Final Research Report

HYDRAULIC FRACTURING AND THE MANAGEMENT, DISPOSAL, AND REUSE OF FRAC FLOWBACK WATERS: VIEWS FROM THE GENERAL PUBLIC IN THE PENNSYLVANIA MARCELLUS SHALE REGION

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ABSTRACT

Data collected in a general population survey from a random sample drawn from 21 counties located in the geological Central Core and Tier 1 of the Marcellus Shale region in Pennsylvania were used to empirically examine issues associated with the public's views on: (1) the process of hydraulic fracturing; (2) the management and disposal of frac flowback wastewater; and, (3) frac flowback wastewater treatment technology. Further, contributions made to self-reported knowledge of hydraulic fracturing by eight different sources and the amount of trust in each of the same sources to deliver unbiased, factual knowledge about the topic were investigated. Building upon previous research on the public's perception of produced water by Theodori and his colleagues (Theodori et al. 2009, 2011), the level of agreement that treated wastewater from hydraulic fracturing operations could safely be used for selected purposes was assessed. Lastly, the associations between level of familiarity with frac flowback wastewater treatment technology and the proposed potential uses of treated wastewater were evaluated using bivariate and multivariate logistic regression techniques. Differences in the information reported by respondents living in high well-density counties (20 or more wells per 100 square miles) and their counterparts living in low well-density counties (fewer than 20 wells per 100 square miles) were also examined. The results contained in this report should prove beneficial to members of the general public, community leaders, oil and gas industry representatives, government and regulatory agency personnel, environmental and non-governmental organization representatives, and other interested stakeholders. Possible implications and recommendations of the findings are advanced.

INTRODUCTION

Technological advances in horizontal drilling and multi-stage hydraulic fracturing were two primary factors spawning the unprecedented shale gas boom during the past decade in the United States (IEA 2012; Veil 2010). The horizontal drilling techniques and hydraulic fracturing methods developed, tested, and refined in the Barnett Shale during the late 1990s and early 2000s were rapidly employed in shale gas basins across the nation (e.g., Fayetteville, Woodford, Haynesville, Marcellus, Utica, Eagle Ford). According to the Energy Information Administration (EIA), the statistical and analytical agency of the U.S. Department of Energy, shale gas contributed roughly one third of the total U.S. natural gas production (7.8 tcf of 23.0 tcf) as of 2011 (EIA 2012). Furthermore, EIA estimates that shale gas production will constitute approximately one half (50.5 percent; 16.7 tcf) of the projected 33.1 tcf total domestic natural gas production in 2040 (EIA 2012).

Accompanying this tremendous surge in shale gas production is a barrage of controversy (Marsa 2011; Walsh 2011). At the center of the debate is the well stimulation/completion process known as hydraulic fracturing (Finkel and Law 2011; Rahm 2011). Shale gas development relies heavily on multi-stage hydraulic fracturing stimulation to maximize commercial viability. Wells are hydraulically fractured by flushing large quantities of “frac fluid” – a mixture of freshwater, proppants, and small amounts of friction reducers and other chemicals – into them at extremely high pressure levels to create small cracks, or “fractures,” in the shale formations. Doing this allows natural gas to flow more freely through the reservoir and, in turn, increases recovery. Frac jobs commonly use 1 to 3 million gallons of water per gas well; in some cases, water use may exceed 5 million gallons per frac (Anderson and Theodori 2009).

After a frac job is completed, the pressure is released and, along with the natural gas, the well generates frac flowback and produced waters. Frac flowback is the term used to describe injected water that returns to the surface during the first few weeks of production. Produced water refers to the water naturally present in the formation brought to the surface throughout the production process (Veil 2010). Both frac flowback and produced waters generally contain high levels of total dissolved solids (TDS) and other contaminants. Operators must manage and dispose of flowback and produced waters using methods complying with state and local regulatory requirements.

Until recently, energy producers used several methods to manage and dispose of flowback and produced wastewaters from shale reservoirs, including underground injection, surface discharge, municipal wastewater treatment plant discharge, commercial industrial wastewater treatment discharge, and beneficial reuse (Veil 2010). Underground injection is the primary wastewater management/disposal method employed in the vast majority of shale gas basins (Veil 2010). Beneficial reuse remains the management/disposal method least adopted and diffused throughout the industry (Clark and Veil 2009). However, in efforts to conserve freshwater resources, reduce social and environmental impacts, improve public confidence, and minimize costs, operators have recently begun to treat and reuse flowback and produced waters in subsequent drilling and hydraulic fracturing operations (Burnett et al. 2012; Veil 2010).

The purpose of this paper is to empirically explore issues associated with hydraulic fracturing and the management and disposal of frac flowback wastewater. Here, survey data gathered in the Marcellus Shale region of Pennsylvania were analyzed to investigate respondents' levels of familiarity with: (1) the process of hydraulic fracturing; (2) the management and disposal of frac flowback wastewater; and, (3) frac flowback wastewater treatment technology. Further, we examine the contribution made to self-reported knowledge of hydraulic fracturing by eight different sources, and the amount of trust in each of the same sources to deliver unbiased, factual knowledge about the topic. Building upon previous research on the public's perception of produced water by Theodori and his colleagues (Theodori et al. 2009, 2011), we assess the level of agreement that treated wastewater from hydraulic fracturing operations could safely be used for selected purposes. Finally, we evaluate the association between level of familiarity with frac flowback wastewater treatment technology and the proposed potential uses of treated wastewater. Differences in information reported by respondents living in high well-density counties (20 or more wells per 100 square miles) and their counterparts living in low well-density counties (fewer than 20 wells per 100 square miles) are examined.

DATA COLLECTION

Between June and October 2012, a random sample of individuals living in 21 counties located in the geological Central Core and Tier 1 of the Marcellus Shale region in Pennsylvania were contacted by telephone or mail and asked to participate in a survey of resident opinions concerning natural gas development.[1] All counties included in the sampling frame had experienced at least some Marcellus Shale drilling, but the density of such wells varied widely. To secure opinions from respondents within this region that reflected industry activity differences, the sample was chosen to reflect the views of individuals living in counties with "low" well densities (fewer than 20 wells per 100 square miles) and those living in counties with "high" well densities (20 or more wells per 100 square miles). Coincidentally, 50% of the total population in the 21 counties included in the sample fell in the low well-density counties and 50% fell in the high well-density counties.[2]

The telephone survey was conducted over the period June 11, 2012, to August 30, 2012, using state-of-the-art CATI software designed to maximize completed surveys from the limited and finite random sample pool over an extended period of time. This meant repeated calls to each unique number at various times of the day and days of week and repeated callbacks to those individuals who expressed interest in participating, when reaching them due to busy schedules

[1] Geologists differ in their estimates of the exact size and location of the Marcellus Shale region. The current research focused on the area defined by Bernstein Research as the Central Core and Tier 1 in Pennsylvania (Dell et al. 2008). The Core and Tier 1 areas were defined in terms of depth, thickness, porosity, thermal maturity, and silica content of the shale – factors that play into the economics of the gas yield. In addition to the 20 counties so defined, Washington County was added to the sampling frame because of the high incidence of drilling that had already taken place there.

[2] Counties included in the low well density category were: Bedford, Blair, Cambria, Cameron, Centre, Clearfield, Clinton, Indiana, Lackawanna, Somerset, Sullivan, and Wayne. The high well density counties included: Bradford, Fayette, Greene, Lycoming, Susquehanna, Tioga, Washington, Westmoreland, and Wyoming.

was a challenge. Calls continued until 200 completed interviews were obtained from each of the well-density county categories. The overall telephone survey completion rate was 27%.[3]

For the mail survey, 800 names and addresses of persons with listed telephone numbers were randomly selected from the low well-density counties and 800 names and addresses were randomly selected from the high well-density counties. An initial mailing, including a cover letter and a printed questionnaire, was sent to these sample members in July 2012, followed by three follow-up reminder letters with duplicate questionnaires over the next three months. A total of 43 questionnaires in the low well-density counties and 52 questionnaires in the high well-density counties were returned as undeliverable.[4] The first 200 replies received from each of the well-density categories were included in the current analysis, resulting in an overall usable response rate of 27%.

MEASUREMENT OF VARIABLES

The questions/items used in the mail and telephone surveys were identical in wording and in the instructions given to the respondents. The ways in which the specific questions/items used in this analysis were measured are specified below.

Measuring Familiarity with the Process of Hydraulic Fracturing

Familiarity with the process of hydraulic fracturing was assessed using a single survey item that ranged from 1 (extremely unfamiliar) to 7 (extremely familiar).

Measuring Contribution Made to Knowledge about the Process of Hydraulic Fracturing

Respondents were asked to indicate to degree to which each of eight sources contributed to what they knew about the process of hydraulic fracturing. The eight sources included: (1) newspapers; (2) *Gasland* (the film by Josh Fox); (3) natural gas industry; (4) regulatory agencies; (5) conservation/environmental groups; (6) Cooperative Extension; (7) university professors; and, (8) landowner groups/coalitions. Response categories were coded: 0 = none; 1 = very little; 2 = some; and, 3 = a great deal.

Measuring Trust to Deliver Unbiased, Factual Knowledge on Hydraulic Fracturing

Respondents were asked to indicate the amount of trust in each of the same eight sources to deliver unbiased, factual knowledge on the process of hydraulic fracturing. The sources were: (1) newspapers; (2) *Gasland*; (3) natural gas industry; (4) regulatory agencies; (5) conservation/environmental groups; (6) Cooperative Extension; (7) university professors; and,

[3] Two thousand random telephone numbers were entered into a telephone bank. Of the 2,000 telephone numbers, 496 were unusable (393 were nonworking/disconnected/other; 43 were computer/fax lines; 60 were business lines/nonresidential). Hence, the usable telephone survey sample was reduced to 1,504. Of these, 400 individuals completed the survey, resulting in a 26.6% completion rate. Two hundred and five individuals answered their telephone and either refused initially (n=174), refused mid-survey (n=19), suspended their effort and agreed to finish the survey at a later time (n=8), or scheduled a callback (n=4). The remaining 899 telephone numbers were all dialed 10 or more times and ended with no answer or with various answering machine/voicemail connections.

[4] The 95 questionnaires returned as undeliverable were not replaced; hence, the sample size for the mail survey was reduced to 1,505.

(8) landowner groups/coalitions. Response categories were coded as follows: 0 = no trust; 1 = very little trust; 2 = some trust; and, 3 = great deal of trust.

Measuring Familiarity with the Management and Disposal of Frac Flowback Water in the Marcellus Shale

Familiarity with the management and disposal of frac flowback water in the Marcellus Shale was assessed using a single survey item that ranged from 1 (extremely unfamiliar) to 7 (extremely familiar).

Measuring Familiarity with Frac Flowback Wastewater Treatment Technology

Familiarity with frac flowback wastewater treatment technology was assessed using a single survey item that ranged from 1 (extremely unfamiliar) to 7 (extremely familiar).

Measuring Potential Uses of Treated Wastewater from Hydraulic Fracturing Operations

Potential uses of treated wastewater from hydraulic fracturing operations were evaluated with a list of six practices. Respondents were asked whether they believed that treated wastewater from hydraulic fracturing operations could be safely used for: (1) re-use by gas and oil industry operators; (2) watering of livestock; (3) industrial use (e.g., manufacturing, etc.); (4) people's drinking water; (5) municipal uses (e.g., watering of golf courses and city parks, etc.); and, (6) irrigation of farmland.

FINDINGS

Familiarity with the Process of Hydraulic Fracturing

Overall Results

As shown in Figure 1, one of every five respondents (20%) reported being *extremely unfamiliar* with the process of hydraulic fracturing, and an additional 23 percent rated their familiarity at "2" or "3" on the five point scale. Conversely, approximately 9 percent of respondents indicated they were *extremely familiar* with the hydraulic fracturing process and about three of ten (31%) indicated they had some familiarity (scores 5 and 6 on the scale). The mean level of familiarity with the process of hydraulic fracturing was 3.73 (*SD* = 1.91).

Results for Respondents in Low Well-density Counties versus High Well-density Counties

Roughly one in four respondents (23.7%) living in the low well-density counties reported being *extremely unfamiliar* with the process of hydraulic fracturing, compared to 16.3 percent of respondents living in the high well-density counties. In the low well-density counties, 7.6 percent of respondents reported being *extremely familiar* with the process of hydraulic fracturing, compared to 9.8 percent in the high well-density counties. The mean level of familiarity with the process of hydraulic fracturing for respondents in the high well-density counties (M = 3.90, SD = 1.89) was significantly higher ($p \leq 0.05$) than for respondents in the low well-density counties (M = 3.55, SD = 1.92).

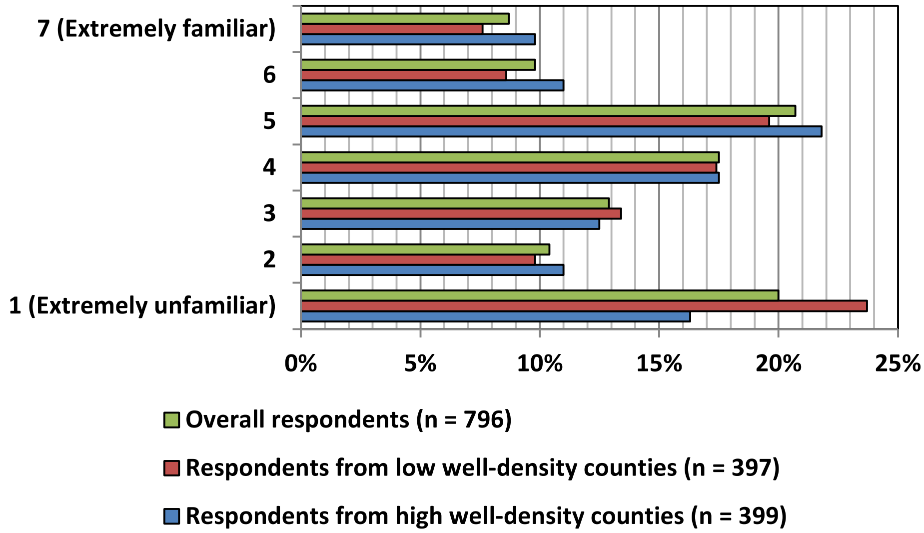

Figure 1. Level of Familiarity with the Process of Hydraulic Fracturing

Contribution Made to Knowledge about the Process of Hydraulic Fracturing

Overall Results

The eight sources that may or may not have contributed to what respondents knew about hydraulic fracturing were ranked in ascending order by overall mean score (see Table 1). Newspapers (*M* = 1.71) were the source of information that contributed most to respondents' knowledge of the hydraulic fracturing process, followed by the natural gas industry (*M* = 1.30) and conservation/environmental groups (*M* = 1.21). *Gasland* (*M* = 0.41) was the source of information that contributed least to respondents' knowledge of hydraulic fracturing.

Results for Respondents in Low Well-density Counties versus High Well-density Counties

The pattern of results for each subgroup of respondents mirrored the overall sample. Newspapers were the source of information that contributed most to respondents' knowledge of the hydraulic fracturing process in both the low well-density counties (*M* = 1.73) and high well-density counties (*M* = 1.69); *Gasland* was the source of information that contributed least to respondents' knowledge of hydraulic fracturing in both county types (*M* = 0.39 in low well-density counties and *M* = 0.43 in high well-density counties).

The statistical significance of the observed differences between the respondents from low well-density counties and high well-density counties regarding sources of information that may or may not have contributed to their knowledge of hydraulic fracturing were tested using a t-test for the difference between means. Results revealed that respondents living in high well-density counties were significantly more likely than those living in low well-density counties to report that the natural gas industry ($p \leq 0.01$) and regulatory agencies ($p \leq 0.05$) have contributed to their knowledge of hydraulic fracturing.

Table 1. Contribution Made by Eight Sources of Information to Knowledge about Hydraulic Fracturing

Sources of Information	Overall Respondents	Respondents from Low Well-Density Counties		Respondents from High Well-Density Counties
	Mean Values[a]			
Newspapers…………………………………	1.71 (n=795)	1.73 (n=397)		1.69 (n=398)
Natural gas industry………………………...	1.30 (n=794)	1.18 (n=397)	**	1.42 (n=397)
Conservation/environmental groups……….	1.21 (n=793)	1.17 (n=396)		1.24 (n=397)
Landowner groups/coalitions………………	1.01 (n=794)	0.96 (n=395)		1.07 (n=399)
Regulatory agencies..……………………….	0.98 (n=791)	0.90 (n=394)	*	1.05 (n=397)
Cooperative Extension……………………...	0.67 (n=789)	0.61 (n=394)		0.72 (n=395)
University professors……………………….	0.65 (n=791)	0.61 (n=394)		0.70 (n=397)
Gasland (the film by Josh Fox)…………….	0.41 (n=786)	0.39 (n=390)		0.43 (n=396)

[a] Contribution of source of information was coded as: 0 = none; 1 = very little; 2 = some; and, 3 = a great deal.

* Statistically significant difference at the $p \leq 0.05$ level in mean values between respondents from low well-density counties and those from high well-density counties.

** Statistically significant difference at the $p \leq 0.01$ level in mean values between respondents from low well-density counties and those from high well-density counties.

Trust to Deliver Unbiased, Factual Knowledge on Hydraulic Fracturing

Overall Results

The eight sources respondents may or may not trust to deliver unbiased, factual knowledge on hydraulic fracturing were ranked in ascending order by overall mean score (see Table 2). University professors and conservation/environmental groups tied as the source respondents trusted most to deliver unbiased, factual knowledge on the hydraulic fracturing process. (M = 1.57). These two sources were followed closely by newspapers (M = 1.56) and landowner groups/coalitions (M = 1.53). *Gasland* (M = 0.80) was the source of information respondents trusted least.

Results for Respondents in Low Well-density Counties versus High Well-density Counties

Respondents in the low well-density counties rated university professors (M = 1.61) as the source they trusted most to deliver unbiased, factual knowledge on hydraulic fracturing, followed by conservation/environmental groups (M = 1.59) and newspapers (M = 1.58). In the high well-density counties, respondents also rated conservation/environmental groups (M = 1.55) and newspapers (M = 1.55), and university professors (M = 1.53) as their most trusted sources. *Gasland* was the source of information respondents trusted the least (M = 0.82 in low well-density counties and M = 0.78 in high well-density counties).

The statistical significance of the observed differences between the respondents from low well-density counties and high well-density counties with respect to sources of information they may or may not trust to deliver unbiased, factual knowledge on hydraulic fracturing were tested using independent sample t-tests. Two of the eight sources were found to differ significantly – respondents living in high well-density counties were more likely than those living in low well-density counties to trust regulatory agencies ($p \leq 0.05$) and the natural gas industry ($p \leq 0.01$).

Table 2. Trust in Eight Sources of Information to Deliver Unbiased, Factual Knowledge on Hydraulic Fracturing

Sources of Information	Overall Respondents	Respondents from Low Well-Density Counties		Respondents from High Well-Density Counties
	Mean Values[a]			
University professors……………………….	1.57 (n=794)	1.61 (n=398)		1.53 (n=396)
Conservation/environmental groups……….	1.57 (n=792)	1.59 (n=395)		1.55 (n=397)
Newspapers…………………………………	1.56 (n=797)	1.58 (n=400)		1.55 (n=397)
Landowner groups/coalitions………………	1.53 (n=796)	1.53 (n=399)		1.53 (n=396)
Regulatory agencies..……………………….	1.44 (n=795)	1.38 (n=399)	*	1.51 (n=396)
Cooperative Extension……………………...	1.43 (n=780)	1.50 (n=393)		1.36 (n=387)
Natural gas industry………………………...	1.32 (n=798)	1.23 (n=400)	**	1.42 (n=398)
Gasland (the film by Josh Fox)…………….	0.80 (n=753)	0.82 (n=379)		0.78 (n=374)

[a] Trust in source of information was coded as: 0 = no trust; 1 = very little trust; 2 = some trust; and, 3 = great deal of trust.
* Statistically significant difference at the $p \leq 0.05$ level in mean values between respondents from low well-density counties and those from high well-density counties.
** Statistically significant difference at the $p \leq 0.01$ level in mean values between respondents from low well-density counties and those from high well-density counties.

Familiarity with the Management and Disposal of Frac Flowback Water in the Marcellus Shale

Overall Results

As shown in Figure 2, approximately one third of the respondents (33.2%) reported being *extremely unfamiliar* with the management and disposal of frac flowback water in the Marcellus Shale. Conversely, 6.8 percent of respondents indicated they were *extremely familiar* with the management and disposal of frac flowback water in the region. The mean level of familiarity with the management and disposal of frac flowback water in the Marcellus Shale was 3.06 (*SD* = 1.94).

Results for Respondents in Low Well-density Counties versus High Well-density Counties

Among respondents living in low well-density counties, 36.9 percent reported being *extremely unfamiliar* with the management and disposal of frac flowback water in the Marcellus Shale, whereas roughly three in ten respondents (29.6%) living in the high well-density counties indicated as such. In the low well-density counties, 5.8 percent of respondents reported being *extremely familiar* with the management and disposal of frac flowback water in the Marcellus Shale, compared to 7.8 percent of respondents in the high well-density counties.

The mean level of familiarity with the management and disposal of frac flowback water in the Marcellus Shale was 2.94 (*SD* = 1.93) for respondents in the low well-density counties and 3.18 (*SD* = 1.94) for respondents in the high well-density counties. The difference between the two groups of respondents failed to reach statistical significance at the 0.05 level.

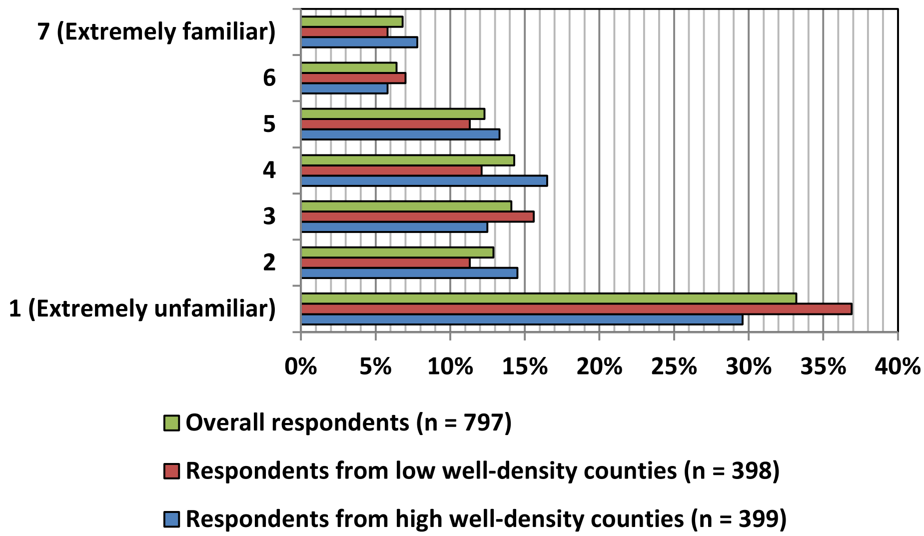

Figure 2. Level of Familiarity with the Management and Disposal of Frac Flowback Water in the Marcellus Shale

Familiarity with Frac Flowback Wastewater Treatment Technology

Overall Results

As shown in Figure 3, almost four in ten respondents (38.5%) reported being *extremely unfamiliar* with frac flowback wastewater treatment technology. Conversely, 3.1 percent of respondents indicated they were extremely familiar with frac flowback wastewater treatment technology. The mean level of familiarity with frac flowback wastewater treatment technology was 2.69 (*SD* = 1.78).

Results for Respondents in Low Well-density Counties versus High Well-density Counties

Among respondents living in the low well-density counties, 42.6 percent reported being *extremely unfamiliar* with frac flowback wastewater treatment technology, compared to roughly one third of respondents (34.3%) living in the high well-density counties. In the low well-density counties, 2.5 percent of respondents reported being extremely familiar with frac flowback wastewater treatment technology, compared to 3.8 percent of respondents in the high well-density counties.

The mean level of familiarity with frac flowback wastewater treatment technology was 2.57 (*SD* = 1.75) for respondents in the low well-density counties and 2.82 (*SD* = 1.80) for respondents in the high well-density counties. An independent sample t-test revealed this difference was statistically significant ($p \leq 0.05$).

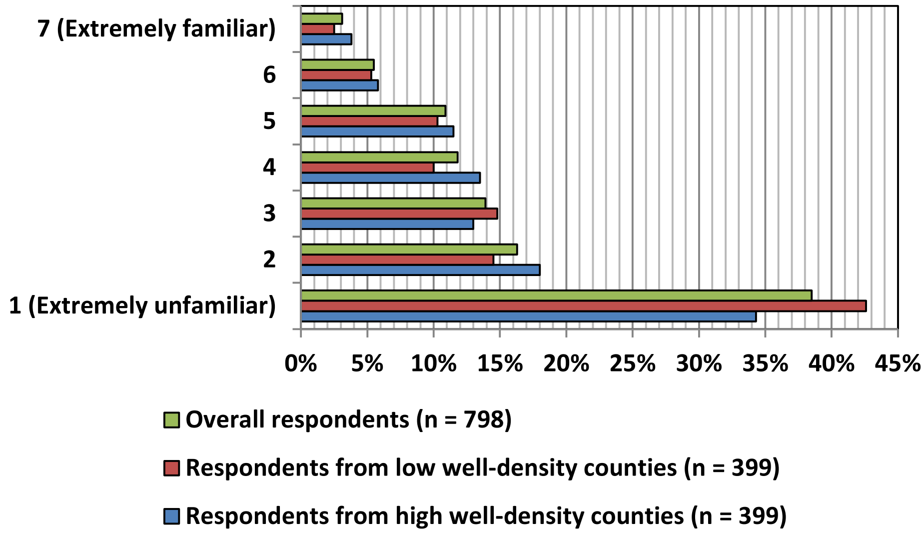

Figure 3. Level of Familiarity with Frac Flowback Wastewater Treatment Technology

Potential Uses of Treated Wastewater from Hydraulic Fracturing Operations

The six potential uses of treated wastewater from hydraulic fracturing operations were ranked in ascending order by the percentage of respondents indicating "yes" (see Table 3). Approximately eight in ten respondents (81%) believed re-use in the gas and oil industry to be the safest potential use. More than three in four respondents (77%) believed treated wastewater from hydraulic fracturing operations could safely be used for industrial use (e.g., manufacturing, etc.), whereas slightly more than one half of respondents (52%) agreed such water could be used for municipal purposes (e.g., watering of golf courses and city parks, etc.). Roughly three in ten respondents (31%) and two in ten respondents (19%), respectively, agreed irrigation of farmland and watering of livestock could safely be accomplished with the use of treated wastewater from hydraulic fracturing operations. Finally, 11 percent of respondents believed that treated wastewater from hydraulic fracturing operations could safely be used by humans as potable water.

Significance tests for the difference in the proportion of respondents from low well-density counties and those from high well-density counties who perceived safe potential uses of treated wastewater from hydraulic fracturing operations were examined using a z-test for the difference between proportions. The results revealed respondents in high well-density counties were significantly more likely than their counterparts in low well-density counties to agree that treated wastewater from hydraulic fracturing operations could safely be re-used by gas and oil industry operators ($p \leq 0.01$). For none of the other uses did the low- and high-density areas differ significantly in the perceptions of safe usages.

Table 3. Perceived Safe Potential Uses of Treated Wastewater from Hydraulic Fracturing Operations

Ways Treated Wastewater from Hydraulic Fracturing Operations Could Safely be Used:	Overall Respondents	Respondents from Low Well-Density Counties		Respondents from High Well-Density Counties
	Percentage "Yes"			
Re-use by gas and oil industry operators.….	81 (n=787)	77 (n=394)	**	85 (n=393)
Industrial use (e.g., manufacturing, etc.).…..	77 (n=787)	74 (n=395)		79 (n=392)
Municipal uses (e.g., watering of golf courses and city parks, etc.)……………...	52 (n=788)	49 (n=395)		55 (n=393)
Irrigation of farmland………………………	31 (n=788)	30 (n=395)		33 (n=393)
Watering of livestock……………...……….	19 (n=789)	19 (n=396)		20 (n=393)
People's drinking water………..…………...	11 (n=785)	10 (n=393)		12 (n=392)

** Statistically significant difference at the $p \leq 0.01$ level in proportions between respondents from low well-density counties and those from high well-density counties who indicated that treated produced wastewater from hydraulic fracturing operations could safely be used for selected purposes.

Following previous research on the public perception of desalinated produced water from oil and gas field operations (Theodori et al. 2009, 2011), we examined the associations between level of familiarity with frac flowback wastewater treatment technology and the perceived safe potential uses of treated wastewater from hydraulic fracturing operations using bivariate and multivariate logistic regression techniques. As in the produced water studies (Theodori et al. 2009, 2011), gender and level of education were included in the multivariate models as control variables. Gender was dummy coded (1 = male); level of education was coded as follows: 1 = did not graduate from high school; 2 = high school graduate/GED; 3 = some college or other post-high school education; 4 = completed a 4-year college degree; and, 5 = graduate work or professional training beyond a college degree. Well-density of the county of residence was also included in the multivariate models as a control variable. Well-density was dummy coded (1 = high well-density county).

As shown in Table 4, the bivariate associations between level of familiarity with frac flowback wastewater treatment technology and each of the six safe possible uses of treated wastewater from hydraulic fracturing operations were positive and statistically significant. This indicated individuals with higher levels of familiarity with frac flowback wastewater treatment technology were more likely than those with lower levels of familiarity to agree that treated wastewater from hydraulic fracturing operations could safely be used for each of the potential purposes. The multivariate results indicated the addition of the control factors had very little effect on the nature or significance levels of the odds ratios for the familiarity with frac flowback wastewater treatment technology variable. One association – between level of familiarity with frac flowback wastewater treatment technology and using treated wastewater for municipal uses – became nonsignificant.

An examination of the control factors (results not shown) indicated males, individuals with higher levels of education, and those living in high well-density counties were significantly more likely than females, individuals with lower levels of education, and those living in low well-density counties to agree that treated wastewater from hydraulic fracturing operations could safely be re-used by gas and oil industry operators. Males were also significantly more likely than females to agree that treated wastewater from hydraulic fracturing operations could safely be used to irrigate farmland. Higher-educated persons were significantly more likely than their lower-educated counterparts to agree that treated wastewater from hydraulic fracturing operations could safely be used for industrial purposes (e.g., manufacturing, etc.).

Table 4. Logistic Regressions of Potential Safe Uses of Treated Wastewater from Hydraulic Fracturing Operations

		Odds Ratios	
Ways Treated Wastewater from Hydraulic Fracturing Operations Could Safely be Used:	**n**	**Bivariate**	**Multivariate[a]**
Re-use by gas and oil industry operators………………………………	782	1.32***	1.24***
Industrial use (e.g., manufacturing)……………………………………	782	1.19**	1.14*
Municipal uses (e.g., watering golf courses and city parks)…………...	783	1.09*	1.07
Irrigation of farmland………………………………………………..	783	1.21***	1.19***
Watering of livestock………………………………………………..	784	1.20***	1.20***
People's drinking water……………………………………………..	780	1.17**	1.15*

[a] Odds ratios computed controlling for gender, education, and well-density of county of residence.
* Statistically significant difference at the $p \leq 0.05$ level.
** Statistically significant difference at the $p \leq 0.01$ level.
*** Statistically significant difference at the $p \leq 0.001$ level.

DISCUSSION

Given the preceding analyses, what substantive insights can be drawn from these data? First, with respect to respondents' level of familiarity with the process of hydraulic fracturing – the controversial gas and oil well stimulation/completion practice that has increasingly dominated public discourse and the media – the results indicate a more or less symmetrical distribution. While two of every five respondents (40%) stated having some level of familiarity with the process (scores 5 through 7 on the 7-point familiarity scale), roughly the same percentage (43%) reported being unfamiliar with this practice (scores 1 through 3 on the 7-point familiarity scale). This balanced response distribution was less pronounced when respondents' level of familiarity with hydraulic fracturing by county of residence (high well-density counties vs. low well-density counties) was examined. Although not a formal hypothesis, we believed there would be a difference in the level of familiarity between residents in areas with low and high levels of natural gas drilling activity; this was confirmed. Respondents living in the high well-density counties were more familiar with the process than their counterparts living in low well-density counties.

When we turn our attention to sources of and trust in information about fracturing-related processes, at least two observations are worth noting. First, respondents reported newspapers, the natural gas industry, conservation/environmental groups, and landowner groups/coalitions contributed more to their knowledge about hydraulic fracturing than did regulatory agencies, Cooperative Extension, university professors, or the film *Gasland*. The pattern of responses differed slightly when it came to whether or not respondents trusted those same sources of information. Conservation/environmental groups, newspapers, and landowner group/coalitions retained their designation as being in the top four sources of information but the natural gas industry was replaced by university professors. Indeed, in regard to "trust," the natural gas industry was viewed as among the *least* trustworthy sources of information. According to these data, it appears that even though the energy industry is educating the general public on hydraulic fracturing, local citizens remain skeptical and continue to distrust the industry (Theodori 2009, 2012). Moreover, these data indicate that although university professors may not have contributed a great deal of information to respondents' knowledge about hydraulic fracturing, respondents are likely to trust them when they do. Further, these data revealed the 2010 film *Gasland* contributed *least* to respondents' knowledge of hydraulic fracturing and was the *least* trusted source of information.

A second observation deals with the statistically significant difference uncovered between respondents from low well-density counties and those from high well-density counties with respect to two sources of information – the natural gas industry and regulatory agencies. As noted above, respondents living in the high well-density counties were more likely than those respondents living in the low well-density counties to report they gained some degree of knowledge about hydraulic fracturing from the natural gas industry and regulatory agencies, and that they were more likely than residents in the low-well density areas to trust these two sources of information to provide unbiased, factual knowledge on the hydraulic fracturing process. Based upon these findings, one could reasonably conclude both the natural gas industry and regulatory agencies are being proactive in the delivery of information on hydraulic fracturing in areas with increased drilling activity.

Other substantive findings dealt with respondents' level of familiarity with the management and disposal of frac flowback water in the Marcellus Shale, their awareness of technologies to remove contaminants from frac flowback wastewaters, and their level of agreement that treated wastewater from hydraulic fracturing operations could safely be used for selected purposes. Most respondents in our study were more unfamiliar than familiar with the management and disposal of Marcellus Shale frac flowback water, as well as with the frac flowback wastewater treatment technologies. With respect to the latter topic, respondents living in the high well-density counties were more familiar with the frac flowback wastewater treatment technology than their counterparts living in low well-density counties. This result is most likely due to the aforementioned finding showing respondents in high well-density counties having higher levels of familiarity with the process of hydraulic fracturing as a whole.

An investigation of respondents' beliefs that treated frac flowback could safely be used for six potential purposes indicated the overall pattern of results paralleled those in the extant literature on the perceptions of the general public about using reclaimed and/or recycled water (Dishman, Sherrad, and Rebhun 1989; Dolnica and Schafer 2006; Hartley 2006) and desalinated produced water (Theodori et al. 2009, 2011). These studies have demonstrated that acceptance of/opposition to the use of reclaimed, recycled, and desalinated produced water varies directly with intimacy or degree of human contact.

Last, bivariate and multivariate logistic regression results revealed that an understanding of frac flowback wastewater treatment technology was associated with higher rates of perceived safe uses of treated wastewater from hydraulic fracturing operations. These findings mirrored the results of previous research on the association between familiarity with desalination technology and potential safe uses of desalinated produced water (Theodori et al. 2009, 2011).

CONCLUDING COMMENTS, IMPLICATIONS, AND RECOMMENDATIONS

The production of shale gas has greatly increased over the past decade. Concomitantly, so have the anti-drilling/anti-fracing debates and grassroots social movements to ban the use of horizontal drilling and multi-state hydraulic fracturing, the two technologies primarily responsible for the development of these once written-off hydrocarbon reservoirs. Despite increased opposition from environmental organizations, concerned citizen groups, and anti-industry activists, as well as intensified scrutiny and possible oversight from federal, state, regional, and local governments, we do not envision a nationwide moratorium on the use of these technologies to develop shale gas resources in the foreseeable future.[5] Other researchers predict a similar scenario (e.g., Rahm 2011). In Rahm's (2011:2980) summation:

> There is too much resource to be had, too much need to satisfy, and too much money to be made. The controversy will probably drive drillers toward discovery and use of non-toxic alternatives for fracking chemicals whenever possible. Fear of liability will impel this shift probably as much as the desire to avoid costly and time consuming conflict with opposition parties. Communities near shale gas plays will continue to be transformed by the drilling activities. Rural pastoral land will be littered with drilling rigs, pipeline will be laid, and 24-7 industrial operations will continue until the play is fully exploited. Urban populations that find themselves in the middle of shale gas plays will likewise see their communities transformed to accommodate the industry. The water resources the drillers need will be diverted from other uses to permit shale gas recovery.

Presuming this inevitability, and based upon the findings presented and discussed above, we propose the following recommendations to the energy industry, community leaders, government and regulatory agencies, environmental and non-governmental organizations, and other stakeholders.

First and foremost, open, honest, and full communication between/among all stakeholders is paramount. The energy industry must inform local residents, community leaders, government and regulatory agency personnel, environmental and non-governmental organization representatives, and other interested parties about the potentially *positive aspects* and *negative consequences* of shale gas development. Included here must be accurate and transparent information about the chemical composition and water volumes in frac fluids and frac flowback wastewaters. These various stakeholders must then effectively communicate their hopes, fears, and/or anxieties associated with shale gas development to each other and, in turn, to the energy industry. We believe open, honest, and full communication will increase objective, factual knowledge and reduce the subjectively perceived knowledge rooted in rumors, inaccuracies, and/or ignorance.

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[5] As the data from the larger study showed (see Theodori, Willits, and Luloff 2012), members of the general public living in the Marcellus Shale region of Pennsylvania are very supportive of natural gas development. Nearly 6 of 10 respondents (58.7%) supported natural gas extraction from the Marcellus Shale, whereas 24.5% opposed Marcellus Shale natural gas extraction. The remaining individuals (16.8% of the sample) were neither supportive nor opposed.

We also strongly encourage industry to share more information about wastewater treatment technologies with government and regulatory officials and the general citizenry. A need exists for honest, unbiased dissemination of information on wastewater treatment technology, information on how industry is implementing such technologies to reduce the amount of freshwater used, and accurate data on the number of trucks on the roads. Moreover, all of this information must be cast in layman's terms – specifying what current technology **can** and **cannot** do.

In addition to disseminating information on these technologies, we recommend the industry organize outreach educational programs and field demonstration site visits of operating wastewater treatment technologies (cf. Burnett et al. 2012). Some energy companies are actively organizing and leading tours of their drilling operations. Researchers working on wastewater treatment technologies must do the same. Anecdotal information from the drilling operation tours suggests they have been relatively successful in changing some of the extreme negative perceptions of skeptical individuals.

Moreover, we recommend for scientists and engineers to downplay the "newness" of these frac flowback and produced wastewater treatment technologies. As research and practice suggests, many individuals are distrustful and fearful of "new" technologies. Hydraulic fracturing has been used for decades, and so too has wastewater treatment technology. We recommend that discussions/explanations of wastewater treatment technologies be rooted to existing technologies that have been and are being used with reclaimed and/or recycled waters.

Finally, we encourage the creation and/or advancement of transdisciplinary research and outreach educational programs to address the vast array of issues surrounding the exploration, drilling, and production of shale gases. The Environmentally Friendly Drilling Program (EFD), founded in 2005 and presently managed by the Houston Advanced Research Center (HARC), is one preeminent example (Dunnahoe 2012; NETL 2009).[6] Through advanced research and outreach, the EFD program listens to and engages the general public and key stakeholders (e.g., university researchers, national laboratory scientists, industry actors, regulatory agency personnel, and non-governmental organization representatives), and transparently addresses any/all concerns through effective communication processes/strategies in an effort to effectively surmount the numerous technological, social, economic, and environmental issues associated with unconventional energy development.

[6] For more information on the EFD program, visit www.efdsystems.org.

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