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How Liquid Volume Metrology Services Underpin the Oil and Gas Industry

NIST metrology services support accurate flow measurement, strengthening the efficiency, integrity, and environmental protection of U.S. oil and natural gas pipelines

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The Challenge

Accurate monitoring of fluids, liquids, and gases in pipelines is critical to supporting manufacturing processes, infrastructure, and the transport of high-value commodities, such as natural gas and crude oil. Because petroleum pipelines transport these commodities at large scale, even small measurement errors can create significant discrepancies in commercial transactions. Reliable custody-transfer measurements depend on metrologically traceable calibration standards to maintain accurate flow measurements throughout operation. The United States (U.S.) relies on hundreds of thousands of miles of pipelines that transport these energy commodities, including crude oil and natural gas, to refineries, processing facilities, storage terminals, and directly to consumers. For example, a single petroleum pipeline can span thousands of miles and transport over 100 million gallons (2.38 million barrels) of refined fuels per day. This can serve numerous delivery locations that, in turn, serve hundreds of shippers and direct customers.

As of early 2026, the United States and Canada have over 20 million gas flow meters deployed, with the oil and gas industry accounting for a significant share of this infrastructure, driven by high adoption of smart technologies. The oil and gas sector remains the second-largest end-use industry for flow meters, with oil and gas/chemical applications expected to account for 39 % of total U.S. flow meter demand in 2025.^{1,2,3} Given the high volume of these products transported through pipelines of various designs and geometries with diameters ranging from 15 cm (6 inches) to nearly 1.2 m (4 feet), countless flow meters are installed along the pipelines to continuously monitor fluid flow rate. Flow meters are calibrated before installation, but their performance and reliability may be affected by environmental conditions and pipe conditions.

The need for standardized flow measurement has long been recognized. Before standardized measurement methods were established, various measurement practices could yield different results for the same petroleum transfer, leaving no universally accepted reference to resolve discrepancies. The National Bureau of Standards (now the National Institute of Standards and Technology (NIST)) made pioneering contributions to the development and standardization of orifice metering in the early twentieth century, helping establish measurement principles and

¹ Gas Flow Meters Market Size, Share, Growth, and Industry Analysis, By Type (Gas Roots Flowmeter, Gas Turbine Flowmeter, Gas Ultrasonic Flowmeter, Others), By Application (Industrial, Commercial), Regional Insights and Forecast to 2033. <https://www.marketreportsworld.com/market-reports/gas-flow-meters-market-14716202>

² Flow Meter Market. <https://www.marketsandmarkets.com/Market-Reports/flow-meters-market-1191.html>

³ Flow Meter Industry Analysis in the USA 2025 to 2035. <https://www.factmr.com/report/united-states-flow-meter-industry-analysis>

practices that shaped modern flow measurement capability.⁴ These early measurement principles and practices helped establish a foundation for the standards and technologies that underpin modern petroleum custody transfer.

For liquid petroleum products, accurate flow measurement supports flow-balance and computational pipeline-monitoring approaches that can identify unexplained imbalances and potential leaks, helping operators investigate and respond to releases that could affect surrounding environments, including surface-water resources.⁵ The reliability of these flow-balance assessments, however, depends on the accuracy and metrological traceability of flow measurements, highlighting the importance of calibration and reference standards for pipeline monitoring. Similarly, for natural gas pipelines, accurate flow measurement allows operators to compare gas entering and leaving a pipeline while accounting for changes in pipeline inventory (line pack). After accounting for inventory changes and other relevant measurement factors, a remaining imbalance may indicate an accounting discrepancy, a potential leak, or another unexplained loss. Reliable measurement, therefore, supports the identification and investigation of lost and unaccounted-for gas and can contribute to pipeline leak-detection and monitoring efforts, enabling operators to identify and respond to potential releases of natural gas, including methane, to the atmosphere.^{6, 7, 8}

While standardized measurement practices establish the foundation for reliable energy transactions, maintaining accuracy throughout decades of operation requires ongoing calibration and verification. The effects of operating conditions on measurement performance are well documented. Hall et al.⁹ found that ultrasonic gas flow meters can remain stable over years of service but may experience measurable calibration shifts due to factors such as debris and internal coating buildup. In one field-returned meter, cleaning restored performance after a calibration deviation of nearly 0.08 % was observed. Similar challenges apply to liquid custody-transfer systems, where calibrated pipe provers serve as the reference for verifying flow meter accuracy. Accurate flow measurement is essential not only for fair commercial transactions but also for identifying unexplained product losses, thereby promoting efficient use of natural resources and maintaining confidence across energy supply chains.

⁴ Buckingham, E. (1932). Notes on the orifice meter: The expansion factor for gases. Bureau of Standards Journal of Research, 9(1), 61–78. Research Paper RP459. <https://doi.org/10.6028/jres.009.009>

⁵ American Petroleum Institute (API). (2022). *API Recommended Practice 1130: Computational Pipeline Monitoring for Liquids* (2nd ed.). API, Washington, DC.

⁶ Costello, K. (2013). *Lost and Unaccounted-for Gas: Practices of State Utility Commissions*. National Regulatory Research Institute (NRRI). <https://pubs.naruc.org/pub/4AD9AE38-2354-D714-51B6-0E79667A52C2>

⁷ Pacific Gas and Electric Company, & Gas Research Institute. (1990). *Unaccounted for gas project, volume 1: Final report*. Pacific Gas and Electric Company.

⁸ U.S. Department of Transportation, Pipeline and Hazardous Materials Safety Administration (PHMSA). (2012). *Leak Detection Study – Final Report No. 12-173, §2.a, Mass Balance with Line Pack Correction..*

⁹ Hall, J., Zanker, K., and Kelner, E., "When Should a Gas Ultrasonic Flow Meter be Recalibrated?", 28th International North Sea Flow Measurement Workshop, St Andrews, Scotland, 26–29 October 2010.

The Solution

NIST, the NMI for the United States, calibrates volumetric field test measures that provide SI traceability for petroleum flow measurement.¹⁰ This is one of many calibration services that NIST provides to support both U.S. and global industry, innovation, and infrastructure for a diverse range of metrologically based applications. Individual volume test-measure calibration is performed using both gravimetric and volumetric methods, and NIST demonstrates its competence in key comparisons of liquid volume and mass under the auspices of the CIPM Mutual Recognition Arrangement (MRA). Furthermore, NIST-calibrated test measures enable water drawdown companies to calibrate essential equipment, including tanks, ball provers, and stationary tanks, thereby establishing metrologically traceable volume references for calibrating flow meters that underpin petroleum custody-transfer measurement. Water drawdown is the process of draining accumulated water and sediment from the bottoms of large crude oil or fuel storage tanks; it is crucial that the separation of product from contaminant be performed correctly.

For liquid petroleum measurement, the need for accurate, metrologically traceable reference standards is addressed in part through the NIST Liquid Volume Calibration Service, which determines the internal volume of precision-engineered steel vessels.¹¹ The U.S. petroleum industry uses these NIST-calibrated test measures (see **Figure 1**) to provide accurate reference volumes that form part of the metrological basis for custody transfer. These NIST-calibrated test measures provide a primary metrological link to the SI for petroleum custody transfer, with their calibrated volumes serving as metrologically traceable reference values for establishing the accuracy of downstream measurement systems. In many pipeline operations, certified volume test methods for hydrocarbon flow measurements are required by the American Petroleum Institute (API) standards to maintain metrological traceability to an accurate volume standard. For example, API Chapter 4.7 – Field Standard Test Measures¹² states that all field standard test measures used for prover calibrations in the U.S. shall have a "Report of Calibration" issued by NIST. Currently, Coriolis mass flow meters are being explored as the next generation of field-test standards for evaluating the performance of such systems.¹³

¹⁰ NIST Liquid Volume Calibration Facility. <https://www.nist.gov/laboratories/tools-instruments/liquid-volume-calibration-facility>

¹¹ Bean, V. E., Espina, P. I., Wright, J. D., Houser, J. F., Sheckels, S. D., & Johnson, A. N. (2009). NIST Calibration Services for Liquid Volume. NIST Special Publication 250-72. <https://doi.org/10.6028/NIST.SP.250-72>

¹² American Petroleum Institute (API) Standards. <https://www.api.org/products-and-services/standards/>

¹³ NIST U.S. National Work Group (USNWG) Field Reference Meters: Coriolis Mass Flow Meters. <https://www.nist.gov/programs-projects/usnwg-field-reference-meters-coriolis-mass-flow-meters>



Figure 1. A metrology technician at a crude oil pipeline location uses NIST-calibrated volume test measures to calibrate industry “provers” that are then used to calibrate pipeline flow meters. This includes test measures of 100 gallons (1 and 2 on the upper left) and 50, 25, 10, and 5 gallons (3, 4, 5, and 6 on the right, respectively).

A Quantifiable Impact

The importance of the accuracy of volume test measures can be illustrated by recent flow data obtained from crude oil pipeline facilities currently in operation in the U.S. A single facility in a crude-oil production state can meter 27 million barrels of crude oil a month. Flow meter accuracy is established through field calibration against volumetric reference standards (e.g., ball prover). If the volumetric reference standard had a 0.05 % bias, the resulting volumetric custody-transfer error would be about $\pm 13\,500$ barrels over the month-long period. At an estimated value of 100 USD per barrel, this measurement error represents a difference in reported value of 1.35 million USD per month, or over 16 million USD per year. For perspective, even 0.01 % systematic bias would correspond to approximately 270 000 USD per month at the same throughput and accumulate to approximately 16.2 million USD over five years if the bias persisted unchanged. This illustrates how the accuracy of volume test measures underpins confidence in petroleum custody-transfer measurements and the economic integrity of pipeline operations.

The oil and natural gas industry is a major economic driver for the U.S., accounting for approximately 7 % of U.S. GDP in 2023.¹⁴ This real-world illustration shows how a ubiquitous, routine service in volume metrology underpins the accuracy of these industrially relevant measurements and directly supports the reliability of the nation’s pipeline infrastructure and overall economic integrity. It is important to note that accurate flow measurements are also

¹⁴ U.S. Bureau of Economic Analysis, Gross Domestic Product: Oil and Gas Extraction (211) in the United States [USOILGASNGSP], retrieved from FRED, Federal Reserve Bank of St. Louis; <https://fred.stlouisfed.org/series/USOILGASNGSP>

paramount for many other industries, including semiconductor fabrication, aerospace, automotive, manufacturing, power generation, and chemical processing. Thus, the economic impact is expansive.

The NIST Liquid Volume Calibration Facility is currently undergoing a major renovation, which is temporarily pausing its calibration service capacity and thus preventing it from providing calibrations to its many customers in the U.S. and globally. Commercial calibration laboratories may be able to partially close the gap, but they must establish and maintain appropriate measurement standards, procedures, uncertainty evaluations, and metrological traceability consistent with ISO/IEC 17025. The temporary unavailability of the NIST's calibration capability illustrates the importance of maintaining a resilient national measurement infrastructure for petroleum custody transfer.

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