Business from technology

Particulate matter emission from transport

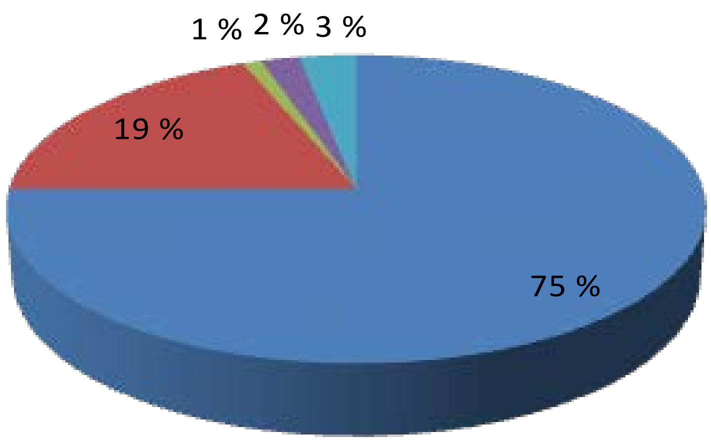
Mustan hiilen päästöjen ja päästövähennysten ilmasto- ja terveysvaikutukset, 11.11.2013
Päivi Aakko-Saksa
VTT Technical Research Centre of Finland

Content

- Particulate matter ”PM” results
- Emission regulations
- PM abatement technologies
- Summary

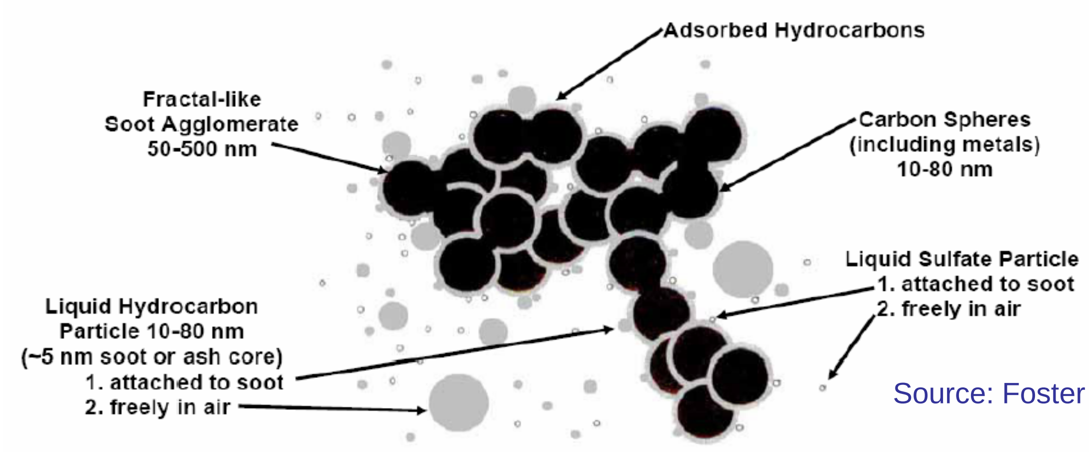
Diesel particle composition

Diesel PM2.5 Chemical Composition



- Elemental carbon (33-90%)
- Organic carbon (7-49%)
- Sulfate, nitrate (1-4%)
- Metals & elements (1-5%)
- Other (1-10%)

Source: US EPA 2002



Source: Foster 2004

International Agency for Research on Cancer

World Health Organization

PRESS RELEASE
N° 213

12 June 2012

IARC: DIESEL ENGINE EXHAUST CARCINOGENIC

Lyon, 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.

http://press.iarc.fr/pr213_E.pdf

Characterisation of exhaust emissions at VTT…

BC not measured, but correlation to existing data could be relevant

- **Regulated emissions**: CO, HC, NO_x, PM, CO_2
- **Speciated hydrocarbons** C1…C8, direct-connected gas chromatograph.
- **Aldehydes**: DNPH collection, HPLC
- **Alcohols**: gas chromatograph
- **Multi-component on-line analysis** by FTIR (Gasmet): 20-30 pollutants on-line at 1 Hz resolution powerful tool for transients and cold-starts

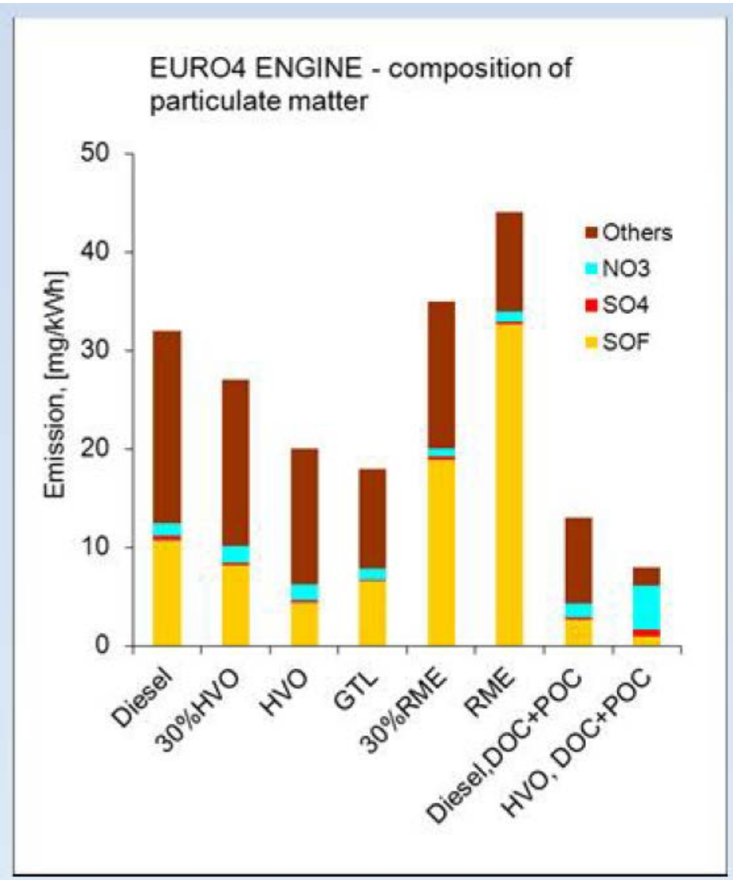
- **Composition and quality of particulate matter**
  - Soluble organic matter (SOF)
  - Organic and elemental carbon (OC/EC)
  - Polyaromatic hydrocarbons (PAH), subcontractor
  - Ames mutagenicity, fellow group at VTT
  - Sulphates, nitrates and other anions

We have also high-capacity particulate collection system for low-emitting vehicles!



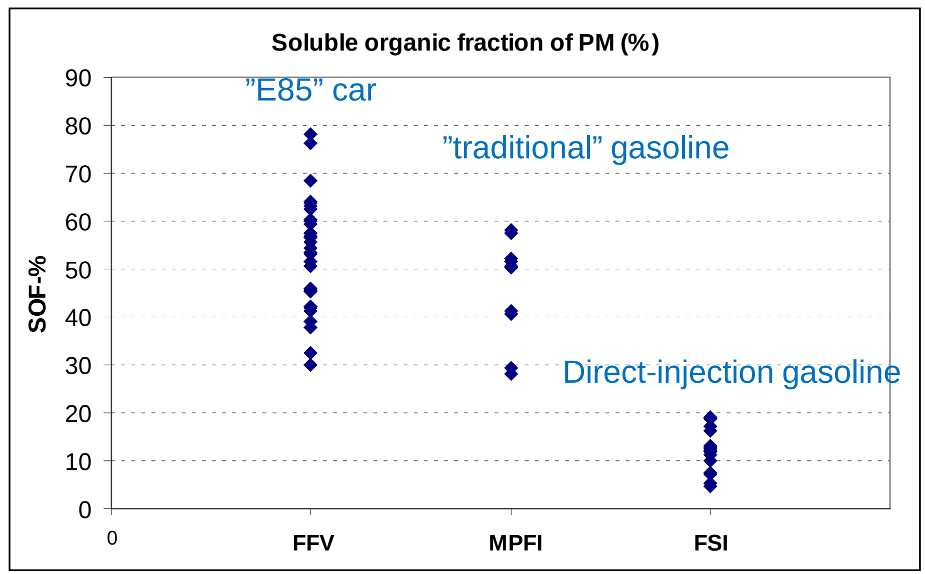


PM composition varies between technologies



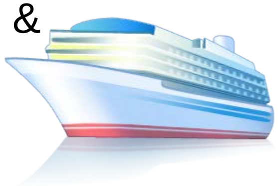
Murtonen, Erkkilä, Aakko-Saksa, NOSA & FAAR 2011 Conference Proceedings.

There is a lot of PM compositional data available from transport applications. Can we find correlation factors to estimate BC emissions?



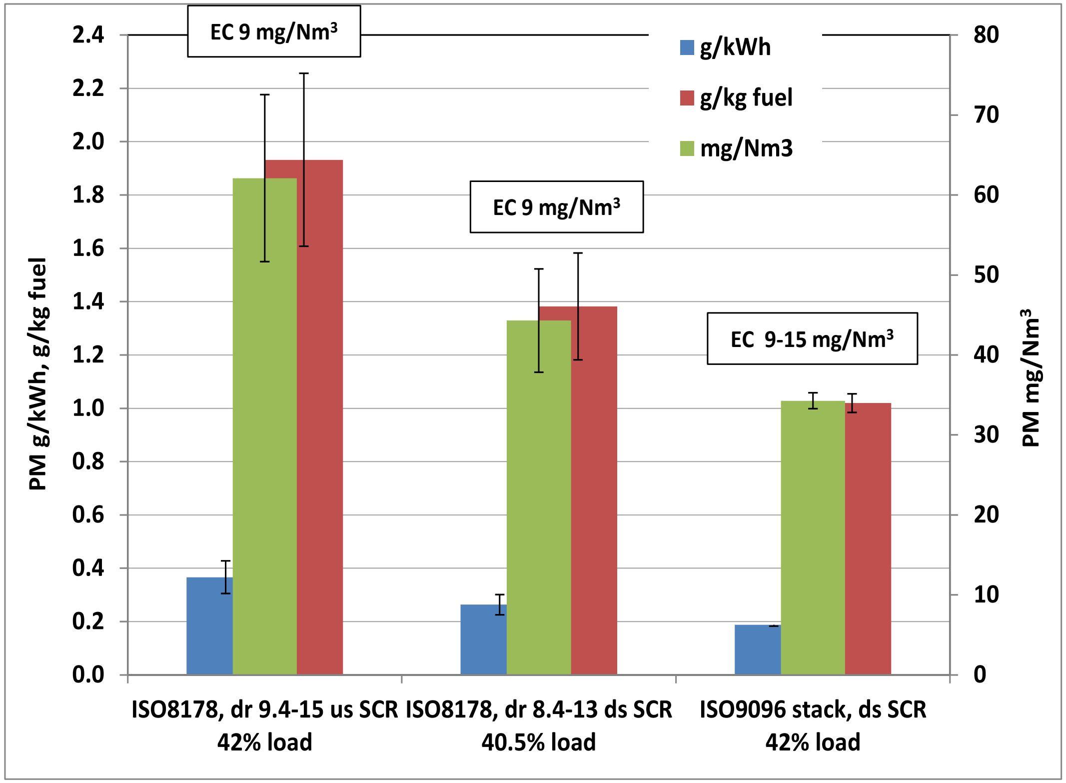
Aakko-Saksa et al. VTT Working Papers 187 & SAE 2011-24-0111.

VTT’s tools in ship (PM) emission research



- ISO 8178 diluted & cooled measurement of PM & gaseous exhaust emissions (test bed & field conditions)
- ISO 9096 raw exhaust (stack) PM measurement (test bed & field conditions)
- Measurement methods for ”BC” (OC/EC), PM constituents, particle numbers & sizes
- Methods for raw gaseous emissions (FTIR) and total hydrocarbons (FID)

- Data related to BC/EC/soot emissions is so far scarce
- A concise emission factor data is available for PM (EU BSR InnoShip project)



Ship emissions: Maija Lappi, VTT

Factors affecting particle emissions

- Engine configuration (diesel vs. spark-ignition, turbocharging, injection system
- **Exhaust after-treatment**
  - Catalysts, particle catalysts (p-DPF), wall-flow filters (DPF)
  - Filter clogging and NO2 formation can cause trouble
- Running conditions
  - High load promotes particle formation
  - Ambient temperature

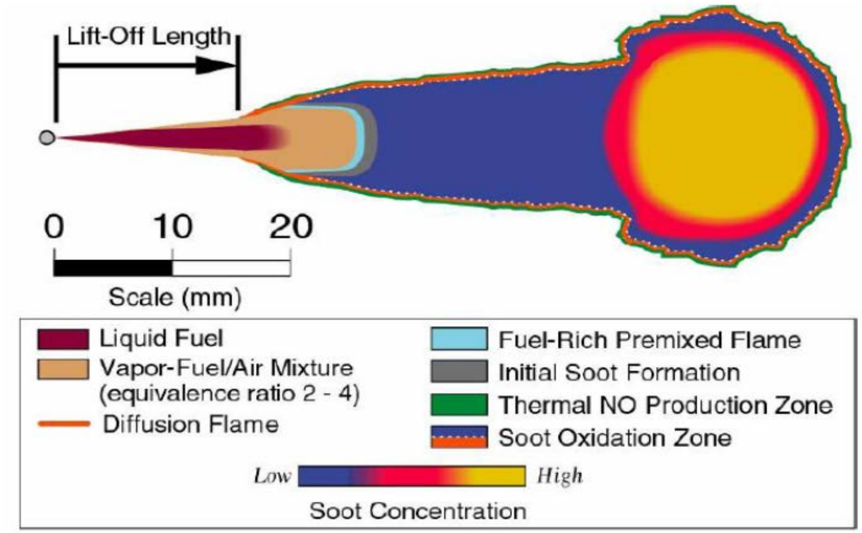


Figure: Musculus et al. 2005

- Many fuels reduce PM
  - Gasoline MPI instead of diesel (note low PM with DPF equipped diesel or DISI (sulfur-free fuel)
  - Some benefit with paraffinic (synthetic) instead of regular diesel
  - Gaseous fuels: natural gas, LPG
  - Oxygenated fuels: alcohols, ethers, esters (conventional biodiesel)

On-road PM regulations are tightening

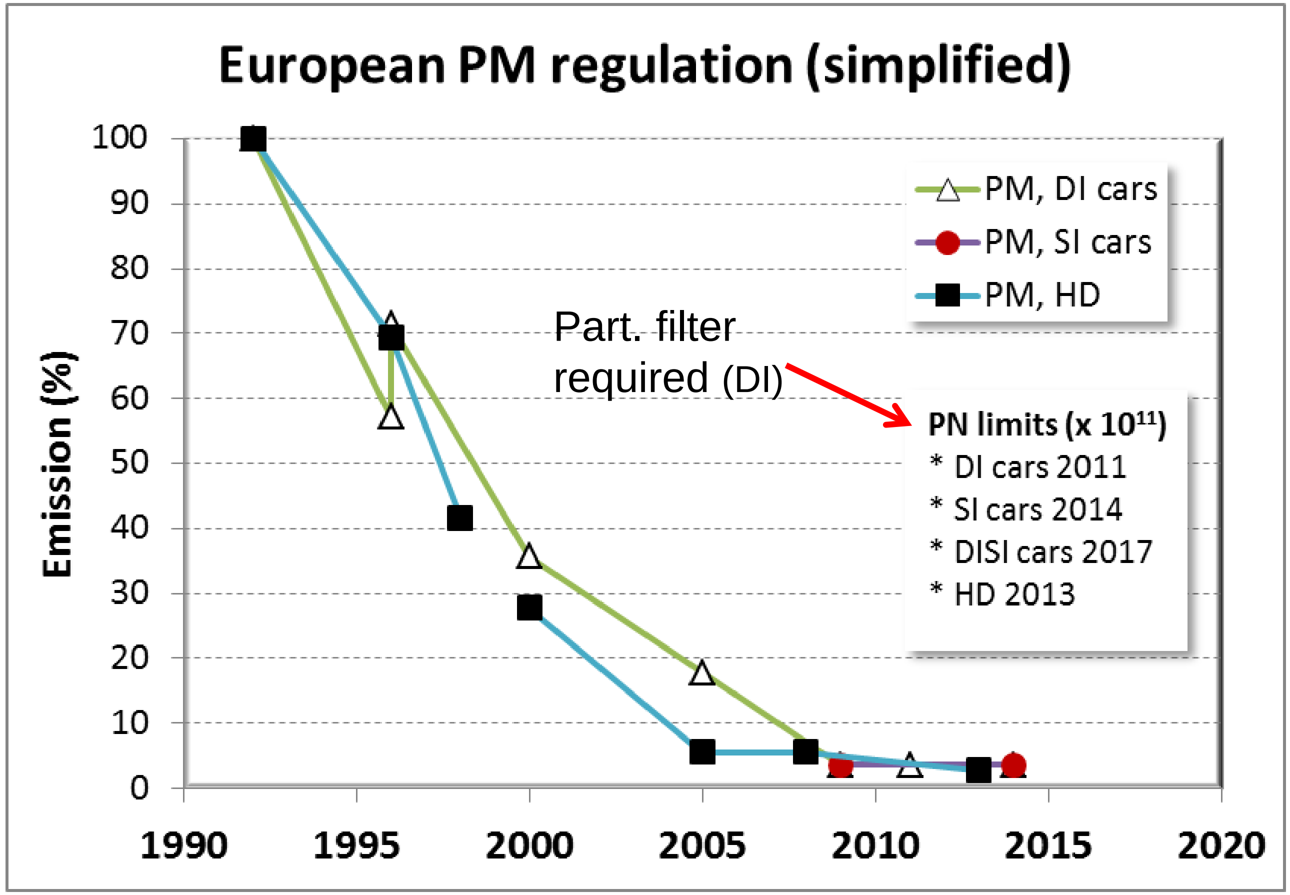


Figure by Aakko-Saksa, VTT

Non-road diesel engine regulations are tightening

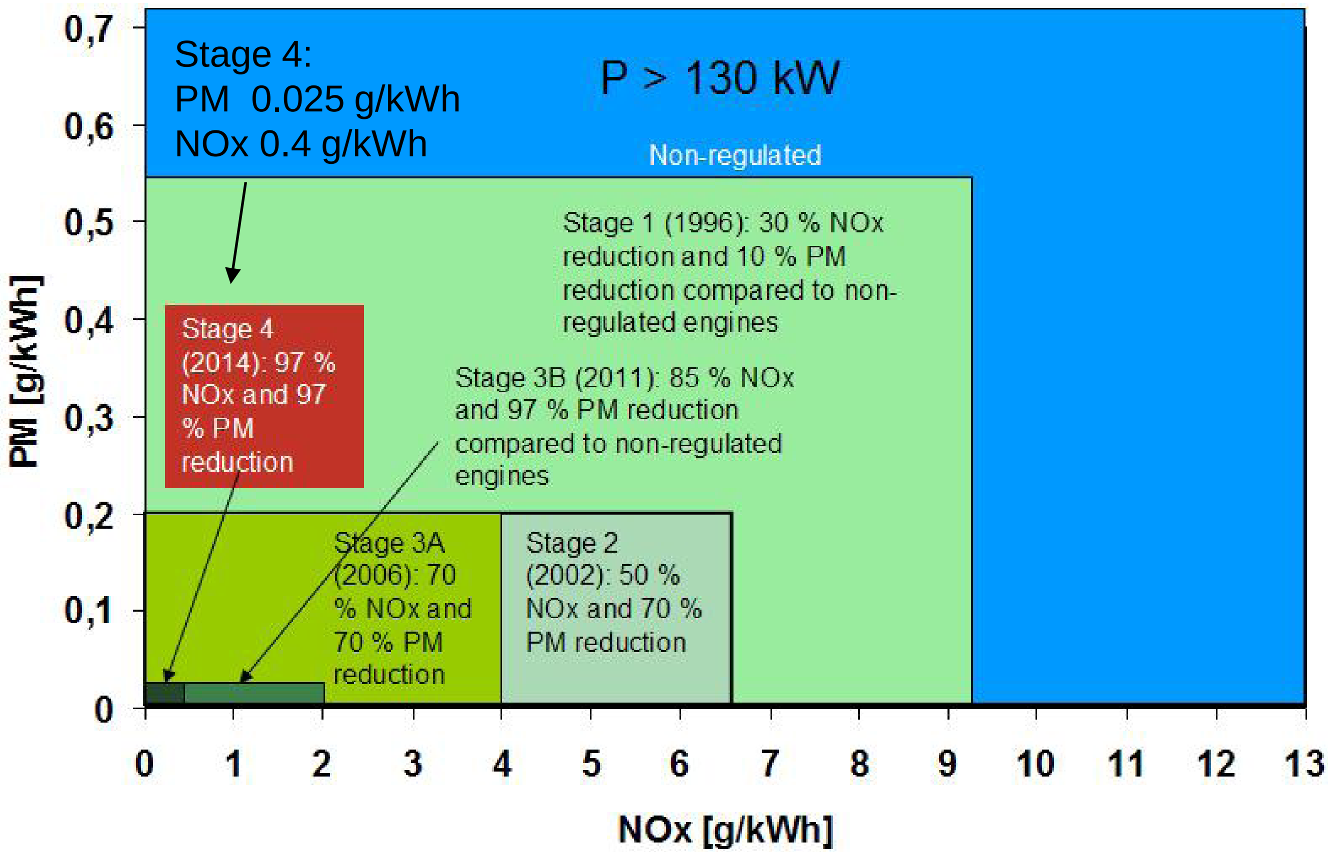
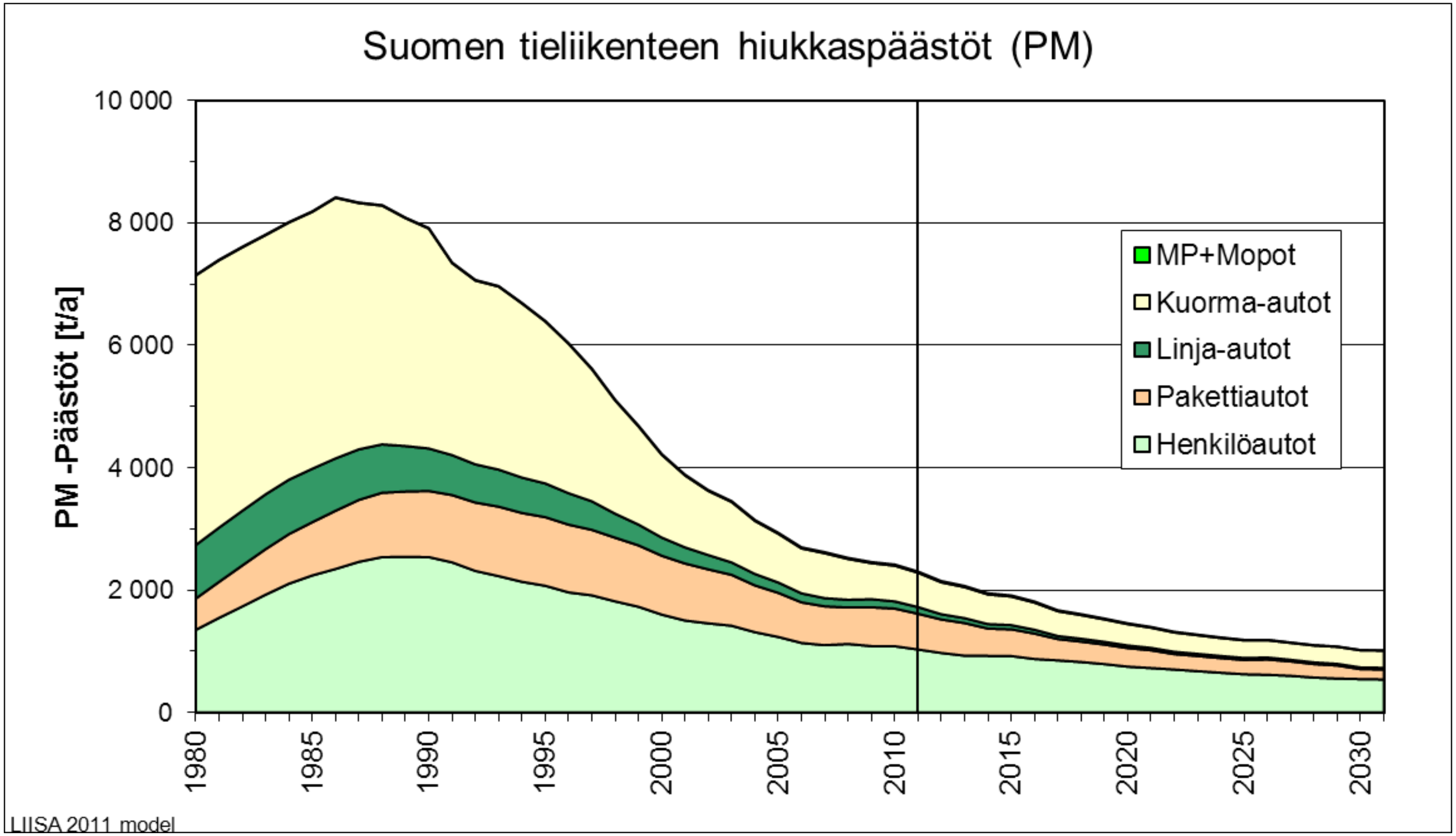


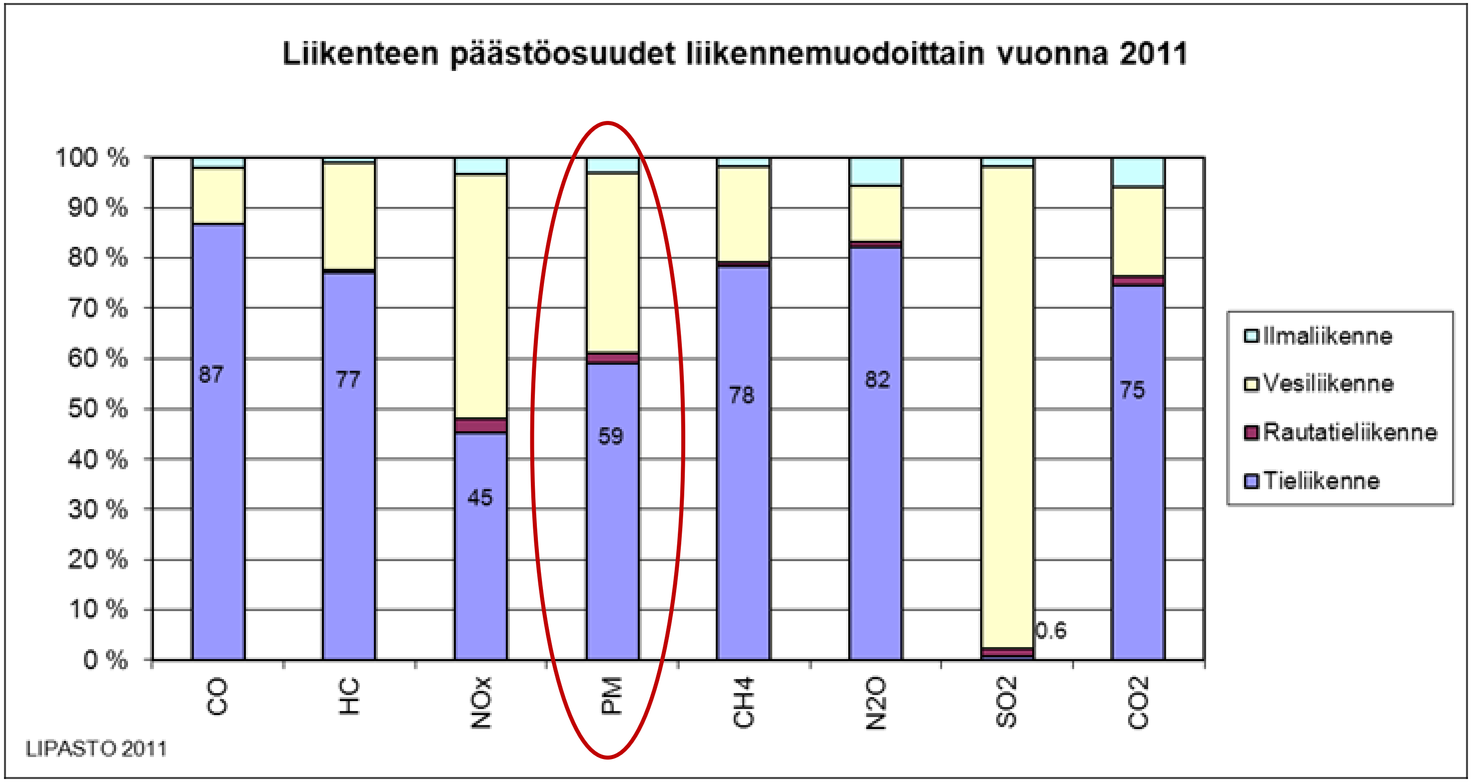
Figure by AGCO

Total PM emissions are decreasing



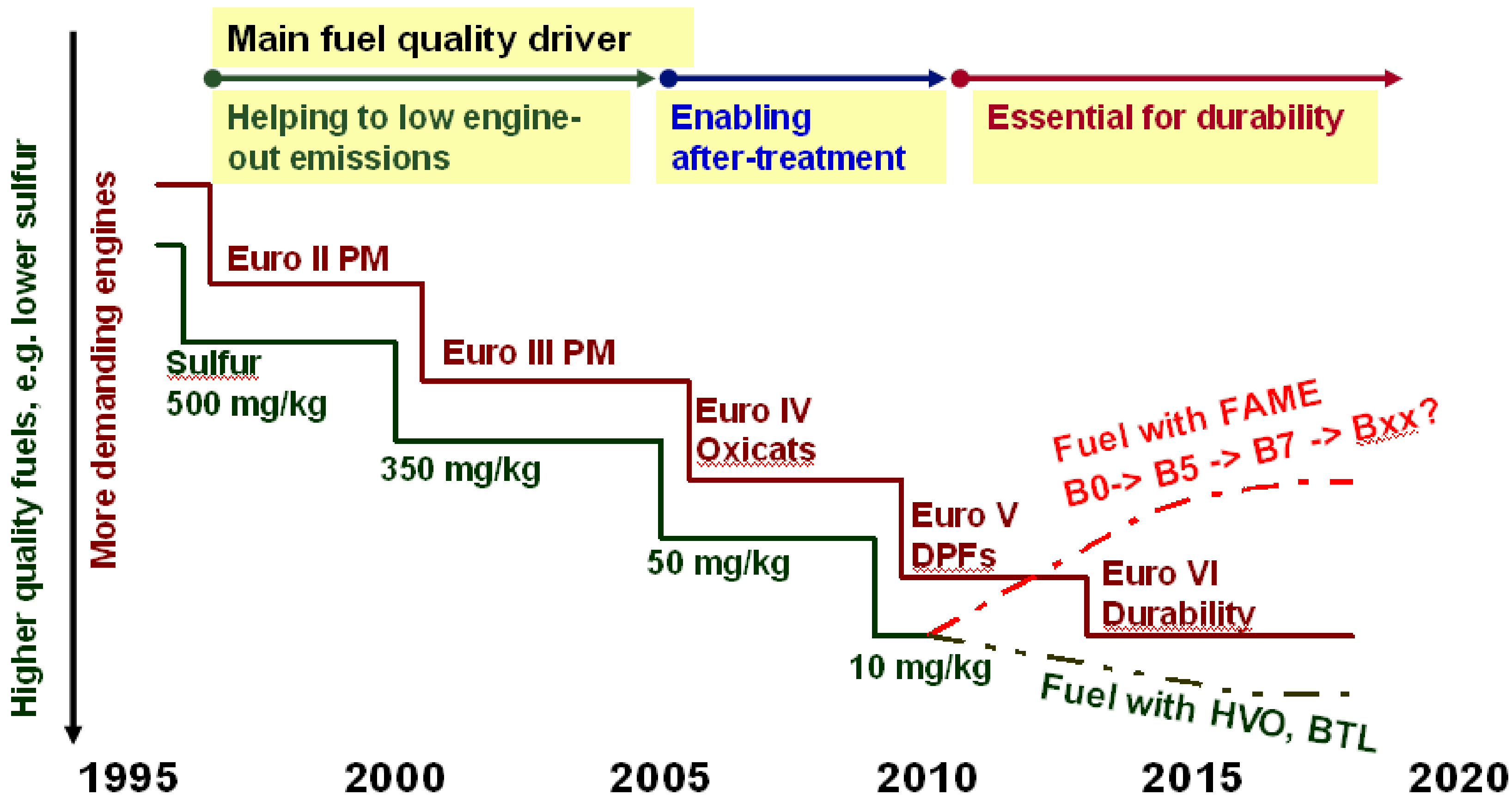
http://lipasto.vtt.fi/

PM from transport sector: 59% from road transport in Finland



Lähde: LIPASTO 2011 (http://lipasto.vtt.fi/liisa/index.htm)

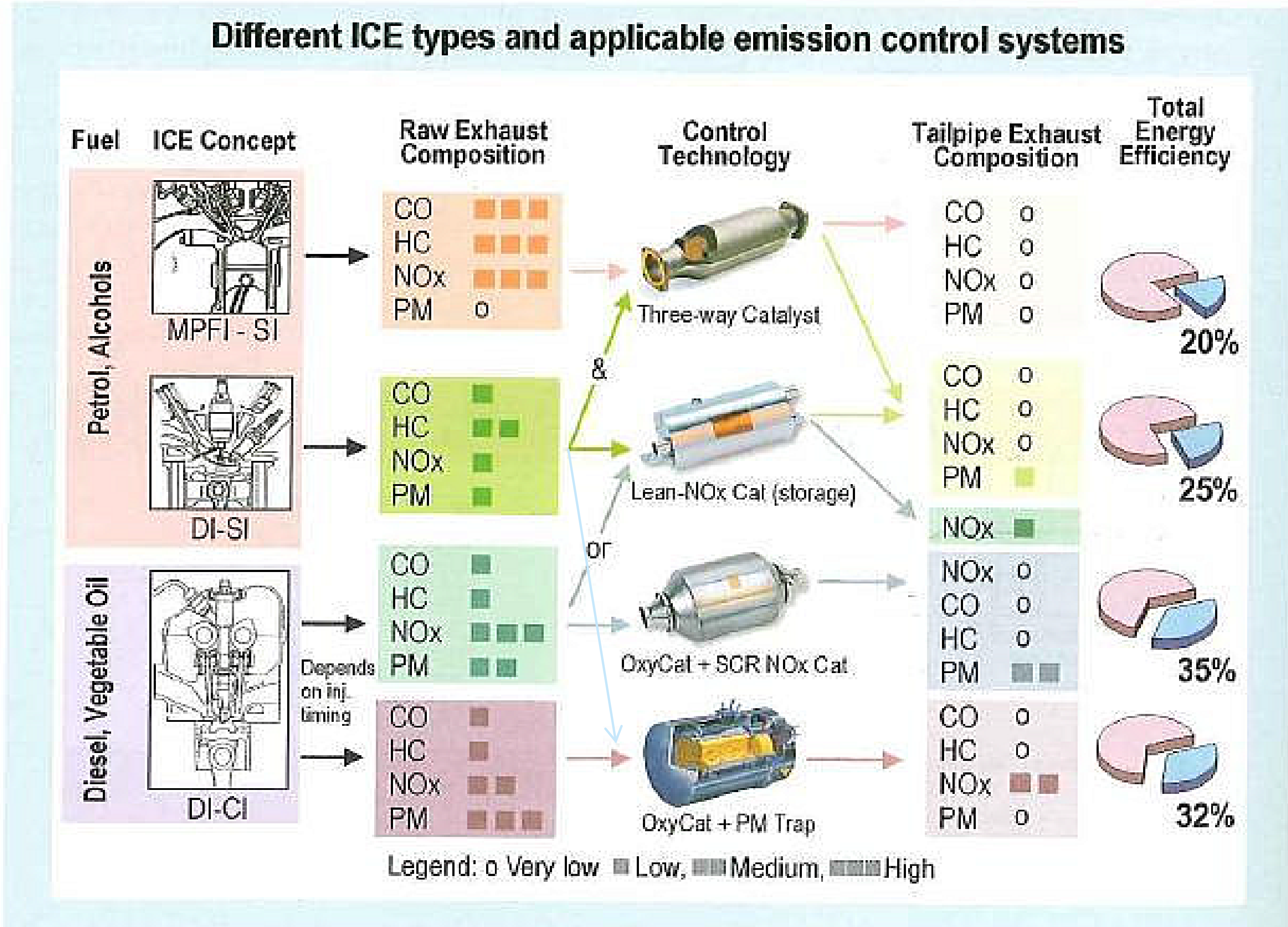
Evolution of diesel emissions and fuel quality



Euro = HD emission regulation

Source: Seppo Mikkonen/Neste Oil 2011

Exhaust catalysts combined with engine technology

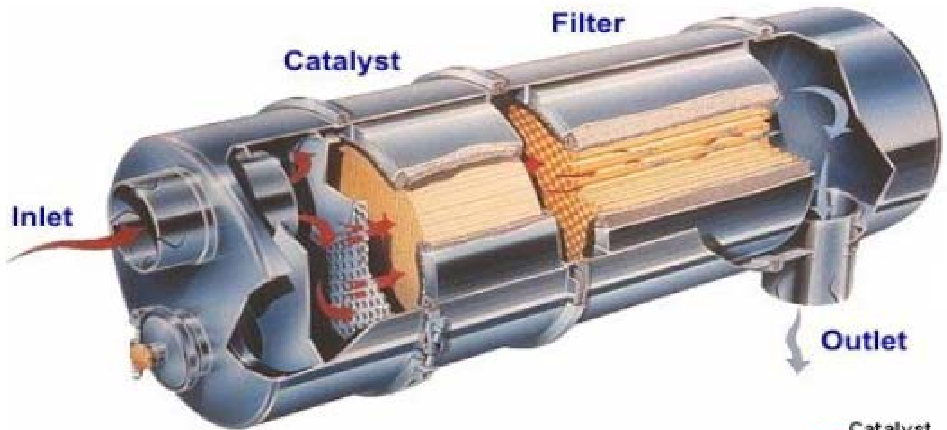


>95% of new vehicles worldwide are fitted with catalytic converters.

Source: VTT's publication: Energy – visions 2030 for Finland (Figure by Laurikko).

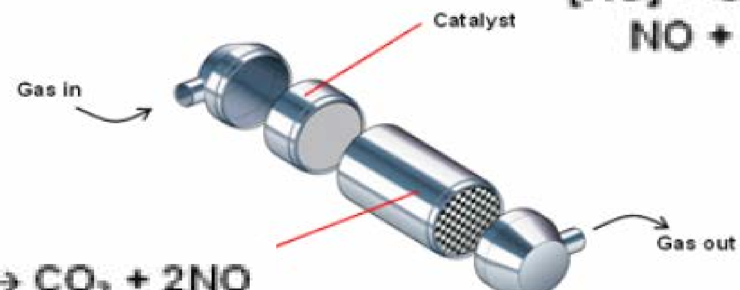
Diesel particulate filters

Diesel particulate filters, DPF, reduces PM efficiently >90% or less efficiently with ”optimized” technology, e.g. Particle Oxidation Catalyst, POC



$$CO + ½O_2 \rightarrow CO_2$$
$$[HC] + O_2 \rightarrow CO_2 + H_2O$$
$$NO + ½O_2 \rightarrow NO_2$$

JM Johnson Matthey

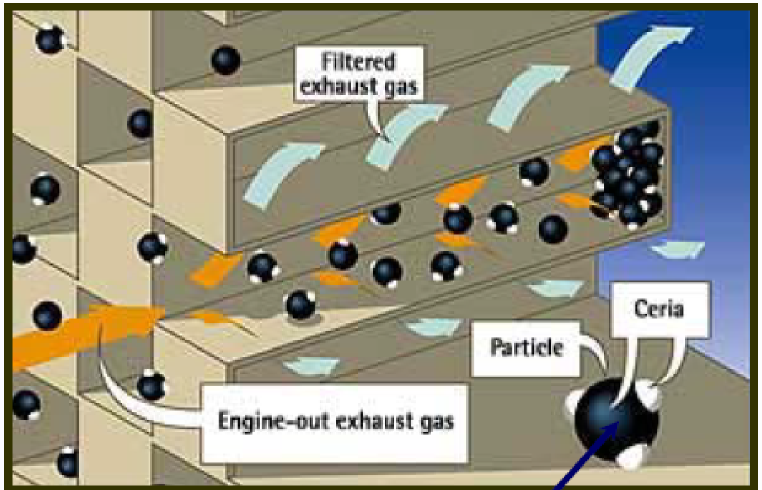


$$[C] + 2NO_2 \rightarrow CO_2 + 2NO$$

particle oxidation catalyst (POC)
partial diesel particle filter (PDPF)
partial particulate filter (PPF)
PM filter catalyst (PM-KAT)
flow-through filter (FTF)

Johnson Matthey’s Continuously Regenerating Trap CRT® launch in 1995. “…**NO_2 could be employed to burn soot at low temperatures** – as low as 275°C, compared with around 600°C when burned with oxygen.”

The use of Eolys™ Fuel-borne Catalyst:
the best approach for solid-solid catalysis

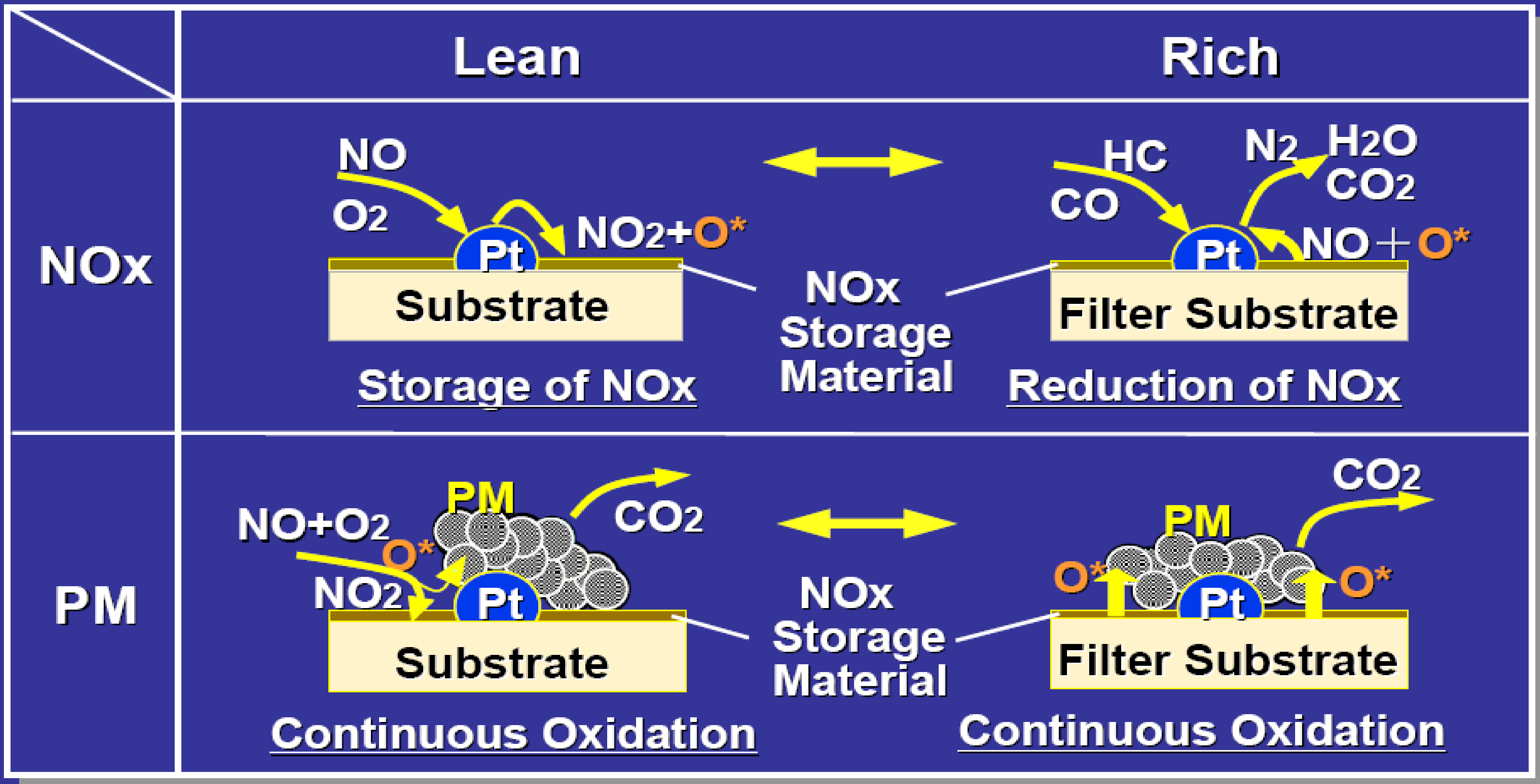


Ceria catalyst and soot aggregate

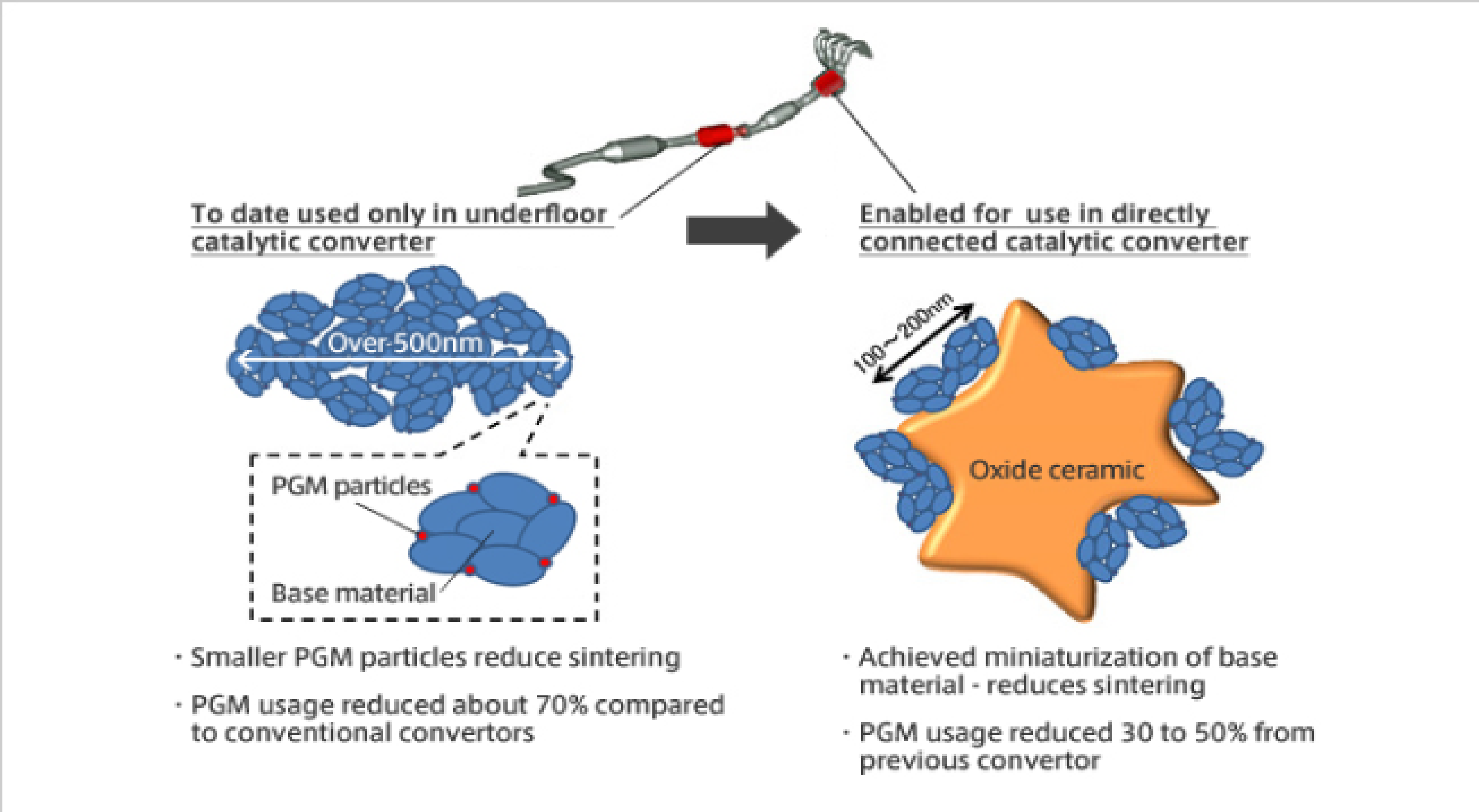
- to lower the temperature of soot combustion process
- continuous and fresh nano-crystal catalyst supplying
- homogeneous Catalyst dispersion (highest contact point numbers)
- to favor diffusion of soot combustion process to the entire soot layer
- fast & complete DPF regeneration
- no Sulfur sensitivity

Civiello, M. RHODIA Electronics & Catalysis Inc. DEER 2003

NOx and PM Reaction Mechanism of DPNR Catalyst



This technology was first introduced with the facelifted Demio featuring SKYACTIV-G 1.3 in July 2011, and has been progressively introduced to SKYACTIV engine models since that time. It is also suitable as a catalyst in diesel particulate filters which remove soot from diesel engines and is employed in Mazda's new generation clean diesel engine SKYACTIV-D.



PGM Single Nano Size Particle Catalyst Technology

Ecocat Product range for Heavy Duty applications up to Euro 6:

- DOC
- POC
- HyCat™ / Mixer
- V-SCR
- CNG

Heavy Duty Diesel

Fuel efficiency, durability and performance are the key items for Heavy Duty applications. Our Diesel Oxidation Catalyst (DOC) technology has achieved global recognition with chemistries developed for European markets as well as formulations designed to tolerate high sulfur fuels in emerging countries.

The combination of our robust DOC with our very own open filter technology, the Particle Oxidation Catalyst (POC®), provides the ideal solution to manage PM emissions up to Euro V. This functional and maintenance free combination shows PM conversions in the range of 50 to 80 %.

Heavy Duty CNG

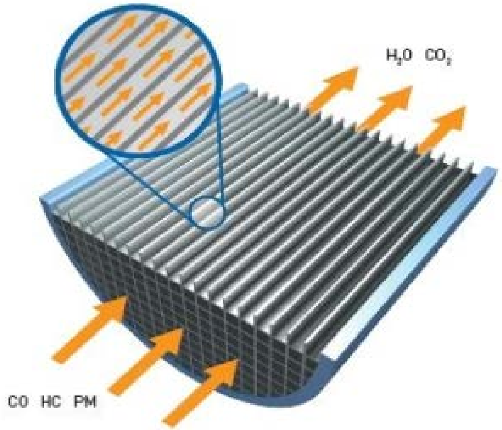
This sector is predominantly represented by bus applications where Ecocat has a long history of successfully applied oxidation and 3-way formulations, tailored specifically for the demands of heavy duty applications.

Light Duty solutions are available for Gasoline, LPG, CNG and Diesel applications up to Euro 6 legislation.

DINEX + ECOCAT

Dinex acquires Finland-based Ecocat group

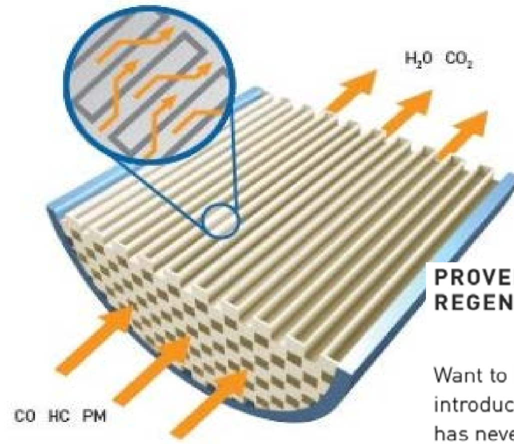
DOC



Diesel Oxidation Catalyst, DOC
Oxidizes the CO, HC and organic fraction (SOF) of PM emissions

Reductions
- Carbon monoxide (CO) > 80 %
- Hydrocarbons (HC) > 80 %
- Organic fraction of diesel particulates (SOF)

DPF



Diesel Particulate Filter, DPF
A ceramic wall-flow filter that collects the particulate matter

Reductions
- Particulate matter (PM) > 90 %

PROVENTIA

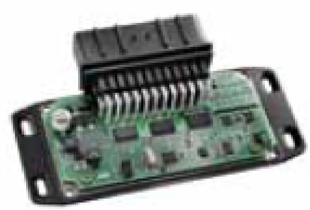
PROVENTIA CHILI™ – INTELLIGENT ELECTRICALLY REGENERATED FILTER

Want to keep your machines up and running without extra downtimes? Let us introduce the self-maintaining Proventia CHILI™ filter. Emission controlling has never been as easy and reliable!

Passive DPF
Passive diesel particulate filter. PM reduction >90%. A wall-flow filter collects the particulate matter. Proventia PROAIR®.

Active DPF
Active diesel particulate filter. PM reduction >90%. Regeneration is independent of the exhaust gas temperature. Proventia CHILI® electrically regenerated filter.

DOC & pDPF
Diesel oxidation catalyst and partial diesel particulate filter. HC & CO reduction 80–90%. PM reduction up to 70%. Uses catalysts to promote oxidation of CO and HC as well as the SOF portion of diesel particulates. Proventia PROCAT™.



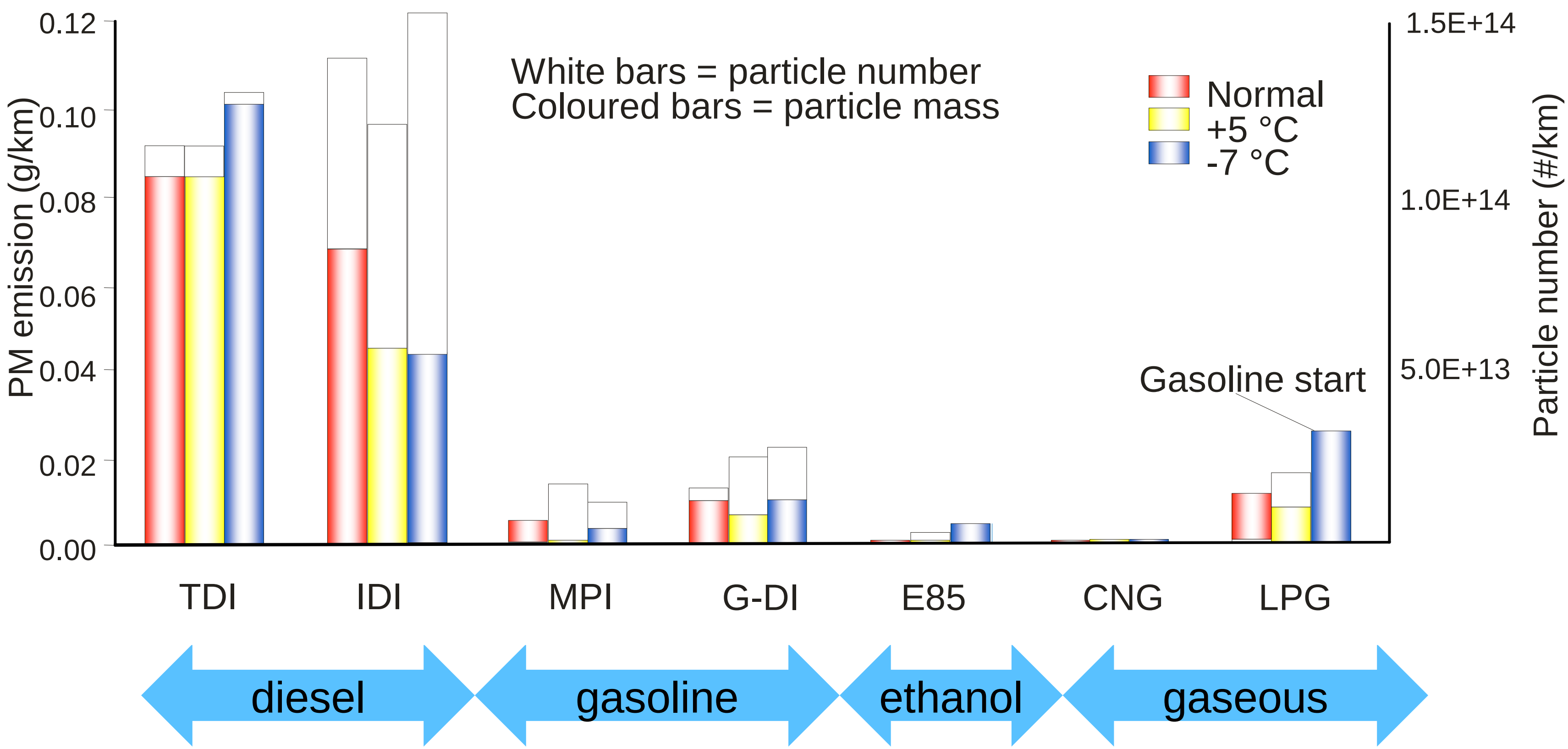
Components & Accessories
Intelligent, user-friendly control systems. Enable easy system monitoring and reporting. Proventia PROCARE™ & GCU, A wide range of SCR accessories; AdBlue tanks, sensors, and urea lines.

Results with older cars (model year ~2000)

IEA-AMF Annex 22: Particulate Emissions at Moderate and Cold Temperatures Using Different Fuels

Example

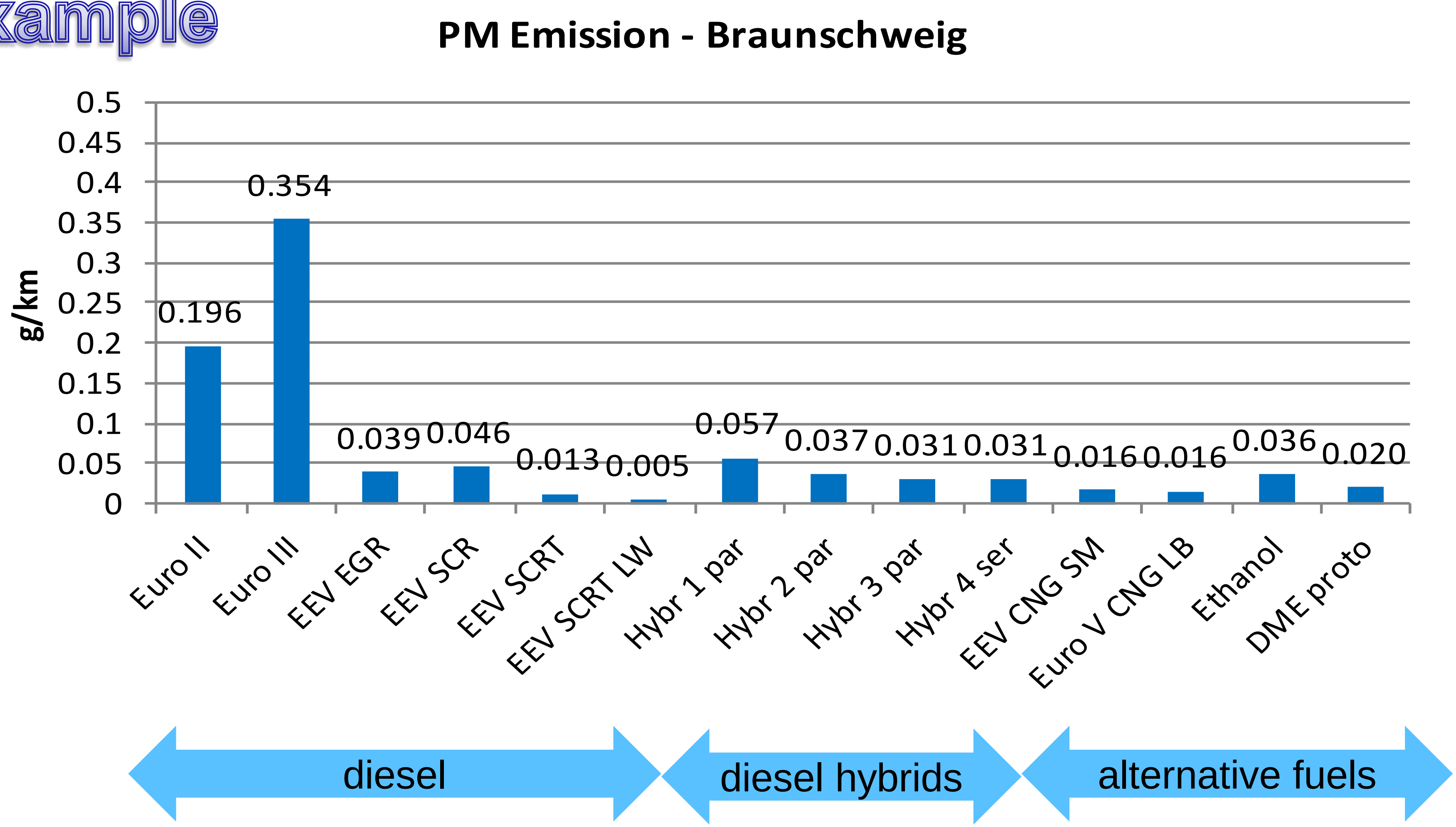
Particle mass and number, European test cycle



http://www.iea-amf.org/content/publications/project_reports

Annex 37: Fuel and Technology Alternatives for Buses

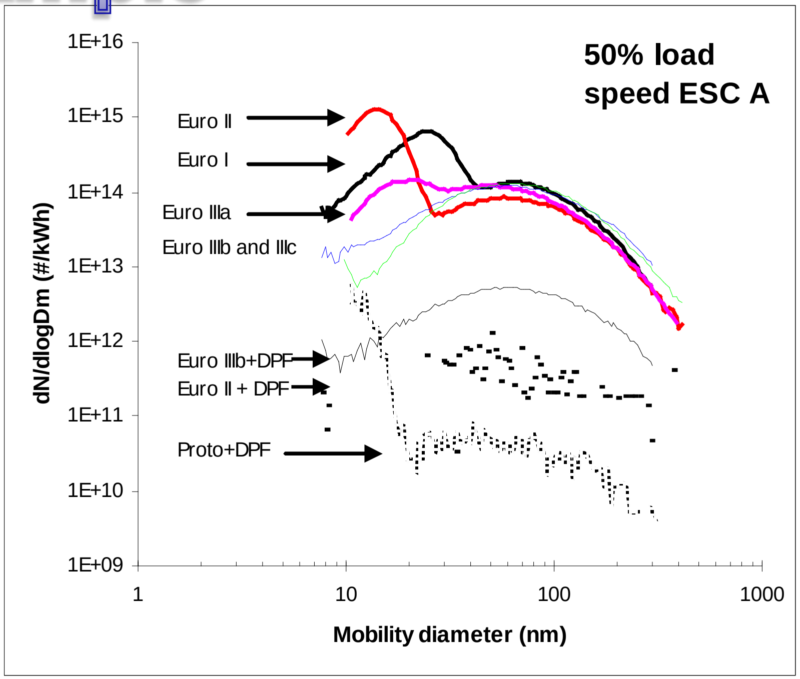
Example

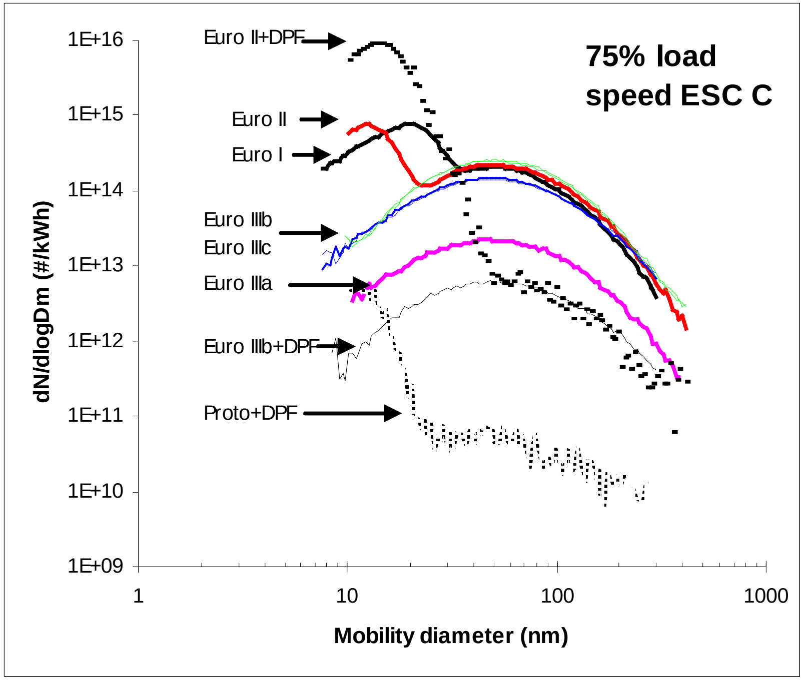


http://www.iea-amf.org/content/publications/project_reports

Particle size distributions with heavy-duty engines

Example

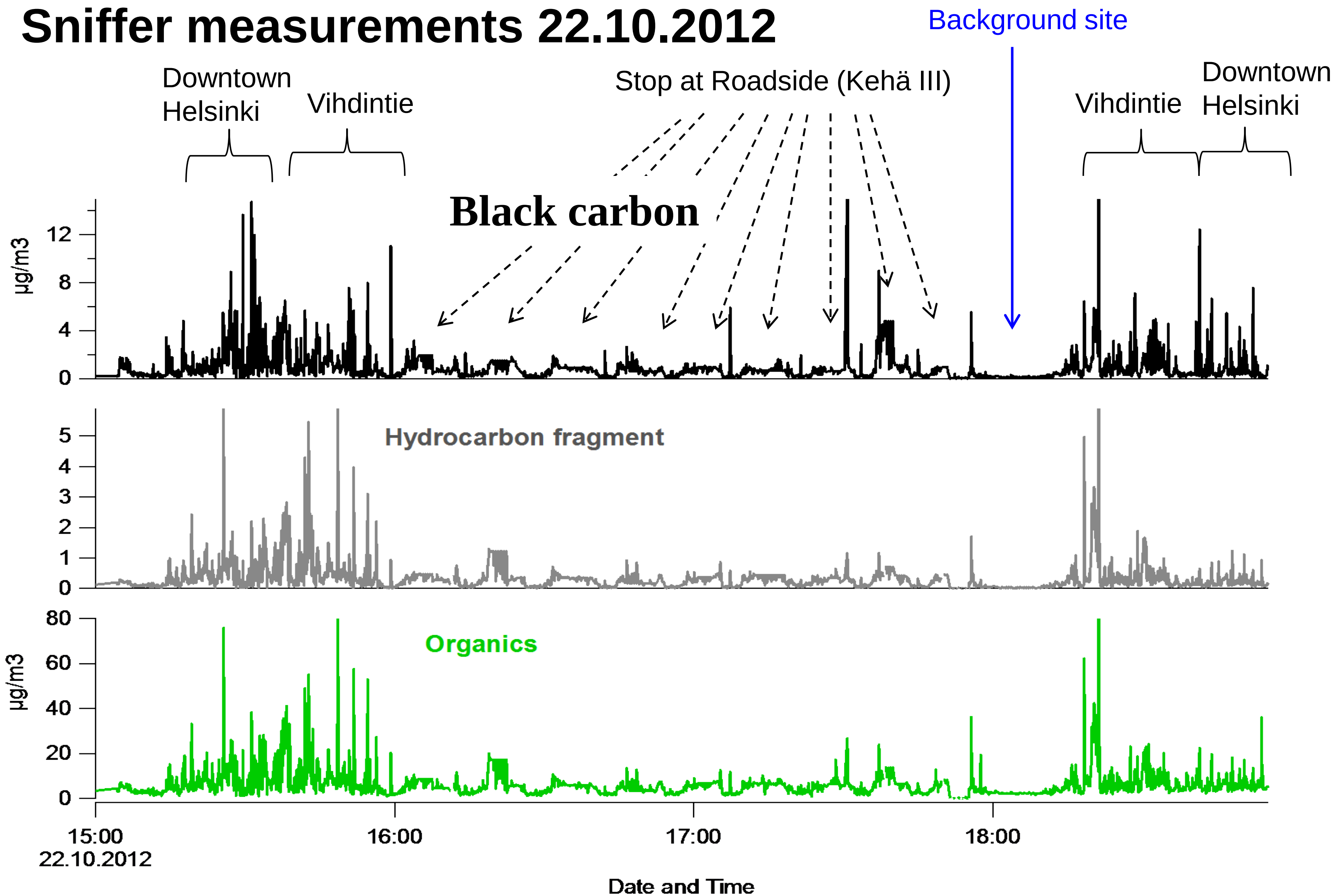




- Fairly consistent size distribution profile for the accumulation mode for the conventional diesel
- Nucleation mode is evident at high load conditions, (even on the low sulphur fuel), especially on the CRT-equipped Euro-II engine

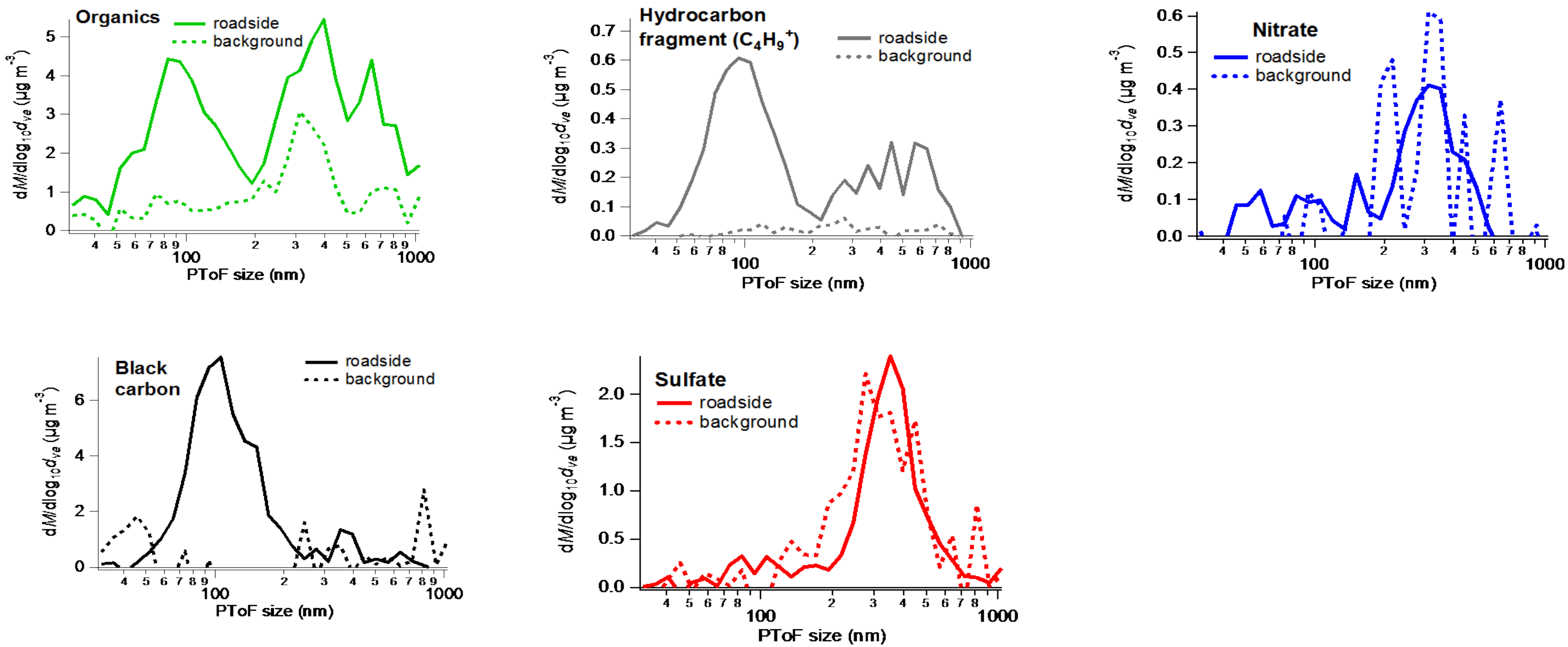
Thompson, Aakko et al. SAE 2004-01-1986. (”EU Particulates project”)

Sniffer measurements 22.10.2012



Joint study within the CLEEN/MMEA program, WP 4.5.2, Participating research institutes: Finnish Meteorological Institute, Tampere University of Technology, Metropolia University of Applied Sciences and participating companies: Helsingin Energia, Proventia, Wärtsilä, Metso, Pegasor, HSY

Standing at 15 m from the roadside



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Black carbon (BC)

- Source of BC in Helsinki: diesel engines and wood combustion

Table 2. The median BC concentrations ($\mu g\, m^{-3}$) and quartile deviations (half of the difference between lower and upper quartiles) measured during each period and campaign.

Period	Campaign 1 (1996–1997)	Campaign 2 (2000–2001)	Campaign 3 (2004–2005)
P1	1.43 (0.62)	0.95 (0.35)	1.12 (0.71)
P2	1.14 (0.54)	0.97 (0.36)	0.68 (0.46)
P3	1.11 (0.61)	0.92 (0.40)	1.04 (0.56)
P4	0.86 (0.54)	0.90 (0.51)	1.05 (0.50)
All	1.11 (0.60)	0.93 (0.40)	1.00 (0.56)
Vehicle number scaled	0.0028±0.0005	0.0022±0.0005	0.0020±0.0002

Järvi, L., Junninen, H., Karppinen, A., Hillamo, R., Virkkula, A., Mäkelä, T., Pakkanen, T., and Kulmala, M. Black carbon variations in Helsinki, Atmos. Chem. Phys., 8,1017–1027, 2008

Liikennesektoreiden eroja

Henkilöautot

- Ajomatkat lyhyitä ja jälkikäsittelylaitteet toimivat optimaalisesti vasta moottorin lämmittyä, joten päästöjen hallinta haasteellista käynnistyksen jälkeen, erityisesti kylmässä lämpötilassa.
- Matalat hiukkaspäästöt mm. perinteisillä bensiiniautoilla sekä mm. etanoli- ja kaasuautoilla. Sähköautoilla ei paikallisia päästöjä.

Raskas kalusto

- Pääosin lämpimällä moottorilla ajoa mikä helpottaa jälkikäsittelylaitteiden toimintaa.
- Mahdollisuus optimoituihin ”fleet”-ratkaisuihin.

Muita

- Työkonesektorilla paljon erilaisia sovelluksia.
- Laivoille sopivat ”huonohkot” polttoaineet, mikä on haaste jälkikäsittelyteknologioille. Ajo lämpimällä moottorilla sen sijaan helpottaa tekniikan optimointia.
- Lentoliikenteen polttoaineet tiukasti standardoituja -> vähän vaihtoehtoja.

Cars: Start-up emissions. Cold temperatures. Transient.

Heavy-duty: Warm start-up. Transient driving.

Ship/rail engines: Steady state running. Warm engines.

Aviation: Stringent fuel quality regulations.

Machinery, small engines: Numerous applications.

Yhteenveto

Liikennesektorilla ei ole mustan hiilen mittausvaatimusta, vaan raja-arvot koskevat kokonaishiukkaspäästöä. Liikenteen hiukkasten koostumuksesta on paljon tietoa, jota voi käyttää hyväksi BC:n arvioinnissa.

Hiukkaspäästöjen raja-arvot Euroopassa ovat tiukat ja tiukkenevat edelleen siten, että kaikkien ajoneuvojen hiukkaspäästöt tulevat olemaan erittäin alhaisia

- Hiukkassuodattimet dieselajoneuvoissa (2011-2014 alkaen) ja suorasuihkutteisissa bensiiniautoissa (tod. näk. 2017 alkaen).
- Hiukkaspäästöt bensiiniautoilla, etanoliteknologioilla ja kaasuautoilla ovat tyypillisesti alhaisia ilman jälkikäsittelyäkin. Sähköautoilla ei ole lähihiukkaspäästöjä.
- ”Real-life” päästöihin yleisesti vaikuttaa esim. ulkoilman lämpötila ja ajo-olosuhteet.

Ajoneuvokannan uusiutuminen vie noin 15-20 vuotta.

Globaalit liikenteen päästöt kehittyvät eri aikataululla kuin Euroopan tai Suomen liikenteen päästöt.

VTT creates business from technology