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

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Finding the ways that work

### CH<sub>4</sub> causes ~25% of today's radiative forcing



Adapted from IPCC AR5, Table 8.SM.6

## **Catalyzing Science**

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 peerreviewed journals

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

### **27 Published Papers Thus Far**

- 1. December 2013: UT Production study: <u>http://www.pnas.org/lookup/doi/10.1073/pnas.1304880110</u>
- 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: <u>http://www.pnas.org/content/early/2015/01/21/1416261112</u>
- 7. February 2015: CSU T&S study: Measurement paper: <u>http://pubs.acs.org/doi/abs/10.1021/es5060258</u>
- 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: <u>http://pubs.acs.org/doi/abs/10.1021/acs.est.5b02275</u> 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<sub>4</sub>/CO<sub>2</sub>)
- 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<sub>4</sub> 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**



### **Barnett: Top-Down and Bottom-Up agree**

Mean Relative Difference:  $0.1\% \pm 21\%$  (total) and  $10\% \pm 32\%$  (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 <sub>4</sub> hr <sup>-1</sup> )			
	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<sub>4</sub> from **biogenic** CH<sub>4</sub> for TD approaches

### **Implications – Barnett Campaign**

Well-designed TD or BU can effectively characterize CH<sub>4</sub> 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<sup>-1</sup> 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%	



## N. 3370433 W. 97.62085

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 highemitters

### **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)**



### CH<sub>4</sub> emissions per site

#### Unpublished: Do Not Cite or Distribute

### 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 CH₄ Emissions (Mg/hr)	Natural Gas Production (bcf/day)	% of Produced Gas Emitted	% of Total Energy From Gas
Fayetteville <sup>1</sup>	Jul-13	1	35 ± 14	2.7	1.0%-2.8%	100%
Northeast Marcellus (PA) <sup>1</sup>	Jul-13	1	13 ± 4	6.0	0.2%-0.4%	100%
Haynesville <sup>1</sup>	Jun-13	1	74 ± 21	7.0	1.0%-2.1%	99%
Barnett Shale <sup>2</sup>	Mar-13 + Oct-13	8	60 ± 11	5.2	1.3%-1.9%	96%
Uintah County (UT) <sup>3</sup>	Feb-12	1	55 ± 15	1.0	6.2%-11.7%	88%
Weld County (D-J) <sup>4</sup>	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%

<sup>1</sup> Peischl et al (2015) JGR:Atmospheres DOI: 10.1002/2014JD022697

<sup>2</sup> Karion et al. (2015) ES&T DOI:10.1021/acs.est.5b00217

<sup>3</sup> Karion et al (2013) GRL DOI:10.1002/grl.50811

<sup>4</sup> Petron et al (2014) JGR: Atmospheres DOI: 10.1002/2013JD021272

<sup>5</sup> Peischl et al (2016) JGR: Atmospheres DOI: 10.1002/2015JD024631

### 1.9% = Production-weighted Avg.









### Consider a shift from diesel to natural gas trucks



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