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EDF U.S. Oil and Gas Methane Studies

- **UT Phase 1**
  - Pneumatics
  - Liquids Unloading
  - HARC/EPA

- **UT Phase 2**

- **CSU Study**
  - Methods
  - Measurements
  - National Scale-up

- **CSU Study**
  - Measurements
  - National Scale-up

- **NOAA Denver-Julesburg**

- **NOAA Barnett Coordinated Campaign**
  - 12 campaign papers
  - Barnett synthesis
  - Barnett component

- **Methane Mapping Boston Study**
  - WSU Multi-City
  - Indianapolis

- **WVU Study**
  - Measuring
  - Modeling

- **Pilot Projects**

- **Gap Filling**
  - Abandoned wells
  - Helicopter IR Survey

- **Synthesis Projects**
  - NETL LCA
  - Synthesis
EDF’s Methane Research

**Science**
Studies employ independent experts and use multiple methods to measure methane emissions

**Collaboration**
More than 130 co-authors from 50 research institutions and 50 O/NG companies

**Results**
Published in peer-reviewed journals with publically available data
Assessment of methane emissions from the U.S. oil and gas supply chain

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Scope of Synthesis Study

- Quantify methane emissions from the U.S. oil and gas supply chain
- Integrates several recently published datasets
  - Production segment emissions based on site-level measurements from 6 U.S. basins
  - Emissions compared to aircraft-based estimates in 9 basins
Synthesis Collaborators

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Washington State University
Brian K. Lamb
Sources of Regional Synthesis Data

Methane study areas
Accounts for 33% of U.S. gas production; 24% of oil production
Emissions Quantified at Different Spatial Scales

- Site-level (primary approach)
- Component-level (comparison)
- Basin-level (validation)
Comprehensive site measurements reveal higher emissions than inventories.

Basin- and site-level quantification methods can find emissions that are overlooked by equipment-level measurements.
For example, site-level measurements find 50% more emissions in the Barnett Shale than estimated by traditional methods.
Synthesis Methods

• Multiple, previously published datasets integrated to estimate 2015 U.S. O&G CH$_4$ emissions by segment
  – **Production**: >400 site-level measurements from 6 basins
    • Basins: Barnett, DJ, Fayetteville, Uintah, Upper Green River, Marcellus
    • Methods: Dual tracer, mobile flux plane, inverse Gaussian, OTM 33A
  – **Gathering & Processing**: Marchese et al 2015
  – **Transmission & Storage**: Zimmerle et al 2015
  – **Local distribution**: Lamb et al 2015

• Basin-level, site-based estimates validated with aerial mass balance data from 9 basins
  • Basins: Haynesville, Barnett, Marcellus, San Juan, Fayetteville, Bakken, Uintah, Weld, West Arkoma

• Synthesis estimate compared to U.S. EPA GHG Inventory and custom component-based inventory
Aircraft- and site-based emission estimates are statistically similar.
U.S. O&G Supply Chain
2015 Methane Emissions

Drilling & Production
- 7.6 Tg (1.3%)

Gathering & Processing
- 3.5 Tg (0.6%)

Transmission & Storage
- 1.8 Tg (0.3%)

Local Distribution
- 0.44 Tg (0.1%)

Methane Synthesis
Alvarez et al 2018

2017 EPA GHG Inventory
(For year 2015)
O&G CH$_4$ emissions 60% higher than EPA GHGI

Synthesis
13±2 Tg CH$_4$
2.3% Leak Rate

US EPA
8.1 (+2.1/-1.4) Tg CH$_4$
1.4% Leak Rate

Methane Synthesis
EPA 2015 Inventory

Production
Gathering
Processing
Transmission & Storage
Local Distribution
Oil Refining & Transportation
Implications for Virginia

- The state includes approximately:
  - 8,000 active O&G wells
  - 3,000 inactive/plugged wells
  - 25 compressor stations
  - 2 storage fields

- Active wells are almost exclusively marginal gas wells with 94% producing less than 15 barrel of oil equivalents per day.
Implications for Virginia

• Measurement data from the state are not available, but studies from a similar production area in southwest Pennsylvania provide insights.

• Marginal conventional wells have relatively low absolute emission rates but very high loss rates:
  – Mean emission factor = 0.8 kg CH$_4$/hr (7.8 tons per year)
  – Median loss rate = 11% gas production

https://pubs.acs.org/doi/abs/10.1021/acs.est.5b05503
Implications for Virginia

- Another study in SW PA used aircraft data to estimate emissions from O&G and coal mines.
  - Both coal and O&G were important methane sources.
  - EPA estimates were accurate for coal but 5X too low for O&G.
  - Production and gathering loss rate of 0.5±0.3% is in agreement with other regional studies.

Preliminary Emission Estimates for Virginia wells and compressor stations

• 8,000 active wells * 7.8 TPY = 62,400 TPY CH₄
  – https://pubs.acs.org/doi/abs/10.1021/acs.est.5b05503

• 3,000 abandoned wells * 0.14 TPY = 400 TPY

• 25 compressor stations * 739 TPY = 18,500 TPY
  – https://pubs.acs.org/doi/abs/10.1021/acs.est.5b01669
Summary

- O&G CH₄ emissions are higher than estimated by official inventories like the EPA GHGI
  - Upstream sources responsible for ~80% of total emissions
  - Site-based estimates validated with basin-level data
- Abnormal conditions cause large emissions often excluded from traditional inventories
  - Avoidable issues such as malfunctions, human error, and poor site design can lead to very high emission rates
  - Abnormal conditions account for about 50% of production segment and 33% of total supply chain emissions
- Regulatory and voluntary actions can reduce emissions
  - Effective monitoring to quickly detect high emissions
  - Root cause analysis and better site design to minimize the recurrence of abnormal conditions
  - Improved reporting to more accurately understand emissions
Additional Slides
Alternative, source-based estimate is substantially lower than site-based estimate. This traditional approach underestimates emissions by failing to account for uncategorized abnormal emissions.

<table>
<thead>
<tr>
<th>Industry Segment</th>
<th>Source Category</th>
<th>GHGI 2015 U.S. Emissions (Gg CH₄ y⁻¹)</th>
<th>This work (source-based)</th>
<th>This work (site-based)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>O/NG Production</td>
<td>Pneumatic Controllers</td>
<td>1,800</td>
<td>1,100 (1,100 - 1,200)</td>
<td>7,200 (5,600 - 9,100)</td>
</tr>
<tr>
<td></td>
<td>Equipment Leaks* S</td>
<td>360</td>
<td>620 (570 - 670)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Liquids Unloading</td>
<td>210</td>
<td>170 (170 - 200)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pneumatic Pumps*</td>
<td>210</td>
<td>190 (180 - 200)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Oil &amp; Condensate Tanks</td>
<td>100</td>
<td>100 (97 - 120)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Produced Water Tanks</td>
<td>40</td>
<td>360 (340 - 380)</td>
<td></td>
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<tr>
<td></td>
<td>Fuel combustion</td>
<td>240</td>
<td>98 (91 - 210)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Associated gas flaring and venting</td>
<td>150</td>
<td>71 (69 - 86)</td>
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<tr>
<td></td>
<td>Other production sources*</td>
<td>40</td>
<td>60 (58 - 68)</td>
<td></td>
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<tr>
<td></td>
<td>Routine Operations Subtotal</td>
<td>3,100</td>
<td>2,800 (2,700 - 2,900)</td>
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<tr>
<td></td>
<td>Completions + Workovers</td>
<td>100</td>
<td>86 (80 - 120)</td>
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</tr>
<tr>
<td></td>
<td>Abandoned and Orphaned Wells</td>
<td>NA</td>
<td>61 (59 - 360)</td>
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<tr>
<td></td>
<td>Onshore Production Subtotal</td>
<td>3,200</td>
<td>2,900 (2,900 - 3,300)</td>
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<tr>
<td></td>
<td>Offshore Platforms</td>
<td>300</td>
<td>300 (240 - 380)</td>
<td></td>
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<tr>
<td></td>
<td>Production Total</td>
<td>3,500</td>
<td>3,200 (3,100 - 3,600)</td>
<td></td>
</tr>
<tr>
<td>Natural Gas Gathering</td>
<td>Gathering Stations</td>
<td>2,000</td>
<td>2,100 (2,100 - 2,200)</td>
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</tr>
<tr>
<td></td>
<td>Gathering Episodic Events</td>
<td>200</td>
<td>170 (7 - 750)</td>
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<td></td>
<td>Gathering Pipelines</td>
<td>160</td>
<td>310 (300 - 330)</td>
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<tr>
<td></td>
<td>Gathering Total</td>
<td>2,300</td>
<td>2,600 (2,400 - 3,200)</td>
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<tr>
<td>Natural Gas Processing</td>
<td>Processing Plants</td>
<td>410</td>
<td>680 (610 - 880)</td>
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<tr>
<td></td>
<td>Routine Maintenance</td>
<td>36</td>
<td>36 (29 - 46)</td>
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<tr>
<td></td>
<td>Processing Total</td>
<td>450</td>
<td>720 (650 - 920)</td>
<td></td>
</tr>
<tr>
<td>Transmission and Storage (T/S)</td>
<td>T/S Stations</td>
<td>1,100</td>
<td>1,100 (860 - 1,400)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>T/S Uncategorized/Superemitters</td>
<td>NA</td>
<td>440 (350 - 570)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Transmission Pipelines</td>
<td>220</td>
<td>220 (180 - 290)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>LNG Storage and Import Terminals</td>
<td>70</td>
<td>67 (54 - 87)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>T/S Total</td>
<td>1,300</td>
<td>1,800 (1,600 - 2,100)</td>
<td></td>
</tr>
<tr>
<td>Local Distribution</td>
<td>All sources through customer meters</td>
<td>440</td>
<td>440 (220 - 950)</td>
<td></td>
</tr>
<tr>
<td>Petroleum Midstream</td>
<td>Oil Transportation + Refining</td>
<td>34</td>
<td>34 (26 - 84)</td>
<td></td>
</tr>
<tr>
<td>Total U.S. Oil &amp; Gas Supply Chain</td>
<td></td>
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</tbody>
</table>
Over 30% of emissions are from very marginal (<10 Mcf/d) sites responsible for <1% of U.S. gas production.

Table S4. Distribution of the activity data of U.S. oil and natural gas wells in 2015. The last row shows the percent of emissions from production sites calculated with the model described in this section. The production cohorts in this table were selected based on breakpoints evident in the dataset of production site emission measurements (Fig. S2 and Section S1.9), and 0.68 Mcf/d is the minimum production of the sampled population. The measurement dataset predominantly contains sites with gas production within the bolded gas production cohorts.

<table>
<thead>
<tr>
<th>Natural Gas Production Cohorts (Mcf d⁻¹)</th>
<th>% of US 2015 Activity Data by Gas Production Cohort</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sites*</td>
<td>0 (%) 7.6% (8.9%) 29% (34%) 48% (57%) 0.38% (0.45%)</td>
</tr>
<tr>
<td>Wells</td>
<td>19% 5.1% 20% 53% 3.3%</td>
</tr>
<tr>
<td>Gas Production</td>
<td>0% 0.015% 0.84% 59% 40%</td>
</tr>
<tr>
<td>Oil Production</td>
<td>7.3% 0.49% 3.0% 74% 15%</td>
</tr>
<tr>
<td>Emissions*</td>
<td>6.4% (0%) 5.1% (5.5%) 20% (21%) 64% (68%) 4.8% (5.1%)</td>
</tr>
</tbody>
</table>

*The main value includes oil wells with zero reported gas production; the value in parentheses excludes them.