JISEA Joint Institute for Strategic Energy Analysis

Environmental, Economic, and Technological Effects of Methane Emissions and Abatement

Garvin Heath, Ethan Warner, and David Keyser

April 20, 2016

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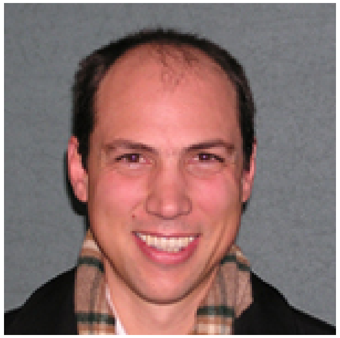
Presenters



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Natural Gas Methane Emissions in the United States Greenhouse Gas Inventory: Sources, Uncertainties, and Opportunities for Improvement

April 20, 2016

Garvin Heath, Ph.D.

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

JISEA Report

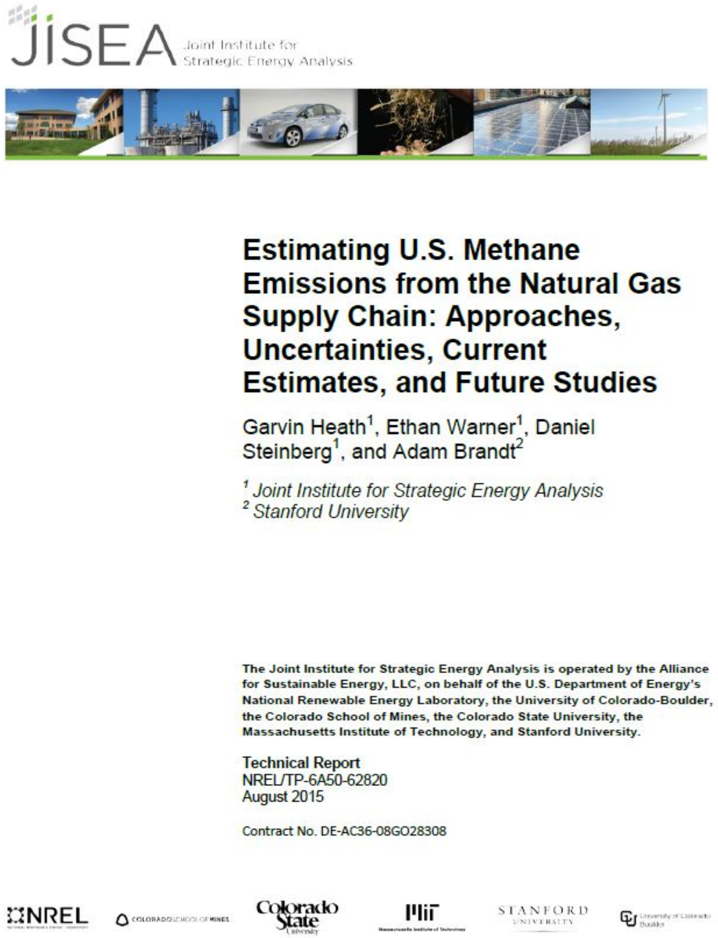
With a focus on methane emissions from the natural gas (NG) sector, the purpose of this report is to:

1. Summarize methods and results of the U.S. Greenhouse Gas Inventory (GHGI)
2. Identify potential gaps and barriers to improvement
3. Identify opportunities to improve accuracy.

Observations and suggestions in this presentation focus on providing an overview of recommendations.

- Additional detail on these recommendations can be found in the report.

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



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

Garvin Heath[1], Ethan Warner[1], Daniel Steinberg[1], and Adam Brandt[2]

[1] Joint Institute for Strategic Energy Analysis
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Technical Report
NREL/TP-6A50-62820
August 2015

Contract No. DE-AC36-08GO28308

Report focuses on 2014 U.S . EPA GHG Inventory, the latest available during the project.

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.

U.S. Environmental Protection Agency publishes the U.S. GHGI; many agencies, organizations, and researchers rely on its results for analyses and decision making.

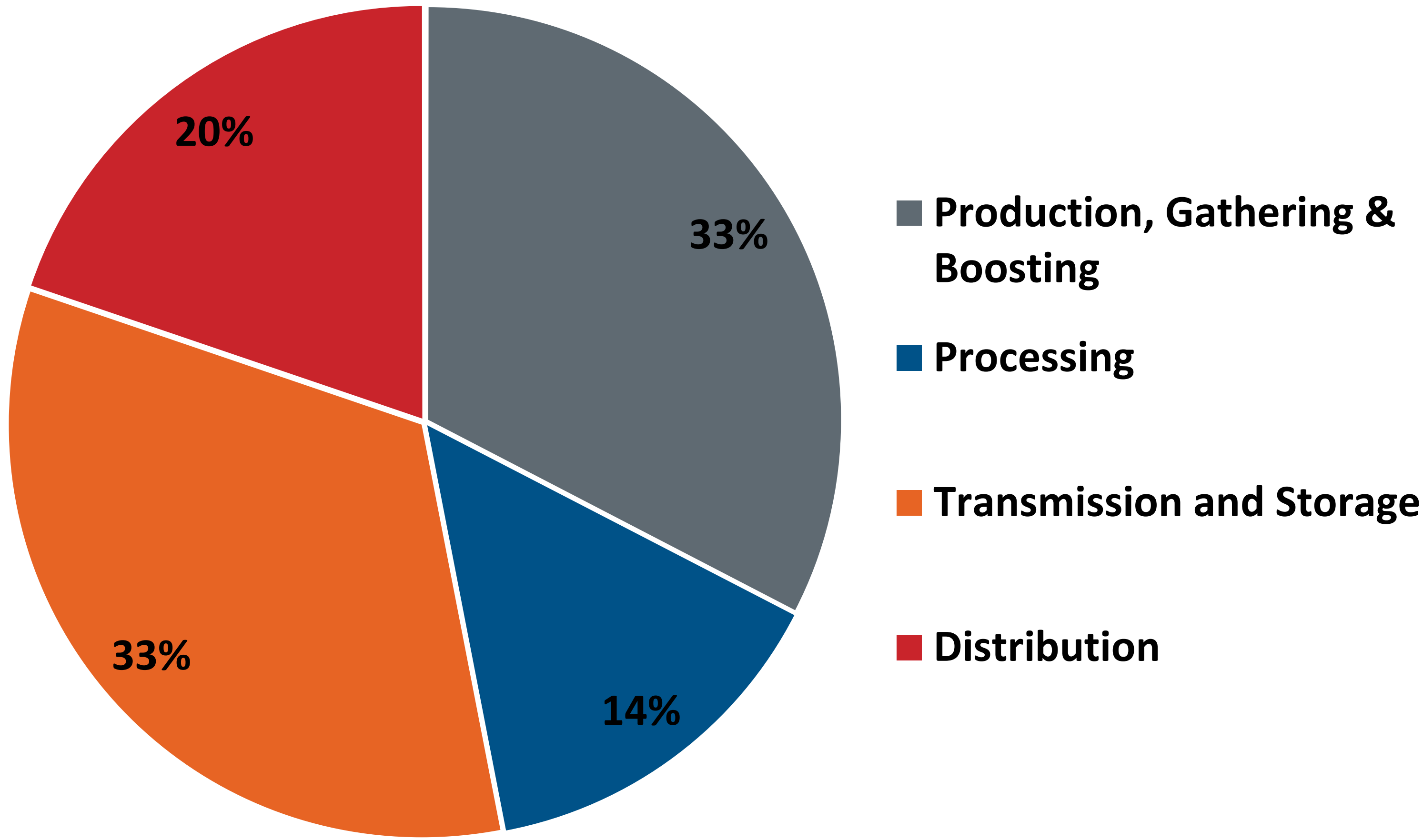
The U.S. GHGI is a critical resource for:

- 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.

NG Produces ~23% of U.S. Anthropogenic Methane Emissions from Several Segments

2012 NG emissions = 156 MMt CO_2e/yr

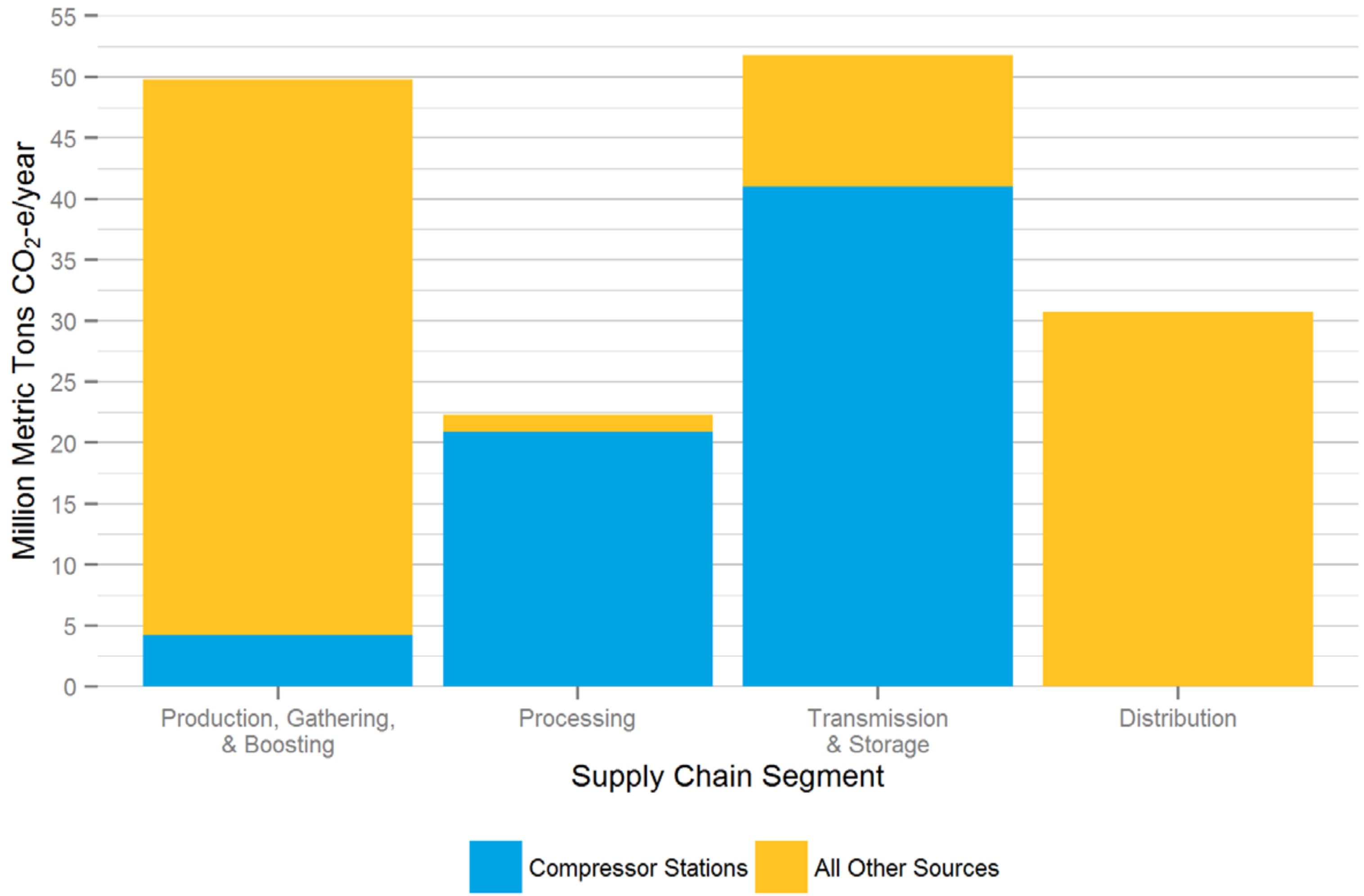
Emissions are distributed among segments



Note: *All GHG emissions in this presentation assumes 100-yr GWP of CH4 = 25. GWP reflects IPCC 2007 (not IPCC 2013) to align with the most recent United Nations Framework Convention on Climate Change (UNFCCC) for national inventories.*

Source*: 2014 U.S. EPA GHG Inventory*

About 43% of NG Methane Emissions are from Compressors



Note: *GHGIs miscellaneous "compressor station" category for emissions is applied proportionally to all components of the compressor station.*

Source*: 2014 U.S. EPA GHG Inventory*

Cast Iron and Unprotected Steel Pipe is ~33% of Distribution Segment Emissions

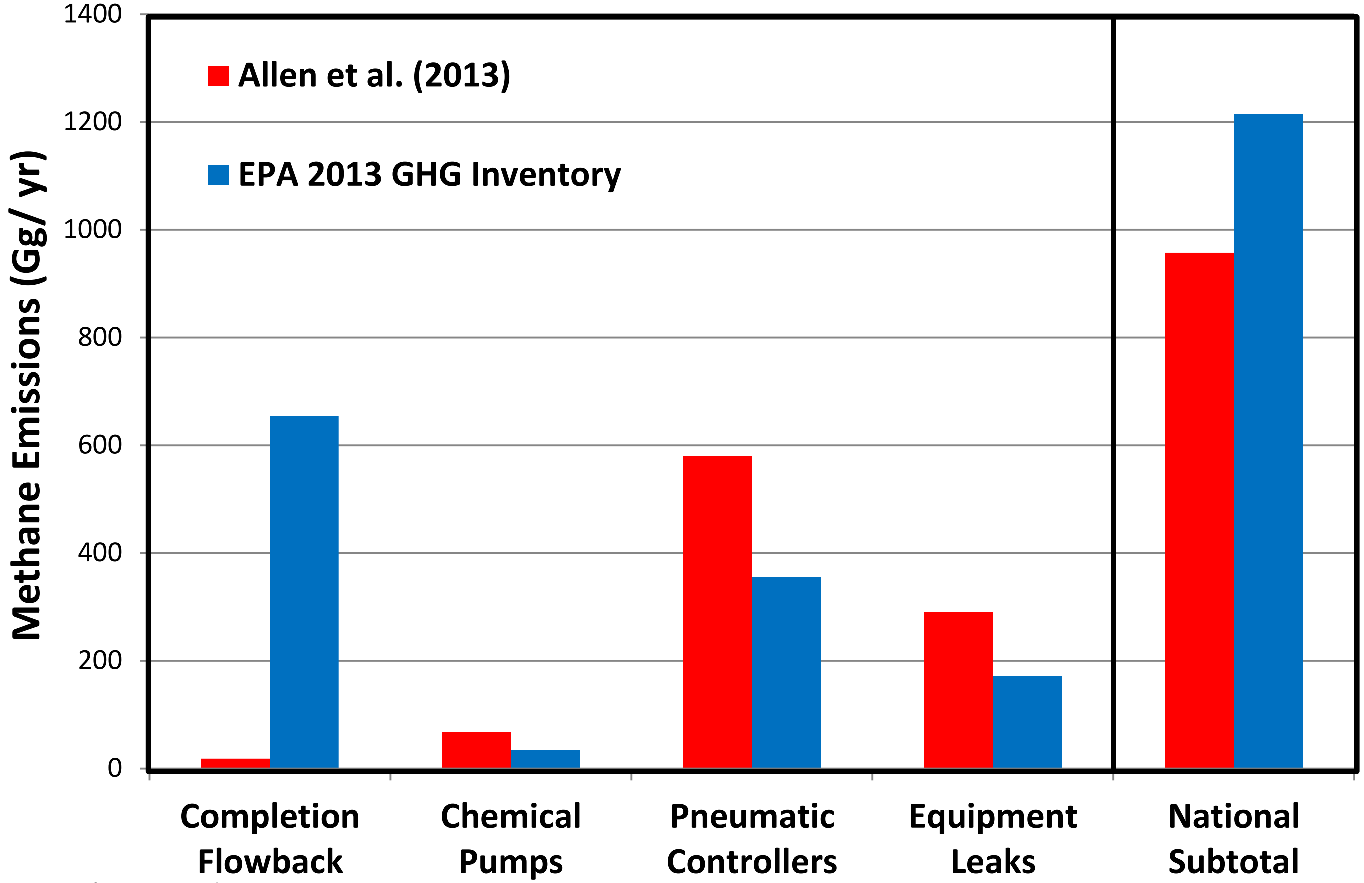
Category	Emission Activity	Emission Factor
Cast Iron Mains	~ 32k miles	240 Mcf/mile-yr
Unprotected Steel Mains	~ 64k miles	110 Mcf/mile-yr
Plastic Mains	~ 660k miles	9.9 Mcf/mil-yr
Protected Steel Mains	~ 490k miles	3.1 Mcf/mil-yr
Unprotected Steel Services	~ 3.9 million services	1.7 Mcf/service
Protected Steel Services	~ 15 million services	0.18 Mcf/service
Copper Services	~ 1 million services	0.25 Mcf/service
Plastic Services	~ 45 million services	0.01 Mcf/service

Cast iron and unprotected steel have highest total emissions despite lowest miles of piping

Source: *U.S. EPA 2014 GHG Inventory*

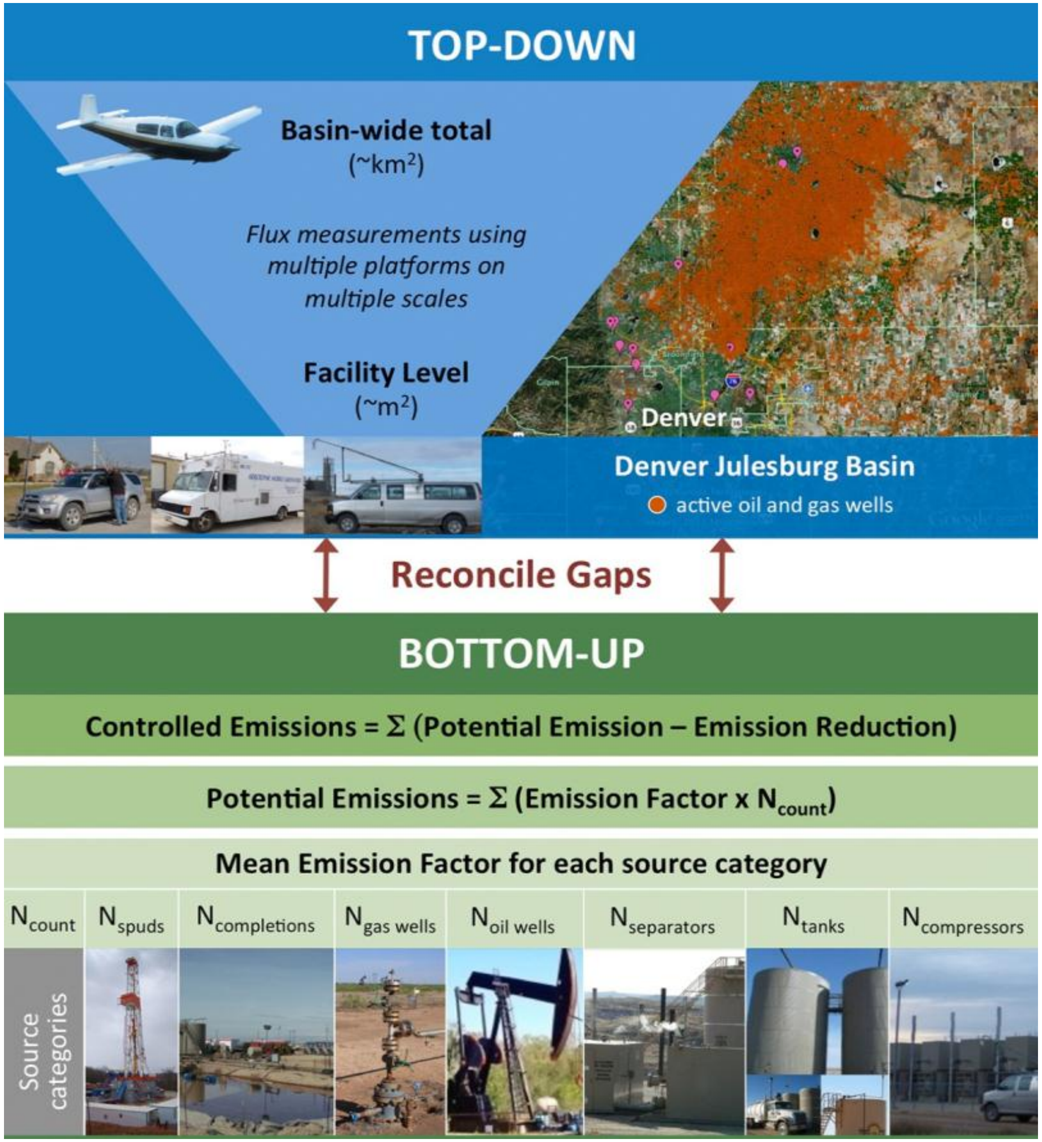
Source Prioritization is Affected by Accuracy of Source-Level Emission Estimates

Even when the sum of measured emissions from different sources is equivalent to the inventory, is it due to compensating errors?
(Allen et al. 2013)



***Gg** = gigagrams or thousand metric tonnes*

Top-Down (TD) and Bottom-Up (BU) Studies



Nomenclature not consolidated on definition of top-down and 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 left 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, e.g.:

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

Inventory Improvement Through BU Measurement Studies

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

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

Prioritized gaps in current knowledge, e.g.:

- 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

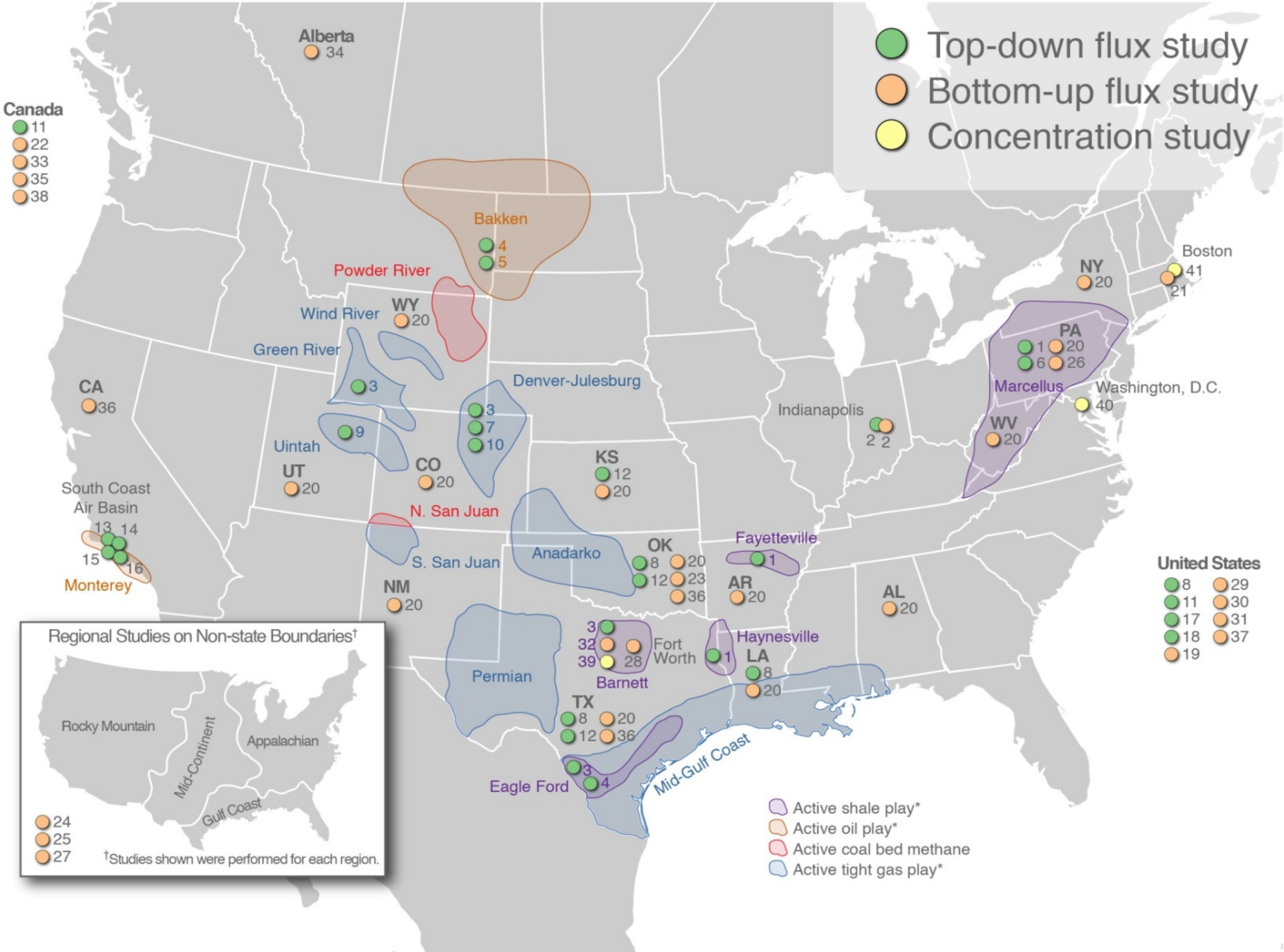
Uncertainty quantification is critical for informed decision making, communication, and verification with measurements. Currently, the GHGI:

- Uses Monte Carlo parametric uncertainty quantification, with lognormal distributions assumed in almost all cases
- Reports an uncertainty range that hasn't 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 Many Other Studies



POTENTIAL IMPROVEMENTS:

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

Source: Heath et al. 2015

For Further Information

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JISEA Joint Institute for Strategic Energy Analysis

Potential Cost-Effective Opportunities for Methane Emission Abatement

April 20, 2016

Ethan Warner

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

JISEA Technical Report

Potential Cost-Effective Opportunities for Methane Emission Abatement

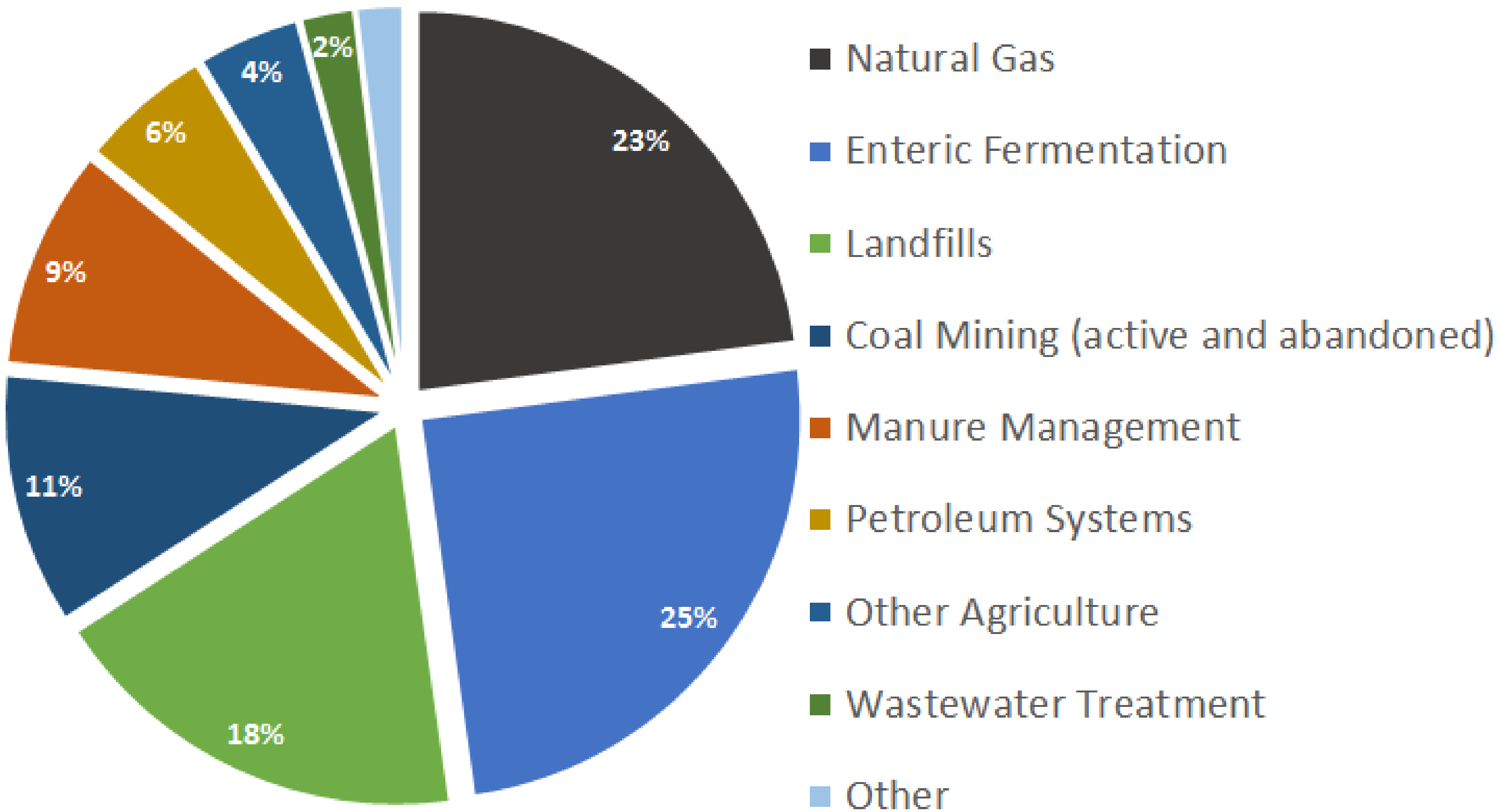
Ethan Warner,[1] Daniel Steinberg,[1]
Elke Hodson,[2] Garvin Heath[1]
[1] *Joint Institute for Strategic Energy Analysis*
[2] *U.S. Department of Energy, Office of Energy Policy and Systems Analysis*

- Technical Report: 6A50-62818
- *One of several JISEA reports used as supporting information for the Quadrennial Energy Review*

Link: http://www.nrel.gov/docs/fy16osti/62818.pdf.

U.S. Anthropogenic Methane Emissions are about 9% of Total Greenhouse Gases (GHGs)

Total emissions: 675 million metric tonnes (MMt) carbon dioxide equivalent (CO_2e)/yr.



Source: *US GHG Inventory 2014*

Goals of the JISEA Report and this Presentation

- Identify potential targets for reducing methane emissions
- Identify strategies for reducing methane emissions.
  - Many possible, but highly variable opportunities are available
- Synthesize published estimates of emissions reduction potential and costs (ICF [2014] and EPA [2013]) to:
  - Provide a comprehensive national analysis of opportunities .
  - Identify the largest opportunities for "low cost"* abatement.
  - Report under what conditions these opportunities are low cost.

*Defined as <$0/Mt CO_2e

Source: *US GHG Inventory 2014, Whitehouse "Fact Sheet" 2015*

Breakdown of Low Cost Emission Reduction Opportunities

Sector	Supply Chain Segment	Total Potential Reduction	Low Cost Reduction	
		MMt CO_2e/yr	No revenue from capturing gas in transmission	Revenue from capturing gas in transmission
Natural Gas (NG)	Production	20	32%	
	Gathering and Boosting	7.2	69%	
	Processing	12	81%	
	Transmission	21	0%	81%
	Storage	3.1	94%	
	LNG Import/ Export	0.8	88%	
	Distribution	3.4	0%	
	Total	67	37%	63%
Oil	Production	19	31%	
Coal	Production	37	6.2%	
NG, Oil and Coal	Total	120	28%	

Overview of Findings

- Some opportunities are already low cost or can become low cost through revenue from capturing the natural gas.

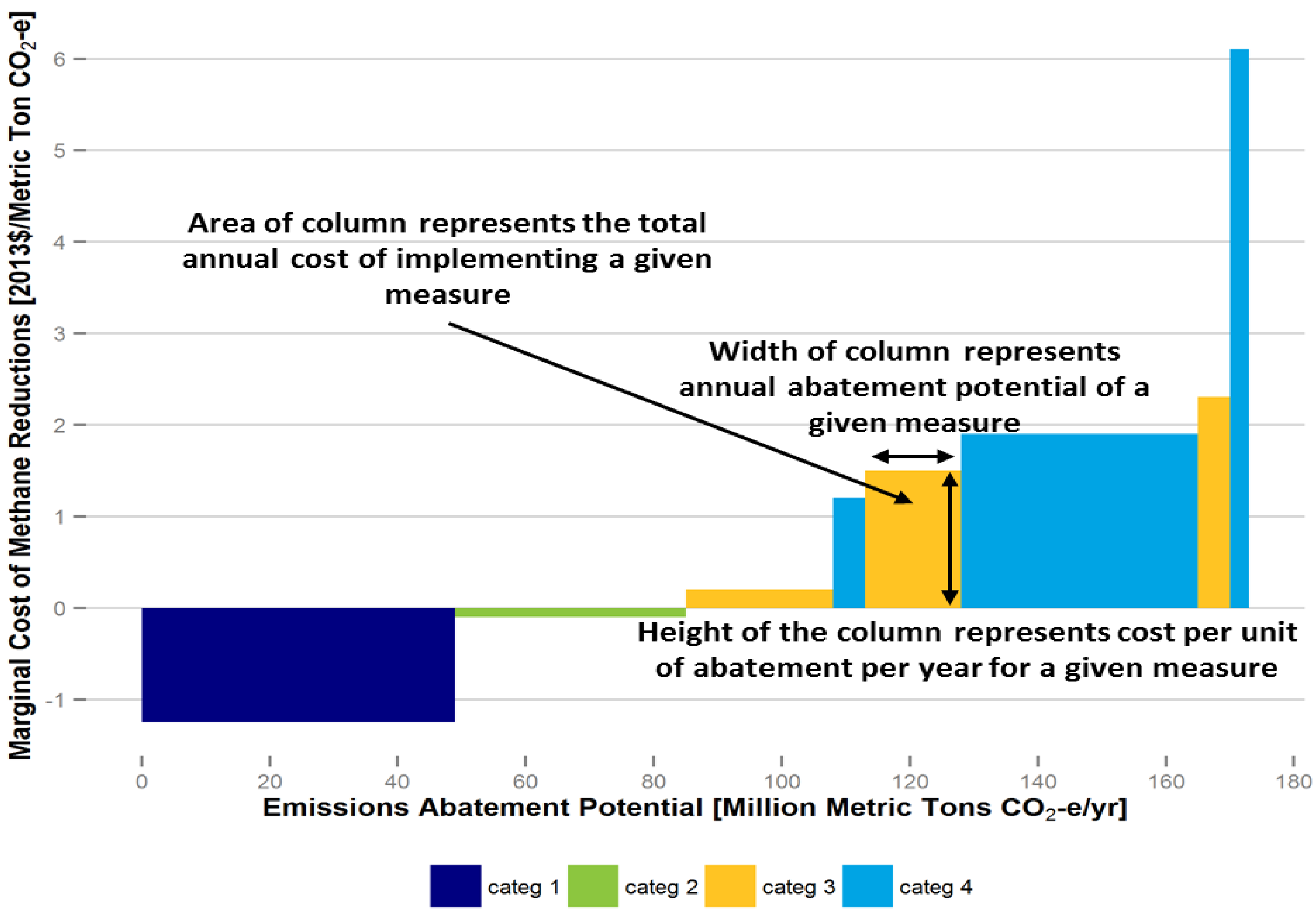
- Four largest low cost emission reduction approaches:
  - Leak detection and repair of sources of fugitive emissions
  - Capturing vented gas
  - Replacing high-bleed pneumatic devices with low- bleed pneumatics
  - Replacing gas-powered pumps with electric pumps.

- These low cost emission reduction options exist across most of the natural gas supply chain and oil production.
  - Abatement in the distribution sector should not be considered for cost reasons alone.

Methane Reduction and Cost Data in this Presentation…

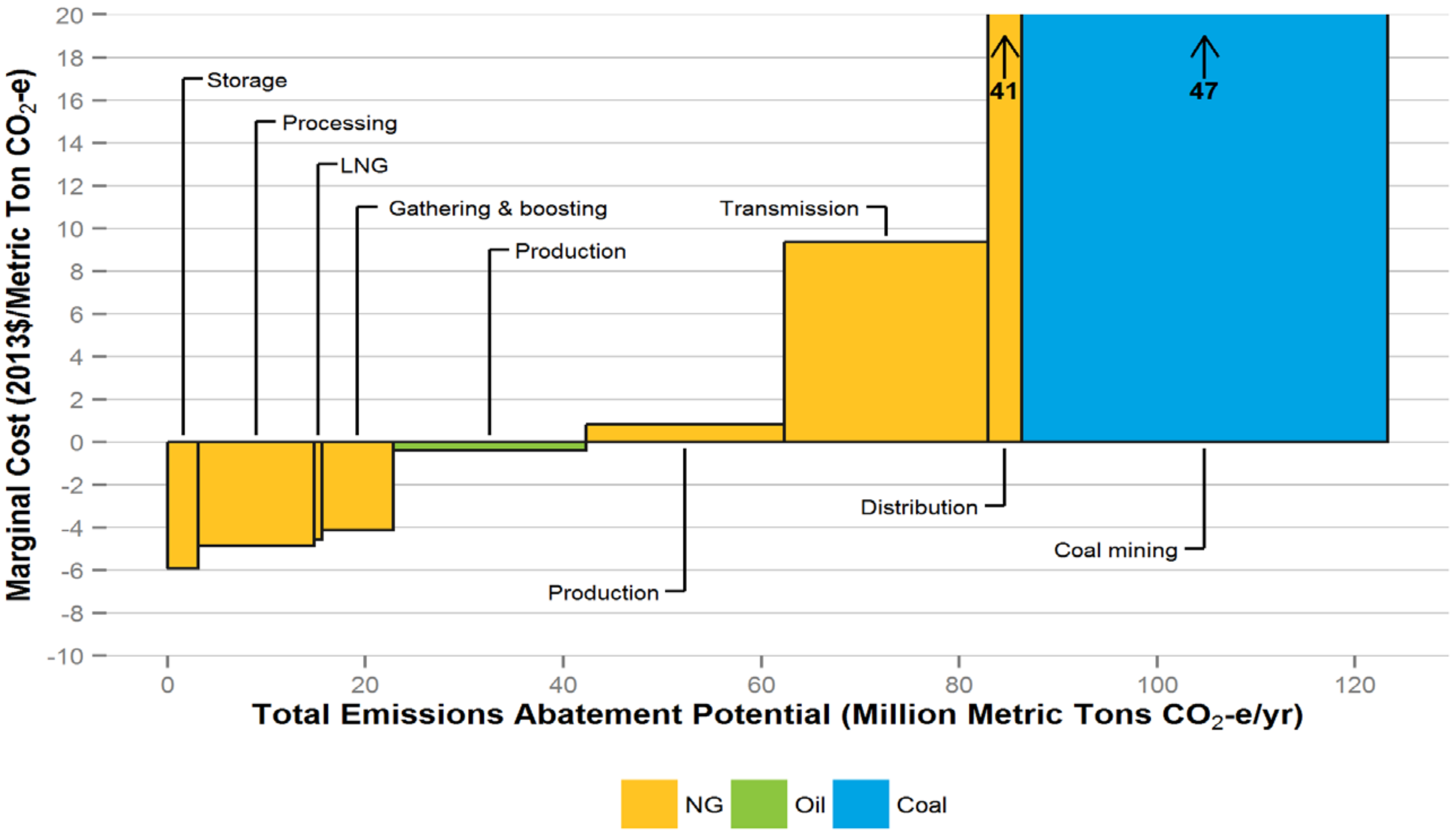
- Explain <u>average</u> cost estimates for potential opportunities to reduce methane missions.
  - Actual opportunities are highly variable and site specific
  - Estimates do not capture the large ranges in primary data sources
- Only represent a subset of potential costs and benefits.
  - E.g., Externalities excluded; social cost of carbon included
- Have potential co-benefits such as:
  - VOC/HAP co-reductions
  - Improved safety by replacing leaking pipelines

Reading Marginal Abatement Cost Curves



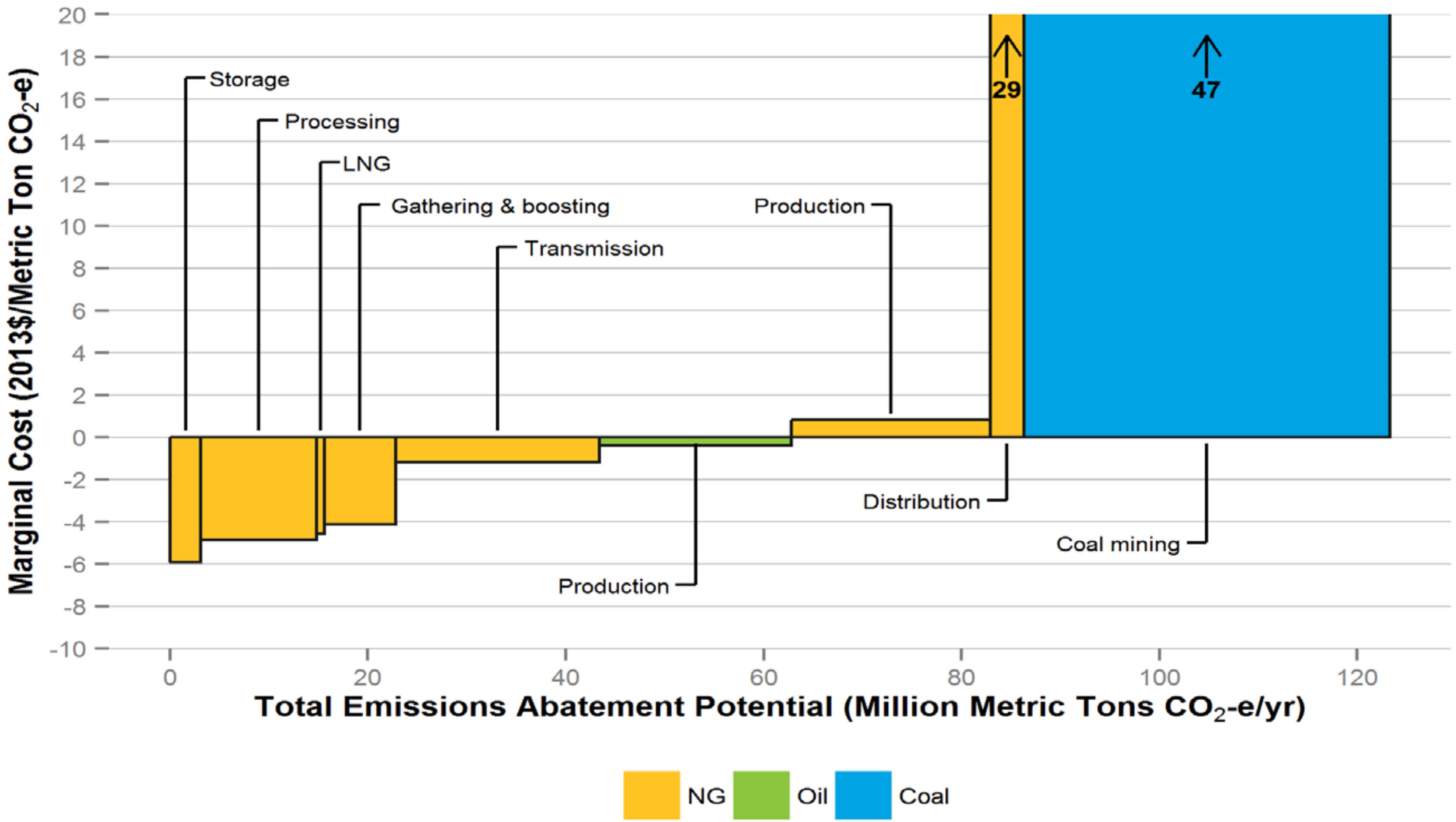
Source: Modified illustration from ICF (2014).

~40 MMt CO_2e/yr Could be Reduced at a Low Cost



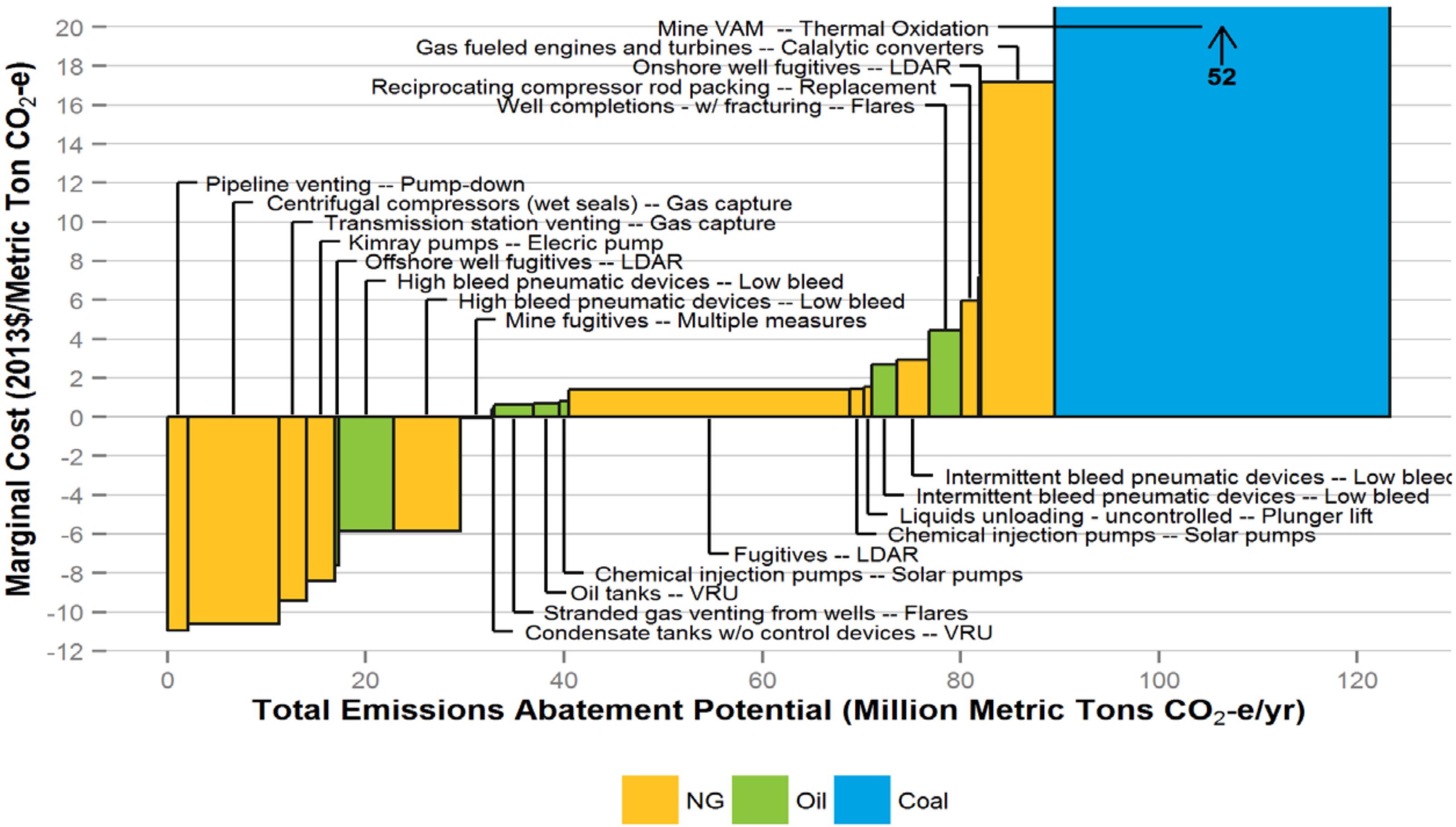
CAUTION: This figure shows national average costs of all analyzed opportunities in a single segment of the supply chain.

Low Cost Opportunities Become Available in Transmission when Revenue Can be Captured



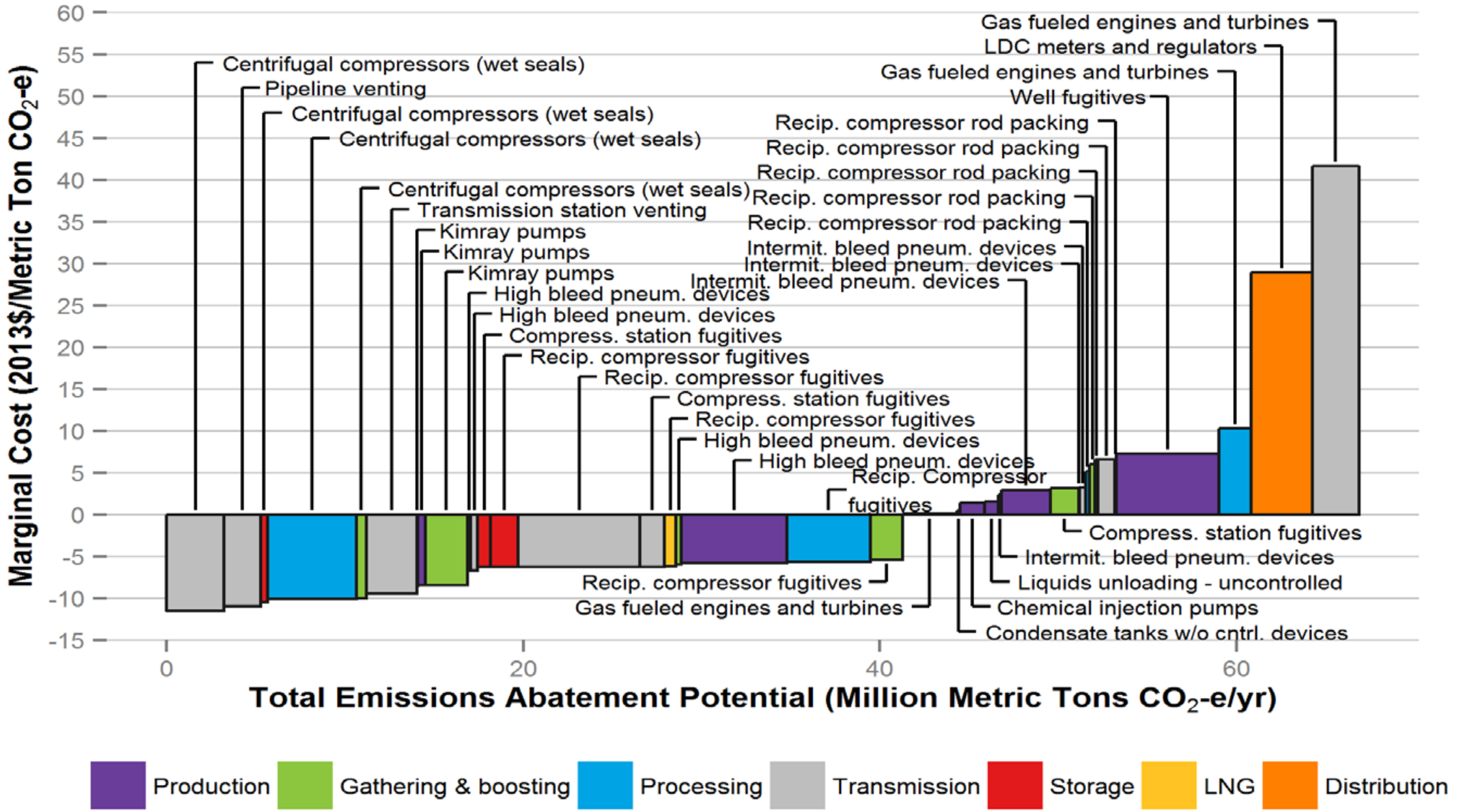
CAUTION: This figure shows national average costs of all analyzed opportunities in a single segment of the supply chain.

Low Cost Opportunities by the Opportunity



CAUTION: This figure shows national average costs of all analyzed opportunities across all segment of the supply chain.

Low Cost Opportunities by Opportunity and Segment



CAUTION: This figure shows national <u>average</u> costs.

Thanks to

- This work was funded by the U.S. Department of Energy's (DOE's) Office of Energy Policy and Systems Analysis (EPSA).
- The authors acknowledge the support of the Joint Institute for Strategic Energy Analysis.
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JISEA Joint Institute for Strategic Energy Analysis

Quantification of the Potential Gross Economic Impacts of Five Methane Reduction Scenarios

April 20, 2016

David Keyser

Overview

- This analysis estimates gross employment impacts and other economic activity that could be supported by enacting different methane reduction measures
- Summary of Keyser, Warner, Curley analysis in 2015*
- It independently assesses these impacts from five options for reducing methane emission during natural gas storage, transmission, and distribution (T/S/D) segments of the supply chain
    1. Leak detection and repair (LDAR)
    2. Gas capture
    3. Low bleed pneumatic devices (LBPD)
    4. Pump down
    5. Pipeline replacement
- These measures represent a subset of available opportunities for reducing methane emissions within the TS&D segments and do not include consideration of reduction opportunities within other segments of the supply chain, including processing, gathering and boosting and production
- Estimates are of the number of gross jobs and other economic activity that could be supported by each of these methane reduction measures independently – no consideration is made for potential interactions between measures

*Keyser, D.; Warner, E.; Curley, C. (2015). Quantification of Potential Gross Economic Impacts of Five Methane Reduction Scenarios. Joint Institute for Strategic Energy Analysis. NREL/TP-6A50-63801. Golden, CO.

Methodology

- All estimates were made using the IMPLAN input-output (I-O) model at the national level
- I-O models represent the way that sectors in an economy interact with each other at a point in time via purchased inputs and sold outputs:
  - Inputs are purchases made from other businesses or industries that are necessary for production
  - Outputs are the sales that businesses or industries make to one another
- An advantage of these models is that they allow analysts to capture a wide range of activity that arises as a result of these linkages
- Methane reduction expenditures are modeled as demand for output from the industries that provide the respective good or service
  - Increased pipeline maintenance, for example, is demand from the natural gas distribution sector
- I-O models do have certain limitations such as the assumption that prices remain fixed and that all inputs necessary for production will be available

Results Taxonomy

- **Direct** effects are first order impacts that are solely associated with an expenditure. The direct effect of a generator purchase, for example, would be jobs at the generator manufacturer.
- **Indirect** effects are second order impacts that arise as industries purchase goods and services in an economy. The generator manufacturer may need to purchase copper wire, so employment at the copper wire manufacturer would be part of the indirect effect.

Interpreting Results and Limitations

- Estimates are gross, not net, and do not consider many other far-reaching effects that could also impact net jobs such as changes in wages, land use, migration, input substitution, changes in consumer behavior, productivity, or changes in technology
- Opportunity costs are not considered – this analysis does not consider alternative uses of investment funds
- Estimates assume that prices remain constant and that inputs needed for production such as raw materials, workers, are available
- Social costs of carbon are not included in this analysis – value of captured gas is solely what could conceivably be sold
- Each measure is considered independently. It is conceivable that there could be economies of scale associated with implementation of multiple scenarios simultaneously – these are not estimated

Summary of Cost and Abatement Data

	Pipeline Replacement[1]	LDAR[2]	Gas Capture[2]	LBPD[2]	Pump Down[2]
Cost ($ Million, 2013)	$45,833	$1,561	$368	$81	$118
Emission Abatement (Tg CO2e/yr)	0.94	14	6.5	0.97	2.0
Total Abatement (Tg CO2e, 2015 - 2019)	4.7	69	32	4.8	10.0

[1] Blue Green Alliance (Barrett and McCulloch 2014) and the US Environmental Protection Agency (2013)

[2] ICF International (2014)

Employment, Earnings, and GDP – Pipeline Replacement

- Over 83,000 direct and indirect jobs could be supported annually from 2015 through 2019 with earnings per worker ranging from $60,000 to $75,000
- Estimated $7.8 billion in GDP could be supported annually

	Employment	Earnings ($ Million, 2013)	GDP ($ Million, 2013)	Average Annual Earnings per Job
Direct	46,000	$3,400	$4,100	$75,000
Indirect	37,000	$2,200	$3,700	$60,000
Total	83,000	$5,700	$7,800	$68,000

Totals may not sum due to rounding

Employment, Earnings, and GDP - LDAR

- Over 1,600 annual direct and indirect jobs could be supported from 2015 through 2019 with average salaries ranging from $79,000 to $100,000
- Nearly $240 million in GDP could be supported annually

	Employment	Earnings ($ Million, 2013)	GDP ($ Million, 2013)	Average Annual Earnings per Job
Direct	570	$60	$100	$100,000
Indirect	1,000	$80	$140	$79,000
Total	1,600	$140	$240	$87,000

Totals may not sum due to rounding

Employment, Earnings, and GDP – Gas Capture

- Nearly 500 direct and indirect jobs could be supported annually from 2015 through 2019 with average earnings between $72,000 and $95,000 per worker
- Over $60 million in GDP could be supported annually

	Employment	Earnings ($ Million, 2013)	GDP ($ Million, 2013)	Average Annual Earnings per Job
Direct	150	$10	$20	$95,000
Indirect	340	$20	$40	$72,000
Total	490	$40	$60	$79,000

Totals may not sum due to rounding

Employment, Earnings, and GDP - LBPD

- Over 100 direct and indirect jobs could be supported annually from 2015 through 2019 with average earnings from $72,000 to $95,000 per worker
- Estimated $13 million contribution to GDP annually

	Employment	Earnings ($ Millions, 2013)	GDP ($ Million, 2013)	Average Annual Earnings per Job
Direct	30	$3	$5	$95,000
Indirect	80	$5	$9	$72,000
Total	110	$8	$13	$79,000

Totals may not sum due to rounding

Employment, Earnings, and GDP – Pump Down

- Over 60 direct and indirect jobs could be supported annually from 2015 through 2019, with average earnings per worker ranging from $97,000 to $160,000 each year
- Estimated $16 million in GDP could be supported annually

	Employment	Earnings ($ Million, 2013)	GDP ($ Million, 2013)	Average Annual Earnings per Job
Direct	20	$3	$8	$160,000
Indirect	40	$4	$7	$97,000
Total	60	$7	$16	$118,000

Totals may not sum due to rounding

Summary – Employment (2015 – 2019)

- Over 85,000 jobs, on average, could be supported annually by undertaking all five of the methane reduction measures under the scenarios studied
- Employment impacts vary considerably across the scenarios addressed, with pipeline replacement accounting for the majority

Annual Average Employment, 2015 - 2019

	LDAR	Gas Capture	LBPD	Pump Down	Pipeline Replacement	Total
Direct Jobs	570	150	30	20	46,000	47,000
Indirect Jobs	1,000	340	80	40	37,000	39,000
Total Jobs	1,600	490	110	60	83,000	85,000

Totals may not sum due to rounding

Emissions Reduction Summary: Implementing All Measures

- Potential decrease of up to 24 Tg of CO_2 annually - this represents approximately 28% of current (2011) annual methane emissions from natural gas transportation, storage, and distribution
- Total market value of gas captured from 2015 to 2019 of $912 million at a 10% discount rate

	LDAR	Gas Capture	LBPD	Pump Down	Pipeline Replacement
Emission Abatement (Tg CO_2e/yr)	13.5	6.3	0.9	2.0	0.9
Total Abatement (Tg CO_2e, 2015 - 2019)	67.3	31.5	4.6	9.8	4.7
Value of Captured Gas (10% Discount Rate)	$520	$244	$36	$76	$37

All dollar figures are millions of 2013 dollars; totals may not sum due to rounding
Source: ICF 2014, EIA AEO 2014

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- Christina Curley: christina.curley@colostate.edu

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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

Potential Cost-Effective Opportunities for Methane Emission Abatement
http://www.nrel.gov/docs/fy16osti/62818.pdf

Quantification of the Potential Gross Economic Impacts of Five Methane Reduction Scenarios
http://www.nrel.gov/docs/fy15osti/63801.pdf

Next Webinar

Wednesday, May 4 at 10 a.m. MDT

Spatiotemporal Considerations in Energy Decisions

Dr. Sarah Marie Jordaan, University of Calgary

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