Benchmarking Methane and Other Greenhouse Gas Emissions
Of Oil & Natural Gas Production in the United States

June 2024
Data downloads at: www.erm.com
At Ceres our mission is to transform the economy to build a just and sustainable future for people and the planet. To truly do this, we must acknowledge the deeply traumatic history of colonialism against Indigenous people and their land.

We acknowledge that our office headquarters is in Boston and is on the traditional land of the Massachusetts People.
Benchmarking Methane and Other Greenhouse Gas Emissions
Of Oil & Natural Gas Production in the United States

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Speakers

Lesley Feldman
Research and Analysis Manager, Methane Pollution Prevention
Clean Air Task Force

Andrew Logan
Senior Director, Oil and Gas, Climate and Energy
Ceres

Luke Hellgren
Principal Technical Consultant
ERM
Methodology overview
Methodology – GHG Reporting Program Sources

EPA’s publicly available GHGRP Subpart W data set is the primary source of information for this report. All hydrocarbon production data and over 99% of emissions data are sourced from EPA GHGRP.

The GHGRP requires facilities that emit more than 25,000 metric tons of CO$_2$e per year to report emissions. Subpart W defines an onshore production segment facility as all production-related equipment under common ownership or operating control within a hydrocarbon production basin. Onshore production facilities are therefore made up of many individual well pads and associated equipment.

For the onshore production segment, facilities are required to report emissions for 17 individual source categories; emissions are calculated using a variety of methodologies, including default emission factors and engineering calculations.

<table>
<thead>
<tr>
<th>Source</th>
<th>CH$_4$</th>
<th>CO$_2$</th>
<th>N$_2$O</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acid Gas Removal Units</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Associated Gas Venting/Flaring</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Atmospheric Storage Tanks</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Centrifugal Compressors</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Combustion Equipment</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Completions/Workovers w/ Hydraulic Fracturing</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Completions/Workovers w/o Hydraulic Fracturing</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Dehydrators</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>EOR Hydrocarbon Liquids</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EOR Injection Pumps</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Equipment Leak Surveys/Population Counts</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Flare Stacks</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>NG Pneumatic Devices</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>NG-Driven Pneumatic Pumps</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Reciprocating Compressors</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Well Testing</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Well Venting (Liquids Unloading)</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
</tbody>
</table>
Methodology – GHG Inventory Sources

The report captures six additional emission sources that are not reported under GHGRP. Emissions from these sources are calculated using EPA GHG Inventory emission factors and activity data reported under GHGRP.

Emissions from these sources represent a small fraction (<1%) of total emissions included in the report.

<table>
<thead>
<tr>
<th>Emissions Source</th>
<th>GHG Inventory CH₄ Emissions Factor</th>
<th>GHG Inventory CO₂ Emissions Factor</th>
<th>Activity Factor (unit)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vessel Blowdowns (applies to separators, heater-</td>
<td>1.6</td>
<td>1.6</td>
<td>1.6</td>
</tr>
<tr>
<td>treaters, dehydrators, and in-line heaters)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Compressor Blowdowns</td>
<td>76.8</td>
<td>76.7</td>
<td>76.6</td>
</tr>
<tr>
<td>Compressor Starts</td>
<td>171.7</td>
<td>171.6</td>
<td>171.4</td>
</tr>
<tr>
<td>Pressure Relief Valve Upsets</td>
<td>0.7</td>
<td>0.7</td>
<td>0.7</td>
</tr>
<tr>
<td>Well Drilling</td>
<td>51.3</td>
<td>51.2</td>
<td>51.2</td>
</tr>
<tr>
<td>Acid Gas Removal Units</td>
<td>598.3</td>
<td>598.3</td>
<td>598.3</td>
</tr>
</tbody>
</table>

Well count from GHGRP; 0.87 vessels/well as per GHG Inventory (kg/vessel)

Compressor count from GHGRP (kg/compressor)

Valve count from GHGRP (kg/valve)

Gas wells completed from GHGRP (kg/well)
For purposes of comparison within this report, the 23 individual emission sources (17 from GHGRP, 6 from GHG Inventory) are grouped into five categories:

- **Process & Equipment Vented** Vented emissions are intentional releases of natural gas from equipment and processes. Common sources of vented emissions include gas-driven pneumatic devices, compressor seals, tanks, and liquids unloading.

- **Process & Equipment Flared** Flared emissions consist primarily of CO$_2$ from the combustion of gas that is captured from equipment and processes. Flaring also results in methane emissions from uncombusted gas that escapes through the flare stack.

- **Associated Gas Vented & Flared** Associated gas vented and flared emissions occur at oil wells that do not capture a portion or any of the gas that is produced alongside oil. The gas is directly released to the atmosphere or combusted in a flare rather than captured for sale, on-site use, or reinjection.

- **Fugitive** Fugitive emissions are unintentional releases, or leaks, of natural gas. These emissions are often caused by faulty or worn-out equipment. Sources of fugitive emissions include seals and cracks on equipment such as tanks and piping, and leakage from infrastructure components such as valves and connectors.

- **Other Combustion** Non-flaring combustion is a significant source of CO$_2$ emissions from oil and gas production. Diesel and natural gas engines used to power equipment and provide electricity represent the largest source of other combustion emissions. Other combustion also includes methane emissions from uncombusted gas.
Intensity Metrics

This report uses two emissions intensity metrics to compare producer performance.

- **Methane Intensity.** Calculated using the Edison Electric Institute and American Gas Association Natural Gas Sustainability Initiative (NGSI) protocol. This approach focuses on the natural gas value chain and calculates intensity as methane emissions assigned to natural gas on an energy basis divided by the total methane content of produced natural gas. This methane intensity is expressed as a percentage.

- **GHG Intensity.** Calculated as total production-segment GHG emissions in kilograms of carbon dioxide equivalent (CO$_2$e) divided by total hydrocarbon production in barrel of oil equivalent (BOE). The GHG emissions intensity is expressed as kilograms CO$_2$e per BOE.

### NGSI Methane Emissions Intensity

\[
\frac{\text{CH}_4 \text{ Emissions (MT)} \times \text{Gas Ratio}}{\text{Produced Gas (mcf)} \times \text{Methane Content} \times (0.0192 \text{ MT/mcf})}
\]

**where:**
- Gas Ratio = Energy content of produced gas / Energy content of total hydrocarbons
- Methane Content = Molar fraction of methane in produced gas

### Greenhouse Gas Emissions Intensity

\[
\frac{\text{CH}_4 \text{ Emissions (kg CO}_2\text{e)} + \text{CO}_2 \text{ Emissions (kg CO}_2\text{e)} + \text{N}_2\text{O Emissions (kg CO}_2\text{e)}}{\text{Produced Gas (BOE)} + \text{Oil Sales (BOE)}}
\]

**where:**
- CO$_2$e = CO$_2$-equivalent of gases adjusted by GWP
- Produced Gas (BOE) + Oil Sales (BOE) = Hydrocarbons as barrel oil equivalent

Note that the NGSI methane intensities in this report may differ slightly from those calculated by companies due to assumptions made in this analysis and its use of publicly reported data.
Thank you

Luke Hellgren
luke.Hellgren@erm.com
2022 Reported Emissions: Considerations

- Important to recognize the gap between reported emissions and measured emissions. A big portion of this gap is the result of large release events (aka “super-emitters”). Thus, reported emissions are an underestimate of actual emissions and not all sources are accurately captured in reports.

- Nevertheless, these reported emissions provide a useful starting place to compare companies and their practices.
2022
Reported Emissions: Key Findings

- The **reported** methane emissions intensity of natural gas production and the GHG emissions intensity of oil and gas production varies dramatically across producers.

- The highest emitting oil and gas companies had a **reported** methane emissions intensity nearly 32 times that of the lowest emitting companies (up from 26x in 2021).

- Emissions intensity varies even between similarly-sized operators in the same geographic area, according to the data, largely due to different equipment choices and operational practices.

- Pneumatic controllers were the largest source of **reported** production-segment methane emissions, making up 67% of the total.

- Fuel combustion equipment, including engines and heaters, was the largest source of total reported production-segment CO₂ emissions, responsible for 61% of all reported CO₂ emissions.

- Venting and flaring are significant contributors in oil-heavy basins.
Sources of Emissions

2022 Reported Production Emissions, by Source Category

2022 Reported Process & Equipment Vented Emissions, by Source

*Includes: Centrifugal compressors, Completions/workovers, dehydrators, reciprocating compressors, compressor blowdowns and starts, well drilling, pressure relief valves, well testing, and acid gas removal units

85% of all vented CO$_2$e (includes pneumatic devices and pumps)
Basin Level Results
In basins that primarily produce gas, like the Appalachian Basin, methane makes up the majority of total GHGs. In basins with oil production, like the Permian Basin, CO₂ often represents the largest share of total GHGs.

Across all basins, methane and CO₂ represent 37% and 62% percent of total GHGs, respectively. N₂O emissions make up less than 0.1% of total GHGs.
GHGRP Basin Emissions by Source

- Associated gas flaring and venting and equipment flaring are major sources of GHG emissions in the largest oil-producing basins, such as the Permian and Williston Basins.
- In dry basins, such as the Appalachian Basin, methane from leaks and venting is responsible for the majority of total GHG emissions.
- Other combustion is responsible for about a third of total GHG emissions.
GHGRP Basin Methane & GHG Intensity

- Methane and GHG emissions intensities vary substantially across basins.
- Ranking in methane intensity does not always correspond to the same GHG intensity rank, reflecting the higher contribution of CO₂ to total emissions in some basins.
- Differences in emissions intensities can be driven by operator practices, type of hydrocarbon production, and infrastructure age.
National Company Level Results
Hydrocarbon Production & Emissions

- Across the 100 largest producers, methane and CO₂ represent 37% and 63% of total GHGs, respectively. N₂O makes up approximately 0.06% of total GHG emissions.
- There is not a linear relationship between production and emissions; emissions are driven by company operations and types of equipment.
Higher proportions of CO₂ contribution to GHG intensities are concentrated at companies with significant flaring emissions, which are often the result of burning associated gas at oil wells.

Higher methane intensities are generally consistent with higher emissions from pneumatic devices.
National Trends
2015-2022 Trends Analysis

GHGRP Data Trends, 2015-2022

Combined Data Metrics
Indexed: 2015 = 100

Index (2015=100)

All Metrics
2015-2022 Trends Analysis, detail

Although combustion emissions have risen by over 40% since 2015, emissions from all other categories have decreased. Vented and fugitive emissions have experienced relatively consistent declines, while flared and associated gas vented/flared emissions increased through 2019 before falling back below 2015 levels in 2021 and 2022.
Impacts of Previous Rulemaking

The reported emissions levels and calculated emissions intensities must be viewed in the context of the broader regulatory landscape in the U.S. Compliance with these regulations has led to emissions reductions. For example:

- Each year, as old wells are retired and new wells are drilled and reworked, a larger portion of the nation’s reported oil and gas production and associated equipment become subject to the 2016 New/Modified Source rules;
- Requirements for reduced emissions completions are driving down emissions from well completions and workovers;
- Requirements to replace or prohibit new high-bleed pneumatic are lowering pneumatic controller emissions;
- Leak detection and repair (LDAR) requirements leading to lower fugitive emissions rates.
- Regulations that put limits on flaring volumes or prohibit routine venting and flaring of associated gas have likely lowered CO\textsubscript{2} and CH\textsubscript{4} emissions from associated gas venting and flaring in some basins.
Impacts of Previous Rulemaking (cont)

However, it is difficult to separate the impact of regulatory compliance from other factors:

- GHGRP reporting basins do not fall within one state, complex to isolate the impact of state-level regulatory actions;
- As of 2024, EPA regulations only apply to new/modified facilities, not feasible to separate in the reported GHGRP data;
- If a company sells assets in a basin to small firms that are not required to report to GHGRP, reported changing;
- GHGRP reported data does not accurately capture LDAR emissions because of abnormal process conditions;
- Companies may choose to invest in lower emissions equipment (such as zero-emitting pneumatic controllers) prior to full implementation of the recently finalized 2024 OOOOb New/Modified Source requirements, the OOOOc Existing Source Guidelines, or the Waste Emissions Charge;
- An increase in new (and productive) wells reduces emissions intensity, regardless of voluntary/regulatory actions;
- Voluntary company actions may play a role but are difficult to document and quantify.
New Rulemaking Across the U.S.

- A number of new laws and regulations will soon be finalized and implemented across the U.S., significant impact on both reported and actual methane emissions in the coming years.
- In 2022, Congress passed the Inflation Reduction Act (IRA), which included the Methane Emissions Reduction Program (MERP).
  - Requires EPA to impose and collect an annual methane waste emissions charge (WEC) on methane emissions that exceed emissions intensity thresholds.
  - Will first be imposed in 2025 and calculated using 2024 reporting year emissions data.
- In March 2024, EPA finalized its New/Modified Source Standards (OOOOb) and Existing Source Guidelines (OOOObc), (Section 111 rules).
  - New/Modified Source Standards effective in 2024 (or within 1-2 years for some sources)
  - For Existing Source Standards, states have until March 2026 to develop own regulations at least as stringent as in OOOObc. States must ensure fully implemented by March 2029.
Thank you!

Contact:
Lesley Feldman
lfeldman@catf.us
Online data tool

Hydrocarbon Production & GHG Emissions (2015-2022 data)
Top 100 hydrocarbon producers

- View hydrocarbon production and GHG emissions (by selected GWP values) of the top 100 hydrocarbon producers.
- Slide the "View Top "X" Producers" bar to view a subset of the top 100 producers.

GWP Values
- Applied to methane/GHG intensity dash
- IPCC: AR6 (100-yr)

Highlight Company
- Highlight Company

Hover cursor over bar features to view associated company and detailed data.

- Natural Gas
- Oil

- CH4 (GWP=29.8)
- CO2
- NOx (GWP=273)

The information analyzed in this dashboard was gathered from publicly available sources and was not independently verified by ERM. ERM does not represent or warrant that the information contained in this dashboard is accurate, sufficient, or appropriate for any purpose. See report for description of methodology.

Thank you

Contact

Luke Hellgren
luke.Hellgren@erm.com
Questions and Answers
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Methodology – Emissions Source Categories

Emissions sources in this report are grouped into five categories: process and equipment vented (“vented”), process and equipment flared (“flared”), associated gas vented and flared, fugitive, and other combustion. The table to the right shows the assignment of individual emissions sources to source categories.

Emissions data on individual sources and their relative contribution to total emissions, by both individual GHG and total CO₂e, are available at the national, basin, and company level on the Oil and Gas Benchmarking interactive data website.

<table>
<thead>
<tr>
<th>Source</th>
<th>CH₄ &amp; N₂O Emissions Category</th>
<th>CO₂ Emissions Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acid Gas Removal Units</td>
<td>Vented</td>
<td>Vented</td>
</tr>
<tr>
<td>Associated Gas Venting/Flaring</td>
<td>Associated Gas Vented/Flared</td>
<td>Associated Gas Vented/Flared</td>
</tr>
<tr>
<td>Atmospheric Storage Tanks</td>
<td>Vented</td>
<td>Flared</td>
</tr>
<tr>
<td>Centrifugal Compressors</td>
<td>Vented</td>
<td>Flared</td>
</tr>
<tr>
<td>Combustion Equipment</td>
<td>Combustion</td>
<td>Combustion</td>
</tr>
<tr>
<td>Completions/Workovers w/ Hydraulic Fracturing</td>
<td>Vented</td>
<td>Flared</td>
</tr>
<tr>
<td>Completions/Workovers w/o Hydraulic Fracturing</td>
<td>Vented</td>
<td>Flared</td>
</tr>
<tr>
<td>Dehydrators</td>
<td>Vented</td>
<td>Flared</td>
</tr>
<tr>
<td>EOR Hydrocarbon Liquids</td>
<td>NA</td>
<td>Vented</td>
</tr>
<tr>
<td>EOR Injection Pumps</td>
<td>NA</td>
<td>Vented</td>
</tr>
<tr>
<td>Equipment Leak Surveys/Population Counts</td>
<td>Fugitive</td>
<td>Fugitive</td>
</tr>
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<td>Flare Stacks</td>
<td>Flared</td>
<td>Flared</td>
</tr>
<tr>
<td>NG Pneumatic Devices</td>
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<td>Vented</td>
</tr>
<tr>
<td>NG-Driven Pneumatic Pumps</td>
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<td>Vented</td>
</tr>
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<td>Reciprocating Compressors</td>
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<td>Flared</td>
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<tr>
<td>Well Testing</td>
<td>Vented</td>
<td>Flared</td>
</tr>
<tr>
<td>Well Venting ( Liquids Unloading )</td>
<td>Vented</td>
<td>Vented</td>
</tr>
<tr>
<td>Vessel Blowdowns</td>
<td>Vented</td>
<td>Flared</td>
</tr>
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<td>Compressor Blowdowns</td>
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<tr>
<td>Compressor Starts</td>
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<td>PRV Upsets</td>
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<tr>
<td>Well Drilling</td>
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<td>Flared</td>
</tr>
</tbody>
</table>
Methodology – NGL Content

EIA Natural Gas Liquids Data

Companies in the oil and gas sector produce oil and natural gas as well as NGLs. NGLs include ethane, propane, butane, isobutane, and natural gasoline. These hydrocarbons are separated from oil and natural gas after production during processing and refining. In the production stage, NGLs are entrained with oil and natural gas and can impact the energy content of the produced hydrocarbons, as they have an energy content that is higher than natural gas but lower than oil.

For the purposes of the calculations in this report, the energy content of the reported natural gas production is adjusted to include the energy content of produced NGLs. The natural gas production data reported under Subpart W includes information on the methane and CO₂ molar content of produced gas but does not include information on other components of the gas. Because the percentage of methane and CO₂ does not add up to 100 percent, a portion of the gas content is unknown. NGLs are commonly coproduced with natural gas and oil and in most cases represent some of the unknown gas composition. This analysis assumes the unknown portion of gas composition is made up of NGLs and allocates it to five individual NGLs based on EIA regional NGL production data. Each NGL is allocated a share of the unknown percentage based on its regional production share. This approach recognizes the energy content of non-oil and non-methane hydrocarbons; because methane emissions are allocated to the natural gas value chain using an energy-weighted gas ratio, the allocation of NGLs affects company methane emissions and methane intensity. This impact is minor for most companies and only significantly impacts companies that report low methane and CO₂ molar fractions.

The regional NGL percentages applied to the unknown gas component are shown in the table to the right. Company-specific data were used where available or provided. It is important to note that nitrogen is also a common component of natural gas and represents a portion of the unknown gas component. However, little public data is available on the nitrogen molar fraction of natural gas produced across the U.S. This analysis assumes that produced gas contains no nitrogen and fills the missing gas component entirely with NGLs. This conservative approach slightly increases the amount methane emissions allocated to the natural gas value chain and methane intensity for most companies.

<table>
<thead>
<tr>
<th>Region</th>
<th>Area</th>
<th>Ethane</th>
<th>Propane</th>
<th>Butane</th>
<th>Isobutane</th>
<th>Natural Gasoline (pentane plus)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PADD 1</td>
<td>East Coast</td>
<td>0%</td>
<td>33%</td>
<td>67%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td>Appalachian</td>
<td>41%</td>
<td>34%</td>
<td>10%</td>
<td>5%</td>
<td>10%</td>
</tr>
<tr>
<td></td>
<td>IN, IL, &amp; KY</td>
<td>36%</td>
<td>41%</td>
<td>8%</td>
<td>9%</td>
<td>6%</td>
</tr>
<tr>
<td>PADD 2</td>
<td>MN, WI, ND, &amp; SD</td>
<td>30%</td>
<td>36%</td>
<td>15%</td>
<td>5%</td>
<td>14%</td>
</tr>
<tr>
<td></td>
<td>OK, KS, &amp; MO</td>
<td>41%</td>
<td>31%</td>
<td>10%</td>
<td>6%</td>
<td>12%</td>
</tr>
<tr>
<td>PADD 3</td>
<td>LA (Gulf)</td>
<td>39%</td>
<td>33%</td>
<td>12%</td>
<td>6%</td>
<td>10%</td>
</tr>
<tr>
<td></td>
<td>N. LA &amp; AR</td>
<td>19%</td>
<td>30%</td>
<td>13%</td>
<td>11%</td>
<td>28%</td>
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<tr>
<td></td>
<td>NM</td>
<td>39%</td>
<td>32%</td>
<td>12%</td>
<td>5%</td>
<td>12%</td>
</tr>
<tr>
<td>PADD 4 (Rocky Mountain)</td>
<td>TX (Inland)</td>
<td>44%</td>
<td>30%</td>
<td>11%</td>
<td>5%</td>
<td>10%</td>
</tr>
<tr>
<td>PADD 5 (West Coast)</td>
<td>32%</td>
<td>35%</td>
<td>14%</td>
<td>6%</td>
<td>14%</td>
<td></td>
</tr>
</tbody>
</table>