U.S. DEPARTMENT OF ENERGY

Fossil Energy and Carbon Management

DOE's Methane Measurement, Monitoring, and Mitigation R&D Program

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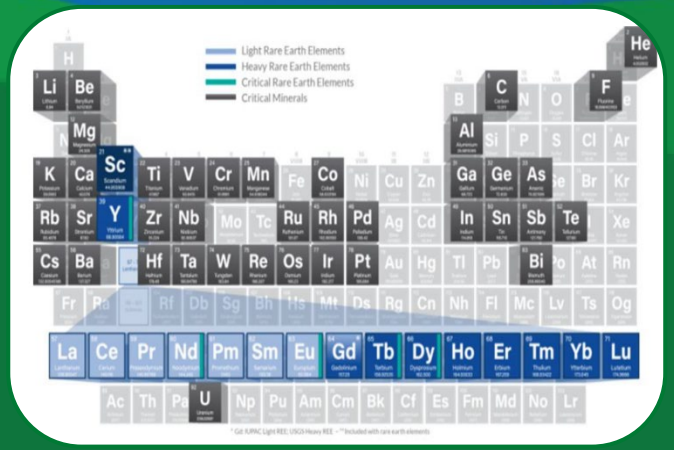


Methane Mitigation Technologies Division Overview

Methane Emissions Mitigation

Advanced materials, data management tools, inspection and repair technologies, and dynamic compressor R&D for eliminating fugitive methane emissions across the natural gas value chain

Methane Emissions Quantification

Direct and remote measurement sensor technologies and collection of data, research, and analytics that quantify methane emissions from point sources along the upstream and midstream portion of the natural gas value chain

Decarbonization of Natural Gas Resources

Technologies for carbon-neutral hydrogen production, safe and efficient transportation, and geologic storage technologies supported by analytical tools and models

Undocumented Orphaned Wells Research

Developing tools, technologies, and processes to efficiently identify and characterize undocumented orphaned wells in order to prioritize them for plugging and abandonment.

METHANE MITIGATION TECHNOLOGIES

Administration Goals:

50% emissions reduction by **2030**
100% clean electricity by **2035**
Net-zero carbon emissions by **2050**

NETL EFFORTS SUPPORTING THE EPA GHGI

Extramural Projects Supporting the EPA GHGI

Gathering and Boosting Stations, DE-FE0029068

Enhanced a 2015 EDF funded study focused on facility-level gathering compressor stations by extending the field research to focus on assessing device-level emission factors, characterize episodic emission rates, and testing of new methods to characterize intermittent emissions.

COLORADO STATE UNIVERSITY

Industrial Meters, Vintage vs New Plastic Pipe, and Plastic-lined Steel and Cast-Iron Pipe, DE-FE0029061

Completed in 2019, project focused on emissions from industrial meters in the natural gas distribution system, differences between vintage and new plastic pipelines, and gather data to compare steel and cast iron pipelines with and without plastic liners. (>500 meters, miles of pipelines assessed)

gti GAS TECHNOLOGY INSTITUTE

Marginal Oil and Natural Gas Wells, DE-FE0031702

589 oil and gas production sites were visited in coordination with 15 participating host operators, who in addition to direct access to perform emission screening and measurements, provided valuable activity data quantify methane emissions data from marginal well sites.

GSI ENVIRONMENTAL

Gathering and Boosting Stations (~2018)

COLORADO STATE UNIVERSITY

Project Objectives

- (1) develop nationally-representative, activity-weighted, methane emission factors for each type of equipment located at typical gathering compressor stations, suitable for use in the GHGI

- (2) develop estimates of episodic emissions; and (3) test new methods to characterize intermittent device emissions.

Key Efforts

- Supported estimates of facility level methane emissions estimated in 2015 (EDF funded assessment), newly estimated device-level emission factors that contributed to back-casting to GHGI's 1992 baseline year. Additional elements of the study provided data suitable for a broad range of emission modeling efforts.

- Results supported modeling of non-methane emissions (such as volatile organic compounds), including life-cycle analyses, and (if regional differences are seen in activity data) regionalized models of emissions.

- Characterization of intermittent device emissions (e.g. pneumatic controllers)

Natural Gas Distribution System (~2019)

GAS TECHNOLOGY INSTITUTE

Project Objectives

- (1) characterize methane emissions from industrial meters, differences between vintage and new plastic pipelines, and compare steel and cast-iron pipelines with and without plastic liners.

- (2) Conduct an assembly of existing and new field data on methane leaks that will feed advanced statistical methods to offer a new perspective on methane emissions, the metrics/categories used to estimate emissions, and techniques used to curb those emissions.

Key Efforts and Example Results

1. Thirteen weeks of field campaigns, across six regions, ten different companies, six types of industrial/commercial meter sets (Rotary, Turbine, Diaphragm, Orifice, Ultrasonic and Regulating), and examined more than 24,000 components

2. 1,474 components had methane leaks >100 ppm, resulting in emission rate quantification for 458 individual components

3. Previous factor used in the GHGI for a combined nationwide industrial/commercial meter category is 9.7 kg CH4/meter/yr. Our data indicate that this nationwide value may be closer to 78.9 kg CH4/meter/yr.

4. Turbine meters were emitting larger amounts of CH4 than rotary and diaphragm meters (indicated by the higher EF), and significant differences were observed in EFs calculated for industrial facilities and commercial facilities.

Marginal Oil & Gas Wells (2021)

GSI ENVIRONMENTAL

Background

- Marginal wells (<15 barrels of oil equivalent (BOE) per day of combined oil and natural gas). More than 1.1 million oil and natural gas wells in the U.S., of which approximately 770,000 (~70%) are considered "marginal"

Key Study Questions

How do marginal vs. non-marginal wells compare in terms of:

- Fugitive methane emission rates?
- Type and quantity of equipment?
- Equipment type/age/condition?
- Hydrocarbon Production rates?
- Frequency/timing of episodic high-emission events?
- Absolute contribution to total emissions?

Three Field Campaigns

- Appalachia: 168 well sites visited with 120 discrete emissions recorded at 72 sites.
- Midwest and Rocky Mountain: 151 well sites were visited with 137 discrete emissions recorded at 57 sites.
- Western US region: 270 well sites were visited with 357 discrete emissions recorded at 124 sites.

Results

- The top 10% of emitting sources contributed 90% of total methane emissions observed
  - 65% of natural gas well sites had no measurable emissions.
  - 75% of oil well sites had no measurable emissions.

1) https://nswa.us/stripper-wells/

NETL – Research Innovation Center GHGI Efforts

Gathering Natural Gas Pipelines in Colorado/Utah/Ohio/New Mexico/Pennsylvania

Measure methane emissions from natural gas pipelines utilizing vehicle-based surveys, unmanned aerial vehicle (UAV) surveys, and handheld emission rate quantification technology.

Orphaned Wells

Locating and estimating the greenhouse gas emissions of orphaned wells utilizing ground-based and aerial-based technologies

Underground Natural Gas Storage Incident Emissions

Estimate emissions at underground natural gas storage locations by determining the correlation between well integrity and anomalous emission events.

Life Cycle Analysis (LCA) Studies

Life Cycle Analysis of Natural Gas Extraction and Power Generation, DOE/NETL-2019/2039
Uncertainty Input Development for Natural Gas Systems in the U.S. GHG Inventory

Gathering NG Pipeline Emissions — PA example

Northwestern Pennsylvania Campaign

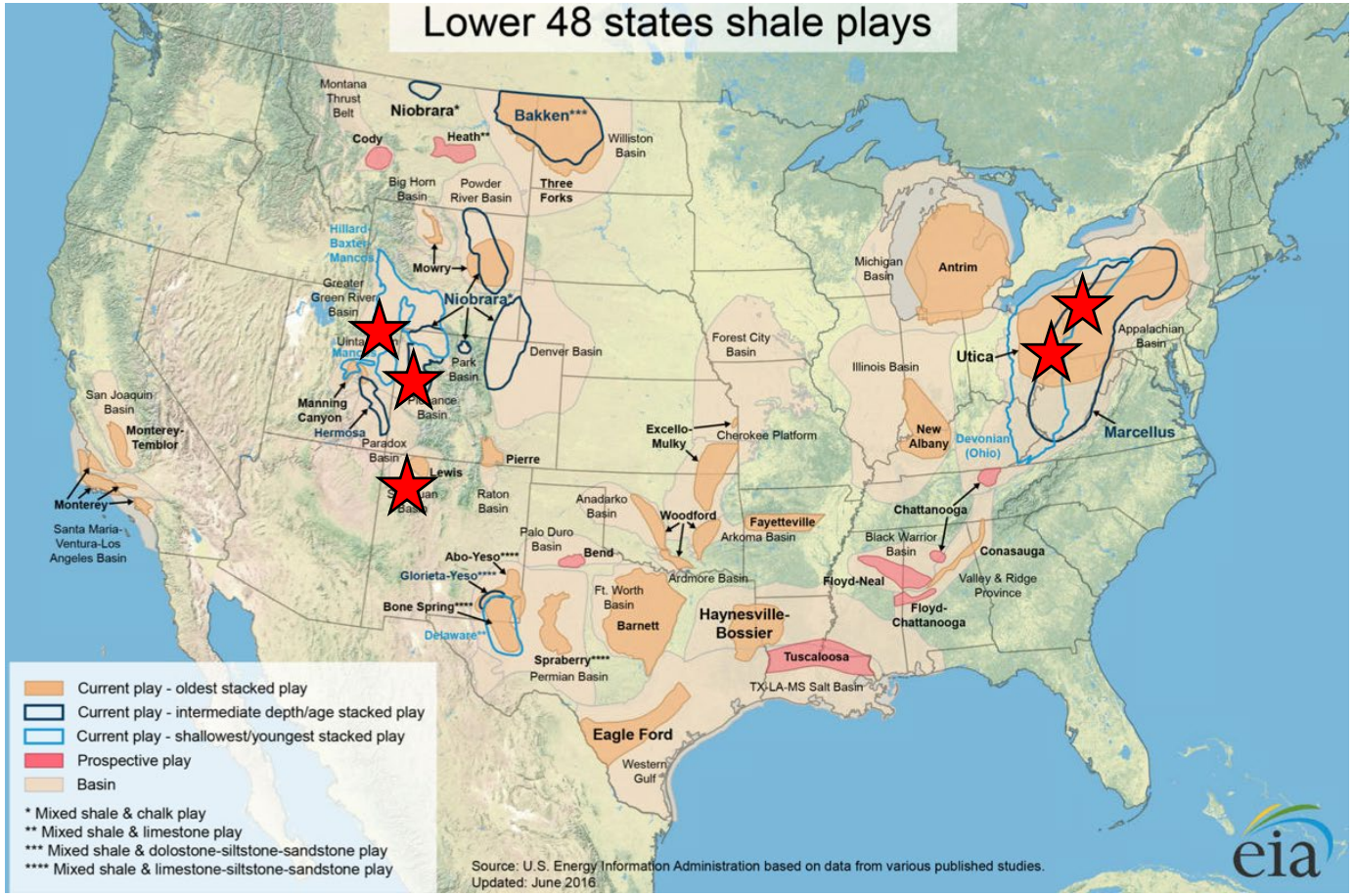
- Natural gas gathering pipeline system at the border of Crawford and Venango County in Northwestern Pennsylvania near Oil Creek State Park.

- Leak surveys were conducted along pipelines that ran parallel to public roads eliminating the need for site owner/operator access approval.

- In EY21-Q3 and Q4 approximately 50-mile of pipelines were surveyed in Venango County using two passes (total of 100 pipeline miles surveyed).
  - No significant pipeline leaks were identified.

- To date, there is insufficient data to calculate an emission factor for natural gas gathering pipelines

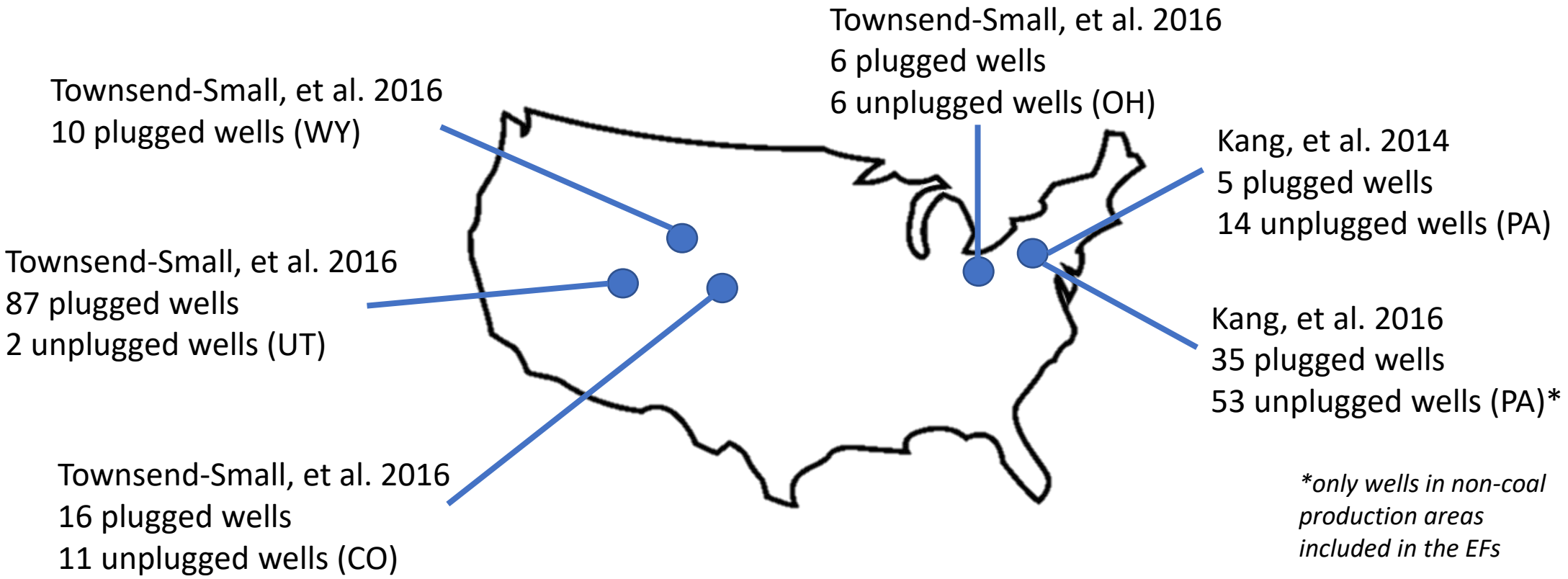
Completed Campaigns



Red stars identify the location of completed field campaigns

Estimating GHG Footprint of Orphaned Wells – EPA GHGI

Abandoned Well Methane Emission Factors: Sample Size and Distribution Across the US



**only wells in non-coal production areas included in the EFs*

Kang M, *et al.* (2014) Direct measurements of methane emissions from abandoned oil and gas wells in Pennsylvania. *Proc Natl Acad Sci USA* 111(51):18173-18177.
Kang M, et al. (2016) Identification and characterization of high methane-emitting abandoned oil and gas wells. *Proc Natl Acad Sci USA* 113 (48) 13636-13641.
Townsend-Small *et al.* (2016) Emissions of coalbed and natural gas methane from abandoned oil and gas wells in the United States. *Geophys Res Lett* https://doi.org/10.1002/2015GL067623.

Estimating GHG Footprint of Orphaned Wells

Abandoned Well Methane Emission Factors: Plugged vs. Unplugged

Table 2. Methane EFs from Townsend-Small et al. Study

Well Category	Number of Measured Wells	Mean (g/h/well)	95% Upper Confidence Limit (g/h/well)
All wells (entire U.S.)	138	1.38	3.17
All wells (eastern U.S.)	12	14.00	32.87
All wells (western U.S.)	126	0.18	0.41
Plugged wells (entire U.S.)	**119**	**0.002**	**0.005**
Unplugged wells (entire U.S.)	**19**	**10.02**	**22.47**
Plugged (eastern U.S.)	6	0	NA
Unplugged (eastern U.S.)	6	28.01	64.00
Plugged (western U.S.)	113	0.002	0.005
Unplugged (western U.S.)	13	1.71	3.83

Bold indicates value used in the 2018 GHGI.

Table 3. Appalachian Basin Methane EFs Developed from Combining Studies

Data Source	Number of Measured Wells	Mean (g/h/well)
Plugged wells		
Kang et al. 2016 – All production types, noncoal areas	23	0.45
Townsend-Small et al. 2016 – Eastern U.S.	6	0
Combined	**29**	**0.36**
Unplugged wells		
Kang et al. 2016 – All production types, noncoal areas	36	31
Townsend-Small et al. 2016 – Eastern U.S.	6	28.01
Combined	**42**	**30.57**

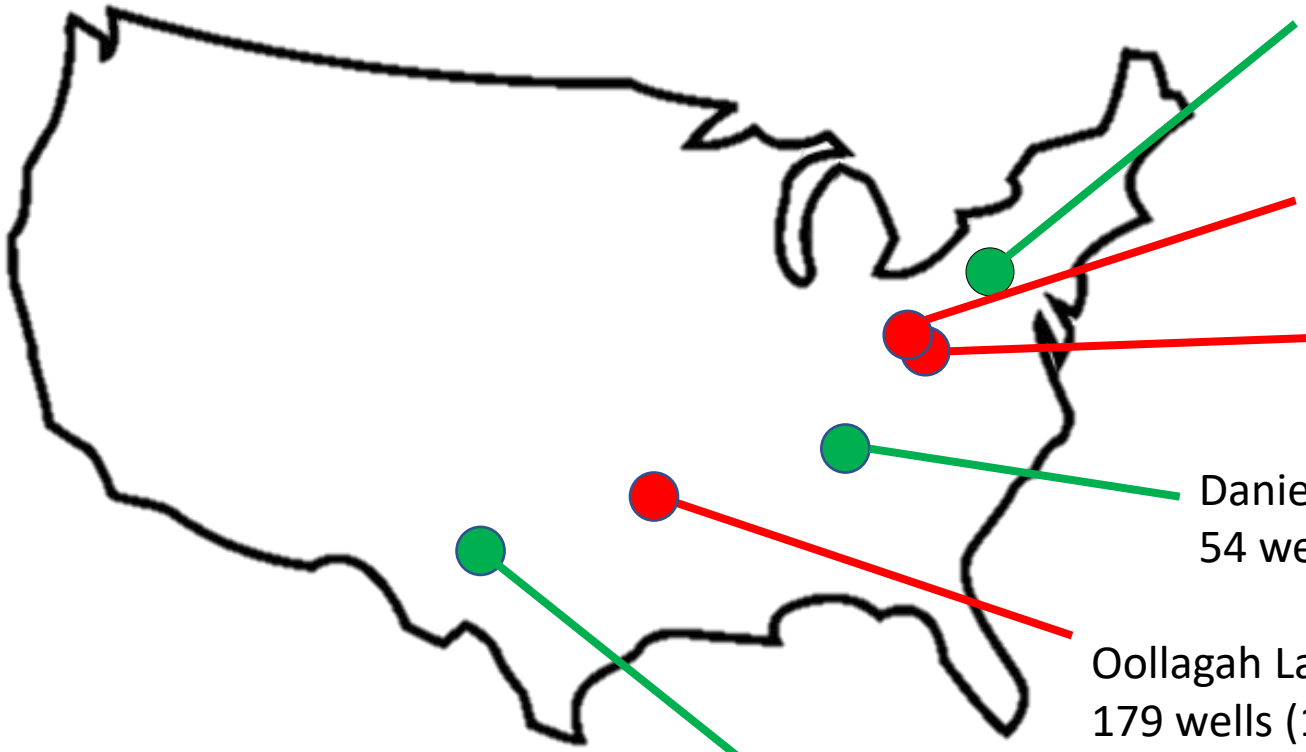
Bold indicates value used in the 2018 GHGI.

Average methane emission rate for unplugged, abandoned wells in the U.S. is 5,000 times more than for plugged wells

https://www.epa.gov/sites/default/files/2018-04/documents/ghgemissions_abandoned_wells.pdf

Estimating GHG Footprint of Orphaned Wells – NETL R&D

Completed (red) and In-progress (green) Study Areas



Private Property near Olean, NY
Approx. 77 wells (21 unplugged/56 plugged)

Oil Creek State Park, PA
138 wells (67 unplugged/71 plugged) (up to 1kg/day)

Hillman State Park, PA
31 wells, all unplugged (up to 4kg/day)

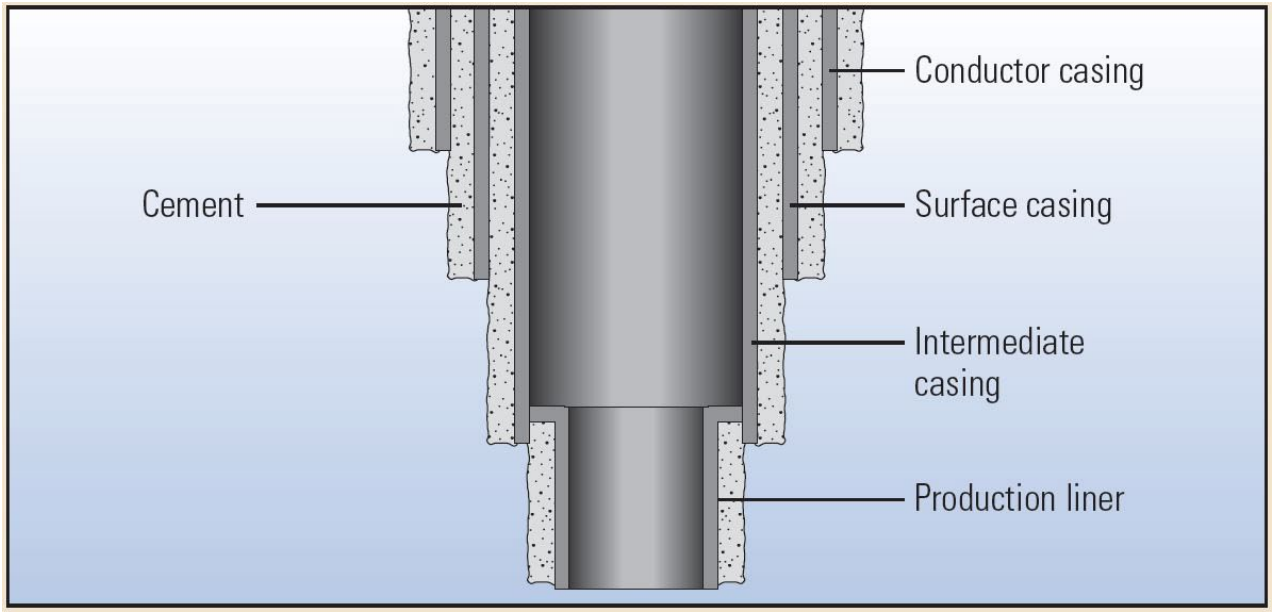
Daniel Boone National Forest, KY
54 wells (53 unplugged/1 plugged)

Oollagah Lake area, OK
179 wells (159 unplugged/20 plugged)

Private Property near Midland, TX
Approx. 100-200 wells, unplugged

Underground NG Storage Incident Emissions

- Currently, there are over 14,000 active storage wells distributed across **388 UGS** fields in the continental U.S.
- Approximately round **200 wells** were constructed before the adoption of the **cement zonal isolation method**.



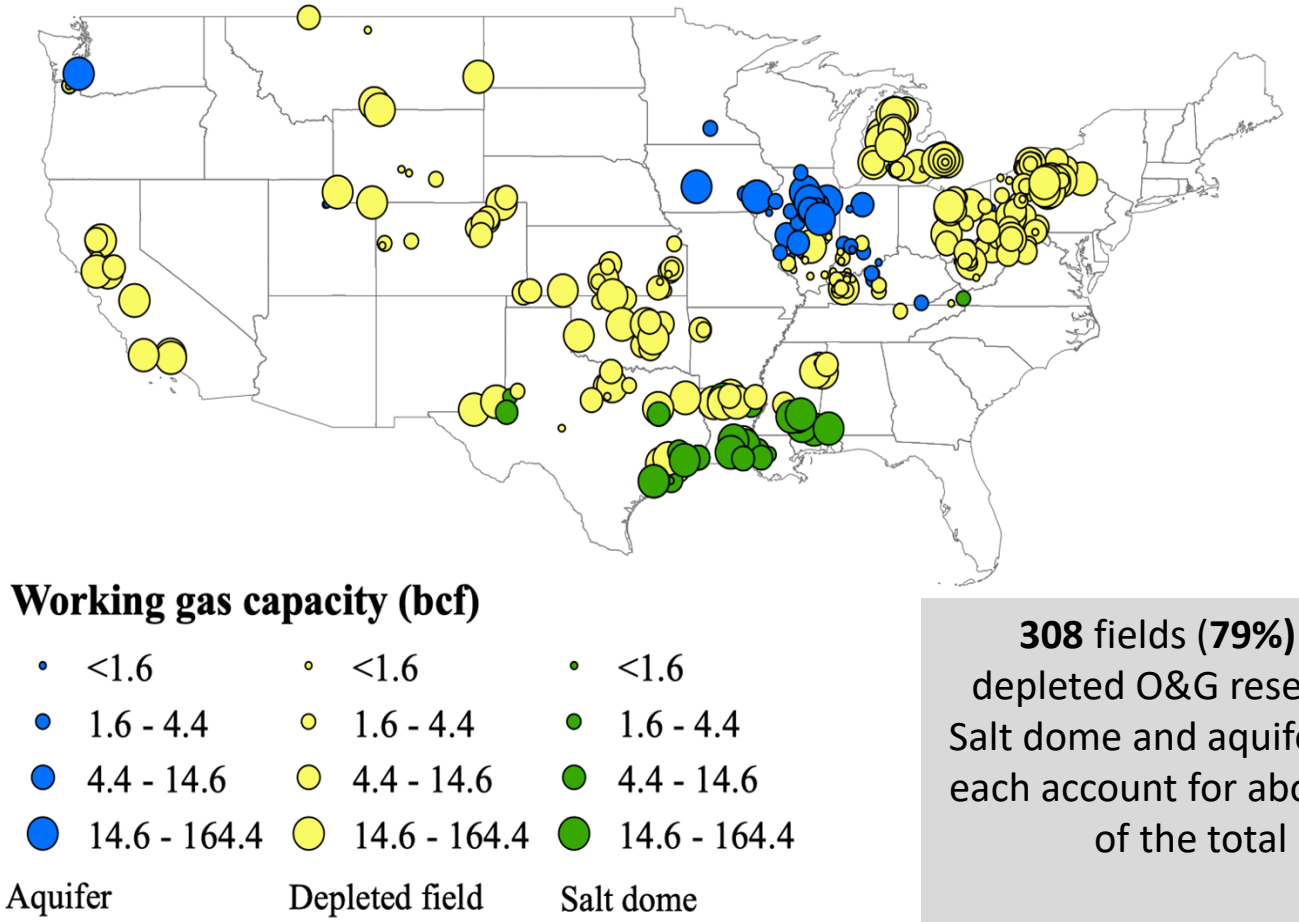
Oilfield Review Summer 2012: 24, no. 2 2012 Schlumberger

- Pre cement adoption wells may have a higher risk in experiencing a similar rupture like Aliso Canyon event.

Underground NG Storage Incident Emissions

The compiled database is largely based on incident records from 1940 to 2016.

- **78** entries were from the **Pipeline and Hazardous Materials Safety Administration** (PHMSA), a DOT agency.
- **51** records from Literature reviews - **Folga et al., 2016**
- **7** records were retrieved based on **FERC Form 576** (FERC, 2020).



308 fields (**79%**) are depleted O&G reservoirs. Salt dome and aquifer fields each account for about **10%** of the total

Underground NG Storage Incident Emissions

PHMSA Incident Distribution & Trends (1984 to 2016)

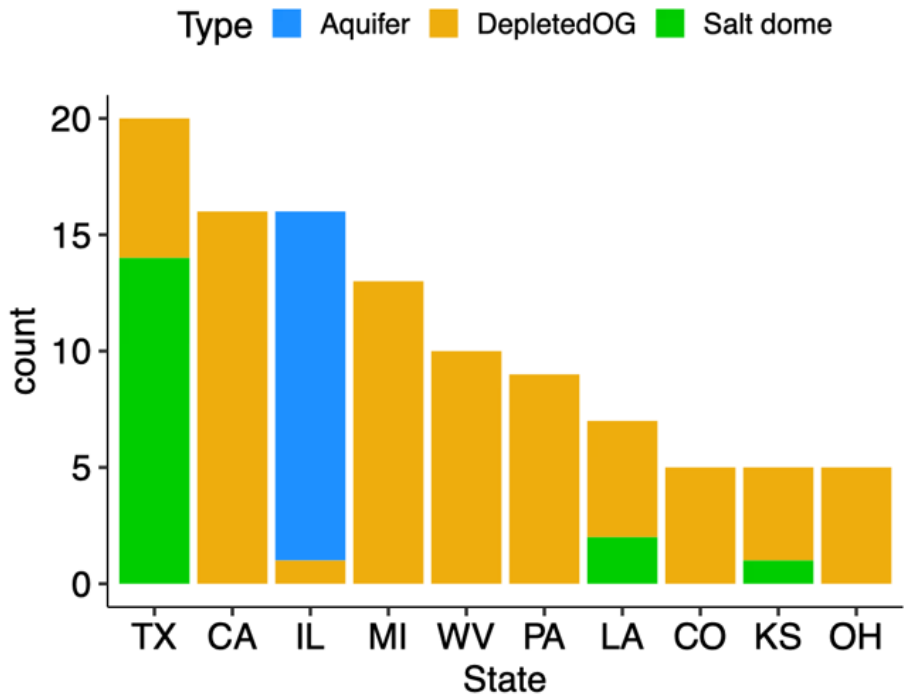
- The most common failure mechanism was corrosion.
- Equipment failure is the second most common cause of failure.

In Progress…

Increasing Data Quality and Decreasing Uncertainty

- Previous emission factor work at NETL used an intuitive method based on fluid mechanics to estimate gas volumes from events with no direct gas loss reported.
- Volumes were determined by multiplying the sonic speed, duration, and cross-sectional area assuming the gas exits at sonic speed.
- However, with this method, emission estimates could deviate from actual values by an order of magnitude.
- Updating NETL UNGS database with post 2016 datasets (collaborating with PHMSA)
- Improving current UNGS emission factor model

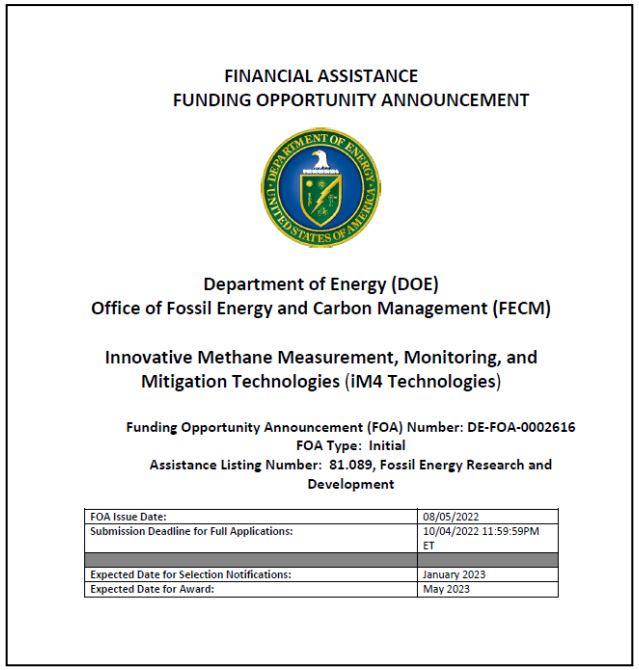
Top 10 States with Highest Number of UGS Incidents



- Texas has the highest number of incidents (20), but also the 3rd highest number of storage fields in any state (30).
- CA ranks 2nd in incident count, with 16 incidents in the dataset.
- IL is distinct from the other states, with all but one incident in the saline aquifers.

Future Work

Methane Measurement, Monitoring, and Mitigation Funding Opportunity Announcement



FINANCIAL ASSISTANCE
FUNDING OPPORTUNITY ANNOUNCEMENT

Department of Energy (DOE)
Office of Fossil Energy and Carbon Management (FECM)

Innovative Methane Measurement, Monitoring, and Mitigation Technologies (iM4 Technologies)

Funding Opportunity Announcement (FOA) Number: DE-FOA-0002616
FOA Type: Initial
Assistance Listing Number: 81.089, Fossil Energy Research and Development

FOA Issue Date:	08/05/2022
Submission Deadline for Full Applications:	10/04/2022 11:59:59PM ET
Expected Date for Selection Notifications:	January 2023
Expected Date for Award:	May 2023

Storage Tank Emissions Assessment and Quantification

The objective is to deliver a scientific basis for enhanced emissions factors and equipment counts to be applied within the EPA GHGI to estimate emissions from storage tanks across the oil and natural gas production sector.

Research includes assessments of the varying tank types, associated equipment, equipment counts and condition, environmental impacts, and user interfaces to develop statistically relevant, defensible conclusions to characterize and quantify methane emissions from storage tanks.

- Regional/basinal based field surveys aimed to better quantify the number of tanks and associated equipment as well as their current conditions, operational status, and operating practices that will be used to improve emissions factors.
- Identification and characterization of the primary sources of methane emissions from storage tanks and their associated equipment, as a function of equipment configuration, equipment condition, and operating conditions (including contents, throughput, pressure and temperature).
- Processes to monitor, quantify, collect, and calculate methane emissions from storage tanks and their associated equipment.

Storage Tank Emissions Assessment and Quantification

Technology developments that are anticipated to result from these R&D efforts include:

- Improve the quality and quantity of data used for EPA's GHGI and other national emission inventories
- More thorough understanding of methane emission sources related to varying types of tanks, tank construction, tank usage, and associated equipment related to tank operations
- Further the understanding of how to integrate technologies, the boundaries of effectiveness, and possible barriers to adoption.
- Statistically relevant, defensible conclusions to characterize and quantify methane emissions from storage tanks.

Specific results that are anticipated by 2024

Methane Quantification

- Projects will develop an enhanced understanding of methane emissions that originate at storage tanks and their associated equipment for the purpose of improving emissions factors for related components and integration within the EPA GHGI.

Appendix

Field Campaign Equipment

VEHICLE-BASED SURVEY

Figure 1: Sample representation of vehicle used for ground-based methane survey

Vehicle- Mounted Equipment	*Function*
Ultraportable Methane/ Acetylene Cavity Ring Down Spectrometer (CRDS)	methane measurements
Ultrasonic Weather Station	wind, pressure, temperature data
R2 GNSS Receiver	GPS unit
Power Inverter	DC to AC
Power Center	GPS, weather station power
DC Power Pack for CRDS	CRDS power
Laptop Computer	datalogger

UAV-BASED SURVEY

Figure 2: DJI Matric 600 UAV used during the survey

UAV- Mounted Equipment	*Function*
Mirage (TDLAS)Tunable Diode Laser Absorption Spectrometer	methane measurements with sensitivity of 0 pmm.m - 40,000 pmm.m
Mirage HC OGI Camera	Methane visualizations
GPS	Geo-location

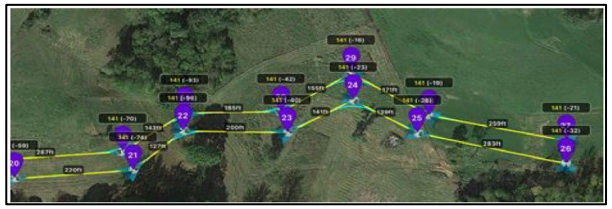


Figure 2: Survey flight lines along the pipeline right-of-way

EMISSION RATE QUANTIFICATION

Figure 3: A Hi-Flow Sampler is used to quantify the leak rate once a leak is identified. *Photo by Jansil Yang, Colorado State University*

Flight Parameters	
UAV	DJI Matric 600
Sensor	TDLAS sensor by Aeris Technologies *
Mileage Surveyed	56 km
Air Speed	3-4.5 m/s
Altitude	42 m- 45 m
Flight Time	Flight Time: 10.5 minutes -18.5 minutes
Flight Plan	Autonomous Litchi 3rd party app
Survey Method	Two passes ~ 6-9 apart

* A DOE ARPA-E's Methane Observation Networks with Innovative Technology to Obtain Reductions (MONITOR) recipient.