

MJB&A Issue Brief ■ January 18, 2016

## EDF-Sponsored Studies Attempt to Reconcile Top-Down and Bottom-Up Estimates of Methane Emissions in Barnett Shale Region of Texas

On December 7, 2015, researchers from the Environmental Defense Fund (EDF) published a peer-reviewed paper<sup>1</sup> in the *Proceedings of the National Academy of Sciences*, which attempts to reconcile region-wide top-down and bottom-up estimates of methane emissions from natural gas production activities using data collected during measurement studies in the Barnett Shale region of Texas. This paper, and the measurement studies on which it relies, were sponsored by EDF with funding from numerous foundations and individuals.<sup>2</sup>

Previous estimates for the Barnett and other gas-producing regions have shown wide disagreement between the two estimating methods, with top-down studies generally estimating that emissions are 2 – 5 times higher than bottom-up methods that use emission and activity factors to estimate emissions. By improving both methodologies the researchers demonstrate significant convergence of results – in this new paper central top-down and bottom-up estimates of region-wide emission rates (Mg CH<sub>4</sub>/hr) in the 25-county Barnett region agree within 10 percent for fossil methane and within 0.1 percent for total methane. These new estimates suggest that fossil-related methane emissions in the Barnett region during the study period amounted to 1.5 percent of total regional natural gas production over the same time period. These estimates of fossil-related methane are almost twice as high as emissions estimated in EPA's Greenhouse Gas Inventory.

This paper is the most recent product of an EDF initiative, launched in 2012, to better understand methane emissions from the oil and gas industry. The paper summarizes the findings of EDF's Barnett Coordinated Campaign, one of 16 projects that make up the EDF effort. The Barnett campaign yielded ten peer-reviewed articles that were published in July 2015, as well as an opinion piece summarizing the studies. The article described in this issue brief is the peer-reviewed document that synthesizes the Barnett campaign's findings.

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### Key Takeaways

- This research indicates that neither previous top-down estimates, nor previous bottom-up estimates, were “correct” – to achieve convergence of results, improvements to both methodologies were required.
- For their top-down estimate the researchers reduced uncertainty by integrating seven different mass-balance estimates that were based on atmospheric measurements on different geographic transects through the Barnett region in two different seasons (March and October). Prior top-down estimates have generally relied on atmospheric measurements that were more limited, both spatially and temporally. The researchers

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<sup>1</sup> Zavala-Araiza et al. “Reconciling divergent estimates of oil and gas methane” Proc Natl Acad Sci 2015. Available at: <http://www.pnas.org/content/early/2015/12/03/1522126112.abstract>

<sup>2</sup> Funders include the Alfred P. Sloan Foundation, Fiona and Stan Druckenmiller, Heising-Simons Foundation, Bill and Susan Oberndorf, Betsy and Sam Reeves, the Robertson Foundation, TomKat Charitable Trust, and the Walton Family Foundation.

also used atmospheric measurements of ethane to attribute the estimated methane emissions to fossil and non-fossil sources.

- For their bottom-up estimates the researchers used both improved activity factors and improved emission factors compared to previous estimates. Activity factors were based on a more complete and accurate count of facilities of different types within the 25-county Barnett region, spatially matched to the top-down estimates. Emissions factors were basin-specific and were based on actual measurements at over 400 Barnett production sites, compressor stations, and gas processing plants. The emission factors also accounted for the influence of “super-emitter” sites based on advanced statistical modeling.
- This research indicates that 50 percent of fossil-related methane emissions in the Barnett region at any point in time are likely emitted by only 2 percent of oil and gas facilities. These “super-emitter” sites seem to be both spatially and temporally dynamic – indicating that high emissions are based on malfunctions or other temporary conditions that could potentially occur at any site at any time, rather than permanent design flaws at a few problematic facilities.
- Based on the central estimate of methane emissions from this study, and EDF’s Technology Warming Potential framework, the researchers estimate that leakage during production and processing of Barnett natural gas increases net radiative forcing by 50 percent over 20 years, compared to the fuel-cycle CO<sub>2</sub> emissions from combusting the gas for various end uses. Nonetheless, they estimate that the use of Barnett gas for regional electricity production would provide climate benefits compared to coal-fired electricity over all time scales. However, they estimate that the use of Barnett gas instead of diesel fuel to power freight trucks would not produce an immediate climate benefit, but rather would result in greater climate forcing for several decades.

## Background – Bottom-up vs Top-down

The most widely used estimate of methane emissions from oil and gas production activities is EPA’s annual *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (GHG Inventory). This is a national-scale bottom-up inventory that calculates emissions from each sector of the economy based on activity factors and emission factors – for example the number of gas production sites (activity factor) times average annual methane emissions per site (emissions factor). The emission factors used in the GHG inventory are also often used to develop facility-specific or regional-scale bottom-up emission estimates using various sources for activity factors.

In the last few years, a number of groups have published top-down estimates of methane emissions at both national and regional scales, which are based on atmospheric measurements of methane concentration. These atmospheric measurements are generally collected using aircraft. To create a top-down emissions estimate, up-wind and down-wind concentrations are combined with atmospheric data to calculate the emission flux (mass per unit time) across a specific geographical area based on mass-balance equations.

Published top-down studies generally estimate that total methane emissions in a given area are much higher than estimates based on bottom-up inventories of oil and gas infrastructure and other sources for the same geographic area. Top-down estimates are as much as five times higher than estimates based on the GHG Inventory.

Potential sources of mismatch between top-down and bottom-up estimates include:

- Top-down estimates are generally based on only one or two measurement flights of limited duration (hours); the emission rates estimated from the data may not therefore fully represent average emission rates over a longer time span

- Bottom-up inventories may not fully capture all of the bio-genic sources in an area, which are captured in atmospheric data; likewise bottom-up inventories may not capture emissions from inactive or abandoned oil and gas infrastructure.
- The activity factors for active oil and gas facilities used in bottom-up inventories may be incomplete, out-of-date, or may be spatially mismatched to the top-down inventory.
- The emissions factors used in bottom-up inventories may be inaccurate. In particular, GHG Inventory emission factors are based on a limited set of emission measurements collected over 20 years ago. In addition, recent measurements at various oil and gas production sites show that emissions are not equally distributed across all facilities. Typically there are a small number of “super emitter” sites that account for a significant percentage of total emission from a large group of facilities. Current “average” emission factors used in the GHG Inventory do not account for the effects of these high emitting sites.

The disparity between top-down and bottom-up inventories of methane emissions from oil and gas production has resulted in conflicting claims about the climate impact of fuel switching to natural gas from coal (for electricity production) and oil (for transportation). It has also contributed to confusion about the best policies and strategies for reducing emissions from the sector.

The new study seeks to reduce the confusion by using recent, best available data to carefully reconcile top-down and bottom-up methane emission estimates for one oil and gas producing region.

The Barnett Shale region of north Texas is a mature oil and gas basin that was the first in the U.S. to see widespread use of horizontal drilling and hydraulic fracturing for oil and gas development. This region produces approximately 7% of U.S. marketed natural gas.

## Study Details

In 2013 EDF sponsored a coordinated campaign to measure methane emissions from oil and gas production activities in the 25-county Barnett Shale region of north Texas. These studies included regional scale atmospheric methane and ethane measurements using aircraft, as well as aircraft- and land-based measurements of methane emissions from individual production sites, compressor stations, and gas processing plants. The results of these studies have previously been published in *Environmental Science and Technology*.<sup>3</sup> The paper summarized here integrates data from seven different data sets drawn from this campaign, as well as from other more recently published studies, to develop regional scale top-down and bottom-up estimates of total and fossil-related methane emissions in the Barnett region.

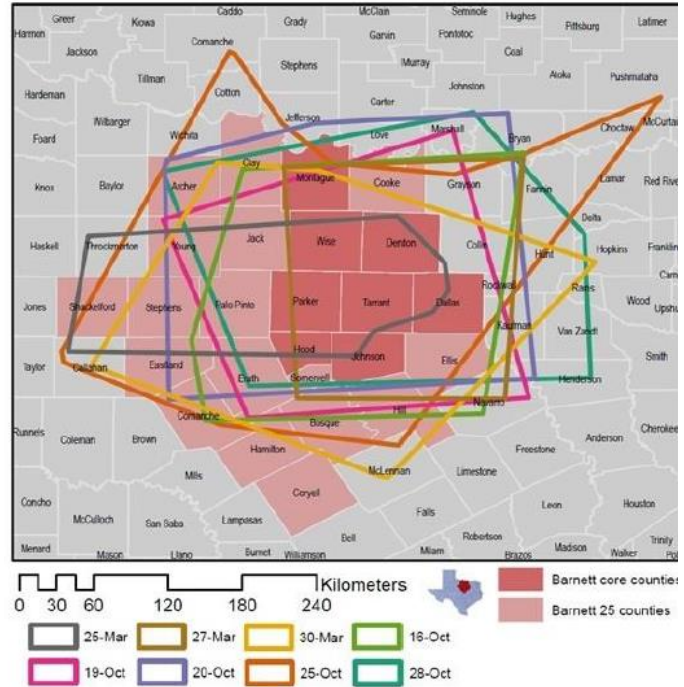
Using mass-balance, the researchers produced seven different top-down emission estimates, based on the atmospheric concentration of methane and ethane measured by aircraft flying transects bordering the core Barnett producing region on seven different days in March and October 2013. The estimated boundaries of the source regions measured in each flight are shown in Figure 1. Both fossil-related and biogenic sources (wetlands, landfills, feedlots) produce methane, but only fossil sources produce ethane, which is typically the second largest constituent of natural gas. The ethane measurements were therefore used to apportion measured methane to fossil-related and non-fossil, biogenic sources.

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<sup>3</sup> Volume 49, Issue 13, published July 7, 2015. Available at: <http://pubs.acs.org/toc/esthag/49/13>

The study authors also constructed separate bottom-up emission estimates corresponding to each of the seven top-down estimates, using spatially detailed facility inventories matching the geographic boundaries shown in Figure 1. Each inventory included oil and gas production sites (wells), as well as processing facilities and compressor stations; these facilities were located spatially based on public records and remote imagery. The authors also included in the bottom-up inventories biogenic sources (including wetlands, landfills, and feedlots), as well as minor fossil sources not captured by the major oil and gas infrastructure inventories (well completions, gathering and transmission pipelines, and local distribution infrastructure). Emission factors for these sources were taken from the literature.

For production sites, processing plants and compressor stations, the authors developed Barnett-specific emission factors using data collected in the coordinated Barnett campaign. This data included measured methane emissions from 288 Barnett production, compressor station, and processing sites; as well as measured emissions from an additional 125 compressor stations and processing plants located throughout the country. The authors used a statistical method to estimate emissions probability functions, which were then applied



**Figure 1 Geographic Boundaries of Top-Down Estimates**

Source: Zavala-Araiza et al., supporting information

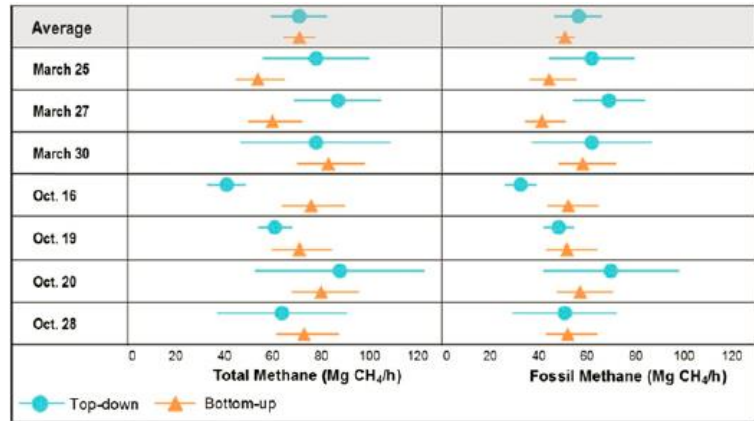
to the measured data to calculate emission factors that account for the effect of high emitting sites on the average emissions rate. Table 1 shows the emission factors derived by the authors, compared to “model facility” emission factors developed by EPA for use in recently proposed New Source Performance Standards for the oil and gas sector.<sup>4</sup> These model facility emission factors are based on the GHG Inventory and are intended by EPA to represent emissions from the average facility in the US.

**Table 1 Natural gas Infrastructure Emission Factors**

Source	Emission Factors (kg CH <sub>4</sub> /hr)	
	Barnett Study EF	EPA NSPS Model Facility
Production Sites	1.76	0.47
Compressor Stations	64.2	3.63 / 6.46 <sup>1</sup>
Processing Plants	195	NA
<sup>1</sup> Gathering & boosting / transmission		

<sup>4</sup> EPA’s Technical Support Document for the proposed NSPS can be downloaded at: <http://www.regulations.gov/#!documentDetail;D=EPA-HQ-OAR-2010-0505-5120>

Figure 2 shows a comparison of the authors’ top-down and bottom-up methane emission estimates for each of the seven separate regional atmospheric measurement flights, which represent emissions on different days and in slightly different geographic sub-sets of the Barnett region (Figure 1). Also shown in Figure 2 (top line) is the authors’ central estimate, based on the average of the seven individual estimates. As shown, the difference between the top-down and bottom-up values of the central estimate of total methane emissions is less than 0.1 percent; the difference in the central estimates of fossil methane is 10 percent.



**Figure 2 Comparison of Top-down and Bottom-up Estimates**

Source: Zavala-Araiza et al.

The authors’ bottom-up central estimate of fossil methane emissions in the Barnett region is 59 Mg/h (48 – 73 Mg/hr 95 percent confidence interval). This equates to a loss rate of 1.5 percent of produced gas. By comparison the GHG Inventory assumes a US average loss rate of approximately 0.6 percent for natural gas production and processing activities, about 60 percent lower than the authors’ estimate for the Barnett basin.

The author’s bottom-up estimate of Barnett methane emissions also indicates that only 2 percent of natural gas production related facilities are responsible for 50 percent of total emissions, and that 10 percent of facilities are responsible for 90 percent of emissions. The authors note that more work is required to understand what factors cause a given site to be a high emitter, but that available data suggests that these high emitting sites are temporally and geographically dynamic – while there will likely always be high emitting sites at any given time within a population of sites, the specific sites that are high emitting changes over time.

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