

The background of the entire page is an abstract, high-tech visual. It features numerous thin, flowing lines in shades of bright blue and red, which curve and swirl together to create a sense of dynamic movement and depth, resembling a digital or data-driven environment.

The pipeline to the future

Garry Hanmer, Atmos International, UK, explains how advanced AI algorithms are transforming hydrogen pipeline monitoring and safety.

Hydrogen is set to play a central role in the global energy transition, with governments and industry investing heavily in production facilities, transmission pipelines and cross-border infrastructure. As these networks evolve from isolated demonstration projects into interconnected energy systems, operators face an increasingly complex operational environment. Hydrogen's unique physical properties, combined with variable production sources, changing demand profiles and more dynamic network configurations, require new approaches to pipeline monitoring and operational decision-making.

Traditional pipeline monitoring systems remain fundamental to safe operations, providing operators with

continuous measurements of pressure, flow, temperature, and gas quality. However, as hydrogen networks grow in scale and complexity, the volume of operational data generated can quickly exceed what engineers can realistically interpret in real time. The challenge is no longer collecting data, but transforming it into meaningful operational insight.

Advanced artificial intelligence (AI) algorithms are increasingly being integrated alongside proven pipeline simulation and monitoring technologies to help address this challenge. Rather than replacing engineering judgement, AI enables operators to analyse large volumes of operational data, identify subtle patterns that may otherwise go unnoticed and evaluate potential future operating scenarios before they

affect pipeline performance. By combining AI with high-fidelity hydraulic simulation, operators can move beyond reactive monitoring towards more predictive, data-driven decision making.

Why hydrogen networks demand greater operational intelligence

Hydrogen presents several challenges that distinguish it from conventional natural gas transmission. Its lower density influences pressure losses and flow behaviour, while hydrogen's interaction with pipeline materials requires careful management to minimise the risk of embrittlement in suitable steel infrastructure. In blended gas networks, hydrogen concentration can also vary spatially and temporally as gas moves through the system, creating operational conditions that are significantly more dynamic than those experienced in traditional networks.

At the same time, hydrogen infrastructure is becoming increasingly interconnected. New production facilities, storage sites, industrial consumers, and export terminals introduce multiple injection and withdrawal points, while cross-border transmission projects require operators to work within different regulatory frameworks and operating constraints. These developments increase the number of variables influencing pipeline operations, making it more difficult to understand how changes in one part of the network will affect conditions elsewhere.

Conventional monitoring systems provide accurate measurements at instrumented locations, but they cannot directly observe every kilometer of pipeline. As networks become more complex, operators need greater visibility into what is happening between physical measurement points, as well as confidence in how the system is likely to behave over the coming hours rather than simply understanding its current state.

From data collection to operational intelligence

Modern hydrogen pipelines already generate vast quantities of operational data through SCADA systems and

field instrumentation. Pressure transmitters, flow meters, temperature sensors and gas quality analysers continuously monitor key parameters across the network. Individually, these measurements provide valuable local information. Collectively, they form a rich dataset describing the behavior of the entire pipeline system.

The challenge lies in extracting actionable insight from this data.

This is where advanced AI algorithms can add significant value. Machine learning techniques can identify recurring operating patterns, detect subtle deviations from expected behaviour and prioritise anomalies that warrant further investigation. Rather than requiring engineers to manually interpret thousands of individual measurements, AI can rapidly assess changing operating conditions across the network and present the information in a way that supports faster, more informed decision-making.

Importantly, AI is most effective when combined with engineering models that accurately represent the underlying physics of pipeline operation. Rather than relying solely on statistical relationships within historical data, AI-assisted systems can analyse live operational data alongside high-fidelity pipeline simulations, allowing recommendations to be grounded in both observed behaviour and established hydraulic principles.

AI-powered digital twins and virtual instrumentation

One of the most significant developments in hydrogen pipeline operations is the growing use of digital twins, virtual representations of physical pipeline systems that combine real-time operational data with high-fidelity hydraulic simulation. Rather than simply displaying current operating conditions, digital twins provide operators with a continuously updated picture of how the entire network is behaving over time.

In conventional pipeline systems, operators rely on strategically positioned field instrumentation to measure pressure, flow, temperature, and gas quality. While these

measurements provide highly accurate information, they only represent conditions at specific locations. Between those measurement points, pipeline behaviour must be inferred.

Virtual instrumentation extends this visibility by combining live measurements with transient simulation models to estimate operating conditions throughout the network. Pressure profiles, flow distribution, and gas composition can all be calculated in areas where physical sensors do not exist, creating a far more complete operational picture without significantly increasing instrumentation costs.

AI further enhances this capability by continually analysing incoming operational data (see Figure 1) and comparing it with historical behaviour and simulated operating conditions. Instead of simply reporting measured values, AI algorithms can identify

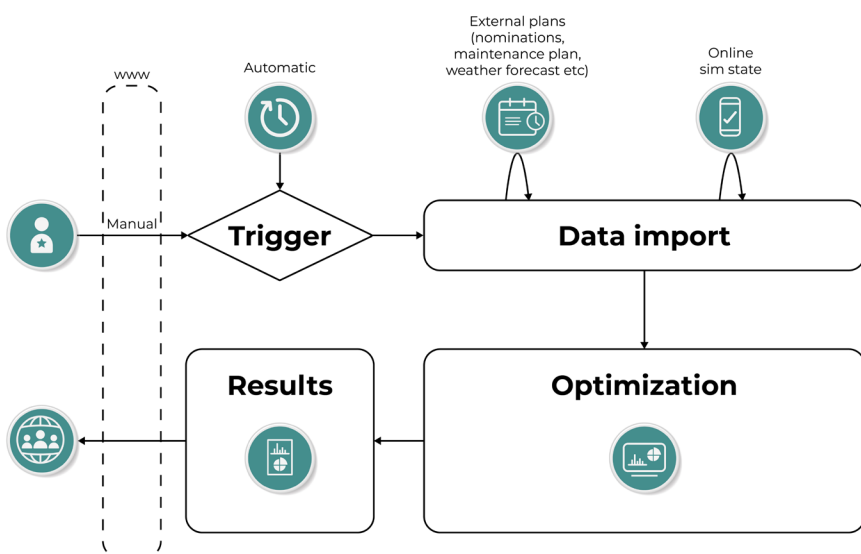


Figure 1. A visual workflow of the process involved in Atmos AIO providing recommendations for optimised pipeline operation.

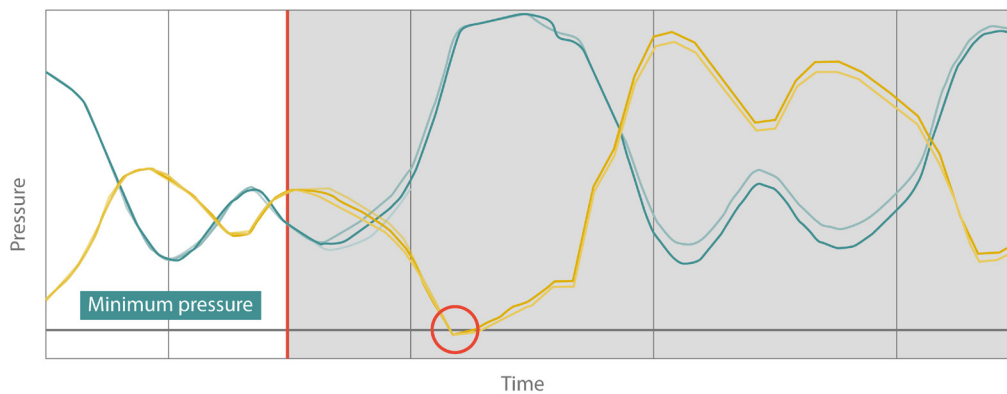


Figure 2. Trending data from a live pipeline's recent activity (light background), along with the look-ahead's prediction of a future scenario. The circled area signposts a potential minimum pressure violation that can be prevented by taking actions early.

relationships between multiple variables simultaneously, helping operators distinguish between expected operational changes and behaviour that warrants further investigation.

As hydrogen networks become increasingly interconnected, this system-wide visibility allows operators to make decisions based on the behaviour of the entire network rather than isolated pipeline points.

Looking ahead, not back

Historically, pipeline control has been largely reactive. Operators identify changing conditions through alarms or operational limits before taking corrective action. While this remains an effective approach for many situations, hydrogen networks present additional operational challenges that benefit from greater foresight.

Changes in hydrogen production, storage operation or industrial demand can propagate through a pipeline over time, influencing pressure, flow and linepack well beyond the point where the original change occurred. Similarly, variations in hydrogen concentration can alter the physical behaviour of the gas, affecting pressure losses and operating margins across the network.

By combining AI with transient pipeline simulation, operators can move beyond monitoring current conditions to evaluating how the network is likely to behave over the coming hours.

Forecast-based simulation (see Figure 2) enables multiple operating scenarios to be analysed before they occur. AI can then evaluate these scenarios, identify those most likely to violate operational constraints and highlight the most effective response. Rather than overwhelming operators with hundreds of possible outcomes, intelligent algorithms can prioritise the scenarios requiring attention and present recommended actions based on predicted system behaviour.

This allows operators to identify potential pressure violations, capacity constraints or inventory issues before they affect live operations, providing valuable time to adjust compressor operation, storage schedules or network configuration.

Supporting safer pipeline operations

Hydrogen's physical properties require operators to manage a wider range of operational constraints than traditional natural gas systems. Material compatibility, operating pressure, gas velocity, hydrogen concentration and available

linepack all influence the safe operation of the network. These constraints are closely interconnected, meaning changes made to optimise one parameter can have unintended consequences elsewhere.

Advanced AI algorithms help operators understand these complex relationships by analysing multiple operational

variables simultaneously. Rather than monitoring individual measurements in isolation, AI can evaluate how changing operating conditions influence overall system performance and identify emerging trends that may otherwise remain hidden within large volumes of operational data.

Importantly, these algorithms do not replace engineering analysis. Pipeline behaviour continues to be governed by well-established physical principles, and high-fidelity simulation remains essential for accurately representing transient flow, gas quality and hydraulic performance. AI complements these models by accelerating analysis, identifying patterns and supporting faster operational decision-making.

The result is improved situational awareness, allowing operators to respond more effectively to changing operating conditions while maintaining confidence that operational decisions remain grounded in validated engineering models.

The future of AI-assisted hydrogen infrastructure

As hydrogen infrastructure continues to expand, operators will be required to manage increasingly diverse pipeline systems. Future networks are expected to incorporate multiple hydrogen production pathways, blended gas supplies, underground storage, industrial consumers, and cross-border transmission, all operating within evolving regulatory frameworks.

Successfully managing this complexity will require more than additional instrumentation or increased computing power. It will require intelligent systems capable of transforming vast quantities of operational data into practical engineering insight.

Advanced AI algorithms are beginning to fulfil this role by supporting anomaly detection, predictive analysis and operational optimisation across increasingly complex hydrogen networks. Combined with digital twins, transient simulation and high-quality operational data, they provide operators with a more complete understanding of pipeline behaviour and greater confidence when making operational decisions.

AI will not replace experienced pipeline engineers. Instead, it is becoming an increasingly valuable decision-support tool, helping operators interpret complex system behaviour, evaluate future operating scenarios and maintain the high standards of safety and reliability required as hydrogen becomes an integral part of the global energy system. 

