Critical Issues Forum

America’s Increasing Reliance on Natural Gas: Benefits and Risks of a Methane Economy

Wifi network: FWC Wireless
Password: (no password needed)
Session 3:
Environmental, health, and safety impacts
Alan Krupnick
Resources for the Future
The health and environmental impacts of shale gas development:
What we know and don’t

Alan Krupnick
Director, Center for Energy and Climate Economics

Environmental, Health and Safety Issues
American Geosciences Institute
Dallas, TX, November 19, 2014
Damage function chain

Activity ➔
burden ➔
toxicity ➔
probability in environment ➔
probability of exposure ➔
impact ➔
value
This talk

Comprehensive risk matrix
Risks from liquid wastes: produced water, ponds and tanks, surface water, seismic
Ecological
Health (truck accidents, low birth weight)
Quality of life (property values)
Valuation
Research priorities

Activity ➔ burden ➔ toxicity ➔ probability in environment ➔ probability of exposure ➔ impact ➔ value
## Site Development and Drilling Preparation

After locating a site for shale gas development, the area must be excavated and prepared for drilling. Preparation activity also often includes leveling of the site.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Intermediate Impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Groundwater</td>
</tr>
<tr>
<td>Clearing of land/construction of roads, well pads, pipelines, other infrastructure</td>
<td>Stormwater flows</td>
</tr>
<tr>
<td></td>
<td>Invasive species</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>On-road vehicle activity</td>
<td>Stormwater flows</td>
</tr>
<tr>
<td>Off-road vehicle activity</td>
<td>Stormwater flows</td>
</tr>
</tbody>
</table>

## Drilling Activities

Drilling begins by boring a single well shaft vertically into the desired formation. One or more lateral wells are then drilled from the end of the vertical wellbore, angling to run horizontally through the shale formation.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Intermediate Impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Groundwater</td>
</tr>
<tr>
<td>Drilling equipment operation at surface</td>
<td>Drilling fluids/cuttings</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Drilling of vertical and lateral wellbore</td>
<td>Methane</td>
</tr>
</tbody>
</table>
Wastewater characteristics from Marcellus shale gas development in PA

- Researchers: J. Shih, S. Olmstead (UT Austin), J. Chu, L. Muehlenbachs (U. Calgary), J. Saiers (Yale), S. Anisfeld (Yale).

- Statistically analyzes characteristics of flowback, produced water, and drilling fluid waste sent to wastewater treatment facilities in PA, 2008-2011.

- Data Source: Form 26R, submitted to PADEP by “residual waste” generators.

- 432 different analytes were identified in the data, in the following categories:
  1. General chemicals
  2. Organics
  3. Pesticides
  4. Metals
  5. Radioactive Materials
Comparison of **General Chemicals** in Produced Water and Fracking Fluid Waste

* Number at the bottom of the boxplot is the sample size
Comparison of Metals in Produced Water and Fracking Fluid Waste
Comparison of Organics in Produced Water and Fracking Fluid Waste

- **Oil & Grease**: 53 mg/L (Flowback) vs. 50 mg/L (Produced Water)
- **Benzene**: 54 mg/L (Flowback) vs. 53 mg/L (Produced Water)
- **Toluene**: 52 mg/L

MCL values:
- **Oil & Grease**: MCL = 1 mg/L
- **Benzene**: MCL = 0.005 mg/L
- **Toluene**: Not specified

Legend:
- **Flowback (804)**
- **Produced Water (802)**
Comparison of Naturally Occurring Radioactive Materials in Produced Water and Fracking Fluid Waste

![Box plot showing concentration of Radium 226 and Radium 228 in produced water and flowback compared to MCL (5 pCi/L).](chart.png)
Analysis of state databases of spills and releases

- New Mexico, Colorado, and Oklahoma (not comparable)
- Only reported spills/releases
- Materials spilled: Produced water, fracturing fluid, brine, drilling mud/fluid, HCl, KCl, crude oil, fresh water

Figure: Spills from pits and frac tanks as reported to New Mexico OCD.
Number of spills in New Mexico by category (2000 – 2013)

Panel A: Pits

<table>
<thead>
<tr>
<th>Cause of spill</th>
<th># spills</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overflow</td>
<td>33</td>
</tr>
<tr>
<td>Liner malfunction</td>
<td>31</td>
</tr>
<tr>
<td>Unidentified or undocumented</td>
<td>19</td>
</tr>
<tr>
<td>Discovery of historical spill</td>
<td>8</td>
</tr>
<tr>
<td>Blowover</td>
<td>7</td>
</tr>
<tr>
<td>Improper closure or reclamation</td>
<td>3</td>
</tr>
<tr>
<td>Sinkhole</td>
<td>2</td>
</tr>
<tr>
<td>Other</td>
<td>2</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>105</strong></td>
</tr>
</tbody>
</table>

Panel B: Frac Tanks

<table>
<thead>
<tr>
<th>Cause of spill</th>
<th># spills</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leak</td>
<td>21</td>
</tr>
<tr>
<td>Unidentified or undocumented</td>
<td>13</td>
</tr>
<tr>
<td>Overflow</td>
<td>9</td>
</tr>
<tr>
<td>Other</td>
<td>3</td>
</tr>
<tr>
<td>Collapse</td>
<td>2</td>
</tr>
<tr>
<td>Vandalism</td>
<td>2</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>50</strong></td>
</tr>
</tbody>
</table>
We exploit spatial and temporal variation in the proximity of shale gas wells, waste treatment facilities, and surface water quality monitors in Pennsylvania to estimate:

1. the impact of *shale gas wells* on downstream chloride and TSS concentrations; and

2. the impact of *shale gas waste treatment* and release to surface water on downstream chloride and TSS concentrations.
Conclusions

• No statistically significant impact of shale gas wells on downstream chloride concentrations.
  • A positive result here would have been consistent with contamination problems from spills, dumping, etc.

• Release of treated shale gas waste to surface water by permitted waste facilities appears to increase downstream chloride concentrations.
  • Effect is significant only for POTWs, not CWTs.

• Shale gas wells appear to increase downstream TSS concentrations.
Induced Seismicity

- Seismicity from fracking NOT a problem
- Deep well injection
  - #3 in anthropogenic earthquakes):
  - 40,000 wells taking oil and gas liquid wastes.
  - Growth in earthquakes > 3.0 since 2009, “coincident with” oil and gas waste injections.”
  - In CO, TX, OH, ARK, OK. a few “caused by.”
Cumulative number of earthquakes with a magnitude of 3.0 or larger in the central and eastern United States, 1970–2013. The dashed line corresponds to the long-term rate of 20.2 earthquakes per year, with an increase in the rate of earthquakes starting around 2009.
Induced Seismicity, cont.

• DWI better than pits, which leak; better than CWTs which can’t treat some elements of produced water

• Can it be managed?
  • Industry cutting water flows through reuse/recycling, using less liquids
Figure 3. Satellite image of Mesa in 1999 (left) compared to 2009 (right).
Truck Traffic Accidents in Pennsylvania by Well Activity

![Graph showing truck traffic accidents in counties with more than 20 wells, less than 20 wells, and well pads drilled from 1997 to 2012. The graph includes data points for each year with a trend line for each category.]

- **Accidents in counties with more than 20 wells**
- **Accidents in counties with less than 20 wells**
- **Well pads drilled**
Property Values

- Great aggregator of local perceived risks – with **real** effects
- Effects of proximity and intensity
- Proximity Matters
  - Within 1.5 km and on groundwater: $33,000 decrease versus homes further away and on public water
- Intensity Matters a little
Figure 2. Estimated WTP ($ household⁻¹ year⁻¹), on average, for the reduction of risks associated with shale gas development.
Research priorities for the future

- Remainder of the water cycle
- **Net** benefits to communities of SGD
- Approaches for internalizing externalities and compensating locals.
  - Act 13. Turned down by PA Supreme Court.
- Mental health effects of SGD? Low Birth Weight effect?
- Legacy
Thank you!

krupnick@rff.org
Mark Brownstein
Environmental Defense Fund
Natural Gas in a Low Carbon Future
Environmental Opportunities & Challenges

Mark Brownstein
Associate Vice President
U.S. Climate & Energy Program
Must address the ‘fracking’ issues

Hydraulic Fracturing

Hydraulic fracturing, or “fracing,” involves the injection of more than a million gallons of water, sand and chemicals at high pressure down and across into horizontally drilled wells as far as 10,000 feet below the surface. The pressurized mixture causes the rock layer, in this case the Marcellus Shale, to crack. These fissures are held open by the sand particles so that natural gas from the shale can flow up the well.
And then, there’s methane…

Gas storage tank

Same tank, same time, infrared camera view

...an increasingly ‘visible’ problem
CH$_4$ traps more heat than CO$_2$...

EACH METHANE MOLECULE TRAPS $84x$ MORE HEAT

Ratio of direct radiative efficiencies, $W \text{ m}^{-2} \text{ ppb}^{-1}$ (IPCC AR5)
...but breaks down faster than CO$_2$

METHANE DISSIPATES FASTER THAN CARBON DIOXIDE

- CH$_4$ produces tropospheric ozone and stratospheric water vapor as it decays
- Increases the direct warming effect by 65% (IPCC AR5)
Methane and CO$_2$ reductions required

Gas can be worse than alternatives

Depending on emission rate and timeframe

Updated calculations of fuel-switching scenarios in EDF’s 2012 PNAS paper.*

Individual results vary by the technology choice(s) made in each case. EDF is expanding the range of technologies evaluated.

---

*Adapted from Alvarez et al. (2012) PNAS, 109: 8435–8440, reflecting new IPCC AR5 & 2013 EPA GHG data. IPCC updates: (1) direct/indirect radiative forcing of CH₄ and CO₂, (2) CH₄ lifetime, (3) CO₂ impulse response function. Additional effects due to climate-carbon feedbacks and CO₂ from the oxidation of CH₄ not included (AR5 lacks data to support time-dependent analysis but EDF believes these effects to be small). Emissions updates include factors in Table 1 and corresponding Lₜₜ values in Table S1 of PNAS paper; an Lₜₜ value specific to heavy-duty CNG vehicles is now used.
Comprehensive emission study effort

Over-flight/Coordinated Campaign Work

Production module
- Well pad
- Gathering lines
- Compressors
- Gas processing plants

Gathering and processing module
- Compressors
- Gas processing plants
- Storage
- Long distance pipelines
- City gate
- Compressors
- Local distribution systems
- Local distribution systems
- Natural gas fueling station
- Heavy and medium duty natural gas vehicles

Transmission and storage module

Local distribution module
- Natural gas vehicles and fuel stations module
Highly cost-effective reductions

http://www.edf.org/icf-methane-cost-curve-report

Economic Analysis of Methane Emission Reduction Opportunities in the U.S. Onshore Oil and Natural Gas Industries
ICF International, March 2014,
Doug Jordan
Southwestern Energy Company
Forward-Looking Statements

All statements, other than historical facts and financial information, may be deemed to be forward-looking statements within the meaning of Section 27A of the Securities Act of 1933, as amended, and Section 21E of the Securities Exchange Act of 1934, as amended. All statements that address activities, outcomes and other matters that should or may occur in the future, including, without limitation, statements regarding the financial position, business strategy, production and reserve growth and other plans and objectives for the company’s future operations, are forward-looking statements. Although the company believes the expectations expressed in such forward-looking statements are based on reasonable assumptions, such statements are not guarantees of future performance and actual results or developments may differ materially from those in the forward-looking statements. The company has no obligation and makes no undertaking to publicly update or revise any forward-looking statements. You should not place undue reliance on forward-looking statements. They are subject to known and unknown risks, uncertainties and other factors that may affect the company’s operations, markets, products, services and prices and cause its actual results, performance or achievements to be materially different from any future results, performance or achievements expressed or implied by the forward-looking statements. In addition to any assumptions and other factors referred to specifically in connection with forward-looking statements, risks, uncertainties and factors that could cause the company’s actual results to differ materially from those indicated in any forward-looking statement include, but are not limited to: the timing and extent of changes in market conditions and prices for natural gas and oil (including regional basis differentials); the company’s ability to fund the company’s planned capital investments; the company’s ability to transport its production to the most favorable markets or at all; the timing and extent of the company’s success in discovering, developing, producing and estimating reserves; the economic viability of, and the company’s success in drilling, the company’s large acreage position in the Fayetteville Shale play overall as well as relative to other productive shale gas plays; the impact of government regulation, including any increase in severance or similar taxes, legislation relating to hydraulic fracturing, the climate and over the counter derivatives; the costs and availability of oilfield personnel, services and drilling supplies, raw materials, and equipment, including pressure pumping equipment and crews; the company’s ability to determine the most effective and economic fracture stimulation for the Fayetteville Shale formation; the company’s future property acquisition or divestiture activities; the impact of the adverse outcome of any material litigation against the company; the effects of weather; increased competition and regulation; the financial impact of accounting regulations and critical accounting policies; the comparative cost of alternative fuels; conditions in capital markets, changes in interest rates and the ability of the company’s lenders to provide it with funds as agreed; credit risk relating to the risk of loss as a result of non-performance by the company’s counterparties and any other factors listed in the reports the company has filed and may file with the Securities and Exchange Commission (SEC). For additional information with respect to certain of these and other factors, see the reports filed by the company with the SEC. The company disclaims any intention or obligation to update or revise any forward-looking statements, whether as a result of new information, future events or otherwise.

The SEC has generally permitted oil and gas companies, in their filings with the SEC, to disclose only proved reserves that a company has demonstrated by actual production or conclusive formation tests to be economically and legally producible under existing economic and operating conditions. We use the terms “estimated ultimate recovery,” “EUR,” “probable,” “possible,” and “non-proven” reserves, reserve “potential” or “upside” or other descriptions of volumes of reserves potentially recoverable through additional drilling or recovery techniques that the SEC’s guidelines may prohibit us from including in filings with the SEC. These estimates are by their nature more speculative than estimates of proved reserves and accordingly are subject to substantially greater risk of being actually realized by the company.

The contents of this presentation are current as of August 1, 2013.
Areas of operation

**Exploration & Production Segment**

2013
6,976 Bcfe* of proved reserves
657 Bcfe of production

2014 est. production: 740 – 752 Bcfe

**New Brunswick**
Acreage: 2.5 million net acres

**Marcellus Shale**
Acreage: 292,446 net acres (at 12/31/13)
2013 Reserves: 1,963 Bcfe (28% of total)
2013 Production: 151 Bcfe (23% of total)

**Fayetteville Shale**
Acreage: 905,684 net acres (at 12/31/13)
2013 Reserves: 4,795 Bcfe (69% of total)
2013 Production: 486 Bcfe (74% of total)

**Ark-La-Tex**
Acreage: 152,937 net acres (at 12/31/13)
2013 Reserves: 215 Bcfe (3% of total)
2013 Production: 18 Bcfe (3% of total)

**Brown Dense Project**
Acreage: 459,000 net acres

**Denver Julesburg Basin**
Acreage: 302,000 net acres

* Bcfe is an equivalent measurement of one billion cubic feet of mixed oil and gas reserves

** Arkoma acreage excludes 124,653 net acres in the conventional Arkoma Basin operating area that are also within the company’s Fayetteville Shale focus area.
A true HSE culture exists when:

- HSE becomes part of everyday business.
- One has pride in HSE just like having pride in being excellent in production, footage drilled, and customer satisfaction.
- HSE is not an afterthought, but a way of doing business.

Culture is a key to continued HSE excellence!
Key Steps in Developing an HSE Culture

1. HSE Awareness
2. Company Recognition
3. Senior Management Support
4. Accountability for HSE
5. Employee Involvement
6. Embrace HSE as a value integral to the organization

HSECulture
SWN Management Philosophy

**SWN Values**

Safety

SWN makes HSE equal to production/operations and profits/expenses.

**HSE Compliance is Key**

If it can’t be done within HSE compliance, it will not be done at SWN.
A SWN priority is to ensure that health, safety and environmental management is integrated into all of our business activities.
SWN HSE Culture “Tools”

- **HSE “Training”**
  - New Hire Orientation
  - HS&E Leadership Training
  - “R2 Training”

- **HSE Handbook**

- **HSE Programs**

- **HSE Goals**
  - Balanced Scorecard
  - Industry Peer Group Comparisons

- **HSE Steering Committees**

- **HSE Awards/Recognition**
**The Path Forward – “HSE Next Generation”**

**Phase 1**
- Assess current state
- Evaluate and benchmark safety culture and systems

**Action**
- Safety Perception Survey completed Q1, 2014

**Phase 2**
- Envision future state
- Gain management alignment and commitment

**Phase 3**
- Plan Transition
- Design corporate & local change management plans

**Phase 4**
- Implement Change
- Build foundation & instill changes in organization

**Action**
- Develop and implement local change management plans (2015 Balanced Scorecards)
- Begin development of observation and intervention data collection and processing tools
- Organize and develop enterprise-wide HSE governance

**Phase 5**
- Sustain & Improve
- Monitor, measure and continuously improve

**Action**
- Using Scorecard results, observation findings and lessons learned from incident investigations, develop long-term plans to continuous improvement

**Complete Safety Perception Survey again in 2017**
• SWN’s commitment to the health and safety of our employees, contractors and to our neighbors begins with collaboration – **A ONE Team Approach**

• **Agency Engagement**
  – NIOSH Flowback and Silica Studies
  – OSHA STEPS Program

• **Contractor Engagement**

• **Community Benefits**
SWN Health & Safety Collaborative Programs

Short Service Employee program.

Continuous development of the TAP initiative (business unit specific modules).

ISNetworld company wide re-launch.

Contractor Assessment process which includes desktop reviews, onsite visits, and field observations.

Continuation of Street Smart, TEAMworks, eLearning, vendor forums, and SWNlink communications.
SWN Methane Emission Reduction Activities

- EPA Natural Gas Star – member since 2005
  - Cumulative reductions = 37 BCF
  - 2011 Production Partner of the Year

- SWN SMART LDAR Program – voluntary program to survey and repair emission leaks from facilities.
  - Midstream initiated program in 2012
  - Production initiated program in 4th Quarter, 2013.

- SWN Dual fuel drilling rigs – replacing fleet (2014 / 2015)

- Fuel cell field test
  - Pnuematic controller conversion from gas to air
Environmental Collaboration

• Collaborative effort with industry, academia and environmental community to solve issues such as air emissions, water protection and community impact.
OUR GOAL
Enhance the energy delivery efficiency of the natural gas supply chain by limiting energy waste and by achieving a methane “leak/loss rate” of no more than one percent.
SWN Methane Research - Collaboration

• **Top-Down Methane Emissions Studies**
  - DOE/Penn State Marcellus Study
    - SWN’s participation includes funding additional tower and study participation

• **“Bottom-Up” Methane Emissions Studies**
  - Production Sector Phase 1 and Phase 2
    - University of Texas
      - URS
      - Aerodyne
    - EDF and 9 Industry Participants
  - Gathering & Processing Sector
    - Colorado State University
      - Carnegie Mellon University
      - Aerodyne
    - EDF and 4 Industry Participants

• **“Top-down” and “bottom-up” methane measurements**
  - D-J Basin Reconciliation Study
    - Research Partnership to Secure Energy for America

• **New Measurement Technology Partnerships**
  - EDF “Methane Detectors Challenge”
  - Picarro “Surveyor” field trial
  - Rebellion Photonics “gas cloud imaging camera” field trial
Offset 100% of the volume of fresh water used in SWN operations by 2016:

- PROTECTION
- REDUCTION
- INNOVATION
- CONSERVATION
• **Protection**
  - Protection of existing water sources
    - Model Regulatory Framework – Environmental Defense Fund
    - Marcellus Water Well Monitoring - Install monitoring wells before SWN pad activity. One year of monitoring prior to development activity – Yale University
    - Streamsmart – Erosion/sediment control project - Nature Conservancy

• **Reduction**
  - Minimize the total quantity of water needed
  - Recycle produced water for future completions
  - Replace fresh water with alternate sources
  - Minimize the use of potable water

• **Innovation**
  - Develop compact, low cost water treatment technologies
  - Research / Develop approaches to economic low water stimulation.

• **Conservation**
  - Increase water availability or improve water quality.
Fall Brook Acid Mine Drainage Completion - 2016

- **Location:** Tioga River Watershed, Tioga Co, PA
- **Description:** AMD Remediation Project
- **Conservation Type:** Stream and River Restoration
- **Benefits:**
  - Place 325 million gallons (10.7 million barrels) a year of clean water into Susquehanna River for PA and NY
  - Increase recreational and aesthetic value of river
  - Decrease bridge maintenance cost
- **Partners:**
  - PA Fish and Boat Commission
  - PA Dept. of Env. Protection
  - SRBC
  - Trout Unlimited
  - Tioga Co. Concerned Citizens Committee
  - Tioga Co. Conservation District
  - Tioga Co. Commissioners
- **Timeline:**
  - 2014 – Survey and Design
  - 2015 – Construction
Environmental Protection Collaboration

Well Bore Integrity

Typical Fayetteville Shale Well

- Several layers of protective steel casing & cement
- Typical fresh water aquifer zone
- Cement layer surrounding casing
- Drilling shaft
- Fayetteville Shale

Right Products Program

Systematic approach to evaluating chemicals that SWN may use in its operations.

Stream Smart

Erosion Control Training
The Right People Doing The Right Thing

\[ \frac{R^2}{A} \xrightarrow{} V^+ \]

Will create Value+

Wisely investing the cash flow from the underlying assets
Session 3:
Environmental, health, and safety impacts
Critical Issues Forum

America’s Increasing Reliance on Natural Gas: Benefits and Risks of a Methane Economy

Wifi network: FWC Wireless
Password: (no password needed)