Process Insights
Premium Insights Into Process

TigerOptics

extrel
a Process Insights Brand

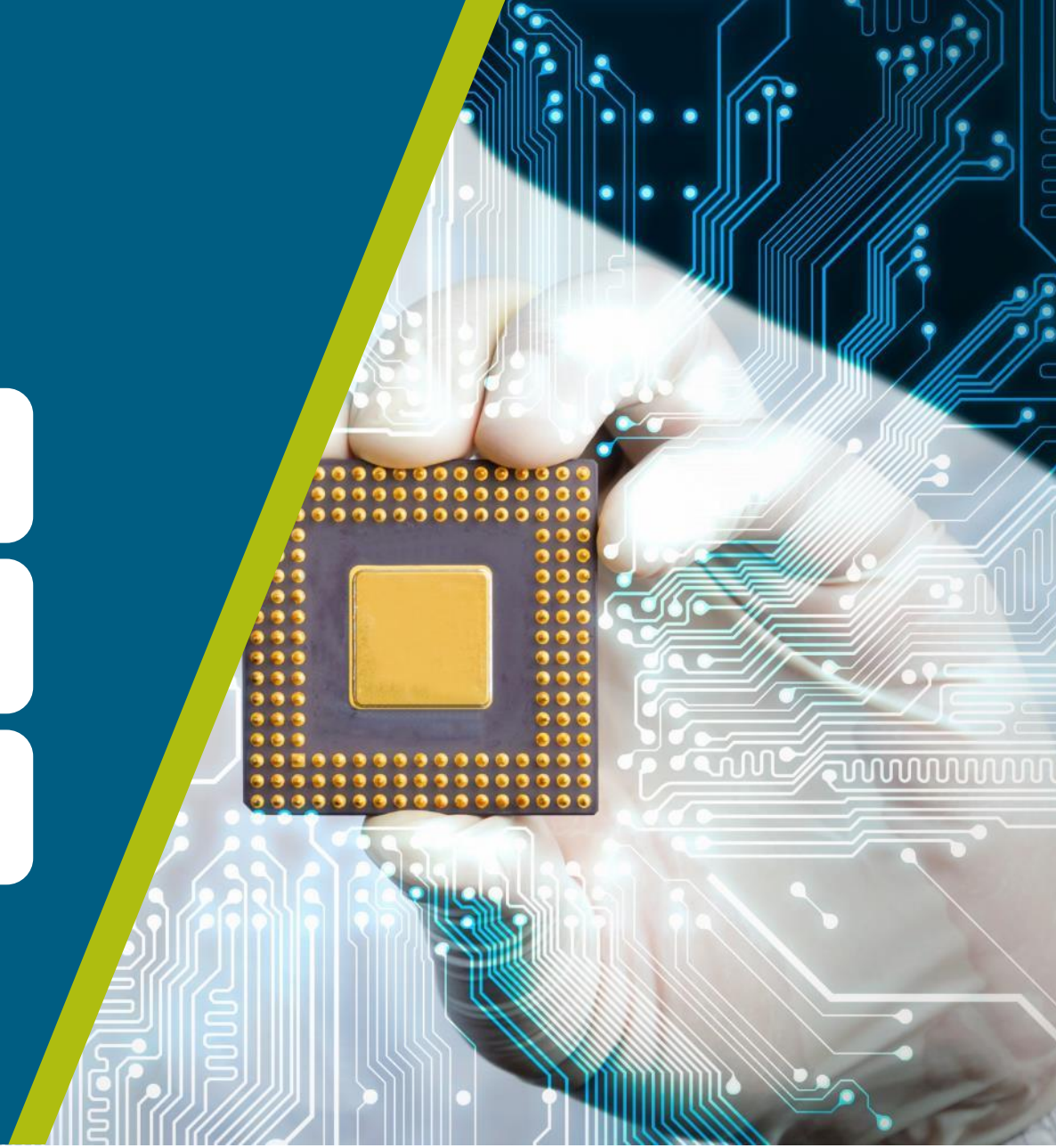
PREMIUM INSIGHTS
INTO PROCESS

Hydrogen & P2X Presentation

Advanced Spectroscopic Solutions for H2 purity measurement at ppb and ppt level.

Agenda

- Introduction to Process Insights
- APIMS – ppt level impurities
- Fuel Cell – ppb level impurities



Process Insights Value

- **Analytical instrumentation solution provider** with depth and breadth to cover many industries for process control and safety monitoring
- Highly **reputable brands** with differentiated products
- Commitment to **innovation** and **continuous improvement**
- Regional sales & service teams providing **unparalleled customer support**
- Global presence with regional sales & service teams to provide unparalleled customer support
  - PI Americas HQ in Houston, Texas
  - PI EMEA HQ in Frankfurt, Germany
  - PI APAC HQ in Suzhou, China

Process Insights Technologies

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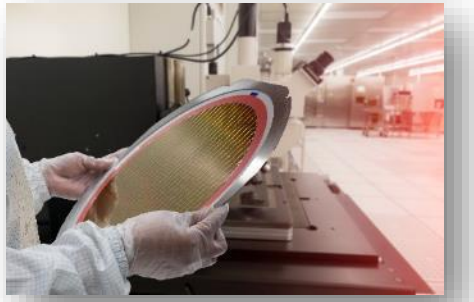
Low Level „ppt“ Impurity Detection

Extrel APIMS for Semiconductor Bulk Gas Purity

Target markets and applications

- Bulk Gas Quality Control and Process Control in Semiconductor and Electronics
- Pure Gas Manufacturing
- Ambient Air Monitoring
- Purifier Performance



NEW

Extrel VeraSpec APIMS

Advantages for Contamination Control:

- Real-time, multi-species monitoring for ALL Critical Impurities in bulk electronic gases including trace O_2, H_2, H_2O, CH_4, CO, CO_2, Xe and more
- Well-established, powerful mass spectrometry technology
- Developed in conjunction with UHP gas analysis experts at Tiger Optics
- Unparallel measurement range from PPT to 100% with unique dual-source ionization configuration
- Easy to use with integrated User Interface and scheduled automated calibrations
- Industry-best customer support and applications team

Made in U.S.A.

APIMS System Detection Limits

Trace Impurity*	Bulk Gas				
	N_2	Ar	He	H_2	O_2**
Hydrogen (H_2)	100 ppt	100 ppt	50 ppt	n/a	500 ppb
Oxygen (O_2)	10 ppt	10 ppt	10 ppt	10 ppt	n/a
Methane (CH_4)	10 ppt	10 ppt	10 ppt	10 ppt	100 ppb[1]
Water (H_2O)	10 ppt	10 ppt	10 ppt	10 ppt	100 ppb[1]
Carbon Monoxide (CO)	50 ppt	10 ppt	10 ppt	50 ppt	100 ppb[1]
Carbon Dioxide (CO_2)	5 ppt	5 ppt	5 ppt	5 ppt	100 ppb[1]
Nitrogen (N_2)	n/a	200 ppt	10 ppt	150 ppt	100 ppb
Argon (Ar)	200 ppt	n/a	10 ppt	50 ppt	75 ppb

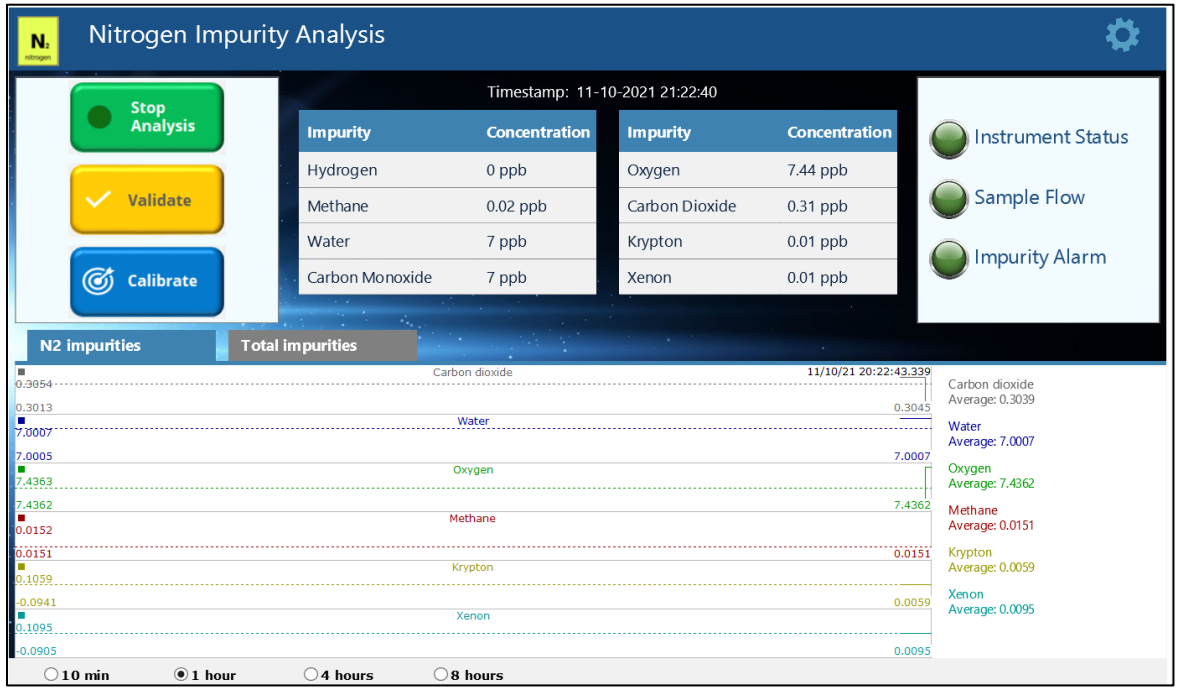
*Additional impurities are available

** Impurities in O_2 are measured using the included EI source

[1] See next slide for additional complimentary products from Tiger Optics for lower detection limits in O2

Easy to Use

- Extrel‘s Questor5 process control software designed for continuous gas monitoring
- Integrated User Interface and scheduled automated calibrations
- Unlimited configurable data tags and alarms
- External analysis triggers
- Automatic removal of spectral overlap
- Full network accessibility
- 21 CFR Part 11 compliant
- Modbus, digitial I/O, analog I/O, and OPC external communications available



Low System Maintenance

- Dual ion source for convenience of diagnostics
- Heated API ion source
- Built-in software calibration procedures
- Oil-free pumping system
- Low maintenance frequency – once per year
- Low calibration frequency

System Specifications

Dual Ionization Source	Atmospheric Pressure Ionization (API) / Electron Ionization (EI)
API Source Background	Less than 1 ppt
Mass Range Options	1-500 amu (other mass ranges available)
Quadrupole Tri-Filter Rod Diameter	19 mm
Detector	Pulse Counting Electron Multiplier
Detection Noise	< 3 counts in 10^6
Detection Limit	< 5 ppt (component dependent)
Analysis Time	< 1 Second per Component
Sample Switching Time	15 Minutes to < 1 ppb
Bulk Gas Suitability	H_2, N_2, He, Ar, O_2
Impurities Monitored	H_2, CO, CO_2, H_2O, O_2, CH_4, Kr, NH_3, Xe, C_2-C_6 (other impurities available)
Dimensions	74” (H) x 28” (W) x 26” (D) (1.9 m x 0.7 m x 0.7 m)
Maximum Number of Components	Unlimited
Maximum Number of Digital I/O	16 (standard) Unlimited available
Maximum Number of Analog I/O	20 (standard) Unlimited available
Communication Protocols	Modbus, OPC, digitial I/O, analog I/O

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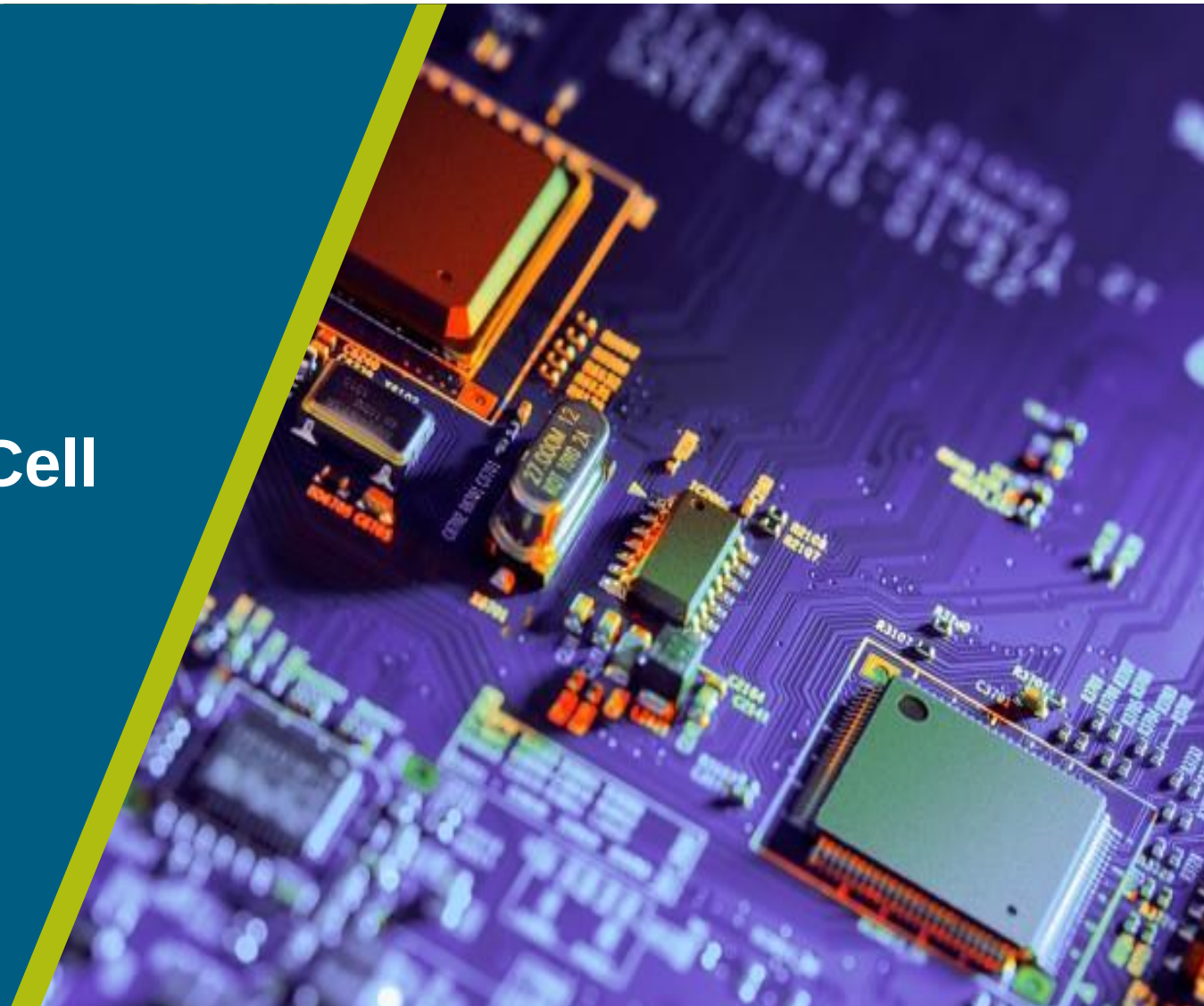
Solutions for Hydrogen Purity at ppb level

Analysis of Hydrogen for Fuel Cell Applications



Purity Requirements for Fuel Cell H_2

Molecule	Limit
Helium (He)	300 ppm_V
Nitrogen (N_2)	300 ppm_V
Argon (Ar)	300 ppm_V
Methane (CH_4)	100 ppm_V
Moisture (H_2O)	5.0 ppm_V
Oxygen (O_2)	5.0 ppm_V
Total Hydrocarbons (ex CH_4)	2.0 ppm_V
Carbon Dioxide (CO_2)	2.0 ppm_V
Carbon Monoxide (CO)	0.2 ppm_V
Formaldehyde (CH_2O)	0.2 ppm_V
Formic Acid (CH_2O_2)	0.2 ppm_V
Ammonia (NH_3)	0.1 ppm_V
Total Sulfur (H_2S, SO_2, COS,…)	0.004 ppm_V

SAE J2719

ISO 14687:2019

Considerations

- Effect of the impurity on the fuel cell
- Sensitivity of the fuel cell to specific impurity

Complete Tiger Optics/Extrel Portfolio for H_2 Purity

Summary of SAE J2719 / ISO 14687 Requirements and Analyzer Detection Limits

Contaminant	SAE J2719/ ISO 14687 Limit	Tiger Optics LDL (3σ)	Tiger Optics Analyzer	Extrel/Other LDL (3σ)	Extrel/Other Analyzer
Helium (He)	300 ppm			0.5 ppm	MAX300-LG
Nitrogen (N_2)	300 ppm			1.0 ppm	MAX300-LG
Argon (Ar)	300 ppm			0.02 ppm	MAX300-LG
Methane (CH_4)	100 ppm	0.2 ppm 0.1 ppm	Spark CH_4 Prismatic 3	1.0 ppm	MAX300-LG
Moisture (H_2O)	5 ppm	0.0075 ppm 0.1 ppm	Spark H_2O Prismatic 3		
Oxygen (O_2)	5 ppm	0.003 ppm	HALO OK	1.0 ppm	MAX300-LG
Carbon Dioxide (CO_2)	2 ppm	0.4 ppm 0.32 ppm	Spark CO_2 Prismatic 3		
Carbon Monoxide (CO)	0.2 ppm	0.05 ppm 0.05 ppm	HALO 3 CO Prismatic 3		
Formaldehyde (CH_2O)	0.2 ppm	0.006 ppm	HALO 3 CH_2O	0.02 ppm	MAX300-LG
Formic Acid (CH_2O_2)	0.1 ppm			0.02 ppm	MAX300-LG
Ammonia (NH_3)	0.1 ppm	0.0003 ppm	HALO 3 NH_3		
Total Hydrocarbons, ex. CH_4	2 ppm			0.05 ppm	GC
Total Sulfur compounds (e.g. H_2S, COS, CS_2,…)	0.004 ppm			0.002 ppm	GC
Halogenated compounds (e.g. HBr, HCl, Cl_2,…)	0.05 ppm			0.01 ppm	MAX300-LG

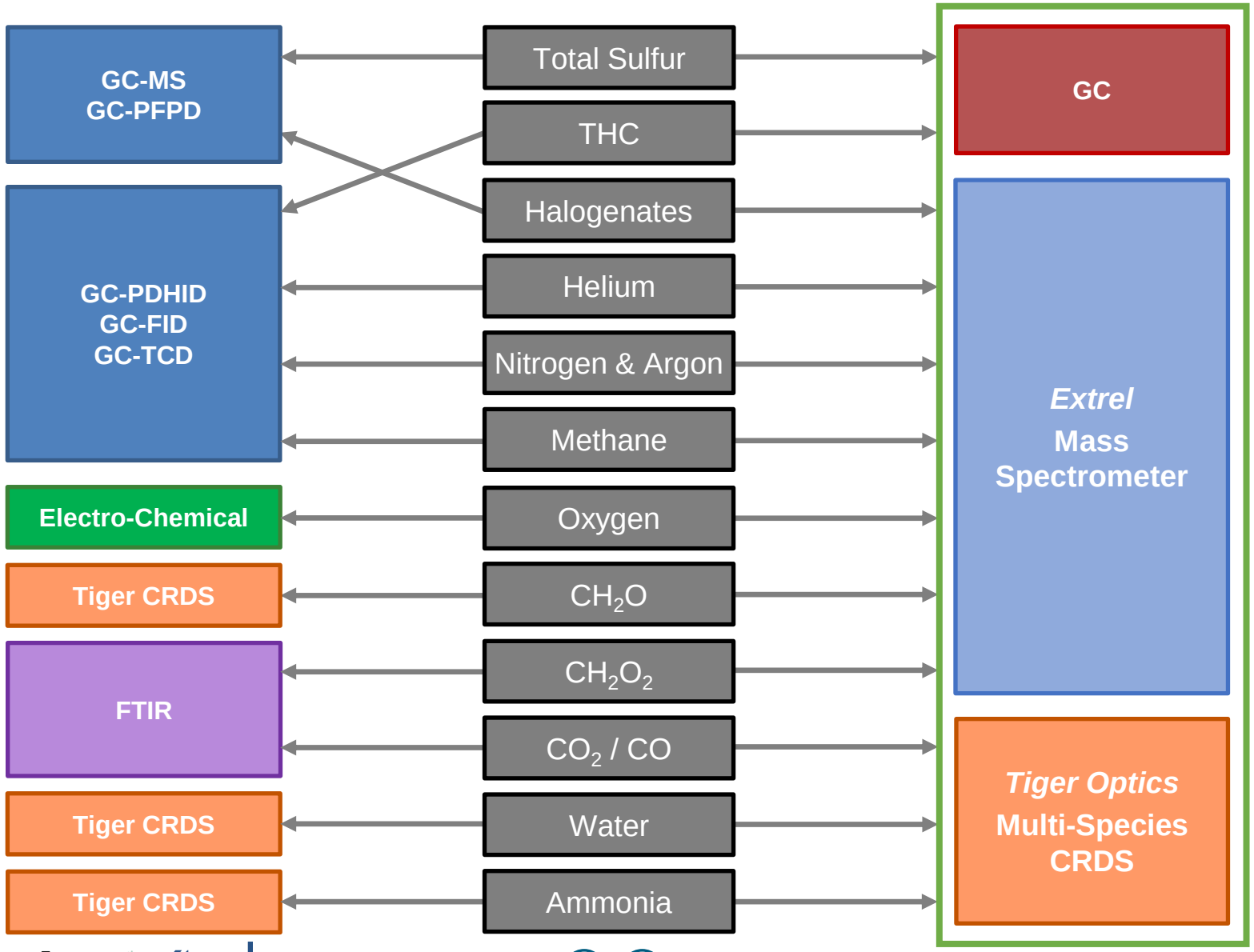
Comparison of H_2 Purity Monitoring Solutions

Typical Traditional Setup

- Complex solution
- Multiple providers
- Not integrated

2 GCs
3 CRDS
1 Electro-Chem.
1 FTIR

7 Analyzers



Setup with Process Insights' Total Solution

- One solution
- One provider
- Fully integrated

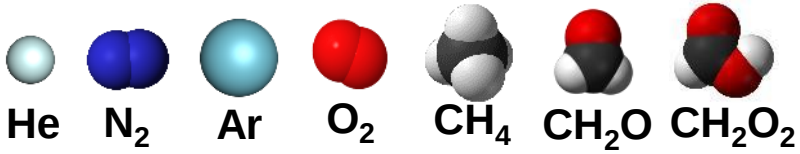
1 MS
1 CRDS
1 GC

3 Analyzers

Total Solution for Hydrogen Purity

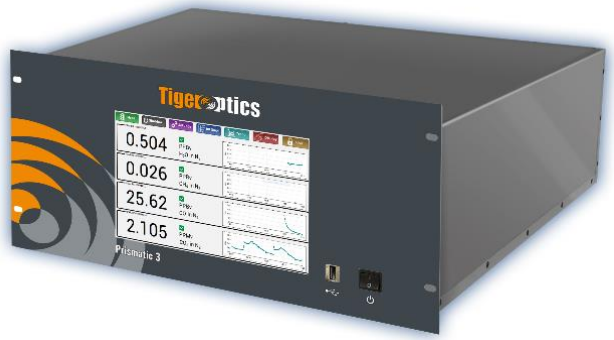
Cover **13 critical contaminants** with only **three** high-performance instruments!

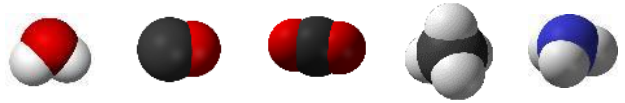
MAX300-LG
Quadrupole Mass Spectrometer



He N_2 Ar O_2 CH_4 CH_2O CH_2O_2

Prismatic 3
Multispecies CRDS Analyzer





H_2O CO CO_2 CH_4 NH_3

Sulfur & THC GC
GC Analyzer

Sulfurs:
H_2S
COS
CH_3SH
C_2H_5SH
C_3H_8S
C_4H_4S

THC

Hydrogen Analysis

- Extrel and Tiger Optics analyzers cover all stages of the hydrogen life cycle
- Mass spectrometer and CRDS for HyCO/SMR process control and purity
- Mass spetrometer and CRDS for quality control (Hydrogen Production, Transportation, Refueling)

Production

Transportation

Storage

Fueling

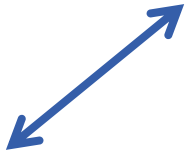
Advantages of Extrel's Mass Spec Technology

Fast, Complete Analysis in Seconds

Flexibility: Can Measure Any Gas or Vapor

Full, Speciated Composition

Ultra-High Sensitivity Down to PPB Levels



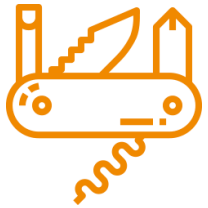
Linear Dynamic Range from Trace Levels to 100%

Multi-Species Detection Requiring Fewer Analyzers

Advantages of Tiger's CRDS Technology

High Accuracy,
Specificity & Stability

Rapid Deployment &
Fast Speed of Response



Versatility &
Ease of Use

Unparalleled
Sensitivity

Outstanding
Reliability

Exceptionally Low
Cost of Ownership

Conclusions

- Process Insights provides the ideal fully integrated solution for monitoring contaminants in fuel-cell hydrogen with the powerful combination of Tiger Optics' CRDS and Extrel's MS
- Detection limits are perfectly-suited to qualify hydrogen for compliance with SAE J2719 and ISO 14687
- Save manpower and operating cost with easy to use, low-maintenance analytical instruments
- Multi-species analyzers dramatically reduce the number of required instruments for your laboratory setup
- Ideal for remote operations

Resources & References

- **ASTM Standard for Analysis of Fuel Cell Hydrogen using CRDS, D7941/D7941M-14**
  http://www.astm.org/Standards/D7941.htm
- **SAE J2719 Impurity Limits for Fuel Cell Hydrogen**
  https://www.sae.org/standards/content/j2719_202003/
- **NREL Study "H2FIRST Hydrogen Contaminant Detector Task"**
  http://www.nrel.gov/docs/fy15osti/64063.pdf
- **Tiger Optics Brochure "Advanced Spectroscopic Solutions for Fuel-Cell Hydrogen Analysis"**
  https://www.tigeroptics.com/files/media/tigeroptics/products/Brochures/Process_Insights_Fuel_Cell_App_Brochure.pdf

THANK YOU