Climate, Energy Transition and the Use of Natural Gas in Freight Transportation: Pros and Cons

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Webinar Series | Chair in Energy Sector Management, HEC Montréal
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About STEPS

- **STEPS** is a multidisciplinary research consortium, part of the Institute of Transportation Studies at the University of California Davis (ITS-Davis) – a world leading university center on sustainable transportation.

- **Research:** generate new insights and tools, grounded in technical and economic realities, to study the sustainable transportation energy future for California, the U.S. and the world.

- **Consortium:** bring together the world's leading auto OEMs, energy companies, and government agencies to collaborate on sustainable vehicle and energy solutions; inform industry planning and government policy with timely and sophisticated science-based analysis.

- **Website:** steps.ucdavis.edu

Context for use of natural gas in transportation: CO_2 and NO_x emission reductions

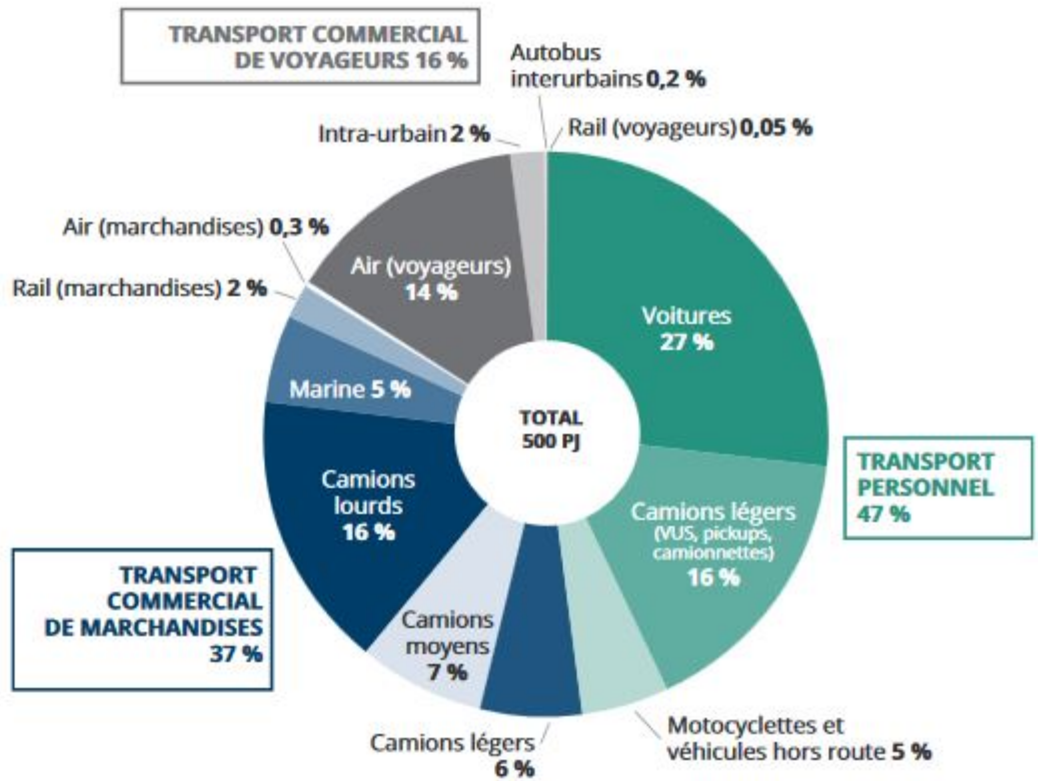
Québec and California Link

Both Quebec and California participate in the Western Climate Initiative (WCCI)

Québec GHG Targets and Transportation

-20 % by 2020
-37.5% by 2030
-80% by 2050

- Electricity is local and 99% renewable
  = 47% primary energy
- Hydrocarbons are imported
  = 53% primary energy
- Freight transportation account for 37% of all energy consumed in the transportation sector and is the fastest growing (GHG and energy consumption levels)



Source: Whitmore and Pineau, 2016.

“**Natural gas for vehicles: A proven solution**.”

“Generally less expensive and **always more environmentally friendly than diesel**, natural gas has a major potential in the transportation sector.”

“For the 2015 fiscal year, the 22 fueling sites in Québec and 630 vehicles that run on natural gas helped replace 14.8 million liters of diesel.”

“In total, 19,404 tons of CO_2 equivalent were avoided by using natural gas as fuel during the 2015 fiscal year, including 12,900 tons by **using renewable natural gas** produced by EBI.”

Source: Gaz Métro, 2016. Sustainable Development Report 2015, p.22, 69, 78, www.gazmetro.com/en/about/sustainable-development/report/resources/pdf-documents

"[NGVs] **reduces CO_2** emissions by 25% compared to **gasoline**, and **reduces NO_x** emissions by 80% compared to light **diesel** vehicles."

Source: ENGIE, 2017. "GNVERT, opérateur de mobilité durable", www.engie.fr/gaz-naturel/gnvert/

To be clear: Near-ZEV refers to criteria pollutants only

- Natural gas is low NOX and low PM

  Sometimes called Zero Emission Vehicles (ZEV) or near-ZEV
- Refers to criteria pollutants, not GHG
- For GHG, Natural gas is **allowed 20% reduction (not 100%)** from gasoline/diesel in California LCFS

Pounds of CO_2 emitted per million British thermal units (Btu) of energy for various fuel (combustion only)

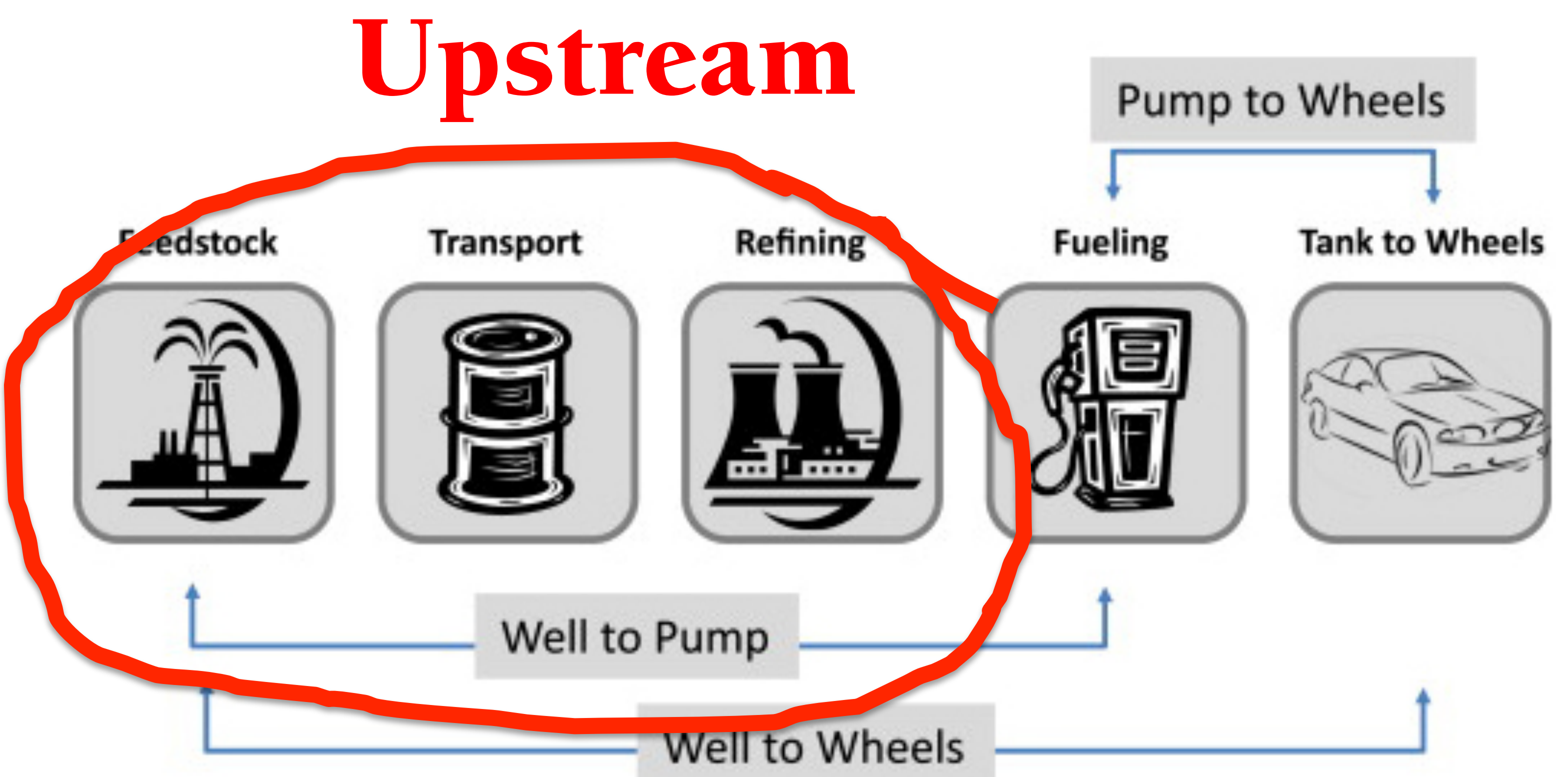
Diesel fuel and heating oil	161.3
Gasoline	157.2
Propane	139.0
Natural gas	117.0

Source: https://www.eia.gov/tools/faqs/faq.php?id=73&t=11

But it is a little more complicated than that

Life Cycle Analysis
or Well to Wheels (WTW):

- ◆Well to Pump (WTP)
- ◆Pump to Wheels (PTW)

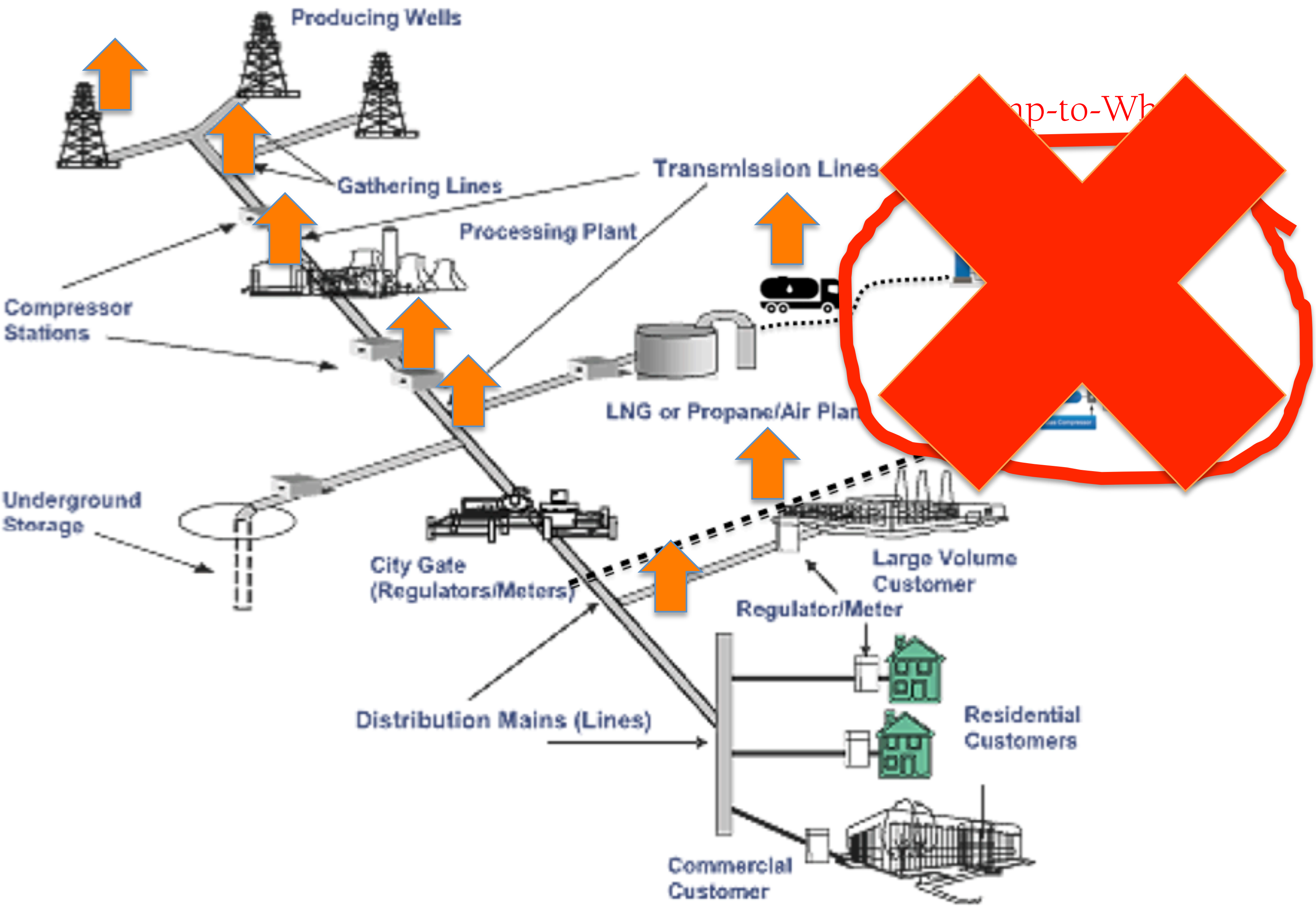


Source: Curran et al. 2014. Well-to-wheel analysis of direct and indirect use of natural gas in passenger vehicles, *Energy*, Vol. 75, 1 October 2014, p.194–203, http://www.sciencedirect.com/science/article/pii/S0360544214008573

Well-to-Pump Methane Leakage

(a.k.a. Upstream or Fuel Cycle)

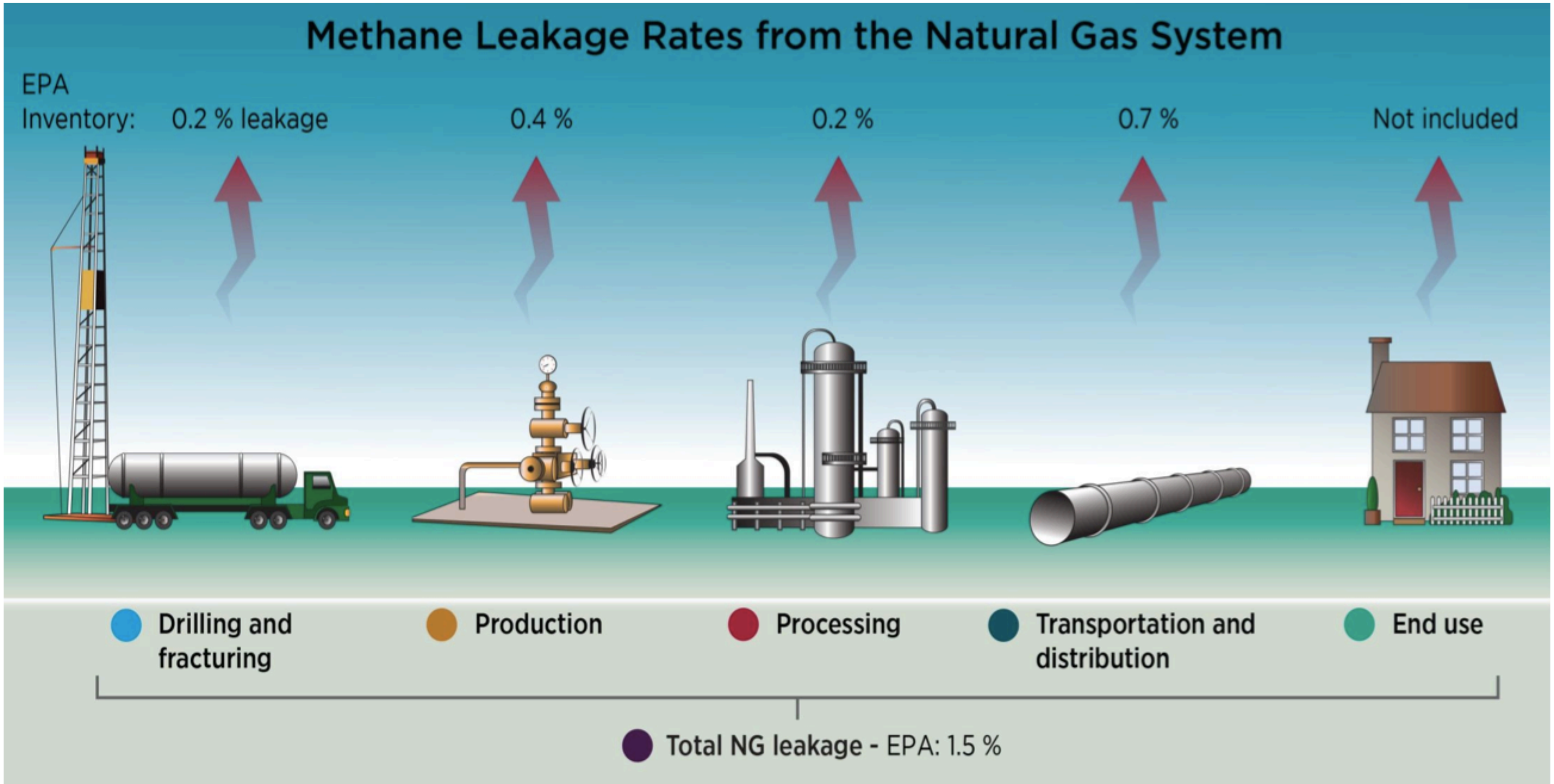
Natural Gas Supply Chain



Methane Leaks

Source: EPA, www.epa.gov/gasstar/tools/videos.html

Upstream Methane Leakage



Source: EDF based on 2013 EPA GHGI

EPA estimates of leakage goes up and down a little

Gas/Source	1990	2005	2010	2011	2012	2013	2014
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	+	+	+	+	+	+	+

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

Source: EPA, Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2014, www3.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2016-Chapter-Executive-Summary.pdf

Production also changes a little

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	Graph / Clear	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	5,834,703	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

Source: EIA, 2017. Natural Gas Gross Withdrawals and Production, www.eia.gov/dnav/ng/ng_prod_sum_dcu_NUS_a.htm

EPA: ~1.5% Leakage

But Many Disagree with EPA….

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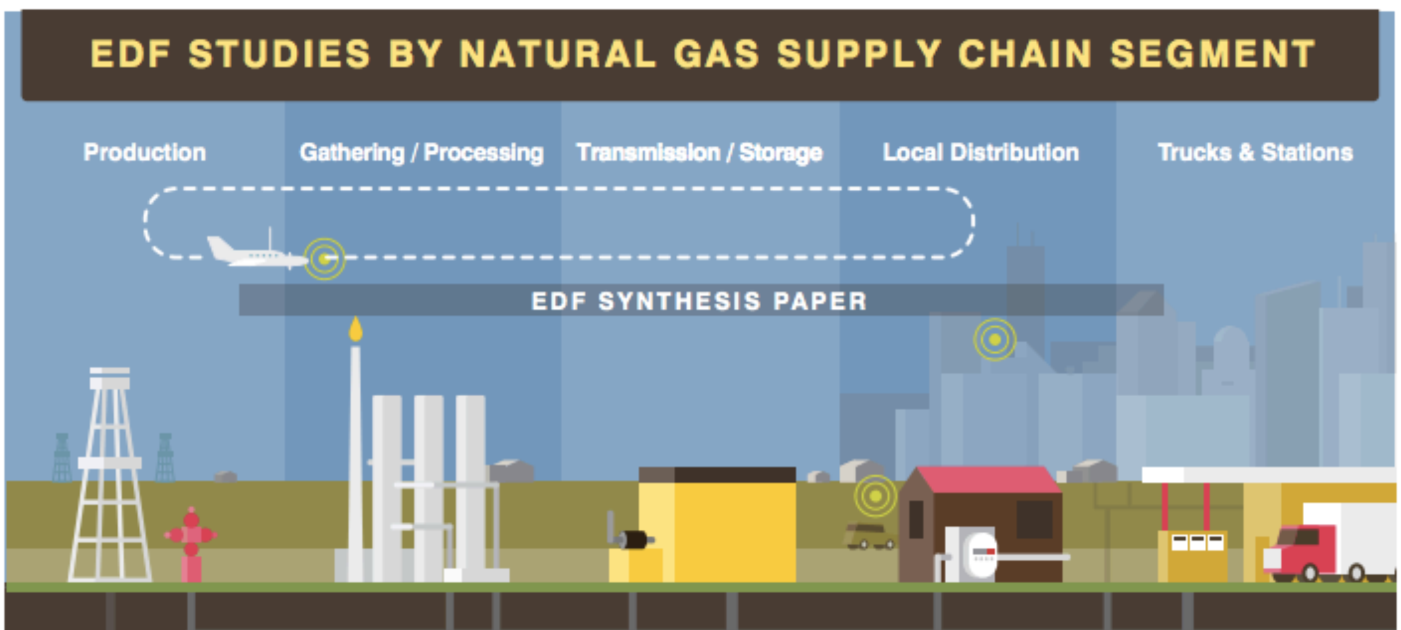
Finding the ways that work

Methane Research: The 16 Study Series

AN UNPRECEDENTED LOOK AT METHANE FROM THE NATURAL GAS SYSTEM

Methane (CH4) 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.



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 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. 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 on emission rates. Learn more »

Methane Maps Release
July 2014
EDF and Google Earth Outreach release interactive maps that show methane leaking from pipelines under city streets. Learn more »

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 »

Boston Study
January 2015
Using tower-based measurements, the study found methane emissions were are more than two times higher than inventory data would suggest, with a yearly average loss rate between 2.1 and 3.3 percent. Learn more »

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 methane that was previously vented to the atmosphere, providing a data-based example of EPA regulations working.

Found a range of estimates

Bottom-up vs. Top-down

- **Bottom-up** studies coincide with EPA
- **Top-down** studies find EPA estimates are low.

Why!?!?

EPA might be missing a small number of super emitters

Table S6. Evidence of heterogeneity of emissions magnitudes across studies.

Study name	Industry stage	Measurement technique	Degree of heterogeneity noted	Pages with relevant statistics, tables, or quotes.
Allen *et al.* 2013	Production	Direct measurement of unloading events	"Four of nine events contribute more than 95% of total emissions"	Article p. 3.
Alvarez 2012	Production	Analysis of reported emissions	"10% of well sites accounted for 70% of emissions"	Article p. 3. Also see SI dataset in Microsoft Excel format.
Chambers 2006	Processing	Down-wind differential absorption LIDAR	"At plant B a single intermittent leak from a pressure relief valve was located that increased site emissions from 104 kg/hr to 450 kg/h."	p. 6
Clearstone 2002	Processing	Direct measurement using Hi-Flow sampler	>100,000 devices sampled across 4 facilities. between 35.7% and 64.6% of leakage from each facility was found leaking from top 10 leaks in each facility.	Executive summary, Table 4 (p. 24).
Cormack, 2007	Transmission compressors	Direct measurement with Hi-Flow	Top single leak accounted 40% of leakage. Top 20% of leaking components accounted for 80% of leakage.	Figure p. 15
Harrison *et al.* 2011	Compressor stations	IR camera, Hi-Flow sampler	Reported data in Appendix B show outliers. For example, ~2,800 valves and flanges were screened with IR camera and 29 leaks were found. The single largest of these leaks (>1000 mscf/year) is >100,000 times larger than valve and flange EF (0.05 or 0.09 mscf/year). Similar results seen elsewhere. See, e.g., blowdown line leaks from centrifugal compressors (table B2) where largest leak represents 70% of the total leakage.	See tabular data in Appendix B.
NGML, Clearstone, IES 2006	Processing, well sites, gathering compressor stations	Direct measurement using Hi-Flow sampler and optical methods	> 74,000 components sampled. Approx. 1600 were found to be leaking (~2%). From executive summary: "Repairs to 10 largest emitting cost-effective-to-repair components at each site…would reduce natural gas losses by approximately…58%"	Executive summary (p. iii). For details, see Appendix 1 (separate PDF) which ranks leaks by emissions rate for ~1600 leaking sources.
Picard, 2005	All stages	Sampling via various methods	"Top 10 leaks typically contribute more than 80% of emissions from leaks."	p. 3
Shorter, 1997	All stages	Remote sampling via tracer methods	Repeated evidence of skewed emissions distributions: See tables 1–7. Evidence includes: top emitters of size 100x to 10,000x larger than small emitters (table 9); standard deviations in excess of mean emissions rate in many cases, indicating heavy-tailed distribution (table 7).	Tables 1-9
Trefiak 2006	Compressor stations and gas plants	Optical measurement and Hi-Flow sampler	23% of the 144 fugitive emissions sources were responsible for 77% of leakage.	Fig. 2.1

Source: Brandt A.R., Heath G.A., and Cooley, D *Methane Leaks from Natural Gas Systems Follow Extreme Distribution.* Environ. Sci. Technol., 2016, 50 (22), pp 12512–12520

EPA not measuring abandoned wells

- Mary Kang (Princeton) Summer 2014 Thesis: Leakage from Abandoned Oil and Gas Wells
- Methane emissions from AOG wells **are not accounted for in any GHG emissions inventories** , either at the state or national levels in the U.S. or abroad.
- Leakage rates are **equivalent to 0.3 to 0.5% of gross gas withdrawal** (in PA for 2010)

Source: Kang, M., Christian, S., M, Celiac, M.A., Mauzerall, D.L. Bille, M., Miller, A.R., Chen, Y., Conrade, M.E., Darrah, T.H., Jackson, R.B. *Identification and characterization of high methane-emitting abandoned oil and gas wells.* 13636–13641 | PNAS | November 29, 2016 | vol. 113 | no. 48

More or less established: Actual leakage 25-75% higher than EPA's estimate

EPA: 1.5%

Corrected: 1.85% -2.95 % due to sub-estimation of super emitters

- Unaccounted for: abandoned wells, other sources, add 0.5% points

Source: Brandt et al. 2014. Methane Leaks from North American Natural Gas Systems. *Science* 343, 733.

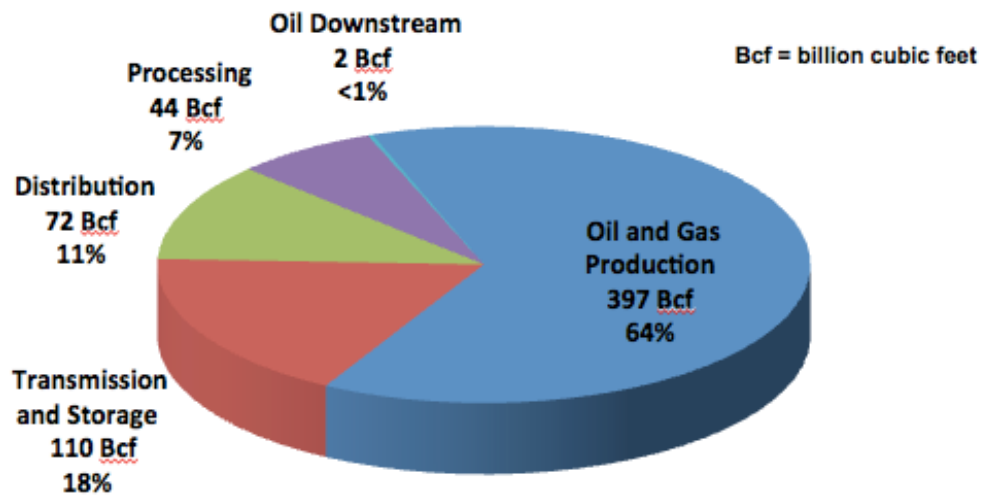
Solutions to Reduce Upstream Methane Leakage

EPA Natural Gas STAR Program (voluntary reductions)

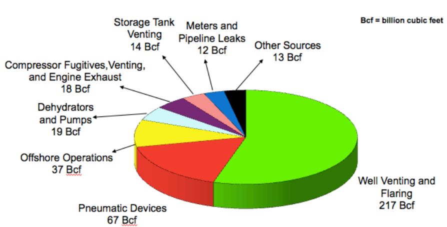
- There is also for Coalmining, agriculture, landfills
- Objective: Voluntary reductions in methane
- As of May 2016 Methane Rule in NSPS… but those only apply to new and modified wells, not old, not abandoned, etc…

Where are the leaks?

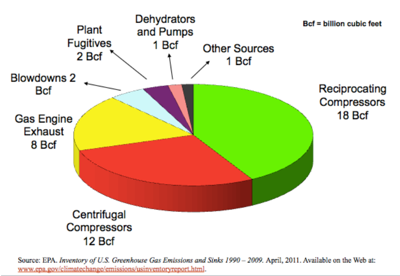
- 2009 U.S. methane emissions from oil and natural gas industry: 624 Bcf (3.8% of total U.S. greenhouse gas emissions)



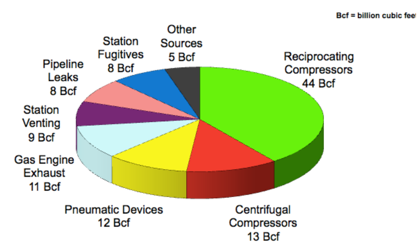
Production



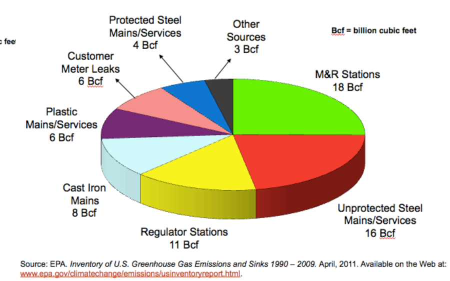
Gathering & Processing



Transmission



Distribution



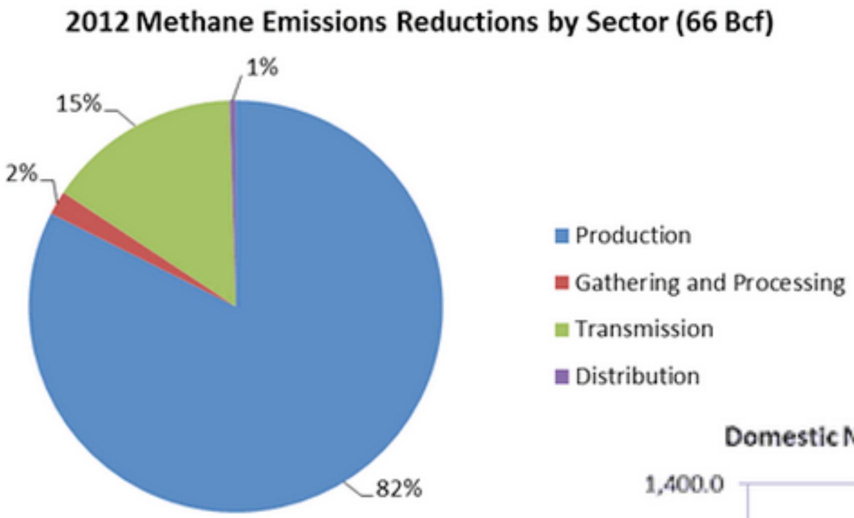
Technology Payback

Table 4: Methane Capture Technology Costs and Benefits				
Technology	**Investment Cost**	**Methane Capture**	**Profit**	**Payout**
Green Completions	$8,700 to $33,000 per well	7,000 to 23,000 Mcf/well	$28,000 to $90,000 per well	< 0.5 – 1 year
Plunger Lift Systems	$2,600 to $13,000 per well	600 to 18,250 Mcf/year	$2,000 to $103,000 per year	< 1 year
TEG Dehydrator Emission Controls	Up to $13,000 for 4 controls	3,600 to 35,000 Mcf/year	$14,000 to $138,000 per year	< 0.5 years
Desiccant Dehydrators	$16,000 per device	1,000 Mcf/year	$6,000 per year	< 3 years
Dry Seal Systems	$90,000 to $324,000 per device	18,000 to 100,000 Mcf/year	$280,000 to $520,000 per year	0.5 – 1.5 years
Improved Compressor Maintenance	$1,200 to $1,600 per rod packing	850 Mcf/year per rod packing	$3,500 per year	0.5 years
Pneumatic Controllers Low-Bleed	$175 to $350 per device	125 to 300 Mcf/year	$500 to $1,900 per year	< 0.5 – 1 year
Pneumatic Controllers No-Bleed	$10,000 to $60,000 per device	5,400 to 20,000 Mcf/year	$14,000 to $62,000 per year	< 2 years
Pipeline Maintenance and Repair	Varies widely	Varies widely but significant	Varies widely by significant	< 1 year
Vapor Recovery Units	$36,000 to $104,000 per device	5,000 to 91,000 Mcf/year	$4,000 to $348,000 per year	0.5 – 3 years
Leak Monitoring and Repair	$26,000 to $59,000 per facility	30,000 to 87,000 Mcf/year	$117,000 to $314,000 per facility per year	< 0.5 years

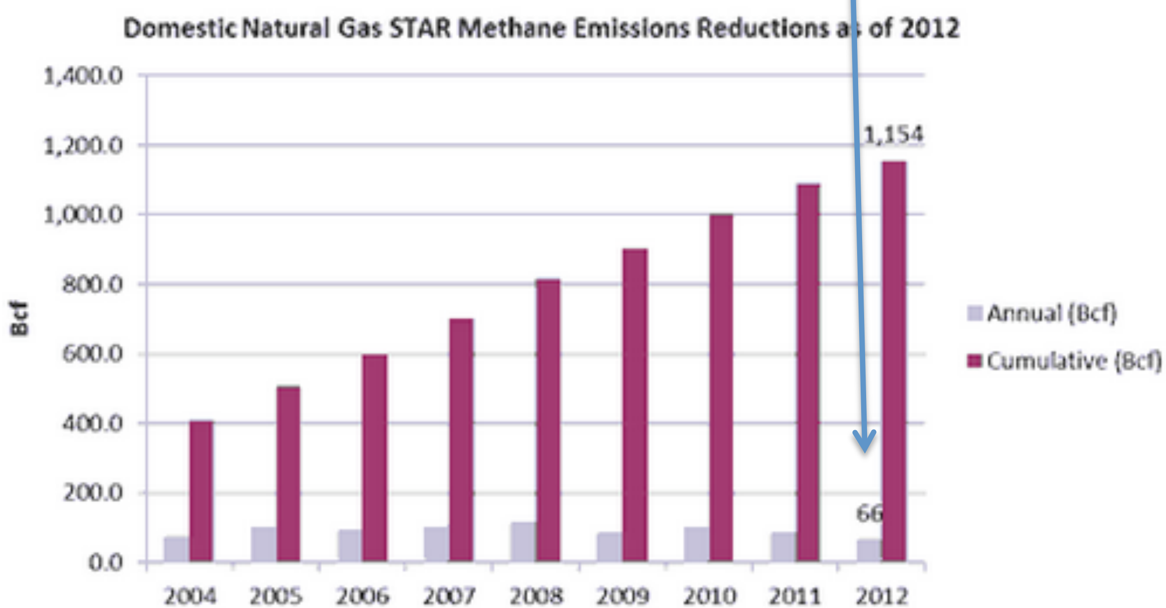
Note: Profit includes revenue from deployment of technology plus any O&M savings or costs, but excludes depreciation. Additional details provided in Appendix A.
Source: NRDC analysis of available industry information. Individual technology information sources cited in Chapter 4.

Source: EPA Natural Gas STAR Program. NRDC leaking profits

EPA Natural Gas STAR Program



Less than 10% of what is being emitted



In 2016, leakage reduced by 16% while production increased by 35%

Source: EPA Natural Gas Star Program, www.epa.gov/gasstar/accomplishments/index.html

Upstream Leakage Summary

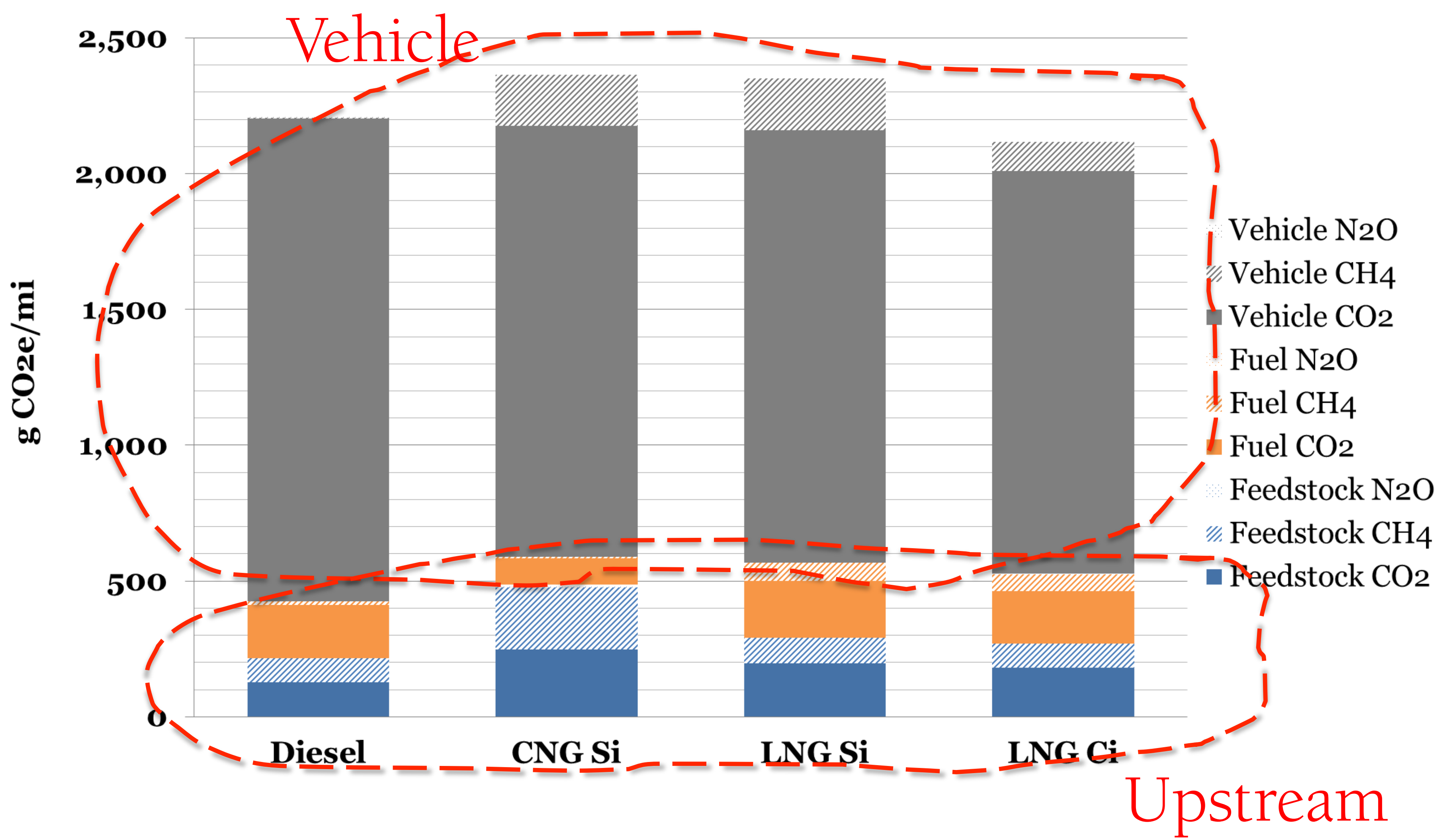
- Variable: Company culture and geography often reflect regulations
- Measured with Bottom-up vs. Top-down
- **EPA bottom-up average is under 1.5%**
- **Realistically, could be as high as ~3% or 3.5%**
- In some specific cases, top-down suggests as high as 8%, but difficult to attribute to sources.

My way to deal with uncertainty?

Test scenarios for upstream leakage:

- <u>Baseline</u>: 1.14%
- <u>Zero Leakage</u> Scenario
- High Leakage Scenario (up to 10%)

And I will get to that in a minute...



Source: Dominguez-Faus, R. The CARBON INTENSITY of NGV C8 TRUCKS. STEPS Working Paper
https://steps.ucdavis.edu/wp-content/uploads/2017/05/Dominguezfaus-The-Carbon-Intensity-of-NGVS.pdf

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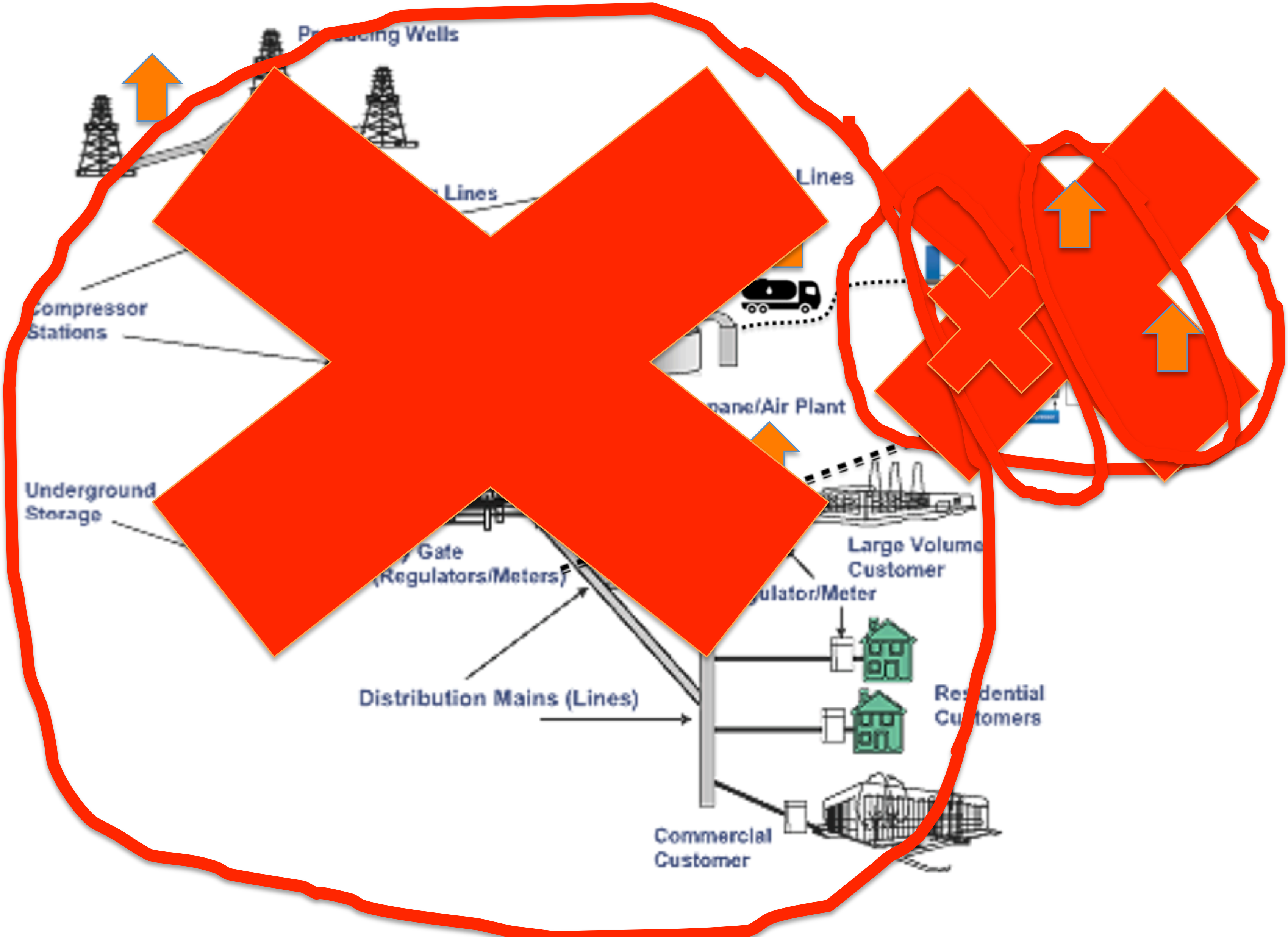
Natural Gas Supply Chain



Vehicle Emissions
(vehicle Leakage)

Methane leakage in Long-Haul Trucks

(based on data provided by Westport)

Diesel:

- 0.005 gCH_4/mi (methane slip)

Natural Gas:

- 3.6 g CH_4/mi HPDI
- 6.3 g CH_4 /mi Si

(For natural gas fueled engines that will be used in <u>long-haul trucks)</u>

<u>It will be different in other applications</u>

Source of difference with other studies

ARB: Uses values for average application using natural gas (was traditionally a mix of taxis and buses)

Me: Long-haul Trucks

1. Different drive cycles means <u>Different Emission Profile and Fuel Economies</u>
2. Natural gas is substituting <u>gasoline</u> in taxis and buses (whereas natural gas substitutes <u>diesel</u> in long haul trucks)

What does it matter which fuel it substitutes?

- Related to the efficiency of the combustion process
- Diesel: Uses Compression Ignition – Efficiency of 55%
- Gasoline: Spark Ignition (SI) engines about 10% less efficient than compression ignition (CI) diesel engines
- Natural gas engines: Spark Ignition (SI) engines about 10% less efficient than compression ignition (CI) diesel engines

So…..

- In taxis and buses → No difference in efficiency when switching from gasoline to natural gas
- In long-haul trucks → 10% efficiency loss when switching from diesel to natural gas.

Newer models seem to control crank-case leakage, but exhaust Ch4 is still a bit tricky

- Crank case

Easy to control

- Exhaust

Not so easy to control:
Incomplete combustion promoted when combustion temperature lowered for NOx control

Westport designs the HPDI dual fuel engine which has efficiency similar to diesel's

- 10% diesel for compression ignition (great efficiency)
- 90% on natural gas

I will test both for the SI and HPDI natural gas engines in long haul applications

Well-to-Wheel Carbon Intensity of CNG and LNG

My Baseline Assumptions about

Upstream

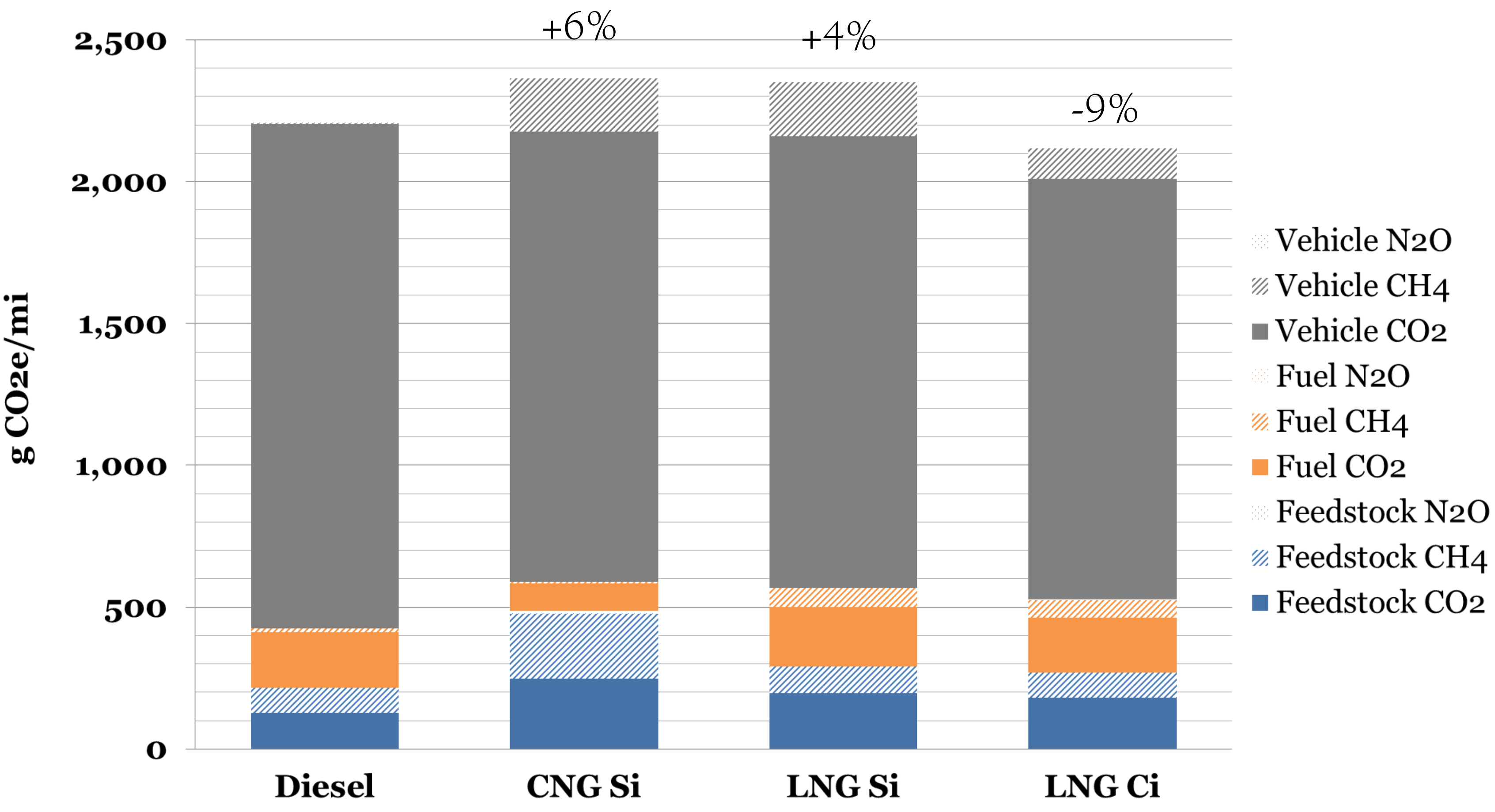
	Conventiona l NG	Shale gas
Recovery - Completion CH4 Venting	0.00%	0.03%
Recovery - Workover CH4 Venting	0.00%	0.01%
Recovery - Liquid Unloading CH4 Venting	0.05%	0.05%
Well Equipment - CH4 Venting and Leakage	0.25%	0.25%
Processing - CH4 Venting and Leakage	0.13%	0.13%
Transmission and Storage - CH4 Venting and Leakage	0.41%	0.41%
Distribution - CH4 Venting and Leakage	0.33%	0.33%
Total	1.18%	1.22%

Average ~1.2%

Vehicle

		Vehicle leakage	Vehicle fuel economy
NG	SI	6.3 g/mi	4.68 mpg
	HPDI (CI)	3.6 g/mi	5.36 mpg
Diesel	CI	0.005 g/mi	5.36 mpg

Carbon intensity of Diesel and 3 combinations of natural gas trucks



Source: Dominguez-Faus, R. The CARBON INTENSITY of NGV C8 TRUCKS. STEPS Working Paper https://steps.ucdavis.edu/wp-content/uploads/2017/05/Dominguezfaus-The-Carbon-Intensity-of-NGVS.pdf

Carnegie Mellon University (long-haul trucks)

- Another study by Carnegie Mellon University (CMU) offers probabilistic ranges rather than point estimates in order to account for the variety in fuels and transportation systems.
- For the WTW emissions, in addition to the variability in feedstock systems, they include variability in vehicles and fuel options.
- "for Class 8 tractor-trailers and refuel trucks, <u>none of the natural gas pathways</u> provide emissions reduction per unit of freight-distance moved compared to diesel trucks".
- When compared with petroleum fuels, CNG and centrally produced LNG emissions <u>increased by 0-3% and 2-13%,</u> respectively.

Source: Tong, F., Jaramillo, P., Azevedo I.M., Comparison of Life Cycle Greenhouse Gases from Natural Gas Pathways for Medium and Heavy-Duty Vehicles. Environ. Sci. Technol., 2015, 49 (12), pp 7123–7133

EDF and Columbia University (long-haul trucks)

- They consider the difference in the engine efficiencies of natural gas 8.9L and 11.9 L spark ignition (SI) engines and include a 15L HPDI engine technology
- Relative efficiencies of the SI and high performance direct injection (HPDI) are 13% and 5.5% lower than diesel respectively.
- For methane slip (i.e., methane from the vehicle) is 4.2 gCH4/mi for HPDI and 2.6 g/CH4 for the SI.
- <u>Converting heavy-duty truck fleets (to natural gas) leads to damages to the climate for several decades.</u>
- <u>After some period of time, 72 years (CNG) and 90 years (LNG) in the case of the SI NGV trucks and 51 years in the case of the HPDI truck (LNG), a climate benefit occurs as the initial warming created by methane dissipates and the benefits of lower CO2 emissions are reaped.</u>

Source: Camuzeaux, J.R., Alvarez, R.A., Brooks, S.A., Browne, J.B., Sterner, T. Influence of Methane Emissions and Vehicle Efficiency on the Climate Implications of Heavy-Duty Natural Gas Trucks. Environ. Sci. Technol., **2015**, 49 (11), pp 6402–6410

LCFS (buses and taxis)

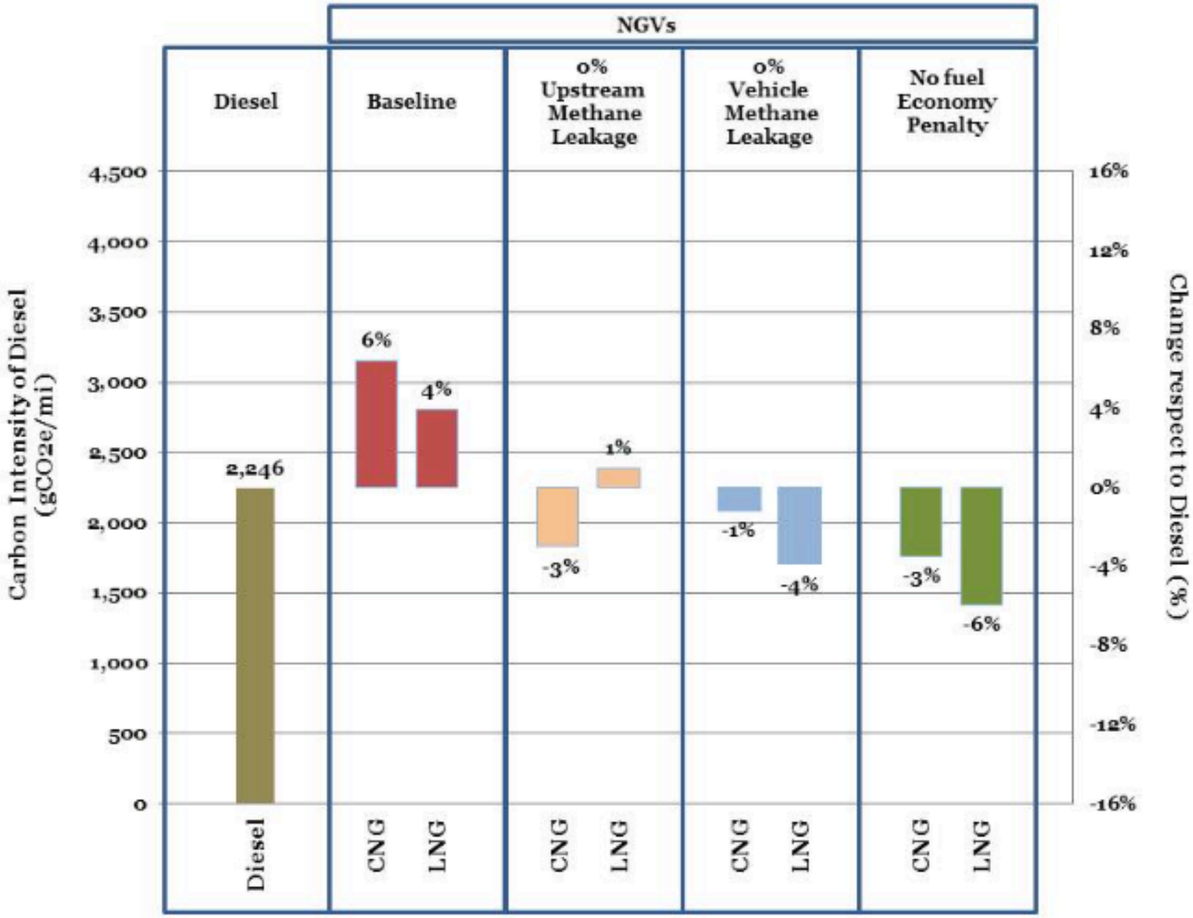
- The LCFS value is revised periodically.
  - In the original LCFS lookup tables calculate gasoline, diesel, CNG and LNG at a carbon intensity of 95.86, 94.71, 68, and 72.38 gCO2e/MJ (not EER adjusted) respectively.
  - In more recent public hearings, ARB is considering a modification to 98.38, 98.03, 75.56, 80.42 g/MJ (not EER adjusted) or 100.53, 102.76, 88.29, 96.19 g/MJ respectively if EER adjusted.
- Reductions of 12-28% (CNG), and 6-24% (LNG)

Source: https://www.arb.ca.gov/fuels/lcfs/fuelpathways/pathwaytable.htm

Why different? And Which variables are more important?

Testing the Sensitivities

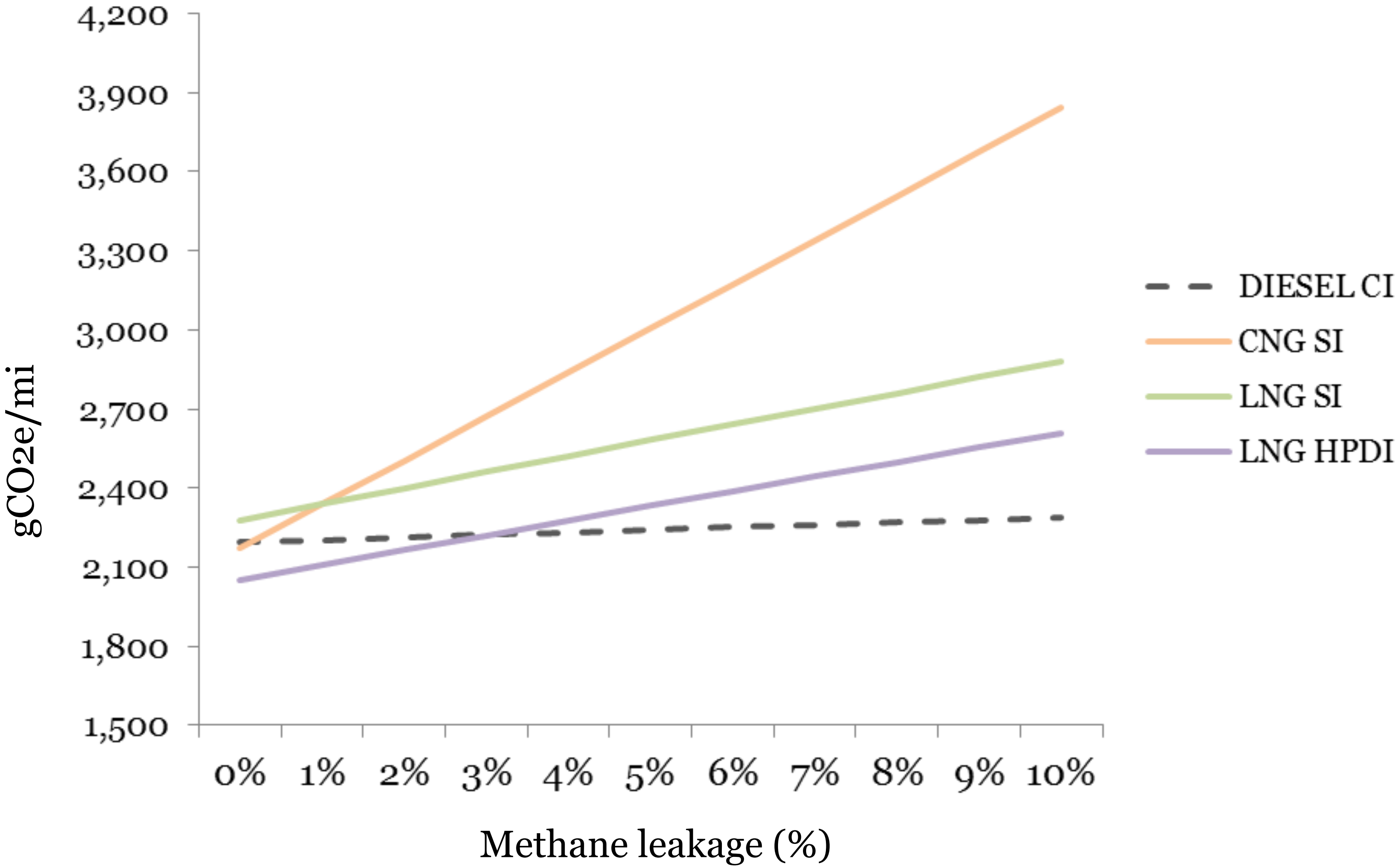
But is upstream leakage really that important in the LCA?



Source: Dominguez-Faus, R. The CARBON INTENSITY of NGV C8 TRUCKS. STEPS Working Paper https://steps.ucdavis.edu/wp-content/uploads/2017/05/Dominguezfaus-The-Carbon-Intensity-of-NGVS.pdf

ITS UCDAVIS INSTITUTE OF TRANSPORTATION STUDIES

Carbon Intensity under different methane leakage



Source: Dominguez-Faus, R. The CARBON INTENSITY of NGV C8 TRUCKS. STEPS Working Paper
https://steps.ucdavis.edu/wp-content/uploads/2017/05/Dominguezfaus-The-Carbon-Intensity-of-NGVS.pdf

One value does not fit all.
One single estimate is not valid,
there is variability,
there is uncertainty,
not only in upstream leakage but
also vehicle leakage and fuel
economy (largest sensitivities)

I am not saying….

Natural Gas cannot provide GHG reductions

I am saying….

1. It is not always the case
2. Upstream leakage is important, but so is what happens in the vehicle
3. Vehicle depends on:
   - The application: Bus, truck, marine?
   - The fuel it substitutes
4. There are ways to lower carbon intensity of NG:
   - Reduce upstream methane (effect: high)
   - Reduce vehicle methane (effect: high)
   - Increase fuel economy (effect: higher)
5. Reductions will be modest (unless you blend with H_2 or RNG). Definitely not a Near-ZEV in terms of GHG

Studies in STEPS website

- Exploring the Role of Natural Gas in U.S. Trucking (Revised Version) https://steps.ucdavis.edu/wp-content/uploads/2017/05/2015-UCD-ITS-RR-15-05-1.pdf

- The CARBON INTENSITY of NGV C8 TRUCKS https://steps.ucdavis.edu/wp-content/uploads/2017/05/Dominguezfaus-The-Carbon-Intensity-of-NGVS.pdf

Thank you.

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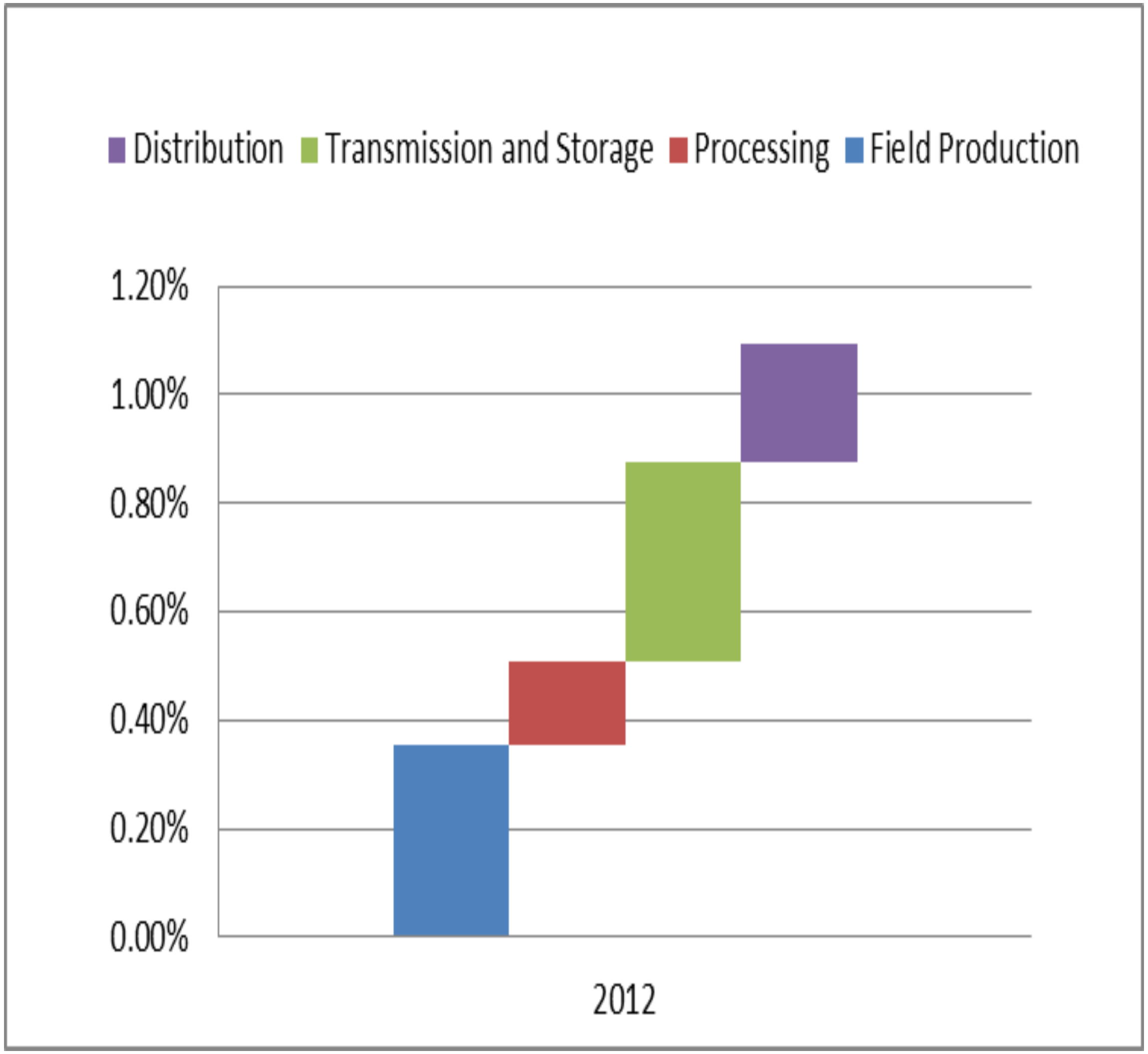
EPA Inventory: Actual Methane Leakage, 2012

Official

EPA= 1.12%



Source: EPA

U.S. Methane Rule
(May 2016)

- 20-30% reductions from Energy industry
- Not clear how to achieve the rest up to 40% reduction over next decade (over 2012 levels) Obama's Climate Action Plan
- That is 40%of 35% of 900BCF = 126 BCF
- 14% of total leakage
- Applies to new or modified wells and storage tanks (NSPS) and expands restrictions to wells producing less than 15b/d.
- Does not apply to existing, abandoned wells.
- Will cost $530M in 2025
- Will produce benefits of $690
- Will eliminate:
- About 510,000 tonnes of methane (11 million metric tons of CO2)210,000 tonnes of ozone-forming VOCs
- 3,900 tonnes of air toxics such as toluene, benzene, ethylbenzene and xylene.
- Now ICR for data for existing sources.

Make sure is tonnes not short tons!!!

Renewable Natural Gas in Transportation: Key Findings

Blending of Dairy and MSW RNG with fossil natural gas produces the most carbon benefits but blending landfill or WWTP (waste water treatment plant) with fossil natural gas produces more limited improvements in its

	% Reduction from fossil CNG			
% RNG ble	**Landfill**	**WWTP**	**MSW**	**Dairy**
5%	-2%	-4%	-6%	-23%
15%	-6%	-11%	-19%	-68%
20%	-8%	-15%	-26%	-90%
25%	-10%	-19%	-32%	-113%
35%	-14%	-26%	-45%	-158%
45%	-18%	-34%	-58%	-204%
50%	-20%	-38%	-65%	-226%
55%	-22%	-41%	-71%	-249%
65%	-26%	-49%	-84%	-294%
75%	-31%	-56%	-97%	-339%
80%	-33%	-60%	-103%	-362%
85%	-35%	-64%	-110%	-385%
100%	-41%	-75%	-129%	-452%

Quebec's 2030 Energy Policy

The Efficiency of Freight Transportation (p.36)

- Support the conversion of transportation vehicles already on the road to fuels with lower carbon content, in particular liquefied natural gas (LNG), compressed natural gas (CNG) and propane.
- Support the decarbonization of transportation in the industrial sector by promoting therein forms of energy with lower GHG emissions.
- Enhance the eco-trucking program to promote conversion to natural gas for heavy-duty vehicles.

The distribution of alternative fuels (p.38)

- Establish within the coming year a network of multi-fuel service stations offering gasoline, biofuels, natural gas, propane, electricity and hydrogen and extend it by 2030 throughout Québec.
- Support Gaz Métro's objective of increasing by 15% by 2030 the heavy-duty vehicle fleet powered by LNG or CNG. To ensure supplies, the government will collaborate with Gaz Métro to evaluate the possibility of extending along the north-south axis the Blue Corridor, a network of LNG fueling stations for heavy-duty vehicles, which would ensure complete coverage of Québec.

Natural gas supply (p.54)

- Natural gas is a transition energy that is profitable for Québec and will play a key role in the coming decades in supporting economic development and the competitiveness abroad of Québec companies. The government therefore intends to ensure that Québec households and businesses have reliable, secure, stable access to natural gas throughout the territory where demand and economic profitability warrant it. To this end, the government intends to: pursue the extension of the gas network; develop a liquefied natural gas supply network; expand renewable natural gas production.

Source: Government of Québec, 2016. The 2030 Energy Policy - Energy in Québec, A Source of Growth, https://politiqueenergetique.gouv.qc.ca/wp-content/uploads/Energy-Policy-2030.pdf