Methane Leakage Update

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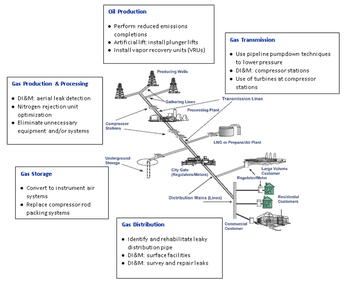
How is the methane leakage rate estimated?

1. EIA bottom up approach based on sample measurements and activity inventory data

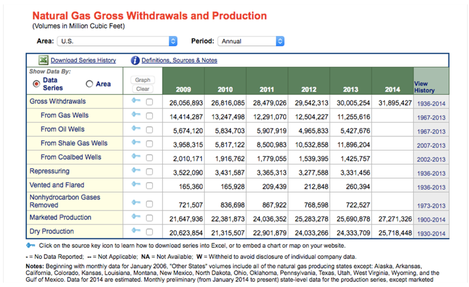


2. EPA GHG emission inventory says 360BCF annually

Table ES-2: Recent Trends in U.S. Greenhouse Gas Emissions and Sinks (MMT CO_2 Eq.)

CH_4	773.9	717.4	722.4	717.4	714.4	721.5	730.8
Natural Gas Systems	206.8	177.3	166.2	170.1	172.6	175.6	176.1
Enteric Fermentation	164.2	168.9	171.3	168.9	166.7	165.5	164.3
Landfills	179.6	154.0	142.1	144.4	142.3	144.3	148.0
Petroleum Systems	38.7	48.8	54.1	56.3	58.4	64.7	68.1
Coal Mining	96.5	64.1	82.3	71.2	66.5	64.6	67.6
Manure Management	37.2	56.3	60.9	61.5	63.7	61.4	61.2
Wastewater Treatment	15.7	15.9	15.5	15.3	15.0	14.8	14.7
Rice Cultivation	13.1	13.0	11.9	11.8	11.9	11.9	11.9
Stationary Combustion	8.5	7.4	7.1	7.1	6.6	8.0	8.1
Abandoned Underground Coal Mines	7.2	6.6	6.6	6.4	6.2	6.2	6.3
Composting	0.4	1.9	1.8	1.9	1.9	2.0	2.1
Mobile Combustion	5.6	2.7	2.3	2.2	2.2	2.1	2.0
Field Burning of Agricultural Residues	0.2	0.2	0.3	0.3	0.3	0.3	0.3
Petrochemical Production	0.2	0.1	+	+	0.1	0.1	0.1
Ferroalloy Production	+	+	+	+	+	+	+
Silicon Carbide Production and Consumption	+	+	+	+	+	+	+
Iron and Steel Production & Metallurgical Coke Production	+	+	+	+	+	+	+
Incineration of Waste	+	+	+	+	+	+	+
International Bunker Fuels[b]	*0.2*	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*

3. EIA says Natural Gas Production in the US was ~23,000 BCF



Natural Gas Gross Withdrawals and Production
(Volumes in Million Cubic Feet)

Area: U.S. Period: Annual

Download Series History | Definitions, Sources & Notes

Show Data By: Data Series / Area

	2009	2010	2011	2012	2013	2014	View History
Gross Withdrawals	26,056,893	26,816,085	28,479,026	29,542,313	30,005,254	31,895,427	1936-2014
From Gas Wells	14,414,287	13,247,498	12,291,070	12,504,227	11,255,616		1967-2013
From Oil Wells	5,674,120	5,634,703	5,907,919	4,965,833	5,427,676		1967-2013
From Shale Gas Wells	3,958,315	5,817,122	8,500,983	10,532,858	11,896,204		2007-2013
From Coalbed Wells	2,010,171	1,916,762	1,779,055	1,539,395	1,425,757		2002-2013
Repressuring	3,522,090	3,431,587	3,365,313	3,277,588	3,331,456		1936-2013
Vented and Flared	165,360	165,928	209,439	212,848	260,394		1936-2013
Nonhydrocarbon Gases Removed	721,507	836,698	867,922	768,598	722,527		1973-2013
Marketed Production	21,647,936	22,381,873	24,036,352	25,283,278	25,690,878	27,271,326	1900-2014
Dry Production	20,623,854	21,315,507	22,901,879	24,033,266	24,333,709	25,718,448	1930-2014

Click on the source key icon to learn how to download series into Excel, or to embed a chart or map on your website.

- = No Data Reported; -- = Not Applicable; NA = Not Available; W = Withheld to avoid disclosure of individual company data.

Notes: Beginning with monthly data for January 2006, "Other States" volumes include all of the natural gas producing states except: Alaska, Arkansas, California, Colorado, Kansas, Louisiana, Montana, New Mexico, North Dakota, Ohio, Oklahoma, Pennsylvania, Texas, Utah, West Virginia, Wyoming, and the Gulf of Mexico. Data for 2014 are estimated. Monthly preliminary (from January 2014 to present) state-level data for the production series, except marketed

4. Divide!

360/23,000

= **1.5%**

What do Independent Studies Say?

1. Estimation methodology (top down vs bottom up analysis). In top down takes atmospheric samples, some sources not in the GHI inventory, such as abandoned gas wells[1] (Mary Kang Thesis 2014).
2. Sampling error. EPA is ignoring a small group of superemitters (Brand et al. 2014)
3. EPA might be underestimating leakage by 20-40%
4. Leakage rate is likely **1.85% - 2.95%** in natural gas systems

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Finding the ways that work

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 greenho gas that is contributing to climate change. Science confirms methane is a problem tha 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.

Recent findings

Barnett Study
July 2015
Scientists estimated regional and facility level methane emissions in the Texas Barnett Shale, collecting data using aircraft, vehicular, and other ground-based platforms. Researchers estimate regional methane emissions are 50 percent higher than estimates based on the Environmental Protection Agency's Greenhouse Gas Inventory. Learn more

Local Distribution Study
March 2015
The study shows that methane emissior from local natural gas distribution syster are significant, especially in regions suc as the Northeast where distribution infrastructure is older, but that progress being made in reducing emissions from

UT Study, Phase 1
December 2013
The study found that methane emissions from equipment leaks and pneumatic devices were larger than previously thought and that techniques to reduce emissions from well completions are effective at capturing 99% of the meth that was previously vented to the atmosphere, providing a data-based example of EPA regulations working. Learn more »

UT Study, Phase 2
December 2014
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. Learn more

HARC/EPA Study
November 2014
A statistical analysis of national production data suggests unpredictable events, such as malfunctions and maintenance, have a strong influence or emission rates. Learn more »

Methane Maps Release
July 2014
EDF and Google Earth Outreach releas interactive maps that show methane

Denver-Julesburg Flyover Study
May 2014
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. Learn more »

Gathering and Processing Study
February 2015
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. Learn more »

Transmission and Storage Study
February 2015
The paper confirms compressors and equipment leaks are two primary sources for the sector's methane emissions. Learn more »

ston Study
uary 2015
ng tower-based measurements, the ly found methane emissions were are e than two times higher than inventory a would suggest, with a yearly average rate between 2.1 and 3.3 percent.
Learn more »

References

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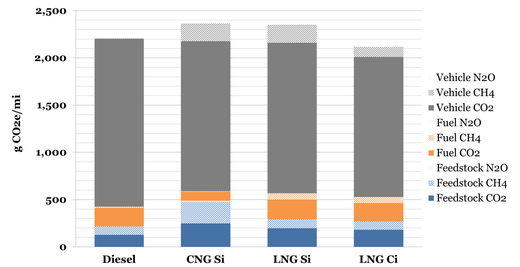
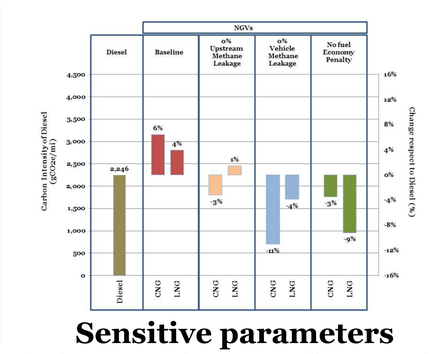
Kang M, Nanno C., Reid M.C., Zhang X., Mauzeralla D.L., Celia M.A., Chen Y., Onstott T.C. "Direct measurements of methane emissions from abandoned oil and gas wells in Pennsylvania." PNAS | December 23, 2014 | vol. 111 | no. 51 | 18173–18177

How does it affect the WTW of natural gas fuels?



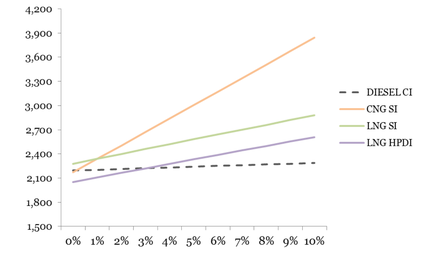
WTW CI at 1.5% Leakage

- We can see majority of emissions come from the vehicle (grey).
- Methane in the vehicle (methane slip) contributes as much as upstream methane



Sensitive parameters

- 1.5% leakage not a large contributor to the WTW
- Vehicle slip and lower fuel economy are major aspects



WTW CI at different leakages

- Leakage affects CNG more than LNG
- Even at low upstream methane leakage, natural gas vehicles more carbon intensive than diesel due to relative lower engine efficiency and higher vehicle methane slip

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