Impurity Analysis and Process Monitoring in Pure CO_2 with Cavity Ring-Down Spectroscopy

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Tigeroptics
High-Performance Gas Analyzers

Tiger Optics Profile

Established Company

- Pioneered CRDS in 2001
- 40+ employees
- 100% U.S.-based manufacturing

Global Customers

- Thousands of installations worldwide
- Global network of distributors

Customer Satisfaction

More than 70% of sales go to repeat customers

Certified Technology

ISO 9001 certification since 2008

Part of Process Insights Holdings since 2018

Process Insights
Premium Insights into Process

cosa+xentaur INNOVATIVE MEASUREMENT SOLUTIONS

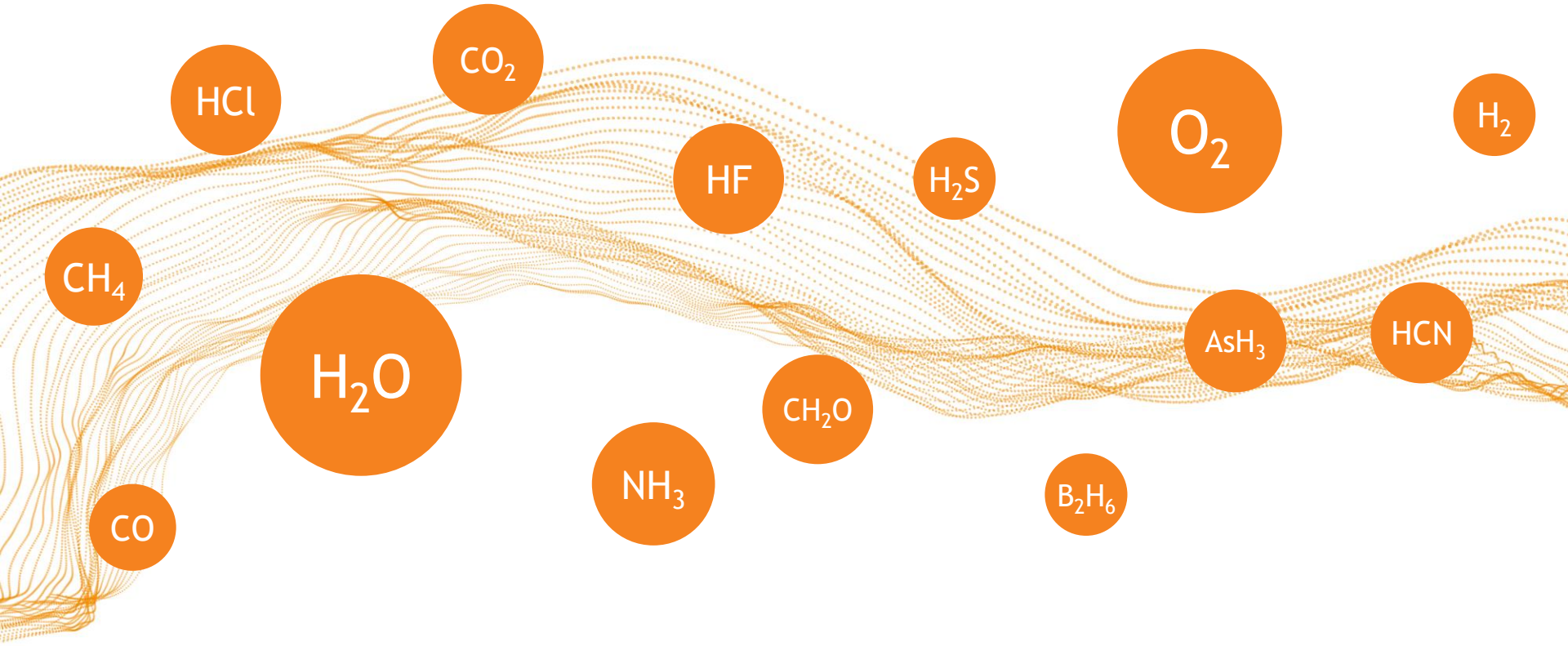
ALPHA OMEGA INSTRUMENTS

LAR PROCESS ANALYSERS AG

Tigeroptics

What Can We Detect?

Extensive Analysis Capability from PPT to % Levels

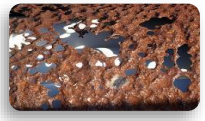


Where Can We Detect?

Compatibility with a Large Array of Background Gases

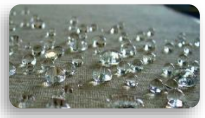
Inert & Passive Gases — N_2 H_2 Ar He Ne Kr Xe

Oxygenated Gases — O_2 CDA CO CO_2 N_2O NO



Corrosives — Cl_2 HCl HBr

Hydrides — NH_3 PH_3 AsH_3 GeH_4 SeH_2



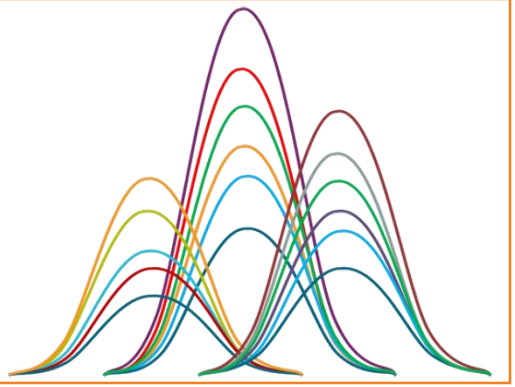
Fluorinated Gases — SF_6 NF_3 BF_3 C_xF_y

Various Mixtures *(stack gas, Syngas, ambient air etc.)*

Advantages of Tiger's CRDS Technology

Unparalleled Sensitivity

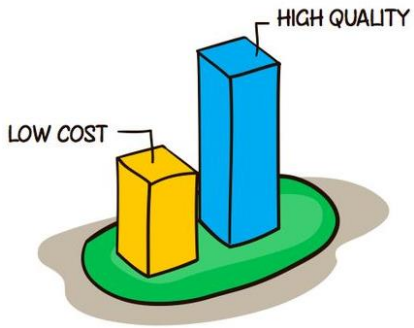
Absolute Measurement
No Calibration Needed



Intrinsically Linear
Wide Dynamic Range

Non-contact Measurement
Fast Speed of Response

High Specificity &
Versatility



Exceptionally Low
Cost of Ownership

CO_2 Matrix: Selected Applications & Markets

Semiconductor/Purifier Makers

- Trace O_2 in electronic grade UHP CO_2
- Photolithography

Beverage

- PPM level H_2O and NH_3
- Process control guideline species

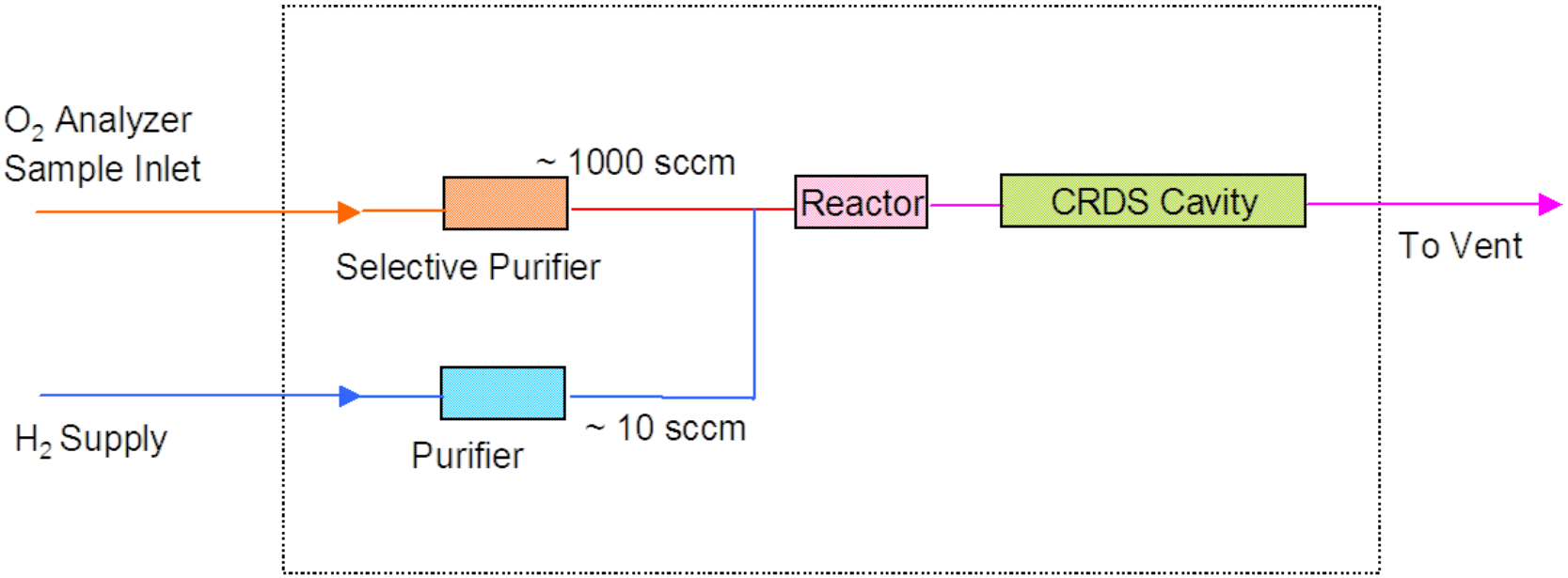
Gases & Chemicals

- Trace HCl in product CO_2
- CO_2 gas manufacturing, purification, and liquefaction plants

Trace O_2 in Electronic Grade UHP CO_2

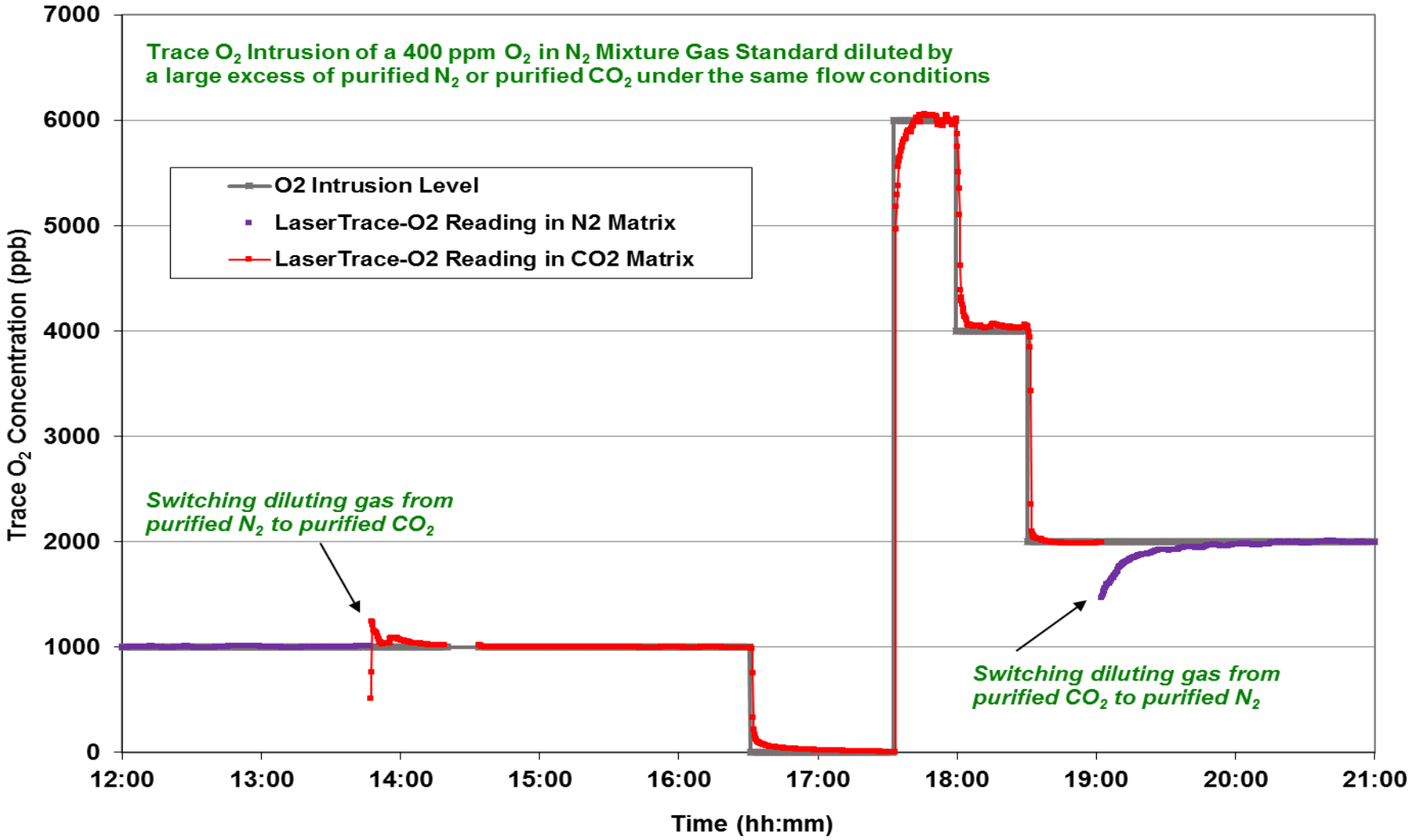
Fast, quantitative conversion of trace oxygen to water*

$$O_2 + 2\,H_2 \longrightarrow 2\,H_2O$$

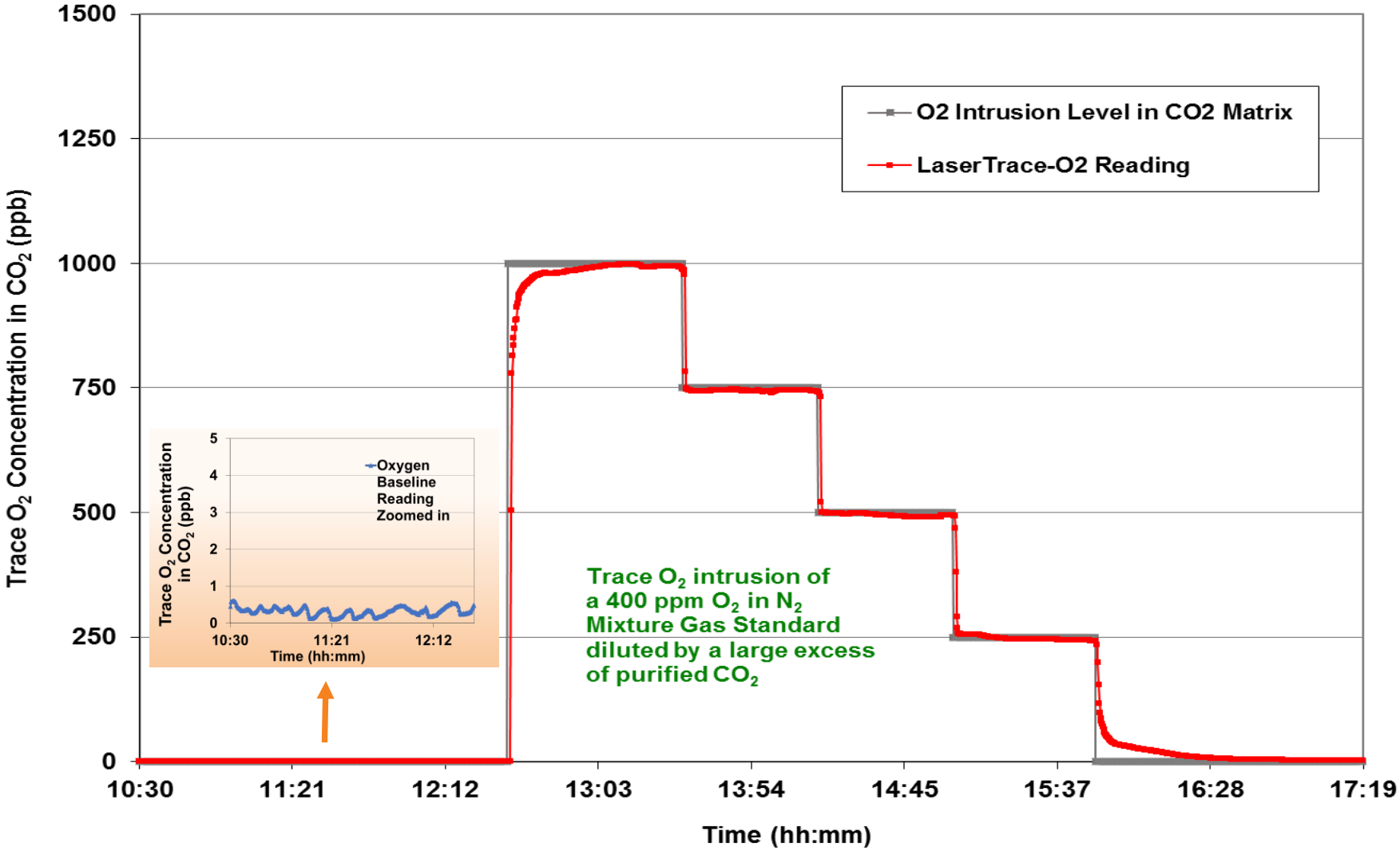


*U. S. Patent # 7,255,836—Lehmann KK, et al.

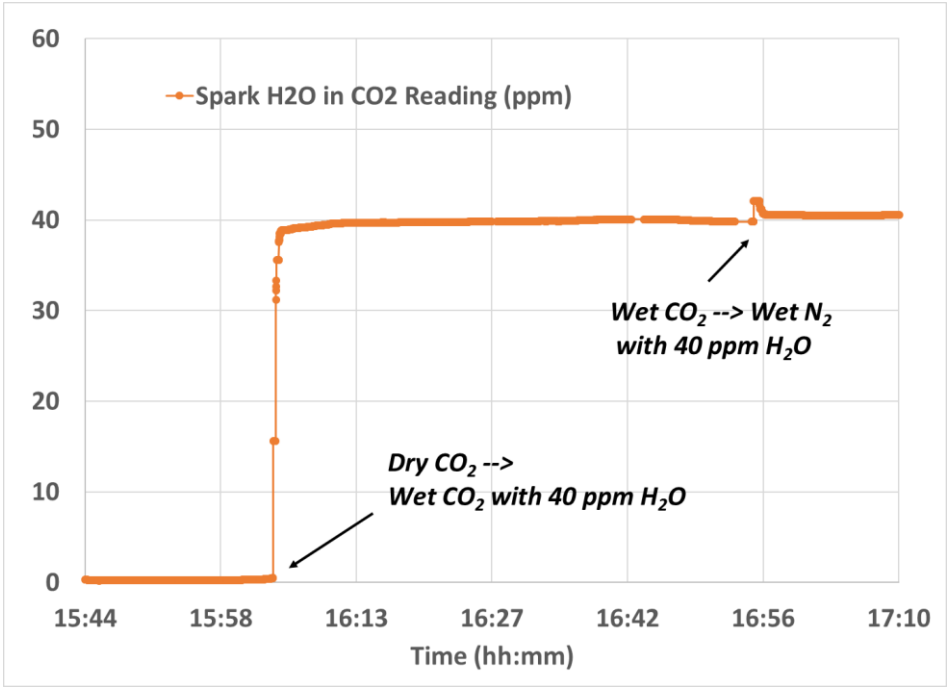
Trace O_2 in Electronic Grade UHP CO_2



Trace O_2 in Electronic Grade UHP CO_2



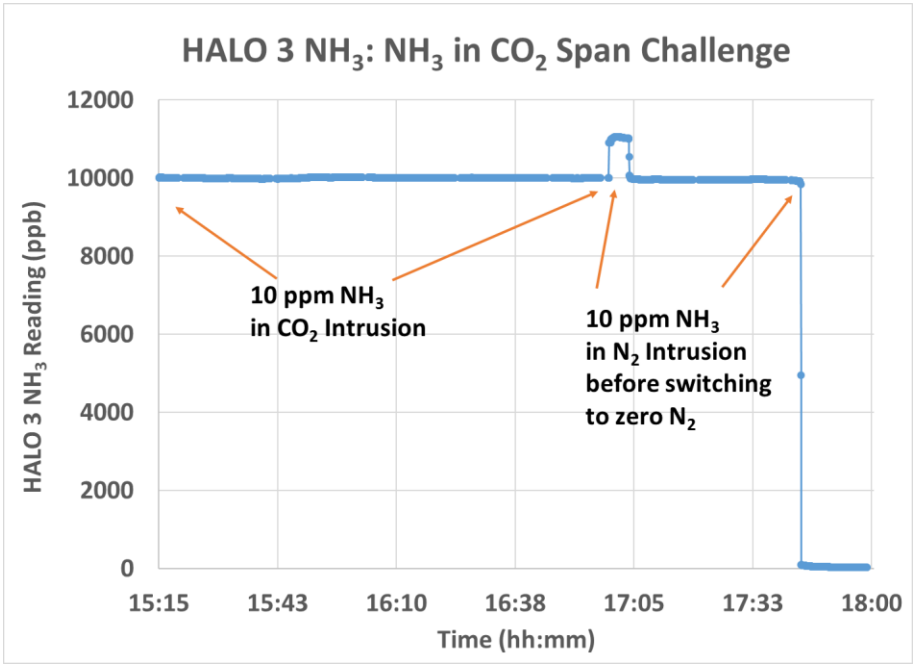
Trace H_2O: A Key Guideline Species in Beverage CO_2

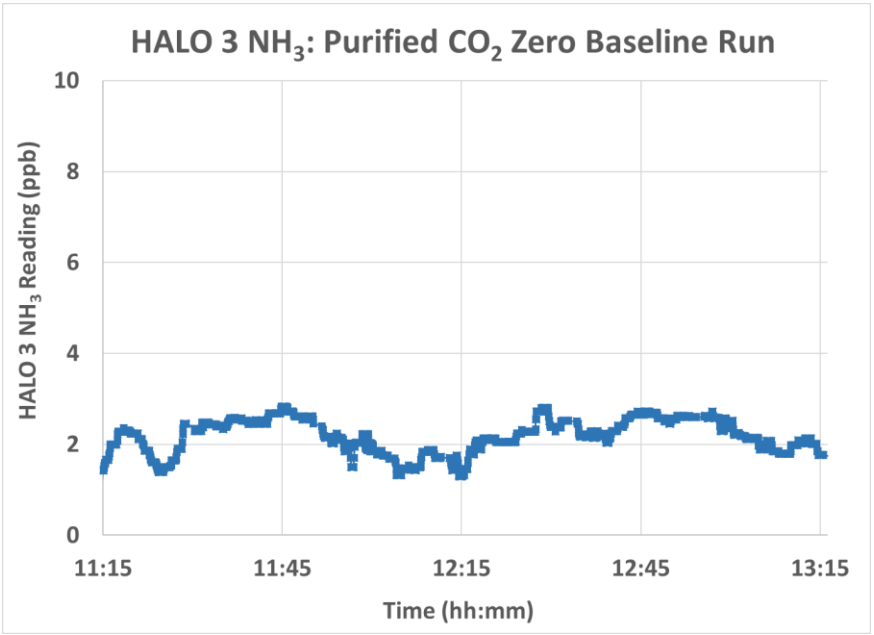


Parameter		Rationale [1]
Purity	99.9% v/v min.	Process
Moisture	20 ppm v/v max.	Process
Acidity	To pass test	Regulatory
Oxygen	30 ppm v/v max.	Sensory
Nitrogen compounds		
Ammonia	2.5 ppm v/v max.	Process
Nitric oxide/nitrogen dioxide	2.5 ppm v/v max. each	Regulatory

ISBT (*International Society of Beverage Technologists*) Carbon Dioxide Guidelines

Trace NH_3: A Key Guideline Species in Beverage CO_2

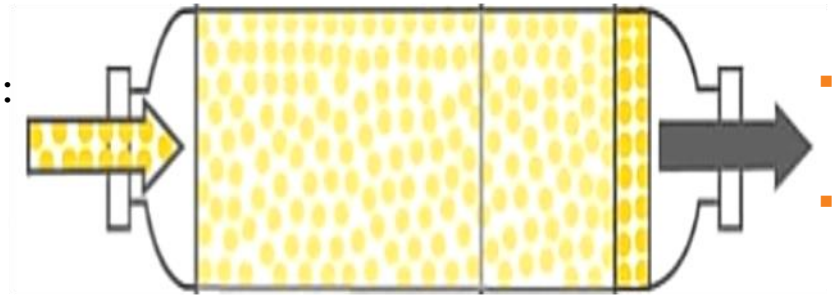




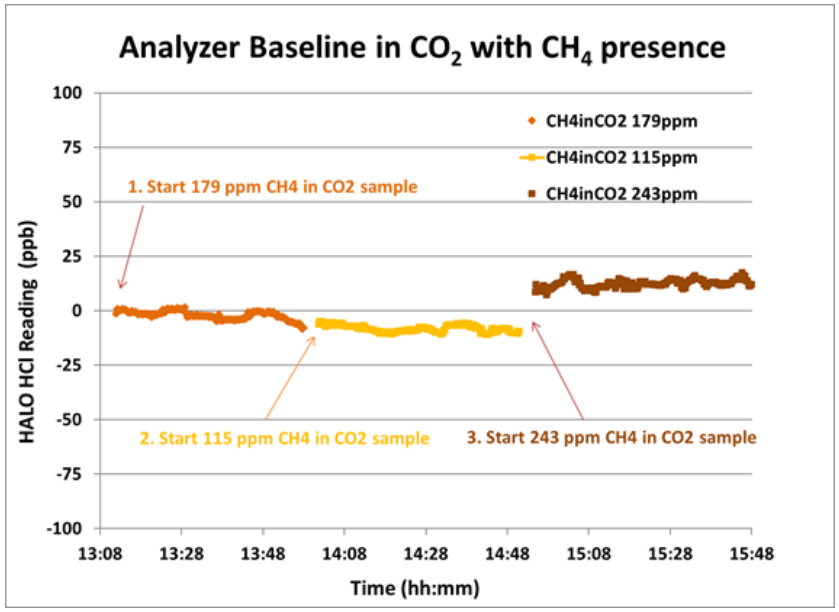
ISBT (*International Society of Beverage Technologists*) Carbon Dioxide Guideline: Ammonia 2.5 ppm v/v max.

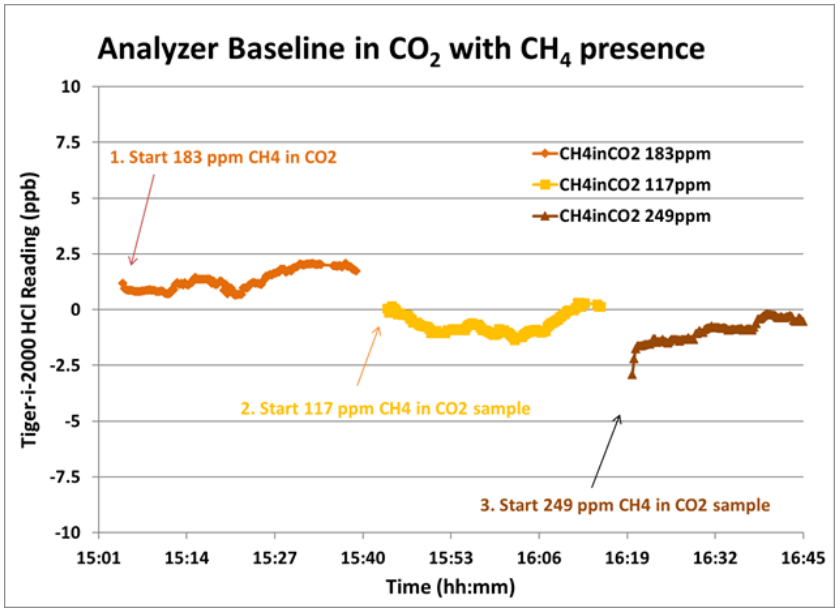
HCl in Product CO_2 Pre and Post Chloride Adsorber

- Application LDL/Range: 50 ppb/10 ppm
- LDL Limiting Factor: CH_4 @ 115 – 243 ppm

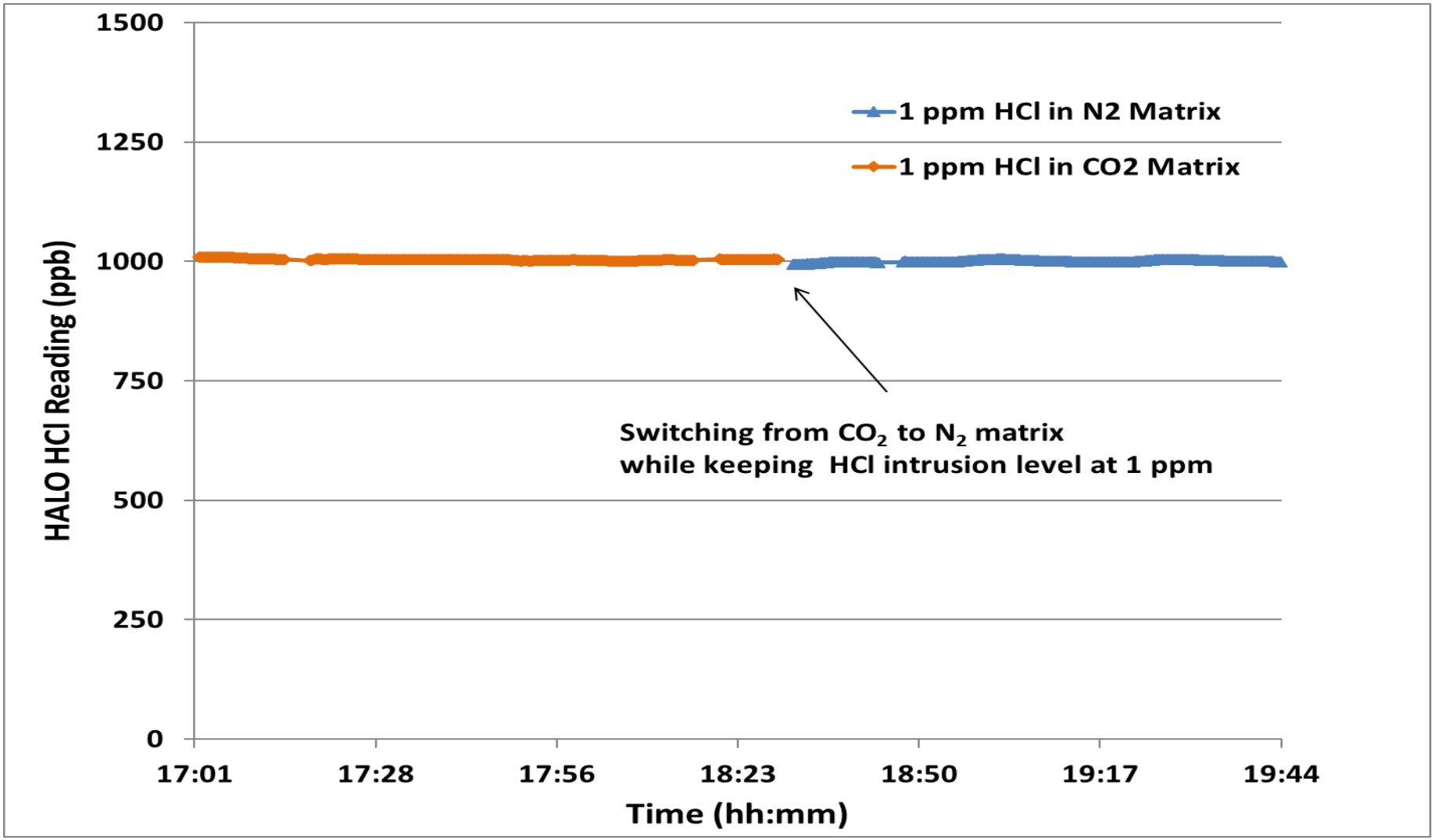


- Application LDL/Range: 5 ppb/4 ppm
- LDL Limiting Factor: CH_4 @ 117 – 249 ppm





HCl in CO_2 Span Calibration Test



Tiger CRDS Measurement Capability in Pure CO_2

Analyte	LDL	Range	Industry/Application
O_2	5 ppb	5 ppm	Electronics/Photolithography/Purifier Maker
H_2O	0.8 ppb	25 ppm	Electronics/Photolithography/Purifier Maker
H_2O	0.6 ppm	600 ppm	Beverage/Gas Manufacturing
H_2O	5 ppm	2%	Nuclear Industry/coolant CO_2
NH_3	2.5 ppb	30 ppm	Beverage/Gas Manufacture
HCl	5 ppb	4 ppm	Gas Manufacturing Post Chloride Adsorber
HCl	50 ppb	10 ppm	Gas Manufacturing Pre Chloride Adsorber
H_2S	0.1 ppm*	500 ppm	Beverage/Gas Manufacture
CO	0.4 ppm*	3000 ppm	Beverage/Gas Manufacture
CH_4	0.1 ppm*	500 ppm	Beverage/Gas Manufacture
HF	0.5 ppb*	1 ppm	Multiple
N_2O	0.1 ppm*	1000 ppm	Multiple

*Subject to development testing

Summary

- CO_2 is an important gas matrix used in a diverse range of industries, from semiconductor and purifier makers, to beverage, as well as gases & chemicals
- Tiger CRDS can detect critical impurities in pure CO_2, such as O_2, H_2O, NH_3 & HCl, over a wide concentration range in various process control scenarios
- An innovative partner with customers in addressing challenging, real-world applications, Tiger looks forward to more exciting, new developments