Onshore Petroleum and Natural Gas Operations on Federal and Tribal Lands in the United States

Analysis of Emissions and Abatement Opportunities

June 22, 2015

Project Outline

- Project Scope and Objective
- Results and Findings
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  - BLM Royalty Revenue Loss
  - Reduction Opportunities Costs
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  - Detailed Results

Project Scope and Objective

1. Characterize natural gas and methane emissions from federal and tribal lands
   - By state
   - By segment (Production, Gathering, Processing, Transmission, and Storage)
   - By emission source (e.g., pneumatics, compressors, flaring)
2. Determine the value of gas lost due to venting, flaring, and fugitives from federal and tribal lands
3. Determine the potential for mitigation on federal and tribal lands
   - Estimate any differences in cost efficiency of reduction options between National and federal/ tribal lands

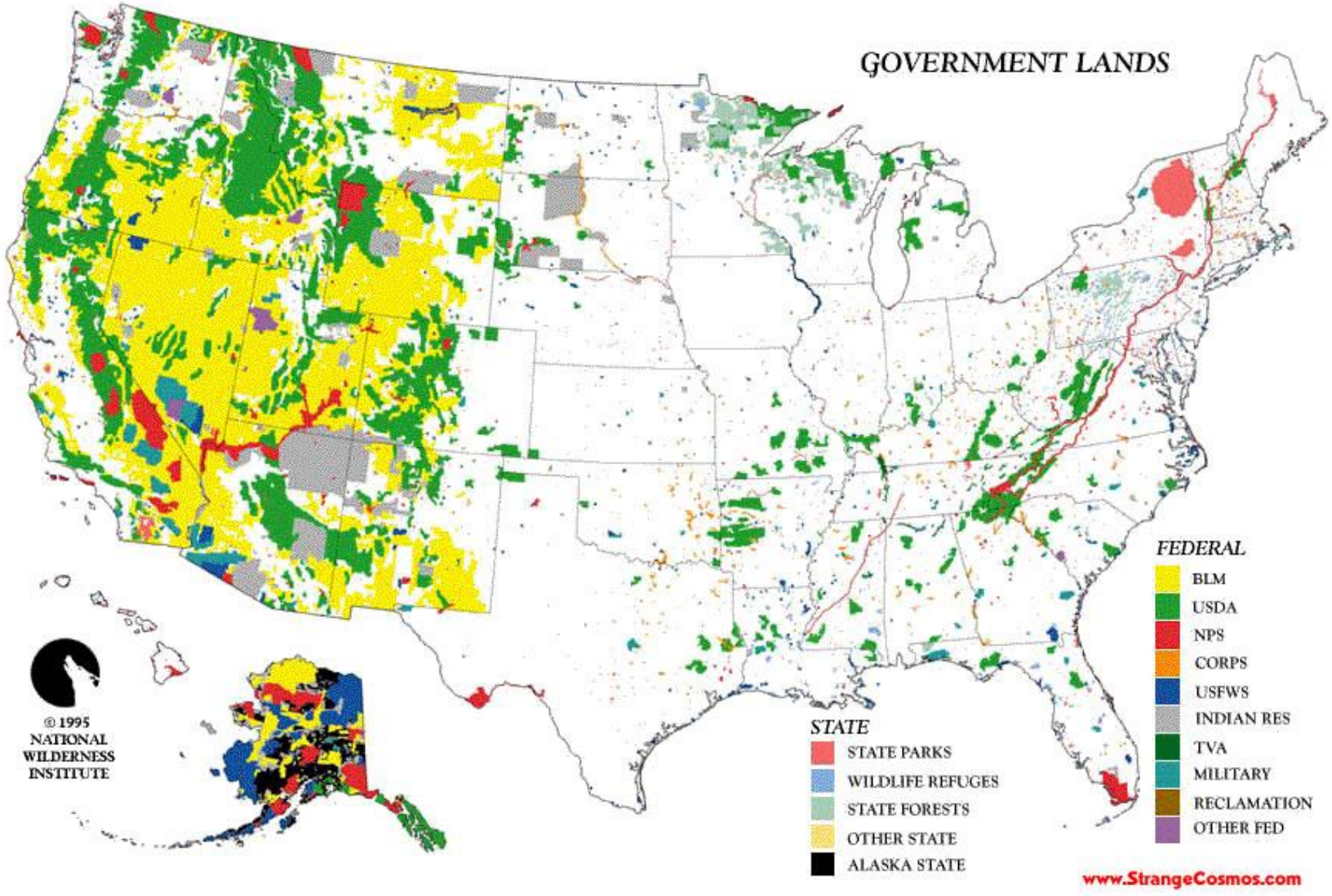
Federal/ Tribal Baseline Inventory Development Methodology

- Step 1 – Revise ICF/EDF MAC Curve[1] baseline inventory with new data
  - Subpart W used to develop emission factors (EF's) and activity factors (AF's)
  - Other ICF studies for EDF
- Step 2 - Use revised methodologies where applicable
- Step 3 – Establish activity drivers to allocate emissions from each source and segment to federal and tribal lands
- Step 4 – Develop baseline inventory for federal, and tribal lands
- Other general changes include;
  - The base year was changed from 2011 (ICF/EDF MAC) to 2013 (Fed-Tribal)[2]
  - The LNG, Oil Transportation, and Oil Refining segments are not included in this analysis
  - Use of Natural Gas STAR reductions reported in year 2012
    - *reductions in subsequent years have declined due to non-reporting rather than drop in reduction activities*

[1]EDF/ICF, Economic Analysis of Methane Emission Reduction Opportunities in the U.S. Onshore Oil and Natural Gas Industries, March 2014

[2] The base year for the EDF/ICF study was 2011 and the base year for the federal/ tribal study is 2013

Government Lands



Source: State University of New York, College of Environmental Science and Forestry (http://www.esf.edu/es/felleman/Gov%20Land%20Map.jpg.jpe)

Glossary of Terms

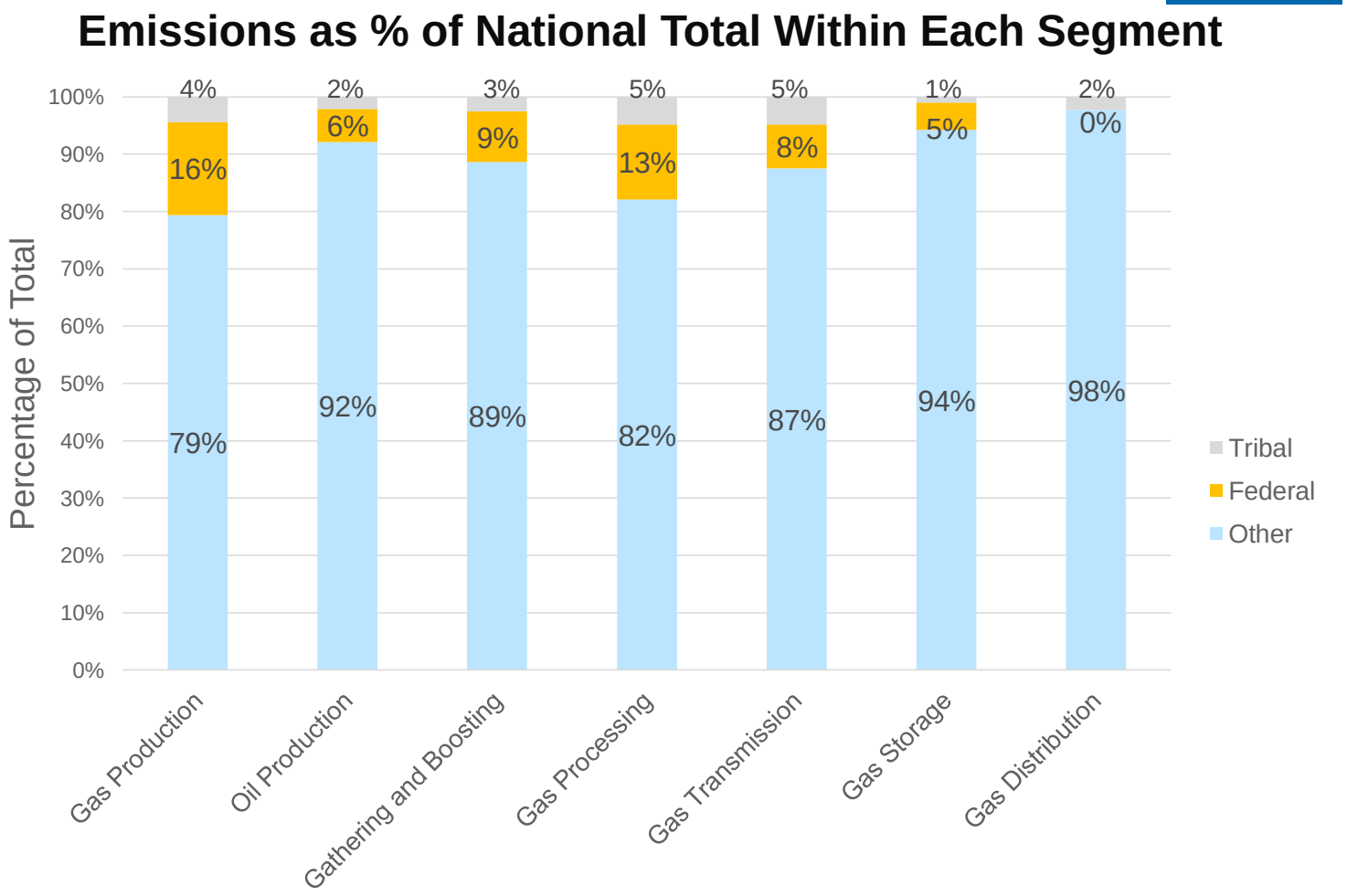
- Natural gas Emissions – natural gas released from oil and gas system as leaks, vents, uncombusted fuel gas, or uncombusted flare gas into the atmosphere
- Methane (CH_4) Emissions – natural gas emissions adjusted for amount of methane in natural gas (assumed to be 78.8% in production, 87.4% in processing, 94% in transmission and downstream segments)
- Gas sent to flare – natural gas sent to the flare for combustion
- Fuel gas use – natural gas sent to a combustion device, such as engine, for beneficial use
- Uncombusted gas from flaring (fuel use) – gas that passes through a flare (or combustion device in the case of fuel use) without combusting and is released to the atmosphere (includes methane as well as other natural gas constituents)
- Federal Lands – Includes all government lands, primarily including BLM and USFS lands
- National Lands – All lands in the country, including federal and tribal lands

Emissions by Land Type and Segment

- The largest contribution of emissions from federal and tribal lands is in the gas production segment

Segment	EDF 2013	
	Federal	Tribal
	Whole Bcf	Whole Bcf
Gas Production	21.4	5.9
Gathering and Boosting	5.6	1.6
Gas Processing	7.9	2.9
Gas Transmission	6.6	4.1
Gas Storage	0.9	0.2
Gas Distribution	0.0	1.7
Oil Production	5.4	2.0
Total	*47.7*	*18.4*

"Whole Bcf" refers to emissions of whole natural gas



Some percentages do not add to 100% due to decimal rounding
National emissions are a sum of federal, tribal, and other emissions. "Other" category to non-federal and non-tribal lands.

Distribution of Emissions by Land and Source Type

- Oil and Natural Gas Activity:
  - Federal lands account for 11% of gas production and 5.7% of oil production nationally
  - Tribal lands account for 3% of gas production and 3% of oil production nationally

- Total Emissions
  - Federal Lands Only: *47.7 Bcf of whole natural gas (39.4 Bcf CH_4) or 9.1% of national whole gas emissions (8.8% of national methane emissions)*
  - Tribal Lands Only: *18.4 Bcf of whole natural gas (15.6 Bcf CH_4) or 3.5% of national whole gas emissions (3.5% of national methane emissions)*

- *The proportion of emissions by emissions type is similar between the two land types*

2013 Emissions (Whole Bcf)	Federal	Tribal
Fugitive	18.5	9.0
Vented	26.4	8.3
Uncombusted gas from fuel use	2.0	0.7
Uncombusted gas from flaring	0.8	0.3
Total	47.7	18.4

Royalty Loss from Federal Lands

- Lost royalty on 62 Bcf of whole natural gas from fugitive, vented, and flared emissions on federal lands
  - This amounts to $31 million in lost royalties at $4/Mcf and 12.5% royalties
- A total of 212 Bcf of whole natural gas was used as fuel on federal lands
  - Land leases allow for gas as fuel use, hence royalties do not apply

Gas Lost from Venting, Flaring, and Fugitives – 2013

Type (Bcf Whole Gas)	Gas Production	Gathering and Boosting	Oil Production
Fugitive	3.4	-	-
Vented	18	0.39	0.4
Gas Sent to Flare	-	-	39.7
Fuel Use	201.7	-	10.1
Total*	223.00	0.39	50.2

*Totals may not add due to rounding

Ranking of Major Emission Sources by Land Type

- Major sources of emissions on federal and tribal lands are similar to those nationally, but the relative significance of these sources differ.
  - This is most likely due to the distribution of oil and gas production across these lands that drives the split in emissions across all the segments
- M&R 100-300 stations are ranked very low in federal lands and hence listed as NA
- Major sources listed below include EPA white paper methane and VOC emission sources, except for oil well hydraulic fracturing, which is not included in this inventory

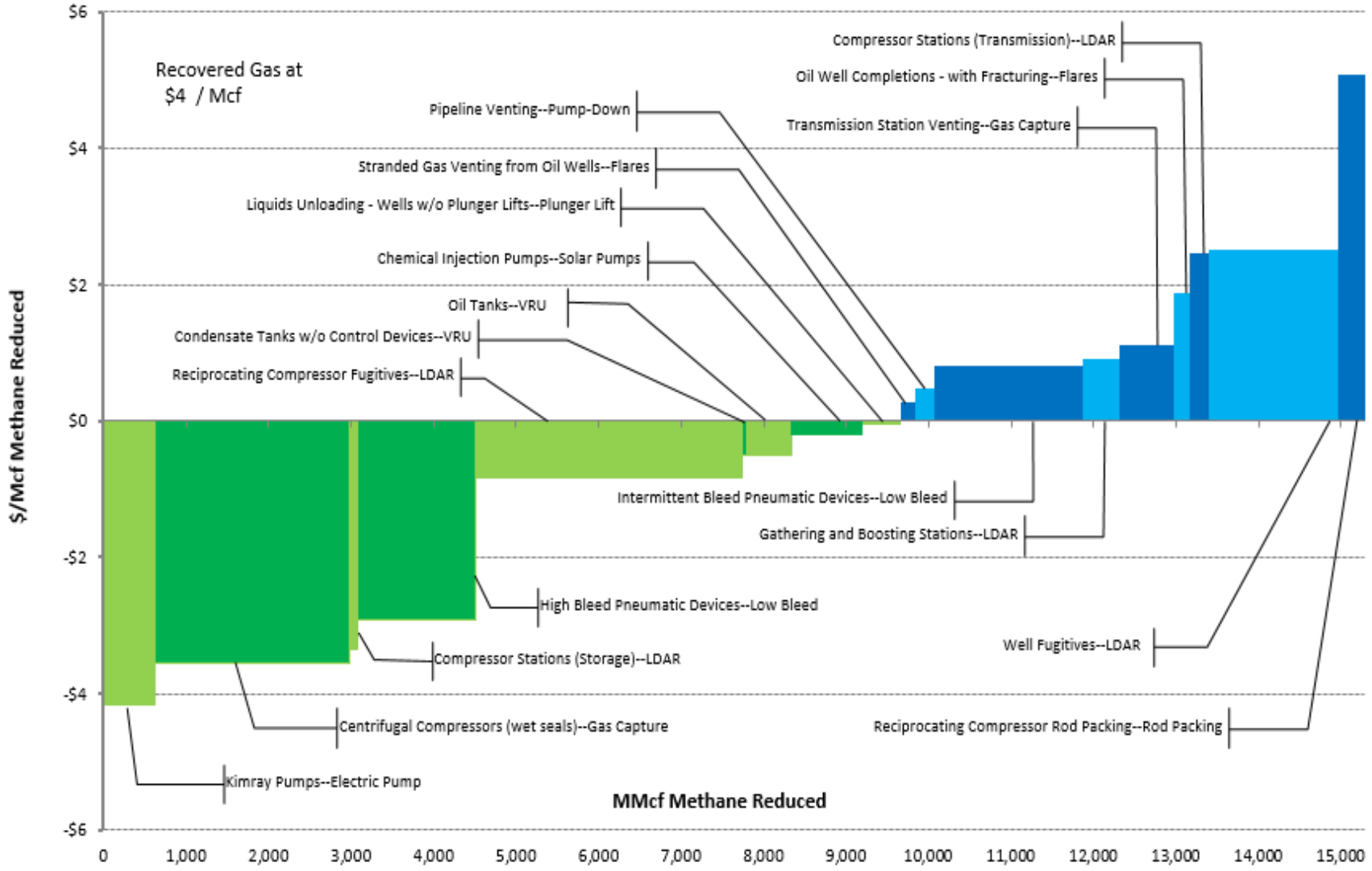
Major Emission Sources by Land Type

Top National Emission Sources	Segment	National Rank	Whole Bcf	Federal Rank	Whole Bcf	Tribal Rank	Whole Bcf
Reciprocating Compressors-Non Seal	Gas Transmission	1	29.5	3	2.3	2	1.4
Oil Tanks	Oil Production	2	26.0	8	1.4	4	0.8
Reciprocating Compressors-Non Seal	Gas Processing	3	21.9	2	2.9	3	1.1
Liquids Unloading - Wells w/ Plunger Lifts	Gas Production	4	20.1	1	8.3	1	2.3
Kimray Pumps	Gas Processing	5	18.3	9	1.3	10	0.4
Centrifugal Compressors (wet seals)	Gathering and Boosting	6	16.6	4	2.2	5	0.8
Liquids Unloading - Wells w/o Plunger Lifts	Gas Production	7	16.6	5	2.1	11	0.4
Intermittent Bleed Pneumatic Devices	Gas Distribution	8	14.1	6	1.9	7	0.5
M&R 100-300	Gas Transmission	9	12.7	NA	0.0	15	0.3
Well Head Fugitives	Gas Production	10	12.2	10	1.3	17	0.3
Centrifugal Compressors (wet seals)	Gas Production	11	11.9	15	0.9	6	0.6
High Bleed Pneumatic Devices	Gas Transmission	12	11.2	7	1.5	12	0.4
Gathering and Boosting Stations	Gas Transmission	13	10.7	14	1.0	21	0.3
Gas Well Completions w/ Hydraulic Fracturing	Gas Production	14	10.5	24	0.5	32	0.2
Reciprocating Compressors-Seals	Gathering and Boosting	15	9.8	19	0.8	8	0.5

Uncertainties in Midstream and Downstream Segment Emissions

- We were not able to obtain data on processing, transmission, and storage facilities that are on federal and tribal lands, though maps of BLM and USDA surface rights indicate the possibility of some processing, transmission, and storage facilities being located on these lands.
- The national emissions estimates for midstream and downstream segments are split between federal and tribal lands using the proportion of oil and gas production from these lands on a state-by-state basis.
- Since midstream and downstream emissions are not directly correlated to oil and gas production, the emissions and abatement potential estimates for these segments have significant uncertainty associated with them. Our approach may overstate or understate emissions and potential reductions in particular areas.

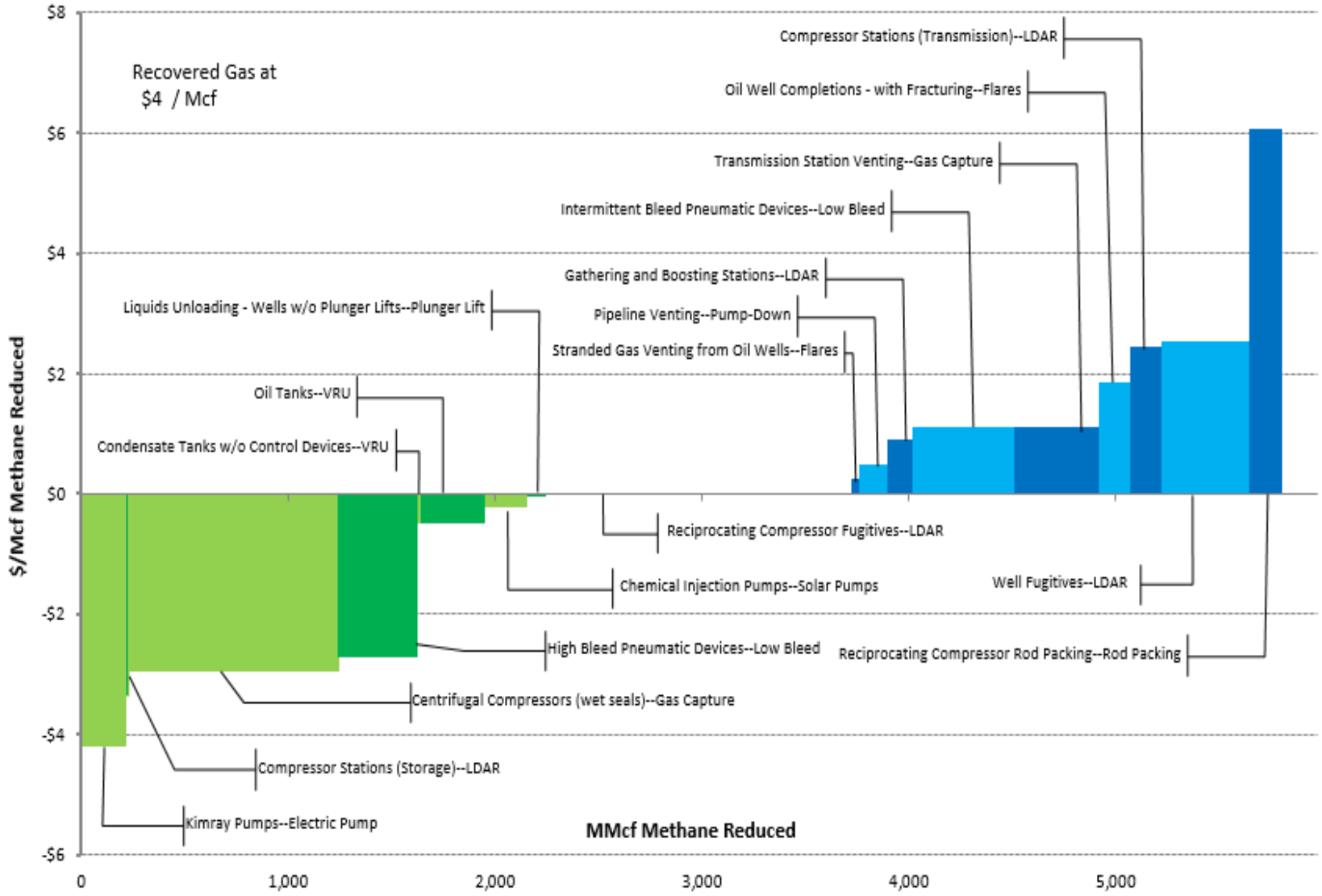
MAC Curve for Methane Mitigation on Federal Lands



Total reduction:
39% of estimated emissions

Estimated cost:
-$0.62/Mcf reduced
(net savings)

MAC Curve for Methane Mitigation on Tribal Lands



Total reduction:
38% of estimated emissions

Estimated cost:
$0.25/Mcf reduced
(< $0.01 per Mcf produced)

Total Abatement Potential

Total Reductions (BCF Whole)	EDF 2013	
	Federal	Tribal
Gas Production	6.5	1.7
Gathering and Boosting	1.9	0.6
Oil Production	2.2	0.9
Gas Processing	3.7	1.4
Gas Transmission	3.5	2.2
Gas Storage	0.4	0.1
Gas Distribution	0.0	0.2
Total	**18.3**	**7.0**

Percent Abatement refers to the reduction potential divided by the total emissions from that segment

Percent Abatement	EDF 2013	
	Federal	Tribal
Gas Production	39%	37%
Gathering and Boosting	44%	45%
Oil Production	53%	57%
Gas Processing	54%	54%
Gas Transmission	57%	57%
Gas Storage	45%	44%
Gas Distribution	NA	13%

Reduction Opportunities Cost

- The total reduction costs for production (both oil and gas) are higher in the current analysis compared to the 2014 ICF/EDF MAC analysis, but relatively low on a per Mcf basis
  - This is mainly because the Subpart W 2013 data reflects a lower high bleed emissions estimate that was used in the current analysis
  - The decrease in proportion of reduction coming from high bleed pneumatic conversion to low bleed in the current analysis is resulting in the net increase in the federal and tribal costs relative to the previous ICF analysis

- There is no significant change observed in the other segment reduction opportunity costs between 2014 ICF/EDF MAC analysis and current analysis, or between the different land types

$/Mcf (Whole Gas)	2011 EDF MAC	EDF 2013	
	National	Federal	Tribal
Gas Production	($0.20)	$0.11	$0.12
Gathering and Boosting	($1.82)	($1.55)	($1.70)
Oil Production	($0.38)	($0.17)	$0.03
Gas Processing	($3.30)	($3.32)	($3.31)
Gas Transmission	$1.85	$1.89	$1.89
Gas Storage	($3.02)	($2.85)	($2.67)

Appendix

Step 1: Revise Previous EDF MAC Baseline with New Data

- Well counts, completions, and production values are from HPDI
- ICF revised the following source EF's and emissions using the most recent Subpart W data for year 2013
  - EF's – Gas well completions with or without fracturing, gas well workovers without fracturing, oil well completions with or without fracturing, oil well workovers without fracturing, blowdowns/venting, and dump valve venting (transmission)
  - Emissions from Subpart W scaled to a national level using Subpart W coverage – Well testing, dump valve venting (gas prod.), gas well workovers with fracturing, liquids unloading with or without plunger lifts, dump valve venting (oil prod.), oil well workovers with fracturing, and stranded gas venting
- ICF used the count of booster stations in the gathering and boosting segment using the latest analysis conducted for EDF
  - Used 4,100 compressor stations in place of 2,727 compressor stations in the ICF/ EDF MAC analysis

Step 2: Use Revised Methodologies – Flare Gas

- Flare gas volumes are now a combination of data from Energy Information Administration (EIA) and National Oceanic and Atmospheric Administration (NOAA) data
  - Neither of the data sources is complete – EIA is missing data for key states such as Pennsylvania and Louisiana
  - NOAA raw data and communications with NOAA indicate that they have not converted all of the satellite data into equivalent flare gas volumes
  - NOAA reports national total flare whole gas volume in 2013 to be 247 Bcf
  - EIA reports national total vented and flare whole gas volume in 2013 to be 272 Bcf (note that all of the EIA reported volume has been assumed to be flared in the EPA Inventory, which has been carried over into this analysis)
  - For each state, ICF assumed that the flare volume is greater of the two values reported from EIA and NOAA.
  - The net result is that we estimate 307 Bcf of whole gas is sent to flares (note that this is the total flare gas volume; the uncombusted methane from flaring is a small portion of this volume)

Step 2: Use Revised Methodologies – Flare Gas

- ICF analyzed potential associated gas being produced nationally that is not being sent to the market
  - In HPDI, ICF determined the gas-to-oil ratio of each oil production play for wells reporting both oil AND gas being sent to the market
  - This GOR was then applied to oil wells in the respective oil production plays that do not report any gas sales
  - This estimate of 556 Bcf of whole gas provides an upper bound on how much associated gas is potentially being vented or sent to a flare nationally
- The Department of Interior Office of Natural Resources Revenue (ONRR) reports the amount of "gas lost – flared or vented" from federal lands to be approximately 46 Bcf
  - 20 Bcf from BLM owned mineral rights
  - 26 Bcf from BLM ownership of 51% gas rights on mixed ownership lands (BLM reports that 51 Bcf gas is sent to vent or flare on mixed ownership lands)

Step 2: Use Revised Methodologies – Liquids Unloading

- One source that changed substantially was liquids unloading
  - Emission factors were updated to include 2013 subpart W data
  - Emissions factors were broken out to a state level
  - Used EPA Inventory assumption that 160,000 wells have liquids loading issues in order to scale up total count of wells venting (both with and without plunger lifts)
- Methane Emission factors (national level only)
  - Without Plunger Lifts: From 163 to 238 Mscf/yr
  - With Plunger Lifts: From 277 to 175 Mscf/yr
- Overall methane emissions changed substantially due to increase in wells venting assumption
  - Without Plunger Lifts: From 5.1 to 13.1 Bcf CH_4
  - With Plunger Lifts: From 12.3 to 15.8 Bcf CH_4

Table of Major Changes in Activity Data

Change	MAC (2011 Value)	Fed-Tribal (2013 Value)	Result
Change in well count	Gas: 486,862 Oil: 530,369	Gas: 546,708 Oil: 750,431	These drive many other source categories, resulting in a complex change in overall emissions.
Breakout of production pneumatics updated to reflect 2013 subpart W data	High: 10% Int: 50% Low: 40%	High: 5% Int: 67% Low: 28%	A 6% decrease in methane emissions
Development of state specific emission factors	Only national values used	10 emission sources have state EFs	Provides a more accurate state-level estimate. Further discussion in subsequent tables.
Updated Gas STAR and Regulation Reductions	96 Bcf methane	82 Bcf methane	The most recent EPA inventory changed reduction allocations, resulting in the net emissions from some sources (e.g., dehydrators) changing. Additionally, overall reported reductions were down.
Incorporation of compressor memo for production and gathering compressors	15,878 "large" compressors in production and gathering	33,814 "small" compressors in production. 4,100 booster stations with 13,433 "large" compressors in gathering.	A 26% increase in fugitive methane emissions from compressors in these segments (8.5 Bcf to 10.8 Bcf)

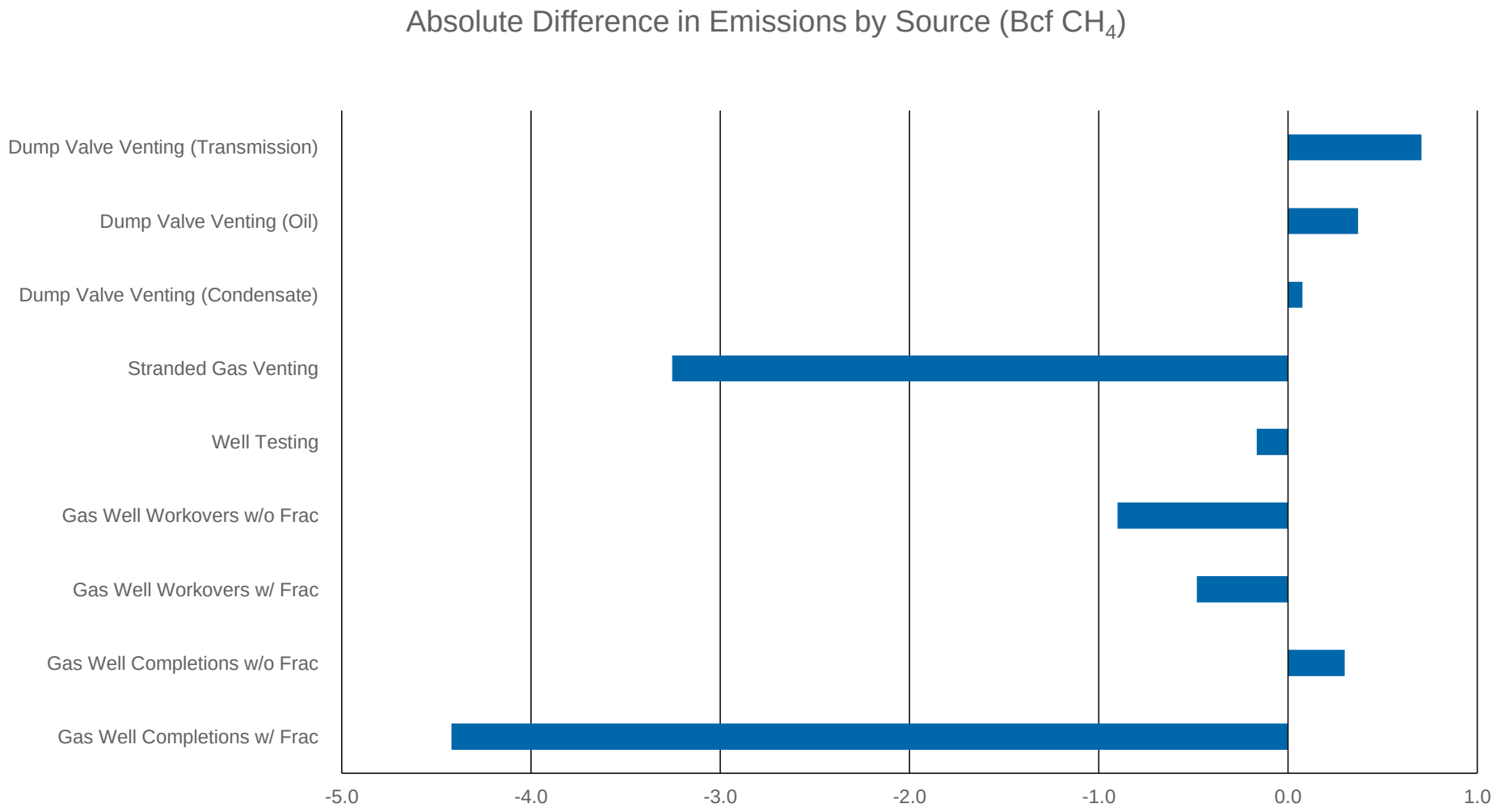
Sources with State Specific EFs using Subpart W

- Gas Production
  - Dump Valve Venting
  - Gas Well Completions with Hydraulic Fracturing
  - Gas Well Completions without Hydraulic Fracturing
  - Gas Well Workovers with Hydraulic Fracturing
  - Liquids Unloading with Plunger Lifts
  - Liquids Unloading without Plunger Lifts
- Oil Production
  - Dump Valve Venting
  - Oil Well Completions with Fracturing
  - Oil Well Completions without Fracturing
  - Oil Well Workovers with Fracturing

Table of Major Changes in Methane Emission Factors

Emission Factor	MAC (2011 Value) (scf CH_4)	Fed-Tribal (2013 Value) (scf CH_4)	Result
Gas Well Completions w/ Frac	7,738,447	836,050	Update to use Subpart W data. Results in a decrease in emissions by 35% to 8.3 Bcf
Gas Well Completions w/o Frac	70,000	239,378	Increase in emissions by 94% to 0.6 Bcf
Gas Well Workovers w/ Frac	790,000	502,616	Decrease in emissions by 49% to 0.5 Bcf
Gas Well Workovers w/o Frac	135,000	81,891	Decrease in emissions by 49% to 1.0 Bcf
Well Testing	95,000	62,566	Decrease in emissions by 13% to 1.1 Bcf
Stranded Gas Venting	570,000	280,198	Decrease in emissions by 50% to 3.3 Bcf
Dump Valve Venting (Condensate)	15,000	36,402	Increase in emissions by 55% to 0.2 Bcf
Dump Valve Venting (Oil)	17,000	58,051	Increase in emissions by 609% to 0.4 Bcf
Dump Valve Venting (Transmission)	950,000	667,496	Increase in emissions by 199% to 1.1 Bcf

Visual Representation of Major Changes



Step 3: Establish Activity Drivers

- For onshore production and gathering and boosting segments well counts, well completions, and production values on a per well/lease basis from federal and tribal lands was used to apportion state level emissions to federal and tribal lands
- Activity data for other segments cannot be disaggregated at a federal and tribal lands level
- The following two-step approach was used to assign activity to federal and tribal lands in other segments

Segment	Step 1	Step 2
Processing	Emissions estimated using state specific plant count	Use HPDI gas production split between federal, tribal, and state lands to apportion segment emissions between these lands
Transmission	Emissions estimated using state specific transmission miles by nominal pipe size	
Underground Storage	Emissions estimated using state specific count of storage locations	
Distribution	Emissions estimated using state specific pipeline mileage	

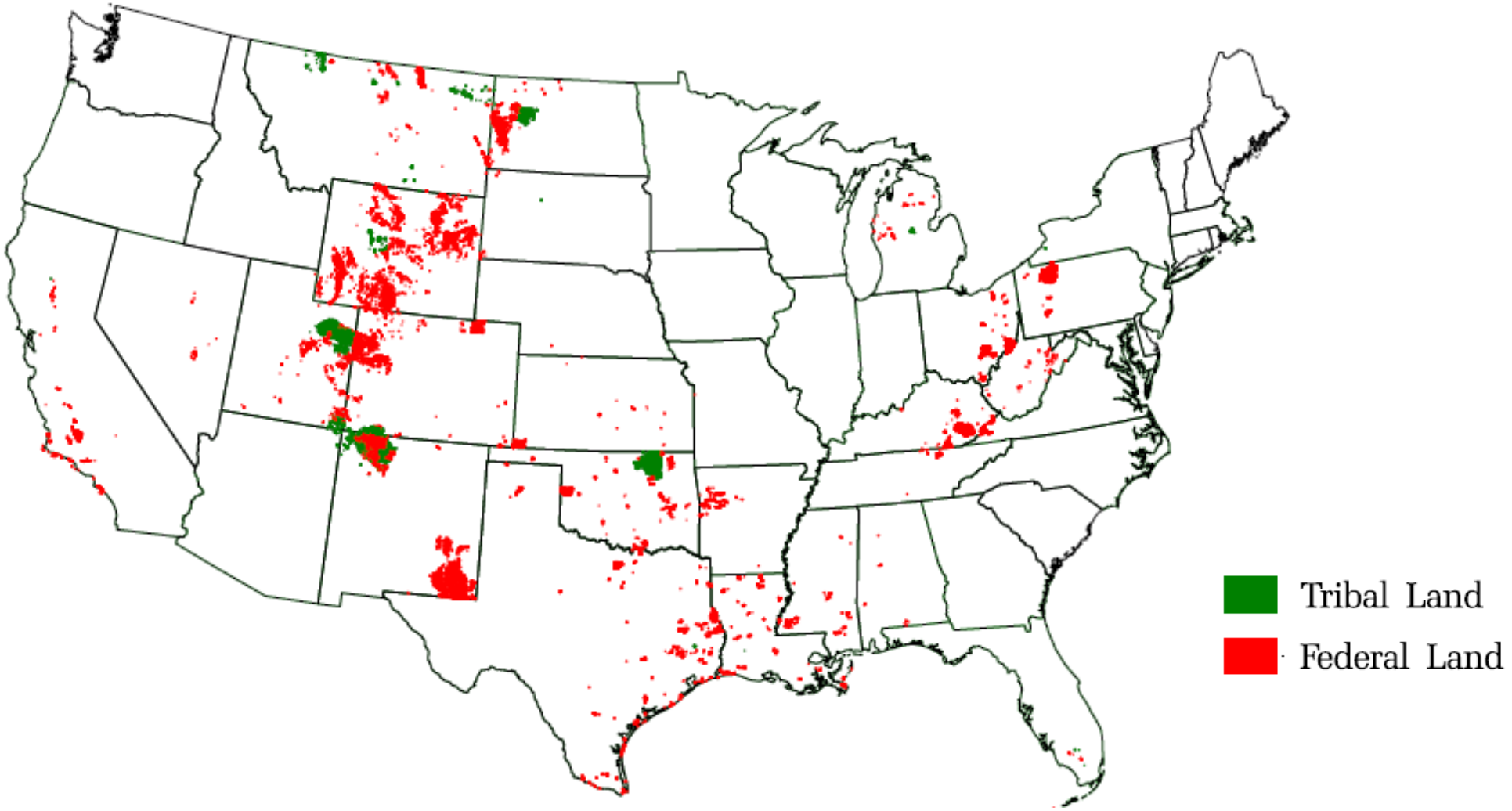
Methodology to Determine Cost of Mitigation Options

- ICF assumed that the cost for implementing methane mitigation options is the same between federal, tribal, and national lands
  - Hence the same costs from the 2014 ICF/EDF MAC analysis were applied to the federal and tribal analysis
- The proportion at which the costs are applied across the federal, tribal, and national lands differ because the proportion of emission from various sources within each segment differ across these lands
- Therefore, the segment level cost ($) per unit volume (Mcf) of methane emissions reduced is different across the federal, tribal, and national level analysis

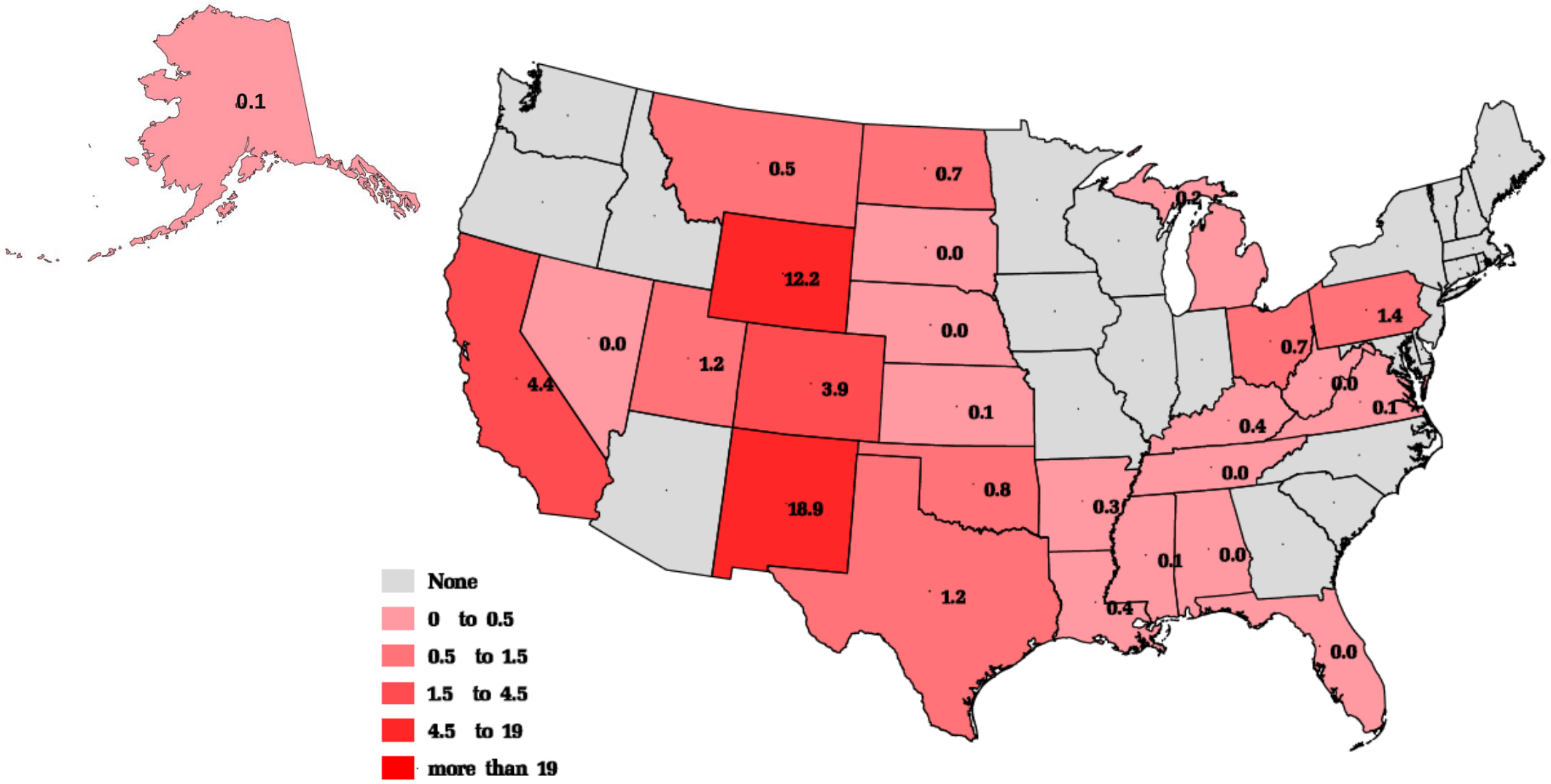
Methodology for Determining BLM Royalty Loss

- Royalty is paid by producers for all gas metered at the lease meter
- Any emission sources upstream of the lease meter
- BLM has collected revenues for all gas lost downstream of the production segment
- Royalty loss for upstream production was estimated as follows;
  - Assume that emissions from all emission sources in upstream production, do not incur any royalty payment
  - Assume that three emission sources in gathering and boosting do not incur any royalty payments – condensate tanks with control measure, condensate tanks without control measure, and mishaps
  - Determine value of emissions at a gas price of $4/Mcf whole gas
  - Assume 12.5% of this value this value is not collected by BLM as royalties

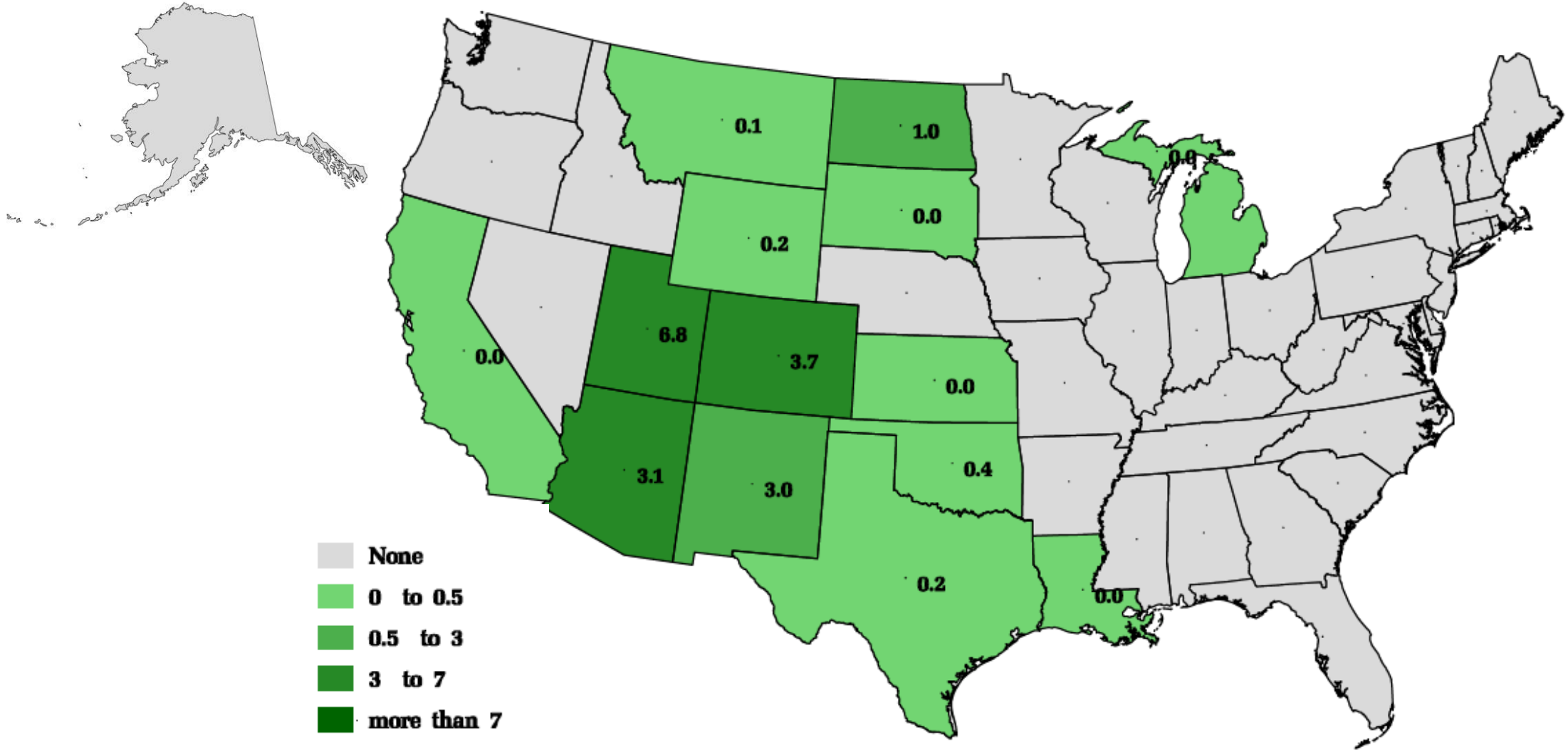
Oil and Gas Leases on Federal and Tribal Lands



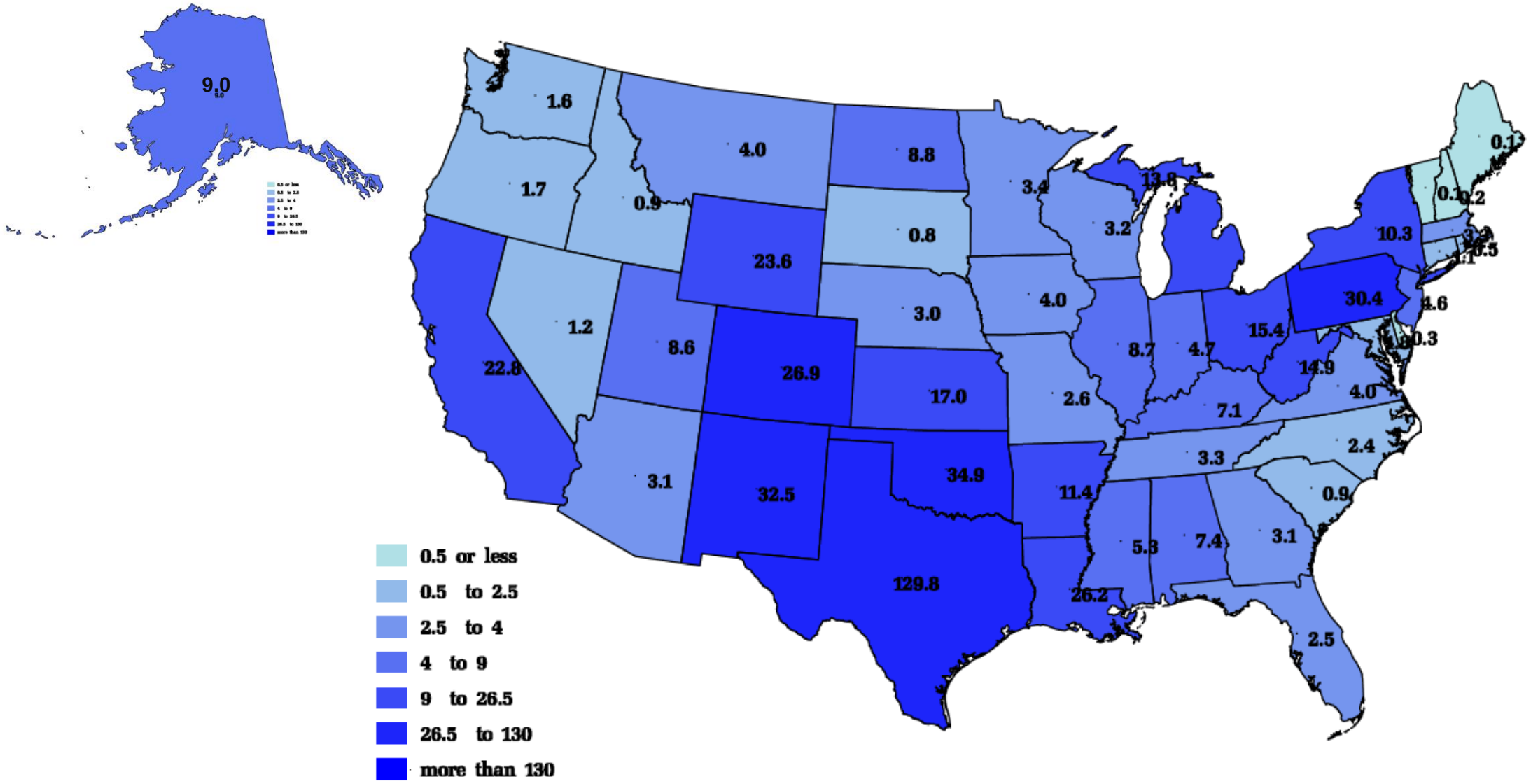
Whole Gas Emissions from Federal Lands (Bcf)



Whole Gas Emissions from Tribal Lands (Bcf)



Whole Gas Emissions from All Lands (Bcf)



Distribution of Emissions Reductions by Land Type and Reduction Activity

Gas Production	EDF 2013	
	Federal	Tribal
LDAR Wells	29%	31%
Early replacement of high-bleed devices with low-bleed devices	21%	21%
Early replacement of intermittent-bleed devices with low-bleed devices	26%	26%
Replace Pneumatic Chemical Injection Pumps with Solar Electric Pumps	14%	13%
Replace Kimray Pumps with Electric Pumps	2%	2%
Install Plunger Lift Systems in Gas Wells	9%	7%
Total	100%	100%

Gathering and Boosting	EDF 2013	
	Federal	Tribal
Early replacement of high-bleed devices with low-bleed devices	2%	2%
Early replacement of intermittent-bleed devices with low-bleed devices	3%	3%
Replace Kimray Pumps with Electric Pumps	33%	38%
Install Vapor Recovery Units	4%	3%
LDAR Gathering	30%	27%
LDAR Reciprocating Compressor Non-seal	17%	16%
Replacement of Reciprocating Compressor Rod Packing Systems	3%	3%
Wet Seal Degassing Recovery System for Centrifugal Compressors	7%	7%
Total	100%	100%

Distribution of Emissions Reductions by Land Type and Reduction Activity

Oil Production	EDF 2013	
	Federal	Tribal
LDAR Wells	4%	2%
Early replacement of high-bleed devices with low-bleed devices	16%	9%
Early replacement of intermittent-bleed devices with low-bleed devices	20%	11%
Replace Pneumatic Chemical Injection Pumps with Solar Electric Pumps	9%	5%
Install Vapor Recovery Units	30%	44%
Install Flares-Completion	11%	22%
Install Flares-Venting	10%	6%
Total	100%	100%

Gas Processing	EDF 2013	
	Federal	Tribal
Replace Kimray Pumps with Electric Pumps	1%	1%
LDAR Reciprocating Compressor Non-seal	46%	47%
Replacement of Reciprocating Compressor Rod Packing Systems	2%	2%
Wet Seal Degassing Recovery System for Centrifugal Compressors	51%	50%
Total	100%	100%

Distribution of Emissions Reductions by Land Type and Reduction Activity

Gas Transmission	EDF 2013	
	Federal	Tribal
Early replacement of high-bleed devices with low-bleed devices	1%	1%
Early replacement of intermittent-bleed devices with low-bleed devices	2%	2%
LDAR Transmission	7%	7%
LDAR Reciprocating Compressor Non-seal	39%	39%
Replacement of Reciprocating Compressor Rod Packing Systems	5%	5%
Wet Seal Degassing Recovery System for Centrifugal Compressors	19%	19%
Pipeline Pump-Down Before Maintenance	7%	7%
Redesign Blowdown Systems and Alter ESD Practices	20%	20%
Total	100%	100%

Gas Storage	EDF 2013	
	Federal	Tribal
Early replacement of high-bleed devices with low-bleed devices	7%	8%
Early replacement of intermittent-bleed devices with low-bleed devices	2%	2%
LDAR Transmission	24%	23%
LDAR Reciprocating Compressor Non-seal	54%	59%
Replacement of Reciprocating Compressor Rod Packing Systems	7%	8%
Wet Seal Degassing Recovery System for Centrifugal Compressors	6%	0%
Total	100%	100%