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Communication Science for Science Communication:

Water Management for Oil and Natural Gas Extraction

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Abstract: Water management for oil and natural gas extraction in the United States has become a topic of public interest and concern. This societal relevance simultaneously heightens the need for rigorous performance and dissemination of scientific work and invites caution from experts who are communicating within what is likely a politicized public conversation. This research uses interviews to investigate experts' current practices and comfort with communicating about water use for oil and natural gas. Participants cite face-to-face interactions and trust-based relationships as important in their interactions, which is consistent with research about effective communication. However, few participants highlight techniques specific to communicating about water as it relates to oil and gas or about controversial issues generally. Participants also rarely use communication science related to objective setting, framing, and measuring success for improvement, likely related in part to lack of evidence-based training. In many cases, interviewees expressed attitudes consistent with the deficit model of scientific communication, which holds that presentation of scientific facts will change public opinion. This model has been shown to be relatively ineffective. This work highlights the need for careful communication and

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evidence-based opportunities for improvement, including a suggestion that professional societies host communication training and coaching sessions.

Keywords water, hydraulic fracturing, science communication, best practices, oil, gas

Introduction

Public attention to oil and natural gas production—particularly to its relationship with water resources—has grown quickly (Mazur 2016), with commercial production of natural gas, then oil, from shales becoming substantial starting between 2008 and 2010 in the United States (EIA 2016). The attendant multistage high volume hydraulic fracturing of horizontal wells in shales and other low permeability formations (henceforth abbreviated as "hydraulic fracturing" or "HF") is a clearly political topic, taking Lupia's (2013) definition of political topics as those characterized by "salient social disagreements." Concerns about water consumption, water disposal, and water quality issues have emerged in many settings (e.g. Boudet et al. 2014, Jackson et al. 2014, Jacquet 2014, Keranen et al. 2014, Scanlon et al. 2014, Theodori et al. 2009, Warner et al. 2013). While this work focuses on the United States, similar concerns have been noted internationally (e.g. Clarke et al. 2014, Davies et al. 2015, Espig and de Rijke 2016, Gregory et al. 2011, Hu and Xu 2013, Rasch and Köhne 2016).

One of the reasons that communicating about water use for oil and natural gas is challenging is that the issue is characterized by scientific uncertainty and differing social priorities. These challenges are also observed with other complex issues like climate change and water resources management (Pahl-Wostl et al. 2007, Weingart et al. 2000). Ongoing discussions about policy as it relates to water management for oil and gas motivate both production and discussion of rigorous relevant data, which further motivates interest in how experts communicate technical information in this contentious context.

Why Communicate?

Scientists and engineers increasingly recognize the importance of communicating work in public forums, evidenced by a proliferation of training opportunities, fellowships, and articles (e.g. AAAS 2016, Fischhoff and Scheufele 2013, Kuehne et al. 2014, Trench and Miller 2012). Such communication activities are seen as important both in personal and public settings. For example, individuals use public communication to disseminate research, seek grant support via broader impacts, and establish a recognizable public persona in pursuit of job and other opportunities (e.g. Bombaci et al. 2015, Iber 2016, McGranahan 2013, Priem and Costello 2010, Roberts 2009). Scientists and engineers also communicate publicly in response to requests from journalists, government organizations, and other decision makers, as well as in settings where publics seek out scientific input or where individual scientists and engineers feel a responsibility to contribute to public debates.

Many agree that communicating results is important—a goal of disseminating results underpins academic publishing—but there remain disagreements about the role experts play in science communication (e.g. Schneider 1992). In particular, many are concerned that communicating about heavily politicized topics can be viewed as advocacy or otherwise compromise public trust in science and individual scientists (Rykiel 2001). Simultaneously, others argue that science ought to play a role in policy making processes and that such input fulfils a social contract between scientists and the broader public to use science to solve societal problems (e.g. Lubchenco 1998). Some argue further that scientists have a responsibility to use expertise to advocate for science-based policy action, including by taking positions on matters of public concern (e.g. Mooney and Ehrlich 1999). Ultimately, while science communication is

generally seen as a positive activity that represents a professional responsibility, the nature of appropriate communication is debated.

It is with this context of unease about science communication, and in particular about the appropriateness of persuasive or values-driven communication (Rykiel 2001), that this article explores specific communication efforts within the water resources science and engineering community related to water management associated with the oil and natural gas industry. Despite disagreement about what should be communicated and why, careful attention to science communication is warranted if only because bad communication can be actively damaging (Fischhoff 2013). Specifically, bad communication can erode trust in science, prevent access to science that is relevant for decisions, or otherwise reduce the impact of scientific research. These outcomes are important for oil and gas-related water management, as such water management is highly salient for many communities. Salience is particularly high for those communities experiencing rapid development associated with technological advancements like HF.

Returning to Lubchenco's argument that using science to solve environmental problems is part of the social contract between scientists and society (1998), this work argues that science communication focused on societal solutions is necessary despite its difficulty. Further, this work argues that the communication efforts of the water- and HF-engaged scientific community are impeded by ad hoc approaches that do not draw on modern communication science. Many existing efforts are well-intentioned and can be locally effective, often because of the skill of an individual communicator. However, this work finds that reliance on outdated understanding of information transmission and a lack of clear objectives reduces the power of scientific communication about water and HF. The overall goal of this work is to demonstrate that current approaches can and should be improved given the salience of water issues, oil and gas issues,

and ongoing policy issues related to hydraulic fracturing: as Fischhoff and Scheufele (2013) write, "the stakes are too high to rely on intuitive theories and anecdotal observations about communication."

What Makes Communication Effective?

Organization throughout this article mirrors a communication process with three main steps: defining objectives, framing communication, and measuring success (Fig. 1). This section introduces some of the relevant literature; the results section uses interviewee quotations to illustrate findings; and the discussion section integrates the literature with this work's findings.

Defining Objectives

Communicators can articulate both personal objectives (i.e. cultivating presence or dressing appropriately) and process objectives (i.e. ensuring a particular study is recognized by decision makers). As is discussed in more detail below, personal objectives are relatively well understood by communicators interviewed for this research. This literature review therefore focuses on process objectives. Why do communicators communicate, and how do they define goals? Dudo and Besley suggest that the goal of public engagement in particular might be to inform the public, excite the public, strengthen the public's trust, tailor messages about science, or defend science from misinformation, finding that scientists tend to prioritize informing the public and defending science (2016). Van der Sanden and Meijman suggest goals can be classified as public awareness, public engagement, public participation, or public understanding (2008). Nisbet and Scheufele focus more explicitly on goals concerning the relationship between scientific facts and other information, like values: for example, goals can include achieving a mutual understanding of a fact base to enable a more direct discussion of values, which in turn requires attention to constructing an appropriate audience during outreach (2009). Science

communicators might also wish to ensure science is used in a decision process, to ensure science is privileged in a decision process (e.g. Suldovsky 2016), or to explicitly advocate for a particular outcome in a decision process. Effective engagement in decision-making and policymaking benefits from clear understanding of the specific processes, the social values and salient controversies, and the relationships among decision makers, influential stakeholders, and other parties (e.g. Dietz 2013, Haya et al. 2016, Molinatti and Simonneau 2015, Priscoli 1989).

A major and frequently observed obstacle to successful engagement is the prevalence of the knowledge deficit model, an intuitive but poorly supported model that asserts that differences of opinion are due to differences in access to facts (e.g. Cormick et al. 2015, Cortassa 2016, Simis et al. 2016, Suldovsky 2016). Accordingly, one-way provision of information from experts to non-experts is seen as sufficient to eliminate differences of knowledge and thus of opinion. Such thinking inherently suggests that conveying information is the only process objective a communicator needs. While the deficit model has become unpopular in modern science communication literature (e.g. Bray et al. 2012), deficit model thinking remains common among many scientists—particularly those not exposed to communication training (Simis et al. 2016)—in part because it is intuitive (Cortassa 2016). As Simis et al. note, scientific training emphasizes objectivity and rational decision-making, which can contribute to a belief that all human thought follows this standard (2016). In practice, however, knowledge is not usually the main driver of attitudes, and outcomes are not clearly linked to knowledge levels (Dudo and Besley 2016, Scheufele 2013). Though the assumption that increased agreement on facts will reduce controversy can be well intentioned (Nisbet and Mooney 2007), it is not well supported.

A major critique of the deficit model as it relates to science communication objectives is that it encourages establishment of a strict dichotomy between those with the correct information

(and implicitly, the correct opinion) and those without it. Wynne describes the deficit model as an "institutional alibi" that enables scientists to dismiss concerns as unscientific (2006). By establishing the notion that science is objective and directly linked to values-based positions, the deficit model also establishes the notion that some values are wrong. Relatedly, this line of critique also suggests that the deficit model excuses science communicators from trying to understand concerns or change their communication strategies, as it suggests the failure is on the part of the receiving audience, not the communicating scientist (Nisbet and Scheufele 2009). The dichotomous nature of deficit model relationships between "the scientific community" and "the public" also establishes social distance, otherizing non-experts in ways that can be counterproductive in their implication that either scientists or nonscientists are monolithic entities (e.g. Bucchi 2016, Simis et al. 2016, Walker et al. 2010).

Given these criticisms of the deficit model, more recent scientific communication literature emphasizes the value of participatory approaches that provide opportunities for thought exchange, deliberation, and critique (e.g. Bray et al. 2012, Cormick et al. 2015, Kuehne et al. 2014, Suldovsky 2016). This emphasis on participation stands in particular contrast to the deficit model's assumption of a passive audience and benevolent communicator (Bray et al. 2012). Notably, at least one investigation has found that communicators often favor participatory models but feel impeded by a lack of resources and support ("Inspiring Australia," as referenced by Cormick et al. 2015).

One area where participatory models of communication allow for more sophisticated goal setting than deficit-based models is in defining the boundaries of fact-based versus value-based concerns in a communication activity. Such boundary determination is challenged by considerable disagreement about the delineation between objectivity and advocacy (Nelson and

Vucetich 2009). Some argue that advocacy for science, and sometimes for particular policy outcomes, is not incompatible with a goal of being as objective and science-based as possible (Lackey 2007, Meyer et al. 2010). That is, objectivity is not the same thing as neutrality. Some argue further that true objectivity is not possible (Allen et al. 2001, Nisbet and Mooney 2007). A concern, however, is that advocacy by scientists—or even the perception of advocacy by scientists—risks damaging the credibility of the scientific community as a whole (Lach et al. 2003, Mills and Clark 2001). Many argue this is not true, highlighting goals like ensuring policy processes use science, ensuring that the science needed for certain types of decisions is available, and ensuring that the fact base used during decision-making is accurate (e.g. Fischhoff and Scheufele 2013, Haya et al. 2016, Lackey 2007, Nisbet and Mooney 2007). Persuasive scientific communication is common in many fields, like medical sciences where communication focuses on the superiority of certain procedures or instruments with a goal of increasing their uptake (e.g. Feinstein 1985, Greer 1998, Rost et al. 1994).

Best practices include both being clear about when a conversation is really about values, particularly once participants agree on a shared fact base, and being clear about the nature of one's own value system (e.g. Meyer et al. 2010, Rykiel 2001). Effective engagement often requires facility with separating factual disagreement from value disagreement. This skill is needed even when the communicator's goal is only to present factual information, as disagreement on values can increase resistance to facts that are understood to be highly relevant to a decision. A challenge is that sometimes, as with water and HF, the relevant science carries uncertainty—particularly related to the precise effects of known stimuli—and needs to be adapted to local circumstances (Dietz 2013). In such cases, communicators are additionally challenged to present the nature of uncertainty, help identify where decisions are robust, and

preserve trust-based relationships even when new results might change a previous understanding of the science—all of which can be cast as process objectives useful in designing, or framing, a communication strategy.

Framing Communication

Framing a communication broadly refers to choices of what to say and how to say it. There are different ways to present the same information (Scheufele 2013), and the choice of which approach to take can be particularly important for controversial science topics (Huttunen and Hilden 2014). Framing can be intentional or unintentional: every communication has a frame (e.g. Nisbet and Mooney 2007, Nisbet and Scheufele 2009, Dudo and Besley 2016). Complex ideas are necessarily simplified, and a communicator's values, background, familiarity with the topic, and many other factors combine with those of the audience to produce a frame (e.g. Kunda 1990**,** Scheufele 2013).

Despite the reality that framing is unavoidable, many scientists are uncomfortable with the concept (e.g. Besley et al. 2016). This discomfort is likely a product of the real and perceived differences between unavoidable and intentional, designed framing. One exchange in the literature demonstrates this conflict clearly. Nisbet and Mooney (2007) argue that framing is important for organizing complex ideas and clarifying the main points; however, multiple respondents (Holland et al. 2007) raise concerns about whether intentional framing is dishonest or suggestive of the public's inability to handle complexity, among others. Framing is often associated with marketing or spinning an idea, which some interpret as a type of lying (Besley et al. 2016). Given that all communication involves presentation, which necessarily requires subjective choices about what and how to present (Dudo and Besley 2016), and given that poor communication can be actively damaging (Fischhoff and Scheufele 2013), taking control of a

frame and considering how best to communicate information in a specific context is an important element of communication best practices.

Measuring Success

A final major element of strategic communication, in addition to defining objectives and designing a communication frame, is measuring success to support continuous improvement. Communicators gain more from establishing objectives and strategically framing communication to achieve the objectives when performance can be evaluated and used for future improvements. Understanding how people behave, how decisions are made, and why certain behaviors are observed supports communicators by clarifying where adjustments are likely to be the most useful, for example by recognizing when people do not understand something versus do not want or cannot execute something (Wong-Parodi and Strauss 2014, Wong-Parodi et al. 2016).

Study Goals

Given the limited discussion about communication in many technical communities (e.g. Kuehne et al. 2014), understanding where the water resources community is now relative to where communication science suggests it should be is a useful goal. This study thus addresses the research question of how professionals who work with water resources in the context of oil and natural gas production, particularly in settings with HF, communicate with scientists, regulators, and the public. Specific focal points include best practices communicators have identified regarding water and oil and natural gas, how the intended recipients of the messages interpret and view communication activities, and how communicators assess their own effectiveness. To investigate these questions, this research uses primary qualitative data from interviews and focus groups with communicators and audiences in the oil and gas-related water

management community. These data are synthesized with scientifically supported best practices from the communication disciplines to recommend future steps.

Methods

This work provides a descriptive analysis of ongoing communication efforts based on interviews and a prescriptive presentation of best practices and recommendations from communication literature and suggestions from interviewees. The remainder of this section describes participant recruitment and interview design for the descriptive analysis.

Interview Participants

Confidential interviews with 32 individuals and one 11-person focus group were recorded upon consent of the participants, then transcribed and analyzed. Transcripts were entered into NVivo 10 for data management and coding. Open coding themes coalesced around assessing participants' evaluation of their own effectiveness, best practices, and perceptions of their audiences and other communicators, in addition to specific pre-defined focuses on experience with communication training, preferred communication modes, and specific perceptions of and interactions with the oil and natural gas industry (industry-related findings are reported specifically in Cook and Grubert 2017).

Of the 43 people who participated, 30 were expert participants who represent the oil and gas industry, government, media, academia, and other nongovernmental organizations (NGOs), including both research NGOs and nonresearch NGOs like consultancies (Table 1). Initial expert recruitment proceeded through the authors' personal networks combined with snowball sampling, where interviewees suggested further people who might be interested in participating. To increase geographic, experiential, and other forms of diversity in the group, the authors also directly solicited participants from specific sectors. Academics and scientists at NGOs were

recruited through water-related professional societies, including at conferences where the research design was presented. Government representatives were invited to participate by door-knocking at relevant government officials' offices, requesting participation by representatives, aides, analysts, and others with some direct responsibility for communicating about water as it relates to HF. Media representatives were contacted directly, based on recent reporting in television, print, and web settings. Industry representatives were identified both through the snowball sample and direct contact.

The remaining 13 participants identified as community members whose primary role is in receiving rather than designing and presenting communication. Community members were recruited through Google Adwords advertisements in specific regions with HF activity and through the authors' personal networks. Two community members were interviewed as individuals, while the other 11 were interviewed in a focus group. This relatively large community sample is in part attributable to one author's experience and cultural understanding of a region where water and HF issues are present, allowing a trust-based connection in an area where recruitment can be challenging. Despite this advantage, recruiting community members willing to speak on record was extremely difficult, which motivated the use of a focus group despite the lower response detail and greater tendency for internal agreement associated with focus groups relative to interviews.

Interview Design

Interviews used for this study were semi-structured and conversational in tone. Each participant was asked several specific questions (see Appendix), but follow-up questions were tailored to the conversation, and some participants introduced topics themselves. If participants requested clarification, it was given. The interview guide was designed to elicit both current

practices and community senses of best practices for communicating about water as it relates to oil and natural gas, which in most cases focused on hydraulic fracturing. It was also designed to enable detailed investigation of differences between participants with primarily water versus primarily oil and natural gas backgrounds, between participants with different audiences and major activities, and between participants with different levels of experience. In practice, responses were not sufficiently distinct to warrant this categorical differentiation.

Results

Overall, this study indicates that the interviewed communicators have a literature-supported sense of how to behave when communicating, but they do not have a literature-supported sense of how to design their messages or measure successful communication. This section introduces quotes related to defining objectives, framing communication, and measuring success that are further contextualized in the discussion.

Defining Objectives

Participants had clear suggestions about best practices for individual interactions, including a focus on trust-based relationships, a preference for face-to-face communication, and basic mechanics of communicating successfully. When asked about their objectives for communicating, almost all respondents spoke exclusively about personal objectives. These personal objectives mainly focused on establishing trust through their personal comportment, including by moving beyond comfort zones of facts and figures to establish rapport through narrative:

I should make sure I include emotional anecdotes or ideas in my storytelling. The storytelling almost matters more than the truth. The truth is almost irrelevant. The details of our research is less relevant than the idea of the research...So I the automaton, must realize my audience is

probably not all automatons, and I have to speak emotionally to them. –Quote 1, Academic interviewee

Interviewees frequently recommended being conscious of word choice and personal comportment to establish trust:

So the first thing I do when I talk about water issues, and horizontal drilling and multi stage frac(k)ing and conventional oil and gas is I never deny the problem. –Quote 2, Academic interviewee

[People should] get over the fact that they think they're good at giving presentations and stuff and just get some friends to critique what they do. So, you know, go give it and listen to the feedback of how people perceive you. – Quote 3, Industry interviewee

And [a consultant is] like, this is how you talk to stakeholders. you know, don't do this, don't do that, you know, this is what you should wear, this is how you should be in the room when they arrive...Should I be at the front? Should I be in the middle? Should I be sitting with them? You know, what's the most effective way to make them trust me, that kind of thing. – Quote 4, Research NGO interviewee

In addition to suggestions about concrete but relatively superficial actions—like wearing blues and grays rather than large patterns or trying to match the tone of an audience—respondents acknowledged that true trust-based relationships take time, effort, and respect:

The most successful, I think, stakeholder leaders, as it were, are people who can really establish trust, and I think that that takes a lot of time. You know, you can see someone and think that you trust them immediately, but 20 minutes later you might change your mind. So someone who's established in the community, who's built up a rapport, is really huge. – Quote 5, Research NGO interviewee

I don't try and dumb [my presentation] down...I spent a lot of time up front just explaining the problem...just because I had a feeling there could be some homeowners or public groups that need a little bit of intro. – Quote 6, Nonresearch NGO interviewee

Many of the personal best practices suggested in these interviews are consistent with communication literature (e.g. Dietz 2013, Greenaway et al. 2015). In discussing objectives for the communication itself, however, most interviewees denied having objectives beyond one-way transmission of information in a value-free manner. In other parts of the interviews, however, participants' comments frequently expressed overt, if unacknowledged, objectives for their communication:

When [members of the audience] tell you you're terrible, but, and then they can't deal with some convoluted—they make fun of your scientific arguments and say they're too convoluted, it just kind of shows me how unwilling they are to engage in the factual basis for decision-making. – Quote 7, Industry interviewee

I had it confirmed in two different labs independently and blindly, it didn't matter. I mean, they already had their mind made up that whatever I had to say was completely wrong, so I would just

always ask, you know, of these interactions, that they have an open mind and be willing to learn from someone like myself. – Quote 8, Nonresearch NGO interviewee

So we're not out there trying to promote certain ideas. We're just wanting to ensure that best practices are identified, that they get commercialized. – Quote 9, Research NGO interviewee

We just, we get money from concerned citizens, and that allows us to obviously portray that we're just working in the best interest of human beings and concerned citizens on this issue, and we let the data speak for itself. – Quote 10, Nonresearch NGO interviewee

Usually, the implicit objective was for people to act in a manner that the interviewees saw as an obvious consequence of the facts being presented—an objective strongly aligned with deficit model thinking, which was also observed in conversations about framing.

Framing Communication

Many interviewees appeared to subscribe to the intuitive but poorly scientifically supported deficit model of scientific communication, holding that there is a divide between expert and non-expert opinions based on fact-based knowledge and that providing facts to the public will increase support for science-based outcomes. The implication to many is that framing is unnecessary and possibly harmful, which follows in part from the reluctance to design communication objectives. Related to this perception is the idea that facts are neutral, which was common across sectors:

If people understood issues better, they might come to different conclusions. – Quote 11, Industry interviewee

That's how we know we're 100% neutral, we just let the data speak for itself. – Quote 12, Nonresearch NGO interviewee

We do the science, we let the science speak for itself...we will stand up in a room and say, the science says that this is right and that is wrong. – Quote 13, Research NGO interviewee

One interviewee—notably, one who is actively engaged with community decision-making—critiques this perception while acknowledging its persistence:

[That reaction is related to] the environmental science perspective of thinking like "Well, this is what the science says, so like, it's right. Why are we arguing?" [laughs] It's like, "You're stupid. Clearly." And that's like obviously a really terrible, elitist position to take. – Quote 14, Academic interviewee

Community members' perspectives of "fact-oriented" communication similarly expressed their critique that such communication is not objective:

I would have a very, frankly say that with the amount of experience that I've had with various organizations, I recognize their biases, and I take what they say as information, and recognize that there is a bias, and so I don't take anybody just for their word. I take their information and evaluate it. – Quote 15, Community member interviewee

Despite commonly expressed suspicion of framing, the rare instances where respondents specifically noted how communicating about HF is different from other communications implicitly acknowledged framing efforts:

One of the things that we were pointed out by a sociologist who's involved with us is to not shorten the word 'hydraulic fracturing.' Here we want, our mission is to provide unbiased science...We looked at our mission [that] included the term 'reducing environmental impact.' And right away, our industry advisor pointed to that and said, there's a better way that you may want to consider approaching that...So we've changed that over to 'addressing environmental and societal issues,' which softens it and opens up a way for dialogue. Because then you start communicating, 'Well what issues are you having?' and all. – Quote 16, Research NGO interviewee

Measuring Success

Many participants had limited clarity on how to design their communication, which manifested both as dismissal of communication frames (in favor of "neutral" facts) and as imprecise or nonexistent success metrics. One such imprecise metric was to be perceived as a neutral resource:

We do a good job if we feel we kept the science intact in our summary and discussion of the topic...we know it's successful when we're considered trustworthy by other sources. – Quote 17, Research NGO interviewee

Participants often referenced audiences' immediate reactions as their indicators of success, even when a clear objective or measurement strategy was not stated:

Successful? Well I think it's a gut. It's a gut feeling at the end of the conversation. – Quote 18, Nonresearch NGO interviewee

I look for nods, and I look for you know, smiles and nods, and I look for follow up questions. – Quote 19, Government interviewee

Some respondents explicitly stated that a negative reaction is an indicator of success, suggesting a personal belief that their position is the correct one regardless of reaction:

If governmental entities abhor my presence, my emails, or my phone calls, that tells me I'm doing my job right. – Quote 20, Media interviewee

I have other people track the hate mail I get...And when I get a lot of it, I decided I was really successful. I know I'm, that's being smug, but really, that's what happens. – Quote 21, Industry interviewee

Notably, media and industry respondents articulated success metrics much more clearly than most of the NGO and academic scientists who participated in this study. This observation might be attributable to the higher uptake of formal communication training among the media and industry respondents in this study, suggesting that participants in these groups might have more evidence-based perceptions of how to design effective communication.

Discussion

In addressing the research question of how water professionals working in oil and natural gas production contexts communicate, the most unexpected finding of this research is that few interviewees indicated that communicating about oil and natural gas, and HF in particular, warrants particular strategies. Given both authors' experience of being consistently warned about the need to exercise additional caution and finesse when talking about water in the oil and natural gas setting, more specific and sophisticated strategies were expected. In probing the data through the lens of a communication process—defining objectives, framing the communication, and measuring success—this research indicates a broad and continued need for communication training in politically challenging contexts, with particular focus on the persistence of the deficit model among scientists and engineers. This research suggests that the community's needs are still fairly general rather than specific to water and HF or other oil and natural gas contexts, which also means that the findings discussed here are likely applicable in other water management and other science communication contexts. This discussion puts the quotes introduced in the results section in more context and offers specific commentary on why conditions might need to change, again using the process frame from the introduction and results.

Defining Objectives

"I think I've become increasingly more successful once I stopped caring about whether I was right or not." –Quote 22, Academic interviewee

The interviews conducted for this study suggest that while some people communicating about water as it relates to oil and gas think carefully about the specific objectives of their communication, many communicators are unclear about what their objectives are. This finding is

not unique to water in oil and gas, as science communication literature more generally indicates a limited understanding of what, precisely, scientists are trying to achieve by communicating (Besley et al. 2016). The lack of clarity on objectives is important because the nature of interaction, specifics of data, and expectations of a communicator's role might be quite different depending on the goal. Objectives affect how communicators position their work, and "the" goal might not be singular. For example, goals might be different for different actors or be established only upon co-creation (see e.g. Tidwell and van den Brink 2008 for a water resources management example) during the communication event itself.

This work finds that while people consistently establish and easily articulate *personal* communication goals, like dressing right or cultivating presence (e.g. quotes 1, 3, 4, and 5), evidence of more *process*-oriented goals, like ensuring scientific information is represented during decision-making, is lacking (see Hopkins 2009 for an overview of personal versus process orientation in a safety setting). A possible reason for the lack of process-oriented goals articulated by interviewees is continued belief in the deficit model, evidenced in quotes like 7 and 8. Interviewees frequently used language setting themselves and their organizations—and often, scientists as a group—apart from their audience. In some cases, this separation was respectful, even when it explicitly acknowledged the expert's goal of conveying information in one direction (quote 6). In other cases, both in interviews conducted for this work and in published literature on social components of water management in energy-producing communities, the separation was framed in more condescending terms, with audiences referred to explicitly as simple or uneducated. Based on these observations, the separation between communicator and audience established by deficit model thinking appears to complicate the articulation of objectives beyond sharing information. For example, of Van der Sanden and

Meijman's categories of objectives—public awareness, engagement, participation, or understanding (2008)—only public awareness is an easily achieved goal when the communicator assumes great separation from the audience. Public understanding requires the communicator to understand audience values and concerns, for example.

A recurring topic of the interviews conducted for this work is the distinction between appropriate and inappropriate communication. Interviewees recommended best practices like being clear about the nature and boundaries of their expertise (e.g. quote 1) and having citations to support their claims, which are generally supported by the communication literature (e.g. Meyer et al. 2010). Overall, though, interviews conducted for this study revealed a persistent tension between objectives and objectivity (e.g. quotes 9, 10). Very few participants explicitly stated objectives beyond immediate awareness like nods or requests for published information (e.g. quote 19). (Notable exceptions include industry representatives who referenced observable objectives like influencing regulation as part of their success metrics for communication.) Participants largely subscribed to the perspective that any sign of advocacy could be damaging to the credibility of their profession or themselves, especially those who identified as scientists (see also Blockstein 2002, Pace et al. 2010).

In practice, evidence of harm to a scientist's or profession's credibility based on participation in decision processes is not prevalent. By contrast, this study revealed evidence of harm to credibility and to collaboration based on communicators' refusal to acknowledge goals or subjectivity in their position when communicating (e.g. quote 15) despite fairly clear evidence of implicit objectives within claims of neutrality (e.g. quotes 7, 8, 9, 10). In defending the lack of explicit objectives, many alluded to a sense of responsibility to be objective sources of factual information rather than advocates for a particular outcome, using language like "we let the facts

speak for themselves" (e.g. quotes 12, 13)—though one social scientist was notably critical of this attitude (quote 14). This attitude is consistent with deficit model thinking, particularly the "institutional alibi" (Wynne 2006) that allows communicators to perform objectivity by expressing a belief that anyone who has the same facts will come to the same conclusion. This line of thinking simultaneously allows communicators to believe in their own objectivity while reducing trust by audiences who perceive an unstated agenda.

Based on interviews conducted for this study, it appears that a major challenge for communicating about policy-relevant, political issues like HF is ensuring that communicators understand and are comfortable with best practices that differentiate fact- and values-based communication. Participants' desire to remain objective, present scientific facts neutrally, and ensure audiences have a fact base sufficient to aid in decision-making is not incompatible with engagement in decision processes, but understanding the boundaries of science communication does require additional thought. Thus, literature-based best practices regarding communication—and particularly regarding communication about politicized issues—should be sought, taught, and used in the HF-engaged water community and others.

Framing Communication

"I think any time you walk into a room, people are going to wonder where you're from and how that colors the opinions that you're going to give." –Quote 23, Research NGO interviewee

One unexpected finding of the interviews conducted for this study is that participants did not typically reference differences between their strategies for communicating about the

relatively controversial topic of water related to oil and gas and communicating about other topics. Even when participants were directly asked about how their communication regarding water and HF differed from their other communication, specific best practices were rare (but see e.g. quotes 2, 16).

Based on literature about communicating other controversial energy- and environment-related topics (e.g. Walker et al. 2010, Shome et al. 2009), the expectation was that HF communicators might identify strategies associated with framing communication given expectations of audience preconceptions and experiences, addressing controversy and uncertainty directly, and testing the effectiveness of their communication at achieving objectives so as to improve their approach in the future. While some specific strategies were identified, most participants did not draw a contrast between their controversial HF communication (even when they acknowledged the controversy) and their more conventional communication (like emails with colleagues). The most common feedback specific to HF was to ensure that definitions are consistent and clearly understood during a communication activity, particularly since the technical definition of hydraulic fracturing is somewhat different from the popular understanding of the term (e.g. quote 16). However, no participants discussed explicit framing strategies for effective communication, which was unexpected.

Concern about framing as an opportunity to spin information in a way that is misleading or otherwise inconsistent with a scientific approach is legitimate and founded. Many participants noted that they trust information less when it comes from sources known or suspected to have a particular bias, and many respondents (particularly academics) noted their active management of funding sources in attempts to avoid suggestion that they are not independent. Similarly, community members who participated in this research noted that they actively look for biases

and adjust their interpretations accordingly (e.g. quote 15). One community member noted a preference for written communication, "because usually when it's printed and mailed out, they can't say that it wasn't said," a comment that reveals the extent to which community members expect to receive information not framed in their best interests. Other work on community member trust of HF information can be found in Theodori and Ellis (2016).

Among communicator participants, several comments intended to illustrate commitment to neutrality and a lack of framing indicated contours of subjectivity, further supporting community members' senses that claims of unbiased information and pro-social engagement cannot always be taken at face value (quotes 9, 10). In these two cases, values on the part of the communicator are clearly visible even though the speaker is suggesting their communication is value-free. In quote 9, there is a goal of commercializing certain techniques in industry. In quote 10, there is an assumption that the communicator believes both that their own perception of society's best interest is correct and that concerned citizens who donate are the appropriate group to serve. By contrast, the academic participant in quote 1, who received unprompted praise from community members by name, directly acknowledges bias even while making similar comments about the importance of remaining neutral. This third participant's perspective reflects a commitment to acknowledging and designing around bias rather than an assumption that the bias is not present.

Perhaps counterintuitively, more careful attention to communication framing and design can actually reduce bias and subjectivity precisely because it forces communicators to consider and name goals and strategies. Concerns about frames that prioritize a specific outcome are valid; concerns that lack of framing can inadvertently prioritize a specific outcome, reduce trust, or otherwise be damaging are also valid. Framing is a critical component of effective

communication, largely because it is important for making scientific work available for use and application. A well-designed frame need not be persuasive, but lack of intentionality about a frame can result in loss of relevant information because of poor timing, poor context, or poor linkage to pertinent issues.

Measuring Success

In this study, while few participants referenced explicit effort to define objectives or frame, no participants noted using a process to measure their success and determine what to do differently in the future. Participants did identify a number of indicators to determine whether they were successful, but none were used as an explicit input to a cycle of improvement. Most were not measurable (e.g. quotes 17, 18, 19, 20), and those that were measurable were typically binary and unable to measure a given communicator or communication's role in the outcome—for example, completing a project or adding language to a regulation. Some success indicators participants mentioned regarded social cues like nods that are not necessarily indicative of engagement and agreement. These cues are often given by inattentive people performing attentiveness (Lupia 2013). Other metrics, while also not directly related to future improvements, mostly related to interpersonal feedback like questions or requests for more information.

It is likely that most participants implicitly apply lessons from their prior communication efforts, for example by realizing they need to speak more slowly or dress differently, but explicit, designed efforts to learn and improve over time was not evident in this research. Effectively, participants have little sense of their efficacy and success even when they do have explicit objectives. While a lack of well designed, measurable success metrics aimed at enabling improvement is understandable, particularly given a lack of exposure to communication science

and challenges regarding defining objectives and establishing communication frames, bringing such metrics to HF communicators can support better engagement and better integration of scientific information to decisions.

Conclusions and Recommendations

The results of this interview-based research focused on professionals who communicate about science issues associated with water and oil and gas, particularly hydraulic fracturing, suggest that many practicing communicators in the community have a strong intuitive sense of the personal mechanics of communication—like establishing trust, speaking clearly, and dressing appropriately—but much less clarity on the science of effective communication. Specifically, this research indicates gaps in communicators' use of objective setting, strategic framing, and measuring success for improvement. Long-held beliefs about the nature of communication, grounded in the deficit model, and concerns about the interplay between designing a communication and being an objective communicator of information are the most evident cultural barriers to uptake of communication science.

Notably, very few participants in this group (selected for diversity of age, gender, industry, and professional history) have received communication training, though many expressed interest and self-reported spending large amounts of their time communicating about HF and water in often politicized settings. Multiple participants noted difficulty in identifying training opportunities, echoing findings that the division of opportunities for later career scientists versus those in school is challenging (e.g. Kuehne et al. 2014). Methods, support, and reasons for training scientists to communicate are widely reported in the literature (e.g. Besley et al. 2015, Besley et al. 2016, Bray et al. 2012, Kuehne et al. 2014). This work accordingly joins

some participants in recommending that the scientific community consider offering training opportunities focused on communicating science about controversial and political issues like HF. Such trainings could be offered through professional societies, much as workshops for publications and other topics of general interest already are.

This research uncovered not only a demand for training among practicing science communicators, but also a dearth of knowledge of best practices going beyond immediate personal media skills. This finding supports the assertion in Bray et al. (2012) that communicators should "develop a broad understanding of the scientific and social issues rather than narrowly focusing on technical media skills development." This work recommends that the scientific community continue successful modeling and discussion of personally-oriented elements of communicating, like establishing trust, but focus training efforts on process-oriented elements of communicating, like defining objectives, framing communication, and measuring success against objectives.

One proposed objective for training is to provide guidance for scientists on what and how to communicate. For example, the scientific community might emphasize identifying policy-relevant but not policy-prescriptive scientific issues to explain and contextualize to decision makers and broader stakeholder audiences. This type of communication is common among organizations like the Intergovernmental Panel on Climate Change and the National Academy of Sciences (e.g. Dietz 2013). As Fischhoff outlines (2013), effective communication involves identifying the science relevant to a decision, rigorously determining what people already know, designing communication to fill the gap, and learning from and repeating the process. Communication is a science, and science communication should use established communication science rather than relying on intuition (Fischhoff 2013), especially in controversial arenas like

HF and other water management topics, like hydropower licensing (Ulibarri 2015) and groundwater resource allocation (Tidwell and van den Brink 2008).

A second proposed objective for training is to ensure that the fact bases required by stakeholders exist and are accessible. For example, another way to promote good science communication is to train scientists to seek and interpret public conversations on topics relevant to their research areas and to support scientists in designing research and work products that make answers to these questions available. This objective similarly focuses on making science communication relevant but not prescriptive and addresses the important challenge of determining an audience's context. Information about an audience's value systems, existing knowledge, existing attitudes, and preferences for engagement modes is important for designing effective communication that brings relevant information in an understandable format (de Bruin and Bostrom 2013, Nisbet and Scheufele 2009).

A third objective is to train scientists to investigate their own personal value systems and perspectives to support thoughtful engagement that acknowledges multiple perspectives. Understanding one's own expertise and personal values is important for enabling transparent, honest engagement, particularly given that decisions are based on both facts and values (Dietz 2013). The science community has generally accepted that its role is not to prescribe values, but individual scientists certainly have value systems that are important to understand. Science has an important role to play in supporting decisions about controversial, political issues with many social and environmental implications, like water use for oil and gas, and a scientific approach to communicating will best serve the communication of that science.

Appendix. Interview Questions

- What is your primary role when you consider issues related to water use for oil and gas?
- How long have you been in that role?
- How much of your time do you spend related to water in the oil and natural gas industry?
- What is your background?
- How well equipped do you feel to answer questions about the oil and natural gas industry?
- How well equipped do you feel to answer questions about water?
- What is your major activity related to water in the oil and natural gas industry?
- Who is your primary audience (source) related to water in the oil and natural gas industry? (Audience used with communicators; source used with community members)
- Thinking about the major activity you stated, what characterizes a successful such activity? Do you have any specific anecdotes?
- Thinking about the major activity you stated, what characterizes an unsuccessful such activity? Do you have any specific anecdotes?
- Do you find a particular mode of communication is most effective? Why do you think that is?
- Particularly in relation to your primary audience, how effective do you think your current communication strategies are at reaching your goals? Do you have any specific anecdotes?
- What strategies for communicating about water issues in oil and gas would you recommend for others in your role? Why?
- What strategies for communicating about water issues in oil and gas would you advise against for others in your role? Why?
- (For academics and NGO scientists) Do you feel your funding sources affect your effectiveness as a communicator related to water in oil and gas? Do you have any specific anecdotes?

- Do you have any other information related to your experience with water, oil, and natural gas that you think would be useful or that you would like us to know?

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References

Allen, T. F. H., Tainter, J. A., Pires, J. C., and Hoekstra, T. W. (2001). "Dragnet Ecology—'Just the Facts, Ma'am': The Privilege of Science in a Postmodern World Science of intrinsic quality needs narratives with explicit values—not just facts—particularly as it faces multiple-level complexity in advising on environmental policy, such as planning for energy futures." *BioScience*, 51(6), 475–485.

American Association for the Advancement of Science. (2016). "AAAS Mass Media Science and Engineering Fellows Program." *AAAS Mass Media Science and Engineering Fellows Program*, <https://www.aaas.org/page/about-1> (Dec. 18, 2016).

Besley, J. C., Dudo, A. D., Yuan, S., and Ghannam, N. A. (2016). "Qualitative Interviews With Science Communication Trainers About Communication Objectives and Goals." *Science Communication*, 38(3), 356–381.

Besley, J. C., Dudo, A., and Storksdieck, M. (2015). "Scientists' views about communication training." *Journal of Research in Science Teaching*, 52(2), 199–220.

Blockstein, D. E. (2002). "How to Lose Your Political Virginity while Keeping Your Scientific Credibility." *BioScience*, 52(1), 91–96.

Bombaci, S. P., Farr, C. M., Gallo, H. T., Mangan, A. M., Stinson, L. T., Kaushik, M., and Pejchar, L. (2016). "Using Twitter to communicate conservation science from a professional conference." *Conservation Biology*, 30(1), 216–225.

Boudet, H., Clarke, C., Bugden, D., Maibach, E., Roser-Renouf, C., and Leiserowitz, A. (2014). "'Fracking' controversy and communication: Using national survey data to understand public perceptions of hydraulic fracturing." *Energy Policy*, 65, 57–67.

Bray, B., France, B., and Gilbert, J. K. (2012). "Identifying the Essential Elements of Effective Science Communication: What do the experts say?" *International Journal of Science Education, Part B*, 2(1), 23–41.

de Bruin, W. B., and Bostrom, A. (2013). "Assessing what to address in science communication." *Proceedings of the National Academy of Sciences*, 110(Supplement 3), 14062–14068.

Bucchi, M. (2016). "Editorial." *Public Understanding of Science*, 25(3), 264–268.

Clarke, H., Eisner, L., Styles, P., and Turner, P. (2014). "Felt seismicity associated with shale gas hydraulic fracturing: The first documented example in Europe." *Geophysical Research Letters*, 41(23), 2014GL062047.

Cook, M., and Grubert, E. (2017). "Water Use in the Oil and Gas Industries: An Evaluation of Best Practices for Communicating with Scientists, Policymakers, and the Public." *Proceedings of the Society of Petroleum Engineers Health, Safety, Security, Environment, & Social Responsibility Conference-North America*, Paper SPE-184431-MS.

Cormick, C., Nielssen, O., Ashworth, P., Salle, J. L., and Saab, C. (2015). "What Do Science Communicators Talk About When They Talk About Science Communications? Engaging With the Engagers." *Science Communication*, 37(2), 274–282.

Cortassa, C. (2016). "In science communication, why does the idea of a public deficit always return? The eternal recurrence of the public deficit." *Public Understanding of Science*, 25(4), 447–459.

Davies, P. J., Gore, D. B., and Khan, S. J. (2015). "Managing produced water from coal seam gas projects: implications for an emerging industry in Australia." *Environmental Science and Pollution Research*, 22(14), 10981–11000.

Dietz, T. (2013). "Bringing values and deliberation to science communication." *Proceedings of the National Academy of Sciences*, 110(Supplement 3), 14081–14087.

Dudo, A., and Besley, J. C. (2016). "Scientists' Prioritization of Communication Objectives for Public Engagement." *PLOS ONE*, 11(2), e0148867.

Energy Information Administration. (2016). "Shale in the United States." <https://www.eia.gov/energy_in_brief/article/shale_in_the_united_states.cfm> (Dec. 18, 2016).

Espig, M., and de Rijke, K. (2016). "Unconventional gas developments and the politics of risk and knowledge in Australia." *Energy Research & Social Science*.

Feinstein, A. R. (1985). "Clinical Epidemiology: The Architecture of Clinical Research." *eweb:57078*, <https://repository.library.georgetown.edu/handle/10822/806669> (Dec. 18, 2016).

Fischhoff, B. (2013). "The sciences of science communication." *Proceedings of the National Academy of Sciences*, 110(Supplement 3), 14033–14039.

Fischhoff, B., and Scheufele, D. A. (2013). "The science of science communication." *Proceedings of the National Academy of Sciences*, 110(Supplement 3), 14031–14032.

Greenaway, K. H., Wright, R. G., Willingham, J., Reynolds, K. J., and Haslam, S. A. (2015). "Shared Identity Is Key to Effective Communication." *Personality and Social Psychology Bulletin*, 41(2), 171–182.

Greer, A. L. (1988). "The State of the Art Versus the State of the Science: The Diffusion of New Medical Technologies into Practice." *International Journal of Technology Assessment in Health Care*, 4(1), 5–26.

Gregory, K. B., Vidic, R. D., and Dzombak, D. A. (2011). "Water Management Challenges Associated with the Production of Shale Gas by Hydraulic Fracturing." *Elements*, 7(3), 181–186.

Haya, B., Strong, A., Grubert, E., and Cullenward, D. (2016). "Carbon Offsets in California: Science in the Policy Development Process." *Communicating Climate-Change and Natural Hazard Risk and Cultivating Resilience*, J. L. Drake, Y. Y. Kontar, J. C. Eichelberger, T. S. Rupp, and K. M. Taylor, eds., Springer International Publishing, Cham, 241–254.

Holland, E. M., Pleasant, A., Quatrano, S., Gerst, R., Nisbet, M. C., and Mooney, C. (2007). "The Risks and Advantages of Framing Science." *Science*, 317(5842), 1168b–1170b.

Hopkins, A. (2009). "Thinking About Process Safety Indicators." *Safety Science*, 47(4), 460–465.

Hu, D., and Xu, S. (2013). "Opportunity, challenges and policy choices for China on the development of shale gas." *Energy Policy*, 60, 21–26.

Huttunen, S., and Hildén, M. (2014). "Framing the Controversial Geoengineering in Academic Literature." *Science Communication*, 36(1), 3–29.

Iber, P. (2016). "How academics can use Twitter most effectively." *Inside Higher Ed*, <https://www.insidehighered.com/advice/2016/10/19/how-academics-can-use-twitter-most-effectively-essay> (Dec. 18, 2016).

Jackson, R. B., Vengosh, A., Carey, J. W., Davies, R. J., Darrah, T. H., O'Sullivan, F., and Pétron, G. (2014). "The Environmental Costs and Benefits of Fracking." *Annual Review of Environment and Resources*, 39(1), 327–362.

Jacquet, J. B. (2014). "Review of Risks to Communities from Shale Energy Development." *Environmental Science & Technology*, 48(15), 8321–8333.

Keranen, K. M., Weingarten, M., Abers, G. A., Bekins, B. A., and Ge, S. (2014). "Sharp increase in central Oklahoma seismicity since 2008 induced by massive wastewater injection." *Science*, 1255802.

Kuehne, L. M., Twardochleb, L. A., Fritschie, K. J., Mims, M. C., Lawrence, D. J., Gibson, P. P., Stewart-Koster, B., and Olden, J. D. (2014). "Practical Science Communication Strategies for Graduate Students." *Conservation Biology*, 28(5), 1225–1235.

Kunda, Z. (1990). "The case for motivated reasoning." *Psychological Bulletin*, 108(3), 480–498.

Lach, D., List, P., Steel, B., and Shindler, B. (2003). "Advocacy and Credibility of Ecological Scientists in Resource Decisionmaking: A Regional Study." *BioScience*, 53(2), 170–178.

Lackey, R. T. (2007). "Science, Scientists, and Policy Advocacy." *Conservation Biology*, 21(1), 12–17.

Lubchenco, J. (1998). "Entering the Century of the Environment: A New Social Contract for Science." *Science*, 279(5350), 491–497.

Lupia, A. (2013). "Communicating science in politicized environments." *Proceedings of the National Academy of Sciences*, 110(Supplement 3), 14048–14054.

Mazur, A. (2016). "How did the fracking controversy emerge in the period 2010-2012?" *Public Understanding of Science*, 25(2), 207–222.

McGranahan, C. (2013). "The Academic Benefits of Twitter." *Savage Minds*, <http://savageminds.org/2013/05/08/the-academic-benefits-of-twitter/> (Dec. 18, 2016).

Meyer, J. L., Frumhoff, P. C., Hamburg, S. P., and de la Rosa, C. (2010). "Above the din but in the fray: environmental scientists as effective advocates." *Frontiers in Ecology and the Environment*, 8(6), 299–305.

Mills, T. J., and Clark, R. N. (2001). "Roles of research scientists in natural resource decision-making." *Forest Ecology and Management*, The Science Basis for Ecosystem Management in the Interior Columbia River Basin, 153(1–3), 189–198.

Molinatti, G., and Simonneau, L. (2015). "A Socioenvironmental Shale Gas Controversy Scientists' Public Communications, Social Responsibility and Collective Versus Individual Positions." *Science Communication*, 37(2), 190–216.

Mooney, H., and Ehrlich, P. (1999). "Ecologists, Advocacy and Public Policy." <https://www.nceas.ucsb.edu/files/projects/resources/ecoessay/wagner/rev1.html> (Dec. 18, 2016).

Nisbet, M. C., and Mooney, C. (2007). "Framing Science." *Science*, 316(5821), 56–56.

Nisbet, M. C., and Scheufele, D. A. (2009). "What's next for science communication? Promising directions and lingering distractions." *American Journal of Botany*, 96(10), 1767–1778.

Pace, M. L., Hampton, S. E., Limburg, K. E., Bennett, E. M., Cook, E. M., Davis, A. E., Grove, J. M., Kaneshiro, K. Y., LaDeau, S. L., Likens, G. E., McKnight, D. M., Richardson, D. C., and Strayer, D. L. (2010). "Communicating with the public: opportunities and rewards for individual ecologists." *Frontiers in Ecology and the Environment*, 8(6), 292–298.

Pahl-Wostl, C., Craps, M., Dewulf, A., Mostert, E., Tabara, D., and Taillieu, T. (2007). "Social Learning and Water Resources Management." *Ecology and Society*, 12(2).

Priscoli, J. B. (1989). "Public involvement, conflict management: means to EQ and social objectives." *Journal of Water Resources Planning and Management*, 115(1), 31–42.

Priem, J., and Costello, K. L. (2010). "How and why scholars cite on Twitter." *Proceedings of the American Society for Information Science and Technology*, 47(1), 1–4.

Rasch, E. D., and Köhne, M. (2016). "Hydraulic fracturing, energy transition and political engagement in the Netherlands: The energetics of citizenship." *Energy Research & Social Science*, Energy Transitions in Europe: Emerging Challenges, Innovative Approaches, and Possible Solutions, 13, 106–115.

Roberts, M. R. (2009). "Realizing Societal Benefit from Academic Research: Analysis of the National Science Foundation's Broader Impacts Criterion." *Social Epistemology*, 23(3–4), 199–219.

Rost, K., Kashner, T. M., and Smith Jr., G. R. (1994). "Effectiveness of psychiatric intervention with somatization disorder patients: Improved outcomes at reduced costs." *General Hospital Psychiatry*, 16(6), 381–387.

Rykiel, E. J. (2001). "Scientific Objectivity, Value Systems, and Policymaking." *BioScience*, 51(6), 433–436.

Scanlon, B. R., Reedy, R. C., and Nicot, J. P. (2014). "Will water scarcity in semiarid regions limit hydraulic fracturing of shale plays?" *Environmental Research Letters*, 9(12), 124011.

Scheufele, D. A. (2013). "Communicating science in social settings." *Proceedings of the National Academy of Sciences*, 110(Supplement 3), 14040–14047.

Schneider, S. H. (1992). "The role of the university in interdisciplinary global change research: Structural constraints and the potential for change. An editorial." *Climatic Change*, 20(1), vii–x.

Shome, D., Krantz, D., Leiserowitz, A., LoBuglio, M., Logg, J., Mazhirov, A., Milch, K., Nawi, N., Peterson, N., Soghoian, A., and others. (2009). "The psychology of climate change communication: A guide for scientists, journalists, educators, political aides, and the interested public."

Simis, M. J., Madden, H., Cacciatore, M. A., and Yeo, S. K. (2016). "The lure of rationality: Why does the deficit model persist in science communication?" *Public Understanding of Science*, 25(4), 400–414.

Suldovsky, B. (2016). "In science communication, why does the idea of the public deficit always return? Exploring key influences." *Public Understanding of Science*, 25(4), 415–426.

Theodori, G. L., and Ellis, C. (2016). "Hydraulic fracturing: Assessing self-reported familiarity and the contributions of selected sources to self-reported knowledge." *The Extractive Industries and Society*.

Theodori, G. L., Wynveen, B. J., Fox, W. E., and Burnett, D. B. (2009). "Public Perception of Desalinated Water from Oil and Gas Field Operations: Data from Texas." *Society & Natural Resources*, 22(7), 674–685.

Tidwell, V. C., and van den Brink, C. (2008). "Cooperative Modeling: Linking Science, Communication, and Ground Water Planning." *Ground Water*, 46(2), 174–182.

Trench, B., and Miller, S. (2012). "Policies and practices in supporting scientists' public communication through training." *Science and Public Policy*, 39(6), 722–731.

Ulibarri, N. (2015). "Tracing Process to Performance of Collaborative Governance: A Comparative Case Study of Federal Hydropower Licensing." *Policy Studies Journal*, 43(2), 283–308.

Van Der Sanden, M. C., and Meijman, F. J. (2008). "Dialogue guides awareness and understanding of science: an essay on different goals of dialogue leading to different science communication approaches." *Public Understanding of Science*, 17(1), 89–103.

Walker, G., Cass, N., Burningham, K., and Barnett, J. (2010). "Renewable Energy and Sociotechnical Change: Imagined Subjectivities of 'the Public' and Their Implications." *Environment and Planning A*, 42(4), 931–947.

Warner, N. R., Christie, C. A., Jackson, R. B., and Vengosh, A. (2013). "Impacts of Shale Gas Wastewater Disposal on Water Quality in Western Pennsylvania." *Environmental Science & Technology*, 47(20), 11849–11857.

Weingart, P., Engels, A., and Pansegrau, P. (2000). "Risks of communication: discourses on climate change in science, politics, and the mass media." *Public Understanding of Science*, 9(3), 261–283.

Wong-Parodi, G., Krishnamurti, T., Davis, A., Schwartz, D., and Fischhoff, B. (2016). "A decision science approach for integrating social science in climate and energy solutions." *Nature Climate Change*, 6(6), 563–569.

Wong-Parodi, G., and Strauss, B. H. (2014). "Team science for science communication." *Proceedings of the National Academy of Sciences*, 111(Supplement 4), 13658–13663.

Wynne, B. (2006). "Public engagement as a means of restoring public trust in science--hitting the notes, but missing the music?" *Community Genetics*, 9(3), 211–220.

Table 1. Interview Participants by Sector

Role	Sector	Number of Participants
Experts		**30**
	Oil and gas industry	4
	Government	6
	Media	3
	Academia	8
	Scientific NGOs	5
	Other NGOs	4
Community members		**13**
	Individuals	2
	In focus group	11
Total		**43**