Online Mass Spectrometry for Ultra-Sensitive Detection of CO_2 Impurities: Meeting Updated Northern Lights Specifications

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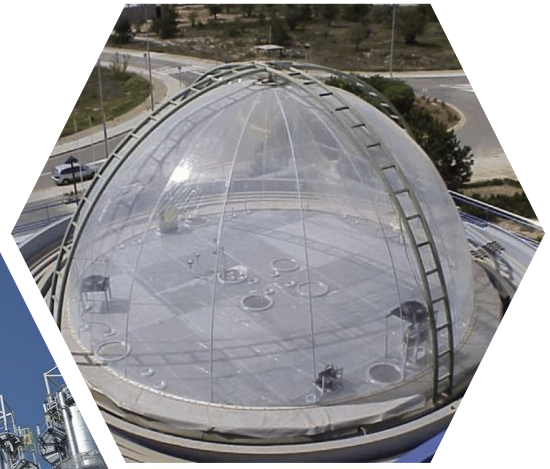
8th Post-Combustion Capture Conference (PCCC-8) – September 18, 2025

TCM

Expertise in trace gas analysis

Laboratory measurements



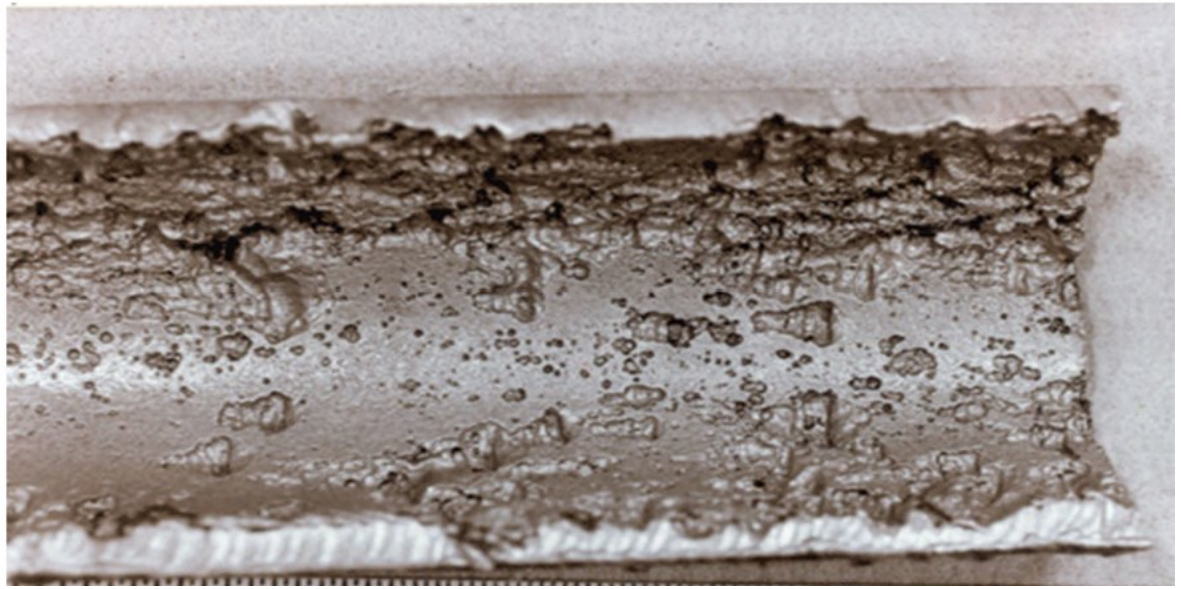
Emissions from amine plants

Measurement of CO_2 impurities

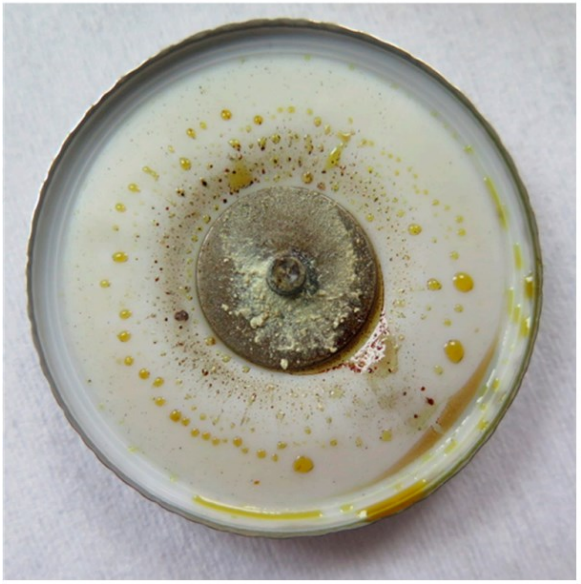
Atmospheric Measurements

Potential impact of impurities on CO_2 transport

- Corrosion
- Alteration of the physicochemical properties of CO_2
- Liquid (water, acids) or solid phase dropouts



Razak et al., 2023



Morland et al., 2021

Northern Lights Liquid CO_2 quality specifications

Component	Unit	Limit for CO_2 Cargo within Reference Conditions
Carbon dioxide (CO_2)	mol-%	Balance (Minimum 99.81%)
Water (H_2O)	ppm-mol	≤ 30
Oxygen (O_2)	ppm-mol	≤ 10
Sulphur oxides (SO_X)	ppm-mol	≤ 10
Nitrogen oxides (NO_X)	ppm-mol	≤ 1.5
Hydrogen Sulfide (H_2S)	ppm-mol	≤ 1
Amine	ppm-mol	≤ 10
Ammonia (NH_3)	ppm-mol	≤ 10
Formaldehyde (CH_2O)	ppm-mol	≤ 20
Acetaldehyde (CH_3CHO)	ppm-mol	≤ 20
Mercury (Hg)	ppm-mol	≤ 0.0003
Carbon Monoxide (CO)	ppm-mol	≤ 100
Hydrogen (H_2)	ppm-mol	≤ 50
Methane (CH_4)	ppm-mol	≤ 100
Nitrogen (N_2)	ppm-mol	≤ 50
Argon (Ar)	ppm-mol	≤ 100
Methanol (CH_3OH)	ppm-mol	≤ 30
Ethanol (C_2H_5OH)	ppm-mol	≤ 1
Total Volatile Organic Compounds [1]	ppm-mol	≤ 10
Mono-Ethylene Glycol (MEG)	ppm-mol	≤ 0.2
Tri-Ethylene Glycol (TEG)	ppm-mol	≤ 0.2
BTEX [2]	ppm-mol	≤ 0.5
Ethylene (C_2H_4)	ppm-mol	≤ 50
Hydrogen Cyanide (HCN)	ppm-mol	≤ 100
Aliphatic Hydrocarbons (C_3+) [3]	ppm-mol	≤ 1,100
Ethane (C_2H_6)	ppm-mol	≤ 75
Solids, particles and/or dust	µm	≤ 1.0

[1] Total Volatile Organic Compounds (VOC) are VOC in addition to the ones listed separately in this specification, i.e., Ethanol, Methanol, Formaldehyde, Acetaldehyde, and BTEX, and includes the following components: 1-propanol < 1 ppm-mol, 2-butanol <1 ppm-mol, 1,2,4-trimethylbenzene <5 ppm-mol.

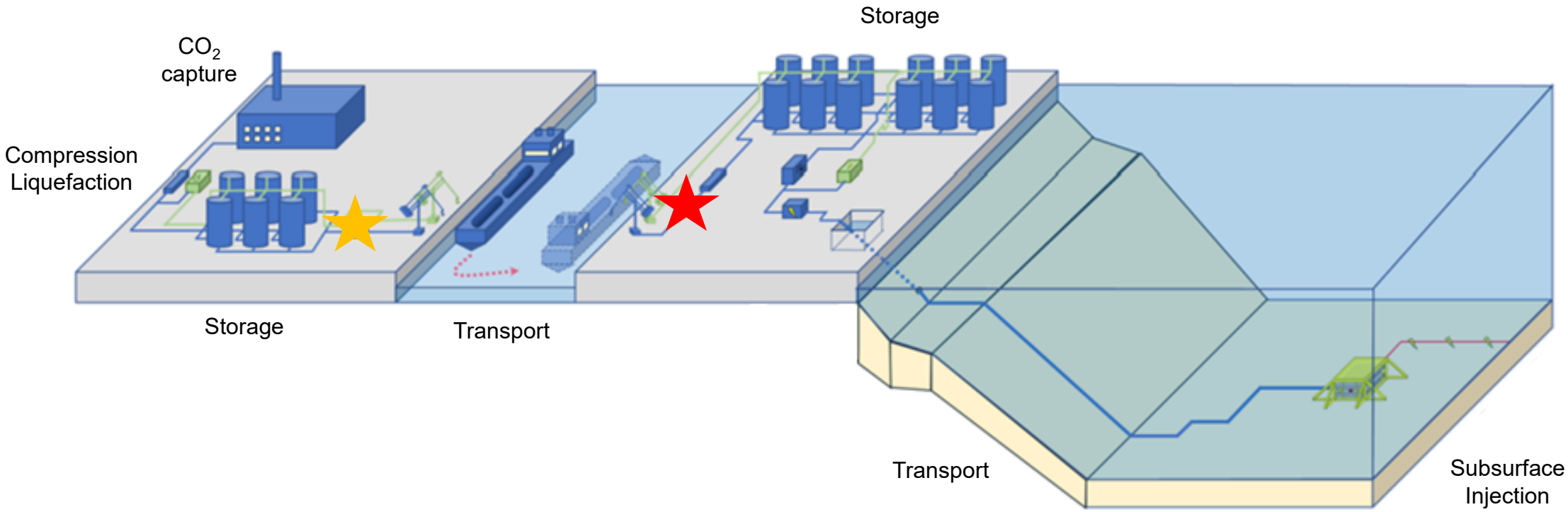
[2] BTEX refers to the following chemical compounds: Benzene, Toluene, Ethylbenzene and Xylene.

[3] Total amount of hydrocarbons not to exceed 1,100 ppm-mol. Individual limits for groups of HCs: C3 <1,100 ppm-mol, C4-C5 < 815 ppm-mol, C6-C7 < 75 ppm-mol, C8-C9 < 8 ppm-mol.

- Measuring a broad spectrum of inorganic and organic impurities – both polar and non-polar – down to sub-ppm levels in a liquid CO_2 matrix poses a significant analytical challenge.

Northern Lights, 2025

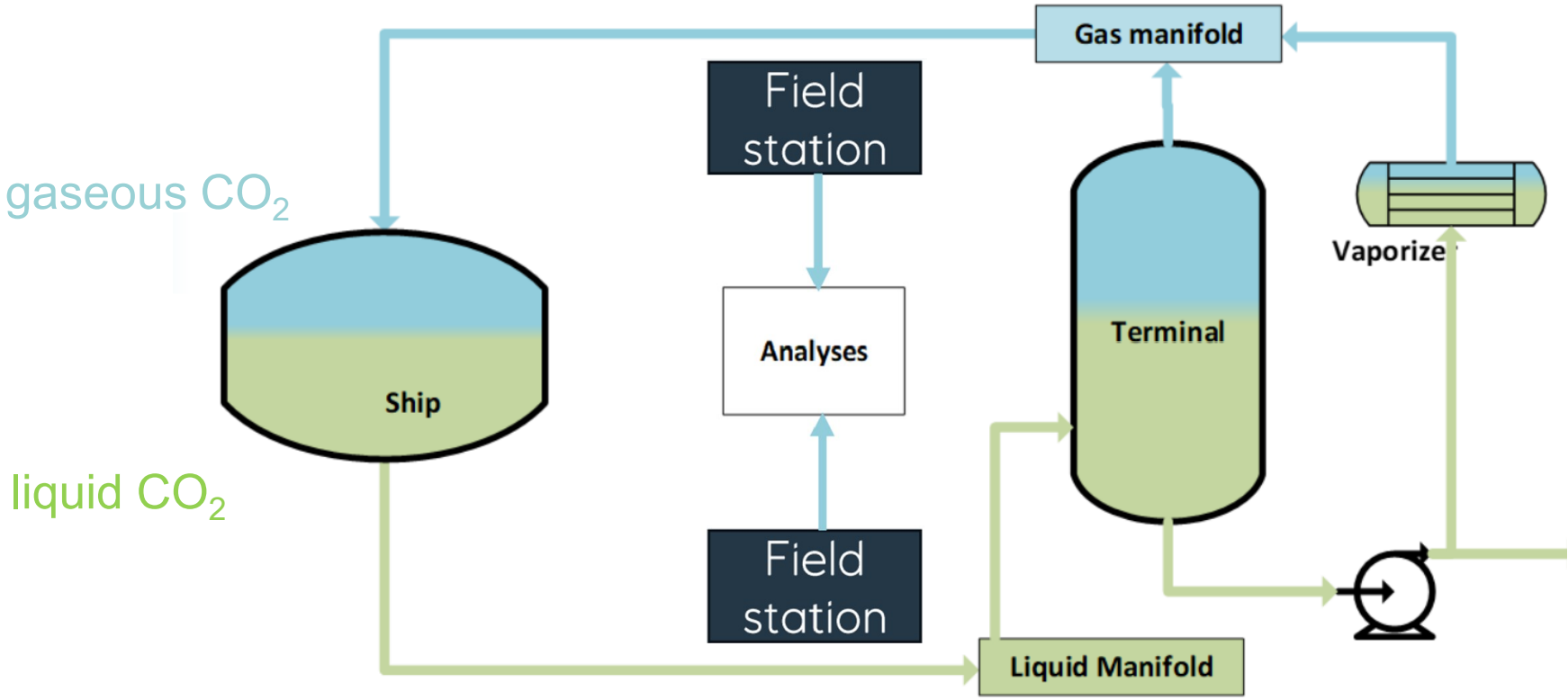
CO_2 quality checkpoints



- At the receiving terminal, it is essential to monitor CO_2 impurities online and in real time.

Northern Lights

Sampling challenges

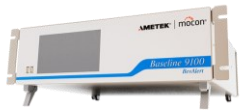


Kvilhaug Simonsen and Drageset, 2025

- Impurities must be analyzed both in the LCO_2 stream and in the CO_2 gas return.

Existing commercial solutions for CO_2 analysis (organic impurities)

GC



- Offline
- No real-time monitoring (12 min)
- Measurement range: ppb-ppm

FTIR

- Online
- No real-time monitoring (10 min)
  - Slow time response even for non-sticky* compounds
- Measurement range: ppb-ppm

MS

- Online
- Real-time monitoring
  - Slow time response for sticky* compounds
- Measurement range: ppb-ppm

* Sticky compounds adsorb to sampling and analyzer surfaces, causing delayed or distorted signals.

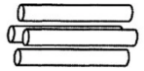
- These instruments were originally designed for beverage-grade CO_2, which has simpler impurity specifications (*i.e.*, does not include analytically challenging compounds such as amines and glycols).
- No method has yet been validated for LCO_2 derived from amine-based CO_2 capture.

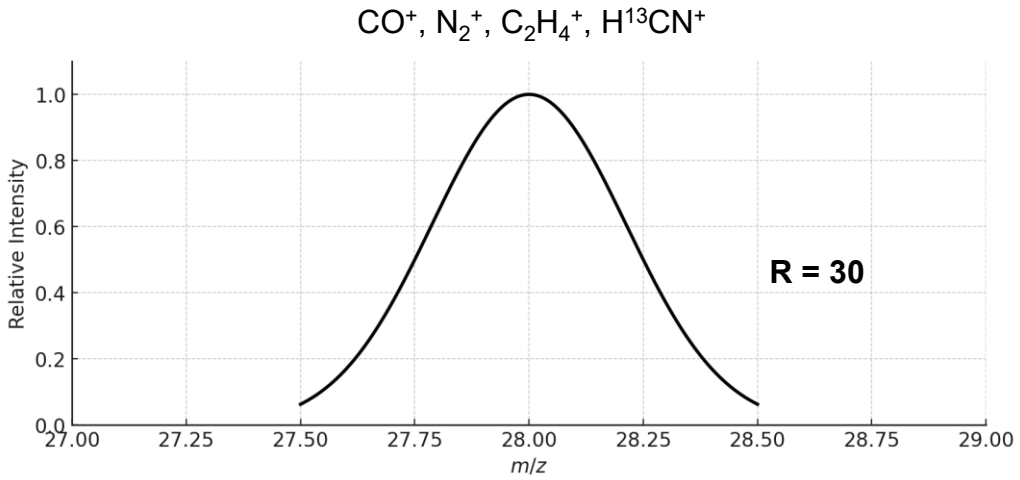
New development

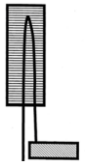
Prototype instrument (“PTR-TOF CO_2*Guard”)* for online and real-time analysis of impurities in liquid and gaseous CO_2

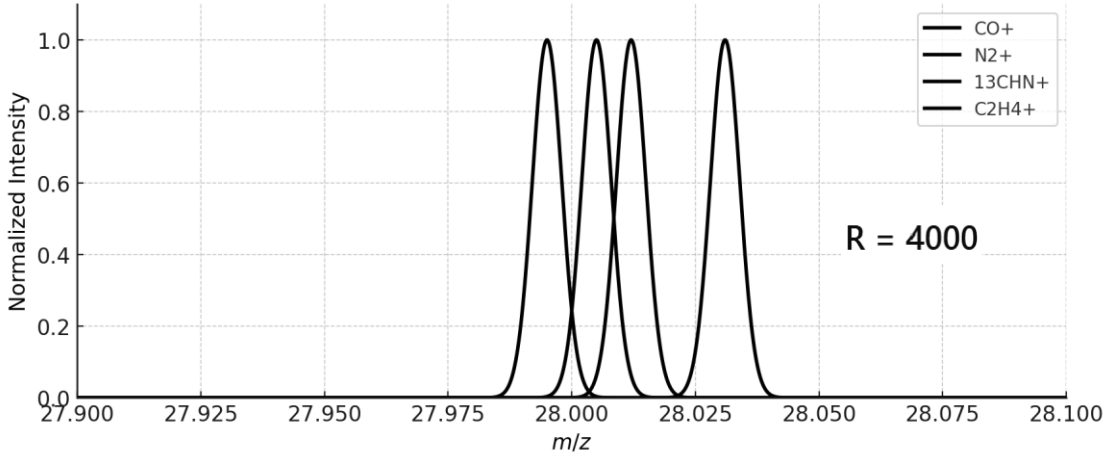
1. Distinctive feature: high-resolution analysis of complex mixtures using time-of-flight (ToF) mass spectrometry
2. Builds on proven PTR-TOF technology for sensitive detection of amines, alcohols, and aromatics
3. Optimized LCO_2 vaporization system (in development) ensures fast response to challenging “sticky” compounds (*e.g.*, glycols, alkanolamines)
4. Modified ionization system extends detection to key inorganic pollutants (NO_2, SO_2)

Time-of-Flight MS for complex mixture analysis

QMS 

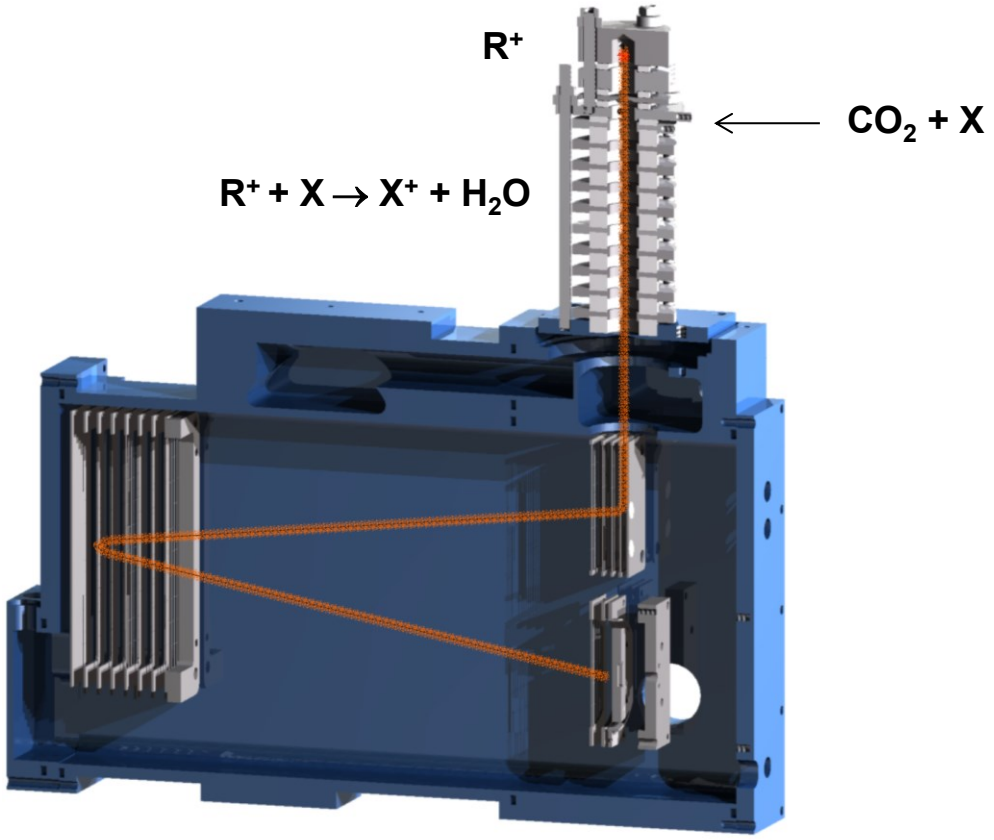


ToF-MS 



- High resolution mass analysis significantly enhances detection capabilities, enabling clear separation and identification of individual constituents in complex mixtures

Proven PTR-TOF technology



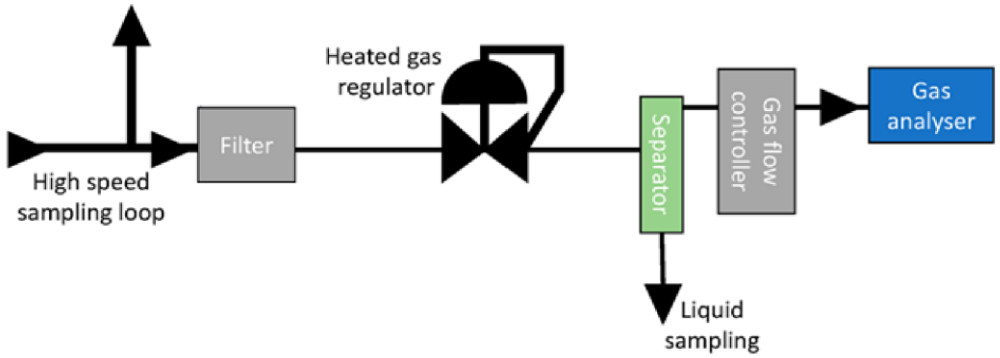
1. Water
2. Oxygen
3. SO_2
4. NO_2
5. H_2S
6. Amines
7. Ammonia
8. Formaldehyde
9. Acetaldehyde
10. Methanol
11. Ethanol
12. Monoethylene Glyol
13. Triethylene Glycol
14. BTEX
15. HCN

- Importantly, the instrument can also detect untargeted impurities - those not included on the specification list (see next slide).

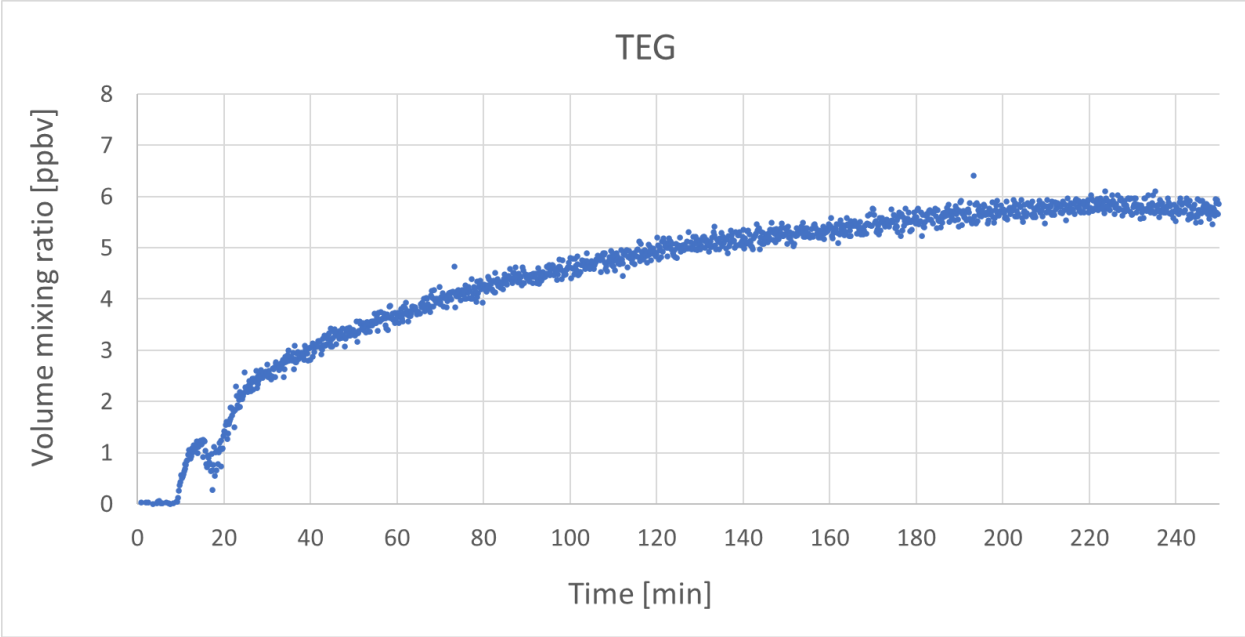
Impurities detected in the CO_2 product (MEA-based CO_2 capture)

Name	Formula	Stripper (ppbV)
2-aminoethanol	$H_2NCH_2CH_2OH$	8
Ammonia	NH_3	358
Formaldehyde	HCHO	190
Acetaldehyde#	CH_3CHO	7300
Acetone	$(CH_3)_2CO$	300
Acetic acid	CH_3COOH	20
Formamide*	$CHONH_2$	210
2-amino acetaldehyde*	NH_2CH_2CHO	40
Methane, nitro-*	CH_3NO_2	1800
Ethane, nitro-*	$CH_3CH_2NO_2$	1
Pyrrole*	C_4H_4NH	5
Benzene*	C_6H_6	2
Pyrazine*	$C_4H_4N_2$	500
Pyrazine methyl-*	$C_4H_3N_2CH_3$	80
Pyrazine dimethyl-*	$C_4H_2N_2(CH_3)_2$	20
Pyrazine trimethyl-*	$C_4HN_2(CH_3)_3$	5
Oxadiazole*	$C_2H_2N_2O$	5

Sticky analytes – development of an optimized LCO_2 vaporization system



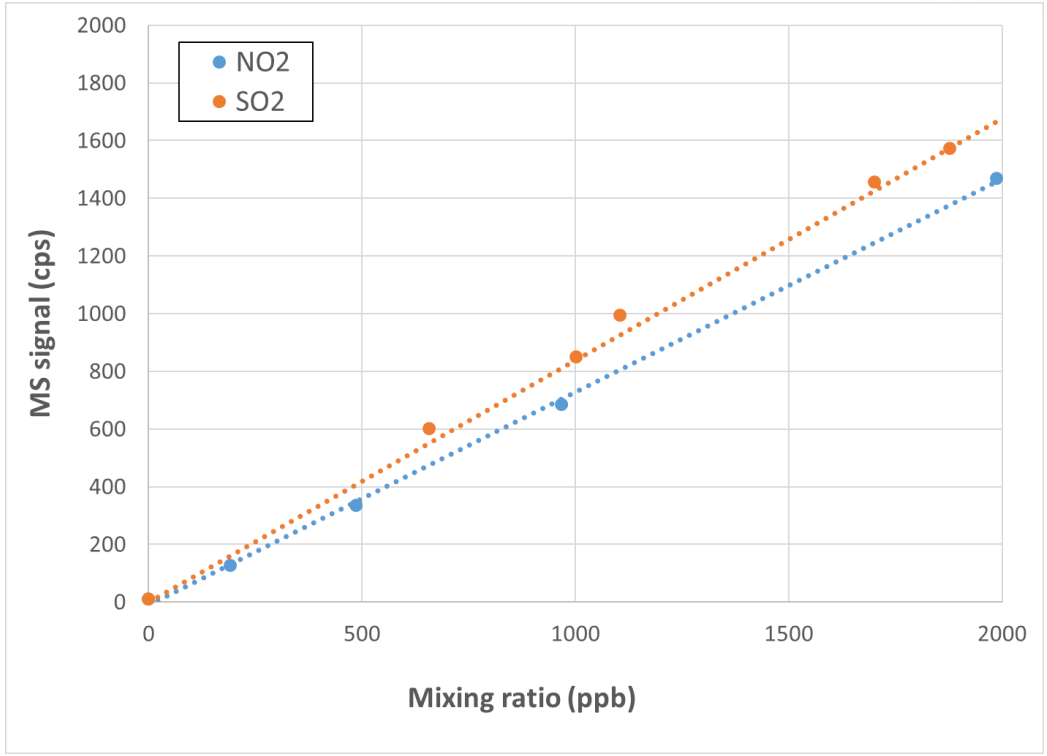
Morland et al., 2021 (modified)



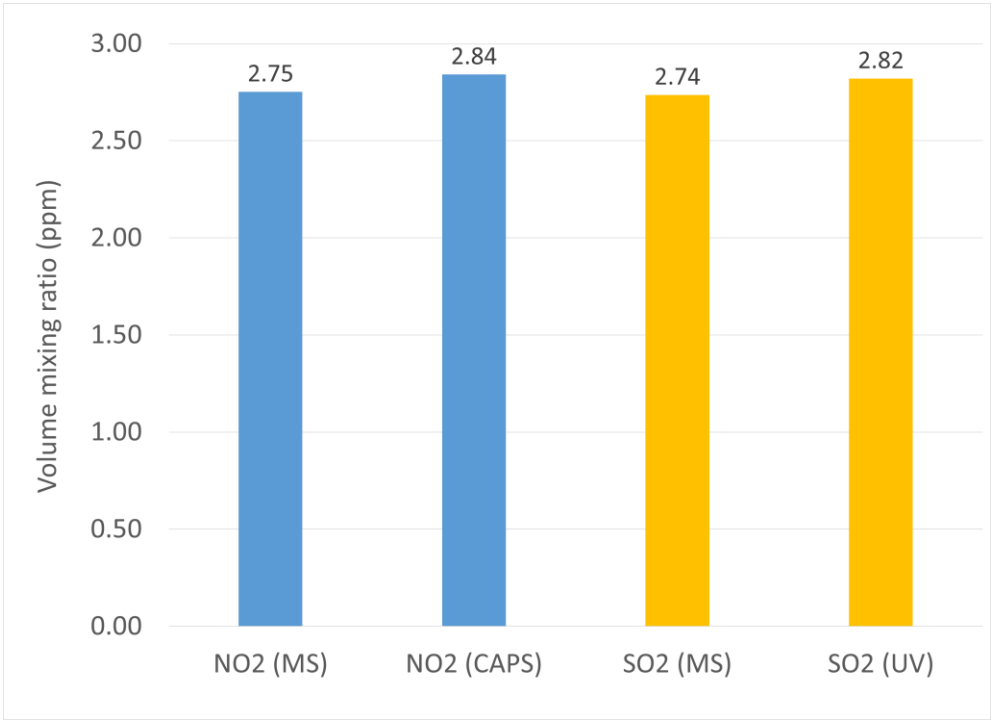
- Existing vaporization systems on the market do not deliver fast response to challenging "sticky" compounds (*e.g.*, glycols, alkanolamines).
- An optimized LCO_2 vaporization system is under development to overcome this challenge.

Earlier work (2022) – analysis of inorganic compounds (NO_2, SO_2)

Limit of Detection: NO_2 3 ppb
SO_2 20 ppb



Test gas with 2.73 ppm NO_2 and 2.75 ppm SO_2 in CO_2



Thank you for you attention!

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