Basin Methane Reconciliation Study overview of results

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A landmark study providing the first temporally- and spatially-aligned top-down and bottom-up methane emission estimates for a US shale gas production basin has been published in the *Proceedings of the National Academy of Sciences* (PNAS), October 29, 2018. This unprecedented study was able to reconcile a longstanding "gap" between large-scale, top-down aircraft measurements and small scale, bottom-up measurements for individual facilities and equipment by – for the first time – aligning a host of measurements across three scales (basin, site, component) in the same time and place. The results are based on an intensive, month-long field campaign in 2015 in the Fayetteville shale gas play of Arkansas, consisting of:

1) Seven research teams deploying eight different measurement methods coordinated through a master research plan, including the largest method intercomparison at production pads and compression stations.
2) Detailed contemporaneous records of natural gas equipment counts, locations, production volumes and activities during the study period.
3) On-site access for study teams to observe operations and to freely and independently take measurements within a randomized selection of sites.
4) Emission measurements of many methane source categories existing in the basin, including all source categories in the natural gas value chain of this basin (production, gathering, transmission and distribution) and a selection of non-oil and gas sources (landfills, animal operations).

Unique to this study was the degree of cooperation among the researchers, government and industry sponsors, and local operators leading to important advancements in methods and understanding. The project was primarily funded by the United States Department of Energy (DOE). It was additionally supported by industrial cost share and an innovative energy research collaboratory in Colorado. (See below for a complete list of funders and data/site access partners.) Innovative agreements were formed across all parties securing independence of the research performance along with protection of operator proprietary data never previously shared on this scale in publicly-funded methane emission research.

This ~$5 million study has resulted in the publication of eight peer-reviewed journal articles describing various subsets of the research, culminating in the capstone paper "Temporal Variability Largely Explains Difference in Top-down and Bottom-up Estimates of Methane Emissions from a Natural Gas Production Region," published October 29, 2018 in the *Proceedings of the National Academy of Sciences*. (Full titles and links to each of the papers is provided below.)

Key learnings from the overall study are provided here; additional highlights including those appearing in the seven support papers are presented further below:

Key Findings

1) While both top-down and bottom-up measurements are equally valid approaches to estimate methane emissions on a regional scale, this study illustrates that the measurements must be carefully aligned in both time and space to be compared. This alignment requires adjustments to measurement protocols – namely requiring near-simultaneous measurements at all scales – and also requires access to highly-resolved operational data on the timing and location of emissions during the study period. As such, this study showed excellent agreement between these two approaches to methane emission quantification, without requiring guesswork or statistical assumptions that have been used to close the gap in prior research.
2) The key source that explained the difference between top-down and bottom-up estimates in the Fayetteville play are manual well-clearing activities (called "liquids unloading" by industry, where "manual" refers to operator initiation and supervision). Emissions from these sources systematically occur during daytime operator shifts, which is also when meteorological conditions are ideal for basin-scale aircraft methane emission measurements. Bottom-up inventories that follow the standard practices of representing averages of daily, monthly or annual periods do not capture the diurnal coincidence of aircraft top-down measurements during peak emission periods. Collecting information about where and when liquids unloadings occurred during the study was critical to ensuring accurate bottoms-up emissions modeling and for proper temporal and spatial alignment for comparison with the top-down aircraft measurements.
3) The study for the first time deployed multiple measurement methods in a systematically designed method intercomparison framework to provide guidance on the accuracy and use cases for each. The study found systematic trends for three methods designed to quantify site-level methane emissions: two ground-level, downwind methods, one of which required site access to release a tracer gas at a known release rate which is measured along with methane downwind of the site ("tracer") and another only measuring methane downwind of the site ("OTM33A"); the third site-level method sums emissions measured at the equipment and activities existing within a site ("onsite").[1]
    a. At production sites (well pads), on average, the downwind OTM33A method estimates lower (and is less accurate) than onsite estimates while the tracer method estimates higher than both. Based on the tests performed in this study, OTM33A can be best deployed to discern "large" and "small" emissions. The study also found a similar systematic estimation trend for compression stations (in the gathering segment of the natural gas value chain) where tracer method estimates slightly lower than onsite estimates.[2]
    b. While these first-of-kind, site-level comparisons provide high confidence that both onsite and downwind methods can do an adequate job of capturing total site emissions, the methods have different use cases and more method intercomparison is needed to

[1] A fourth method tested, using a spiral aircraft flight pattern over large sites, was not deployed with large enough sample size to draw conclusions.
[2] OTM33A isn't suitable for use at larger emission sites.

discern when each can be most accurately deployed, considering the desired level of accuracy required of the measurement.

4) When focused on science, strong safeguards for integrity coupled with robust and regular knowledge sharing between researchers, industry and government can lead to unprecedented advances in understanding of the role of industrial practices in GHG emissions. This in turn provides industry opportunity to improve profitability and sustainability from reducing the loss of natural gas through controllable emissions.
5) Operator direct participation in field studies, including providing physical access to sites as well as sharing data on location, count, timing, duration and strength of emissions sources is critical to the development of high-resolution spatio-temporal inventories of methane emissions. We were able to achieve kilometer-scale, hourly-resolution inventories based on contemporaneous measurements, yet note that an even higher temporal resolution could further improve top-down and bottom-up alignment (e.g., to better understand sources whose emission rate can vary significantly within an hour). Nevertheless, the resolution achieved in this study improved the identification of specific large emission sources.

The results achieved in this study lead to several important insights and Implications for industrial practice and future studies:

1) Understanding the relative contribution of specific sources, and their time dependency, forms a sound basis for prioritizing emission reduction at the regional level. Episodic sources can be significant on longer timescales (e.g., annual) but are especially important to understand when interpreting shorter duration measurements (e.g., hourly, daily). In the Fayetteville shale gas play, manual liquids unloading is the most important episodic source in terms of methane emissions. Where practiced, this source might be important in other basins, but will require further research to confirm and quantify.
2) While our understanding of sources and methods continue to advance, coordinated use of multiple methods will remain an important research approach. The findings from this study would have been impossible to achieve using conventional top-down or bottom-up estimates alone. As demonstrated here, the two approaches used in tandem and with appropriate time resolution of source emission profiles allow for greater insight into sources than either method alone, yet also requires better understanding and documentation of the temporal resolution of emission sources than has typically been achieved in prior research. The results of this study provide greater confidence in discerning and prioritizing the sources of methane emissions in a given region.
3) The methods developed in this study can be adapted and applied to other regions to improve understanding of methane sources, identify opportunities to reduce losses of valuable products (and associated pollutant emissions) and improve the efficiency of industrial practices. The Fayetteville shale gas play is a relatively "simple" basin from the perspective of natural gas operations in terms of gas type, number of operators and other factors. We recommend that the methods developed here be applied in other regions to develop new and regionally

appropriate insights, for instance for wet gas regions and regions with unconventional oil production.