Life Cycle Greenhouse Gas Emissions: Natural Gas and Power Production
Agenda

• Importance of Understanding GHG Emissions from the Power and Natural Gas Sectors

• Understanding the Life Cycle GHG Emissions of Natural Gas

• Understanding the Life Cycle GHG Emissions of Power Production
Electricity Generation Forecast: 25% Growth in Next 20 Years
EIA, AEO 2015: Reference Case

- ** Coal: 37%**
- ** Natural Gas: 31%**
- ** Renewables: 18%**
- ** Nuclear: 16%**

Source: EIA, AEO 2015
• 6,673 Million Metric Tons CO$_2$e (AR4 GWP) in 2013
  – 82% Carbon Dioxide
  – 10% Methane
  – 5% Nitrous Oxide
  – 3% Fluorinated Gases

• Electricity Sector
  – 98.2% Carbon Dioxide

• GHG Emissions are 9% below 2005 Levels

- Methane emissions are 10% of total 2013 U.S. GHG emissions (in AR4 CO$_2$e)

- Current U.S. fossil fuel related methane emissions are ~ 40% of U.S. anthropogenic methane emissions
  - Natural Gas: 25%
  - Coal Mining: 11%
  - Petroleum Systems: 4%

Source: 2013 US EPA GHG Inventory
“Curbing emissions of methane is critical to our overall effort to address global climate change. ... To achieve additional progress, the Administration will”:

- Develop a comprehensive Interagency Methane Strategy – July 2014
- *Initiated* a collaborative approach with state governments as well as the private sector and cover all methane emitting sectors

**Three Pillars**

- Assessing Current Emissions Data and Addressing Data Gaps
- Identifying Technologies and Best Practices for Reducing Emissions
- Identifying Existing Authorities and Incentive-based Opportunities for Reducing Emissions
Understanding the Life Cycle GHGs of Natural Gas

Extraction / Production

Gathering/Processing

Transmission / Storage

Distribution

Graphical Image is a modified version of American Gas Association image: https://www.aga.org/at-a-glance.
<table>
<thead>
<tr>
<th>Region</th>
<th>Basin</th>
<th>Shale Play</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alaska</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Alaska Offshore</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Appalachian</td>
<td>Appalachian</td>
<td>Marcellus</td>
</tr>
<tr>
<td>Black Warrior</td>
<td>Black Warrior</td>
<td>-</td>
</tr>
<tr>
<td>Central</td>
<td>Anadarko, Ardmore, Cherokee Platform, Palo Duro</td>
<td>Woodford, Fayetteville</td>
</tr>
<tr>
<td>Fort Worth</td>
<td>Ft. Worth</td>
<td>Barnett</td>
</tr>
<tr>
<td>Gulf of Mexico</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Gulf Coast</td>
<td>Western Gulf</td>
<td>Eagleford</td>
</tr>
<tr>
<td>North-Central</td>
<td>Williston</td>
<td>Bakken</td>
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<td>Pacific Offshore</td>
<td>Ventura</td>
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<td>Rocky Mountains</td>
<td>Bighorn, Denver, Greater Green River, Paradox, Piceance, Powder River, Raton, San Juan, Unita, Wind River, Wyoming Thrust Belt</td>
<td>Niobrara</td>
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<td>TX-LA-MS Salt</td>
<td>Arkoma, TX-LA-MS Salt</td>
<td>Haynesville</td>
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<tr>
<td>West Coast</td>
<td>Sacramento</td>
<td>-</td>
</tr>
<tr>
<td>West Texas-Permian</td>
<td>Permian</td>
<td>Barnett-Woodford</td>
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</tbody>
</table>
## 2012 Production Mix for Techno-Regions

<table>
<thead>
<tr>
<th>Region</th>
<th>CBM (%)</th>
<th>Onshore Conventional (%)</th>
<th>Offshore Conventional (%)</th>
<th>Oil Wells (%)</th>
<th>Shale (%)</th>
<th>Tight Gas (%)</th>
<th>Total (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alaska</td>
<td>-</td>
<td>0.31%</td>
<td>-</td>
<td>0.70%</td>
<td>-</td>
<td>-</td>
<td>1.0%</td>
</tr>
<tr>
<td>Alaska Offshore</td>
<td>-</td>
<td>-</td>
<td>0.14%</td>
<td>0.31%</td>
<td>-</td>
<td>-</td>
<td>0.44%</td>
</tr>
<tr>
<td>Appalachian</td>
<td>0.44%</td>
<td>2.8%</td>
<td>-</td>
<td>0.050%</td>
<td>9.1%</td>
<td>0.32%</td>
<td>13%</td>
</tr>
<tr>
<td>Black Warrior</td>
<td>0.37%</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.37%</td>
</tr>
<tr>
<td>Central</td>
<td>0.41%</td>
<td>5.4%</td>
<td>-</td>
<td>0.21%</td>
<td>6.0%</td>
<td>1.6%</td>
<td>14%</td>
</tr>
<tr>
<td>Fort Worth</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>22%</td>
<td>-</td>
<td>22%</td>
</tr>
<tr>
<td>Gulf of Mexico Offshore</td>
<td>-</td>
<td>-</td>
<td>4.6%</td>
<td>2.0%</td>
<td>-</td>
<td>-</td>
<td>6.5%</td>
</tr>
<tr>
<td>Gulf Coast</td>
<td>-</td>
<td>9.2%</td>
<td>-</td>
<td>1.8%</td>
<td>-</td>
<td>7.8%</td>
<td>19%</td>
</tr>
<tr>
<td>Illinois-Michigan</td>
<td>-</td>
<td>0.34%</td>
<td>-</td>
<td>0.018%</td>
<td>0.44%</td>
<td>0.038%</td>
<td>0.84%</td>
</tr>
<tr>
<td>North-Central</td>
<td>-</td>
<td>0.087%</td>
<td>-</td>
<td>0.40%</td>
<td>0.75%</td>
<td>0.026%</td>
<td>1.3%</td>
</tr>
<tr>
<td>Pacific Offshore</td>
<td>-</td>
<td>-</td>
<td>0.063%</td>
<td>0.071%</td>
<td>-</td>
<td>-</td>
<td>0.13%</td>
</tr>
<tr>
<td>Rocky Mountains</td>
<td>4.7%</td>
<td>4.6%</td>
<td>-</td>
<td>0.093%</td>
<td>0.89%</td>
<td>10%</td>
<td>21%</td>
</tr>
<tr>
<td>TX-LA-MS Salt</td>
<td>-</td>
<td>0.15%</td>
<td>-</td>
<td>0.049%</td>
<td>-</td>
<td>0.21%</td>
<td>0.41%</td>
</tr>
<tr>
<td>West Coast</td>
<td>-</td>
<td>0.42%</td>
<td>-</td>
<td>0.21%</td>
<td>0.22%</td>
<td>-</td>
<td>0.84%</td>
</tr>
<tr>
<td>West Texas-Permian</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.21%</td>
<td>0.25%</td>
<td>-</td>
<td>0.46%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>6.0%</td>
<td>23%</td>
<td>4.8%</td>
<td>6.1%</td>
<td>39%</td>
<td>20%</td>
<td>100%</td>
</tr>
</tbody>
</table>
Regional Variability is Reduced at National Level
(14.8 g/MJ CO₂e, 1.6% CH₄ Emission Rate thru Distribution)
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(14.8 g/MJ CO₂e, 1.6% CH₄ Emission Rate thru Distribution)
CH$_4$ emission rates and GHG emissions

6.5% of NG goes through distribution after transmission.

Shale, Ft. Worth Basin
Tight Gas, Rocky Mountains
Onshore Conventional, Gulf Coast
Shale, Appalachian Basin
Tight Gas, Gulf Coast

CH$_4$ emission rate
GHG emissions (g CO$_2$e/MJ NG delivered)
Emission rates change as boundaries change

<table>
<thead>
<tr>
<th>Upstream boundary</th>
<th>Consumers</th>
<th>CH₄ Emission Rate</th>
<th>GHG Emissions (g CO₂e/MJ in 100-yr GWP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cradle through transmission</td>
<td>Large scale (power plants)</td>
<td>1.4%</td>
<td>12.7</td>
</tr>
<tr>
<td>Cradle through transmission/distribution</td>
<td>40%/60% mix of large/small scale</td>
<td>1.6%</td>
<td>13.6</td>
</tr>
<tr>
<td>Cradle through distribution</td>
<td>Small scale (industrial, commercial, residential)</td>
<td>1.8%</td>
<td>14.8</td>
</tr>
</tbody>
</table>
• CH₄ makes up 77% of the GHG footprint
  – 73% of this comes from Distribution, Transmission and Completions
  – 97% from 8 sources in the system

• 62% of CO₂ emissions come from the operations of compressors

• These limited set of sources represent significant opportunities for improvement
Detailed GHG Results for Next Appalachian Well
(12.0 g CO₂e/MJ, 1.1% CH₄ Emission Rate thru Distribution)

- Next Well: Post-January 2015 NSPS implementation & increased recovery efficiency
- GHG footprint reduced by 22%
- Improvements to operations reduce the contribution of CH₄ to 69%
  - Over 72% from TS&D
  - 98% now come from 6 sources

![Diagram showing Cradle-to-gate GHG Emissions (g CO₂e/MJ, ARS GWP) for different processes and their emission contributions.]
DOE Actions to Reduce Methane Emissions

• Fossil Energy funded methane emissions quantification research

• Conducted public meeting on energy efficiency standards for natural gas compressors

• Working with FERC on Incentives: Requested efforts to provide certainty for cost recovery for natural gas infrastructure modernization

• NARUC Partnership on Infrastructure Modernization

• Natural Gas Modernization R&D strategy across DOE:
  – Pipeline Efficiency Research, Development & Demonstration Program (FE)
  – Advanced Natural Gas System Manufacturing R&D Initiative (AMO)
  – Loan Guarantees for Adv. FE Projects that Reduce Methane Emissions (LPO)
  – Investing in Technologies for Leak Detection & Measurement (ARPA-E)
  – Developing a clearinghouse of information on technologies, policies, and strategies (EPSA)
Understanding the LCA of Power Production

Extraction / Production

Gathering/Processing

Transmission / Storage

Electricity Transmission

Power Generation
Life cycle GHGs for natural gas-fired power generation

![Graph showing life cycle GHG emissions for different power generation scenarios.](image-url)
GHG Emission Profiles for Fossil Power Production

90% Carbon Capture at the Power Plant Results in ~80% Reduction in LC GHG Emissions for Coal-fired Power Plants and ~70% Reduction for Natural Gas-fired Power Plants

Life Cycle GHG Emissions (g CO₂e/kWh)

- Fuel Extraction/Processing
- Fuel Transport
- Power Plant
- T&D

average Illinois No. 6
Coal
Fleet Baseload
EXPC
SCPC
IGCC
NGCC
Peaking
Fleet Baseload
Fleet Load-Following
NGCC
With Carbon Capture

45% Decrease
49% Decrease

45% Decrease
49% Decrease
Could Natural Gas be Worse than Coal if Methane Losses are Higher than we Estimate?

![Graph showing the relationship between CO₂e/kWh and CH₄ Emission Rate for different coal types.]

- **Fleet Coal**: 5.8% Fleet Coal, 13.3%
- **Adv. Coal**: 4.4% Adv. Coal, 10.0%

**Legend**:
- **20-yr GWP**
- **100-yr GWP**
- **Coal-Gas Breakeven**
- **Current Practice (1.4%)**
- **Reduced CH₄ (0.9%)**
• Reducing CO$_2$ from fossil power production is critical to achieving greenhouse gas reduction goals

• Reducing both CH$_4$ and CO$_2$ across the life cycle of power production is achievable thru CCS, nuclear, and renewable power technology

• Knowledge of CH$_4$ emissions continues to improve as new measurements and analysis are performed – reduction strategies will be adjusted accordingly

Advancing energy options to fuel our economy, strengthen our security, and improve our environment!
Timothy J. Skone, P.E.
Sr. Environmental Engineer • Strategic Energy Analysis & Planning Division • (412) 386-4495 • timothy.skone@netl.doe.gov

Joe Marriott
Lead Associate • Booz | Allen | Hamilton • (412) 386-7557 • joseph.marriott@netl.doe.gov

James Littlefield
Associate • Booz | Allen | Hamilton • (412) 386-7560 • james.littlefield@netl.doe.gov

netl.doe.gov/LCA  LCA@netl.doe.gov  @NETL_News