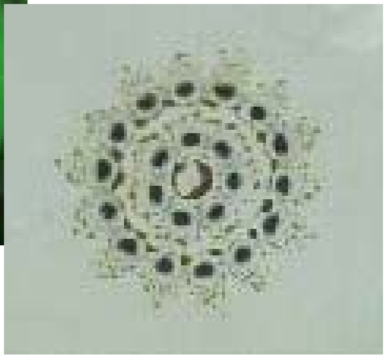


LOW TEMPERATURE PARTICULATES FROM ALTERNATIVE FUELS

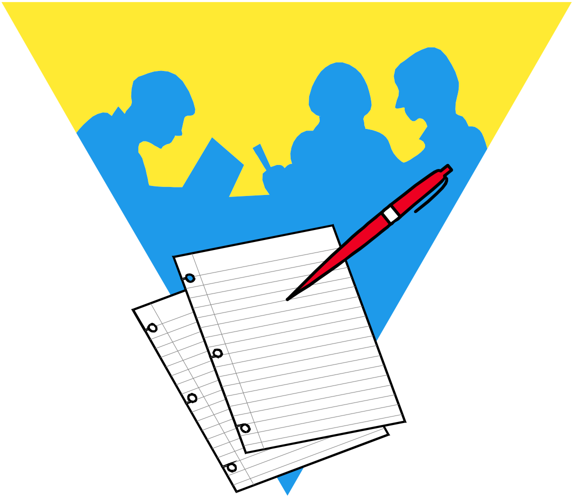
IEA/AMF ANNEX XXII

Päivi Aakko & Nils-Olof Nylund

Windsor Workshop June 14-17. 2004

OUTLINE

- IEA framework
- Objective
- Test fuels
- Test vehicles
- Methodology
- Results
- Summary



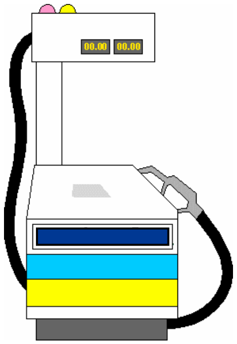
IEA FRAMEWORK

- This project was carried out within the International Energy Agency (IEA) Implementing Agreement on Advanced Motor Fuels (AMF)
- Within AMF, this project had the designation “Annex XXII”
- Participants in the task were:
  - Canada (NRC)
  - Finland (represented by the Operating Agent VTT)
  - Italy (AgipPetroli)
  - Japan (LEVO and NEDO)
  - Sweden (STEM)
  - USA (DOE)
- Financial and technical support was also received from:
  - Ford Motor Company (Ford University Research Program)
  - Honda R&D Europe

OBJECTIVE

- The objective of the task was to produce new emission data on particle emissions in “off-cycle” conditions with a variety of fuels
  - a comparison of different fuel and engine technologies
  - tests with commercially available fuels and vehicles (availability of E85 and biodiesel blends limited)
  - regulated and unregulated emissions
  - special emphasis on particle emissions
    - total particle mass and particle size distribution
  - influence of test temperature on emissions, tests at:
    - “normal” temperature, +23 ^{o}C
    - intermediate temperature, +5 ^{o}C
    - low temperature, -7 ^{o}C

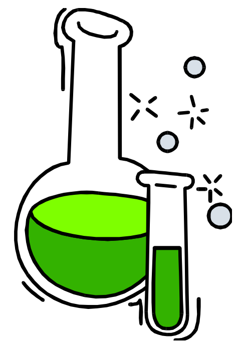
TEST FUELS..

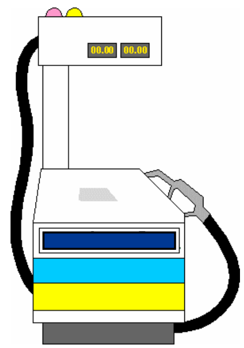


- Gasoline
  - commercial gasoline corresponding to Directive 98/70/EC (EU2000)
    - sulfur content 40 ppm (permissible 150 ppm)
- Diesel
  - commercial diesel corresponding to Directive 98/70/EC (EU2000)
    - sulfur content 306 ppm (permissible 350 ppm)
  - Swedish MK1 reformulated diesel
    - sulfur content < 10 ppm
  - blends of diesel and biodiesel
    - 30 % of RME (rapeseed methyl ester) in EU2000 diesel and MK1

..TEST FUELS

- E85
  - 85 % absolute (water-free) ethanol and 15 % commercial gasoline (EU2000)
  - sulfur content 6 ppm
- CNG (natural gas)
  - methane content 98 %
  - sulfur content less than 5 ppm
- LPG
  - 95 % propane
  - sulfur content not analysed





TEST VEHICLES

	Diesel TDI	Diesel IDI	Gasoline MPFI	Gasoline DI	FFV	CNG	LPG
MY	1996	1999	2001	2002	2002	1998	2001
Fuel system	direct injection	indirect injection	indirect multip.	direct injection	indirect multip.	indirect multip. monofuel	indirect multip. bi-fuel
Engine (l)	1.9	2.0	1.6	2.0	1.6	1.6	2.5
Gearbox	auto	man. 5	man. 5	man. 5	man. 5	auto	auto
Emission control	EGR, catalyst	EGR	catalyst	catalyst	catalyst	catalyst	catalyst
Mileage (km)	33,800	114,000	6,400	6,300	9,500	10,100	20,400
Origin	Europe	Japan	Europe	Europe	Europe/ USA	Japan	Europe

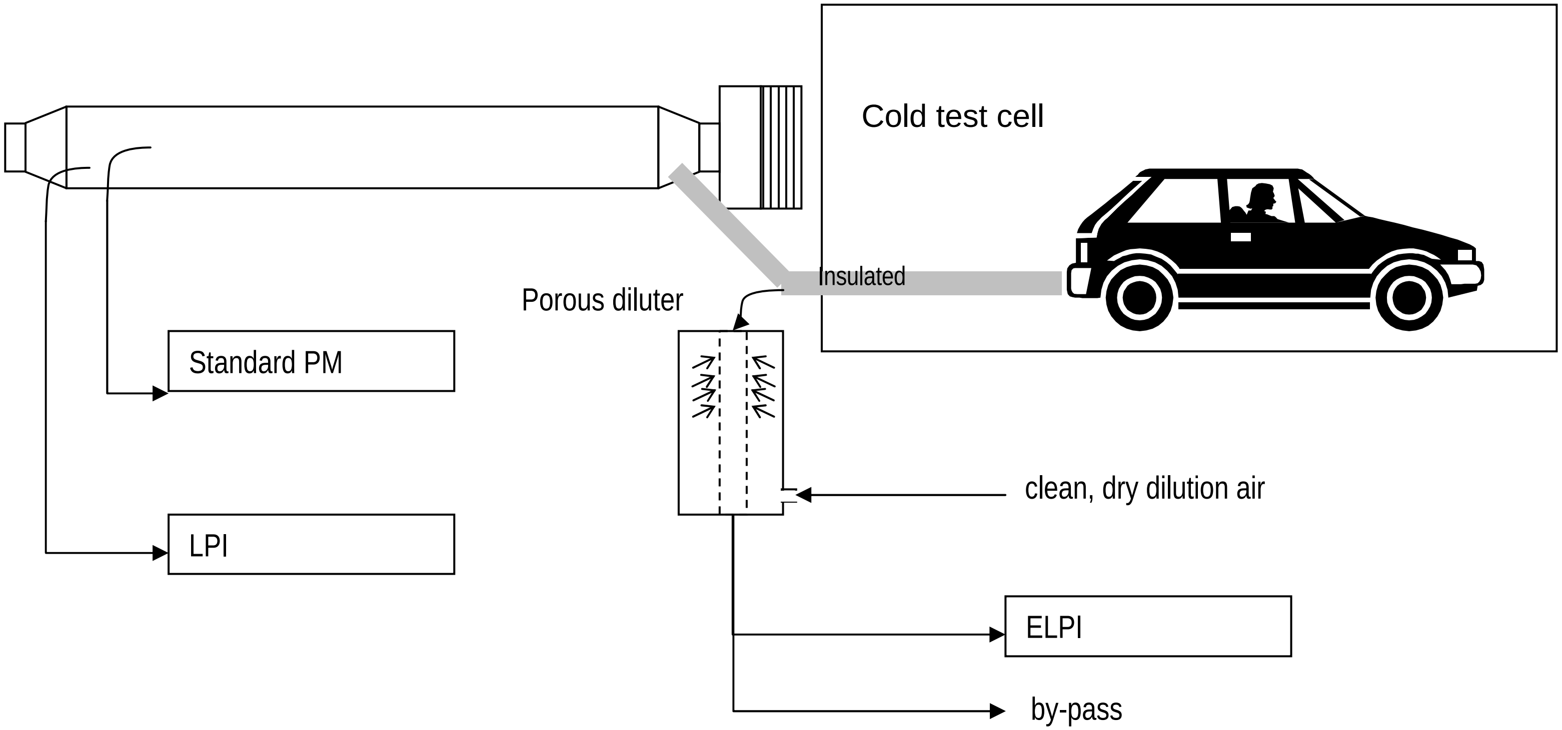
METHODOLOGY

- Emission tests on a light-duty chassis dynamometer installed in a climatic test chamber
- All equipment used for measurements of regulated emissions conforming to the specifications of Directive 70/220/EEC
- Major part of the testing carried out using the European test cycle
- Also selected tests using the Japanese 10-15 mode test

UNREGULATED EMISSIONS

- Gaseous components
  - aldehydes by DNPH cartridges and HPLC chromatography
  - speciated C_1 - C_8 hydrocarbons by gas chromatography
- Particles
  - total particle mass and particle mass size distribution from diluted exhaust
    - mass size distribution by LPI (low-pressure impactor)
  - particle number size distribution from undiluted exhaust
    - porous tube type dilutor
    - targeted dilution ratio 40:1
    - flow control by bypass adjustment
    - particle number size distribution by ELPI (electric low-pressure impactor, on-line measurement)

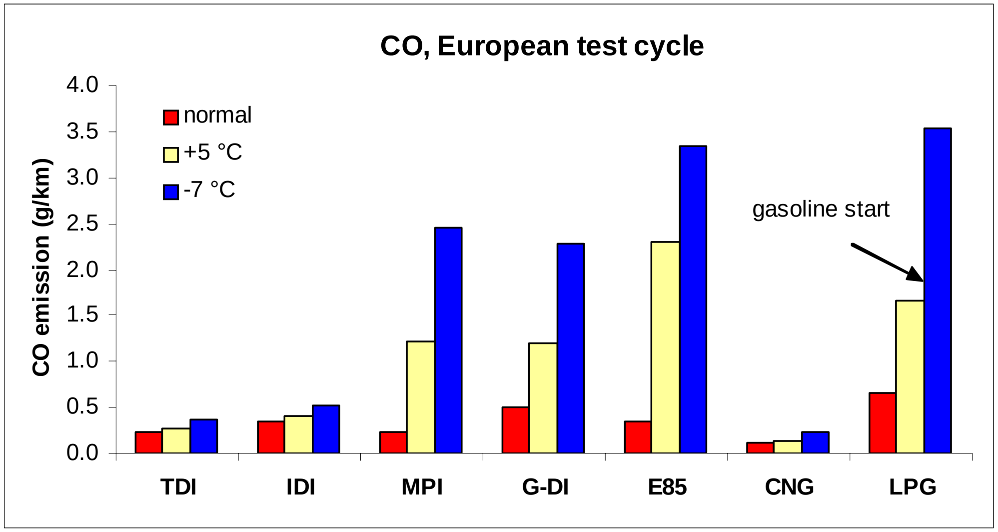
PARTICLE SAMPLING SYSTEM

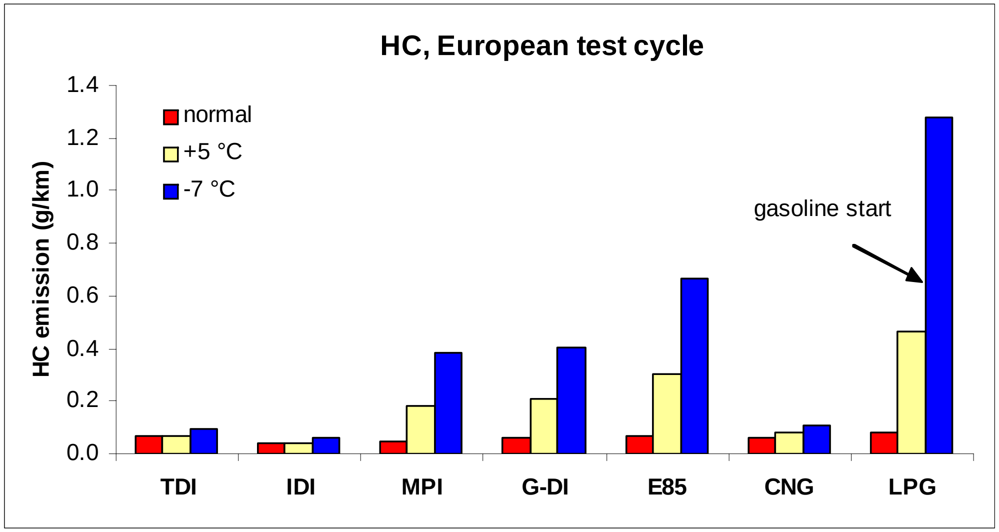


PRESENTATION OF RESULTS

- Regulated emissions (CO, THC, NO_x, PM)
  - ordinary diesel fuel, PM also for spark-ignition engines
- Aldehyde emissions
- 1,3-butadiene and BTEX
- Particle number size distribution (particle numbers in different size classes)
- Total particle numbers
- Particle number flow (instantaneous particle flux)

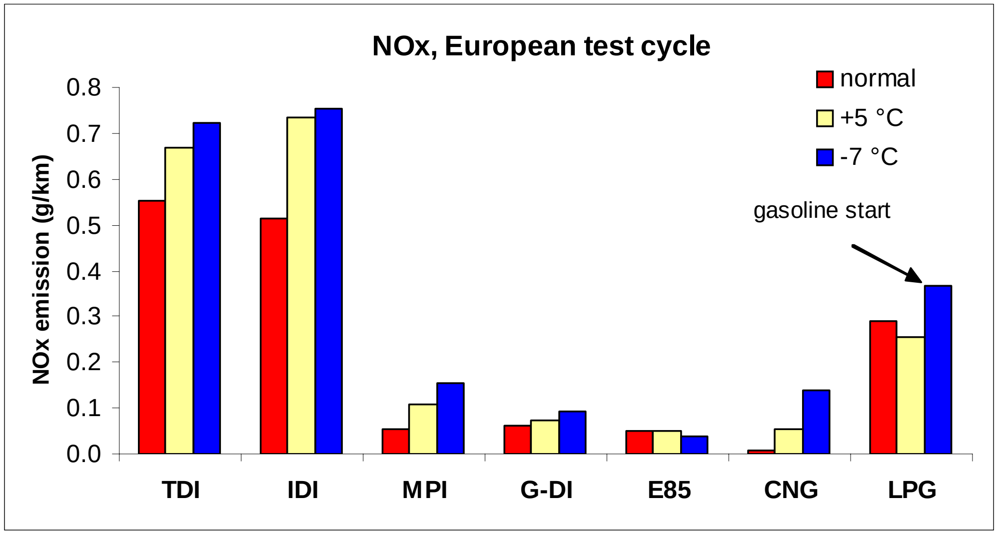
RESULTS - REGULATED EMISSIONS

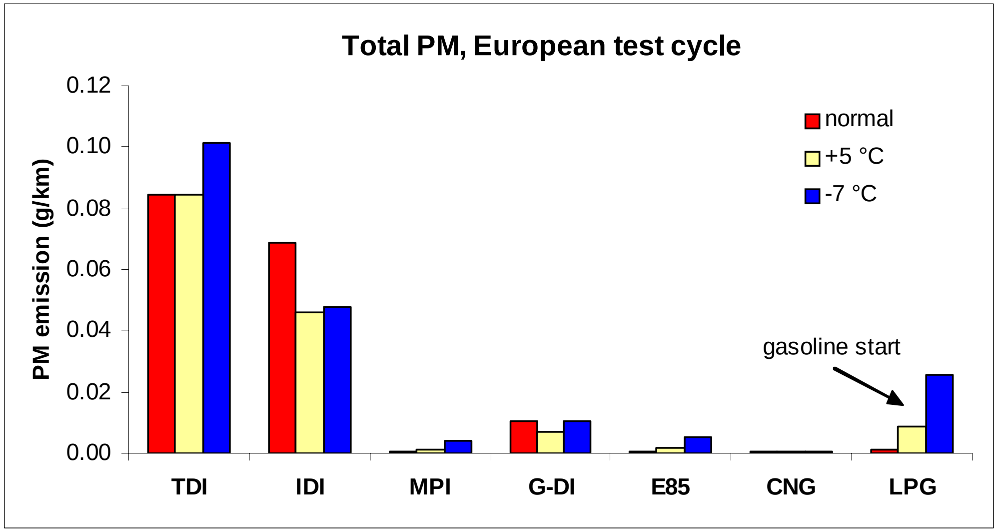




- At normal temperature, CO and HC ~ the same level with all cars
- The effect of falling temperature
  - diesel cars and the CNG insensitive regarding CO and THC
  - gasoline, E85 and LPG: CO and THC increased significantly
  - the bi-fuel LPG car uses gasoline for start-up, and this spoils the low-temperature performance: dramatic increase in CO and THC

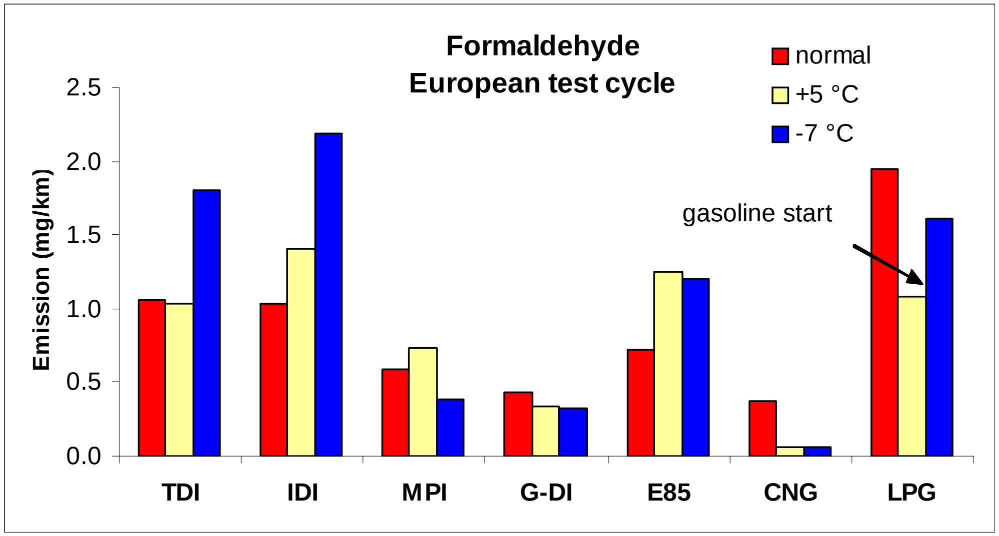
RESULTS - REGULATED EMISSIONS

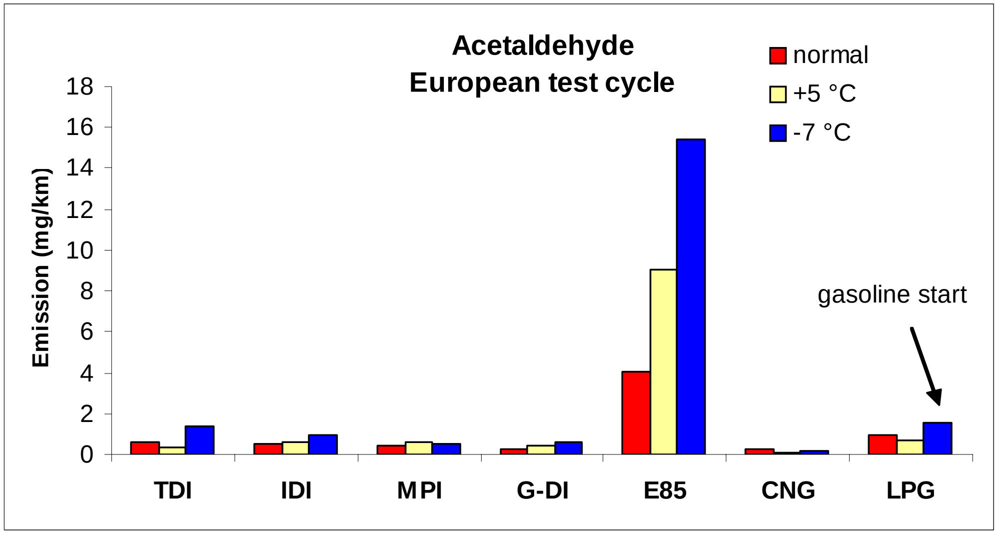




- Higher NO_x and PM for diesel than for the other cars
- The effect of falling temperature
  - the CNG car: highest relative increase in NO_x, but absolute level low
  - no increase in NOx with FFV (E85 car)
  - the bi-fuel LPG (gasoline start-up): dramatic increase in PM

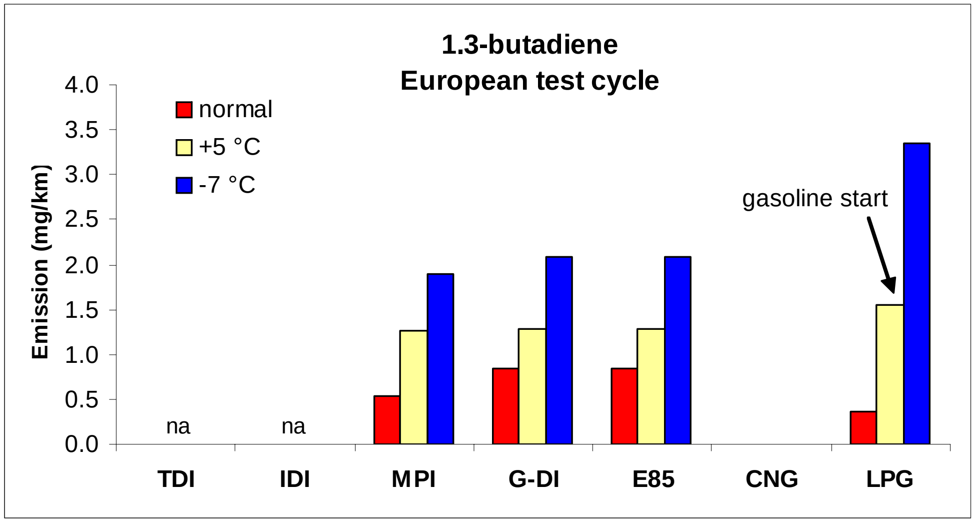
RESULTS - ALDEHYDE EMISSIONS

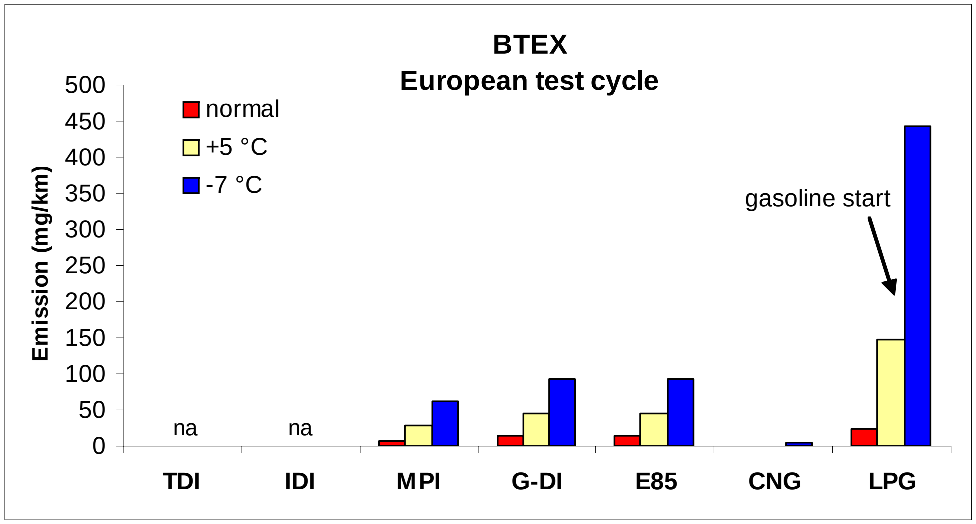




- Low formaldehyde emissions with all cars (< 2.5 mg/km)
- Order from highest to lowest diesel->LPG->E85->gasoline->CNG
- CNG: extremely low formaldehyde, especially at low temperatures
- Acetaldehyde high with E85, a clear effect of temperature can be seen

RESULTS - 1,3 BUTADIENE AND BTEX

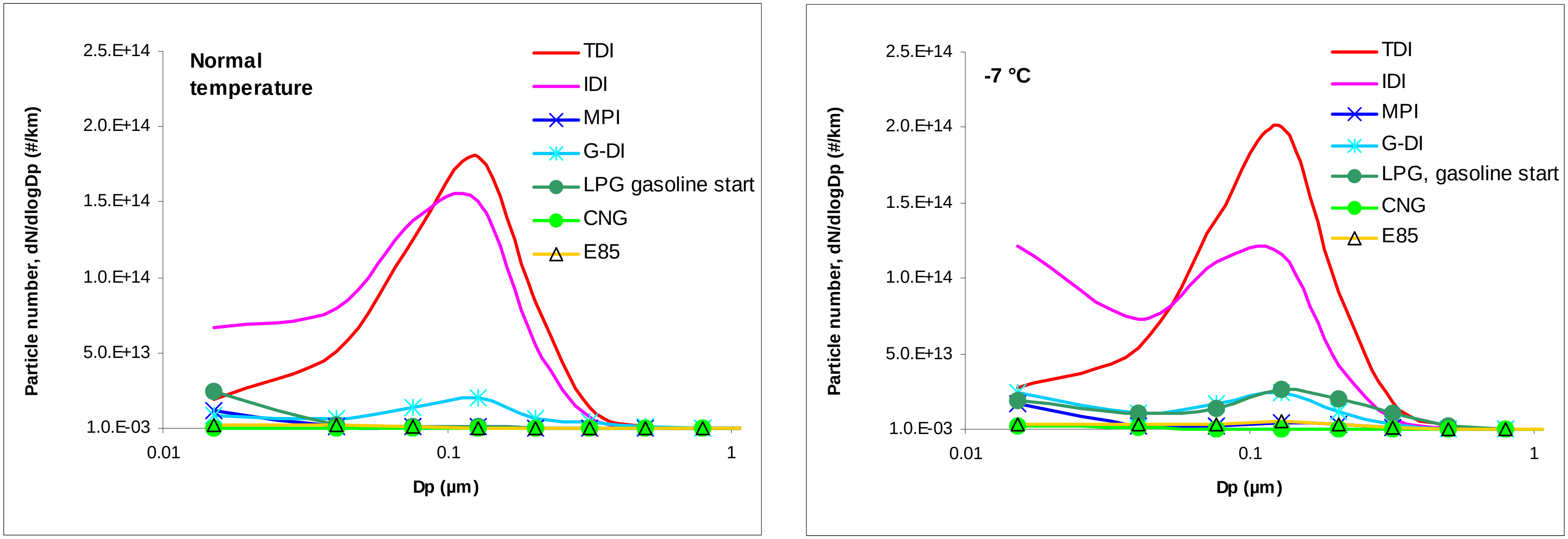




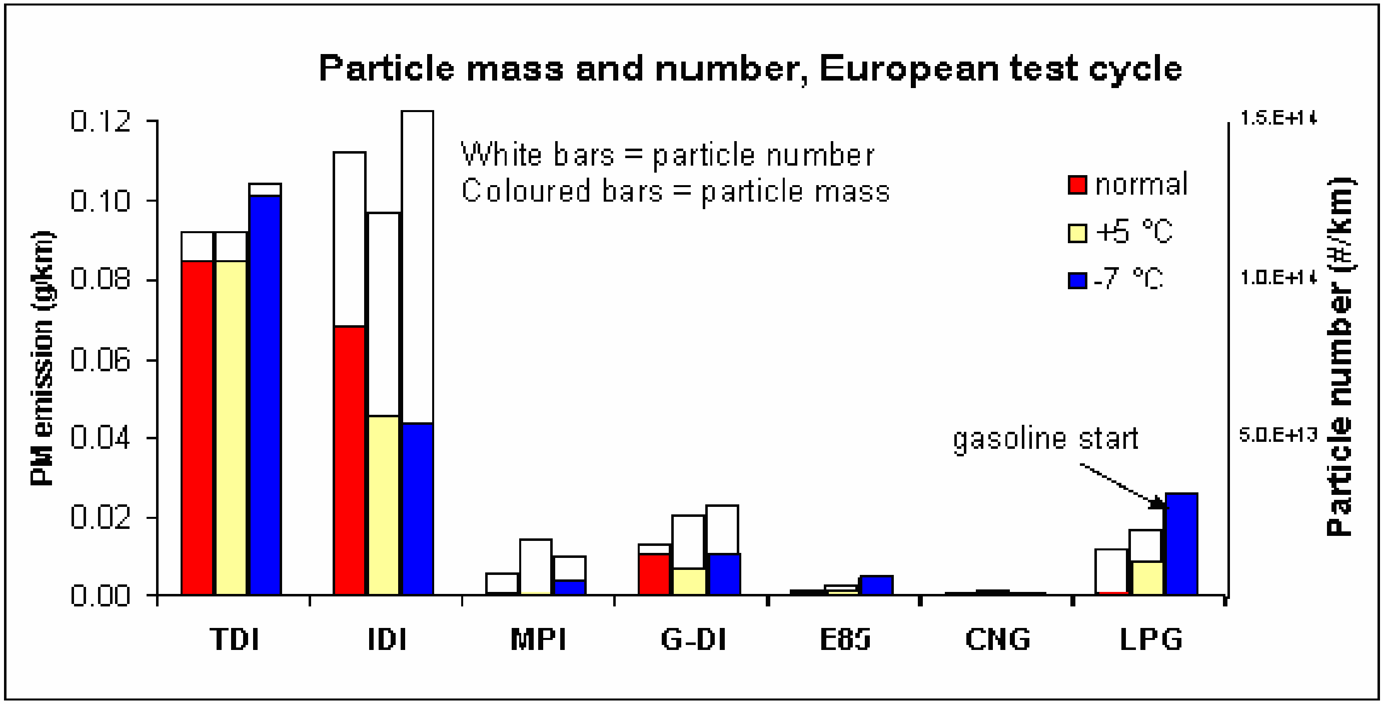
n.a= not analysed

- CNG: methane 50-90 mg/km, only traces of 1,3-butadiene and BTEX
- Gasoline and E85: equivalent 1,3-butadiene and BTEX levels
- LPG showed high 1,3-butadiene and BTEX emissions at low temperatures due to over-fuelling with gasoline in the start-up phase

PARTICLE NUMBER SIZE DISTRIBUTION

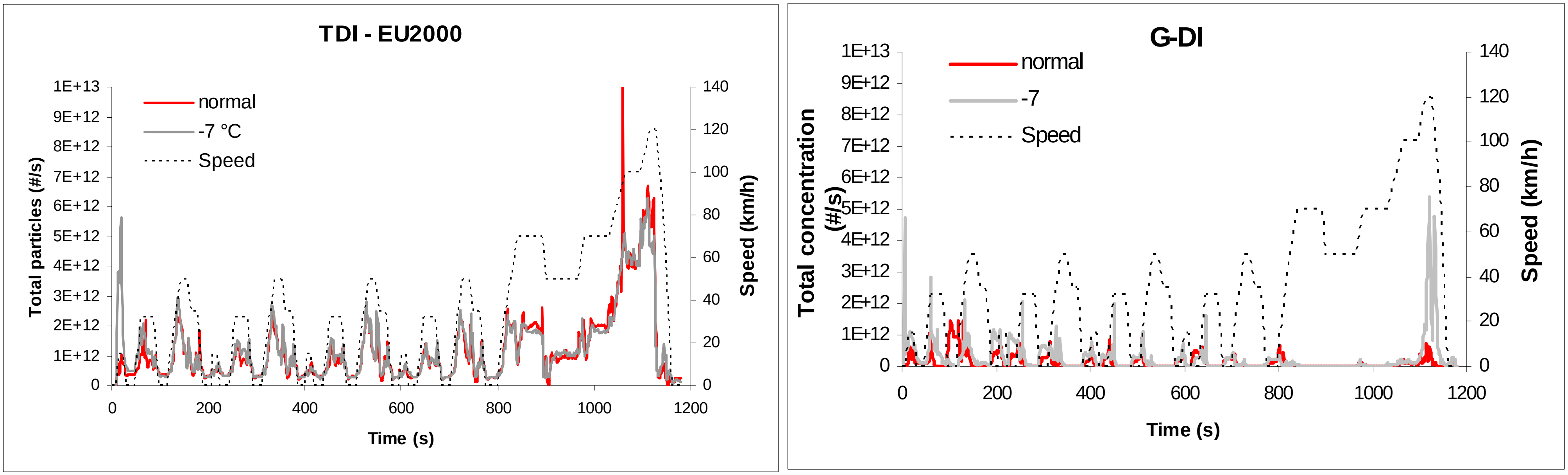


- Diesel cars: the highest number of particles in all size classes
- Accumulation mode particles (~100 nm, "soot mode") with diesel, GDI, and at low temperatures also with LPG
- No significant nucleation (nanoparticles) detected in these tests



- Number of particles increased only moderately with falling temperature, effects limited to start-up situations only
- Low temperature reduces IDI PM mass, but not PM numbers
- Particle mass and number from CNG close to nil at all temperatures
- SI: number of particles CNG < E85 < MPI < GDI ~ LPG

PARTICLE NUMBER FLOW, DIESEL TDI vs. GDI



- Particle number emission followed speed with diesel cars
- Also with the G-DI car continuous emission of particles

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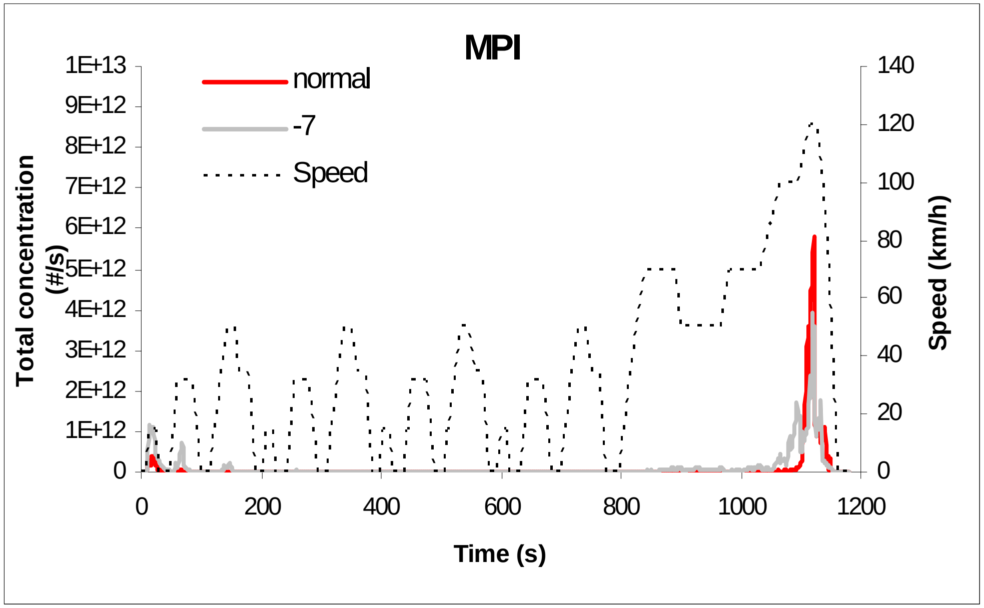
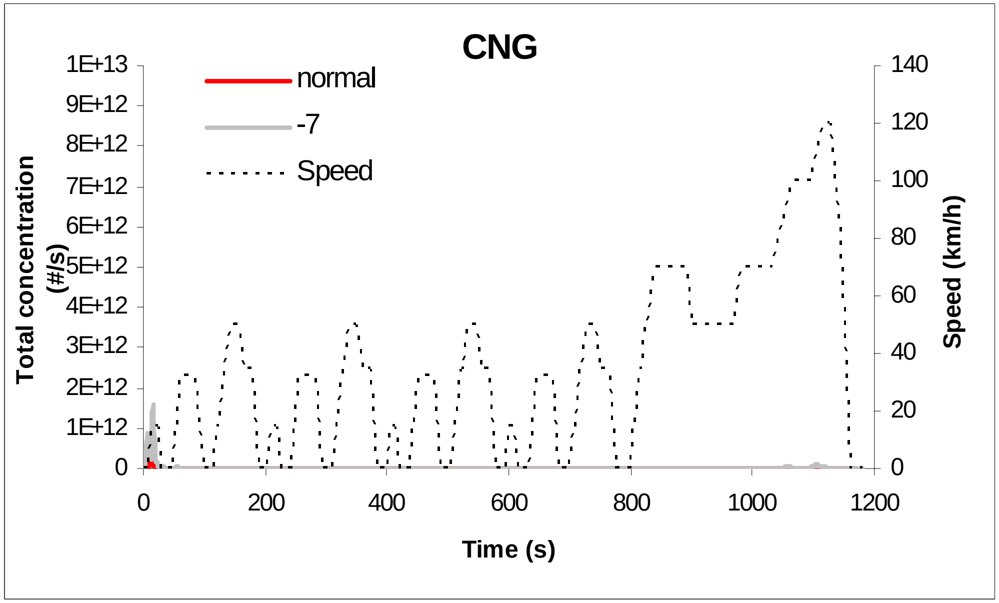
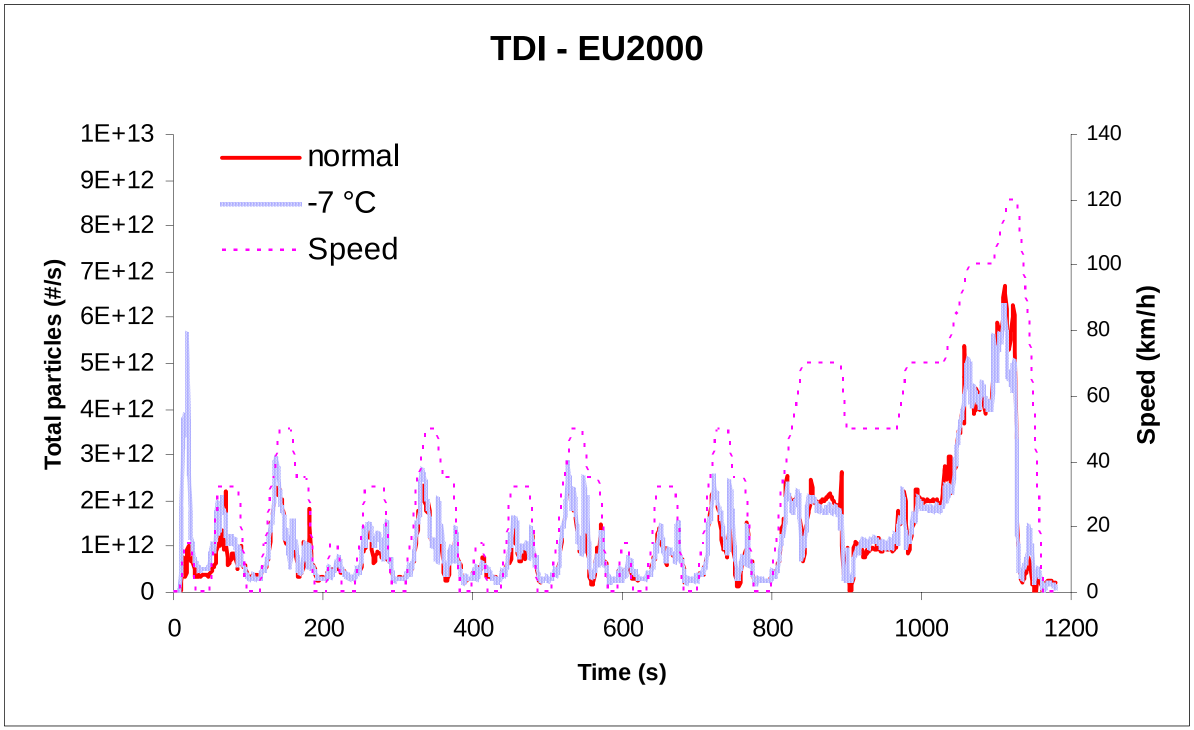
PARTICLE NUMBER FLOW, GASOLINE MPI vs. CNG

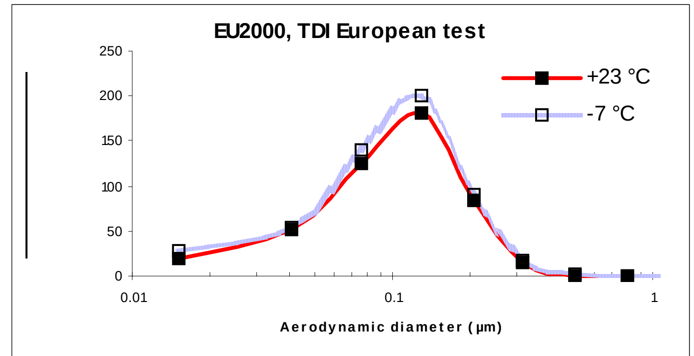


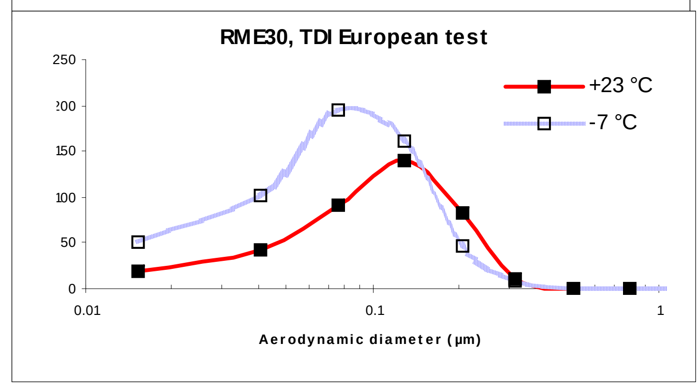


- Particles observed after cold-start and at high speed with MPI car
- Only a small peak after cold-start with the CNG car

PARTICLE NUMBER FLOW, DIESEL TDI /RME30







- RME increases small particles at -7 °C (also for the IDI engine)

SUMMARY (1)

- In this study, particle number emission was measured on-line for several fuel/engine technologies at three different temperatures
- Huge differences in emissions between different fuels/engines were seen
- Diesel vehicles produced highest NO_x and PM emissions
  - PM mass and particle numbers ~10 times higher than with the other cars
  - low temperature reduces IDI PM mass, but not PM numbers
- Rather small temperature effects on PM mass and numbers
  - noticeable only immediately after start

SUMMARY (2)

- Temperature effect substantial for CO and THC with gasoline and E85
- CNG gives superior overall emission performance including low-temperature operation
  - very low or close-to-zero emissions in all conditions
  - in this study, the low-temperature performance of the bi-fuel LPG vehicle was ruined by the calibration of the gasoline system used for start-up (vehicle and not a fuel specific issue)

Full results were published in SAE Technical Paper 2003-01-3285

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- We also would like to thank several companies that provided cars for the tests free of charge, and to the devoted personnel of VTT Processes for their active contribution