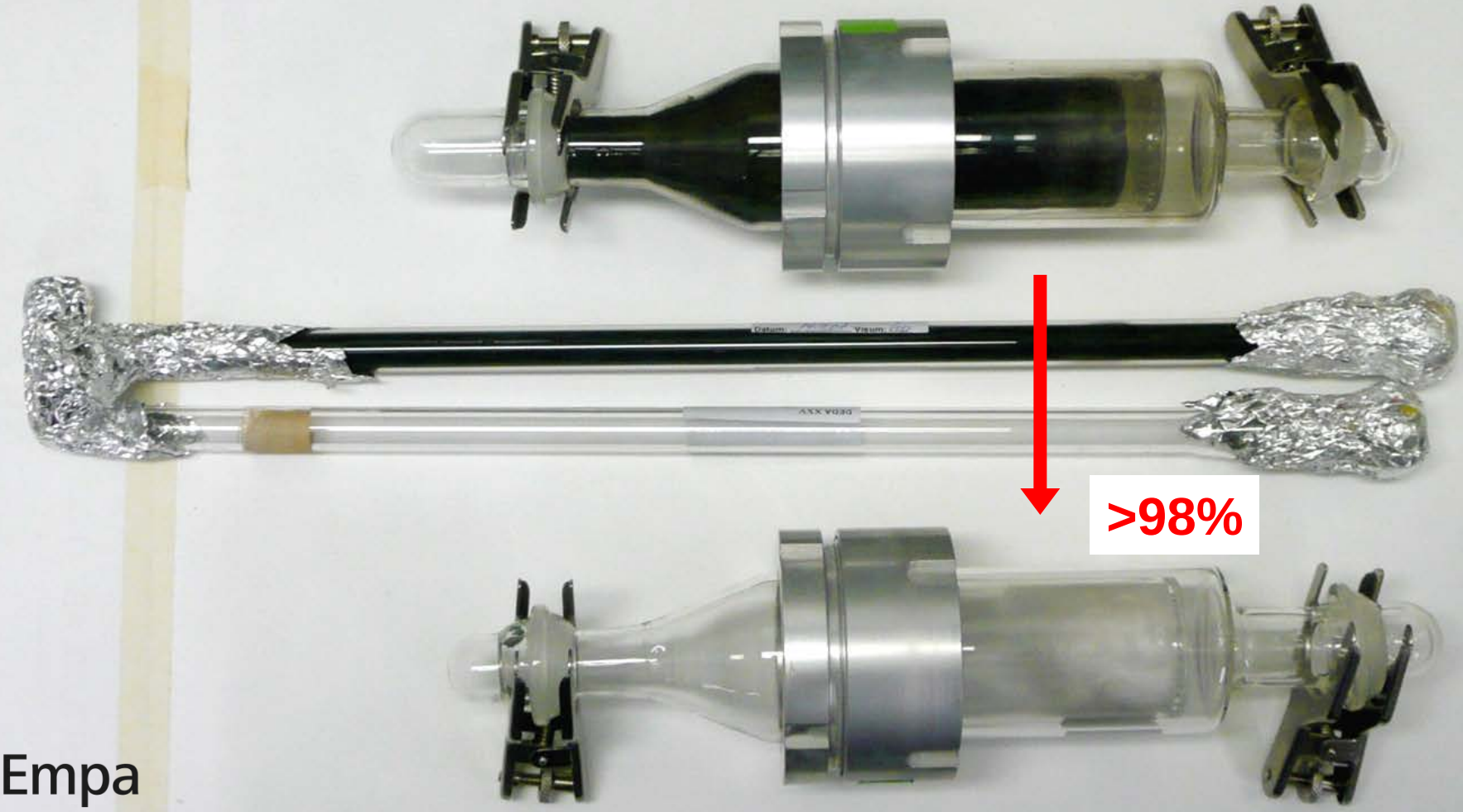
Kein Diesel ohne Filter!

The visible effect of an efficient DPF

About 7 m^3 of exhaust (3 min operating time of a 3.0 Liter Euro-3 engine (100 kW)



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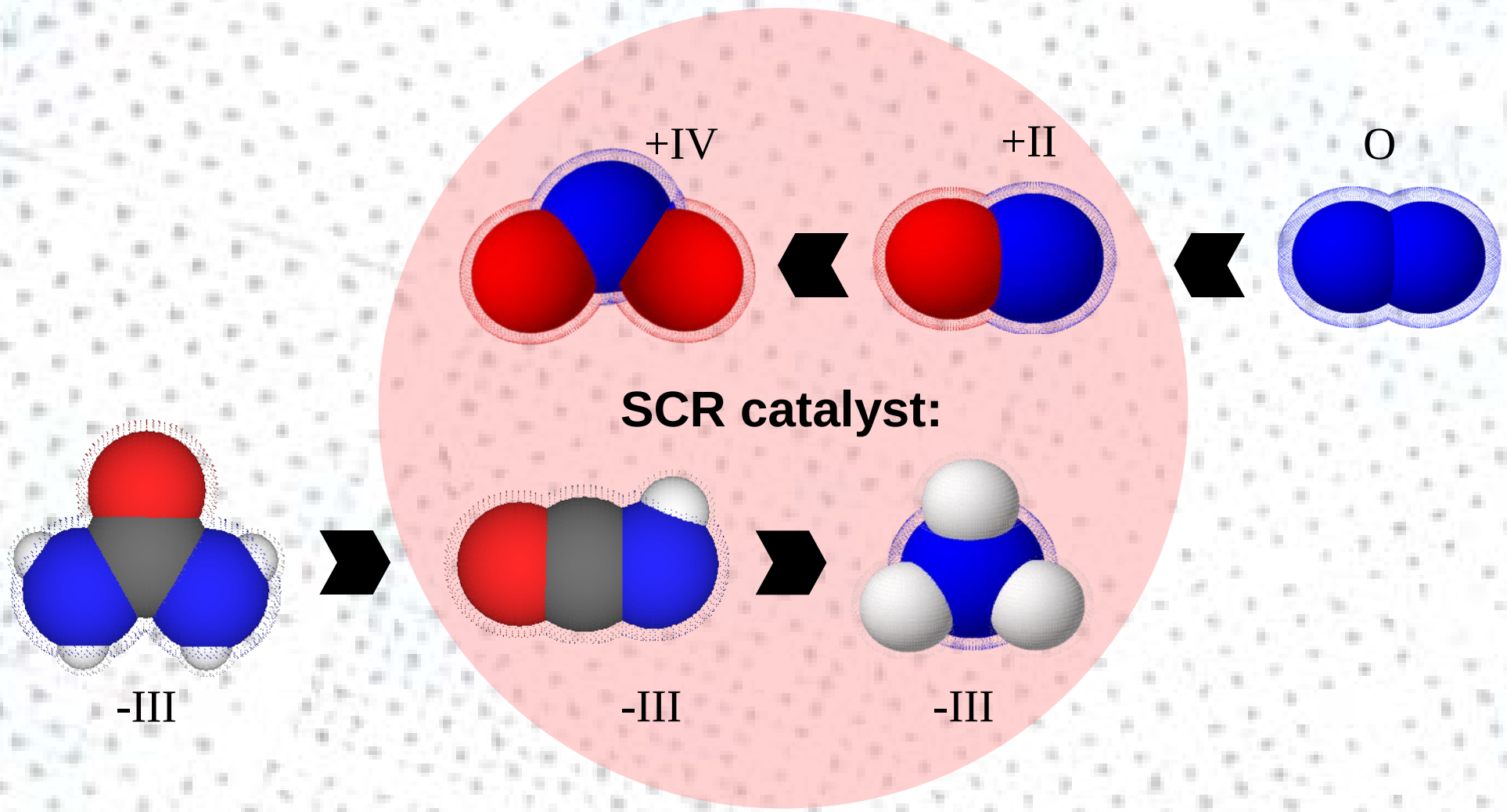
Reactive nitrogen compounds (RNCs)

What are reactive nitrogen compounds?



Europa's NOx Problem – Eine Folge ineffizienter deNOx-Katalysatoren und schlechter Abgasgesetzgebung

Outlook

Some suggestions

- test new technologies in advance (by independent bodies)
- develop specific regulations for NO, NO_2, NH_3, HNCO
- protection from toxic secondary pollutants
- incentives for efficient converter technologies (best available technology)
- avoid stupid legislation (e.g. ppm based NH_3 emission limit)