



Ensuring Hydrogen Purity for Fuel Cell Applications

An Engineering Approach to Sampling Systems Based on International Standards

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1. The Importance of Hydrogen Sampling for Fuel Quality Assurance

Hydrogen fuel purity plays a critical role in the performance and longevity of proton exchange membrane (PEM) fuel cells. As defined in ISO 14687 and SAE J2719, the minimum purity requirement for gaseous hydrogen used in road vehicles is 99.97%, with stringent limits for more than a dozen contaminants, including water, oxygen, argon, helium, nitrogen, hydrocarbons, ammonia and several others. These substances, even in trace amounts measured in parts per billion, can lead to irreversible degradation of fuel cell components, reduced system efficiency, and operational failure.

While hydrogen is typically delivered with a certificate of analysis (CoA) from the producer or supplier, this certification reflects conditions at the point of production. However, hydrogen quality can degrade at various stages of the value chain—including compression, storage, transfer, and dispensing—posing challenges at the point of end-use applications, such as fuel cells.

Impurities may be introduced through materials incompatibility, system leakage, back-diffusion from compressors, or cross-contamination within refueling infrastructure. For this reason, direct sampling at the point of dispensing is essential to verify that the hydrogen delivered to the vehicle meets the specified purity requirements.

International standards such as ISO 19880-1, DIN EN 17124, ASTM D7606-17 and DIN ISO 21087 acknowledge this challenge and provide detailed procedures for sampling gaseous hydrogen intended for PEM fuel cell applications. These procedures address both the collection of representative samples and the avoidance of contamination during sampling, handling, and transport. Proper sampling not only enables compliance with specifications such as ISO 14687 but also serves as a technical safeguard for system integrity and long-term fuel cell performance.

This paper presents an overview of the principles and challenges of hydrogen sampling and highlights different system architectures—mobile, stationary, and online—designed to support accurate, compliant, and application-specific fuel quality verification.

Dispenser

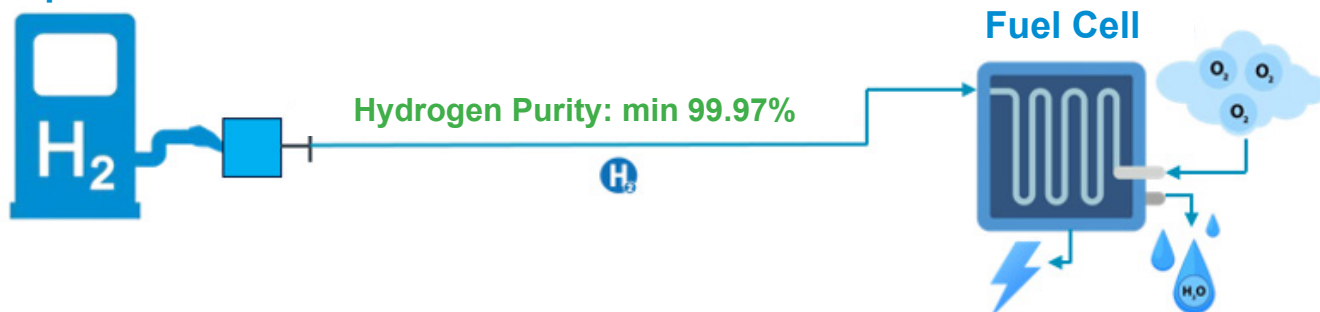


Figure 1. Required hydrogen fuel purity ($\geq 99.97\%$) from the dispenser to the fuel cell.



2. Overview of Applicable Standards for Hydrogen Quality and Sampling

Sampling hydrogen for quality assurance is not simply a technical task. It is a standards-driven process that must be carefully engineered to ensure the representativeness and accuracy of hydrogen sampling. International standards define not only the allowable impurity levels in hydrogen, but also the requirements for how samples are collected, handled, and analyzed.

A sampling system that does not follow these standards may produce unreliable results, even if it functions correctly from a mechanical point of view.

2.1 What Must Be Measured: Hydrogen Fuel Specifications

ISO 14687 and SAE J2719 define the allowable concentration limits for contaminants in hydrogen. These specifications serve as the analytical targets for any sampling effort.

Sampling systems must therefore support the collection of samples that can be used to verify these values at trace levels without introducing changes to the gas composition.

2.2 How the Sample Must Be Taken: Sampling Procedural Standards

Standards such as ISO 19880-1 and ASTM D7606-17 provide detailed guidance on the correct procedures for hydrogen sampling, including purging, pressure regulation, grounding, and safe venting.

These operational parameters are essential for ensuring that the sample truly reflects the quality of hydrogen being delivered at the point of use.

2.3 How the Sample Must Be Preserved and Analyzed: Analytical Standards

After collection, the hydrogen sample must remain chemically stable until analysis. DIN ISO 21087 sets out requirements for analytical methods and for the containers used to store samples.

Materials, surface treatments, and sealing mechanisms must be compliant to prevent any contamination or loss of trace components.



3. Engineering Challenges in Hydrogen Sampling

Hydrogen sampling is often underestimated in its complexity. While the objective is simple—to capture a gas sample that reflects the true composition of the hydrogen being delivered—the technical execution requires close attention to gas behavior, system design, and surface interactions. In high-purity applications such as PEM fuel cells, even trace-level deviations can invalidate analytical results or lead to regulatory non-compliance.

3.1 Contamination and Loss of Representativeness

Contamination can occur at nearly every stage of the sampling process. Sources include residual process gas, incomplete purging, ambient air ingress, valve leaks, and system dead legs.

These pathways can cause either dilution of target impurities or the unintentional addition of external components.

The result is a sample that no longer reflects the composition of the hydrogen being dispensed—potentially invalidating the analytical outcome.

3.2 Adsorption of Contaminants

Adsorption becomes especially critical when measuring impurities at low concentrations. Molecules like water (H_2O), ammonia (NH_3), and hydrogen sulfide (H_2S) can stick to the internal surfaces of the sampling system, particularly if those surfaces are rough or chemically reactive. When this happens, some of the impurity may not be captured in the sample at all, leading to inaccurate results. In some cases, the trapped molecules can slowly detach later and appear in a new sample—creating what is known as a memory effect, where residues from a previous test interfere with the next one.

To mitigate this, internal surfaces should be electropolished or coated with inert materials such as silicon-based layers to reduce adsorption and improve sample reliability.

3.3 Hydrogen Embrittlement and Material Compatibility

Hydrogen embrittlement is a critical material degradation phenomenon in which hydrogen atoms diffuse into metal structures, reducing ductility and causing premature cracking or failure. This effect is particularly relevant in high-pressure hydrogen environments, where factors such as pressure, temperature, and mechanical stress collectively influence the rate of atomic diffusion and contribute to hydrogen embrittlement.

However, the risk is not limited to high pressure; embrittlement can also develop under lower-pressure conditions over time, depending on the material, stress state, and exposure duration. To mitigate this, material selection for hydrogen sampling systems must be carefully evaluated. Components must meet not only pressure and mechanical performance requirements but also exhibit long-term resistance to hydrogen-induced damage.

Proper alloy specification, chemical composition (such as sufficient nickel content in stainless steel), and surface treatments—such as electropolishing—are essential to ensure safety, durability, and reliability throughout the sampling system's service life.



3.4 Purging and Flammable Mixtures

Before each sampling, the system must be thoroughly purged to remove any residual gases from previous samples. This step is critical to prevent contamination and to ensure that the collected sample accurately reflects the hydrogen being delivered.

Purging is also essential for safety. Hydrogen has an unusually wide flammability range in air—from 4% to 75% by volume—which means that even small traces of trapped air can create an explosive mixture during pressurization or venting. Incomplete purging can lead to the formation of flammable gas-air mixtures, significantly increasing the risk of ignition, especially in confined or poorly ventilated spaces.

To eliminate these risks, hydrogen sampling systems must include a dedicated purging function using an inert gas such as nitrogen. Just as importantly, the design must allow for purging of all flow paths within the system, ensuring that no residual gases remain trapped in dead legs, valves, or bypass lines.

3.5 Venting and Safety

During purging and depressurization, hydrogen must be vented safely to prevent the accumulation of flammable gas near personnel or equipment. Improper venting can lead to localized gas build-up and significantly increase ignition risk.

To minimize this hazard, hydrogen sampling systems should direct vented gas to a safe atmospheric location, which promotes proper gas dispersion and aligns with recommendations from safety standards such as CGA G-5.5 and ISO 19880-1

3.6 Grounding and Electrostatic Discharge

One of the most overlooked but serious risks in hydrogen sampling is electrostatic discharge (ESD). As hydrogen flows through fluid system components, it can generate static electricity on internal surfaces and external fittings. This charge may suddenly discharge as a spark, which is sufficient to ignite a hydrogen-air mixture. Given hydrogen's extremely low ignition energy, even minor static buildup can trigger ignition in the presence of residual gas.

The risk is especially high during connection or disconnection of the sampling container, or during purging, when hydrogen and air may temporarily coexist within the system or vent lines. If the system is not properly grounded, a momentary discharge can ignite the gas, potentially leading to fire, flash-back, or explosion—particularly in confined or poorly ventilated areas.

To avoid this, the sampling system must include a dedicated grounding cable with an industrial-grade clamp, securely connected to a verified ground point before hydrogen is introduced into the system.

4. Sampling System Approaches: Design Types and Use Cases

There is no one-size-fits-all solution for hydrogen sampling. Sampling systems are typically classified into three types - mobile, stationary, and on-line- each suited to different operational needs.

Regardless of type, all must be engineered to fully comply with applicable safety and quality standards.

4.1 Mobile Sampling Systems

Mobile systems are compact and portable, designed for use at refueling stations, trailers, or other hydrogen distribution points. They are primarily employed for periodic quality verification and offer a key advantage in operational flexibility, as they do not require permanent installation.

Despite their temporary nature, mobile systems must deliver full functionality, including complete purging, electrostatic grounding, controlled venting, and secure sample handling to ensure safety and compliance with applicable standards.

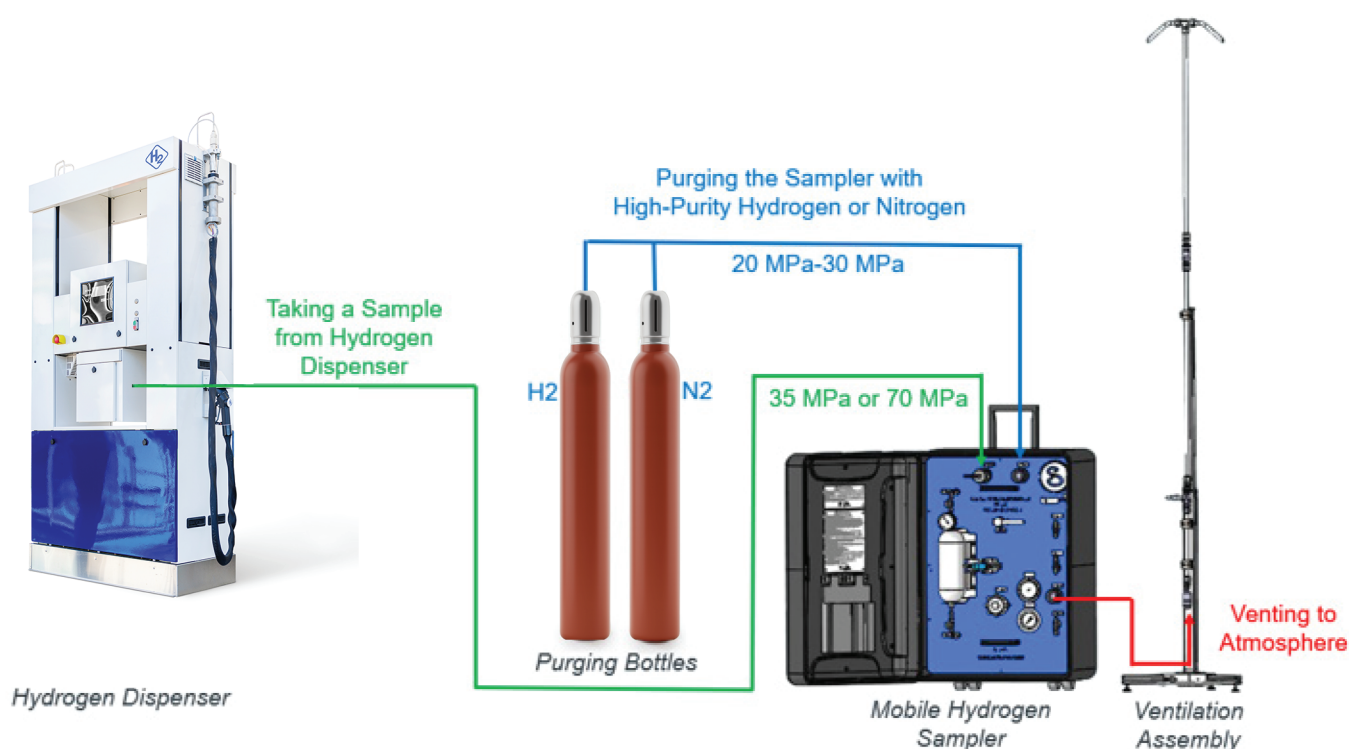


Figure 2 - Example of a Hydrogen Mobile Sampler with Venting - according to ASTM D7606-17 and CGA G-5.5

4.2 Stationary Sampling Systems

Stationary sampling systems are permanently installed at fixed points within the hydrogen infrastructure, including electrolyzers, storage vessels, compressor outlets, distribution headers, and refueling dispensers. They are primarily used for routine quality monitoring and regulatory compliance.

These systems offer high consistency and can be designed with fixed venting structures, automated

purging, and secure enclosures for continuous or high-frequency operation. Their permanent installation makes them ideal for critical control points across the hydrogen ecosystem, where representative sampling and traceability are required.



Figure 3 - Example of a Stationary Sampling System for Hydrogen [9]

4.3 On-line Sampling and Continuous Monitoring

On-line sampling systems feature analytical instruments—such as gas chromatographs or mass spectrometers—that are connected directly to the process line to enable real-time or high-frequency monitoring of hydrogen quality. These systems are typically deployed at critical locations such as electrolyzer outlets, reformer units, pipeline networks, or test facilities, where immediate feedback on gas purity is essential for operational control.

They operate with minimal manual intervention and rely on stable flow control, low dead volume, and clean, inert sample transfer lines to preserve trace-level impurities. On-line sampling enables automated quality validation, early fault detection, and tight process control, making it essential in high-throughput and safety-critical hydrogen environments.

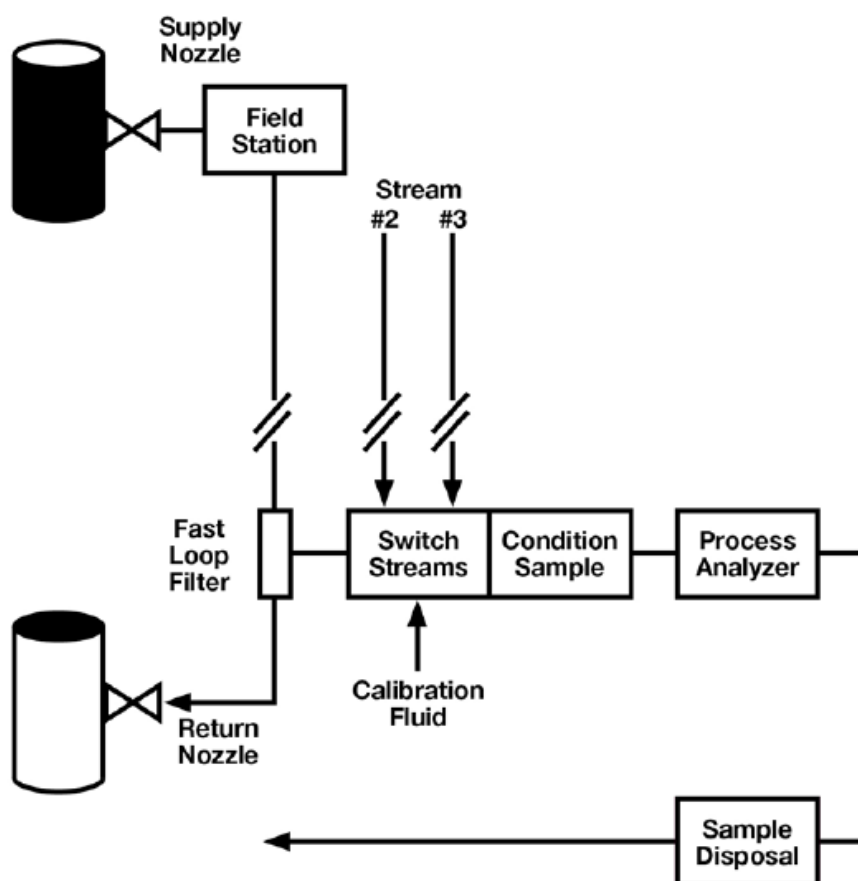


Figure 4 - Basic Sections of an AI Sampling System [10]



5. Conclusion

Hydrogen fuel purity is essential for the safety, efficiency, and durability of fuel cells. Ensuring this purity depends not only on analytical precision in the laboratory but also on the design and operation of sampling systems that enable the extraction of a hydrogen sample in a way that is compatible, timely, and representative.

This white paper outlines the core engineering challenges of hydrogen sampling and emphasizes the importance of aligning system design with standards such as ISO 14687, ISO 19880-1, ASTM D7606-17, DIN ISO 21087, and SAE J2719. Whether deployed in mobile, stationary, or online configurations, compliant systems must prevent contamination, preserve sample integrity, mitigate hydrogen embrittlement and ensure safe operation.

As hydrogen infrastructure expands, the need for reliable and standards-based sampling will continue to grow. Ensuring compatibility with procedural and analytical requirements is not only necessary for compliance—it is foundational to building trust in hydrogen as a clean, high-quality energy vector.

6. References

- [1] - ISO 14687:2019 Hydrogen fuel quality — Product specification.
- [2] - ISO 19880-1:2020 Gaseous hydrogen — Fuelling stations — Part 1: General requirements. (Annex K: Sampling procedures and hardware for hydrogen fuel quality analysis)
- [3] - ASTM D7606-17 Standard Practice for Sampling of High Pressure Hydrogen and Related Fuel Cell Feed Gases.
- [4] - DIN EN 17124:2022-12 Hydrogen as a fuel — Specification and quality assurance for hydrogen refuelling stations dispensing gaseous hydrogen — PEM fuel cell applications for vehicles.
- [5] - DIN ISO 21087:2022-03 Gas analysis — Analytical methods for hydrogen fuel — Proton exchange membrane (PEM) fuel cell applications for road vehicles.
- [6] - CGA G-5.5 Hydrogen Vent Systems — Guidelines for the safe design and installation of hydrogen vent systems.
- [7] - SAE J2719:2020 Hydrogen Fuel Quality for Fuel Cell Vehicles
- [8] - SAE J2600:2015 Compressed Hydrogen Surface Vehicle Refuelling Connection Devices.
- [9] - Grab Sampling Systems – Application Guide, Swagelok Company.
- [10] - Industrial Sampling Systems – Reliable Design & Maintenance for Process Analyzers, Tony Water, a Swagelok Company Publication.