Methane Synthesis Study: Quantifying CH_4 Emissions from the U.S. Oil and Gas Supply Chain

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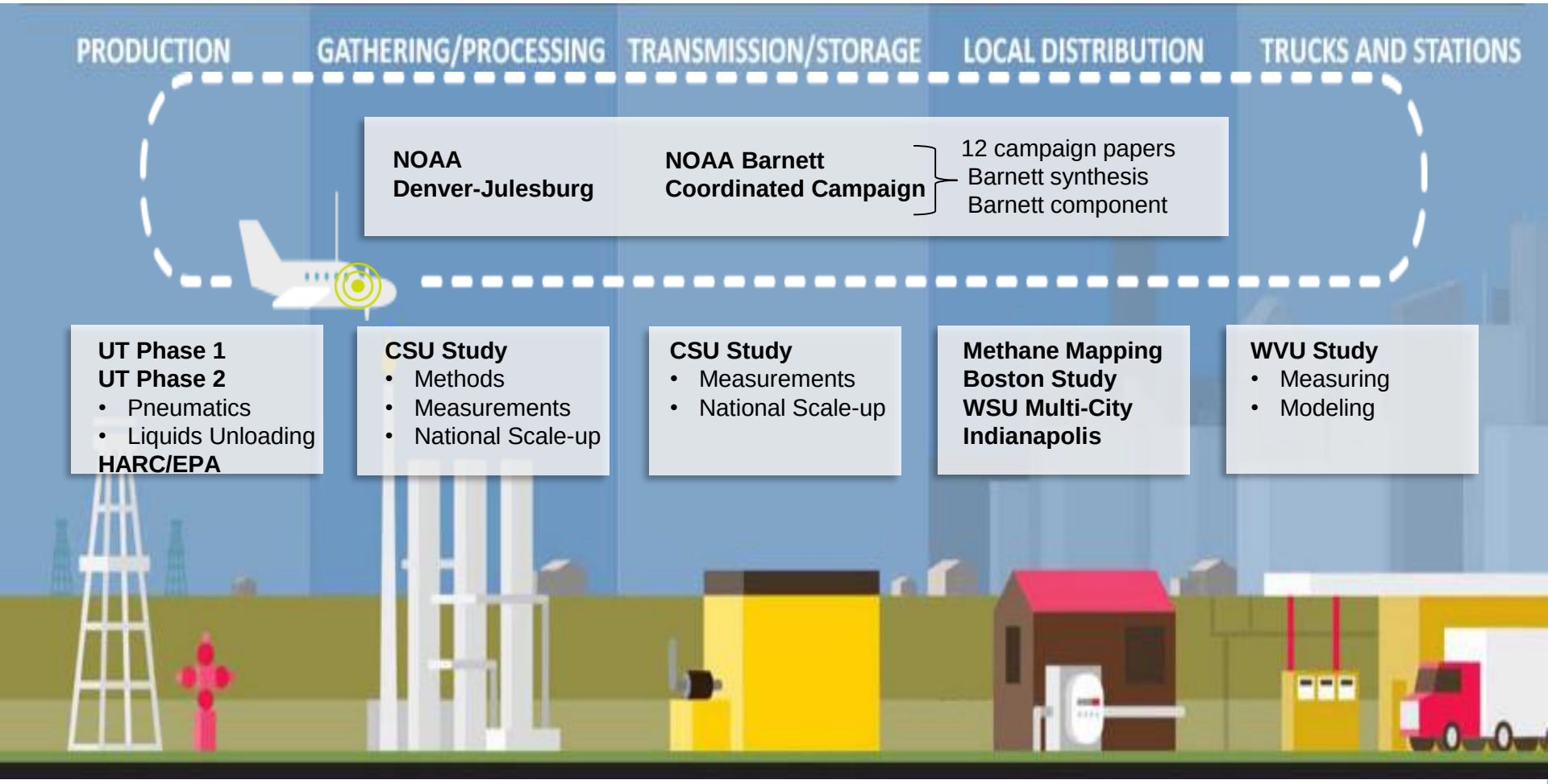

Pilot Projects

Gap Filling
- Abandoned wells
- Helicopter IR Survey

Synthesis Projects
- NETL LCA
- **Synthesis**

Science

REPORTS

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Assessment of methane emissions from the U.S. oil and gas supply chain

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Scope of Synthesis Study

- Quantify methane emissions from the U.S. oil and gas supply chain
- Integrates several recently published datasets
  - Production segment emissions based on site-level measurements from 6 U.S. basins
  - Emissions compared to aircraft-based estimates in 9 basins

Drilling & Production

Gathering & Processing

Transmission & Storage

Local Distribution

Regional Research

Synthesis Collaborators

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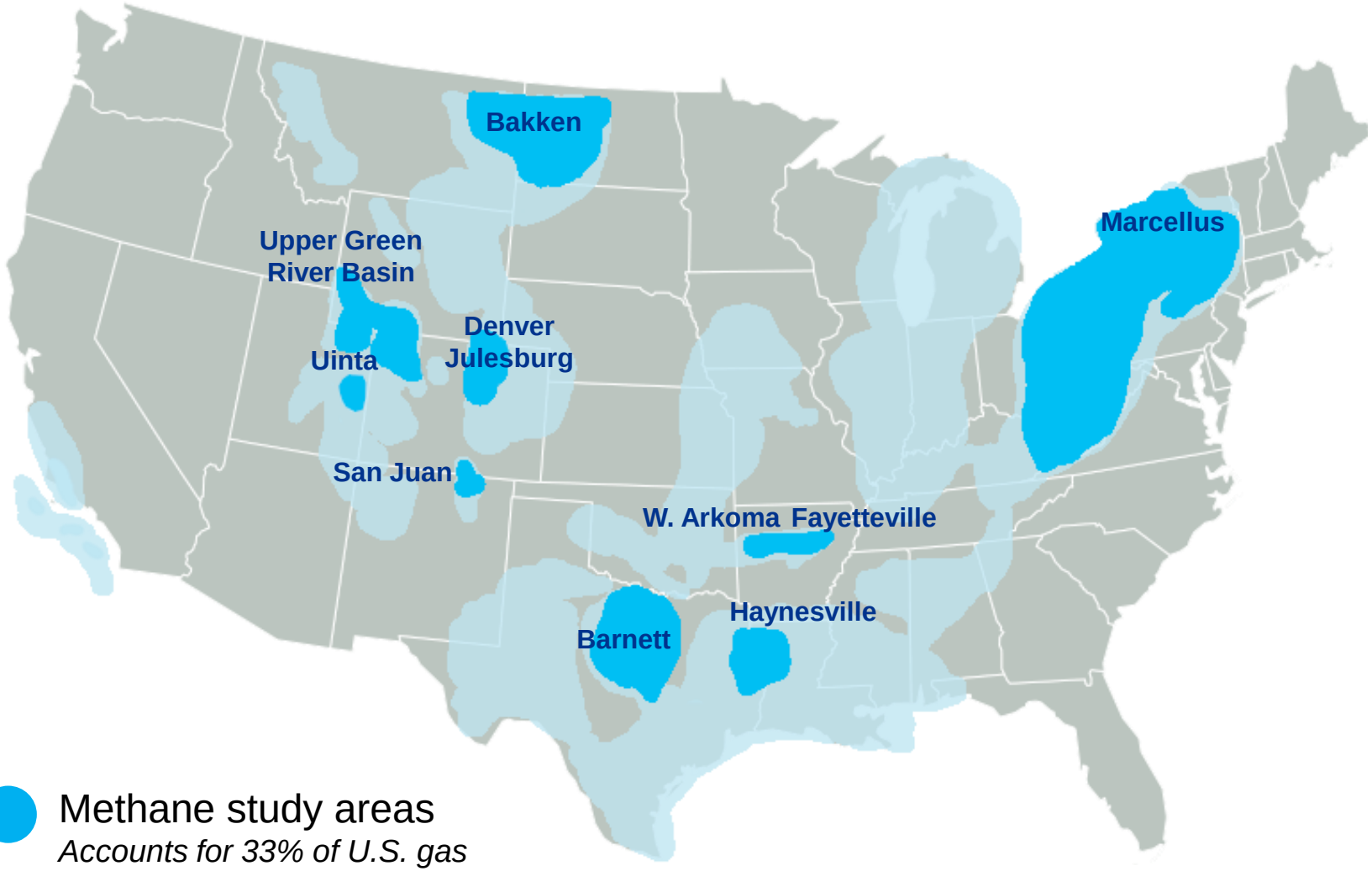
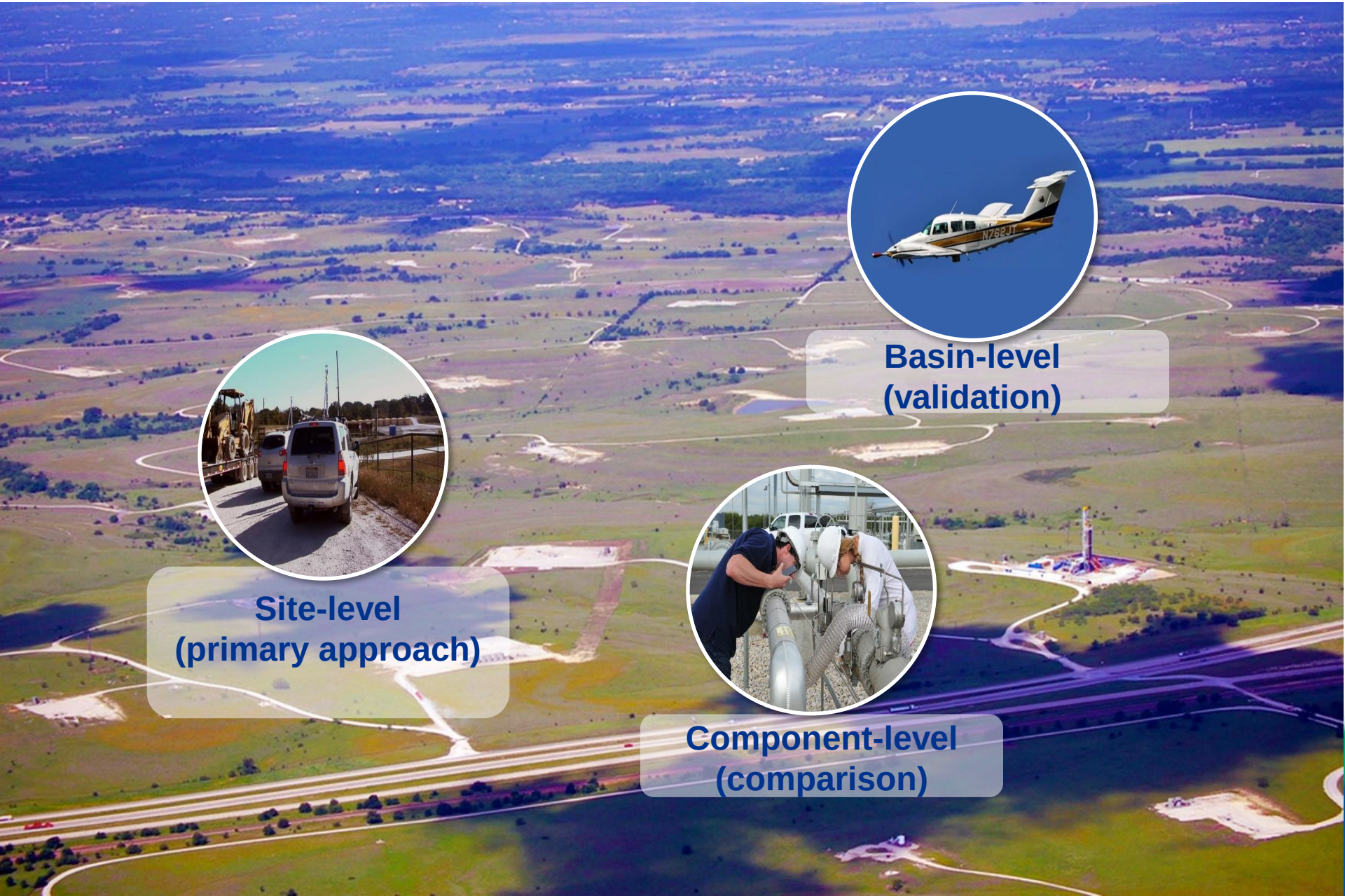
Sources of Regional Synthesis Data



Methane study areas

Accounts for 33% of U.S. gas production; 24% of oil production

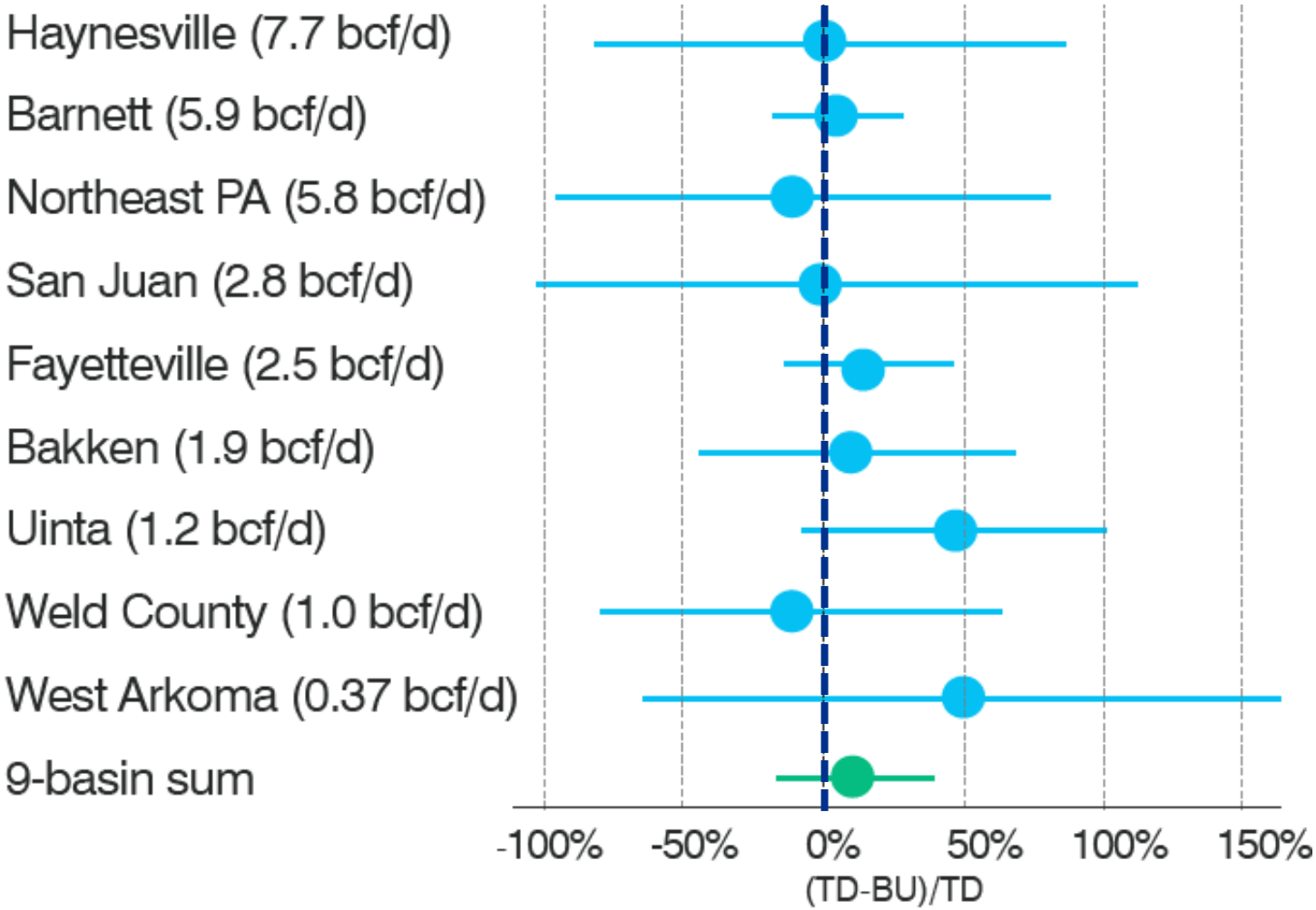
Emissions Quantified at Different Spatial Scales



Synthesis Methods

- Multiple, previously published datasets integrated to estimate 2015 U.S. O&G CH_4 emissions by segment
  - **Production**: >400 site-level measurements from 6 basins
    - Basins: Barnett, DJ, Fayetteville, Uintah, Upper Green River, Marcellus
    - Methods: Dual tracer, mobile flux plane, inverse Gaussian, OTM 33A
  - **Gathering & Processing**: Marchese et al 2015
  - **Transmission & Storage**: Zimmerle et al 2015
  - **Local distribution**: Lamb et al 2015
- Basin-level, site-based estimates validated with aerial mass balance data from 9 basins
    - Basins: Haynesville, Barnett, Marcellus, San Juan, Fayetteville, Bakken, Uintah, Weld, West Arkoma
- Synthesis estimate compared to U.S. EPA GHG Inventory and custom component-based inventory

Aircraft- and site-based emission estimates are statistically similar



U.S. O&G Supply Chain 2015 Methane Emissions

Drilling & Production

7.6 Tg
1.3%

3.5 Tg
0.6%

Gathering & Processing

3.3 Tg
0.6%

2.7 Tg
0.5%

Transmission & Storage

1.8 Tg
0.3%

1.4 Tg
0.2%

Local Distribution

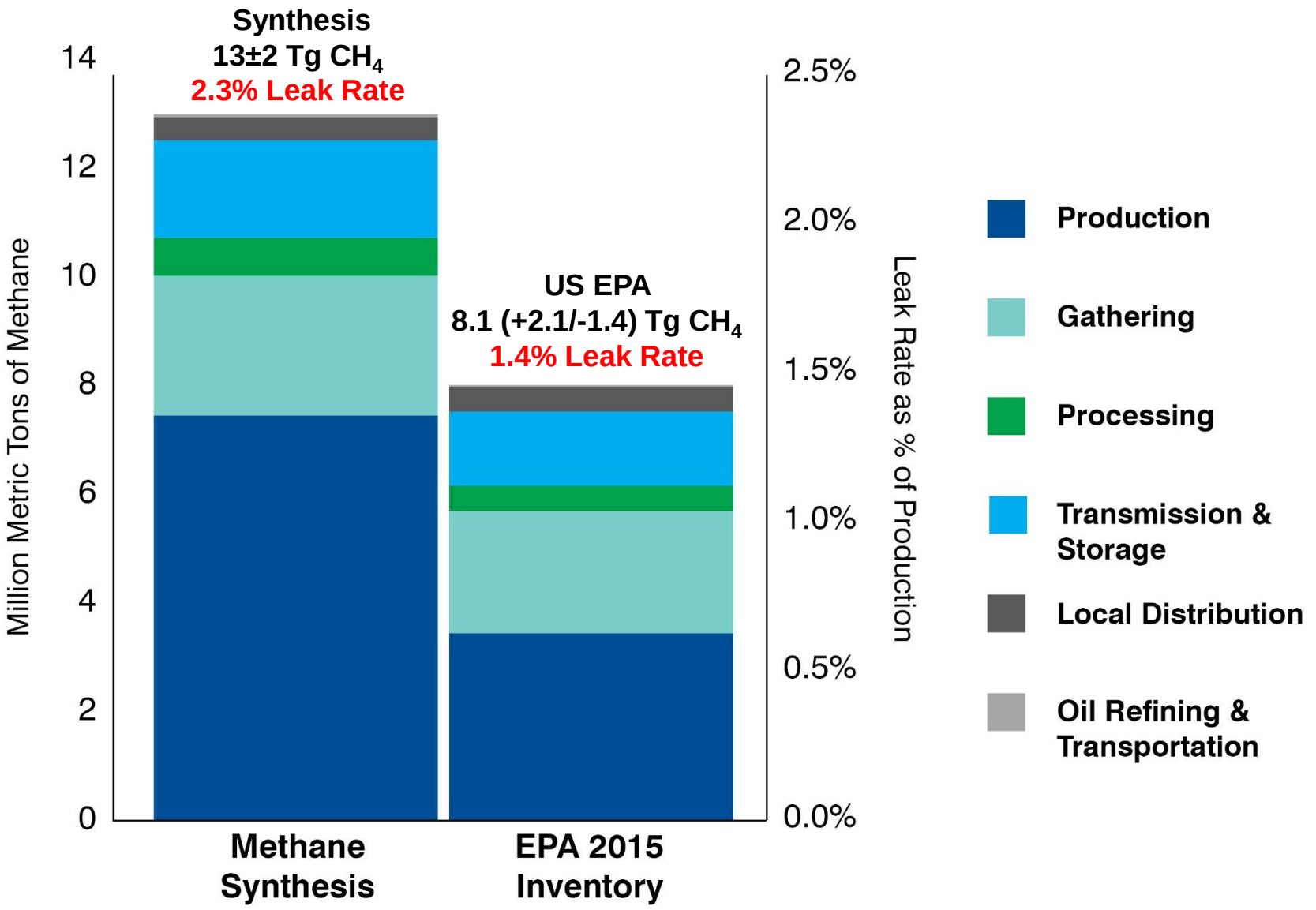
0.44 Tg
0.1%

0.44 Tg
0.1%

Methane Synthesis
Alvarez et al 2018

2017 EPA GHG Inventory
(For year 2015)

O&G CH_4 emissions 60% higher than EPA GHGI



Summary

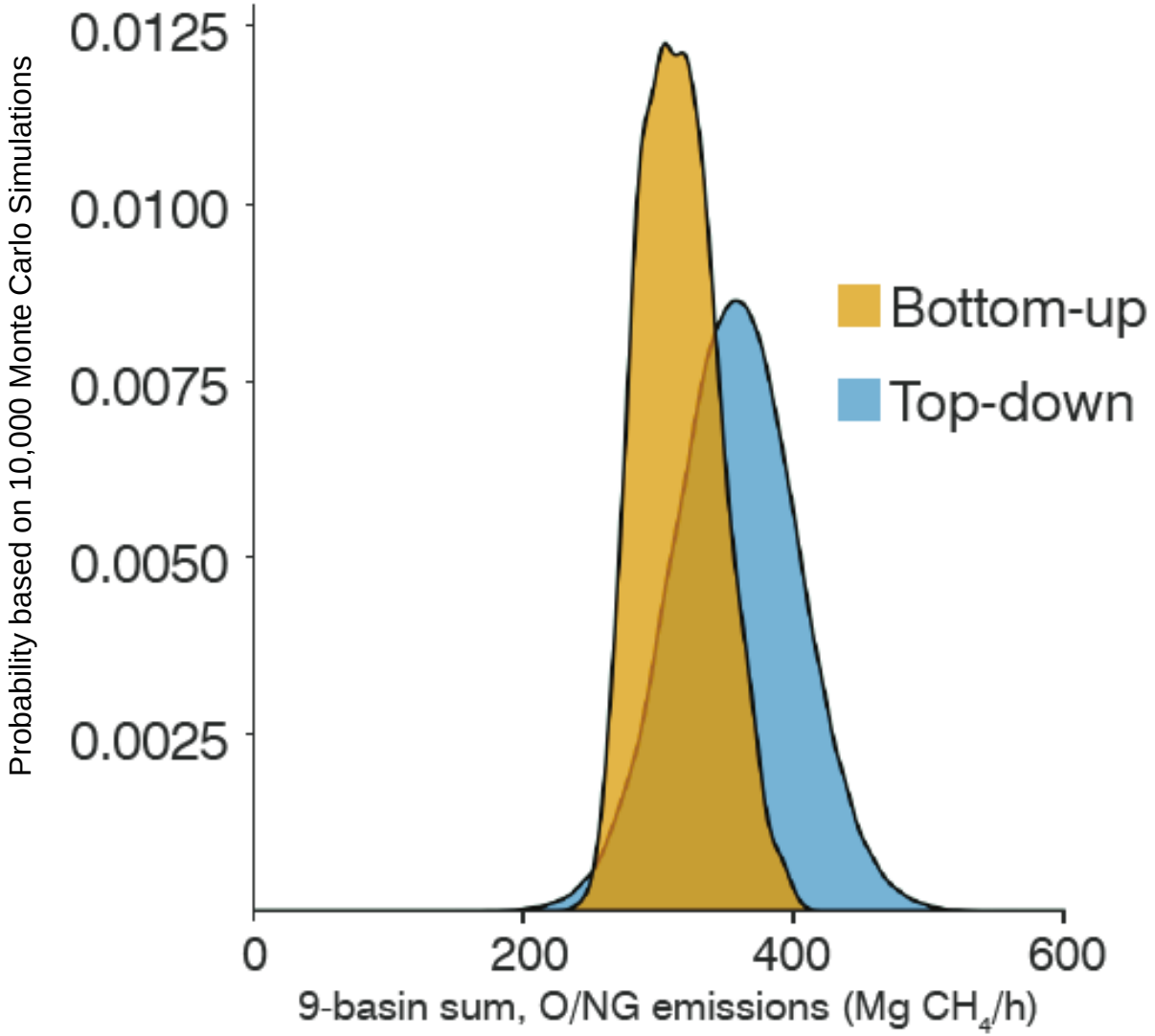
- **O&G CH_4 emissions are higher than estimated by official inventories like the EPA GHGI**
  - Upstream sources responsible for ~80% of total emissions
  - Site-based estimates validated with basin-level data
- **Abnormal conditions cause large emissions often excluded from traditional inventories**
  - Avoidable issues such as malfunctions, human error, and poor site design can lead to very high emission rates
  - Abnormal conditions account for about 50% of production segment and 33% of total supply chain emissions
- **Regulatory and voluntary actions can reduce emissions**
  - Effective monitoring to quickly detect high emissions
  - Root cause analysis and better site design to minimize the recurrence of abnormal conditions
  - Improved reporting to more accurately understand emissions

Implications for Four Corners Region

- Synthesis paper estimates national emissions using data from 10 basins
  - Site-level: No 4C but includes DJ, Uintah, UGR
  - Basin-level: San Juan (Smith et al 2017)
- Assuming loss rate is same as U.S., then NM 2015 O&G emissions ≈ 570,000 tons CH_4
- EDF analysis of GHGRP data adjusted for abnormal conditions also estimates 570,000 tons CH_4
  - https://www.edf.org/sites/default/files/new-mexico-methane-analysis.pdf
- We currently are refining estimate with new site-level measurements data from NM and TX Permian

Additional Slides

Emission estimates agree with top-down measurements from 9 basins



Log likelihood function used to estimate two-term power law parameters describing relationship of gas production and emissions by basin.

$$\mu_j = a_j + b{x_P}^{\theta_1} + c{x_P}^{\theta_2} \quad (1)$$

We selected a two-term power law to characterize the relationship between emission and production to capture the apparent features of the data in Fig. S2. The first power law term is intended to characterize the relatively constant behavior of the first part of the gas production range, and the second power law term is intended to characterize the observed increase in emissions from the highest producing sites.

The log likelihood function is:

$$l(\mu_j, \sigma_j) = \sum_{j=1}^{J}\left[S_{0_j} ln\, \Phi\left(\frac{{x_E^*}_j - \mu_j}{\sigma_j}\right) - S_{r_j} ln\sigma_j - \sum_{i=1}^{S_{r_j}} \frac{\left(x_{E_{ij}} - \mu_j\right)^2}{2{\sigma_j}^2}\right] \quad (2)$$

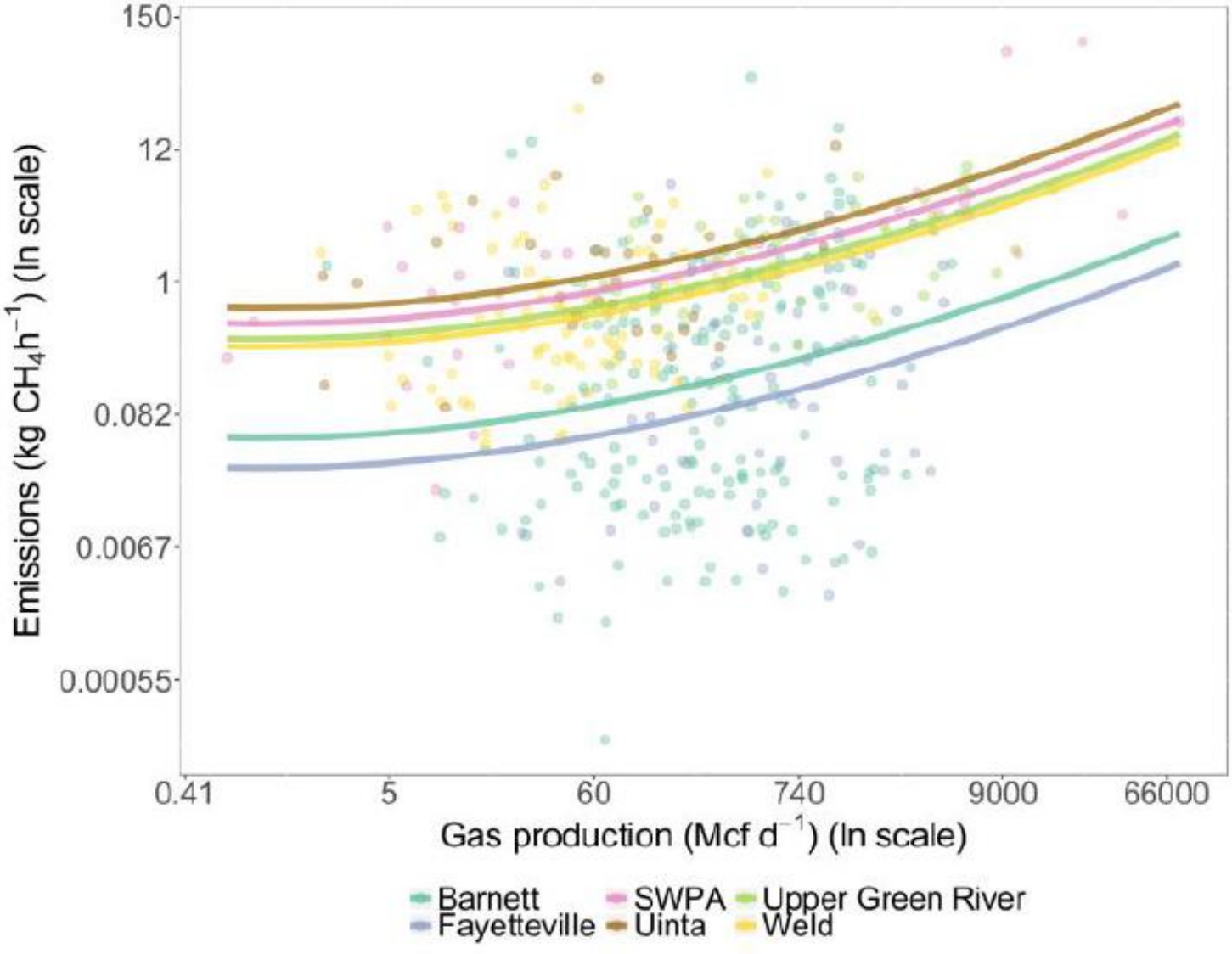
where J is 6, the total number of basins with site-level data; S_{0_j} is the number of samples at or below the detection limit ${x_E^*}_j$; S_r is the number of samples above the detection limit; μ_j is given by Equation 1, and $\Phi\left(\frac{{x_E^*}_j - \mu_j}{\sigma_j}\right)$ is the cumulative normal.

We estimate the 16 parameters $(a_j, b, c, \theta_1, \theta_2, \sigma_j)$ by solving for the values that maximize Eq. 2 and use a direct search algorithm to calculate 95% confidence limits by inverting the Likelihood Ratio Test. Table S5 summarizes parameters that describe $p(x_E|x_P)$.

Table S5. Parameters that describe the emission distribution function conditional on production; 95% confidence intervals are shown between parentheses.

Basin	a	b	c	θ_1	θ_2	σ
Barnett Shale	0.83 (0.55, 1.1)	-2.2 (-2.6, -1.8)	0.20 (0.050, 0.42)	0.60 (0.44, 0.81)	1.4 (1.3, 1.8)	2.1 (2.0, 2.4)
Weld	2.6 (2.3, 2.8)					1.3 (1.1, 1.4)
Fayetteville	0.26 (-0.075, 0.54)					2.1 (1.9, 2.4)
SWPA	3.0 (2.6, 3.2)					1.3 (1.1, 1.6)
Uinta	3.3 (3.0, 3.5)					1.3 (1.1, 1.5)
Upper Green River	2.7 (2.5, 2.9)					0.90 (0.79, 1.0)

Non-linear models show relationship between site gas production and emissions



Alternative, source-based estimate is substantially lower than site-based estimate. This traditional approach underestimates emissions by failing to account for uncategorized abnormal emissions.

Industry Segment	Source Category	2015 U.S. Emissions (Gg CH_4 y^{-1})		
		GHGI	This work (source–based)	This work (site–based)
O/NG Production	Pneumatic Controllers	1,800	1,100 (1,100 - 1,200)	7,200 (5,600 - 9,100)
	Equipment Leaks* $	360	620 (570 - 670)	
	Liquids Unloading	210	170 (170 - 200)	
	Pneumatic Pumps*	210	190 (180 - 200)	
	Oil & Condensate Tanks	100	100 (97 - 120)	
	Produced Water Tanks	40	360 (340 - 380)	
	Fuel combustion	240	98 (91 - 210)	
	Associated gas flaring and venting	150	71 (69 - 86)	
	Other production sources*	40	60 (58 - 68)	
	Routine Operations Subtotal	3,100	2,800 (2,700 - 2,900)	7,200 (5,600 - 9,100)
	Completions + Workovers	100	86 (80 - 120)	
	Abandoned and Orphaned Wells	NA	61 (59 - 360)	
	Onshore Production Subtotal	3,200	2,900 (2,900 - 3,300)	7,300 (5,700 - 9,300)
	Offshore Platforms	300	300 (240 - 380)	
	Production Total	3,500	3,200 (3,100 - 3,600)	7,600 (6,000 - 9,600)
Natural Gas Gathering	Gathering Stations	2,000	2,100 (2,100 - 2,200)	
	Gathering Episodic Events	200	170 (7 - 750)	
	Gathering Pipelines	160	310 (300 - 330)	
	Gathering Total	2,300	2,600 (2,400 - 3,200)	
Natural Gas Processing	Processing Plants	410	680 (610 - 880)	
	Routine Maintenance	36	36 (29 - 46)	
	Processing Total	450	720 (650 - 920)	
Transmission and Storage (T/S)	T/S Stations	1,100	1,100 (860 - 1,400)	
	T/S Uncategorized/Superemitters	NA	440 (350 - 570)	
	Transmission Pipelines	220	220 (180 - 290)	
	LNG Storage and Import Terminals	70	67 (54 - 87)	
	T/S Total	1,300	1,800 (1,600 - 2,100)	
Local Distribution	All sources through customer meters	440	440 (220 - 950)	
Petroleum Midstream	Oil Transportation + Refining	34	34 (26 - 84)	
Total U.S. Oil and Gas Supply Chain		8,100 (6,800 – 10,000)	8,800 (8,400 - 9,700)	13,000 (12,000 - 15,000)

Over 30% of emissions are from very marginal (<10 Mcf/d) sites responsible for <1% of U.S. gas production.

Table S4. Distribution of the activity data of U.S. oil and natural gas wells in 2015. The last row shows the percent of emissions from production sites calculated with the model described in this section. The production cohorts in this table were selected based on breakpoints evident in the dataset of production site emission measurements (Fig. S2 and Section S1.9), and 0.68 Mcf/d is the minimum production of the sampled population. The measurement dataset predominantly contains sites with gas production within the bolded gas production cohorts.

	% of US 2015 Activity Data by Gas Production Cohort				
Natural Gas Production Cohorts (Mcf d^{-1})	0	>0–0.68	**0.68–10**	**10–5,000**	>5,000
Sites*	15% (0%)	7.6% (8.9%)	29% (34%)	48% (57%)	0.38% (0.45%)
Wells	19%	5.1%	20%	53%	3.3%
Gas Production	0%	0.015%	0.84%	59%	40%
Oil Production	7.3%	0.49%	3.0%	74%	15%
Emissions*	6.4% (0%)	5.1% (5.5%)	20% (21%)	64% (68%)	4.8% (5.1%)

*The main value includes oil wells with zero reported gas production; the value in parentheses excludes them.