RELIABLE CARBON CAPTURE THROUGH SMART ANALYZER INTEGRATION

1 Abstract

Carbon capture, Utilization, and Storage (CCUS) technologies are vital for achieving global decarbonization goals. However, the success of CCUS depends not only on capture efficiency or storage security, but also on maintaining consistent gas quality, optimizing processes, and ensuring compliance with strict safety and environmental standards. This is where process analytics emerges as a strategic enabler. Beyond individual analyzers, it is the integration of sampling, conditioning, monitoring, and digital control systems into cohesive solutions that drives efficiency and reliability. This article highlights system integration, analyzer platforms, and the importance of robust probe sampling in hazardous environments.

2 The value of Integrated Process Analytics in Decarbonization Processes

The global energy transition requires both rapid expansion of renewable energy and effective strategies to manage existing CO_2 emissions. CCUS has become a cornerstone technology, but its success hinges on reliable process data. Process analytics provides this foundation by measuring gas compositions, detecting trace components, and ensuring environmental compliance. As part of process management, process analytics helps make operations as economically efficient as possible. This enhances plant yields, optimizes energy costs, and ensures product quality and specifications - even in innovative and sustainable processes. Therefore, the payback period of process analytical equipment is often under one year.

3 Analytical Checkpoints Across The CCUS Chain

3.1 Key Technology Steps in Carbon Capture and Storage

CO_2 has been captured from industrial process streams for many years using established technologies. Proven methods include pre-combustion, post-combustion, and oxyfuel processes. As an example, the post-combustion process works as follows: CO_2 is separated from the flue gas after combustion using a chemical solvent. A well-established method for decades is amine absorption. In the first stage, the flue gas comes into contact with the amine solution, which binds the CO_2. The CO_2-rich solution (an amine/water mixture) is then sent to a stripper column, where CO_2 is released at elevated temperatures, and the amine solution is recycled. After a dehydration step, the purified CO_2 is compressed for transport via pipeline.

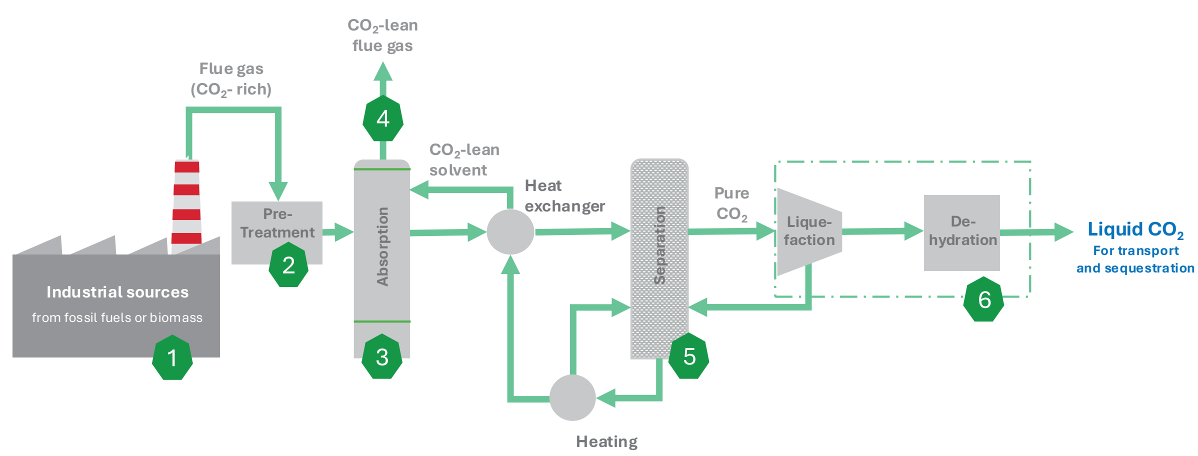

Figure 1: Measuring points for Process Analytics in the Carbon Capture Post-Combustion Process

3.2 Process Analytics in Carbon Capture Facilities

In CO_2 capture, multiple gas components must be measured to optimize both energy efficiency and capture performance. Additionally, the flue gas released into the atmosphere must meet environmental standards, requiring it to be clean and free of pollutants. Further processing requires the removal of trace gases such as N_2, O_2, NOx, SOx, and H_2S to minimal levels, and the complete drying of the CO_2. All of these steps are continuously monitored using online analytical systems.

After combined purification and liquefaction, the CO_2 quality must be verified again to ensure it meets specifications for transport, for example via pipeline in liquefied form (LCO_2) at approximately 20 bar or higher, and for final use. Across the entire value chain, multiple measurement points for process analyzers, employing a variety of analytical technologies, can be identified, as illustrated above.

For flue gas monitoring at the boiler up to CO_2 capture as well as emission monitoring at the stack, continuous gas analyzers based on various spectroscopic principles such as infrared (e.g. NDIR or FTIR) or others (UV, CLD, TDLS) are proven in use, if required combined with FID or paramagnetic Oxygen analyzers.

Regardless of the analyzer technology used across the CCUS chain, sample preparation systems play an important role in terms of measurement accuracy, reliability, and availability.

3.3 Probe Sampling and Conditioning - The Gateway to Reliable Analytics

To ensure that the online analysis delivers representative and reliable measurement results, it is essential that the entire analysis system—from probe sampling to the analyzer—is well coordinated. Measurement inaccuracies often result from poor compatibility between sampling, transport, and conditioning components, the sample itself, and the surrounding environmental conditions. The complexity increases further when measurements are conducted in hazardous and explosive environments, which demand a careful selection of components.

Below the key elements of the probe sampling and conditioning and the specific requirements for equipment in hazardous areas are described:

The Gas Sampling Probe

The gas sampling probe is the primary entry point for the gas analysis system, making efficient sample filtration critical for reliable operation. While many probes exist for safe areas, ATEX-certified probes capable of maintaining temperatures of 150–180°C are limited. Most probes operate at 180°C, and ATEX regulations require temperature limiters to prevent exceeding rated temperature classes. Products like the PSG Process Probe integrate built-in limiters, simplifying installation and compliance.

Table 1: Measuring points, typical analyzers and AGT-PSG sample handling offerings in CCUS plants

(IR=infrared, CLD=chemiluminescence, UV=Ultraviolet, GC=gas chromatograph, EC=electrolytic conductivity)

	Measuring Point	Measuring Task	Measuring Components	Typical process analyzers	AGT-PSG sample handling solutions
1	Boiler	Combustion control	CO, O_2	IR, paramagnetic O_2	Gas sample probes, heated lines, sample gas coolers
2	Flue gas pre-treatment	Treatment optimization	SO_x, CO_2, NO, NO_2	IR, CLD, UV	Gas sample probes, heated lines, sample gas coolers
3	CO_2 Absorption	Treatment optimization	SO_x, CO_2, NO, NO_3, Amines	IR, CLD, UV	Gas sample probes, heated lines, sample gas coolers
4	Stack	Emission monitoring	CO, CO_2, NO_x, SO_2, O_2	IR	Gas sample probes, heated lines, sample gas coolers
5	CO_2 separation	CO_2 quality monitoring	O_2, H_2, H_2O, Amines (traces, impurities)	GC, IR	Gas sample probes, heated lines
6a	Dehydration / Deoxygenation	CO_2 quality control	H_2O, O_2 (traces, impurities)	EC, paramagnetic O_2, moisture analyzers	Gas sample probes, heated lines
6b	CO_2 compression	CO_2 quality control	CO_2, H_2O, H_2, Ar, CO, H_2S, COS, R-SH, C_2, alcohols	GC, (IR)	Complete sample conditioning systems and system integration

Figure 2: PSG Plus Probe

Minimizing human presence in hazardous areas is crucial. Although CO_2 capture systems typically process clean gas streams, dust can be present at the extraction point—especially in combustion or cement processes. Reliable sampling and filtration technology are key to maintaining measurement accuracy and system uptime. Therefore, maintenance can be reduced by maximizing filter surface area— PSG utilizes a filter design offering one of the largest active surface areas on the market. — and by employing back-purging options for self-cleaning under high dust conditions. For toxic gas measurements, the sample stream must be fully shut off when necessary. This requires a shut-off valve at the probe's entry, integrated into the probe's heating system to avoid cold spots and condensation. Implementing this safely is technically complex but essential for accurate and safe operation.

Heated Sample Line for Gas Transportation

After primary gas extraction via the sampling probe, the sample must be transported to the conditioning or analyzer system. Maintaining temperatures between 150–180°C (or up to 200°C) is crucial to prevent acid dewpoint condensation, and interfaces must be free of cold spots to avoid altering gas composition. High-temperature heating technologies for heated sample lines are limited, and safety remains paramount. Modern standards, such as DIN EN IEC 60079-0, require assessment of the entire line, including electrostatic discharge risks. Safe operation is ensured using conductive jackets with proper grounding. Cut-to-length technology is also important, as lines are often ordered longer than necessary, which can increase energy demand. Effective insulation is essential to maintain temperature and reduce energy loss. Innovations like PSG Basic Extruded heated cables offer up to 25% energy savings while providing a durable outer jacket for industrial use.

Figure 3: PSG Basic Extruded

Table 2 shows typical key features of the various sample preparation steps using the example of an emission monitoring system (measuring point 4 on the chimney).

Component	Function	Key Features
Gas Sampling Probe	Extracts representative samples	Holding temperatures at 150-180°C (optional ATEX-certified) to prevent condensation High filter capacity to extend mainentance frequency Temperatured shut-off valve to avoid cold spots and secure safety isolation Back-purge option for self-cleaning against high dust-loads Built-in temperature limiters to simplify installation and ATEX compliance
Heated Sample Line	Transports gas without condensation	Holding temperatures at 150-180°C (optional ATEX-certified) to prevent condensation Robust and effective insulation to maintain temperature and reduce energy loss Cut-to-length technology to reduce cost and energy loss
Gas Conditioning System	Prepares gas for analysis (Coolers, dryers, pumps, filters, etc.)	Flexible configuration with multiple gas paths for reliable operation Membrane drying alternatives with reduced supply media (only instrument air, no electrical components) - inherently safe for hazardeous area.

Gas Conditioning System

Gas conditioning is the final step before analysis, following sample extraction via the Gas Sampling Probe and transport through the Heated Sample Line. While probe and line placement is often dictated by plant layout and ATEX/IECEx requirements, conditioning and analyzer systems are typically housed in a controlled analyzer shelter or container. If this is not possible, all components—including the Sample Gas Cooler, Dryer, Pump, and analyzer—must comply with hazardous area classifications. Certified solutions like the PSG Process Cooler BCR ATEX provide flexible configurations with one to four gas paths for reliable operation. For sample gas drying, alternatives to traditional condensate coolers, adsorption, or permeation dryers include Nafion® membrane dryers, which preserve gas composition via selective water transport. Nafion technology operates using only instrument air, with no electrical components, making it inherently safe for hazardous environments. Proper evaluation of process parameters is necessary to determine feasibility for a given application.

4 Conclusion

The CO_2 economy represents a key pillar in global decarbonization efforts. Ensuring consistent product quality is essential to the successful development of sustainable CO_2-based products. To maintain high quality and reliability in Carbon Capture and CO_2 pipeline management, the integration of process analytics throughout the network is strongly recommended.

Flexibility is essential when adapting technical equipment to sustainable processes such as those within the carbon capture economy—and the same holds true for process analytics. Superior analytical performance depends on robust, solution-oriented concepts. In this context, not only the gas analyzers themselves but also the sampling probes and conditioning systems play a vital role in ensuring the efficiency and reliability of the overall analytical setup.

Ultimately, sustainability must become second nature - and process analytics is a key enabler in making this a reality.

5 References

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