Turning the tide: Upstream Permian methane emissions drop 26% in 2023

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Turning the tide: The Permian's path to lower methane emissions

The efforts of upstream companies to reduce methane emissions appear to be gaining traction. The latest, high frequency and high-resolution observation data from the partnership of S&P Global and Insight M Inc. show that methane emissions from upstream oil and gas operations fell 26% in 2023 versus the 2022 benchmark. Given rising production of oil and gas in the basin, overall methane intensity — a ratio of total emissions over total output — fell even more steeply, recording a decline exceeding 30%. On an absolute basis, the impact is equally significant: Total emissions of methane declined about 34 Bcf to 96 Bcf in 2023.[1] When converted to CO_2 equivalence (on a 100-year basis), this reduction was over 18 million metric tons (MMt) — roughly equal to the annual greenhouse gas (GHG) emissions of the state of Hawaii.

The figures presented here represent a new level in accuracy that is emerging due to the maturation of detection technologies and computation. Based on about 700 high-resolution aerial surveys covering 88% of the basin's active wells and detecting leaks as low as 10 kg/hour, these results offer the most accurate public, basin-wide estimate of venting and fugitive leaks of this potent GHG. Total emissions were measured and aggregated to the basin level by Insight M, ensuring complete operator anonymity. The aggregate total was then combined with S&P Global's best-in-class data on oil and gas assets and operations. The resulting dataset thus offers an independent assessment of observed methane emissions that does not rely on self-reporting of emissions by oil and gas operators or on regulatory data.

1. All figures cover upstream extraction and wellhead processing. Associated methane emissions from midstream and even downstream infrastructure in the region are mostly due to a distinct set of operators. Historically, they have been roughly equal to the upstream emissions.

Spin cycle: How methane emissions are expressed matters

As we discussed when we published the methane emissions level for 2022 here, there is no universally accepted way to express methane emissions quantities. Each variant offers important advantages and disadvantages, as described in the table below, and tells a story about 2023 performance and the trend versus 2022:

Metric	Permian upstream in 2023	Permian upstream in 2022	Pros	Cons
Methane emissions	96 Bcf	131 Bcf	– Simple – Consistent with climate impact	– Offers no context or cost-benefit – Does not allow meaningful comparison between areas of varying size
Percent of natural gas produced	1.36% of natural gas	2.01% of natural gas	– Logical elegance in comparing gas with gas – Provides gas loss rate	– Oil production deemed free of methane emissions – Penalizes oilier operations with little gas production – Most methane emissions come from oil-processing equipment
Percent of energy produced	0.63% of barrels of oil equivalent	0.92% of barrels of oil equivalent	– Compares environmental cost with benefit (energy) for society – Reflects reality of full integration of oil and gas operations	– Energy equivalency of 6 Mcf of gas per 1 barrel of oil does not reflect value equivalency of approximately 20:1 – Actual uses of the fuel may be irrelevant to energy content
Percent of value produced	0.12% of estimated revenue	0.43% of estimated revenue	– Exposes economic considerations, which drive real-world decisions – Reflects location factors influencing gas prices	– Depends heavily on uncontrollable factors (prices) – High volatility makes it unusable as an index to show improvement over time

Data compiled Oct. 15, 2024.
Sources: Insight M; S&P Global Commodity Insights.

Absolute volume: 96 Bcf of methane (1.8 MMt of methane and 51 MMt of CO2 equivalent on a 100-year basis)

The scale of the oil and gas industry in the Permian is staggering. The basin produced just over 3.5 billion barrels of oil equivalent in 2023. The accompanying emissions are large. When looking strictly at the absolute volume of methane released to the atmosphere, it is helpful to have frames of reference to comprehend the size. How much is the 96 Bcf of methane emitted in 2023 by Permian upstream operations? It is

- Enough to power about 3 GW of combined cycle natural gas-fired power capacity running around 70% base-load utilization for an entire year.
- Equal to the annual gas usage of 1.7 million households.
- Equivalent to about 60% of the 2023 GHG emissions emitted by Canadian oil sands operations.

At the same time, the absolute decrease in 2023 Permian Basin upstream methane emissions — 34 Bcf — is also huge. And because methane is such a potent GHG (about 28 times on a 100-year basis), the equivalent amount of CO_2 avoided (18.5 MMt) is also outsized. How does this reduction size up? For the year 2023, that decrease was

- More than the total 2023 driving emissions avoided by every electric vehicle ever sold in the United States, even if powered 100% with zero-carbon electricity.
- Enough gas to produce the nitrogen fertilizer used annually in all the farmland east of the Mississippi River.
- Roughly the same as the total GHG emission from all sources for the state of Hawaii during the same period.

Natural gas intensity: 1.36% of total natural gas production

A second way of understanding methane emissions is to express it as a percentage of total gas output — effectively a leakage rate. While oil steals the limelight and is the target fluid for the operators, Permian gas production has likewise boomed over the last decade as oil-directed development has generated large volumes of associated gas. In fact, the world's largest oil field now produces more than a fifth of total US gas supply. In 2023, annual gas production notched another gain, jumping 9% versus 2022 to top 23 Bcf/d.

Natural gas is more infrastructure-intensive than oil, and it has been difficult for the natural gas gathering and transport companies to build pipes and plants at the breakneck pace that production has grown. In addition, because the composition of shale well output in the basin becomes gassier as wells age, gas production growth tends to outpace oil expansion. The net result is that Permian gas producers have had to deal with infrastructure shortages and logistical timing issues in their efforts to gather, process and transport gas to industrial and residential demand centers. This challenging commercialization dynamic, plus the very remote nature of the area and the presence of more than 50,000 wells more than a quarter of a century old, have complicated the ability to estimate and manage methane emissions. Numerous academic studies have found a wide range of leakage rates for the basin as a whole, and satellite data have confirmed widespread methane emissions.[2]

In 2022, S&P Global, using Insight M data, estimated that methane emissions equaled 2.01% of total natural gas supply from the basin. In 2023, our data show that this intensity improved (fell) by 33% to reach 1.36%, despite the rise in natural gas production output. This gain is impressive, although it is also important to note that the 2023 mark remains well above the 0.2% and "near-zero" marks that many companies and governments aspire to achieve. If we dig deeper into the data, we find that the distribution of performance is wide. Anonymized data presented here show that some companies have already reduced methane emissions below 0.2%, while others are as high as 5%. We will analyze this range of upstream operators' intensities in upcoming analysis.

2. Sherwin, E.D., Rutherford, J.S., Zhang, Z., Chen, Y., Wetherley, E.B., Yakovlev, P.V., Berman, E.S.F., Jones, B.B., Cusworth, D.H., Thorpe, A.K., Ayasse, A.K., Duren, R.M., Brandt, A.R., 2024. US oil and gas system emissions from nearly one million aerial site measurements. Nature 627, 328–334.

Energy intensity: 0.63% of total barrels of oil equivalent production

Perhaps the main reason that the Permian gas intensity remains elevated compared with plays such as the Haynesville or Marcellus/Utica is that oil production dominates the Permian. Virtually all methane emissions sources are quite straightforward: emissions originate from the intersection of processes and equipment. Operational venting, as well as fugitive leakage, occur in specific activities happening at specific pieces of equipment. And while dry gas production has its own headaches, the complexity of equipment configuration and the number of processing stages is generally much greater when facilities must separate and stabilize production of oil plus gas (plus water). More kit — featuring an abundance of temperatures and pressures means greater interconnection of more valves, pumps, tanks, engines, controllers, etc. — means more chances for methane emission to escape.

Because oil production drives methane emissions, our preferred unit of measure for methane emissions intensity expresses it as a percentage of the barrel of oil equivalent (boe) produced. In 2023, Permian upstream methane emissions intensity on this basis was 0.63%, compared with 0.92% the previous year.

Percent of value: 0.12% of upstream gross revenue

A fourth way to express the level of methane emissions is to frame it in terms of the loss of economic value. In the Permian Basin in 2023, this would only have increased upstream revenue by a scant 0.12%, down more than 70% from the 2022 mark of 0.43%.

The argument is often made that capturing and selling methane emissions represent an important source of economic gain for producers and justifies mitigation expenditures. But while incremental revenue is obviously advantageous, it is important to note that as companies achieve success in reducing emissions, the economics of the effort deteriorate because the incremental volume of gas to be captured and sold decreases.

These diminishing volumes, however, only partially explain the collapse in the potential value of recapturing methane emissions last year. The larger driver is the low price of gas during 2023 relative to robust oil sales. As a percentage of the total revenue, sales of natural gas simply did not contribute much, so the value of reselling the fraction emitted to the atmosphere amounts to essentially a rounding error. Of course, because companies still incur most operating expenses to produce the leaked or vented gas, the impact on net cash flows will be greater than 0.12%. But the financial reality is that the economic value to be gained is insufficient to significantly drive producer behavior; furthermore, the impact will eventually diminish as companies further improve emissions performance. Oil and gas prices will continue to move the needle for companies. In fact, we calculate that a reduction of just 2 cents in the Permian's 2023 gas price would have more than offset the revenue increase from the sale of every mcf of methane emissions.

On a brighter note, finding and fixing leaks makes financial sense most of the time, even at low gas prices and with no regulatory impetus. The absolute level of foregone revenue due to methane emissions is large enough to cover the cost of leak detection and simple remediation and repair. In the Permian, the selling of the total 2023 methane emissions would have led to about $215 million of incremental revenue for producers. For large leaks — especially "super-emitter" leaks above 100 kg/hour — detection is relatively inexpensive, and the revenue gained from fixing the leak is large, making this a profitable venture. However, the advantage diminishes as leak size declines: the cost

of detection per leak rises as more sensitive equipment or labor-intensive inspections become necessary; the number of leaks to address increases yet the revenue gain shrinks. Eventually, the cost of fixing smaller and smaller leaks turns a net gain into a net cost, especially if costly manual inspections are used. In effect, all companies are engaged in a dynamic exercise to optimize methane emissions reductions as technologies evolve, regulations change and mitigation progress continues. At this stage in the Permian, companies will still derive a net benefit.

In thinking about the finances of methane mitigation in the US, it is important to note that the math may change dramatically owing to the US Environmental Protection Agency's methane emissions fee (known formally as the Waste Emissions Charge or WEC). If adopted in its current form and if it had been applied to the emissions levels in this report for a single entity operating the entire basin, it would have potentially generated penalties far exceeding the level of foregone revenue, massively boosting the economic incentive to reduce emissions further. In reality, however, the issue is complex and a number of factors will reduce, delay or even eliminate the fees payable under the WEC. Accordingly, we will cover this issue in subsequent research.

How good are these data? Leveraging measurement to create an accurate benchmark

Because methane intensity numbers are important and because debates about emissions from oil and gas operations have featured such a wide range of results, it may be helpful to discuss the issue of data integrity. The methane measurements presented in this report come from a collaboration of S&P Global Commodity Insights and Insight M (formerly known as Kairos Aerospace). In contrast to previous estimates, these data provide a very high level of reliability because they combine proven measurement accuracy with near-total coverage of the basin and high frequency.

Are there better sources of data? In many cases, yes. However, those data are not useful for purposes of understanding absolute and relative methane emissions for several reasons:

- Detailed data are largely in the possession of individual operators and are rarely, if ever, made public.
- Company observations are not geographically comprehensive but rather cover assets scattered across the play.
- Data are usually obtained for the purpose of leak detection and repair (LDAR).
- Emissions metrics and methodologies are not standardized from one operator to the next, so they cannot be aggregated even if made public.

There are many technologies in various stages of deployment and development in the service of methane emissions quantification. But for now and the foreseeable future, no single technology can provide a practical, perfect quantification of methane emissions, and most companies ascribe to a layered approach that features multiple technologies. Companies gauge performance in six desired dimensions:

- **Resolution:** High spatial resolution allows for accurate pinpointing of leaks to specific equipment at specific sites.
- **Frequency:** Higher frequency (or even continuous monitoring) allows companies to take action sooner, reducing the total volumes emitted.

- **Coverage:** Technologies that can cover large areas provide more completeness and certainty.
- **Threshold:** Ideally, companies would wish to know every emission, no matter how small.
- **Reliability:** Technologies that can accurately assess the rate of leaks help operators to calculate total emission volume and prioritize remediation. Also, avoiding false positive and false negatives is critical.
- **Affordability:** The imperative to manage and optimize costs runs through every methane detection program as budgets are limited and competition for capital is high.

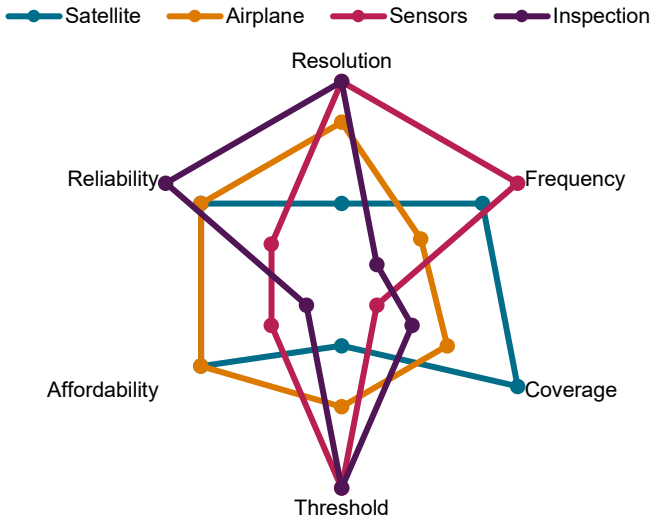
Looking at four of the most common technologies in use today, we find that companies must inevitably trade off some of the parameters, making gains in some while accepting the inevitable shortcomings. Figure 1 provides a visual representation of those trade-offs, with the outer perimeter representing the highest performance and the center representing the lowest. While there can be significant variation with each of the technology categories presented, this chart is useful in contrasting the pros and cons of each.

The S&P Global methane benchmark presented in this report, powered by Insight M observations, offers a good combination of these metrics.

- Coverage: The observed area covered by the overflights is shown in red in the map (Figure 2) and accounts for
  - 88.2% of the 162,000 active Permian wells, (85.1% of conventional wells and 95.6% of unconventional wells).
  - Assets supplying 96.3% of the 3.5 billion boe produced in 2023.
- Frequency: The observed data contains roughly 700 Permian flights that took place on 185 separate days spread over the course of the year. As seen in the pie charts in Figures 3 and 4, roughly half the basin was observed once in each of the first and second halves of the year, with another 15%-20% measured quarterly.

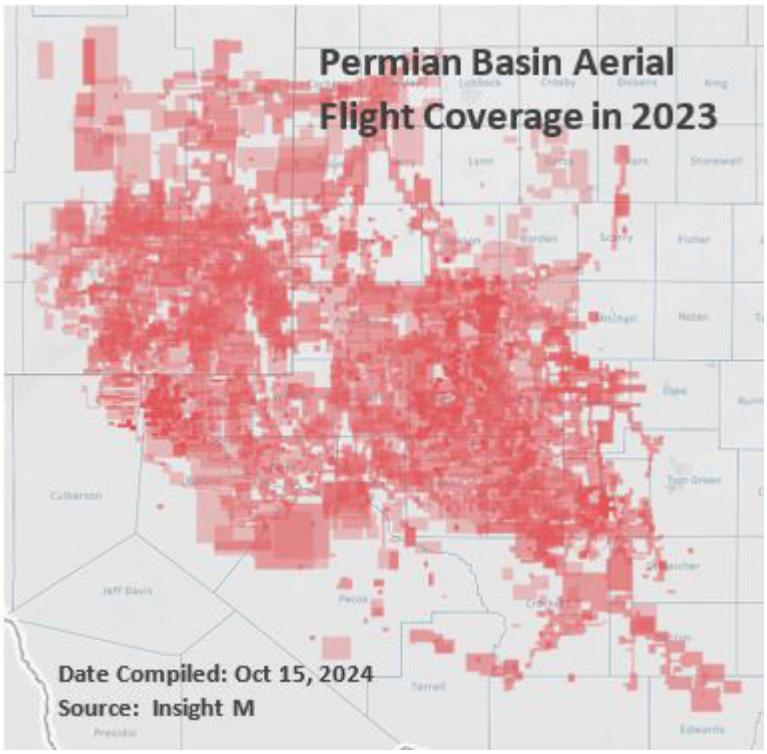
Figure 1

Nothing is perfect: Trade-offs among methane measurement technologies



As of Oct. 15, 2024.
Sources: S&P Global Commodity Insights; Insight M.

Figure 2



– Threshold: Measurements taken in 2023 detected emissions as low as 10 kg/hour, which account for over 72% of total methane released to the atmosphere from upstream oil and gas operations. The volumes from all sources below this threshold were estimated using the Rutherford model developed by Stanford University.[3] The false positive and false negative rates for Insight M for releases above 10.5 kg/hour are 0% in calibrated tests.[4] More information on the methodology employed by Insight M can be found here.

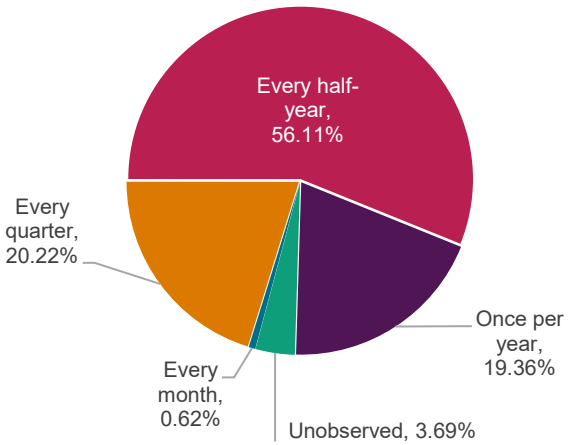
– Resolution: Overflights offer a level of resolution that allows reliable attribution not only by facility, but in most cases to specific assets or pieces of equipment. Pixel size for Insight M's 2023 data collection varies between 1 meter by 1 meter and 5 meters by 5 meters depending on job parameters. In comparison, the precision satellites that have been launched recently have a native pixel size of 25 meters by 25 meters — much higher resolution than in the past but still limited by their altitude.

– Reliability: Measuring an invisible fluid that disperses rapidly in the wind is inherently difficult, and all emissions technologies have significant error bars. Importantly, the errors are normally distributed, which dramatically reduces the overall error when the estimates are aggregated to the basin level as reported above.

Given these parameters, this benchmark provides what we believe is the most reliable estimate ever provided publicly of annual Permian methane emissions. Future data should be better still, as the 2025 observations promise higher frequency at the same or even a lower threshold.

Figure 3

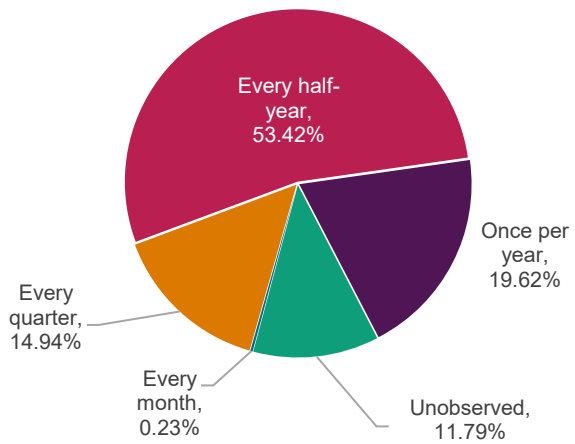
Coverage frequency by 2023 production (3.5 billion boe)



As of Oct. 15, 2024.
Sources: S&P Global Commodity Insights; Insight M.

Figure 4

Coverage frequency by 2023 well count (162,000 wells)



As of Oct. 15, 2024.
Sources: S&P Global Commodity Insights; Insight M.

3. Rutherford, J.S., Sherwin, E.D., Ravikumar, A.P., Heath, G.A., Englander, J., Cooley, D., Lyon, D., Omara, M., Langfitt, Q., Brandt, A.R., 2021. Closing the methane gap in US oil and natural gas production emissions inventories. Nat Commun 12, 4715.

4. In a 2022 single-blind controlled release conducted by Stanford University, Insight M detected 100% of releases greater than 10.5 kg/hour when deployed at its maximum sensitivity. ACS Publications, "Technological Maturity of Aircraft-Based Methane Sensing for Greenhouse Gas Mitigation."

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