Workshop Agenda

12:00pm  Welcome and Overview of DOE FECM Undocumented Well Program
12:15pm  Environmental Defense Fund
12:30pm  Independent Petroleum Association of America
12:40pm  Overview of DOI Documented Well Plugging Program and Data Collection
1:00pm   IOGCC and State Representation Across the United States
1:20pm   Technical Session #1: Defining the Need for Undocumented Orphaned Wells RDD&D
1:55pm   Break
2:10pm   Technical Session #2: Undocumented Well Finding Technologies
2:45pm   Technical Session #3: Undocumented Well Characterization Technologies
3:20pm   Technical Session #4: Outcomes (Framework, Best Practices) Strategy
3:55pm   Closing Remarks
4:00pm   Adjourn
Undocumented Orphaned Wells Program Overview

Tim Reinhardt
April 5, 2022
Conduct research and development activities in cooperation with the Interstate Oil and Gas Compact Commission to assist the Federal Land Management Agencies, States, and Indian Tribes in--

(A) identifying and characterizing undocumented orphaned wells; and
(B) mitigating the environmental risks of undocumented orphaned wells;

DOE’s Undocumented Orphaned Well Program will be executed over 5 years with $30M in appropriated budget.
Need for Identification and Characterization

• It is estimated that there are hundreds of thousands of undocumented orphaned wells in the U.S. that need to be located.¹

• Total estimated number of undocumented orphaned wells reported by the states is between 310,000 and 800,000.²

• According to a 2015 study cited by the EPA, unplugged wells leaked significantly more methane than plugged wells.³

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1) Management of Abandoned and Orphaned Oil and Gas Wells, The American Association for the Advancement of Science
Undocumented Orphaned Well Program Focus

Bipartisan Infrastructure Law Abandoned Well Scope

**DOE/FECM ($30M)**
- Well Finding
- Identification
- Characterization

“Conduct R&D in cooperation with IOGCC”

“assist the Federal land management agencies, States, and Indian Tribes in--
(A) identifying and characterizing **undocumented** orphaned wells”
(B) mitigating the environmental risks of undocumented orphaned wells

**Federal/States/Tribes ($4.7B)**
- Well Plugging Programs
  - Inventorying
  - Ranking Prioritization
  - Plugging
  - Remediation
  - Reclamation
  - Well Sites
  - Pipelines
  - Human Health
  - Other (see BIL)
**DOE Undocumented Orphaned Well Program Focus**

**Undocumented**  
*DOE Supported R&D*
- Remote Sensing
- Data Analytics
- Advanced Sensors & Monitoring
- Geophysical Characterization

**Identification & Characterization R&D Example**

**Location**
- Ownership

**Well Construction**
- Surface Equipment

**Air Emissions**

**Water Impact**

**Documented**  
*Fed and State Supported P&A*
- Assessment
- Plugging
- Surface Reclamation

**Undocumented Well** – Refers to a well that is entirely unknown to the agency or a well of which the agency has some evidence, but which requires further records research or field investigation for verification.

**Documented Well** – Refers to a well for which the regulatory agency has a drilling report, completion report, inspection report, or other record establishing the existence of the well.
Key Partnerships and Stakeholders

**National Laboratories**
- Data Analytics/Machine Learning (critical to disparate datasets).
- Well characterization (subsurface and surface).
- Experience with detecting and characterizing undocumented wells.
- **NLs** will be critical in identifying existing and new technology pathways.

**IOGCC (States)**
- **IOGCC** will collaborate with individual State Agencies to gain critical insight into best practices and technology development needs.
- **IOGCC** will develop and maintain a list of critical points of contact within the **States** and assist in maintaining effective communications.

**Department of the Interior**
- Understanding the technology needs and estimation of undocumented orphaned wells.
- Collaborate with **IOGCC** to ensure effective communications and project engagement.
- Conduct critical identification and characterization of undocumented orphaned wells on Federal Lands.
Next Steps for Program Development and Implementation

**Develop and Refine Program Structure**

- Leverage lead National Laboratory (Los Alamos) to establish team objectives and external engagements.
- Align core capabilities of National Laboratory team to develop preliminary program plan.

**Implementation**

- Engage state regulators to determine critical RDD&D needs.
- Complete evaluation of existing identification and characterization technologies.
- Establish framework for DOE-lead workshop.
Questions

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Documented Orphan Wells in the US

As of Fall 2021
Bipartisan Infrastructure Law:
Legacy Pollution Remediation & Reclamation Program

April 2022
What is the Legacy Pollution Remediation & Reclamation Program?

The Bipartisan Infrastructure Law (IIJA) Includes:

- **Orphaned Well Site Plugging, Remediation, & Restoration (40601)**
  - $4.677 billion total (OEPC & BLM)

- **Abandoned Coal Mine Reclamation (40701)**
  - $11.3 billion (OSMRE)

- **Abandoned Hardrock Mine Reclamation Section (40704)**
  - Establishes a program to address physical safety & contamination at abandoned hardrock (non-coal) mines
  - Authorizes $3.0 billion (50/50 Feds/States&Tribes)
  - *No appropriations provided in BIL*
  - FY22 budget provides start-up funding (OEPC)
What is the Orphaned Well Program?

Title VI – Methane Reduction Infrastructure, Section 40601
Orphaned Well Site Plugging, Remediation, & Restoration
• $4.677 billion total
• Expires 9/30/2030

1. State and Tribal Grant Program – OEPC Lead
   • $4.3 billion for State and private lands [91.4%]
   • $150 million for work on Tribal lands [3.2%]

2. Federal Program – BLM Lead
   • BLM, NPS, FWS, BOEM, USFS
   • $250 million
What is the ECRP?

Benefits of properly closing orphaned wells:

• Remove health & safety hazards
• Reduce methane & other GHG emissions
• Cleanup surface water & groundwater contamination
• Restore habitat
• Create jobs, particularly in disproportionately impacted communities
• with respect to **Federal land or Tribal land** = a well...

1. that is not used for an authorized purpose, such as production, injection, or monitoring; and
2. for which no operator can be located;
3. the operator of which is unable—
   a. to plug the well; and
   b. to remediate and reclaim the well site; or
   c. that is within the National Petroleum Reserve AK

• with respect to **State or private land** –

1. has the meaning given the term by the applicable State; or
2. if that State uses different terminology, has the meaning given another term used by the State to describe a well eligible for plugging, remediation, and reclamation by the State.
Definitions – Documented, Undocumented

• Terms not defined in BIL

• IOGCC definitions (emphasis added):

  Documented - a well for which the regulatory agency has a drilling report, completion report, inspection report, or other record establishing the existence of the well.

  Undocumented – a well that is entirely unknown to the agency or a well of which the agency has some evidence, but which requires further records research or field investigation for verification.
1. **Plug, remediate, & reclaim** orphaned wells
2. **Identify and characterize** *undocumented* orphaned wells
3. **Rank** orphaned wells based on factors including, public health / safety, potential environmental harm, & other land use priorities
4. Make information available on a **public website**
5. **Measure and track** –
   - emissions of **methane** and other gases associated with orphaned wells
   - **contamination** of groundwater or surface water
6. Remediate soil & **restore native species habitat** that has been degraded due to the presence of orphaned wells & associated pipelines, facilities, infrastructure
7. Remediate land adjacent to orphaned wells and decommission or remove associated **pipelines, facilities, infrastructure**
8. Identify and address any **disproportionate burden** of adverse human health or environmental effects of orphaned wells on disadvantaged communities, including communities of color, low-income communities, and Tribal & indigenous communities
State Grants

• Initial Grant ($775M)
  1. Large-scale – up to $25M
     • May 13, 2022 application deadline
  2. Small-scale – up to $5M (capacity)

• Formula Grant ($2B)
  1. Job losses in O&G industry
  2. # documented orphaned wells
  3. Cost of plugging, reclamation, etc
     • December 31, 2021 - NOI deadline (26)
     • January 31, 2022 - eligibility published

• Performance Grants ($1.5B)
  1. Matching Grants
  2. Regulatory Improvements Grants
Tribal Well Options

Direct Grant
- 5 years to obligate
- One of two approaches
  - Competitive Grant
  - Formula Grant

or

In Lieu of a Grant
- Tribe requests that DOI perform well closure on behalf of the Tribe
Federal Program

- Federal Land = USDOI & USDA
  1. BLM
  2. NPS
  3. USFWS
  4. BOEM
  5. USFS

- Technical Working Group
  - Matrix, Methane, GW/SW, EJ subgroups

- Shall Prioritize (scoring matrix):
  1. Public health and safety
  2. Potential environmental harm
  3. Other subsurface impacts or land use priorities
  4. Disproportionate burden (~EJ)

- Slate of FY22 project awaiting funds
1. Updated inventory of wells located on Federal, Tribal, State & private lands that are—
   a. orphaned wells (OW) or
   b. at risk of becoming OW

2. Estimate of the quantities of—
   a. methane & other gasses emitted from OW
   b. emissions reduced as a result of plugging, remediating, and reclaiming OW

3. # jobs created, jobs saved through the plugging, remediation, & reclamation of OW

4. Acreage of habitat restored, with a description of the purposes for which that land is likely to be used
Contacts & Resources

• DOI Infrastructure Site
  
  www.doi.gov/priorities/investing-americas-infrastructure

• State & Tribal Grants Program
  
  Orphanedwells@ios.doi.gov
  
  www.doi.gov/oepc/legacy-pollution-remediation-and-reclamation

• Federal Well Program
  
  Orphanedwells@blm.gov
  
Challenges

• Information on orphaned wells is difficult to obtain

• Some information that DOI needs is not available, requires new science to develop, and will change over time

• Additional information required under the BIL requires synthesis and analysis of well-specific and Program-level information
What are Orphaned Wells?

- Orphan well – an unplugged idle oil or gas well for which the operator is unknown or insolvent
  - Interstate Oil and Gas Compact Commission (IOGCC, 2021)
- Abandoned well – an oil or gas well with no recent production, often implies well was plugged
  - Environmental Protection Agency (2022)
- IOGCC estimates 310,000-800,000 **undocumented unplugged** orphan wells in 21 participating states in 2020

<table>
<thead>
<tr>
<th>Term used</th>
<th>State</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shut In</td>
<td>AL*, NE*, NV*</td>
</tr>
<tr>
<td>Orphan</td>
<td>AK, AR, CA*, CO, IN,</td>
</tr>
<tr>
<td></td>
<td>KY, LA, MI, MS*, NM,</td>
</tr>
<tr>
<td></td>
<td>OK, TX, UT AR, PA, WY</td>
</tr>
<tr>
<td>Deserted, Potentially Deserted</td>
<td>CA*</td>
</tr>
<tr>
<td>Temporarily Abandoned</td>
<td>IL</td>
</tr>
<tr>
<td>Abandoned</td>
<td>AL*, KS, NE*, NV*, ND, PA, WV</td>
</tr>
<tr>
<td>Potential Orphan</td>
<td>MS*</td>
</tr>
<tr>
<td>Unknown, Unknown Not Located</td>
<td>NY*</td>
</tr>
<tr>
<td>Unknown Located</td>
<td></td>
</tr>
<tr>
<td>Orphan Ready, Orphan Pending</td>
<td>OH*</td>
</tr>
<tr>
<td>Forfeited</td>
<td>TN</td>
</tr>
</tbody>
</table>

*States that use multiple terms to refer to orphaned wells*
Many potential sources for basic information

- USGS-led effort to gather stakeholder input identified many tools, but no single “best” tool
- Any effort to draw from these databases will need to:
  - Recognize different terminologies and definitions
  - Accommodate and interact with the unique data structures within each system
- A separate USGS-led effort to collect publicly available information on orphaned wells illustrates some of the challenges
• USGS compiled data from 27 States
• Only publicly available data compiled
• Targeted 10 parameters, included any well in the dataset that has at least an API# and well location
• A 14-month effort (to date)

Map of States with wells included in the USGS database
• Currently in quality control phase. Not yet finalized.
• 79,072 documented unplugged orphan wells from 27 states
• 77,647 wells with location coordinates
  • Final numbers pending QC work
• Data received from States in 2019-2022
## Comparison to existing data

<table>
<thead>
<tr>
<th>Agency</th>
<th>States</th>
<th>Well count</th>
<th>Well location</th>
<th>Publicly available</th>
</tr>
</thead>
<tbody>
<tr>
<td>U.S. Geological Survey</td>
<td>27</td>
<td>79,072</td>
<td>77,647</td>
<td>Summer 2022</td>
</tr>
<tr>
<td><a href="https://www.usgs.gov">dataset under review</a></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Environmental Defense Fund &amp; McGill University</td>
<td>28</td>
<td>81,283</td>
<td>77,839</td>
<td>Not currently</td>
</tr>
<tr>
<td>Interstate Oil and Gas Compact Commission</td>
<td>32</td>
<td>92,198</td>
<td>0</td>
<td>No</td>
</tr>
<tr>
<td>Bipartisan Infrastructure Law: Notices of Intent to Apply to DOI for a</td>
<td>26</td>
<td>128,846</td>
<td>0</td>
<td>No</td>
</tr>
<tr>
<td>formula Grant to Plug State and Orphan Wells</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. Environmental Defense Fund/McGill University, 2021
2. IOGCC, 2021
## Preliminary data structures for a DOI orphaned wells data system

<table>
<thead>
<tr>
<th>Well-specific data fields potentially available from one or more existing systems</th>
<th>New data requirements (fields not currently or consistently available)</th>
<th>New synthesis data requirements (Program-level; not well-specific)</th>
</tr>
</thead>
<tbody>
<tr>
<td>API well identifier</td>
<td>Subsurface managing entities</td>
<td>Jobs created</td>
</tr>
<tr>
<td>~14 parameters related to well type, status, location, and surface managing entity</td>
<td>~18 parameters related to pre- and post-plugging impacts of the well, including methane emissions, habitat impacts, surface and ground water contamination, community impacts)</td>
<td>Jobs saved</td>
</tr>
<tr>
<td></td>
<td>Costs of plugging and remediation</td>
<td>At-risk wells</td>
</tr>
</tbody>
</table>
New information needs and related science

- Methane emissions for orphaned wells (pre- and post-plugging)

- Newly funded USGS exploratory project “Identifying Fugitive Methane Emission Factors in Orphaned Oil & Gas Wells”

- Habitats affected / habitat restored
  - USGS/BLM partnership: “Surface Disturbance Analysis and Reclamation Tracking Tool (SDARTT)”
  - Active research on how to successfully and efficiently achieve reclamation success across different ecological sites

- Surface and ground water impacts

- Ongoing, multi-year study of brine contamination from development in the Plains and Prairie Potholes region
Identifying Fugitive Methane Emission Factors in Orphaned Oil and Gas Wells

• USGS is working to identify geologic and drilling factors that contribute to fugitive methane emissions.

• Why do some orphaned wells emit methane while others do not?

• What geologic and/or drilling conditions enable the highest methane emitters?

• Can we establish a correlation between methane emissions and geologic factors, drilling history, or petroleum production?
Bringing subsurface expertise to the challenge of estimating emissions

- Methane Emissions
- Well Information: Date, Type, Operator
- Production History
- Stratigraphy
- Permeability / Porosity
- Other Formations
- Pressure and Temperature
- Producing Formation

Corresponding USGS Assessments

Not to Scale.
Benefits of this work

- Refining fugitive methane emission factors would provide the multi-agency Orphaned Well Program a geologic context for the prioritization of orphaned wells on state, tribal, and federal lands.
- States receiving grant money would benefit from a deeper understanding of emissions factors to help identify the highest emitting wells.
- Improved understanding of fugitive methane sources can inform policy on methane emissions and implementation of greenhouse gas management.
Connections between DOE and DOI

• DOE focus is on undocumented wells; DOI focus is on “known” orphaned wells

• Once undocumented wells are located, they become “known” and may become candidates for DOI support for plugging, remediating and restoring orphaned wells

• It would be very useful to DOI if DOE data collection on undocumented wells included the same data parameters needed for the DOI data system
Connections between DOE and DOI (2)

• Results from DOI tools (existing and under development) for quantifying impacts from “known” orphaned wells could provide useful information for detection approaches that DOE may develop

• For example
  • Estimates of methane emissions from abandoned wells could be used with broad-scale methane detection to identify sources likely to be wells
  • Understanding the scale and type of habitat disturbance around abandoned wells could feed pattern recognition tools for finding undocumented wells based on land imaging
  • Data on the type and the spatial extent of water contamination associated with known wells could inform the use of existing or newly sampled water quality data to identify undocumented sites
Undocumented Orphaned Wells Workshop

Natalie Pekney, NETL and the National Laboratories Consortium

Technical Session #1 Defining the Need for Undocumented Orphaned Well RDD&D
Undocumented Orphaned Wells

*U.S. Oil and Gas Drilling Started in 1859 – Poor Recordkeeping for Decades*

Photos Courtesy of the Drake Well Museum and Park Collection
How Many Orphaned Wells are there in the U.S.?

Orphaned Wells Activity Level: Documented vs. Undocumented Wells

Number of Documented Orphaned Wells by State
Total: 131,227

How Many Orphaned Wells are there in the U.S.?

**Orphaned Wells Activity Level: Documented vs. Undocumented Wells**

- IOGCC Estimates of Undocumented Orphaned Wells: Between 310,000 and 800,000 as reported by the states[^1]
- EPA: The GHGI uses Enverus (DrillingInfo, [www.enverus.com](http://www.enverus.com)) for wells with added estimate of number of wells not included in Enverus dataset[^2]
  - The U.S. population of abandoned wells is around 3.5 million (with around 2.9 million abandoned oil wells and 0.6 million abandoned gas wells).
  - Comparing the counts (i.e. 1.93 million abandoned wells from analysis of historical records and USGS data, and 776,000 abandoned wells in the DrillingInfo database), EPA estimates that **1.15 million** abandoned wells in the U.S. are not captured in the DrillingInfo-based methodology.

Estimating GHG Footprint of Orphaned Wells

**EPA's Inclusion of Abandoned Oil and Gas Wells into the Greenhouse Gas Inventory**

The US EPA began including abandoned wells as a GHG Emissions source in 2018 (2016 GHGI)

From the Inventory:

The term "abandoned wells" encompasses various types of wells:

- Wells with no recent production, and not plugged. Common terms (such as those used in state databases) might include: inactive, temporarily abandoned, shut-in, dormant, and idle.

- Wells with no recent production and no responsible operator. Common terms might include: orphaned, deserted, long-term idle, and abandoned.

- Wells that have been plugged to prevent migration of gas or fluids.

The GHGI estimates methane emissions from abandoned wells by multiplying emission factors (mass of methane emitted per well) by activity levels (number of wells)

**Significant uncertainty in both Emission Factors and Activity Levels**

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Estimating GHG Footprint of Orphaned Wells

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

10 plugged wells (WY)
87 plugged wells
2 unplugged wells (UT)
16 plugged wells
11 unplugged wells (CO)

Kang, et al. 2014
5 plugged wells
14 unplugged wells (PA)

35 plugged wells
53 unplugged wells (PA)*

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

Estimating GHG Footprint of Orphaned Wells

Abandoned Well Methane Emission Factors: Plugged vs. Unplugged

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

<table>
<thead>
<tr>
<th>Well Category</th>
<th>Number of Measured Wells</th>
<th>Mean (g/h/well)</th>
<th>95% Upper Confidence Limit (g/h/well)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All wells (entire U.S.)</td>
<td>138</td>
<td>1.38</td>
<td>3.17</td>
</tr>
<tr>
<td>All wells (eastern U.S.)</td>
<td>12</td>
<td>14.00</td>
<td>32.87</td>
</tr>
<tr>
<td>All wells (western U.S.)</td>
<td>125</td>
<td>0.18</td>
<td>0.41</td>
</tr>
<tr>
<td>Plugged wells (entire U.S.)</td>
<td>119</td>
<td>0.002</td>
<td>0.005</td>
</tr>
<tr>
<td>Unplugged wells (entire U.S.)</td>
<td>19</td>
<td>10.02</td>
<td>22.47</td>
</tr>
<tr>
<td>Plugged (eastern U.S.)</td>
<td>6</td>
<td>0</td>
<td>NA</td>
</tr>
<tr>
<td>Unplugged (eastern U.S.)</td>
<td>6</td>
<td>28.01</td>
<td>64.00</td>
</tr>
<tr>
<td>Plugged (western U.S.)</td>
<td>113</td>
<td>0.002</td>
<td>0.005</td>
</tr>
<tr>
<td>Unplugged (western U.S.)</td>
<td>13</td>
<td>1.71</td>
<td>3.83</td>
</tr>
</tbody>
</table>

Bold indicates value used in the 2018 GHG.

Table 3. Appalachian Basin Methane EFs Developed from Combining Studies

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

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

Estimating GHG Footprint of Orphaned Wells

Abandoned Well Methane Emission Factors: Fat-tailed Distribution Characterized by “Super Emitters”
Estimating GHG Footprint of Orphaned Wells

Abandoned Well Methane Emission Factors: Fat-tailed Distribution Characterized by “Super Emitters”

Hillman State Park, PA: No plugged wells

Daniel Boone National Forest, KY: No plugged wells

Oil Creek State Park, PA

Oolagah Lake Area, OK
Major Challenge: Finding Undocumented Orphaned Wells

Aerial Magnetic Surveying Approaches for Finding Undocumented Wells
Major Challenge: Finding Undocumented Orphaned Wells

Aerial LiDAR Surveying Approaches for Finding Undocumented Wells
Orphaned Well Potential Hazards

*Improved Well Characterization Aids in Strategizing Mitigation Approach*

- **Proximal**
  - **Human Receptors**
    - Stray gas/oil/brine in or near buildings
    - Gas/oil/brine in water supply
    - Near groundwater supply
    - Agricultural – on land used for crops or pasture
  - **Ecological Receptors**
    - Distance to (or in) streams, water bodies, swamps, wetlands
    - Near Endangered/threatened/protected species (plants and animals)
Orphaned Well Potential Hazards

Proximal, Biological

• Leaks
  • Methane
  • H₂S
  • NORM
• Well Integrity
  • Wellhead pressure, leaks outside surface casing
• Physical Hazards
  • Open pits, instability
• Coal/Mining Issues
  • Wells within underground mine
Detection and Measurement of Methane Emissions from Orphaned Wells

Variety of Well Configurations Makes Measurement a Challenge: One Approach Does Not Work at All Wells

Chosen Approach Depends on Need: Qualitative vs. Quantitative

Evaluation Criteria

• Cost
• Time
• Accuracy/Limit of Detection
• Ease of use/Field portability
• Skill level/training required
• Effectiveness for any/many well types
Detection and Measurement of Methane Emissions from Orphaned Wells

Published Emission Rates Based on High Flow Sampling or Flux Chamber Approaches

Chamber: Flux = Flow Rate * (C_{out} – C_{in})/Area
Bag: Emission Rate = Flow Rate * (C_{out} – C_{in})
Available Resources for Mitigation

**State Agencies’ Well Plugging Programs**

- Median cost of plugging and reclaiming a well is $76,000, although that figure can vary widely depending on the age, location, well depth, and other key factors.¹

- Using estimates from a 2021 Government Accountability Office report, the cost of plugging all 130,000 documented orphaned wells could range from $2.6 billion to nearly $19 billion.

- **Undocumented** wells: IOGCC estimates 310,000 – 800,000; EPA estimates 1.15 million

- **Infrastructure Investment and Jobs Act Funds** to supplement states’ existing well plugging programs: $4.7 Billion to plug and reclaim orphaned and abandoned wells

- Non-profit organizations working to locate, document, and plug orphaned wells

Prioritizing Well Plugging

Optimizing Reductions in Hazards with Available Resources

• Rapid regional assessments to locate and characterize undocumented wells (and improve documented well data)
• Strategies for targeting high-priority wells for plugging
• Tools/technologies for continued future assessments and monitoring
Research Technology Areas

DOE Multi-Lab Research Effort Focused on Developing New Tools, Technologies and Processes for Robust, Efficient Identification and Characterization of Undocumented Orphaned Wells

• Methane Detection and Quantification
• Magnetics and Electromagnetics
• Sensor Fusion and Data with Machine Learning
• Characterization
• Integration and Real-Time Best Practices
BREAK
We will resume the workshop at 2:15 PM ET
Undocumented Orphaned Wells Workshop

Technical Session #2
Undocumented Well Finding Technologies

Brian Wihl (Lawrence Livermore National Lab)
and the National Laboratories consortium
Outline

- Motivation
- Challenges
- Current state-of-the-art sensing technologies
- Sensor suitability
- Success metric
Well Identification - Motivation

- Orphaned wells can provide pathways for subsurface fluid migration, leading to groundwater contamination and methane emissions to the atmosphere.
- It is important to identify the characteristics of orphaned wells that lead to high methane emissions for prioritized mitigation (plugging).
- Before wells can be characterized to a high degree, they must be found and identified to queue other technologies.
Well Identification - Challenges

• Non-uniform features (surface and sub-surface)
• Challenging environments
• Requires wide area search
Well Identification – Current Sensing Technologies Ready For Application

• Sensor Technologies:
  • High resolution 3D stereo vision camera
  • Hyperspectral imaging (visible and infrared)
  • Magnetometer (magnetic gradiometer)
  • LIDAR
  • Ground Penetrating Radar
  • Gas detectors (methane)
• Sensor Fusion:
  • Machine learning and traditional sensor fusion techniques
  • Signal processing to create physically meaningful data products for each sensor technology
  • Visualization of data layers and fused results
• Vehicle Integration:
  • Unmanned Aerial Systems (UAS)
  • Manned aircraft
  • Unmanned Ground Vehicles (UGV)
  • Handheld/wearables
Well Identification – Current Sensing Technologies Ready For Application

High resolution 3D stereo vision camera:
• Low-weight
• Low-power
• High scan speed
• Medium standoff
• Depth and optical imagery

Detects surface features and structures
Well Identification – Sensing Technologies Ready For Application

Hyperspectral imaging:
- Heavy-weight
- Medium-power
- Slow scan speed
- High standoff
- Spectrum response of surface

Detects surface features and materials
Well Identification – Sensing Technologies Ready For Application

Magnetometer:
- Medium-weight
- Low-power
- Medium scan speed
- Low standoff
- Magnetic fluctuations/features

Detects wells with ferrous materials
Well Identification – Sensing Technologies Ready For Application

LIDAR:
• Medium-weight
• Low-power
• Medium scan speed
• High standoff
• Depth imagery

Detects surface structures
Well Identification – Sensing Technologies Ready For Application

Ground Penetrating Radar:
- Heavy-weight
- Low-power
- Low scan speed
- Low standoff
- Subsurface imagery

MiRadar systems enable smarter threat-detection strategies and improved troop safety.

- MODULAR
  Small, low-power arrays mount on any vehicle

- SIMPLE TO USE
  Intuitive displays require little training

- AUTOMATIC ALERTS
  Allows fast detection and unmanned operations

- BRIDGE SCANNING
  Inspects integrity of concrete structures

D deteces subsurface features

LLNL MiRadar Systems
Well Identification – Sensing Technologies Ready For Application

Gas Detector (Methane):
• Light-weight
• Low-power
• High scan speed
• Medium/High standoff
• Methane gas concentration

Detects methane emitting wells
Well Identification – Technology Suitability Process

Develop Technology Metrics:
- Detections score:
  - Percentage of wells associated with technology
  - Directivity of detection method
    - Primary features: well structure
    - Secondary features: supporting structures
    - Tertiary features: process/environmental
- Standoff (ft)
- Scan speed (rate of progress, ft/s)
- Processing requirements (TFLOPS)
- Size (cubic in)
- Weight (lbs.)
- Power (W)
- Cost ($)

Based on requirements, goals, and specifications – can be different for each phase (identification vs. characterization)

Interaction between Stakeholders and technology developers is key to developing meaningful metrics to drive sensor selection.
### Well Identification – Technology Suitability Process

<table>
<thead>
<tr>
<th></th>
<th>Stereo Camera</th>
<th>HSI Camera</th>
<th>Magnetometer</th>
<th>LIDAR</th>
<th>GPR</th>
<th>Gas Detector</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detection Score</td>
<td>0.19</td>
<td>0.28</td>
<td>0.39</td>
<td>0.05</td>
<td>0.72</td>
<td>0.01</td>
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<tr>
<td>Percentage of wells</td>
<td>1</td>
<td>1</td>
<td>.5</td>
<td>.5</td>
<td>1</td>
<td>.1</td>
</tr>
<tr>
<td>Directivity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Primary Quality</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Secondary Quality</td>
<td>0.5</td>
<td>0.75</td>
<td>0.5</td>
<td>0.25</td>
<td>0.25</td>
<td>0</td>
</tr>
<tr>
<td>Tertiary Quality</td>
<td>0.5</td>
<td>0.75</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
<td>1</td>
</tr>
<tr>
<td>Standoff (ft)</td>
<td>100</td>
<td>300</td>
<td>30</td>
<td>300</td>
<td>3</td>
<td>300</td>
</tr>
<tr>
<td>Scan speed (ft/s)</td>
<td>30</td>
<td>15</td>
<td>10</td>
<td>15</td>
<td>10</td>
<td>30</td>
</tr>
<tr>
<td>Processing Requirement</td>
<td>2</td>
<td>30</td>
<td>1</td>
<td>1</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>(TFLOPS)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Size (in^3)</td>
<td>9</td>
<td>54</td>
<td>864</td>
<td>64</td>
<td>6480</td>
<td>12</td>
</tr>
<tr>
<td>Weight (lbs.)</td>
<td>0.37</td>
<td>1.5</td>
<td>4</td>
<td>2</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>Power (Watts)</td>
<td>2</td>
<td>20</td>
<td>5</td>
<td>10</td>
<td>20</td>
<td>.5</td>
</tr>
<tr>
<td>Cost ($)</td>
<td>500</td>
<td>30000</td>
<td>20000</td>
<td>5000</td>
<td>30000</td>
<td>1000</td>
</tr>
</tbody>
</table>

*Representative estimates, not actual/real

Technology developers grade each technology based on metrics
Well Identification – Technology Suitability Process

Utilize multiple sensor modalities and latest sensor fusion algorithms – use stakeholder metrics to optimize sensor solution

<table>
<thead>
<tr>
<th>Metric Weight</th>
<th>Detection Score</th>
<th>Standoff</th>
<th>Scan Speed</th>
<th>Processing</th>
<th>Size</th>
<th>Weight</th>
<th>Power</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.26</td>
<td>0.19</td>
<td>0.13</td>
<td>0.07</td>
<td>0.07</td>
<td>0.1</td>
<td>0.07</td>
<td>0.13</td>
<td></td>
</tr>
</tbody>
</table>

Utility = (Detection Score * 0.26) + (Standoff * 0.19) + (Scan Speed * 0.13) + (Processing * 0.07) + (Size * 0.07) + (Weight * 0.1) + (Power * 0.07) + ((Target Cost – Cost) * 0.13)

Ideal Sensor Combinations

<table>
<thead>
<tr>
<th>Cost</th>
<th>Utility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas Detector</td>
<td>1000</td>
</tr>
<tr>
<td>Stereo Camera-Gas Detector</td>
<td>1500</td>
</tr>
<tr>
<td>Stereo Camera-LIDAR</td>
<td>5500</td>
</tr>
<tr>
<td>Stereo Camera-LIDAR-Gas Detector</td>
<td>6500</td>
</tr>
<tr>
<td>Stereo Camera-Magnetometer-LIDAR-Gas Detector</td>
<td>26500</td>
</tr>
<tr>
<td>Stereo Camera-HSI Camera-Magnetometer-LIDAR-Gas Detector</td>
<td>56500</td>
</tr>
<tr>
<td>Stereo Camera-HSI Camera-Magnetometer-LIDAR-GPR-Gas Detector</td>
<td>86500</td>
</tr>
</tbody>
</table>

Process provides data and metric driven approach to optimizing sensor platform
Wells Identification – Success Metrics

• Provide easy-to-deploy, cost-effective sensors for well detection and identification
• Provide data visualization and sensor fusing algorithms for user and automated well identification
• Generate new data sets with existing deployments to quickly increase data density for future development
• Establish best practices on currently available data
• Identify gaps in current data sets and concepts of operations
Undocumented Orphaned Wells Workshop

Technical Session #3
Undocumented Wells Characterization Technologies

Sébastien Biraud (Berkeley Lab)
and the National Laboratories consortium
Outline

• Motivation: Why well characterization is important

• Challenges

• Current state-of-the-art of well characterization technologies

• Project team to address this problem

• Success metric
Wells Characterization - Motivation

• Oil & Gas wells: provide leakage pathways that connect oil and gas reservoirs to groundwater aquifers and to the atmosphere, contributing to water and air quality degradations and anthropogenic greenhouse gas emissions.

• Wells characterization should be coordinated across states to maximize the impact of our program.

• Quantification of methane emissions from orphaned wells will improve US EPA estimates of (avoidable) GHG emissions.
Wells Characterization - Challenges

• Ecosystem of wells is very diverse across the nation
• Heterogeneous subsurface and surface conditions across oil and gas basin
• Plugging priority criteria are different across oil and gas producing states
• Not one technology will work everywhere
• Cost-effective scaling of state-of-the-art technologies
## Wells Characterization - Current State-of-the-art

<table>
<thead>
<tr>
<th>Key Attributes</th>
<th>Computer-based</th>
<th>Ground-based</th>
<th>Remote sensing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Autonomous</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Continuous</td>
<td>N/A</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Leak Localization</td>
<td>no</td>
<td>1-10 meters</td>
<td>1-50 meters</td>
</tr>
<tr>
<td>Leak Quantification</td>
<td>no</td>
<td>Component-scale</td>
<td>Component-scale / Pad-scale</td>
</tr>
<tr>
<td>Cost</td>
<td>$</td>
<td>$-$-$</td>
<td>$$$-$$$</td>
</tr>
</tbody>
</table>
Characterization of Undocumented Wells Using Data Mining, Fusion and Machine Learning Approaches

Conceptual Ideas:
Significant amounts of data that have potential to be mined using natural language processing and image classification ML to identify potential well locations:
1. Existing well records (may need OCR)
2. Remote sensing to identify relevant hydrogeological properties
3. Historical archives of news/photos/maps
Wellbore Integrity Assessment with Electromagnetic Time Domain Reflectometry (EM-TDR)

**Working principle:** Guided EM wave traveling along steel casing. Reflections are generated when damages (or bottom) are encountered. **No downhole sensor deployment needed.**

\[ \Gamma = \frac{v_{\text{reflected}}}{v_{\text{incident}}} = \frac{z_d - z_0}{z_d + z_0} \]

**UOW application:**
- Identify depth or damages of wells
- Quick integrity screening tool

**Numerical simulation**
- Model
- V-field
- Current density

**Field tests**
- O/G well – CA central valley; >700ft
- Wang and Wu, 2020
Atmospheric Methane sensing: Static Chamber Measurements

**Working principle:** $Q = dC/dt \cdot V$
- $Q$ is the leak rate (in liters per hour [L/hr]),
- $dC$ is the change in methane concentration (in ppm) over time period $dt$ (in hours),
- $V$ is the volume of the chamber (in L).

**UOW application:** time-intensive (requiring approximately 1 hour per well) but extremely sensitive (less than 0.001 g CH4/hr)
Atmospheric Methane sensing: mobile survey

**Working principle:**
- Measures methane concentrations at three heights (1, 2, 4 m above ground level) and winds (2.5 m)
- Integration of flux plume quantifies near-surface emissions
- Controlled release testing demonstrates measurement of low level emissions (~ 0.5 g CH4/hr)
- Applied to measure O&G wells, Compressed NG, fueling stations, dairy manure lagoons, and urban NG leak.

**UOW application:** Rapid assessment (requiring approximately 10 minutes per well) but less-sensitive than static chamber method.
Atmospheric Methane sensing: manned and unmanned airborne

**Working principle:**
- Mass-balanced approach
- 400 ft above ground level (AGL) flight altitudes
- Semi-real-time methane emission estimate

**Working principle:**
- Emissions measurements uses same principle as manned aircraft
- Surface to 400 ft AGL flight altitudes
- Real-time methane concentrations

(Tadic et al., 2019)

(Zhang et al., 2021)
Spaceborne methane monitoring is an active and growing field. There are two relevant methods of observation:
1) infrared imaging spectrometers (GOSAT, GOSAT-2, TROPOMI, and SCIAMACHY)
2) visible and infrared imaging of flaring at night (VIIRS).

**Pros:** Observing the world from space has obvious advantages for identifying emission irrespective of site access restriction

**Cons:** Sensitivity of these systems is much poorer than aircraft and ground-based systems, which limits them to detecting only large and super-emitter sources (>10kg/hr)

Spaceborne sensing not yet suited for this project, but we will keep in an eye on progress made on leak detection as a handful of private-sector missions have recently emerged (GHGSat, WorlView-3, ...)

(courtesy www.methanesat.org)
Wells Characterization – Project Team

• Machine Learning (LANL/LBNL/LLNL)

• Methane Emissions (LANL/LBNL/NETL)

• Well Integrity (LBNL/NETL)
Wells Characterization – Success Metric

- Establish best practices on wells characterization

- Improve methane emission estimates from (Un)documented Orphaned Wells

- Provide easy-to-deploy, cost-effective measurement technics for well characterization
Thank You!
Undocumented Orphaned Wells Workshop

Technical Session #4
Outcomes (Framework, Best Practices) Strategy

Chester J Weiss (Sandia National Laboratories) and the National Laboratories consortium

A problem of scale – “smaller, faster, cheaper” doesn’t even come close.

Wideband Usability Spectrum to maximize workforce engagement
  • Citizen Scientist
  • At-the-wellhead assessment
  • Standoff detection and characterization
  • Natural language processing
  • Advanced data reduction (3D, multi-physics, etc.) and specialized measurement discrimination

Comprehensive risk assessment model to inform prioritization

Challenges to realization
  • The technical – advancing technical readiness levels (concept -> field trial -> commercialization)
  • The handoff: teaming with industry, intellectual property, database hosting, maintenance and updates, points of contact, indemnity, access to lab specialists, others?
  • Workforce engagement
Survey Responses – Thank you!

- 37 respondents representing 30 states
- 70% indicated “moderate” or “low” priority -> constrained resources

Q5 What approach/methods has your state been using or contemplated using to identify undocumented orphan wells?

Top Three Responses

State of Practice
- Labor intensive, largely non-technical
- Where is it? What’s the state of health?
- Varying local constraints on inspection (e.g. Idaho’s no-drone laws)
End-User Scalability Constraints on DOE Products/Framework

- It is estimated that there are hundreds of thousands of undocumented orphaned wells leaking methane in the U.S. that need to be located.¹
  - The total estimated number of undocumented orphaned wells reported by the states is between 310,000 and 800,000.²
  - Per the EPA, there are 2M unplugged and abandoned wells in the U.S. (which includes orphaned wells).³

- $4,700M Available to DOI/BLM/States/Tribes
  - $2,350 - $23,500 BIL funding per well
  - 21,000 – 200,000 wells/year over 10-year timeline
    - 100's to >10,000 wells/year, depending on state

- Current State of practice: <50 well/year (NM), ~500ish wells/week nationwide.

DOE Products/Framework need to upscale current decisioning by factor of 40-400x to fully meet expected needs.

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¹ Management of Abandoned and Orphaned Oil and Gas Wells, The American Association for the Advancement of Science
³ Wright, B., Hide and Seek: The Orphan Well Problem in America, Journal of Petroleum Technology, August 2021
Strawman Strategy: Wideband Usability Spectrum

Comprehensive risk-assessment model to inform prioritization
(what measurements? where, bigger impacts (e.g. groundwater, geothermal, CCS, etc),
tradeoff between economics and number of analyzed wells

Citizen Scientist with a Smartphone

At-the-wellhead assessment

Offset (satellite, airborne, drone) characterization and detection

Natural Language Processing (NLP) and GIS/Data Fusion for Archival Analysis

3D modeling, integrated analysis, specialized measurement discrimination
Something everyone can use: SmartPhone data collects

- Prior DOE investment/experience with geo-location
- Add to this preliminary geophysical reconnaissance
  - magnetometry
  - lidar

Enabling technology with multiple benefits:

- “rough cut” to prioritize follow-on survey
- Adds another pin on the inventory
- Expands the workforce
- Public engagement/outreach/education
For the technically trained: At-the-wellhead sensor packages

**Usability Vision:** Geophysical analogue of utility detection. An all-in-one, internet-of-things, multi-physics measurement system.

- Wireless (5G, other?) communications
- Uplink for data archiving and access to ML/cloud algorithms to inform in-the-field decision making
- On-board data analysis and geophysical interpretation

[https://dps.mn.gov/blog/Pages/20180419-blog-locate-rodeo.aspx](https://dps.mn.gov/blog/Pages/20180419-blog-locate-rodeo.aspx)
For the technically trained: Standoff sensing/characterization

Unmanned Aerial Systems have flown:
- Wildlife-sensitive areas, e.g. Oliktok Point, Alaska
- Major airports, over NNSA Labs and military installations, e.g. Albuquerque
- Washington, DC Special Flight Rules Area

Power/weight/duration optimized systems for integrated sensing requirements.

Magnetic, LIDAR, SAR, methane, etc. sensor suites

UAS Lab – netted enclosure for indoor flying

SAR system, Skyfront Perimeter 8, hybrid powered, ~1 hour endurance with SAR

Baby Shark VTOL (vertical takeoff and landing), ~1 hour duration, ~5 lb payload
For the technically trained: Natural Language Processing

**def**: programming computers to process and analyze large amounts of “natural language” data to ”understand” content and nuances within.

**Historical Documents**

**Optical Character Recognition**

**Machine Learning Algorithms**
(the modern NLP approach)

**Likelihood estimate of undocumented well locations**

For the technically trained: GIS and Data Fusion, an early win?

Combining georeferenced historical data and other geospatial data sets may help identify areas with high-likelihood of orphaned wells.

Types of geospatial data that could be included:
- Historical maps/roads
- Age & status of known wells
- Population density
- DEM/LiDAR
- Depth to aquifer
- Many other types of data can be evaluated for effectiveness

Collect readily available data and georeferenced historical data that are potentially indicators of abandoned wells.

Geospatial Analysis (later phase: Machine Learning)

Probability maps, classification results, or even just interacting with multiple data sets visually as overlays may help identify areas likely to have undocumented wells.

Magnetic map: Patricia M. B. Saint-Vincent, James I. Sams, Richard W. Hammack, Garret A. Veloski, and Natalie J. Pekney Environmental Science & Technology 2020 54 (13), 8300-8309 DOI: 10.1021/acs.est.0c00044
Oil & Gas Well Map: https://gis.ohiodnr.gov/MapViewer/?config=OilGasWells
For the specialist: Advanced characterization and measurements

High-Fidelity Assessment of Wellbore Failure Modes
- Delamination between outer casing and cement
- Compromised plug seal
- Excess cement porosity
- Broken casing
- Fractured cement
- Delamination between cement and formation

Candidate Characterization Methods

Surface-based casing excitation

Time-domain reflectometry
For the decision maker: Comprehensive Risk Assessment Model

Coupling Plug-and-Abandon activities with...
- Workforce availability
- Tech development timelines
- Tech deployment footprint
- Groundwater impact
- Methane mitigation
- CO₂ production (~6 tons of CO₂ per km of plugging, ~400 lbs/yd³)
- Ecosystem/societal impact
- External drivers (economic, population change, climate projections, repurposing options)

... to inform prioritization options and risks with what measurements to take, and when, to maximize return on investment.
Challenges to Realization

• The technical – advancing technical readiness levels

• The handoff
  o teaming with industry
  o intellectual property
  o database hosting
  o maintenance and updates
  o points of contact
  o indemnity
  o access to technical specialists

• Workforce engagement

Existing mechanisms for transferring IP to commercial sector
• Co-development through Cooperative Research & Development Agreement
• Post-development licensing of IP (no- to low-cost models)

Diverse needs and constraints by the states and stakeholders will require a flexible implementation paradigm.
Closing Remarks (Bill Carey Los Alamos National Lab)

• Objective: Assist State, Federal and Tribal efforts to locate and characterize undocumented wells
• In partnership with States, identify key technology and analysis needs
• Determine effective, cost-efficient and easy-to-use approaches
• Share technology through demonstration, best practice guides, and training seminars
• Establish State-National Laboratory teams for technology deployment
• Integrated toolkit for system analysis and tool and sensor selection
• Potential targets:
  • Schemes for prioritization of where and how to find wells and which wells to fix first
  • Remote-sensing and in-the-field methods to locate undocumented orphan wells
  • Techniques to characterize undocumented well attributes and possible leaks to air and water
  • Quantification of methane emissions avoided through plug & abandonment
  • Data-science and machine-learning methods to integrate and analyze different data sources
Thank you for attending!

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