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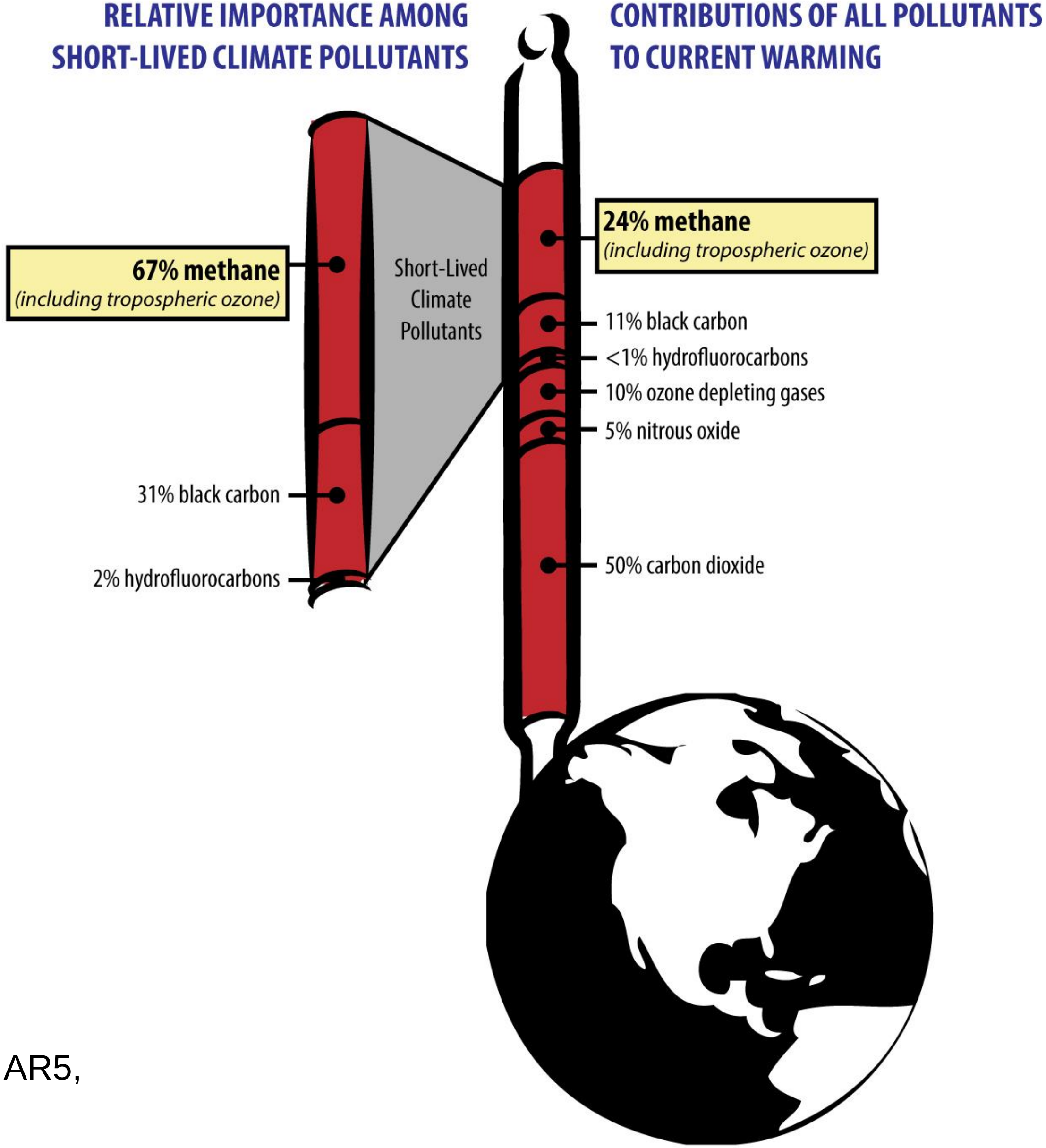
Methane leakage from oil & gas operations: What are we learning?

Ramón Alvarez, Ph.D.
June 6, 2016

ENVIRONMENTAL DEFENSE FUND®
Finding the ways that work

CH_4 causes ~25% of today's radiative forcing



Adapted from IPCC AR5,
Table 8.SM.6

Catalyzing Science

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

16 Studies with ~100 Participants

5 common principles

- Led by academic scientists
- Employ multiple methods where possible
- Seek input from independent scientific experts
- Make all data public to ensure transparency
- Publish results in peer-reviewed journals

27 Published Papers Thus Far

1. **December 2013:** UT Production study: http://www.pnas.org/lookup/doi/10.1073/pnas.1304880110
2. **May 2014**: NOAA DJ Basin Flyover: http://onlinelibrary.wiley.com/doi/10.1002/2013JD021272/pdf
3. **November 2014:** HARC/EPA Fence-line study: http://pubs.acs.org/doi/abs/10.1021/es503070q
4. **December 2014** UT Pneumatics Study: http://pubs.acs.org/doi/abs/10.1021/es5040156
5. **December 2014** UT Liquid Unloadings Study: http://pubs.acs.org/doi/abs/10.1021/es504016r
6. **January 2015:** Harvard Boston Urban Methane Study: http://www.pnas.org/content/early/2015/01/21/1416261112
7. **February 2015:** CSU T&S study: Measurement paper: http://pubs.acs.org/doi/abs/10.1021/es5060258
8. **February 2015:** CSU G&P study: Measurement paper: http://pubs.acs.org/doi/abs/10.1021/es5052809
9. **March 2015:** WSU Local Distribution study: http://pubs.acs.org/doi/abs/10.1021/es505116p
10. **May 2015:** CSU G&P study, Methods paper: http://www.atmos-meas-tech.net/8/2017/2015/amt-8-2017-2015.html
11. **July 2015**: CSU T&S study, National results paper: http://pubs.acs.org/doi/abs/10.1021/acs.est.5b01669
12. **August 2015:** CSU G&P, study National results paper: http://pubs.acs.org/doi/abs/10.1021/acs.est.5b02275

Barnett Coordinated Campaign Papers (July 2015) papers 13-24

13. **Overview:** http://pubs.acs.org/doi/abs/10.1021/acs.est.5b02305
14. **NOAA led Top-down study**: http://pubs.acs.org/doi/abs/10.1021/acs.est.5b00217
15. **Bottom-up inventory - EDF**: http://pubs.acs.org/doi/abs/10.1021/es506359c
16. **Functional super-emitter study - EDF:** http://pubs.acs.org/doi/abs/10.1021/acs.est.5b00133
17. **Michigan airborne study:** http://pubs.acs.org/doi/abs/10.1021/acs.est.5b00219
18. **WVU compressor study:** http://pubs.acs.org/doi/abs/10.1021/es506163m
19. **Princeton near-field study**: http://pubs.acs.org/doi/abs/10.1021/acs.est.5b00705
20. **Purdue aircraft study:** http://pubs.acs.org/doi/abs/10.1021/acs.est.5b00410
21. **Aerodyne mobile study:** http://pubs.acs.org/doi/abs/10.1021/es506352j
22. **U of Houston mobile study:** http://pubs.acs.org/doi/abs/10.1021/es5063055
23. **Picarro mobile flux study**: http://pubs.acs.org/doi/abs/10.1021/acs.est.5b00099
24. **Cincinnati tracer apportionment:** http://pubs.acs.org/doi/abs/10.1021/acs.est.5b00057
25. **December 2015:** Barnett Synthesis: http://www.pnas.org/content/112/51/15597.abstract
26. **March 2016:** Gap Filling**:** Abandoned & Orphaned Wells: http://onlinelibrary.wiley.com/doi/10.1002/2015GL067623/full
27. **April 2016:** Gap Filling**:** Aerial survey of 8,000 production sites: http://pubs.acs.org/doi/abs/10.1021/acs.est.6b00705

Complementary Methodologies

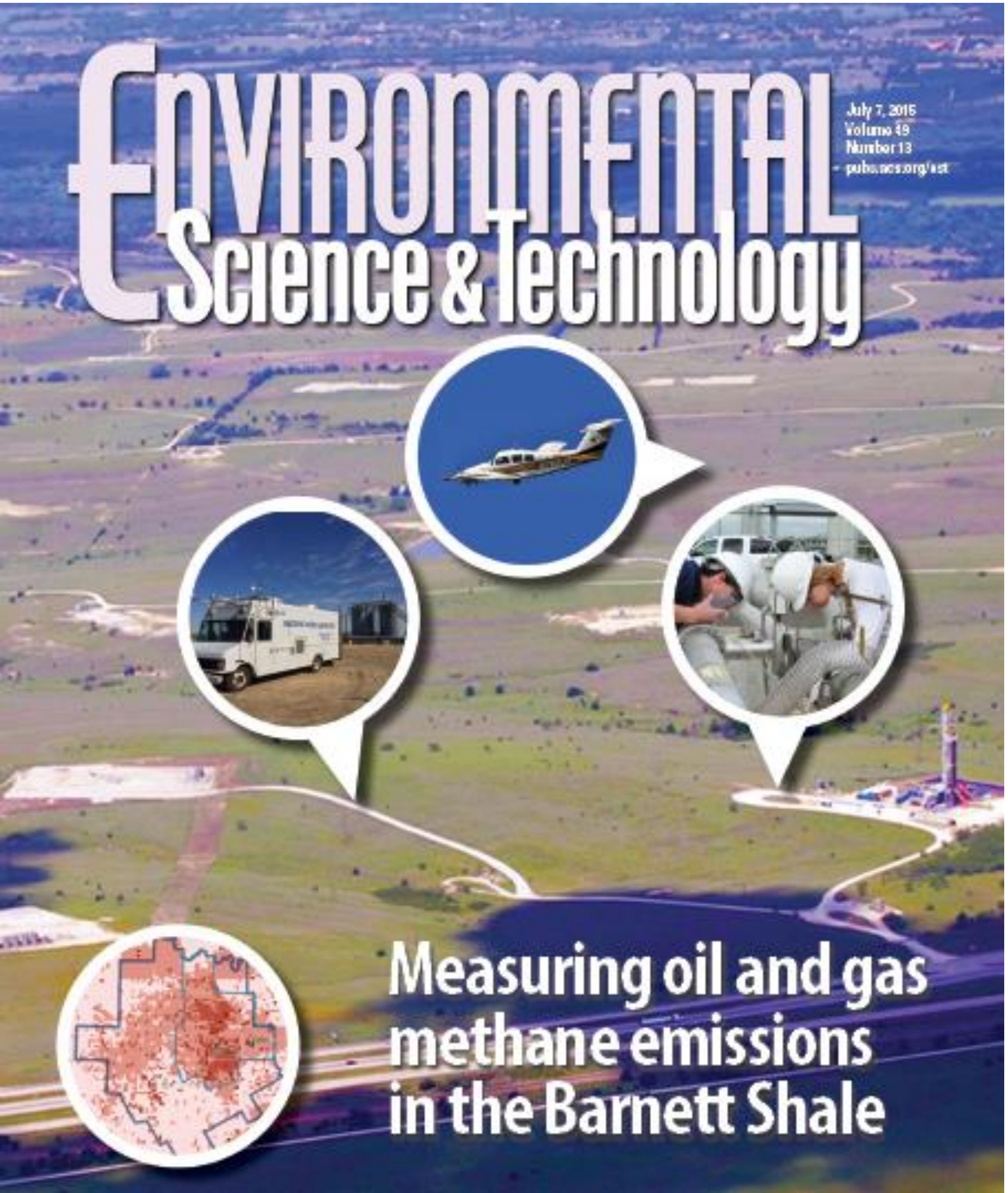
Top Down

- Large scale-regional or national estimates
  - ➢ Mass balance
  - ➢ Atmospheric transport models
  - ➢ Enhancement ratios (e.g., CH_4/CO_2)
- Attribution to oil & gas required

Bottom Up

- Component- or activity-based
- Facility-level (0.05 to 5 km downwind)
- Combine emissions and activity factors

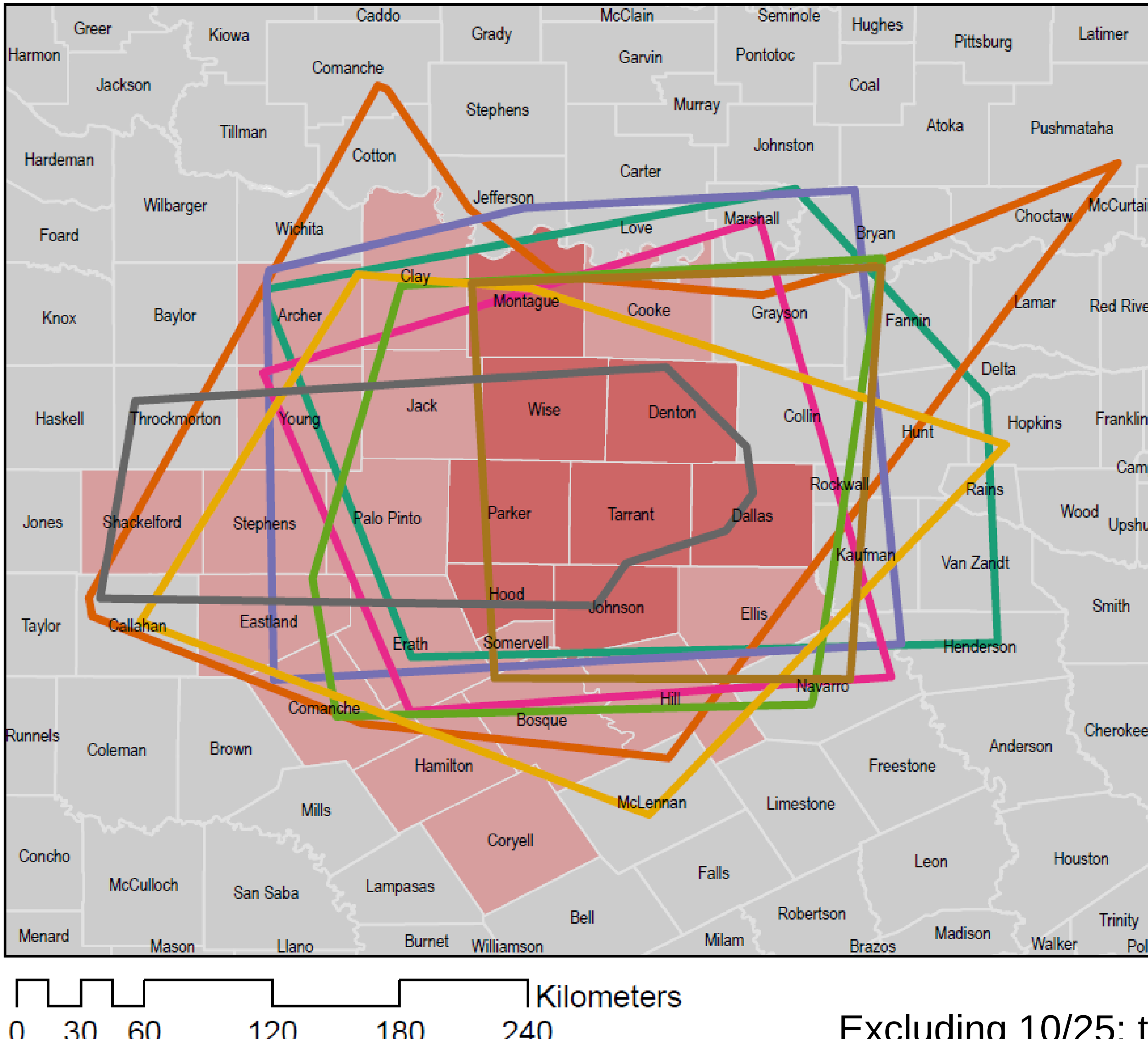
Barnett Shale Campaign

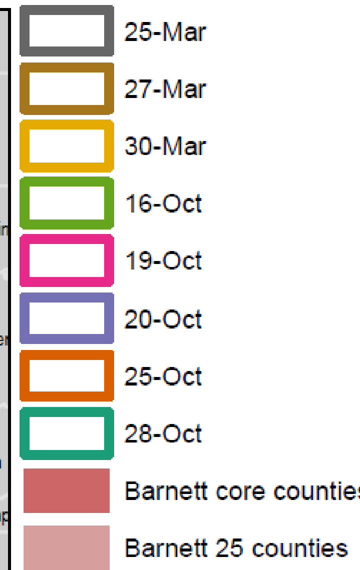


- New bottom-up estimate of oil and gas CH_4 emissions in agreement with top-down
- Bottom-up estimate is 1.9 times higher than an estimate based on EPA GHGI
- Why?

Karion et al, ES&T (2015)
Lyon et al., ES&T (2015)
Zavala-Araiza et al, PNAS 2015

Top-down mass balance flights





Total CH_4: 76 ± 13 Mg/h

Fossil CH_4: 60 ± 11 Mg/h

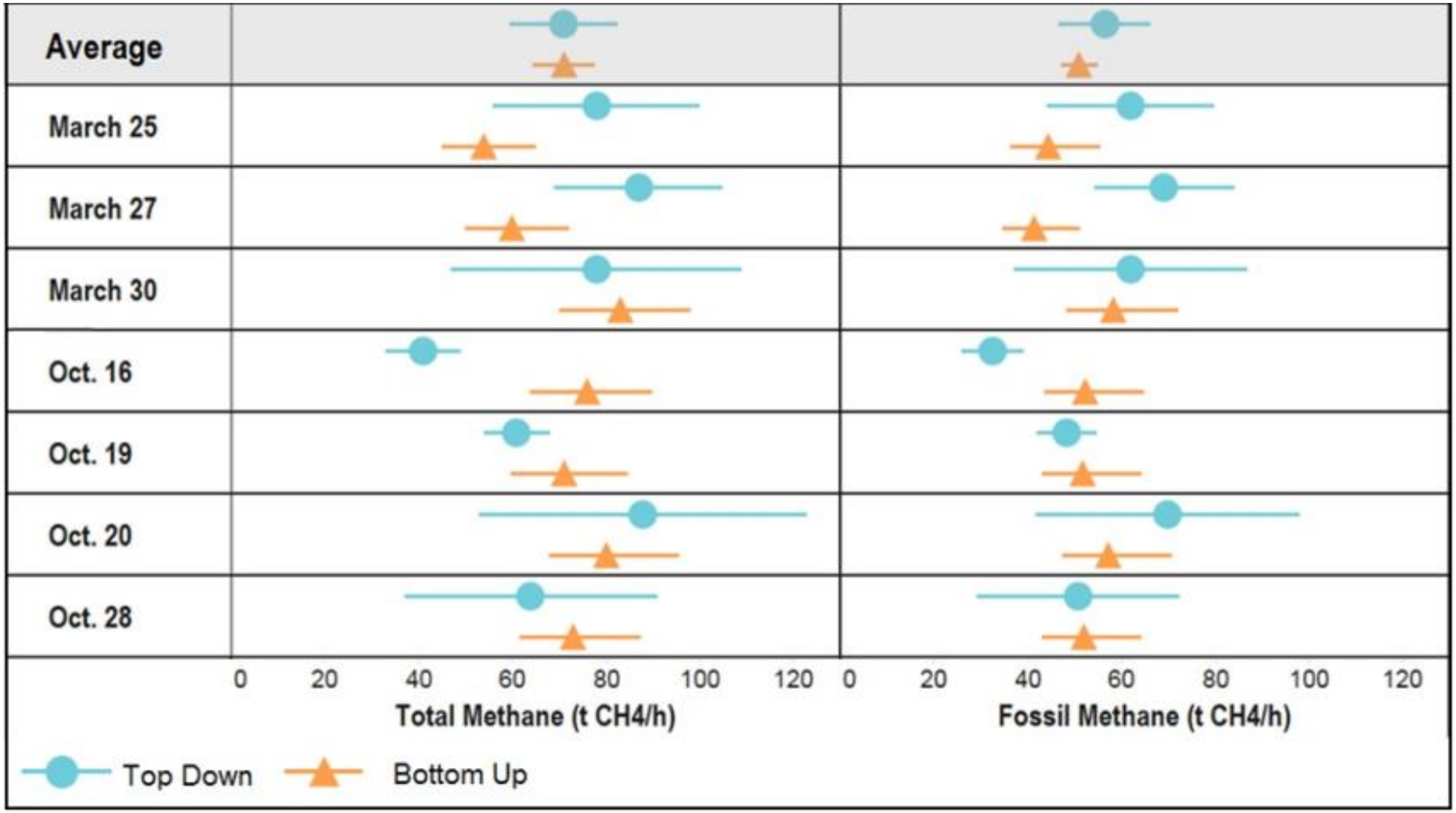
Loss Rate = 1.3 – 1.9% of production

Karion et al. ES&T (2015); Smith et al. ES&T (2015)

Excluding 10/25: total and fossil CH_4 = 71±12 and 56±10 Mg/h, respectively

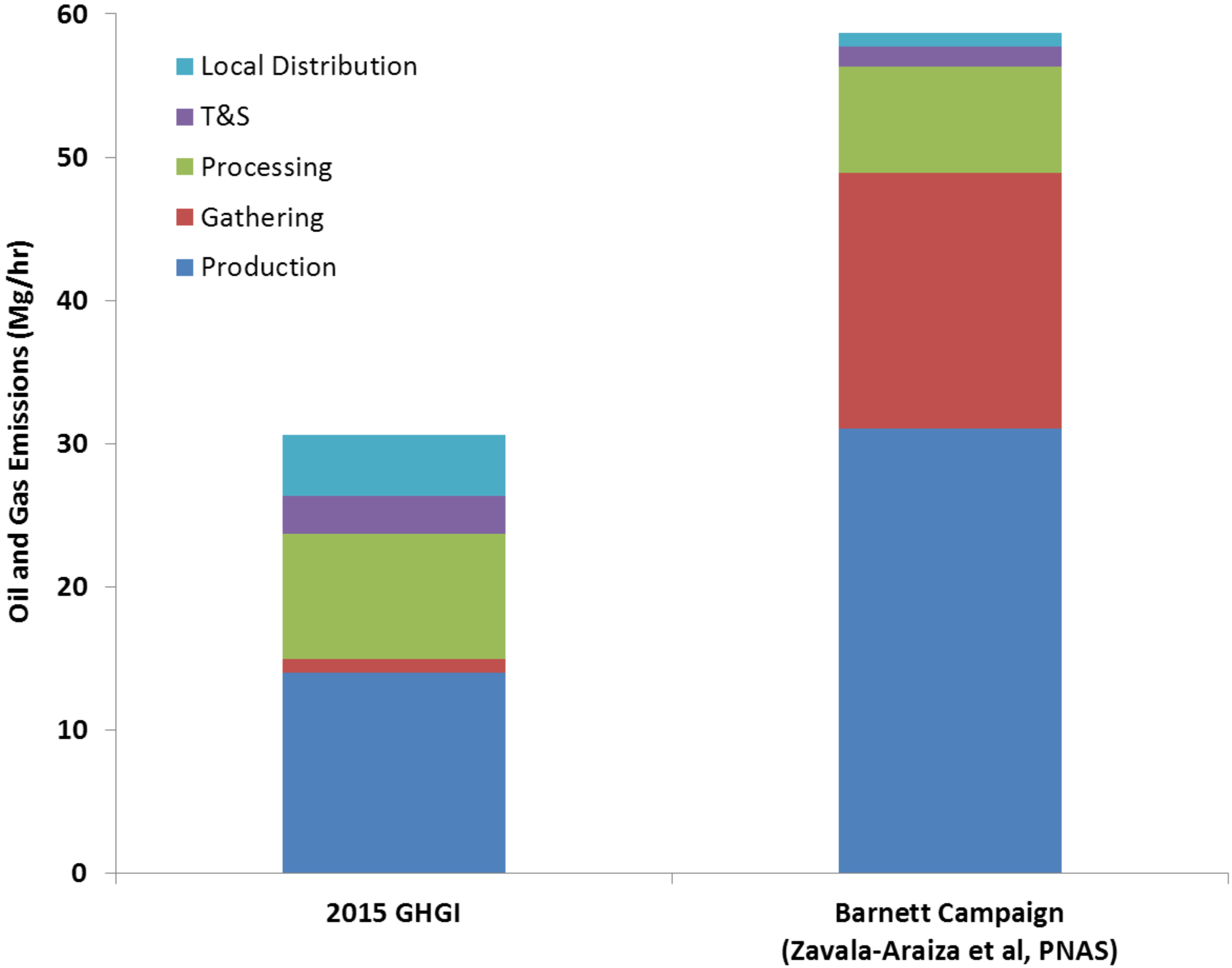
Barnett: Top-Down and Bottom-Up agree

Mean Relative Difference: 0.1% ± 21% (total) and 10% ± 32% (fossil)



Zavala-Araiza et al. 2015 (PNAS)

Bottom-Up Barnett (25-County) vs. EPA



Integrating systematic and fat-tail measurements

Facility Type	Emission Factors (kg CH_4 hr^{-1})	
	Systematic Only	Zavala et al.
Well Pads	0.9	1.8 (1.3 – 2.5)
Compressor Stations	42	64 (49 – 84)
Processing Plants	114	195 (121 – 315)

Keys to achieving convergence

- BU estimates require **accurate facility counts** of all major sources
- Emission factors require **effective characterization of entire distribution** of sources:
  - Sampling must capture low-probability, high-emitting sources
  - Emission distributions must **capture magnitude and frequency of high-emitting sources**

Align the spatial and temporal domain of top-down and bottom-up estimates.

Reduce uncertainty of TD approaches using **replicate mass balance measurements**

Use **signature compound** (ethane) to **distinguish fossil** CH_4 from **biogenic** CH_4 for TD approaches

Implications – Barnett Campaign

Well-designed TD or BU can effectively characterize CH_4 from Oil/Gas operations

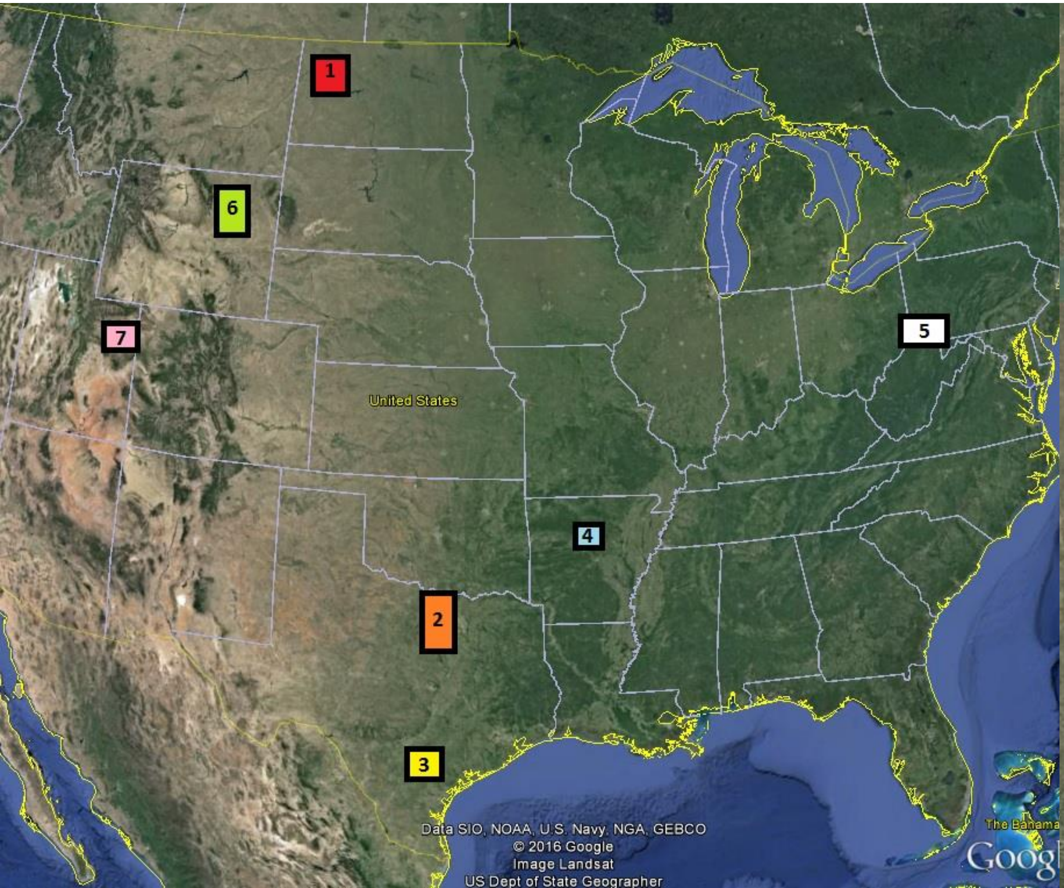
Evidence of low bias in EPA GHGI

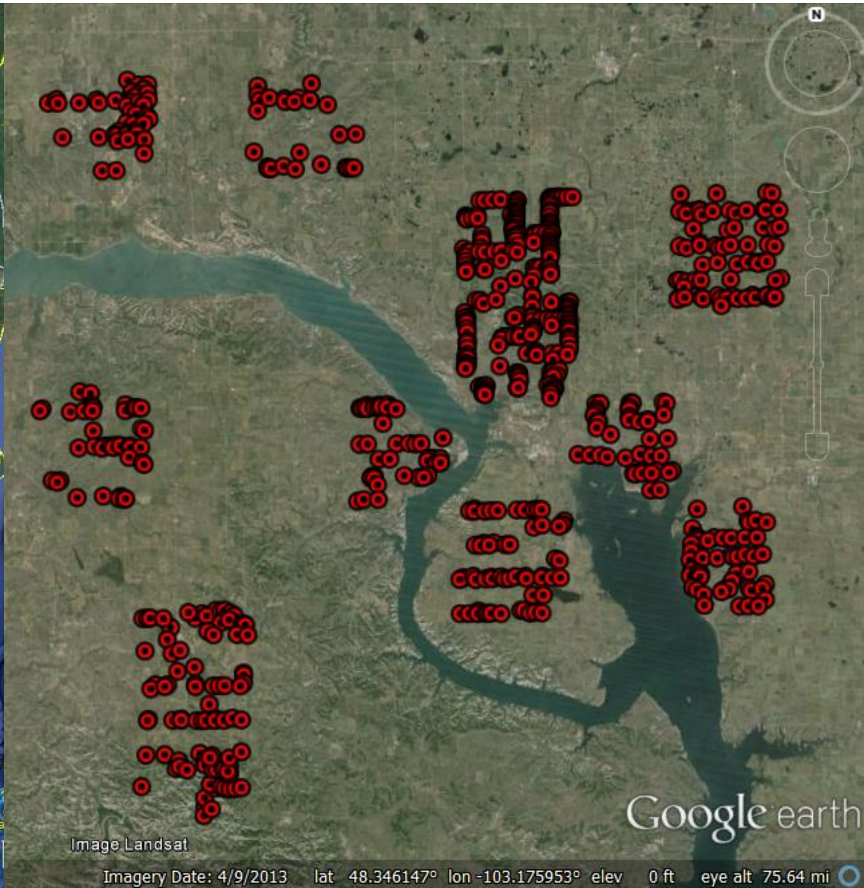
Aerial surveys of elevated hydrocarbon emissions from oil and gas production sites

Lyon et al, *ES&T (2016)* http://pubs.acs.org/doi/abs/10.1021/acs.est.6b00705

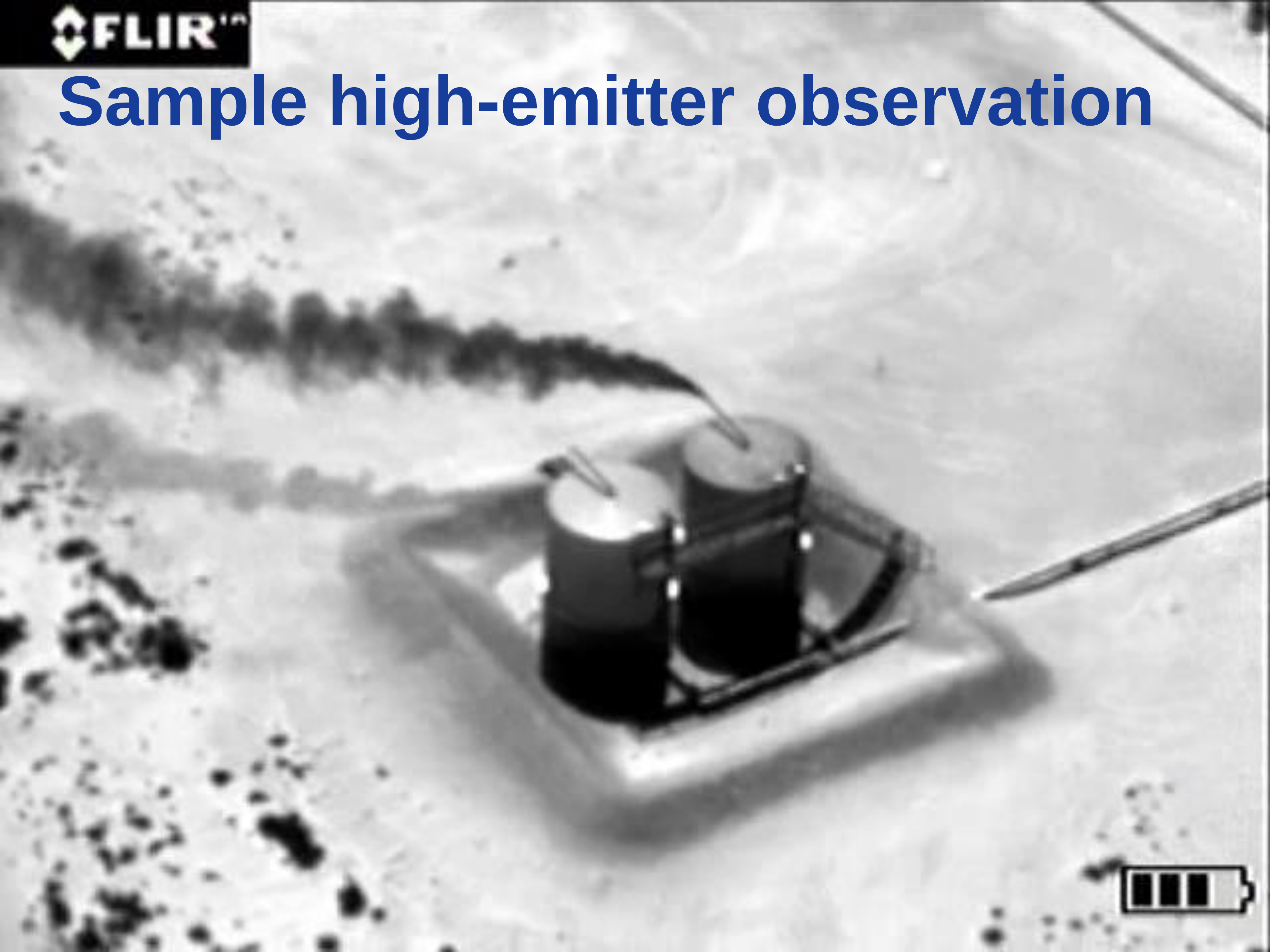
8,220 well pads in 7 basins selected by stratified random sampling

Large sample of national population representing diversity of production types: 1.1% of active wells, 3.7% of gas production, 4.5% of oil production





Sample high-emitter observation



Results

494 sources detected at 327 sites

- detection limit >1-3 g s^{-1} hydrocarbons (35–100 tons/yr)

92% of sources observed were storage tanks

	% of sites with detected emissions	% of detected sources from tanks
Bakken	14%	94%
Barnett	3%	96%
Eagle Ford	5%	96%
Fayetteville	4%	100%
Marcellus	1%	94%
Powder River	1%	83%
Uintah	7%	81%
Total	4%	92%

Tank hatch emissions observed at sites with flares indicate poor capture efficiency.

Implications - helicopter surveys

Large emissions are most commonly from tanks but individual sites cannot be predicted

Tank emissions are a key mitigation opportunity

- Proper design, maintenance, and inspection needed to ensure the effectiveness of control systems

Frequent monitoring required to identify high-emitters

Component-based emissions

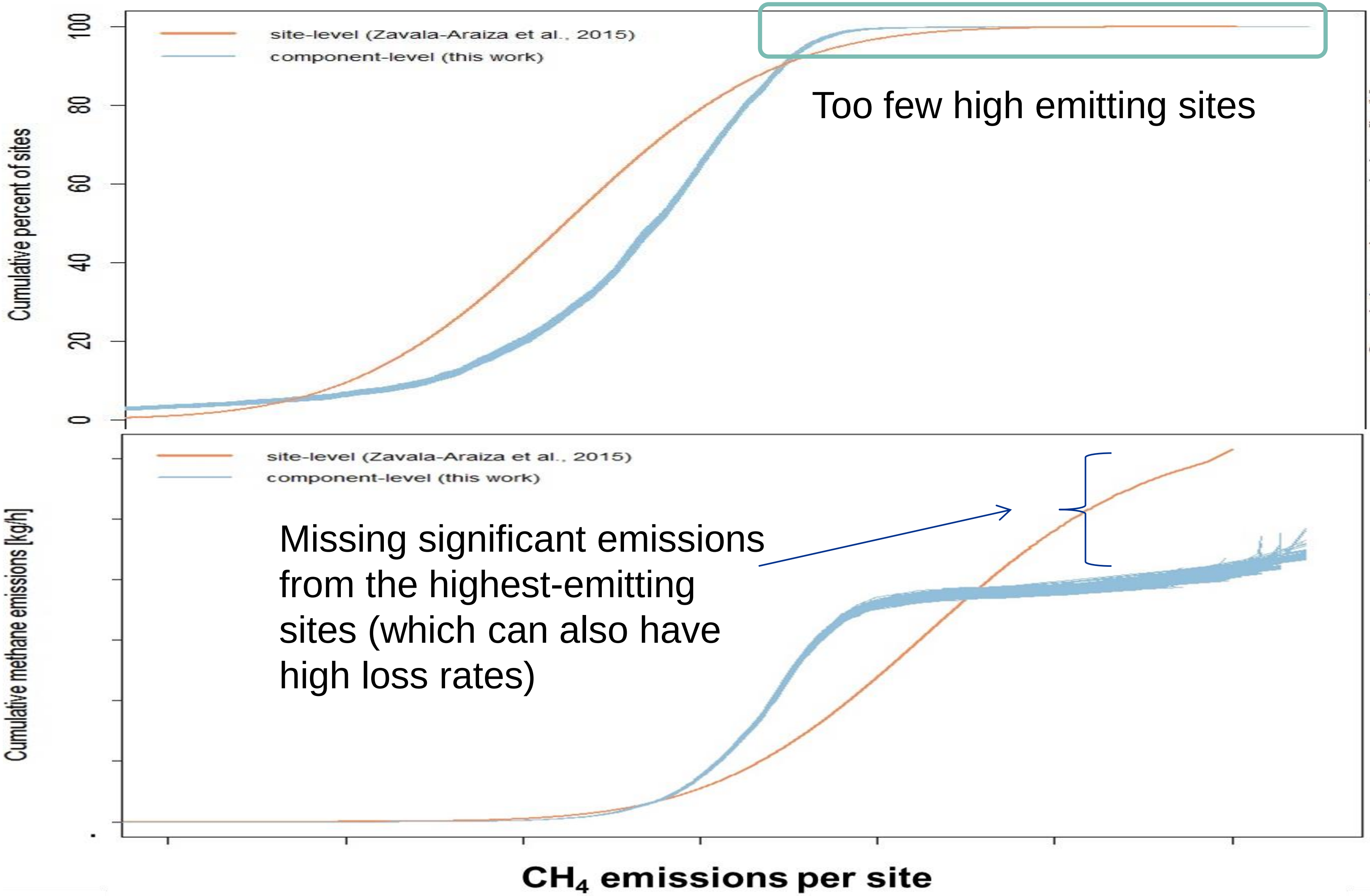
Next 2 slides represent Work in Progress

Preliminary - Subject to Change

Do Not Cite

Comments Welcome

Component-based aggregation vs. site-wide emissions (Barnett production sites)



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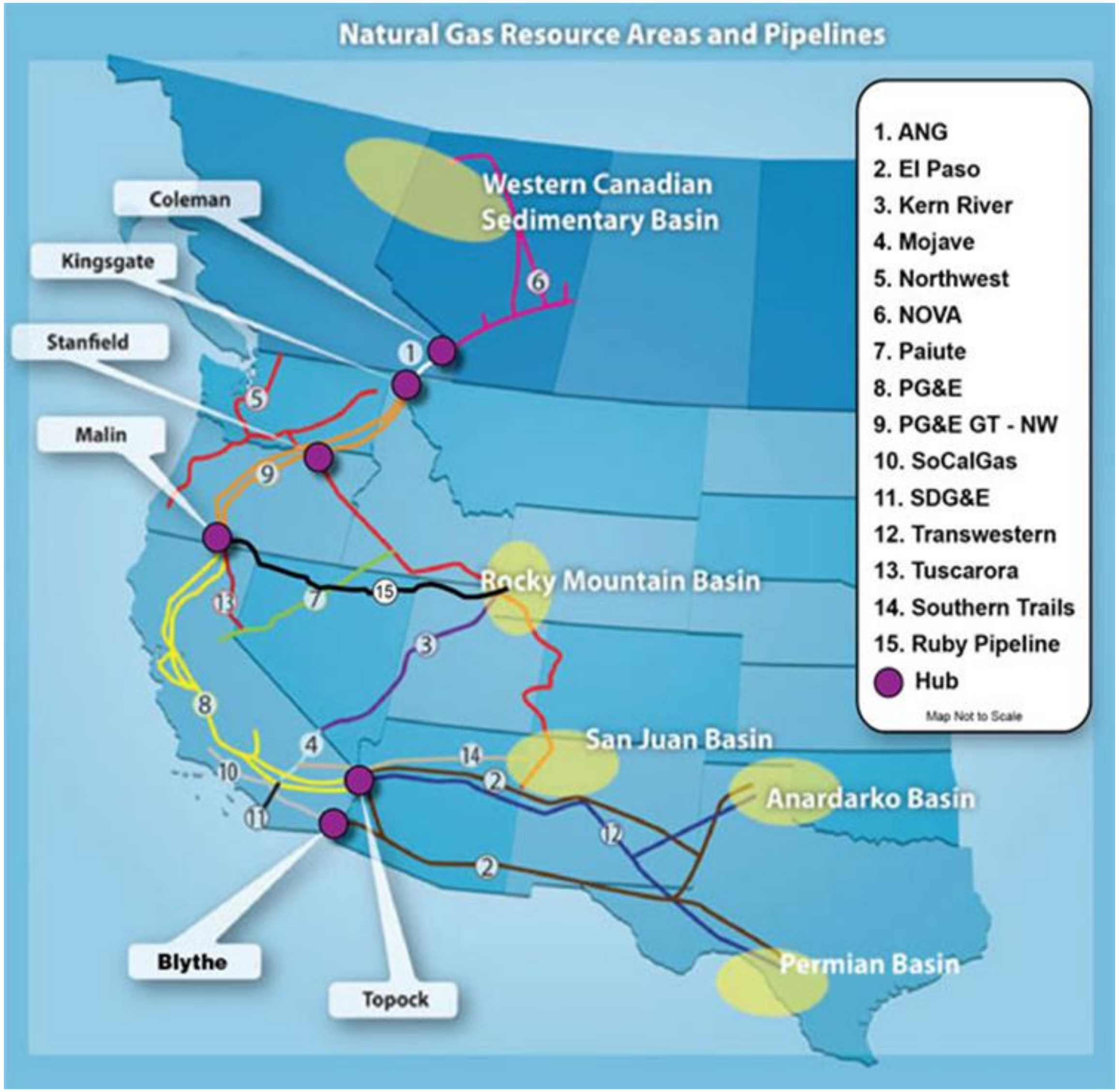
Implications – component aggregation

Expected component emissions fail to account for the influence of highest emitting sites

Frequent monitoring is required

- Find and fix high emitters
- Target root causes (abnormal process conditions?)
- Over time, expect insights leading to reduced frequency of super-emitters

Overall Implications for CA



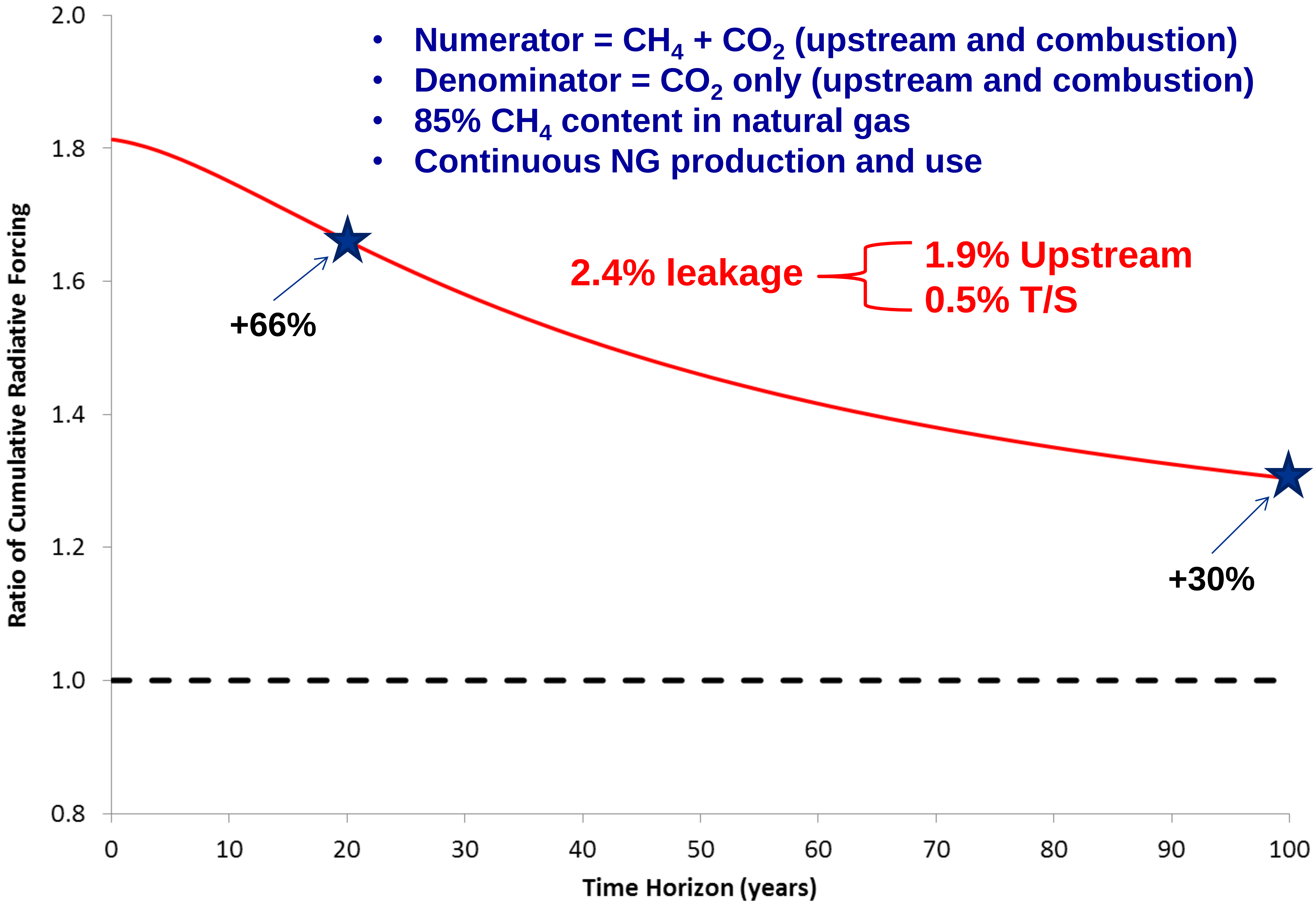
Aircraft Mass-Balance Estimates

Basin	Year	# Flights	Reported Oil/Gas CH_4 Emissions (Mg/hr)	Natural Gas Production (bcf/day)	% of Produced Gas Emitted	% of Total Energy From Gas
Fayetteville[1]	Jul-13	1	35 ± 14	2.7	1.0%-2.8%	100%
Northeast Marcellus (PA)[1]	Jul-13	1	13 ± 4	6.0	0.2%-0.4%	100%
Haynesville[1]	Jun-13	1	74 ± 21	7.0	1.0%-2.1%	99%
Barnett Shale[2]	Mar-13 + Oct-13	8	60 ± 11	5.2	1.3%-1.9%	96%
Uintah County (UT)[3]	Feb-12	1	55 ± 15	1.0	6.2%-11.7%	88%
Weld County (D-J)[4]	May-12	2	19 ± 7	0.8	4.1% ± 1.5%	60%
Bakken (ND)[5]	May-14	3	26 ± 6	1.4	6.3% ± 2.1%	25%

[1] Peischl et al (2015) JGR:Atmospheres DOI: 10.1002/2014JD022697
[2] Karion et al. (2015) ES&T DOI:10.1021/acs.est.5b00217
[3] Karion et al (2013) GRL DOI:10.1002/grl.50811
[4] Petron et al (2014) JGR: Atmospheres DOI: 10.1002/2013JD021272
[5] Peischl et al (2016) JGR: Atmospheres DOI: 10.1002/2015JD024631

1.9% = Production-weighted Avg.

CH_4 impact on climate forcing of natural gas



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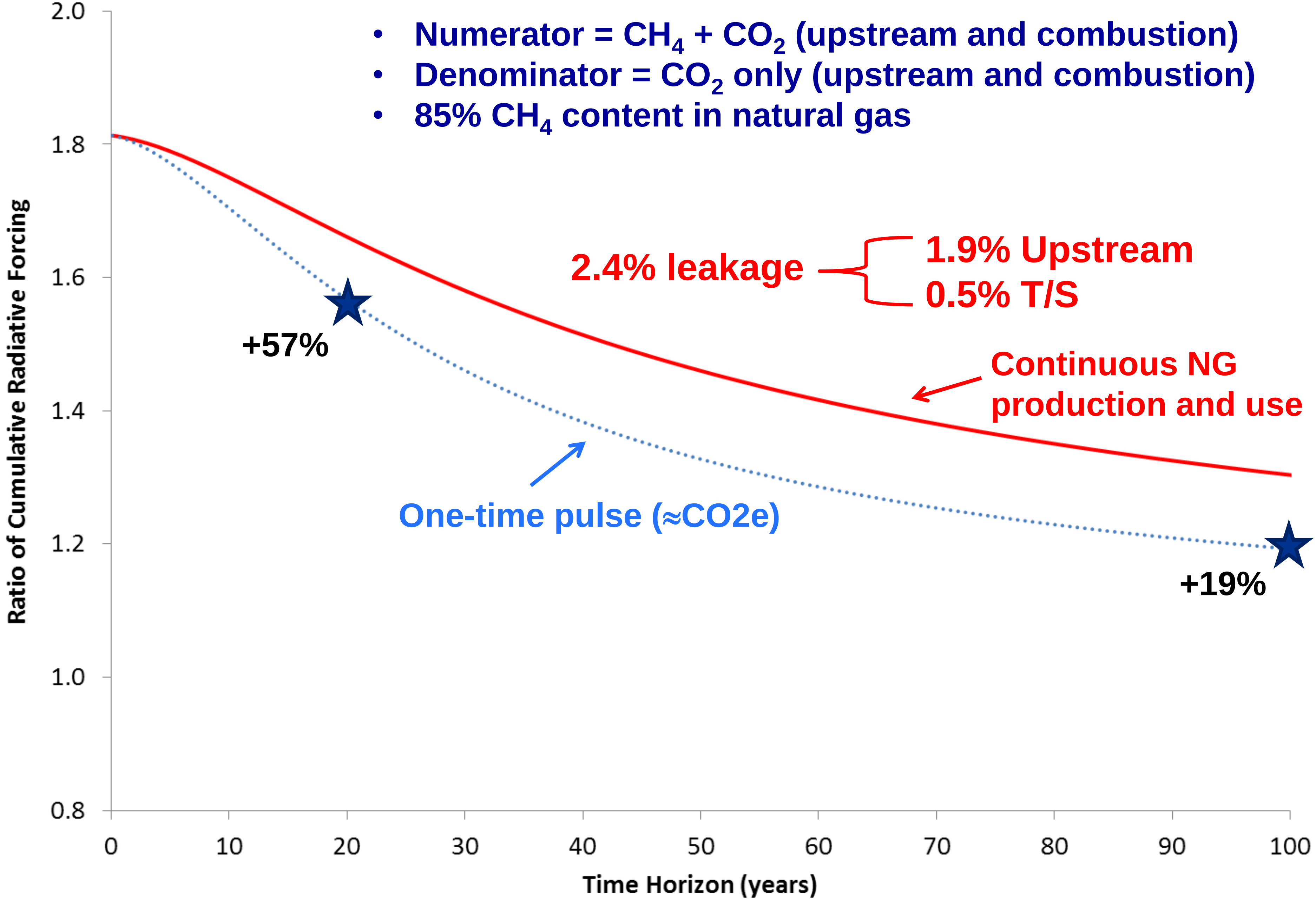
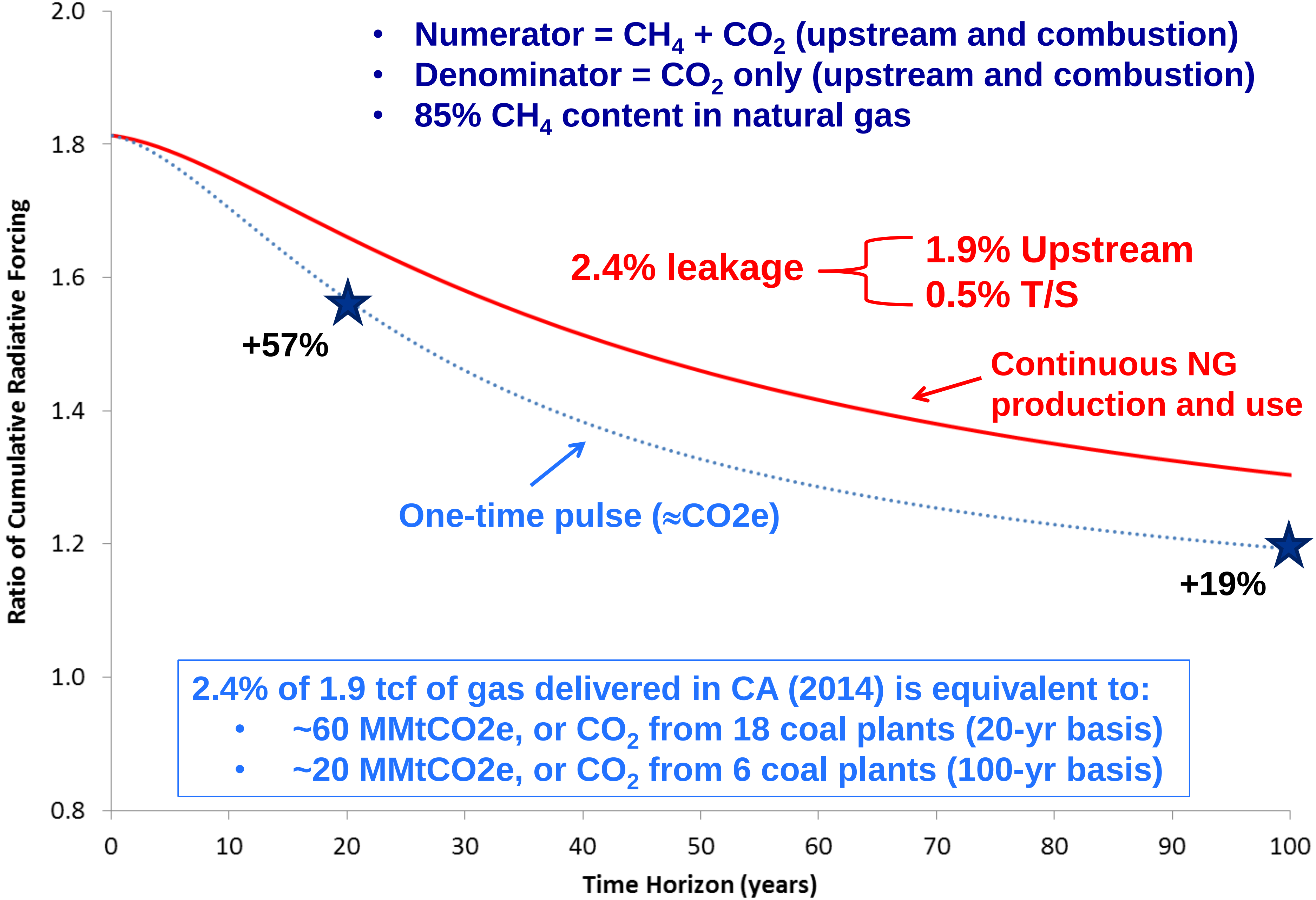
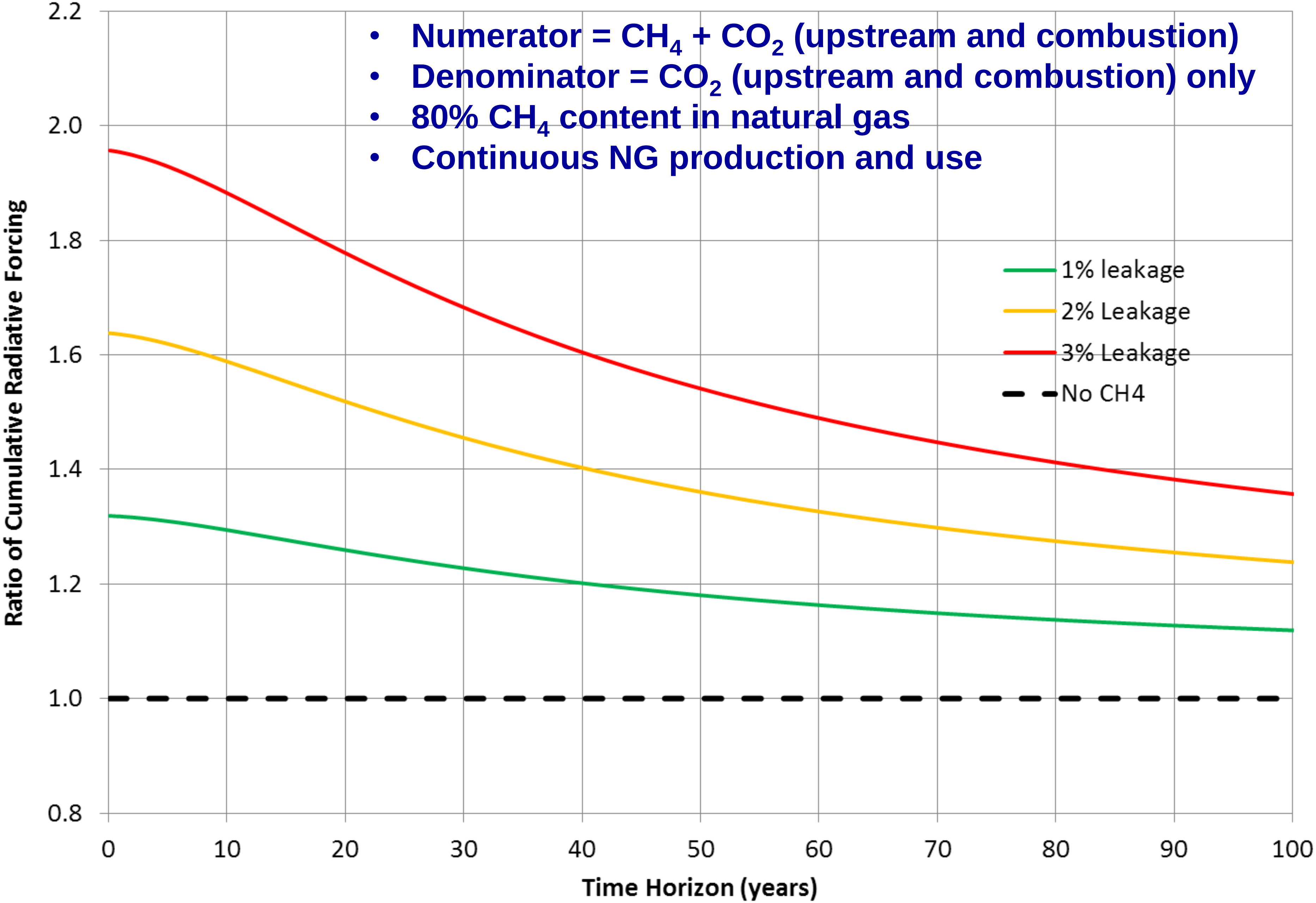


CH_4 impact on climate forcing of natural gas

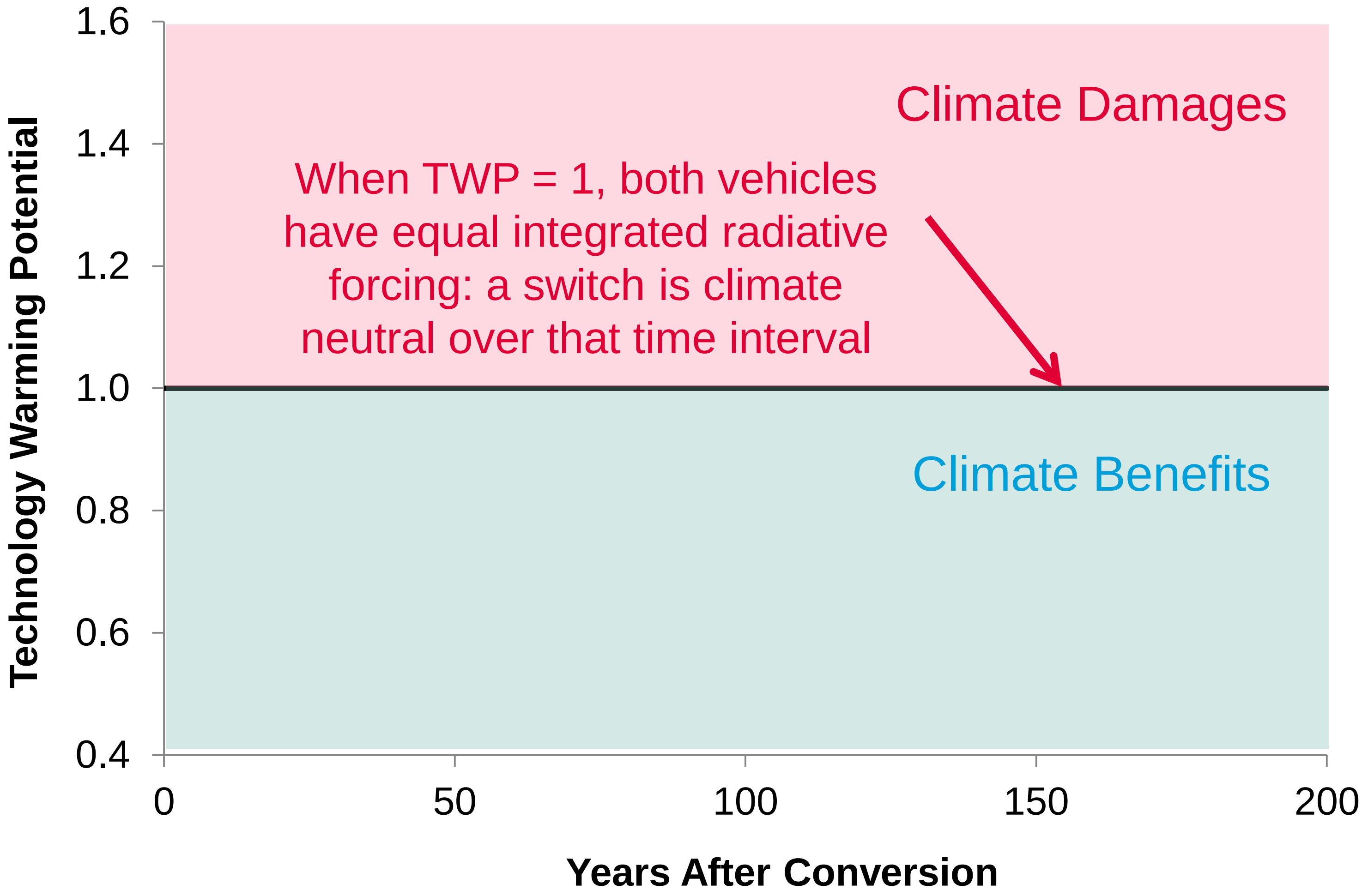


CH_4 impact on climate forcing of natural gas

- **Numerator = CH_4 + CO_2 (upstream and combustion)**
- **Denominator = CO_2 (upstream and combustion) only**
- **80% CH_4 content in natural gas**
- **Continuous NG production and use**



Consider a shift from diesel to natural gas trucks



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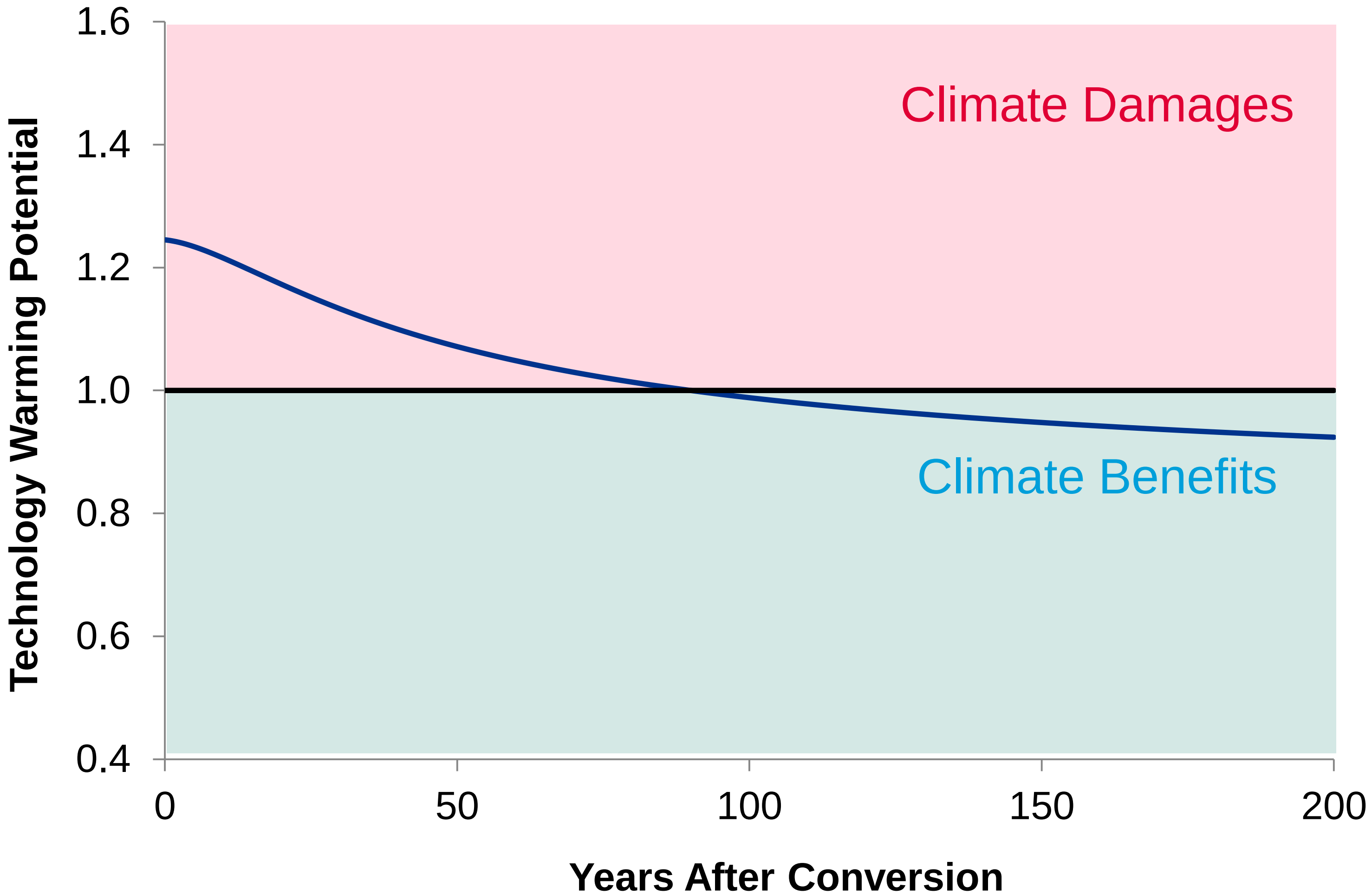

Camuzeaux et al, ES&T 2015 (12 L CNG SI case)