EDF ENVIRONMENTAL DEFENSE FUND®
Finding the ways that work

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Methane Research: The 16 Study Series

AN UNPRECEDENTED LOOK AT METHANE FROM THE NATURAL GAS SYSTEM

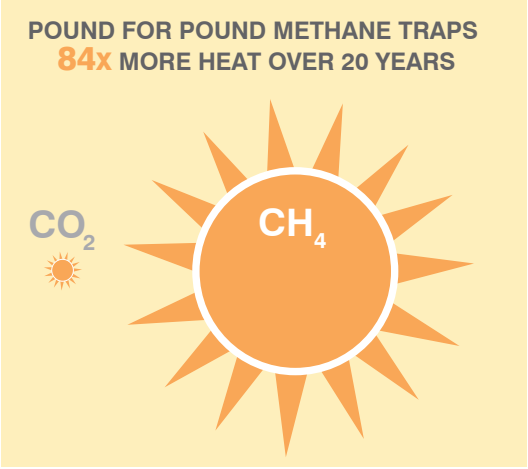
Methane (CH_4) is a growing environmental concern. Methane is a potent greenhouse gas that is contributing to climate change. Science confirms methane is a problem that requires urgent attention. Reducing emissions of both methane and carbon dioxide is critical to slowing the rate of earth's warming and limiting peak warming.

Why methane matters

Methane is the primary component of natural gas, and the oil and gas industry is the nation's largest industrial source of methane emissions. Methane escaping during the production, delivery and use of natural gas can undermine the climate benefit natural gas has over other fossil fuels because methane traps heat in the atmosphere much more effectively relative to carbon dioxide, especially over the short term. In fact, it is 84 times more potent than CO_2 in the first 20 years after it is released.

Methane emissions represent a threat to our climate but also a waste of natural gas, a valuable energy resource -- enough natural gas is lost each year to fuel 6 million homes. Additionally, the gas lost in the U.S. last year had the same negative impact on the climate as the annual carbon emissions of 117 million cars, or roughly half the cars in the United States.

Reducing methane emissions is critical to reducing our overall GHG emissions, and new scientific insights provide more information for crafting effective mitigation strategies. However, there are important actions that can and should be taken today even as the science evolves.



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In 2012, Environmental Defense Fund spearheaded its largest scientific project to date to better understand from where and how much methane is lost across today's U.S. natural gas supply chain, including production, gathering and processing facilities, gas transmission and storage, local utility distribution, as well as end users utilizing natural gas commercial trucks and refueling stations. Insights from this effort will help inform policies and opportunities to minimize these emissions.

This collaborative effort involves partnerships with about 100 universities, research institutions and companies. It is divided into 16 distinct projects that range in their scope from estimating methane emissions in a given geographical area or from specific pieces of equipment across the country. A variety of sophisticated scientific techniques and methodologies--including top-down, bottom up and mobile measuring devices --were deployed across the various projects; no individual method can provide all the answers. Our series was designed to help combine, compare or contrast methods to increase precision, instead of confusion. In many cases, the measurement techniques are paired to provide greater insight and certainty.

Of the 16 studies, data from 13 have been published in more than 30 peer-reviewed papers.

Production Studies

1) Production Study: Phase I

University of Texas at Austin

This study measured methane emissions at natural gas production sites—including some of the first measurements ever collected from hydraulically fractured wells. Diverse methods were used to directly measure methane emissions at well pads operated by nine cooperating U.S. natural gas companies. The study found that methane emissions from equipment leaks and pneumatic devices were larger than previously thought. The study also found that techniques to reduce emissions from well completions are effective at capturing 99% of the methane that was previously vented to the atmosphere, providing a data-based example of EPA regulations working.

- Published in the Proceedings of the National Academy of Sciences (Sept. 2013)

2) Production Study: Phase II

University of Texas at Austin

This study expands on results from the first UT study by collecting additional data from two important emission sources associated with natural gas production: 1) liquid unloadings, when producing wells are cleared of water and other liquids inhibiting the flow of gas, and 2) pneumatic controllers used to regulate routine functions at well sites. UT coordinated with 10 natural gas companies on this effort. The study found that emissions from two sources--pneumatic s and liquids unloadings--were responsible for a significant portion of methane emissions from the production sector.

- Pneumatics paper published in *Environmental Science and Technology* (Dec. 2014)
- Liquids Unloadings paper published in *Environmental Science and Technolog* (Dec. 2014)

3) Production Data Analysis

Houston Advanced Research Center (HARC), U.S. Environmental Protection Agency (EPA

EPA's Office of Research and Development has collected fence line data on methane emissions at well production sites over several years EPA, HARC, and EDF, worked together to analyze the data further to investigate trends in production emissions. The report includes measurements from 210 production sites in the Barnett Shale and Eagle Ford regions of Texas, Colorado's Denver-Julesburg Basin, and the Upper Green River Basin gas fields surrounding Pinedale, Wyoming from 2010 to 2013. A statistical analysis of this data suggests unpredictable events, such as malfunctions and maintenance, have a strong influence on emission rates

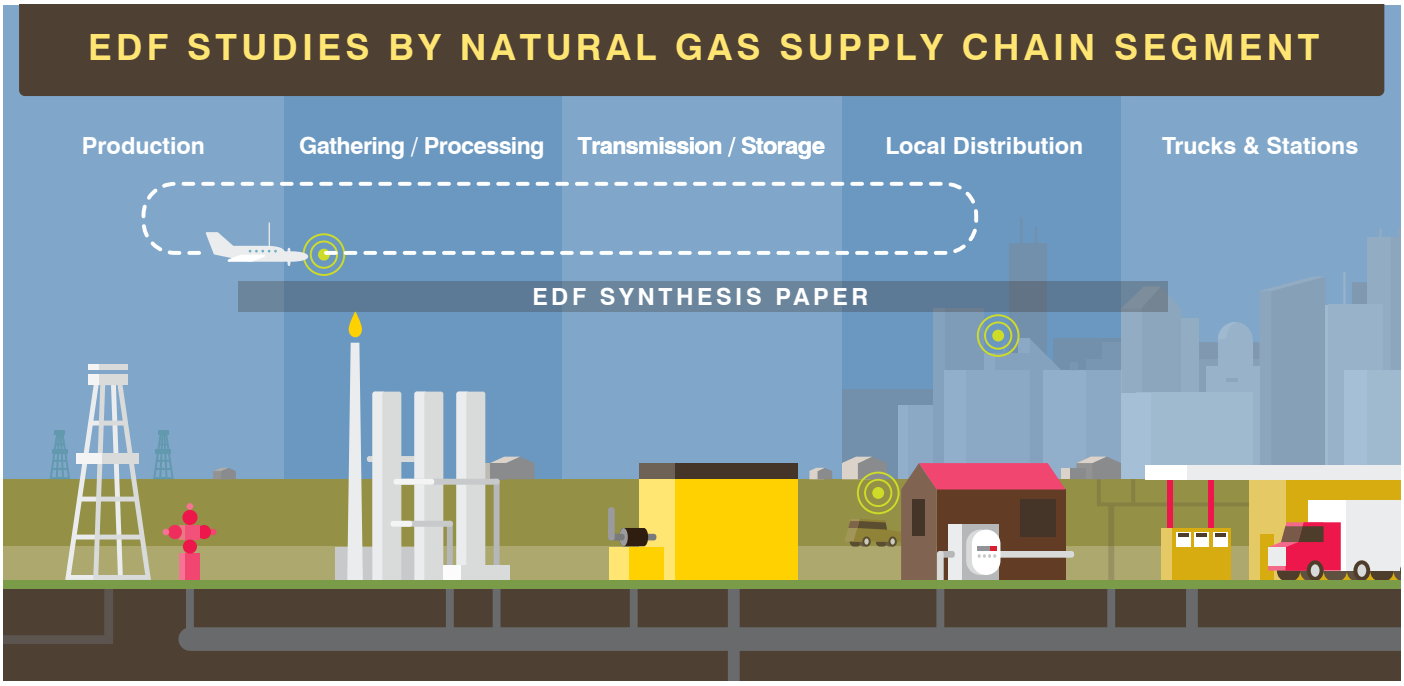
- Published in *Environmental Science and Technology* (Nov. 2014)

Midstream Studies

4) Gathering and Processing Study

Colorado State University

CSU's Engines and Energy Conversion Laboratory led an effort to quantify national methane emissions associated with the natural gas industry's gathering infrastructure and gas processing facilities. Researchers worked with six industry companies and used tracer gas releases to quantify methane emissions



from this sector. The study found methane leakage from gathering activities is 8 times larger than official estimates. Researchers with the study suggest leak detection and repair policies can be effective at minimizing emissions from these sources.

- Published in *Environmental Science and Technology* (Feb. 2015)
- Modeling Paper published in *Environmental Science and Technology* (Aug. 2015)

5) Transmission and Storage Study

Colorado State University, Carnegie Mellon University, Aerodyne Research

This study estimates the amount of methane lost during long-distance transportation and storage of natural gas as it moves across the country in cooperation with seven industry partners. The initial measurements paper used downwind tracer gas methods paired with direct on site measurements to report variable emissions data from site to site. The paper confirms compressors and equipment leaks are two primary sources for the sector's methane emissions. Researchers also developed a model to combine their measurements with data from EPA's Greenhouse Gas Reporting Program to derive a national emissions estimate for this industry segment.

- Published in *Environmental Science and Technology* (Feb. 2015)
- Modeling paper published in *Environmental Science and Technology* (June 2015)

Local Distribution Studies

6) Multi-city Local Distribution Study

Washington State University

WSU's Laboratory for Atmospheric Research led a nationwide field study to better characterize and understand methane emissions associated with the delivery of natural gas. Researchers quantified methane emissions from facilities and pipes operated by 13 utilities in various regions. The data will be used to estimate emissions from distribution systems nationally. The study shows that methane emissions from local natural gas distribution systems are significant, especially in regions such as the Northeast where distribution infrastructure is older, but that progress is being made in reducing emissions from these systems, mainly through regulation and investment by utilities.

- Published in *Environmental Science and Technology* (March, 2015)

7) Boston Study

Harvard, Boston and Duke universities with Aerodyne Research and Atmospheric and Environmental Research

University scientists developed an innovative tower-based quantitative technique for use in the urban environment. The study found Boston's methane emissions are more than two times higher than inventory data suggests, with a yearly average loss rate between 2.1 and 3.3- percent.

- Published in *Proceedings of the National Academy of Sciences* (Jan. 2015)

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Major funding for EDF's methane research series is provided for by the following individuals and foundations: Fiona and Stan Druckenmiller, Heising-Simons Foundation, Bill and Susan Oberndorf, Betsy and Sam Reeves, Robertson Foundation, Alfred P. Sloan Foundation, TomKat Charitable Trust and Walton Family Foundation.

8) Indianapolis Study
Washington State University

To gain further regional insights of urban methane emissions, WSU coordinated with the National Institute of Standards and Technology, Aerodyne, GHD, Purdue and Pennsylvania State universities to measure methane emissions in Indianapolis, as part of a broader NIST project. The study found that natural gas end use sources -- like gas meters, furnaces, boilers and hot water heaters -- as well as landfills, are responsible for a large portion of urban methane emissions.

- Published in *Environmental Science and Technology* (Aug. 2016)

9) Methane Mapping
Colorado State University

Using mobile methane sensors, EDF partnered with Google to map methane emissions from pipelines under city streets. Led by researchers at Colorado State University, this method quantifies methane leaks from local distribution systems that utilities could use to identify and prioritize repair or replacement of leaky pipelines, not otherwise addressed as an immediate public safety risk.

Learn more at edf.org/methanemaps

Big problems call for big collaboration

John Rae

Measuring methane—an odorless, colorless gas that dissipates quickly—is challenging work. It takes more than one approach to achieve solid results.

EDF assembled an incredible team of experts in methane, atmospheric science and the oil and gas industry to work together on this issue. The deep level of collaboration helps ensure this project applies the best available knowledge of what's happening in the oil and gas fields, how methane reacts in the atmosphere and what the most effective techniques are to measure methane across diverse landscapes and types of activities. Together, these studies will complement other scientific efforts underway to provide a clearer national picture of methane emissions.

Basin Specific Studies

10) Denver-Julesburg Basin

National Oceanic Atmospheric Administration and University of Colorado at Boulder

Researchers measured methane emissions from Colorado's most active oil and gas field using data gathered by aircrafts and compared the differences in atmospheric concentrations of hydrocarbons upwind and downwind of production areas. The study estimated methane emissions that were three times higher than estimates derived from EPA data. The study also found that levels of smog-forming VOCs were twice as high as EPA estimates, and Benzene levels were 7 times higher than previously estimated.

- Published in *Journal of Geophysical Research: Atmospheres* (May 2014)

11) Barnett study

Coordinated campaign

EDF convened 12 diverse research teams in October 2013 to measure methane emissions in the Barnett Shale in Texas. This campaign used a variety of aircraft, vehicle and ground-based measurements to quantify methane emitted across the natural gas supply chain. A preliminary study estimated regional methane emissions to be 50 percent higher than emission estimates in EPA's Greenhouse Gas Inventory, with subsequent research estimating emissions could be as much as 90 percent higher.

- Published in *Environmental Science and Technology* (July 2015)
- Synthesis published in *Proceedings of the National Academy of Sciences* (Dec. 2015)

12) Flyover Study: Barnett Shale

National Oceanic and Atmospheric Administration, University of Colorado at Boulder, University of Michigan

As part of a broader project (No. 11), scientists with NOAA and UC-Boulder's Cooperative Institute for Research in Environmental Sciences are measuring atmospheric concentrations of hydrocarbons in order to quantify and allocate regional methane emissions in an active oil-and gas basin that includes infrastructure.

Other Studies

13) Pump-to-wheels Study

West Virginia University

WVU's Center for Alternative Fuels, Engines and Emissions, in cooperation with 10 companies and research organizations, led a study to directly measure methane emissions from the operation of natural gas fueled medium- and heavy duty vehicles, as well as CNG and LNG refueling and maintenance facilities. Researchers found that the largest sources of vehicular-related methane emissions came from tailpipes (30%) and crank cases (39%). Emissions from fueling stations were relatively low, accounting for about 12% of transport segment emissions.

- Published in *Environmental Science and Technology* (Jan. 2017)

14) Pilot Projects

Three initial projects helped build the foundation for some of this research. University of Texas-Arlington collected methane data using mobile methane-sensing technology that helped inform the first UT study (No.1), as well as the Coordinated Campaign (No. 11 & No. 12), and the methane mapping. Harvard, Duke and Boston University researchers experimented with tower-based sensing systems for making methane emissions estimates in an urban environment. This work led to the larger Boston study (No. 7). University of Colorado-Boulder scientists conducted research to identify elevated levels of methane and hydrogen sulfide that provided insights for subsequent overflight work (No. 10 & No. 11).

15) Filling Gaps, Including Super Emitters

In the largest sample size of any methane study performed to date, researchers used infrared technology to conduct an aerial survey of over 8,000 well pads in seven geologic basins across the country to characterize the prevalence of "super emitters" – the sources responsible for a disproportionate amount of methane and VOC pollution in the oil and gas production sector. The study concludes that super emitters are highly widespread and unpredictable, but easily identified through better and more frequent monitoring.

- Published in *Environmental Science and Technology* (April 2016)

16) Project Synthesis

After the series of EDF-initiated studies are completed, EDF will engage stakeholders from across the projects to develop an integrated understanding of what was learned, including the development of an overall methane emissions rate across the natural gas supply chain.

For more information, please contact Kelsey Robinson at 512-691-3404 or krobinson@edf.org

Environmental Defense Fund
257 Park Avenue South
New York, NY 10010

T 212 505 2100
F 212 505 2375
edf.org

New York, NY / Austin, TX / Bentonville, AR / Boston, MA / Boulder, CO / Raleigh, NC
Sacramento, CA / San Francisco, CA / Washington, DC / Beijing, China / La Paz, Mexico