

Highly-selective sensors for detection of liquor adulteration & monitoring of body fat burning

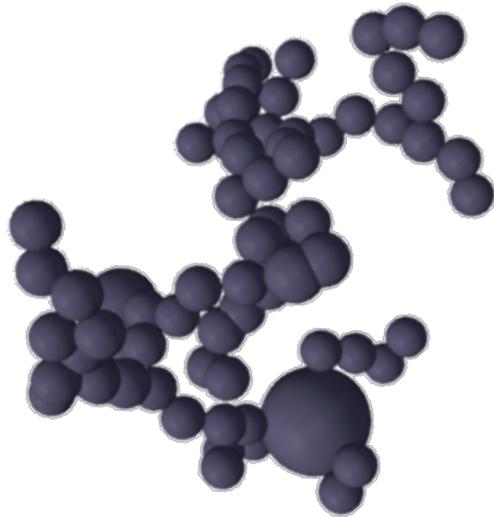


Sotiris E. Pratsinis

Particle Technology Laboratory, Department of Mechanical &
Process Engineering, ETH Zurich, Switzerland

Particle Formation in Gases

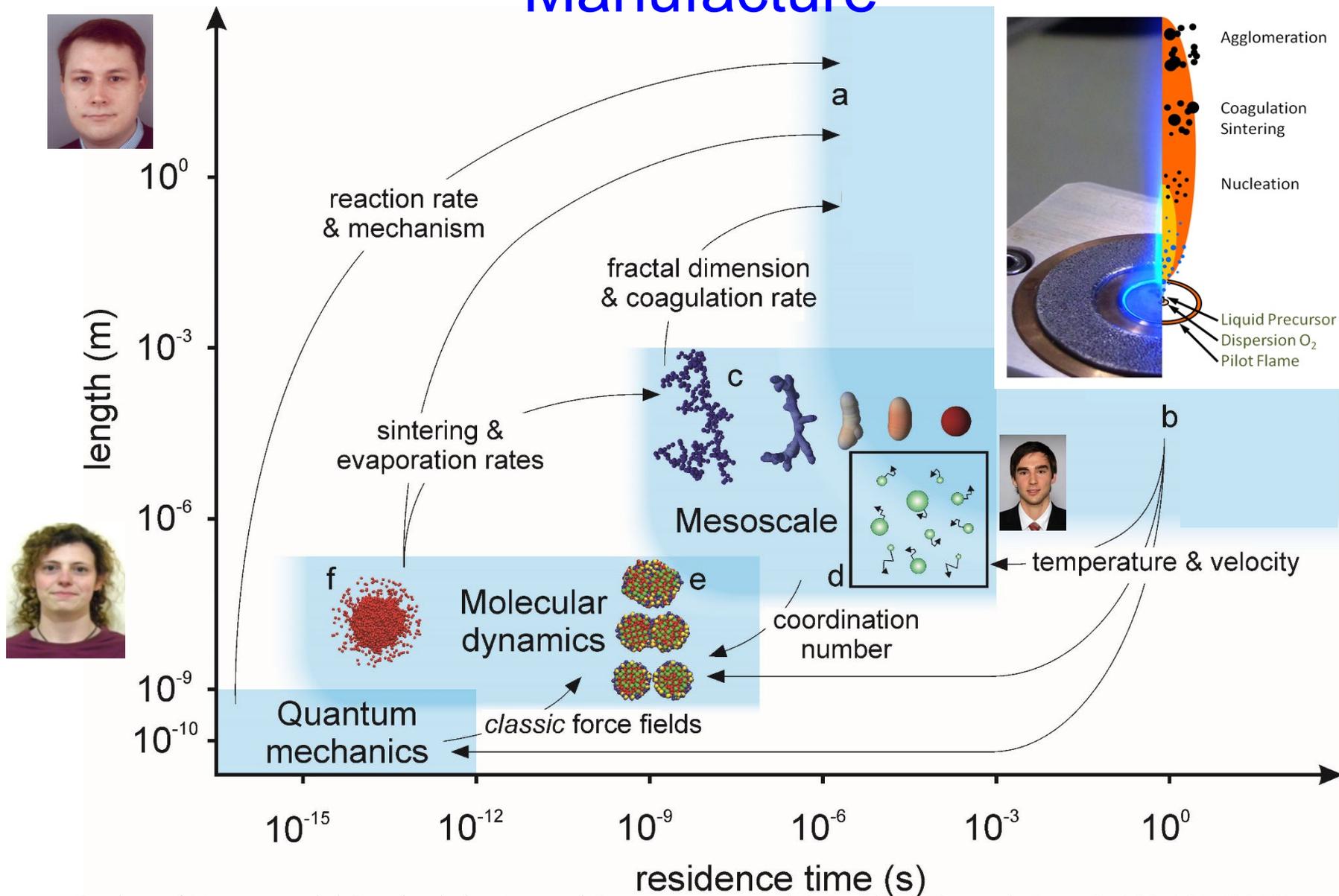
Fundamentals



Particle structure &
size distribution
vs.
Product
performance

Applications

Multiscale Process Design for Particle Manufacture



Quantitative understanding facilitates.....

a) Scale-up

... to 5 kg/h
even @
Univ. labs...



... and b) drives innovation

Multicomponent Nanomaterials en mass by Flame Spray Pyrolysis (FSP)

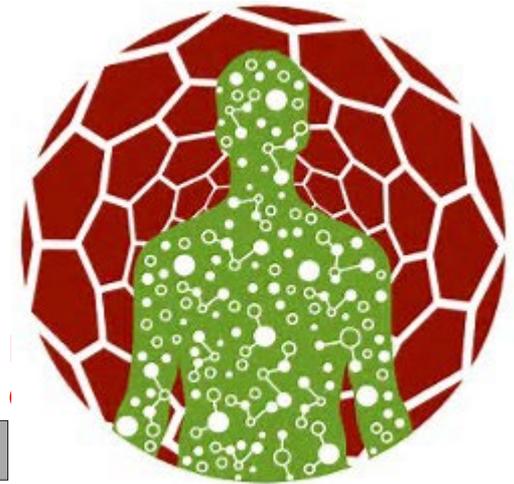


**SPP1980
SPRAYSYN**
NANOPARTIKELSYNTHESE
IN SPRAYFLAMMEN

A 6-year, 6M Euro
program by the
German NSF for 20
PhDs since 2017



HARVARD
SCHOOL OF PUBLIC HEALTH



NIH – NHIR → \$5M

Strobel, R., Stark, W.J., Mädler, L., SEP, Baiker, A., *J. Catal.*, **213**, 296-304, (2003).
Mädler, L., Müller, R., Kammler, H., SEP, *J. Aerosol Sci.* **33**, 369-389 (2002).



New aerosol-made products in the market

Ag/SiO₂ → nanosilver toxicity by ions or particles?

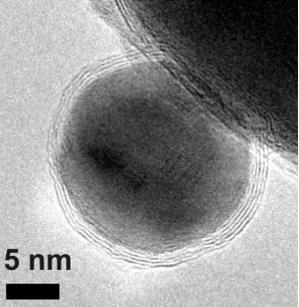


nano-Ag for antibacterial applications



London Stock Exchange
December 2020, 127M £

\$0.3 B



Bio-magnetic ferrofluids:
C-coated Co
100k – 1M\$/kg

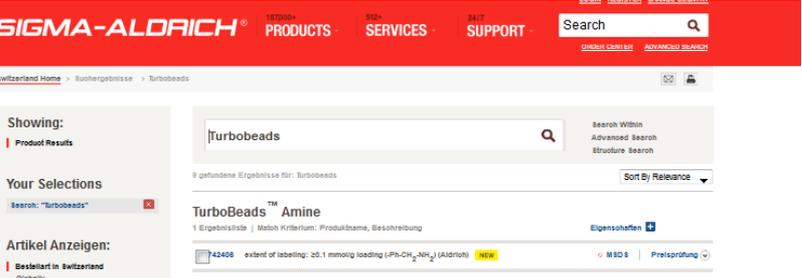
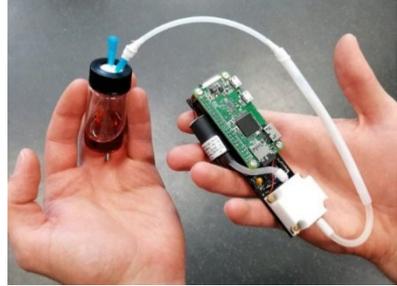


London Stock Exchange
December 2020, 127M £

\$0.3 B



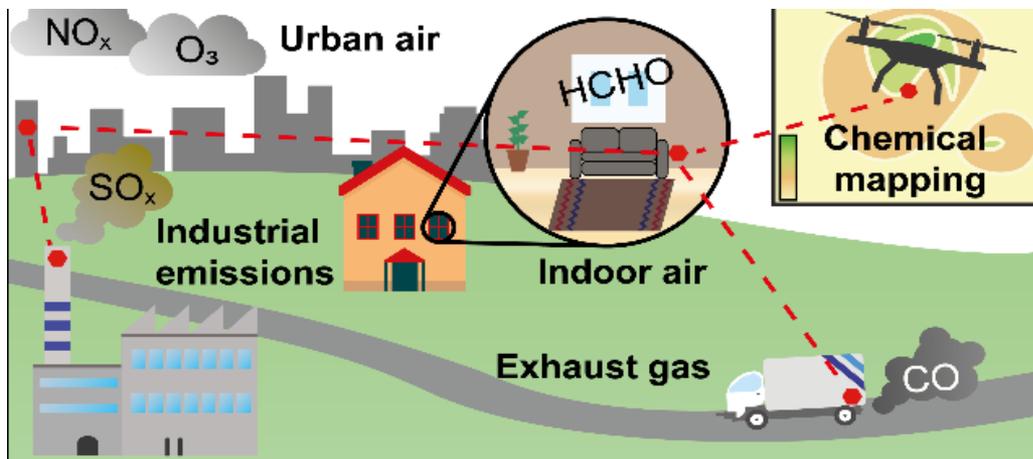
hemotune AG
(Sepsis, blood poisoning)



Product #697745 → 500 mg dry powder @ \$105

F. Meierhofer, U. Fritsching, Synthesis of Metal Oxide Nanoparticles in Flame Sprays: Review on Process Technology, Modeling, and Diagnostics, *ACS Energy Fuels* 35, 5495–5537 (2021)



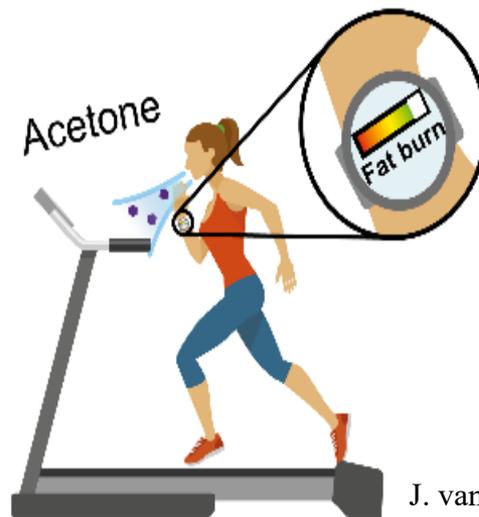
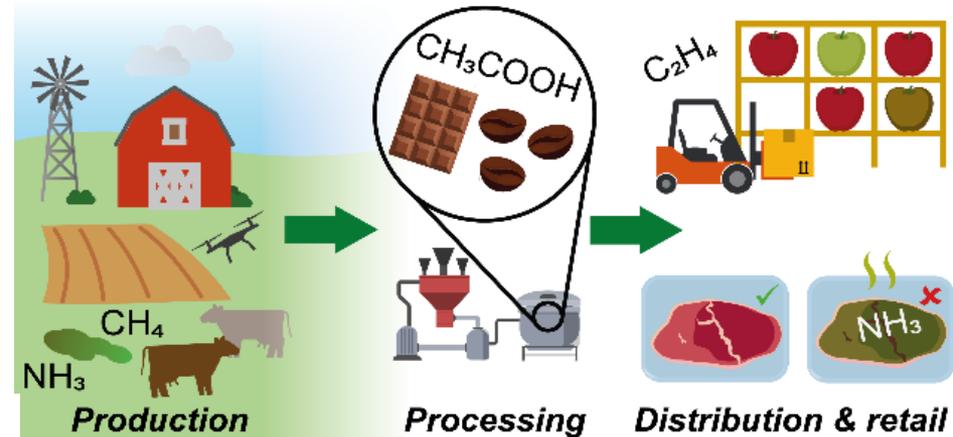


Gas Sensors

Air Quality: Indoors & Outdoors



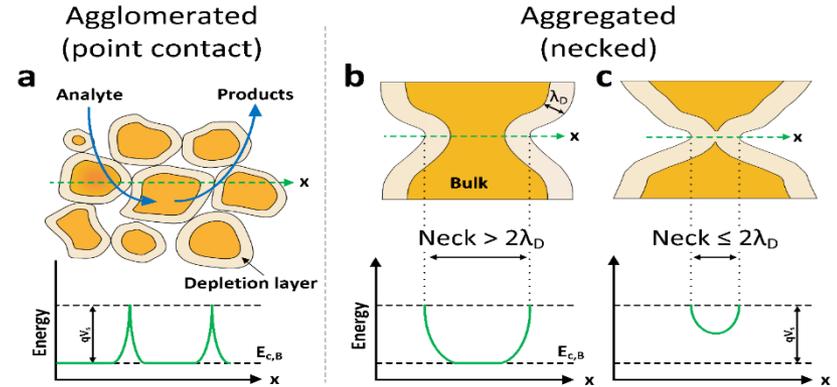
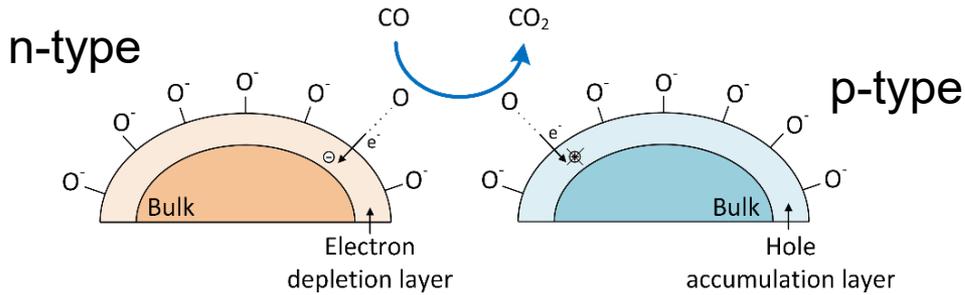
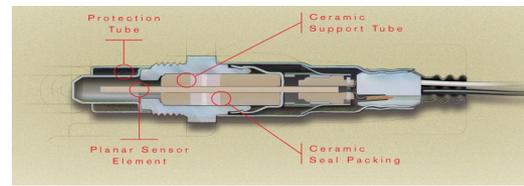
Food and Agriculture



Health and Lifestyle

Medical diagnostics, Fitness tracking

Gas Sensors

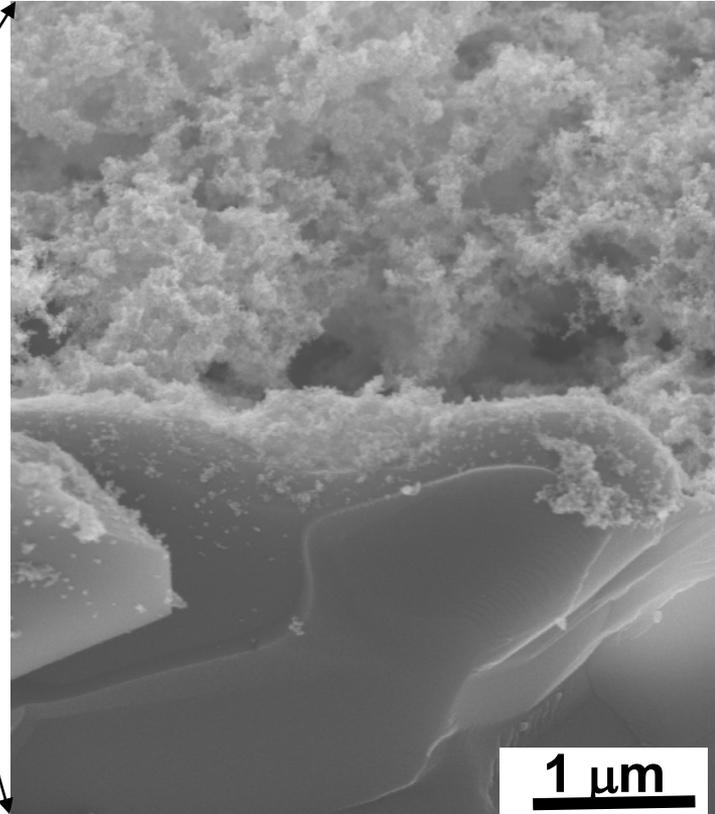
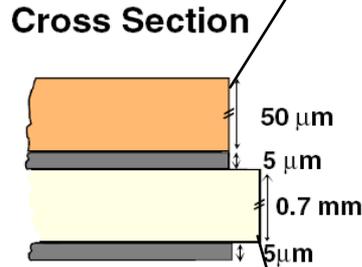
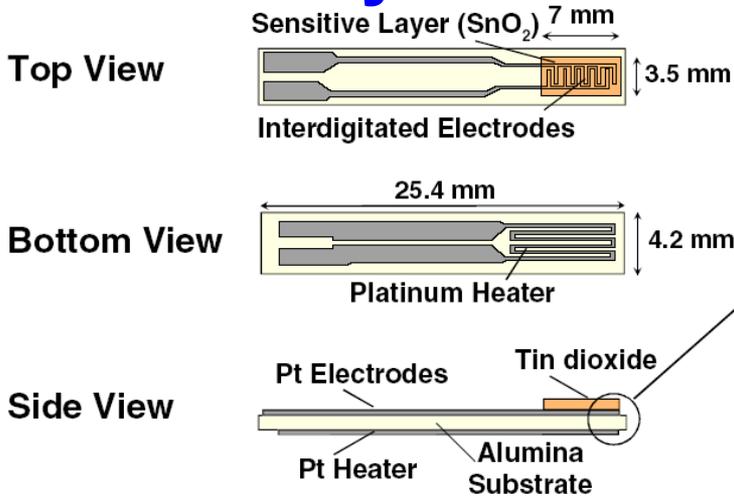


- Sensitivity
- Stability
- Selectivity

3S

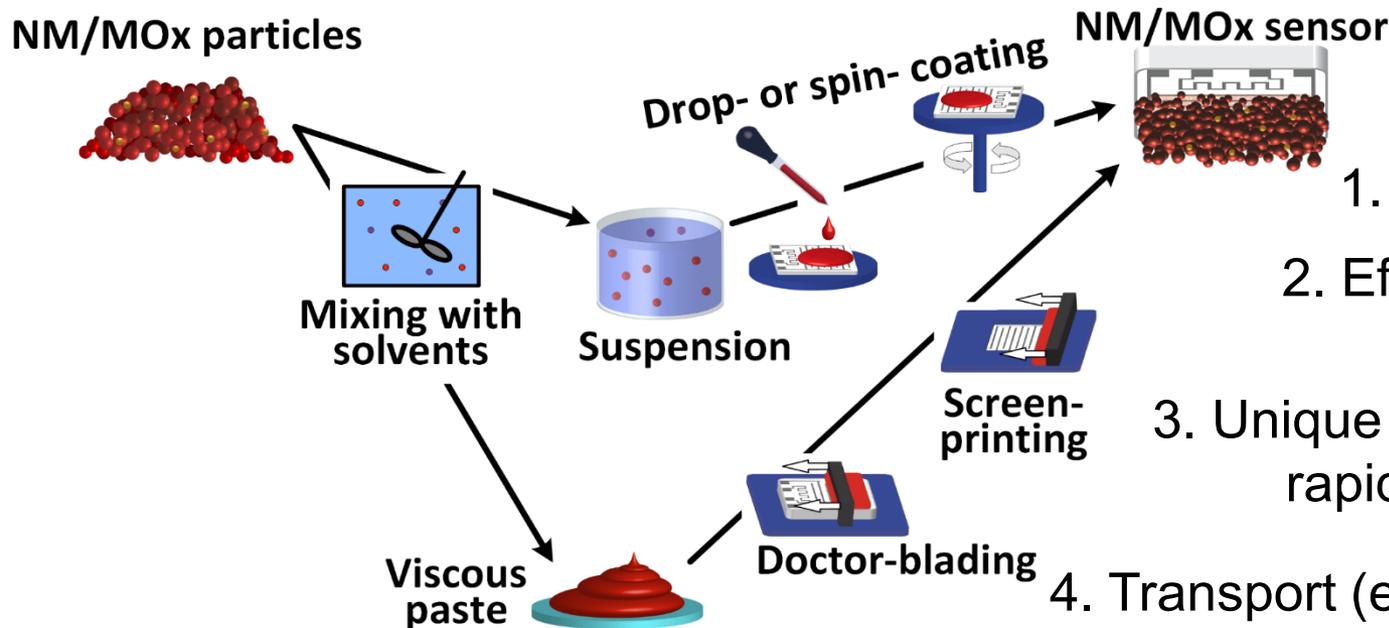
- Response time
- Recovery

2R



Porous, high surface-area films

Assembly of Gas Sensors



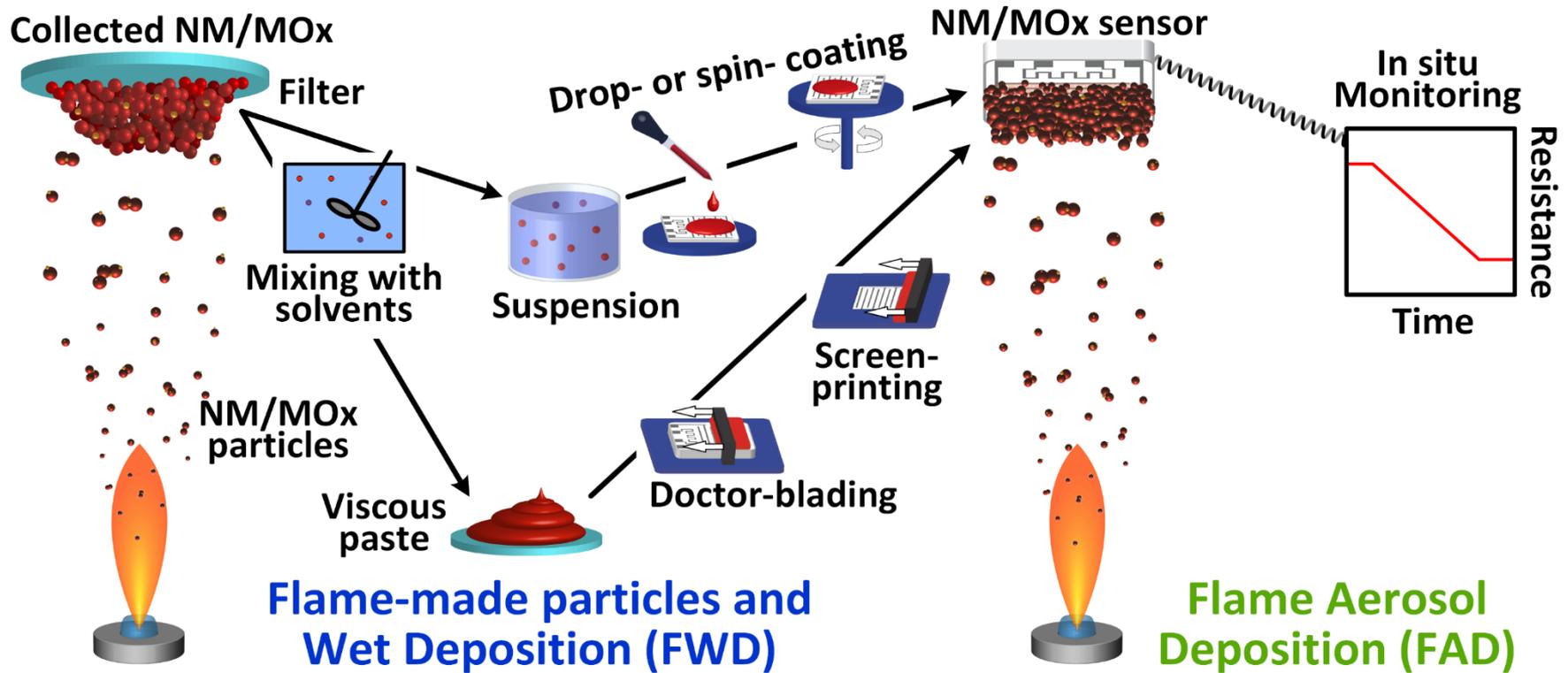
Why use flames?

1. No liquid by-products
2. Efficiency: Few and fast unit operations
3. Unique metastable phases by rapid heating-cooling
4. Transport (e.g. diffusion) is well understood facilitating design from first principles.
5. Extremely porous but robust films

R. Strobel, SEP "Flame aerosol synthesis of smart nanostructured materials", *J. Mater. Chem.*, **17**, 4743 - 4756 (2007).

Aerosol-based Technologies in Nanoscale Manufacturing: from Functional Materials to Devices through Core Chemical Engineering, *AIChE J.*, **56**, 3028-3035 (2010)

Assembly of Flame-made Gas Sensors

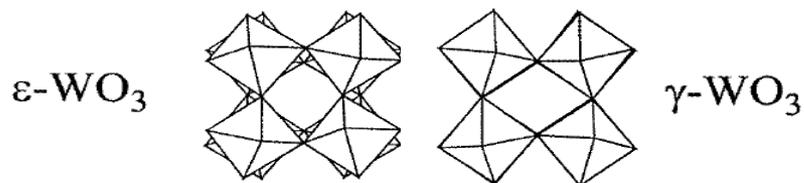


R. Strobel, SEP "Flame aerosol synthesis of smart nanostructured materials", *J. Mater. Chem.*, **17**, 4743 - 4756 (2007).

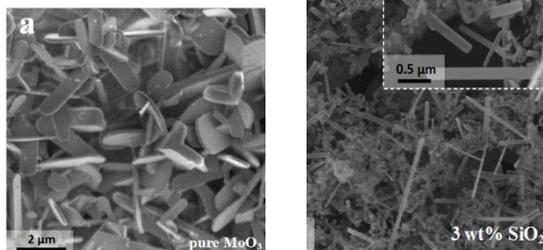
C.O. Blattmann, SEP, "In situ measurement of conductivity during nanocomposite film deposition", *Appl. Surf. Sci.*, **371**, 329–336 (2016).

Aerosol-made selective gas sensors

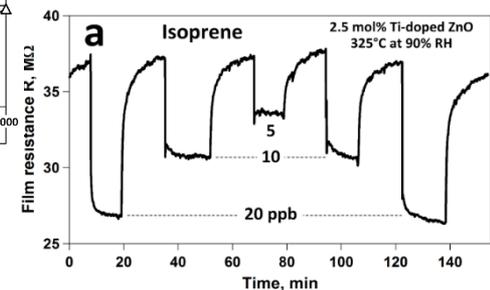
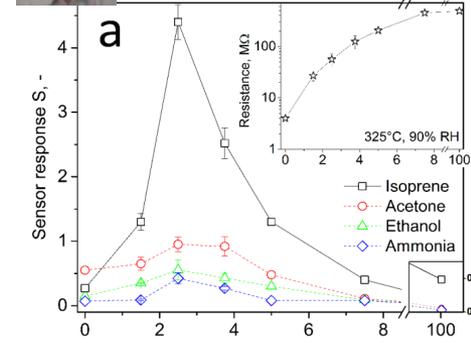
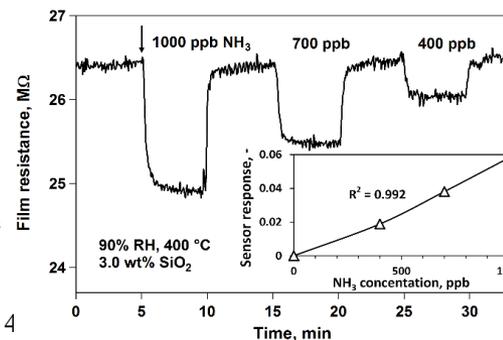
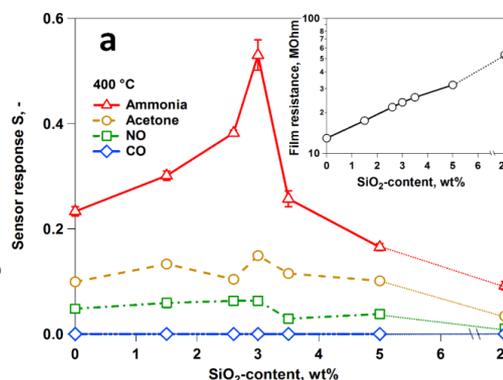
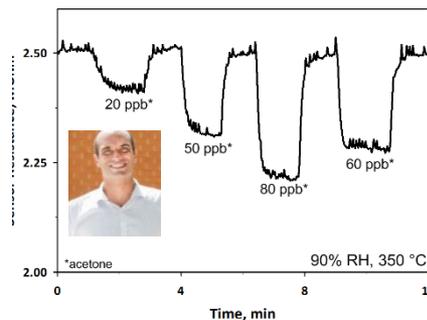
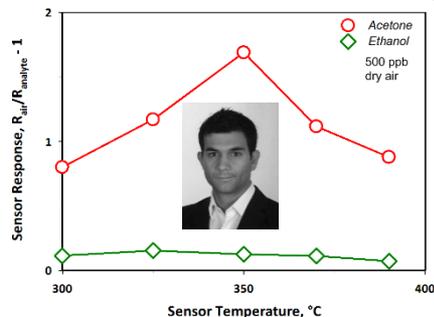
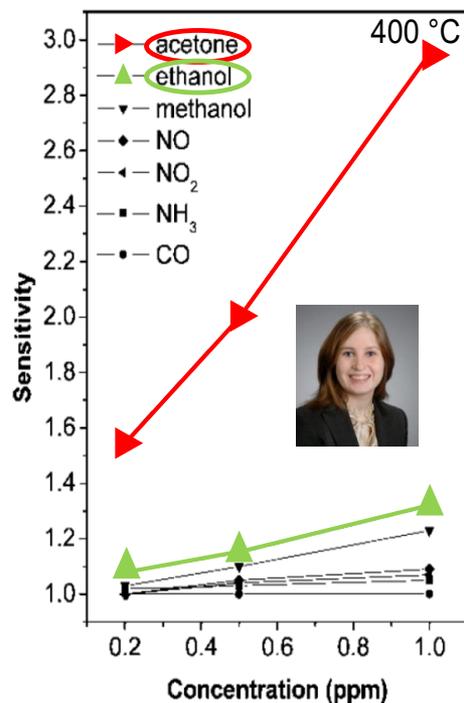
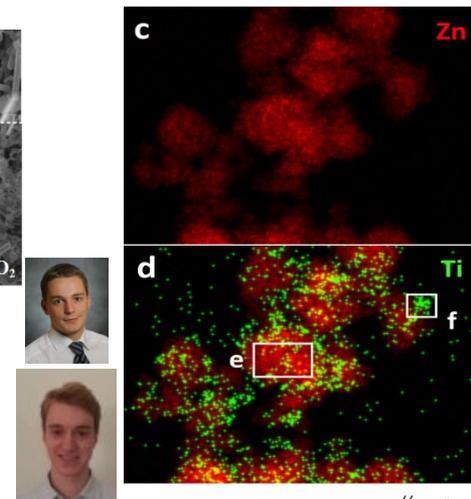
Acetone²
Cr⁻¹ & Si-doped ϵ -WO₃



Ammonia³
Si-doped MoO₃

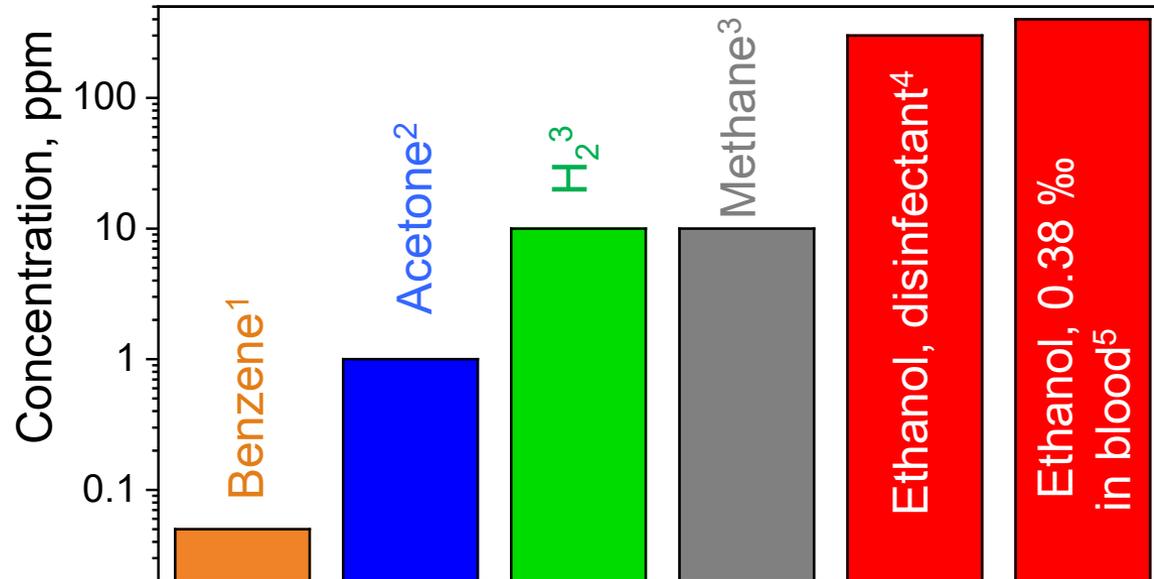


Isoprene⁴
Ti-doped ZnO



1. L. Wang, A. Teleki, SEP, P.I. Gouma, *Chem. Materials*, **2008**, 20, 4
2. Righettoni, M.; Tricoli, A.; SEP. *Anal. Chem.*, **82**, 3581–3587 (2010)
3. Güntner, A. T.; Righettoni, M.; SEP. *Sens. Actuators B* **2016**, 223, 266-273.
4. Güntner, A. T.; Pineau, N. J.; Chie, D.; Krumeich, F.; SEP. *J. Mater. Chem. B* **2016**, 4, 5358-5366

Interference by ethanol → breath analysis & indoor air quality



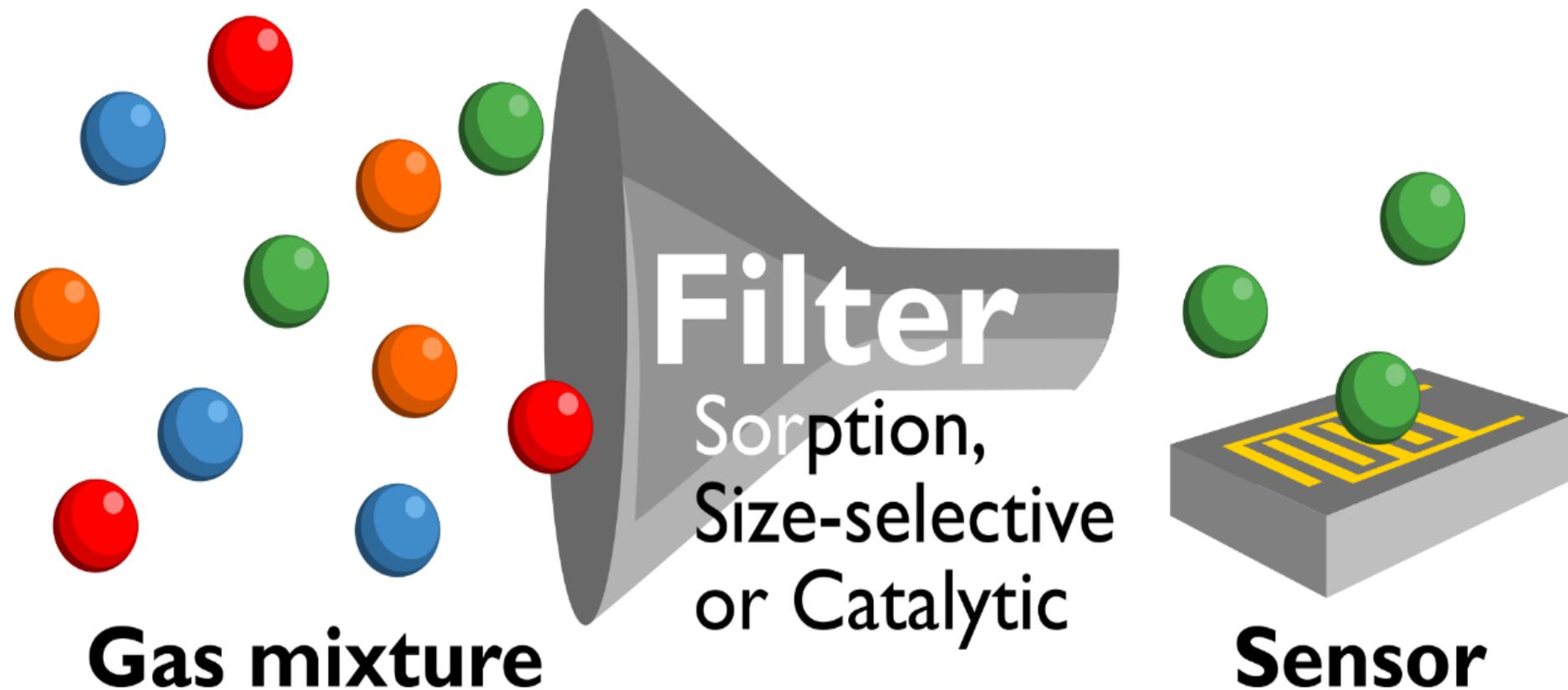
Orders of magnitude higher ethanol concentration!

→ high selectivity required

Insufficient selectivity

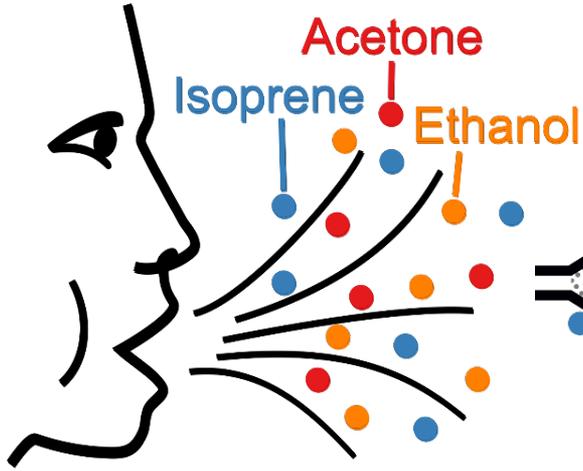
1. M. Barker, M. Hengst, J. Schmid, H.J. Buers, B. Mittermaier, D. Klemp, R. Koppmann, *Eur. Respir. J.* **2006**, 27, 929–936.
2. Turner, C. Španel, P. Smith, *Physiol. Meas.* **2006**, 27, 321–337.
3. Calloway DJ, Murphy EL, Bauer D, *Am. J. Dig. Dis.* **1969**, 14, 811.
4. Bessonneau, V. Thomas, O. *Int. J. Environ. Res. Public Health* **2012**, 9, 868–879.
5. Vukovic J, Modun D, Markovic D, Sutlovic D, *J Subst Abuse Alcohol*, **2015**, 3 1029.

Filter- or Concentrator-enhanced sensor selectivity

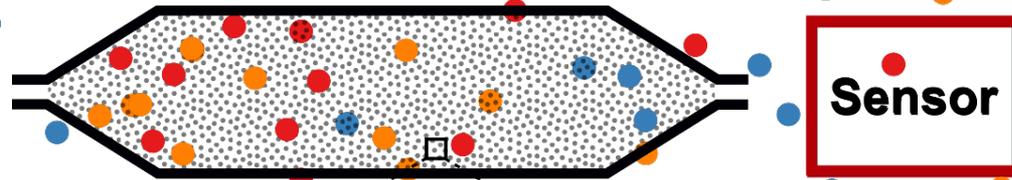


Adsorption

- Commercial powder (1 g)
- Mesoporous
- High specific surface area (155 m²/g)
- **Hydrophilic surface**



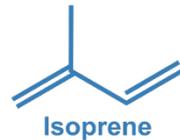
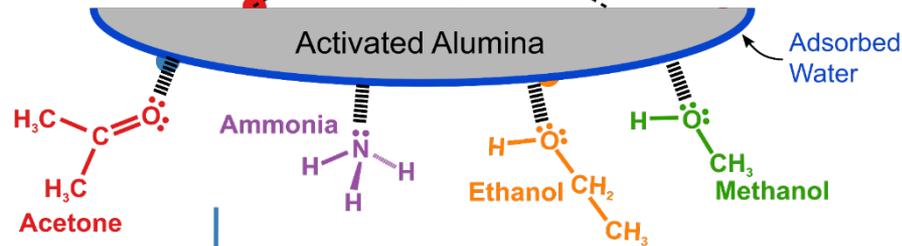
Activated Alumina Filter



Flame-made Pt:SnO₂



van den Broek J, Güntner AT, SEP. ACS Sens. 2018;3:677-683.

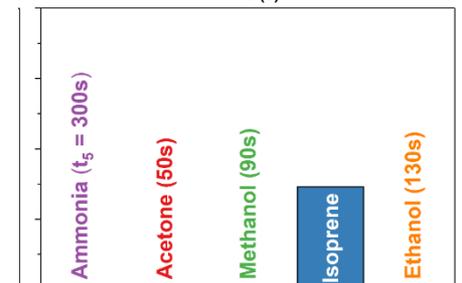
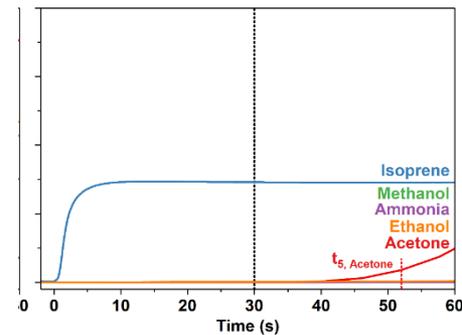
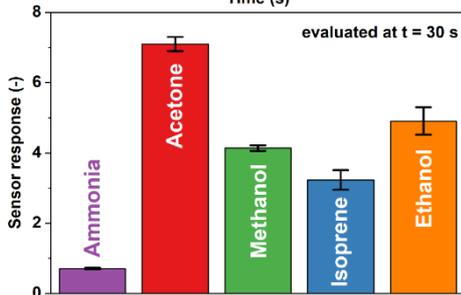
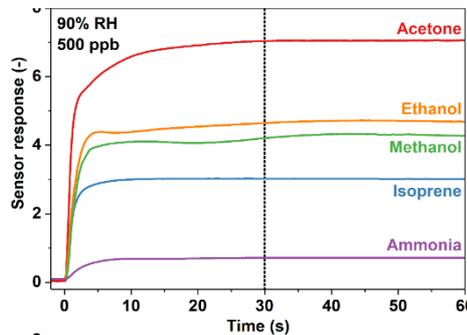


No Retention of Hydrophobic Isoprene

→ Isoprene response unchanged

→ Hydrophilic compounds held back

→ Isoprene selectivity >100



Methanol Poisoning from Laced Liquor

14'000 victims and 3'900 fatalities since 2017 worldwide:

Mexico (189 deaths, May 2020) and Turkey (50 deaths, Oct. 2020)



Contaminated bootleg alcohol kills at least 42 in Iran



Feb. 2019

Over 90 Killed in India by Toxic Homemade Liquor

The New York Times

Toxic coconut wine kills at least 11 people during Christmas celebrations in the Philippines

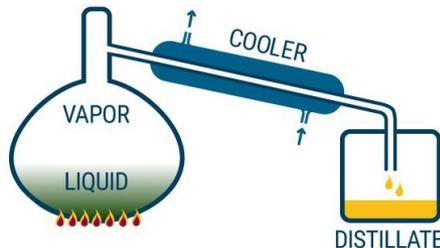
Dec. 2019



Added to save cost



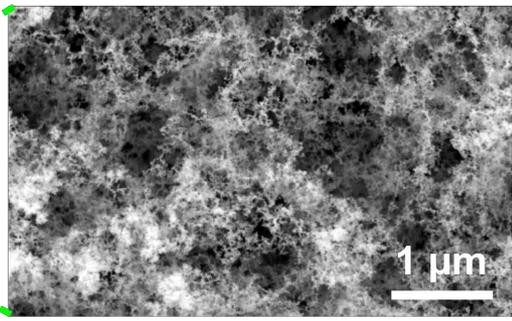
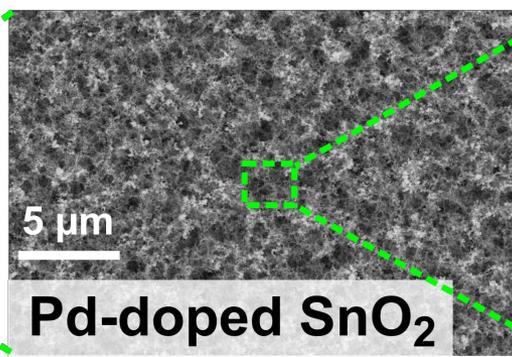
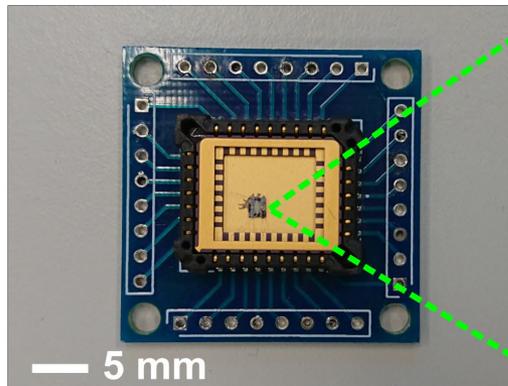
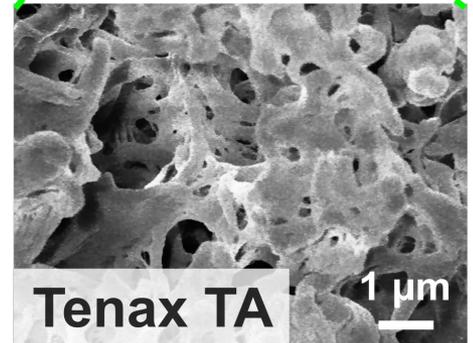
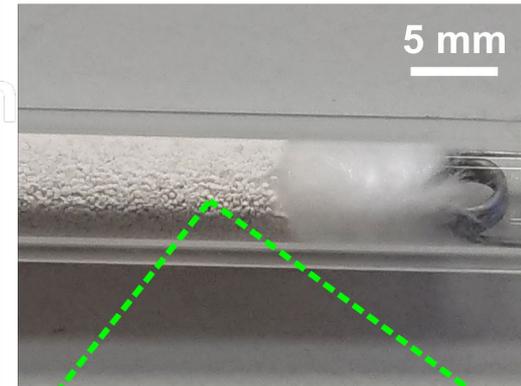
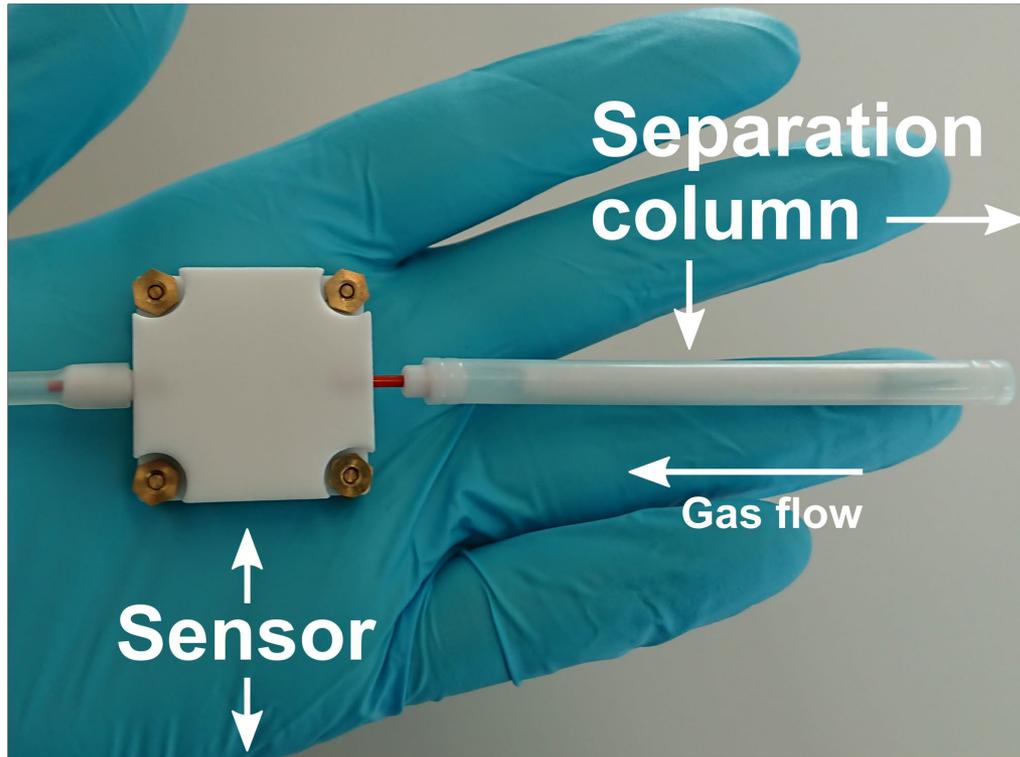
Incorrect distillation



Frequent poisoning outbreaks in **developing countries** with **thousands of victims**.¹

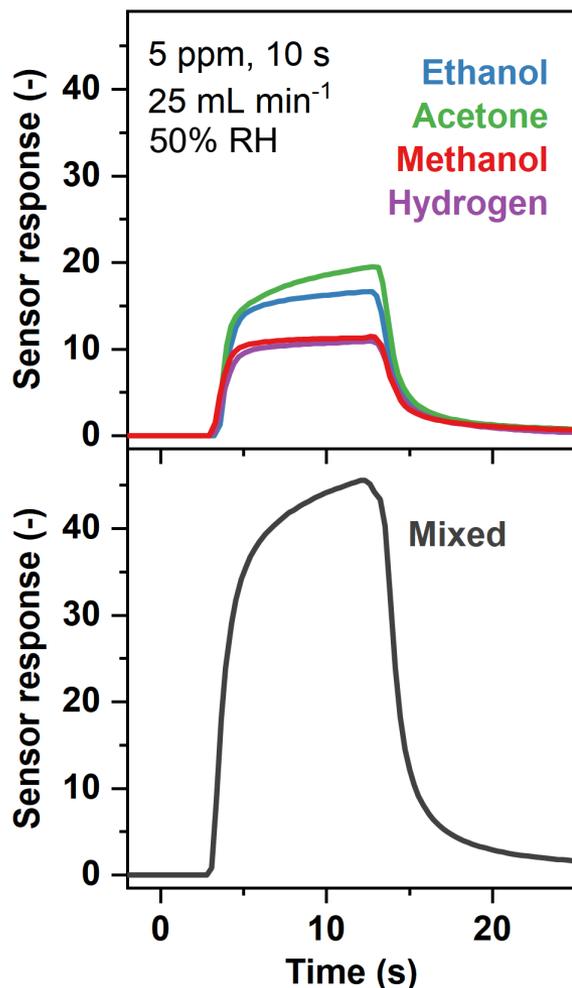
1. Médecins sans Frontières, Oslo University Hospital. Suspected methanol poisoning incidents. 2018. (Accessed 15th January 2019).

Design of Gas Sensing Device

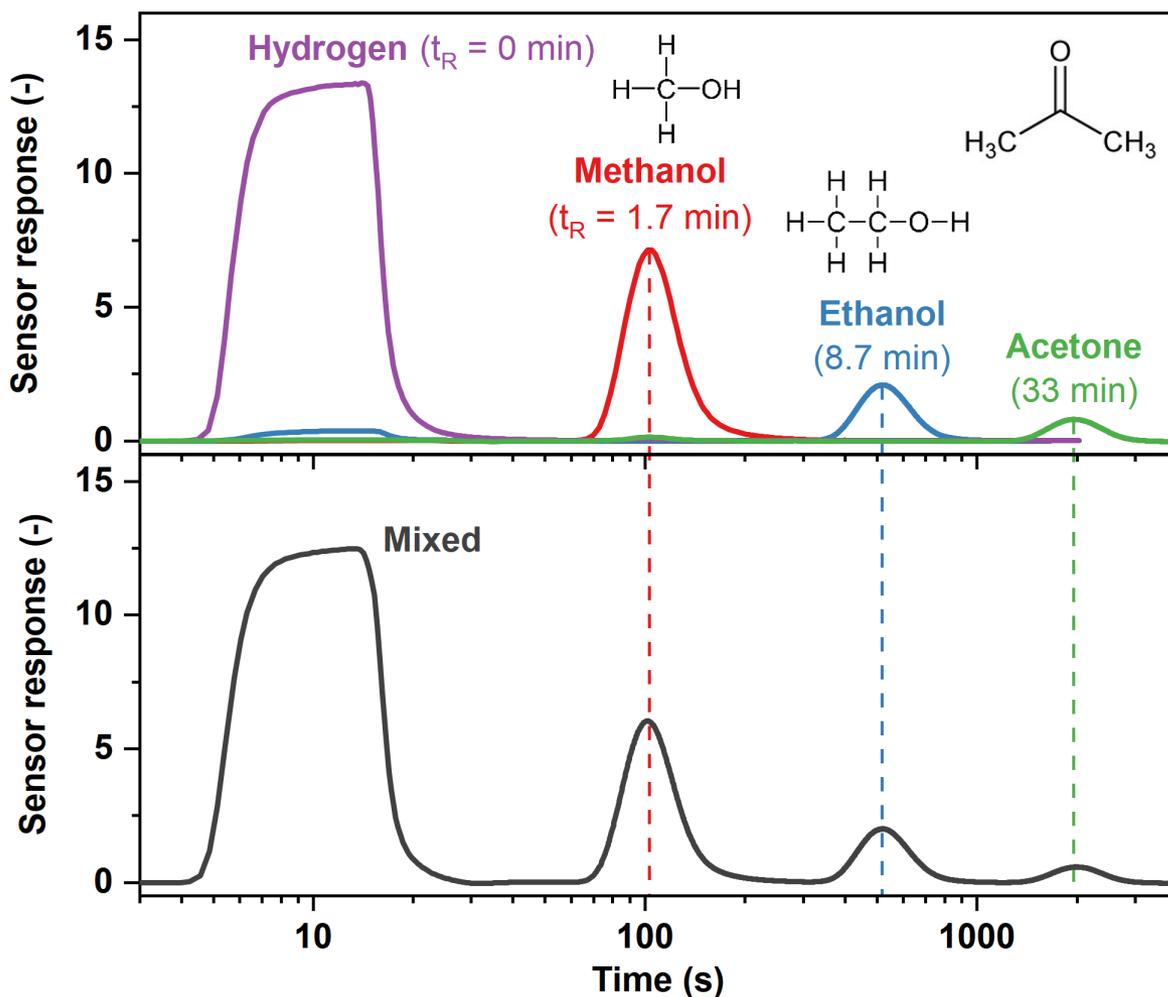


Concept of Gas Sensing Device

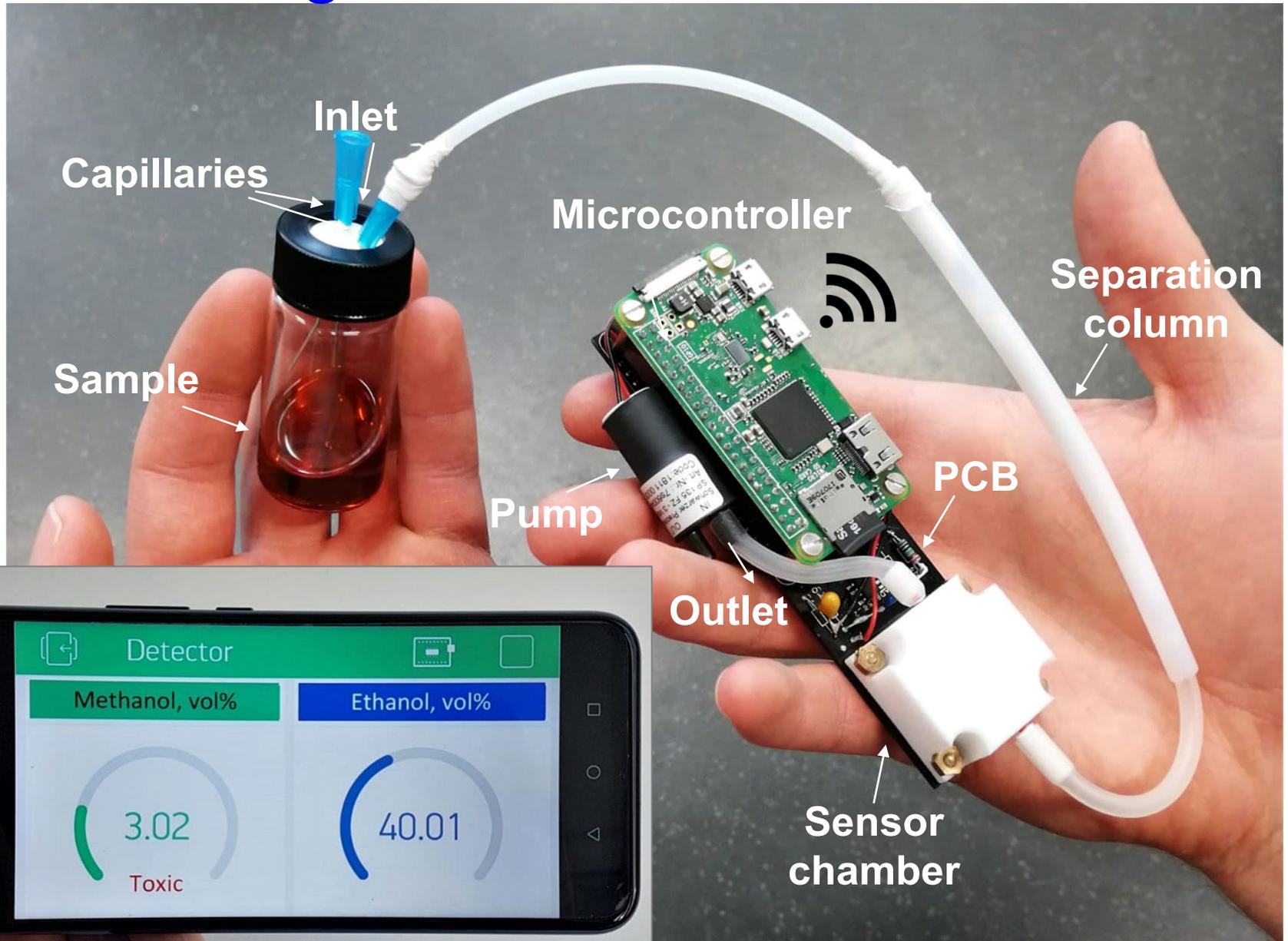
Sensor only



With separation column

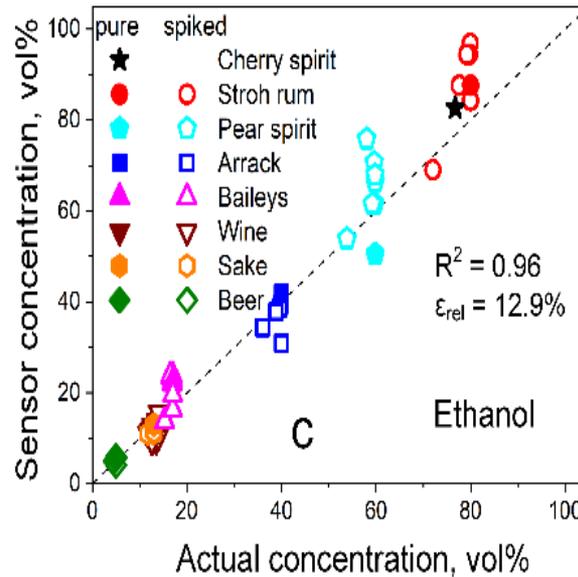
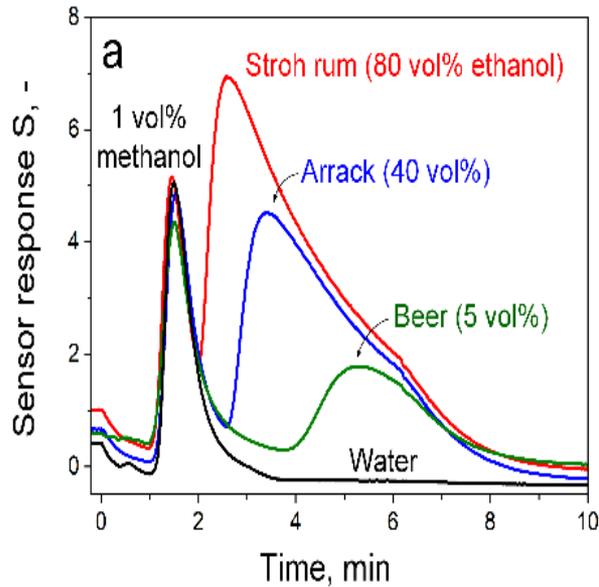


Sensing Device for Methanol Detection

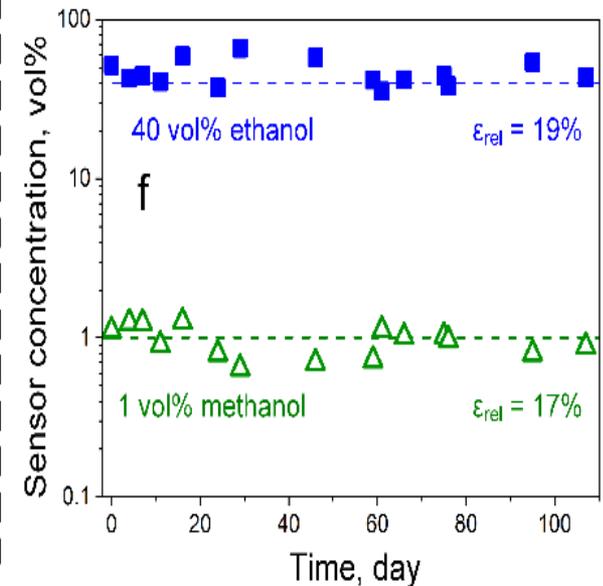
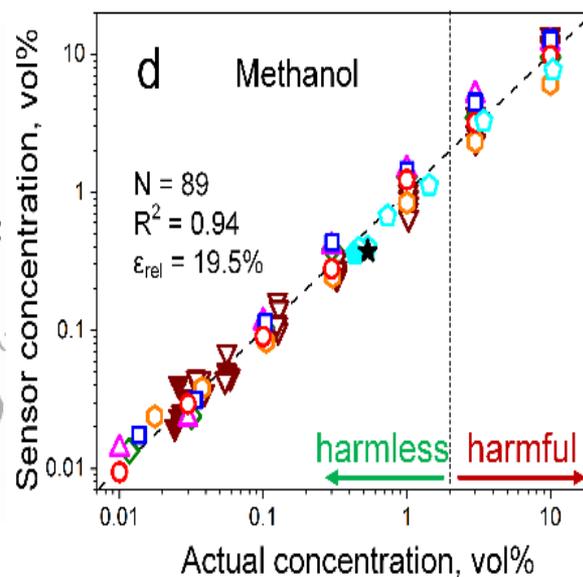
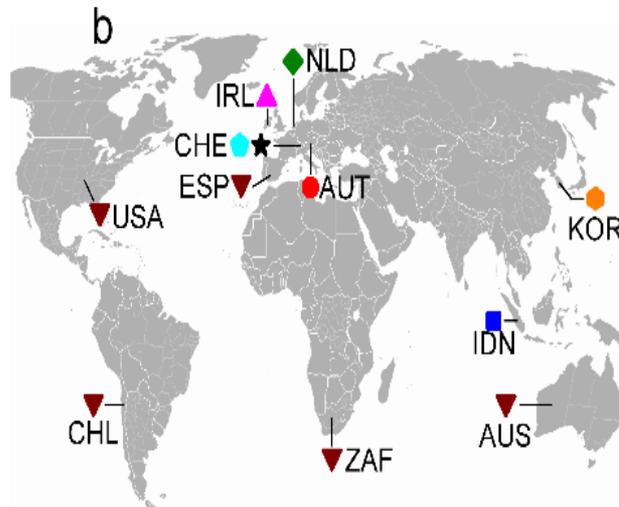
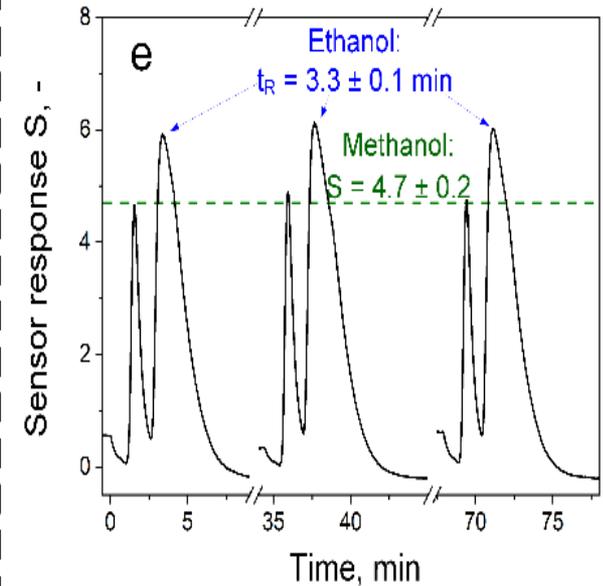


Detection of Methanol in the presence of Ethanol

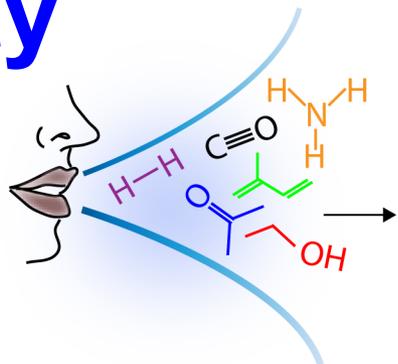
Real beverages



Reproducibility & Stability

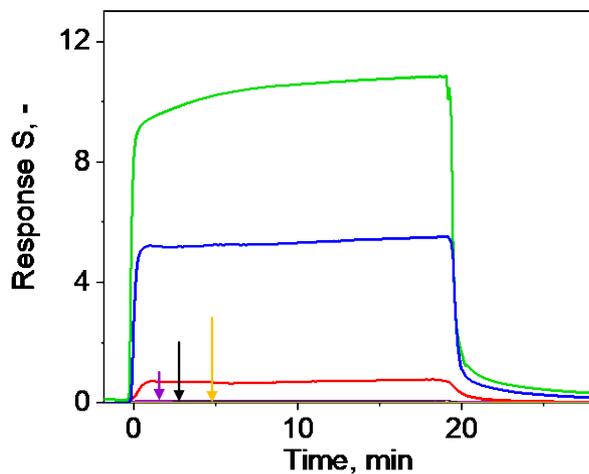
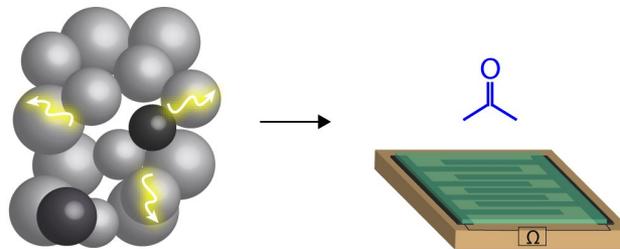


Reactivity

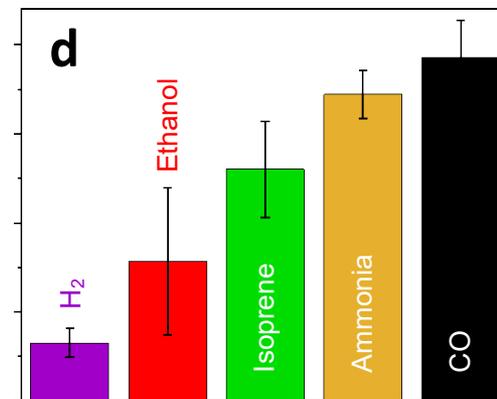
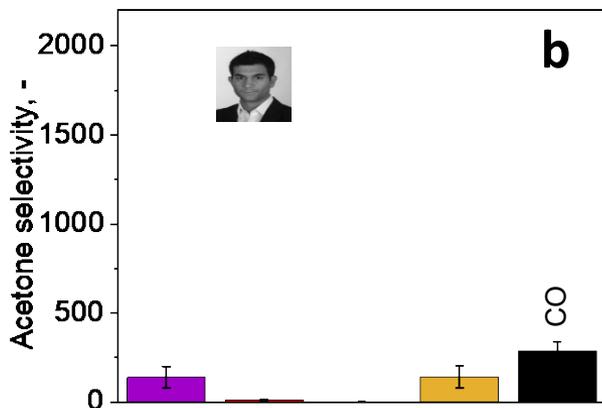
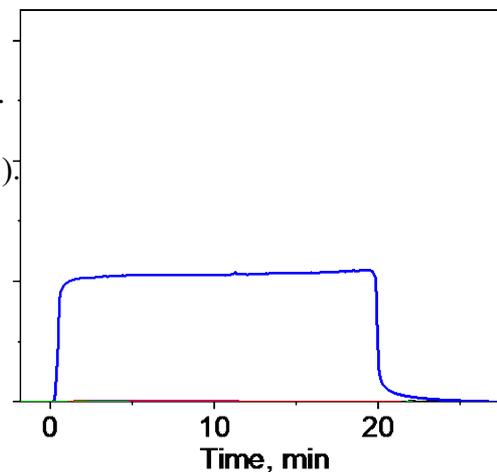


Flame-made¹
Pt/Al₂O₃

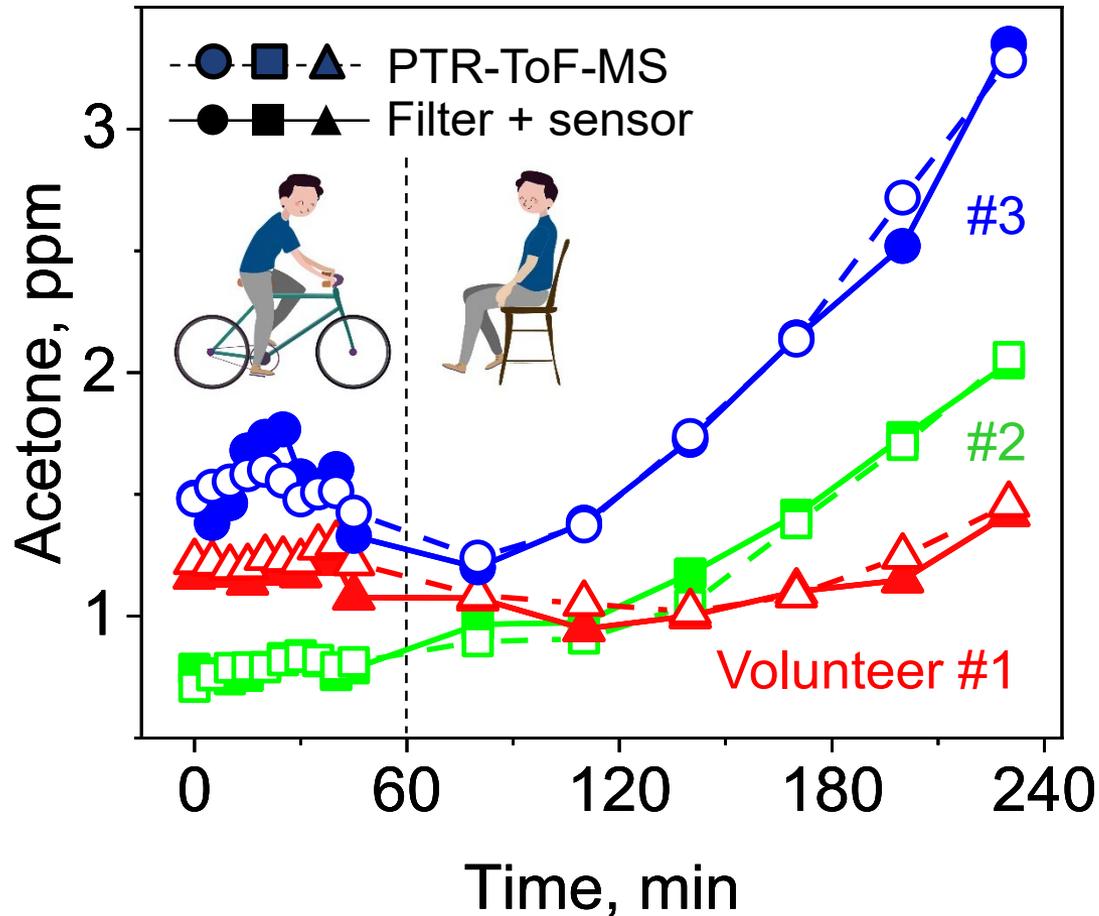
Flame-made
Si/WO₃



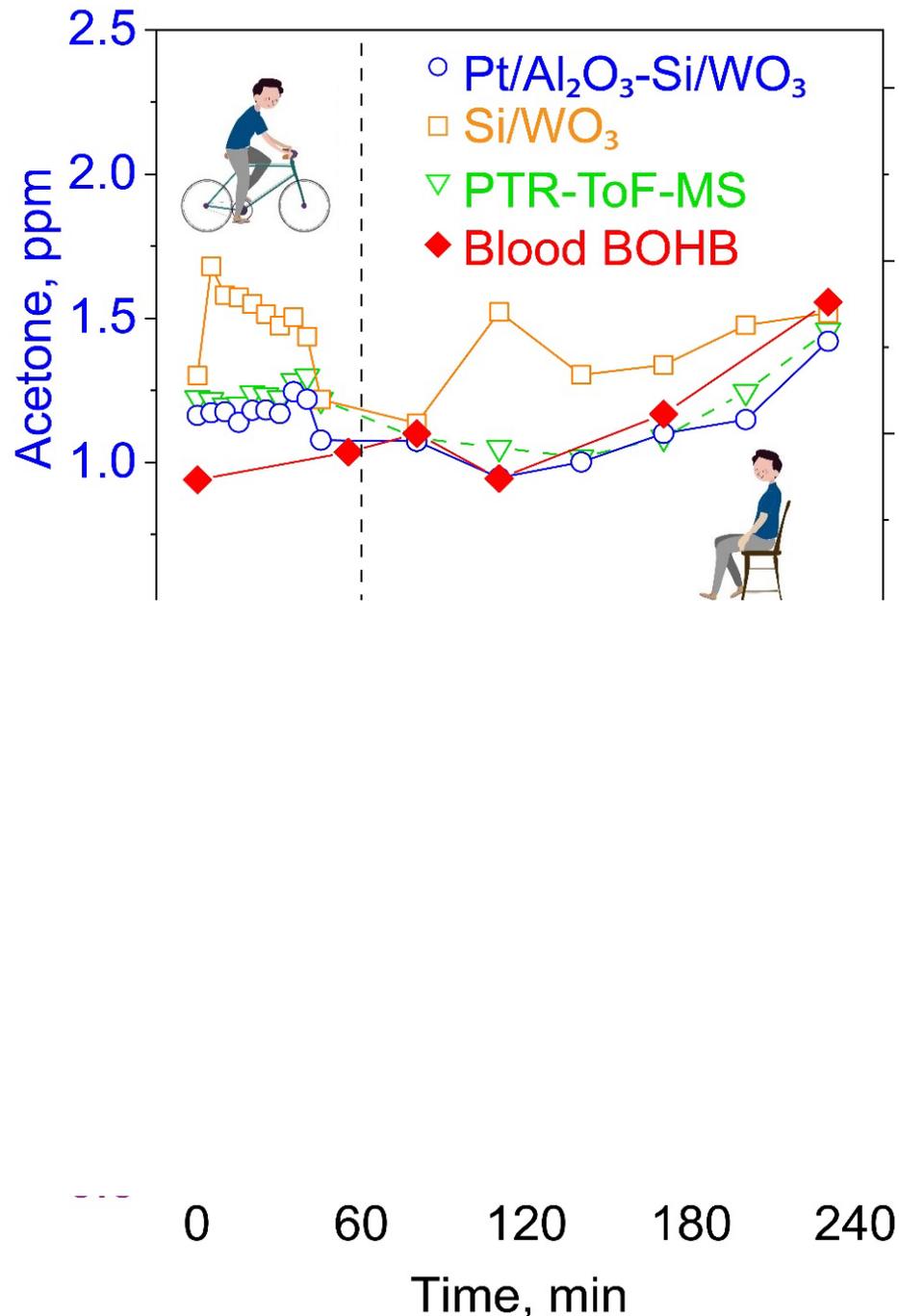
1. R. Strobel, W.J. Stark, L. Maedler, SEP, A. Baiker *J. Catal.*, **213**, 296-304, (2003).



Monitoring Individual Metabolic Changes

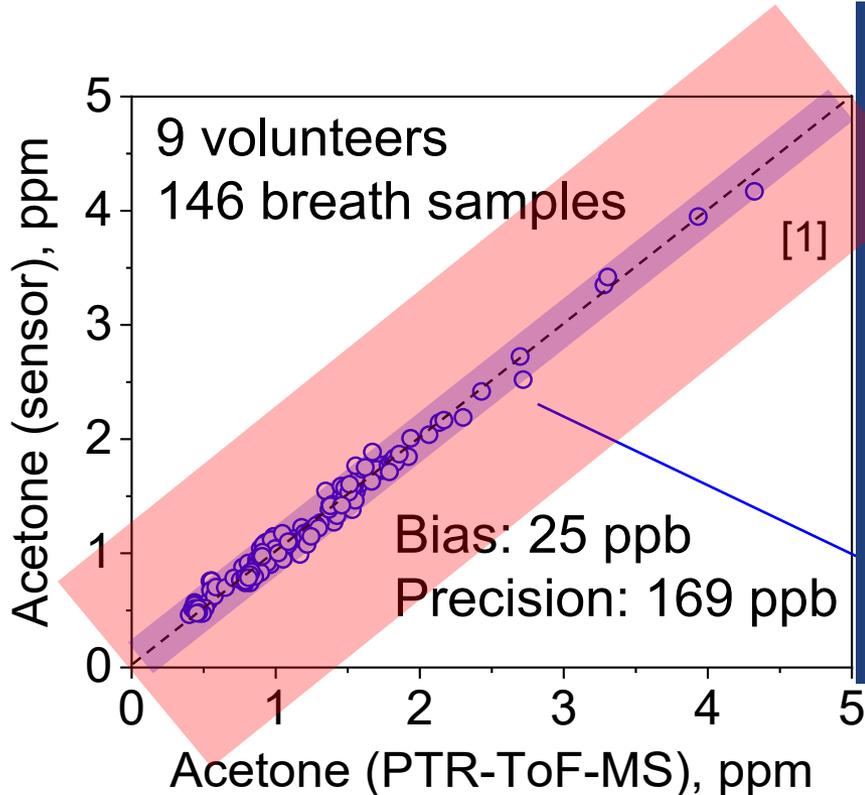


Monitoring Lipolysis from Breath Acetone



- Isoprene spikes during exercise^[1]
- Ethanol from hand disinfection

Statistical Evaluation



Intermittent fasting
Randomized clinical trial
72 volunteers



UniversitätsSpital
Zürich

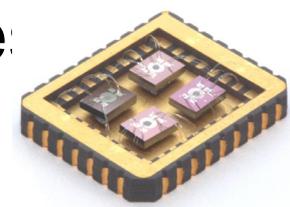
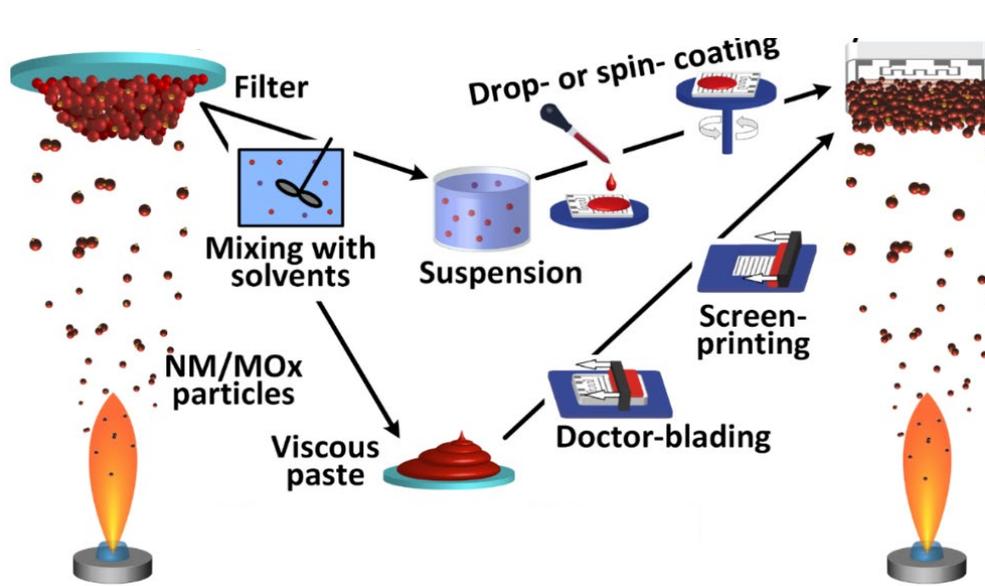
Bias: systematic measurement error^[2] **Precision:** 2 x standard deviation^[3]

1. Weber IC, Derron N, Königstein K, Gerber PA, Güntner AT, Pratsinis SE. *Small Science*, **2021**, 2100004
2. JCGM, BIPM, The international vocabulary of metrology—basic and general concepts and associated terms (VIM), 3rd ed, **2012**.
3. M. Thompson, *Anal. Methods* 2012, 4, 1598.
4. Toyooka T, Hiyama S, Yamada Y, *J. Breath Res.* **2013**, 7, 036005.
5. Landini BE, Bravard ST, *IEEE Sens. J.* **2009**, 9, 1802
6. Kundu SK, Bruzek JA, Nair R, Judilla AM, *Clin. Chem.* **1993**, 39, 87
7. LEVL, <https://levlnow.com>, accessed 11.01.2022

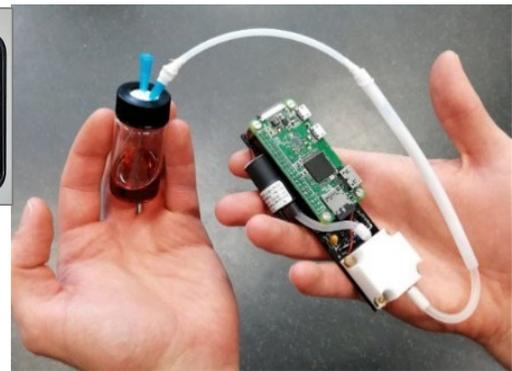
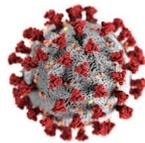
Conclusions

Quantitative understanding of aerosol-made particle formation enables process scale-up and innovation.

Aerosol-made particles facilitate synthesis of novel biomaterials and enable the assembly of device:



Highly-selective sensing devices are made by flame aerosol technology.



Methanol is quantified in **liquor, sanitizers & breath** in the presence of much more ethanol

Thank you for listening!



Aletsch Glacier, Fieschalp → Riederalp → suspension bridge → Belalp *Switzerland*

Psalm (102) 103:2 → Εὐλόγει, ἡ ψυχὴ μου, τὸν Κύριον καὶ μὴ ἐπιλανθάνου πάσας
τὰς ἀνταποδόσεις αὐτοῦ

Bless the Lord, O my soul, and forget not all His benefits