Project number 327341
ACT – Accelerating CCS Technologies

SPRINT 4: How to address, interact and act on the main knowledge gaps related to emissions

SCOPE overview – Emissions monitoring, control and mitigation

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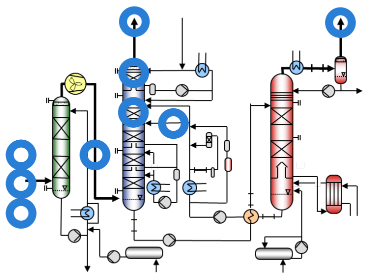
SCOPE – Emissions monitoring, control and mitigation

Demonstration of emission management technologies at capture pilot plants

- **Validated models** to **predict volatile** and **aerosol-based emissions**
- **Reliable process** and **operational data, sample analysis, operational** and **maintenance costs** from tests at
  - **6 industrial sites**
  - for the assessment of the **performance of >20 configurations of emission mitigation technologies for volatile and aerosol-based emission**
- Dependence of emissions on
  - **solvent** (MEA, CESAR1, MDEA/PZ, CDRmax)
  - **solvent aging** (500 – 30,000 testing hours without exchange of the solvent inventory)
  - **flue gas properties** (content of CO_2, O_2, trace components, particle number concentration and particle size distribution)
  - **capture rate** (90%-95%)
  - **plant operation** (stationary and dynamic behaviour)



- **Water wash**
- **Acid wash**
- **Double water wash**
- **Flue gas pre-treatment**
- **Wet Electrostatic Precipitator (WESP)**
- **Dry bed**
- **Brownian Demister**
- **Lean loading tuning**
- **CO_2 quality monitoring**

Demonstration of emission management technologies at capture pilot plants – Team, flue gas sources, and solvents

Hengelo (Twence)

Waste-to-energy plant: 500 kg CO_2/h
Solvent: 30% **MEA** and **CDRmax**
Flue gas: CO_2 9.5 vol.-%, O_2 8.3 vol.-%,
24/7 operation

Alkmaar (HVC)

Waste-to-energy plant: 540 kg CO_2/h
Solvent: **MDEA/Piperazine** blend
Flue gas: CO_2 15,3 vol.-%, O_2 5,6 vol.-%,
24/7 operation

Niederaussem (RWE)

Lignite-fired power plant: 300 kg CO_2/h
Solvent: **CESAR1**
Flue gas: CO_2 15.2 vol.-%, O_2 5.0 vol.-% and **mimicked flue gas from gas turbine/sewage sludge combustion**: CO_2 4 vol.-%, O_2 15.0 vol.-%
24/7 operation

Vindyachal NTPC

Hard coal-fired power plant: 830 kg CO_2/h
Solvent: **CDRmax**
Flue gas: CO_2 ~ 11.8 vol.-%, O_2 8.2 vol.-%,
Campaign operation

Tiller CO_2 Lab (SINTEF IND)

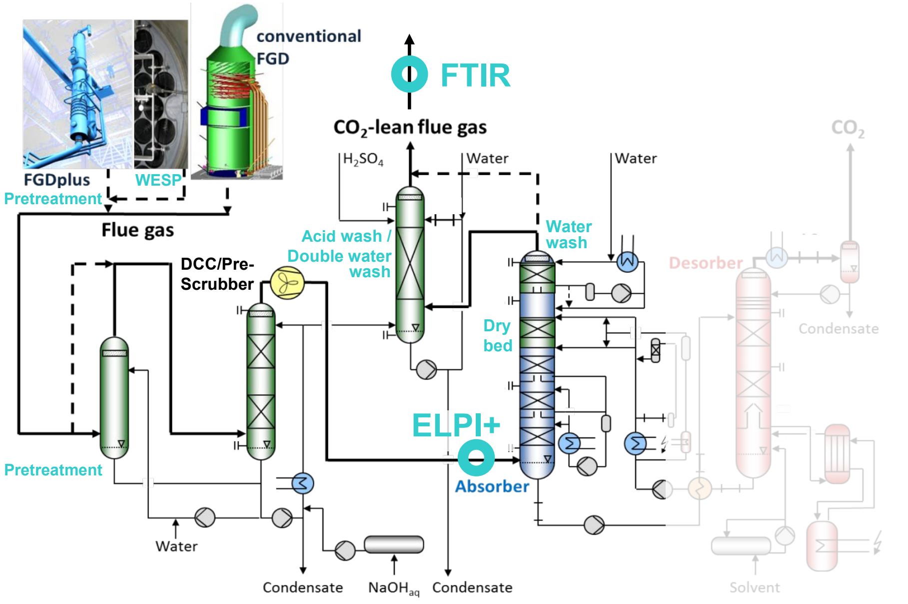
Biomass/propane: 30-40 kg CO_2/h
Solvent: **CESAR1**
Flue gas: CO_2 11 vol.-%, O_2 4 vol.-%,
Campaign operation

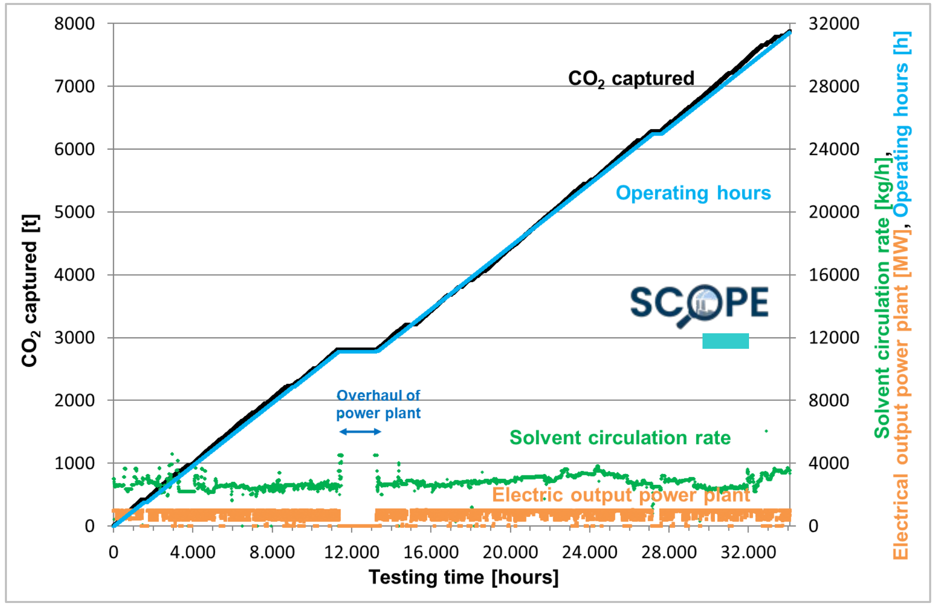
Tuticorin site

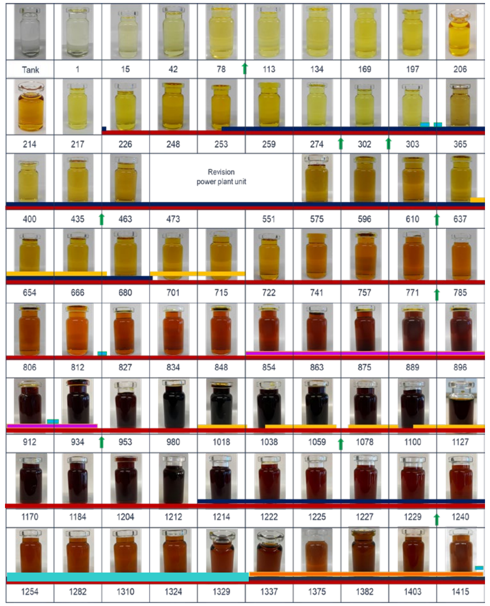
Alkali chemicals and fertilizers: 60 kt CO_2/a
Solvent: **CDRmax**
Flue gas: CO_2 ~ 12 vol.-%, O_2 8 vol.-%,
24/7 operation

Test of emission mitigation technologies for CESAR1 at Niederaussem

- Flue gas source: 1,000 MW **lignite**-fired power plant
- Operation mode: **24/7**, 300 kg_{CO2}/h@90% capture rate, 120-130°C/1.75-2.4 bar(a)
- Solvent: **aged CESAR1**, aqueous blend of 3.0 M AMP and 1.5 M PZ
- Test of more than **20 configurations of emission mitigation technologies** for **aerosol-based** and **volatile emissions** (water wash, double water wash, acid wash, dry bed (OASE aerozone®), pretreatment, WESP)
- Start of measuring campaign: **after 29,800 testing hours** (1,242 days) **without inventory exchange**

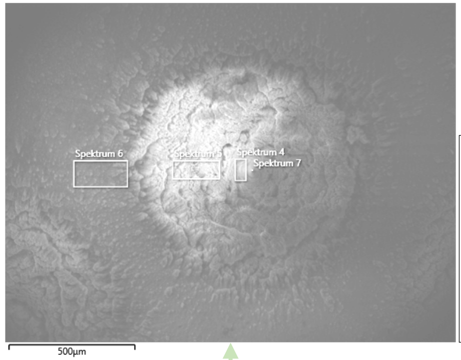




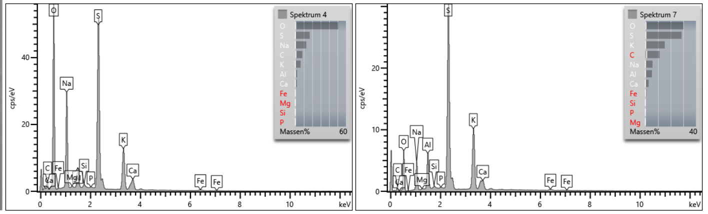


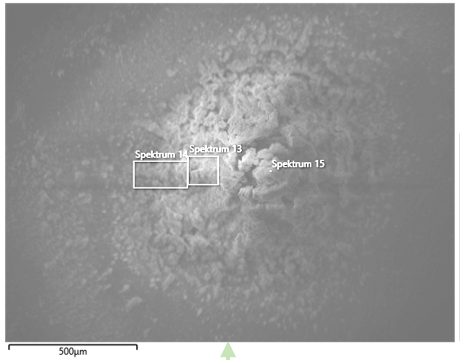
Generation of aerosol nuclei by the WESP and their investigation

- **Macroscopic amounts of aerosol nuclei could be sampled** at the inlet of the CO_2 absorber
- Analysis of samples by **SEM/EDX**
- The **solid material** consists mainly of **Na, S, and O** ($Na_xS_yO_x$, most likely **Na_2SO_4**)
- **Results confirm former analysis** data of single particles

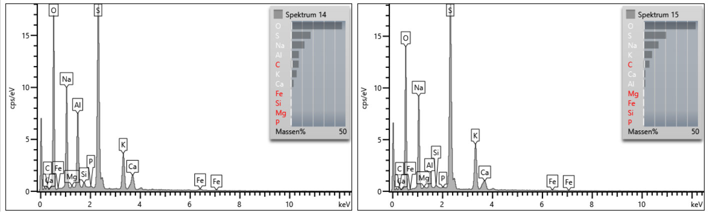


4 days particle collection
SEM/EDX collector plate 6 (0.147 µm)





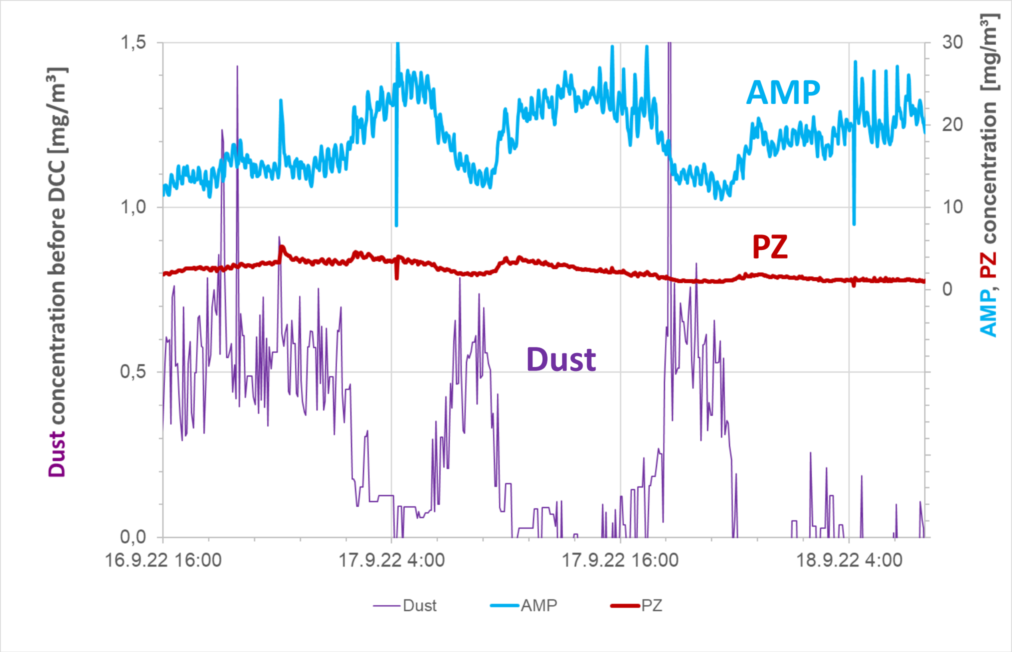
4 days particle collection
SEM/EDX collector plate 7 (0.249 µm)

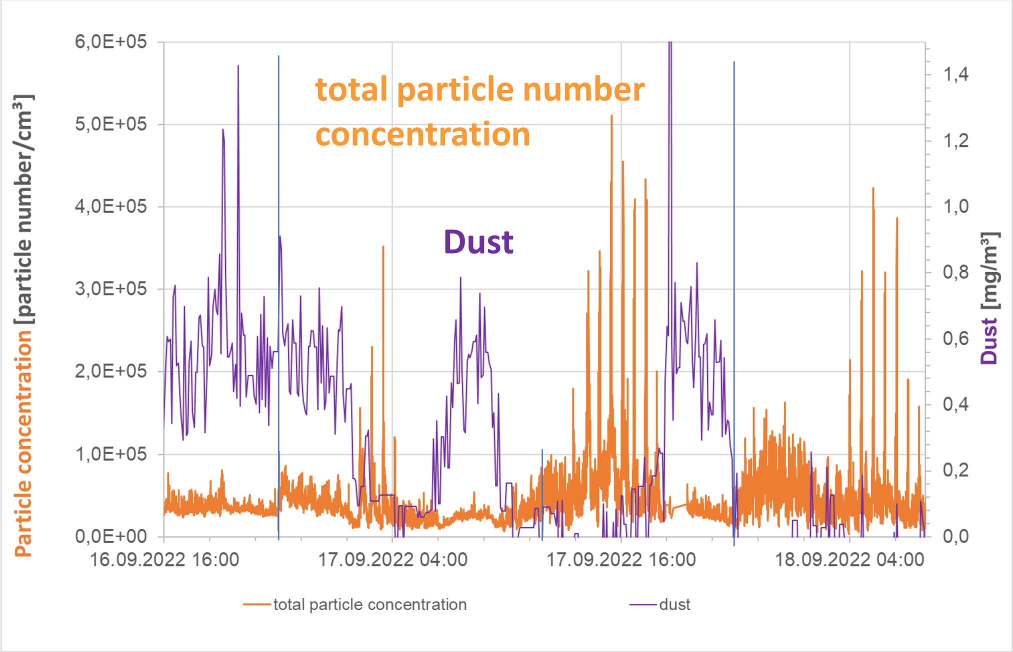


0.0265 µm | 0.0485 µm | 0.087 µm | 0.147 µm | 0.249 µm | 0.377 µm | 0.601 µm | 0.951 µm | 1.64 µm | 2.5 µm

Particles and aerosol-based emissions - Particle number concentration and size distribution

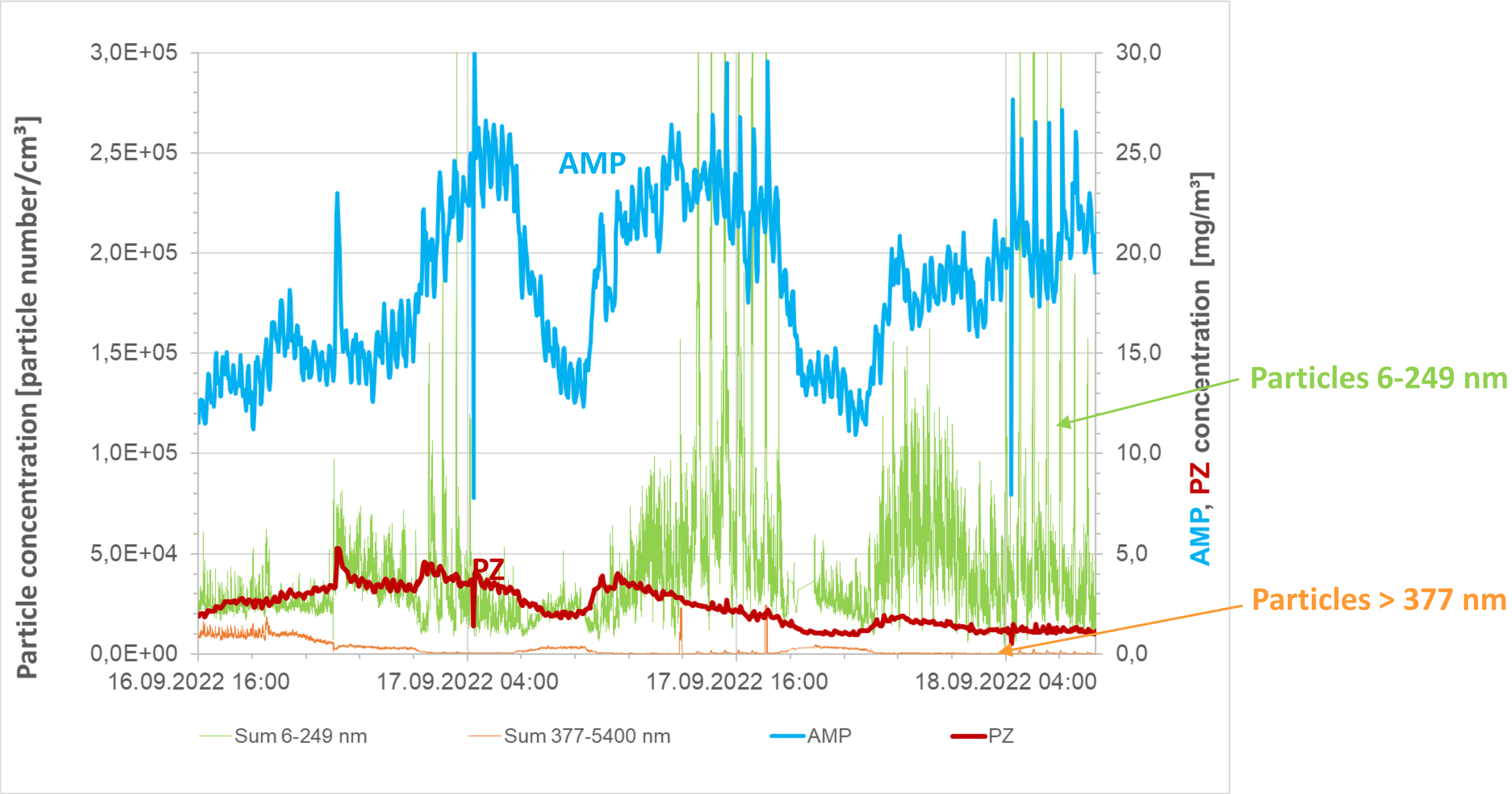
- Seldom the **amine emissions** are anticorrelated with de **dust** concentration in the flue gas before DCC, but more often a positive correlation becomes apparent. However, **the dust concentration in the flue gas is no reliable measure for the likelihood of increased amine emissions**
- Additionally, also the **total particle number concentration** [particle number/cm³] might be anticorrelated with the **dust** concentration [mg/m³]



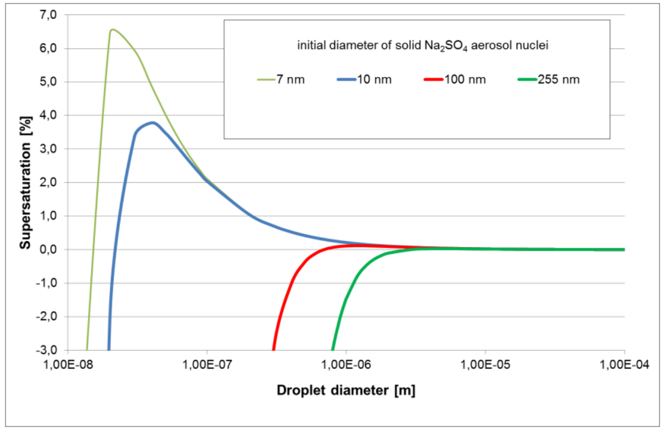


Particles and aerosol-based emissions - Particle number concentration and size distribution

- Generally, the **particle number concentration of the smaller fraction of particles < 249 nm** is correlated with the **amine emissions**



Growth of aerosol droplets as a function of relative humidity / supersaturation is described by the Köhler equation and comprises a **curvature term ~1/d** and a **solute term ~-1/d³**

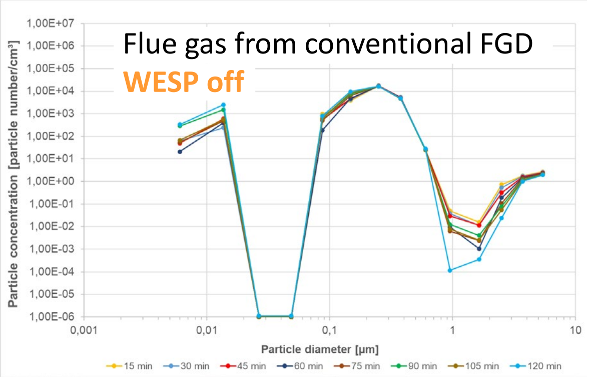


from Moser et al., "Solid Particles as Nuclei for Aerosol Formation and Cause of Emissions – Results from the Post-combustion Capture Pilot Plant at Niederaussem", Energy Procedia, 114, 2017, 1000-1016 https://doi.org/10.1016/j.egypro.2017.03.1245

Generation of aerosol nuclei by the WESP upstream the CO_2 absorber

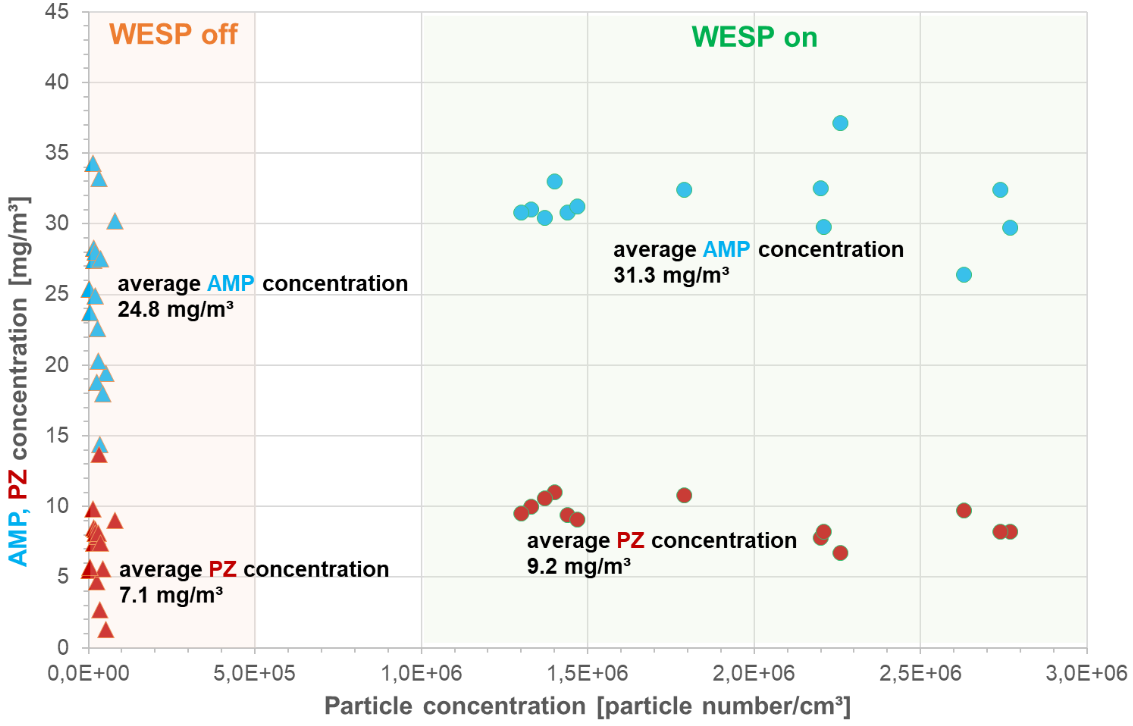
29 Repeat measurements for the benchmark for emission mitigation: Water wash

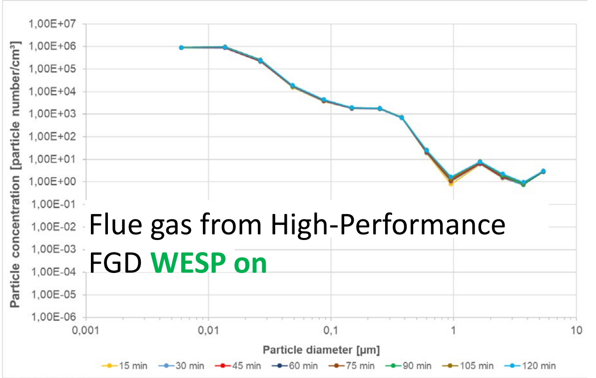
- Operating voltage of the **WESP** (wet electrostatic precipitator) **~35 kV**
- Investigation of aerosol-based emissions by **ELPI+** (14 size classes, diameter 6-5,400 nm), **FTIR** (uncertainty ± 3 % relative)
- As expected, the **WESP** causes **increase of the particle number concentration from ~10^4 to ~10^6 particles per cm^3** by the **formation of small particles <0.1 µm** and **increase of the amine emissions >25%**



WESP off

average (157 hours, 16 tests)
of particle concentration
2.8×10^4
particle number/cm³



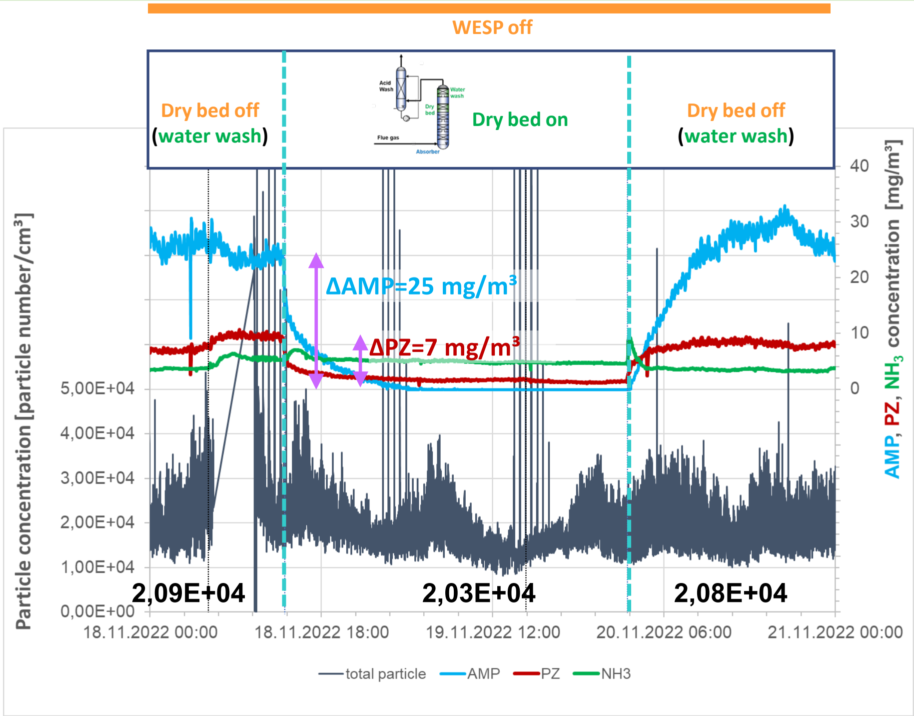


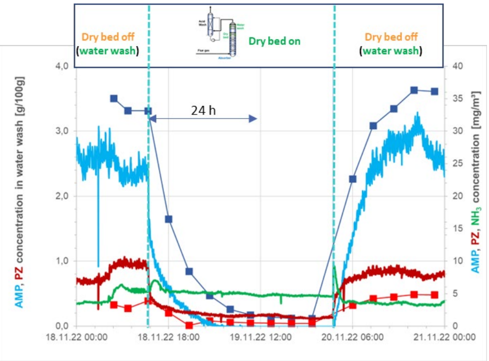
WESP on

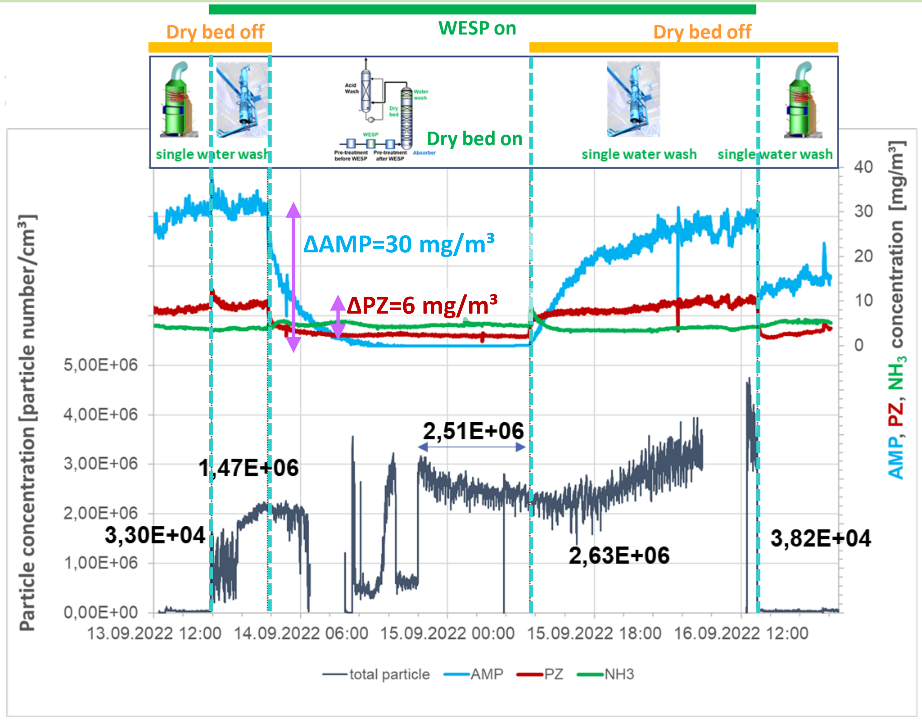
average (101 hours, 13 tests)
of particle concentration
1.9×10^6
particle number/cm³

Control of volatile and aerosol-based emissions - Example: Dry bed

- **Strong reduction of volatile and aerosol-based emissions of AMP and PZ** by the **dry bed**
- **No effect on emission of NH_3**
- Recommendation: **sufficient testing times** of **2-4 days** for individual tests to be able to evaluate the real effects after the amine concentration in the water wash has achieved **steady state**

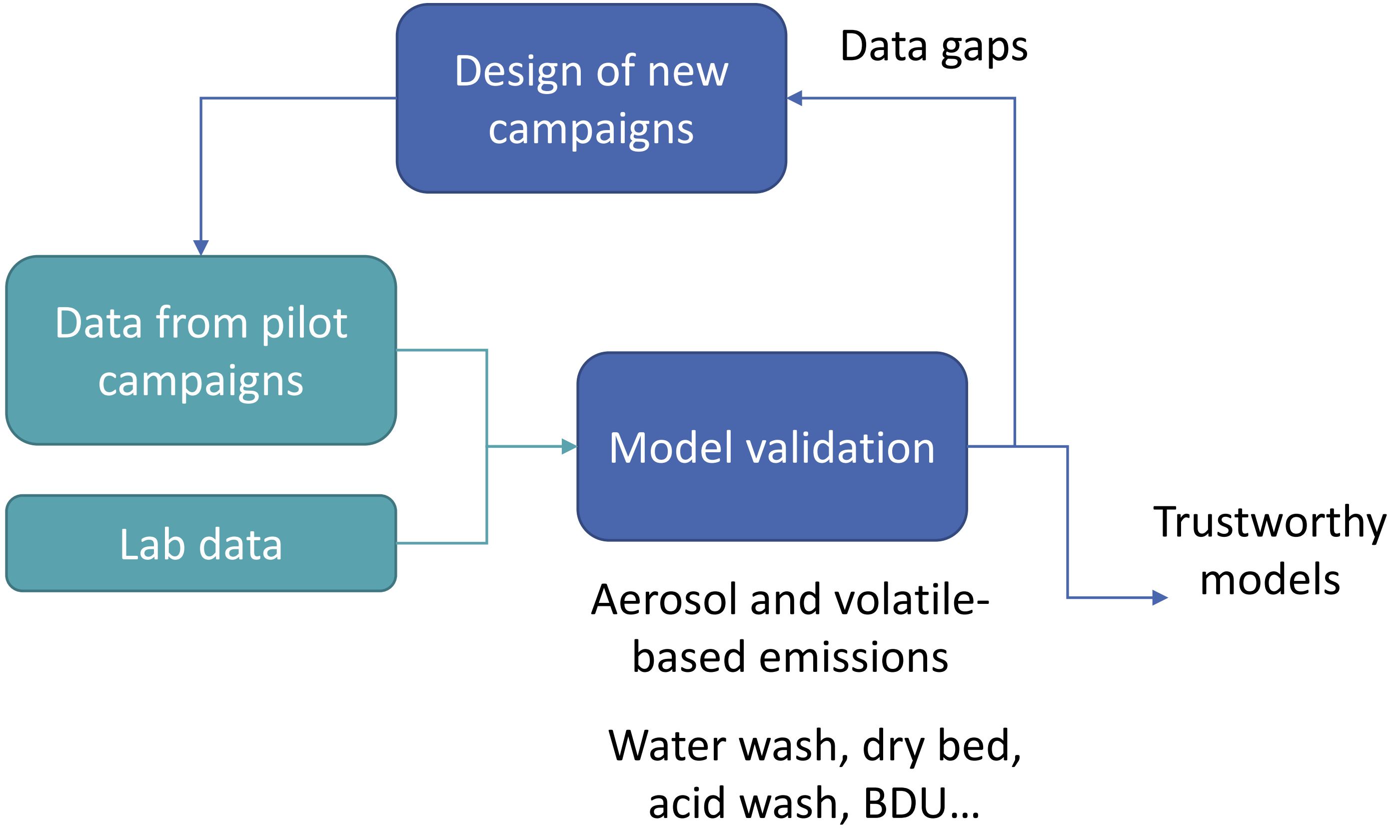






We are producing a lot of data… How do we turn that into applied knowledge?

What to do with data? Put it into models!



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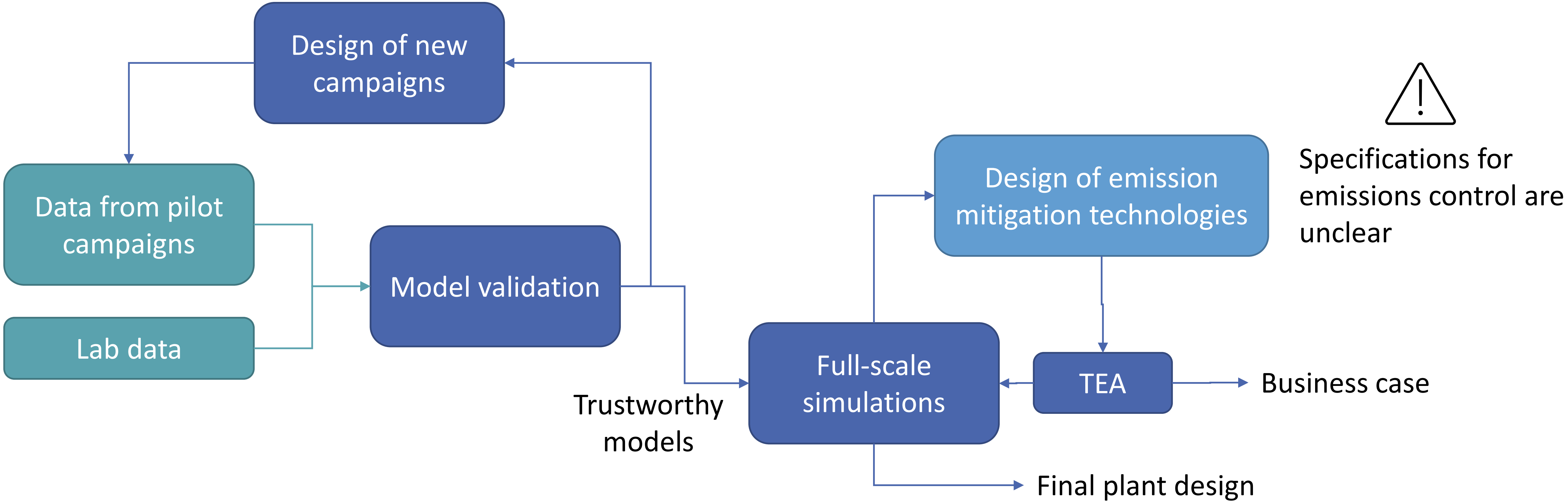

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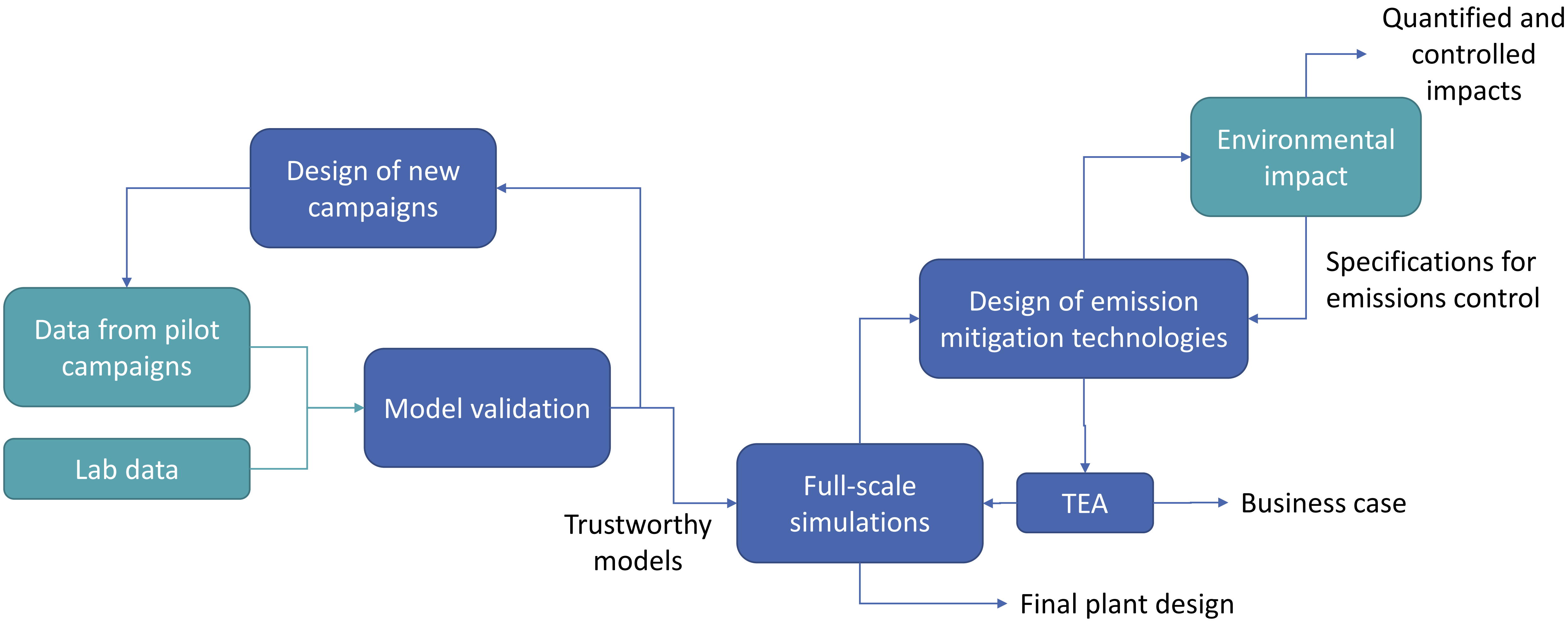


The results from these modelling activities will allow to:

✓ Issue permits with confidence

- Experimental data
- Models
- Literature

✓ Deploy amine-based CO_2 capture at scale

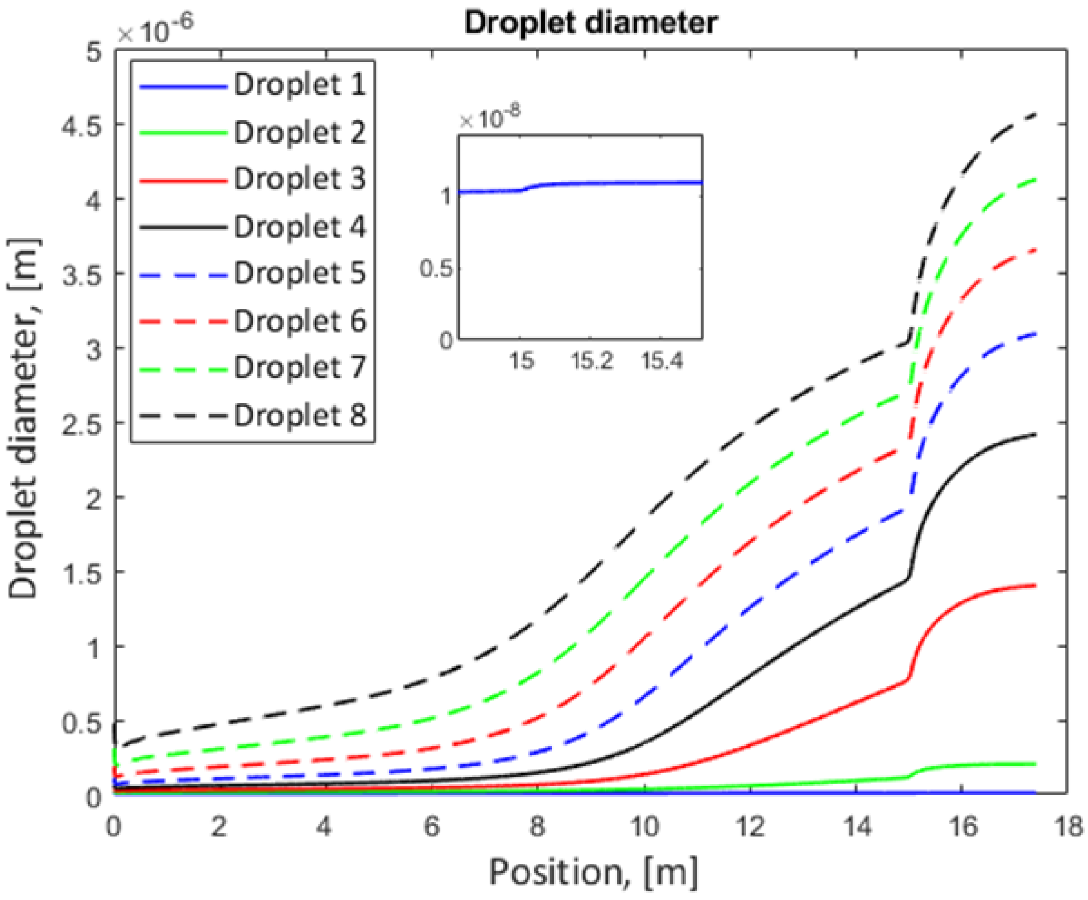
Aerosol and Volatile Emissions modelling

TCCS, June 2023

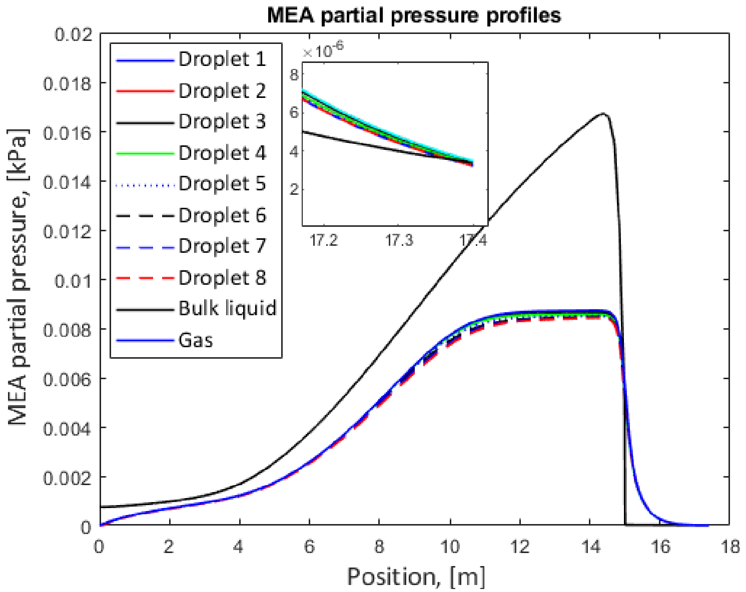
H. F. Svendsen and H. K. Knuutila. Comparison between a distribution function based and a class-based aerosol model.

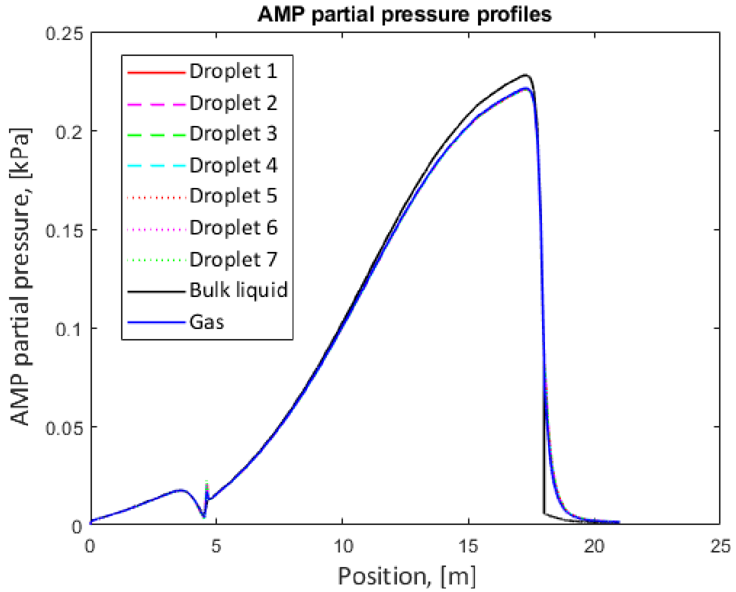
P. Moser and M. François. Volatile and aerosol-based emissions of aged CESAR1 and their mitigation - measurement and simulation.

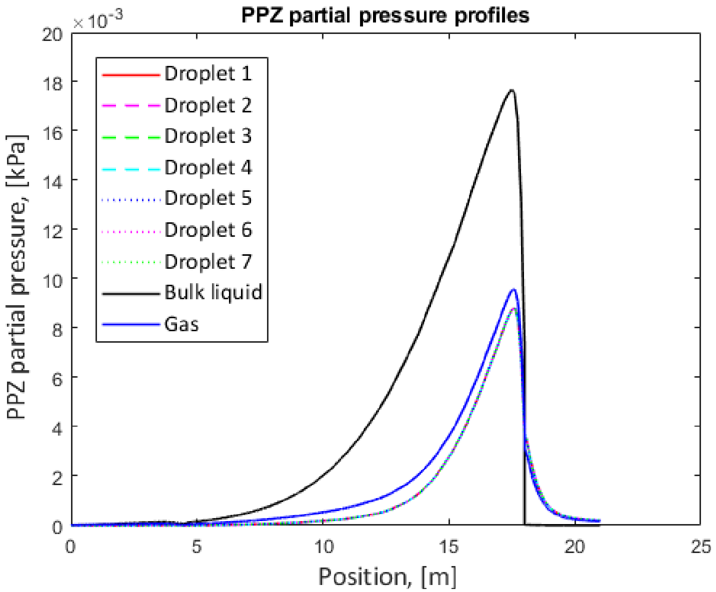
Aerosol and Volatile Emissions modelling



Aerosol and Volatile Emissions modelling







MEA emissions

CESAR1 emissions

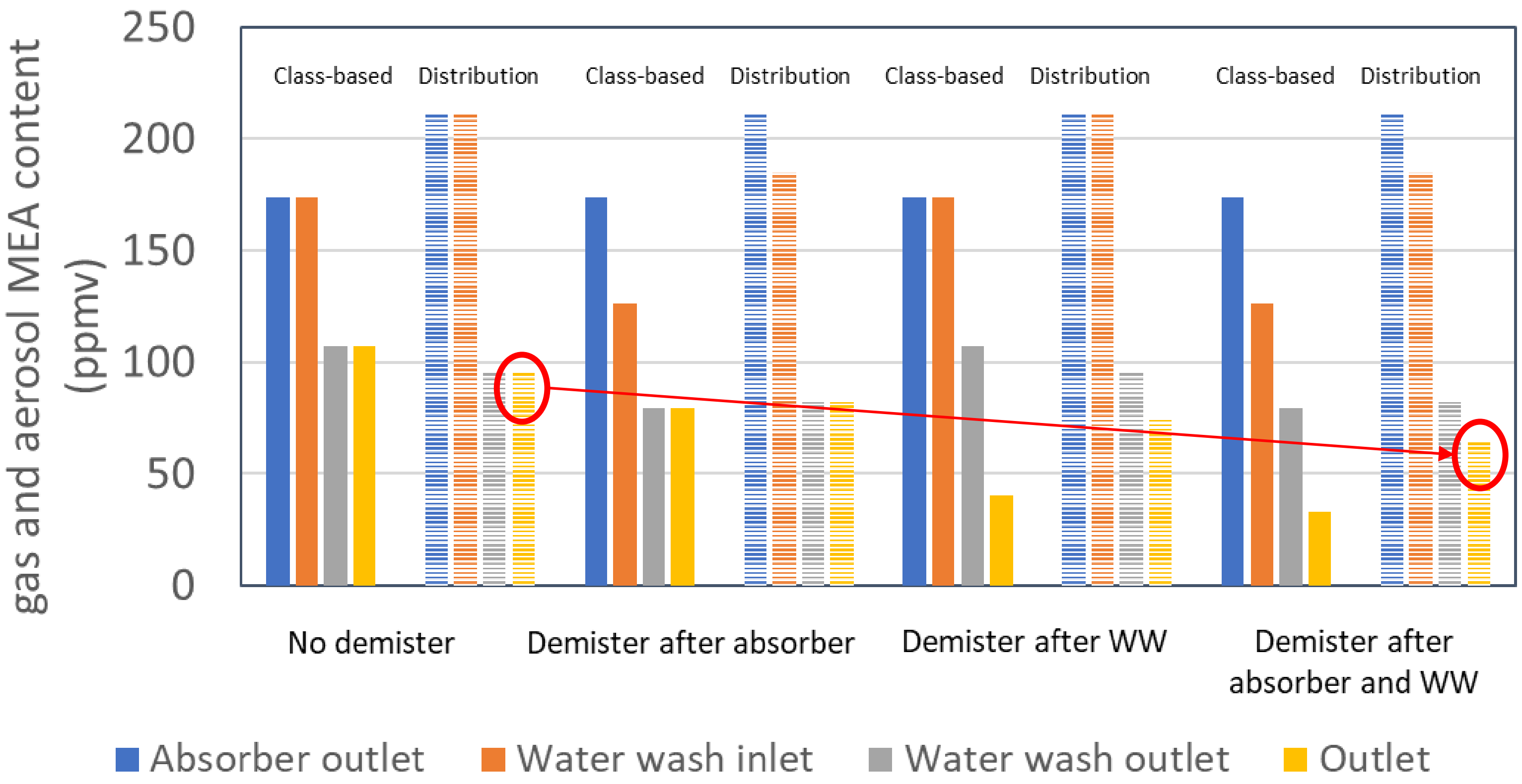
Aerosol and Volatile Emissions modelling

Which classes of particles are responsible for aerosol MEA emissions?

Inlet droplet diam., nm	9	19	36	64	110	190	310	480
Outlet droplet diam., nm	11	204	1401	2412	3088	3650	4123	4558
Outlet droplet no. #/m3	$5.2\ 10^{11}$	$4.32\ 10^{11}$	$3.85\ 10^{11}$	$1.86\ 10^{11}$	$1.11\ 10^{11}$	$5.05\ 10^{10}$	$1.18\ 10^{10}$	$3.70\ 10^{8}$
% aerosol emission out	~0	0.001%	9.8 %	24.7%	31.9%	24.8%	8.5%	0.4%

This can guide the design of mitigation technologies (demister, filters,…)

Aerosol and Volatile Emissions modelling



Demisters contribute to lower aerosol-based emissions, but are not sufficient

Aerosol and Volatile Emissions modelling

In the absence of WESP-generated particles:

Emissions in mg/Nm^3	Only WW		Dry bed + WW	
	AMP	PPZ	AMP	PPZ
Experimental	26-28	8-9	~0	1.5
Model, aerosol	~0	~0	~0	~0
Model, gas phase	45.5	7.2	1.0	0.7

Model explains the volatile CESAR1 emissions (AMP, PZ) relatively well. Deviations come from uncertainties in the experiments, as well as the thermodynamic model

Aerosol and Volatile Emissions modelling

With WESP-generated particles:

Emissions in mg/Nm^3	Only WW		Dry bed + WW	
	AMP	PPZ	AMP	PPZ
Experimental	29-30	9-10	~0	2.3
Model, aerosol	1	5.7	0.1	3.3
Model, gas phase	50.6	5.4	2.1	1.4

Model explains the aerosol emissions of AMP and PZ relatively well. Deviations come from uncertainties in the experiments, as well as the thermodynamic, kinetics and aerosol growth models

Acknowledgements

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