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Attribution

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Agenda

• Background
• Modeling Approach
• Data Sources
• Parameter Development
• Results
• Data Limitations
• Research Needs
NETL’s Life Cycle Natural Gas Model

- Cradle-through-delivery boundaries
- Unit process, bottom-up approach with parameterization
- Supply chain stage delineation
- Metrics
  - Air emissions: Greenhouse gas (GHG), criteria air pollutants, and other air emissions of concern
  - Land use change: Area of land footprint and GHG emissions from change in carbon balance
  - Water: Volumes of withdrawal and discharge as well as quality of discharged water
- Annual time frame
  - NETL’s 2016 report represented 2012 activity
  - NETL’s 2018 report will represent 2016 activity (Fall 2018 release)
- Scenarios
  - 6 extraction technologies
  - 14 basins
  - 31 unique “techno-basins”
Key Water Updates
Updates since 2016 Report

- Updated Water data (majority represents 2016 operations)
- Increased regionalization, 27 onshore techno-basins
- Modeling of produced water releases to environment
- Considers injection of produced water for disposal/recycle
- Allocates water burdens to oil co-produced at the well

https://www.netl.doe.gov/research/energy-analysis/search-publications/vuedetails?id=1830
KR Key Terms

- **Conventional Well** – drilled vertically, no well stimulation necessary, produced water

- **Coalbed Methane (CBM)** – natural gas from coal seams, requires removal of formation waters (produced water)

- **Shale Well** – a shale formation, drilled directionally or horizontally, requires stimulation (hydraulic fracturing), flowback and produced water

- **Tight Well** – a non-shale formation, drilled directionally or horizontally, requires stimulation (hydraulic fracturing), flowback and produced water

- **Flowback Water** – water returning from the formation due to stimulation waters, early in the lifetime of the well

- **Produced Water** – water exiting the well due to formation waters, occurs throughout the lifetime of the well
Modeling Approach

Scenario Structure

- 27 Scenarios capture 95% of U.S. onshore natural gas production
- 4 well types: Conventional, Shale, Tight, CBM
- 14 Greenhouse Gas Reporting Program (GHGRP) Basins
Modeling Approach

Unit Process Structure

- Shale Gas
  - Input (stimulation)
  - Flowback and Produced Volume
  - Water Quality and Emissions

- Tight Gas
  - Input (stimulation)
  - Flowback and Produced Volume
  - Water Quality and Emissions

- Conventional Gas
  - Produced Volume
  - Water Quality and Emissions

- Coalbed Methane
  - Produced Volume
  - Water Quality and Emissions

Water Management
Data Sources

• **Water Injection (input):**
  - FracFocus Database, 2016
  - DI Desktop, 2016

• **Flowback, Produced Volumes:**
  - ANL Produced Water Report, 2009

• **Flowback, Produced Quality:**
  - USGS Produced Water Database, 2017

• **Water Emissions:**
  - EPA Review of State and Industry Spill Data, 2015

• **Water Disposal:**
  - ANL Produced Water Report, 2009
## Parameter Development

<table>
<thead>
<tr>
<th>Data Type</th>
<th>Data Treatment</th>
<th>Examples</th>
</tr>
</thead>
</table>
| Large Data Sets                               | Use central limit theorem and statistical bootstrapping to develop parameters  | • Stimulation Volumes  
• Estimated Ultimate Recovery (Gas & Oil)  
• Water Quality Species Concentrations |
| Parameters from Literature, Small Data Sets   | Create triangular or uniform distributions, dependent on available data        | • Water Source (Fresh, Recycled, etc.)  
• Flowback Volumes  
• Produced Water Volumes  
• Release Volumes  
• Water Management Destination |
The raw data is highly skewed, difficult to develop parameters we are confident in.

Simulating the average of the distribution through random sampling with replacement allows us to be confident in mean values even if we don’t fully understand the raw data.
Stimulation Water Use

Fresh  Recycled or Brackish
Values in liters water/MJ natural gas

Legend

- $1.0 \times 10^{-3}$ L/MJ NG
- $2.0 \times 10^{-3}$ L/MJ NG
- $3.0 \times 10^{-3}$ L/MJ NG
Stimulation Water Use

Fresh Recycled or Brackish

Values in liters water/MJ natural gas

Legend

- $1.0 \times 10^{-3}$ L/MJ NG
- $2.0 \times 10^{-3}$ L/MJ NG
- $3.0 \times 10^{-3}$ L/MJ NG

States Shown:

- Texas
- Louisiana
- Arkansas
- Oklahoma
- Kansas
Stimulation Water Use

**Fresh** Recycled or Brackish
Values in liters water/MJ natural gas

Legend:
- = 1.0E-3 L/MJ NG
- = 2.0E-3 L/MJ NG
- = 3.0E-3 L/MJ NG

States Shown:
- Utah
- Colorado
- Wyoming

[Map of stimulation water use with markers for different water use values in specific regions like Uinta-Shale and Piceance-Tight.]
Stimulation Water Use

Fresh vs. Recycled or Brackish

Values in liters water/MJ natural gas

Legend

= 1.0E-3 L/MJ NG
= 2.0E-3 L/MJ NG
= 3.0E-3 L/MJ NG
Stimulation Water Consumption

Liters of water used per MJ of produced natural gas

- Brackish or Recycled
- Fresh Water

[Bar chart showing water consumption per region and tight/shale distinction]
Produced vs Flowback Volumes
Liters of water per MJ of produced natural gas

Anadarko  Arkla  East Texas  Green River  Gulf Coast  Piceance  Anadarko  Appalachian  Arkla  Arkoma  East Texas  Fort Worth  Gulf Coast  Permian  South Oklahoma  Strawn  Uinta

Tight  Shale
Note: The CBM San Juan Scenario lacks errors bars due to 1) data limitations on produced water rates for CBM wells and 2) San Juan CBM wells were shown to co-produce zero oil.
Produced Water

Conventional Scenarios Scaled to Show Variability

- Due to data limitations, all conventional scenarios are based on the same lifetime produced water rate.
- The small variations are due to differences in co-product allocation (i.e. differences in the amount of oil co-produced from the natural gas well).
## Produced Water Emissions

### Releases to Water, kg/MJ produced NG

<table>
<thead>
<tr>
<th></th>
<th>Shale</th>
<th>Tight</th>
<th>Conventional</th>
<th>CBM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Appalachian</td>
<td>Gulf Coast</td>
<td>Arkla</td>
<td>East Texas</td>
</tr>
<tr>
<td>TDS</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Boron</td>
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<tr>
<td>Bromine</td>
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<tr>
<td>Calcium</td>
<td></td>
<td></td>
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<tr>
<td>Chlorine</td>
<td></td>
<td></td>
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<tr>
<td>Chromium</td>
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<td></td>
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<tr>
<td>Copper</td>
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<tr>
<td>Total Iron</td>
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<tr>
<td>Carbonate</td>
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<tr>
<td>Iodine</td>
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<tr>
<td>Potassium</td>
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<tr>
<td>Lithium</td>
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<tr>
<td>Magnesium</td>
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<tr>
<td>Manganese</td>
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<tr>
<td>Sodium</td>
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<tr>
<td>Sulfate</td>
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<td>Silicon</td>
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<td>Strontium</td>
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<td>Zinc</td>
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<tr>
<td>Alkalinity</td>
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<tr>
<td>Sr-87, Sr-86</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Ra-226</td>
<td></td>
<td></td>
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<tr>
<td>Ra-228</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Blank cells represent data gaps, they do not represent a zero result.**
- **Color gradient was applied across rows for individual emission species, with green representing lowest emitting scenario and red representing highest emitting scenario.**
- **These colors do not signify an impact nor have any relation to regulatory standards.**
## Produced Water Emissions

Releases to Water, kg/MJ produced NG

N/A represents a lack of data, does not signify a “zero” result

### Shale

<table>
<thead>
<tr>
<th></th>
<th>Appalachian</th>
<th>Gulf Coast</th>
<th>Arkla</th>
<th>East Texas</th>
<th>Arkoma</th>
<th>South Oklahoma</th>
<th>Anadarko</th>
<th>Strawn</th>
<th>Fort Worth</th>
<th>Permian</th>
<th>Uinta</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TDS</strong></td>
<td>1.27E-10</td>
<td>5.61E-11</td>
<td>2.08E-10</td>
<td>1.41E-10</td>
<td>1.79E-11</td>
<td>1.71E-10</td>
<td>8.40E-11</td>
<td>1.44E-10</td>
<td>7.44E-10</td>
<td>7.47E-11</td>
<td>4.73E-10</td>
</tr>
<tr>
<td><strong>Boron</strong></td>
<td>1.74E-14</td>
<td>1.17E-13</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
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<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Barium</strong></td>
<td>2.46E-12</td>
<td>1.89E-13</td>
<td>1.27E-13</td>
<td>N/A</td>
<td>5.11E-15</td>
<td>1.34E-13</td>
<td>N/A</td>
<td>N/A</td>
<td>3.98E-13</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Bromine</strong></td>
<td>8.57E-13</td>
<td>8.13E-14</td>
<td>N/A</td>
<td>N/A</td>
<td>1.49E-13</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Chlorine</strong></td>
<td>7.41E-11</td>
<td>3.38E-11</td>
<td>1.28E-10</td>
<td>8.48E-11</td>
<td>1.23E-11</td>
<td>1.05E-10</td>
<td>4.61E-11</td>
<td>8.86E-11</td>
<td>4.54E-10</td>
<td>4.50E-11</td>
<td>4.18E-11</td>
</tr>
</tbody>
</table>

Enhanced view of subsection of previous chart

- Data limitations make comparisons between scenarios difficult
- When scaled to the functional unit, emission releases can vary by two orders of magnitude across scenarios
Produced Water Management

Treatment methods of produced water

- **Injection - Enhanced Recovery**: water is injected to maintain reservoir pressure and drive oil toward a producing well
- **Injection - Disposal**: water is injected into a Class II well for disposal
- **Surface Discharge**: water is discharged directly to the surface (generally limited to low salinity water)
- **Centralized Waste Treatment - Discharge**: water is treated in a centralized waste treatment plant and then discharged
- **Reuse - Not Road Spreading**: water is reused for something other than road spreading
- **Public Sewage Treatment Plant**: water is sent to a public sewage treatment plant for processing
- **Reuse - Road Spreading**: water is reused for road spreading
- **Residual Waste Processing Facility**: water is sent to a residual waste processing facility
- **Centralized Waste Treatment - Recycle**: water is treated in a centralized waste treatment plant and then recycled
### Produced Water Management

#### Treatment of Produced Water

<table>
<thead>
<tr>
<th>Destination</th>
<th>CBM</th>
<th>Conventional</th>
<th>Shale</th>
<th>Tight</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>San Juan</td>
<td>Anadarko</td>
<td>Arkla</td>
<td>Arkoma</td>
</tr>
<tr>
<td>Injection - Enhanced Recovery</td>
<td>0%</td>
<td>43%</td>
<td>10%</td>
<td>28%</td>
</tr>
<tr>
<td>Injection - Disposal</td>
<td>100%</td>
<td>57%</td>
<td>90%</td>
<td>72%</td>
</tr>
<tr>
<td>Surface Discharge</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Cent. Waste Treat. - Discharge</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Reuse - Not Road Spreading</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Public Sewage Treatment Plant</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Reuse - Road Spreading</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Residual Waste Processing Facility</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Cent. Waste Treat. - Recycle</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
</tbody>
</table>

Light Green represents Argonne National Labs Report (2009) as Data Source

Light Blue represents PA DEP Oil & Gas Waste Report (2016) as Data Source
## Produced Water Management

**Treatment of Produced Water**

### Parameter Name

<table>
<thead>
<tr>
<th></th>
<th>Anadarko</th>
<th>Arkla</th>
<th>Arkoma</th>
<th>East Texas</th>
<th>Fort Worth</th>
<th>Gulf Coast</th>
<th>Permian</th>
<th>San Juan</th>
<th>Appalachian</th>
<th>Anadarko</th>
<th>Arkla</th>
<th>Arkoma</th>
<th>East Texas</th>
<th>Fort Worth</th>
<th>Gulf Coast</th>
<th>Permian</th>
<th>San Juan</th>
<th>Appalachian</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Injection - Enhanced Recovery</strong></td>
<td>43%</td>
<td>10%</td>
<td>28%</td>
<td>68%</td>
<td>39%</td>
<td>68%</td>
<td>56%</td>
<td>0%</td>
<td></td>
<td>43%</td>
<td>0%</td>
<td>10%</td>
<td>28%</td>
<td>68%</td>
<td>68%</td>
<td>39%</td>
<td>68%</td>
<td>47%</td>
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<tr>
<td><strong>Injection - Disposal</strong></td>
<td>57%</td>
<td>90%</td>
<td>72%</td>
<td>32%</td>
<td>61%</td>
<td>32%</td>
<td>44%</td>
<td>20%</td>
<td></td>
<td>57%</td>
<td>6%</td>
<td>90%</td>
<td>72%</td>
<td>32%</td>
<td>61%</td>
<td>32%</td>
<td>57%</td>
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<tr>
<td><strong>Surface Discharge</strong></td>
<td>0%</td>
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<td>0%</td>
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</tr>
</tbody>
</table>

Enhanced view of subsection of previous chart

- The majority of scenarios send produced water to some form of injection
- Data limitations did not allow for the distinction between disposal of flowback and produced water (except for Appalachian Basin)
- Increased waste reporting at the state level will allow for enhanced resolution of disposal methods
Data Limitations

• Lack of publicly available waste management reporting
• Indistinguishability between flowback and produced water quality data
• Pretreatment before deep well injection dependent on operator
• Lack of geographically specific data
• Lack of conventional produced water data
Research Needs

• Incorporate waste reporting data into the model as it becomes available
• Differentiate water quality between flowback and produced water
• Enhanced modeling of burdens associated with disposal
• Enhance modeling of conventional scenarios
• Additional scenarios, increased regionalization
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