Shale Gas Production – The GHG Emissions Question

Francis O'Sullivan, Ph.D.

September 13th, 2012

Assessing the GHG footprint of shale gas is complex – One must consider both well performance variability and gas handling practices

A deep-dive data-rich examination of the issue of fugitive emissions associated with the completion of shale wells – Specifically horizontal wells brought on production in five of the major contemporary shale plays during 2010

- **Review the variability in intra and inter-shale play well-to-well performance levels** – There are major differences in well-to-well performance levels that have real implications for the assessment of fugitive emissions

- **Review of the options for gas handling during well completion and the associated GHG intensities of such processes**

- **Describe some quantitative scenarios for shale well completion-related fugitive emissions levels, which can be compared with assessments of total fugitive levels**

Shale gas production has transformed the U.S. natural gas industry – The ability of the resource to support rapid production growth has been particularly notable, with output growing by over 1600% since 2005

Illustration of U.S. marketed natural gas production since 2005
Bcf of gas per day

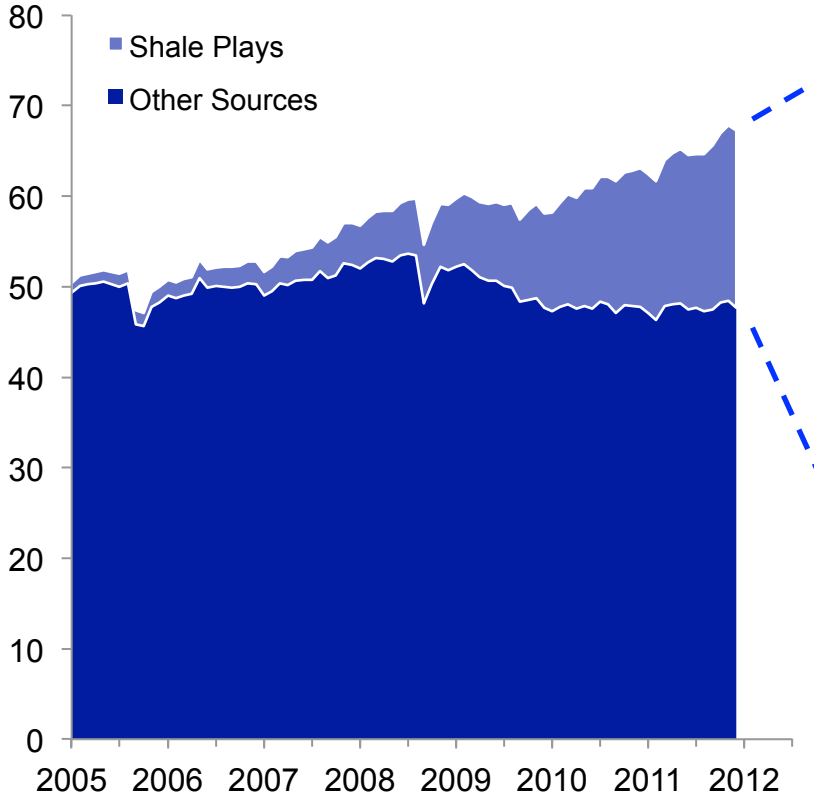
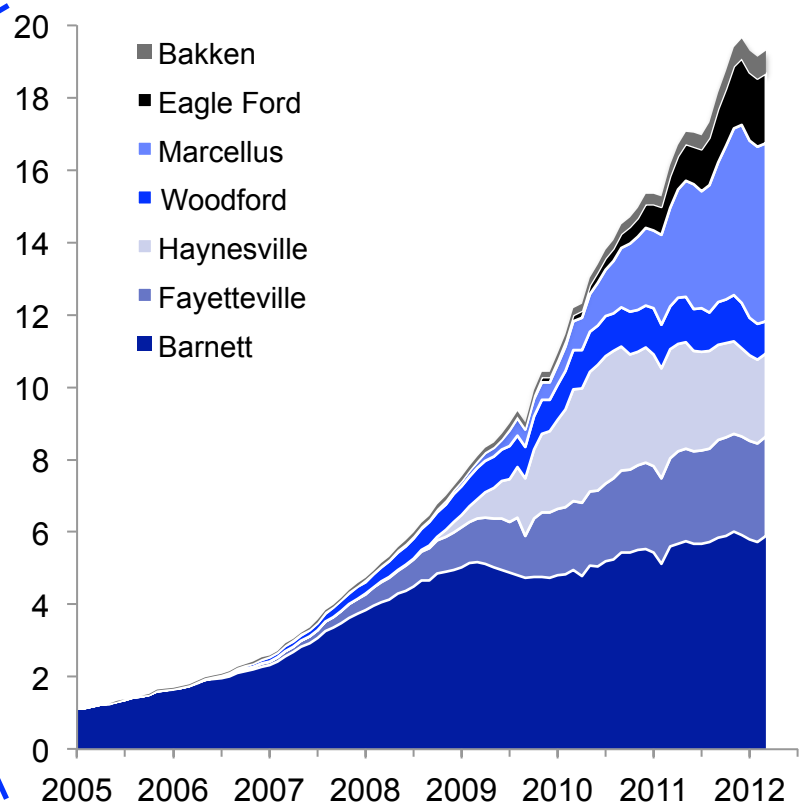


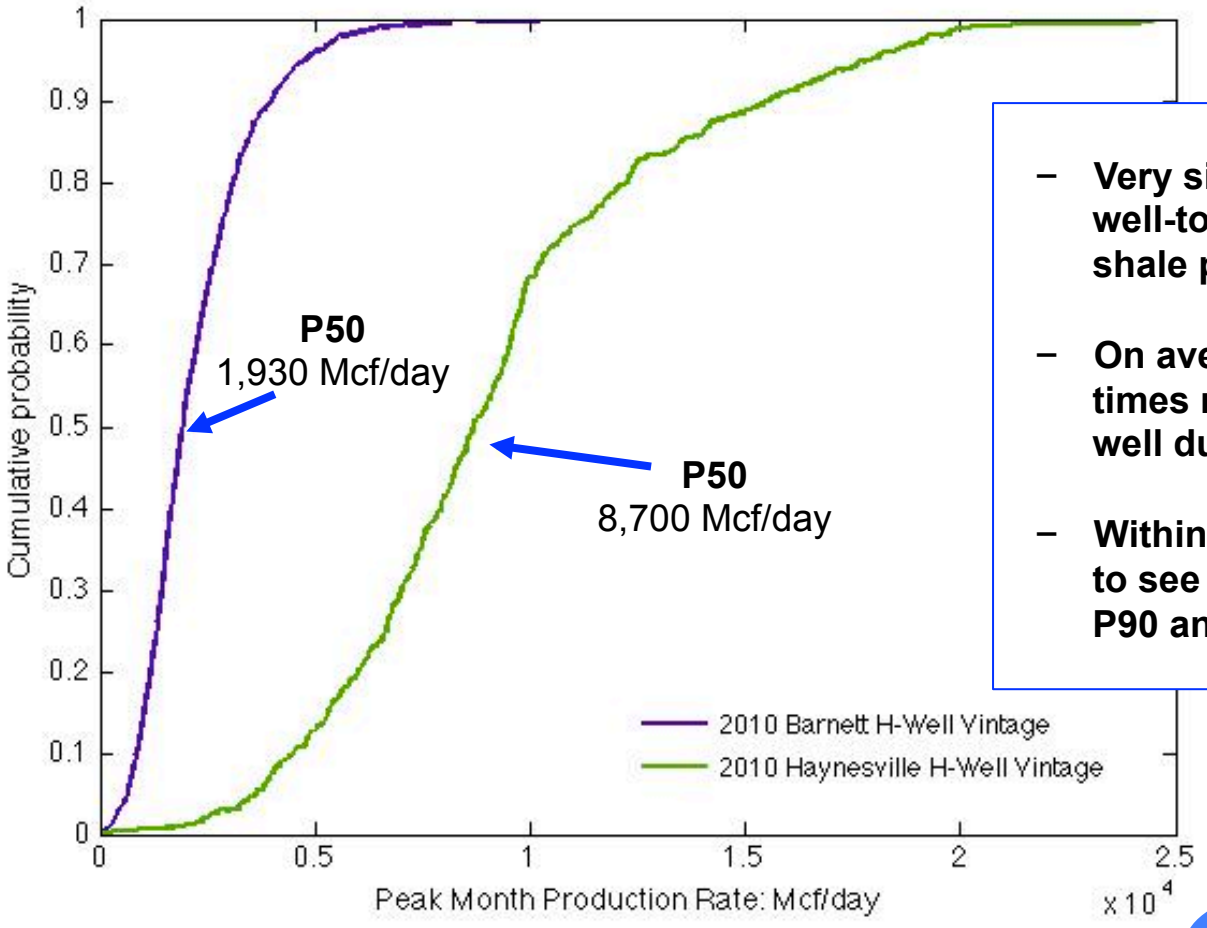
Illustration of production growth in the main U.S. shale plays since 2005
Bcf of gas per day



Source: U.S. Energy Information Administration, HPDI Production Database

When considering fugitive emissions, appreciating the heterogeneity of the shale resource is important – Intra and inter-play variability in well performance is very significant and small well datasets do not fully capture this point

Distribution of peak month well productivity in Barnett and Haynesville shales[1]
All horizontal shale wells drilled in Barnett and Haynesville Shales during 2010



- **Very significant variation is evident in well-to-well performance of all the main shale plays**
- **On average a Haynesville well will be 4-5 times more productive than a Barnett well during the first few months**
- **Within all the main plays you can expect to see at least a 3.5X difference between P90 and P10 well productivity**

P90 – P10 Spread > 3.5X

1. Peak month production rate reported in units of Mcf/day
Source: HPDI production database

A detailed review of horizontal shale wells brought online in 2010 reveals just how the amount of gas produced by individual shale wells varies – Variability in well performance levels has a direct impact on fugitive emissions estimates

		Well Peak Production Data: 1x10³ m³ per day[1]			
Shale Play	***# of H. Wells***	***Mean***	*P80*	*P50*	*P20*
Barnett	**1,785**	**60.6**	85.5	52.1	30.6
Fayetteville	**870**	**65.7**	90.8	63.4	37.1
Haynesville	**509**	**261.5**	339.6	246.2	167.5
Woodford	**208**	**108.1**	152.3	91.7	51.2
Marcellus	**576**	**90.0**	127.4	76.1	43.3

- The main contemporary shale plays are much more productive than the overall gas resource base
- In 2010, ~17,500 gas wells were brought online of which ~4,000 were horizontal wells in the main shale plays, yet these wells delivered 40% of all production additions that year
- When considering early-life well production rates, the horizontal shale well ensemble is twice as productive as the overall well population

1. Derived from per-well peak month production rate data

Source: HPDI production database; F. O'Sullivan & S. Paltsev, "Shale gas production: potential versus actual GHG emissions," *Environmental Research Letters*, In Review

Combining well data with reasonable assumptions regarding flowback can yield a qualitatively useful assessment of potential fugitive levels – Potential fugitives from shale well completion in 2010 could amount to 900 Gg of CH_4

- Estimating the scale of *potential fugitive emissions* from any given well completion is very difficult without specific well details… and even then it is complex

- Useful to develop a reasonable procedure that can yield "qualitatively useful" if not exact estimates

Estimating Potential Fugitives from 2010 Well Vintage - Assumptions:

- 9 day flowback duration; Gas production ramping from 0 to peak recorded daily production rate

	Barnett	Fayetteville	Haynesville	Woodford	Marcellus
Per-well potential fugitives $1x10^3$ m^3 of natural gas	273	296	1,177	487	405
Total potential fugitives $1x10^6$ m^3 of natural gas	487	257	599	102	234
Total potential fugitives Gg of CH_4	262	138	322	54	125

Source: HPDI production database; F. O'Sullivan & S. Paltsev, "Shale gas production: potential versus actual GHG emissions," *Environmental Research Letters*, In Review

***Potential emission levels* are not what matters… it is them in combination with how they are handled that is of relevance** – The GHG impact of any given well completion can vary by an order of magnitude depending on how those potential emissions are handled

The options for gas handling during shale well completion operations

Cold-Venting

- Direct release of natural gas to atmosphere
- 13.5 kg CO_2e / m^3 of natural gas

Flaring

- Burn the natural gas as it is released
- 1.7 kg CO_2e / m^3 of natural gas[1]

Reduced Emissions "Green" Completion

- Capture and deliver gas to gathering system
- 1.3 kg CO_2e / m^3 of natural gas[2]

1 Assuming 98% combustion efficiency per U.S. EPA
2 Assuming 90% of natural gas is captured by system

Different assumptions have been made regarding the practice mix for gas handling during unconventional well completion operations – The lack of verifiable data means that the actual situation remains opaque

Gas handling scenarios for assessing the GHG intensity of contemporary shale well completion operations

	Scenario A	Scenario B	Scenario C	Scenario D
Cold-Venting	85-100%	49%	3%	15%
Flaring	0-15%	51%	4%	15%
Green completions	-	-	93%	70%

- **Scenario A:** Assumptions made by Cornell Group in their evaluation of the GHG intensity of shale well completions[1]
- **Scenario B:** Represents a gas handling scenario for unconventional wells in WY, TX, NM, OK based on state regulation[2]
- **Scenario C:** Mix of gas handling practices reported for unconventional wells in 2011 ANGA survey of ~1,500 completions[3]
- **Scenario D:** Synthetic scenario designed to reflect a practically achievable mix of gas handling practices for well completions in the main shale plays

1 Howarth, R. et al. Methane and the greenhouse-gas footprint of natural gas from shale formations. Climatic Change 106, 679-690 (2011).
2 Greenhouse Gas Emissions Reporting from the Petroleum and Natural Gas Industry: Background Technical Supporting Document (EPA, Washington DC, 2010)
3 ANGA Comments to EPA on New Source Performance Standards for Hazardous Air Pollutants Review (America's Natural Gas Alliance, January 19, 2012)

Analyzing gas handling scenarios reveals how easy it is to arrive at differing conclusions regarding the GHG intensity of shale well completions

Per-well fugitive GHG emissions intensity based on 2010 play-level mean well performance, and assumptions in scenarios A-D for gas handling during well completion
Mg CO_2e per well assuming 100 year GWP of 25 for CH_4

	Barnett	Fayetteville	Haynesville	Woodford	Marcellus
Scenario A 100% Vented	3,669	3,978	15,816	6,544	5,442
Scenario B 49% Vented, 51% Flared	2,036	2,208	8,779	3,632	3,021
Scenario C 3% Vented, 4% Flared, 93% GC	470	510	2,026	838	697
Scenario D 15% Vented, 15% Flared, 70% GC	877	951	3,782	1,565	1,301

- The differences in inter-play average well performance levels means that for any gas handling scenario, the GHG intensity of a “typical” well could vary by a factor of >4X
- The GHG intensity could vary by almost 8X depending on which gas handling scenario is assumed to be “representative” of field practice

Source: F. O’Sullivan & S. Paltsev, “Shale gas production: potential versus actual GHG emissions,” *Environmental Research Letters*, In Review

At the macro level, fugitive emissions from shale well completions are not insignificant; however they are likely manageable under a scenario where flaring and green completions are relatively widely applied

Estimation of total fugitive GHG emissions associated with the completion of 2010 wells in the main U.S. shale plays
Tg CO_2e assuming 100 year GWP of 25 for CH_4

	Barnett	Fayetteville	Haynesville	Woodford	Marcellus	Total
Scenario A 100% Vented	6.5	3.5	8.1	1.4	3.1	22.6
Scenario B 49% Vented, 51% Flared	3.6	1.9	4.5	0.8	1.7	12.5
Scenario C 3% Vented, 4% Flared, 93% GC	0.8	0.4	1.0	0.2	0.4	2.6
Scenario D 15% Vented, 15% Flared, 70% GC	1.6	0.8	1.9	0.3	0.7	5.3

- In 2010, total gas-related CH_4 fugitive emission were estimated at 10,200 Gg CH_4, with 5,980 Gg CH_4 from upstream[1]
- Assuming Scenario D, shale well completion would represent 3.6% of upstream, or 2.1% of total gas-related fugitives in 2010, while those well contributed 40% of new production

1 Draft of 2012 Inventory of U.S. Greenhouse Gas Emissions and Sinks (U.S. Environmental Protection Agency, Washington, DC, 2012).
Source: F. O'Sullivan & S. Paltsev, "Shale gas production: potential versus actual GHG emissions," *Environmental Research Letters*, In Review

Questions & Comments