Gas emissions from thermal runaway and propagation of Li-ion battery cells in short stack and module experiments

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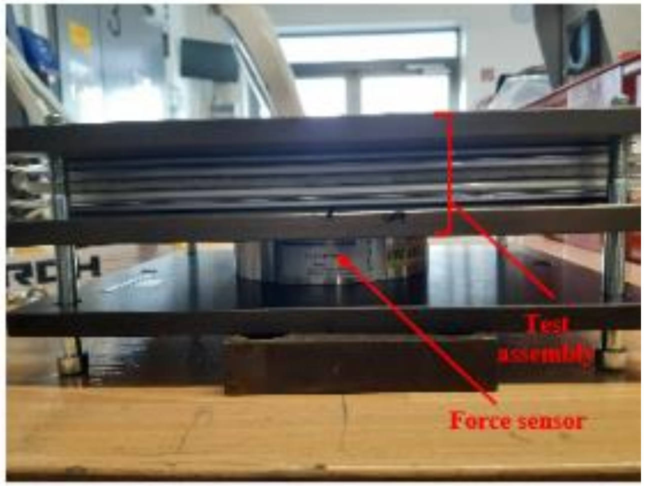
Introduction & Experimental settings

40Ah Ni-rich NMC/Graphite pouch cell extracted from a commercial electric vehicle

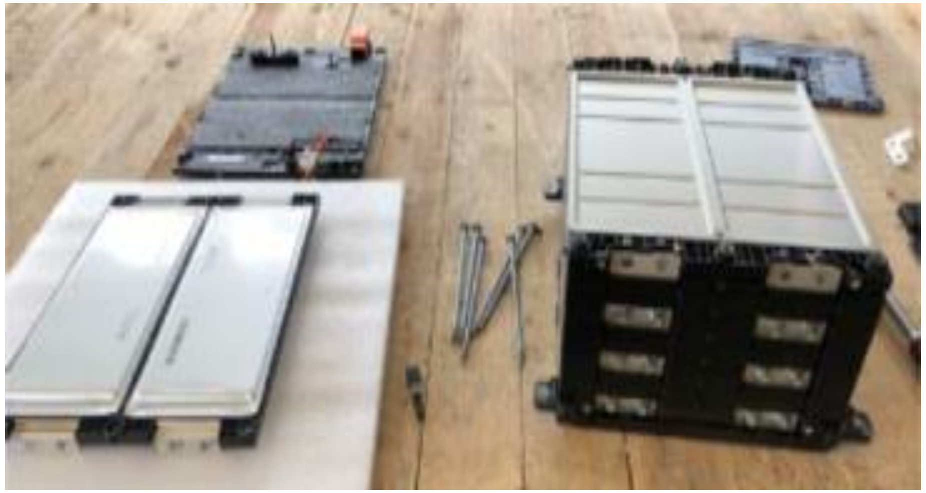
Thermal runaway (TR) and propagation experiments on

- 2-cell short stack (with ML17 insulating material, compression force of 1kN)
- 5-cell short stack (with ML 17 insulating material, compression force of 1kN)
- 10s2p modules



2-cell short stacks

5-cell short stacks

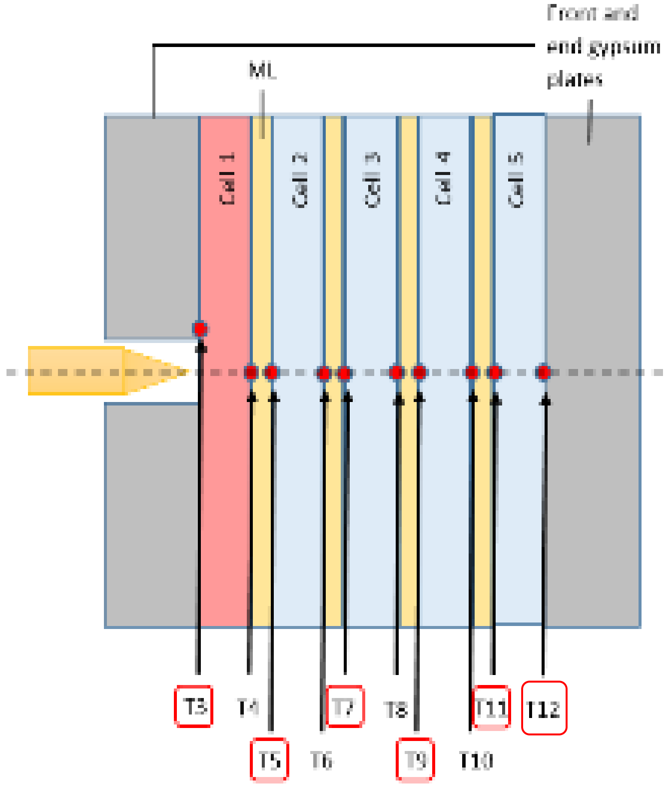


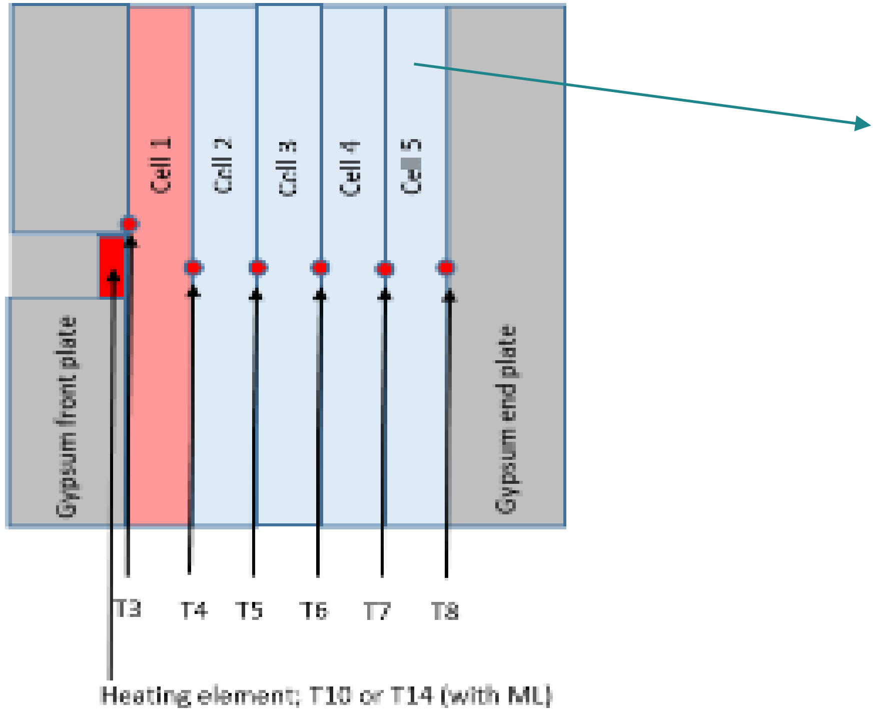
10s2p modules

Introduction & Experimental settings

Different TR triggering methods

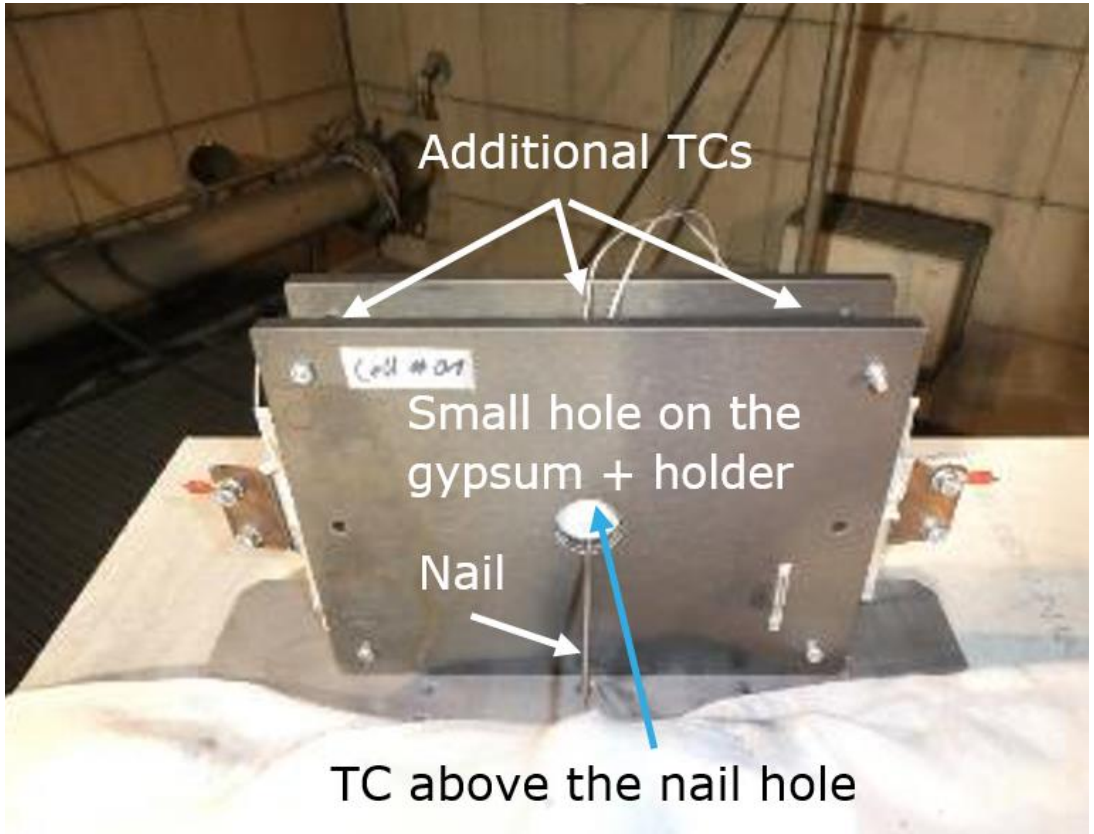
- Ceramic nail penetration – nail diameter: 3mm; circular cone tip angle: 30º, penetration velocity: 0.1mm/sec; criteria to stop: penetrate until event
- Rapid external heating (=TRIM or Canadian method) – target temperature: 600ºC, temperature increase rate: 50ºC/sec, criteria to stop: 600ºC until event



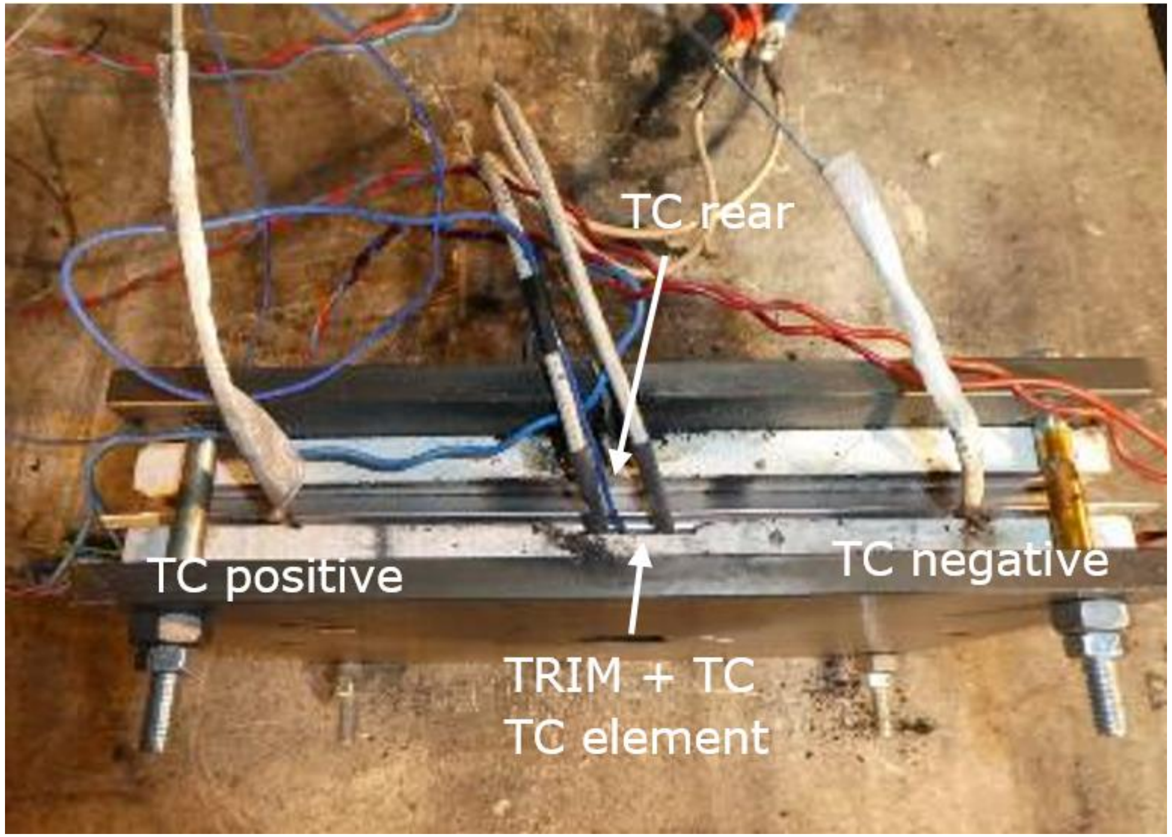


Remark: Image showing 5-cell stack without ML17 while it has been used in the testing campaign

Introduction & Experimental settings



Nail penetration setup

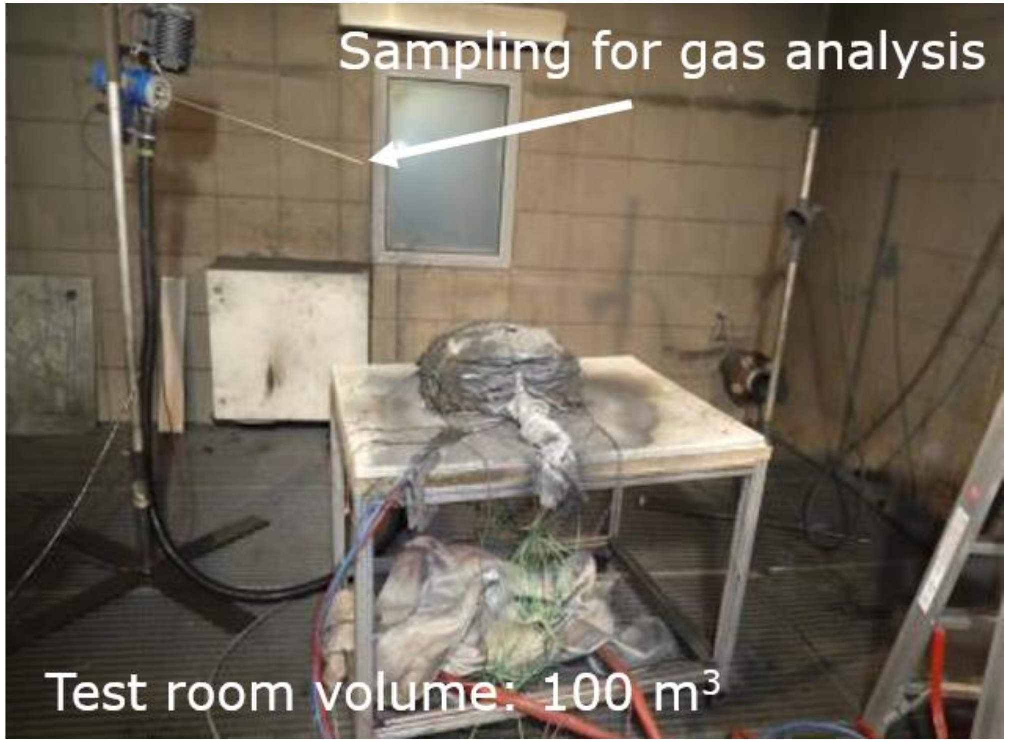


TRIM setup

Introduction & Experimental settings

2 complementary methods used to identify and quantify gaseous emissions: Fourier transform infrared spectroscopy (FTIR) and Gas Chromatography

- Test room volume: 100 m^3
- Delay time of sampling system: 25 s
- Sampling rate: 7 samples/min



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Introduction & Experimental settings

- 46 gas species evaluated from various classes:
    - ► Carbon monoxide, carbon dioxide
    - ► Hydrocarbons: e.g. methane, acetylene, ethylene, ethane
    - ► Alcohols: methanol, ethanol, phenol
    - ► Aldehydes/Ketones: e.g. formaldehyde, acetaldehyde, acrolein
    - ► Acid gases: e.g. hydrogen fluoride, hydrogen chloride
    - ► Carbonates: e.g. vinylene carbonate, ethylene carbonate
    - ► Fluorine-containing gases: e.g. carbonyl fluoride, fluoroform,
    - ► Phosphorus-containing gases: e.g. phosphine, dimethyl phosphite

Questions

- Is there any influence of initiation method on the composition of released gases?
- How does DUT size/architecture influence gas emissions (amount, composition)?
- Evaluation of potential adverse effects on human health upon exposure to the vent gas using Acute Exposure Guideline Levels (AEGL)*.

    ► AEGL-2 (30 and 60 min): airborne concentration (in ppm or mg/m^3) of a substance above which it is predicted that the general population, including susceptible individuals, could experience irreversible or other serious, long-lasting adverse health effects or an impaired ability to escape. In this case, the values corresponding to a short exposure period of 30 and 60 min have been selected.

    ► AEGL standards are appropriate for the evaluation of effects of acute and accidental exposure

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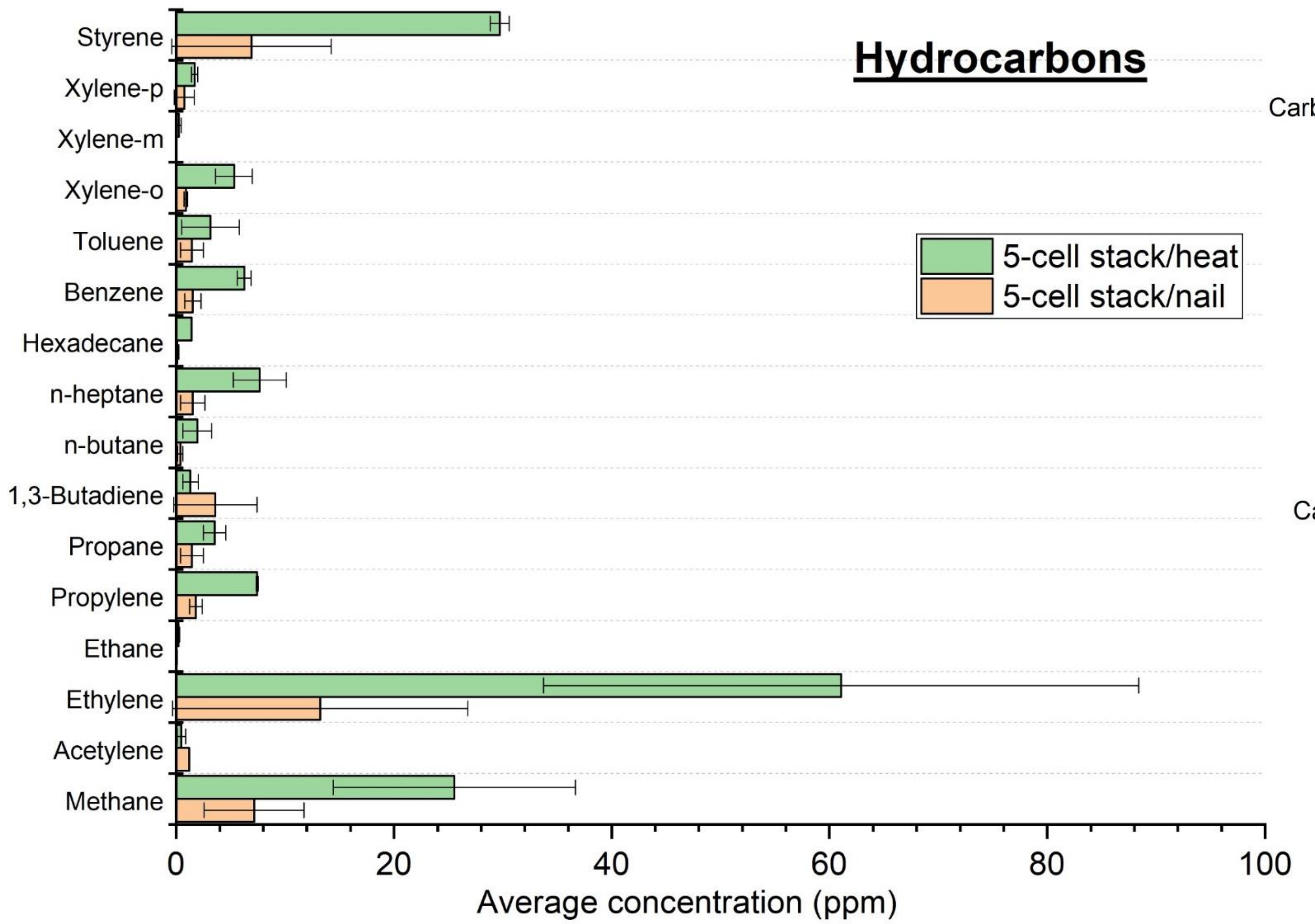
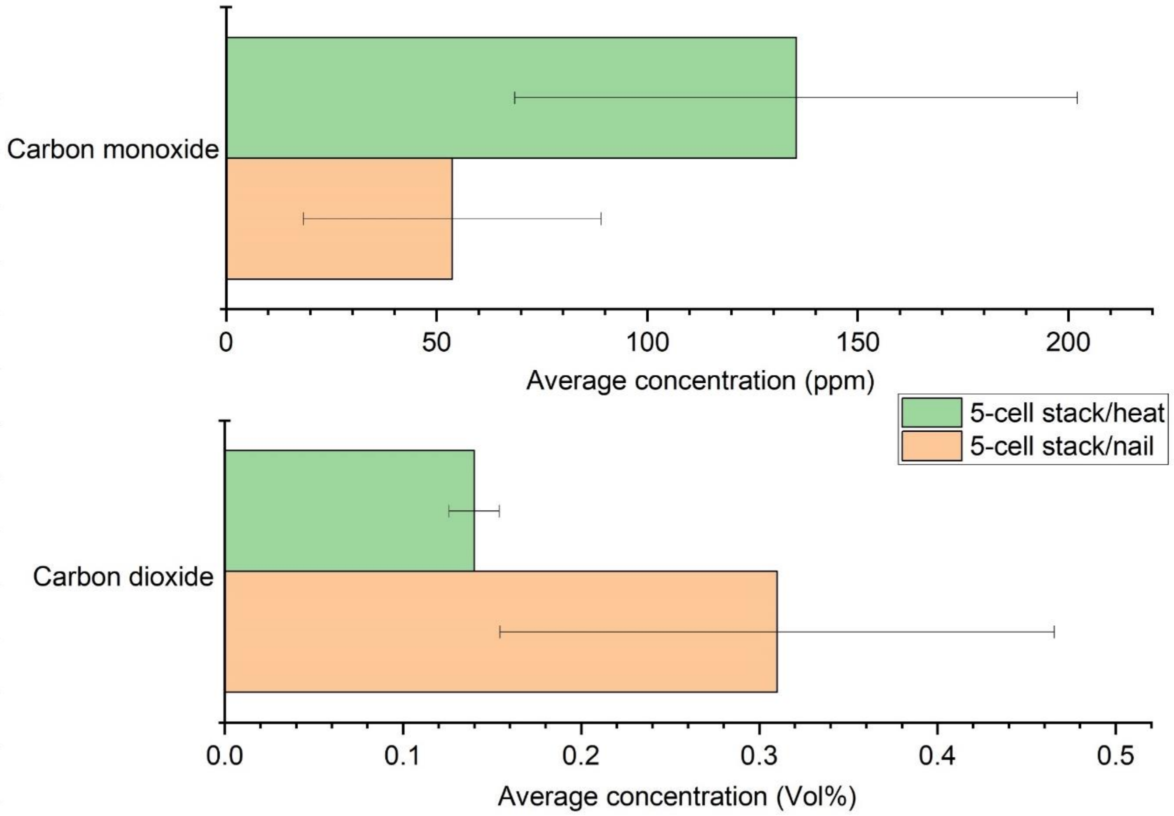
https://www.epa.gov/aegl/about-acute-exposure-guideline-levels-aegls

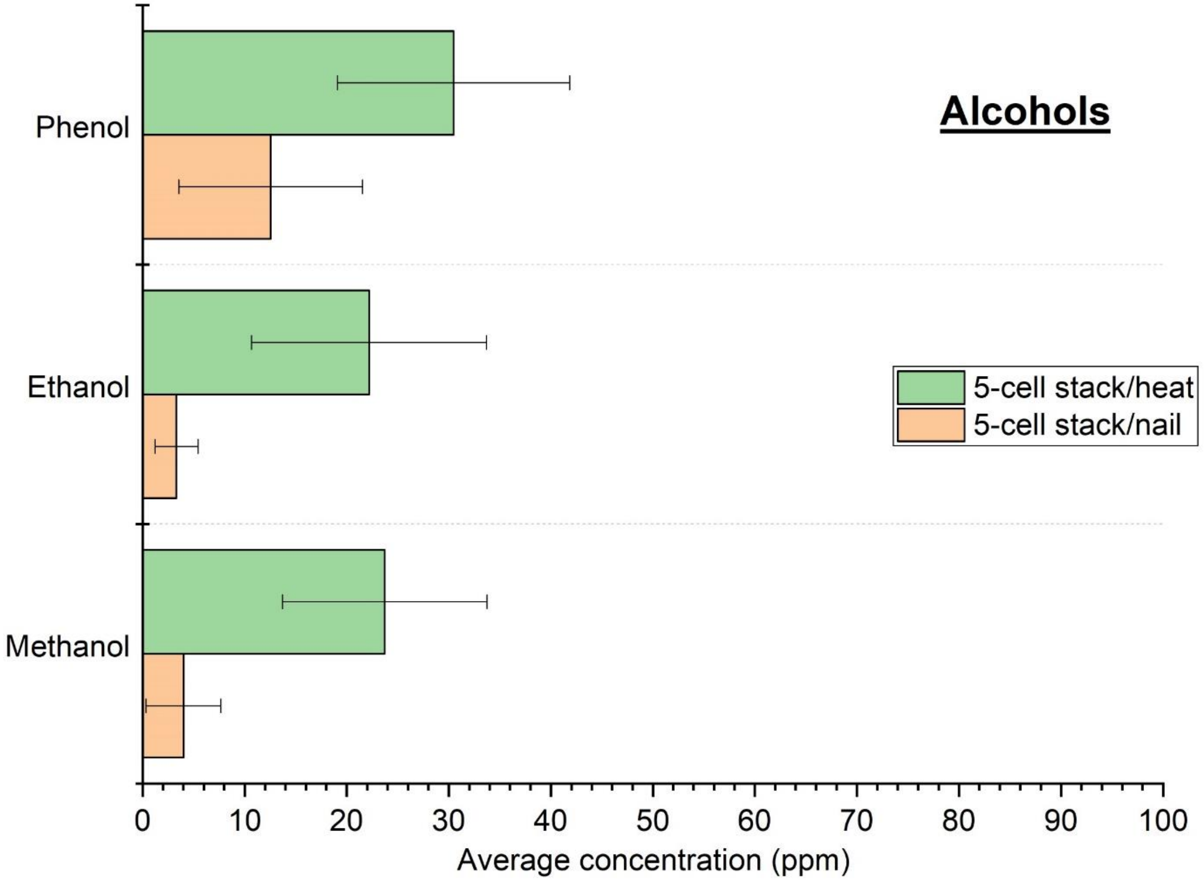
Triggering method influence on vent gas composition : 5-cell short stack

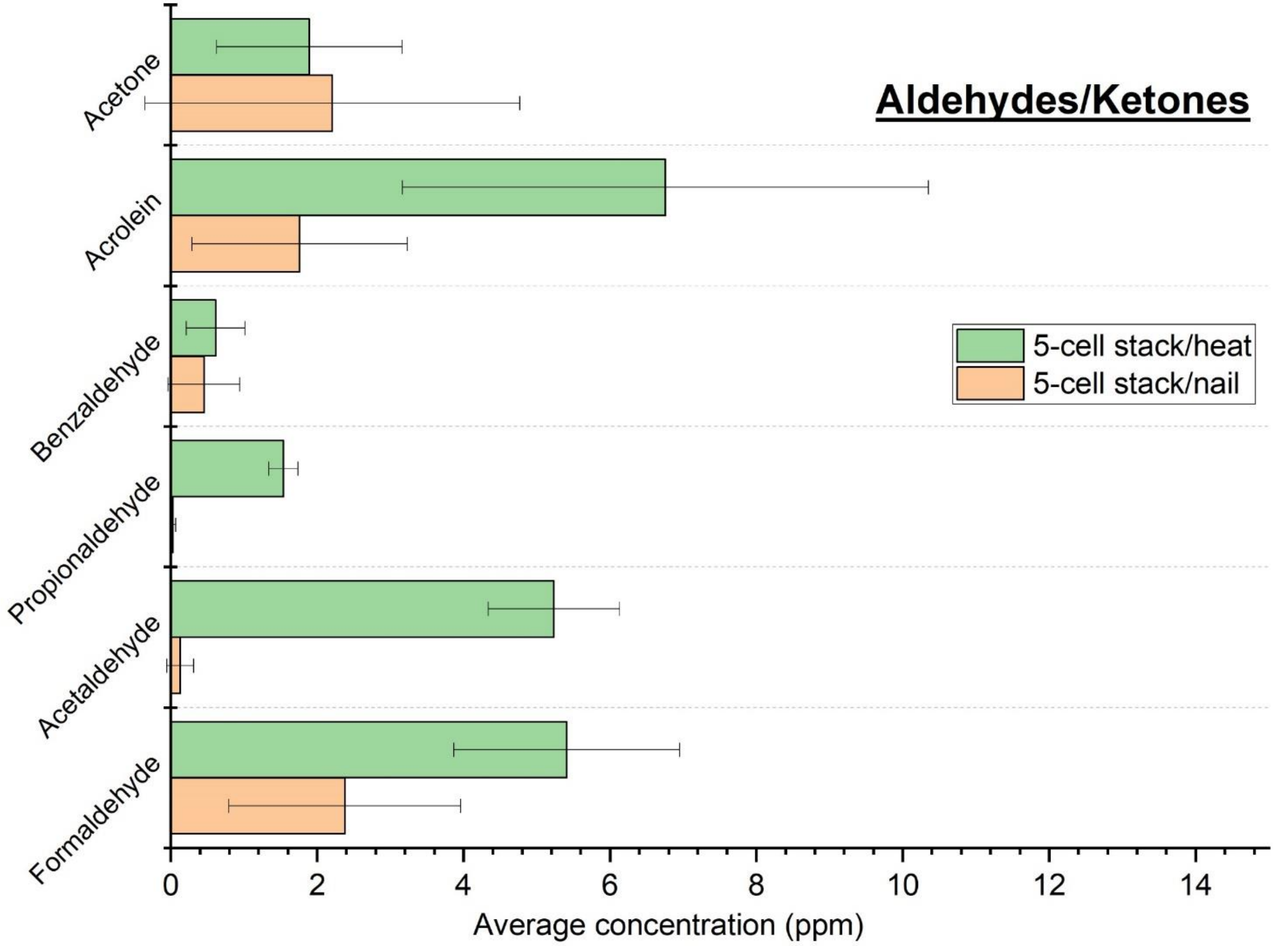
Comparison of nail penetration to rapid external heating for each category of gaseous compounds





Triggering method influence on vent gas composition : 5-cell short stack





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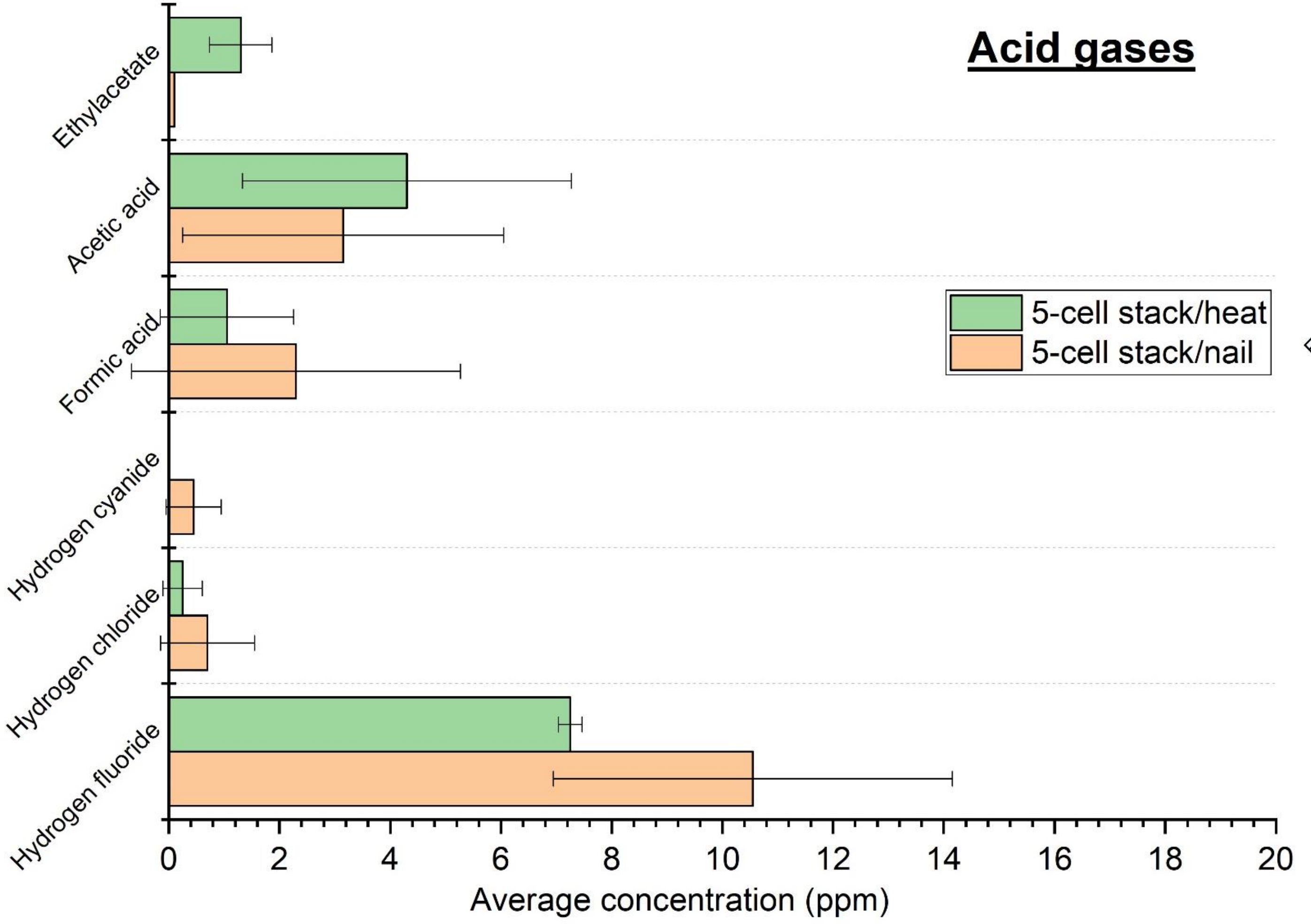

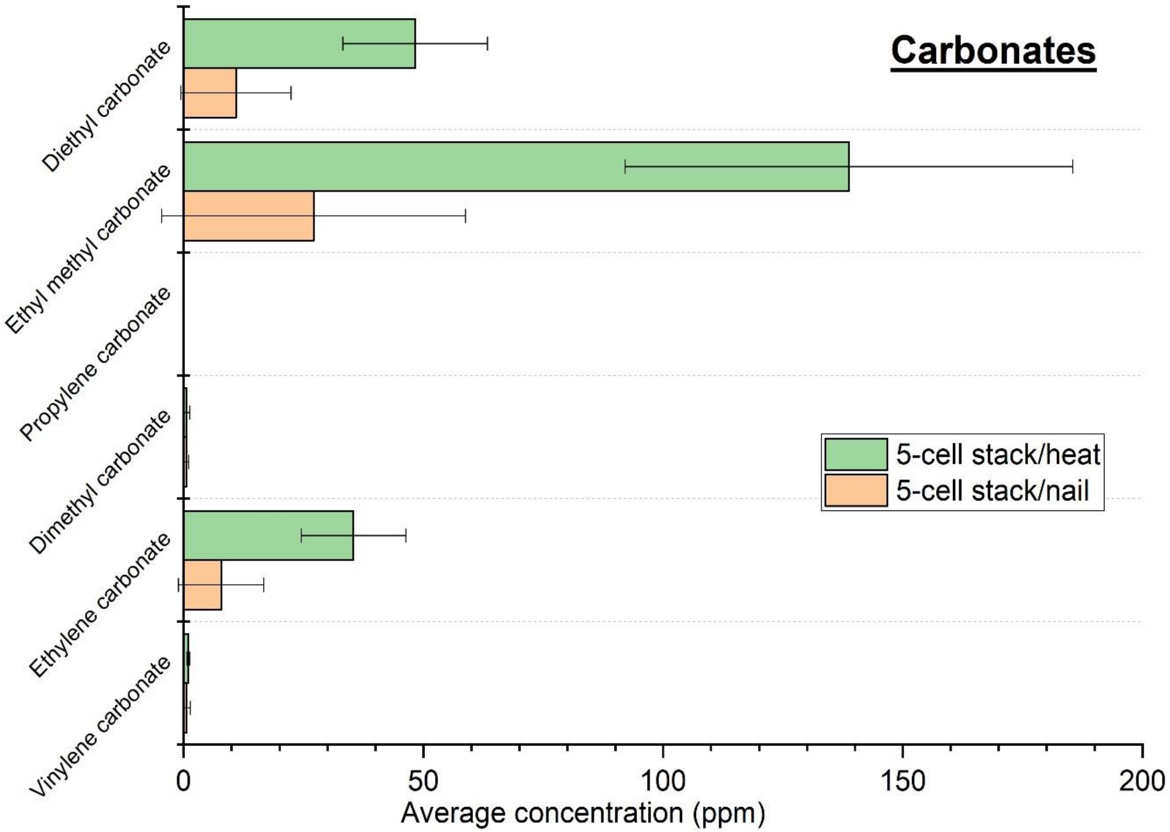

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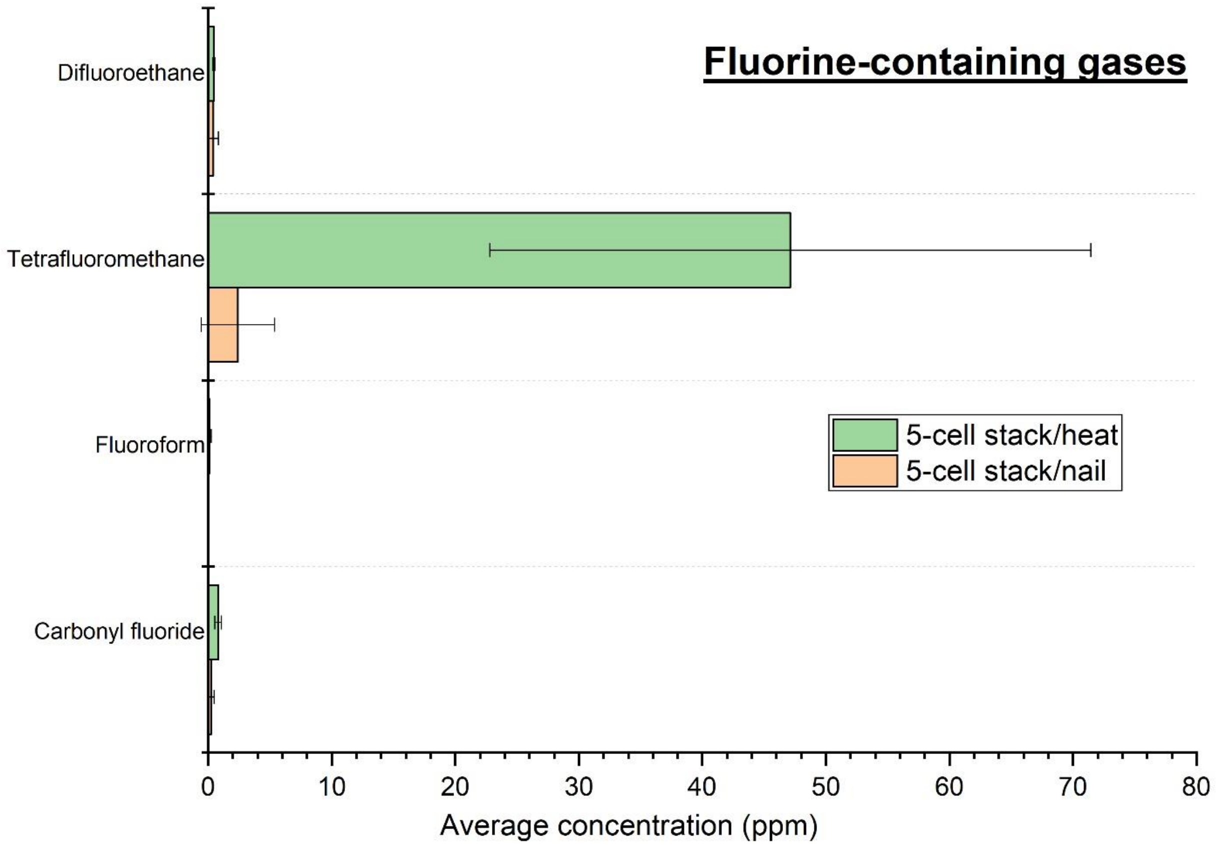

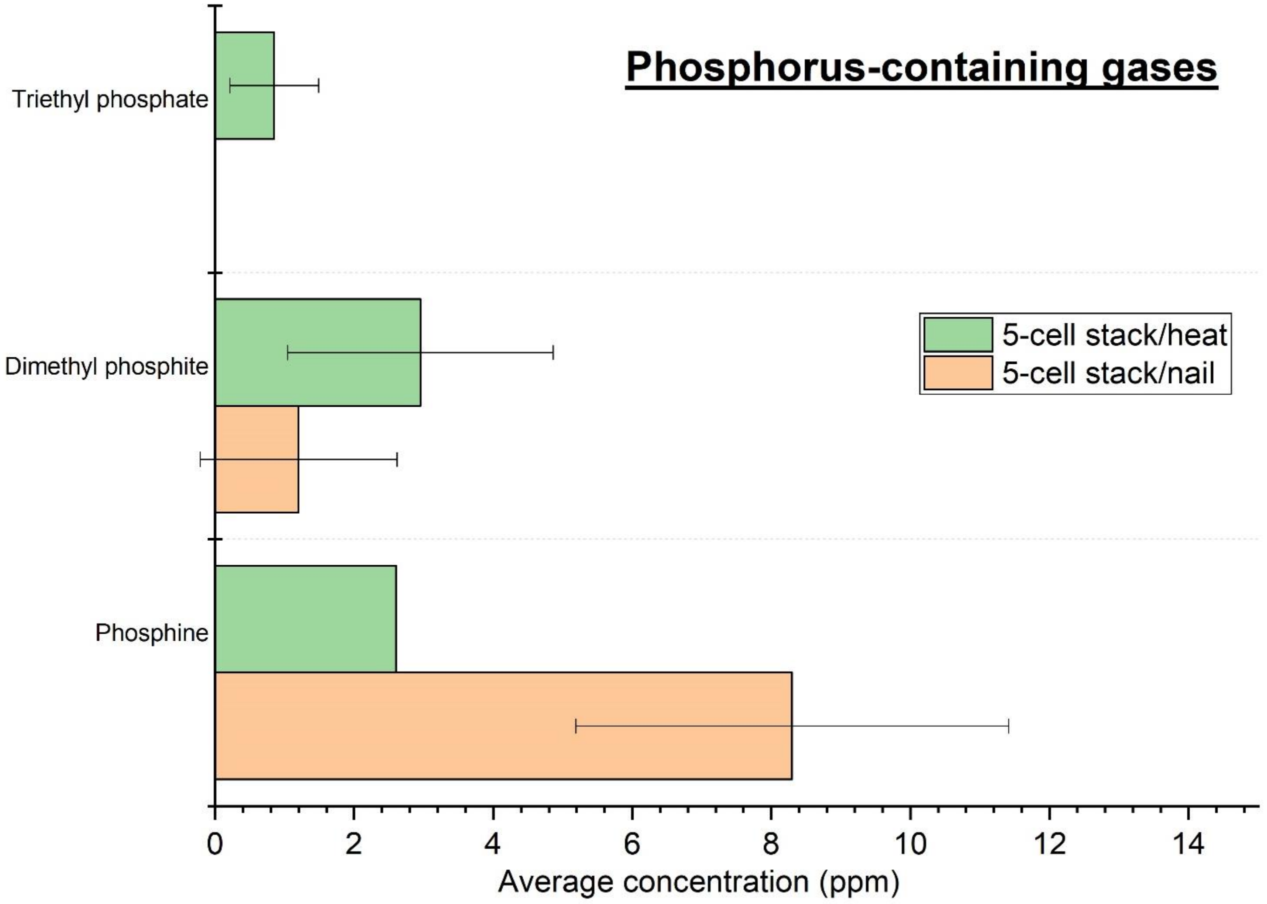

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Triggering method influence on vent gas composition : 5-cell short stack

- Triggering method has an effect on the vent gas composition.
- Thermal runaway triggered with nail results in significant higher concentrations of
  - ► Acid gases: **hydrogen cyanide**
  - ► Phosphorus-containing gases: **phosphine**

- Thermal runaway triggered with TRIM heater results in significant higher concentrations of:
  - ► Hydrocarbons: methane, ethylene, propylene, n-heptane, hexadecane, benzene, styrene
  - ► Alcohols: methanol, ethanol
  - ► Aldehydes/Ketones: acetaldehyde, propionaldehyde
  - ► Acid gases: ethyl acetate
  - ► Carbonates: ethylene carbonate, ethyl methyl carbonate, diethyl carbonate
  - ► Fluorine-containing gases: tetrafluoromethane
  - ► Phosphorus-containing gases: triethyl phosphate

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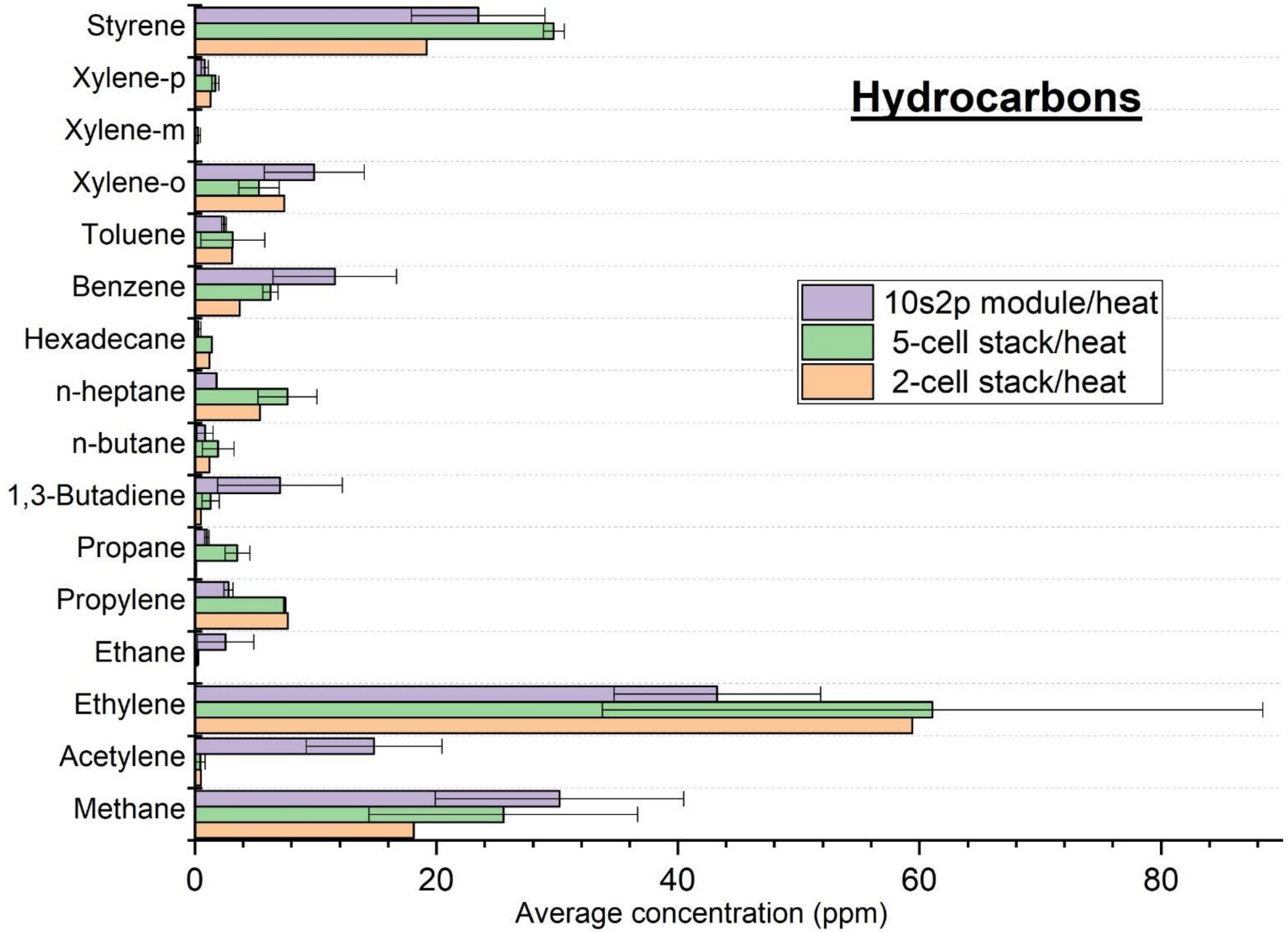
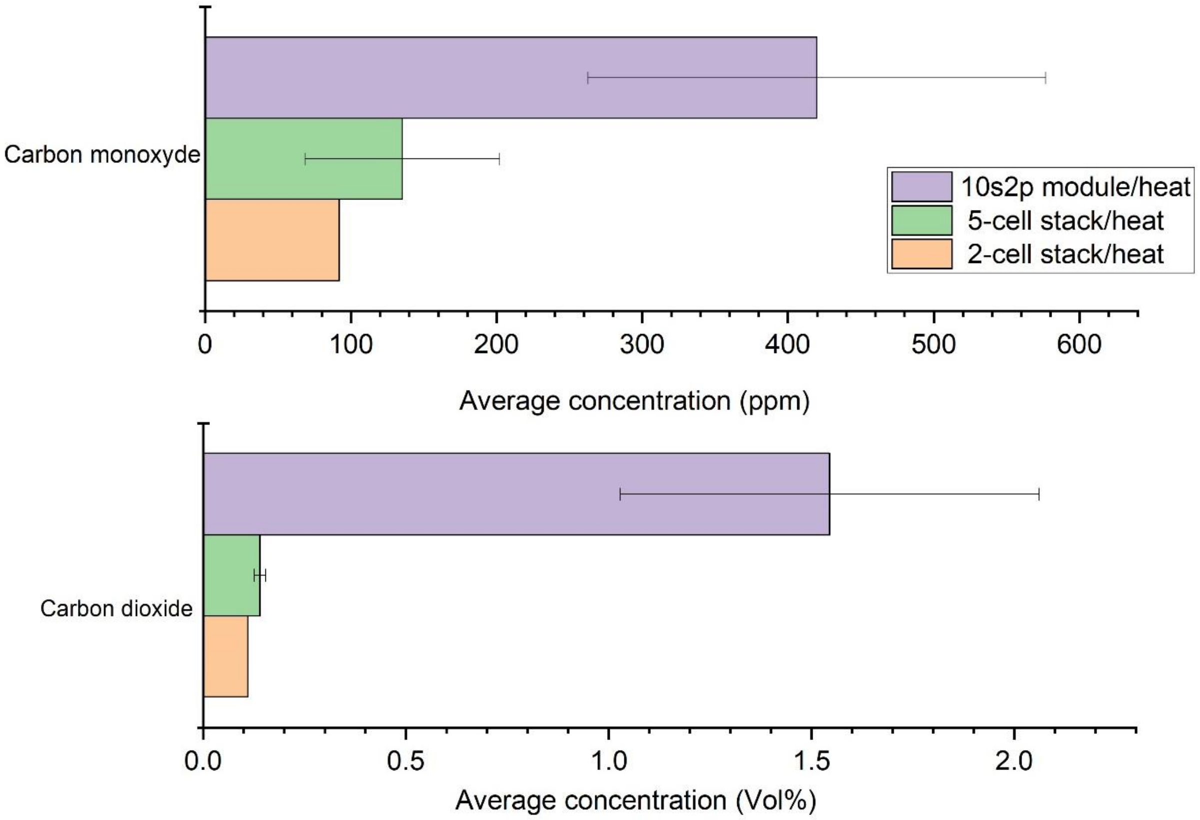
Influence of DUT size on vent gas composition: TRIM heating





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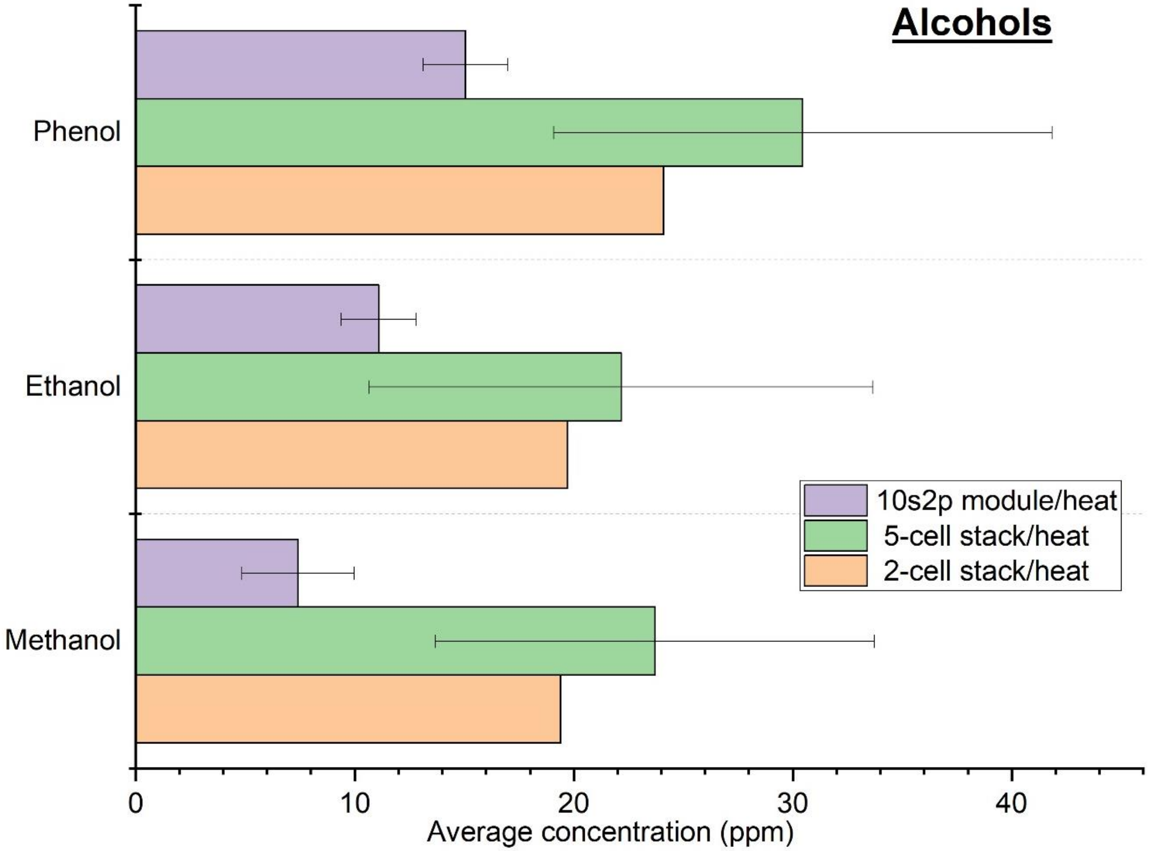

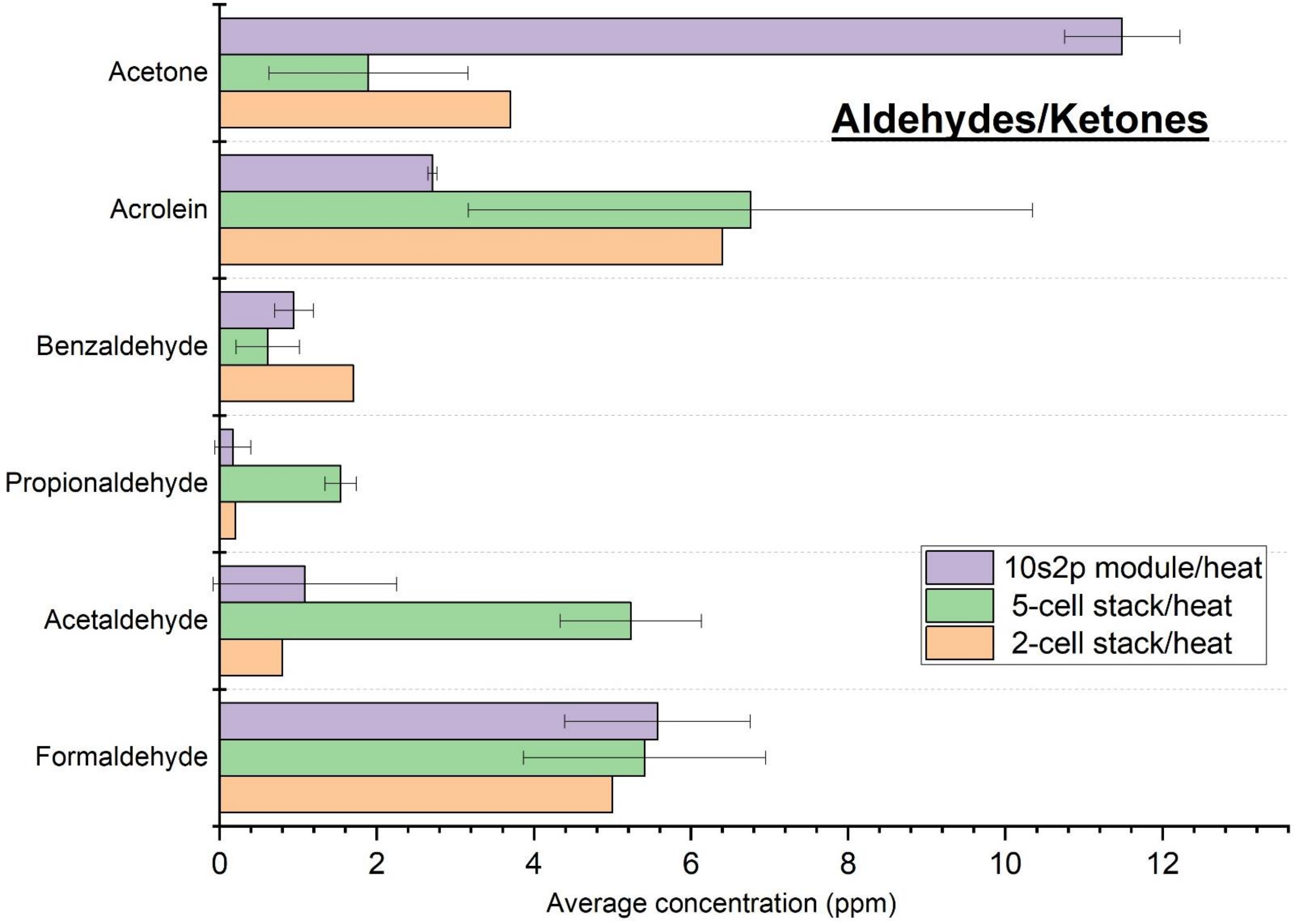

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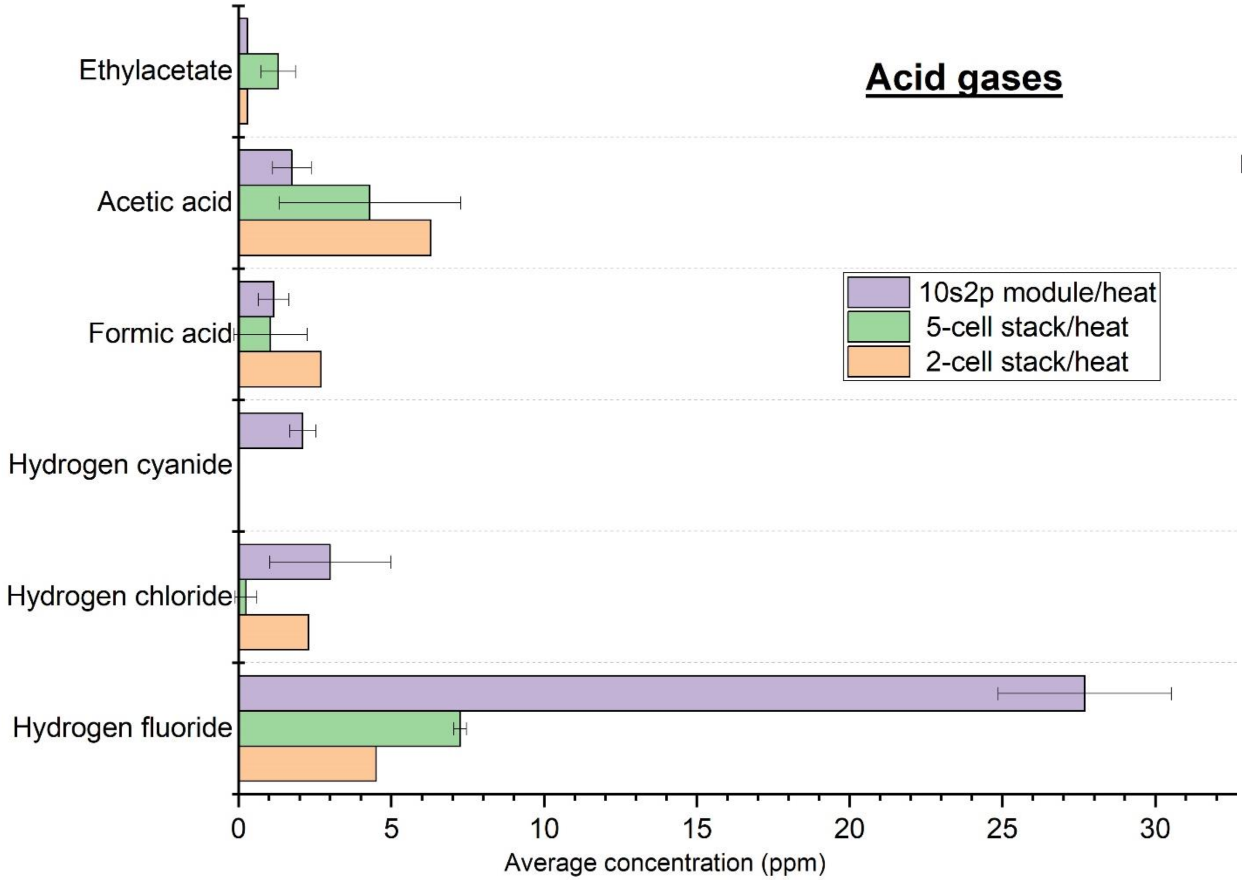

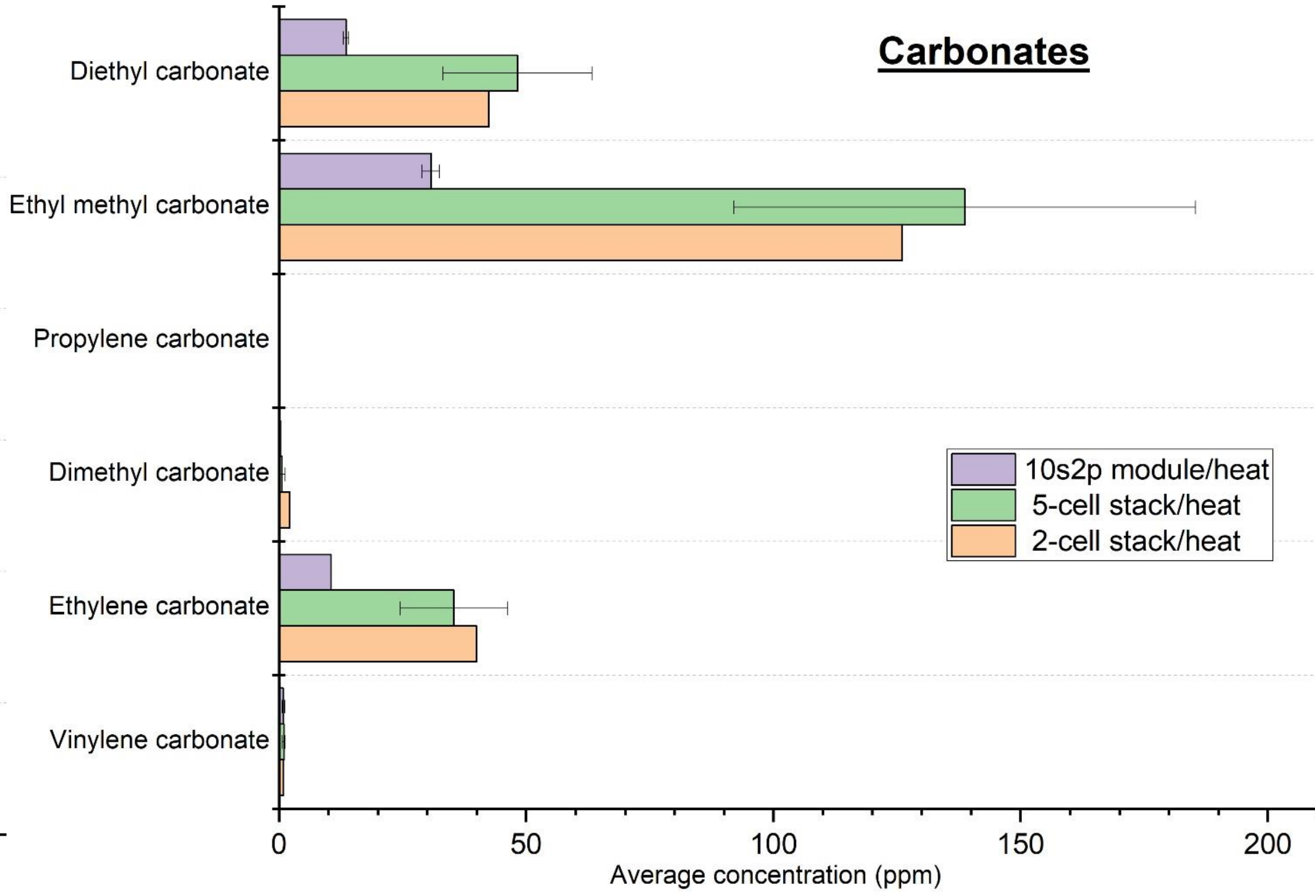

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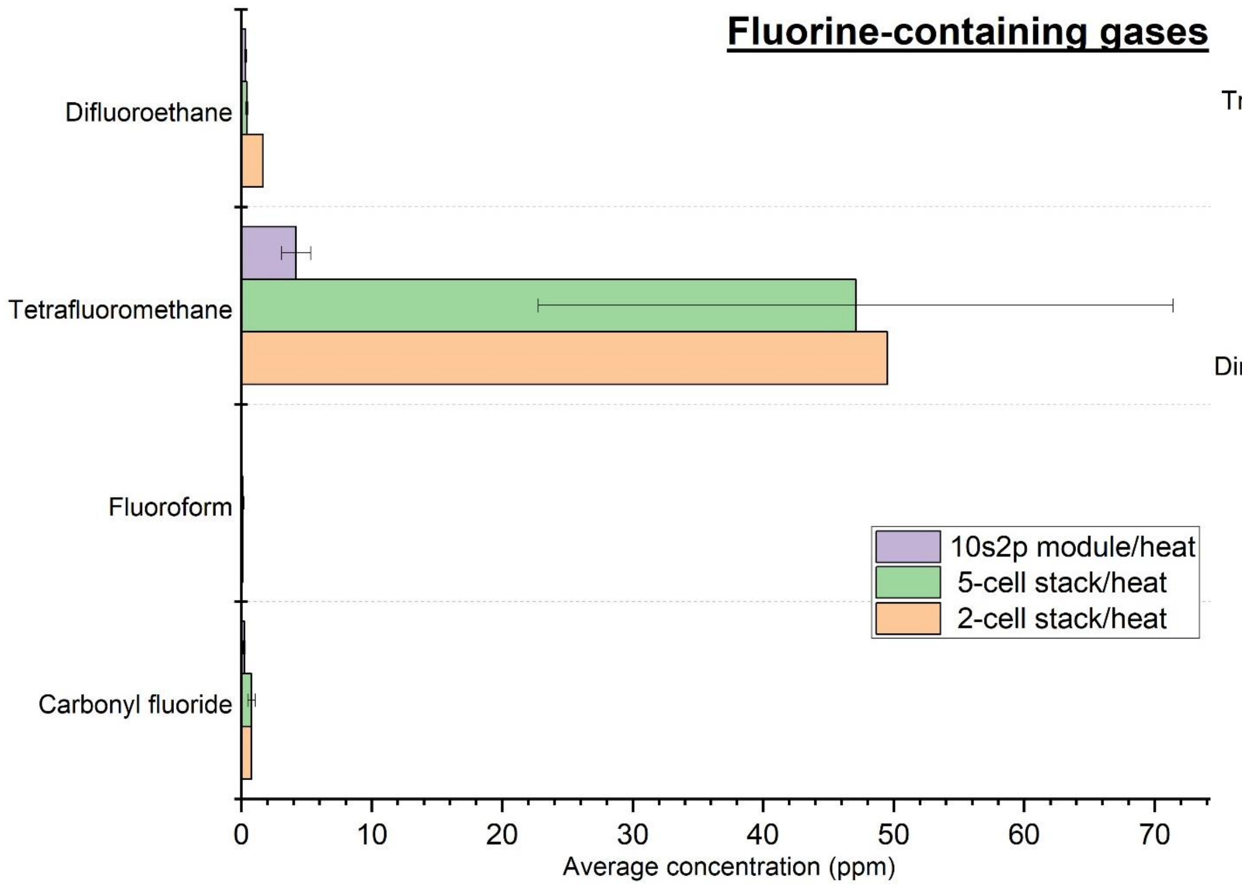

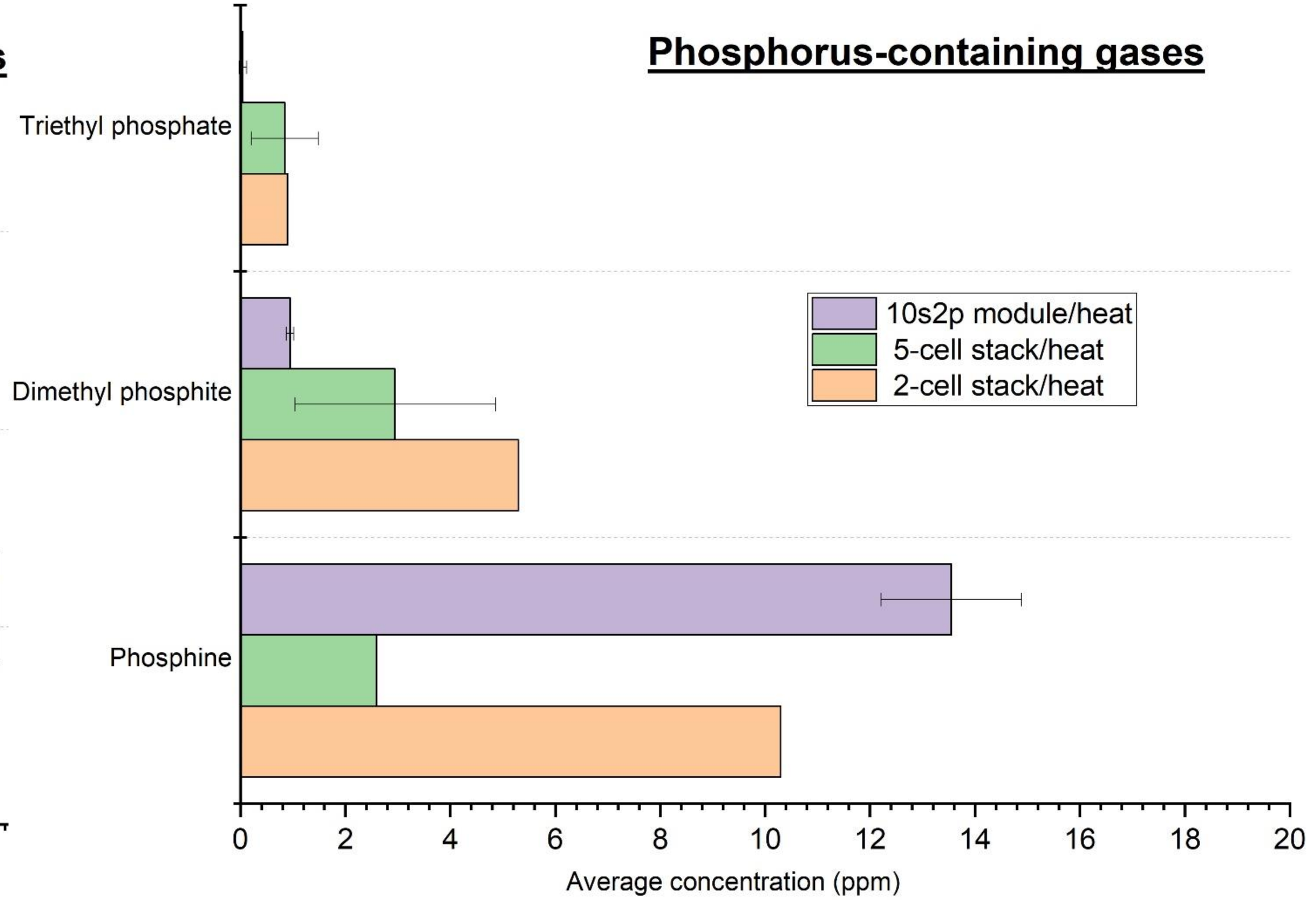

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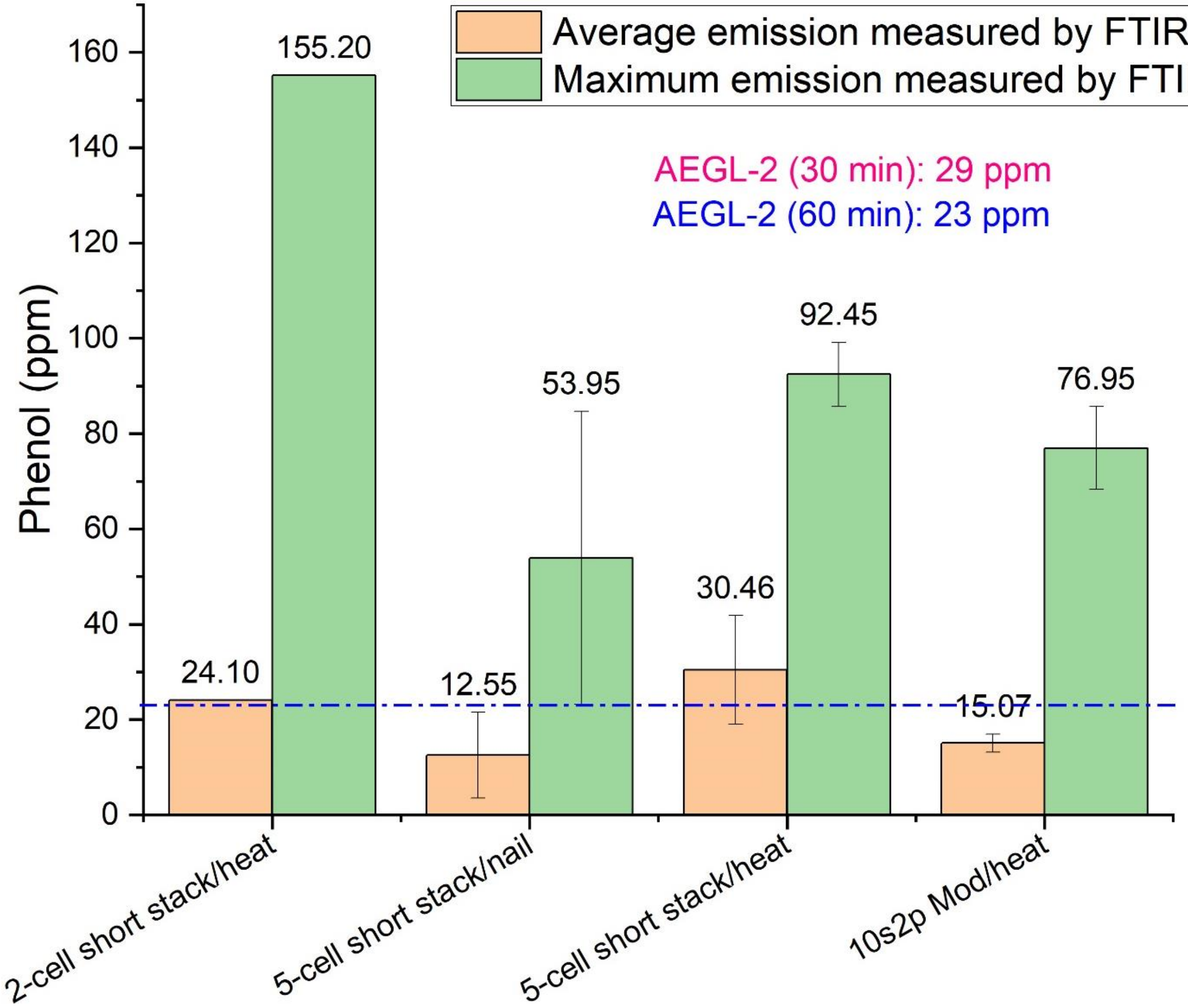
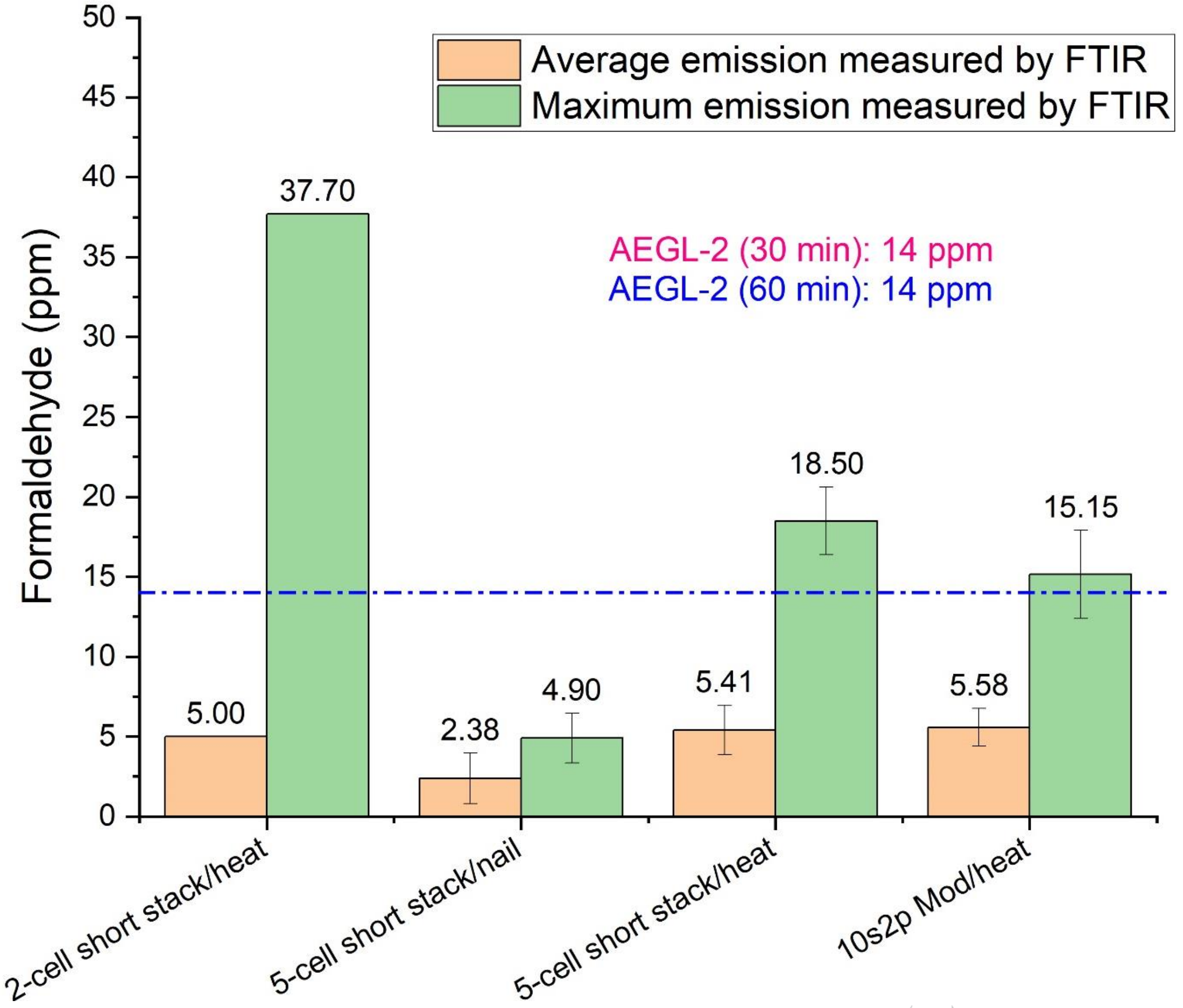
Influence of DUT size on vent gas composition: TRIM heating

- The average concentration of components in the vent gas does not always rise monotonously with increasing number of cells in the DUT.
- In some cases, e.g. for ethylene carbonate and acetic acid, a reverse trend is observed with lower average concentrations of these components identified for larger DUTs.
- An exception for this are CO and CO_2, both showing an exponential relationship between the number of cells in the DUT and their average concentration in the vent gas.

Toxicity evaluation of average concentrations: cases above AEGL-2 level





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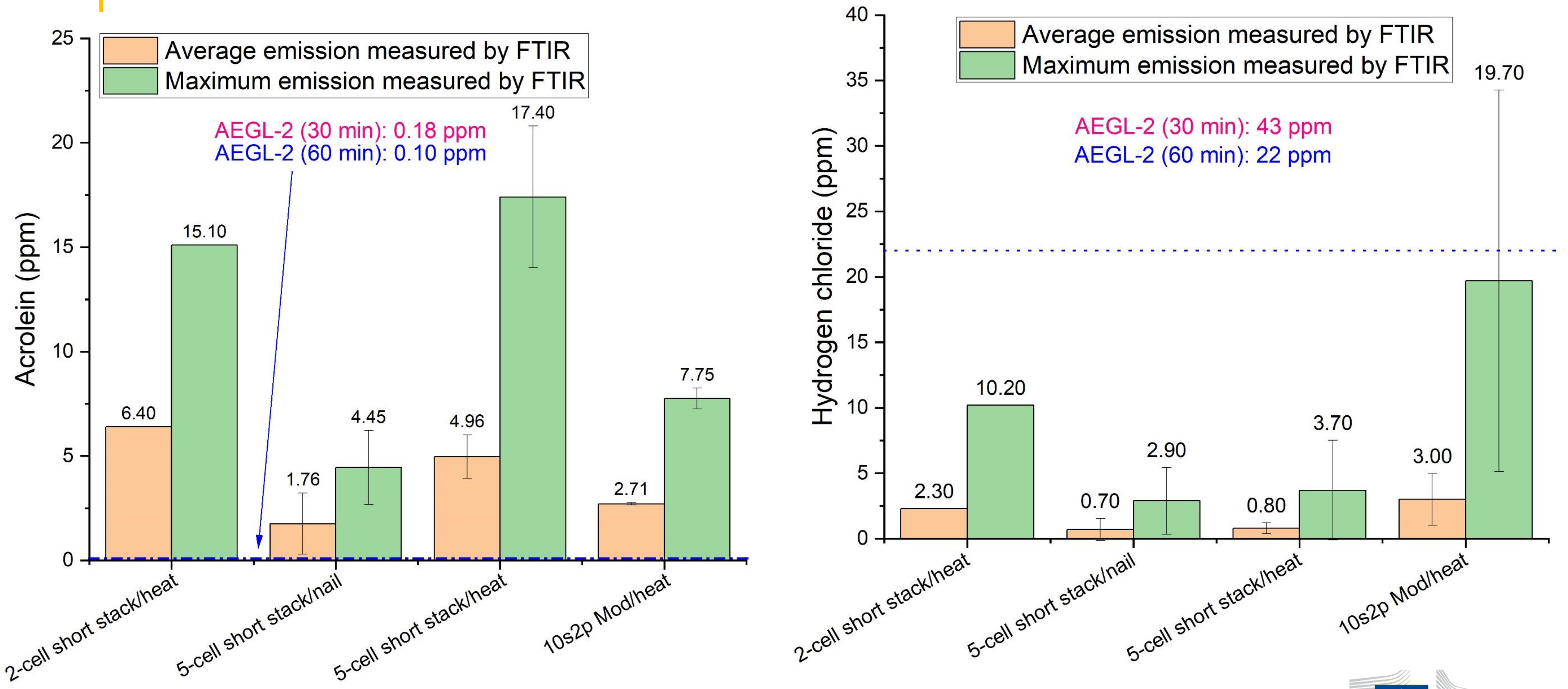

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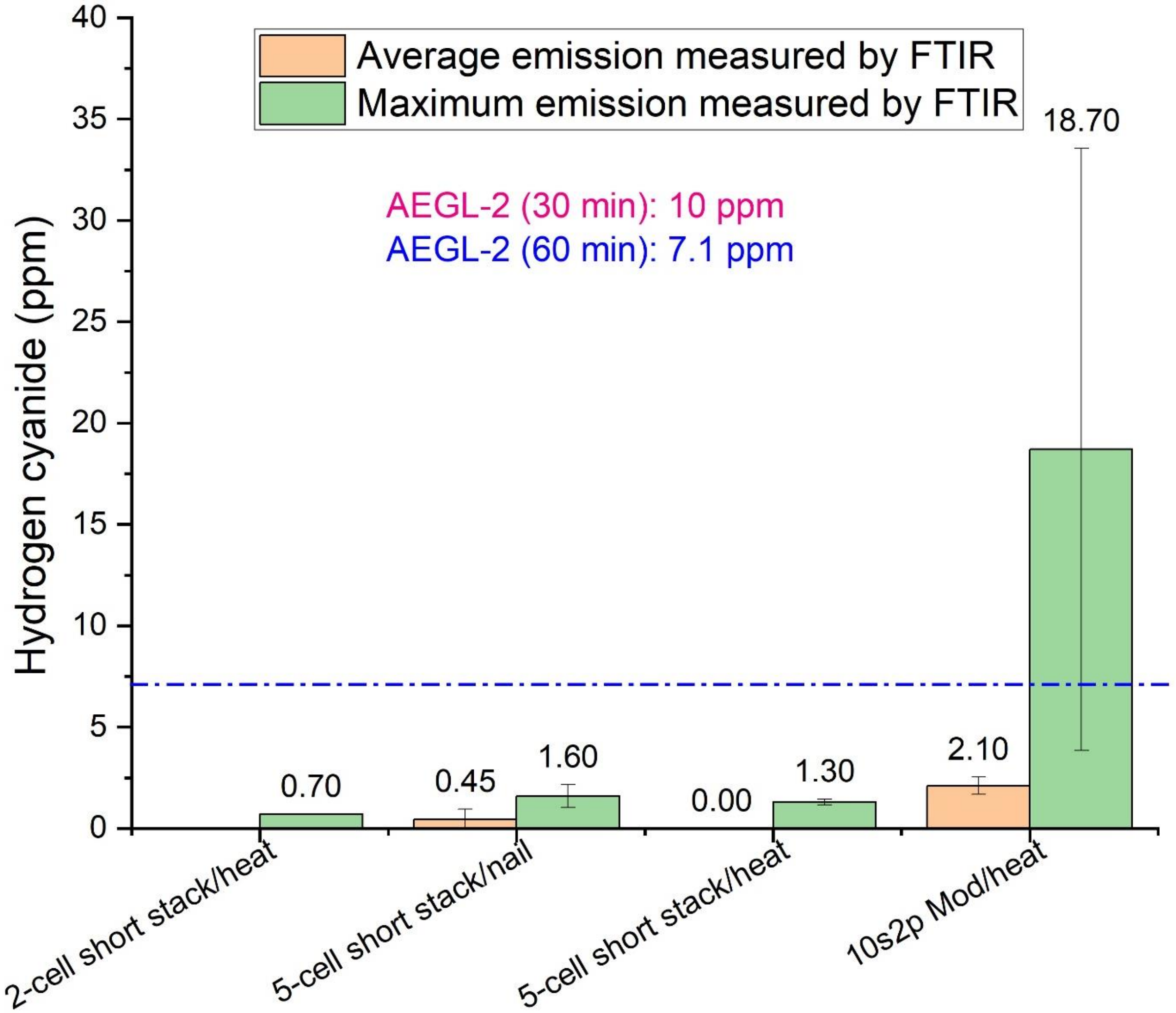

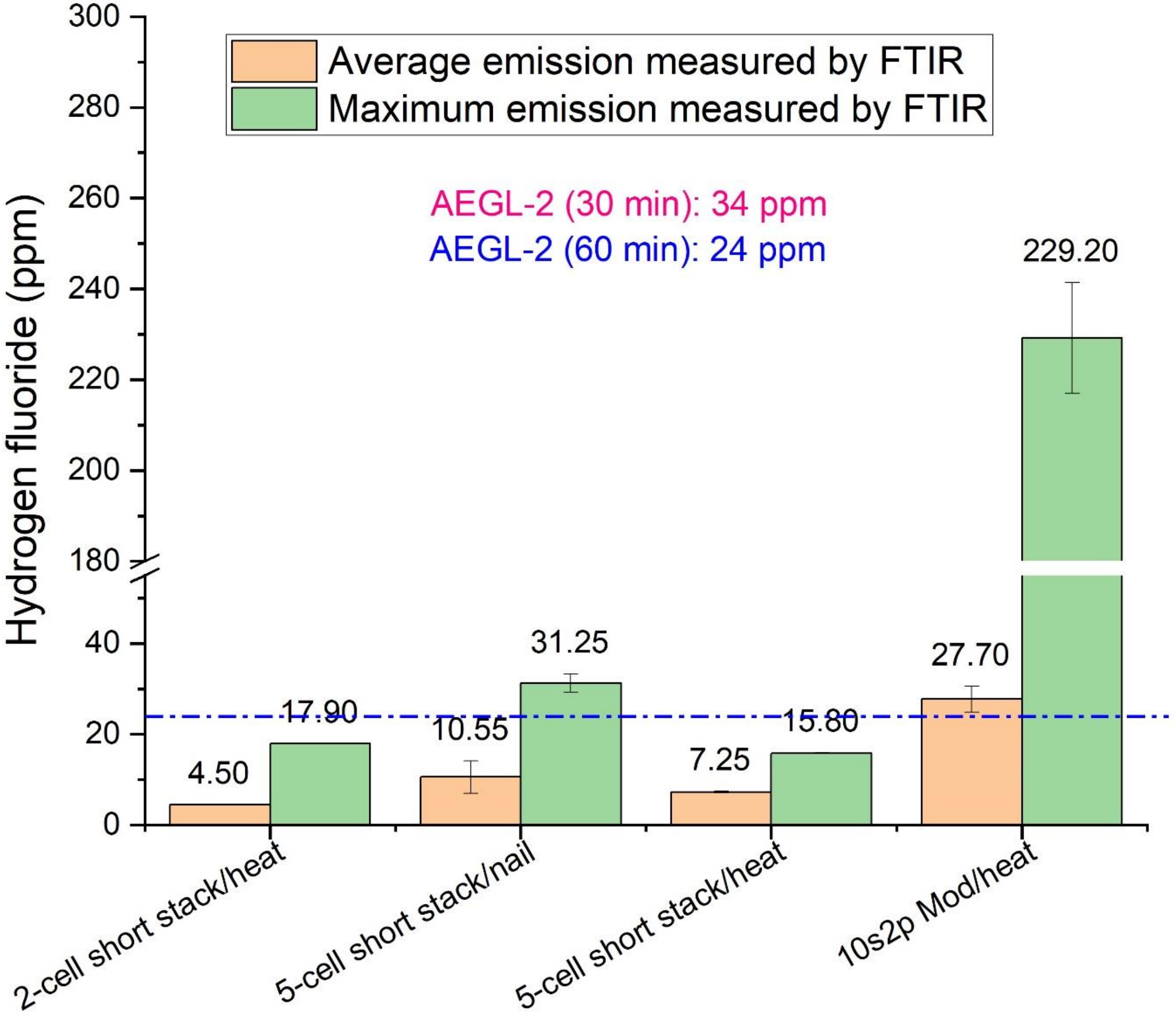

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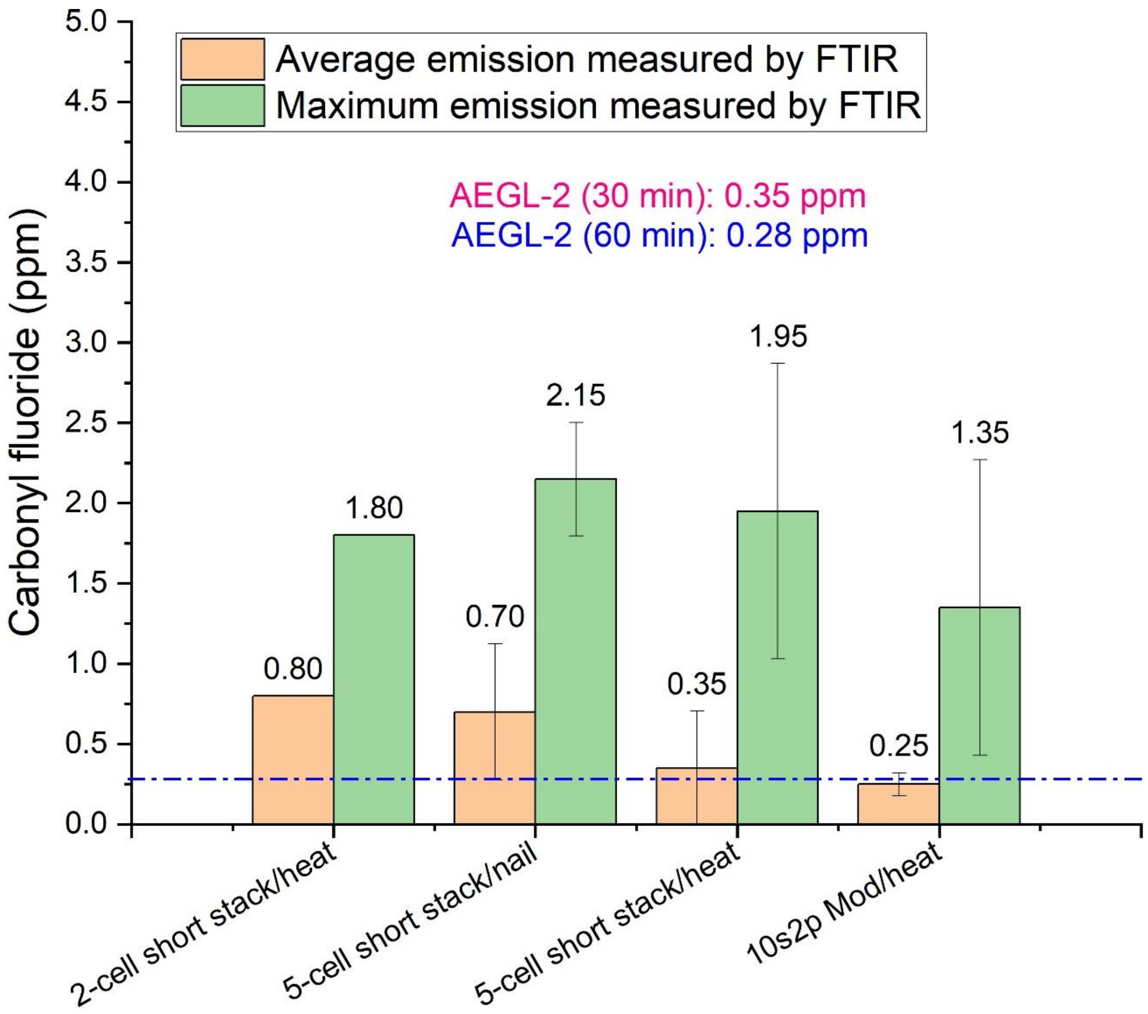

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Toxicity evaluation of average concentrations: cases above AEGL-2 standards

- Regardless of the experimental parameters (number of cells, trigger method), both average and peak concentrations of acrolein and carbonyl fluoride are almost always above AEGL-2 (30 min and 60 min) exposure limits, where irreversible effects to human health are expected.
- Peak concentrations of phenol and formaldehyde are most of the times above AEGL-2 (30 min and 60 min).
- AEGL-2 (30 min and 60 min) exposure limits for hydrogen cyanide, hydrogen fluoride, hydrogen chloride are not exceeded on average.

Summary

- TR propagation experiments in 2-cell short stack, 5-cell short stack and 10s2p modules from 40 Ah Ni-rich NMC/Graphite cells were performed.
- Ceramic nail penetration and localized rapid external heating (TRIM) used to trigger the TR.
- 46 gaseous compounds were identified and quantified by FTIR and gas chromatography.
- Triggering method has an effect on the vent gas composition.
    - Some gases have an increase of concentration with nail while other gas compounds see their amounts rising with TRIM method

Summary

- The average concentration of components in the vent gas does not always rise with increasing number of cells in the DUT.
  - ► An exception for this are CO and CO_2, both showing a monotonous increase of their average concentration in the vent gas with the number of cells in the DUT.
- Regardless of the experimental parameters (number of cells, trigger method), both average and peak concentrations of acrolein and carbonyl fluoride are almost always above AEGL-2 (30 and 60 min) exposure limits, where irreversible effects to human health are expected.
- AEGL-2 (30 and 60 min) exposure limits for hydrogen cyanide, hydrogen fluoride, hydrogen chloride are not exceeded on average.
- Peak concentrations of phenol and formaldehyde are most of the times above AEGL-2

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