# SKEWED NOx EMISSIONS FROM FLARING

## New observational research shows that NOx emission rates for some U.S. natural gas flares are far higher than calculated, implying unaccounted-for local health impacts.

*A bird's eye view of the thousands of pumps, drills, and oil rigs connected by strings of dirt roads in the Permian Basin in western Texas. Photo by Jasmin Pawlowicz.*

In the United States, studies of nitrogen oxides (NOx) have consistently found regionally elevated levels attributable to oil and gas (O&G) activities, whether calculated using bottom-up accounting or measured from the ground, air, or satellite.

A new *in situ* assessment of operational flares in the Bakken, Permian, and Eagle Ford basins confirms NOx elevation in these regions—in some cases, at far higher levels than calculated. The data collected for this assessment is the largest data set of its kind, representing more than 480 intercepts of plumes from an estimated 300 flares.

Collectively, NOx emissions from flaring in these regions contribute less than 1% of the national NOx budget, so undercounting for NOx from individual flares does not have a large impact at the national scale. However, the highest-emitting flares observed in these basins significantly harm air quality downwind, leading to health concerns for nearby communities. Two key strategies could help:

1) **Reduce overall flaring volume through alternative gas capture methods.**
2) **Specifically address the highest-emitting flares.**

Implementing these measures would reduce local health impacts and also benefit climate, as previous work has shown that flaring emits excess methane.

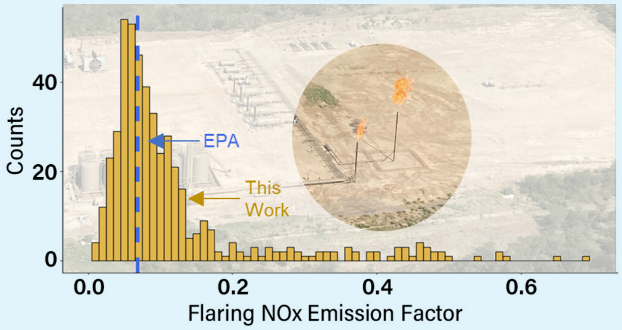
**Table: Emission Factor Comparison**

| | EPA | OBSERVATIONALLY DERIVED | | |
|---|---|---|---|---|
| | | Mean | Minimum | Maximum |
| Bakken | 0.068 | 0.159 | 0.011 | 8.74 |
| Eagle Ford | 0.068 | 0.06 | 0.011 | 0.334 |
| Permian | 0.068 | 0.194 | 0.02 | 1.92 |

***Emission factors are measured in units of lb NOx/$10^6$ Btu.*** *In the Eagle Ford, the average NOx emission factor is comparable to the EPA value, while the Bakken and the Permian averages are 2X-3X the EPA value. Within each basin, a nontrivial number of sampled flares were producing NOx at least an order of magnitude greater than the EPA value. This heavy tail behavior directly harms the air quality downwind of the highest NOx-emitting flares.*

### KEY FINDINGS

- A single NOx emission factor does not capture the range of observed emission factors in the Bakken, Permian, and Eagle Ford. All three basins show a heavy-tail distribution, with a minority of flares emitting the majority of NOx and a nontrivial number of flares producing NOx at least an order of magnitude larger than the EPA value. Bakken and Permian basin averages are 2X-3X the EPA value.
- Extrapolation to basin scale emissions indicates that 20%–30% of flares are responsible for 80% of total basin-wide flaring NOx emissions.
- Overall, NOx emissions from flaring vary widely depending on emission factors and gas composition, challenging to the accuracy of bottom-up inventories.
- Basin-specific emission factors and regional gas composition assumptions better capture average NOx flaring performance at the basin scale. However, a basin-specific approach may still miss high emitters in the heavy tail of skewed distributions.
- It is crucial to count very high NOx-emitting flares in any air quality assessment in surrounding regions, as NOx has direct negative health impacts, such as asthma exacerbations.
- Flaring for the studied region does not contribute significantly to the national NOx emissions estimate. However, flares account for a sizeable portion of NOx in O&G production and offer a potential opportunity for reduction.



## NOx EMISSIONS: CAUSES AND CONCERNS

Natural gas, when it is a byproduct of oil extraction, is often flared in order to manage it in a controlled fashion. The flare's combustion aims to eliminate the predominantly hydrocarbon waste gas, transforming it into carbon dioxide ($CO_2$) and water. This process alleviates safety concerns onsite and reduces climate impact. Along with $CO_2$, the flaring process releases nitrogen oxides (NOx), unburned hydrocarbons, volatile organic compounds, products of incomplete combustion, and soot.

Among air pollutants, NOx stands out as a primary contributor to adverse health effects, exacerbating asthma and negative birth outcomes, among others. Moreover, studies show that the influence of NOx tends to be worst near emissions sources. The highest NOx-emitting flares found in this observational study, then, pose a significant threat to workers and area residents. Reducing these emissions would likely lead to health improvements in neighboring communities.

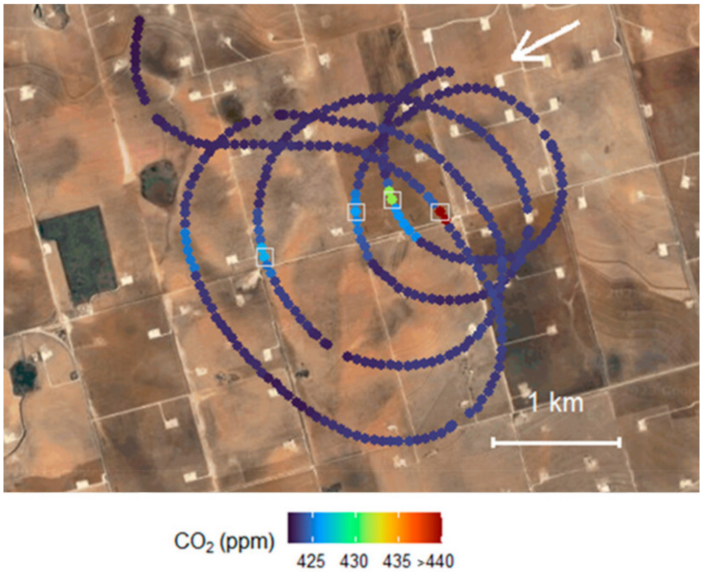



**Figure 2.** *Airborne sampling of a flare in the Permian on September 4, 2020, where the flight track is colored by the observed $CO_2$ concentration (ppm). White squares indicate locations in the $CO_2$ time series where the peak has been attributed to a flare.*

## METHODOLOGY

Two airborne campaigns provided the data for this study. The first took place over the Eagle Ford and Permian basins in 2020. The second took place over the Bakken basin in 2021.

A small aircraft with high-precision instrumentation was used to measure $CH_4$, $CO_2$, NO, and $NO_2$, along with wind speed and direction. Sampling was performed downwind of flare stacks at low altitudes. The sampling approach prioritized the collection of basin-scale statistics of flare performance by measuring many flares under varying operating conditions.

Flare plumes were isolated in the data using observed $CO_2$ peaks, indicating that flare combustion plumes were intercepted. $CH_4$, NO, and $NO_2$ measurements were pulled at corresponding time stamps. The dataset includes over 480 flare intercepts for NOx analysis.

NOx production was estimated for each intercept based on the relative relationship between measured peaks of $CO_2$ and NOx in the combustion plume, along with basin-wide assumptions about the composition of flare gas.

The volumes of gas flared are estimated globally by satellite measurements of the thermal signatures of flare flames. This auxiliary dataset was used to extrapolate the measurement-based emission factors derived in this work to the basin-scale. Space-based estimates of flare volumes may miss smaller flares, so the calculated total flare volumes have the potential to be biased low.

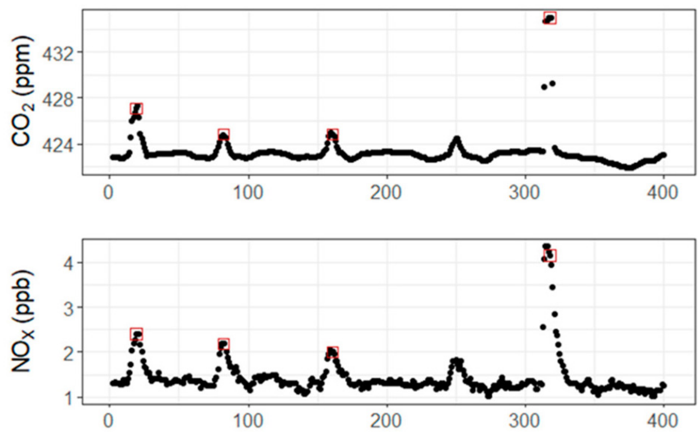



**Figure 3.** *Corresponding concentration time series (relative to the sampling start time for this site) for $CO_2$ (top) and NOx (bottom), where red squares indicate flare peaks derived from the $CO_2$ signal.*


DOI: 10.1021/acs.est.3c08095


## ABOUT THE PROJECT

F3UEL Flaring & Fossil Fuels: Uncovering Emissions & Losses


This research is part of the Flaring and Fossil Fuels: Uncovering Emissions and Losses (F3UEL) project, which aims to enhance public and scientific understanding of environmental impacts of offshore energy production and natural gas flaring. The project is funded by the Alfred P. Sloan Foundation with additional support from the Environmental Defense Fund, Scientific Aviation, and the University of Michigan.