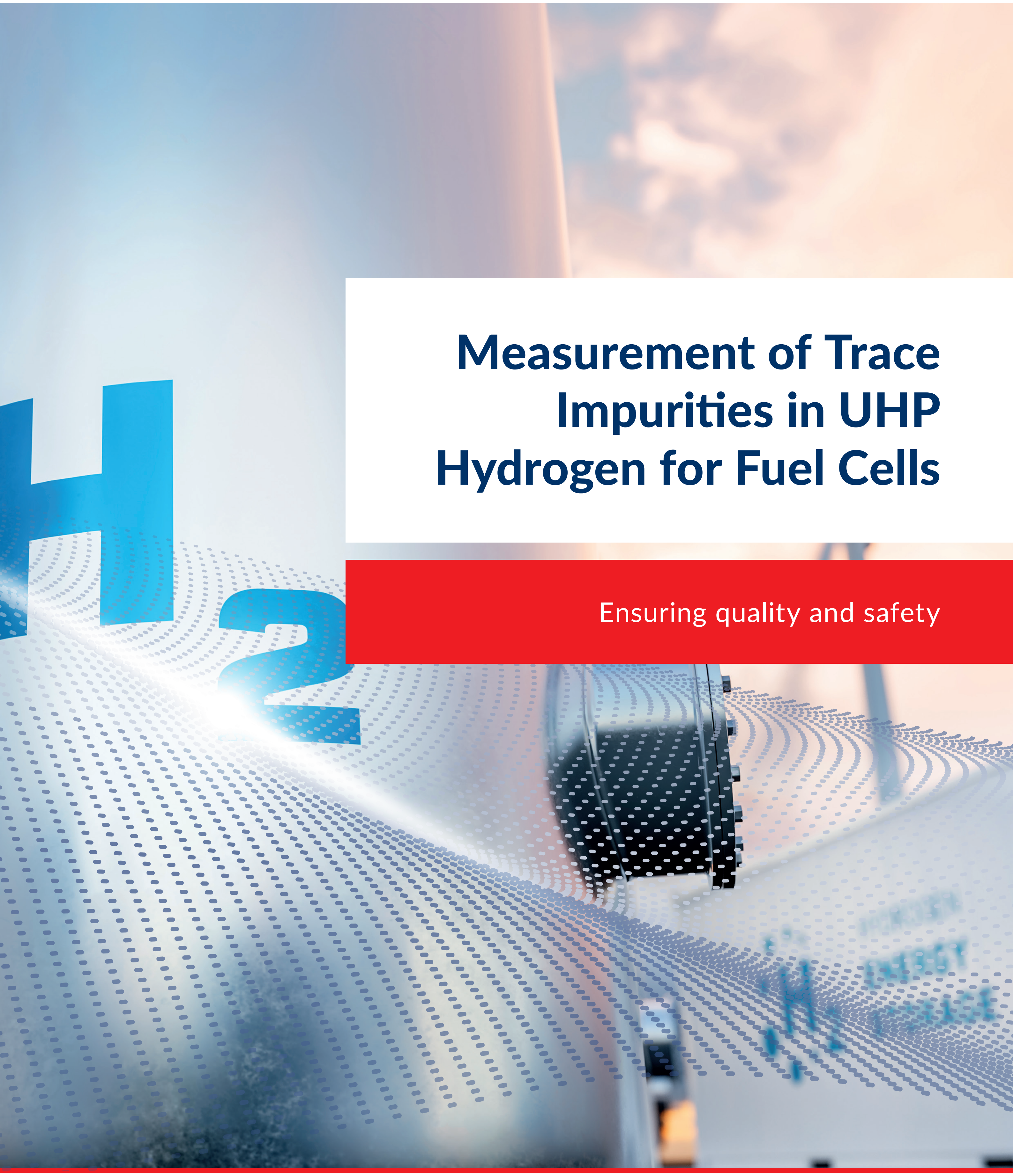
PST
PROCESS SENSING
TECHNOLOGIES

Measurement of Trace Impurities in UHP Hydrogen for Fuel Cells

Ensuring quality and safety



MICHELL Instruments | Analytical Industries Inc | rotronic MEASUREMENT SOLUTIONS | LDetek | DYNAMENT INFRARED GAS SENSORS | NTRON Gas Measurement | SST

Measurement of Trace Impurities in UHP Hydrogen for Fuel Cells

Hydrogen fuel cells offer greater reliability and a smaller carbon footprint compared to diesel and battery systems. Ultra-high purity (UHP) hydrogen is needed to ensure the optimum power generation and meeting rigorous quality standards is a challenge for producers, logistics and end users alike.

Process Sensing Technologies has both the precision measurement instrumentation and the in-depth industry experience to provide a complete trace impurities detection for this application.

What is a Hydrogen Fuel Cell?

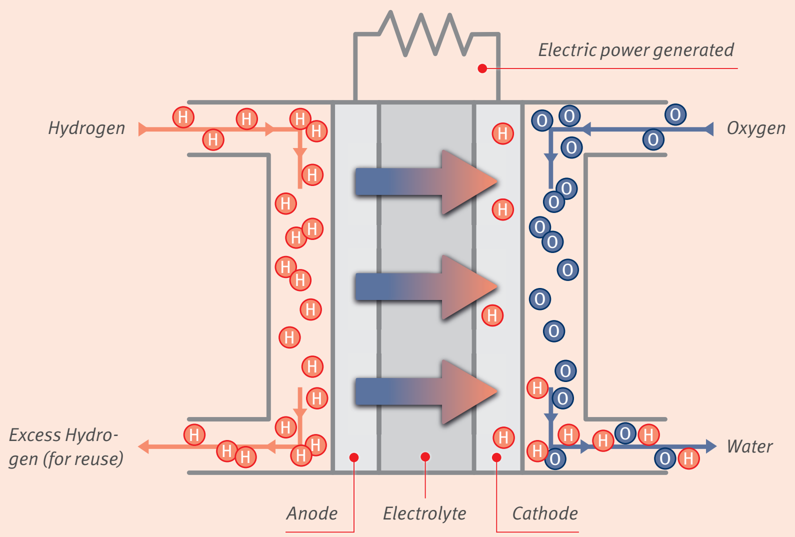
A hydrogen fuel cell is an electrochemical cell that converts the chemical energy of a fuel (in this case, hydrogen) and an oxidizing agent (often oxygen) into electricity through chemical reducing and oxidizing reactions.

Fuel cells come in many varieties; however, they all work in the same general manner. They are made up of three adjacent segments:

- the anode
- the electrolyte
- the cathode

Two chemical reactions occur at the interfaces of the three different segments. The net result of the two reactions is that fuel is consumed, water is created and an electric current is generated, which can be used to power electrical devices, normally referred to as 'the load'.

How a hydrogen fuel cell generates electricity



Where are fuel cells used?

Large stationary fuel cells are used for commercial, industrial and residential primary and backup power generation for:

- spacecraft
- remote weather stations
- large parks
- data farms and communications centers
- rural locations including research stations
- military applications.

Transport

Because a hydrogen fuel cell is compact, lightweight and has no major moving parts, they are ideal for use in transportation, especially larger vehicles:

- buses
- heavy goods vehicles (HGV) and garbage trucks
- forklifts
- trains
- boats
- airplanes
- submarines
- rockets
- automobiles

As the only by-product of the fuel cell is water, it is a much cleaner form of power than traditional combustion engines and avoids the environmental and ethical issues associated with the production and disposal of lithium batteries used in many electric cars.

Why Is The Purity of H_2 So Important and How Is It Achieved?

Ultra-high purity hydrogen is required for use in fuel cells to maximise the lifespan of the electrolyte and catalysts used. The hydrogen used must conform to the ISO 14687 Part 2, which specifies hydrogen fuel quality requirements for all commercial hydrogen fuelling stations for proton exchange membrane (PEM) fuel cell vehicles (FCVs). The acceptable limits of contaminants are listed in the table below:

Constituent	Chemical Formula	Limits	Laboratory Test Methods to Consider and Under Development	Minimum Analytical Detection Limit
Hydrogen fuel index	H_2	›99.97 %		
Total allowable non-hydrogen, non-helium, non-particulate constituents listed below		100 ppm		
Acceptable limit of each individual constituent				
Water	H_2O	5 ppm	ASTM D7653-10, ASTM D7649-10	0.12 ppm
Total hydrocarbons (C_1 basis)		2 ppm	ASTM D7675-11	0.1 ppm
Oxygen	O_2	5 ppm	ASTM D7649-10	1 ppm
Helium		300 ppm	ASTM D1945-03	100 ppm
Nitrogen, Argon	N_2, Ar	100 ppm	ASTM D7649-10	5 ppm
Carbon dioxide	CO_2	2 ppm	ASTM D7649-10, ASTM D7653-10	0.1 ppm
Carbon monoxide	CO	0.2 ppm	ASTM D7653-10	0.01 ppm
Total sulfur		0.004 ppm	ASTM D7652-11	0.00002 ppm
Formaldehyde	HCHO	0.01 ppm	ASTM D7653-10	0.01 ppm
Formic acid	HCOOH	0.2 ppm	ASTM D7550-09, ASTM D7653-10	0.02 ppm
Ammonia	NH_3	0.1 ppm	ASTM D7653-10	0.02 ppm
Total halogenates		0.05 ppm	(Work item 23815)	0.01 ppm
Particulate concentration		1 mg/kg	ASTM D7650-10, ASTM D7651-10	0.005 mg/kg

What Are the different Sources of Hydrogen and How Do the Measurements Differ?

Most hydrogen is produced from natural gas, via the steam methane reforming process – this is known as 'grey' hydrogen and the downside here is the large quantity of carbon dioxide that is produced as a by-product of splitting methane – CH_4 – into its component molecules.

Because natural gas consists of a mixture of hydrocarbon gases and liquids along with other contaminants, this method of producing hydrogen also results in some highly toxic pollutants such as sulfur dioxide and formaldehyde among others.

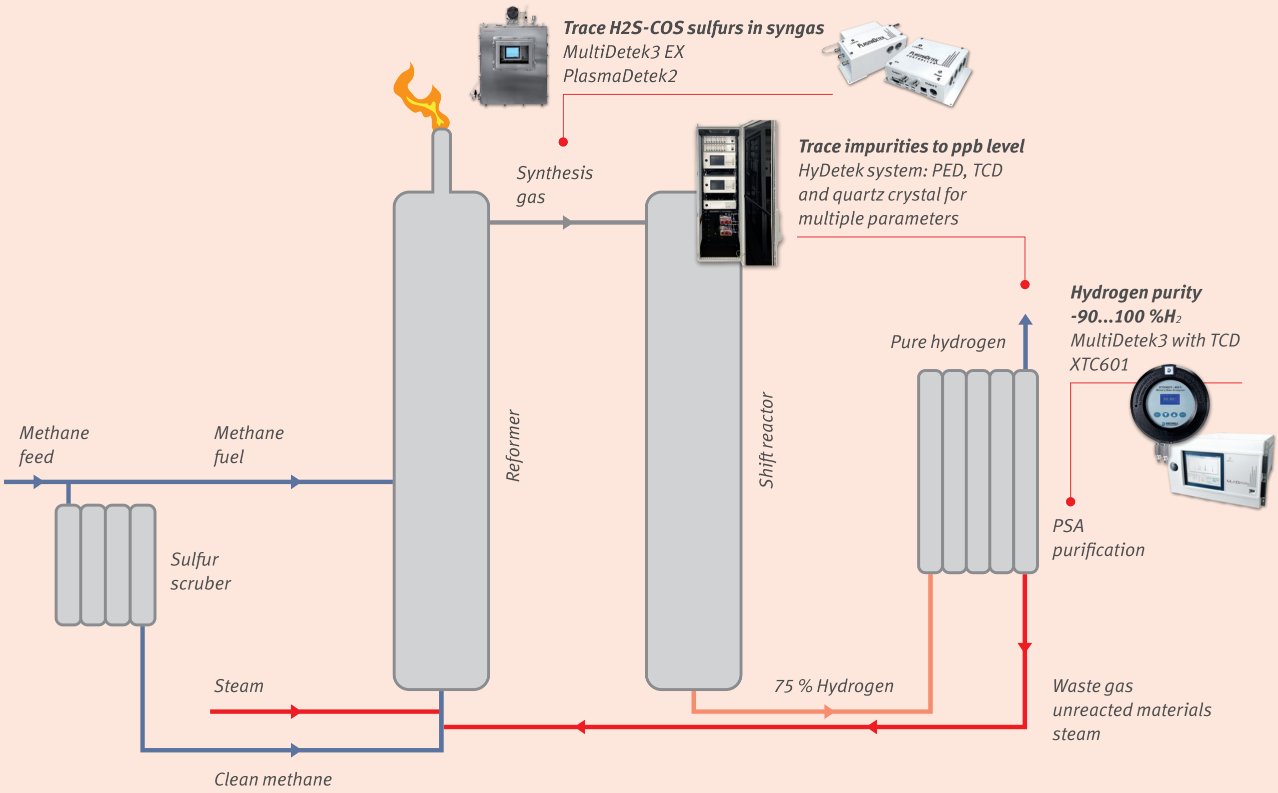
'Green' hydrogen is produced using electrical energy from renewable sources (wind, solar power etc) to power the electrolysis of water. This splits the H_2O into molecules of hydrogen and oxygen.

Although electrolysis is a cleaner and produces no dangerous pollutants as a side effect, it is more expensive than processing natural gas. Despite the drawbacks, hydrogen from natural gas is still a more environmentally-friendly option than using natural gas as a fuel because processors can capture the carbon dioxide as it's produced.

Because of these two reasons, grey hydrogen is still set to dominate the supply for some time to come.The steam reforming process that is used to extract hydrogen from natural gas can also be used with biomethane. It has the advantage of producing fewer harmful by-products and can be carried out at the site of production.

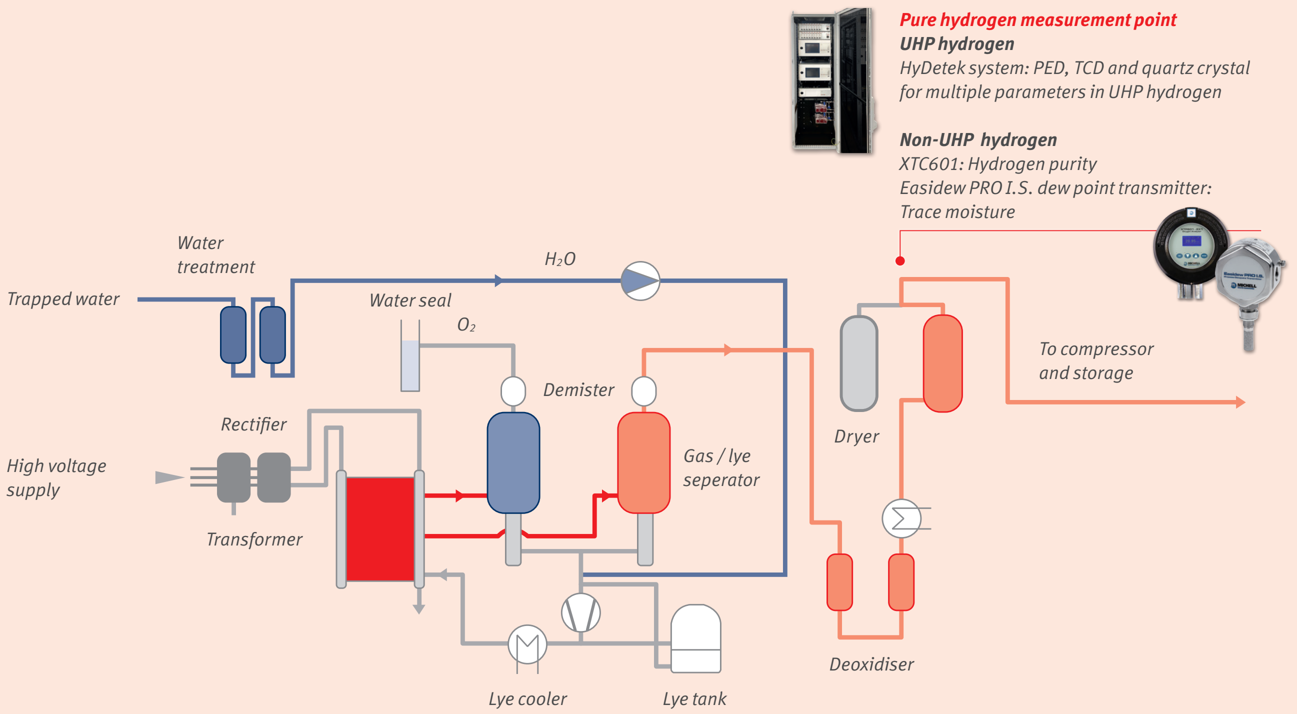
Measurement points for biogas reforming are the same as for natural gas reforming and are shown in the diagram overleaf.

Impurity analyzers and measurement points recommended for steam methane reforming process



This simplified diagram shows the key measurement points for hydrogen purity in the steam methane reforming process.

Analyzers and measurement points recommended for hydrogen produced via electrolysis of water



This simplified diagram shows the key measurement points for impurities and hydrogen purity in the electrolysis of water.

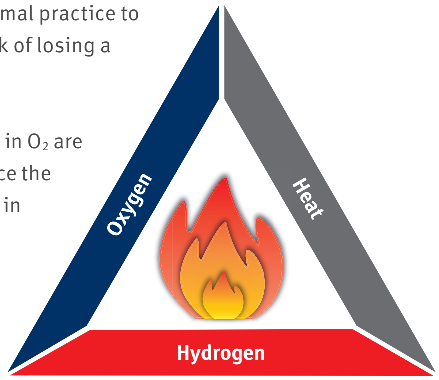
Product Selector

Process	Purpose of measurement	Range	Gas measured/back-ground gas	Recommended products
Converting natural gas to syngas	To determine the composition of the syngas and the range of impurities	Low ppm/ppb H_2S and COS	Trace H_2S, COS sulfurs in syngas (H_2-CO_2-CO)	• MultiDetek3 EX • PlasmaDetek2 • HyDetek system
Pressure swing absorption purification	Confirming the purity of the hydrogen produced	90-100 % for pure H_2	Pure H_2	• XTC601 (up to 99 %) • MultiDetek3 (UHP Hydrogen) • HyDetek System
Trace impurities to ppb level	Final confirmation of H_2 purity	ppb levels for trace impurities	N_2, Ar, He, O_2, CH_4, CO, CO_2, NMHC, sulfurs, formaldehyde, ammonia, halogenated formic acid and H_2O	• HyDetek System
Pure hydrogen measurement Point: UHP H2	Determine the purity of the hydrogen	99-100 % H_2	Pure hydrogen	• HyDetek System using thermal conductivity detector
Pure hydrogen measurement Point: Non-UHP H_2	Determine the purity of the hydrogen	90-100 % H_2	Pure hydrogen	• XTC601 for ATEX • XTC501 for GP
Trace impurities in UHP H_2	Analyze trace impurities present	Sub ppb levels	Ar, O_2, N_2, H_2O in pure H_2	• HyDetek • QMA401/QMA601
Trace moisture in Non-UHP H_2	Ensure purity of H_2 produced	Low ppm levels	H_2O	• Easidew PRO I.S.

Hydrogen Produced by Electrolysis: Purity and Safety Considerations

As well as the overall quality measurements of hydrogen taken by the gas chromatograph, it is normal practice to have on-line measurements for moisture and oxygen in the hydrogen. This will help reduce the risk of losing a whole batch as there is real time data fed into the control systems.

Electrolysis has the potential for dangerous gas mixtures to be present. The flammability limits of H_2 in O_2 are between 4...94 %H_2 at atmospheric pressure. Therefore, safety protocols need to be in place to reduce the risk to operators and plant. The first step is to monitor the O_2 in H_2 produced and also the reverse: H2 in O_2 produced. This is over and above the quality measurements. The second step is to actively reduce the risk. In the event of the concentration levels approaching a flammable mixture, the plant will try to dilute the mixture to a safer level. The final step would be to force a shut down, a costly, but sometimes necessary, step. A tighter control of the process with reliable instruments will allow less safety margins at these last two steps, to keep the plant running longer. With Safety Integrity Level (SIL) Capable analyzers and systems, the plants can be run efficiently with peace of mind.



The Hydrogen Fire Cycle

Measurements for Safety

Michell XTP601 Oxygen Analyzer for Hazardous Areas

A robust thermo paramagnetic oxygen analyzer for stable, linear measurements of oxygen in flammable gases.

- Certified by ATEX, IECEx, cQPSus, TC TR Ex
- Minimal maintenance for low cost of ownership

Ntron Minox-i Intrinsically Safe Oxygen Transmitter

Highly reliable, IECEx/ATEX approved and cost-effective two-wire, loop-powered transmitter.

- Measurement range: 0-25%
- Electrochemical sensor technology

Meets the requirements of IEC61508 (SIL2 Capable)

2 configurable alarm outputs

Trace Impurities in Hydrogen

LDetek MultiDetek3 – Modular Process Gas Chromatograph

This compact gas chromatograph combines the functionality of two GCs in one and has the ability to provide online measurements of moisture and O_2.

- Sub ppb trace measurements
- A single analyzer for trace measurement of multiple impurities
- Temperature controlled to ensure maximum accuracy and stability

Modular design for easy maintenance

LDetek PlasmaDetek2 – Plasma Emission Detector for GCs

A microprocessor-based plasma emission detector system with an intelligent, customizable configuration capability. Make industrial gas chromatography simple and accessible across a wide range of applications.

- All in one detector by replacing existing technologies commonly used
- PPB to % detection
- Fast installation and tune up

Plug and play design

LDetek HyDetek System – Integrated Gas Chromatograph System for Hydrogen Purity

An all-in-one unit for measuring trace impurities(ppb/ppm) N_2-Ar-HeO_2-CH_4-CO-CO_2-NMHC-sulfurs-formaldehyde-ammonia-halogenated-formic acid and water in hydrogen.

- Meets UHP requirements for hydrogen used in fuel cells as set out in ISO 14687
- Multiple detectors: PED, TCD and quartz crystal are possible if desired
- Integrated ultra-high purity sample stream selector system (remote control)

Measures all critical impurities in hydrogen

Michell Easidew PRO I.S. – Intrinsically Safe Moisture Transmitter

A robust intrinsically safe dew-point transmitter for long-term stability and fast response to changes in moisture.

- Measurement range -110...20 °Cdp
- ATEX, IECEx, cCSAus, FM, TC TR Ex certified
- Accuracy ±1 °Cdp
- 450 barg pressure rating

Service exchange program available for easy maintenance

Michell QMA401 and QMA601 – Process Moisture Analyzers

Low maintenance trace moisture analyzer based on quartz crystal sensing technology for highly sensitive and accurate measurements.

- Fast and reliable measurement from 0.1...2000 ppm$_V$
- Accuracy of ±0.1 ppm$_V$ at <1 ppm$_V$ and 10 % of reading from 1...2000 ppm$_V$
- Built-in verification of customer process gas

Intuitive user interface

IECEx, ATEX, TC-TR Ex certified for Exd flameproof, cQPSus certified for explosion proof

Pure Hydrogen Measurements

Michell XTC601/501 – Binary Gas Analyzer for Hydrogen Monitoring

A robust, linear and stable thermal conductivity analyzer for measurement of binary gas mixes such as air in hydrogen. Suitable for use in ATEX, IECEx, TC TR Ex & $_{C}$CSA$_{US}$ certified Hazardous Areas. General purpose version available.

- Accuracy of better than ±1 % full scale
- 90/98 to 100 % hydrogen
- Meets the requirements of IEC61508 (SIL2 Capable)

ATEX and SIL2 Capability available

Lightweight with small foot print

LDetek MultiDetek3 EX – Multi-Stream Gas Chromatograph for Hazardous Areas

The standard industrial compact GC model MultiDetek3 integrated inside a Stainless Steel certified (ATEX-IECEx) purged enclosure to be used in Zone1 and Zone 2 hazardous areas. Highly adaptable, the system allo

- Integrate multiple instruments and sampling system all in one unit.
- Can combine up to 3 detectors in one GC (PED, TCD, FID, Quartz crystal for H_2O, electrochemical sensor or third-party sensor)
- Integrate multiple instruments and sampling system all in one unit. ws for multi-stream analysis using a variety of methods in a single gas chromatograph system.

Explosion proof for use in Zone 1 and Zone 2

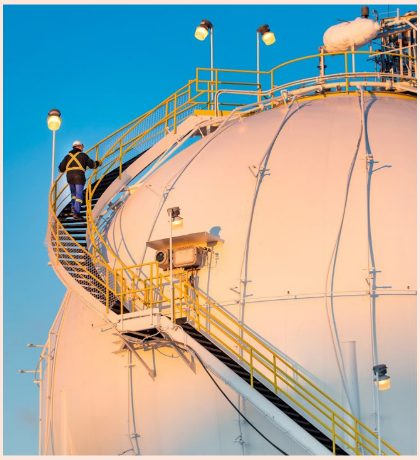


Image of Bécancour PEM, courtesy of Air Liquide

H_2 Case Study

Trace impurities measurements at the world's largest PEM plant

LDetek's HyDetek system was selected to provide trace impurity measurements in hydrogen produced at the world's largest proton exchange membrane (PEM) electrolyzer, which is located at Bécancour, Quebec, Canada. Air Liquide's 20 MW PEM electrolyzer will produce around 3,000 tons of hydrogen each year. It will play a crucial role in supplying North America with low-carbon hydrogen needed for industry and transportation.

The HyDetek system is used to detect traces of oxygen, nitrogen and carbon dioxide in the hydrogen produced at the plant. It uses LDetek's patented plasma emission detector configured with the right selective optical filters for measuring ppb/ppm O_2-N_2-CO_2 (which are the main contaminants to be controlled and measured for the hydrogen produced by water electrolysis). The gas chromatograph uses Argon as carrier gas which reduces the operation costs by a factor of 4-5 times, compared to instruments that use helium.

Reduced carbon output

Air Liquide estimates that the new PEM electrolyzer will reduce carbon emissions by nearly 27,000 tons a year compared to a similar hydrogen output generated by steam methane reforming.

This is equivalent to the annual emissions from 10,000 cars.

Process Sensing Technologies

We provide an unmatched suite of instruments, analyzers and sensors for precision measurements and monitoring in highly demanding end markets. These range from pharmaceutical/ life sciences, speciality gases, semiconductors, O&G, petrochemicals and power to gas detection, food and beverage and building automation.

Using our products, customers save millions of dollars each year through increased energy efficiency in their processes and reduced process disruptions.

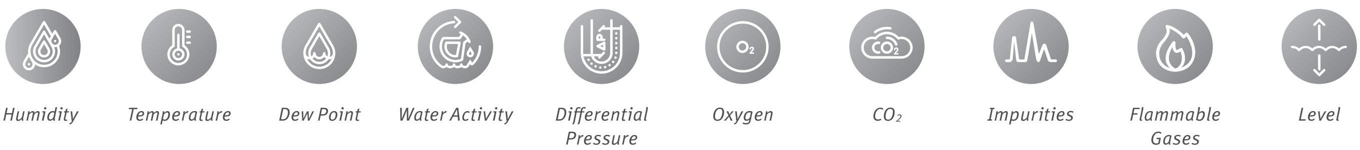
The quality of food, medicines, semi-conductors and thousands of manufactured goods depends on reliable measurements of critical parameters such as humidity, oxygen, CO, N_2, H_2, hydrocarbons, pressure or CO_2 during production, storage and transport. Our products directly improve the profitability of our customers and help them to stay compliant with stringent industry regulations. We own and manufacture the sensing technologies used in the majority of our products. This allows us to remain in a strong leadership position and pass on the benefits of our innovation to our customers.

PST Leading Brands

- **Analytical Industries Inc.** – Electrochemical oxygen sensors and gas-analysis
- **Dynament** – Infrared gas sensors
- **LDetek** – Ultra low range online analyzers
- **Michell Instruments** – Moisture and oxygen sensing and instrumentation
- **Ntron Gas Measurement** – Oxygen sensors and analyzers
- **Rotronic** – Humidity and temperature instruments, monitoring systems
- **SST Sensing** – Oxygen sensors and liquid level switches

Group Facts

- Expertise in measurements for ensuring quality and purity of UHP hydrogen
- 22 Service and sales subsidiaries
- 8 global engineering and manufacturing locations
- 100+ authorized distributors
- 14 proprietary technologies



Global direct sales and service support

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