Measurement of Nanoparticles: From Tailpipe Emissions to Indoor Air

Oliver F. Bischof[1,2]

[1]TSI GmbH, Research & Analytical, Aachen (Germany)
[2]Forschungszentrum Jülich, ICE-3: Troposphere, Jülich (Germany)

16th VERT Forum 2026, METAS, Bern (CH) – 19th March 2026

Measurement of NP – Overview

- Wide choice of instruments
  - Not one that can do it all!
  - Often depends **Field of Use**
- Also determined by e.g.
  - Parameter of interest
  - Size range
  - Concentration limits
- New article in CHIMIA *

* Bischof, O. F., Burtscher, H., Fierz, *CHIMIA*, 80, No. 1-2 (2026)

Graphic adapted from J. Spielvogel (TSI); Pictures © TSI Incorporated; HORIBA, Ltd.

Measurement of NP – Overview (2)

- Different ways of classifying instruments to measure NP
  - This is my own
- Today's focus on particle number concentration (PNC)
  - See highlighted device types

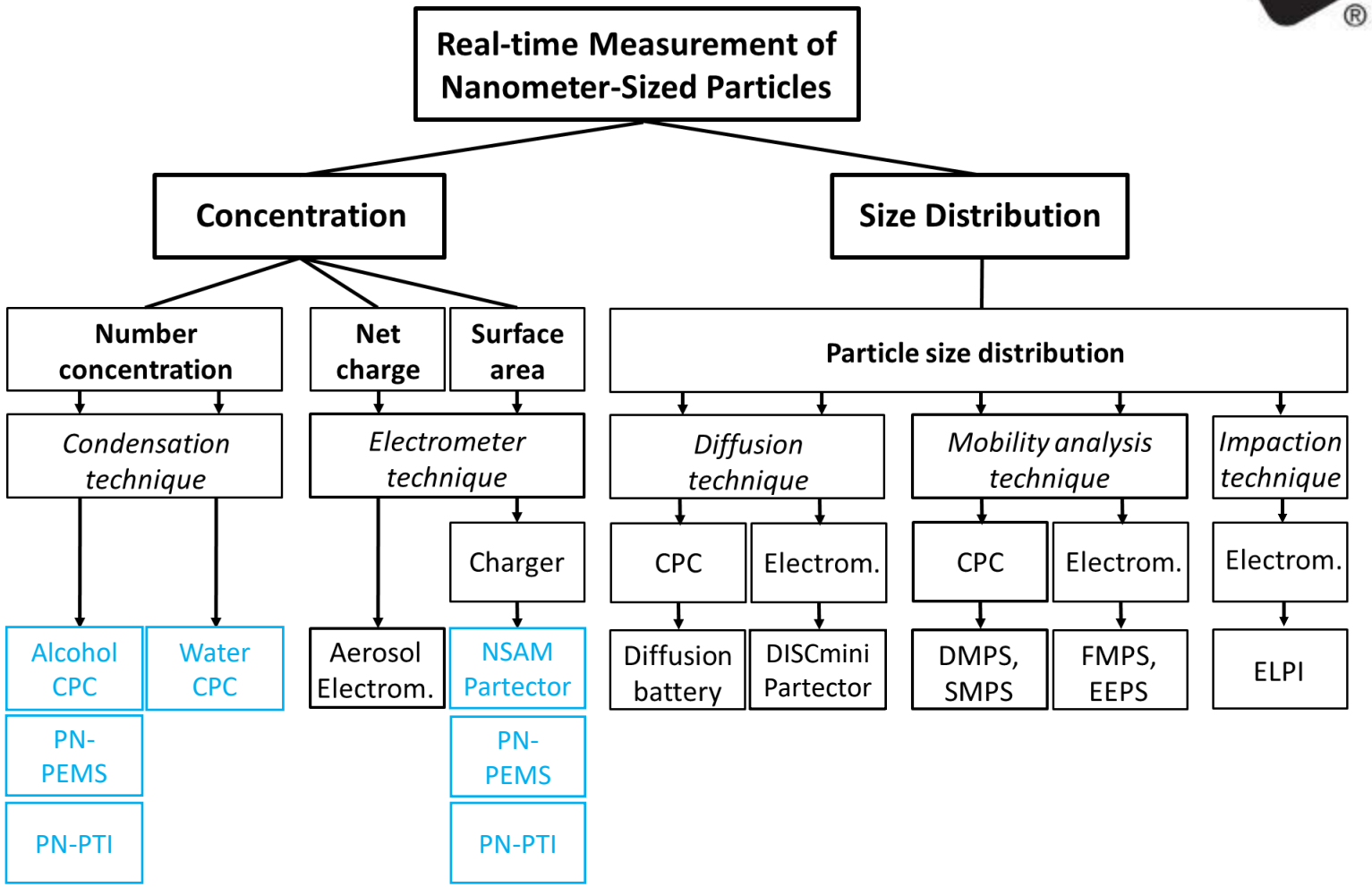


Chart adapted from Bischof, O. F., *Verlag des Forschungszentrums Jülich, Energie & Umwelt* (2022)

Measurement of NP – Tailpipe Emissions

- VERT advocate for best technology to reduce vehicle emissions
- Legislative measurement of NP since Sep. 2011
  - First Particle Number (PN) limit for type approval of LD diesel in Euro 5B
    - Subsequent PN limits for HD diesel in Euro VI (2013) and for LD vehicles with GDI engines in Euro 6b (2014)
  - Since 2013, Swiss Ord. of Air Pollution Control limits *in-use* PN emissions
    - Mandates compliance testing of off-road vehicles in
  - After Dieselgate, real drive emissions measured with portable PN emission measurement systems (PN-PEMS, since early 2016)
- Standards require high accuracy
  - For that reason, devices typically – but not exclusively – CPCs

Pictures © HORIBA, Ltd.; TSI Incorporated

Measurement of NP – Tailpipe Emissions (2)

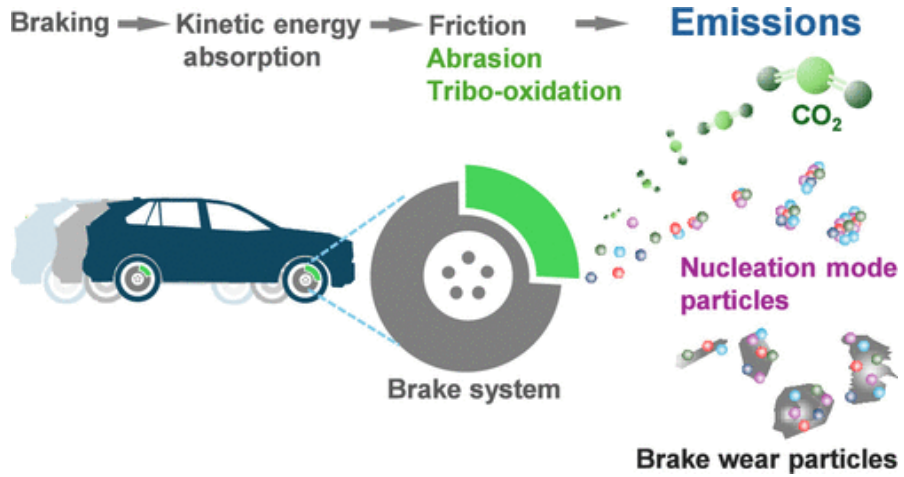
- Introduction of PN-PTI tests in 2022/23
  - For in-use vehicles, to detect malfunctioning DPFs
- Instruments based on two technologies
  - Diffusion chargers (DC), measure electrical current & correlate to PN
    - Compact size, lowest cost
  - Condensation Particle Counters (CPC) physically count all particles
    - Highest accuracy, very reproducible results
- Tens of thousands of PN devices used in B, CH, D & NL
  - Regulations allow for lesser accuracy of ±25%
  - METAS made recommendations for type examination & verification *

* Vasilatou, K. et al., *J Aerosol Sci.,* Vol. 172 (2023)

Picture credit SAXON Junkalor GmbH; Continental Aftermarket & Services GmbH; MAHLE GmbH; Robert Bosch GmbH

Measurement of NP – Other Emissions

- Non-exhaust vehicle emissions (Euro 7)
  - Requires meeting limit values for particulates (end of 2026)
  - Brake wear
    - PN limits for both LDV and HDV, starting 2030
    - Based on number of solid particles (SPN10) and total particles (TPN10), both ≥10 nm, commonly done by CPC
  - Tire wear
    - Defined PM test method, limits from July 2028 on
    - Based on “loss of particle mass” measurement after on-road test
- Aircraft emissions
  - ICAO’s non-volatile Particulate Matter (nvPM) standards
    - Limits for both non-volatile particulate mass and PN implemented, effective since 2023
    - Butanol CPC, single count mode & no splitting of sample flow

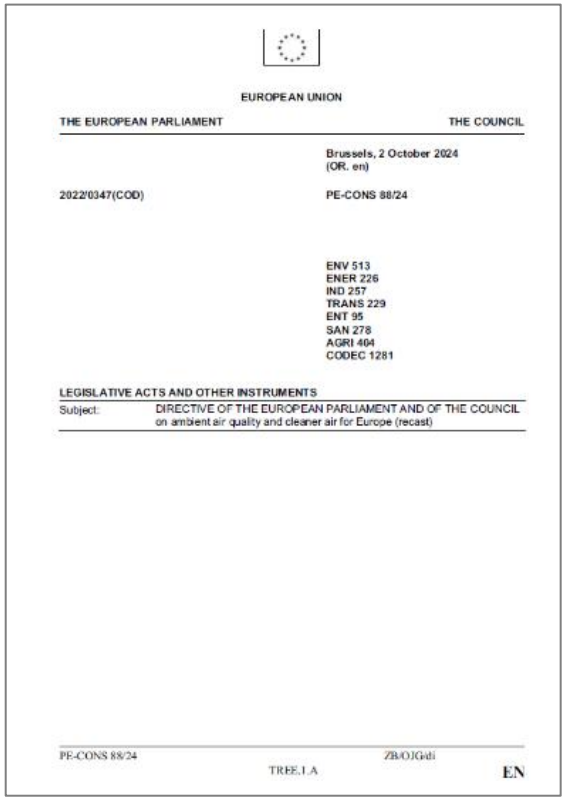


Hagino, H., *ACS ES&T Air*, Vol 2, Issue 6 (2025)

Picture credit U.S. EPA (2016)

Measurement of NP – Ambient Air

- Measurement of ambient NP a/k/a ultrafines
  - New EU Directive on Ambient Air Quality & Cleaner Air for Europe
  - Sets stricter AQ standards for pollutants
  - Entered into force (Nov 2024)
- PN concentration (PNC) and size distribution (PSD) measurements
  - EU member states required to incorporate metrics into local AQ monitoring
  - Min. one sampling point per 5 million inhabitants at locations where high UFP concentrations likely occur
  - PNC and PSD measured in line with EN 16976 and CEN/TS 17434
    - Butanol CPCs and SMPS/DMPS
- Next steps
  - EU member states have two years to apply new rules (= end of 2026)
  - Goal of meeting them by 2030



EUROPEAN UNION

THE EUROPEAN PARLIAMENT — THE COUNCIL

Brussels, 2 October 2024
(OR. en)

2022/0347(COD) — PE-CONS 88/24

ENV 513
ENER 226
IND 257
TRANS 229
ENT 95
SAN 278
AGRI 404
CODEC 1281

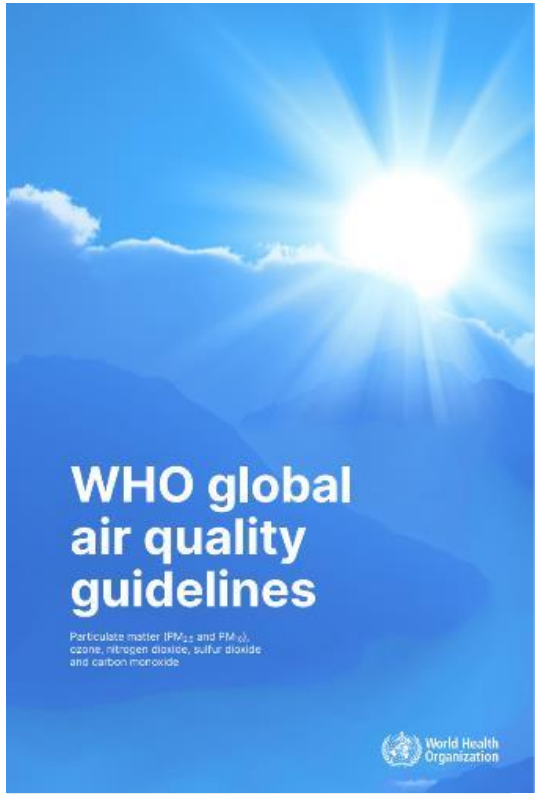
LEGISLATIVE ACTS AND OTHER INSTRUMENTS

Subject: DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on ambient air quality and cleaner air for Europe (recast)

PE-CONS 88/24 — ZB/OJG/dl
TREE.1.A — EN

Measurement of NP – Indoor Air

- Indoor air still (largely) unregulated!
  - Most countries don't have legislation for IAQ
    - Yet, people spend ~80% to 90% indoors
    - Problem: standards need to be implementable
  - WHO published guidelines, but not enforceable!
    - On indoor air quality (2010) *
      - For benzene, CO, CH_2O, naphthalene, NO_x, PAHs, radon, PCE & TCE
      - No specific guidelines for particles
        - As "indoor air particles not distinctly different from outdoors"
    - On global air quality (2021) **
      - No longer make distinction between indoor and outdoor AQ levels
      - Emphasize health relevance of ultrafines a/k/a NP
        - Advise to monitor them



** WHO global air quality guidelines. Geneva: World Health Organization (2021)0

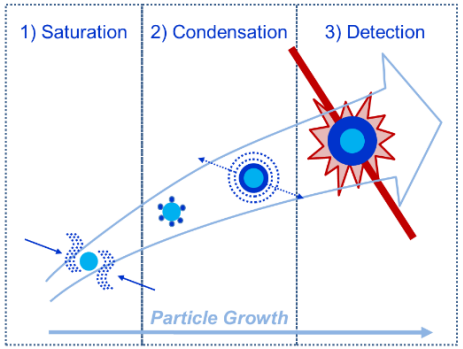
Indoor Air – Solutions for PM & Gases

- Many options for time-resolved IAQ monitors
  - Often for several parameters, incl. PM & gases
    - Help identify specific indoor sources
    - Gases often precursors to particle formation
- From really low-cost devises to professional-grade monitors
  - Low-cost “6 in 1 AQ Tester” starts at ~12 EUR…
  - Professional monitors measure PM2.5 and several gases
    - Often choice of TVOC, CO, CO_2, CH_2O, NO_2, SO_2 and O_3
    - Real-time data reporting, self diagnostics for high up time (>95%)
  - Acceptable technology for indoor pollutants
- None of these is for nanoparticles…

Pictures © Amazon, TSI Incorporated

Indoor Air – Solutions for NP

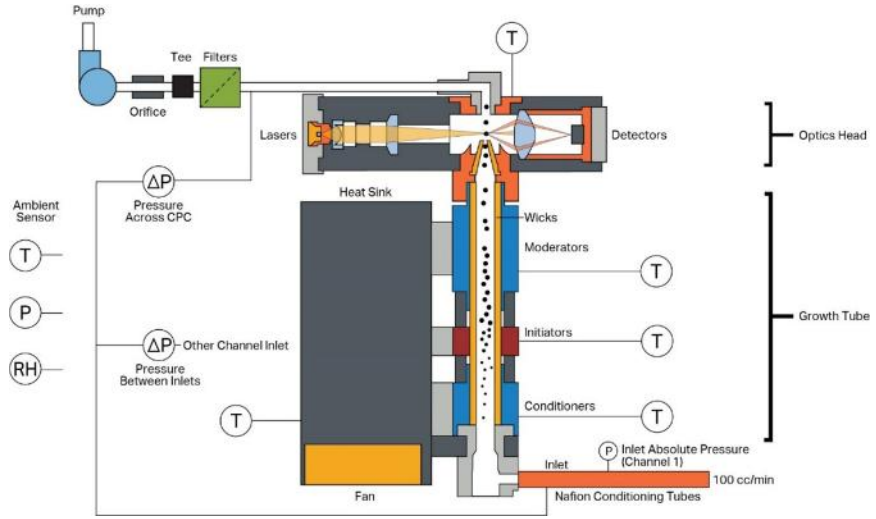
- Measurement of NP requires dedicated devices
- As for PN-PTI, two technologies currently used
  - Diffusion chargers (DC)
    - Small size, light weight
    - Calculate PNC with typical accuracy ±30%
    - Example: Partector 2 (Naneos)
  - Condensation Particle Counters (CPC)
    - Portable isopropanol & water-based CPCs
    - Directly measure PNC with high accuracy
    - Examples: Portable CPC 3007 and OmniCount WCPC (all TSI)



Graphics: Bischof, *Verlag des FZ Jülich,* 2022; Pictures © Naneos, TSI Incorporated

Indoor Air – Portable WCPC

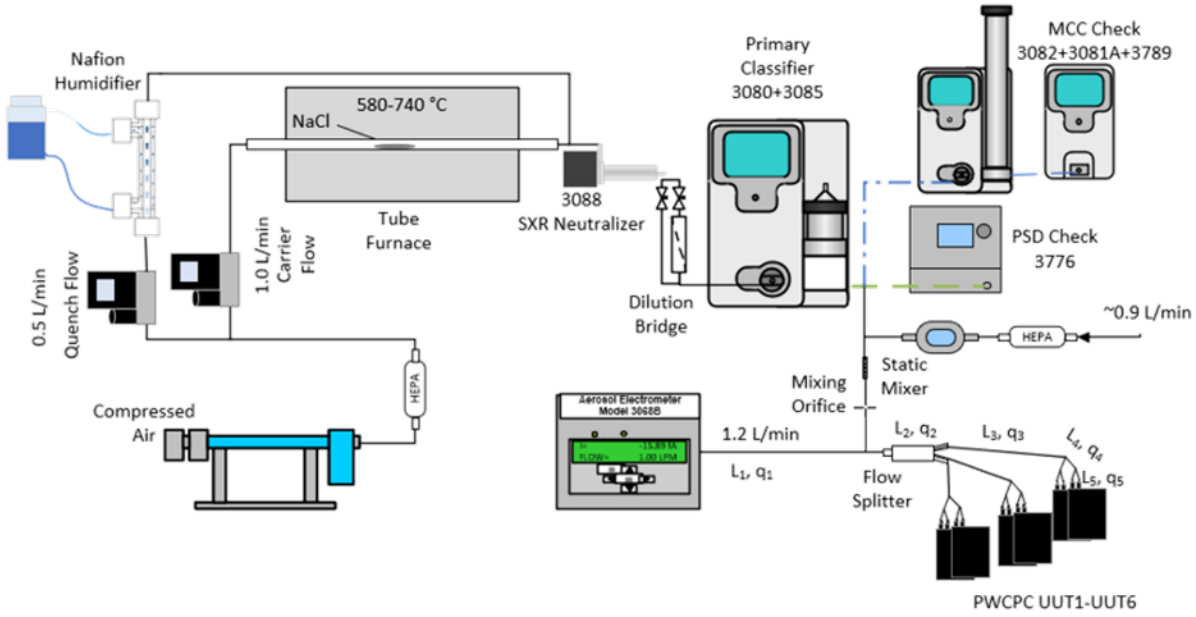
- OmniCount™ Portable WCPC (TSI)
  - Newest model 3001, compact version of lab-grade V-WCPC 3789
    - Same core technology but miniaturized for mobile use
  - For time-resolved measurement of NP concentration
- Made for mobile measurements
  - Small, low weight (850 g)
  - Reliable operation in any orientation (flood resistant)
  - Several hours of operation between water refills
  - Wireless connectivity
- Conducted extensive performance testing
  - Efficiency curve and lower detection efficiency (d_{50})
  - Concentration accuracy

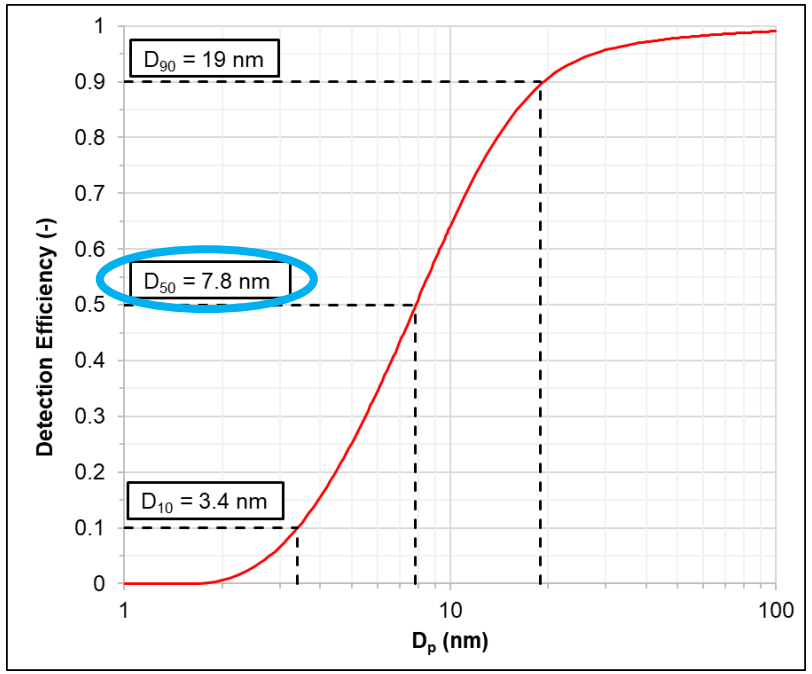


Schematic & Picture © TSI Incorporated

Portable WCPC Characterization

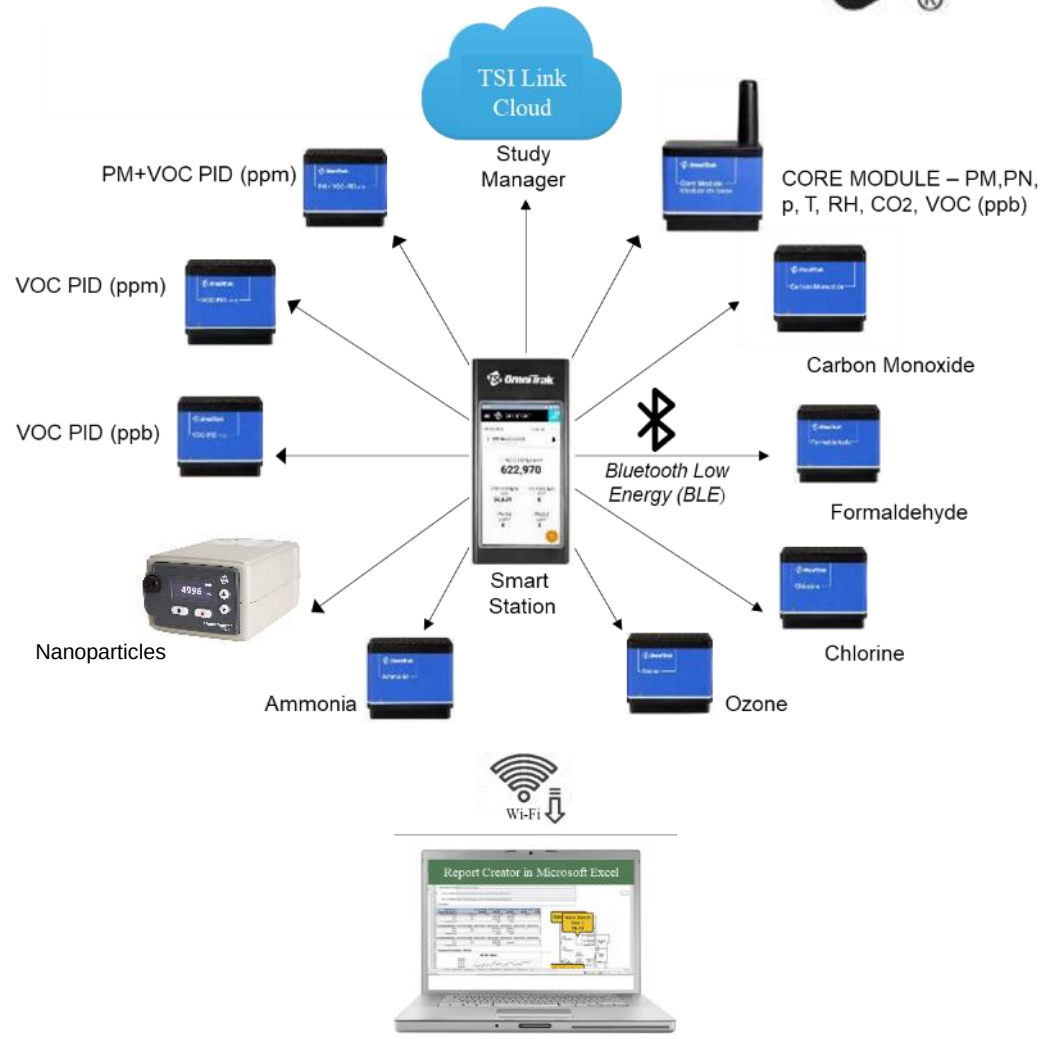
- Set-up for determination of lower cut-off (d_{50})





Indoor Air – Survey Solution

- Surveys to identify indoor air sources
  - Typically at different measurement points for profile of temporal and/or spatial changes
    - Also for baseline screenings
  - Customizable OmniTrak™ solution (TSI)
    - Offers time-synchronized measurements of several parameters, using individual modules
    - Can measure PN and PM fractions
      - For NP, also relies on OmniCount PWCPC
    - Gases: VOC, CO, CO_2, Cl, NH_3, O_3, and CH_2O
    - Modules connect wirelessly to Smart Station
      - Up to 10 at a time



Summary

- Long way in measuring and mitigating NP
  - In 1993, railway tunnel project in 🇨🇭 and creation of VERT
  - Particle Measuring Program, milestone in May 2000
  - Since then, PN limits in several vehicle emission standards
- EU adopted AQ Directive in 2024 for Outdoor air
  - Monitoring of NP concentration and size in networks
  - Harmonized & reliable
- Indoor air still missing standards for public spaces
  - Continuous monitoring of IAQ with modern monitors
  - Surveys can identify sources of contamination
    - Portable devices open up more ways of measuring NP
  - Strategies for source control, filtration & ventilation to be applied

Indoor air quality

Dirty office air picture created with Copilot

Acknowledgments

- TSI GmbH
  - Jürgen Spielvogel, Torsten Tritscher, Carsten Kykal
- TSI Incorporated
  - Noah Bock, Justin Koczak, Brent Schenk

Thank you!

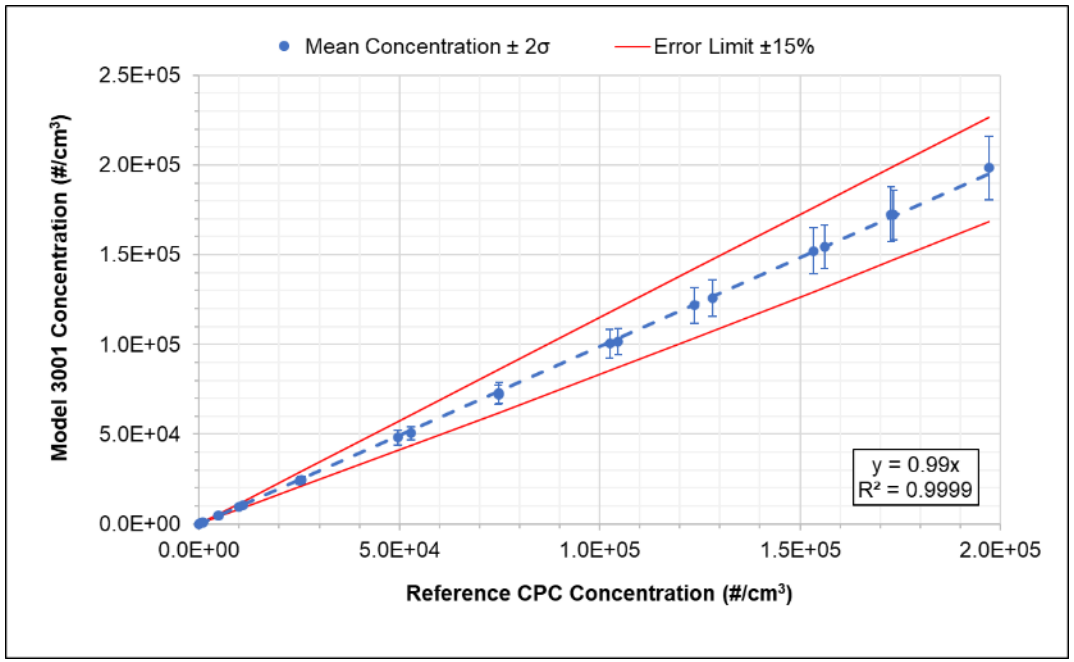
Any Questions?

oliver.bischof@tsi.com

Portable WCPC Characterization (2)

- Performance for atomized polydisperse NaCl aerosol from Atomizer (TSI 3076, GMD ~60 nm)

Agreement with reference CPC



Time response