Joint Institute for Strategic Energy Analysis

Taxonomy, Life Cycle Assessment, and Meta-analyses for Improving Methane Emissions Estimates from Oil and Gas

Garvin Heath, PhD

Committee on Anthropogenic Methane Emissions in the US: Improving Measurement, Monitoring, Presentation of Results, and Development of Inventories

University of California, Davis

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www.jisea.org
www.nrel.gov/harmonization

NREL National Renewable Energy Laboratory | Colorado School of Mines | Colorado State University | Massachusetts Institute of Technology | Stanford University | University of Colorado Boulder

My Talk and the Committee’s Charge

Review relevant highlights of three papers related to most committee charges:

- Charge 4

  Heath et al. 2014. “**Harmonization of Initial Estimates of Shale Gas Life Cycle Greenhouse Gas Emissions for Electric Power Generation**.” *PNAS*. 111(31): E3167–E3176. http://www.pnas.org/content/111/31/E3167.abstract.

- Charges 1, 2, 5, 6, 7

  Heath et al. 2015. ***Estimating U.S. Methane Emissions from the Natural Gas Supply Chain: Approaches, Uncertainties, Current Estimates, and Future Studies***. http://www.nrel.gov/docs/fy16osti/62820.pdf.

- Charges 4, 6, 7

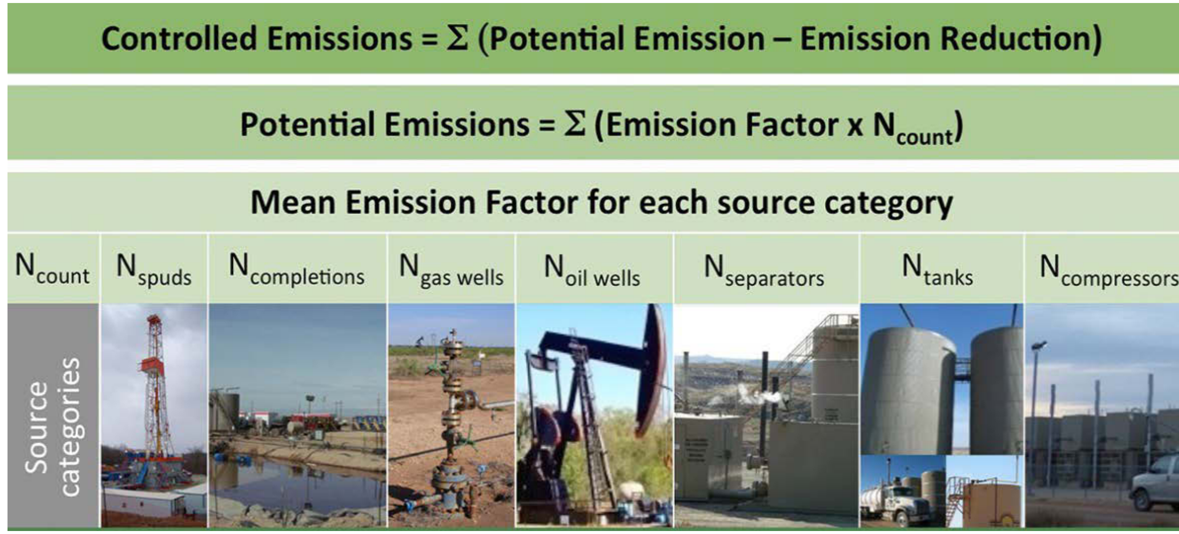
  Brandt A., G. Heath, and D. Cooley. 2016. “**Methane Leaks from Natural Gas Systems Follow Extreme Distributions**.” *ES&T* 50 (22): 12512–12520. http://pubs.acs.org/doi/abs/10.1021/acs.est.6b04303 .

Bottom-up Engineering-based Methods for Environmental Assessment

Inventory

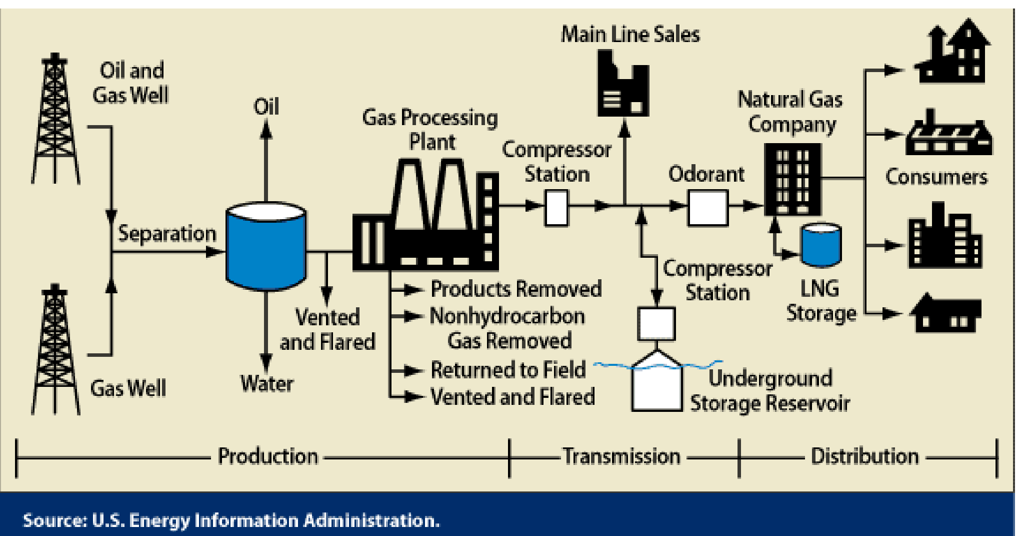
Cross-sectional

- *Temporal boundary*: typically one year
- *Spatial boundary*: global, national, sub-national
- *Sectoral boundaries*



Sources: NREL and NOAA

Life Cycle Assessment



Longitudinal

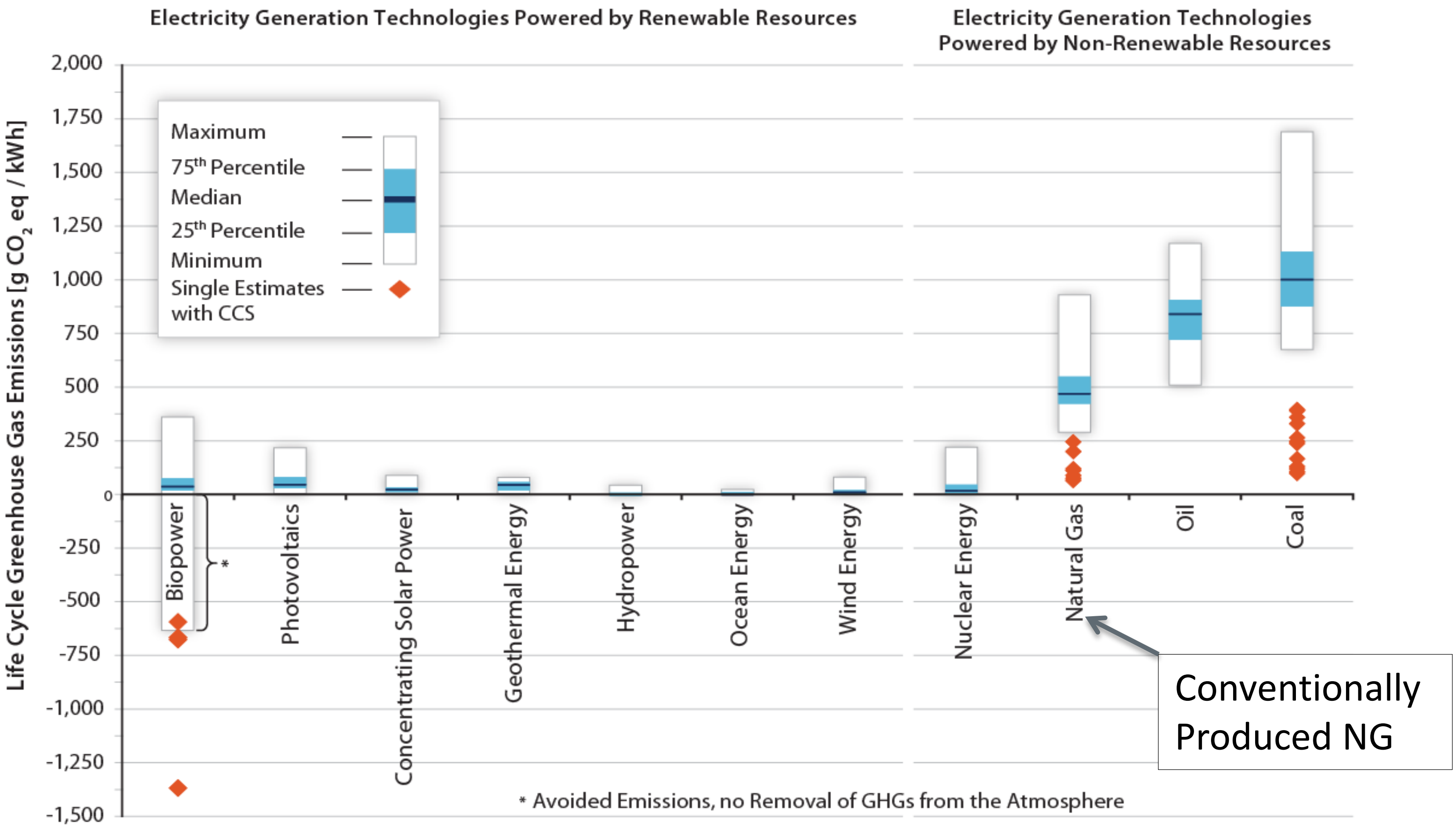
Sequence of processes, each modeled independently, summed across space and time, and scaled to a unit of final product → attributable emissions

$\propto$ → Unit of end product (e.g., kWh)

Synthesis of Life Cycle GHG Emission Estimates for Electricity Generation

IPCC SRREN SPM Fig. 8

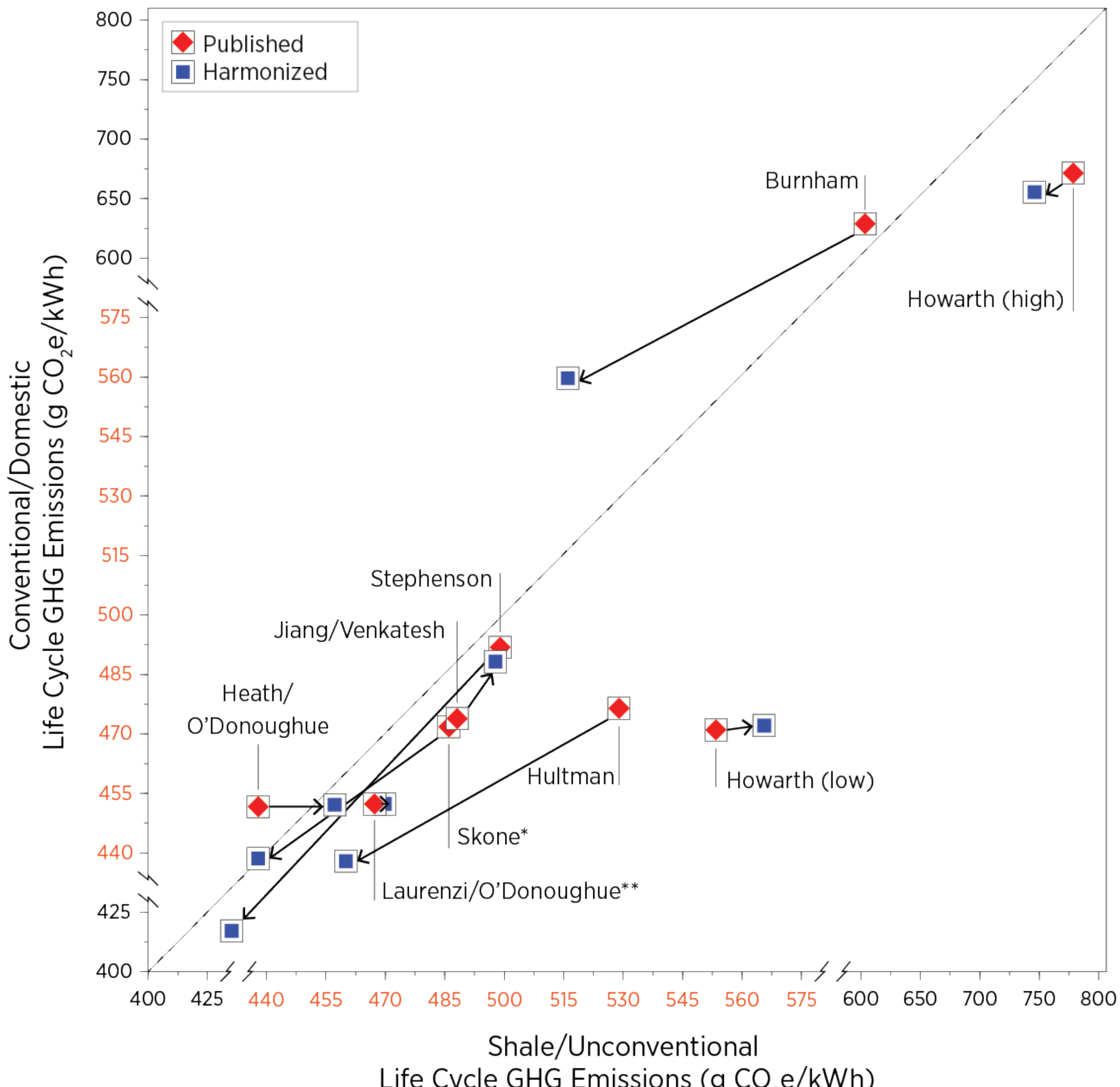
1



	Biopower	Photovoltaics	Concentrating Solar Power	Geothermal Energy	Hydropower	Ocean Energy	Wind Energy	Nuclear Energy	Natural Gas	Oil	Coal
Count of Estimates	222(+4)	124	42	8	28	10	126	125	83(+7)	24	169(+12)
Count of References	52(+0)	26	13	6	11	5	49	32	36(+4)	10	50(+10)

How to Present Results to Facilitate Comparisons: Results of Harmonization of Shale Gas LCAs

1

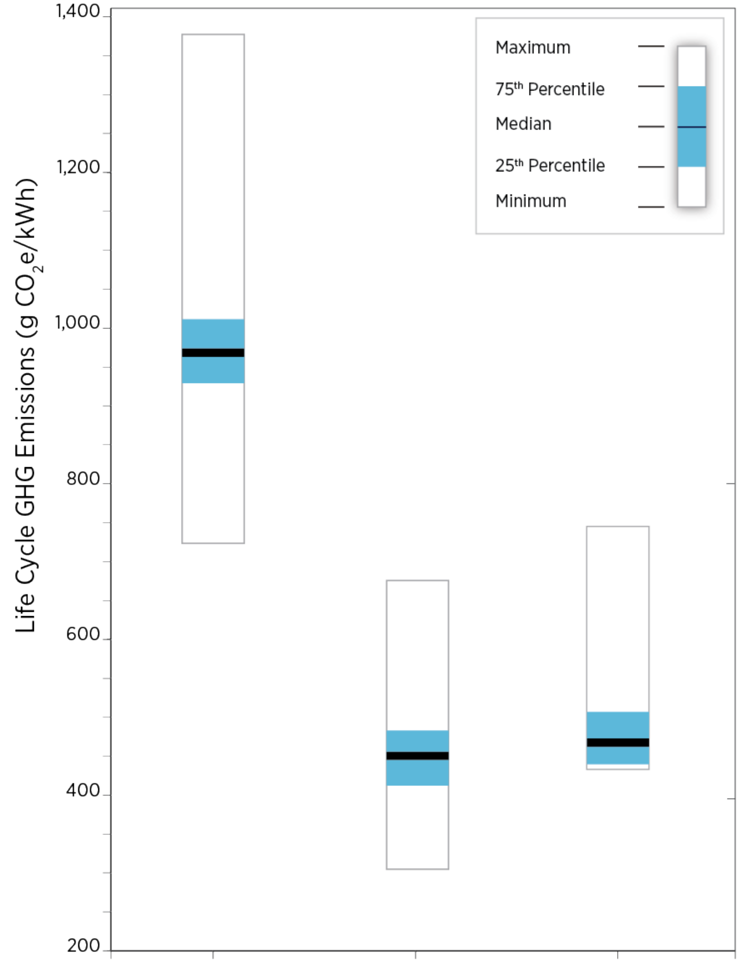


- Methodological harmonization
  - Align system boundaries
  - Adjust certain parameters to align assumptions
- Achieves fair comparison between results of different studies
- Tends to consolidate results

Source: Heath et al. (2014)

NG Life Cycle GHG Emissions:
Comparing Unconventional to Conventional Gas and to Coal

1



	Coal Harmonized	Conventional NGCC Harmonized	Unconventional NGCC Harmonized
Estimates:	164	51	10
References:	53	42	8

Central Conclusions

- After methodological harmonization, unconventional gas when used to generate electricity is roughly equal to conventional gas in life cycle GHG emissions
- Comparing median estimates, both types of natural gas have half the emissions of coal.

Source: Heath et al. 2014

(Methane GWP = 30 for all categories)

Comparing and Interpreting Reported Methane Leakage Rates

Published

	Unconventional Gas Leakage Rate	
Study	**Estimate (%)**	**Reported units**
Howarth-Low	3.6	fugitive CH_4 / CH_4 produced
Howarth-High	7.9	fugitive CH_4 / CH_4 produced
Jiang	NR	
Skone	4.8	fugitive NG / produced gas
Hultman	2.4	CH_4 / consumed gas
Burnham	2	CH_4 / NG produced
Stephenson	0.65	mixed
Heath	1.3	CH_4 / NG produced

Adjusted to Consistent Units

	Unconventional Gas Leakage Rate	
Study	**Estimate (%)**	**Consistent units**
Howarth-Low	2.8	CH_4 / NG produced*
Howarth-High	6.2	CH_4 / NG produced*
Jiang	NR	
Skone	3.9	CH_4 / NG produced
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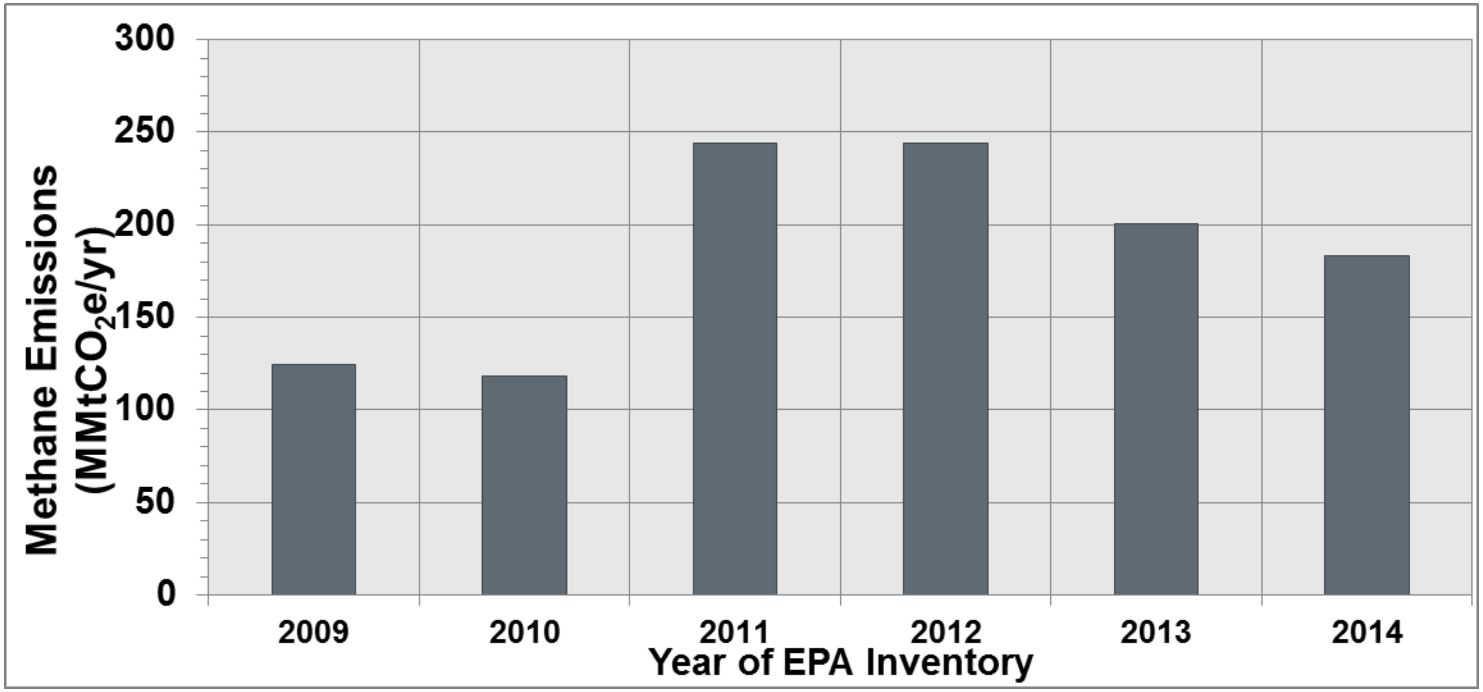
Heath	1.3	CH_4 / NG produced

- Adjusted based on:
  - Methane content of vented gas
  - Loss rate from produced to consumed
  - Volume to mass.

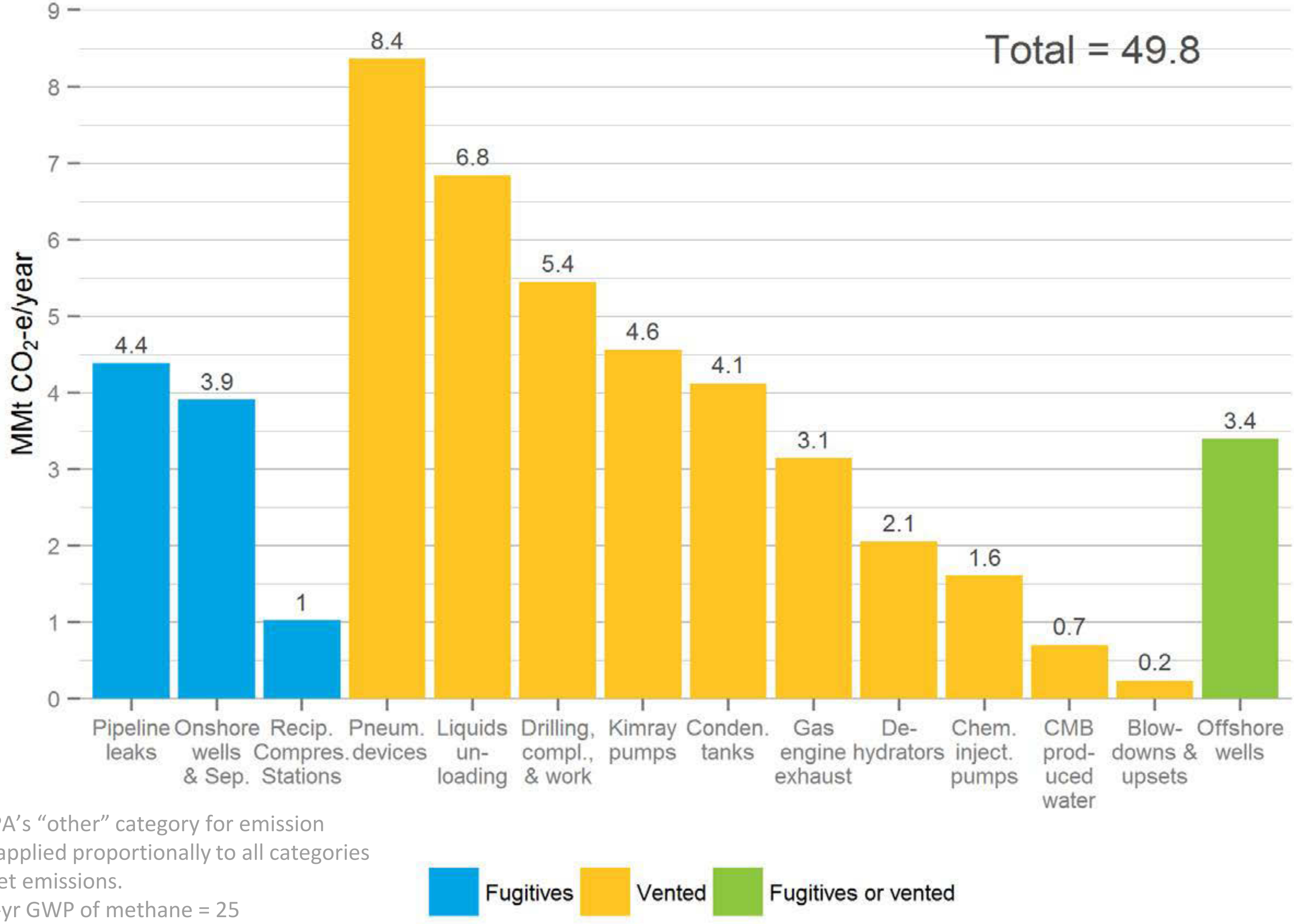
LCAs Rely on Data from Inventories, Which Are Evolving

NG methane inventory for the year 2007 across six U.S. EPA GHG Inventories (2009–2014)



Sources: Larsen 2013 and U.S. EPA 2014

Inventories Support Policy Development and Prioritization:
Natural Gas Production Segment Methane Emissions



Notes: The EPA's "other" category for emission reductions is applied proportionally to all categories to calculate net emissions.
Assumes 100-yr GWP of methane = 25
GWP reflects EPA's GHG Reporting Program as well as its recently published 2015 U.S. GHGI.

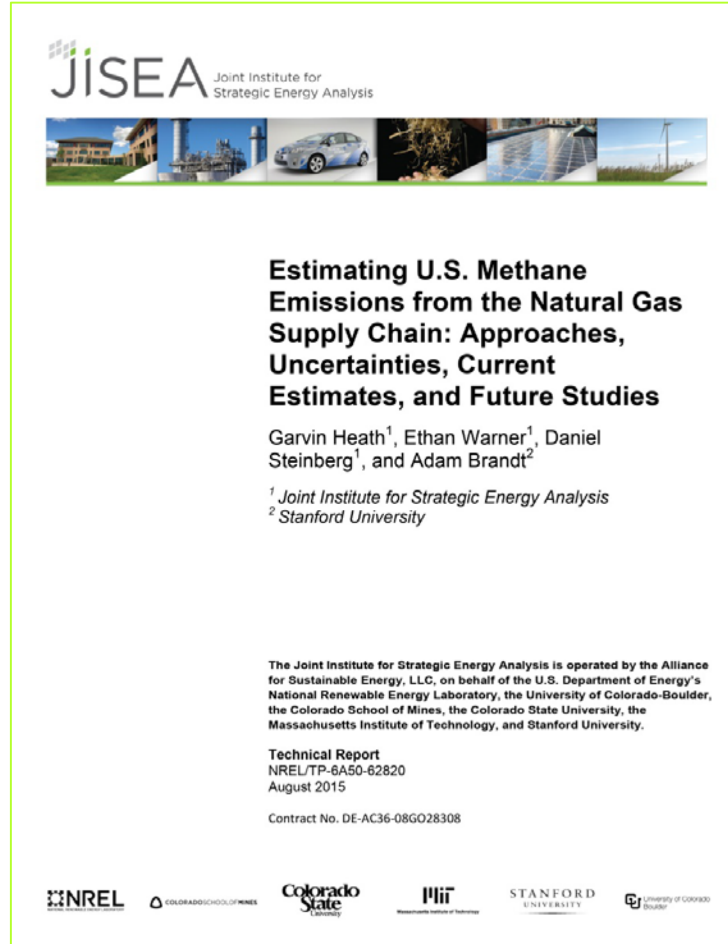
Source: U.S. EPA 2014 GHG Inventory

Charges 1, 2, 5, 6, and 7:

Inventory Improvement Opportunities

2

- Goals:
  - Summarize methods and results of the U.S. GHGI
  - Identify potential gaps and barriers to improvement
  - Identify opportunities to improve accuracy
- Foci:
  - Methane emissions from the natural gas sector
  - National GHG inventory
    - Implications for other inventories (e.g., state) and other pollutants.


JISEA Joint Institute for Strategic Energy Analysis

Estimating U.S. Methane Emissions from the Natural Gas Supply Chain: Approaches, Uncertainties, Current Estimates, and Future Studies

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[2] *Stanford University*

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http://www.nrel.gov/docs/fy16osti/62820.pdf

The U.S. GHGI: A Critical Resource

The U.S. Greenhouse Gas Inventory (GHGI) **identifies and quantifies emission sources and sinks** of greenhouse gases (GHG) from human activities in the United States.

The U.S. Environmental Protection Agency (EPA) publishes the U.S. GHGI. Many agencies, organizations, and researchers rely on its results for analyses and decision making.

The U.S. GHGI is a critical resource for:

- Understanding the U.S. contribution to global climate change
- Tracking trends in GHG emission sources and sinks
- Identifying and prioritizing abatement opportunities within the United States
- Informing policy and investment decision making.

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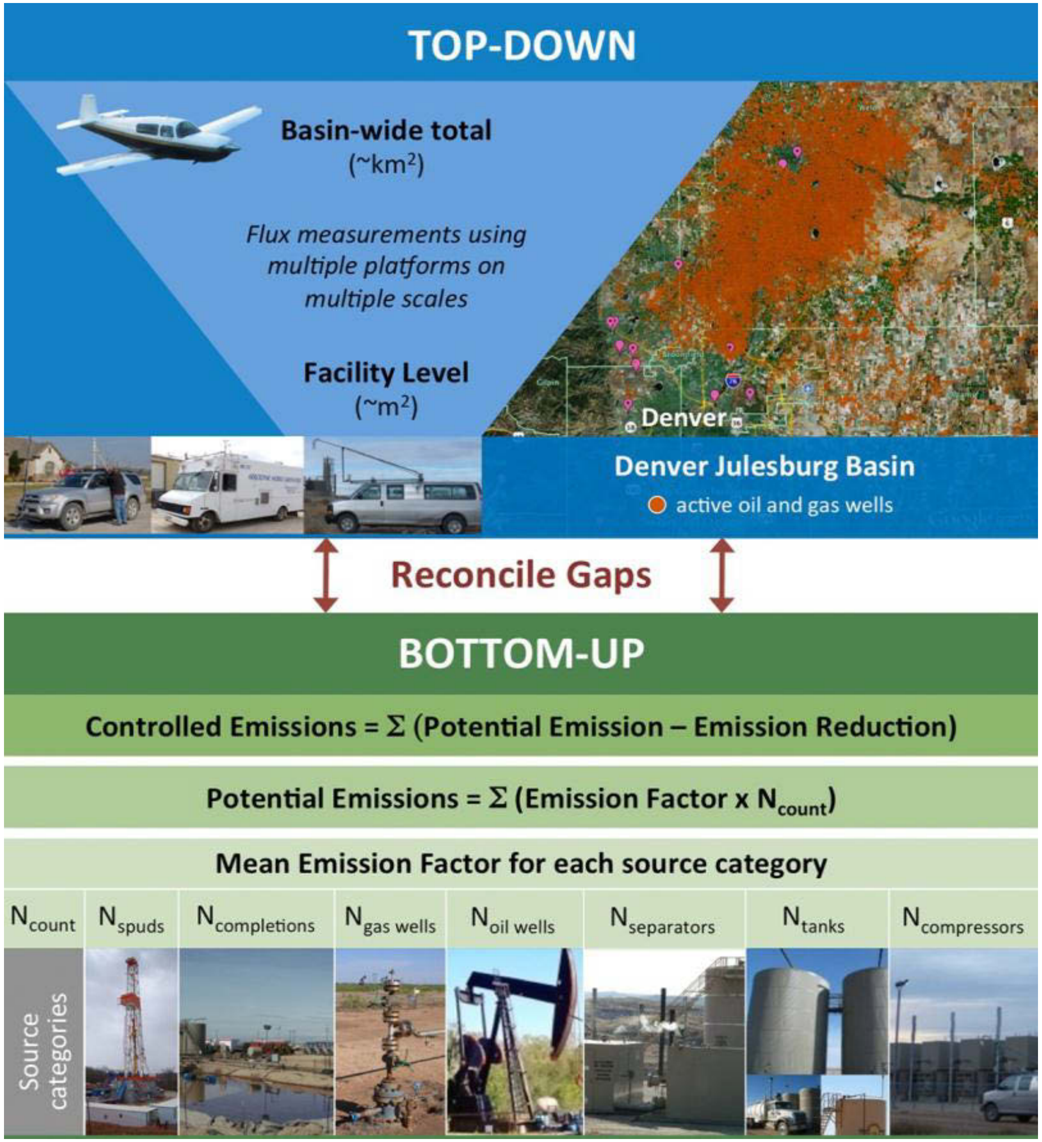
Top-down (TD) and Bottom-up (BU) Studies



Nomenclature not consolidated on definition of top-down or bottom-up:

Top-down: Infers emissions from measurements of atmospheric methane concentrations or atmospheric models.

Bottom-up: Focuses on the specific source or activity causing the emissions.

Measurement-based estimate or modeled (e.g., **inventory** – see bottom panel).

Figure: NREL and NOAA, 2014

Definitions: White House 2014. Climate Action Plan.

Top-down and Bottom-up Studies: Roles to Improve Inventory

Both top-down (TD) and bottom-up (BU) studies have uncertainty and potential for inaccuracy —

neither is "truth"

Both have roles to improve inventory. For example:

- **TD:** Useful as comparison to inventory estimates; any differences could help generate hypotheses
- **BU:** Measurement studies can update outdated emission factors (EFs).

POTENTIAL IMPROVEMENTS

Improve capability of TD measurements to verify inventory, for example:

- Improve source attribution to better align TD and BU study system boundaries
- Improve understanding of non-O&G methane sources, especially ones that confound current attribution methods
- Improve ability to align measurements across scales (e.g., from regional to facility).

Inventory Improvement Through BU Measurement Studies

2

Challenges with currently used EFs:

- Not representative
  - Outdated
  - Sampling bias
  - Sample size
  - Mean emission factors (EFs) capture "fat tail"?
  - All salient dimensions of emission variability captured?

POTENTIAL IMPROVEMENTS

- Update EFs for prioritized emission sources categories
- Focus effort of new studies on ensuring robust sample size, strong sampling design to capture source variability, and minimization of self-selection bias
- Leverage available evidence to explore how to characterize emission variability within the EF metric
- Explore regional variability and variability along other dimensions.

Inventory Improvement for Activity Factors

2

Most efforts to improve the inventory have focused on EFs—activity factors (counts) also need attention:

- Data sources
  - GHGRP or new ones
- Methods: transparency, simplicity, and accuracy
- Balance the need for consistent time series with the need to improve current accuracy.

POTENTIAL IMPROVEMENTS

- Develop new data sources to improve accuracy, completeness, and methodological simplicity
- Develop methods for quantification of activity factor uncertainty.

Inventory Improvement: Completeness and Structure

2

Prioritized gaps in current knowledge, for example:

- Abandoned wells
- Measurements on gathering pipelines
- "After the meter" leaks at site of end use
- Well work-overs that are not recompletions*

Inventory structure

- Currently organized sectorally, which creates challenges when comparing to a measurement representative of a certain spatial domain
  - Oil and gas wells in the same area
  - Associated gas
- Certain segments are grouped (e.g., gathering with production).

POTENTIAL IMPROVEMENTS

- Fill prioritized source gaps in GHGI
- Align future studies to the structure of the GHGI for easier incorporation OR
- Consider restructuring the inventory to better capture robust results of recent studies
- Gridded inventory to enhance measurement-based validation.

*Work-overs are included in the GHGI, but are defined as recompletions. Other work-over activities can also be performed in the industry.

Uncertainty Quantification

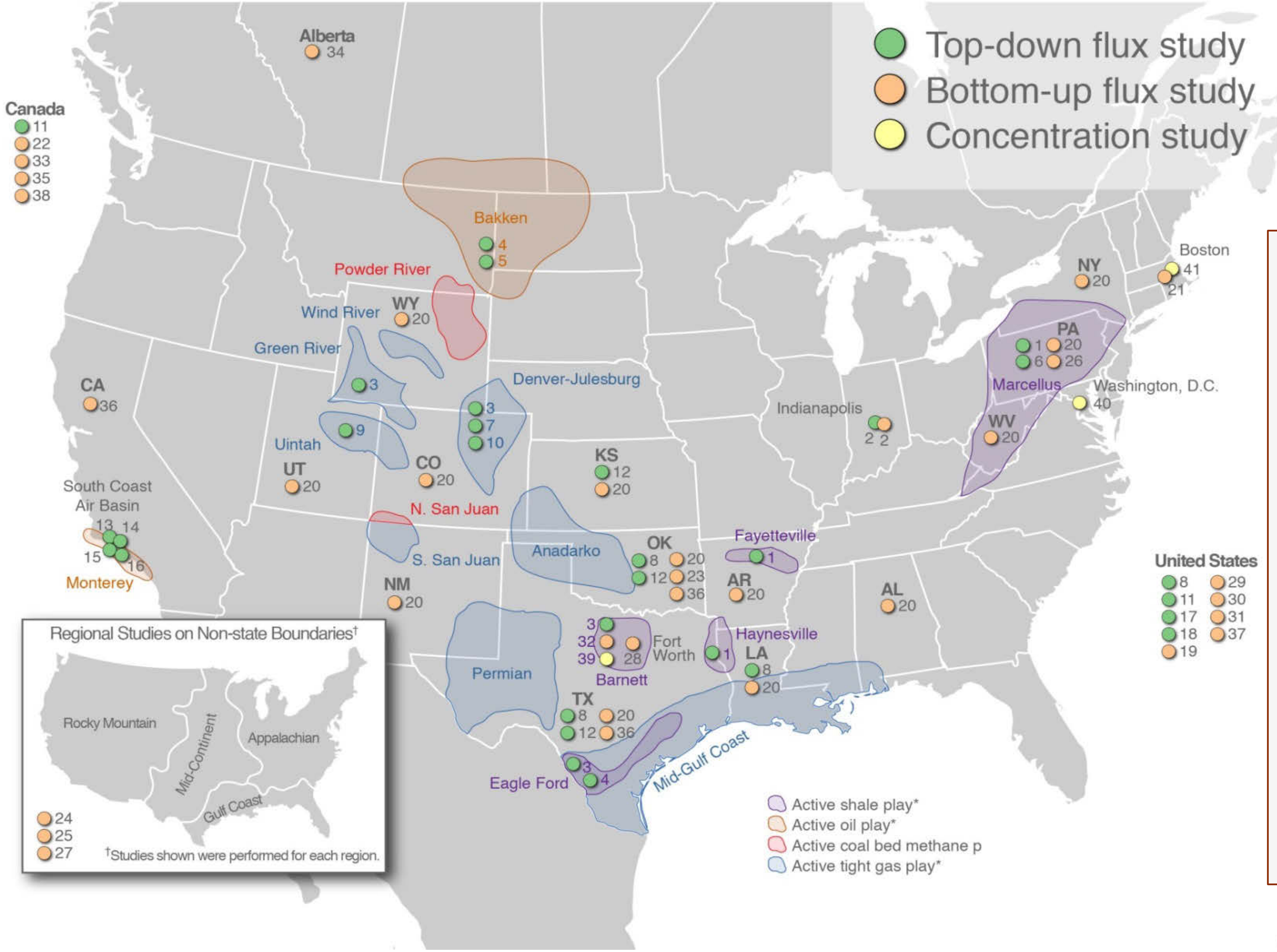
Quantification of uncertainty is critical for informed decision making, communication, and verification with measurements. Currently, the GHGI:

- Uses Monte Carlo parametric uncertainty quantification, with lognormal distributions assumed in almost all cases
- Reports an uncertainty range that has not changed since 2010
- Uses expert judgment to assign uncertainty for activity factors.

POTENTIAL IMPROVEMENTS

- Ensure sponsored studies robustly quantify uncertainty
- Strengthen uncertainty quantification methods and efforts

New Research Efforts in the Context of a Large Number of Studies (as of 2015)



POTENTIAL IMPROVEMENTS

- Enhance coordination among studies
- Increase confidence in inventory accuracy by pairing measurements with inventory contemporaneously and systematically.

Source: Heath et al. 2015

Evidence for Methane Emission Fat Tails and Implications for Science, Policy and Mitigation

Adam Brandt,[1] Garvin Heath,[2] and Dan Cooley[3]

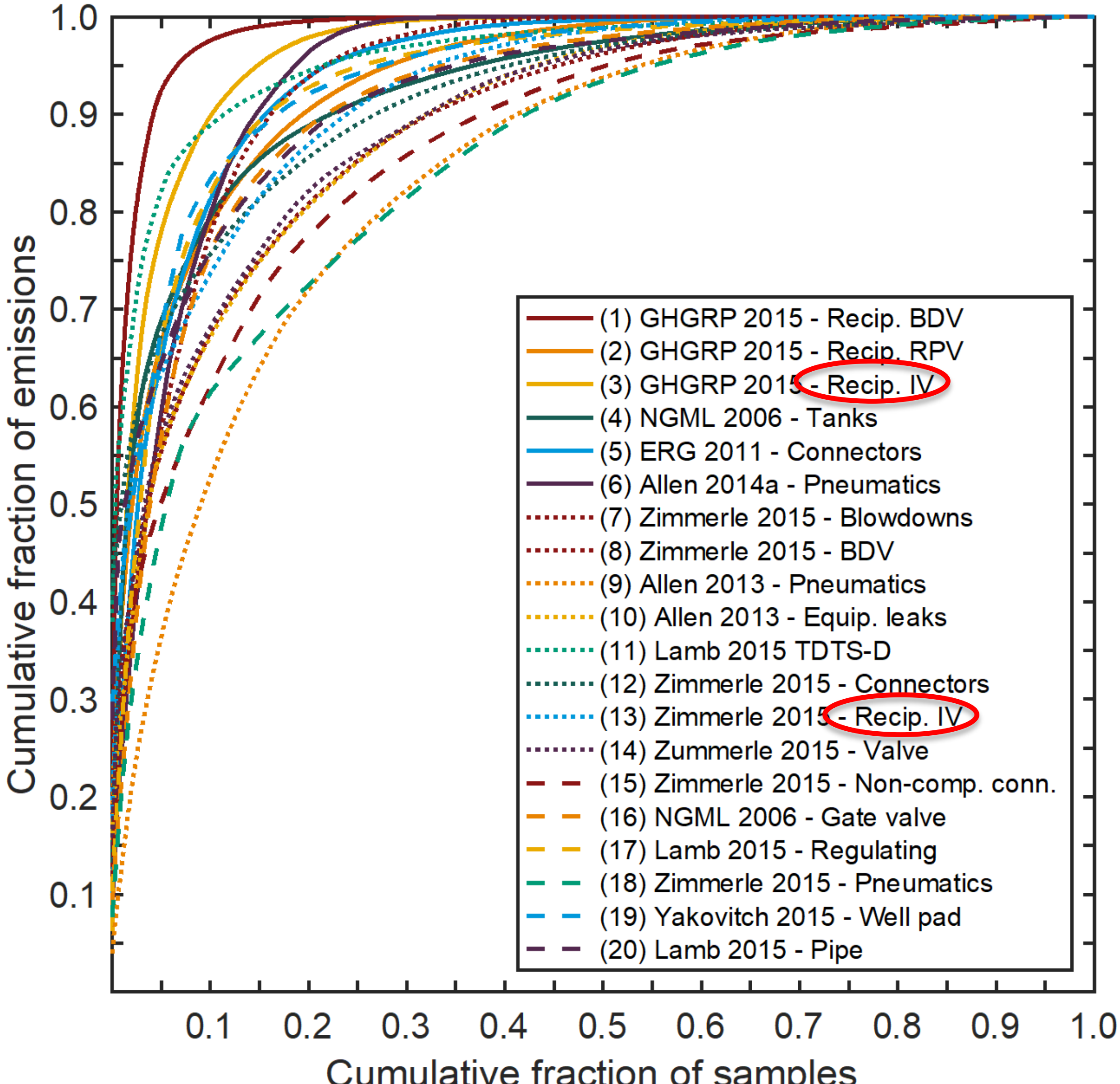
[1] Department of Energy Resources Engineering, Stanford University

[2] National Renewable Energy Laboratory

[3] Department of Statistics, Colorado State University

Brandt, Adam R., Garvin A. Heath, and Daniel Cooley. 2016. **“Methane Leaks from Natural Gas Systems Follow Extreme Distributions.”** *Environmental Science & Technology.* 50 (22), 12512–12520. http://pubs.acs.org/doi/abs/10.1021/acs.est.6b04303.

Several Studies Measured Emissions from Components Named the Same



We (Cooley) tested whether the samples from two different studies that were named the same come from the same underlying population

- Kolmogorov-Smirnov (K-S) test

Charges 4, 6, 7: How to Ensure Comparability and Appropriate Use for Inventories, and Recommended Research

Meta-analysis

- Separate studies of a given device type fail K-S tests, suggesting their samples are not drawn from the same population.
  → **Meta-analysis is not advised.**
  - However, future studies could be designed to match prior ones and take advantage of the increased power of meta-analysis (though practical challenges are acknowledged)
- **Future studies, and especially meta-analyses, would be greatly enhanced with a common taxonomy of equipment, components, and activities**

Other implications of the results of this study

- **Available data could be leveraged to develop empirically-based confidence intervals for source categories to improve accuracy** of inventory uncertainty quantification.
- Researchers and R&D funding organizations can **use these results to improve sampling design of new studies** to enhance the robustness of results, minimize sample sizes, and address critical gaps in knowledge
- **Much remains unknown about distributions of emissions from O&G sources**:
  - Temporal persistence
  - Root causes of super-emitter behavior
  - Source-specific super-emitter properties.

Discussion — Further Information

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