U.S. O&G CH_4 emissions estimated with site and component-level data

David Lyon
Renee McVay
Mark Omara
Hillary Hull
Daniel Zavala-Araiza
Ramon Alvarez
Steve Hamburg

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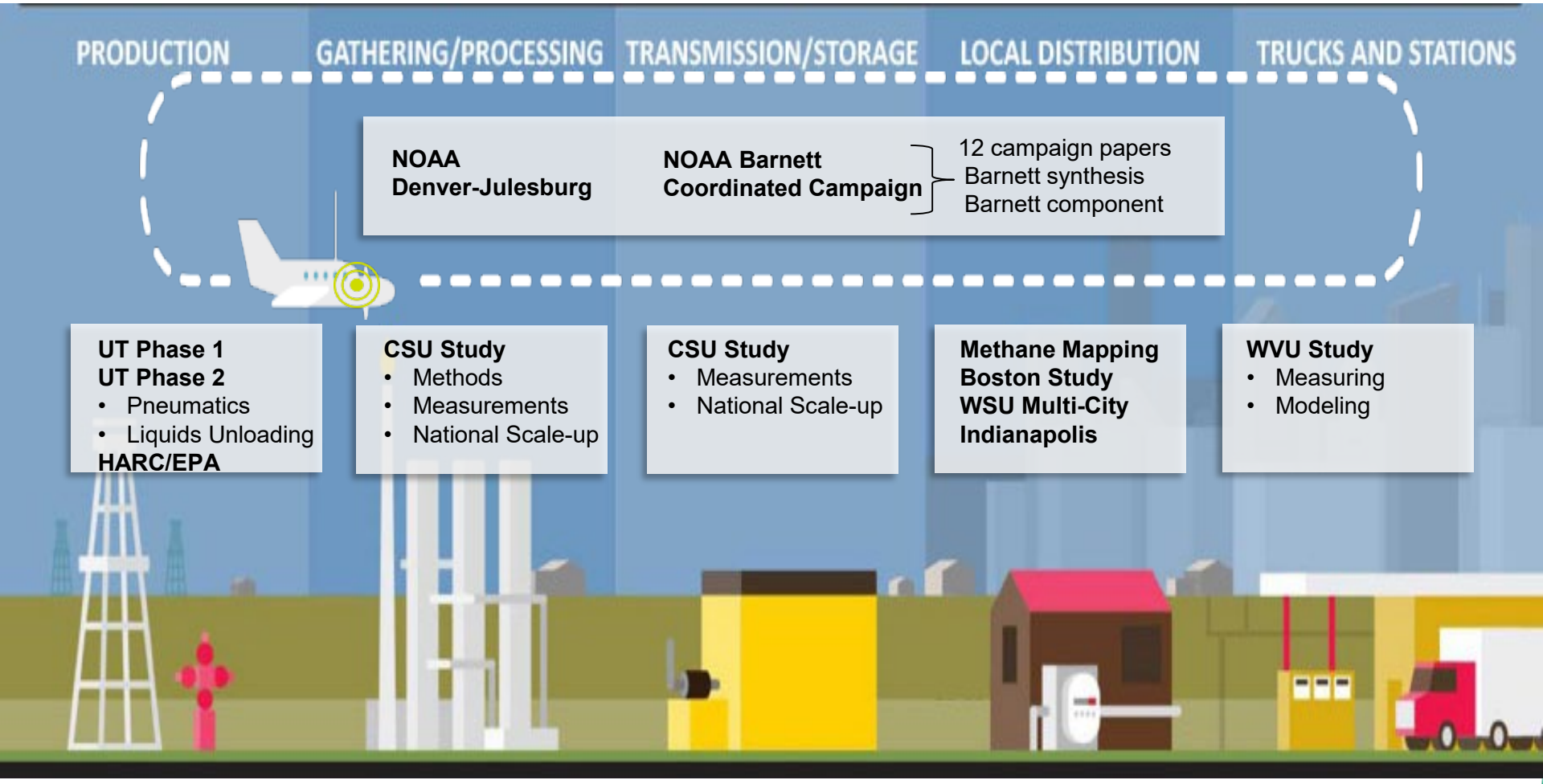
EDF U.S. Oil and Gas Methane Studies



Pilot Projects

Gap Filling
- Abandoned wells
- Helicopter IR Survey

Synthesis Projects
- NETL LCA
- **Synthesis**

Oil and Gas CH_4 Synthesis Paper

- Quantifies 2015 CH_4 emissions from U.S. oil and gas supply chain (well to customer meter)
- Synthesizes multiple recently published datasets
  - Upstream emissions estimated with statistical model based on site-level measurements
  - Emissions validated with aerial mass balance data
  - Emissions compared to custom, component-level inventory model

Drilling & Production

Gathering & Processing

Transmission & Storage

Local Distribution

Regional Research

Synthesis Collaborators

Aerodyne Research
Scott C. Herndon

Carnegie Mellon University
Allen L. Robinson

Colorado State University
Anthony J. Marchese

EDF
Ramon A. Alvarez
David R. Lyon
Daniel Zavala–Araiza
Mark Omara
Steven P. Hamburg

Harvard University
Daniel J. Jacob
Joannes D. Maasakkers
Steven C. Wofsy

National Institute of Standards and Technology
Anna Karion

National Oceanic and Atmospheric Administration
Earth System Research Laboratory

Jeff Peischl
(University of Colorado)
Colm Sweeney

Pennsylvania State University
Zachary R. Barkley
Kenneth J. Davis
Thomas Lauvaux

Princeton University
Stephen W. Pacala

Purdue University
Paul B. Shepson

Stanford University
Adam R. Brandt

University of Cincinnati
Amy Townsend-Small

University of Michigan
Eric A. Kort

University of Texas
David T. Allen

Washington State University
Brian K. Lamb

Science

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

Ramón A. Alvarez[1]*, Daniel Zavala-Araiza[1], David R. Lyon[1], David T. Allen[2], Zachary R. Barkley[3], Adam R. Brandt[4], Kenneth J. Davis[3], Scott C. Herndon[5], Daniel J. Jacob[6], Anna Karion[7], Eric A. Kort[8], Brian K. Lamb[9], Thomas Lauvaux[3], Joannes D. Maasakkers[6], Anthony J. Marchese[10], Mark Omara[1], Stephen W. Pacala[11], Jeff Peischl[12,13], Allen L. Robinson[14], Paul B. Shepson[15], Colm Sweeney[13], Amy Townsend-Small[16], Steven C. Wofsy[6], Steven P. Hamburg[1]

[1]Environmental Defense Fund, Austin, TX, USA. [2]University of Texas at Austin, Austin, TX, USA. [3]The Pennsylvania State University, University Park, PA, USA. [4]Stanford University, Stanford, CA, USA. [5]Aerodyne Research Inc., Billerica, MA, USA. [6]Harvard University, Cambridge, MA, USA. [7]National Institute of Standards and Technology, Gaithersburg, MD, USA. [8]University of Michigan, Ann Arbor, MI, USA. [9]Washington State University, Pullman, WA, USA. [10]Colorado State University, Fort Collins, CO, USA. [11]Princeton University, Princeton, NJ, USA. [12]University of Colorado, CIRES, Boulder, CO, USA. [13]NOAA Earth System Research Laboratory, Boulder, CO, USA. [14]Carnegie Mellon University, Pittsburgh, PA, USA. [15]Purdue University, West Lafayette, IN, USA. [16]University of Cincinnati, Cincinnati, OH, USA.

*Corresponding author. E-mail: ralvarez@edf.org

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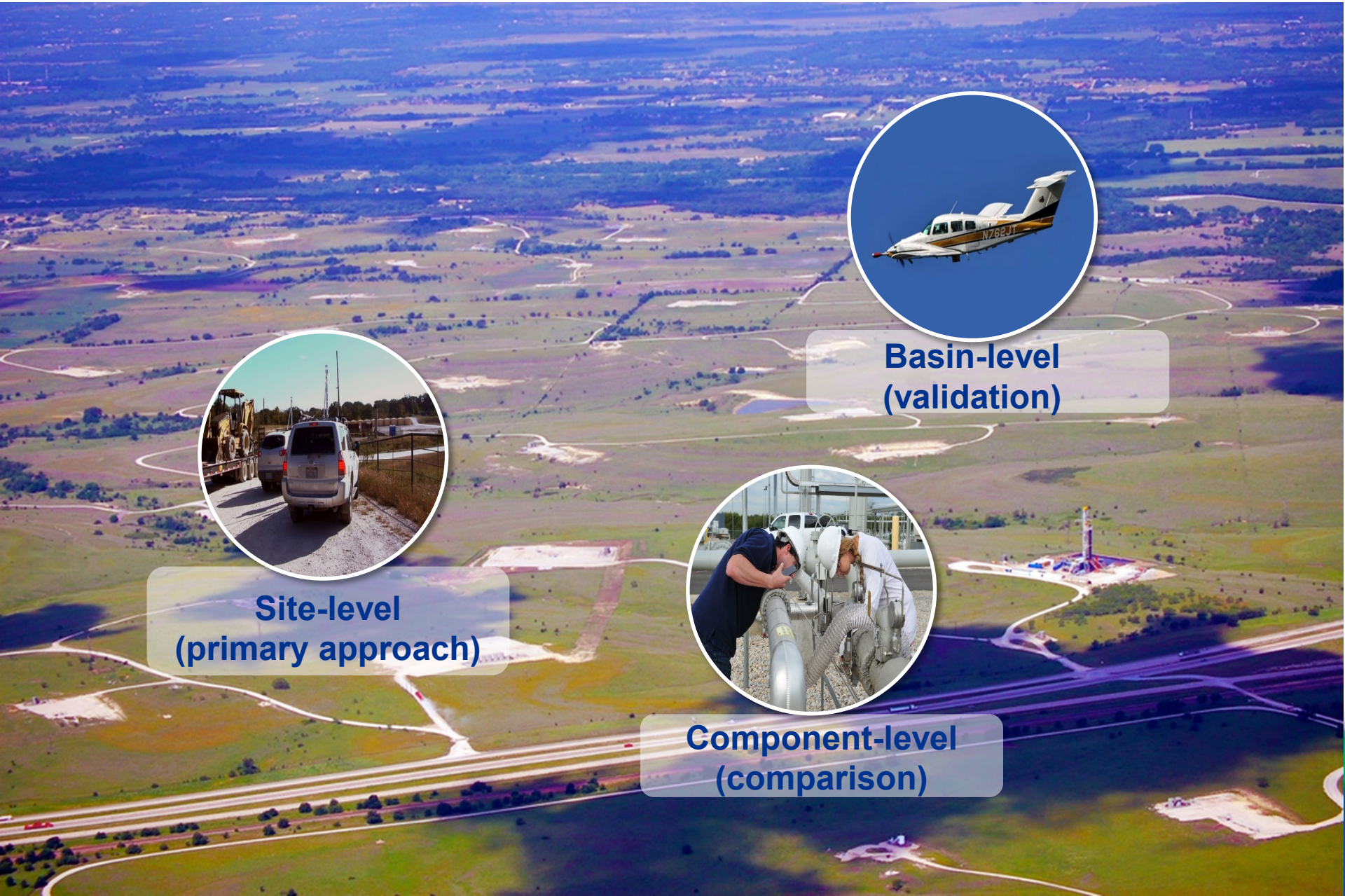
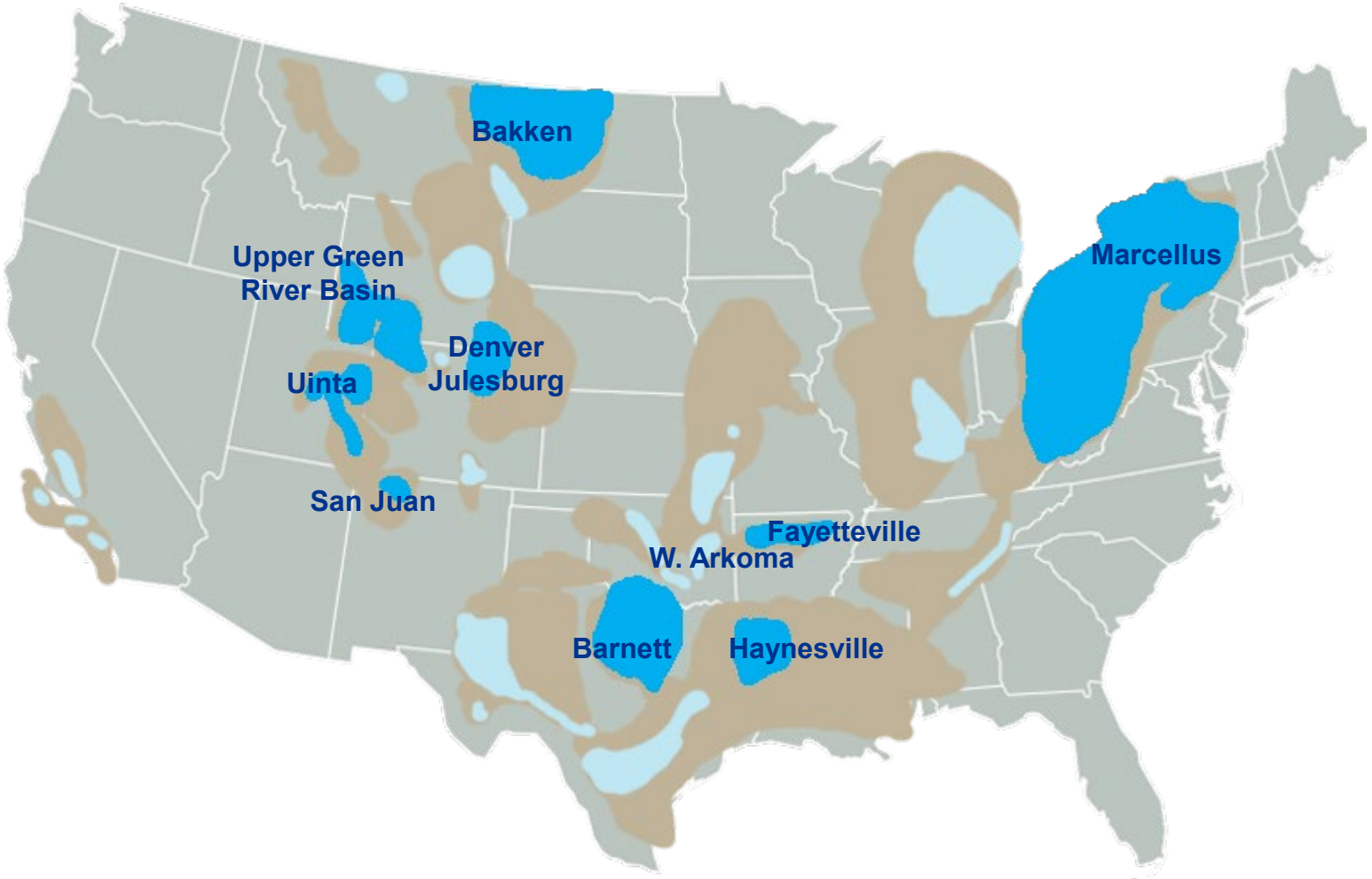
Emissions quantified at different spatial scales



Synthesis data collected from basins accounting for ~24 and 33% of U.S. oil and gas production



Methane study areas

Synthesis Methods: Production

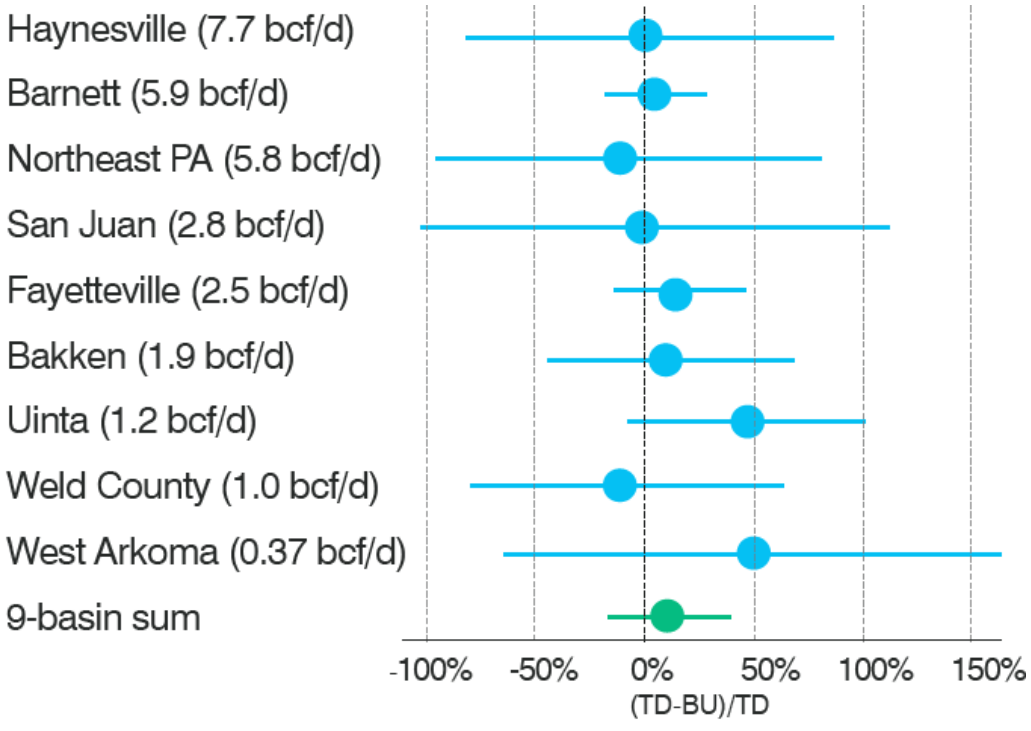
- Data
  - Previously published site-level measurement data from 433 well pads in six basins
  - References: Omara et al 2016, Rella et al 2015, Robertson et al 2017, Brantley et al 2014
  - Basins: Marcellus (SW PA), Barnett, Denver-Julesburg, Fayetteville, Uintah, Upper Green River
  - Methods: Dual tracer, mobile flux plane, inverse Gaussian, EPA OTM 33A
- Analysis
  - Log likelihood function fit measurement data to a two-term power law characterizing the weak relationship between gas production and emissions
  - National emissions estimated by applying function to ~520,000 gas producing well pads

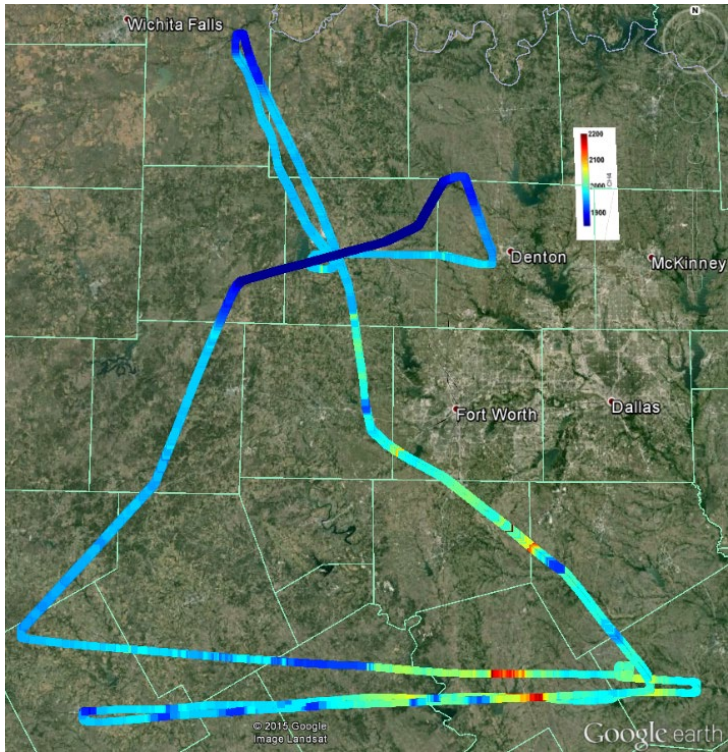
Synthesis Methods: Other Segments

- Gathering & Processing
  - Gathering station and blowdown EFs based on Marchese et al 2015
    - 114 site-level measurements
  - Gathering pipeline EFs from EPA GHG Inventory but applied to all gas producing wells
  - Processing plant EFs based on Marchese et al 2015
    - 16 site-level measurements
  - Gathering station and processing plant EFs were adjusted upward ~20% to account for undersampling of fat-tail
- Transmission & Storage
  - T&S station EFs based on Zimmerle et al 2015
    - 45 site-level measurements
  - Includes ~440 Gg from super-emitters excluded from EPA GHGI
- Local distribution
  - Lamb et al 2015 (same as GHGI)
  - Likely underestimates emissions

Synthesis Methods: Validation

- Primary estimate validated with basin-level, aircraft mass balance data from 9 basins
  - References: Peischl et al 2015, Karion et al 2015, Barkley et al 2017, Smith et al 2015, Schwietzke et al 2017, Peischl et al 2016, Karion et al 2013, Petron et al 2014
  - Basins: Haynesville, Barnett, Marcellus (NE PA), San Juan, Fayetteville, Bakken, Uintah, Weld, West Arkoma





Synthesis Methods: Comparisons to Alternative Inventories

- As a comparison, an alternative, component-level inventory was developed for the production segment
  - Incorporates several data sources including EPA Greenhouse Gas Reporting Program and published studies with component-level measurements
  - For most sources, multi-parameter model uses correlations between GHGRP reporter source-level emissions and production data to both extrapolate non-reporter emissions and disaggregate basin-level emissions
- Difference between primary and alternative estimate attributed to “abnormal process conditions”
- Estimates also compared to EPA Greenhouse Gas Inventory Petroleum and Natural Gas Systems

Summary of emission estimates

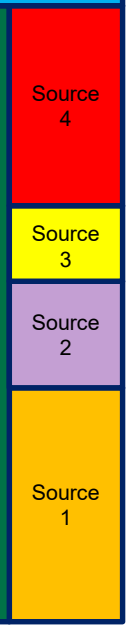
Primary Estimate

Total O&G emissions estimated with statistical model using site-level measurement data

Comparison

"Abnormal Process Conditions" are the difference between the two estimates and may include emissions from several sources

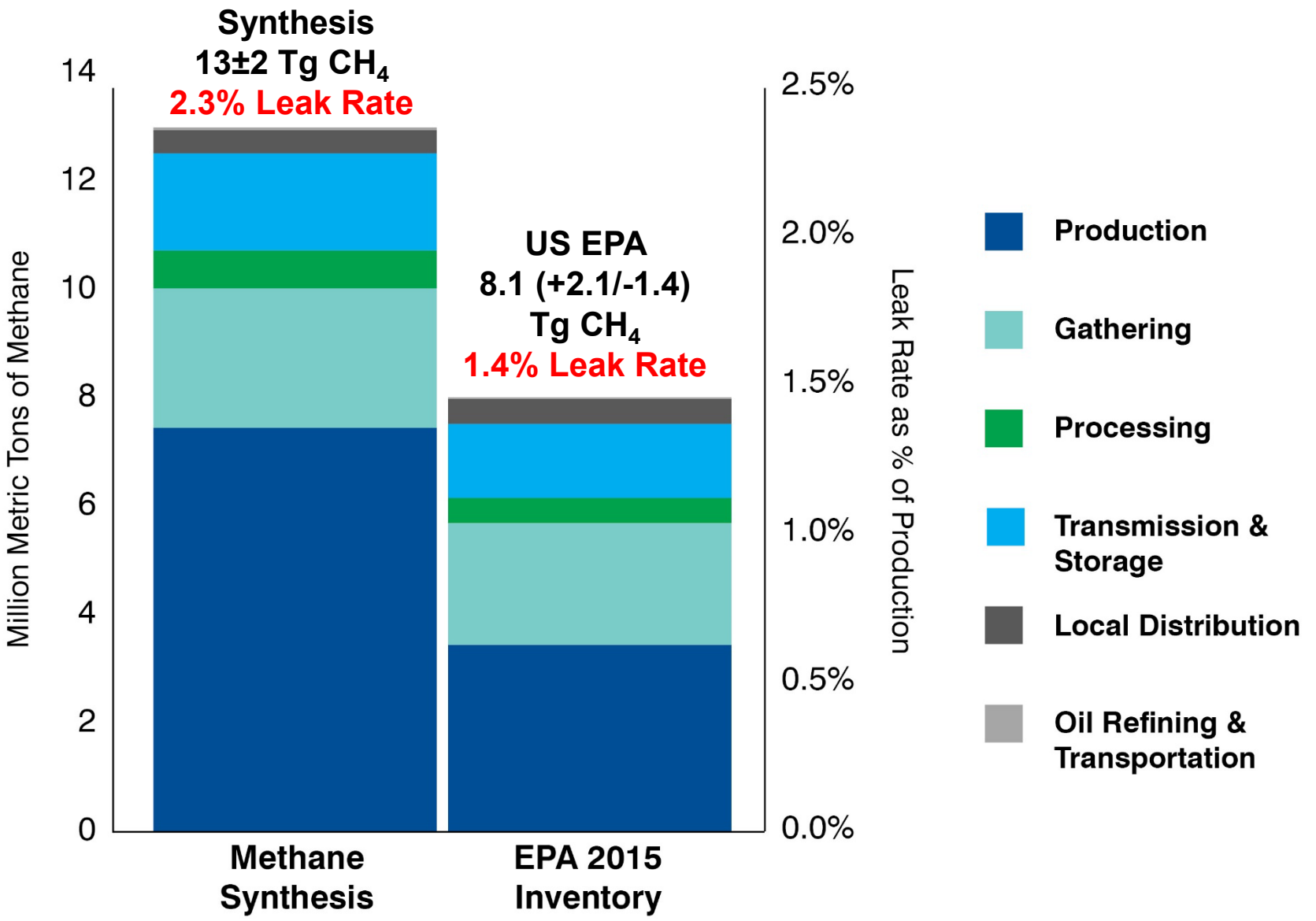
Best estimate of aggregate, source-level emissions based on multiple component-level approaches



Validation

Total O&G emissions validated with top-down data (source apportioned aerial mass balance)

O&G CH_4 emissions are 60% higher than EPA GHGI



Alternative, component-level inventory is similar to EPA GHGI and substantially lower than site-based estimate.

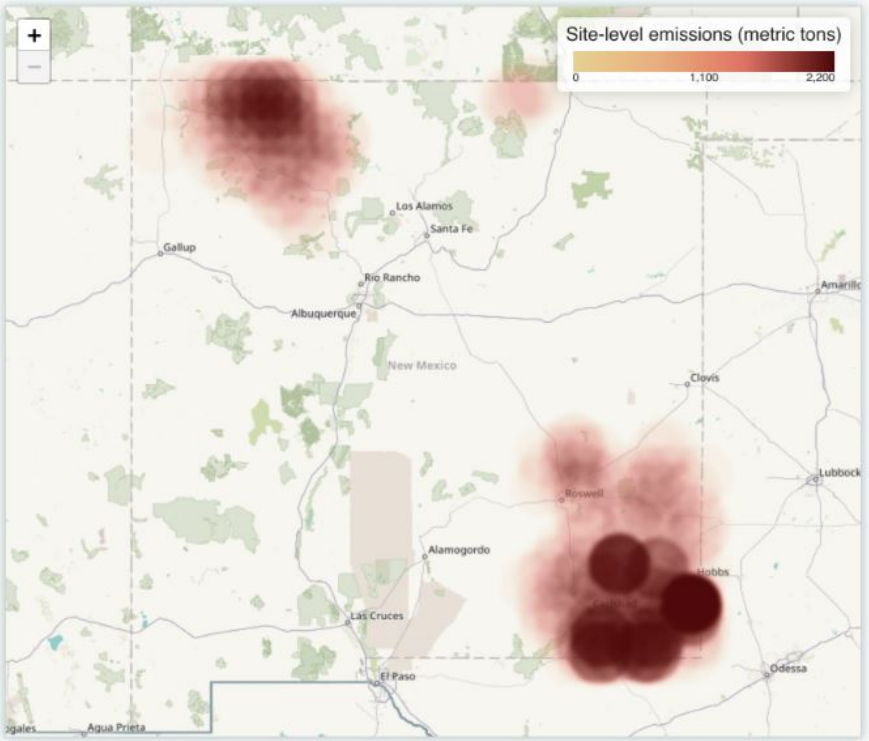
Industry Segment	Source Category	2015 U.S. Emissions (Gg CH_4 y^{-1})		
		GHGI	This work (source–based)	This work (site–based)
O/NG Production	Pneumatic Controllers	1,800	1,100 (1,100 - 1,200)	7,200 (5,600 - 9,100)
	Equipment Leaks* $	360	620 (570 - 670)	
	Liquids Unloading	210	170 (170 - 200)	
	Pneumatic 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)

Model Updates

- Model updated with 2017 GHGRP and Drillinginfo production data including site locations
- Code modified to estimate emissions for individual production sites
  - Allows inventories to be developed for custom spatial domains
- Site-level model incorporating 2018 data from ~90 Permian Basin well pads
  - OTM 33A measurements by University of Wyoming
  - Permian data has two distinct emission rate distributions for simple and complex sites
  - Paper in preparation (Robertson et al)
- Model code (R) will be made available

New Mexico Emission Estimates

- EDF used model including Permian data to estimate NM O&G emissions are 1 million metric tons CH_4 and 3 MMT VOC
- CH_4 emissions are 5X higher than EPA GHGRP
- https://www.edf.org/energy/explore-new-mexicos-oil-and-gas-pollution



Methane emissions density across New Mexico

Credit: Anna Robertson

Summary

- Site-level measurement data were used to accurately estimate total O&G CH_4 emissions.
  - Emission estimates were validated with top-down data such as aircraft mass balance
  - Updated model uses approach to develop spatially explicit upstream emission inventories.
- Emissions are substantially higher than inventories based on component-level approaches.
  - Missing emissions (abnormal process conditions) may include many potential sources and causes.
  - Component-level data are valuable for guiding mitigation but not sufficient to accurately estimate emissions.