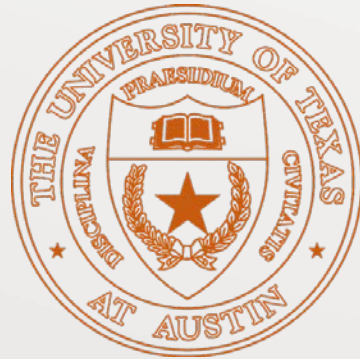


# Methane Emissions from Process Equipment at Natural Gas Production Sites in the United States: Liquid Unloadings



# Need for Study



- Methane, the primary constituent of natural gas, is a potent greenhouse gas
- Liquid unloadings are estimated to account for 14% of methane emissions from the natural gas production sector; very few measurements are available and those measurements indicate that a small subset of wells dominate emissions
  - Average emissions per well with unloadings (all types) in most recent US EPA national inventory (273.6 Gg/60,810 wells = 4.5 Mg per well/yr = 234,000 scf)
  - Regional average emissions/(well-yr) for unloadings of wells without plunger lifts = 78,000 to 2,000,000 scf (<http://www.epa.gov/airquality/oilandgas/whitepapers.html> )
  - Regional average emissions/(well-yr) for plunger lift unloadings = 3,000 to 1,100,000 scf (<http://www.epa.gov/airquality/oilandgas/whitepapers.html> )
- To better inform policy, measurements are needed to (i) quantify methane emissions from unloadings at a diverse set of sites, and (ii) characterize the population of high emitting wells.

# Liquid Unloadings

## Operation of plunger lift wells

(see animation available on YouTube)

If the above link doesn't work, please copy this URL into a new browser window:

[http://youtu.be/hH-Q1JMX4\\_M](http://youtu.be/hH-Q1JMX4_M)

# Well Unloadings with plunger lift

- 23,503 venting plunger lift wells in U.S. according to US EPA (40% of all venting wells); 32,225 venting plunger wells reported through the 2012 GHGRP (55% of venting wells reported through the GHGRP)
- In this work, plungers lift wells categorized as “manually triggered” (generally vent less than once per week) and “automatically triggered” (can vent multiple times per day)



# Liquid Unloadings

Unloadings clear operating wells of liquid to increase gas production

(see animation available on YouTube)

If the above link doesn't work, please copy this URL into a new browser window:

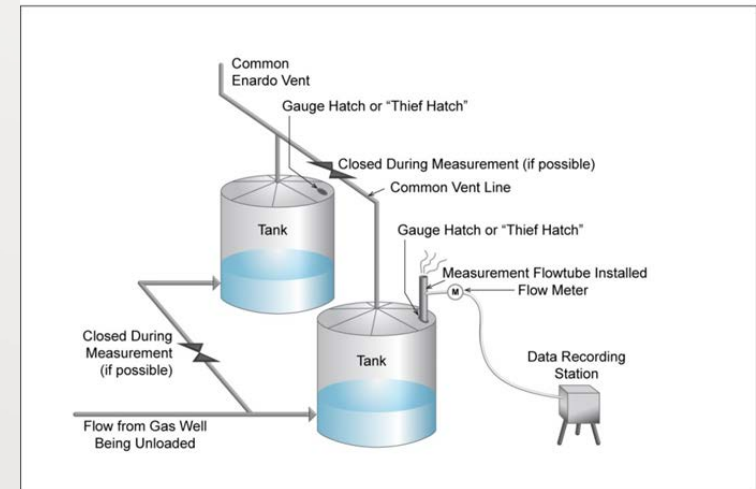
<http://youtu.be/tup1SICEXGY>

# Unloadings of wells without plunger lift

- 37,307 venting wells without plunger lift in U.S. according to US EPA national emission inventory (61% of all venting wells); 26,438 venting wells without plunger lift reported through the 2012 GHGRP (45% of venting wells reported through the GHGRP)
- In this work, 99% of the wells without plunger lifts were “manually triggered” (generally vent less than once per week); approximately 1% of wells unload more than once per week and approximately 0.1% are automatically triggered



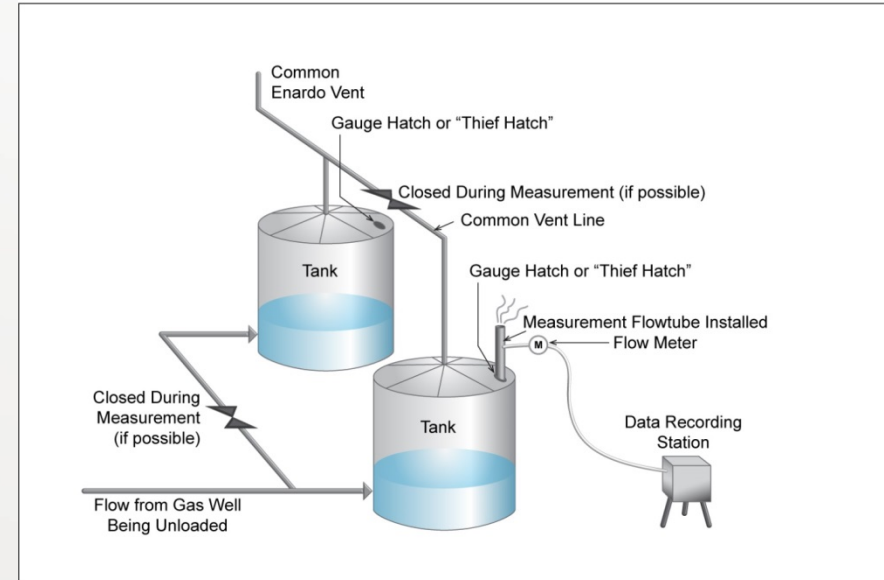
Measurement Connection to Tank (Gas Well Unloading)



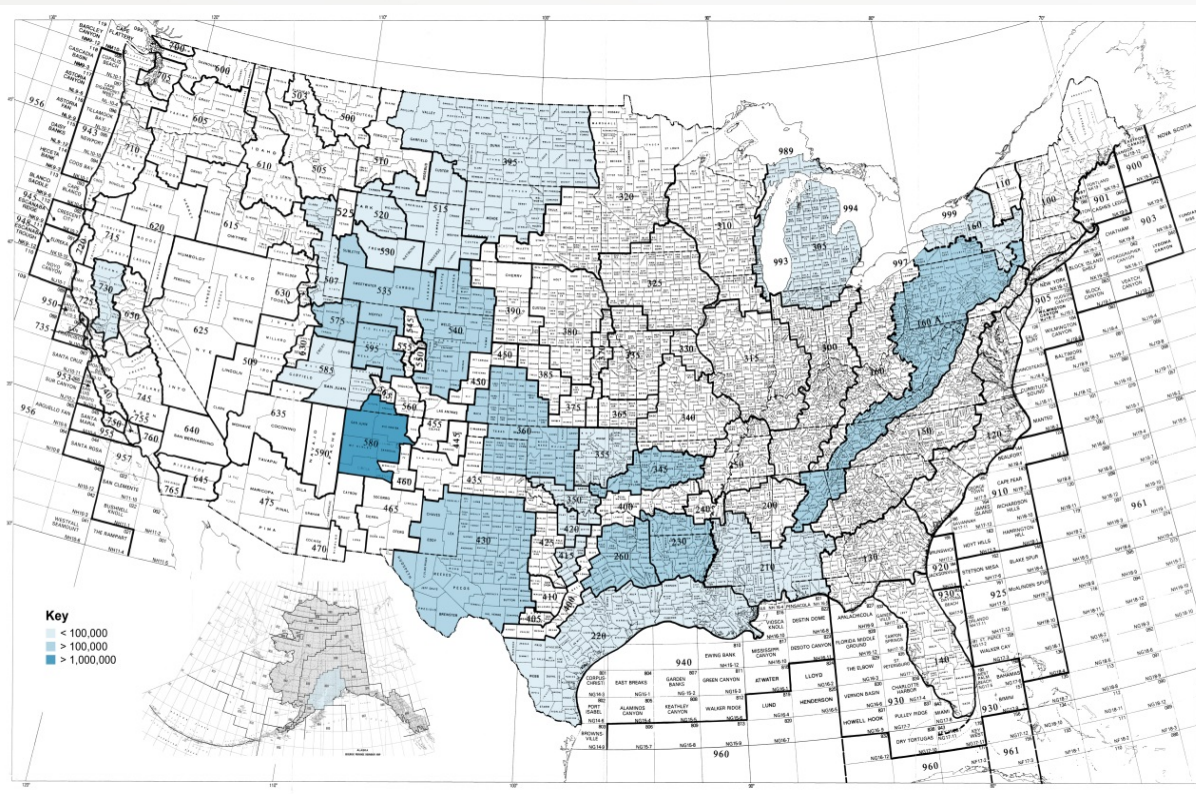
# Emission measurement methods

- Direct measurement of gas volume discharged
- Flow data are collected with one second resolution; detailed time series are available in study data set
- Methane fraction in vented gas assumed to be equal to produced gas
- For automated wells, equipment was installed and left in place until an unloading was triggered in routine operation

Measurement Connection to Tank (Gas Well Unloading)



# Reported emissions (Greenhouse Gas Reporting Program) are concentrated in some regions



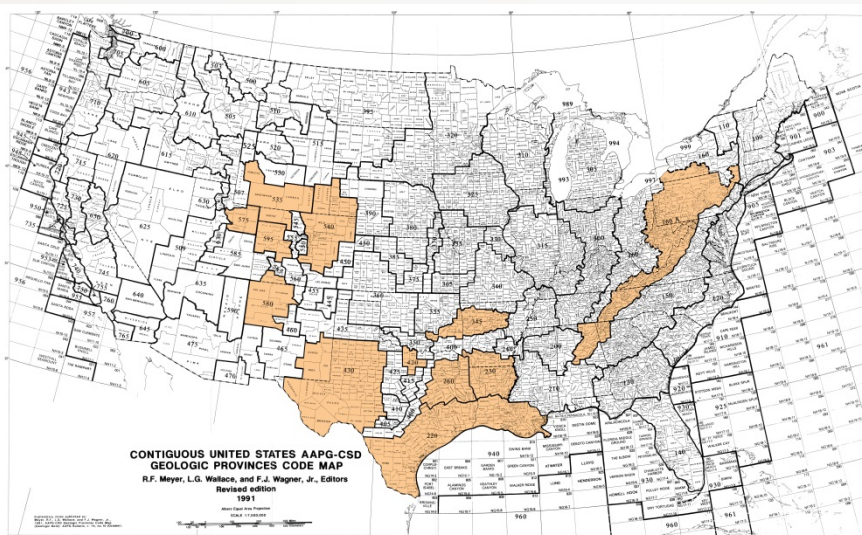
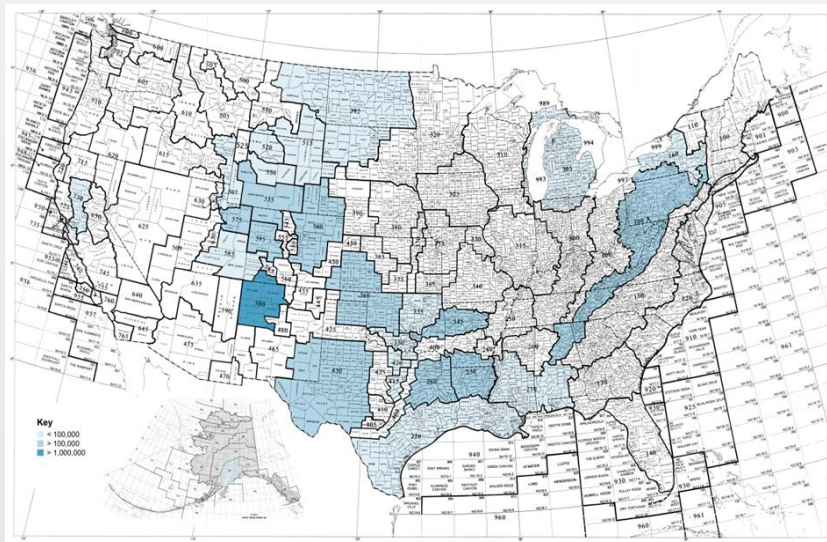
Light blue: <100,000 MT CO<sub>2</sub>e (~5 Gg CH<sub>4</sub>; EPA estimate of US inventory is 274 Gg)

Medium blue: 100,000-1,000,000 MT CO<sub>2</sub>e

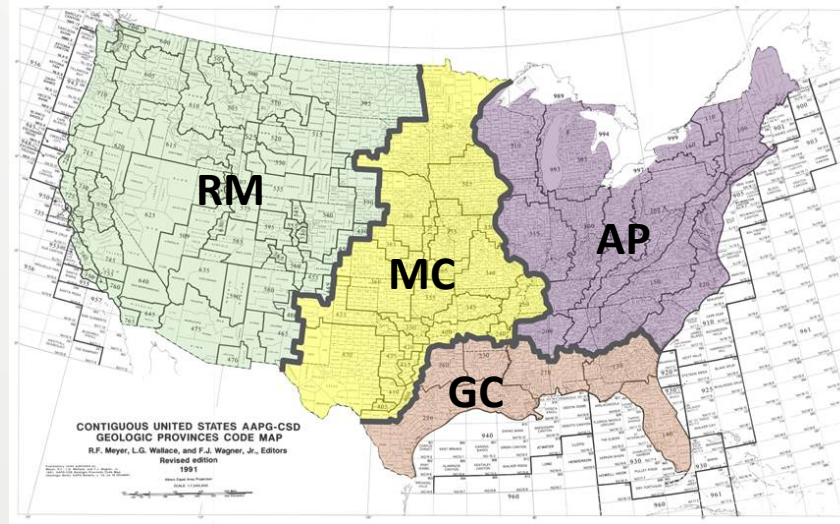
Dark blue: 1,000,000+ MT CO<sub>2</sub>e



# Spatial distribution of unloading emissions vs. regions sampled



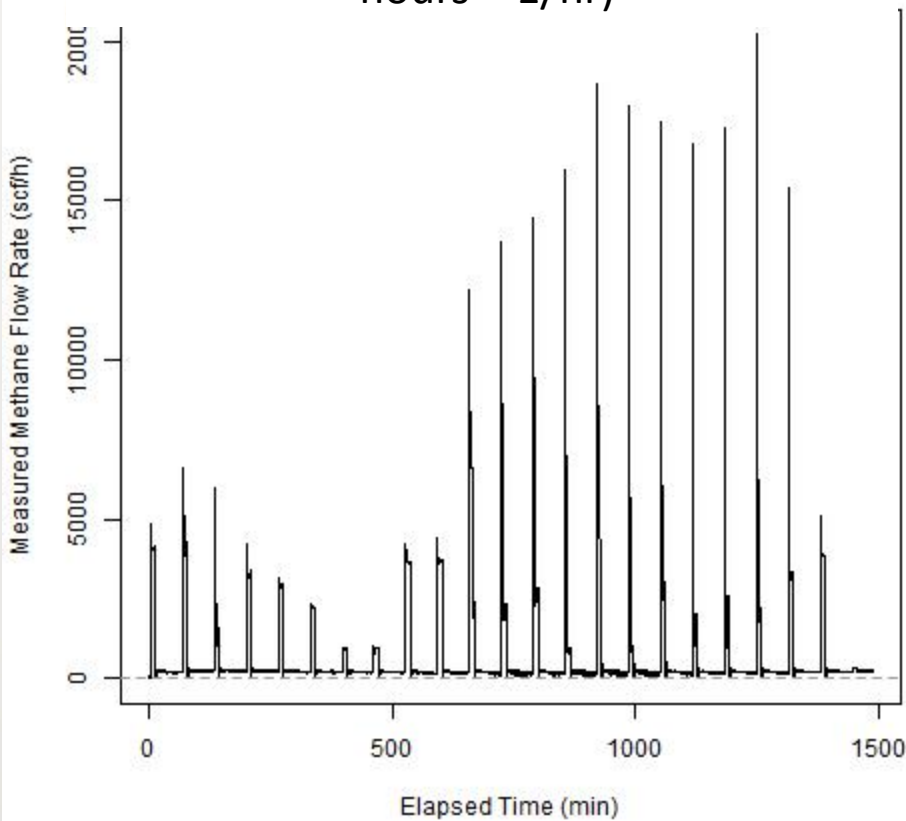
# Geographic Distribution of Measurements



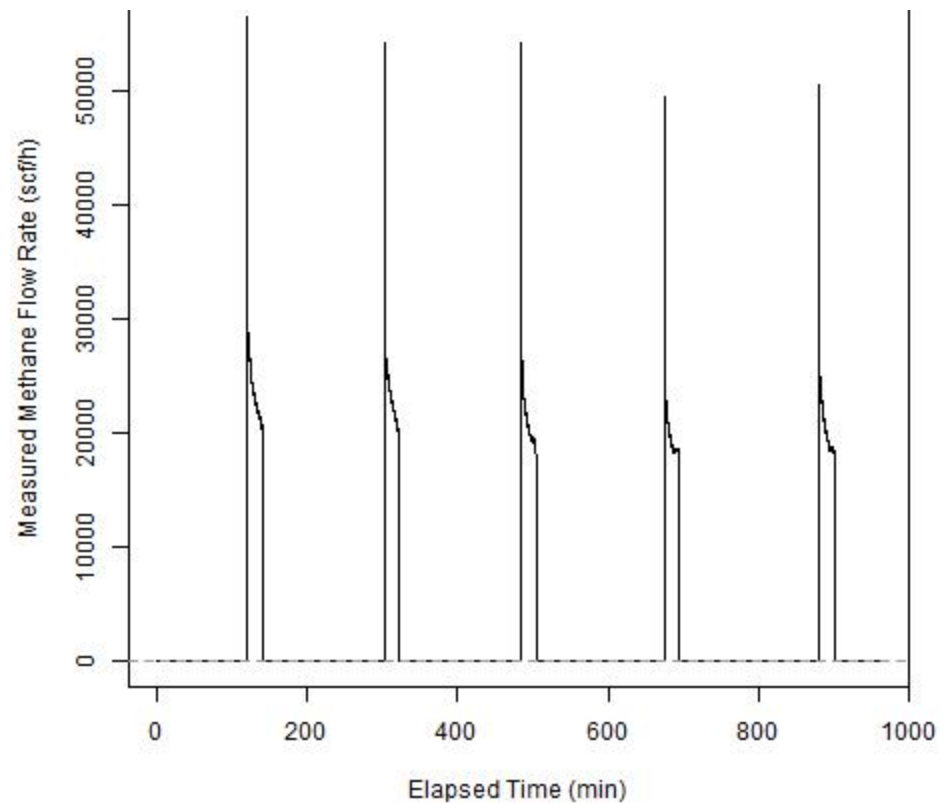
Type of Well	Initiation System	Wells with Unloadings sampled				
		US Total	Appalachian	Rocky Mountain	Gulf Coast	Mid-Continent
<b>Plunger</b>	Auto	25	0	20	1	4
	Manual	50	7	29	1	13
<b>Non-Plunger</b>	Manual	32	4	2	14	12
<b>Total</b>		107	11	51	16	29

# Representative time series for gas flows from automated plunger lift unloadings

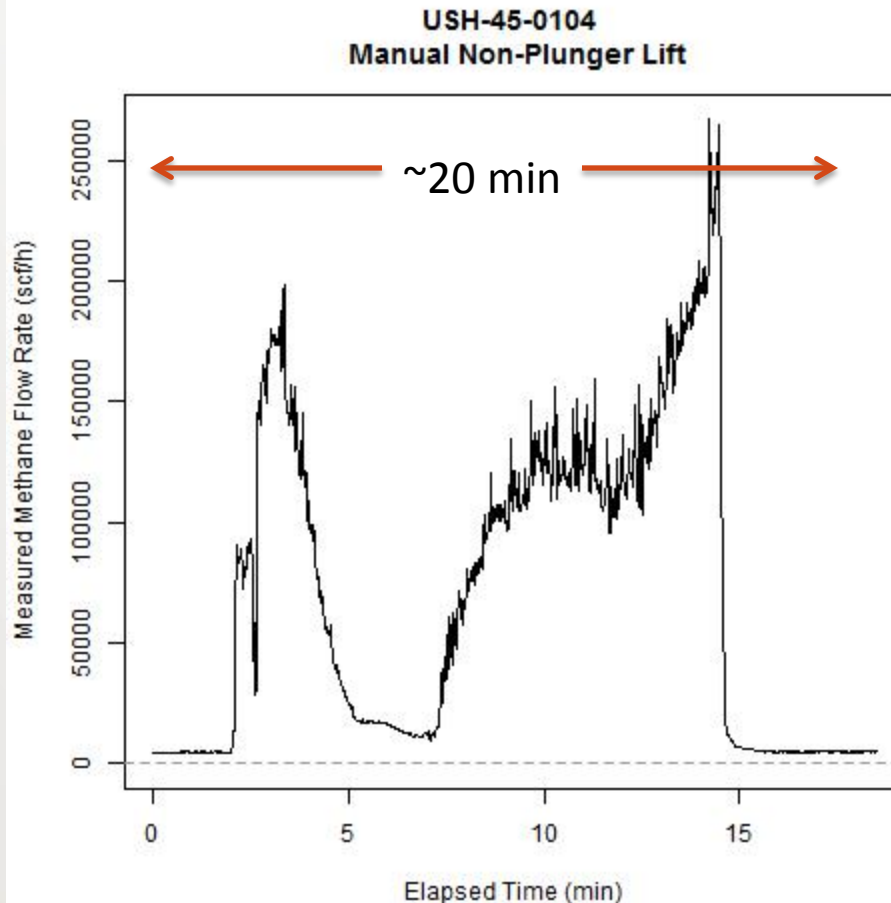
Flow (scf/h; 22 unloadings in 22 hours = 1/hr)



Flow (scf/h; 5 unloadings in 12 hours = 0.42/hr)



# Representative time series for gas flows: unloading of a well without a plunger lift



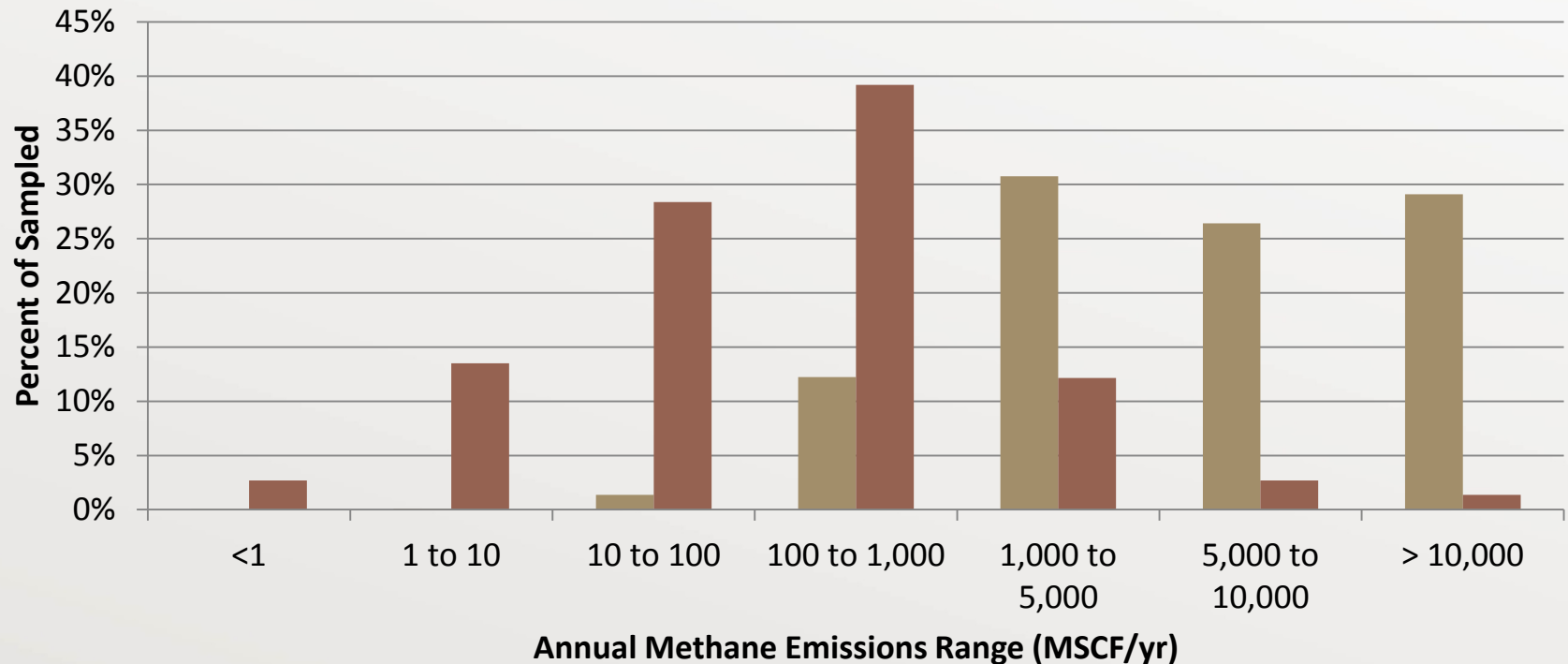
# Findings

- For plunger and non-plunger wells, a small subset of wells dominate emissions
- Measured emissions per well per year depend most strongly on the number of venting events that occur per year
- For wells without plunger lifts, the 1.2% of wells that vent more than weekly account for 25% of estimated annual emissions from wells without plunger lifts
- For plunger lift unloadings, the subset of wells that vent more than once per day (typically several times per day), account for 80% of emissions from plunger lift wells that vent during unloadings
- The central estimate of emissions from unloadings (270 Gg/yr) based on measurements made in this work are within a few percent of the emissions estimated in the EPA 2012 Greenhouse Gas National Emission Inventory, however, confidence bounds are large based on variability in emissions per event and uncertainty in event counts

# Plunger lift wells

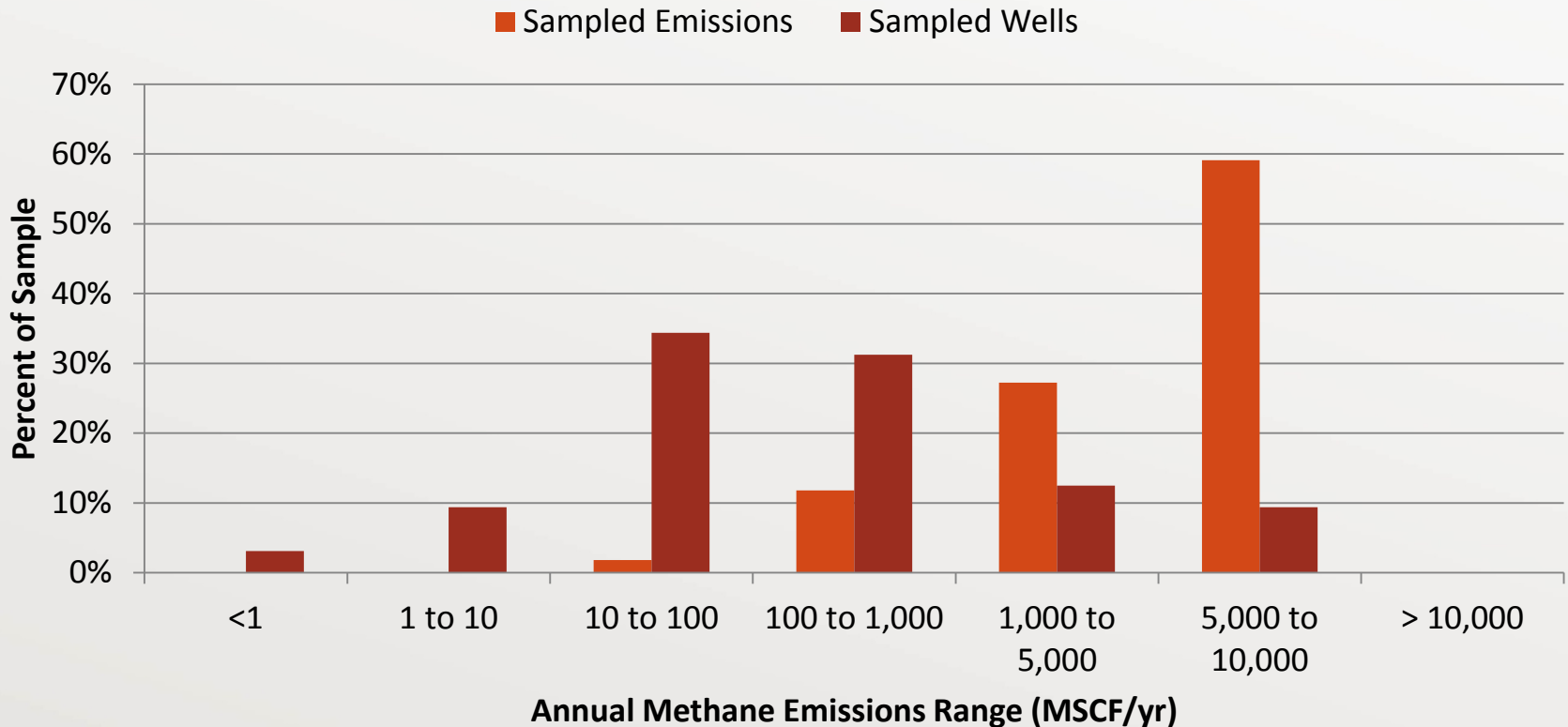
## Plunger Lift Wells (74 total)

■ Sampled Emissions   ■ Sampled Wells



# Wells without plunger lifts

**Wells without Plunger Lift (32 total)**



# For all well types, a small subset of wells dominate emissions; for wells **MEASURED** in this work

- Plunger lift wells, automatically triggered (more than 100 events/yr)
  - 20% of wells account for 72% of annual well emissions
- Plunger lift wells, manually triggered (less than 100 events per year)
  - 20% of wells account for 65% of annual well emissions
- Wells without plunger lifts,
  - 20% of wells account for 83% of annual well emissions



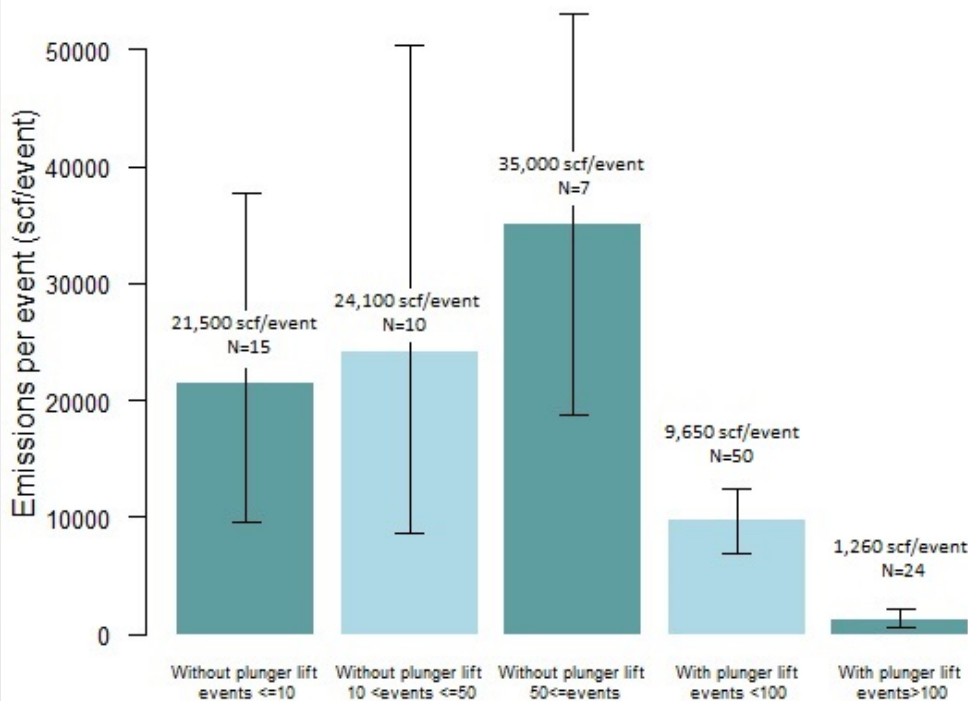
# Findings

- For plunger and non-plunger wells, a small subset of wells dominate emissions
- Measured emissions per well per year depend most strongly on the number of venting events that occur per year
- For wells without plunger lifts, the 1.2% of wells that vent more than weekly account for 25% of estimated annual emissions from wells without plunger lifts
- For plunger lift unloadings, the subset of wells that vent more than once per day (typically several times per day), account for 80% of emissions from plunger lift wells that vent during unloadings
- The central estimate of emissions from unloadings (270 Gg/yr) based on measurements made in this work are within a few percent of the emissions estimated in the EPA 2012 Greenhouse Gas National Emission Inventory, however, confidence bounds are large based on variability in emissions per event and uncertainty in event counts

Measured emissions per well per year depends most strongly on the number of venting events that occur per year

- Statistical relationships were examined relating Emissions per event and Emissions per well per year to:
  - gas production rate, oil production rate, well pressures, well bore volumes, unloading event durations and unloading frequencies
- For annual emissions per well, the strongest statistical relationship was with event frequency

# Measured emissions per well per year depends most strongly on the number of venting events per year



Emissions per event have a much smaller range (21,500-35,000 scf/event for wells without plungers; 1,260-9,650 for wells with plungers) compared to the range in numbers of events (up to three orders of magnitude)

# Findings

- For plunger and non-plunger wells, a small subset of wells dominate emissions
- Measured emissions per well per year depend most strongly on the number of venting events that occur per year
- For wells without plunger lifts, the 1.2% of wells that vent more than weekly account for 25% of estimated annual emissions from wells without plunger lifts
- For plunger lift unloadings, the subset of wells that vent more than once per day (typically several times per day), account for 80% of emissions from plunger lift wells that vent during unloadings
- The central estimate of emissions from unloadings (270 Gg/yr) based on measurements made in this work are within a few percent of the emissions estimated in the EPA 2012 Greenhouse Gas National Emission Inventory, however, confidence bounds are large based on variability in emissions per event and uncertainty in event counts

# Sample set intentionally contains a higher proportion of wells from high emitting regions and frequently venting wells than in the national population

- Study team visited regions predicted to have high emissions from unloadings
- Study team would travel to a region and sample for a week; wells that had unloadings during that week were sampled; measurements were not made on wells that were not scheduled to or expected to have unloadings during the week of sampling
- Sample set has more wells with a weekly or higher frequency of unloading, than their frequency in the overall population
- To account for this sampling bias, national emission estimates will focus on event counts rather than well counts

# Estimates of event counts

- Participating companies provided data on event counts for 8772 wells with plunger lifts and 7481 wells without plunger lift, approximately 28% of all wells with unloadings that vent in the U.S.
- For some categories of wells (especially non-plunger wells with high event frequency) company survey data show different distributions than other sources of event data
- Company survey data were used as the primary data source and the study team conducted rigorous quality assurance of the data

# For plunger lift unloadings, the subset of wells that vent more than once per day (typically several times per day), dominate emissions

- 100 or less events per year
  - 9,450 scf methane/event (measurements); 7.7 events per year (survey data)
  - 73,000 scf/well per year; 83% of wells
- More than 100 events per year
  - 1,200 scf methane/event (measurements), 1200 events per year (survey data)
  - 1,440,000 scf per well per year; 17% of wells

Weighted average of 307,000 scf per well per year

# For wells without plunger lifts, the subset of wells that vent more than three times per week (and more typically several times per day) account for most of the emissions

- 10 events or less per year
    - 21,500 scf methane/event (measurements); 2.9 events per year (survey data)
    - 63,000 scf/well per year; ~85% of wells
  - 11-50 events per year
    - 24,100 scf methane/event (measurements); 20.3 events per year (survey data)
    - 489,000 scf/well per year; ~14% of wells
  - 51-200 events per year
    - 35,000 scf methane/event (measurements); 75.6 events per year (survey data)
    - 2,650,000 scf/well per year; ~1.06% of wells
  - More than 200 events per year
    - No measurements made, 338 events per year (survey data)
    - Assume 11.8 million scf per well per year; 0.107% of wells
- Weighted average of 123,000 scf per well per year

Weighted average of 3,500,000 scf per well per year



# Findings

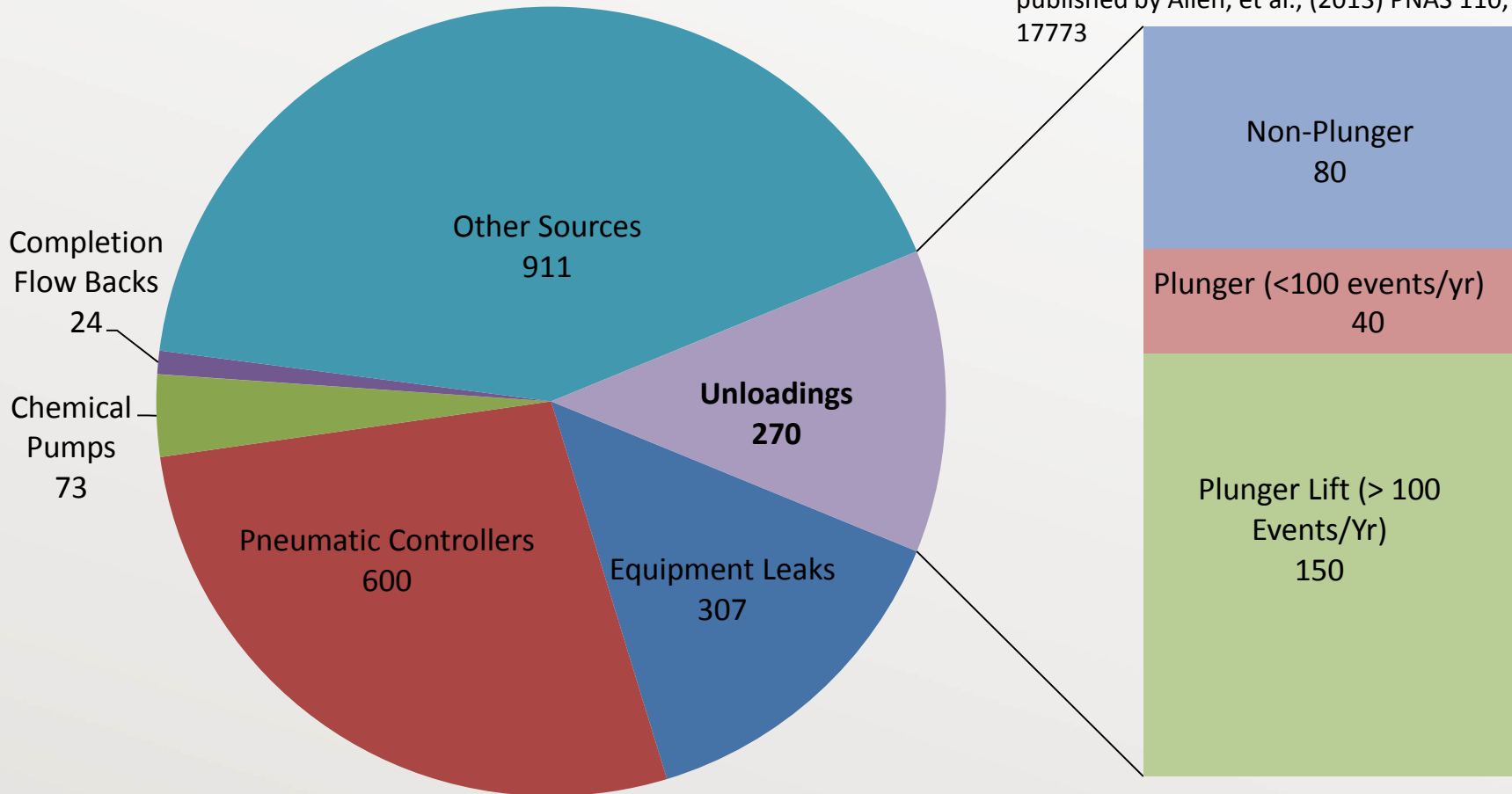
- For plunger and non-plunger wells, a small subset of wells dominate emissions
- Measured emissions per well per year depend most strongly on the number of venting events that occur per year
- For wells without plunger lifts, the 1.2% of wells that vent more than weekly account for 25% of estimated annual emissions from wells without plunger lifts
- For plunger lift unloadings, the subset of wells that vent more than once per day (typically several times per day), account for 80% of emissions from plunger lift wells that vent during unloadings
- The central estimate of emissions from unloadings (270 Gg/yr) based on measurements made in this work are within a few percent of the emissions estimated in the EPA 2012 Greenhouse Gas National Emission Inventory, however, confidence bounds are large based on variability in emissions per event and uncertainty in event counts

# Implications for National Emissions:

- Wells with plunger lift that vent during unloadings
  - 83% of the 32,225 wells nationally (GHGRP) have less than 100 events per year with average emissions of 73,000 scf methane per well, for total emissions of 40 Gg (2 bcf/y).
  - The remaining 17% of wells have emissions of 1,440,000 scf methane per well, for total emissions of 150 Gg/y (7.9 bcf/y).
- Wells without plunger lift that vent during unloadings
  - ~99% of the 26,438 wells without plunger lift nationally (GHGRP) have average emissions of 123,000 scf methane per well, for total estimates emissions of 60 Gg/y (3.3 bcf/y).
  - The remaining 1.2% of wells, with emissions of 3.5 million scf methane per well per year, result in emissions of 20 Gg (1.1 bcf/y).
- Regardless of the exact national total of emissions, wells with high frequencies of unloadings emit at average rates that are an order of magnitude or more greater than wells with low frequencies of unloadings

# Estimated Annual Emissions from Upstream Natural Gas Production Sector in the United States (Gg Methane)

Estimate for unloadings: Emission factors based on measurements in this work with activity data based on survey of participating companies in this work.  
Estimate for pneumatic controllers: From updated measurements on controllers, published in parallel with this work. All other categories: Previously published by Allen, et al., (2013) PNAS 110, 17768-17773



Total of 2180 Gg or 0.38% of 2012 U.S. natural gas withdrawals and production

# Findings

- For plunger and non-plunger wells, a small subset of wells dominate emissions
- Measured emissions per well per year depend most strongly on the number of venting events that occur per year
- For wells without plunger lifts, the 1.2% of wells that vent more than weekly account for 25% of estimated annual emissions from wells without plunger lifts
- For plunger lift unloadings, the subset of wells that vent more than once per day (typically several times per day), account for 80% of emissions from plunger lift wells that vent during unloadings
- The central estimate of emissions from unloadings (270 Gg/yr) based on measurements made in this work are within a few percent of the emissions estimated in the EPA 2012 Greenhouse Gas National Emission Inventory, however, confidence bounds are large based on variability in emissions per event and uncertainty in event counts