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IEPR Commissioner Workshop, in Support of the AB 1257 Report, on Fugitive Methane Emissions in California's Natural Gas System

June 1, 2015

Ramón Alvarez, Lead Senior Scientist
Timothy O'Connor, Director and Senior Attorney

EDF ENVIRONMENTAL DEFENSE FUND®
Finding the ways that work

Presentation Roadmap

1. **Background on the importance of value chain leakage assessments**
2. **Changing value chain leakage assessments based on end use**
3. **EDF's Scientific Efforts to Quantify Natural Gas Methane Leakage**
   – Completed
   – Upcoming
4. **Putting it all together**
   – Leakage science
   – Relevance for California policies and the IEPR

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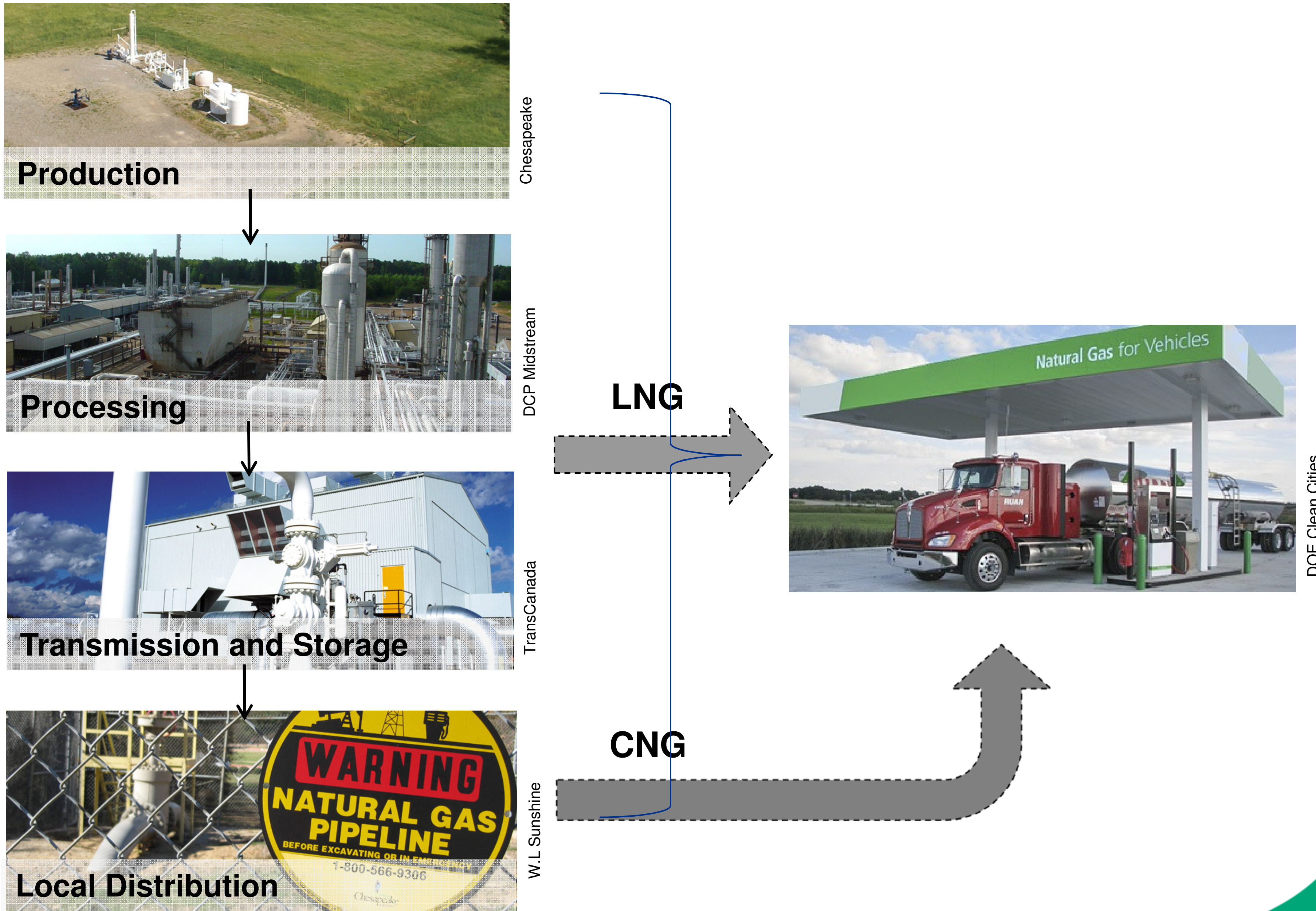
Well-to-Wheels Fuel Cycle



First analysis by EDF scientists on the importance of understanding methane leakage

PNAS PNAS PNAS PNAS PNAS

Greater focus needed on methane leakage from natural gas infrastructure

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Contributed by Stephen W. Pacala, February 13, 2012 (sent for review December 21, 2011)

Natural gas is seen by many as the future of American energy: a fuel that can provide energy independence and reduce greenhouse gas emissions in the process. However, there has also been confusion about the climate implications of increased use of natural gas for electric power and transportation. We propose and illustrate the use of technology warming potentials as a robust and transparent way to compare the cumulative radiative forcing created by alternative technologies fueled by natural gas and oil or coal by using the best available estimates of greenhouse gas emissions from each fuel cycle (i.e., production, transportation and use). We find that a shift to compressed natural gas vehicles from gasoline or diesel vehicles leads to greater radiative forcing of the climate for 80 or 280 yr, respectively, before beginning to produce benefits. Compressed natural gas vehicles could produce climate benefits on all time frames if the well-to-wheels CH_4 leakage were capped at a level 45–70% below current estimates. By contrast, using natural gas instead of coal for electric power plants can reduce radiative forcing immediately, and reducing CH_4 losses from the production and transportation of natural gas would produce even greater benefits. There is a need for the natural gas industry and science community to help obtain better emissions data and for increased efforts to reduce methane leakage in order to minimize the climate footprint of natural gas.

With growing pressure to produce more domestic energy and to reduce greenhouse gas (GHG) emissions, natural gas is increasingly seen as the fossil fuel of choice for the United States as it transitions to renewable sources. Recent reports in the scientific literature and popular press have produced confusion about the climate implications of natural gas (1–5). On the one hand, a shift to natural gas is promoted as climate mitigation because it has lower carbon per unit energy than coal or oil (6). On the other hand, methane (CH_4), the prime constituent of natural gas, is itself a more potent GHG than carbon dioxide (CO_2); CH_4 leakage from the production, transportation and use of natural gas can offset benefits from fuel-switching.

The climatic effect of replacing other fossil fuels with natural gas varies widely by sector (e.g., electricity generation or transportation) and by the fuel being replaced (e.g., coal, gasoline, or diesel fuel), distinctions that have been largely lacking in the policy debate. Estimates of the net climate implications of fuel-switching strategies should be based on complete fuel cycles (e.g., "well-to-wheels") and account for changes in emissions of relevant radiative forcing agents. Unfortunately, such analyses are weakened by the paucity of empirical data addressing CH_4 emissions through the natural gas supply network, hereafter referred to as CH_4 leakage.* The U.S. Environmental Protection Agency (EPA) recently doubled its previous estimate of CH_4 leakage from natural gas systems (6).

In this paper, we illustrate the importance of accounting for fuel-cycle CH_4 leakage when considering the climate impacts of fuel-technology combinations. Using EPA's estimated CH_4 emissions from the natural gas supply, we evaluated the radiative forcing implications of three U.S.-specific fuel-switching scenarios: from gasoline, diesel fuel, and coal to natural gas.

A shift to natural gas and away from other fossil fuels is increasingly plausible because advances in horizontal drilling and hydraulic fracturing technologies have greatly expanded the country's extractable natural gas resources particularly by accessing gas stored in shale deep underground (7). Contrary to previous estimates of CH_4 losses from the "upstream" portions of the natural gas fuel cycle (8, 9), a recent paper by Howarth et al. calculated upstream leakage rates for shale gas to be so large as to imply higher lifecycle GHG emissions from natural gas than from coal (1). (*SI Text*, discusses differences between our paper and Howarth et al.) Howarth et al. estimated CH_4 emissions as a percentage of CH_4 produced over the lifecycle of a well to be 3.6–7.9% for shale gas and 1.7–6.0% for conventional gas. The EPA's latest estimate of the amount of CH_4 released because of leaks and venting in the natural gas network between production wells and the local distribution network is about 570 billion cubic feet for 2009, which corresponds to 2.4% of gross U.S. natural gas production (1.9–3.1% at a 95% confidence level) (6).[†] EPA's reported uncertainty appears small considering that its current value is double the prior estimate, which was itself twice as high as the previously accepted amount (9).

Comparing the climate implications of CH_4 and CO_2 emissions is complicated because of the much shorter atmospheric lifetime of CH_4 relative to CO_2. On a molar basis, CH_4 produces 37 times more radiative forcing than CO_2.[‡] However, because CH_4 is oxidized to CO_2 with an effective lifetime of 12 yr, the integrated, or cumulative, radiative forcings from equi-molar releases of CO_2 and CH_4 eventually converge toward the same value. Determining whether a unit emission of CH_4 is worse for the climate than a unit of CO_2 depends on the time frame considered. Because accelerated rates of warming mean ecosystems and humans have less time to adapt, increased CH_4 emissions due to substitution of natural gas for coal and oil may produce undesirable climate outcomes in the near-term.

The concept of global warming potential (GWP) is commonly used to compare the radiative forcing of different gases relative

Author contributions: R.A.A., S.W.P., and S.P.H. designed research; R.A.A. performed research; R.A.A., S.W.P., and S.P.H. analyzed data; and R.A.A., S.W.P., J.J.W., W.L.C., and S.P.H. wrote the paper.

The authors declare no conflict of interest.

Freely available online through the PNAS open access option.

*Challenges also exist in the quantification of CH_4 emissions from the extraction of coal. We use the term "leakage" for simplicity and define it broadly to include all CH_4 emissions in the natural gas supply, both fugitive leaks as well as vented emissions.

[†]This represents an uncertainty range between −19% and +30% of natural gas system emissions. For CH_4 from petroleum systems (35% of which we assign to the natural gas supply) the uncertainty is −24% to +149%; however, this is only a minor effect because the portion of natural gas supply that comes from oil wells is less than 20%.

[‡]One-hundred-two times on a mass basis. This value accounts for methane's direct radiative forcing and a 40% enhancement because of the indirect forcing by ozone and stratospheric water vapor (10).

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This article contains supporting information online at www.pnas.org/lookup/suppl/doi:10.1073/pnas.1202407109/-/DCSupplemental.

SUSTAINABILITY SCIENCE

ENVIRONMENTAL SCIENCES

Highlighted the need for the natural gas industry and science community to obtain better emissions data and develop solutions to reduce leakage

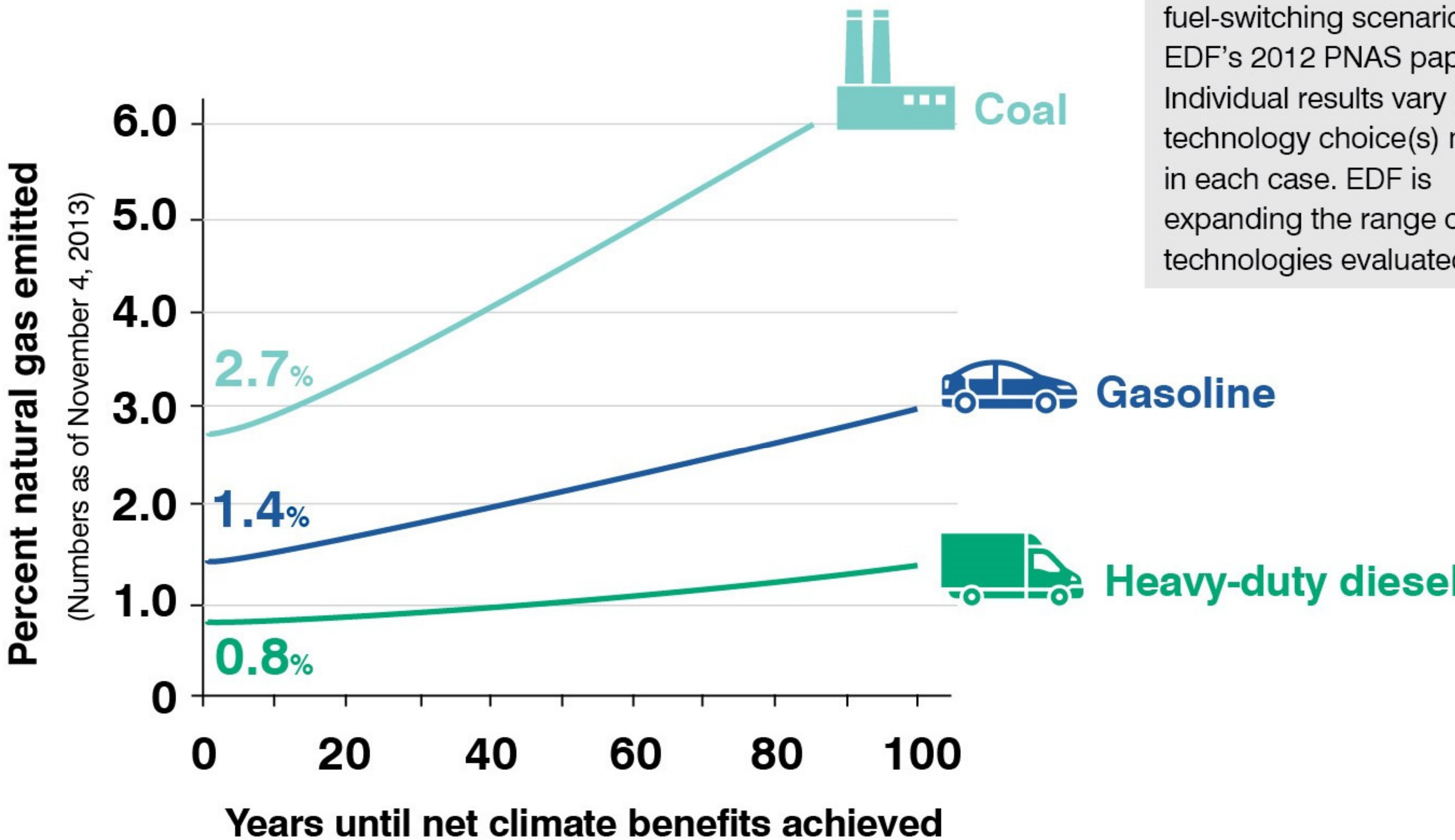
- *Illustrated the importance of accounting for fuel-cycle CH_4 leakage when considering fuel-switching scenarios*
- *With EPA's estimates of CH_4 leakage from natural gas production and delivery infrastructure, in addition to a modest CH4 contribution from the vehicle itself - CNG-fueled vehicles were not a viable mitigation strategy for climate change.*

Paper released on April 9, 2012

Available at www.pnas.org/cgi/doi/10.1073/pnas.1202407109

Can Natural Gas Deliver Sustained Climate Benefits?

Updated calculations of fuel-switching scenarios in EDF's 2012 PNAS paper.* Individual results vary by the technology choice(s) made in each case. EDF is expanding the range of technologies evaluated.



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Finding the ways that work

*Adapted from Alvarez et al. (2012) PNAS, **109**: 6435–6440, reflecting new IPCC AR5 & 2013 EPA GHG data. IPCC updates: (1) direct/indirect radiative forcing of CH_4 and CO_2, (2) CH_4 lifetime, (3) CO_2 impulse response function. Additional effects due to climate-carbon feedbacks and CO_2 from the oxidation of CH_4 not included (AR5 lacks data to support time-dependent analysis but EDF believes these effects to be small). Emissions updates include factors in Table 1 and corresponding L_{REF} values in Table S1 of PNAS paper; an L_{REF} value specific to heavy-duty CNG vehicles is now used.

Most recent example of the relevance of well-to-wheels fuel cycle assessments


Environmental Science & Technology
Policy Analysis
pubs.acs.org/est

Influence of Methane Emissions and Vehicle Efficiency on the Climate Implications of Heavy-Duty Natural Gas Trucks

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Supporting Information

ABSTRACT: While natural gas produces lower carbon dioxide emissions than diesel during combustion, if enough methane is emitted across the fuel cycle, then switching a heavy-duty truck fleet from diesel to natural gas can produce net climate damages (more radiative forcing) for decades. Using the Technology Warming Potential methodology, we assess the climate implications of a diesel to natural gas switch in heavy-duty trucks. We consider spark ignition (SI) and high-pressure direct injection (HPDI) natural gas engines and compressed and liquefied natural gas. Given uncertainty surrounding several key assumptions and the potential for technology to evolve, results are evaluated for a range of inputs for well-to-pump natural gas loss rates, vehicle efficiency, and pump-to-wheels (in-use) methane emissions. Using reference case assumptions reflecting currently available data, we find that converting heavy-duty truck fleets leads to damages to the climate for several decades: around 70–90 years for the SI cases, and 50 years for the more efficient HPDI. Our range of results indicates that these fuel switches have the potential to produce climate benefits on all time frames, but combinations of significant well-to-wheels methane emissions reductions and natural gas vehicle efficiency improvements would be required.

11.9 Liter Diesel to CNG Truck Fleet Conversion

INTRODUCTION

Making natural gas a near-term fuel of choice in the United States has been championed by many, as it provides a number of advantages over other fossil fuel options. Recent technological innovations in extracting natural gas have led to significant expansions of U.S. natural gas reserves. The resulting shale gas boom not only represents a significant source of domestic energy production, thus satisfying pressure for energy independence, it does so at relatively low costs (in fact, low prices in recent years have already contributed to a significant shift toward natural gas in the U.S. electric power industry).[1] In addition, since natural gas has relatively low carbon intensity, releasing less carbon dioxide (CO_2) per unit of usable energy than other fossil fuels, it is often assumed that switching to natural gas is comparatively beneficial for the climate.

As recent literature suggests, the latter statement deserves a closer look. While it is true that natural gas emits less CO_2 than other fossil fuels during combustion, potential climate benefits could be reduced or even delayed for decades or centuries,[2−4] depending on the magnitude of methane (CH_4) loss from the natural gas supply chain—an area of active research.[5−10] Although CH_4 decays more rapidly than CO_2 in the atmosphere, it is a more powerful greenhouse gas (GHG), and its influence on the climate is significant on decadal time frames (Supporting Information, section S3). Even small amounts of CH_4 can potentially overwhelm large CO_2 reductions to increase radiative forcing in the short run. Taking CH_4 emissions into consideration is critical: short-term radiative forcing will determine the rate at which climatic changes occur,[11,12] and it is crucial to address both short and long-term net radiative impacts in order to minimize social and ecological disruptions from climate change.

Alvarez et al. proposed a framework to compare the time-dependent cumulative radiative forcing of a conventional technology, such as a diesel truck or a coal power plant, to a substitute powered by natural gas.[2] This framework deployed Technology Warming Potentials (TWP), which consider the radiative efficiency of both CO_2 and CH_4 and their atmospheric fate as a function of time, thereby providing a view of climate impacts from fuel switching across both short and long time frames. Relying on Environmental Protection Agency (EPA) estimates of CH_4 emissions for 2010,[13] they found that switching from coal to natural gas in the power sector would reduce radiative forcing across all time frames, yet a switch of heavy-duty trucks (HDTs) from diesel to natural gas would result in greater radiative forcing for more than 200 years.[2]

Received: January 23, 2015
Revised: April 15, 2015
Accepted: April 20, 2015

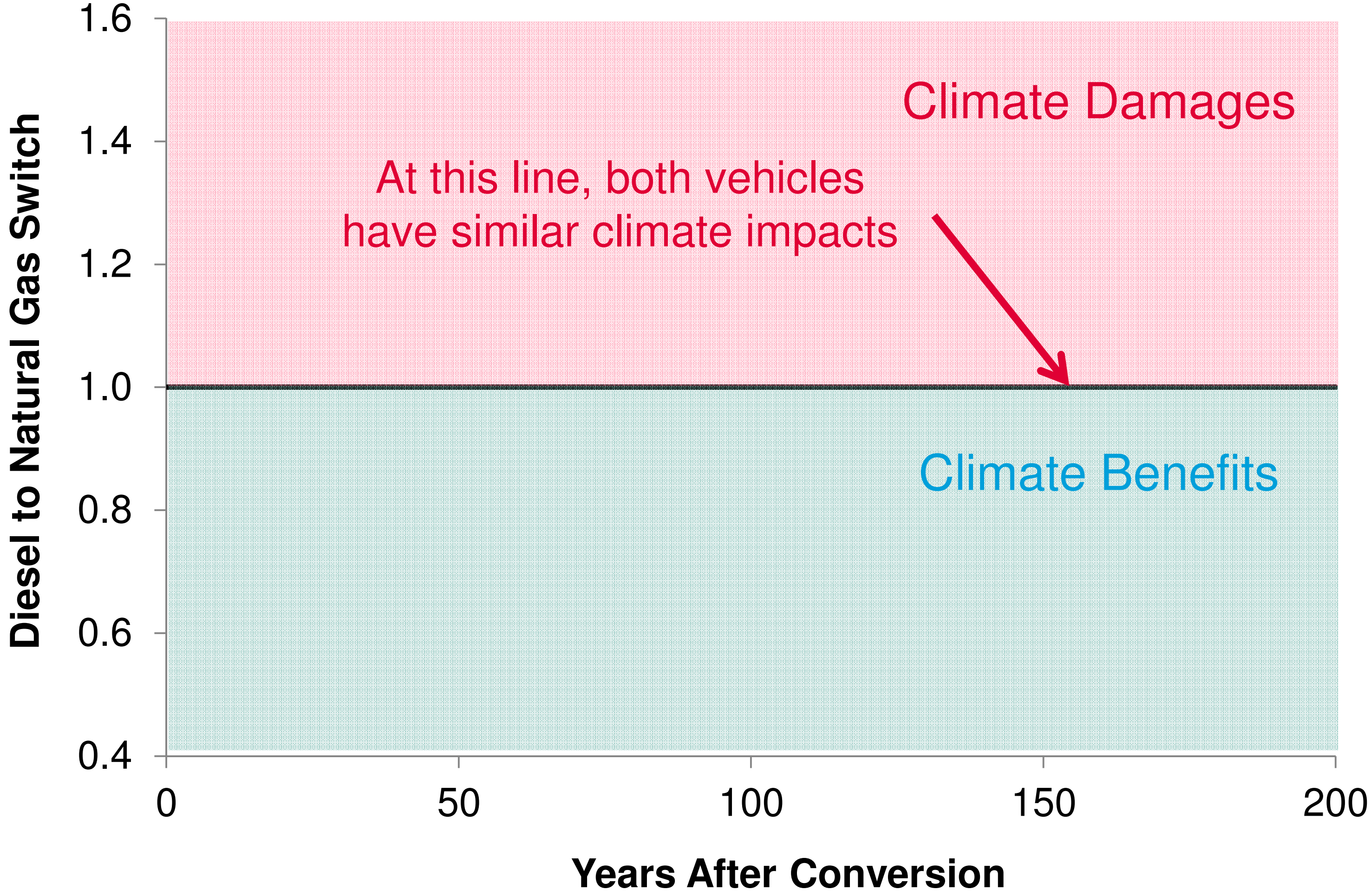
STUDY: Will Switch From Diesel Trucks to Natural Gas Reduce Greenhouse Impact?

- *Unless leaks in gas value chain are fixed, decades of climate damage occur;*
- *Vehicle suppliers, fleet operators and policymakers should look to upstream cleanup*
- *New standards to improve truck efficiency and reduce on-board leakage also important*

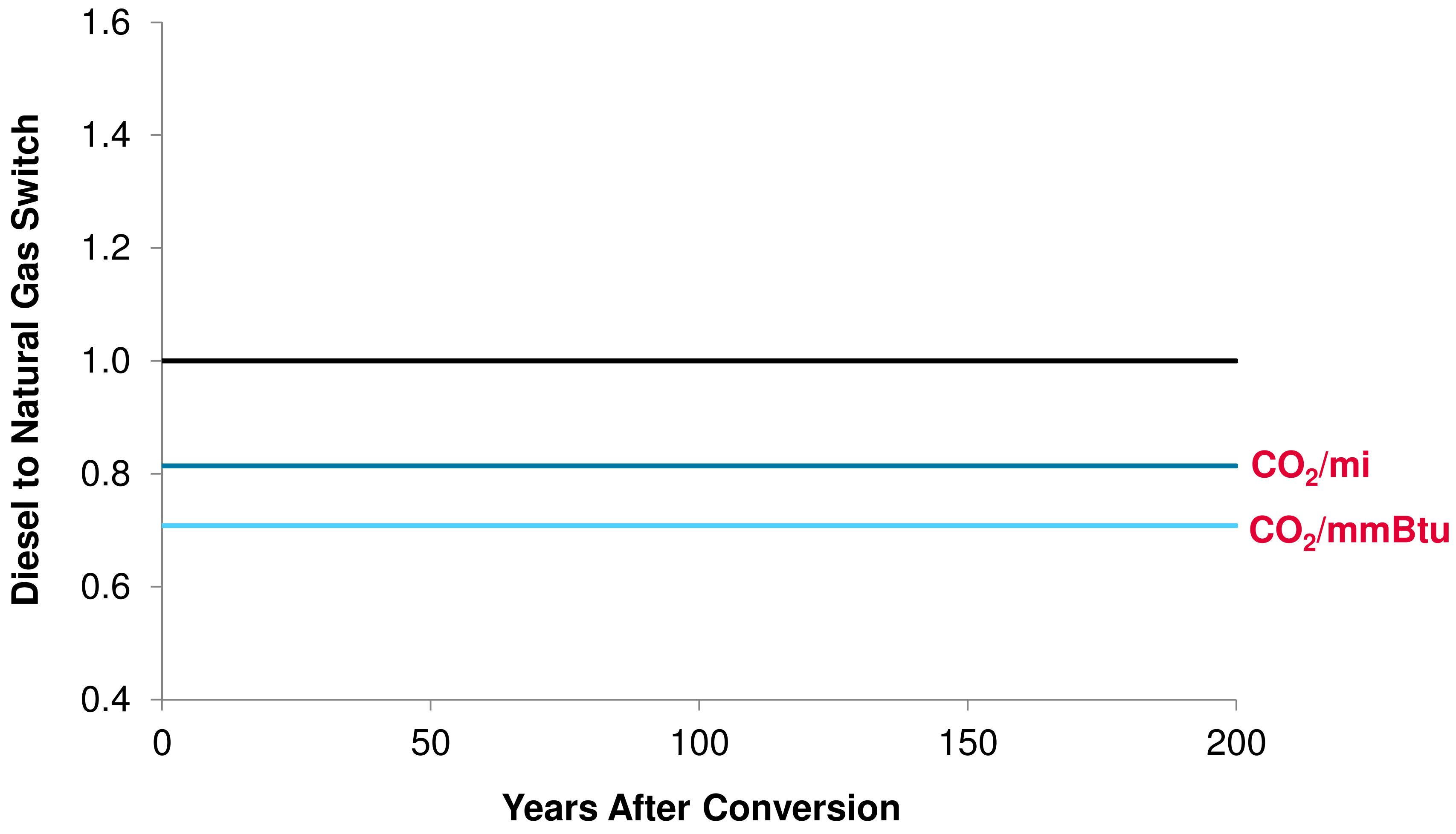
Paper released on May 19, 2015

Available at http://pubs.acs.org/doi/abs/10.1021/acs.est.5b00412

Consider a shift from diesel to natural gas trucks

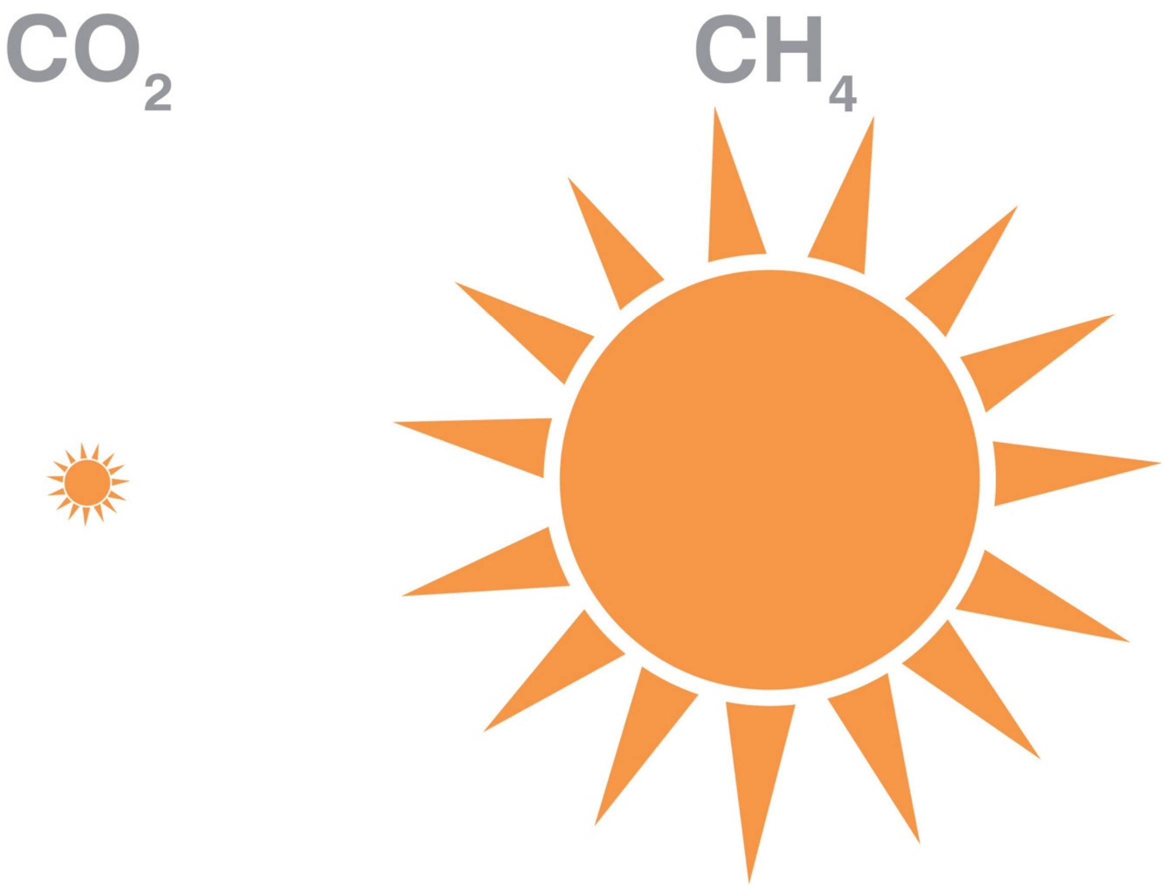


Consider a shift from diesel to natural gas trucks

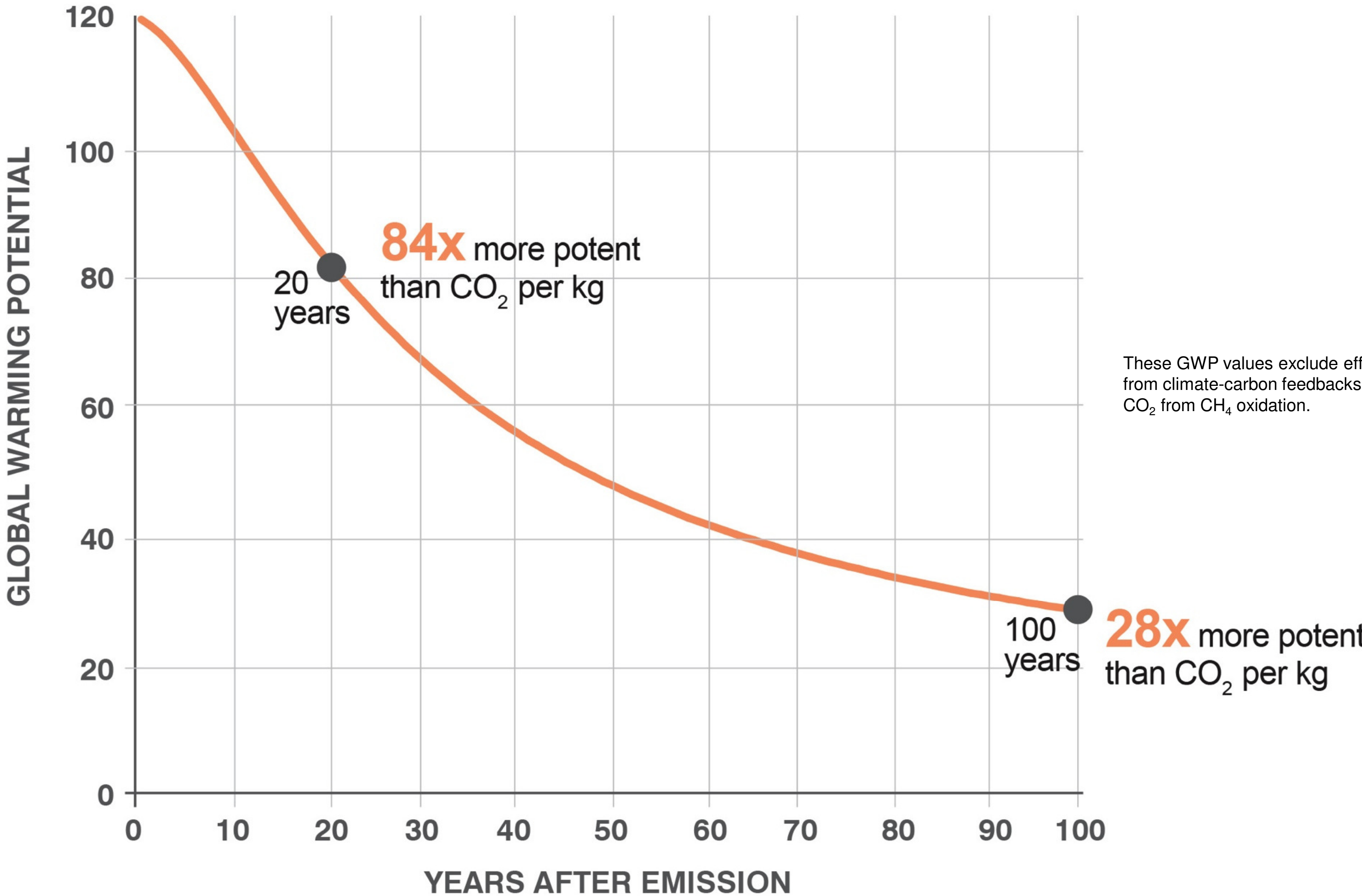


Climate implications of methane

POUND FOR POUND METHANE TRAPS
84x MORE HEAT OVER 20 YEARS

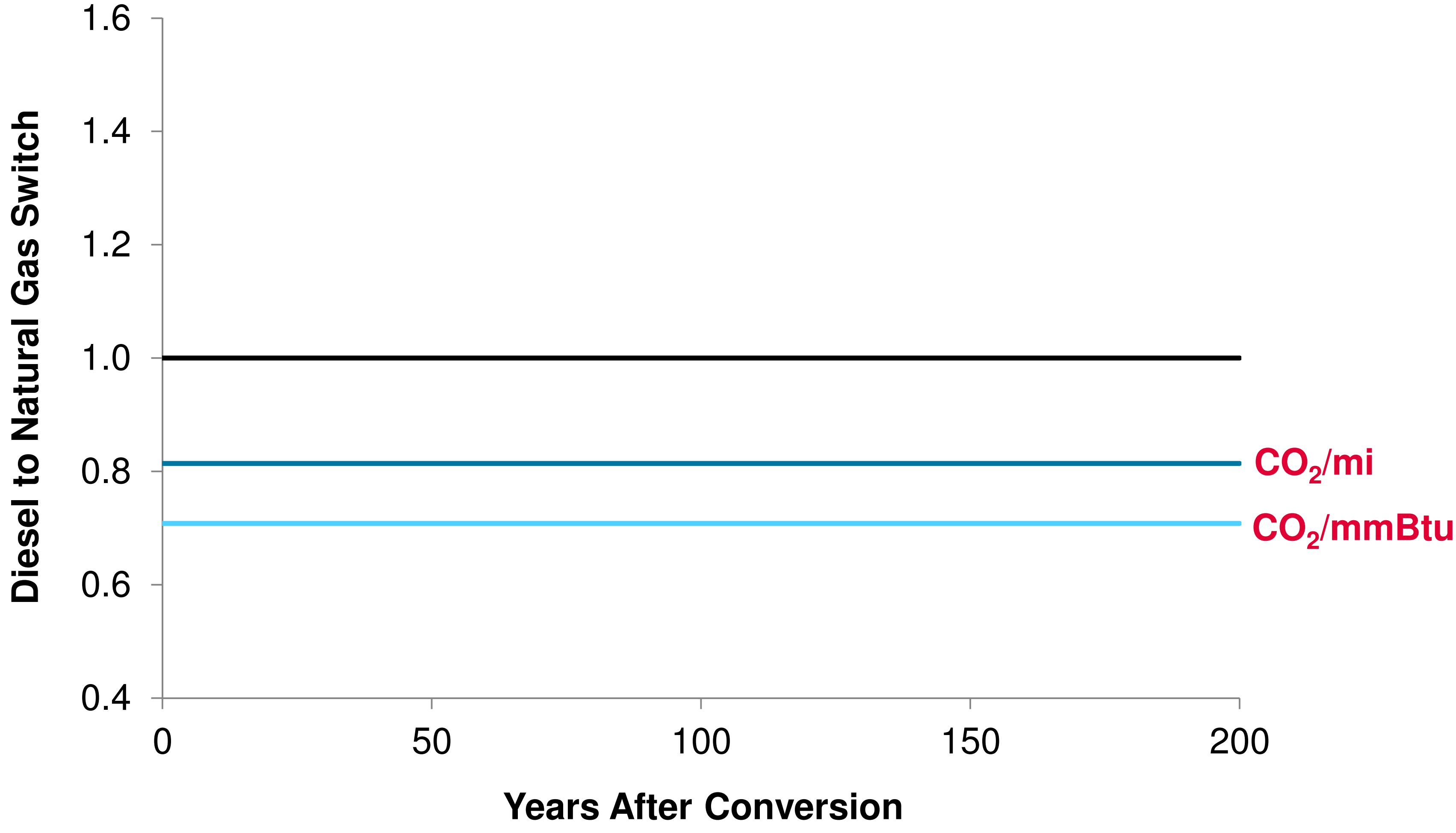


Climate implications of methane

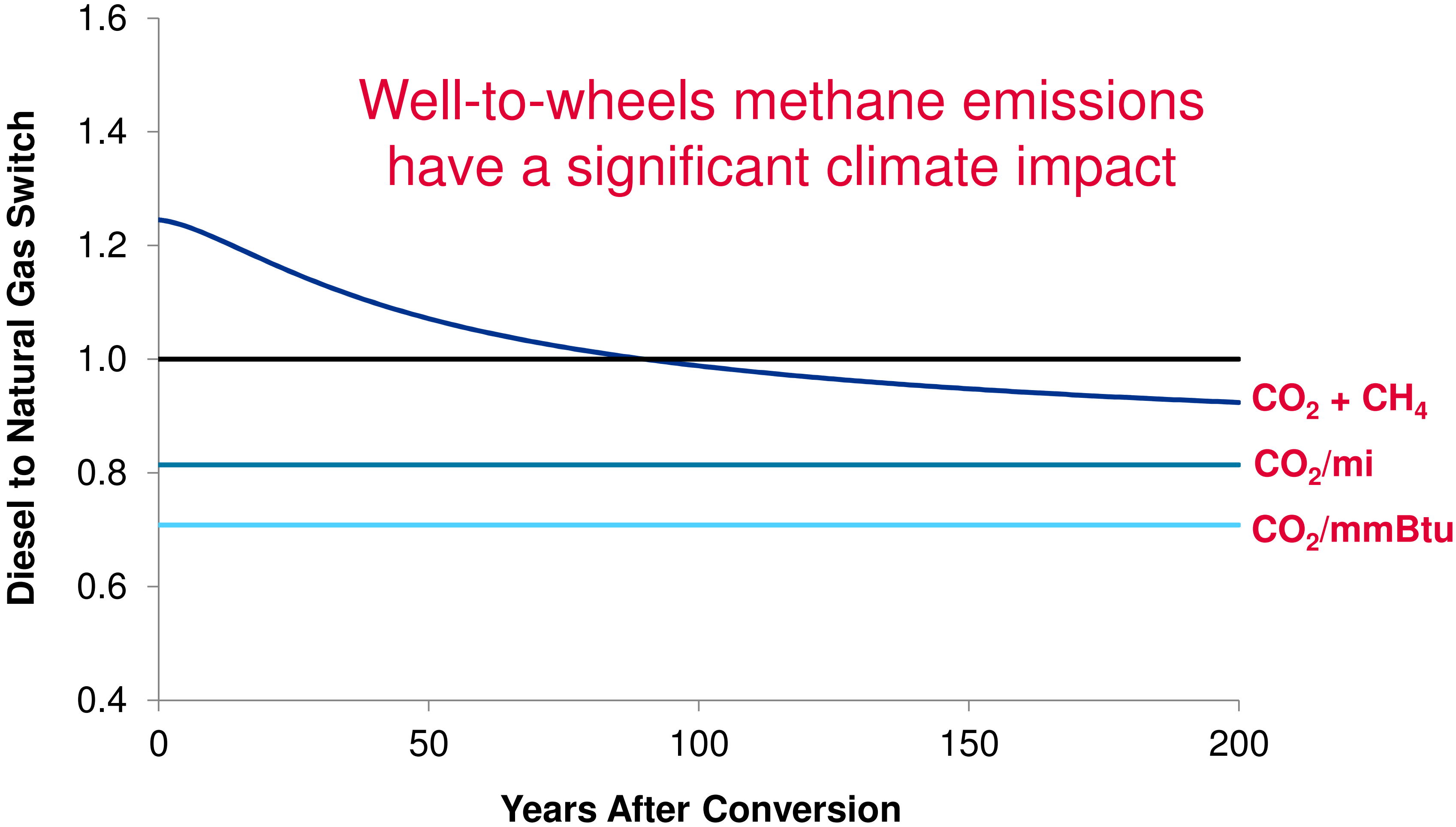


These GWP values exclude effects from climate-carbon feedbacks and CO_2 from CH_4 oxidation.

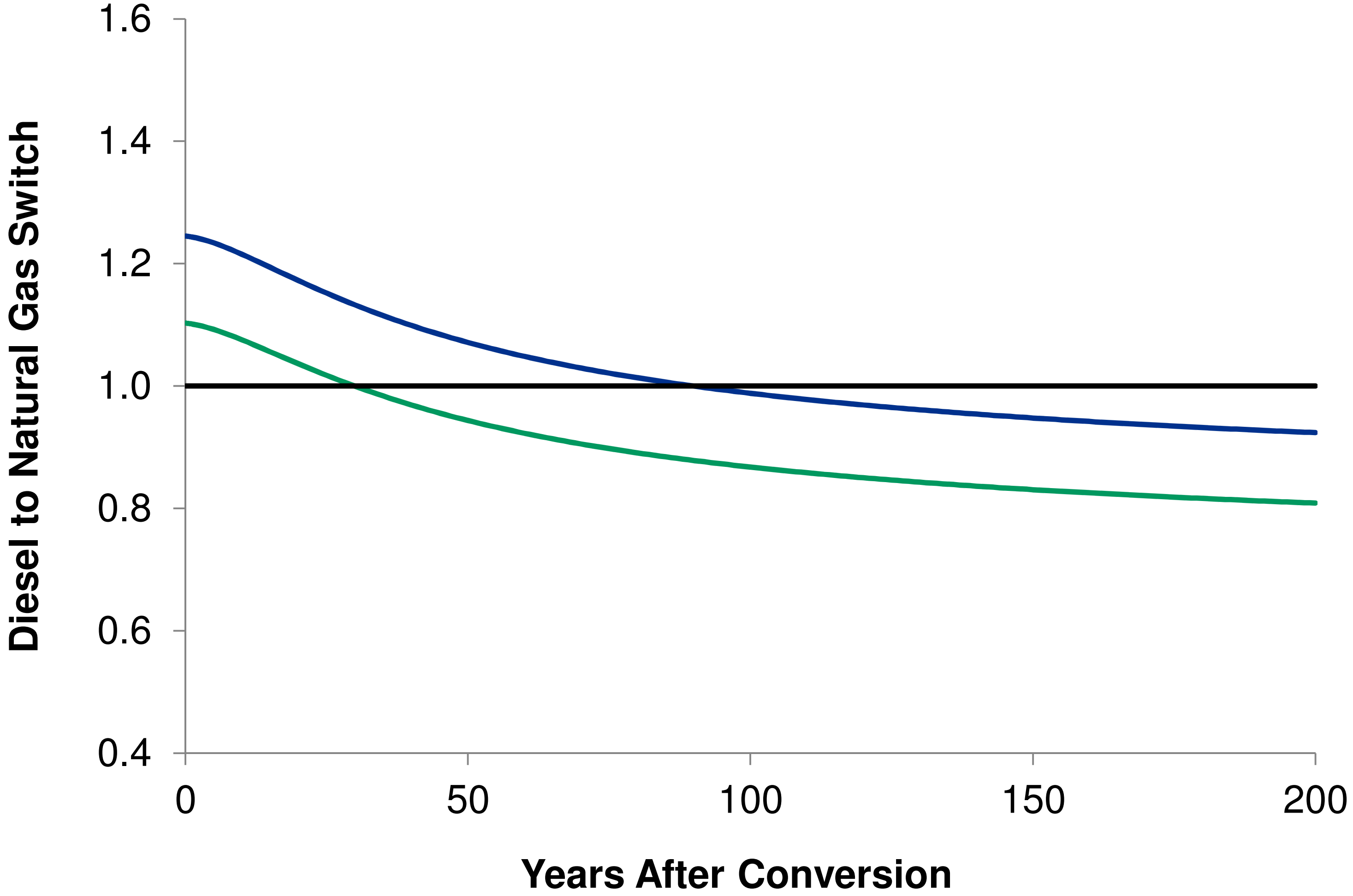
Consider a shift from diesel to natural gas trucks



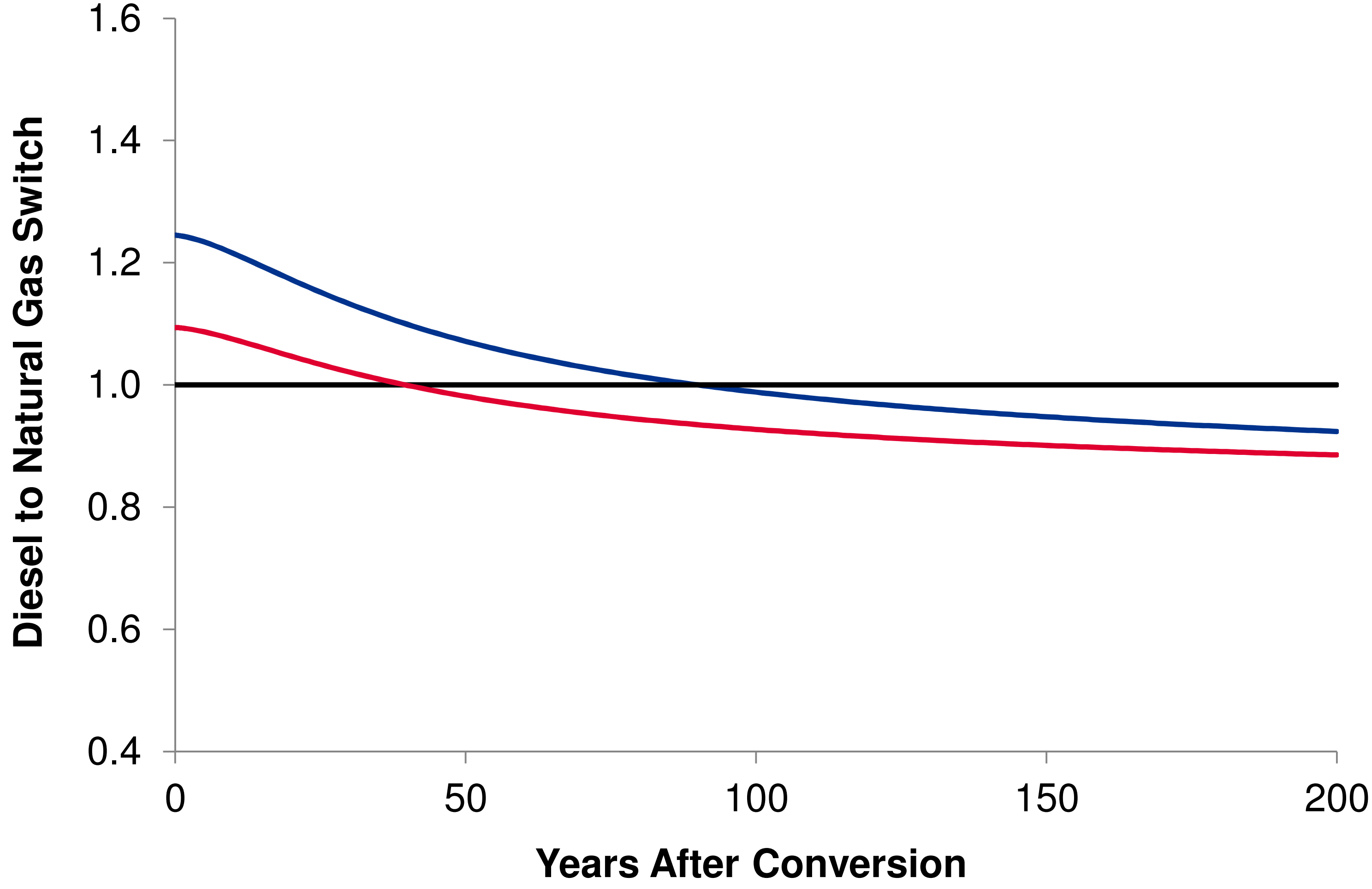
Consider a shift from diesel to natural gas trucks



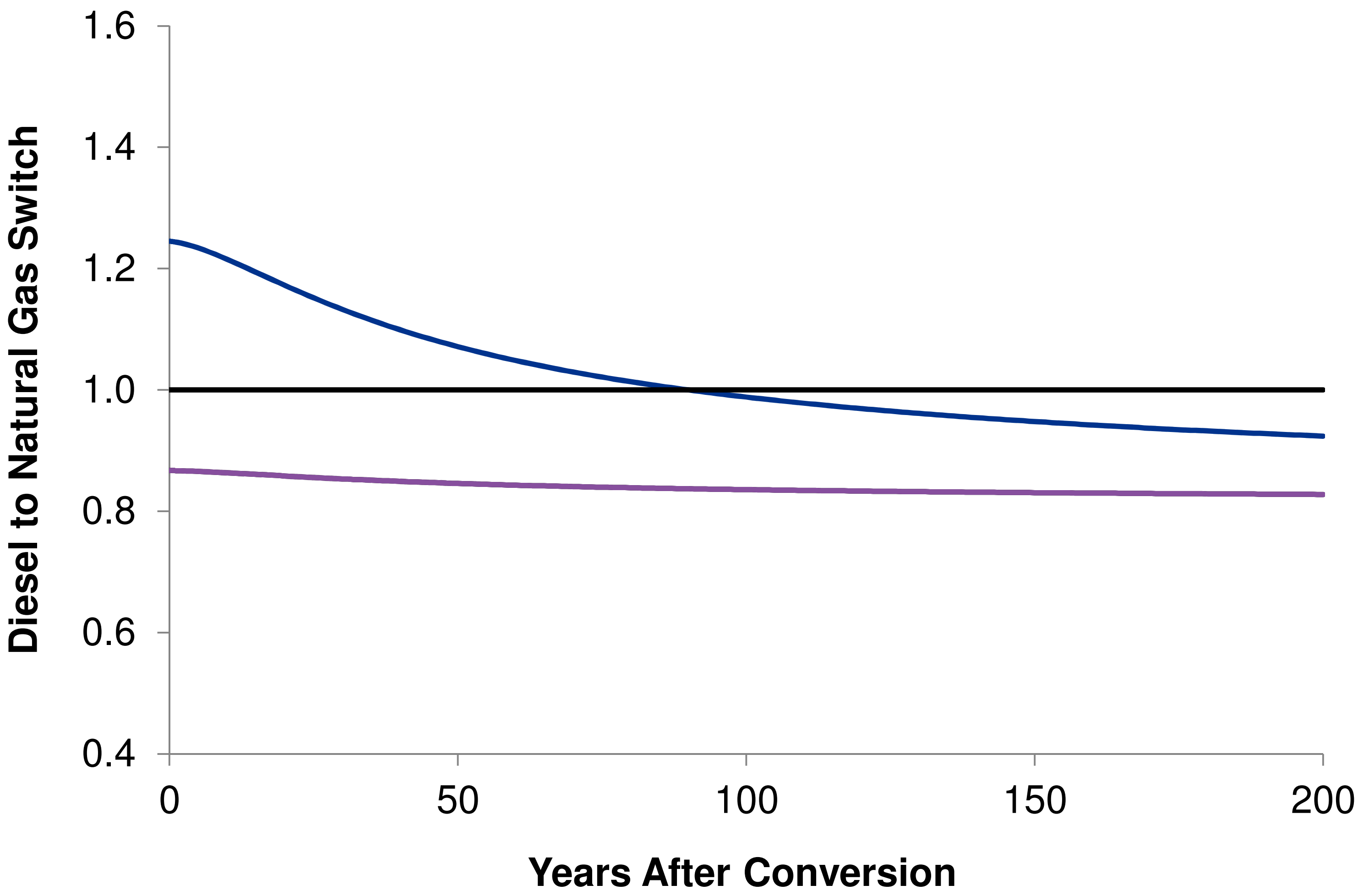
What if natural gas trucks were as efficient as diesel trucks?



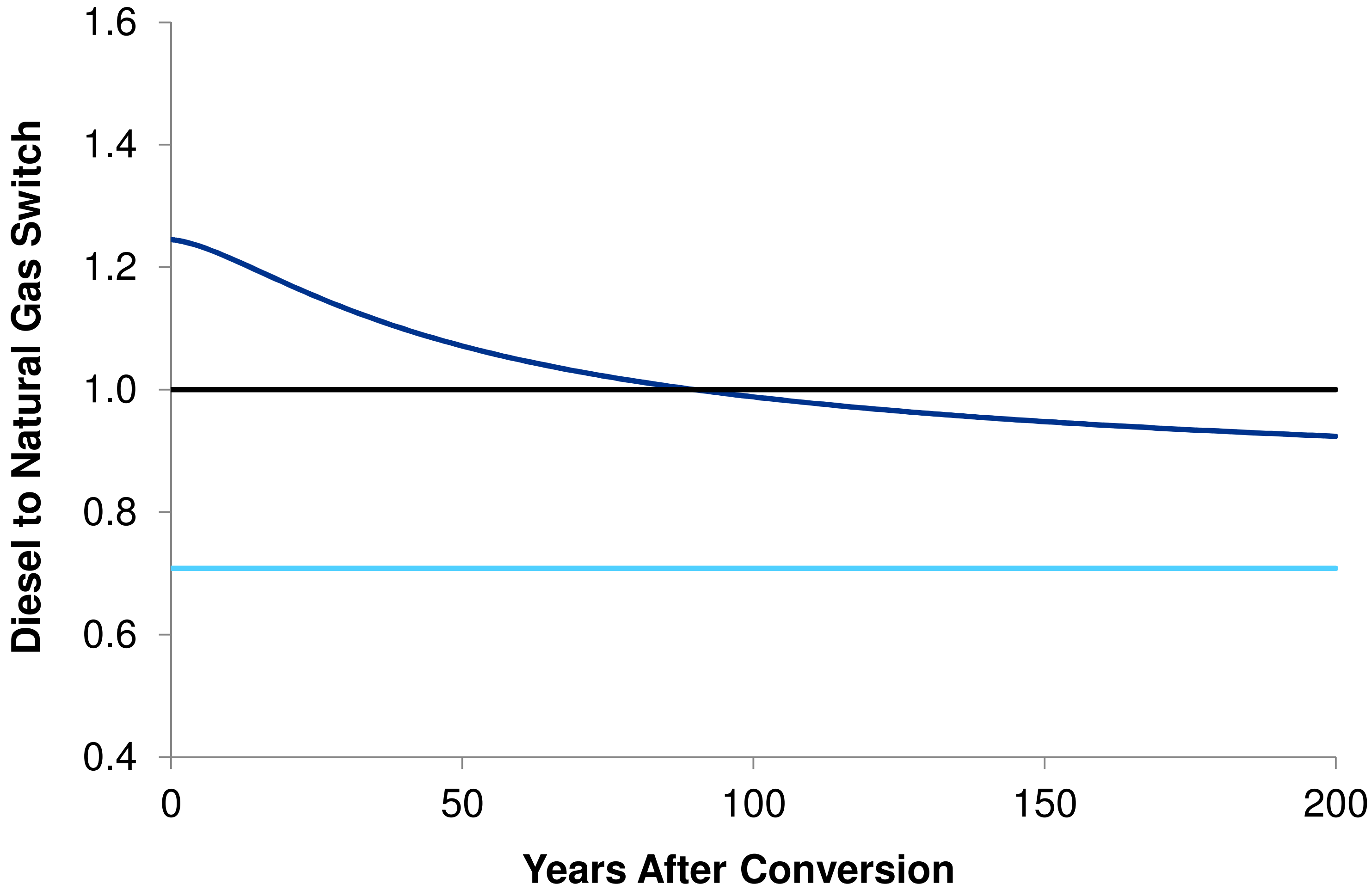
What if there were no methane emissions at the vehicle level?

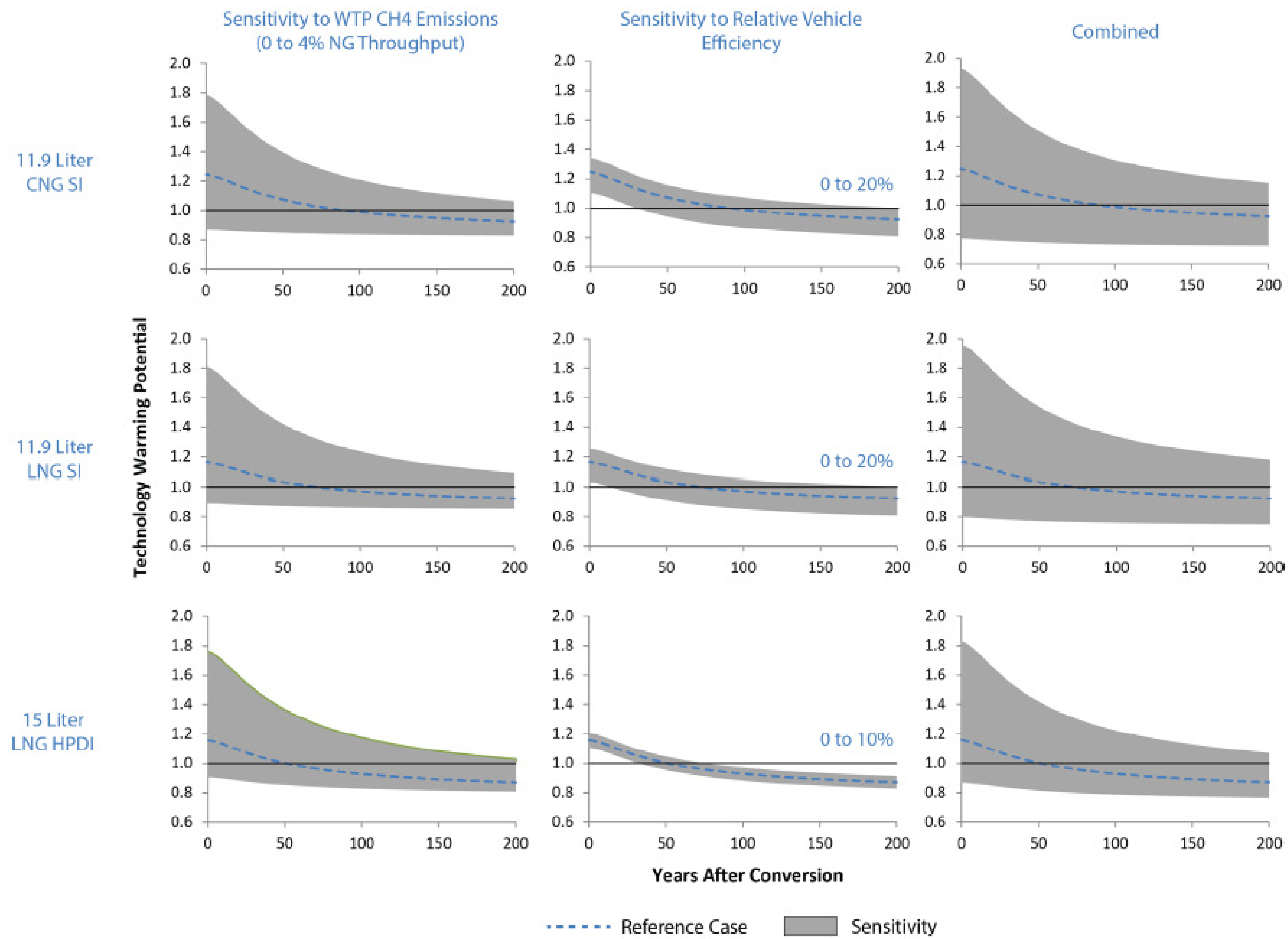


What if there were no methane emissions upstream?



What if we combine efficiency improvements and methane emissions reductions?





Camuzeaux et al., *Environ. Sci. Technol.*, **2015**; DOI: 10.1021/acs.est.5b00412 (Pump-to-Wheels Emissions fixed at 0.6% and 1.0 for SI and HPDI cases, respectively)

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Different Pathways for Each End Use

Natural Gas Production & Processing

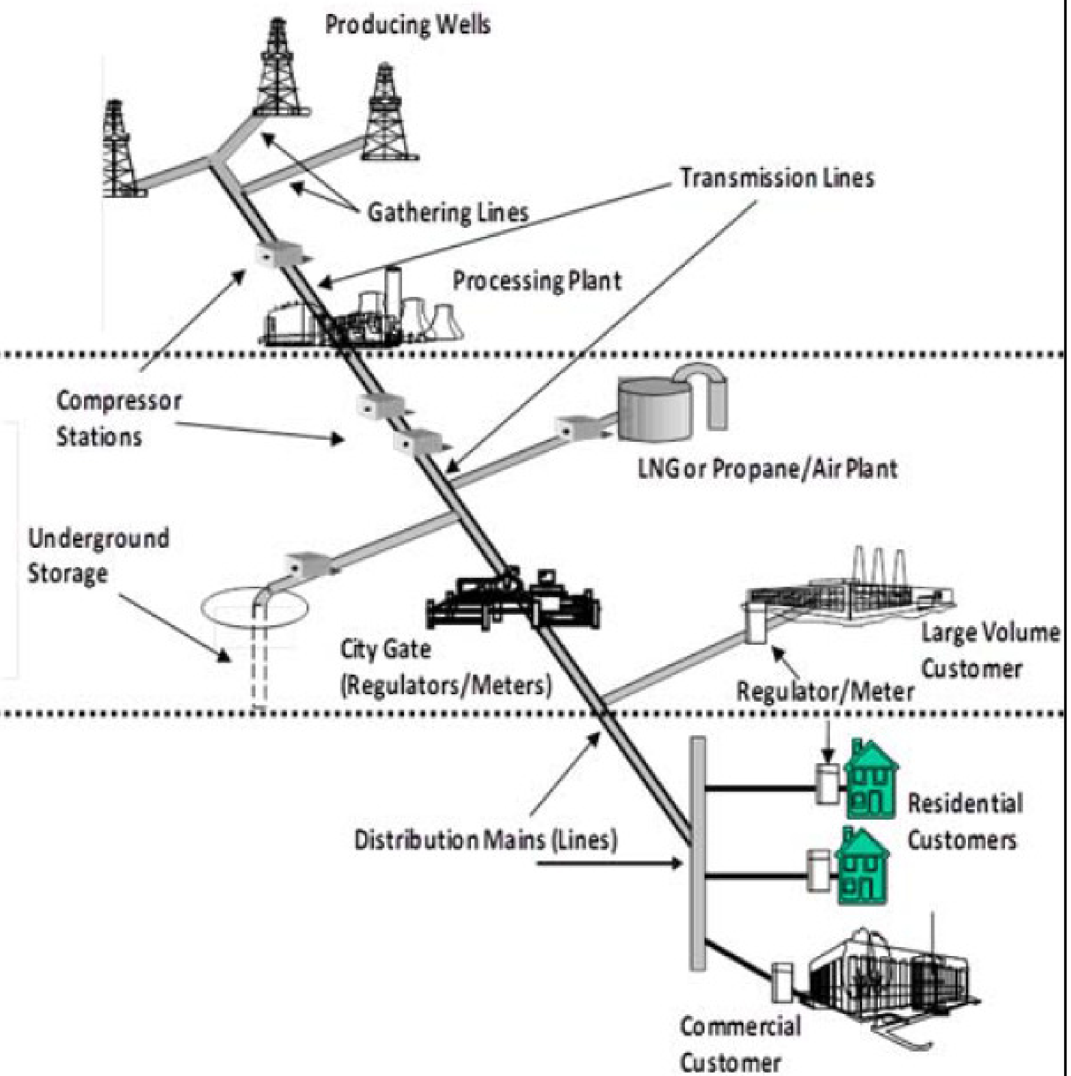
- Well completions, blowdowns, and workovers
- Reciprocating compressor rod packing
- Processing plant leaks
- Gas-driven pneumatic devices
- Venting from glycol reboilers on dehydrators

Gas Transmission

- Venting of gas for maintenance or repair of pipelines or compressors
- Centrifugal compressor seal oil de-gassing
- Leaks from pipelines, compressor stations

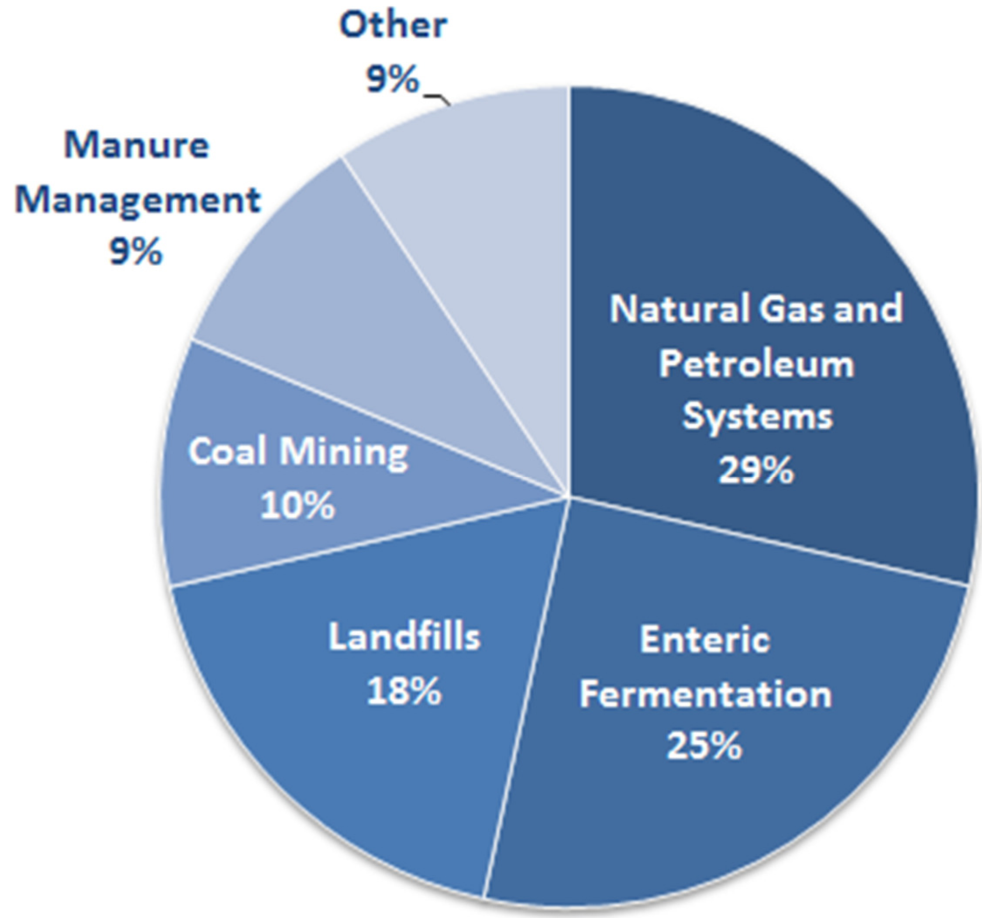
Gas Distribution

- Leaks from unprotected steel mains and service lines
- Leaks at metering and regulating stations
- Pipeline blowdowns



Sources: American Gas Association; EPA Natural Gas STAR Program

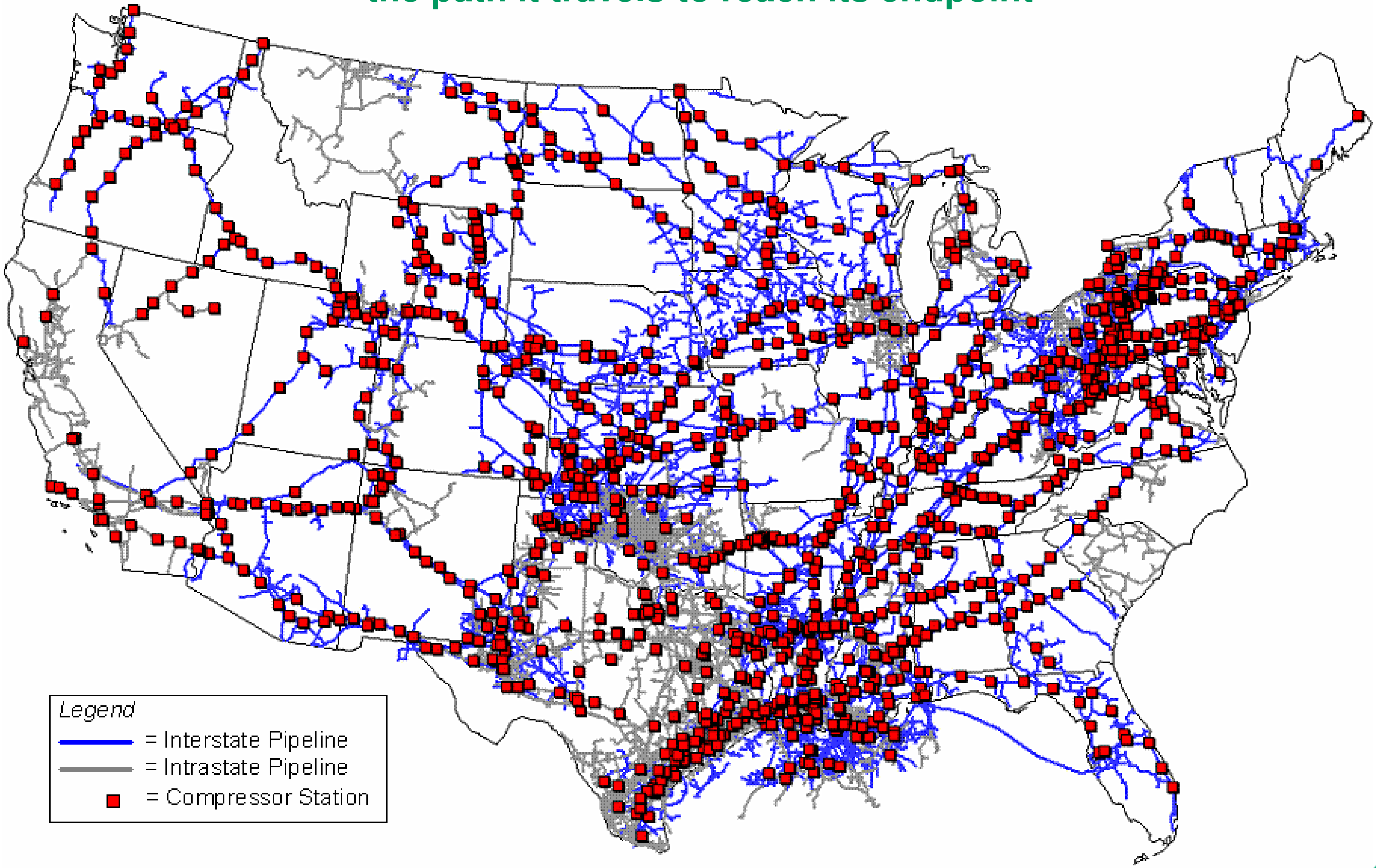
Natural gas and petroleum systems are the largest industrial methane source.



US EPA. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2012 (April 2014)

http://www.epa.gov/climatechange/ghgemissions/usinventoryreport.html

Emissions assessments must take into account the source of the energy and the path it travels to reach its endpoint



Source: Energy Information Administration, Office of Oil & Gas, Natural Gas Division, Natural Gas Transportation Information System.

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EDF Catalyzing More Science

16 Studies with Roughly 100 Participants

- 4 Local Distribution,
- 3 Production,
- 3 Top-Down, and
- 6 Other

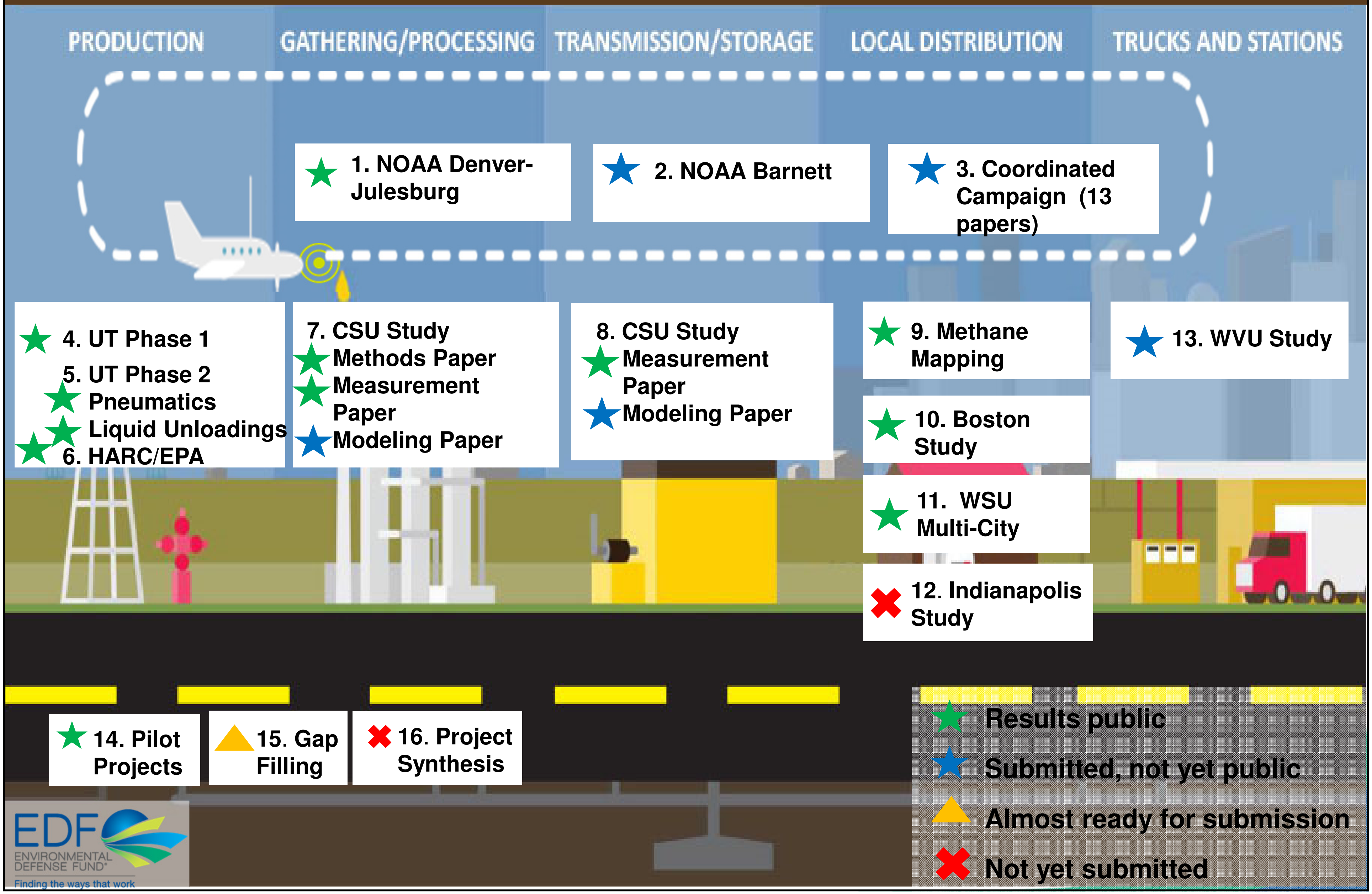
5 common principles:

- Led by academic scientists
- Employ multiple methodologies where possible
- Input from independent scientific experts
- Make all data public to ensure transparency
- Publish results in a peer reviewed journal

STUDY RESULTS THUS FAR:
http://www.edf.org/climate/methane-studies

EDF STUDIES BY SUPPLY CHAIN SEGMENT

(roughly 30 total papers)



Lessons Learned from the Studies Thus Far

- Significant emissions exist across the natural gas supply chain
- Smart regulations work
- Super-emitters exist
- Technology exists to reduce emissions

EDF Methane Studies (2012-2015)

Results of 10 studies publically available:

- **Production Study: Phase 1**
  - Allen, David T. et al. "Measurements of methane emissions at natural gas production sites in the United States." *Proc. Natl. Acad. Sci. U.S.A* **2013**, *110,*17768-17773 (DOI: 10.1073/pnas.1304880110)
- **Production Study: Phase 2**
  - Allen, David T. et al. “Methane emissions from process equipment at natural gas production sites in the United States: Pneumatic controllers.” *Environ. Sci. Technol.* **2015**, *49*, 633–640 (DOI: 10.1021/es5040156)
  - Allen, David T. et al. “Methane emissions from process equipment at natural gas production sites in the United States: Liquid Unloadings.” *Environ. Sci. Technol.* **2015**, *49*, 641–648 (DOI: 10.1021/es504016r)
- **Production Data Analysis**
  - Brantley, Halley L. et al., “Assessment of Methane Emissions from Oil and Gas Production Pads using Mobile Measurements” *Environ. Sci. Technol.* **2014**, *48*, 14508-14515 (DOI: 10.1021/es503070q)

EDF Methane Studies (2012-2015)

- **Denver-Julesburg Flyover Study**
  - Pétron, Gabrielle, et al. "A new look at methane and nonmethane hydrocarbon emissions from oil and natural gas operations in the Colorado Denver-Julesburg Basin." *Journal of Geophysical Research: Atmospheres* **2014** (DOI: 10.1002/2013JD021272).
- **Gathering and Processing (national implications still to come)**
  - Mitchell, Austin. L. et al. “Measurements of methane emissions from natural gas gathering facilities and processing plants: Part 2. Measurement results.” *Environ. Sci. Technol.* **2015**, *49*, 3219-3227 (DOI 10.1021/es5052809).
- **Transmission and Storage (national implications still to come)**
  - Subramanian, R., et al. "Methane Emissions from Natural Gas Compressor Stations in the Transmission and Storage Sector: Measurements and Comparisons with the EPA Greenhouse Gas Reporting Program Protocol." *Environ. Sci. Technol.* **2015**, 49, 3252-3261 (DOI: 10.1021/es5060258).

EDF Methane Studies (2012-2015)

- **Boston Study**
  - McKain, Kathryn et al., "Methane emissions from natural gas infrastructure and use in the urban region of Boston, Massachusetts" *Proc. Natl. Acad. Sci. U.S.A* **2015**, *112*,1941-1946 (DOI: 10.1073/pnas.1416261112)
- **Multi-City Local Distribution Study**
  - Lamb, Brian K. et al. "Direct Measurements Show Decreasing Methane Emissions from Natural Gas Local Distribution Systems in the United States." *Environ. Sci. Technol.* **2015**, *49*, 5161-5169 (DOI: 10.1021/es505116p).
- **EDF/Google Earth Outreach Methane Mapping Project**
  - Maps viewable at www.edf.org/climate/methanemaps
  - Los Angeles area maps released on May 14, 2015
- **Pilot Projects**

1. University of Texas-Austin
Production study – phase I

This study measured methane emissions during production of natural gas—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.

Available at: http://www.pnas.org/content/110/44/17768

2. University of Texas-Austin
Production study – phase II

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.

The study found: that emissions from two sources-- pneumatics and liquids unloadings—were responsible for a significant portion of methane emissions from the production sector.

Available at: http://pubs.acs.org/doi/abs/10.1021/es5040156

3. Houston Advanced Research Center and U.S. EPA

Study on production data

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.

The study found: that a statistical analysis of this data suggests unpredictable events, such as malfunctions and maintenance, have a strong influence on emission rates.

Available at: http://pubs.acs.org/doi/abs/10.1021/es503070q

4. Colorado State Univ. and Carnegie Mellon Univ.
Gathering and processing study

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.

Initial findings from the measurement report show: wide variations in the amount of methane leaking at U.S. gathering and processing facilities. Researchers with the study suggest leak detection and repair policies can be effective at minimizing emissions from these sources. A forthcoming paper will estimate nationwide leaks from this sector.

Available at: http://pubs.acs.org/doi/abs/10.1021/es5052809

5. NOAA, CU-Boulder

Denver flyover study, Colorado

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 that: 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.

Available at: http://onlinelibrary.wiley.com/doi/10.1002/2013JD021272/pdf

6. NOAA, UC-Boulder and Univ. of Mich.
Barnett shale flyover study, Texas

As part of a broader project (No. 5), scientists with the National Oceanic and Atmospheric Administration and the UC-Boulder's Cooperative Institute for Research in Environmental Sciences are measuring atmospheric concentrations of hydrocarbons in order to quantify regional methane emissions in an active oil-and gas basin that includes infrastructure from production through distribution. The study includes modeling emissions from this sector under differing growth scenarios.

7. Coordinated research campaign
Barnett shale basin study, Texas

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. Gathering this data with a variety of techniques allows us to compare methodologies and gain new insights, including better understanding the differences between top-down and bottom-up techniques.

8. Colorado State Univ., Carnegie Mellon Univ., Aerodyne Research
Transmission and storage study

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 that: 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, that paper has not yet been published.

Available at: http://pubs.acs.org/doi/abs/10.1021/es5060258

9. Washington State University
Multi-city local distribution study

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.

<u>The study shows:</u> 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.

Available at http://pubs.acs.org/doi/abs/10.1021/es505116p

10. Harvard, Boston and Duke Univ's with Aerodyne Research and Atmospheric and Environmental Research

Boston local distribution study

Recognizing that detailed estimates of methane emissions from specific urban natural gas systems will provide important insights, Boston University, Duke University and Harvard University scientists developed an innovative tower-based quantitative technique for use in the urban environment. They conducted this work in the Greater Boston area where an old gas distribution infrastructure is believed to cause higher emissions rates than cities with newer infrastructure.

University scientists developed an innovative tower-based quantitative technique for use in the urban environment.

The study found that: 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.

Available at: http://www.pnas.org/content/112/7/1941.abstract

11. Washington State Univ.
Indianapolis local distribution study

To gain further regional insights of local distribution methane leaks, Washington State University is coordinating with the National Institute of Standards and Technology to measure methane lost from the gas utility infrastructure in Indianapolis, which is part of a broader NIST project.

12. Colorado State University
Methane mapping

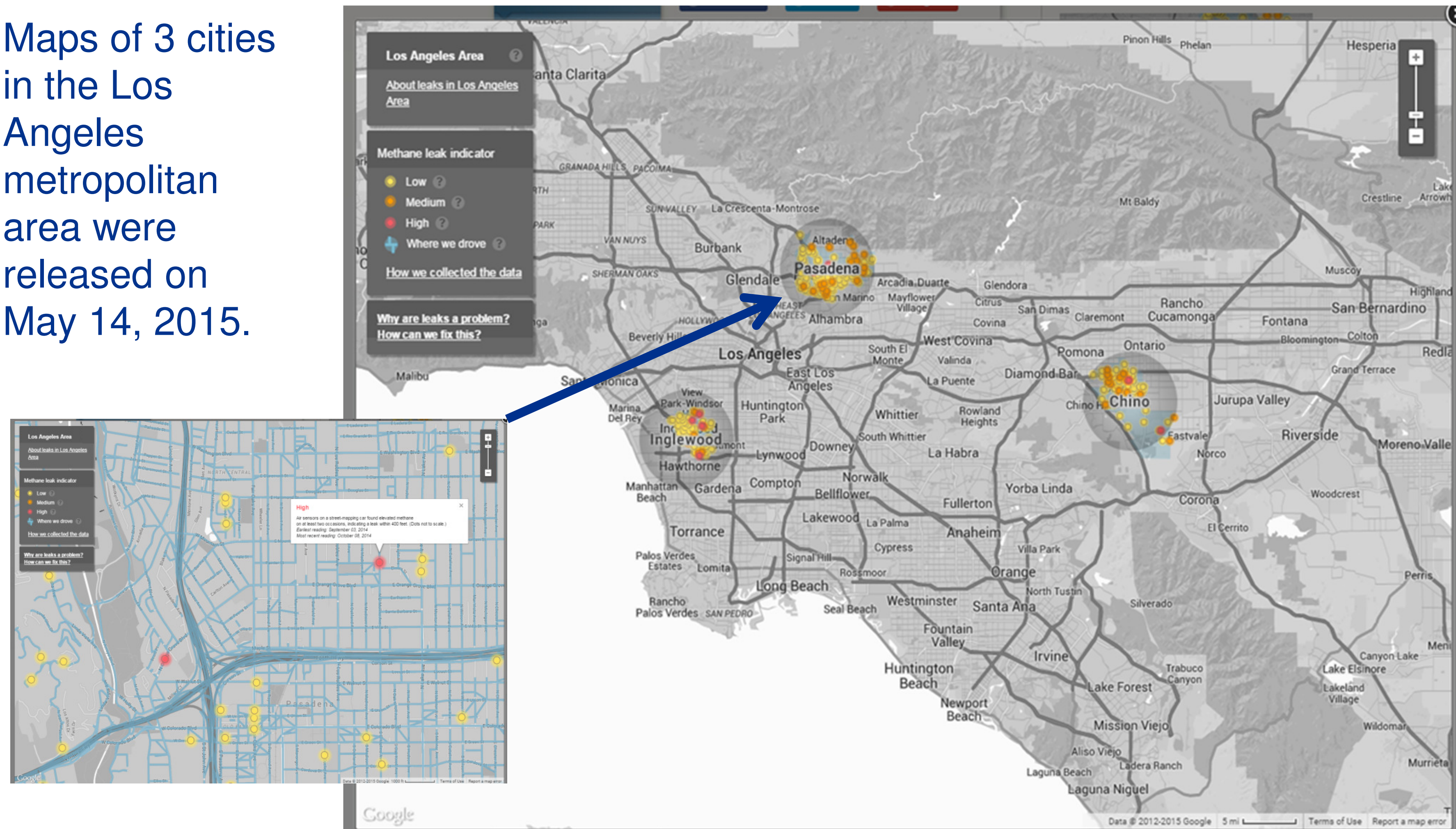
Using mobile methane sensors, EDF partnered with Google to map methane emissions from pipelines under city streets. Led by researchers at Colorado State University, this method quantifies methane leaks from local distribution systems that utilities could use to identify and prioritize repair or replacement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

As of May 2015, the project has mapped leaks in:
Syracuse, Boston, Staten Island, Indianapolis, Burlington, parts of the Los Angeles basin. *(Chicago coming soon)*

Maps are viewable at **www.edf.org/methanemaps**

12 (a). Colorado State University
Methane mapping in Los Angeles

Maps of 3 cities in the Los Angeles metropolitan area were released on May 14, 2015.



12 (a). Colorado State University
Methane mapping in Los Angeles

- All cities mapped are in the SoCalGas territory – SCG has approx. 1 leak per every 4 or 5 miles
- Study confirms the super-emitter phenomenon exists in So. California – the majority of leaks are rather small, but some leaks are very large
- Some of the largest leaks observed in the entire multi-year study (5 other cities) have been found in the SoCalGas territory
- Under current policies, these leaks are allowed to persist – even though we know where they are and how big they are. Study confirms California needs stronger leak reduction policies and a larger investment in new technology and better methods (ex. quantification for prioritization)

13. West Virginia University
Pump-to-wheels study

WVU's Center for Alternative Fuels, Engines and Emissions is leading a study in cooperation with 10 companies and a research organization 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. The study includes modeling emissions from this sector under differing growth scenarios.

14. Filling gaps, including super emitters

The main objective of this effort is to address knowledge gaps not addressed by the other studies, including whether “superemitting” sites or sources produce a large share of emissions. Field work for this study was undertaken in late 2013.

15. 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.

16. Pilot Projects

Three initial projects helped build the foundation for this research series.

- 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 Barnett Coordinated Campaign, 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.

- University of Colorado-Boulder scientists conducted research to identify elevated levels of methane and hydrogen sulfide that provided insights or subsequent overflight work.

EDF Methane Studies (2012-2015)

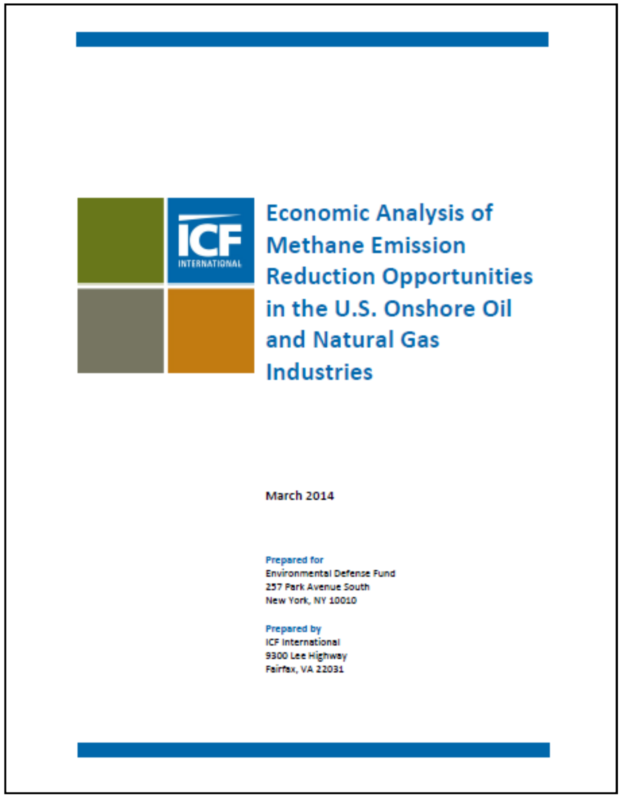
Publishing still to come:

- Barnett Shale Flyover Study (in review, likely July)
- Barnett Campaign (in review, likely July)
- Pump-to-Wheels (in review)
- Indianapolis Study (in preparation)
- Gap filling projects (in preparation)
- Project Synthesis

3 Other studies of Interest

ICF Consulting Methane Cost Curve Report (March 2014)

Cost-effective solutions exist for oil and gas industry to reduce methane emissions


Economic Analysis of Methane Emission Reduction Opportunities in the U.S. Onshore Oil and Natural Gas Industries

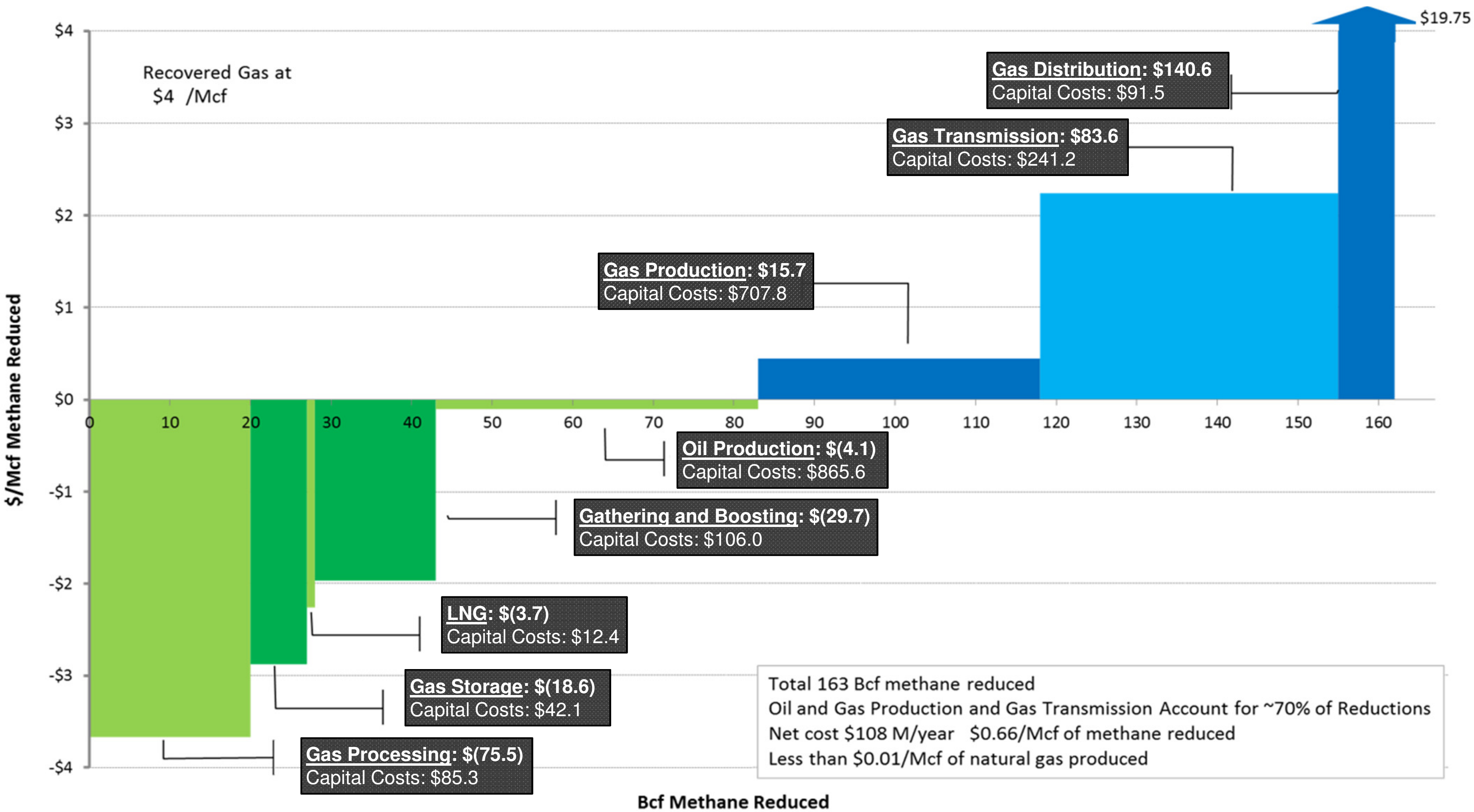
March 2014

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

Prepared by
ICF International
9300 Lee Highway
Fairfax, VA 22031

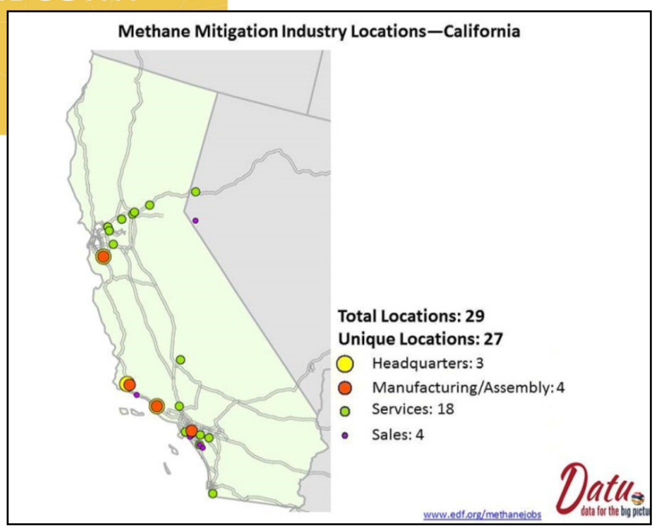
Available at www.edf.org/energy/icf-methane-cost-curve-report

Methane solutions area cost-effective



ICF Analysis: 40% of emissions can be reduced for a penny per mcf of gas

Methane Jobs Report



2014 Report that identified 76 companies nationwide – more than half small businesses – that manufacture methane controls or offer related services from over 500 different locations across 46 states.

Available at:
www.edf.org/methanejobs

EDF Methane Detectors Challenge

The Goal:

- Catalyze the market for **low-cost** continuous methane detectors to **limit leaks** from O&G well pads and compressors

Approach:

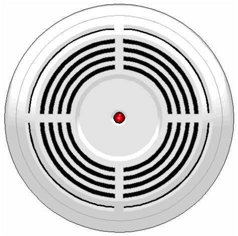
- Define user (O&G company) needs
- Bring together tech supply and demand
- Provide rigorous independent testing
- Pilot best technologies and track results

Timeframe:

- RFP Released: April 3
- Response Due: June 17
- Testing Begins: July 2014 at Southwest Research Institute
- Industry Pilots: September 2015

EDF's Industry Partners

HESS, Shell, Apache, noble energy, SWN Southwestern Energy, BG GROUP, Anadarko Petroleum Corporation



Three quantification methods

- Direct measurements of components
  - Quantification of flow rate and methane content
- Near-field measurements of plumes
  - Tracer correlation
  - Inverse dispersion modeling
- Regional measurements of well-mixed air
  - Aircraft-based mass balance
  - Tower-based inverse modeling

Emerging Insights

- Skewed distributions
- National/Global top-down studies suggest leakage likely in the range of 2-4%
  - Regional variability evident
- Opportunities to reduce emissions
  - Lower emitting equipment and practices
  - Detecting and fixing malfunctioning equipment

Presentation Roadmap

1. **Background on the importance of value chain leakage assessments**
2. **Changing value chain leakage assessments based on end use**
3. **EDF's Scientific Efforts to Quantify Natural Gas Methane Leakage**
   – Completed
   – Upcoming
4. **Putting it all together**
   – Leakage science
   – Relevance for California policies and the IEPR

For additional information:

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