Gas emissions in thermal propagation experiments

26th GTR EVS meeting
18th-20th of April 2023

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Devices under test (DUTs) – Vehicle and Pack

- Factory-new contemporary commercially-available electric vehicle and 2 packs
- Li-ion battery
- 52 kWh, 12 modules, 192 cells
- Pouch cells
- NMC 622 / graphite chemistry
- MY 2021
- Tested in under conditions closely matching “(c) temporary parking” mode

EVS24-E1TP-0300 [EC]JRC's thermal runaway propagation test campaign at .pdf

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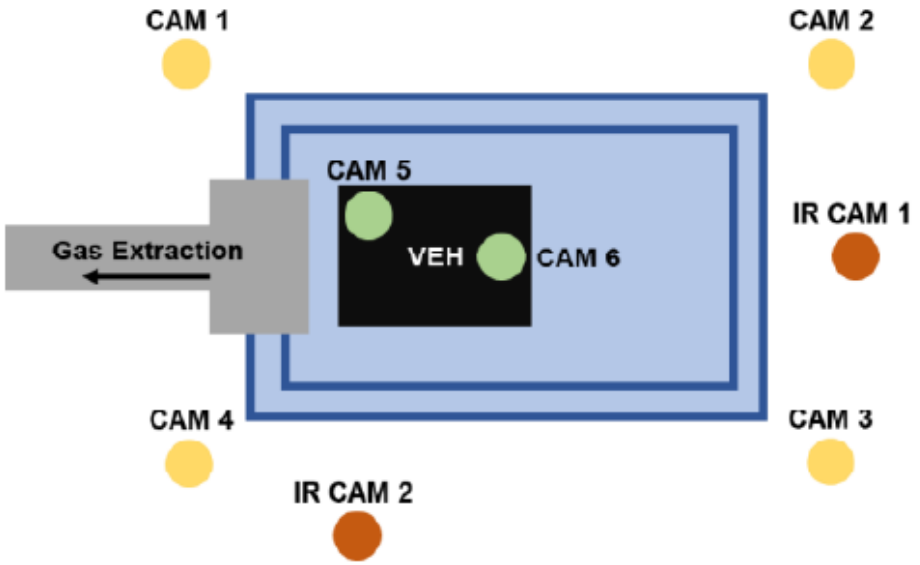
Experimental Set-up



Stainless steel pool.

Aluminium extraction hood, with glass fibre filter.

Smoke gas ventilator.

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Experimental Set-up

Washing bottles and stainless steel canisters.

Open Path Gas Imaging Spectrometer

Online Monitoring FTIR

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Time sequence

Pack

Event	Run time (sec)	
	PACK #1	VEHICLE
Start TRIM	0	0
Gas – 1st venting	23	22
Time to smoke	23	22
Gas – 2nd venting	74	97
Gas – 3rd venting	129	164
Fire breaks out	392	534
Fire quenching	1625	1355

Vehicle

Gas monitoring – Open Path FTIR

Pack

7 seconds after 1st vent

Event	Run time (sec)	
	PACK #1	VEHICLE
Start TRIM	0	0
Gas – 1st venting	23	22
Time to smoke	23	22
Gas – 2nd venting	74	97
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Fire breaks out	392	534
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Vehicle

9 seconds after 1st vent

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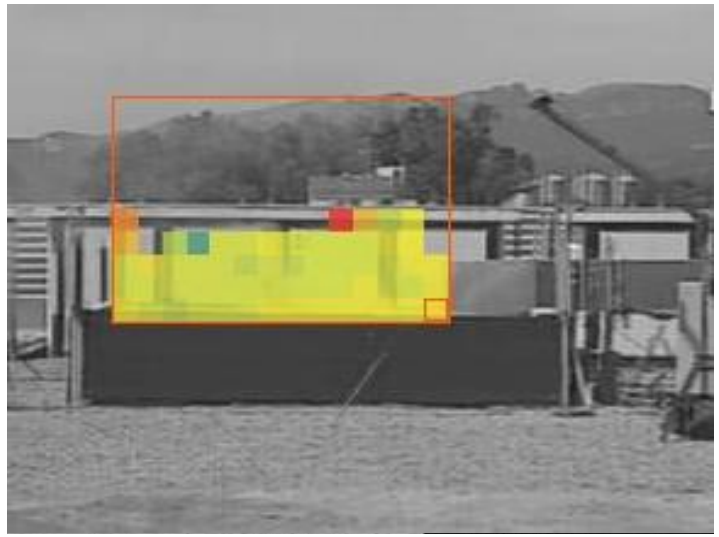
Gas monitoring – Open Path FTIR

Pack



Compounds detected:
Diethyl Carbonate
Dimethyl Carbonate
Ethylmethyl Carbonate
Ethylene

Compounds suspected:
Ethylene Carbonate;
Methanol

Event	Run time (sec)	
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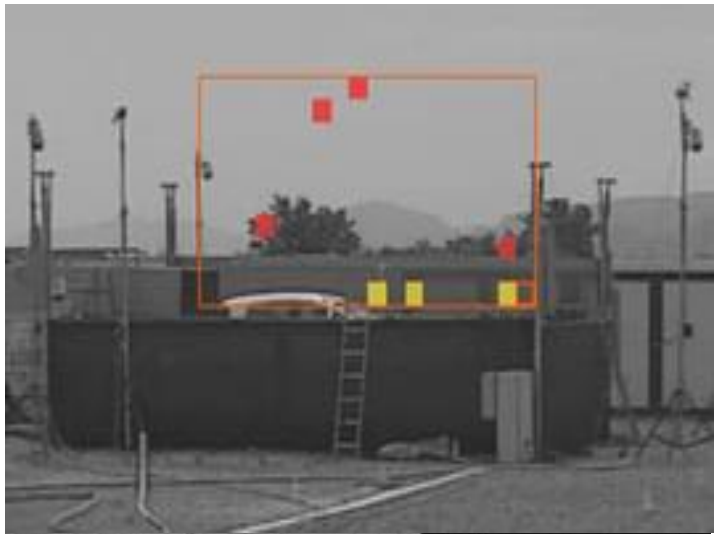
Vehicle



Compounds suspected:
Ethylene Carbonate
Dimethyl Carbonate

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Gas monitoring – Open Path FTIR

Pack

13 seconds after 2nd vent;

Event	Run time (sec)	
	PACK #1	VEHICLE
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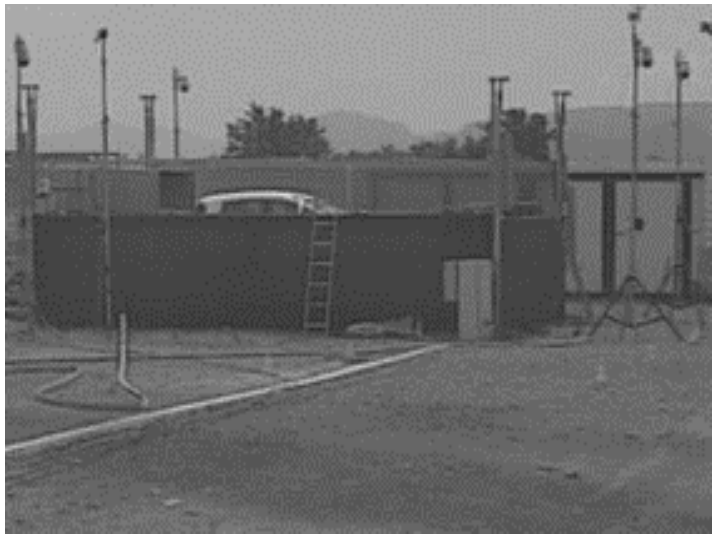
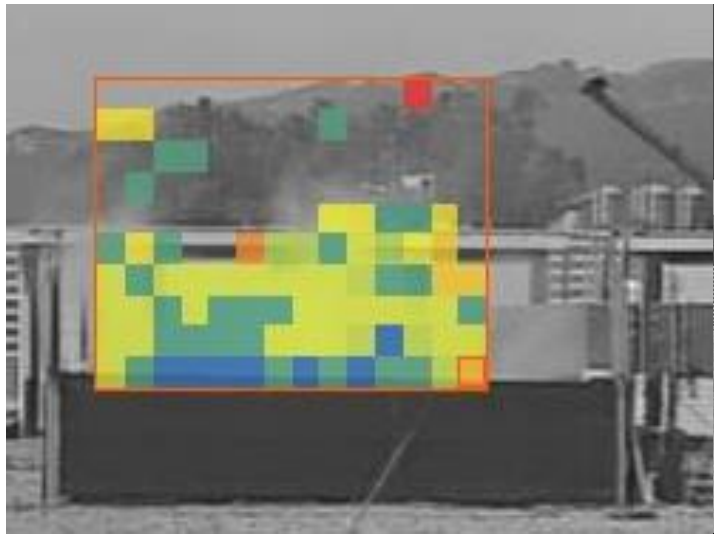
Vehicle



5 seconds after 2nd vent;

Gas monitoring – Open Path FTIR

Pack



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Vehicle

Compounds detected:
Diethyl Carbonate
Dimethyl Carbonate
Ethylmethyl Carbonate
Ethylene

Compounds suspected:
Ethylene Carbonate;
Methanol

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Gas monitoring – Open Path FTIR

Pack

6 seconds after 3rd vent

Event	Run time (sec)	
	PACK #1	VEHICLE
Start TRIM	0	0
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Time to smoke	23	22
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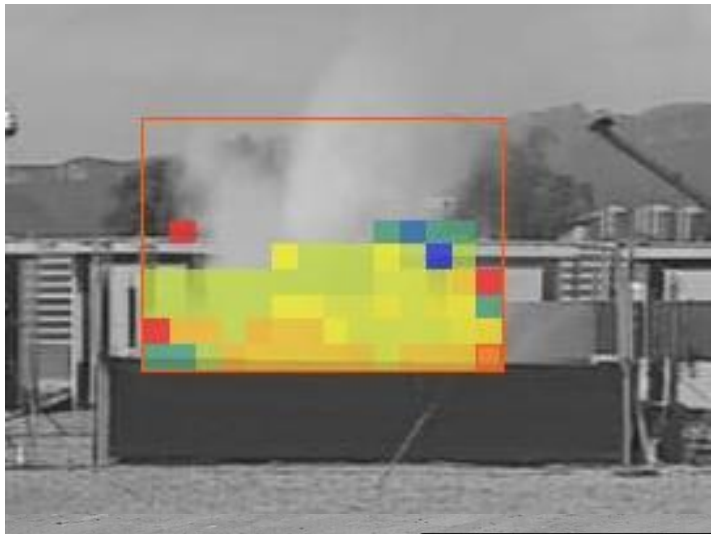
Gas – 3rd venting	129	164
Fire breaks out	392	534
Fire quenching	1625	1355

Vehicle

7 seconds after 3rd vent

Gas monitoring – Open Path FTIR

Pack



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Ethylene
Methanol

Compounds suspected:
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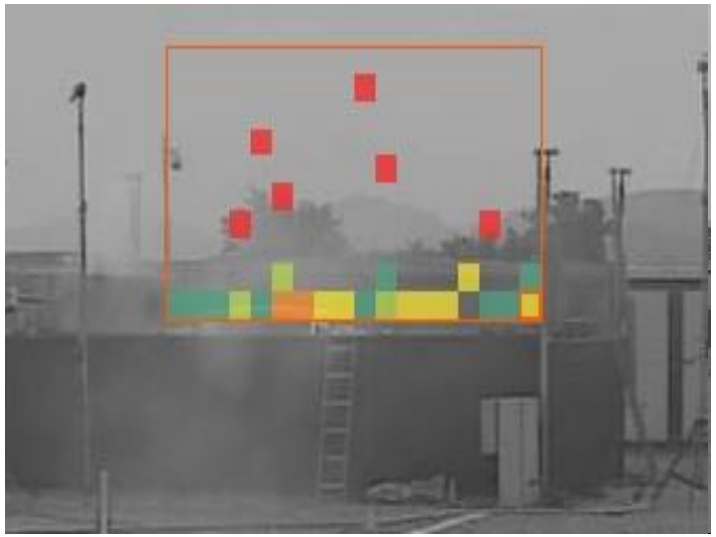
Vehicle



Compounds detected:
Diethyl Carbonate
Dimethyl Carbonate
Ethylmethyl Carbonate
Ethylene

Compounds suspected:
Ethylene Carbonate
Methanol

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Gas monitoring – Open Path FTIR

Pack

13 seconds after fire breaking

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Vehicle

7 seconds after fire breaking

Water screen used by firefighters is visible.

Gas monitoring – Open Path FTIR

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Ethylmethyl Carbonate
Methanol
Ethylene Carbonate

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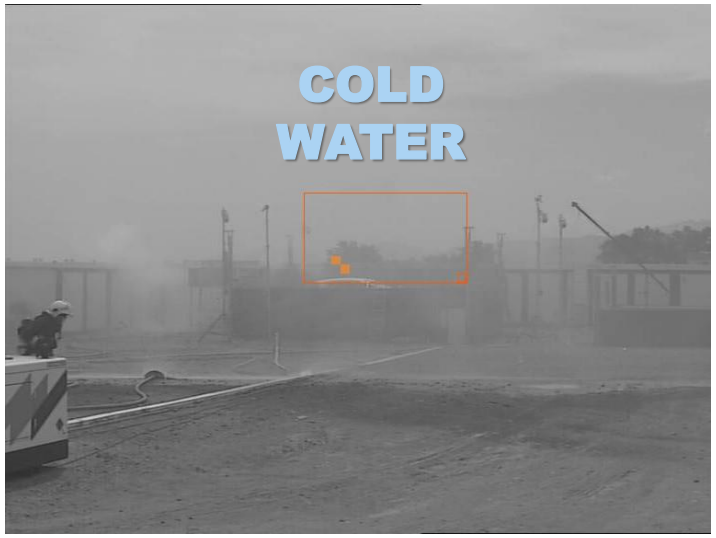
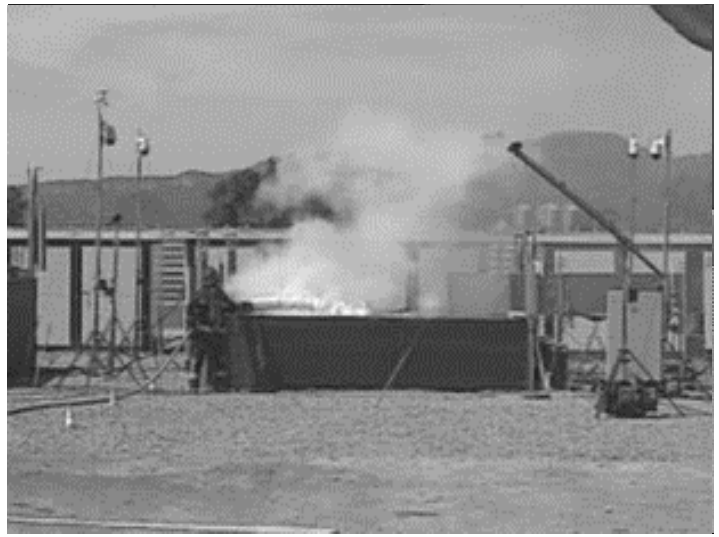
Vehicle



Compounds suspected:
Ethylene Carbonate

Gas monitoring – Open Path FTIR

Pack



10 seconds into fire fighting. Fire brigade uses foam to fill the test pool.

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Vehicle

15 seconds into fire fighting. Fire brigade uses water to fill the test pool.

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Gas monitoring – Open Path FTIR

Pack

Compounds detected:

Dimethyl Carbonate

Ethylmethyl Carbonate

Ethylene Carbonate

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Vehicle

Compounds suspected:

Dimethyl Carbonate

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Open path FTIR so far…

IDENTIFIED	SUSPECTED
Dimethyl Carbonate	Ethylene Carbonate
Diethyl Carbonate	Methanol
Ethylmethyl Carbonate	
Ethylene	
Methanol	
Ethylene Carbonate	

- Allows following evolution of gases in the smoke cloud…
- …From a (safe) distance!

IDENTIFIED	SUSPECTED
Dimethyl Carbonate	Ethylene Carbonate
Diethyl Carbonate	Methanol
Ethylmethyl Carbonate	Dimethyl Carbonate
Ethylene	

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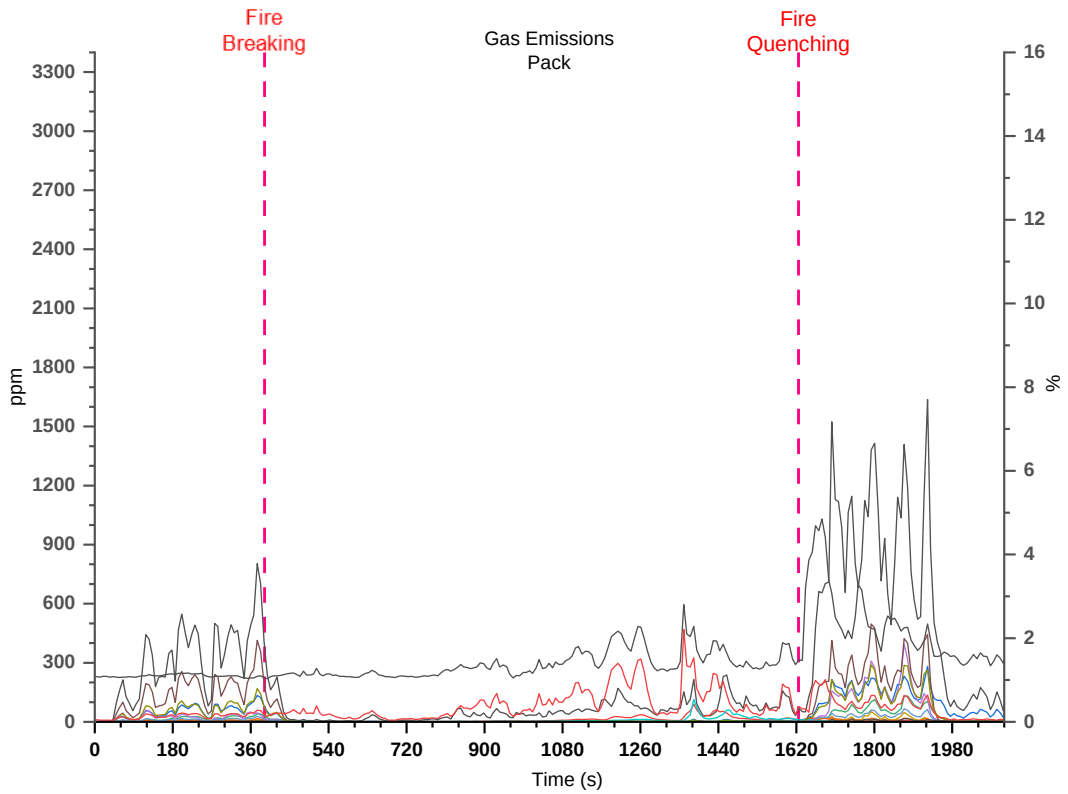
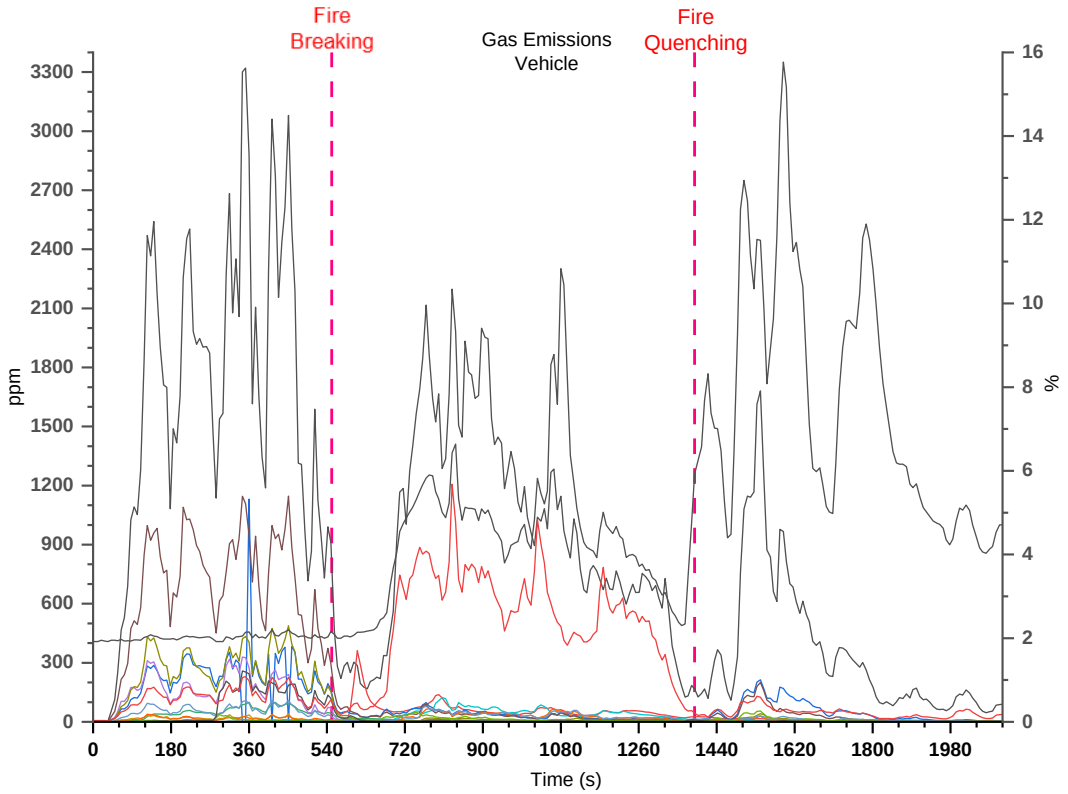
Gas Analysis – On-line FTIR





CO HF METHANE ETHYLENE CARBONATE ETHYLMETHYL CARBONATE DIMETHYL CARBONATE
HCL ETHYLENE METHANOL FORMALDEHYDE ACETALDEHYDE ACETYLENE
R1234YF WATER CO2

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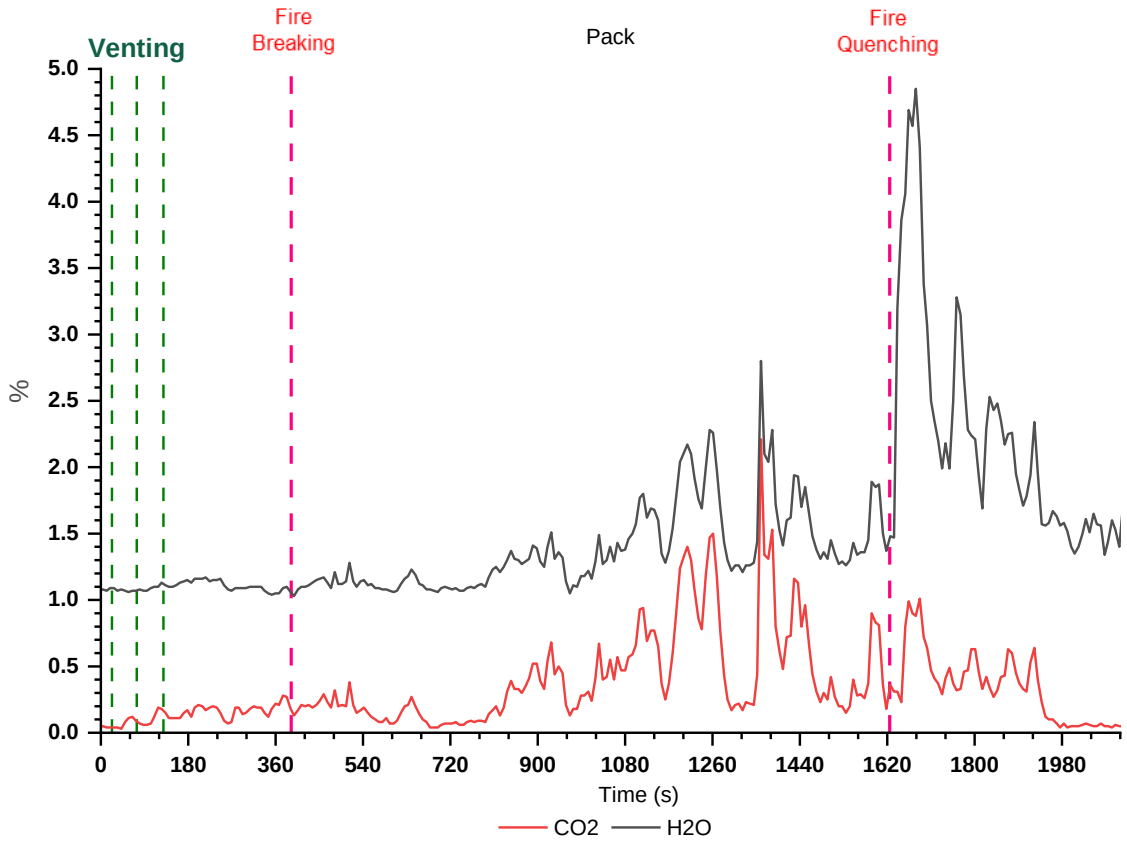
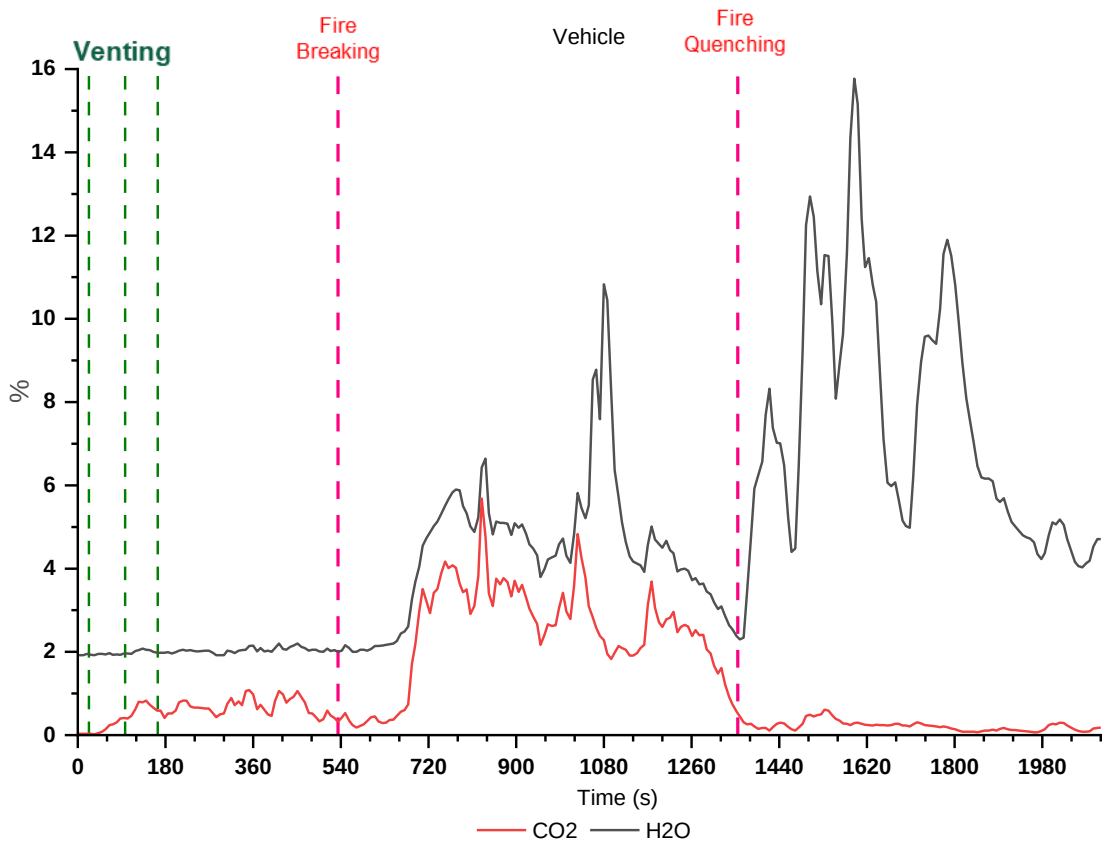
Gas Analysis – On-line FTIR





Water and **CO_2** are the main components of combustion stage.

They show different behaviour in fire quenching stage.

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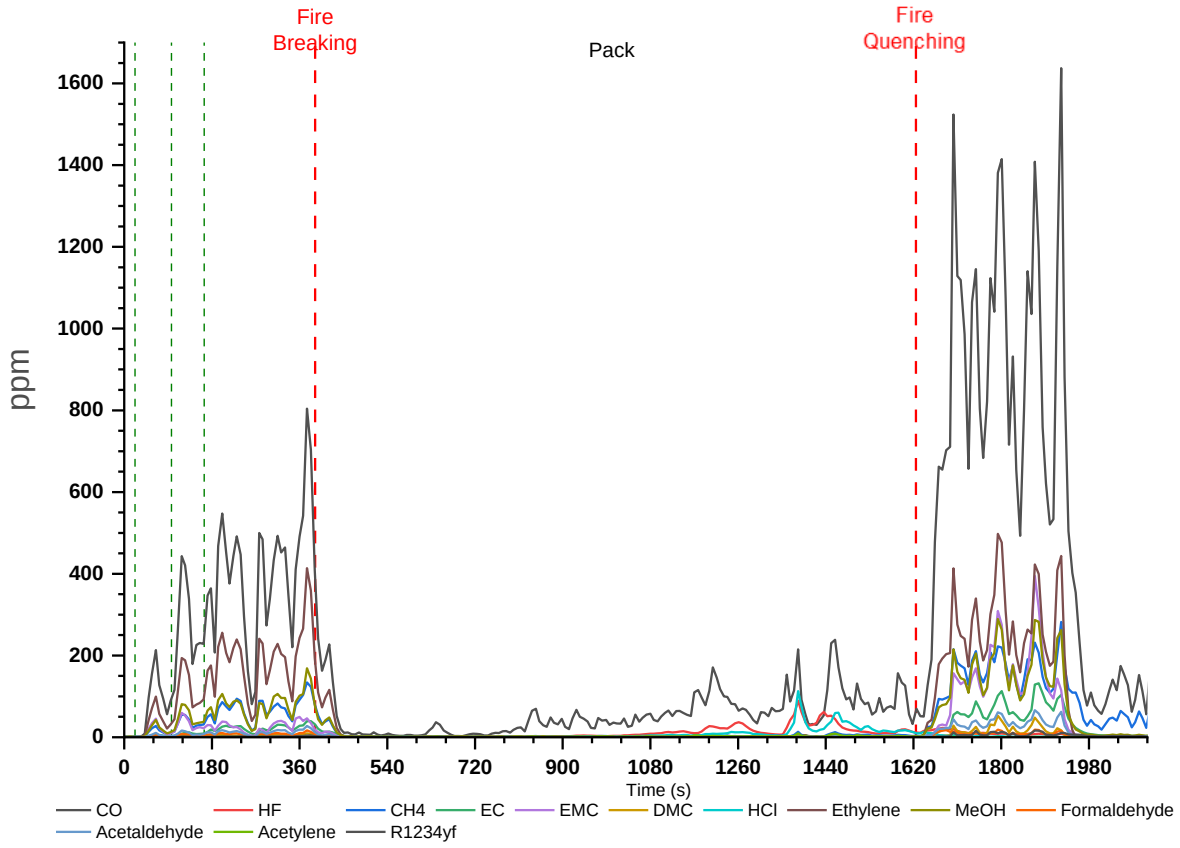
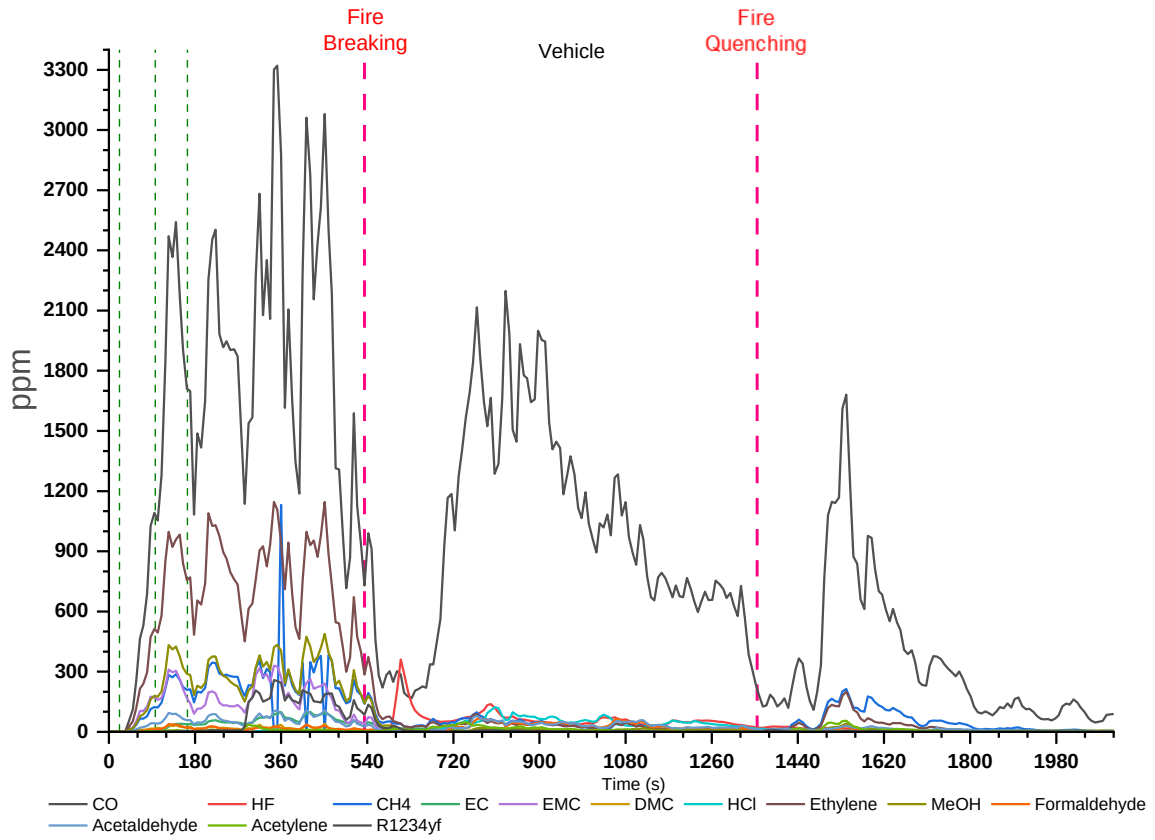
Gas Analysis – On-line FTIR





Up to 13 species.

Similar pre combustion profiles at different scale?

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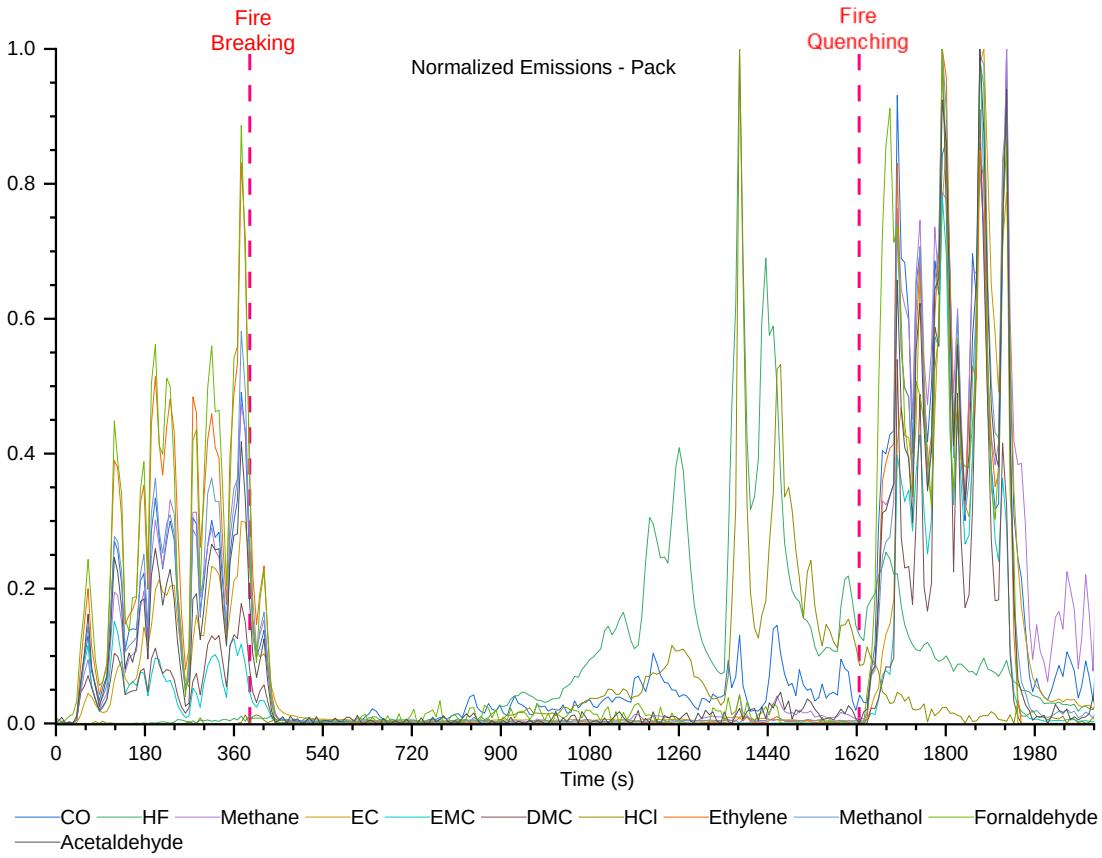
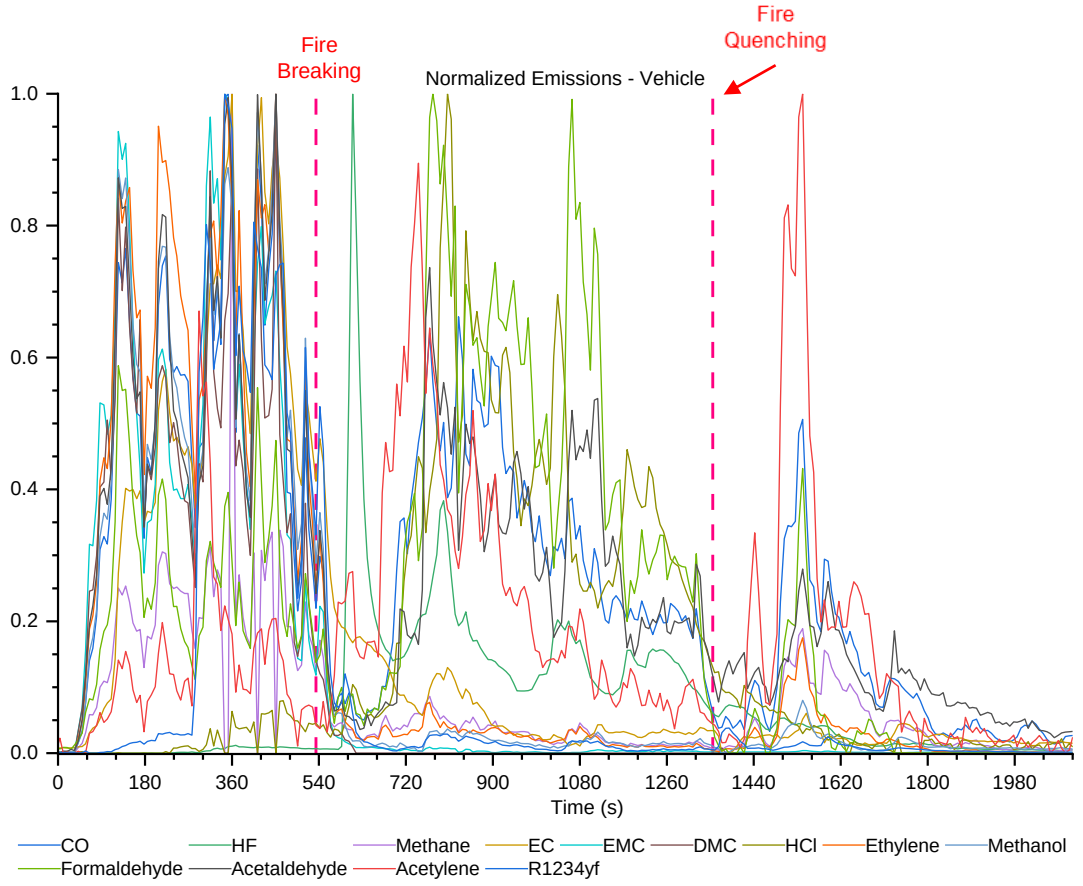
Gas Analysis – On-line FTIR





Different pattern of emissions.
Not only matter of scale!

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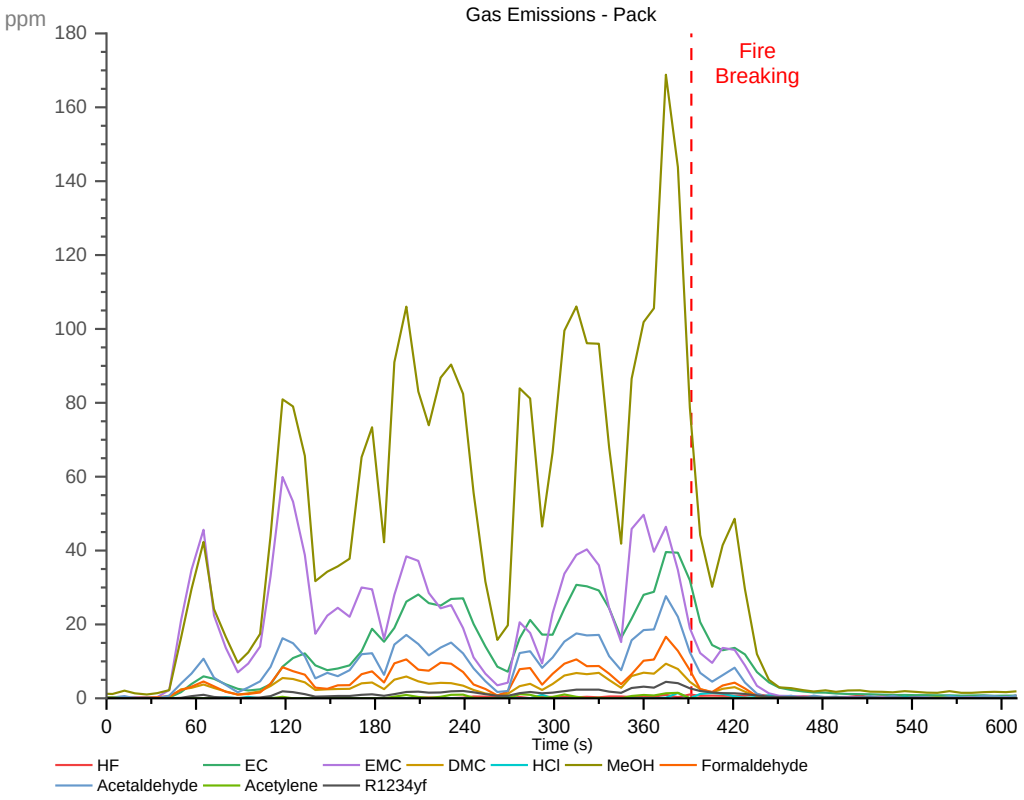
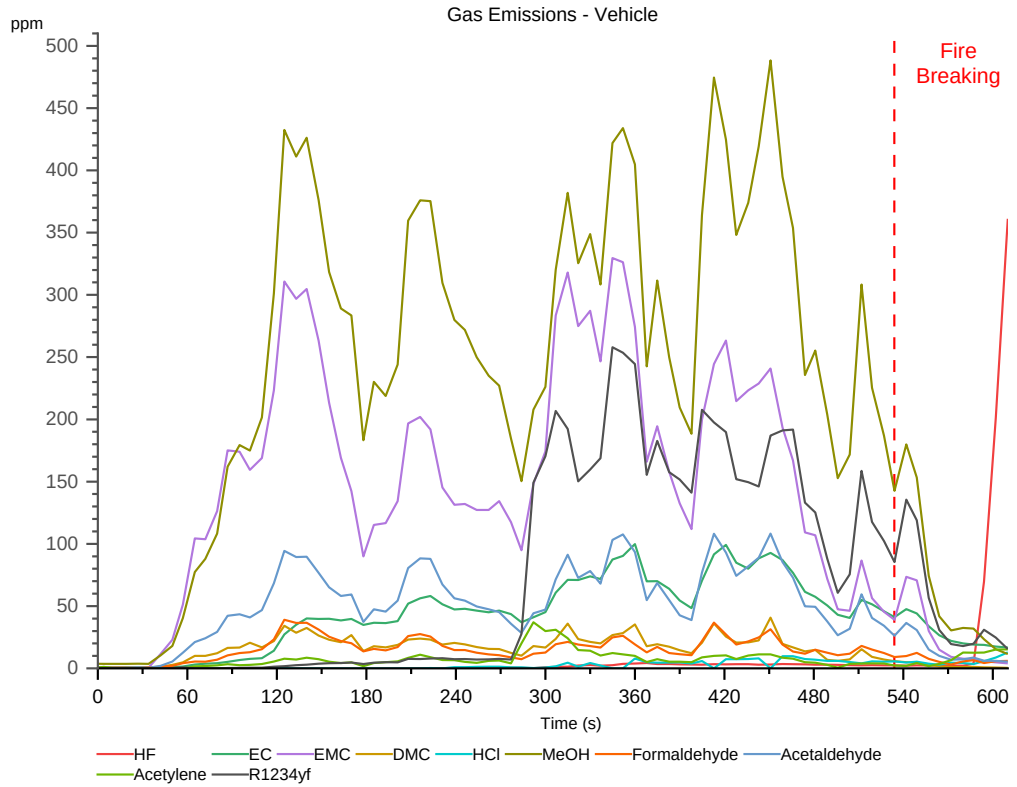
Gas Analysis – First 10 minutes





Fire breaking occurs later in Vehicle (approx. 2 minutes).
Rise of HF less than 1 min after fire breaking in vehicle.
Release of Acetylene and R1234yf in vehicle at around 4’30”.

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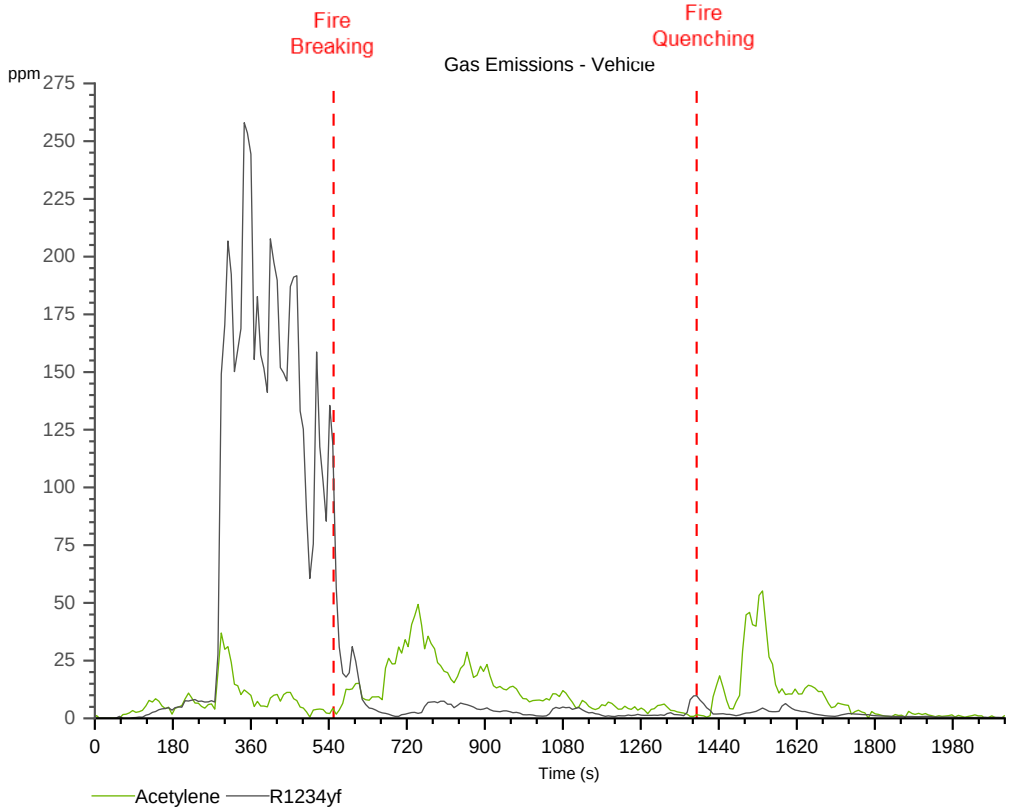
Gas Analysis – Pack vs Vehicle

- R1234yf and Acetylene are present in the emissions from the vehicle but not from pack
- R1234yf is to be expected, due to its use as a coolant gas in Air Conditioning units.
- Release of R1234yf occurs mostly during the pre-fire stage.
- Acetylene is released in bursts, with particular incidence in the combustion and fire quenching stages.



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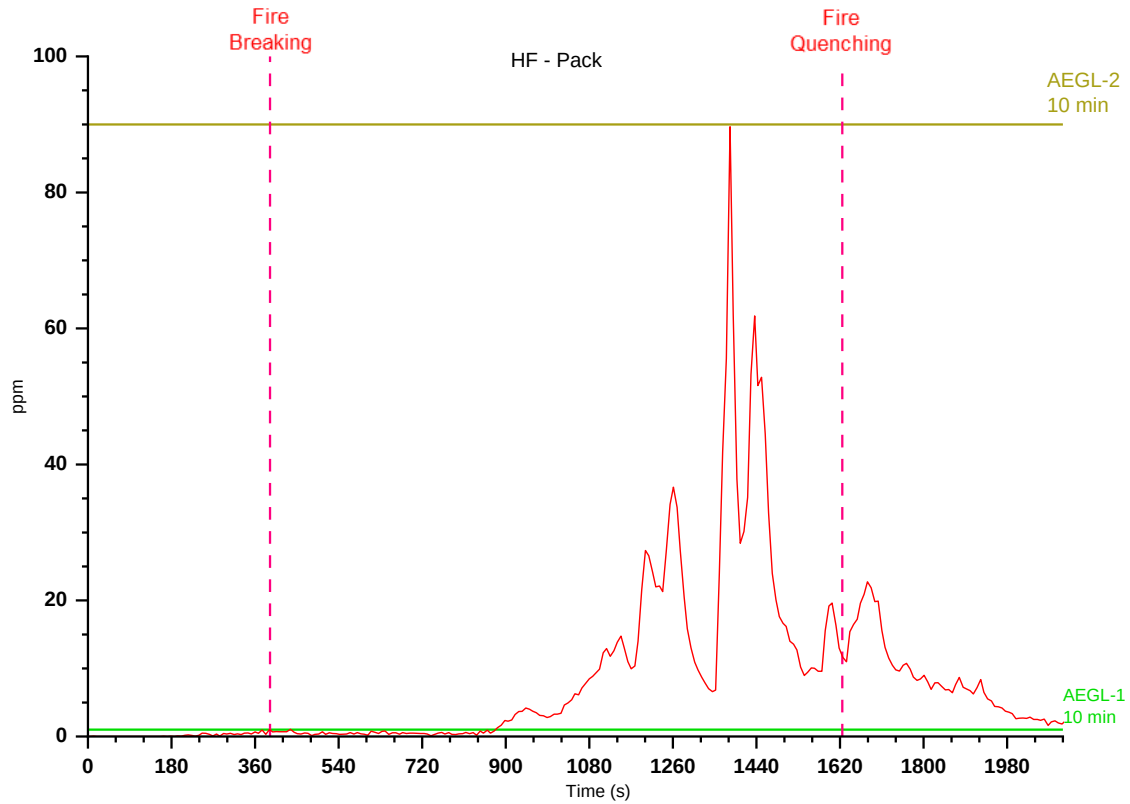
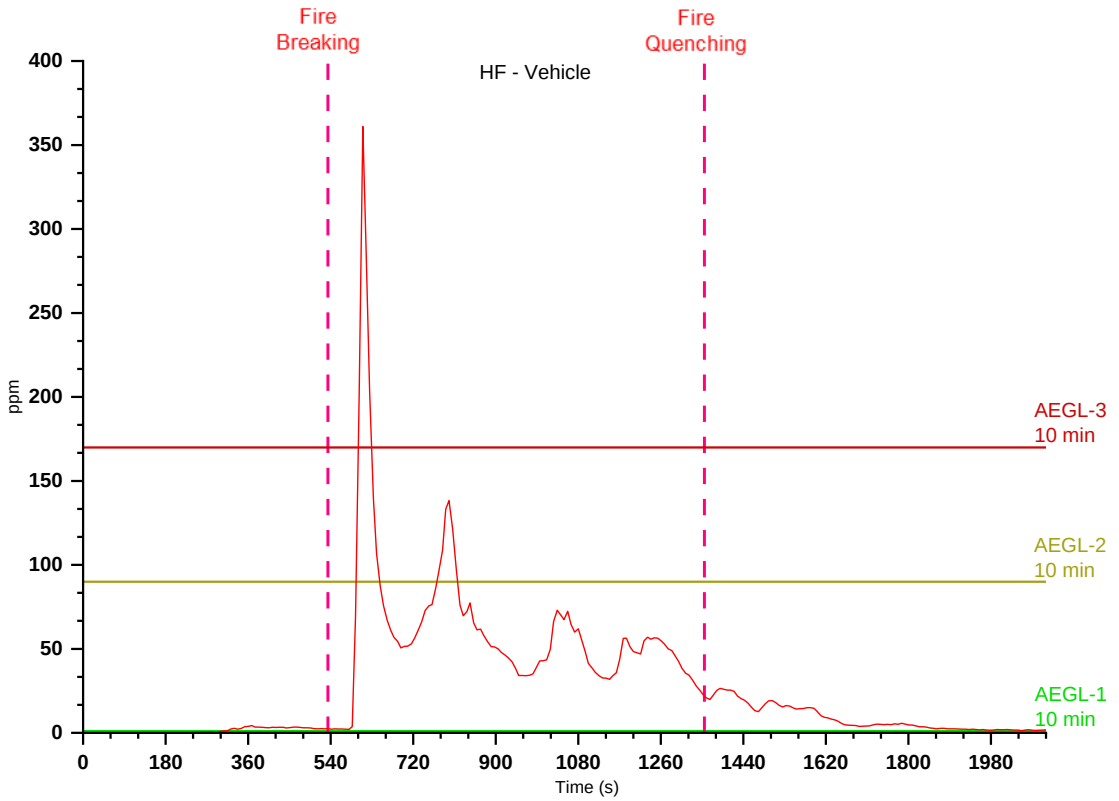
Gas Analysis – Pack vs Vehicle





Amount and dynamics of HF are different.

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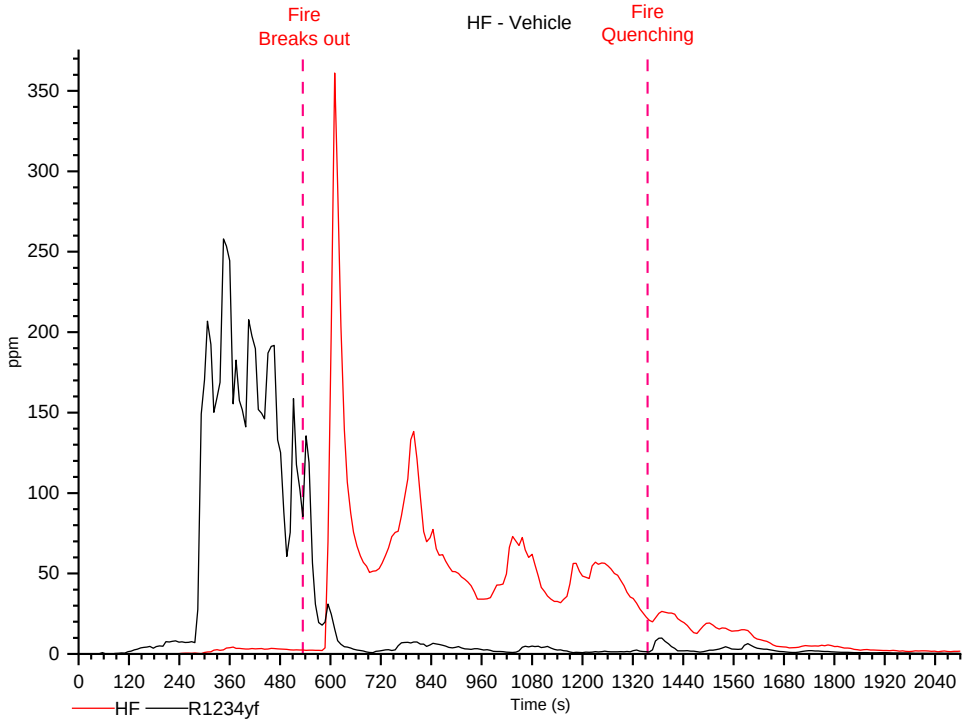
Gas Analysis – On-line FTIR

- R1234yf emissions decrease sharply with the onset of the fire.
- HF emissions spike within less than 2 minutes from fire onset.
- Thermal decomposition of R1234yf will lead to the formation of HF and COF_2.

?



- *JRC Technical and scientific support to research on safety aspects of the use of refrigerant R1234yf on MAC systems.* https://ec.europa.eu/docsroom/documents/4651/attachments/1/translations/en/renditions/native
- M. Ito *et al*, *Thermal Decomposition of Lower-GWP Refrigerants* (2014), International Refrigeration and Air Conditioning Conference Paper 1538. https://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=2537&context=iracc
- Material Safety Datasheet for Solstice® yf Refrigerant (R-1234yf), version 6.6, revised 2023/03/20. Available in different languages and formats at https://www.honeywellmsds.com/ehswww/external/search/search_index.jsp?P_LANGU=E&P_SYS=1

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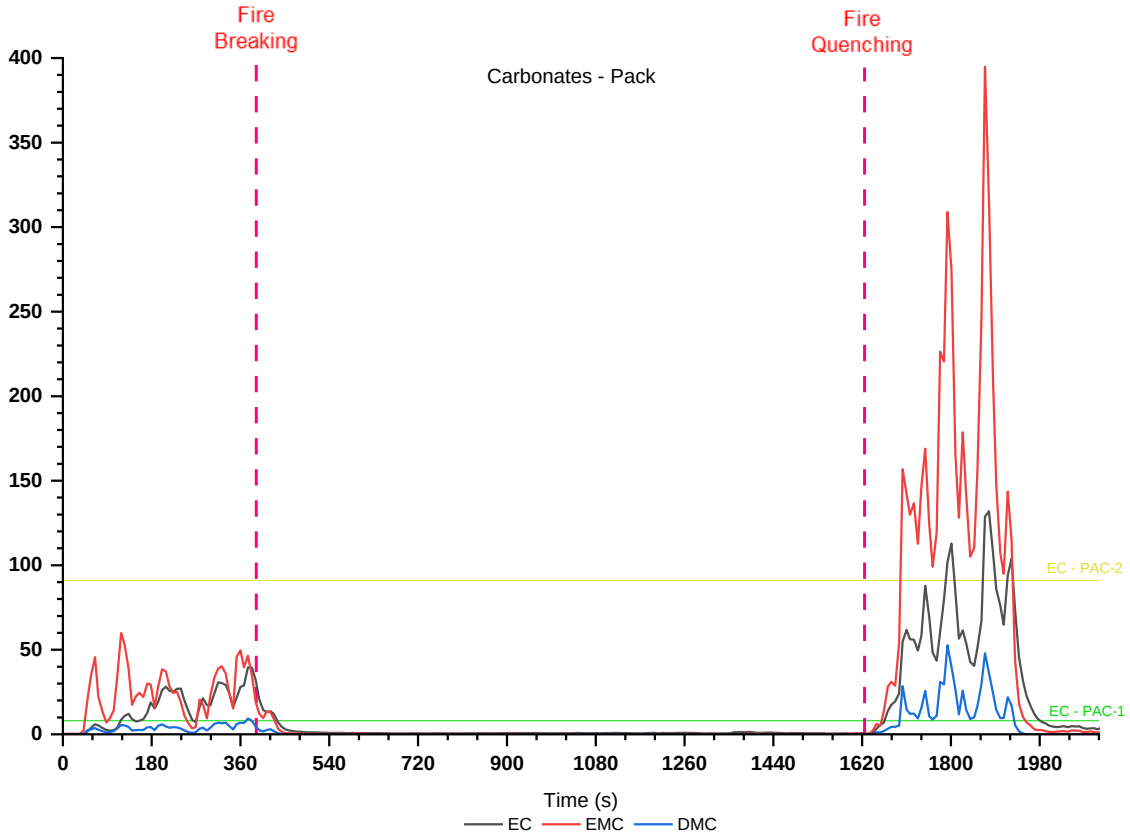
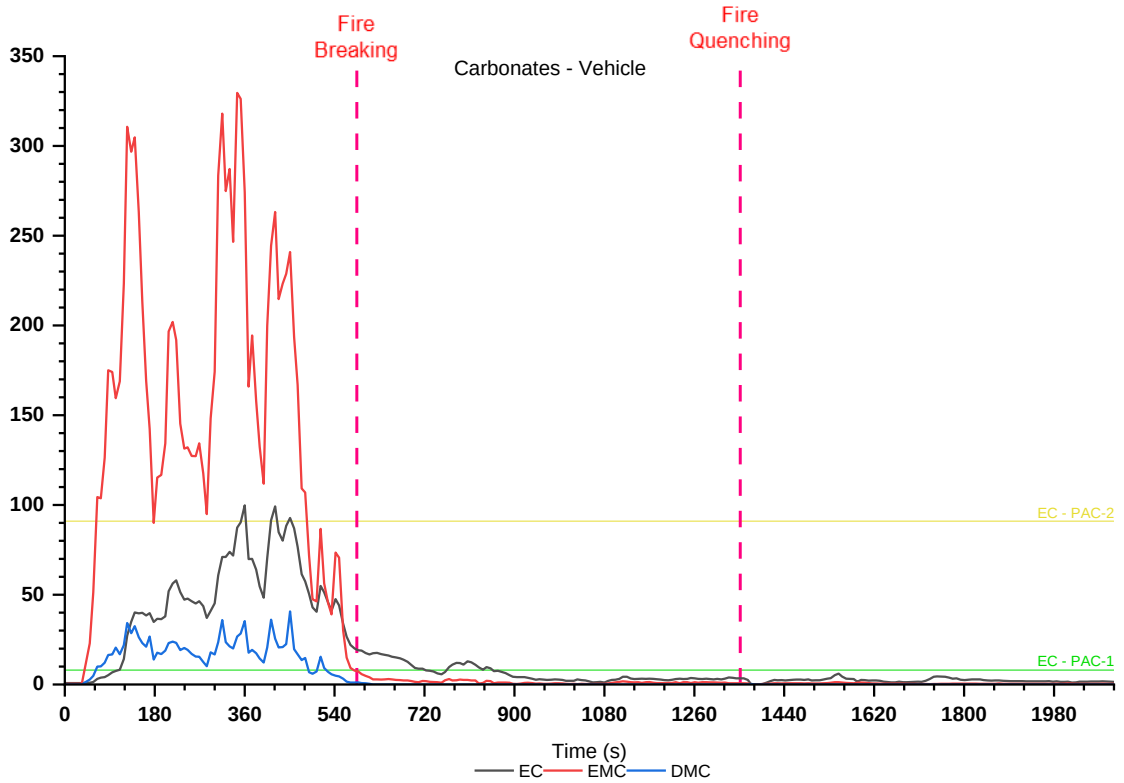
Gas Analysis – On-line FTIR





PAC values for Ethylene Carbonate (CAS No 96-49-1) used due to being the lowest for the organic carbonates

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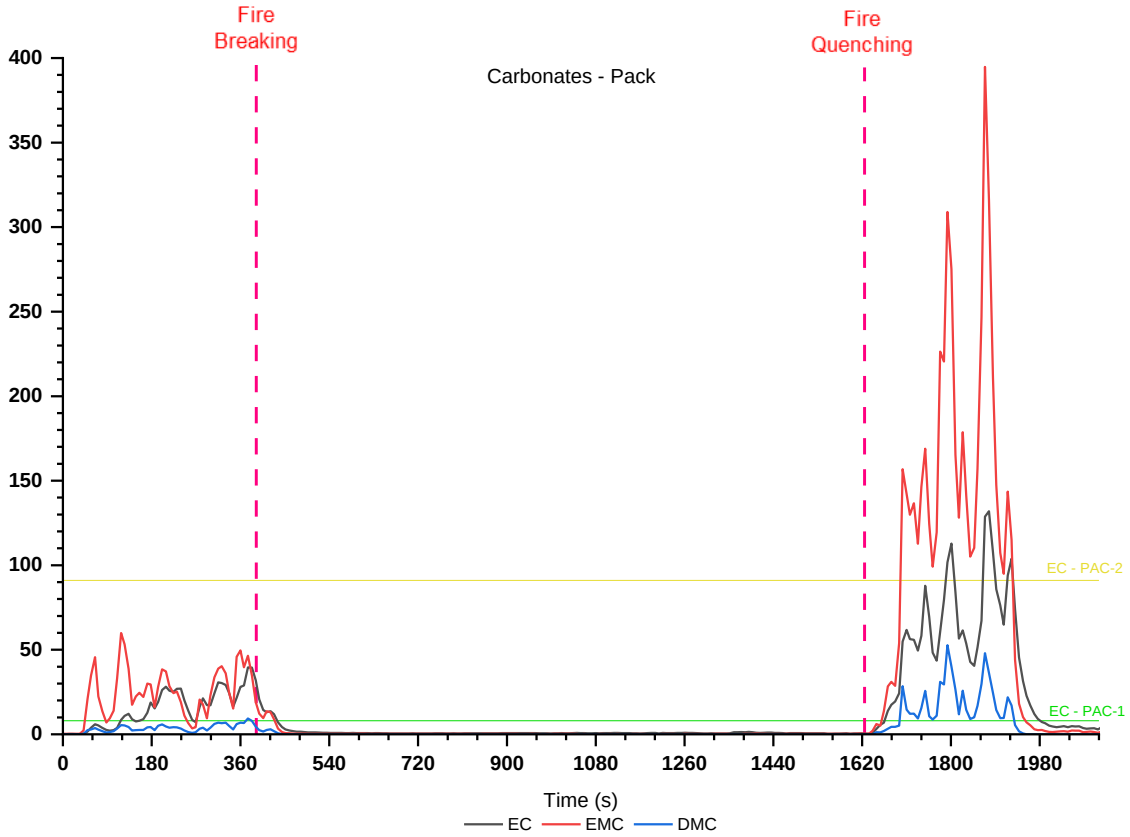
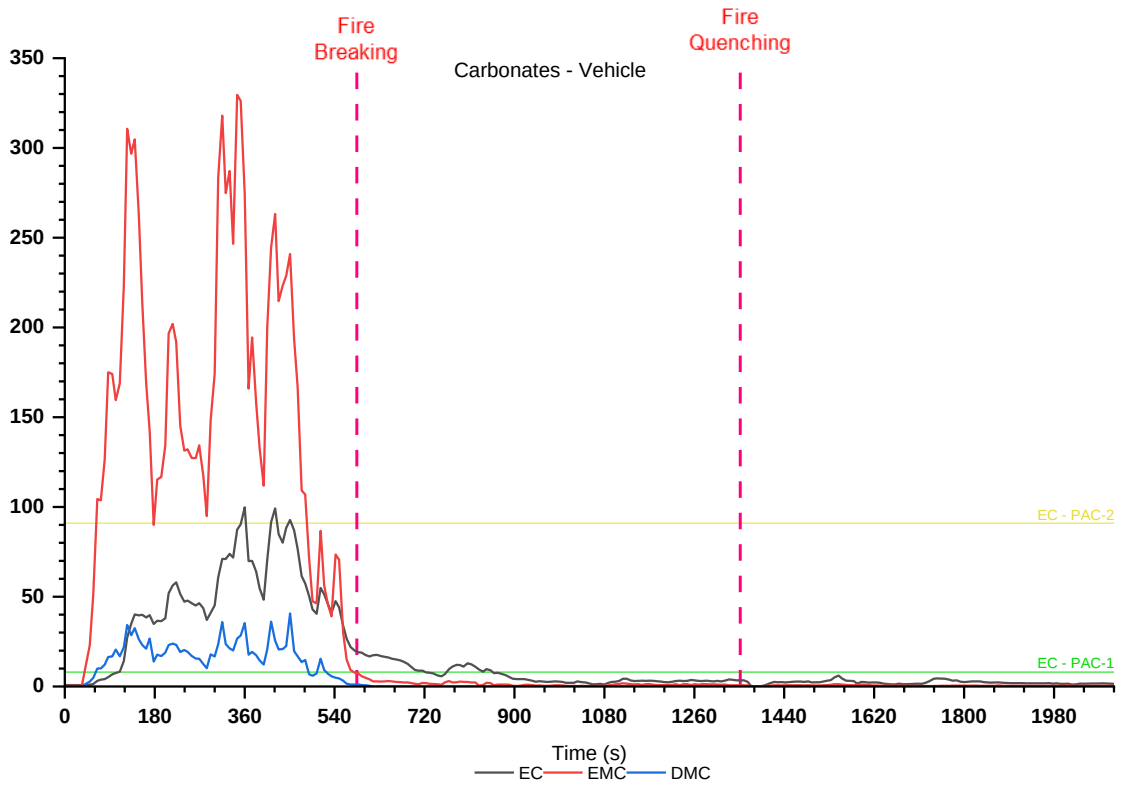
Gas Analysis – On-line FTIR





Different emission profiles for pack and vehicle.
Both with emission before fire breaking, but only pack has emission during fire quenching.
Fire quenching emissions might be related to fire fighting technique.

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Conclusions

- ✓ *Different gas emission dynamics for pack and vehicle level in thermal propagation.*
  - ✓ *HF release in Vehicle happening in the early stages of fire breaking out.*
  - ✓ *HF release in Pack only after a few minutes of fire.*
  - ✓ *Much more significant release of CO in vehicle than in Pack.*
  - ✓ *Release of R1234yf and Acetylene in vehicle but not in Pack.*
- ✓ *Different composition between pack and vehicle gas emissions, starting before 5 minutes, with release of Acetylene and R1234yf.*
- ✓ *HF release in Vehicle above AEGL-2, and for a short time even AEGL-3, for 10 min exposure.*
- ✓ *Combustion of R1234yf refrigerant leads to HF formation.*
- ✓ *Open Path FTIR as a tool for monitoring Thermal Propagation stages, with minimal concerns for sampling.*
- ? *Methodological aspects are important when quantifying. (e.g. position of extraction duct)*
- ? *Fire quenching methods impact on composition and dynamics of gas emissions during fire fighting stage?*

Acknowledgement

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Thank you

European Commission