

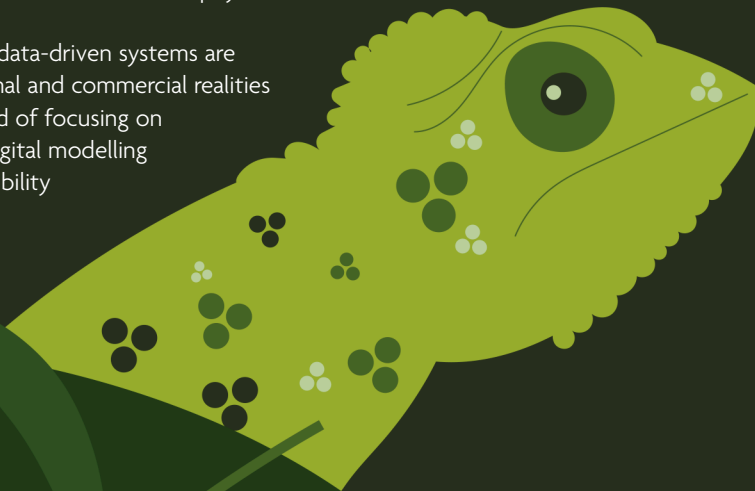
Invisible infrastructure

Garry Hanmer, Principal Simulation Consultant, Atmos International, UK, suggests how data can fill the gaps in hydrogen-ready gas networks.

Gas distribution networks are entering a period of profound change. As hydrogen and biomethane are introduced to support decarbonisation targets, networks originally designed for a single, predictable fuel are being asked to operate under far more dynamic conditions. Pressure behaviour is no longer uniform, gas quality varies across time and location and traditional assumptions around billing and control are no longer valid.

Physical upgrades like injection facilities and material compatibility are only half of the equation. In modern pipeline operations, software, data, and network models have evolved from support tools into critical infrastructure. The ability to simulate complex thermodynamics and maintain a real-time digital record is now as essential to operational safety as the integrity of the steel pipeline itself. In many cases, they are enabling the transition where physical instrumentation alone cannot.

This article explores how advanced data-driven systems are helping operators manage the operational and commercial realities of hydrogen-ready gas networks. Instead of focusing on hardware expansion, it examines how digital modelling and estimation techniques are filling visibility gaps, improving decision-making and supporting fair energy delivery in increasingly complex systems.



From stable networks to variable systems

Traditional gas networks were built around relative consistency. Natural gas composition varies slightly by source, but its physical behaviour is stable enough that networks can be operated using averaged values and predefined operating envelopes. Pressure control, capacity planning, and billing methodologies all evolved within this context. Blending hydrogen and biomethane into the natural gas networks disrupts that stability.

Hydrogen has a significantly lower density than methane, while biomethane composition can vary depending on feedstock and processing methods. When these gases are injected at multiple points across a distribution network, the result is a system where gas properties change continuously as they propagate through the pipelines.

This variability introduces two immediate challenges:

- Operational uncertainty increases as fluctuations in gas composition, such as hydrogen blending or biomethane variability, directly shift pressure drop profiles, gas flow velocities and the established safe operating limits of the network.
- Commercial uncertainty, driven by the challenge of accurately quantifying energy delivery; as gas composition fluctuates across the network, the heating value (energy per unit volume) varies based on the specific source and draw-off timing.

Managing both challenges requires a level of visibility that traditional monitoring approaches struggle to provide.

The role of instrumentation in a dynamic network

Modern gas networks rely on high-quality instrumentation as the foundation of safe and efficient operation. Pressure, flow, temperature and gas quality sensors provide accurate, reliable measurements at critical locations such as supply points, pressure reduction stations and major network interfaces.

Instrumentation strategies are deliberately selective. Sensors are deployed where they deliver the greatest operational and commercial value, balancing coverage, cost, and maintainability.

However, as networks become more dynamic, the challenge is no longer just measurement quality, but data

interpretation and accurate information. In hydrogen-ready systems, gas composition, pressure and flow evolve continuously as blends move through the network. Understanding how measurements at one location relate to conditions elsewhere, and how those conditions will change over time, requires additional context.

Systems and software provide that context. By integrating live data from field instrumentation with physics-based models of the network, operators can extend the value of their existing measurement infrastructure. Sensors provide the ground truth, while models translate distributed measurements into a coherent, system-wide visibility.

In this way, instrumentation and software operate as a unified system instead of separate layers.

Extending visibility beyond measured points

Gas networks generate significant volumes of operational data. Flow rates, pressures, temperatures and injection volumes are continuously collected through SCADA and telemetry systems. Individually, these data streams describe local conditions. Collectively, they can be used to reconstruct the internal state of the whole network.

Instead of relying solely on physical meters, advanced platforms use 'virtual instruments'. By combining live data from key locations with the known physics of the network, the software calculates pressures and gas mixes in areas where no physical sensors exist. This gives operators a complete, real-time view of the entire grid without the need for universal hardware coverage.

This approach maximises the value of limited instrumentation by using key data points to anchor a system-wide simulation. As field conditions change, the model continuously updates, filling the gaps between physical sensors to maintain a reliable digital representation of the entire network's state.

Anticipating operational risk in blended networks

Hydrogen blending introduces operational behaviours that are not always intuitive. Changes in blend ratio affect gas density, which in turn influences pressure losses and flow resistance. A change introduced at one point in the network can propagate over time, creating downstream effects hours later.

For example, a sudden loss of hydrogen injection does not simply reduce hydrogen concentration. It changes the physical characteristics of the gas moving through the network, increasing resistance and altering pressure profiles as the heavier gas front advances.

Without predictive insight, operators may only become aware of these effects once pressures approach operational limits. At that point, response options may be limited.

Look-ahead projections provide a predictive window into future network behaviour by simulating

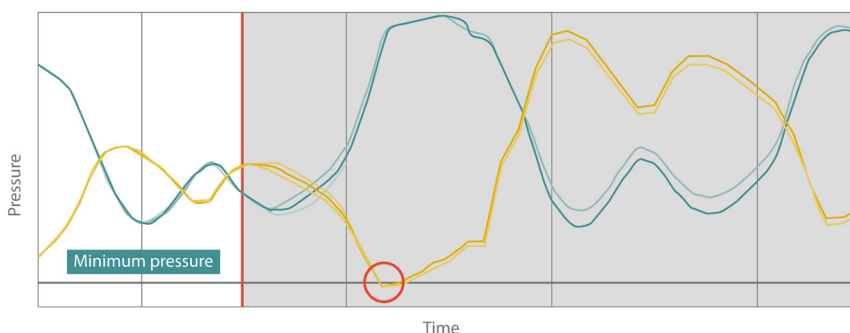


Figure 1. Trending data from a live pipeline's recent activity (light background), along with the look-ahead's prediction of a future scenario. The circled area signposts a potential minimum pressure violation that can be prevented by taking actions early.

diverse 'what-if' scenarios. The process begins with a state initialisation, where the engine pulls the most recent real-time snapshot from the network to serve as a baseline. The simulation then bridges the gap between the live system and the projected operation, modelling the transition from current conditions to the scenario's starting point. By anchoring offline analysis to live production data, operators can pre-emptively identify potential inventory violations and operational bottlenecks before they manifest in the physical system.

This capability does not replace operator expertise. Instead, it augments decision-making by providing foresight that could otherwise result in delivery shortfalls or unexpected shut-downs.

Managing multiple physical constraints simultaneously

Operating a blended gas network requires managing a complex set of interdependent physical constraints. Because hydrogen has a lower energy density, operators must increase flow rates to meet consistent energy demands. These elevated flows drive higher gas velocities, which can reach erosional limits within specific valves and fittings. Simultaneously, these operational adjustments are bounded by material integrity thresholds, which strictly limit hydrogen concentrations to prevent embrittlement in repurposed steel pipelines.

Storage behaviour also changes. Gas networks rely on linepack, the energy stored within pressurised pipes, to manage short-term imbalances. Replacing methane with hydrogen reduces the energy content of that stored volume, shrinking the effective buffer available to operators.

Each constraint influences the others. Increasing flow to meet demand may push velocities higher. Reducing hydrogen concentration to protect materials may limit decarbonisation progress. Managing linepack becomes more complex when its energy value is dynamic.

Simulation tools allow these constraints to be assessed together instead of in isolation. By tracking energy, not just volume or pressure, operators gain a clearer understanding of how close the network is to its true operational limits.

Commercial challenges in a non-uniform system

Operational complexity is mirrored on the commercial side. Gas billing is based on energy delivery. In traditional networks, this is managed using zonal average calorific values applied across defined geographic areas. This approach assumes gas quality is broadly uniform within each zone. In blended networks, that assumption no longer holds.

When hydrogen or biomethane is injected at multiple points, gas quality varies as it moves through the system. Two customers in the same billing zone may receive gas with materially different energy content at the same time.

Applying a single average value risks systematic overcharging or undercharging. These discrepancies can exceed regulatory tolerances and undermine confidence in billing accuracy.

Installing physical gas quality measurements at every customer connection is not practical. Instead, operators increasingly rely on modelled composition tracking, using flow and network data to calculate the energy delivered to each offtake.

Moving beyond zonal averaging

Model-based energy tracking enables a shift away from static billing zones toward more localised insight.

Rather than applying a single average value across a large area, operators can calculate the average energy delivered to each customer over a billing period. Even where meters report only cumulative volume, the corresponding energy value can be derived from the modelled data.

This approach improves regulatory compliance and enhances transparency. Customers are billed for the energy they actually receive, rather than an approximation.

It also provides flexibility. As injection points are added or blend ratios change, the billing methodology adapts automatically, without requiring new zones or additional hardware.

Software as operational infrastructure

As gas networks evolve, the role of systems and software is changing.

Rather than acting as optional overlays, digital models and analytics are becoming integral to day-to-day operations. They connect distributed measurements, provide predictive insight and support both operational control and commercial processes.

This does not diminish the role of physical infrastructure. Pipelines, valves, regulators and sensors remain essential. Instead, software systems extend their capability, allowing existing assets to operate effectively under new conditions.

In hydrogen-ready networks, intelligence becomes as important as capacity. The ability to understand and manage variability determines whether decarbonisation can proceed without compromising safety or fairness.

Preparing for a multi-gas future

Hydrogen and biomethane represent the first stage of gas network diversification. As energy systems continue to evolve, pipelines may be tasked to transport additional products, including synthetic gases and carbon dioxide.

Each new product introduces different physical behaviours and operational constraints. The experience of hydrogen blending highlights a key lesson: adaptability matters more than optimisation for a single fuel.

Networks that invest in flexible, data-driven operating models are better positioned to deal with ongoing changes. Those that rely solely on static assumptions face increasing operational and commercial risk.

The future gas grid will not be defined by one fuel or one technology. It will be defined by how effectively operators can manage complexity and change.

Increasingly, that capability will come not from additional steel in the ground, but from better intelligence running alongside it. 