Still A Bridge to Nowhere: Methane Emissions and the Greenhouse Gas Footprint of Natural Gas

Bob Howarth and Tony Ingraffea
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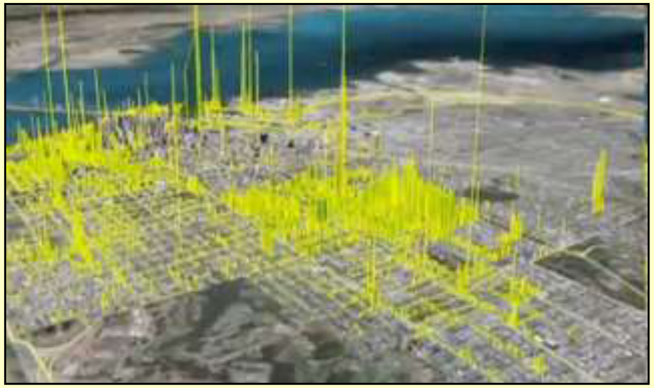
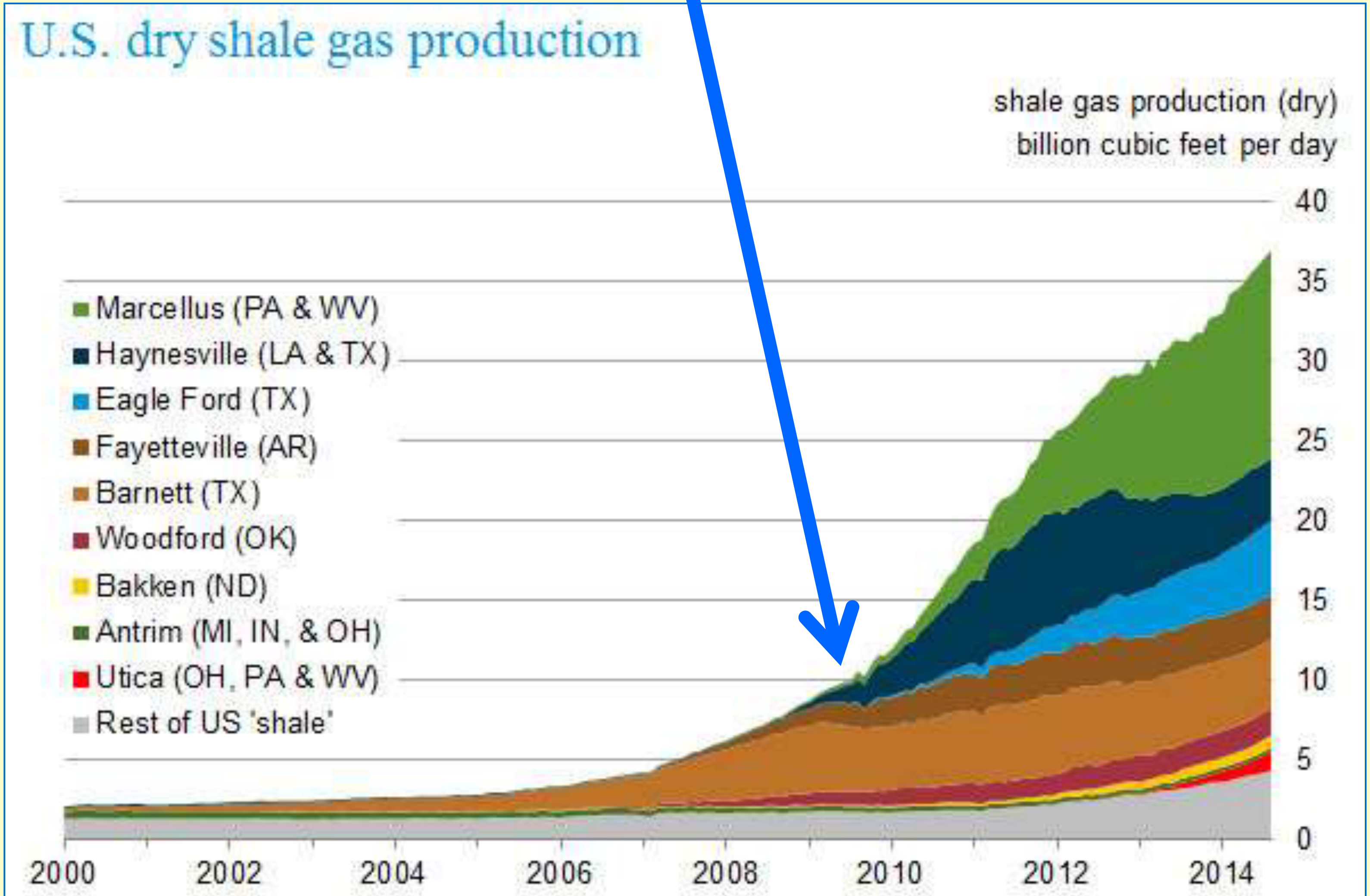
and Dwight C. Baum Professor of Engineering Emeritus
Cornell University, Ithaca, NY USA

School of Civil & Environmental Engineering Seminar Series
Cornell University
April 14, 2015

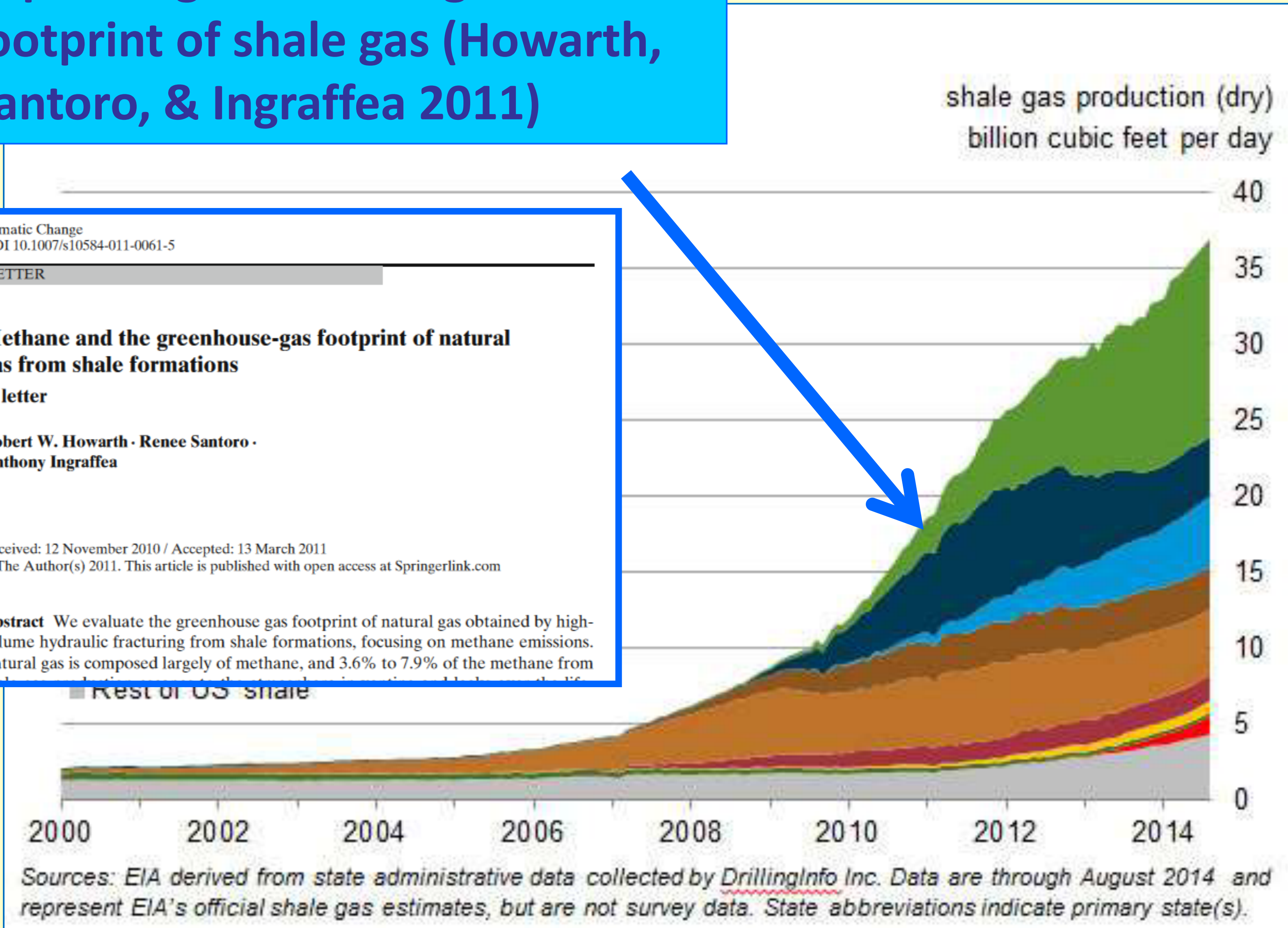


Approximate time Tony Ingraffea, Renee Santoro, and I started working on greenhouse gas footprint of shale gas



Sources: EIA derived from state administrative data collected by DrillingInfo Inc. Data are through August 2014 and represent EIA's official shale gas estimates, but are not survey data. State abbreviations indicate primary state(s).

Publication of first peer-reviewed paper on greenhouse gas footprint of shale gas (Howarth, Santoro, & Ingraffea 2011)



Climatic Change
DOI 10.1007/s10584-011-0061-5

LETTER

Methane and the greenhouse-gas footprint of natural gas from shale formations

A letter

Robert W. Howarth · Renee Santoro · Anthony Ingraffea

Received: 12 November 2010 / Accepted: 13 March 2011

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Keywords Methane · Greenhouse gases · Global warming · Natural gas · Shale gas · Unconventional gas · Fugitive emissions · Lifecycle analysis · LCA · Bridge fuel · Transitional fuel · Global warming potential · GWP

Electronic supplementary material The online version of this article (doi:10.1007/s10584-011-0061-5) contains supplementary material, which is available to authorized users.

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Is natural gas a “bridge fuel?”

For just the release of carbon dioxide during combustion…..

	g C of CO_2 MJ^{-1} of energy
Natural gas	15
Diesel oil	20
Coal	25

(Hayhoe et al. 2002)

Methane emissions – the Achilles' heel of natural gas

- Natural gas is mostly methane.

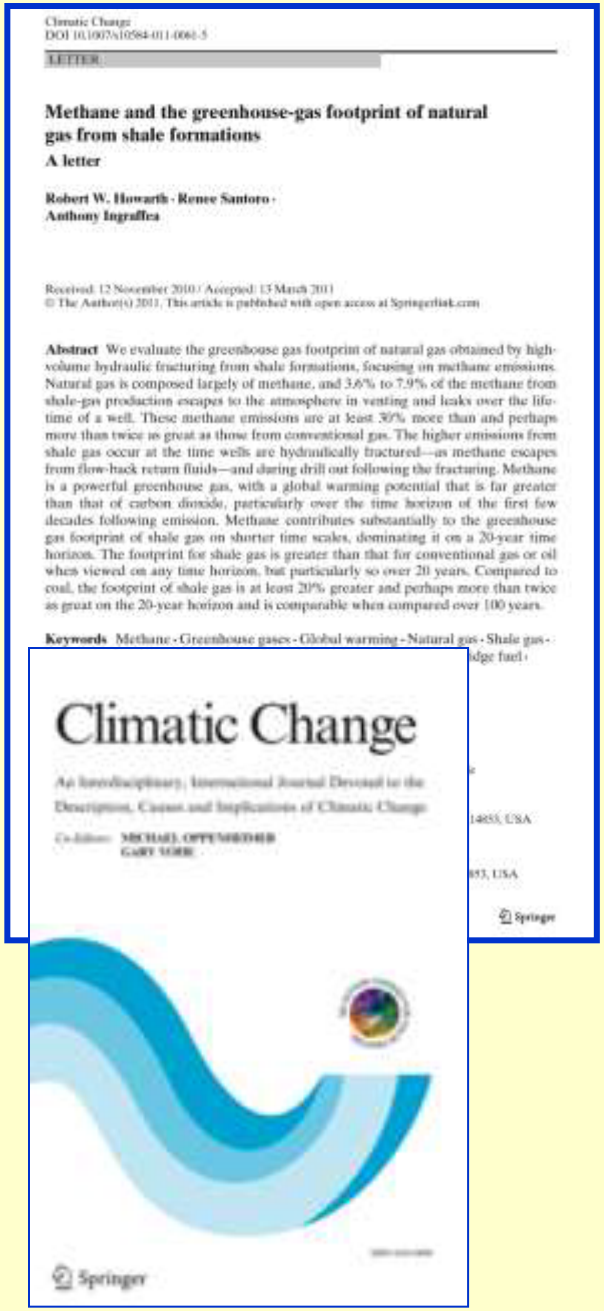
- Methane is 2nd most important gas behind human-caused global warming.

- Methane is much more potent greenhouse gas than carbon dioxide, so even small emissions matter.

Methane emissions

(full life-cycle, well site to consumer), shown chronologically by date of publication (% of life-time production of well)

	Conventional gas	Shale gas
EPA (1996, through 2010)	1.1 %	-----
Hayhoe et al. (2002)	3.8 %	-----
Jamarillo et al. (2007)	1.0 %	-----
Howarth et al. (2011)	3.8 % (1.6 – 6.0)	5.8 % (3.6 – 7.9)



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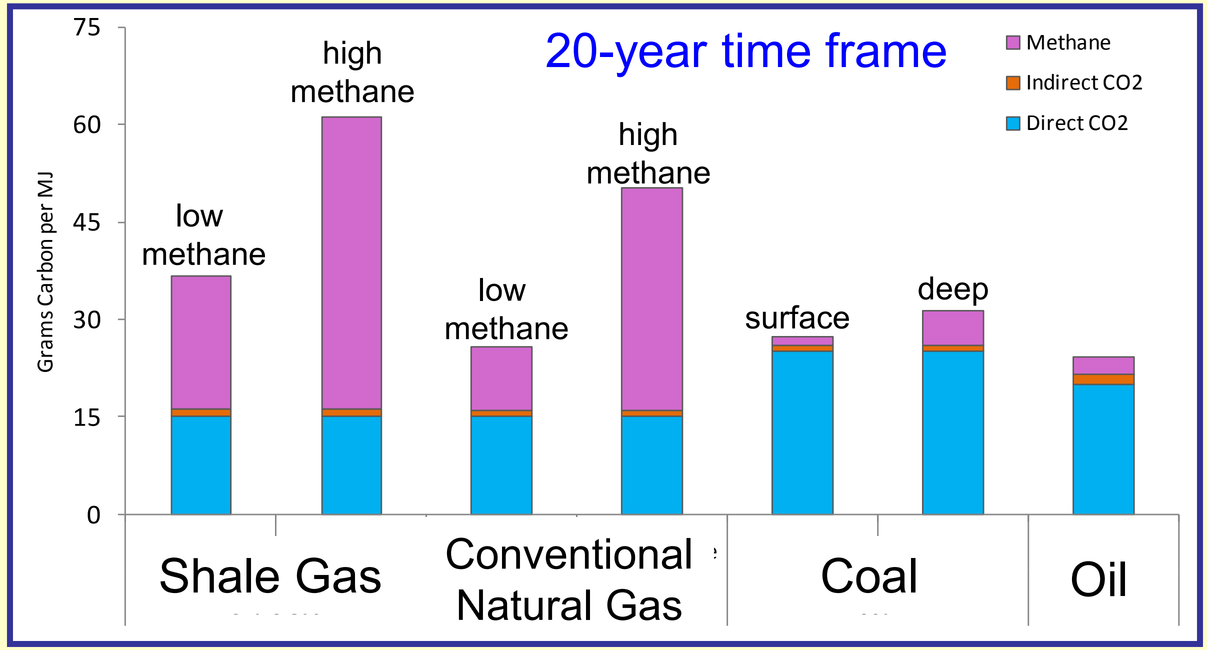

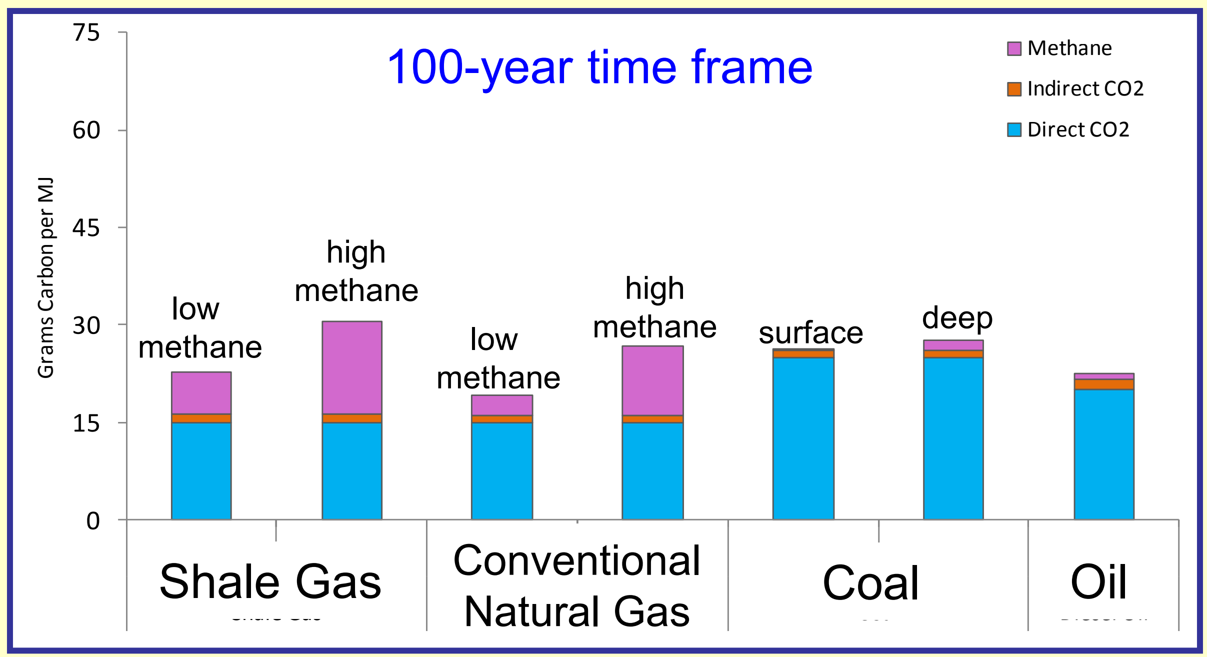

The New York Times

Poking Holes in a Green Image
Tom Zeller
April 11, 2011

"The old dogma of natural gas being better than coal in terms of greenhouse gas emissions gets stated over and over without qualification," said Robert Howarth, a professor of ecology and environmental biology at Cornell University and the lead author ………

"I don't think this is the end of the story," said Mr. Howarth, who is an opponent of growing gas development in western New York. "I think this is just the beginning of the story, and before governments and the industry push ahead on gas development, at the very least we ought to do a better job of making measurements."

The findings are certain to stir debate. For much of the last decade, the natural gas industry has carefully cultivated a green reputation, often with the help of environmental groups that embrace the resource as a clean-burning "bridge fuel" to a renewable energy future.

TIME Person of the Year

People who Mattered

Mark Ruffalo, Anthony Ingraffea, Robert Howarth
By Bryan Walsh Wednesday, Dec. 14, 2011

The biggest environmental issue of 2011 — at least in the U.S. — wasn't global warming. It was hydraulic fracturing, and these three men helped represent the determined opposition to what's more commonly known as fracking. **Anthony Ingraffea** is an engineer at Cornell University who is willing to go anywhere to talk to audiences about the geologic risks of fracking, raising questions about the threats that shale gas drilling could pose to water supplies. **Robert Howarth** is his colleague at Cornell, an ecologist who produced one of the most controversial scientific studies of the year: **a paper arguing that natural gas produced by fracking may actually have a bigger greenhouse gas footprint than coal. That study — strenuously opposed by the gas industry and many of Howarth's fellow scientists — undercut shale gas's major claim as a clean fuel**. And while he's best known for his laidback hipster performances in films like *The Kids Are All Right*, Mark Ruffalo emerged as a tireless, serious activist against fracking — especially in his home state of New York.

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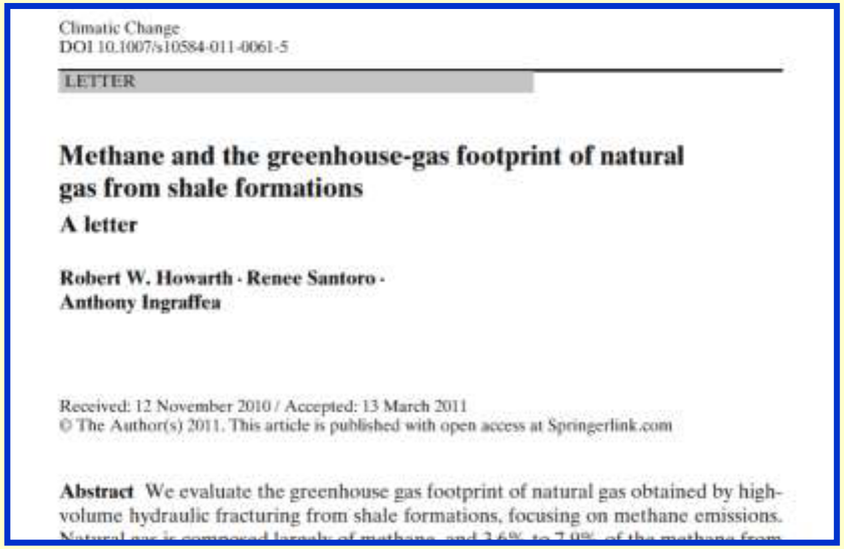
Other "People who Mattered" in 2011:

Newt Gingrich, Osama bin Laden, Joe Paterno, Adele, Mitt Romney, Muammar Gaddafi, Barack Obama, Bill McKibben, Herman Cain, Rupert Murdoch, Vladimir Putin, Benjamin Netanyahu…

What more has been learned or reported in the past 4 years?

And how well has our original study fared?



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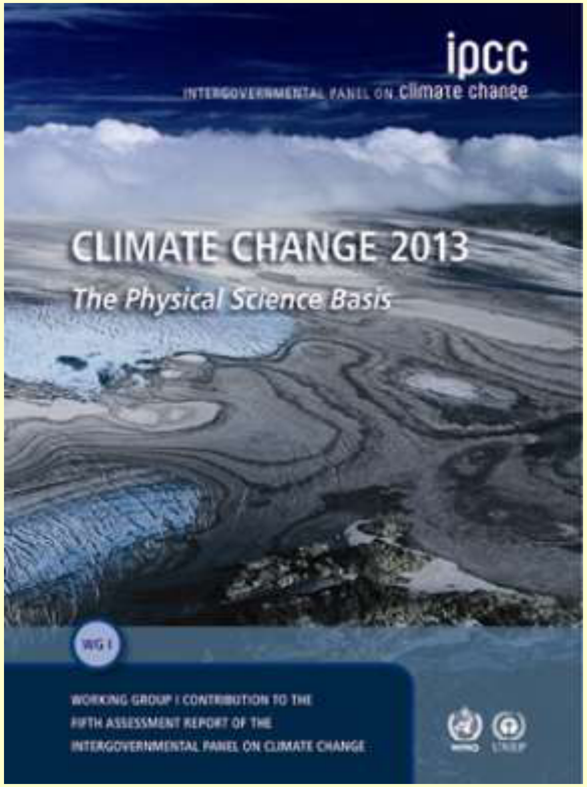
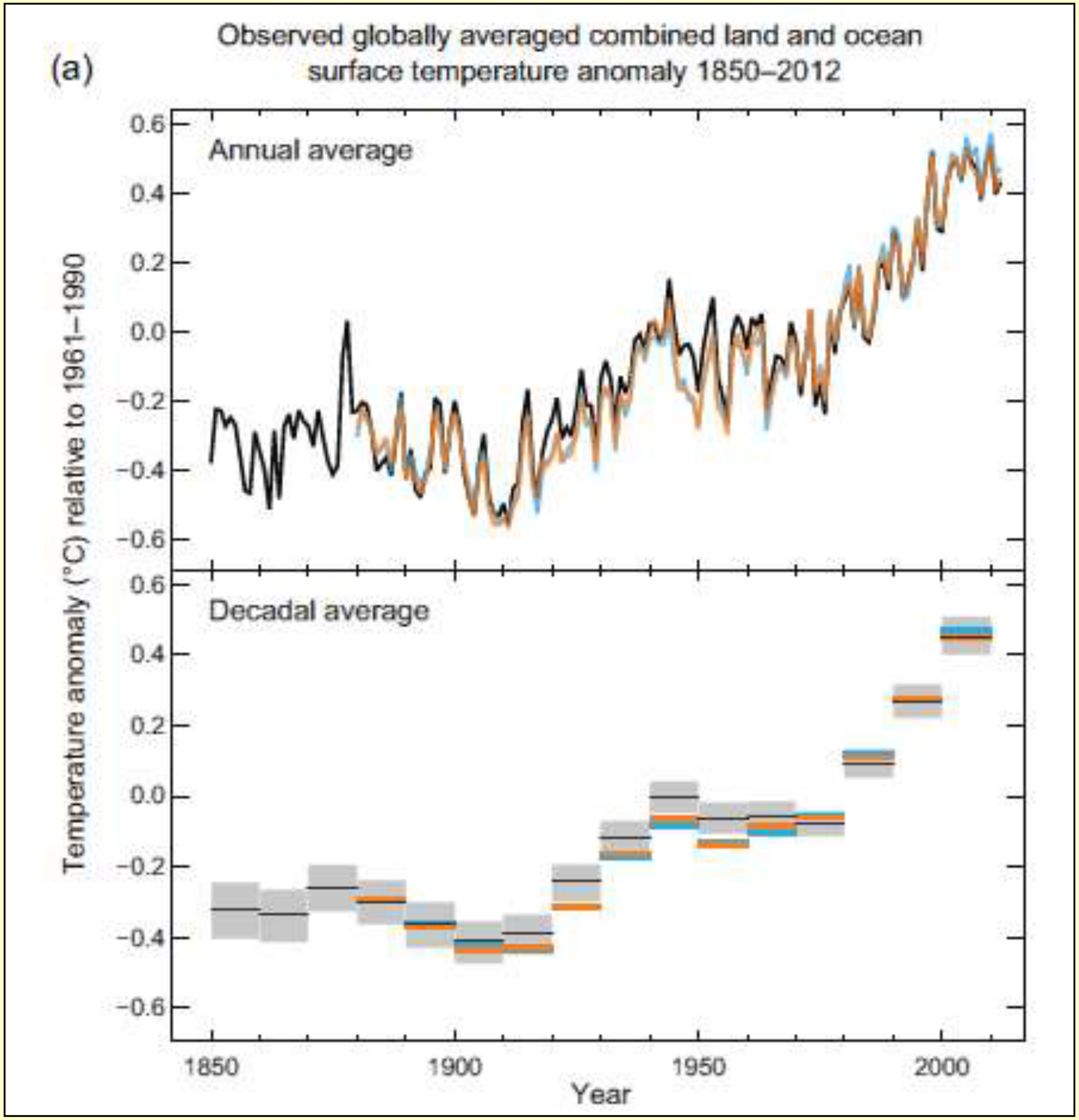
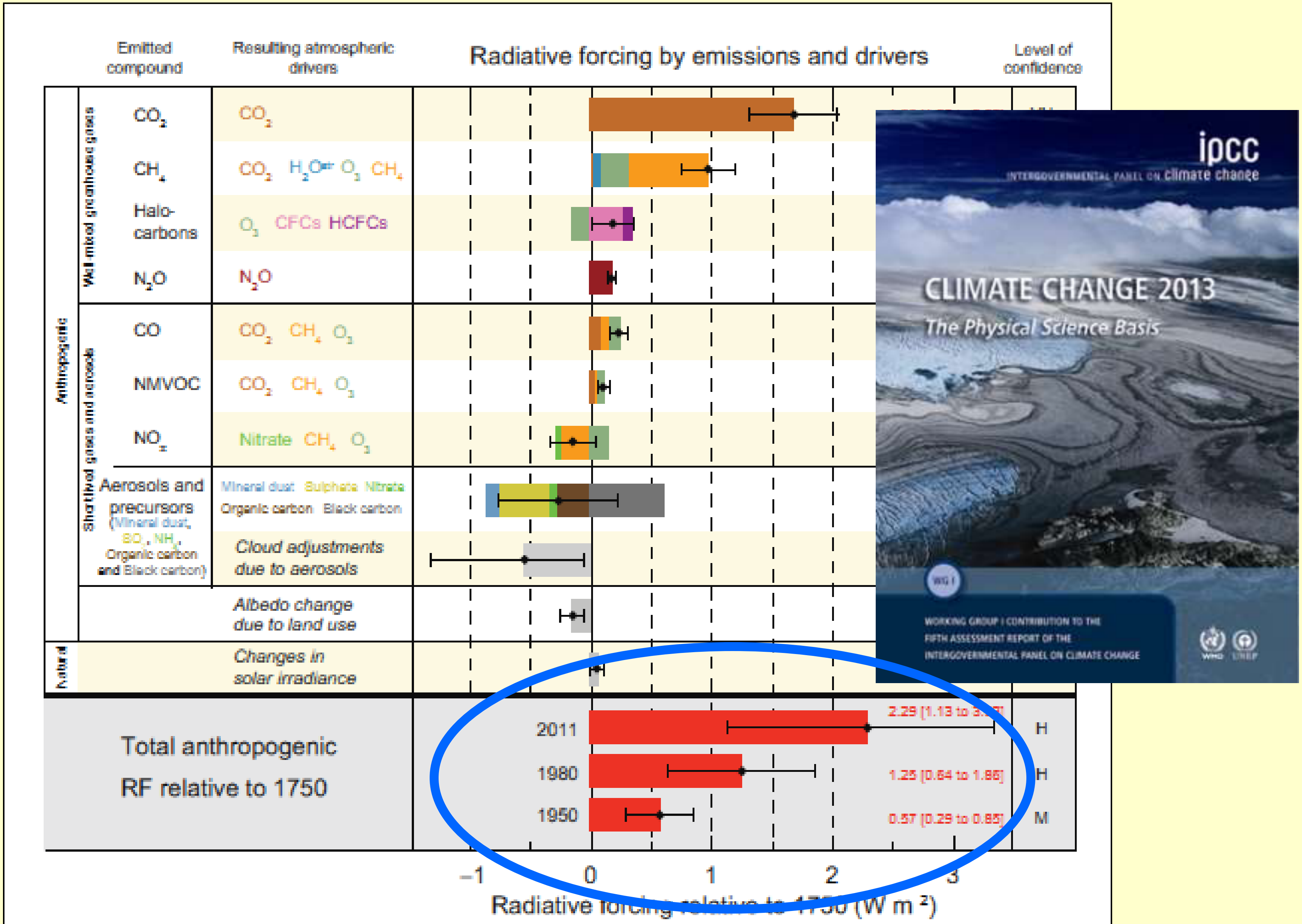




Each of the past 3 decades has consecutively been the warmest in past 120,000 years.

Rate of warming is the fastest ever on Earth.


Emitted compound
Resulting atmospheric drivers
Radiative forcing by emissions and drivers
Level of confidence
Anthropogenic
Well-mixed greenhouse gases
CO2
CH4
Halo-carbons
N2O
H2O
O3
CFCs HCFCs
Short lived gases and aerosols
CO
NMVOC
NOx
Nitrate
Aerosols and precursors
(Mineral dust, SO2, NH3, Organic carbon and Black carbon)
Mineral dust Sulphate Nitrate
Organic carbon Black carbon
Cloud adjustments due to aerosols
Albedo change due to land use
Natural
Changes in solar irradiance
Total anthropogenic RF relative to 1750
2011
1980
1950
1.25 [0.64 to 1.86]
0.57 [0.29 to 0.85]
H
H
M
−1
0
1
2
3
Radiative forcing relative to 1750 (W m−2)
ipcc
INTERGOVERNMENTAL PANEL ON climate change
CLIMATE CHANGE 2013
The Physical Science Basis
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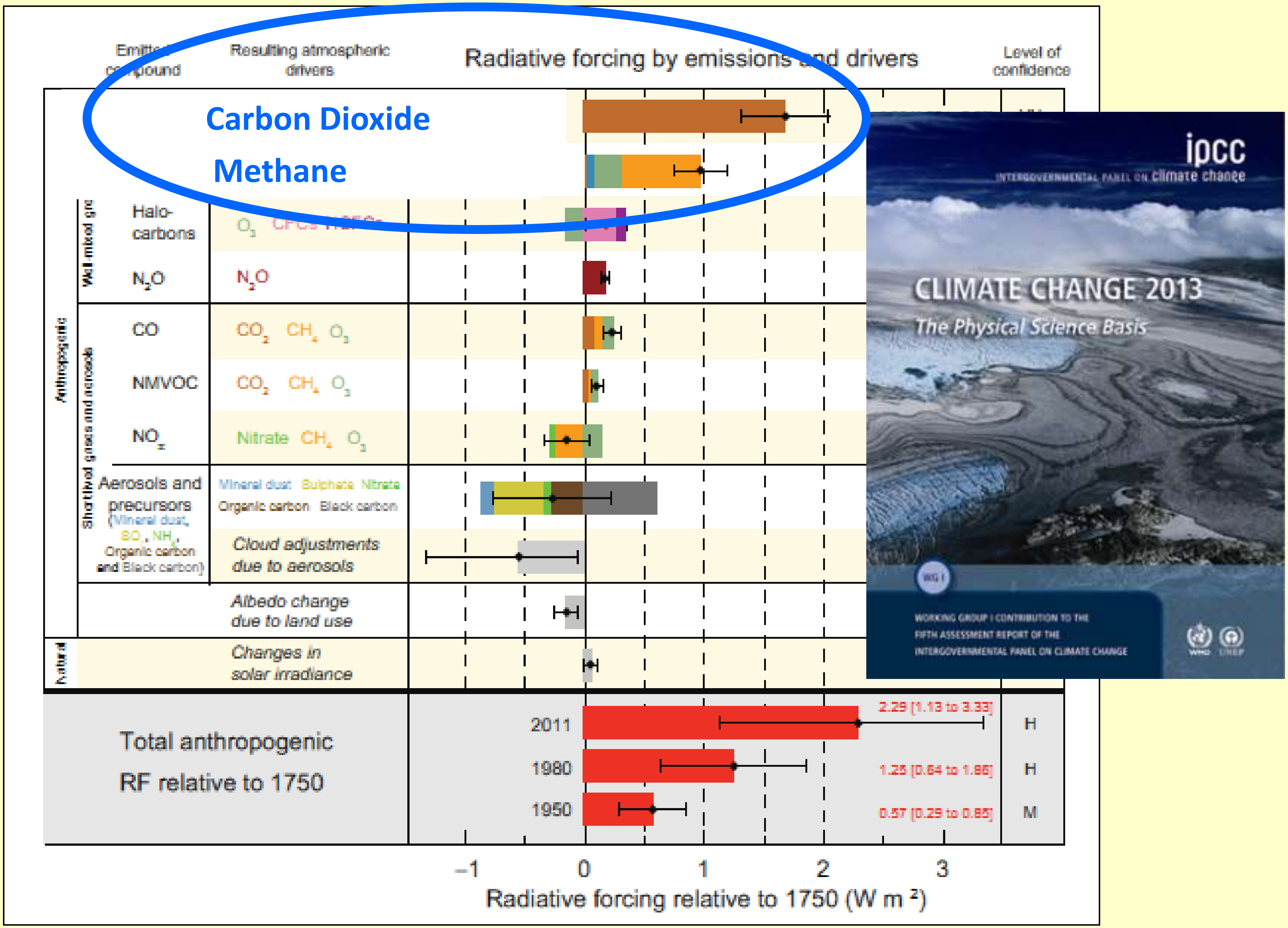
WMO
UNEP



Emitted compound
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Carbon Dioxide
Methane
Halo-carbons
N2O
CO
NMVOC
NOx
Aerosols and precursors
(Mineral dust, SO2, NH3, Organic carbon and Black carbon)
CO2 CH4 O3
Nitrate CH4 O3
Mineral dust Sulphate Nitrate
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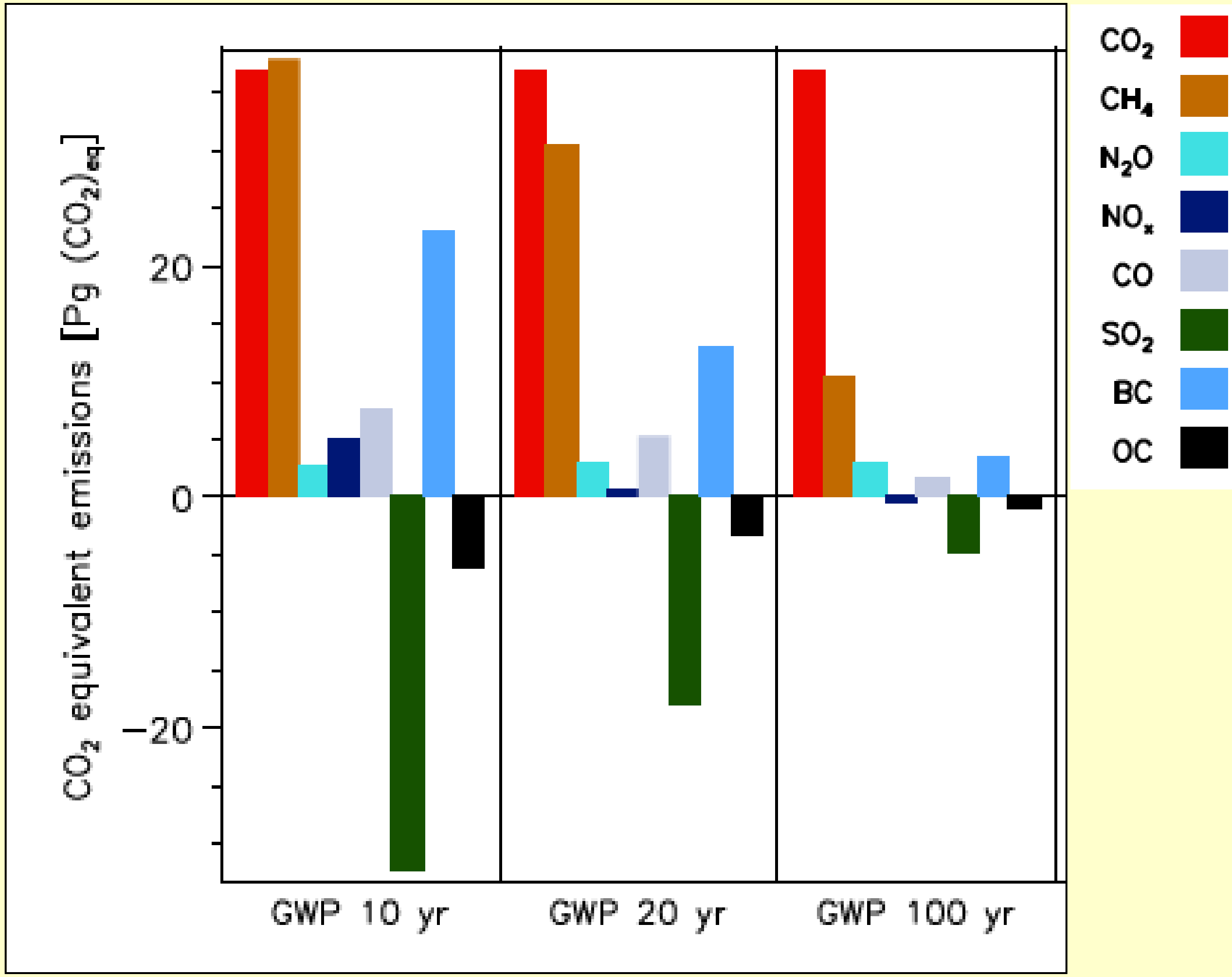
WMO UNEP

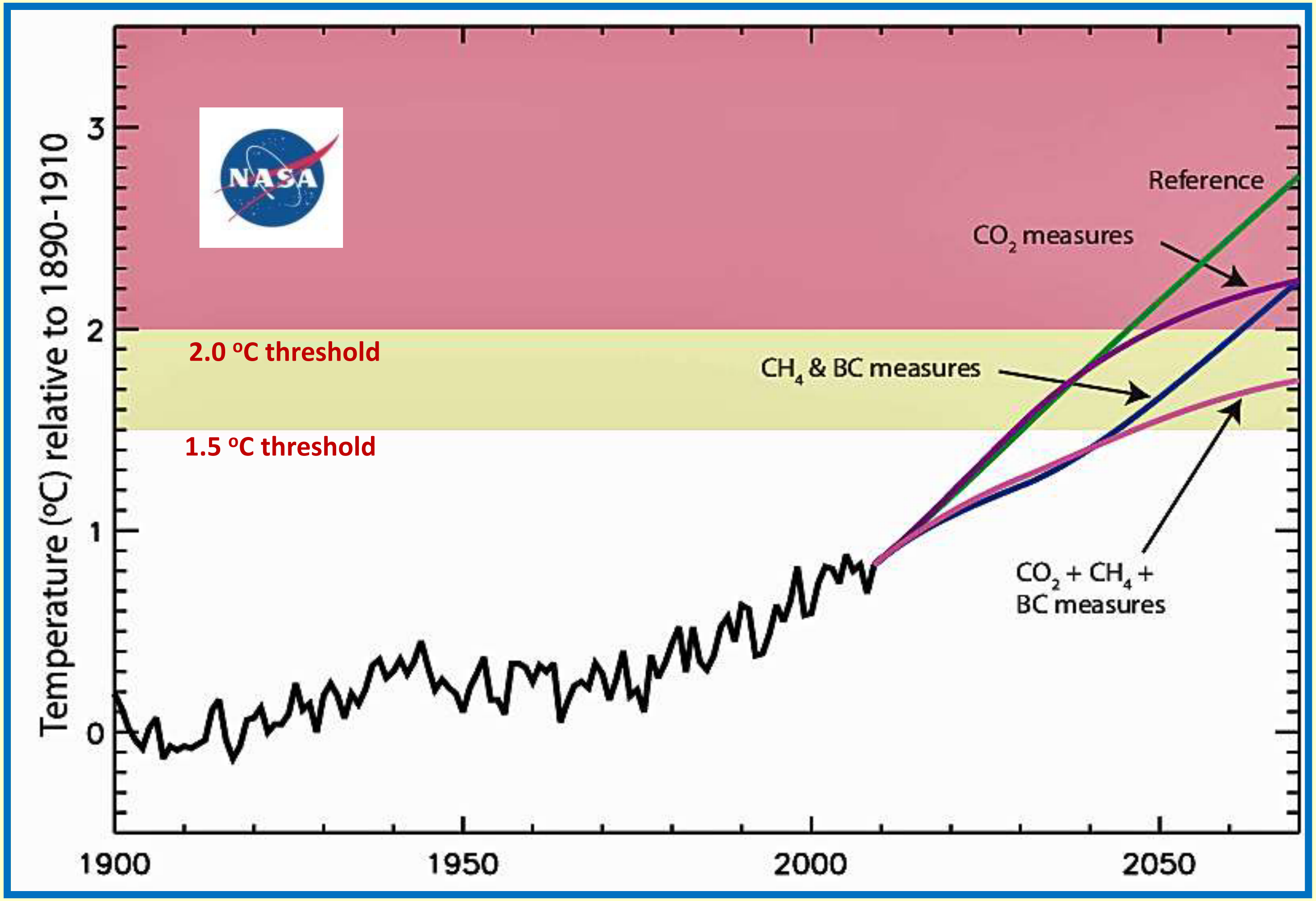
Global greenhouse gas emissions, weighted by global warming potentials (anthropogenic emissions, not total global fluxes)



IPCC 2013

Dangerous temperatures (increased risk of climatic tipping points and runaway global warming) in 15 to 35 years.

Controlling methane is ***CRITICAL*** to the solution!



Shindell et al. 2012

The two faces of Carbon

Carbon dioxide (CO_2)

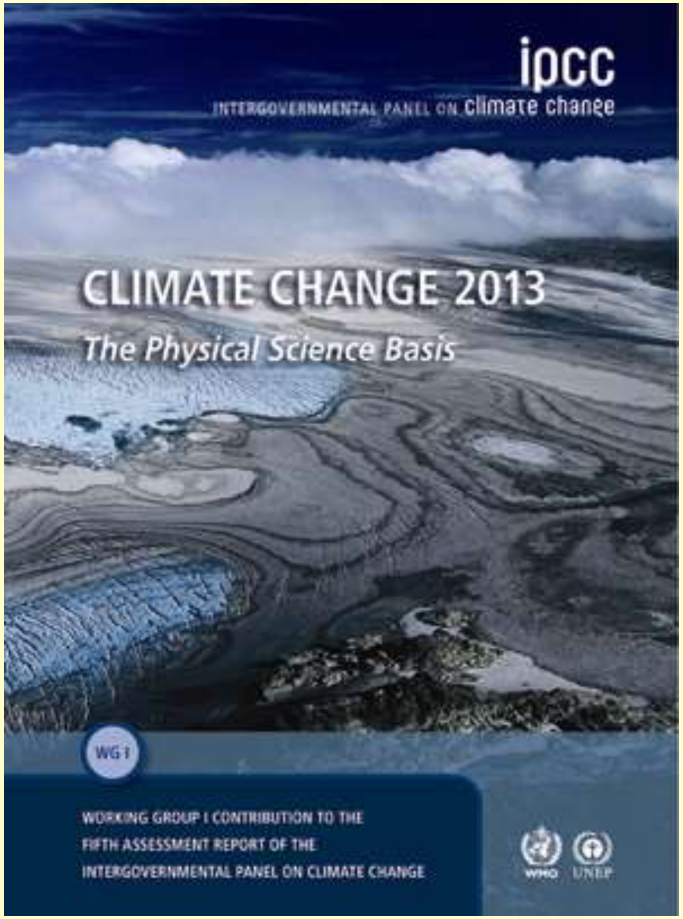
- Emissions today will influence climate for 1,000s of years
- Because of lags in climate system, reducing emissions now will have little influence during next 40 years

Methane (CH_4)

- Persists in the atmosphere for only 12 years
- Only modest long-term influence, unless global warming leads to tipping points in the climate system
- Reducing emissions immediately slows global warming

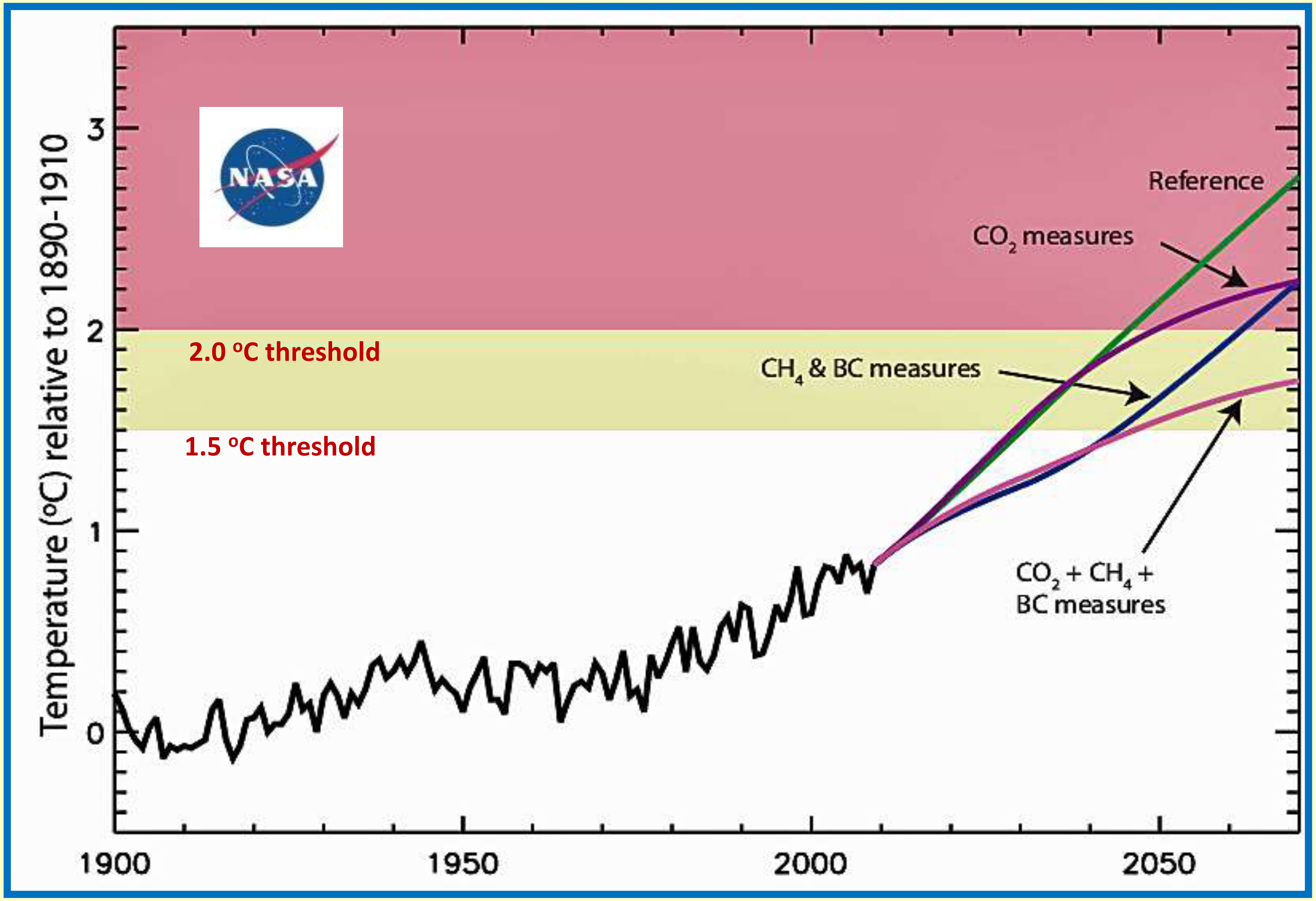
Time frame for comparing methane and carbon dioxide:

• Hayhoe et al. (2002)	0 to 100 years
• Lelieveld et al. (2005)	20 & 100 years
• Jamarillo et al. (2007)	100 years
• Howarth et al. (2011)	20 & 100 years
• Hughes (2011)	20 & 100 years
• Venkatesh et al. (2011)	100 years
• Jiang et al. (2011)	100 years
• Wigley (2011)	0 to 100 years
• Fulton et al. (2011)	100 years
• Stephenson et al. (2011)	100 years
• Hultman et al. (2011)	100 years
• Skone et al. (2011)	100 years
• Burnham et al. (2011)	100 years
• Cathles et al. (2012)	100 years



IPCC (2013): "There is no scientific argument for selecting 100 years compared with other choices."

"The choice of time horizon …. depends on the relative weight assigned to the effects at different times."



Shindell et al. 2012

Methane emission estimates:

	Upstream (well site)	Downstream (storage, distribution, etc.)	Total
Hayhoe et al. (2002), conventional	1.3 %	2.5 %	3.8 %
EPA (2010), US average for 2009	0.16 %	0.9 %	1.1 %
Howarth et al. (2011), US average	1.7 %	2.5 %	4.2 %
conventional gas	1.3 %	2.5 %	3.8 %
shale gas	3.3 %	2.5 %	5.8 %
EPA (2011), US average for 2009	1.8 %	0.9 %	2.7 %
conventional gas	1.6 %	0.9 %	2.5 %
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EPA (2013), US average for 2009	0.88 %	0.9 %	1.8 %

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First re-analysis by EPA since 1996

Re-analyzed again, under pressure from industry, and ignoring new data on emissions from NOAA published in 2012

Methane emissions

(% of life-time production of well)

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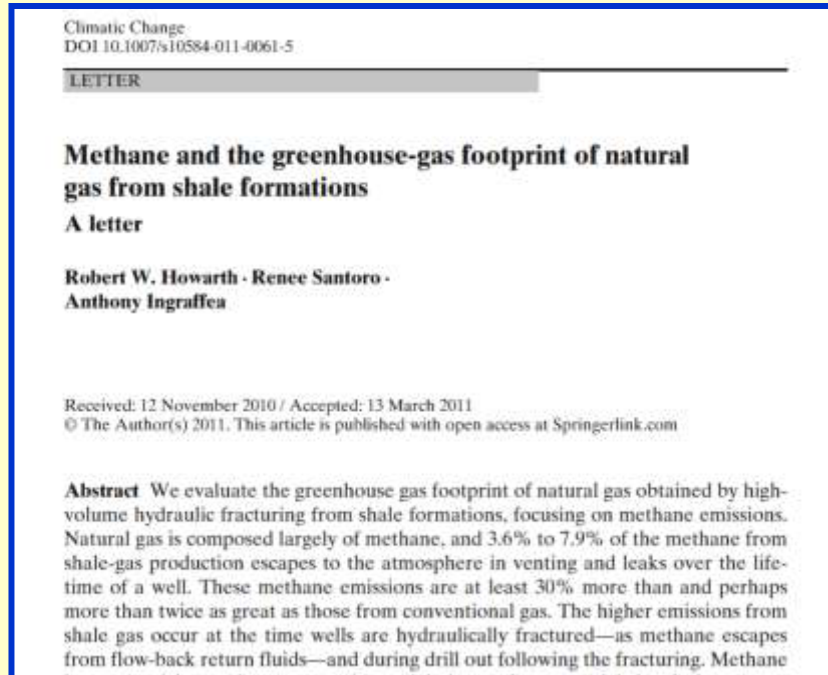
Many things to critique here….

But fundamentally, these are all just reinterpretations of the same pretty limited data set.

EPA estimates are "bottom-up" estimates, summing known sources, and begin with emission factors for these sources supplied by industry.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One of our major conclusions in Howarth et al. (2011): pertinent data were extremely limited, and poorly documented.

Great need for better data, conducted by researchers free of industry control and influence.

The New York Times

Poking Holes in a Green Image

Tom Zeller

April 11, 2011

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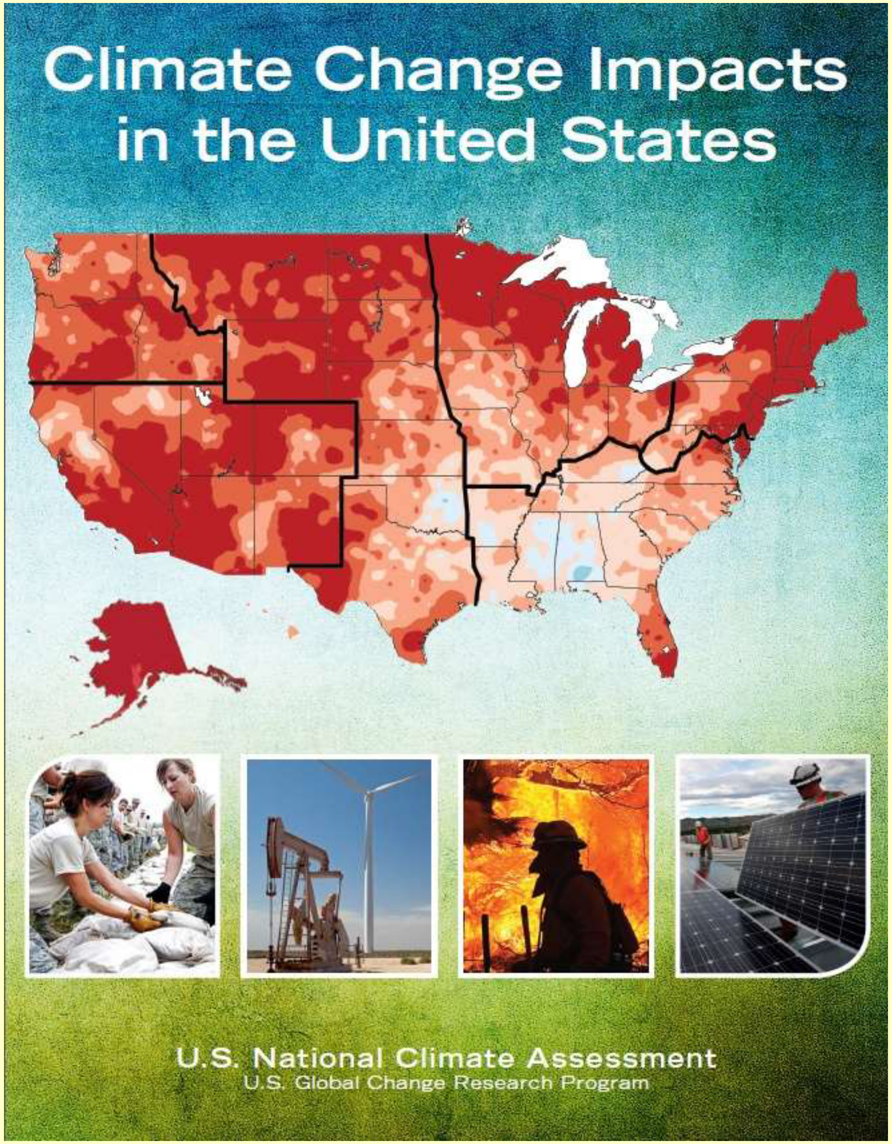
The findings are certain to stir debate. For much of the last decade, the natural gas industry has carefully cultivated a green reputation, often with the help of environmental groups that embrace the resource as a clean-burning “bridge fuel” to a renewable energy future.

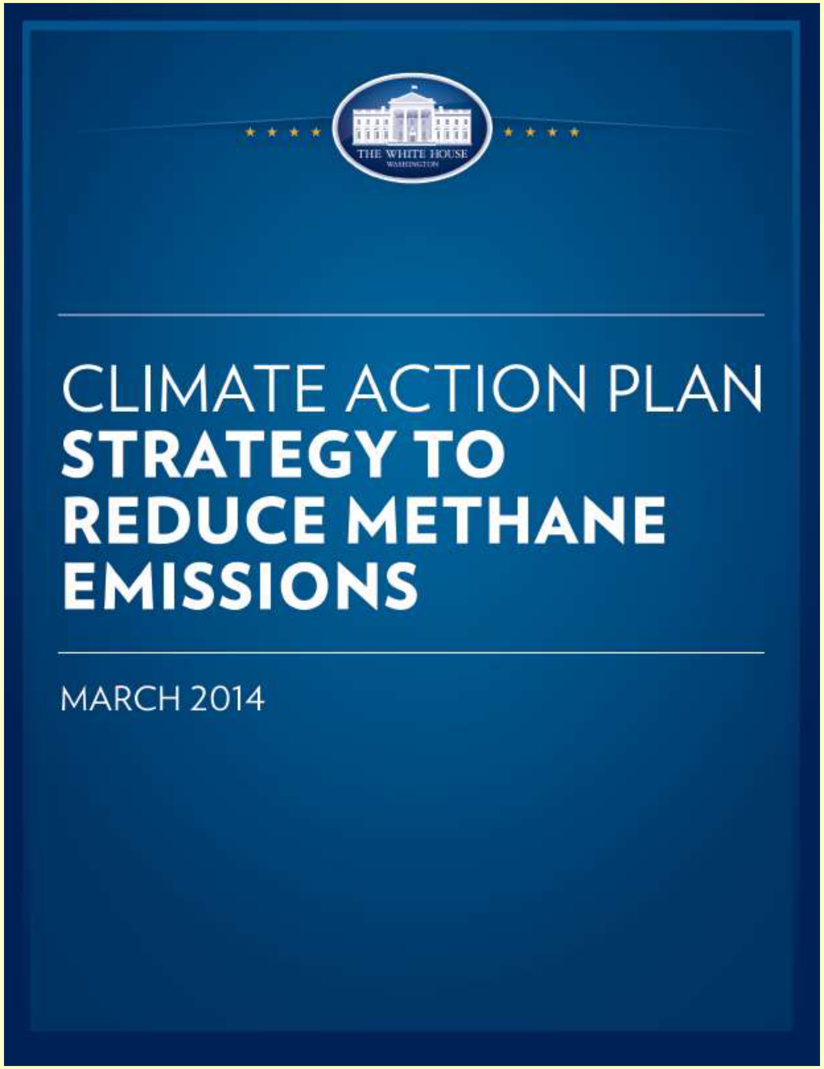
In 2013, White House Judged Our Work Not Credible

"There were numerous studies on fugitive emissions of methane. There was a very famous Cornell report which we looked at and decided was not as credible as…well we didn't think it was credible, I'll just put it that way and it was over estimating fugitive emissions."

Former U.S. Energy Secretary Steven Chu
Sept. 17, 2013 while giving a speech at America's Natural Gas Alliance Think About Energy Summit, Columbus, Ohio

Two Key 2014 White House Reports Directly Address Methane Emissions





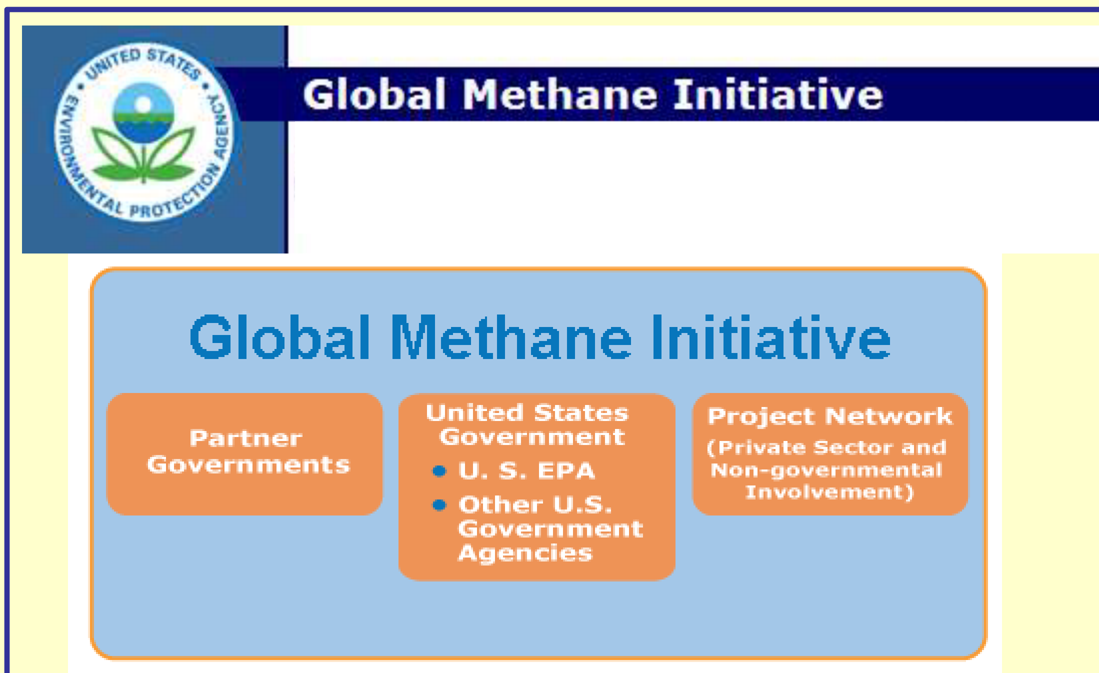
Recent EPA National and International Actions Concerning Methane Emissions

White Papers

White Papers on Methane and VOC Emissions

On April 15, 2014, EPA released for external peer review five technical white papers on potentially significant sources of emissions in the oil and gas sector. The white papers focus on technical issues covering emissions and mitigation techniques that target methane and volatile organic compounds (VOCs). As noted in the Obama Administration's Strategy to Reduce Methane Emissions (PDF) (15pp, 1.9 MB), EPA will use the papers, along with the input we receive from the peer reviewers and the public, to determine how to best pursue additional reductions from these sources. Read a summary of the white papers (PDF) (2pp, 282k)

The five white papers and peer review comments are posted below: Input from the public is being loaded to EPA's nonregulatory docket at www.regulations.gov, docket ID # EPA-HQ-OAR-2014-0557



Peer-reviewed studies on methane emissions since April 2011

Upstream emissions from shale gas and other unconventional:

- **Petron et al. (2012)**
- **Karion et al. (2013)**
- **Allen et al. (2013)**
- **Petron et al. (2014)**
- **Caulton et al. (2014)**
- **Schneising et al. (2014)**
- **Peischl et al. (2015)**

Downstream emissions (transmission, storage, distribution):

- **Lamb et al. (2015)**
- **McKain et al. (2015)**

Total average emissions (before shale gas boom):

- **Miller et al. (2013) – from widespread monitoring data**
- **Brandt et al. (2014) – a review from many sources**

Proceedings of the National Academy of Sciences of the United States of America

Toward a better understanding and quantification of methane emissions from shale gas development

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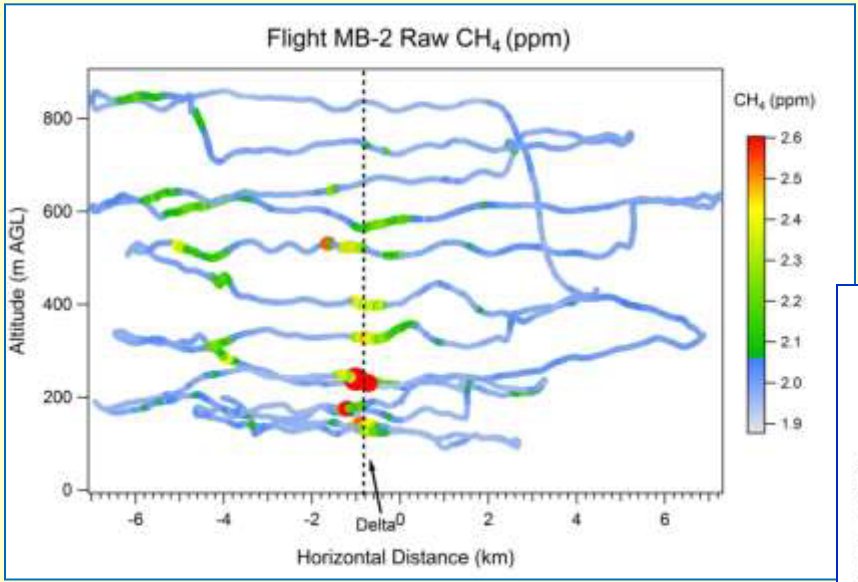

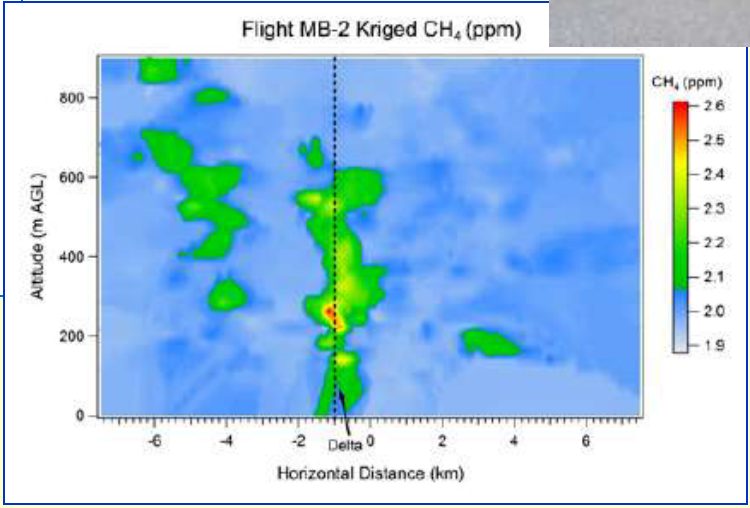

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PNAS

Toward a better understanding and quantification of methane emissions from shale gas development

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Significance

We identified a significant regional flux of methane over a large area of shale gas wells in southwestern Pennsylvania in the Marcellus formation and further identified several pads with high methane emissions. These shale gas pads were identified as in the drilling process, a preproduction stage not previously associated with high methane emissions. This work emphasizes the need for top-down identification and component level and event driven measurements of methane leaks to properly inventory the combined methane emissions of natural gas extraction and combustion to better define the impacts of our nation's increasing reliance on natural gas to meet our energy needs.

Some Imagery of Methane Emission Sources

- Blowdowns from compressor stations*
- Blowdowns from pipeline pig and transfer operations*
- Venting during drilling*
- Blowdowns from shut-in wells**
- Leakage from orphaned and abandoned wells**

*In our opinion, EPA emission factor/activity under-estimated

**Not Included in EPA Emissions Inventory

AGU PUBLICATIONS

Earth's Future

RESEARCH ARTICLE

10.1002/2014EF000265

Remote sensing of fugitive methane emissions from oil and gas production in North American tight geologic formations

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Key Points:

- Emissions of oil and gas industries are constrained using satellite observations
- Current inventories likely underestimate fugitive methane emissions
- Climate benefit of transition to unconventional oil and gas is questionable

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Citation:
Schneising, O., J. P. Burrows, R. R. Dickerson, M. Buchwitz, M. Reuter, and H. Bovensmann (2014), Remote sensing of fugitive methane emissions from oil and gas production in North American tight geologic formations, *Earth's Future*, *2*, 548–558, doi:10.1002/2014EF000265.

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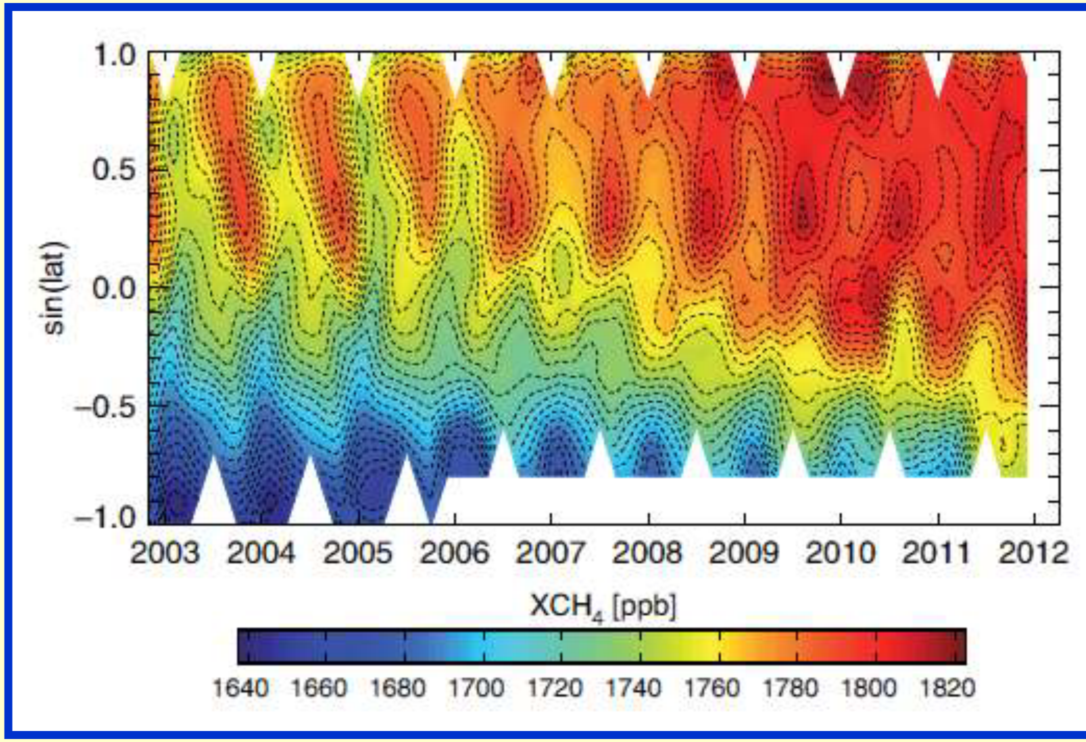
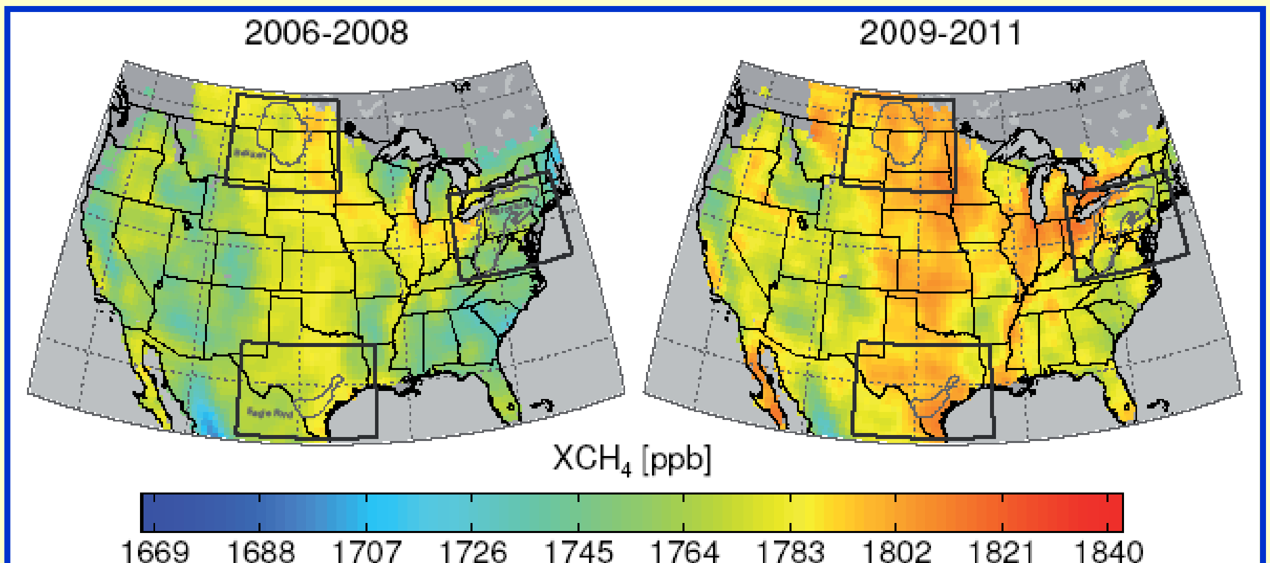
Abstract In the past decade, there has been a massive growth in the horizontal drilling and hydraulic fracturing of shale gas and tight oil reservoirs to exploit formerly inaccessible or unprofitable energy resources in rock formations with low permeability. In North America, these unconventional domestic sources of natural gas and oil provide an opportunity to achieve energy self-sufficiency and to reduce greenhouse gas emissions when displacing coal as a source of energy in power plants. However, fugitive methane emissions in the production process may counter the benefit over coal with respect to climate change and therefore need to be well quantified. Here we demonstrate that positive methane anomalies associated with the oil and gas industries can be detected from space and that corresponding regional emissions can be constrained using satellite observations. On the basis of a mass-balance approach, we estimate that methane emissions for two of the fastest growing production regions in the United States, the Bakken and Eagle Ford formations, have increased by 990 ± 650 $ktCH_4\ yr^{-1}$ and 530 ± 330 $ktCH_4\ yr^{-1}$ between the periods 2006–2008 and 2009–2011. Relative to the respective increases in oil and gas production, these emission estimates correspond to leakages of $10.1\% \pm 7.3\%$ and $9.1\% \pm 6.2\%$ in terms of energy content, calling immediate climate benefit into question and indicating that current inventories likely underestimate the fugitive emissions from Bakken and Eagle Ford.

Schneising et al. (2014) – "Remote sensing of fugitive methane emissions from oil and gas production in North American tight geologic formations." ***Earth's Future*** **2: 548-558**



United States



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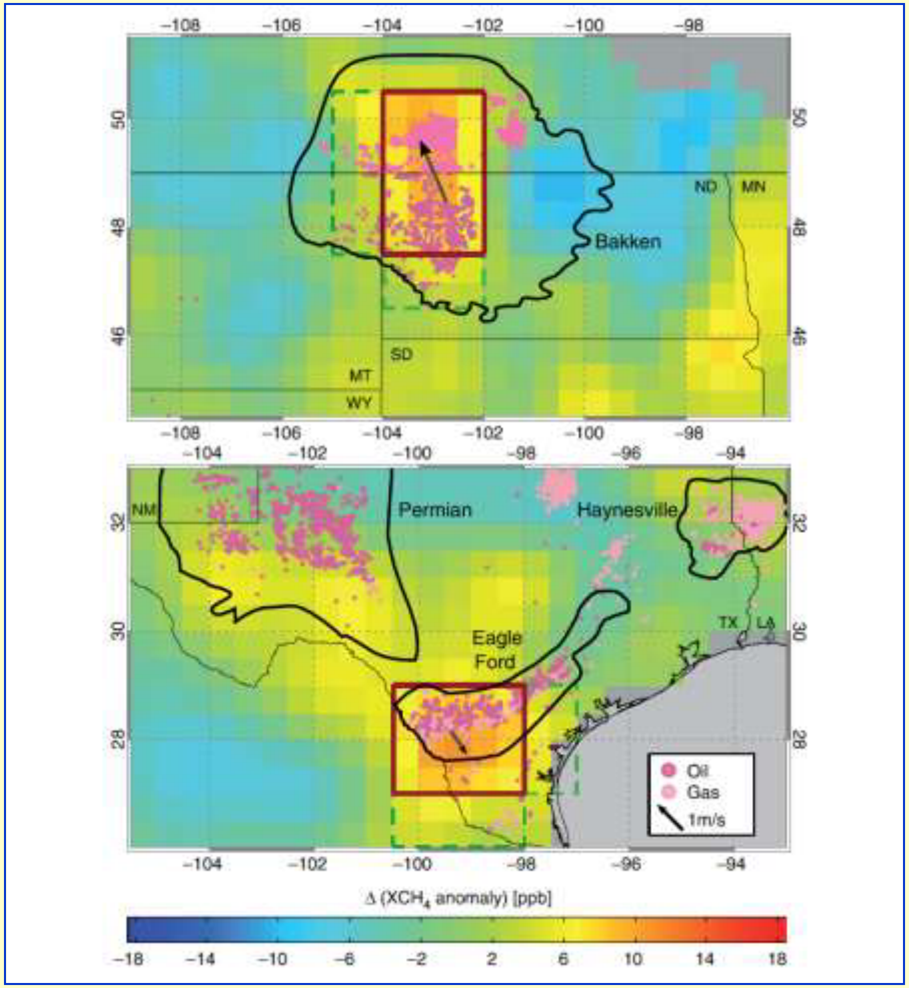
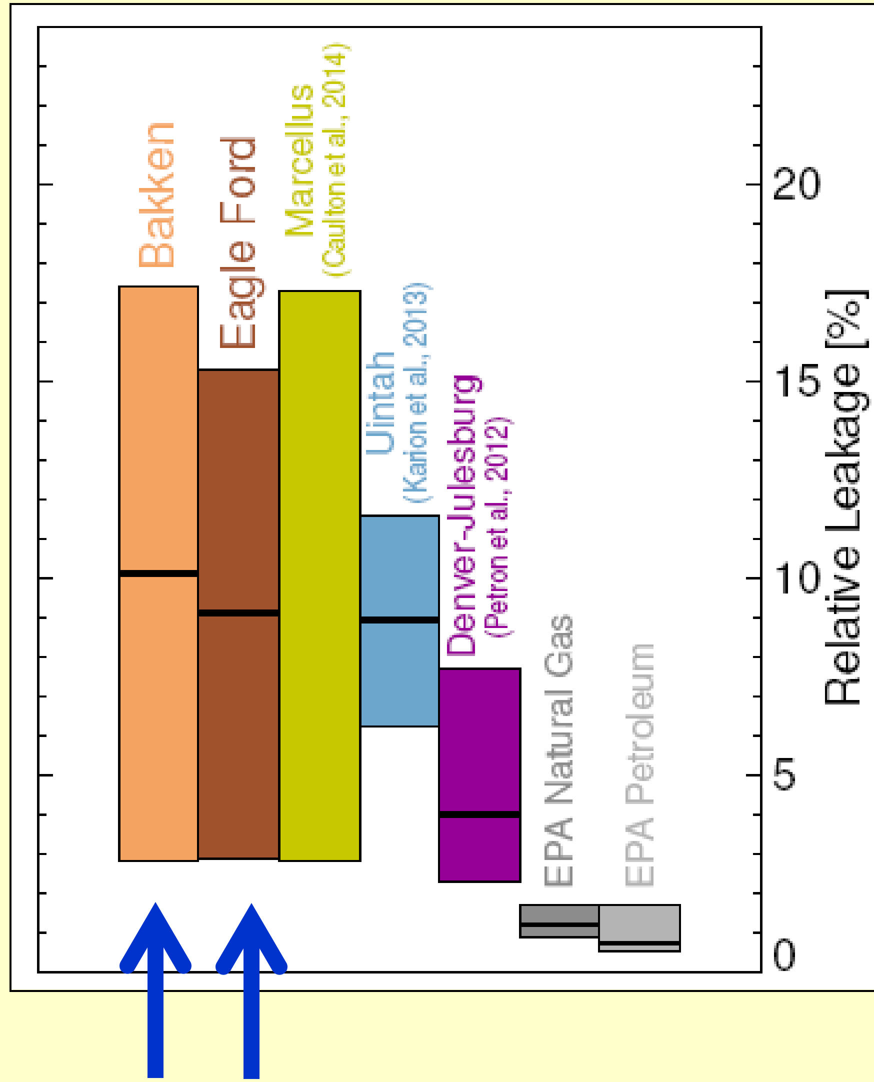
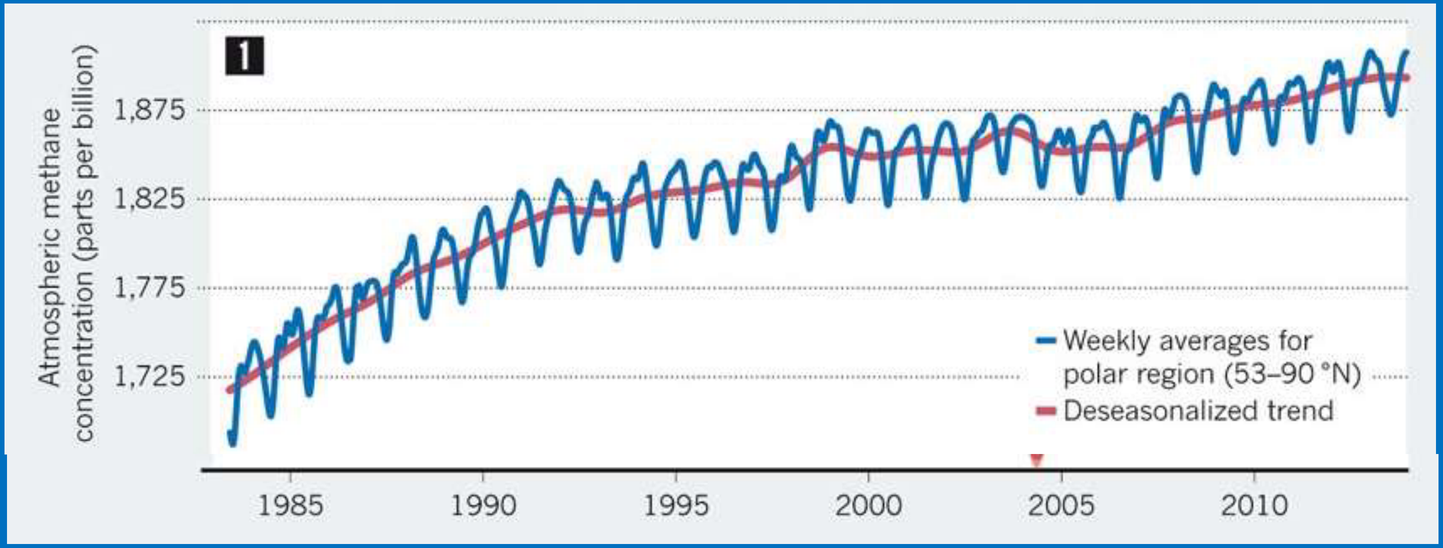




Change in atmospheric methane (polar regions), 1982 - 2013



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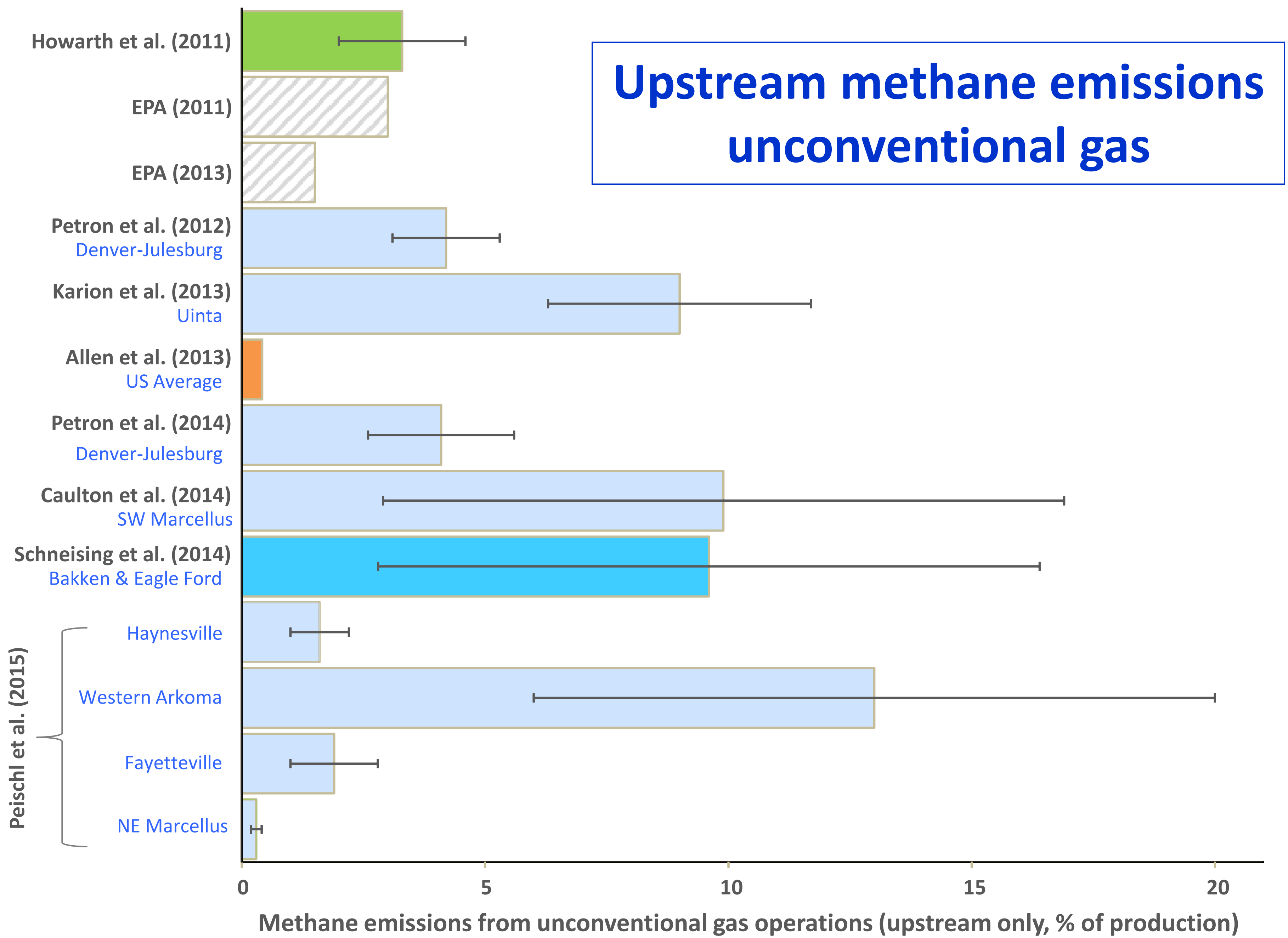
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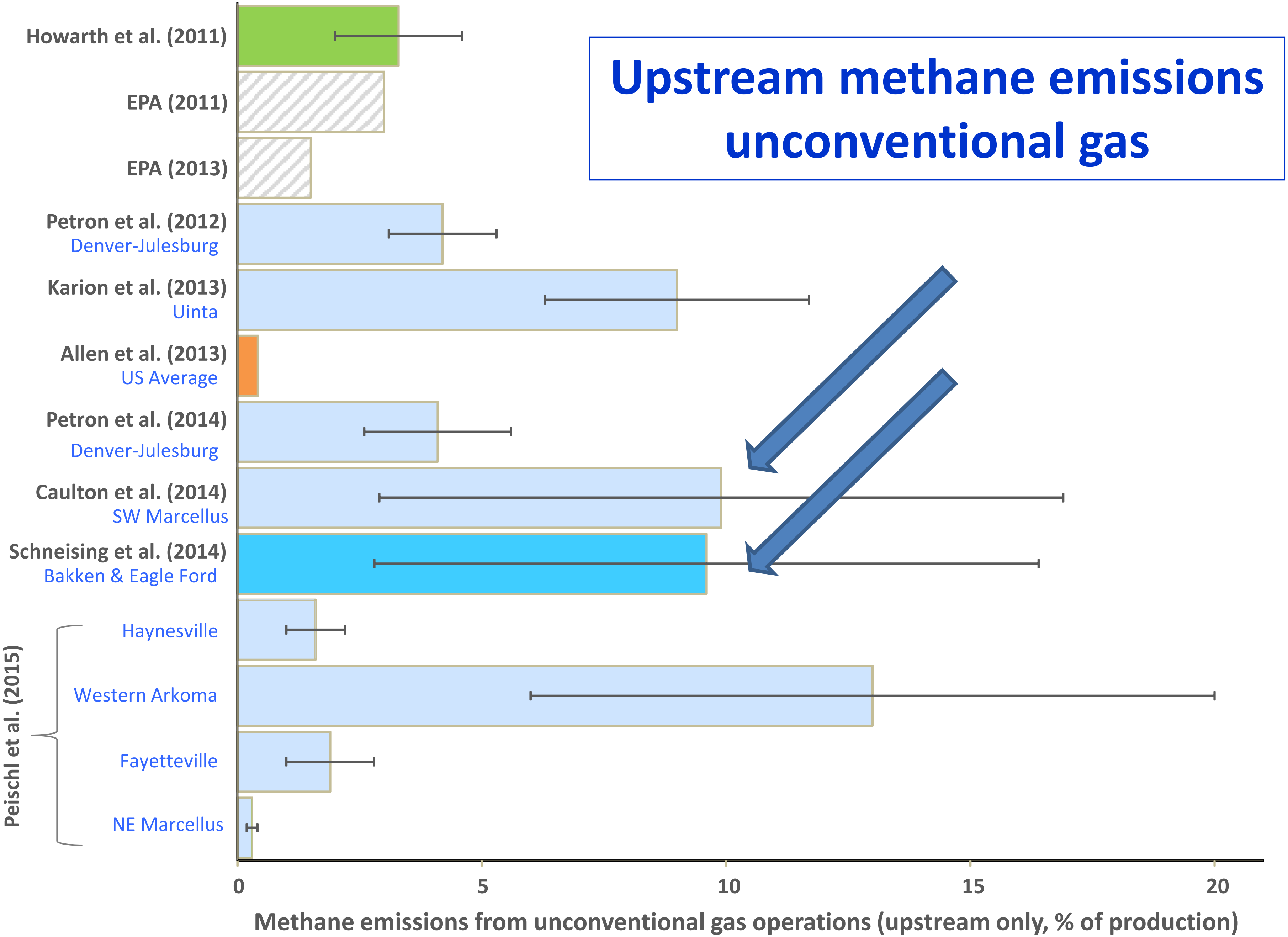
Methane emissions from unconventional gas operations (upstream only, % of production)



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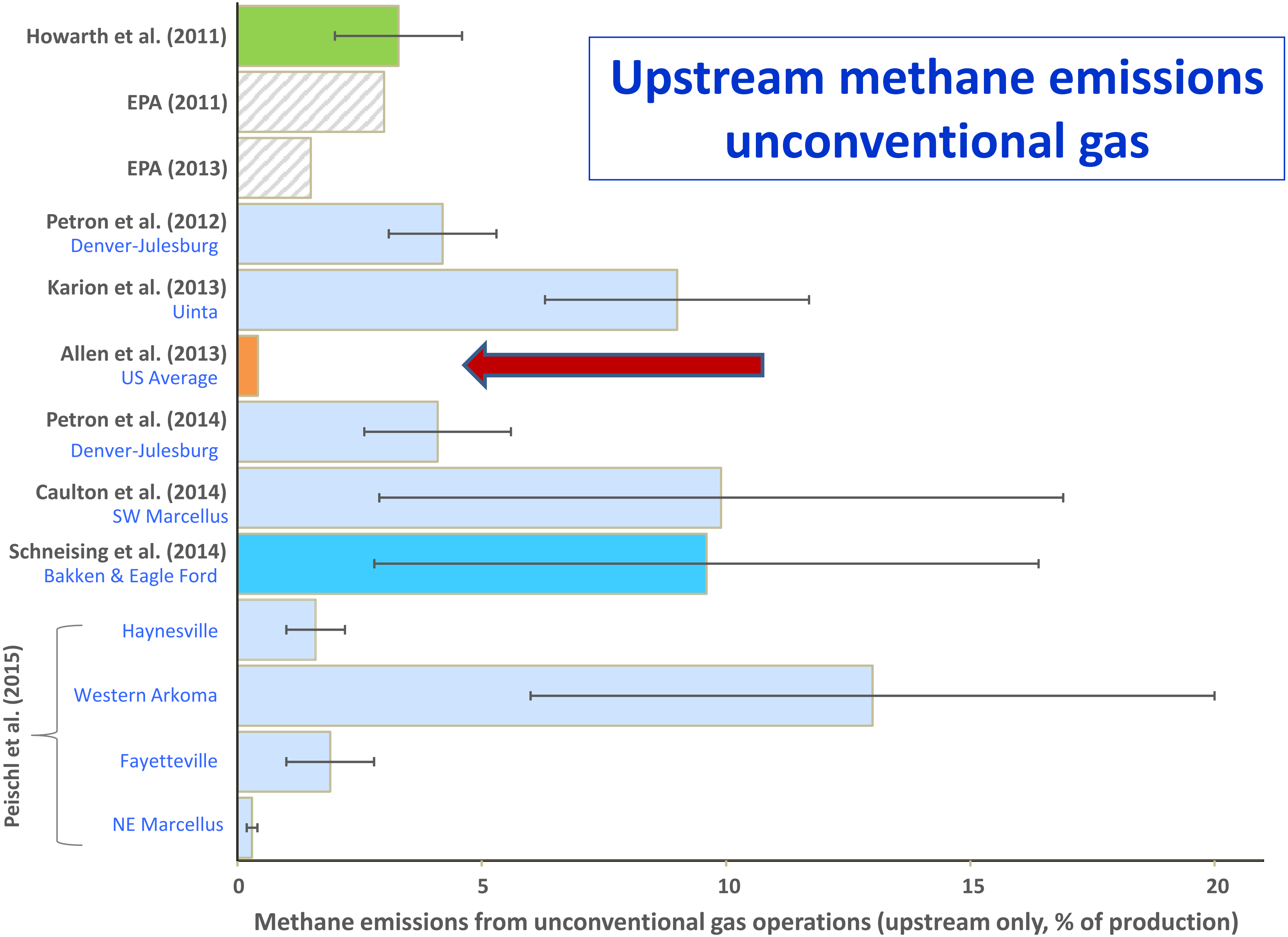

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Methane emissions from unconventional gas operations (upstream only, % of production)

Sensor transition failure in the high flow sampler: Implications for methane emission inventories of natural gas infrastructure

DOI:
10.1080/10962247.2015.1025925

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Publishing models and article dates explained

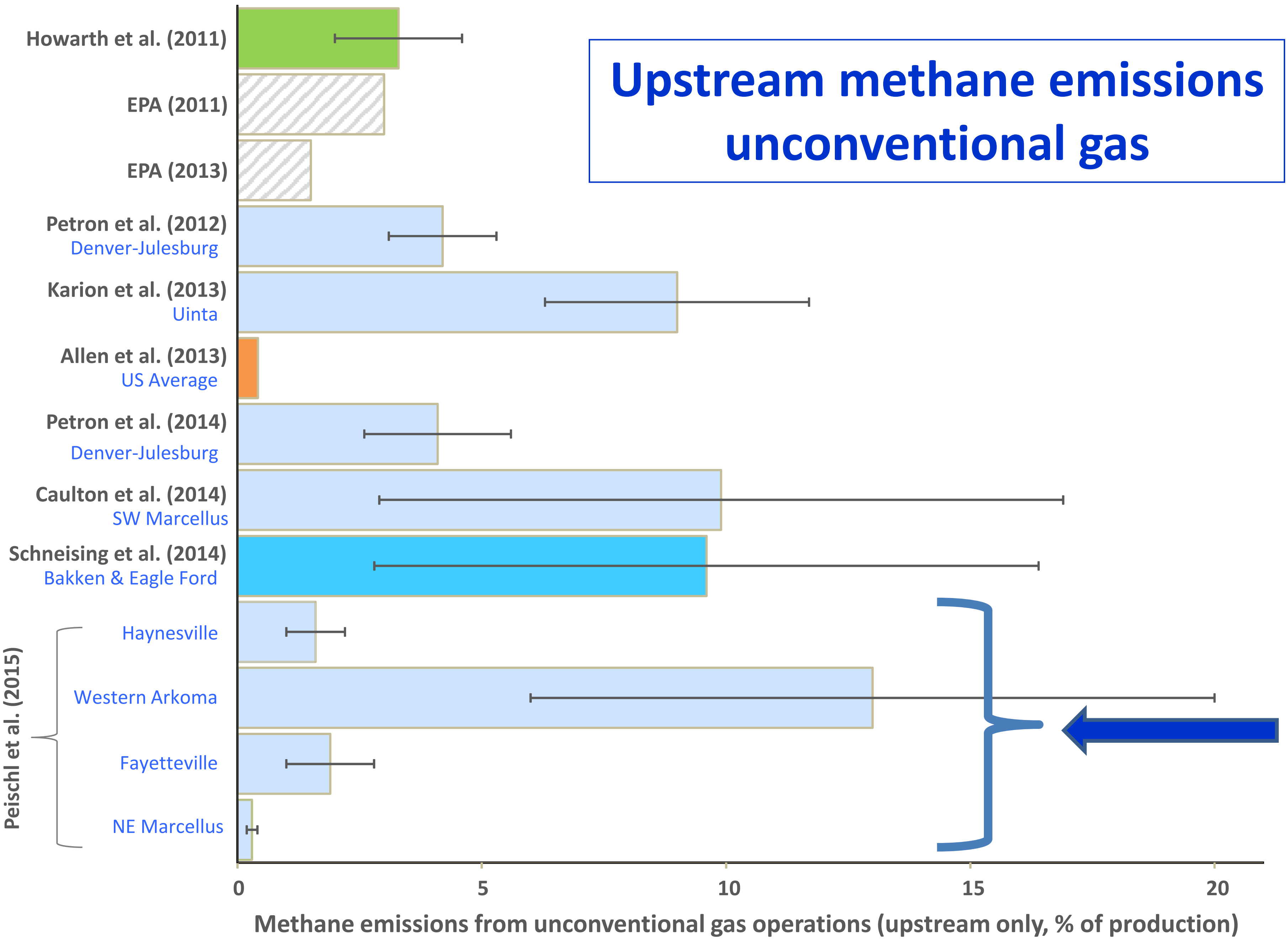
- Accepted author version posted online: 24 Mar 2015

Abstract

Quantification of leaks from natural gas (NG) infrastructure is a key step in reducing emissions of the greenhouse gas methane (CH4), particularly as NG becomes a larger component of domestic energy supply. The United States Environmental Protection Agency (USEPA) requires measurement and reporting of emissions of CH4 from NG transmission, storage, and processing facilities, and the high flow sampler (or high volume sampler) is one of the tools approved for this by the USEPA. The Bacharach Hi-Flow® Sampler (BHFS) is the only commercially available high flow instrument, and it is also used throughout the NG supply chain for directed inspection and maintenance, emission factor development, and greenhouse gas reduction programs. Here we document failure of the BHFS to transition from a catalytic oxidation sensor used to measure low NG (~5% or less) concentrations to a thermal conductivity sensor for higher concentrations (from ~5% to 100%), resulting in underestimation of NG emission rates. Our analysis includes both our own field testing as well as analysis of data from two other studies (Modrak et al., 2012; City of Ft Worth, 2011). Although this failure is not completely understood, and although we do not know if all BHFS models are similarly affected, sensor transition failure has been observed under one or more of these conditions: 1), calibration is more than ~2 weeks old; 2), firmware is out of date; or 3), the composition of the NG source is less than ~91% CH4 . The extent to which this issue has affected recent emission studies is uncertain, but the analysis presented here suggests that the problem could be widespread. Furthermore, it is critical that this problem be resolved before the onset of regulations on CH4 emissions from the oil and gas industry, as the BHFS is a popular instrument for these measurements.

Implications

An instrument commonly used to measure leaks in natural gas infrastructure has a critical sensor transition failure issue that results in underestimation of leaks, with implications for greenhouse gas emissions estimates as well as safety.



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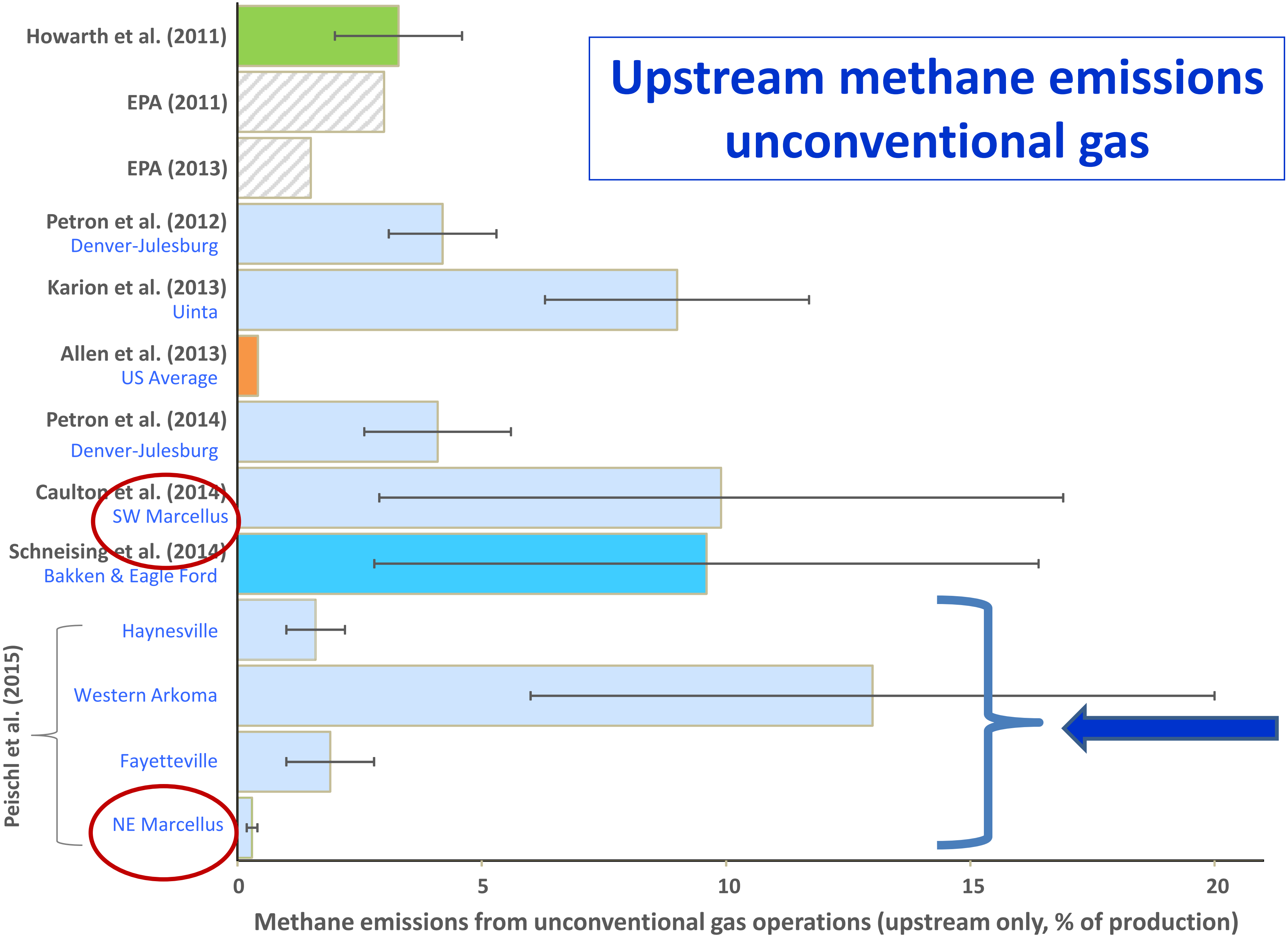

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Methane emissions from unconventional gas operations (upstream only, % of production)

AGU PUBLICATIONS

JGR

Journal of Geophysical Research: Atmospheres

RESEARCH ARTICLE

10.1002/2014JD022697

Key Points:

- CH_4 emissions from Haynesville, Fayetteville, and Marcellus regions quantified
- CH_4 emissions similar to previously studied gas-producing regions
- CH_4 loss rates lower than previously studied gas-producing regions

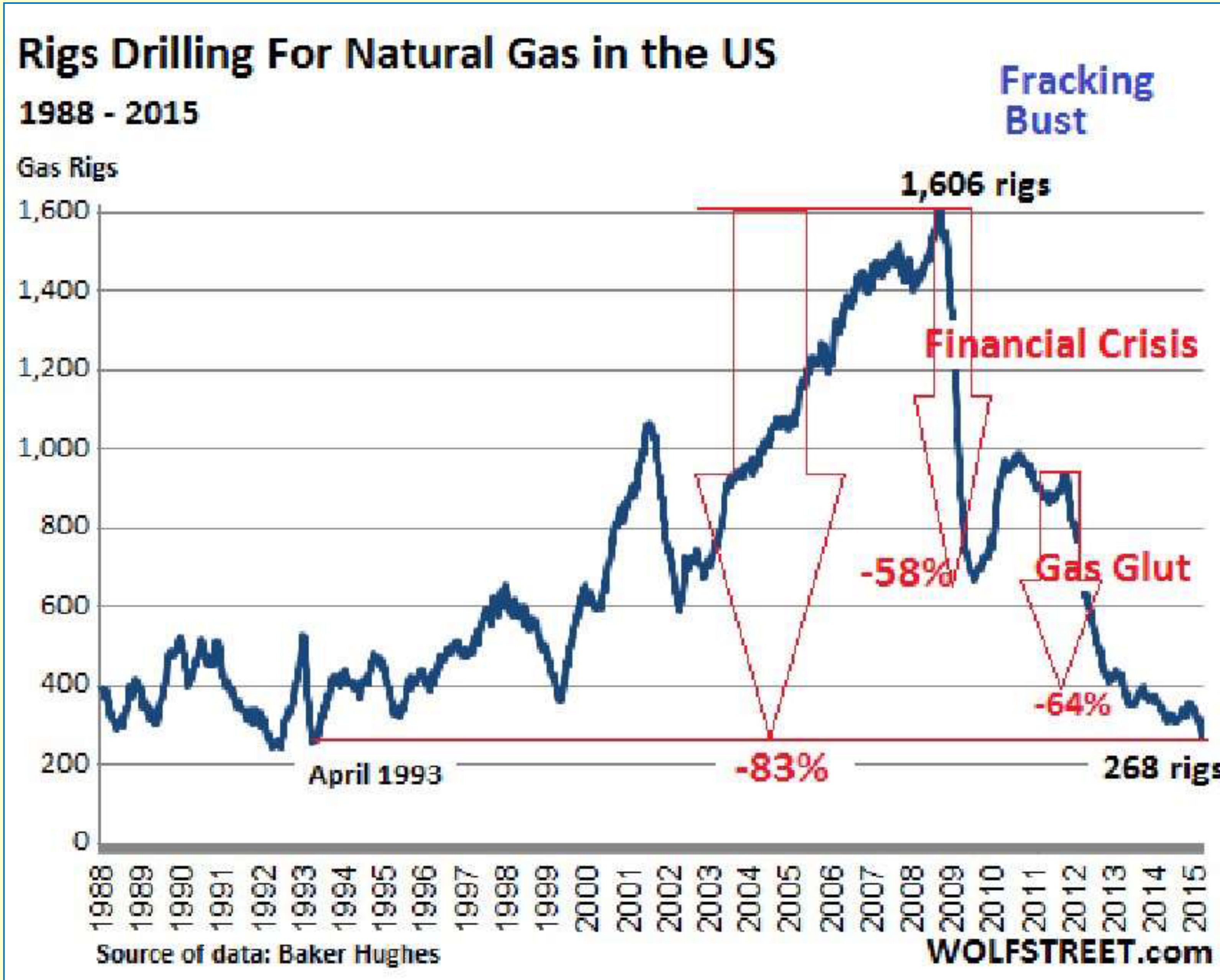
Quantifying atmospheric methane emissions from the Haynesville, Fayetteville, and northeastern Marcellus shale gas production regions

J. Peischl[1,2], T. B. Ryerson[2], K. C. Aikin[1,2], J. A. de Gouw[1,2], J. B. Gilman[1,2], J. S. Holloway[1,2], B. M. Lerner[1,2], R. Nadkarni[3], J. A. Neuman[1,2], J. B. Nowak[1,2,4], M. Trainer[2], C. Warneke[1,2], and D. D. Parrish[1,2]

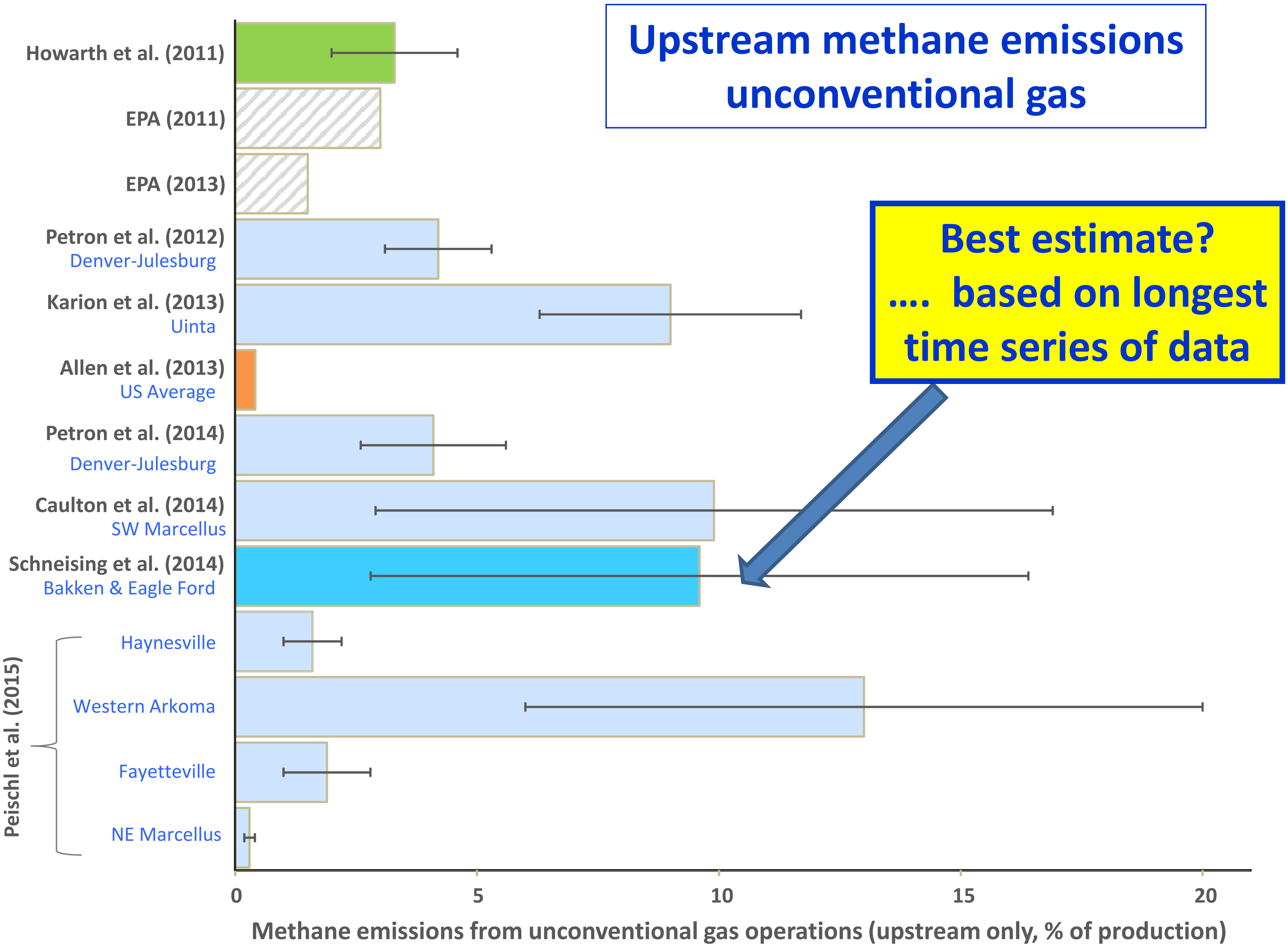
[1]Cooperative Institute for Research in Environmental Sciences, University of Colorado Boulder, Boulder, Colorado, USA, [2]Chemical Sciences Division, NOAA Earth System Research Laboratory, Boulder, Colorado, USA, [3]Texas Commission on Environmental Quality, Austin, Texas, USA, [4]Now at Aerodyne Research, Inc., Billerica, Massachusetts, USA

Peischl et al. (2015) attribute their lower fluxes for the NE Marcellus compared to our Caulton et al. (2014) estimates for SW Marcellus to dry gas vs. wet gas: much higher emissions from wet gas.

Another possibility: non-steady state situation, with much lower drilling and fracking activity at the time of their study (July 2013) compared to that of Caulton et al. (June 2012). Emissions are normalized to production, which was still reasonably high in 2013, but based on drilling and fracking at a previous time.



http://www.businessinsider.com/this-chart-shows-the-true-collapse-of-fracking-in-the-us-2015-3



Upstream methane emissions unconventional gas
Best estimate? …. based on longest time series of data
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Methane emissions from unconventional gas operations (upstream only, % of production)

Methane (natural gas) leaks from tanks, pipelines, compressors, etc.

Naked eye

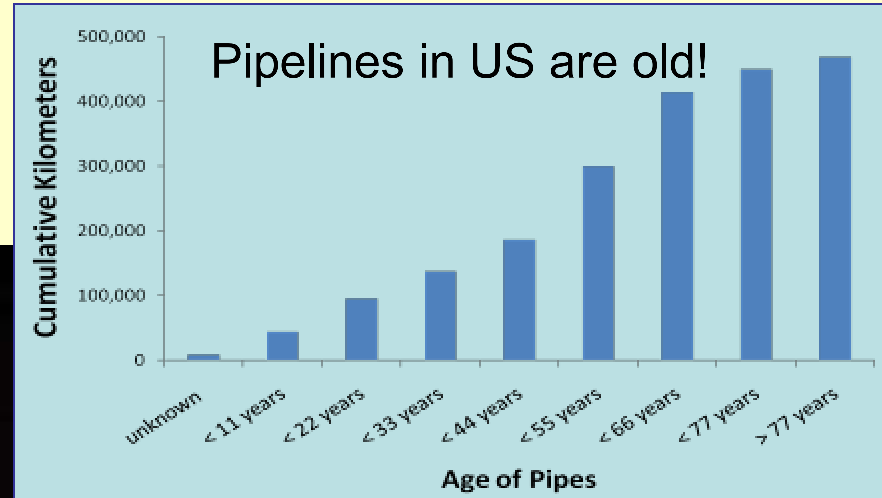
Infra-red (42)

Methane is not visible to naked eye, but can be “seen” with infra-red cameras.

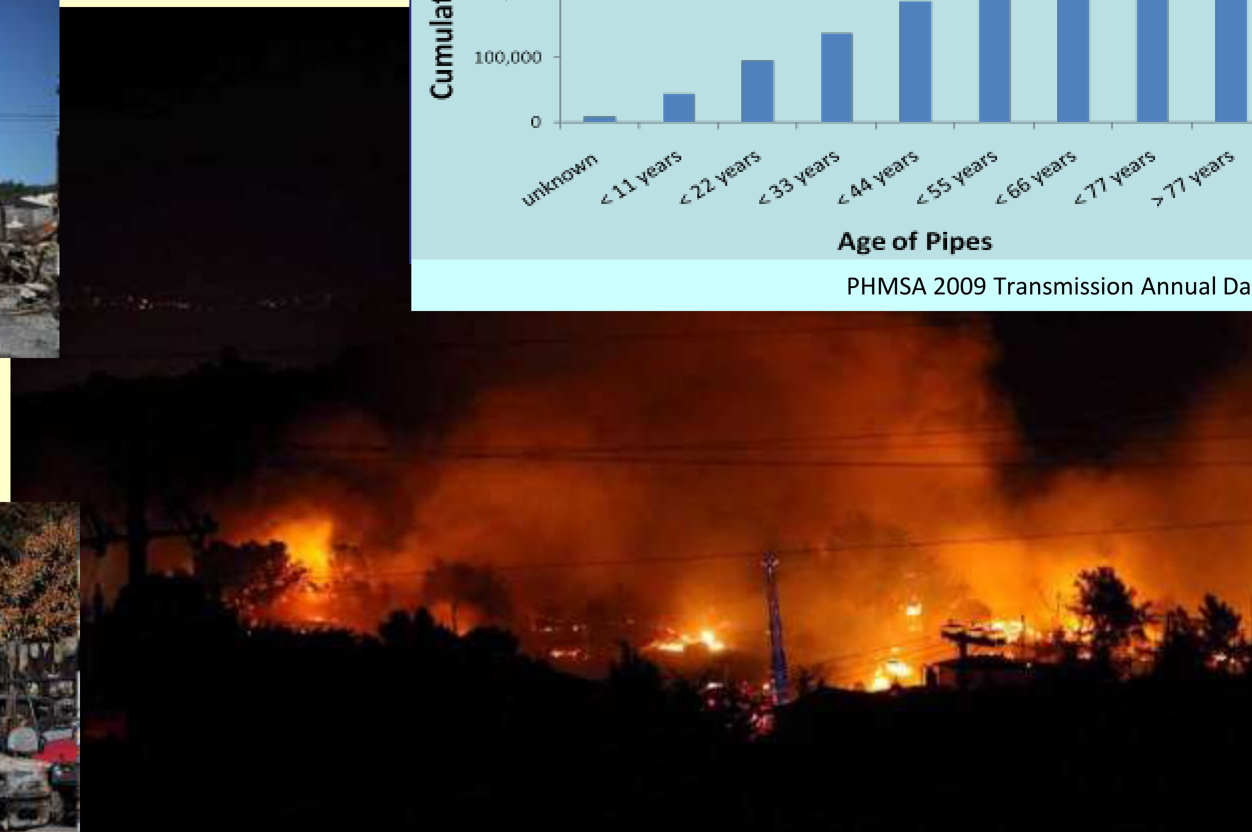
Bruce Gellerman, “Living on Earth,” Jan. 13, 2012, based on work of Nathan Phillips

http://www.loe.org/shows/segments.html?programID=12-P13-00002&segmentID=3

Pipeline accidents and explosions happen, due to large leaks….
….. small leaks are ubiquitous.



PHMSA 2009 Transmission Annual Data



Flames consume homes during a massive fire in a residential neighborhood September 9, 2010 in San Bruno, California. (Photo by Ezra Shaw/Getty Images)

March 12, 2014 – 7 killed in explosion in NYC
(127-year old gas mains)






Methane emission estimates:

	Upstream (well site)	Downstream (storage, distribution, etc.)	Total
Hayhoe et al. (2002), conventional	1.3 %	2.5 %	3.8 %
EPA (2010), US average for 2009	0.16 %	0.9 %	1.1 %
Howarth et al. (2011), US average	1.7 %	2.5 %	4.2 %
conventional gas	1.3 %	2.5 %	3.8 %
shale gas	3.3 %	2.5 %	5.8 %
EPA (2011), US average for 2009	1.8 %	0.9 %	2.7 %
conventional gas	1.6 %	0.9 %	2.5 %
shale gas	3.0 %	0.9 %	3. 9 %
EPA (2013), US average for 2009	0.88 %	0.9 %	1.8 %

Proceedings of the National Academy of Sciences of the United States of America

PNAS

Methane emissions from natural gas infrastructure and use in the urban region of Boston, Massachusetts

Kathryn McKain[a,b,1], Adrian Down[c,d], Steve M. Raciti[e,f], John Budney[a], Lucy R. Hutyra[e], Cody Floerchinger[g], Scott C. Herndon[g], Thomas Nehrkorn[h], Mark S. Zahniser[g], Robert B. Jackson[c,d,i,j,k], Nathan Phillips[e], and Steven C. Wofsy[a,b]

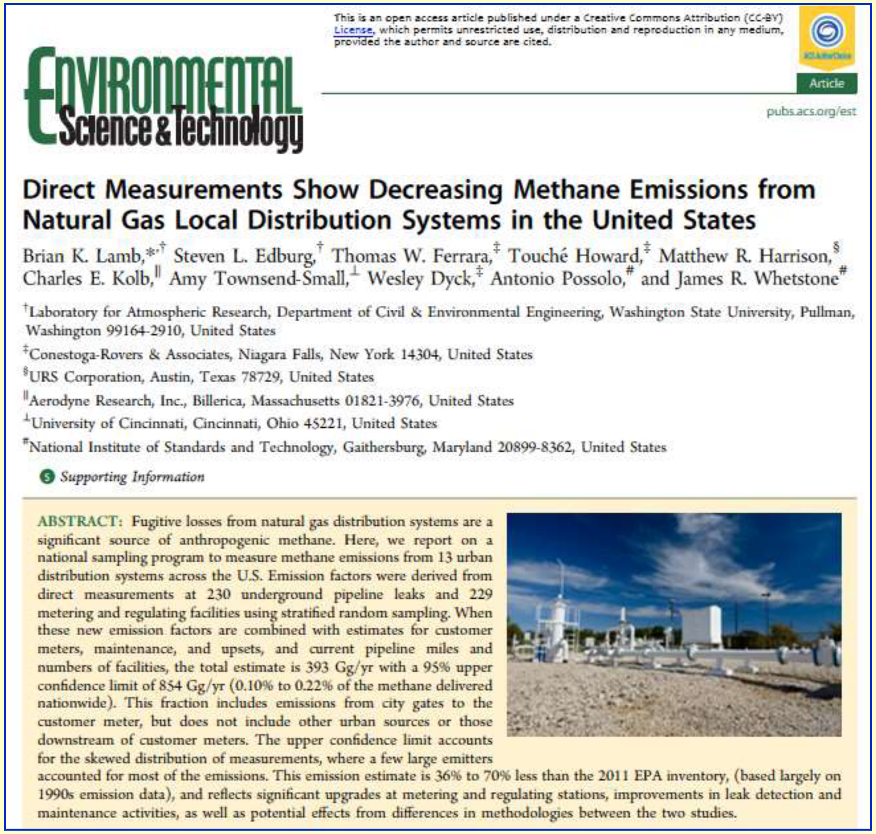
[a]School of Engineering and Applied Sciences and [b]Department of Earth and Planetary Sciences, Harvard University, Cambridge, MA 02138; [c]Nicholas School of the Environment and [d]Center on Global Change, Duke University, Durham, NC 27708; [e]Department of Earth and Environment, Boston University, Boston, MA 02215; [f]Department of Biology, Hofstra University, Hempstead, NY 11549; [g]Aerodyne Research, Inc., Billerica, MA 01821; [h]Atmospheric and Environmental Research, Inc., Lexington, MA 02421; and [i]School of Earth Sciences, [j]Stanford Woods Institute for the Environment, and [k]Precourt Institute for Energy, Stanford University, Stanford, CA 94305

2.7% emission rate, which agrees with “lost and unaccounted for” gas data.

This gives some support for our use of “lost and unaccounted for” gas data.

Estimate is 2.5-fold greater than that derived from EPA approach for Boston.

Infrastructure in Boston (and most NE cities) is older than average for the country, but on the other hand, this estimate does not include losses from transmission pipelines.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Environmental Science & Technology

Article

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Direct Measurements Show Decreasing Methane Emissions from Natural Gas Local Distribution Systems in the United States

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[‡]Conestoga-Rovers & Associates, Niagara Falls, New York 14304, United States

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[∥]Aerodyne Research, Inc., Billerica, Massachusetts 01821-3976, United States

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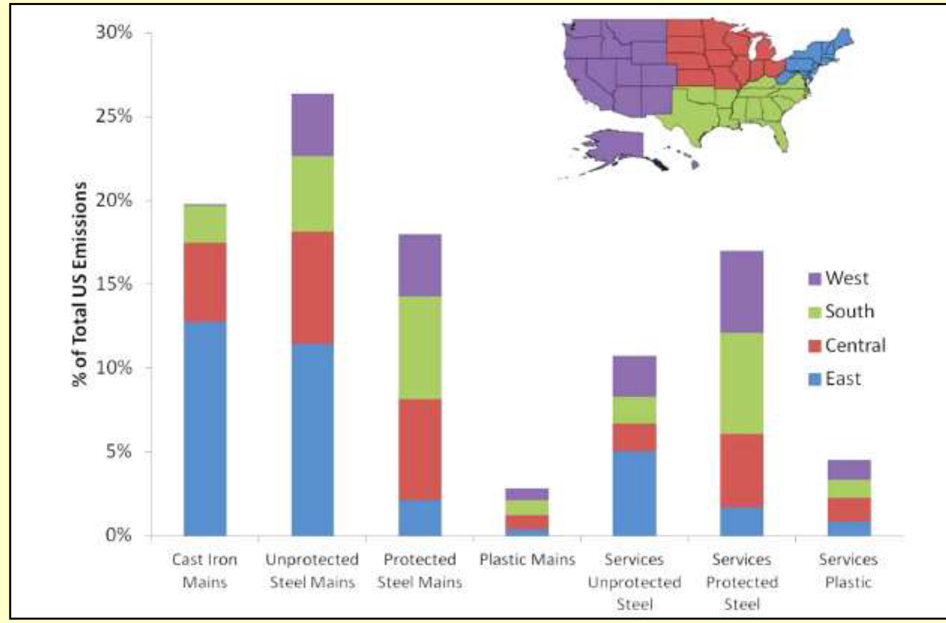
Supporting Information

ABSTRACT: Fugitive losses from natural gas distribution systems are a significant source of anthropogenic methane. Here, we report on a national sampling program to measure methane emissions from 13 urban distribution systems across the U.S. Emission factors were derived from direct measurements at 230 underground pipeline leaks and 229 metering and regulating facilities using stratified random sampling. When these new emission factors are combined with estimates for customer meters, maintenance, and upsets, and current pipeline miles and numbers of facilities, the total estimate is 393 Gg/yr with a 95% upper confidence limit of 854 Gg/yr (0.10% to 0.22% of the methane delivered nationwide). This fraction includes emissions from city gates to the customer meter, but does not include other urban sources or those downstream of customer meters. The upper confidence limit accounts for the skewed distribution of measurements, where a few large emitters accounted for most of the emissions. This emission estimate is 36% to 70% less than the 2011 EPA inventory, (based largely on 1990s emission data), and reflects significant upgrades at metering and regulating stations, improvements in leak detection and maintenance activities, as well as potential effects from differences in methodologies between the two studies.



Emissions from local distribution pipes actually less than EPA estimates, due to improvements by industry over past 20 years.

Did not look at storage and transmission pipelines, but would tend to support a downstream emission estimate of less than 1%.

How to integrate upstream and downstream emissions?

For the time before the shale gas boom:

Miller et al. (2013, PNAS) used nationwide monitoring data on methane in atmosphere (12,694 observations) for 2007-2008, and compared with EPA bottom-up source estimates spatially using inverse model.

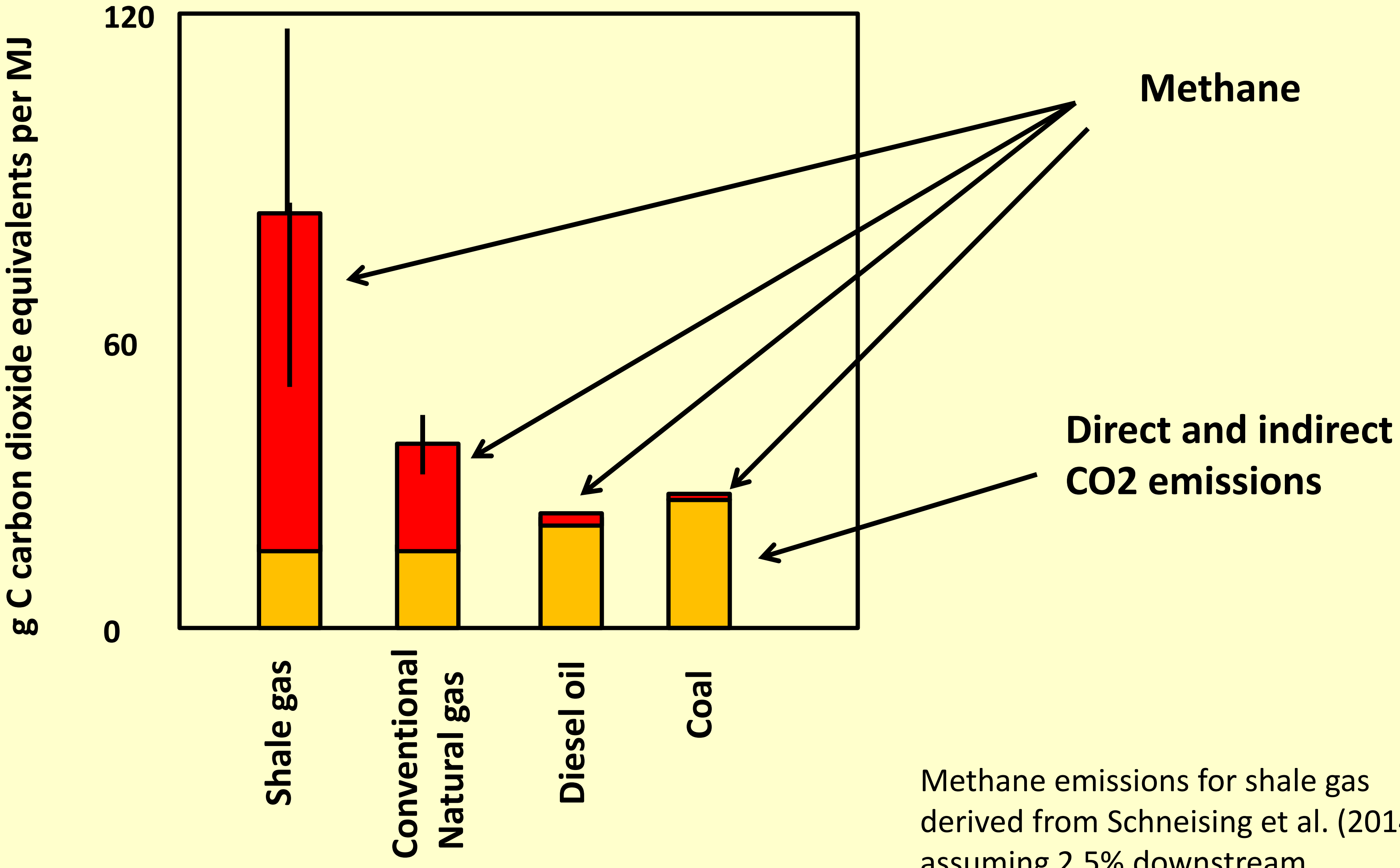
They concluded EPA estimates were at least 2-fold too low for emissions (before the shale gas boom).

Miller et al. (2013), PNAS: > 3.6%

Compare with Howarth et al (2011): 3.8% (+/- 1.2)

Greenhouse gas footprints per unit of heat generated

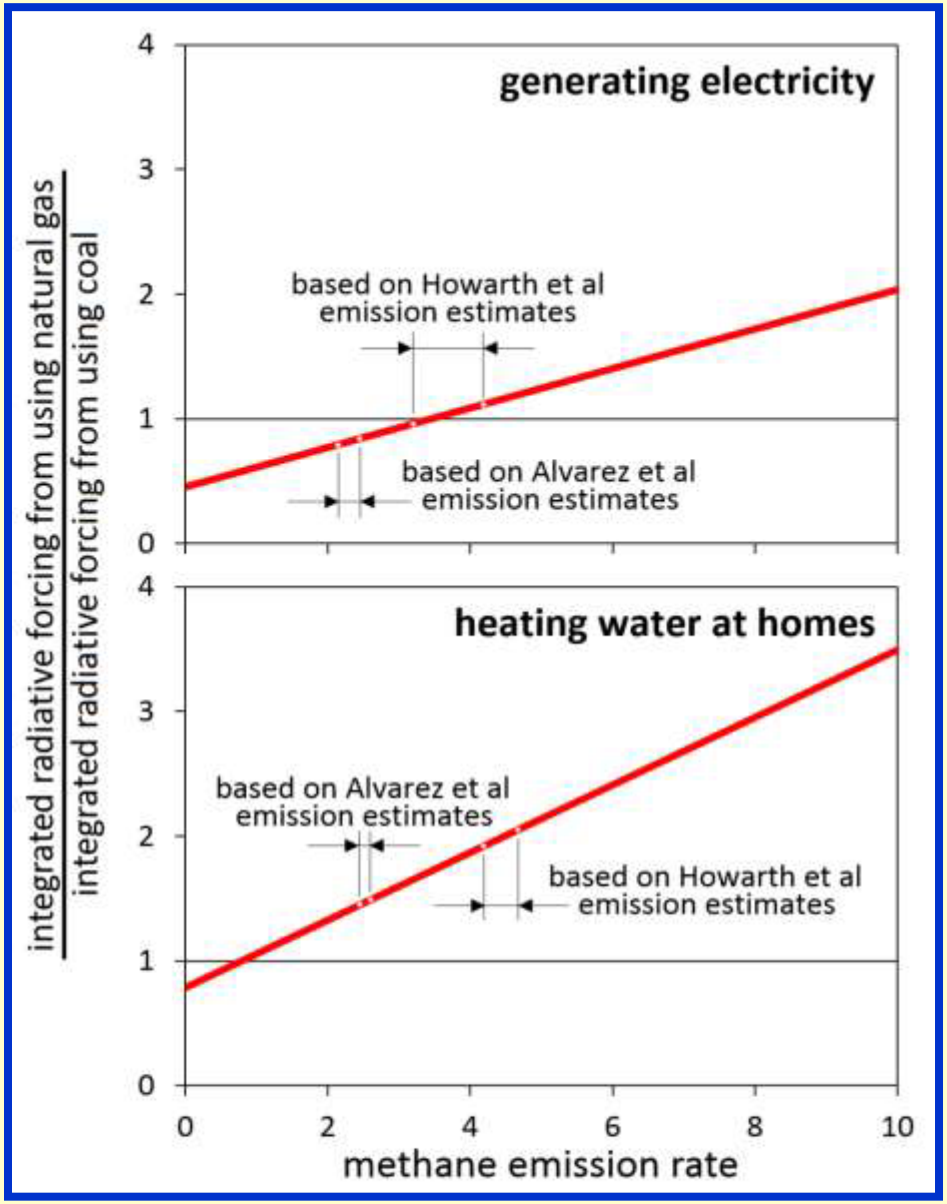
(methane converted to CO2 equivalents using 20-year GWP from IPCC 2013)

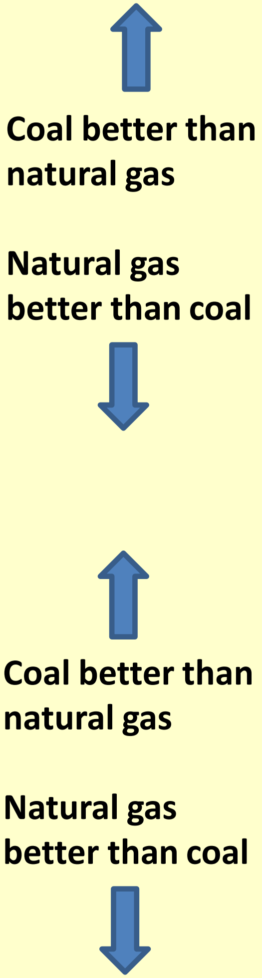


Methane emissions for shale gas derived from Schneising et al. (2014), assuming 2.5% downstream emissions. All other estimates are from Howarth et al. (2011)

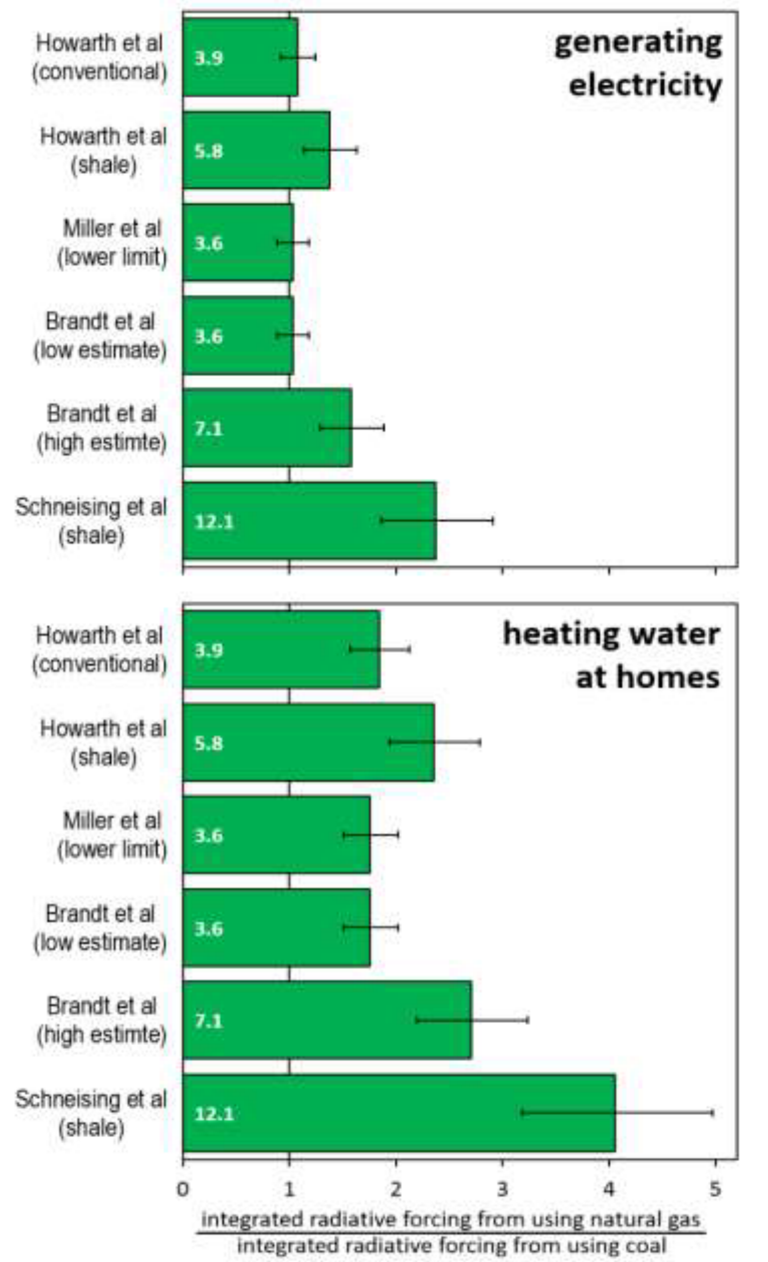
How natural gas is used effects the greenhouse gas footprint.

The largest use of natural gas is for heating.





Hong & Howarth, ms submitted; 20 year time frame; GWP from IPCC 2013



Sensitivity analysis, comparing different estimates for methane emissions:

All show natural gas worse than coal-generated electricity, at the 20-year averaged time scale….. Much worse so in many cases.

Not an argument for coal…. An argument against natural gas as a bridge fuel.

We need some other path.

Hong & Howarth, ms submitted; 20 year time frame; GWP values from IPCC 2013


METHANE
FOSSIL FUELS CAN BE USED RESPONSIBLY
THERE SEEMS TO BE A HOLE IN THAT ARGUMENT...
BUT PEOPLE CAN'T SEE IT.—
TOLES
UNIVERSAL UCLICK
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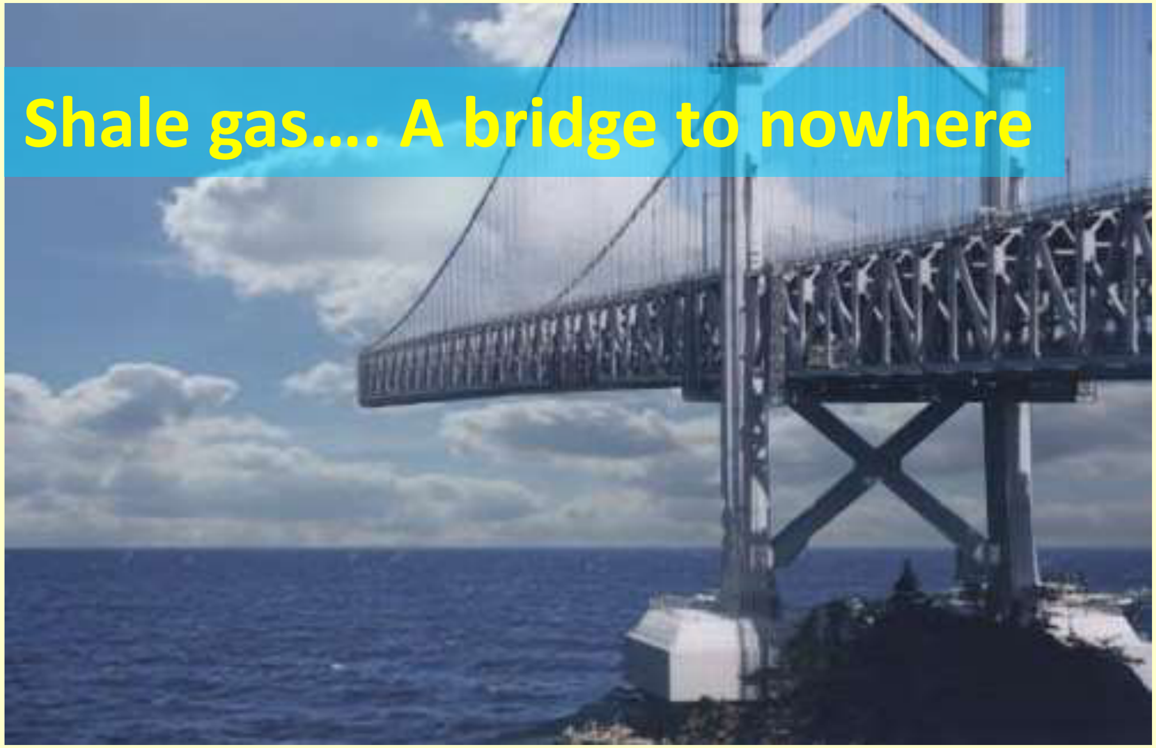
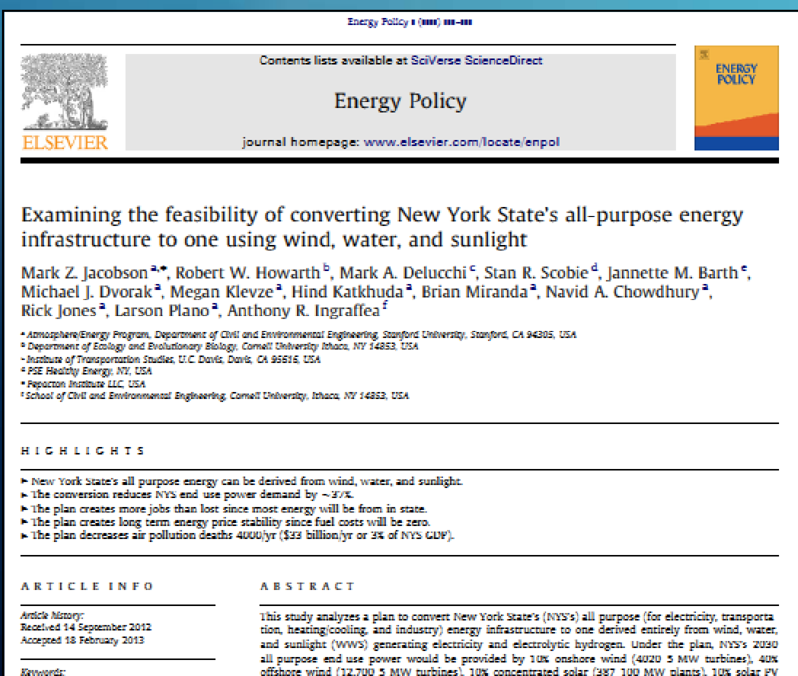
So what should our energy future be?



Powering New York and California with no fossil fuels, largely by 2030, using only current technologies



Energy Policy ■ (■■■■) ■■■–■■■

Contents lists available at SciVerse ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

Examining the feasibility of converting New York State's all-purpose energy infrastructure to one using wind, water, and sunlight

Mark Z. Jacobson[a,*], Robert W. Howarth[b], Mark A. Delucchi[c], Stan R. Scobie[d], Jannette M. Barth[e], Michael J. Dvorak[a], Megan Klevze[a], Hind Katkhuda[a], Brian Miranda[a], Navid A. Chowdhury[a], Rick Jones[a], Larson Plano[a], Anthony R. Ingraffea[f]

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[b] Department of Ecology and Evolutionary Biology, Cornell University Ithaca, NY 14853, USA
[c] Institute of Transportation Studies, U.C. Davis, Davis, CA 95616, USA
[d] PSE Healthy Energy, NY, USA
[e] Pepacton Institute LLC, USA
[f] School of Civil and Environmental Engineering, Cornell University, Ithaca, NY 14853, USA

HIGHLIGHTS

- New York State's all purpose energy can be derived from wind, water, and sunlight.
- The conversion reduces NYS end use power demand by ~37%.
- The plan creates more jobs than lost since most energy will be from in state.
- The plan creates long term energy price stability since fuel costs will be zero.
- The plan decreases air pollution deaths 4000/yr ($33 billion/yr or 3% of NYS GDP).

ARTICLE INFO

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ABSTRACT

This study analyzes a plan to convert New York State's (NYS's) all purpose (for electricity, transportation, heating/cooling, and industry) energy infrastructure to one derived entirely from wind, water, and sunlight (WWS) generating electricity and electrolytic hydrogen. Under the plan, NYS's 2030 all purpose end use power would be provided by 10% onshore wind (4020 5 MW turbines), 40% offshore wind (12,700 5 MW turbines), 10% concentrated solar (387 100 MW plants), 10% solar PV

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A roadmap for repowering California for all purposes with wind, water, and sunlight

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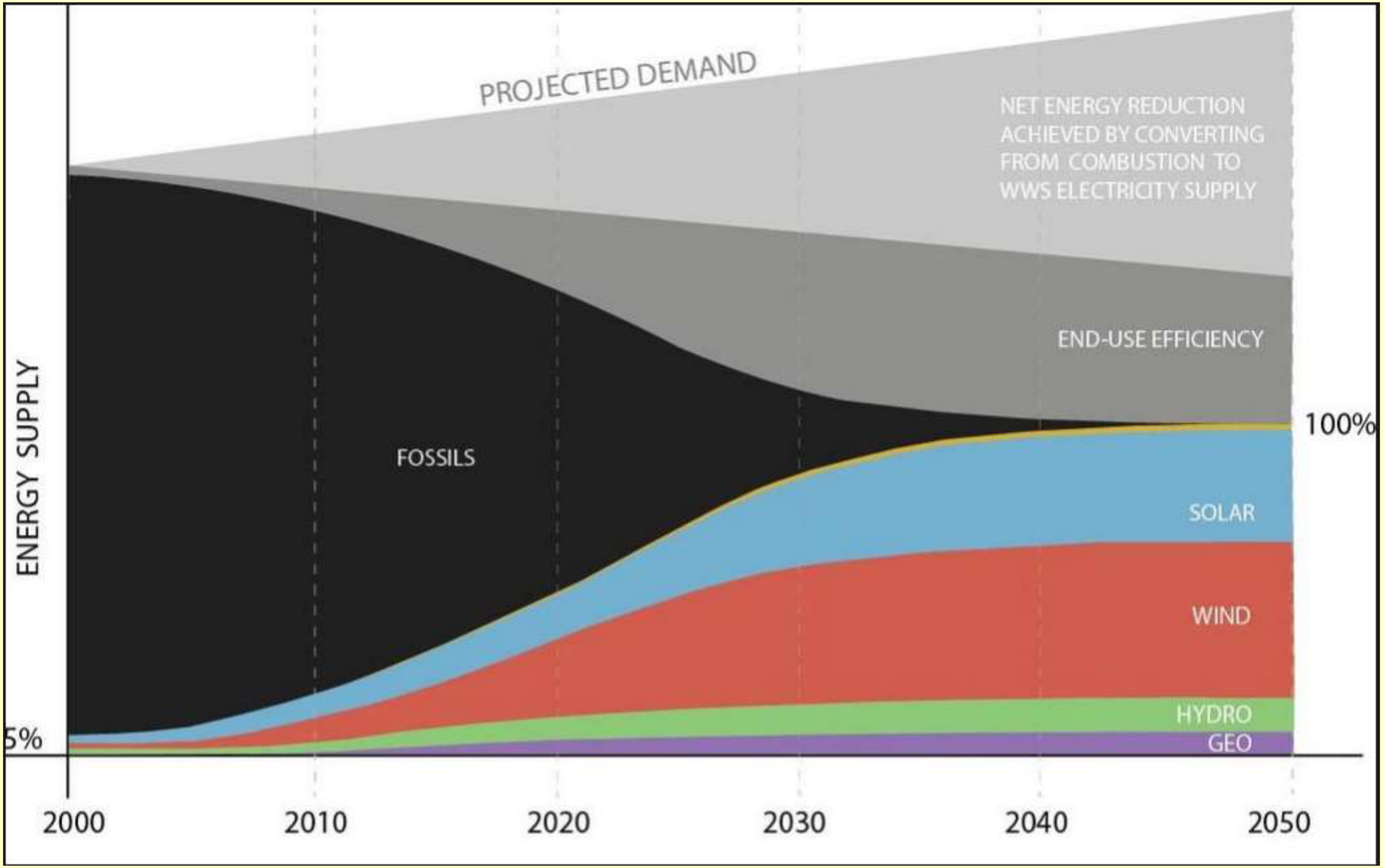
ABSTRACT

This study presents a roadmap for converting California's all-purpose (electricity, transportation, heating/cooling, and industry) energy infrastructure to one derived entirely from wind, water, and sunlight (WWS) generating electricity and electrolytic hydrogen. California's available WWS resources are first

Our Energy Plan for New York State



Jacobson et al., *Energy Policy*, Feb. 2013

Howarth-Marino household is 100% carbon neutral, with geothermal heating and renewable electricity.

Half of our driving is by electric car.

Ingraffea New Home Under Construction to German PassivHaus Standards: Net Zero

Some concluding thoughts:

Our April 2011 paper began a serious inquiry into the greenhouse gas consequences of shale gas and conventional natural gas.

New studies continue at a rapid pace, but growing evidence shows natural gas to be no bridge fuel.

Urgent need to reduce methane emissions, to slow down arrival time of potential tipping points in the climate system.

We must also control carbon dioxide emissions, because of consequences running 1,000s of years into the future.

We should embrace the 21st Century, and power our economy on renewable energy and use energy efficient technologies (electric vehicles, heat pumps) rather than fossil fuels.

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