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ENERGY RESEARCH, DEVELOPMENT, DEMONSTRATION, AND DEPLOYMENT
ENVIRONMENTAL CONSULTANTS

Swedish Experiences from Low-Emission City Buses: Impact on Health and Environment

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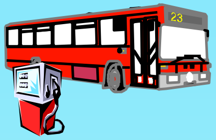

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    - Ozone forming potential
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    - Cancer risk index
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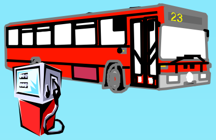
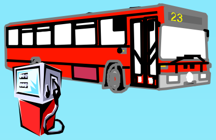


Introduction

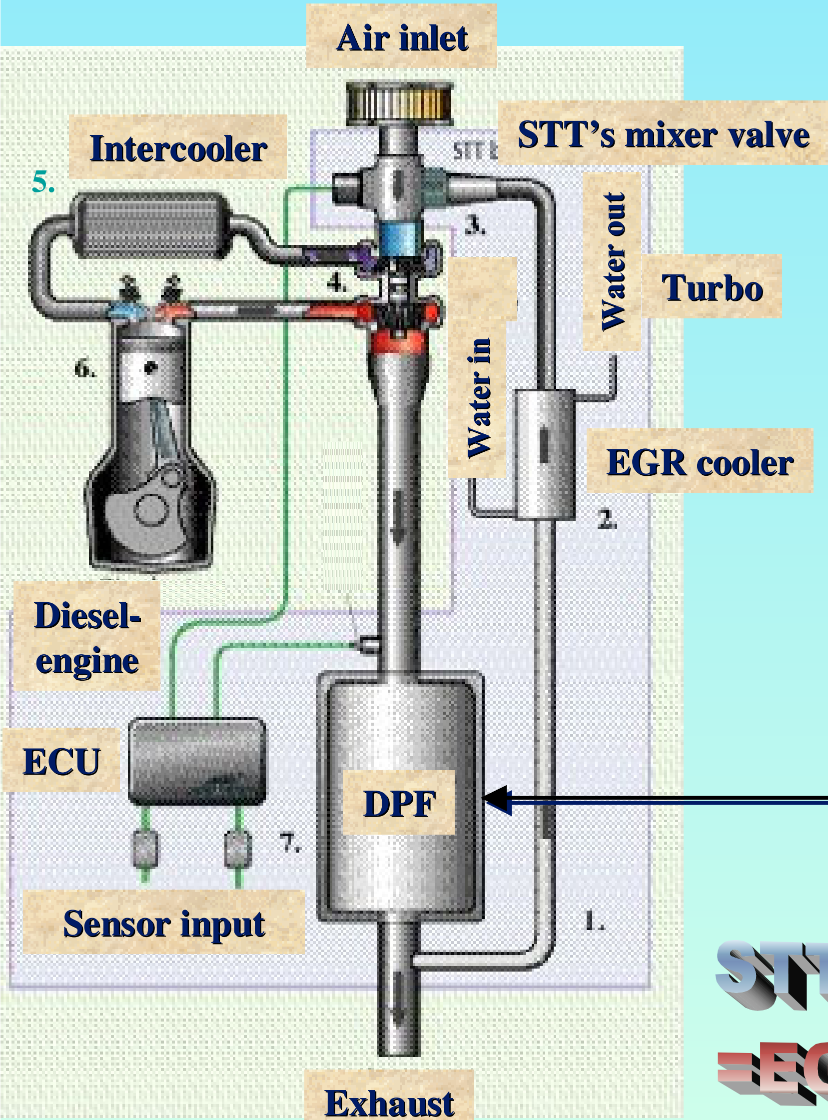
- Increased focus on HDV emissions (PM, NO_X, etc.)
- City buses operate in populated areas and compete with TWC-equipped passenger cars
- 10 years of Swedish experience on low emiss. buses
  - Environmental class 1 (EC1) diesel fuel (<10 ppm S)
  - Environmental zones (Stockholm, Gothenburg and Malmö)
  - Retrofit of aftertreatment devices (catalyst, DPF)
  - Alternative fuels (RME, ethanol, CNG, biogas,...)
- An evaluation of fuel/aftertreatment options for buses and a comparison with gasoline-fueled passenger cars is necessary to assess the environmental impact

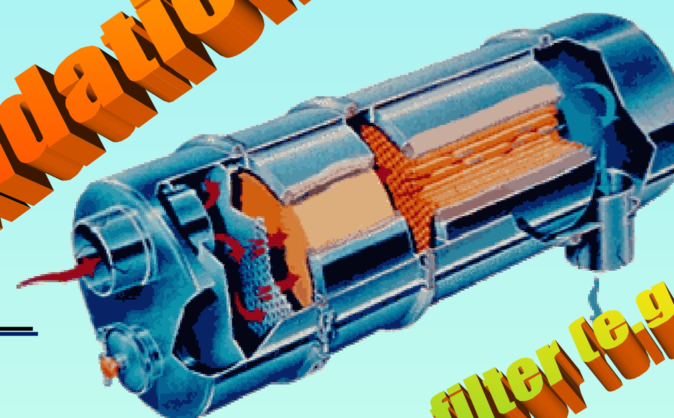


Methodology

- Collection of data on emissions, fuel production, etc.
- Baseline: Diesel Euro II engine, Swedish EC1 fuel
- Diesel aftertreatment: catalyst, DPF and DPF+EGR
- Alternative fuels: ethanol, methane (CNG, biogas)
- Ethanol engine: CI (Diesel) with catalyst
- Methane engine: SI (Otto), lean-burn with catalyst
- Driving cycle: Braunschweig city bus cycle
- Corrections for catalyst and DPF aging (diesel)
- Evaluation of the effects on environment & health
- Comparison with gasoline-fueled cars

Options to reduce the exhaust emissions from diesel engines



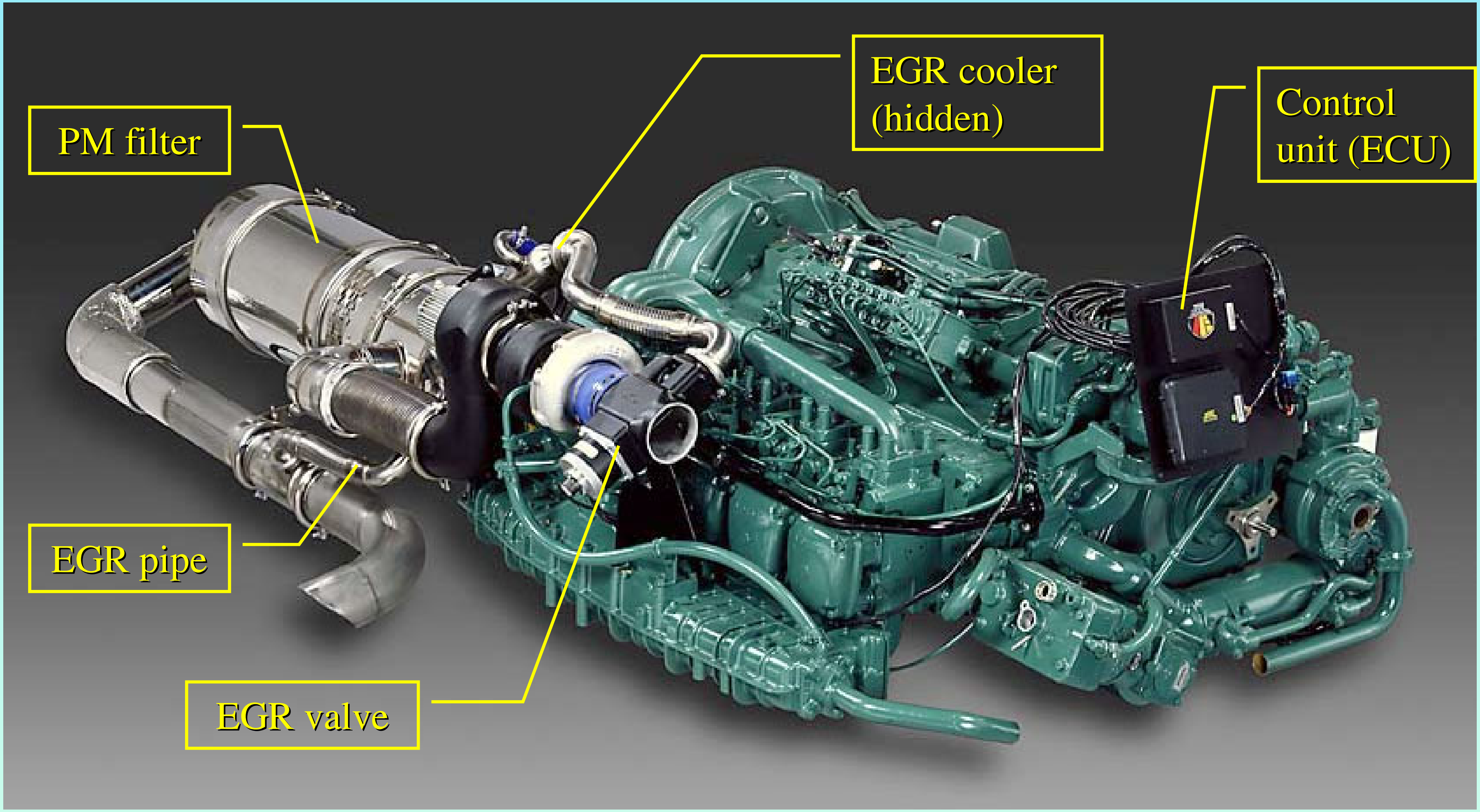


Oxidation catalyst

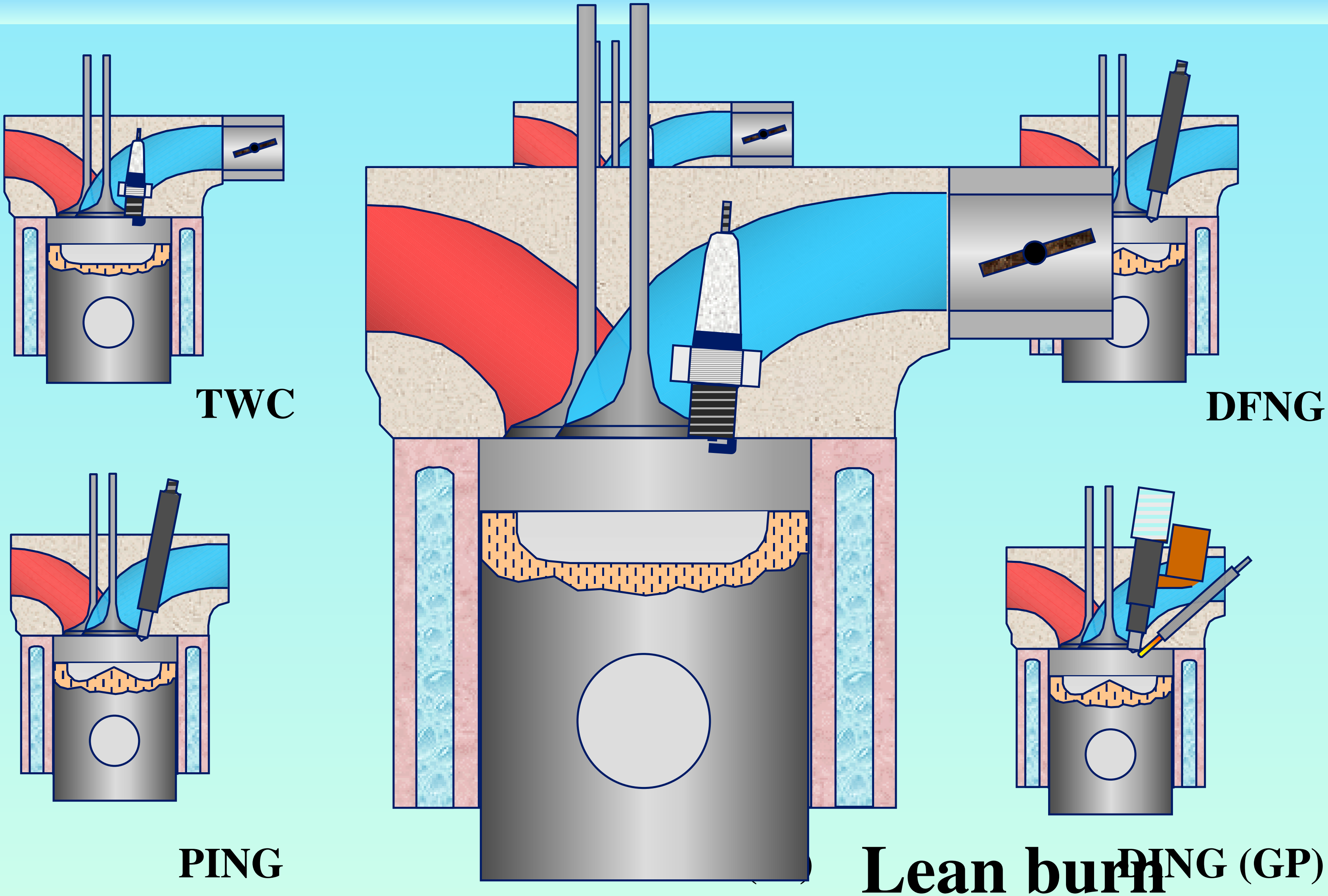
Particulate filter (e.g. CRT)

STT's DNOx =EGR + DPF

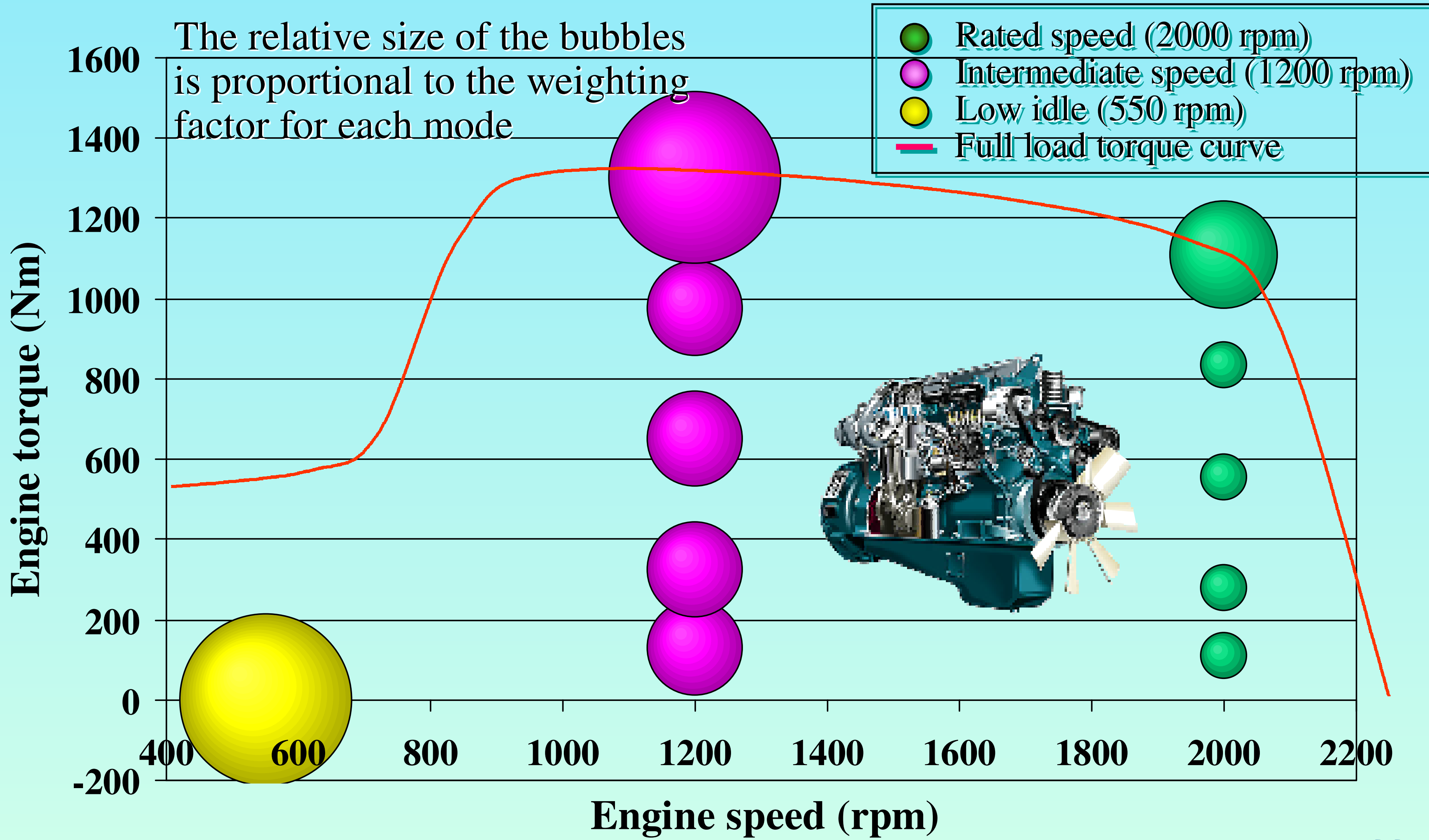
The DNOx(TM) system from STT A retrofit and OEM EGR system



Engine technology for heavy-duty CNG engines



Modes in ECE R49 for a typical bus engine



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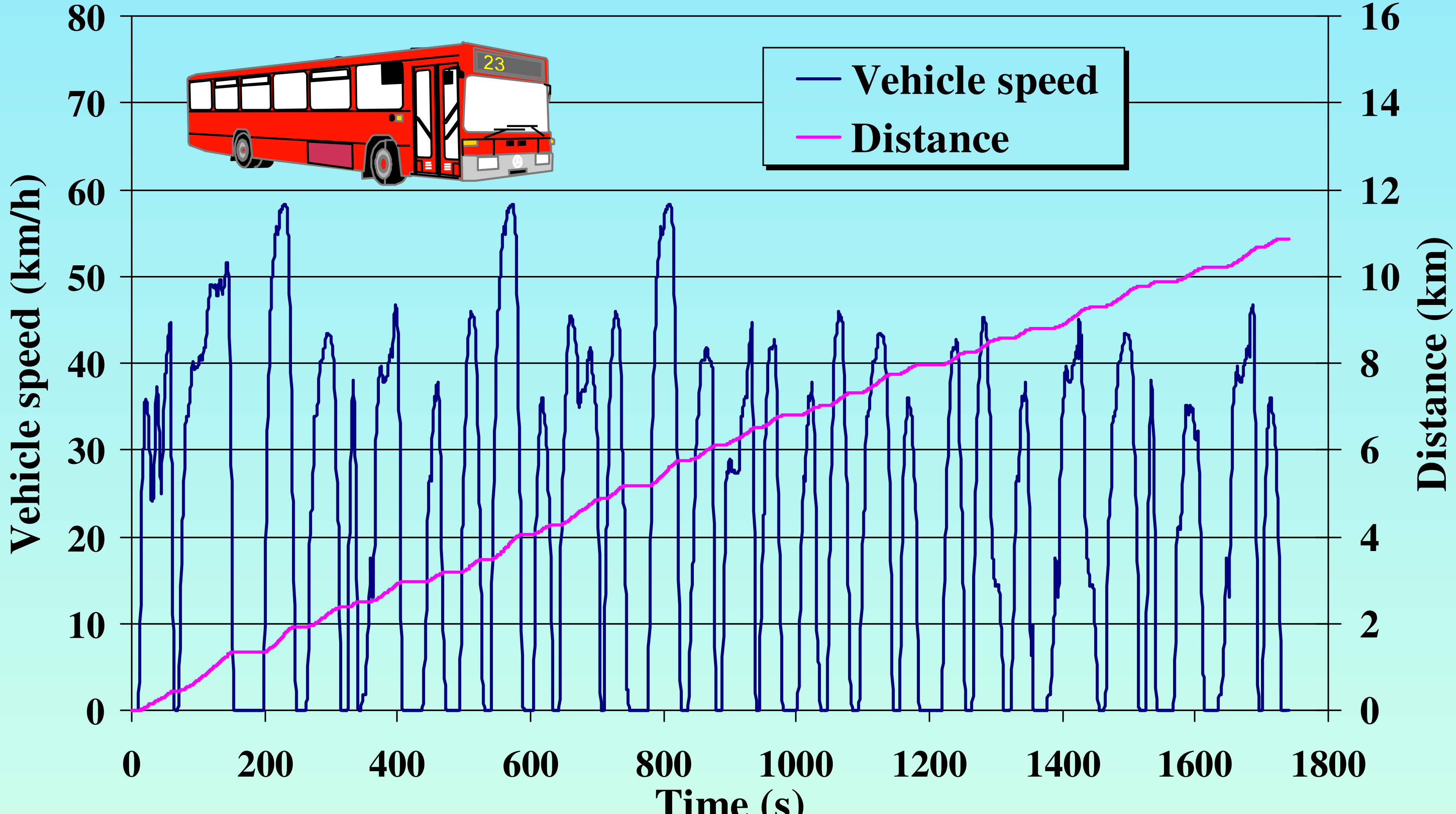
The Braunschweig city bus driving cycle



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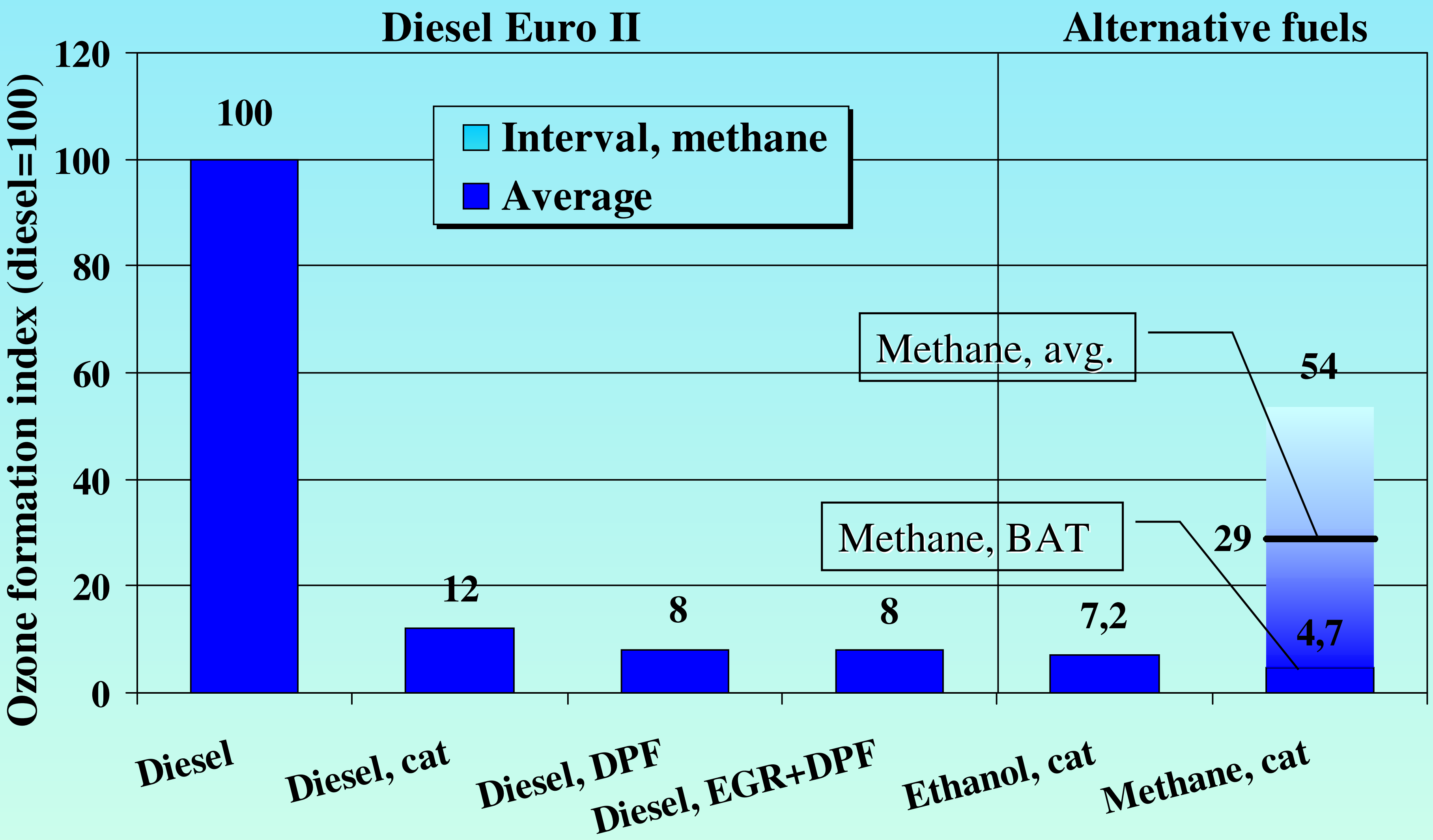
Impact of vehicle emissions

- Ozone forming potential: NO_X and reactive VOC
- Respiratory diseases: ozone (O_3), nitrogen dioxide (NO_2), aldehydes, particulate matter (PM)
- Cancer risk: polycyclic aromatic compounds (PAC), fine particles, benzene, 1,3-butadiene, ethene, propene, aldehydes
- Acidification/eutrophication: SO_X and NO_X
- Greenhouse gases: fossil carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), etc.

Ozone forming potential (diesel=100)



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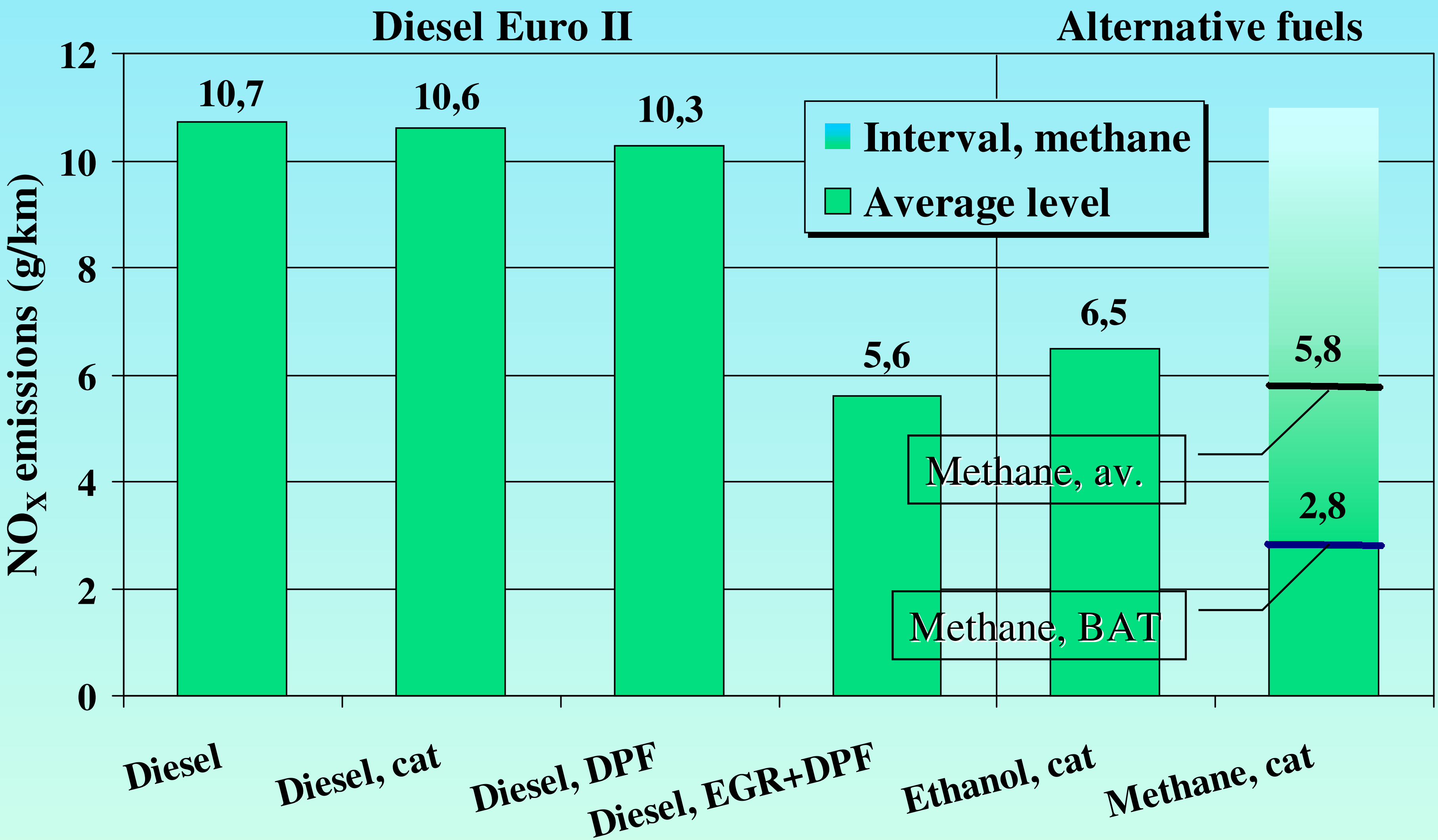
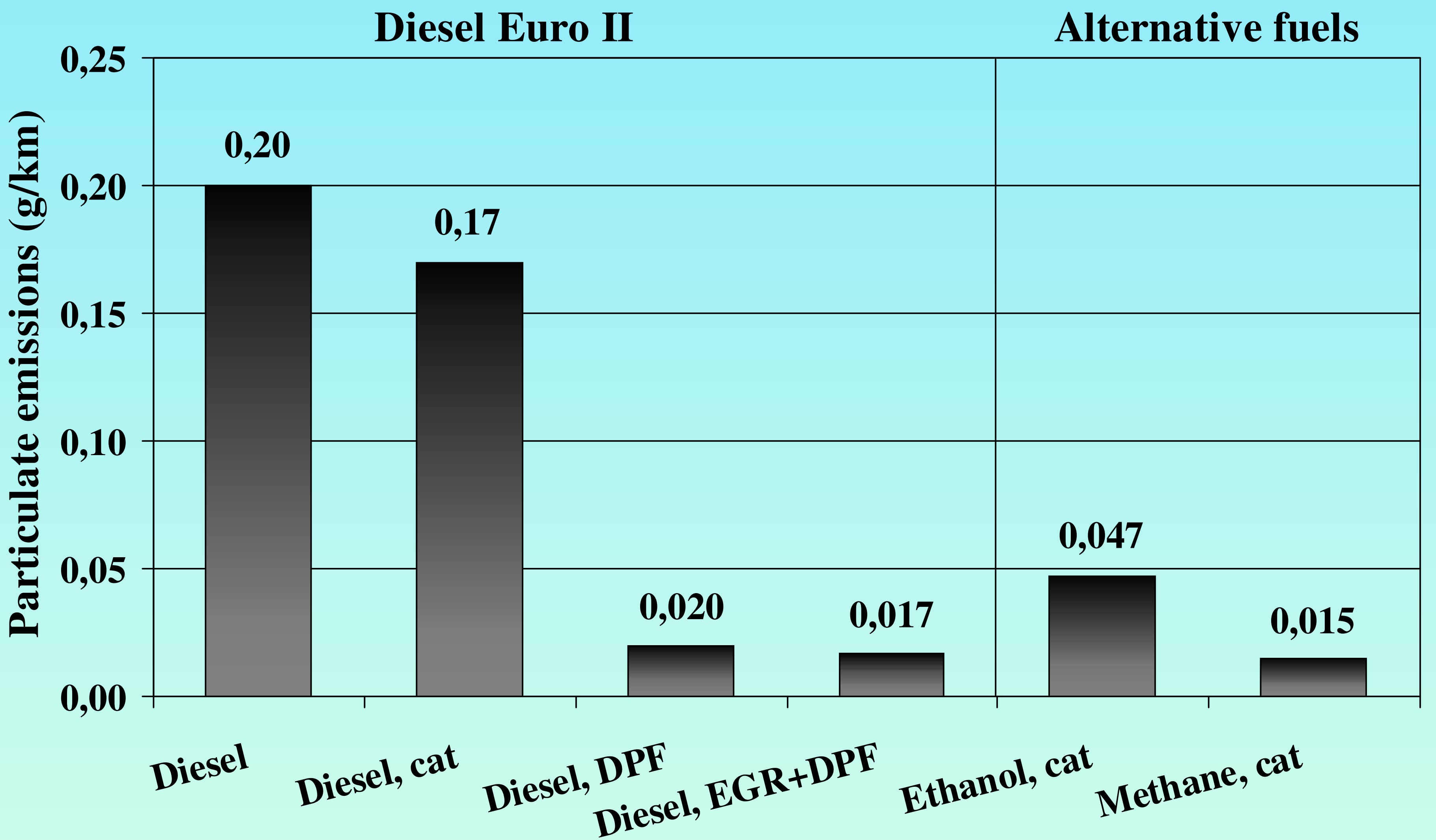
NO_X emissions (g/km)



Particulate emissions (g/km)



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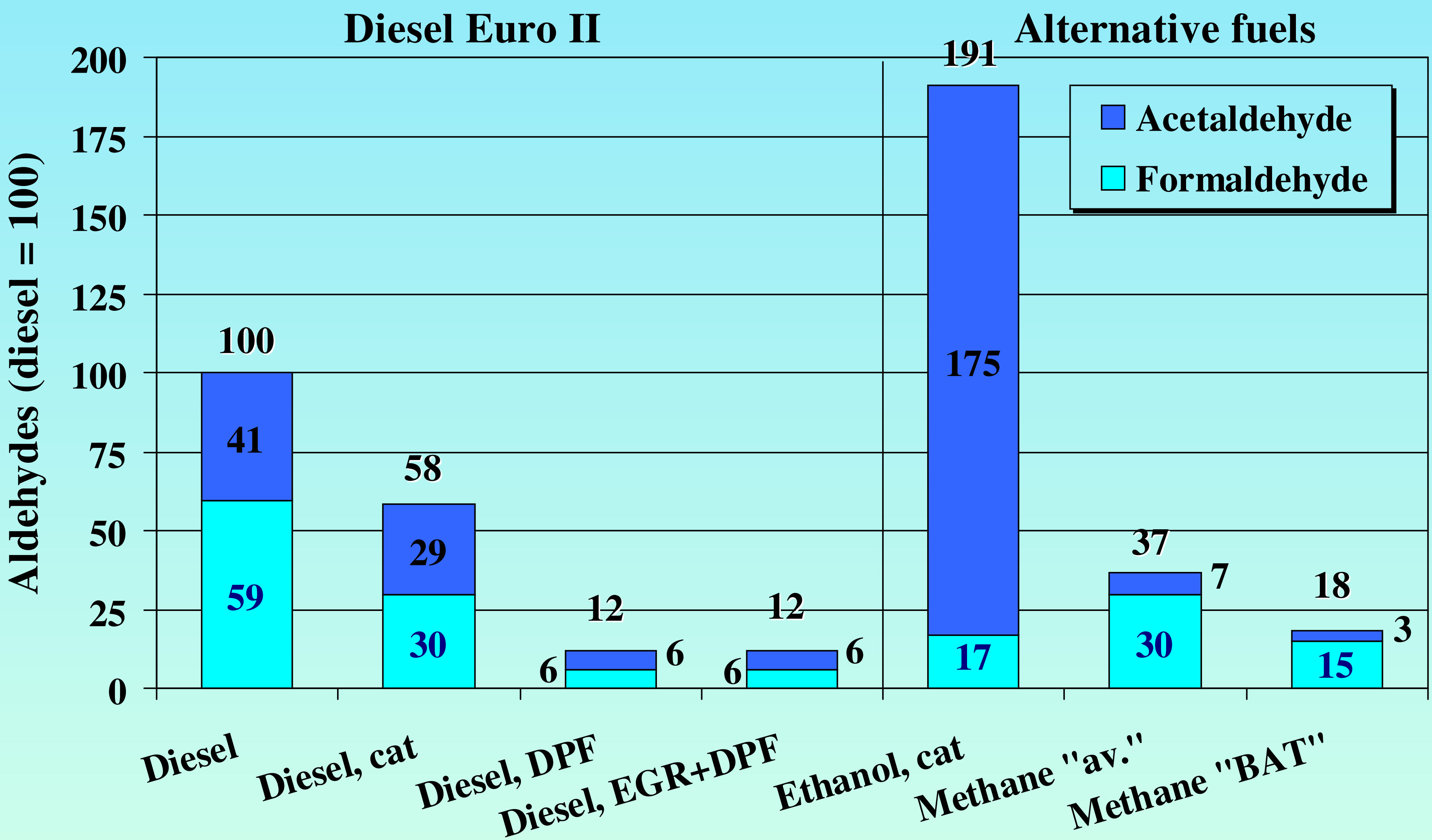
Aldehydes (diesel=100)



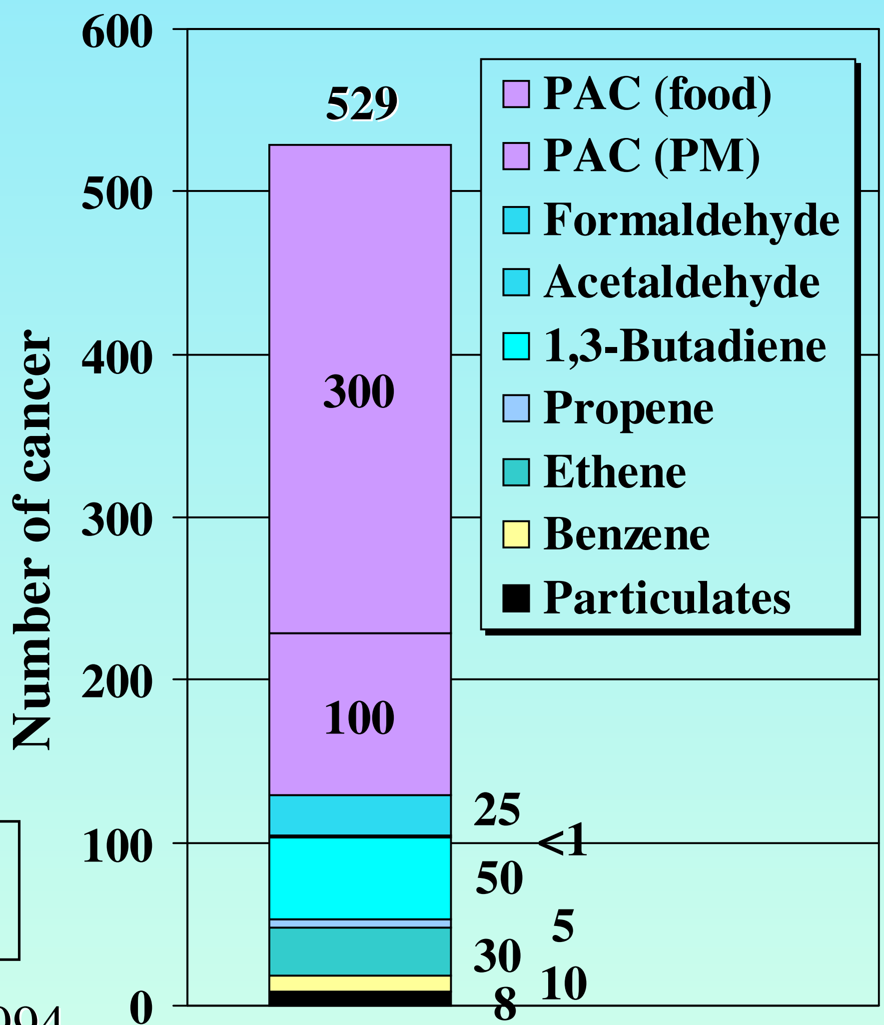
Number of cancer cases due to air pollution in Sweden

Comments:

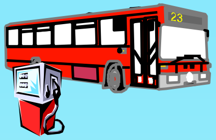
- PAC dominates (100+300)
- Uptake of PAC via food chain important (300)
- Butadiene (~50) important as well as ethene (30)
- Formaldehyde (~25)
- Benzene (10)
- Particulate matter (8)

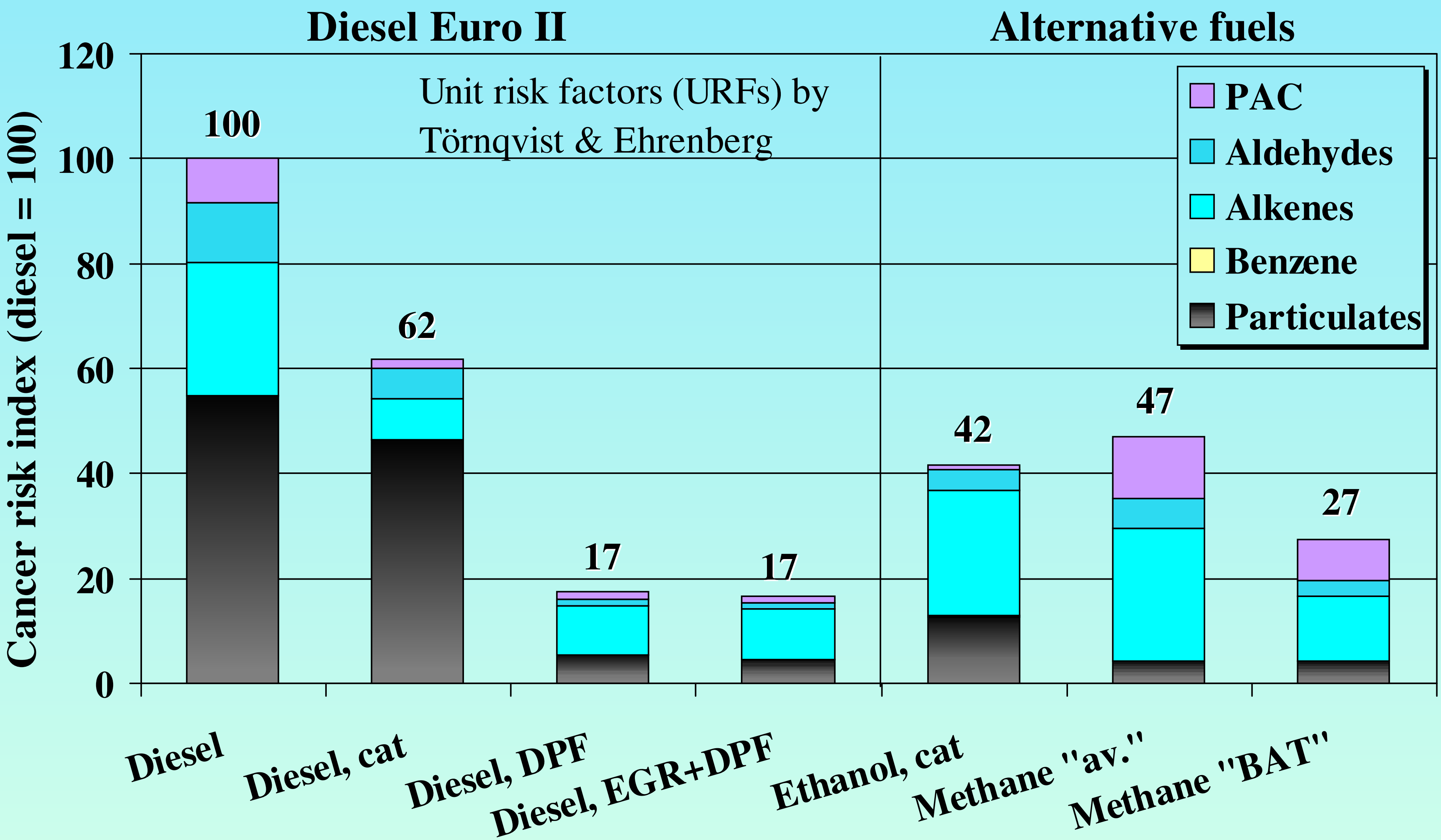
- Population in Sweden: about 9 million
- All cancer forms, not only lung cancer

Adapted from Törnqvist & Ehrenberg, 1994



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





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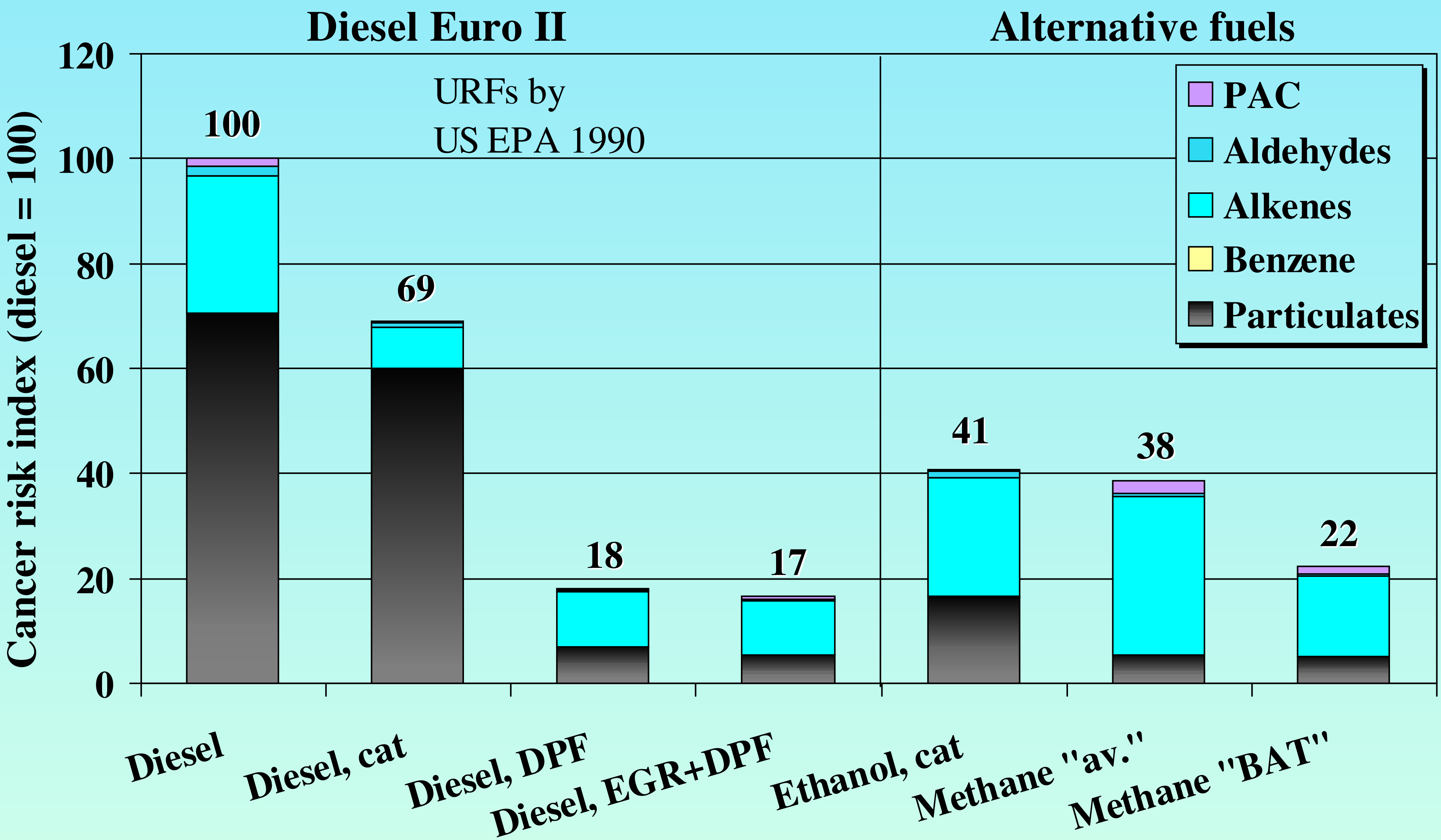
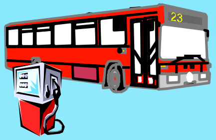
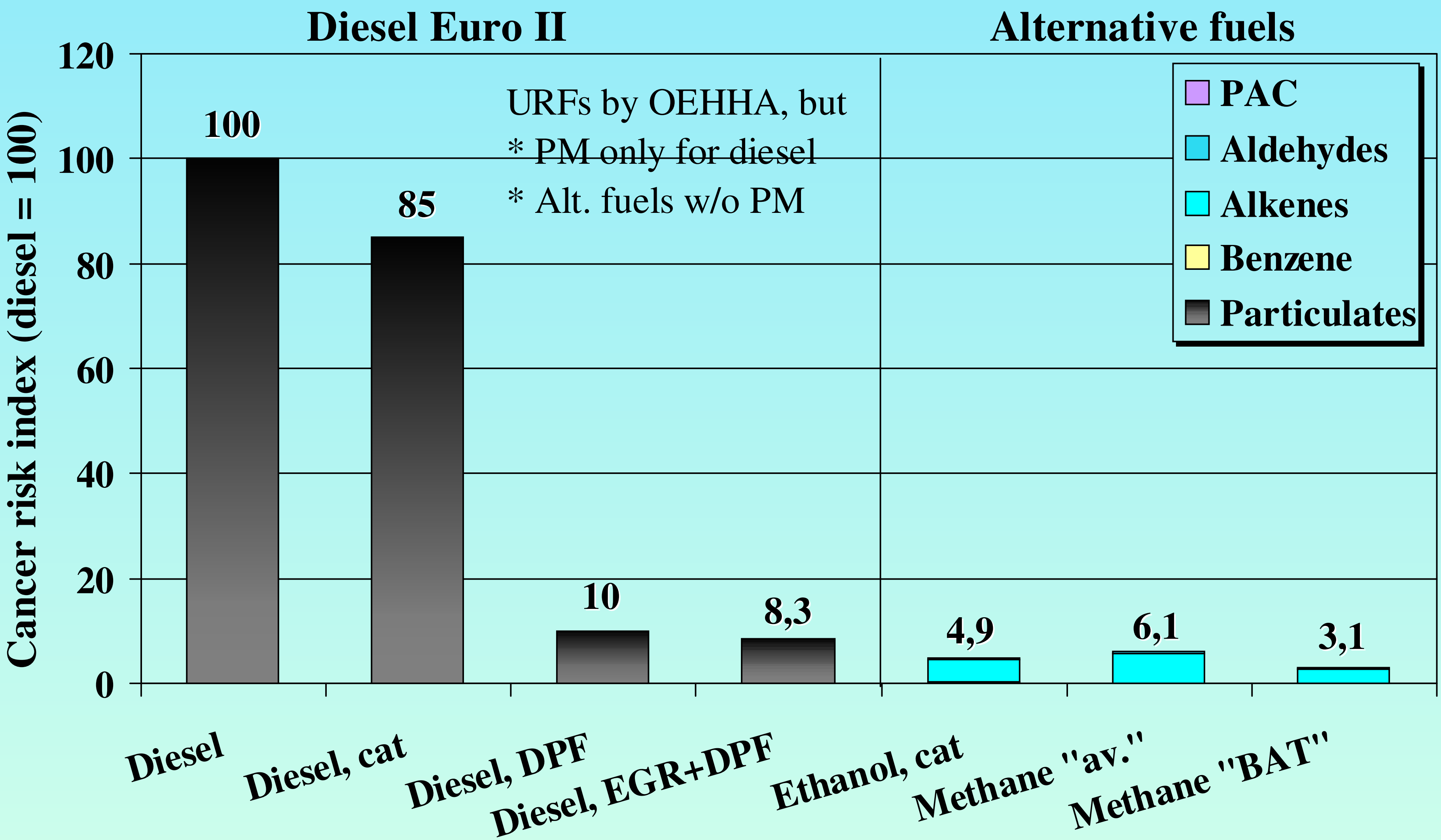
Cancer risk index (diesel=100) URFs by US EPA 1990

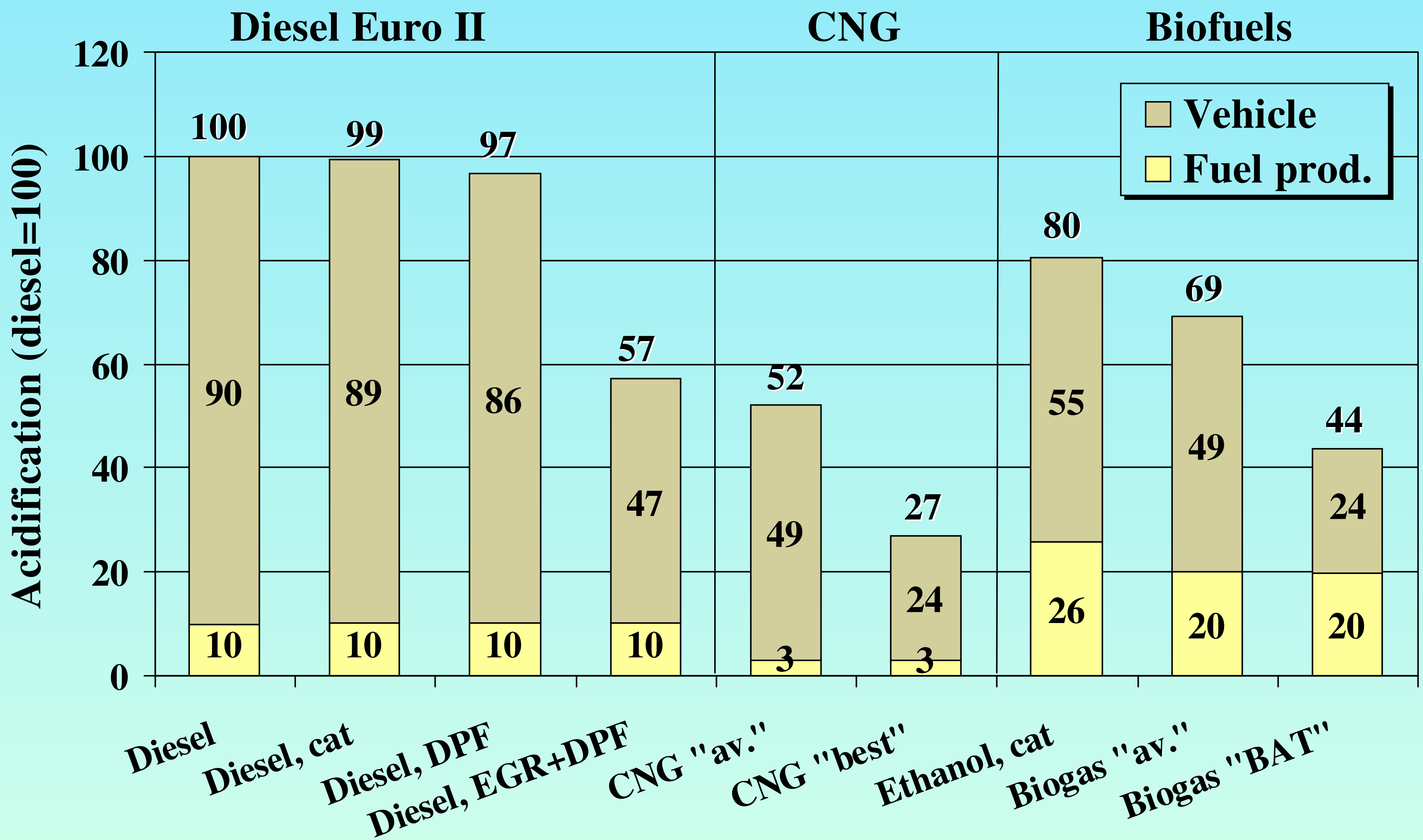




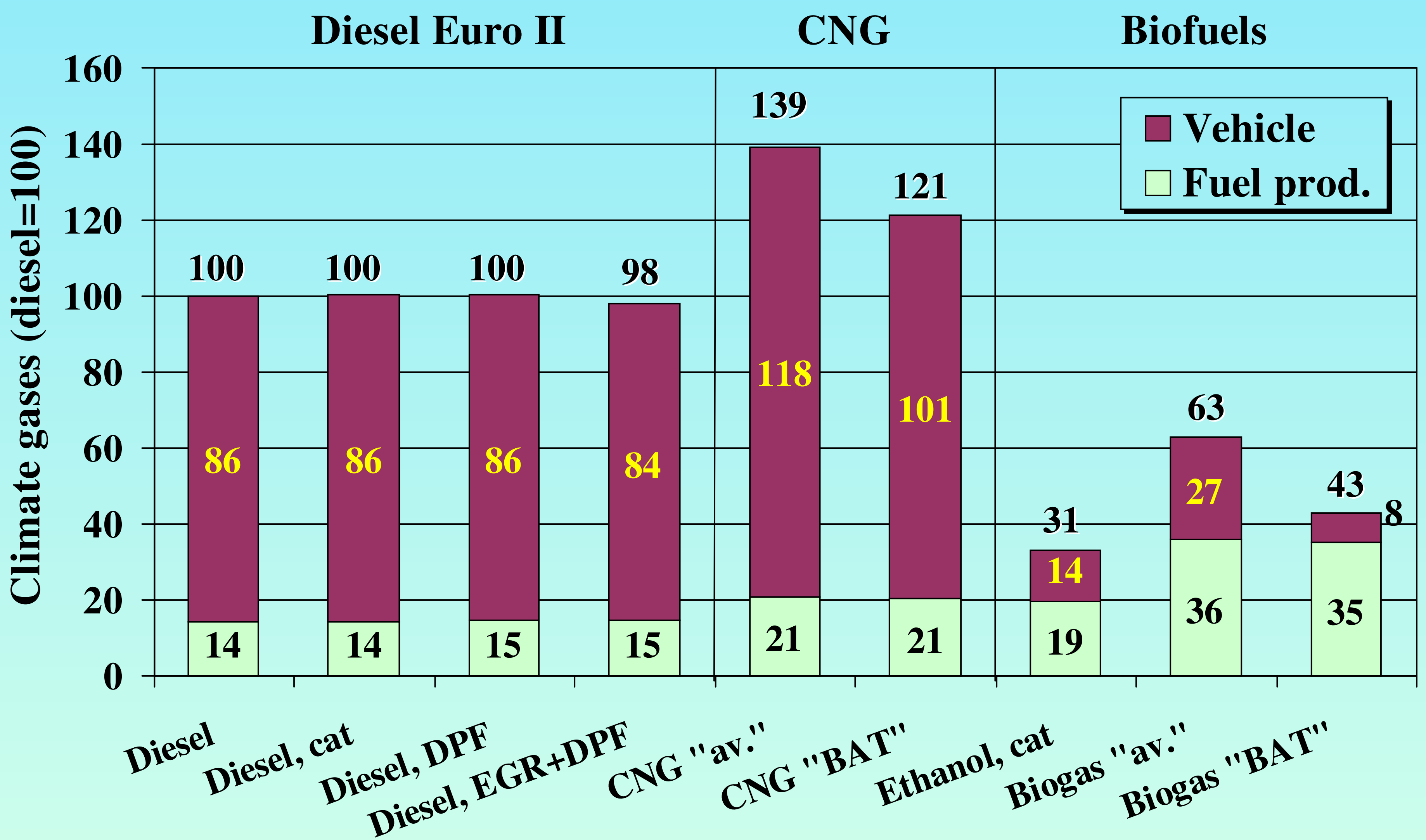
Cancer risk index (diesel=100) URFs by OEHHA, case #1



Acidification potential (diesel=100)



Climate gases (diesel=100)



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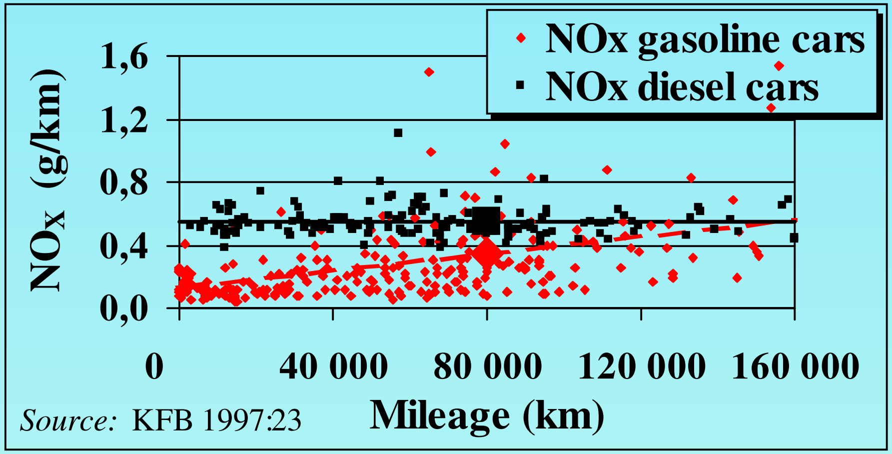
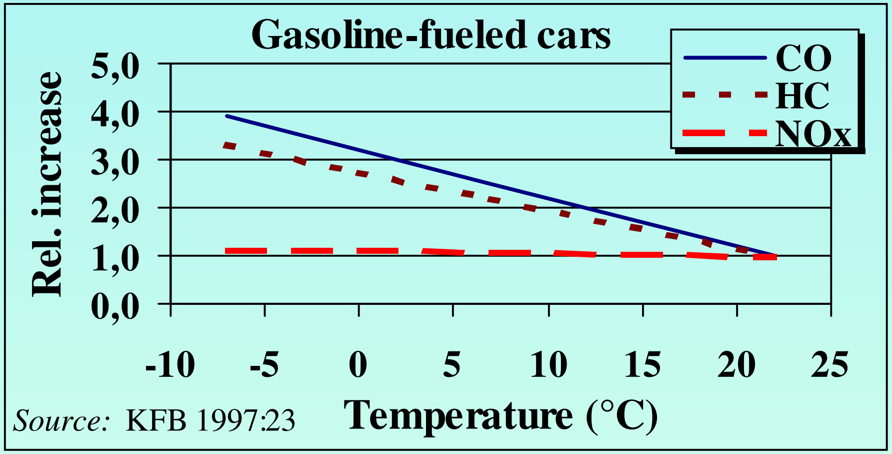
Factors to consider in bus vs. cars comparisons

- Number of occupants
- Corrections should be made for:
  - Emission deterioration (aging)
  - Driving pattern
  - Cold start

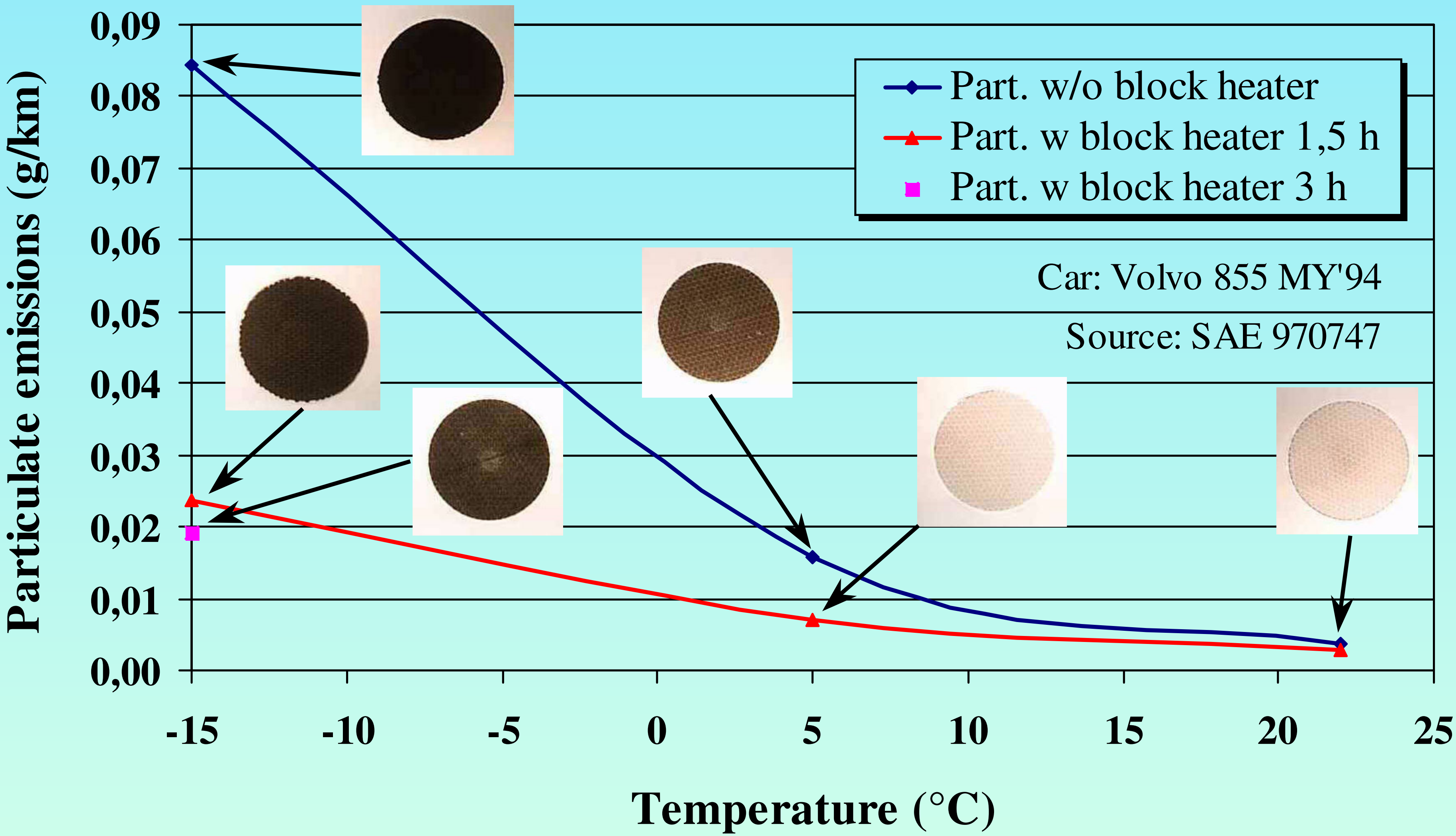




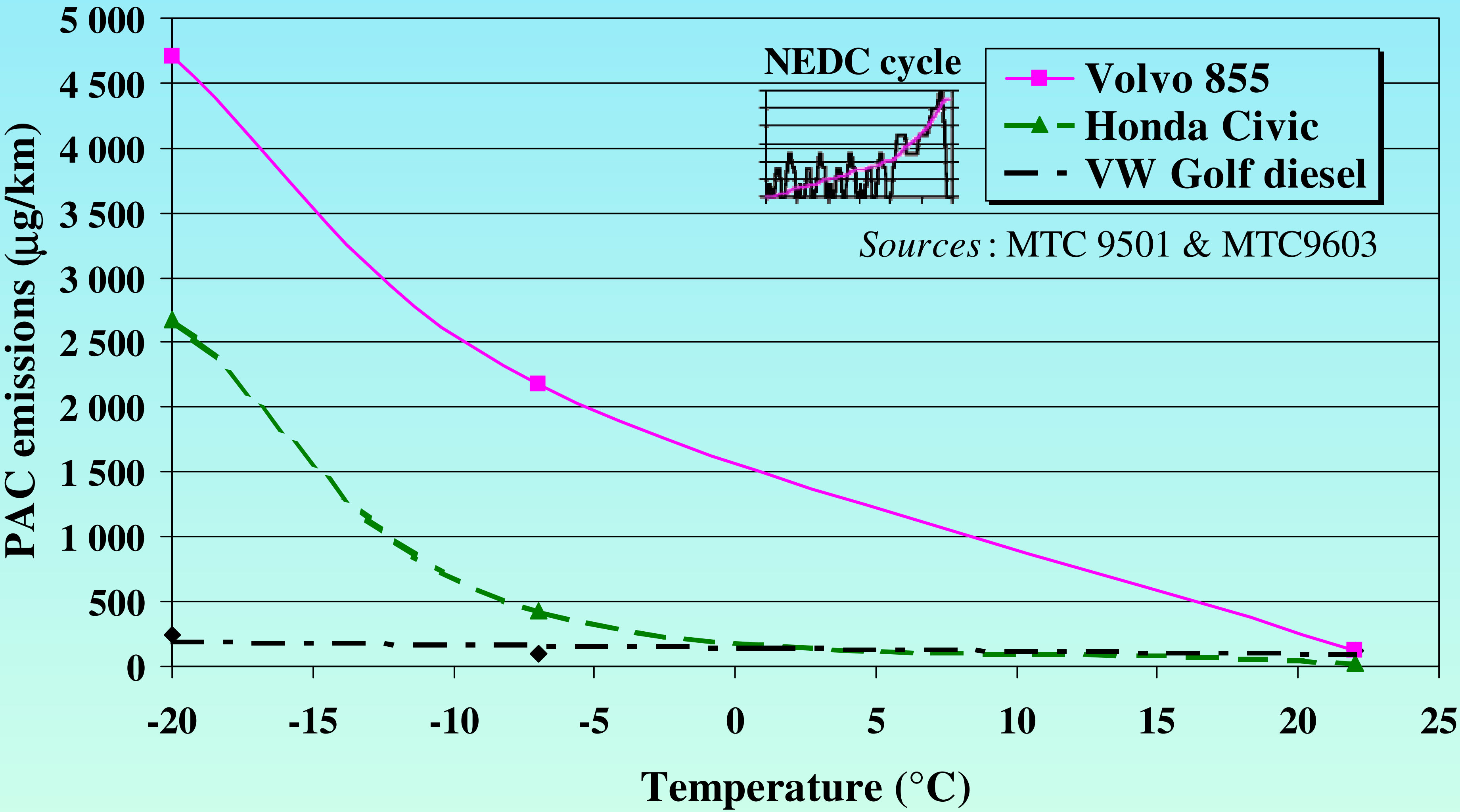
Cold start of buses (?)

- Buses are "never" started w/o cold start aids…
- Cars are "always" started w/o cold start aids...
- Consequently, buses have a considerable advantage over cars in this respect

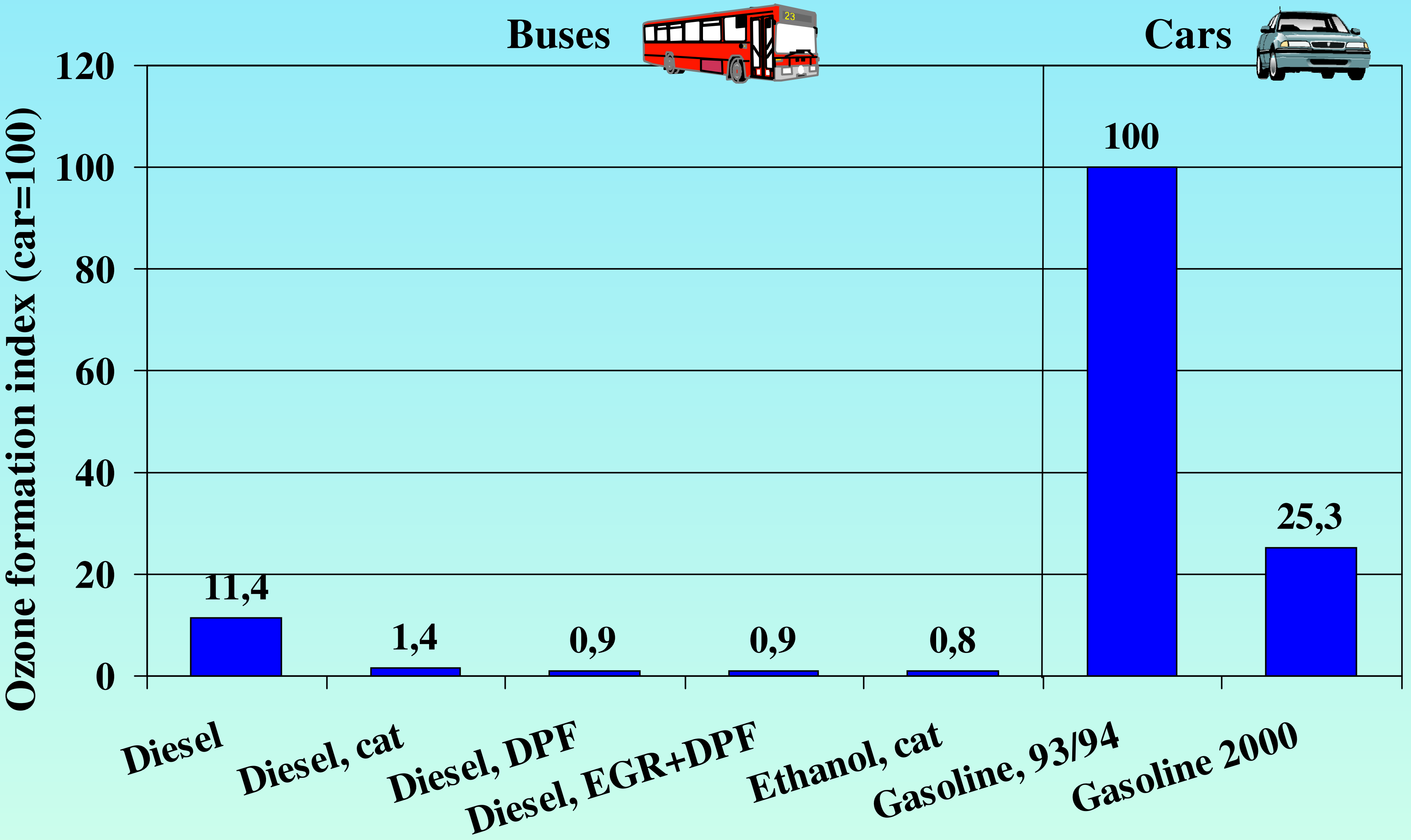
Particulate emissions in the first phase of the US FTP-75 cycle



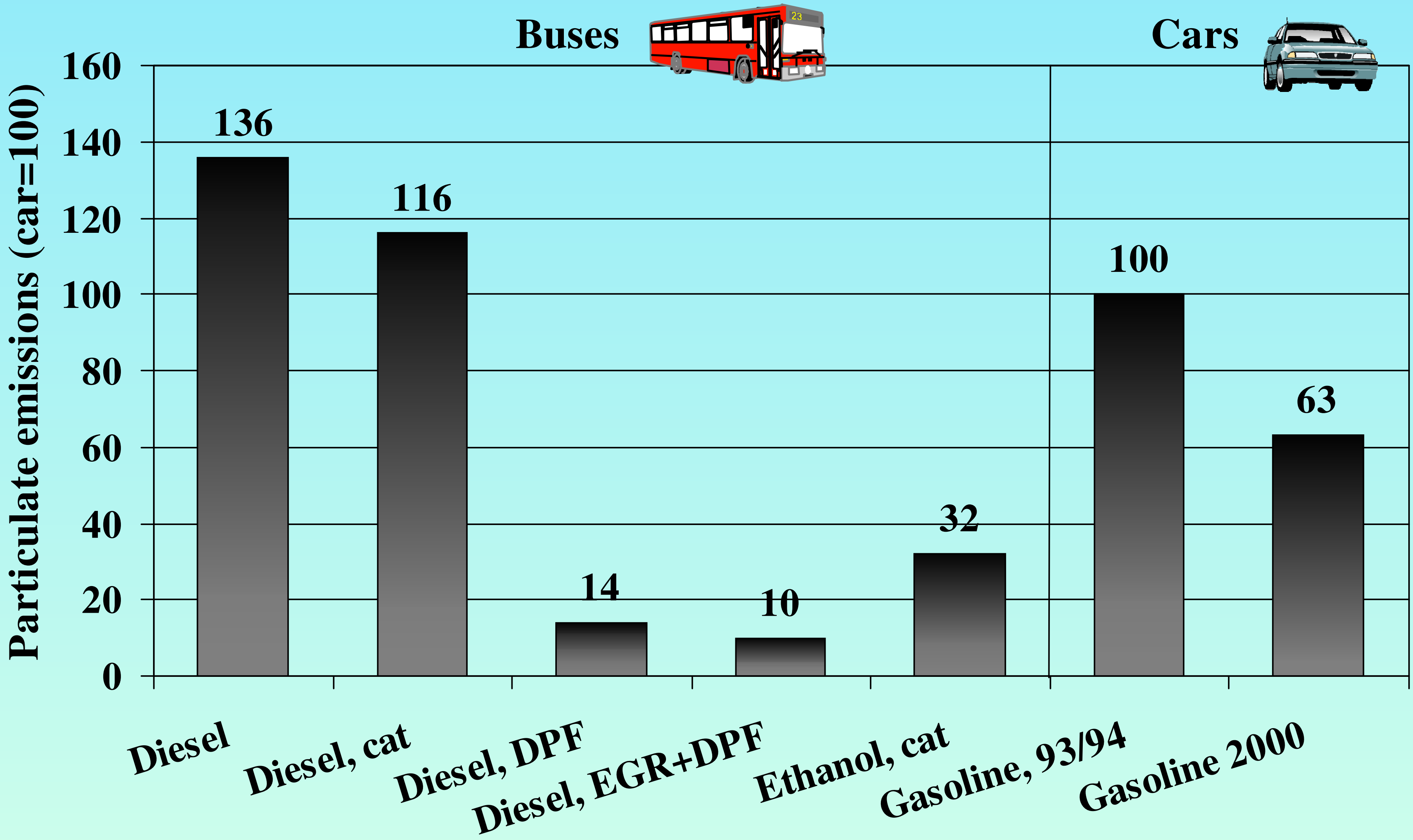
Polycyclic aromatic compounds (PAC) at various temperatures



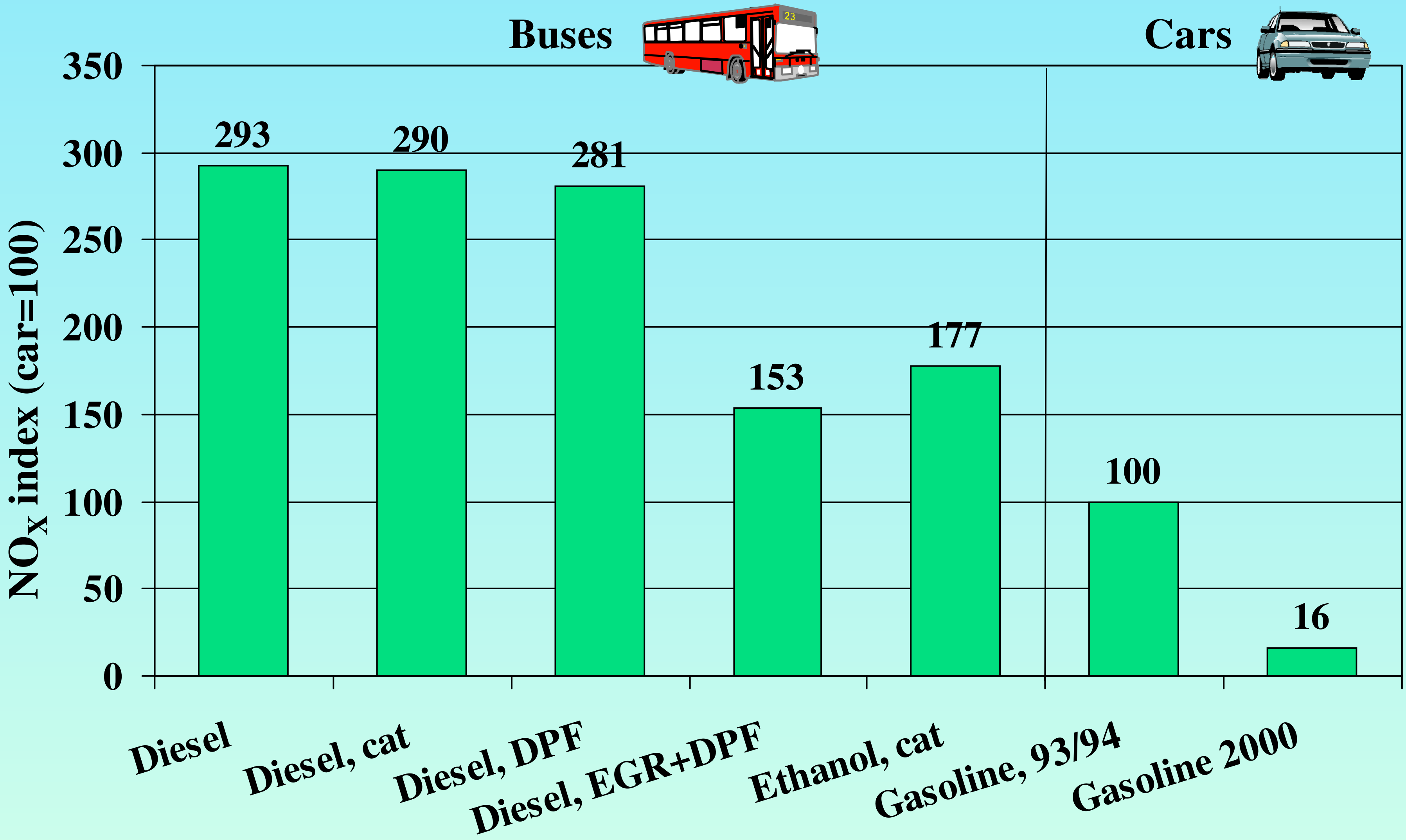
Ozone forming potential (car=100)



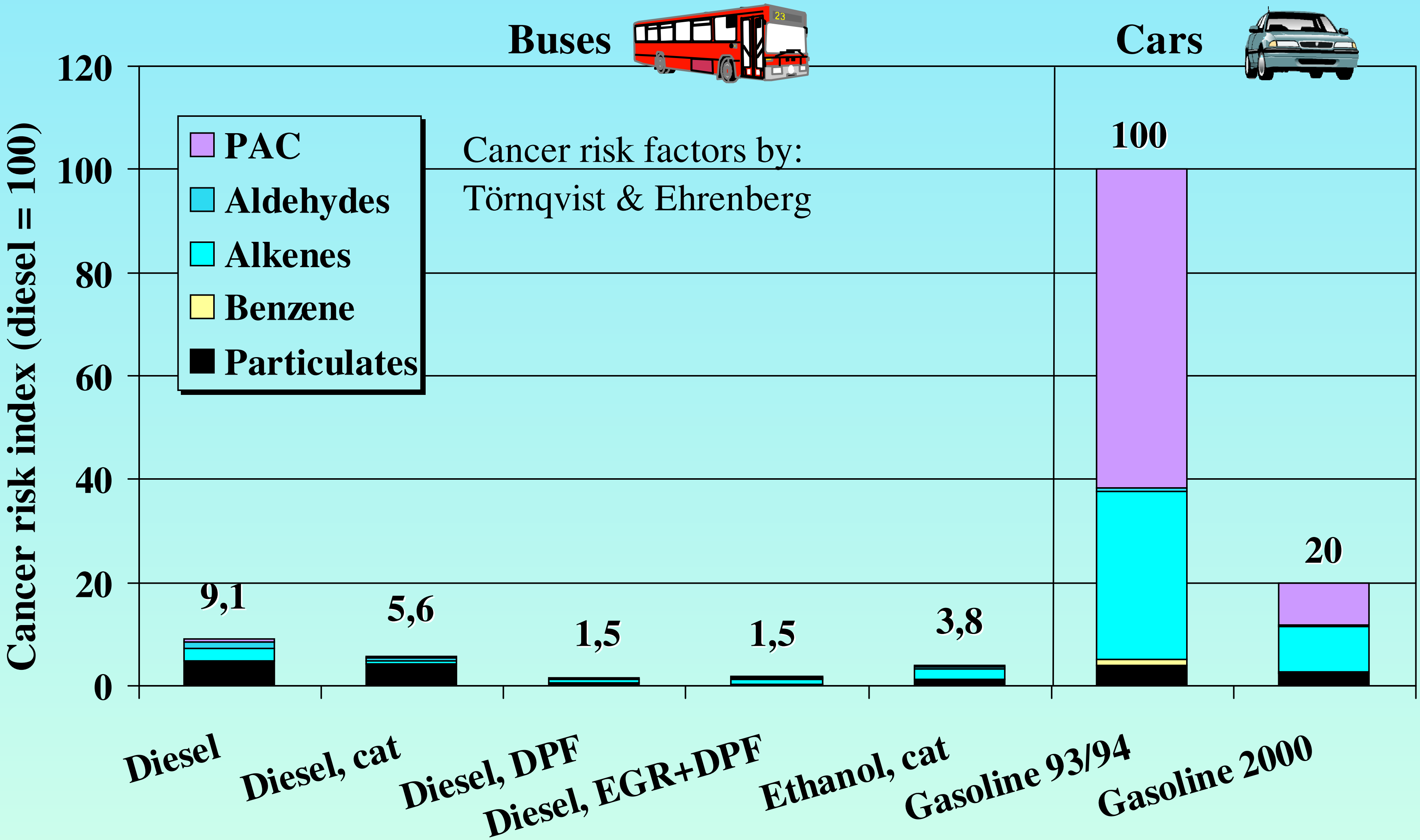
Particulate emissions (car=100)



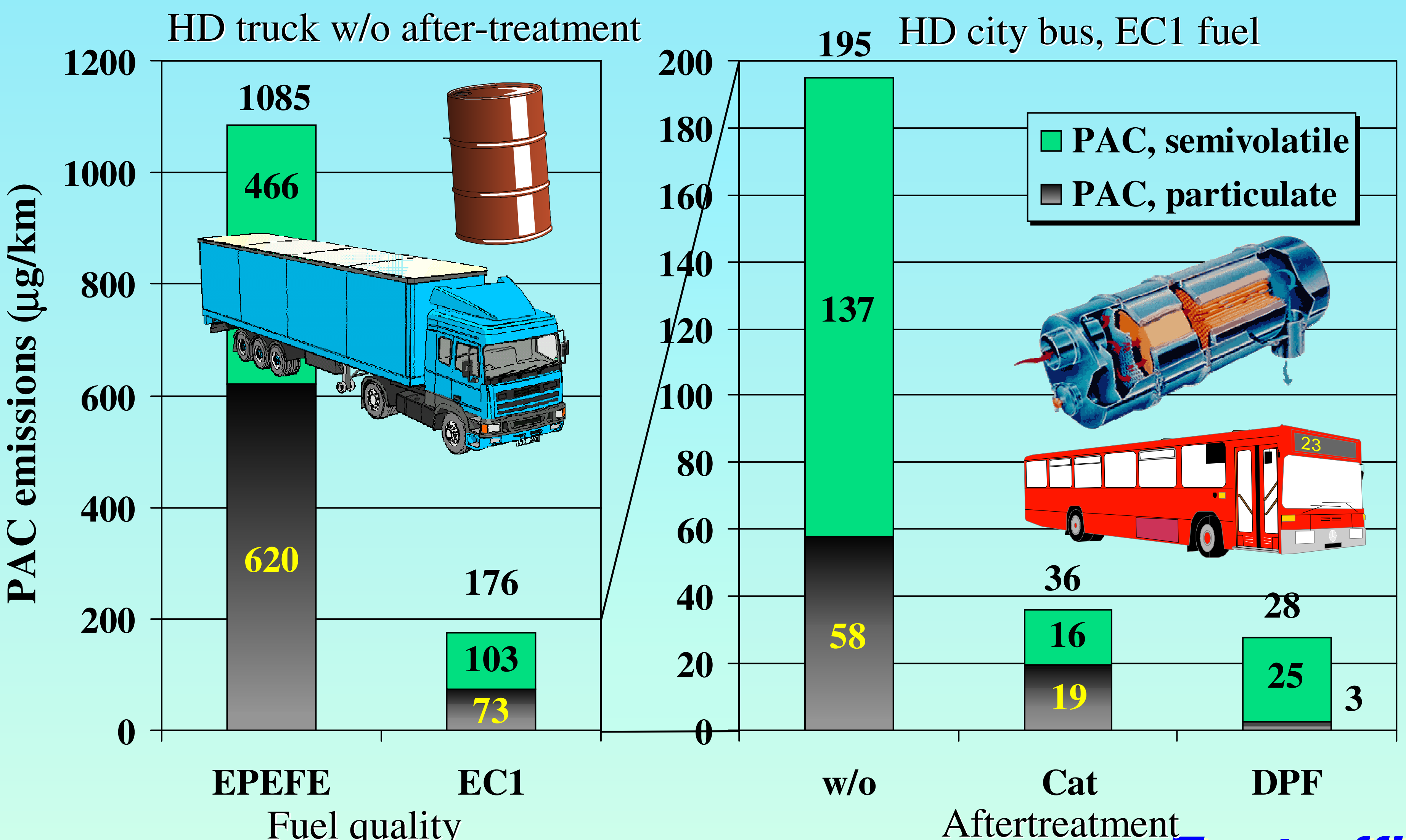
NO_X emissions (car=100)



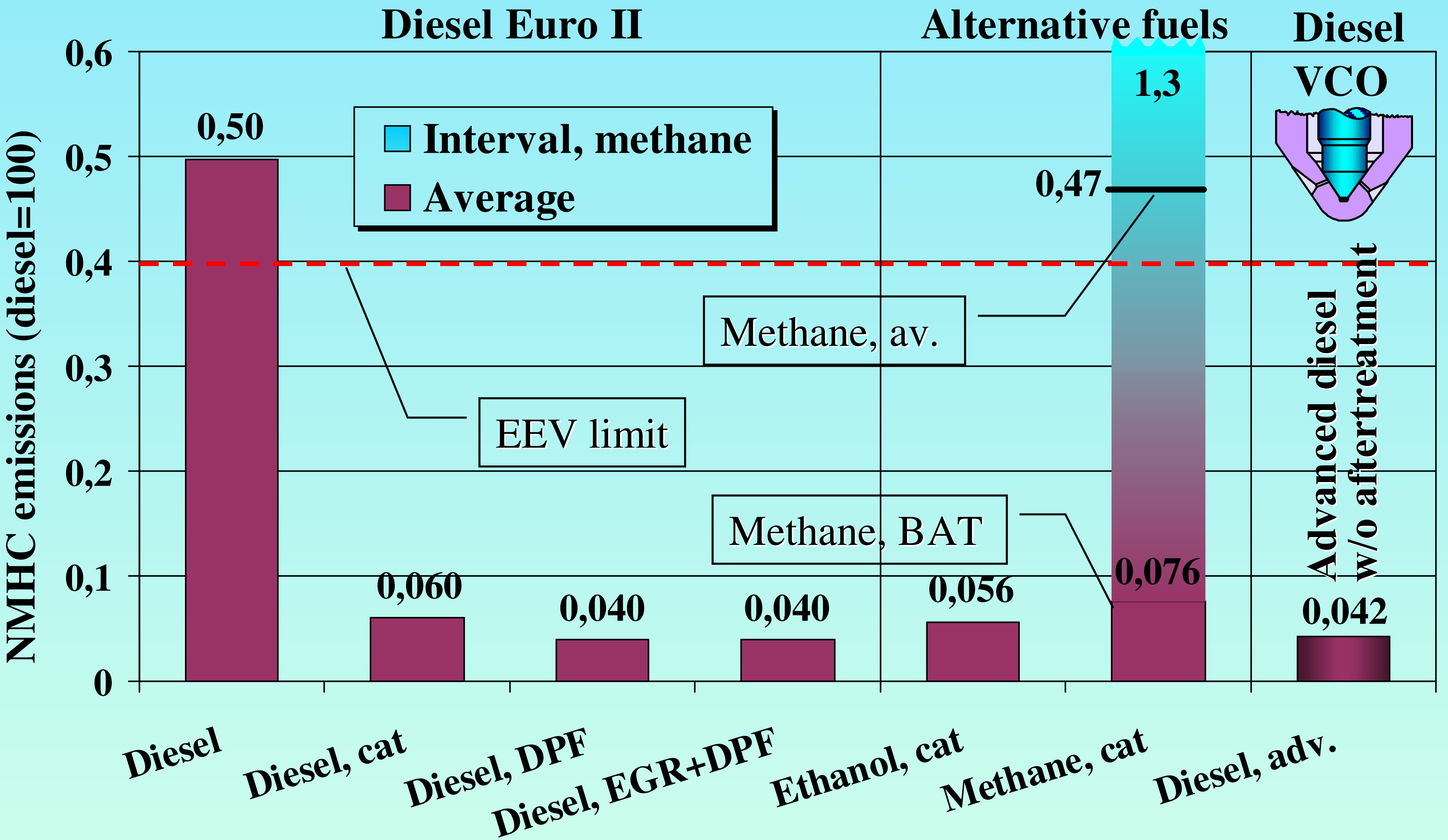
Cancer risk index (car=100)



Impact of fuel quality and aftertreatment on PAC emissions



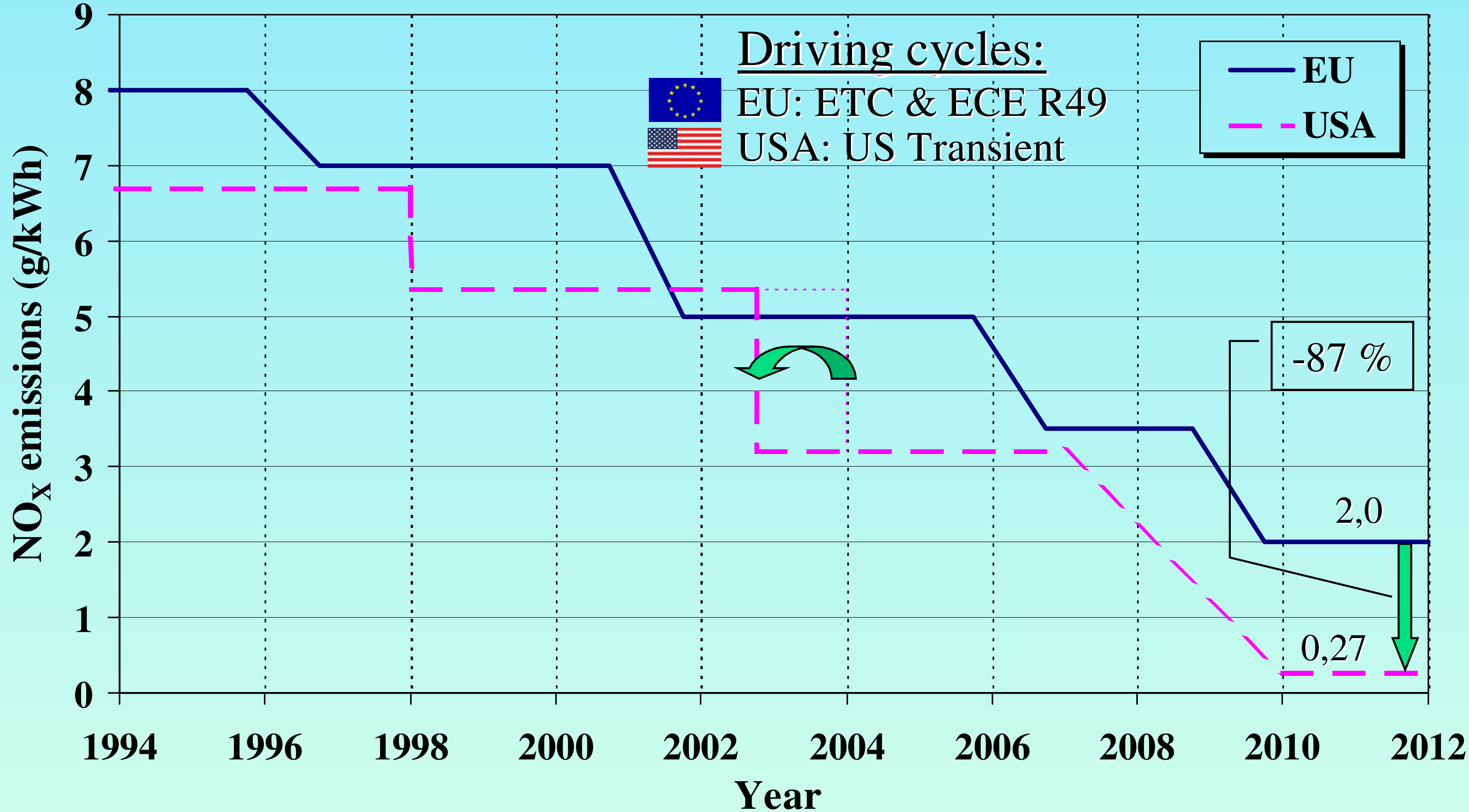
Estimated NMHC potential in the new ETC cycle (g/kWh)



Current achievements and future programs

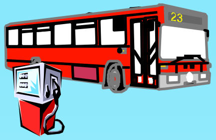
- Latest statistics for city buses (end of 1999)
  - About 7 000 city buses in total
  - About 700 (i.e. 10%) running on alternative fuels
  - About 3 500 diesel buses with catalyst or DPF
- Half a year ago: about 5 000 DPFs on all HDV
- Purchase requirements (optional) by the transit authorities organization (SLTF, www.sltf.se)
  - PM and NO_X fleet average limits, in 2006 equal to Euro IV (fleet average) for buses in city centers
  - Fuel and technology-neutral limits
  - Virtually all diesel buses will have DPF+EGR in 2006
- What else can we do?

NO_X regulations for HD engines in EU and USA



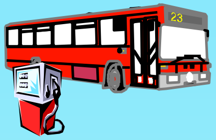
Summary and conclusions 1(2)

- EGR could reduce NO_X from diesel engines. CNG shows a great variation in NO_X (A/F control).
- PM is highest for diesel w/o DPF but is red. by DPF
- Cancer risk is highest for diesel w/o aftertreatment. Diesel with DPF and methane have the lowest risk. Unit risk factors is of considerable importance.
- GHG emissions are lowest for the biofuels, but are highly dependent on fuel production and feedstock
- PAC could be significantly reduced by improving the diesel fuel quality



Summary and conclusions 2(2)

- Buses could have lower emissions than cars for most emission components, except NO_X and acidification
- Cold start has a significant impact on the emissions from passenger cars, especially in cold climate
- Continuous improvement of fuel quality, engine & aftertreatment will reduce the advantage of the alternative fuels in the future
- The biofuel´s advantage of lower GHG emissions will be more pronounced in the future



This concluses my presentation

- Thank you for your attention!
- Questions?

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