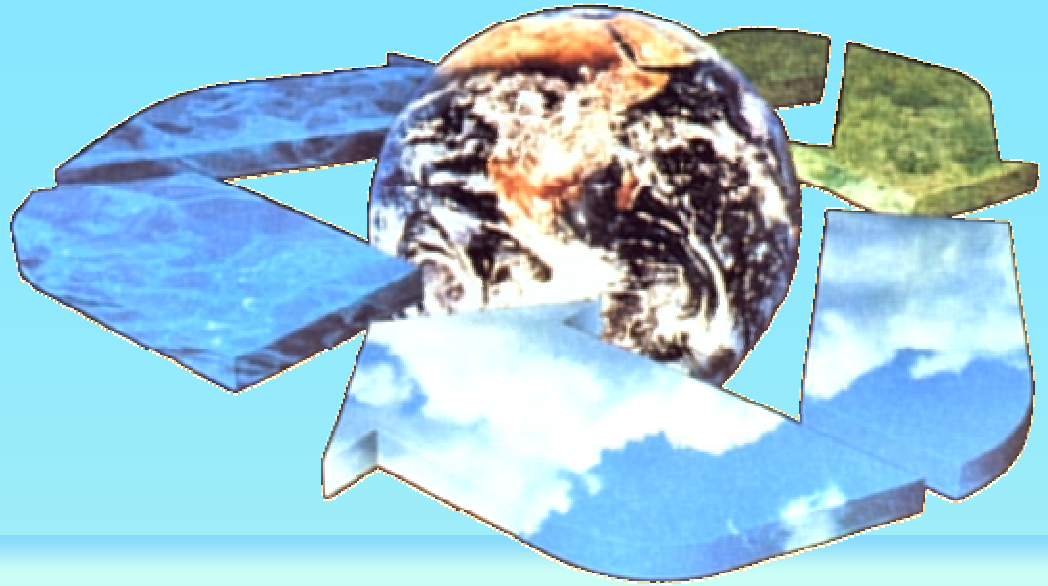

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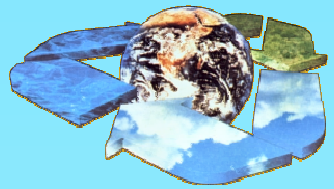
ENERGY RESEARCH, DEVELOPMENT, DEMONSTRATION, AND DEPLOYMENT
ENVIRONMENTAL CONSULTANTS

Summary of Swedish Experiences on CNG and ”Clean” Diesel Buses

DEER 2003, August 24-28

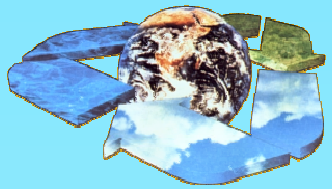
Peter Ahlvik, Ecotraffic ERD^3 AB

Acknowledgements



- Pär Gustafsson and Olle Hådell, the Swedish National Road Administration
- Mats Wallin and Charlotta Sandström, AVL MTC in Sweden
- John Fairbanks, DOE

Outline



- Introduction
  - Swedish auto ind.
  - Background
- Regulations and incentives
  - SLTF vs. US & EU
  - Current bus fleet
- Methodology
  - Data collection
  - Engine & aftertreatment
  - Driving cycles
- Results
  - NO_X emissions
  - PM emissions
  - Formaldehyde
  - Benzene
  - 1,3-Butadiene
  - PAH
  - Cancer risk
- Discussion
- Summary & conclusions

Swedish automotive industry today

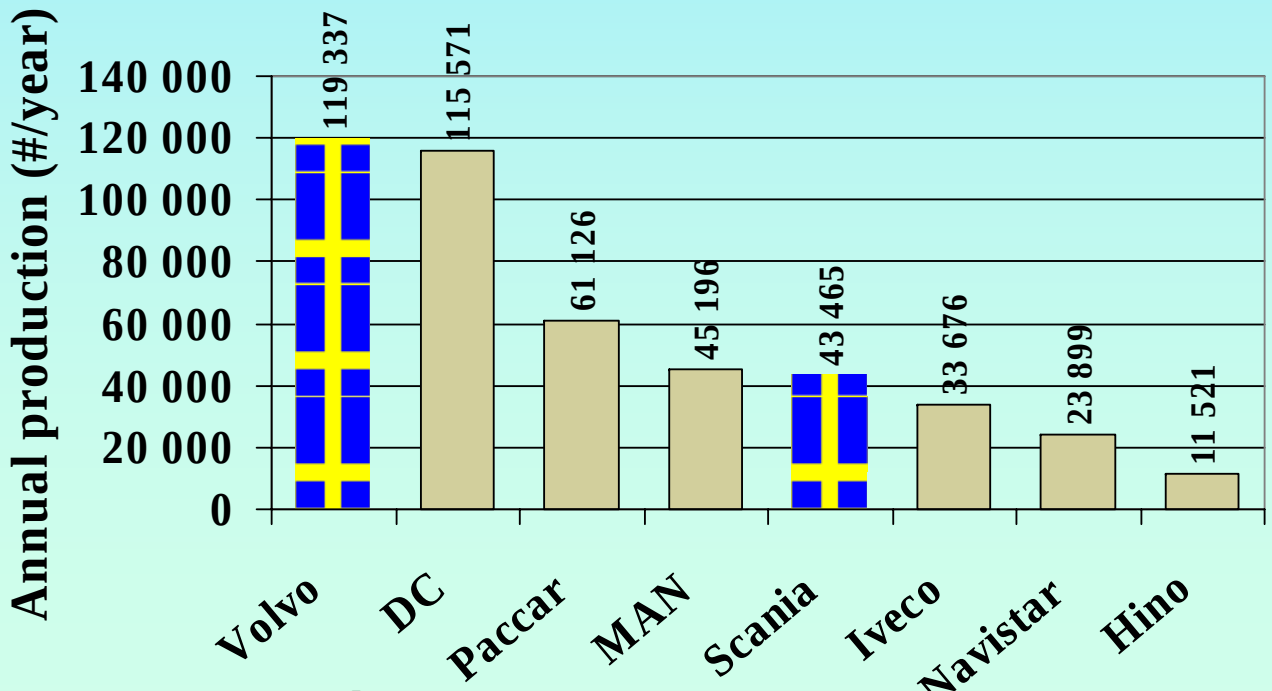
owned by GM

VOLVO

SCANIA

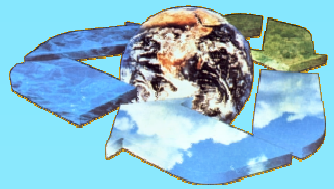
VOLVO owned by Ford

Annual production of heavy-duty vehicles >16 tons



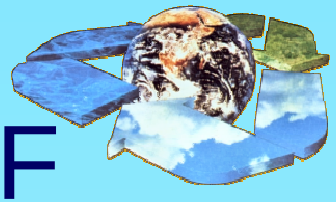
Source: **BIL Sweden**

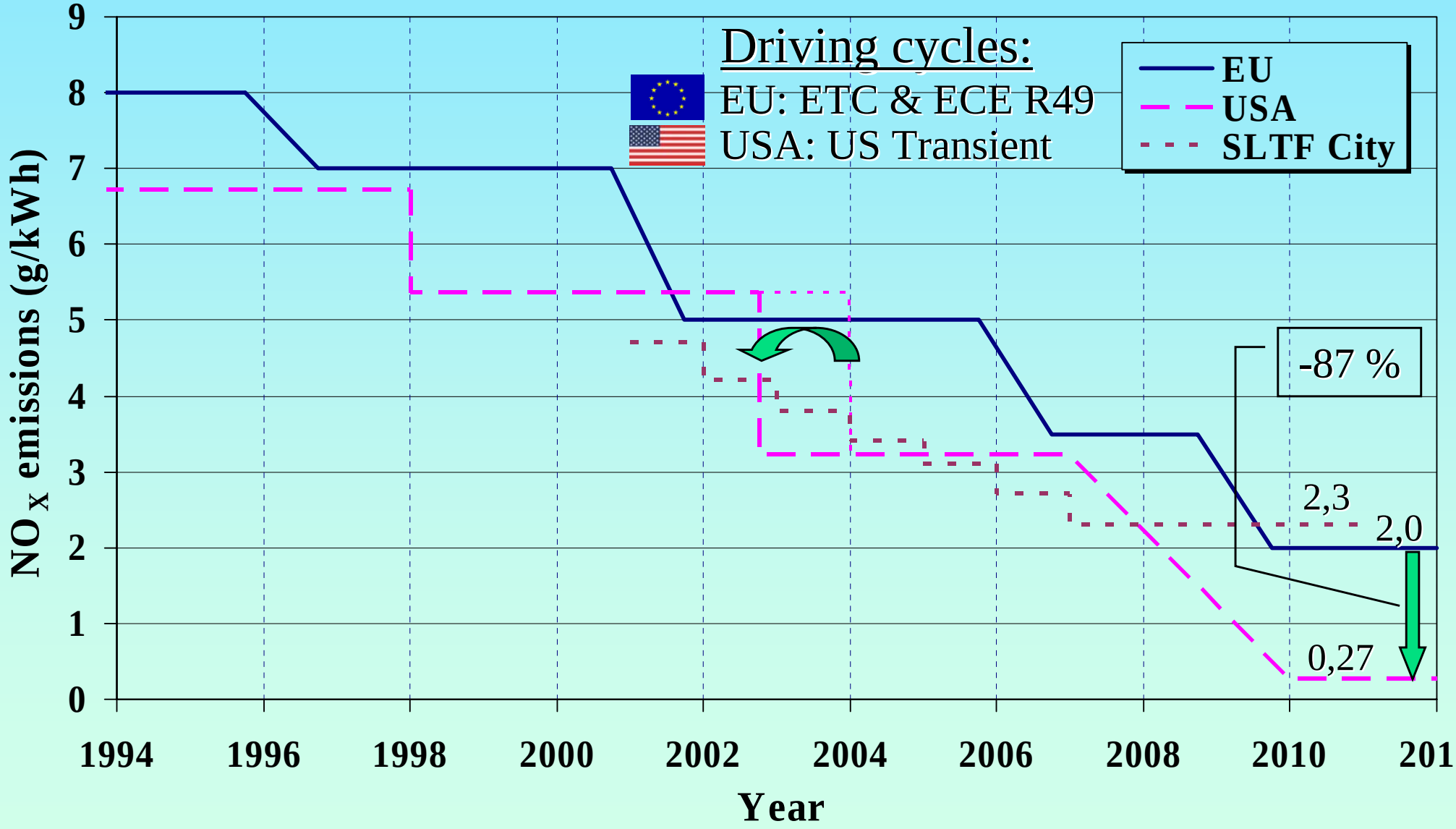
Background



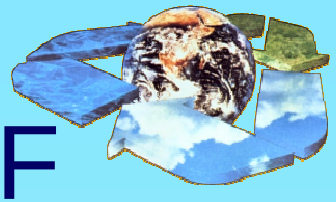
- First large fleet of ethanol buses in 1989 (Stockholm)
- Introduction of ultra-low sulfur diesel fuel in 1990 & “low-emission” diesel (i.e. ~Euro II) with ox cat
- CNG buses in 1992 (Gothenburg); later also biogas
- Retrofit particulate filters (i.e. CRT™) in mid 1990’s
- Environmental zones in larger cities (PM, HC and in 2nd stage also NO_X), 1996 (1st stage), 2002 (2nd stage)
- Retrofit EGR system with particulate filter in 1998
- Purchase *recommendations* by The Swedish Public Transport Association (SLTF) for bus fleets in 2001. Three levels for NO_X and PM: base, rural and *city*.

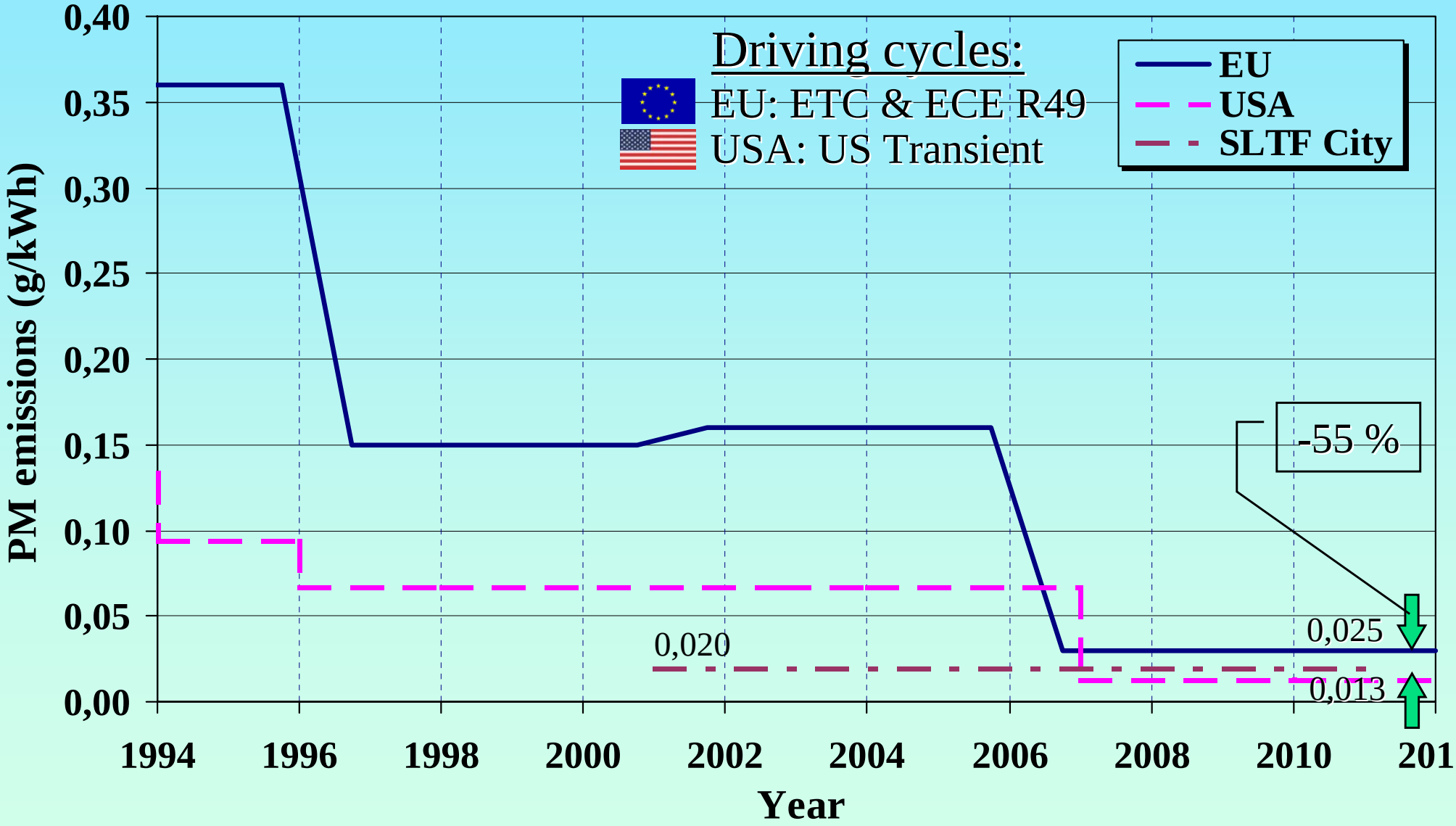
NO_X regulations for HD bus engines in EU and USA vs. SLTF



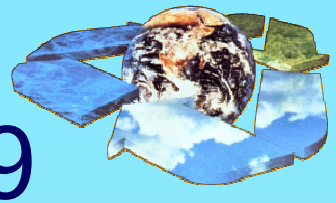


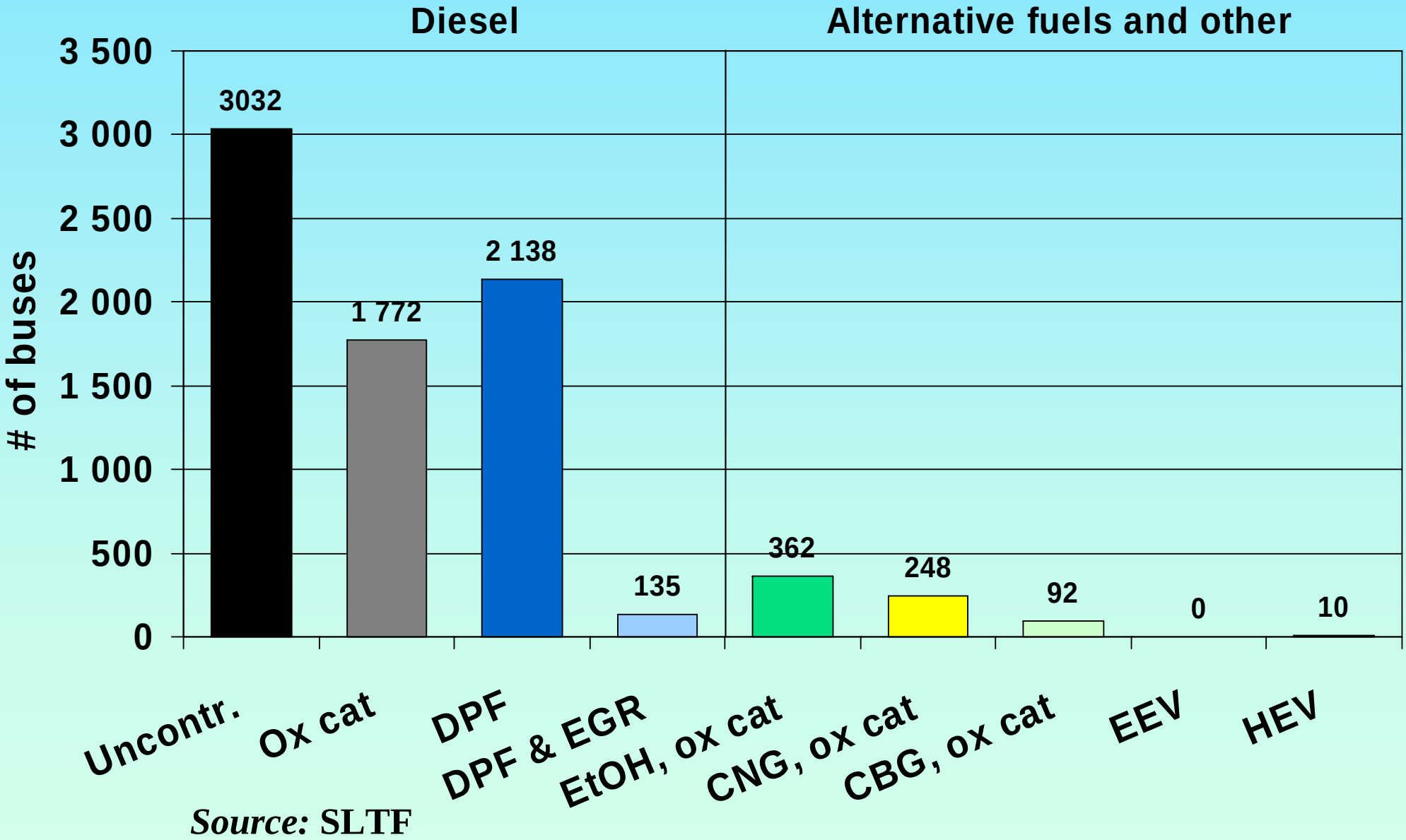
PM regulations for HD bus engines in EU and USA vs. SLTF





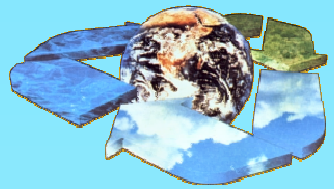
Current fleet of transit buses in Sweden (Sept. 2001); total 7789





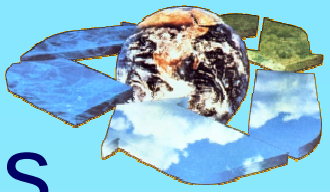
Source: SLTF

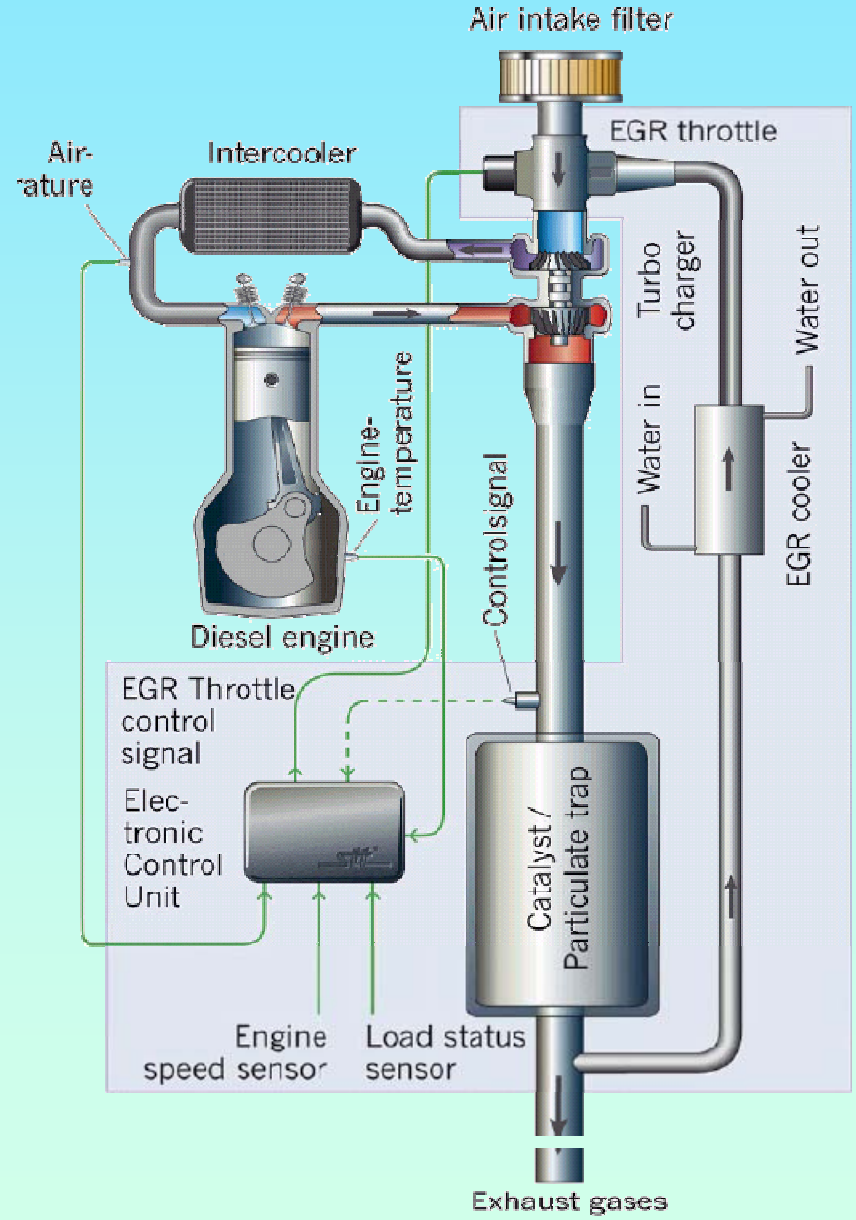
Methodology



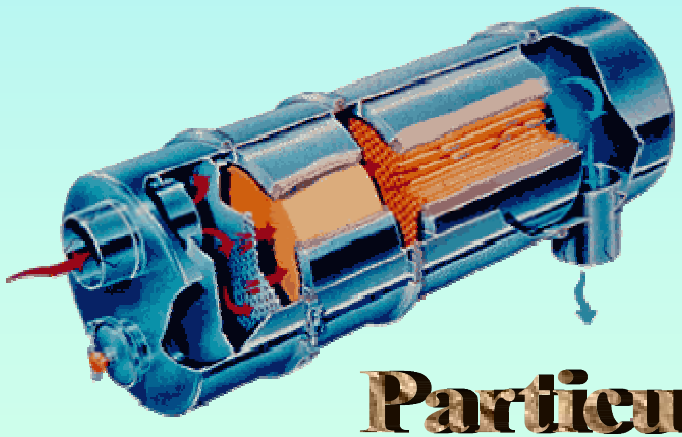
- Collection of data on emissions, fuel production, etc.
- Baseline: Diesel Euro II engine, Swedish EC1 fuel
- Diesel aftertreatment: catalyst, DPF and DPF+EGR. Corrections for catalyst and DPF aging (diesel)
- Methane engine: SI (Otto), lean-burn w/, catalyst. Swedish results are grouped (average & BAT)
- Test cycles: Swe: Braunschweig, US: CBD, CSHVC. Corrections applied (CO_2, diesel) for US tests.
- Comparisons of some selected emission results: Swe vs. US. Comparisons of cancer risk estimations.

Options to reduce the exhaust emissions from in-use diesel engines





Oxidation catalyst



Particulate filter (e.g. CRT)

The DNOx(TM) system from STT
A retrofit and OEM EGR system

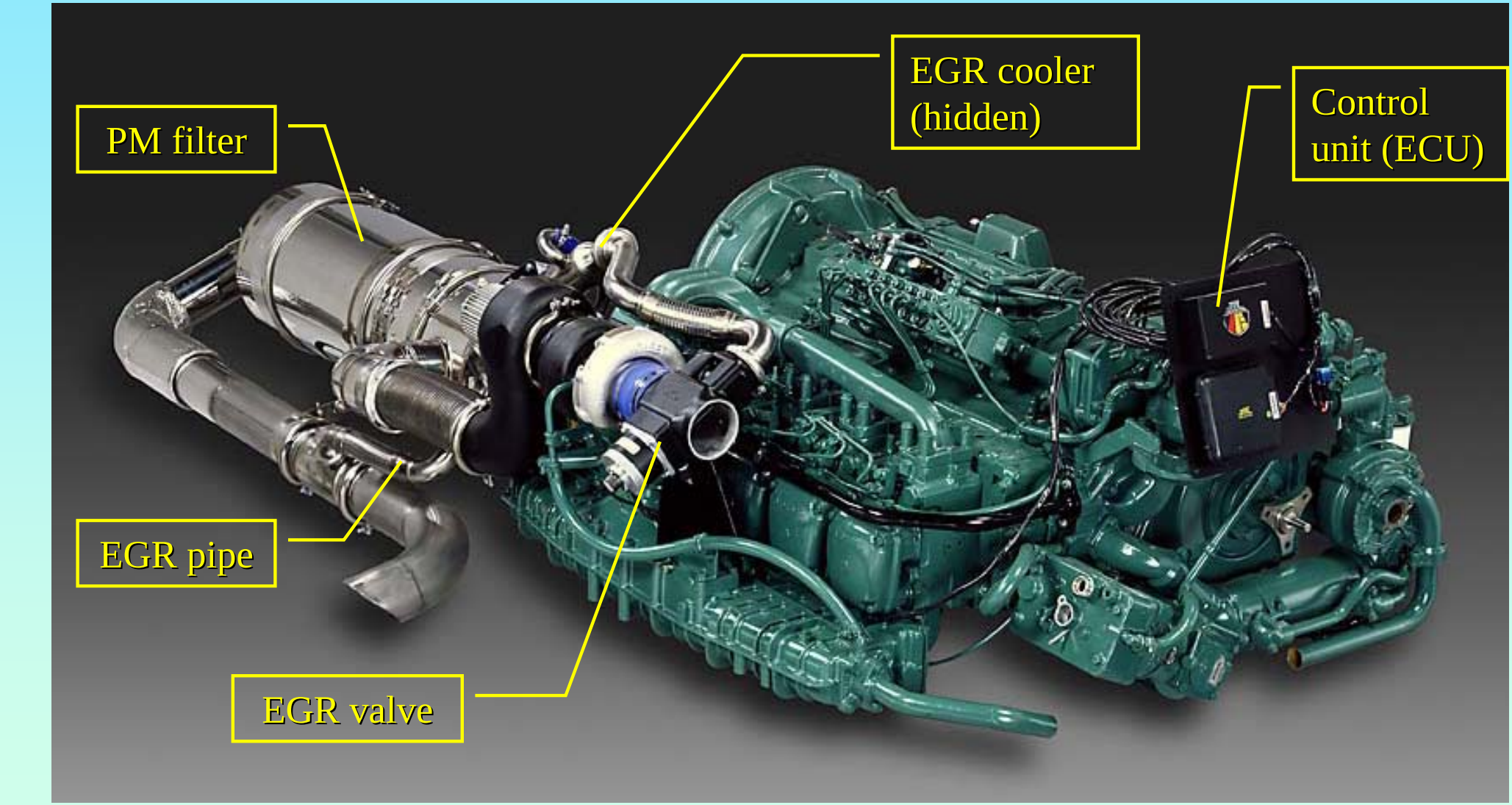
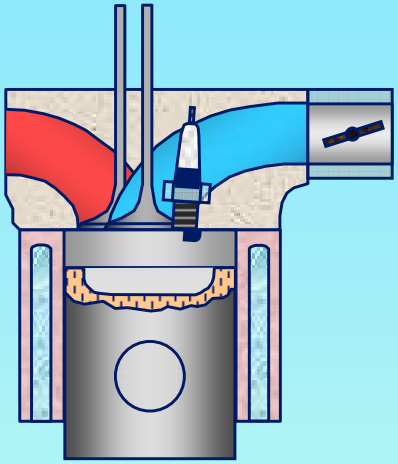
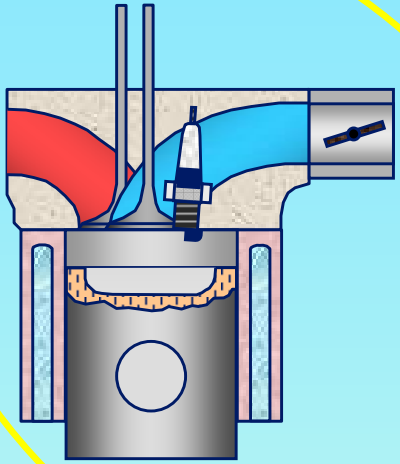


Photo courtesy of STT Emtec

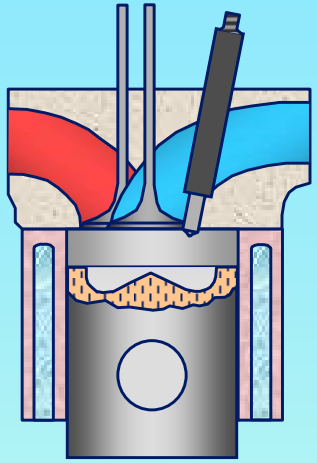
Engine technology for heavy-duty CNG engines



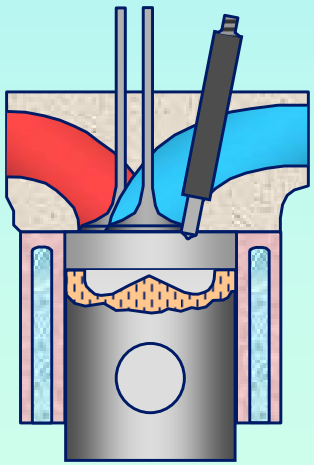
TWC



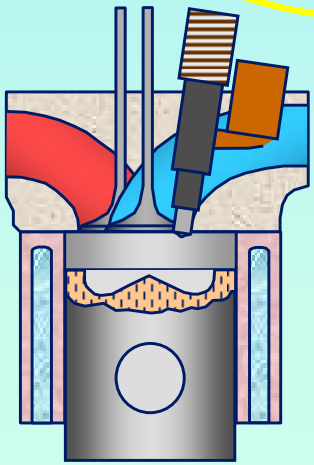
Lean-burn



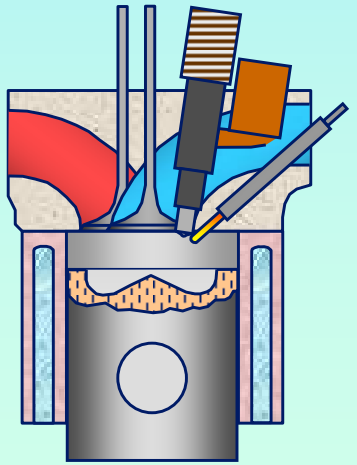
DFNG



PING



DING (PI)



DING (GP)

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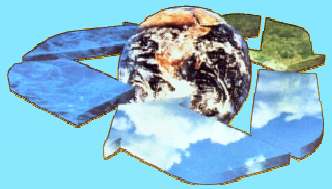
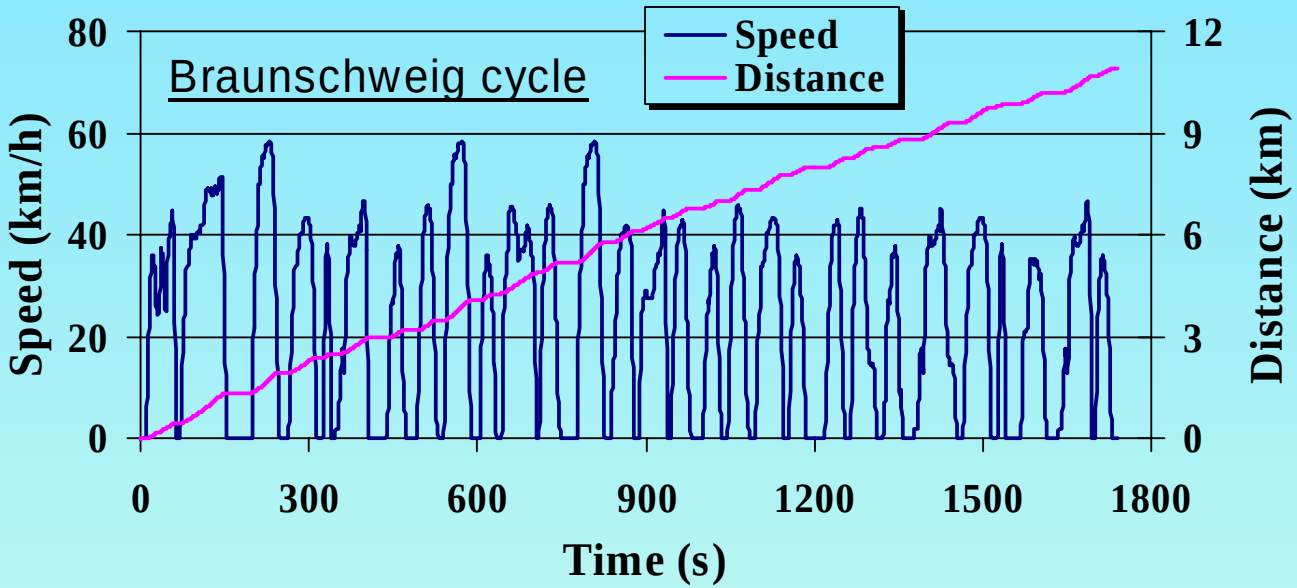
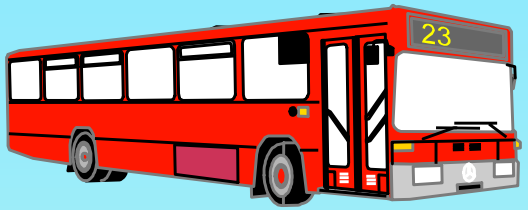
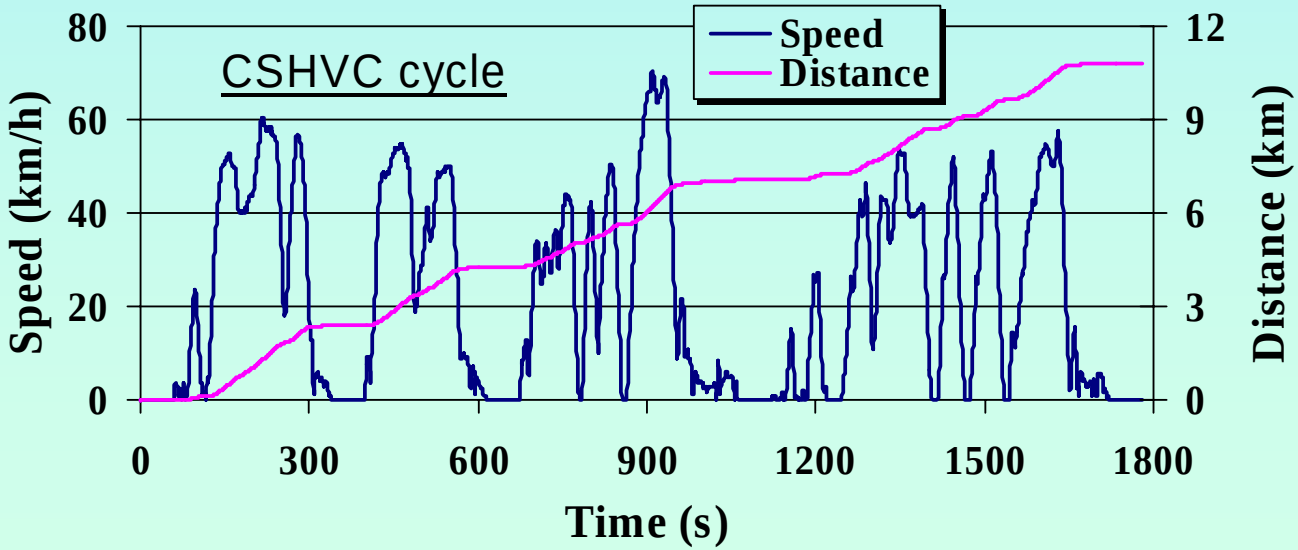
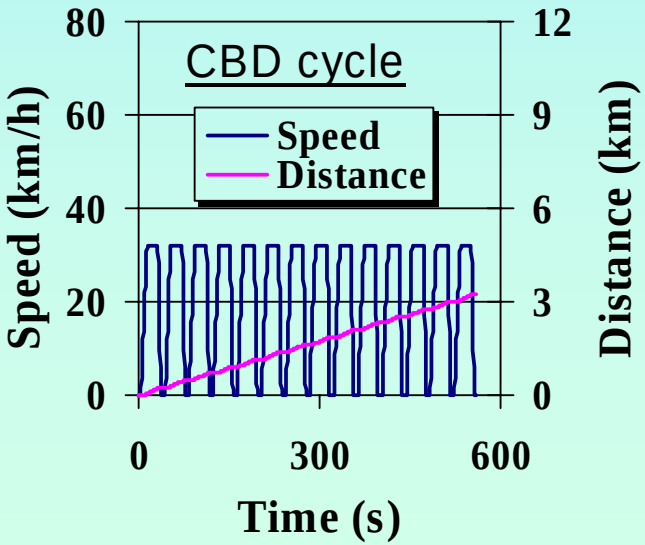
Test cycles for transit buses



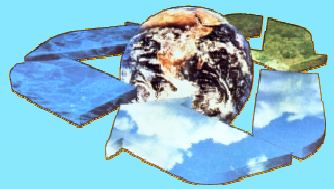


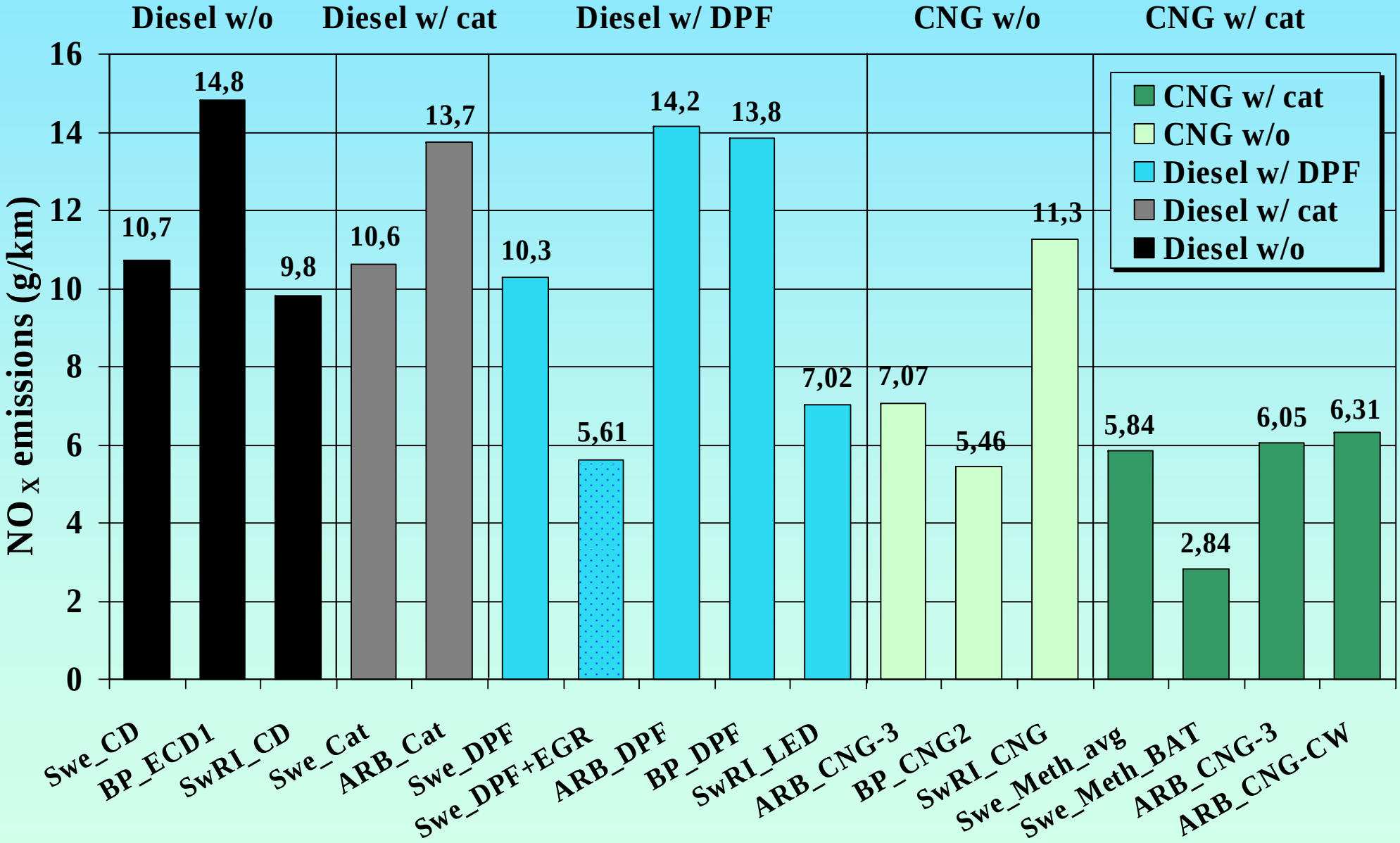




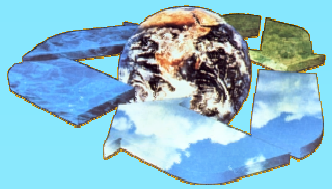


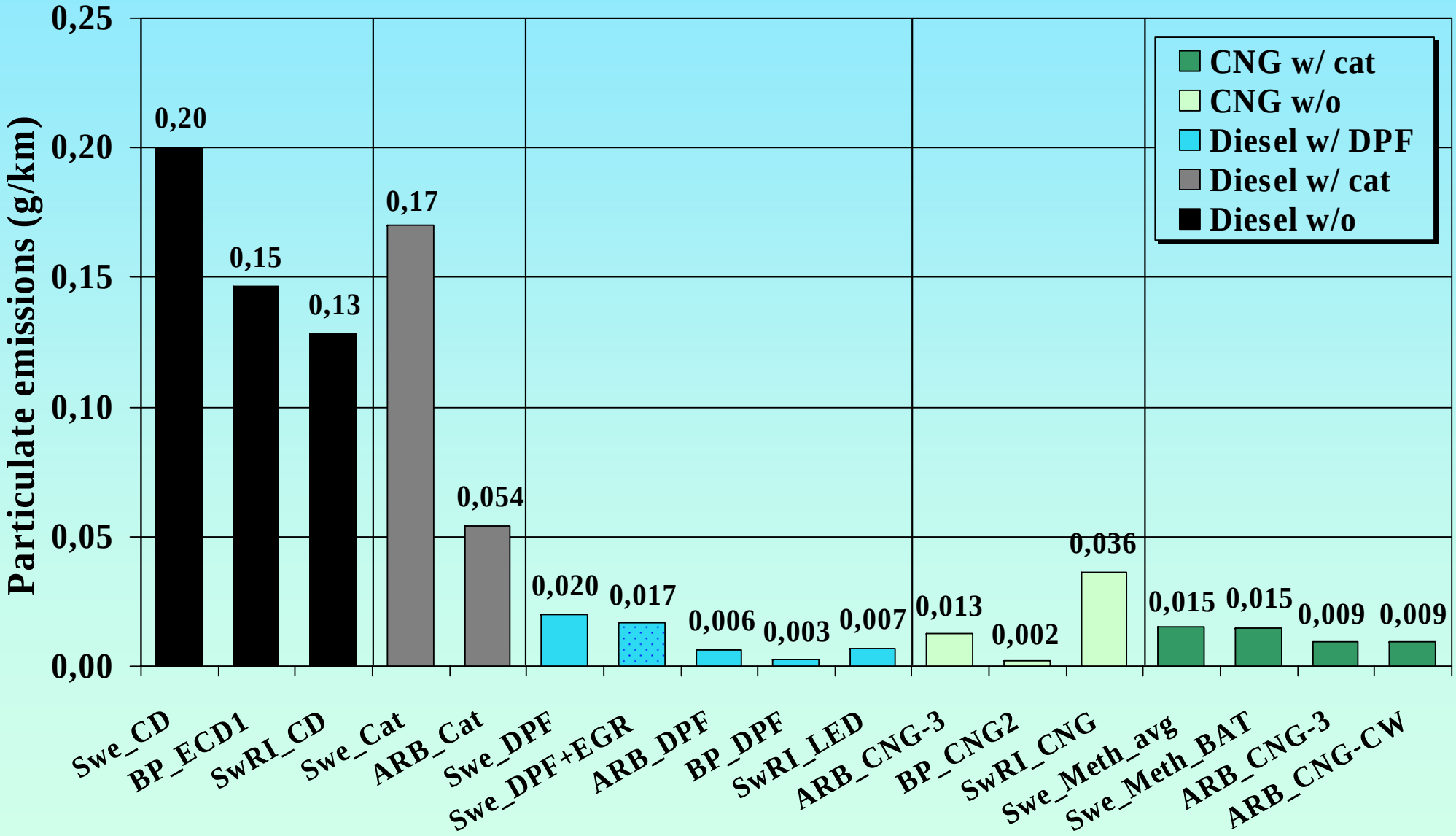
NO_X emissions (g/km)



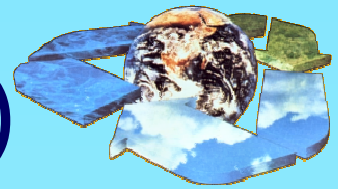


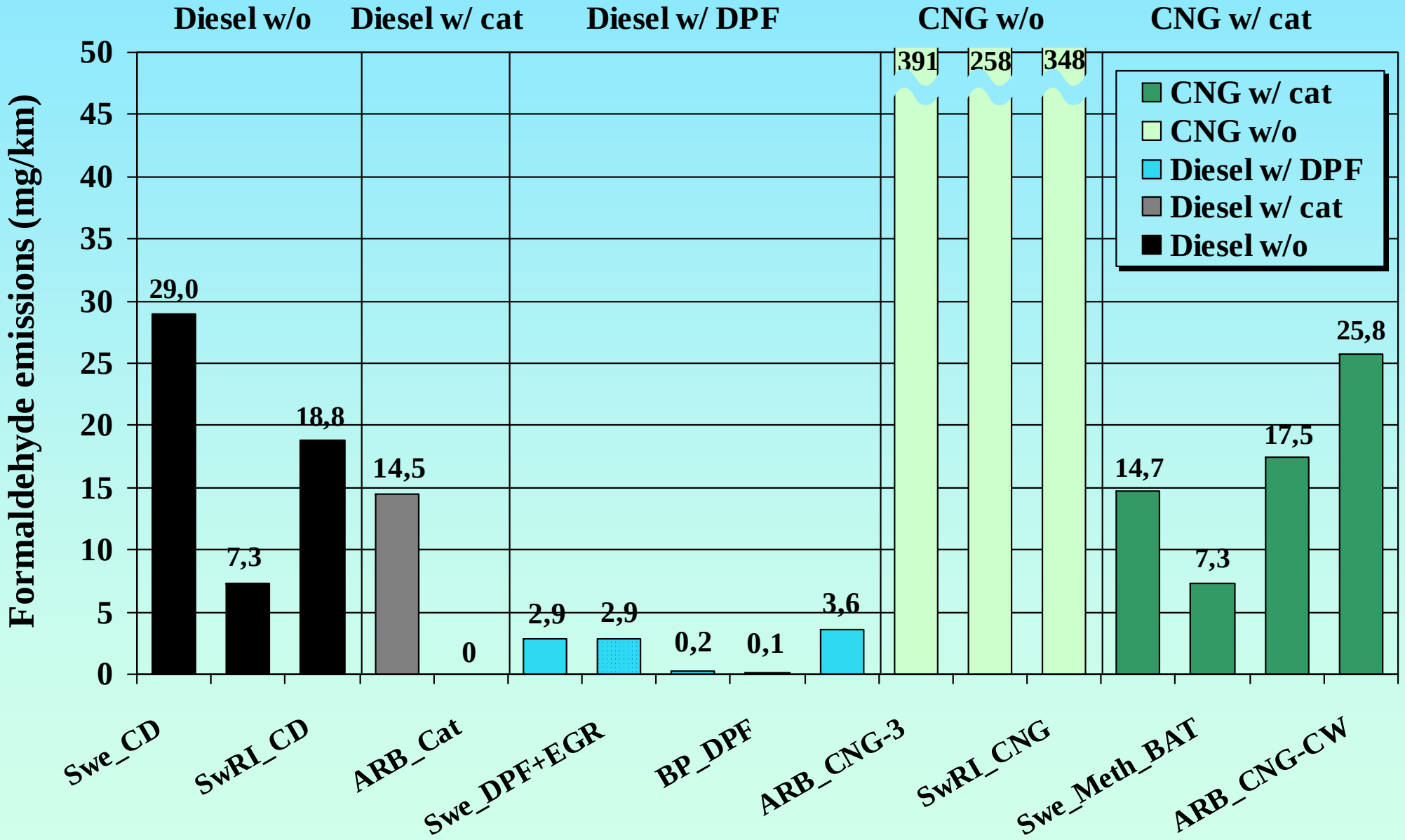
Particulate emissions (g/km)



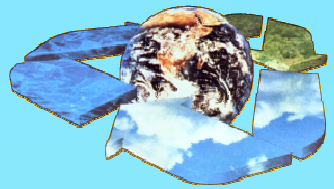


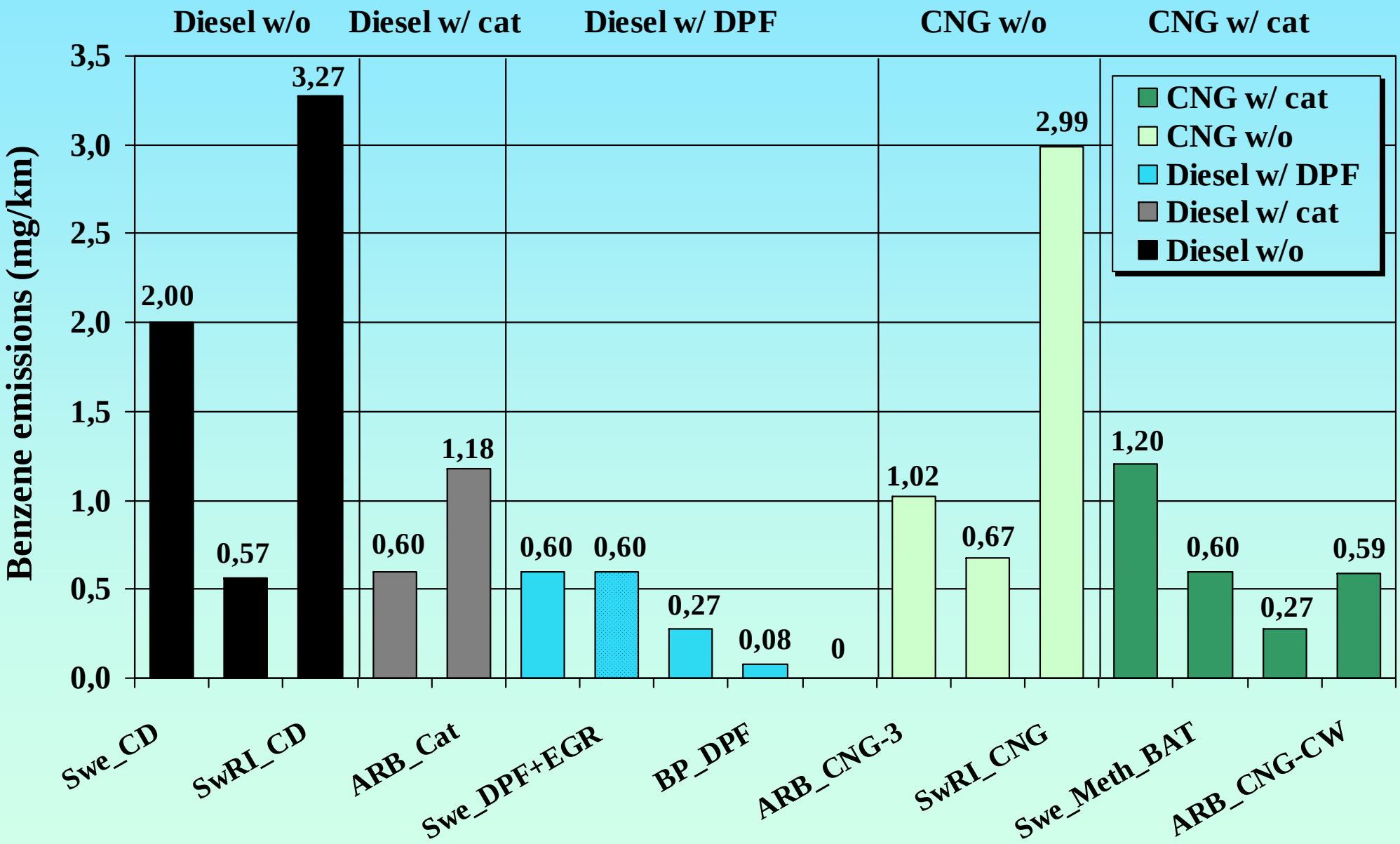
Formaldehyde emissions (mg/km)



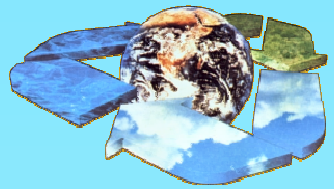


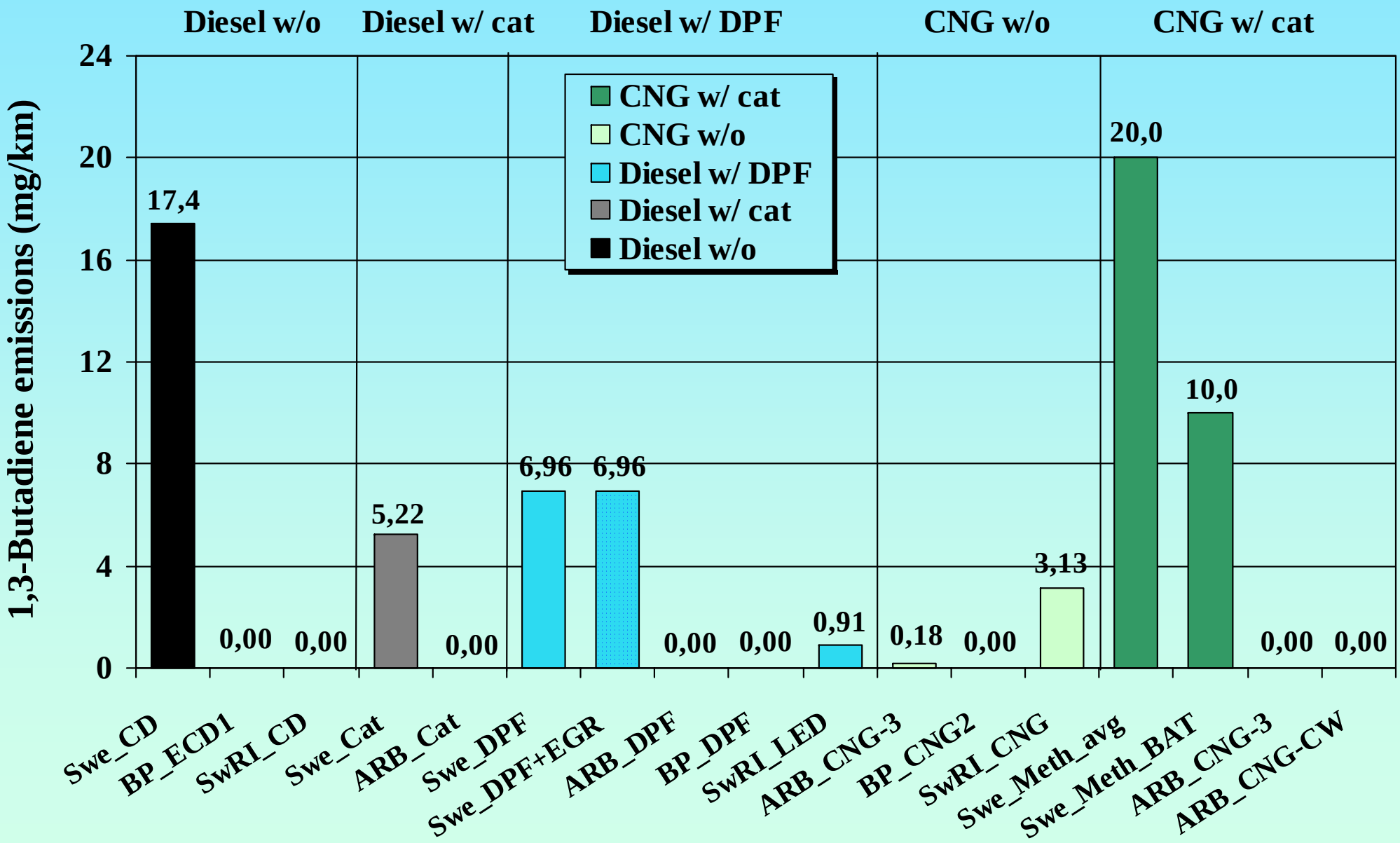
Benzene emissions (mg/km)



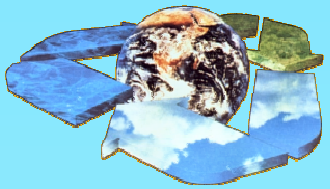


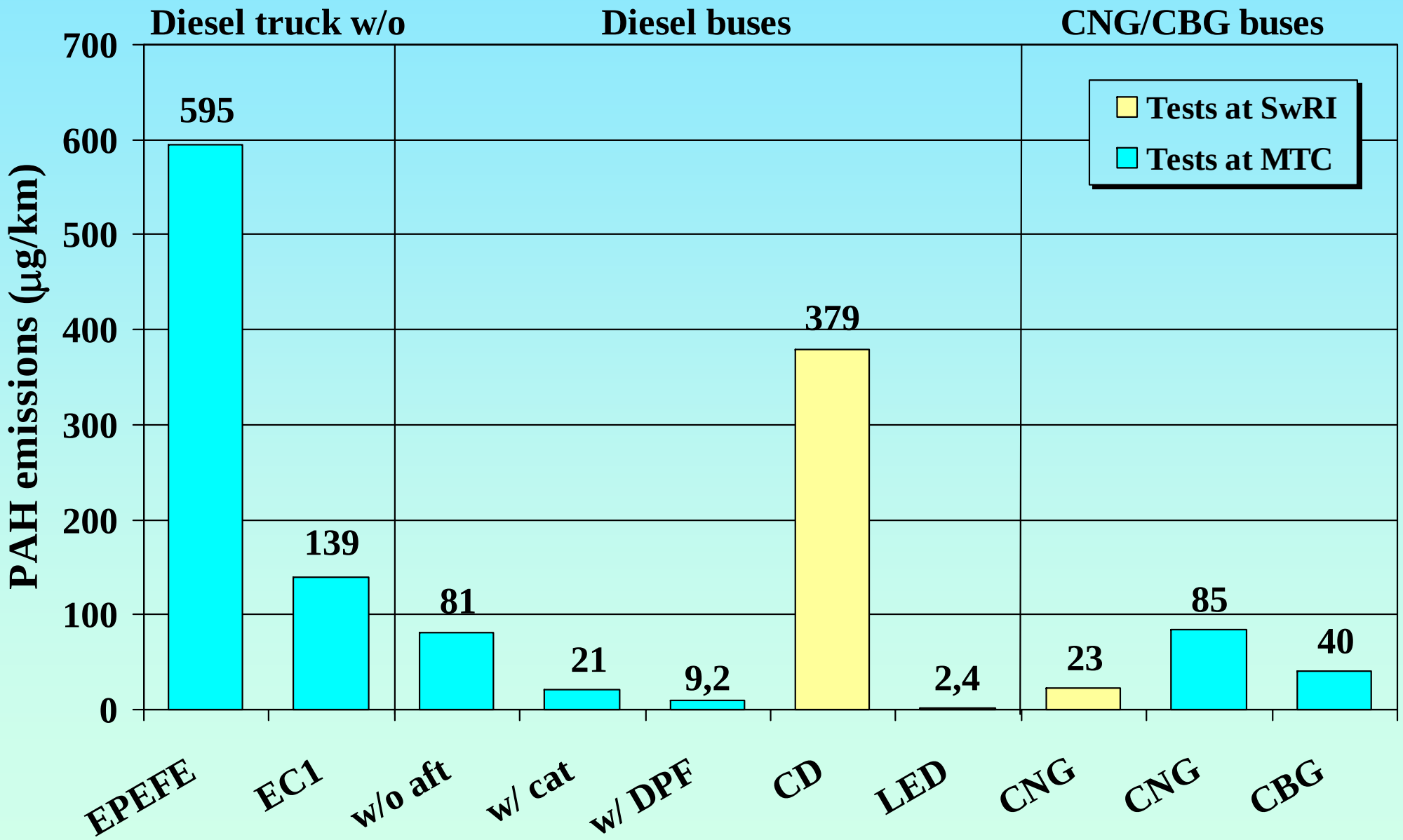
1,3-Butadiene emissions (mg/km)



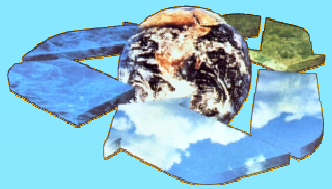


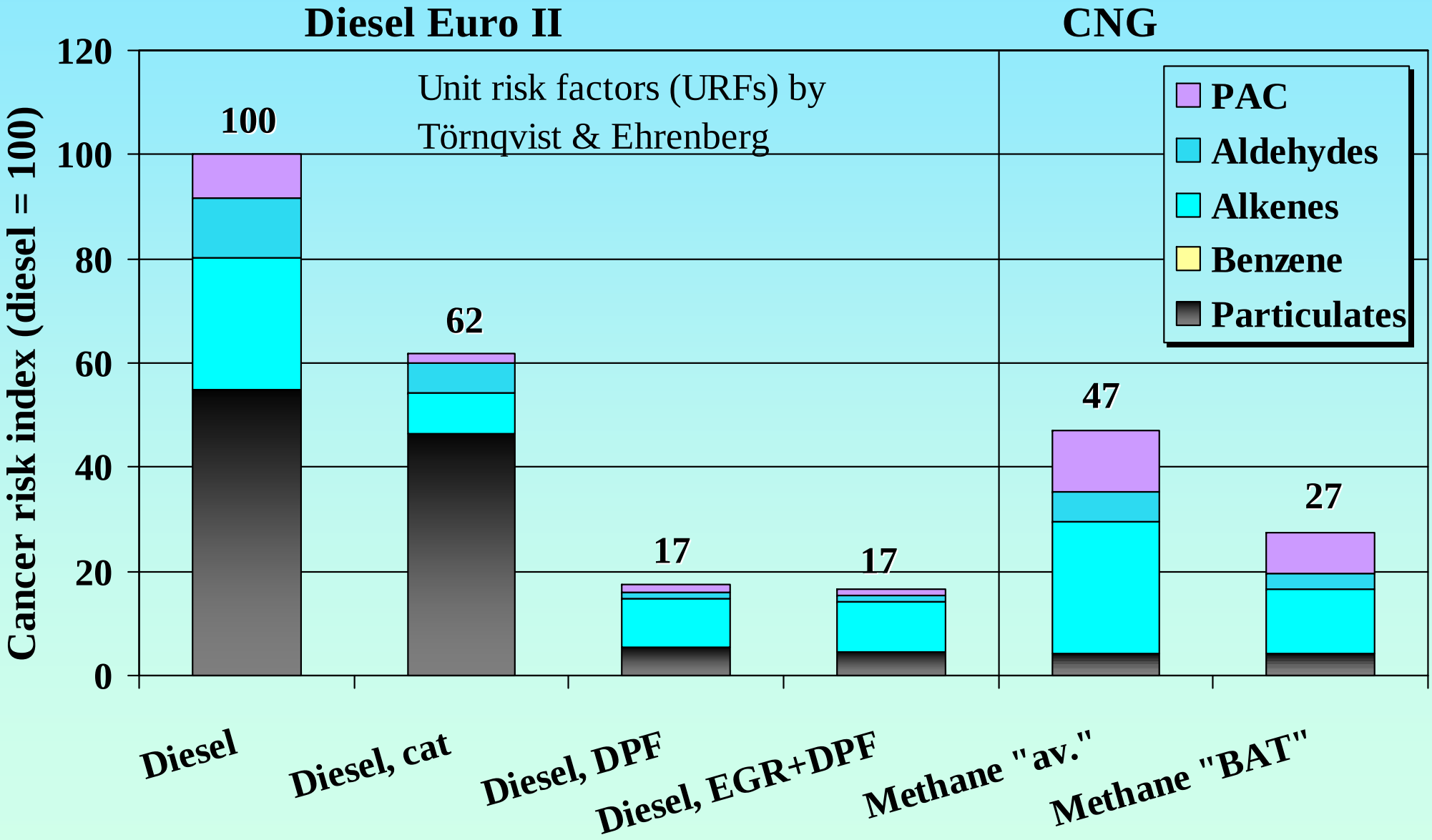
12 species of tri+ PAH emissions for some selected tests



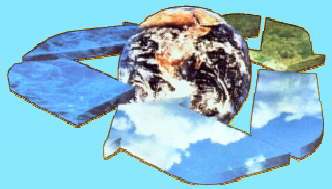


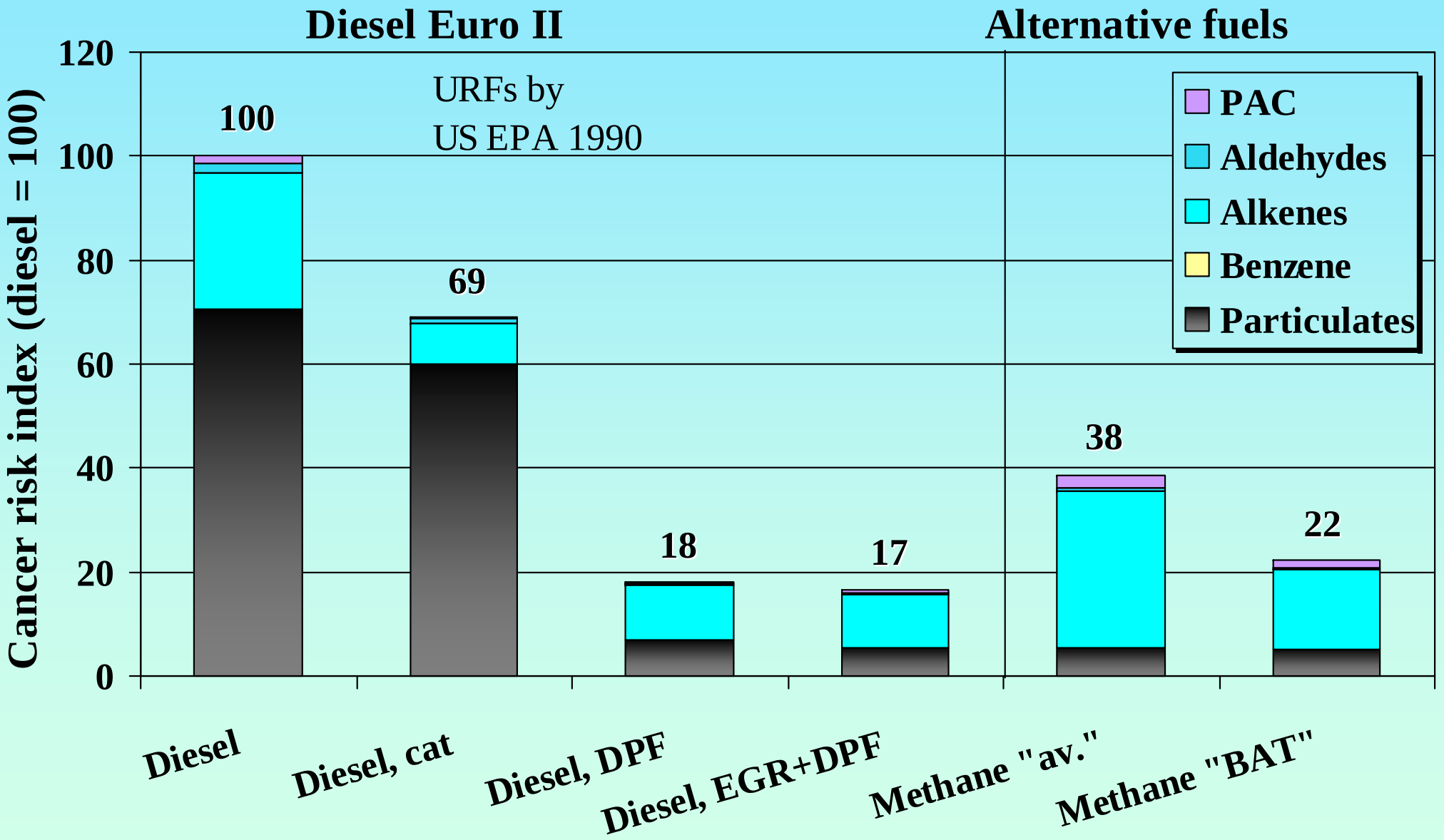
Cancer risk index (diesel=100) Base case (T&E URFs)





Cancer risk index (diesel=100) URFs by US EPA 1990





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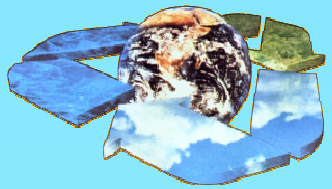
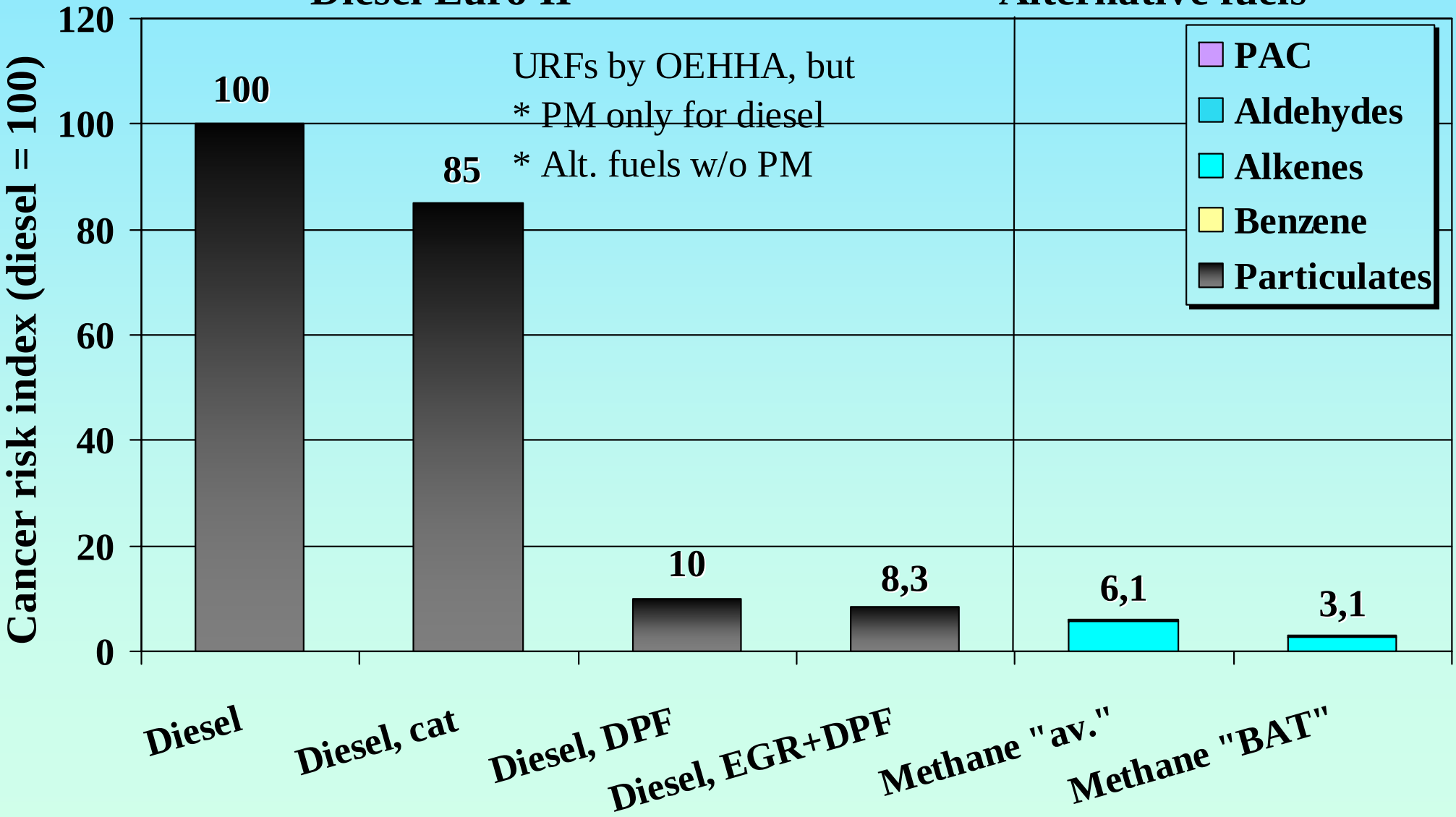
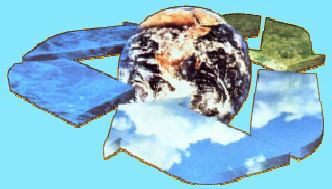
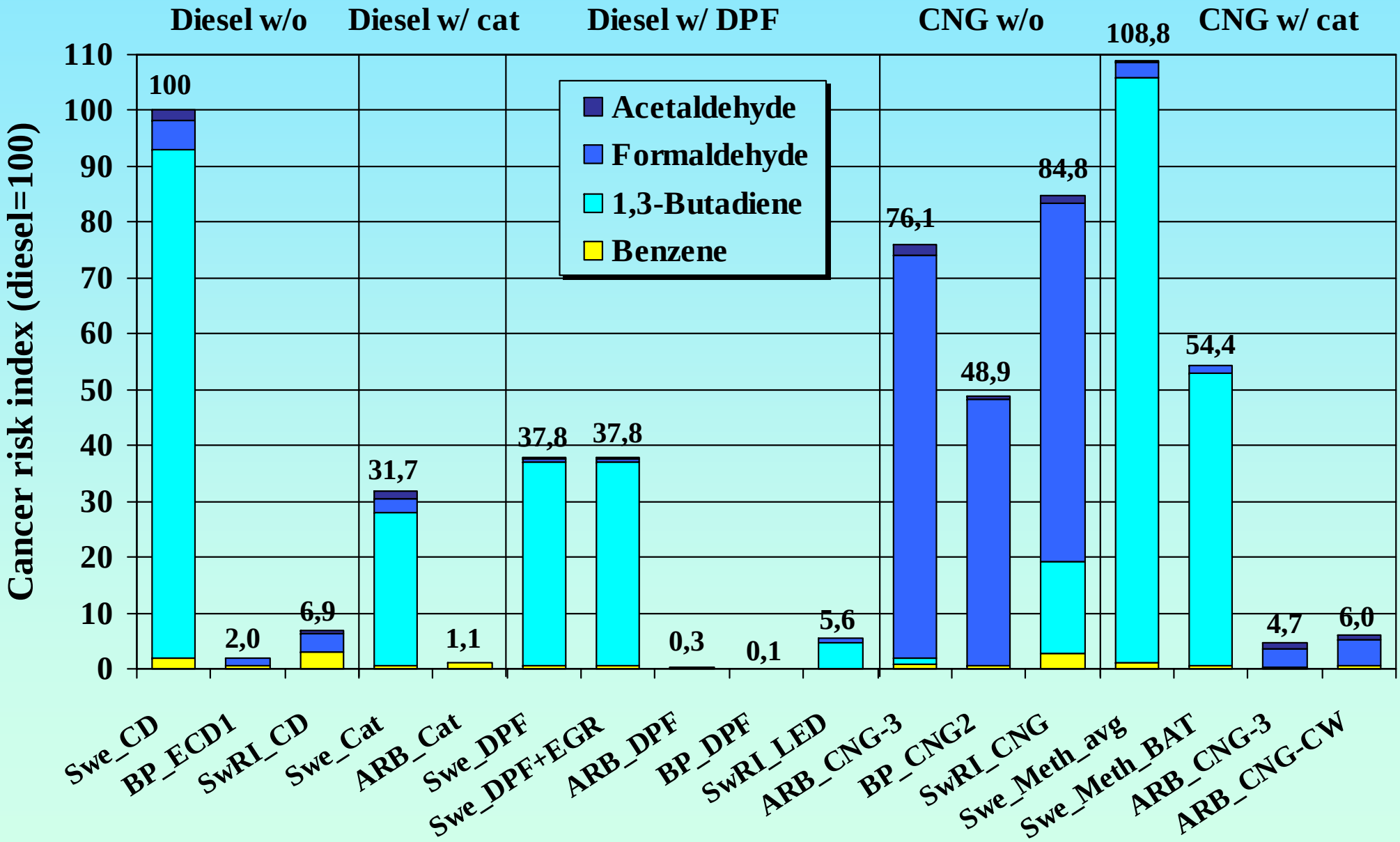
Cancer risk index (diesel=100) URFs by OEHHA, case #1



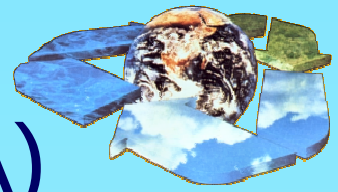


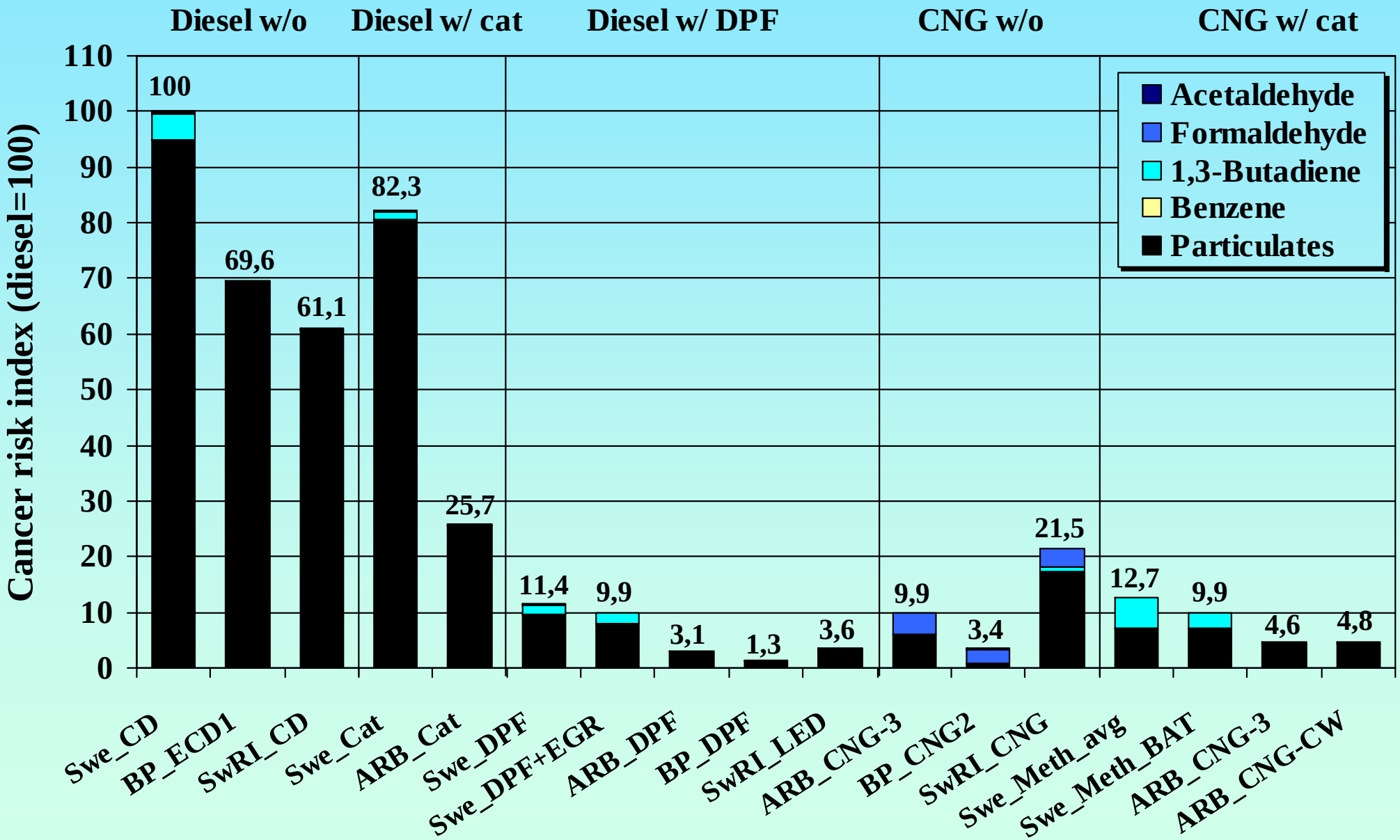
Cancer risk index, four chemical species only (URFs by OEHHA)



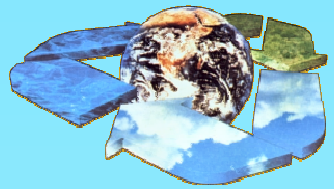


Cancer risk index, four chemical species and PM (URFs by OEHHA)



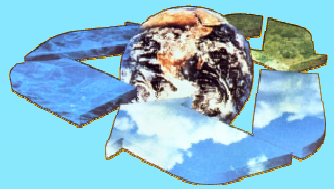


Conclusions 1(2)



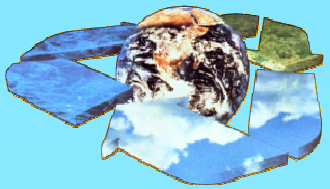
- Regulations and incentives are important
- Transit buses in larger cities use ULSD and DPF/DPF+EGR *or* alt. fuels with ox. catalyst
- NO_X is fairly similar for US & Swe. CNG has lower NO_X than diesel but is matched by EGR. NO_X affected by driving cycle “optimization”?
- PM is generally higher for Euro II than US -98. CNG and diesel with DPF are roughly similar.
- Very high formaldehyde level for CNG w/o cat. No Swedish results for CNG w/o catalyst (!!!)

Conclusions 2(2)



- Benzene is fairly low for both fuels; impact of cat
- 1,3-Butadiene results are inconsistent
- URFs has considerable impact on cancer risk
- Formaldehyde and 1,3-butadiene most important chemical species with OEHHA URFs
- PM is of great importance with OEHHA URFs. What is the impact of PM from alternative fuels?
- Importance of PAH (PAC)?
- The emission technology applied may be of greater importance than the fuel choice

This concludes my presentation



- Thank you for your attention!
- Questions?

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(e.g. reports, presentations, etc.)