WHERE ARE WE NOW? SOCIO-ECOLOGICAL RISKS AND COMMUNITY RESPONSES TO OIL AND GAS DEVELOPMENT IN COLORADO

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Abstract:

Colorado is the sixth largest gas-to-market producer in the nation, situating the state for substantial impact on energy resources at a national scale. The increase in pace and scale of oil and gas development over the last five to seven years can be attributed to technological advances in the process of hydraulic fracturing (HF) and horizontal drilling, favorable market prices, and an investment in long-term federally funded research aimed at nationalizing energy resources.

However, the potential of multiple and contested risks related to HF have led to increases in community activism across Colorado. This report examines community responses to the increased pace and scale of oil and natural gas development in Pennsylvania and Colorado. Grassroots organizations and citizens are concerned with the potential air emissions, water use, economic, and socio-psychological risks associated with the energy development known as "fracking." An assessment of peer-reviewed literature on these potential risks is presented.

Through a review of the most recent peer-reviewed scholarly research and government reports, this paper additionally examines the socio-ecological risks confronted in Pennsylvania and Colorado, and to a lesser extent Wyoming and Texas, as part of developing energy on a large scale. This section begins with a review of economic benefits and challenges of oil and gas development. Input-output models are an important tool for projecting economic impacts at multiple scales. However, much of the literature in this realm critiques the assumptions on which input-output models are based, including exclusion of environmental and social externalities as well as temporal aspects of resource-dependent economies.

This is followed by an examination of Lifecycle Analyses (LCAs), the preferred methodological tool for scientists measuring air emissions. LCAs have the utility of not only documenting the full time span of natural gas emissions, but also providing policy-makers with a standard format for energy portfolio decision-making. A review of the research on socio-psychological health concerns and air emissions is provided. In addition to the full lifecycle studies, regional Health Impact Assessments (HIAs) have been carried out to measure the risk of air emissions near the site of extraction and the potential harm caused to nearby communities. The HIAs were carried out both on the Front Range and the Western Slope of Colorado. These quantitative-based studies are followed by a qualitative analysis of the everyday socio-psychological health impacts that accompany rapid environmental changes and industrialization of the rural countryside with oil and gas development. Residents recount their experiences with a changing social, environmental, and political landscape.

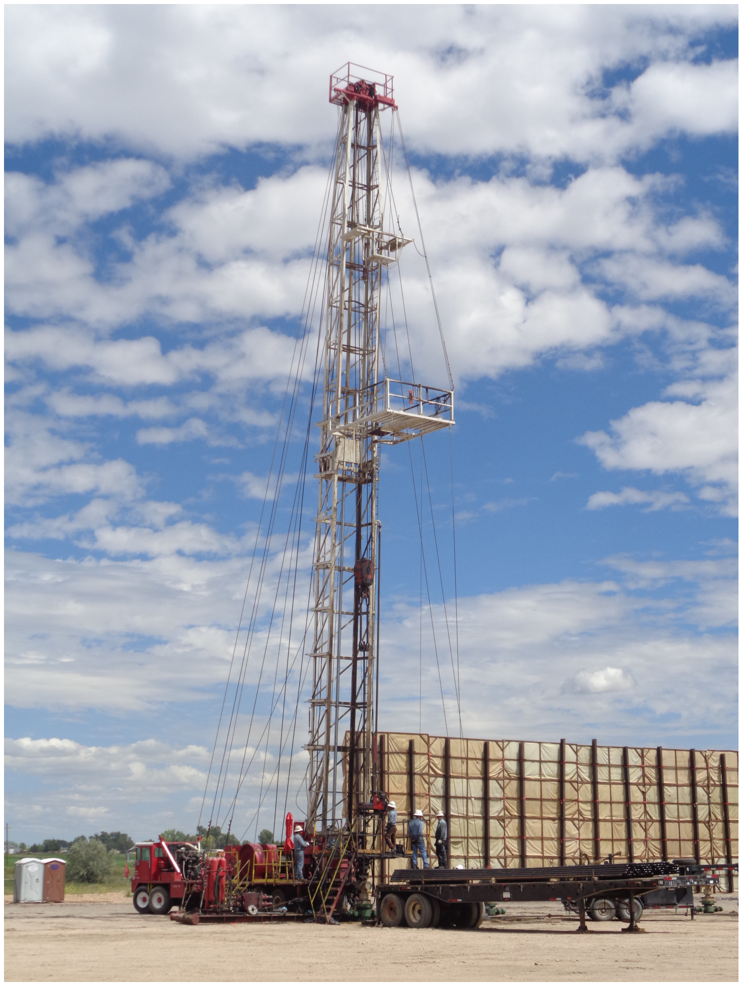
In addition, this report reviews 20 studies that highlight the probable linkages between contamination of ground and surface waters with hydraulic fracturing activities. There is controversy and debate between university academics, industry, and hired consultancy firms over the validity of these linkages. One of these debates is examined, followed by a discussion of the contradictory and complicated contexts within which citizens and policy-makers must take action.

Keywords:

Oil and gas, Colorado, community responses, grassroots, water contamination, air emissions, hydraulic fracturing

Where are We Now?
Socio-Ecological Risks and Community Responses to Oil and Gas Development in Colorado

By Karie Boone and Melinda Laituri



Driling Rig in Weld County, Colorado, 2014 Photo by Beth Plombon, Colroado Water Institute

Community groups rally against fracking in Erie, Colorado, 2012. Photo by Brett Rindt, Creative Commons License

Executive Summary

This report examines community responses to the increased pace and scale of oil and natural gas development in Pennsylvania and Colorado. Grassroots organizations and citizens are concerned with the potential air emissions, water use, economic, and socio-psychological risks associated with the energy development known as “fracking.” An assessment of peer-reviewed literature on these potential risks is presented. This report deals primarily with unconventional natural gas development (UNGD), a term that intends to be inclusive of the social, environmental, economic, industrial, and historical processes related to subsurface tight gas extraction.

Literature Review of Community Responses in the Marcellus Shale Region

A literature review of the community responses in Pennsylvania highlights a locus of community-based organizing in the Marcellus Shale Region since the influx of UNGD in 2004.[1] Pennsylvania communities have chosen to oppose or self-regulate drilling activities through landowner coalitions and civil society watershed monitoring groups. Landowner coalitions are sitting down at the table with companies to strategically plan and negotiate, sign formal agreements, and ultimately ensure that they have a voice in what happens on their lands. Watershed monitoring groups fill knowledge gaps through citizen-organized surface and groundwater monitoring projects. Both strategies aim to address what citizens understand as inadequate regulation and transparency on part of government and oil and gas industries.

Active Grassroots Organizations Across Colorado

In Colorado, the potential of multiple, unknown, or contested risks related to oil and natural gas development has led to increases in community activism across the state. This report presents a descriptive content analysis of websites for 15 grassroots organizations responding to oil and gas development in Colorado. In addition, a list of national and state environmental organizations working in Colorado, regional community alliances, and grassroots organization websites are presented. The analysis focuses on grassroots organizations, or local groups of self-organized citizens active in their communities and concerned by the risks associated with hydraulic fracturing.

Colorado’s Front Range has experienced a relatively recent emergence of grassroots organizations dedicated to addressing the potential impacts of UNGD. Eleven out of 15 grassroots groups began publically questioning UNGD activities between 2008-2013, and these groups focus almost exclusively on oil and gas development. Eight of these 11 are located on the Front Range. Communities in southern Colorado began confronting development in the late 1980s, and Western Slope communities started organizing in the late 1990s. These longer-standing groups are more likely to have 501c3 non-profit status, paid employees, and a broader geographic reach than the more recently organized communities along the Front Range.

Across the state, grassroots organizations employ diverse strategies to have their voices heard: overt forms of protest, petitions to ban fracking in city limits, Health Impact Assessments (HIAs), citizen science and air quality assessments, outreach campaigns, and participation in town hall meetings. Groups organizing to protect public lands focus resources on increasing the quantity and quality of public comments on Resource Management Plans (RMPs) and make no mention of banning UNGD. Further examination of how grassroots organizations on the Front Range are positioning themselves with longer-established groups to form statewide coalitions is needed.

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[1] Throughout this report, the term ‘community responses’ is synonymous with strategies employed by local, self-organized citizens concerned by the risks associated with HF.

Background and Contexts

The emergence of UNGD in Colorado and Pennsylvania rests in a broad context of federal policies, tax supports and regulations, infrastructures, and the collaboration of both private and public entities that began in the early 1900s. Figure ES-1 outlines key federal policies and entities that worked to improve hydraulic fracturing (HF) technologies. Due in part to the success of this intentional federal energy nationalization agenda, citizens are now faced with deciding how they want to respond to the potential risks associated with UNGD.

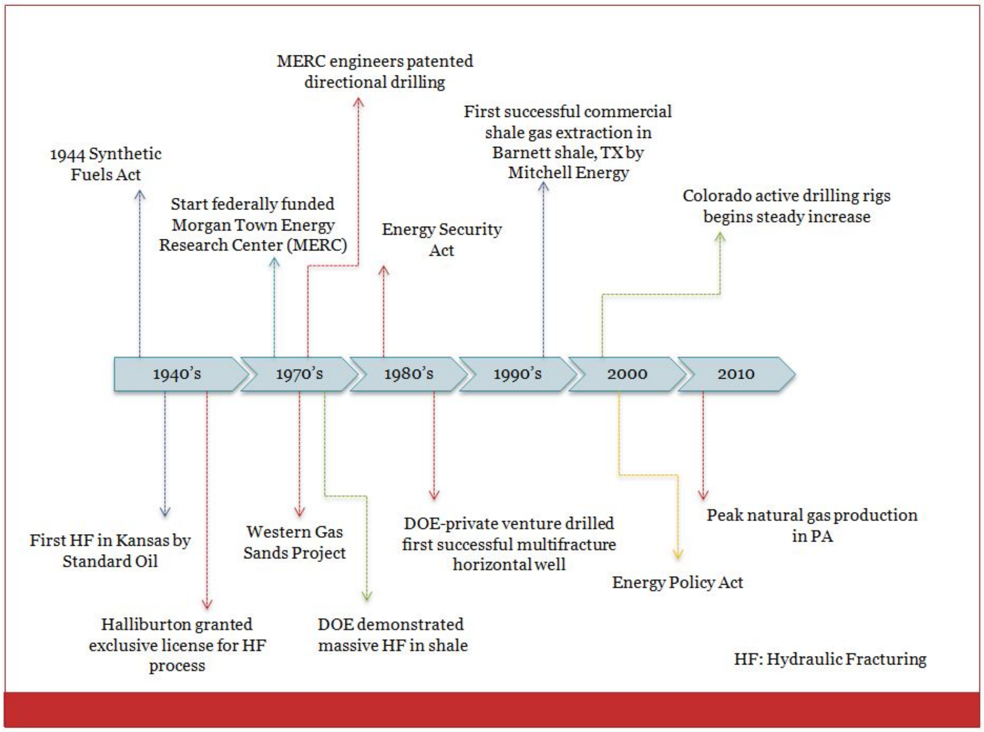

Figure ES-1. Historical timeline of federal policies, organizations, and partnerships relevant to advancing increased pace and scale of UNGD

Assessment of Peer-Reviewed Literature on Potential Risks of UNGD

Through an examination of the most recent peer-reviewed scholarly research and government reports, this paper additionally examines the socio-ecological risks confronted in Pennsylvania and Colorado, and to a lesser extent Wyoming and Texas, as part of developing energy at a large scale. Aspects of UNGD examined include:

- **Economic Opportunities and Challenges**: Input-Output models are an important tool for projecting economic impacts at multiple scales. However, much of the related literature critiques the assumptions on which input-output models are based, including the exclusion of environmental and social externalities, as well as temporal aspects of resource-dependent economies. Research argues that communities experience short-term economic benefits from increased jobs and public revenues, but that in the long-term, those same communities may experience more economic challenges than communities with no UNGD. The challenges are due to externalities of the extraction process that are unaccounted for (i.e., wear and tear on roads and water contamination) and the temporal aspects of boom-bust cycles that weaken other economic sectors such as agriculture and tourism.

- **Air Emissions**: Lifecycle Analyses (LCAs) of total greenhouse gas emissions, or Volatile Organic Compounds (VOCs), are compared between coal, conventional gas, and shale gas.
  - **Five** LCAs find that UNGD emits greater VOCs than conventional gas
  - **One** LCA finds that UNGD emits less VOC emissions than conventional gas
  - **Two** LCAs found that there is no difference between the two

  Multi-disciplinary contexts and inconsistencies in model parameters make any concise conclusions about the total emissions of UNGD compared with other fossil fuels extremely challenging, and this has led to debate and disagreement among scientists, governments, and industry.
  - 2012-2013 Regional HIAs show that UNGD has negative health and environmental effects for counties in Colorado. Table ES-1 identifies these studies, their primary findings, and locations of the most recent HIAs.

Table ES-1. Findings of regional air quality studies in Colorado

Study	Findings	Supporting Institution	Location
McKenzie et al. 2012	• Residents living less than a half mile from wells are at greater risk for health effects from UNGD than others • Higher cancer risks for residents living nearer to wells as compared to residents residing further from wells	Colorado School of Public Health	Garfield County
Colorado Department of Public Health and the Environment (CDPHE) 2012	• Concentrations of high risk carcinogenic chemicals within acceptable limits as defined by the EPA • Do not account for potential risks due to exposure from multiple chemicals at the same time	CDPHE commissioned by city of Erie	Erie
Petron et al. 2012	• Estimated VOCs from oil and gas have been highly underestimated • Oil and gas operations are a significant source of ozone precursors	NOAA	Weld County

- **Socio-Psychological Health Impacts**: Rapid social and economic change from energy development impacts daily lives and community dynamics. Traffic issues and road damage such as traffic noise, dust, and the increased volume of over-sized vehicles traveling dirt roads are the most constant source of stress and the most significant change for some rural Pennsylvania counties. There is a considerable gap in the peer-reviewed literature documenting community-based experiences with natural gas development in Colorado.

- **Water Use**: 20 studies highlight the probable linkages between contamination of ground and surface waters with HF activities in the Marcellus Shale Region. There is controversy and debate between university academics that find linkages between UNGD and contamination of water resources, and industry or hired consultancy firms who argue over the validity of those findings.

Conclusion

The combination of external (or non-local) decision-maker actions, potential social and environmental risks, and the visible infrastructure of industrial activities (such as tanks, trucks, and well heads) has fueled a statewide movement of local grassroots organizations. In some cases, newly radicalized citizens and already established environmental organizations have connected to build nationwide coalitions. Although they occupy different contexts, citizen groups in Colorado may learn from experiences in Pennsylvania's Marcellus Region, where community groups are working to hold the oil and gas operations accountable to local voices and concerns.

In some cases, landowners in Pennsylvania and Colorado receive substantial lease or royalty payments for owning minerals under their property. For example, in 2010, UNGD companies reported payouts totaling $2.07 billion in payments related to development of the Marcellus shale in Pennsylvania (Considine, Watson, and Blumsack 2011). While some landowners may find the economic benefits outweigh the potential risks, others are not interested in jeopardizing their health and the surrounding natural environment for royalty payments. Future research might explore: correlations between environmental inequalities, land, and mineral ownership patterns (Kelsey et al. 2012); political traditions that favor state government control over rules and regulations related to oil and gas development (Davis 2012); and the complications associated with land use policies such as split estate (Duffy 2005; Davis 2012). This would build on research showing that oil and gas development has historically taken place in economically depressed, rural regions where disadvantaged populations have meager avenues to participate in decision-making (Malin 2013).

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Introduction

Natural gas production is nationalizing U.S. energy resources at a rapid pace and increasing scale. Growth is aided by a history of investments in drilling technologies, projected contributions to economic growth, and the vision of U.S. energy independence. Natural gas has been hailed as a boon to the economy, with a forecast of 1.5 million jobs generated in the U.S. in connection with the natural gas industry by 2015, and more than 2.4 million jobs generated by 2035 (IHS 2012: v). Representatives across the political spectrum describe natural gas as a "bridge fuel" that will assist the U.S. transition from its dependence on foreign oil and coal to the use of renewable, cleaner energy sources (Considine et al. 2009). Shale contains an abundance of natural gas, and the Environmental Protection Agency (EPA) estimates that by 2020, shale gas will comprise more than 20% of the U.S. total gas supply (2010).

Colorado is known for having significant hydrocarbon resources, touting 10 of the nation's 100 largest natural gas fields and three of its 100 largest oil fields (EIA 2011). Colorado is the sixth largest producer in the nation (Figures 1 and 2), situating the state to have substantial influence on energy resources at a national scale. The combination of the pace and scale of development in Colorado is paralleled by organized citizen opposition from across the state, making Colorado an exceptional location to study the social aspects of oil and natural gas development.

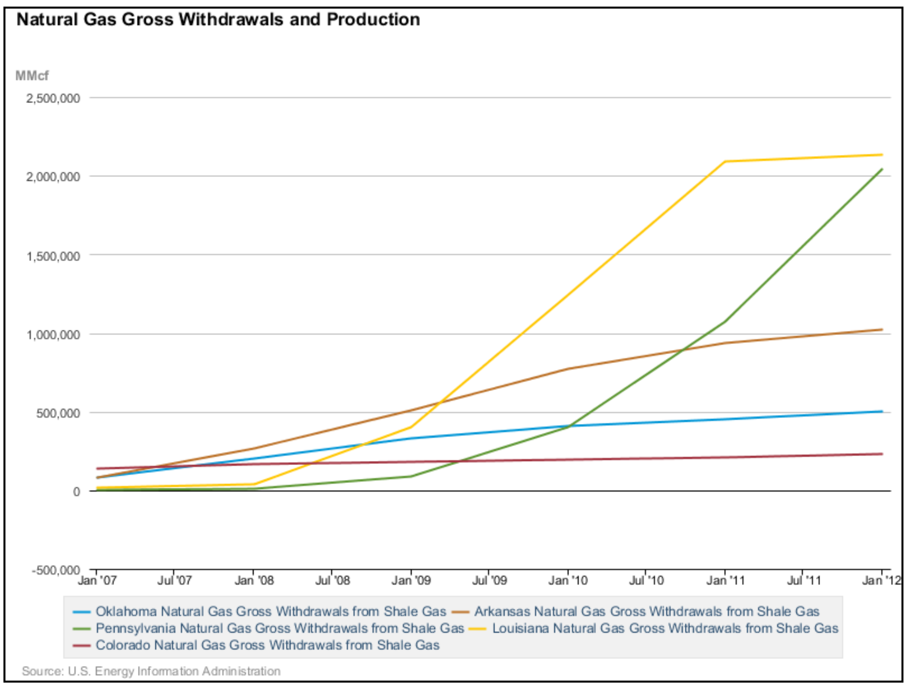
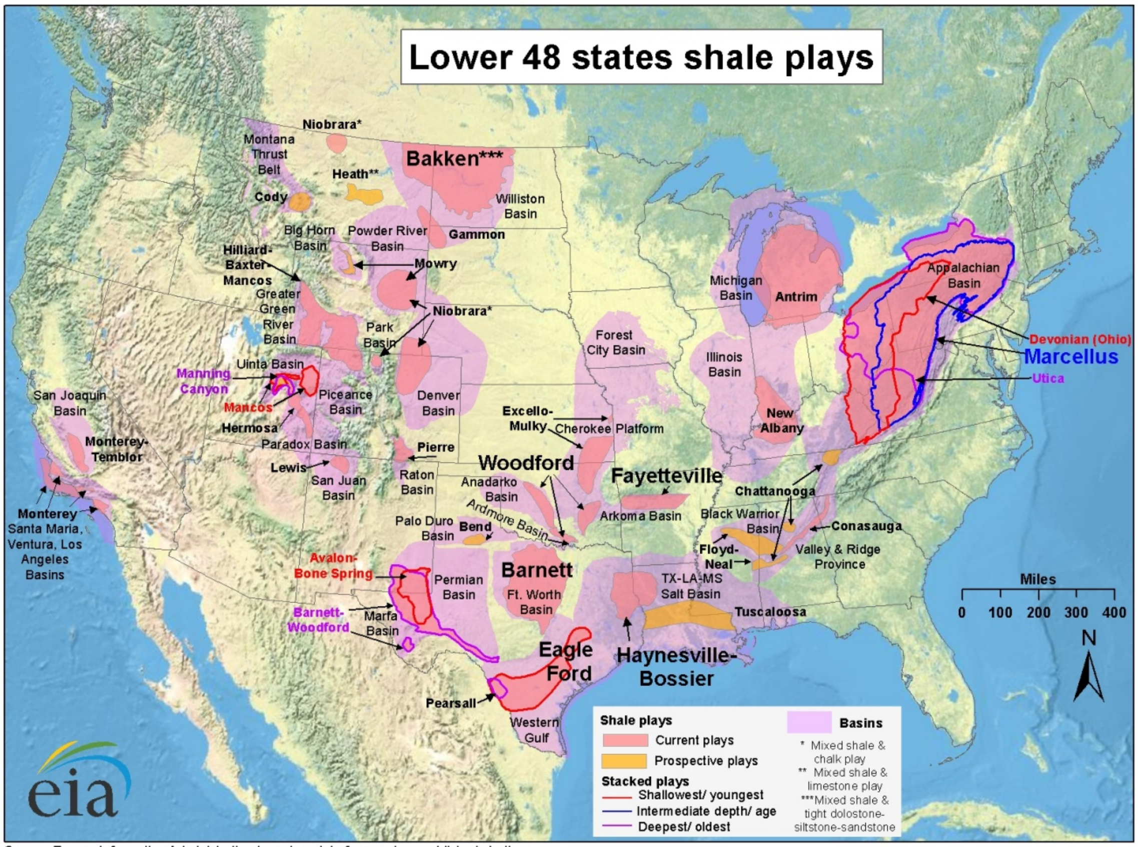


Figure 1. Natural gas gross withdrawals for the top five producing states excluding Texas from 2007-2012

The purpose of this report is twofold: to document community responses to oil and natural gas development in Colorado and Pennsylvania, and to compile peer-reviewed research that examines the associated socio-ecological risks. Given the broad nature of this report, it is not presented within an explicit theoretical framework. However, to holistically understand citizen responses to oil and gas development, there is a need to recognize the social and environmental contexts within which they are operating and to situate community activist responses within this context. The majority of academic literature that populates natural gas development contexts originates from the Marcellus Shale Region, an area spanning more than 100,000 square miles from New York to Tennessee with the majority of drilling occurring in Pennsylvania and West Virginia. The bulk of peer-reviewed science focused on this region entails studies carried out in Pennsylvania; meanwhile, there is relatively little research available from Colorado.



Source: Energy Information Administration based on data from various published studies.
Updated: May 9, 2011

Figure 2. Shale plays in the lower 48 U.S. states

This report begins by examining oil and gas recovery methods including horizontal drilling and the hydraulic fracturing (HF) processes that have revolutionized energy development in the U.S. This is followed by definitions of the language used in the public arena such as “fracking,” unconventional gas, and conventional gas. There are substantial differences in these diverse production processes and their generated social and ecological risks. This report deals primarily with unconventional natural gas development (UNGD), a term that intends to be inclusive of the social, environmental, economic, industrial, and historical processes related to subsurface tight gas extraction.

Next, a review of community responses is presented, beginning with a description of the Marcellus Shale Region, a locus of community-based organizing since the influx of natural gas development in 2004. Some Pennsylvanian citizens have chosen to oppose or self-regulate drilling activities through landowner coalitions and civil society watershed monitoring groups. These community responses aim to address what they understand as inadequate regulation and transparency on behalf of government and oil and gas industries. This segues into the current activist activities in Colorado. A content analysis of community group websites that demonstrate opposition to fracking activities is presented within the governance contexts of Colorado.

This is followed by a historic overview of energy extraction in Colorado, a state endowed with and challenged by its array of energy resources such as coal, gas, and oil. History shows that subsurface energy extraction has contributed to economic prosperity followed by economic retractions, also known as the boom-bust cycle. The federal government's research centers (i.e., Morgantown Energy Research Center) and energy legislation (such as the 1980 Energy Security Act) have promoted national energy agendas through investments and partnerships with private companies. The report then traces the history of HF technology and links it to the federal energy legislation that has planted the seeds for the success of contemporary shale oil and gas development. Although not addressed in depth due the scope of this report, fuel for war efforts and national security agendas are at the core of increased national energy extraction (Mershon and Palucka 2012; Scamehorn 2002). Most recently, the drive to decrease dependence on an unpredictable Middle East further warrants an increase in U.S energy production.

Through a review of the most recent peer-reviewed scholarly research and government reports, this paper additionally examines the socio-ecological risks confronted in Pennsylvania and Colorado, and to a lesser extent Wyoming and Texas, as part of developing energy on a large scale. This section begins with a review of economic benefits and challenges of UNGD. Input-Output models are an important tool for projecting economic impacts at multiple scales. However, much of the literature related to such models critiques the assumptions on which input-output models are based, including exclusion of environmental and social externalities as well as temporal aspects of resource-dependent economies.

This is followed by a discussion of Lifecycle Analyses (LCAs), the preferred methodological tool for scientists measuring air emissions. LCAs have the utility of not only documenting the full time scale of natural gas emissions, but also providing policy-makers with a standard format for energy portfolio decision-making. A review of the research on socio-psychological health concerns and air emissions is provided. In addition to the full lifecycle studies, regional Health Impact Assessments (HIAs) have been carried out to measure the risk of air emissions near the site of extraction and the potential harm caused to nearby communities. The HIAs were carried out both on the Front Range and the Western Slope of Colorado. These quantitative-based studies are followed by a qualitative analysis of the everyday socio-psychological health impacts that accompany rapid environmental changes and industrialization of the rural countryside with UNGD. Residents recount their experiences with a changing social, environmental and political landscape. There is a significant gap in the peer-reviewed literature documenting community-based experiences with natural gas development in Colorado.

In addition, this report reviews 20 studies that highlight the probable linkages between contamination of ground and surface waters with hydraulic fracturing activities. There is controversy and debate between university academics, industry and hired consultancy firms over the validity of these linkages. One of these debates is examined, followed by a discussion of the contradictory and complicated contexts within which citizens and policy-makers must take action.

Description of Hydraulic Fracturing and Horizontal Drilling

New directional drilling techniques have made the process of hydraulic fracturing (HF) more economically viable. Conventional oil and gas wells are drilled at a perpendicular angle to the ground from the surface and are called vertical wells. Improved drilling technologies called horizontal or directional wells are drilled with a horizontal reach and can produce five to twenty times more gas than a vertical well (Hyne 2012) when combined with HF. Horizontal drilling reduces surface impact commonly associated with vertical wells drilled from multiple well pads since several horizontal wells can be drilled from a single well pad (Figure 3).

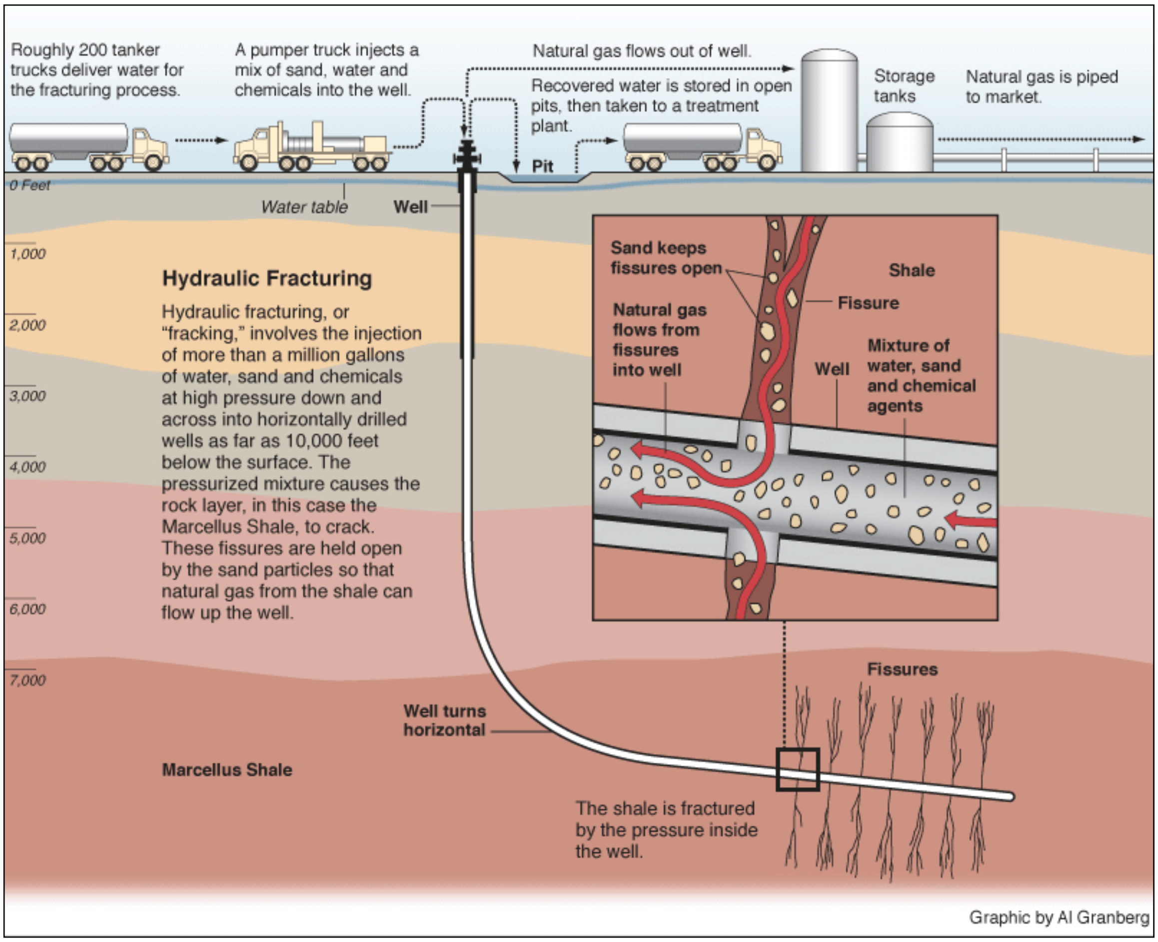


Figure 3. Description of hydraulic fracturing process
Source: http://www.propublica.org

Once the horizontal well is drilled as far as 10,000 feet into the subsurface, hydraulic fracturing injects a mixture of water, sand, and a combination of different chemicals into a targeted natural gas-bearing formation. Injection pressures are high enough to cause the rock within the targeted formation to fracture (API 2009;USHR 2011). The sand acts as a proppant so that when pumping is stopped and the excess pressure is removed, the proppant aids in allowing fluids to flow through the fracture. HF is one step in the unconventional natural gas development process.[2]

[2] For more information on the technical process please see: American Petroleum Institute. (2009). *Hydraulic Fracturing Operations — Well*

Horizontal drilling and HF technologies when applied to tight gas[3], shale, and coalbed methane (CBM) are synonymous with UNGD. While the term 'hydraulic fracturing' references a very specific part of the UNGD process, UNGD is a term that can be applied to all the associated aspects of drilling from exploration to end use as energy, and including the associated social and environmental impacts. Unconventional is differentiated from conventional gas production where gas is extracted from permeable reservoirs entailing differing levels of effort, resource use, and generated waste (Skone 2011). There are three main differences highlighted by Skone: 1) conventional wells are not clustered on multi-well pads, so there are likely to be differences in the number and distribution of wells per unit gas produced, 2) conventional wells are differentiated by vertical drilling techniques that require more preparation and stimulation, and 3) conventional natural gas can be co-extracted with crude oil, and this product is called *associated natural gas* (2011). Since the natural gas is co-produced with petroleum, the use of oil/gas separators is necessary to recover natural gas from the mixed product stream. Approximately seven percent (1.4 trillion cubic feet, or 1.4 TCF) of U.S. natural gas production is from conventional onshore oil wells (EIA 2011a).

Operators are increasingly extracting from tight gas and shale formations utilizing hydraulic fracturing and horizontal drilling technologies. These technologies have made natural gas more economically viable by increasing the pace and scale of extraction. At the same time, the potential associated environmental and socio-psychological risks (see p.22) have spurred citizens to question the long-term benefits of such technologies.

Overview of Community Responses to Increased Pace and Scale of Energy Extraction in Pennsylvania and Colorado

The potential for multiple, unknown, or contested risks to communities in proximity to UNGD has led to increases in community activism throughout Colorado. Daily news stories report on citizens organizing for moratoriums, bans, and ballot initiatives across Colorado's Front Range (Zaffos 2013), protesting in the streets of Boulder (Rubino 2012), and city councils passing strict rules and prohibiting residential drilling in Longmont (Marcus 2013). Citizen groups in Delta, Huerfano, and Garfield counties have sued oil and gas companies, participated in public lands Resource Management Plans, and been protesting what they view as insufficient industry regulation since the late '90s. Peer-reviewed studies of community response strategies, perceptions, and experiences in Colorado are few. However, there have been several studies from the Marcellus Shale Region in Pennsylvania where useful insights can be gleaned.

While Colorado residents, politicians, and industries can learn from experiences in other states, it is important to remember that not only are state and local policies, attitudes, rules, and regulations location-specific, but also that different physical geologic formations exist (Nelson 2011). Real and perceived risks from UNGD including distribution of benefits, industry transparency, socio-

Construction and Integrity Guidelines. API Guidance Document HF1 First Edition. Washington, DC.

[3] Tight gas – Gas extracted from low-porosity or low-permeability sandstones and carbonate reservoirs

psychological disruptions, and trust influence the types, goals, agency, and structures of community-based efforts. While we can learn and build on the research and community experiences from the Marcellus Shale Region, it will be imperative to value the complexities of local socio-ecological contexts in Colorado's regional shale gas plays.[4]

Description of Marcellus Shale Region

The Marcellus play is the largest shale gas formation in the U.S. and the second largest play in the world with estimates of 489 trillion feet of gas (Considine et al 2009). In geologic terms, a reservoir of more than 30 trillion cubic feet is classified as a "supergiant" (Wilber 2012). Located in the northern region of the Appalachian Basin, the Marcellus play spans more than 100,000 square miles from New York to Tennessee, with the majority of drilling occurring in New York, Pennsylvania, Ohio, and West Virginia (EIA 2012). New York and Pennsylvania's portion of the Marcellus play is of particular interest due to its proximity to key markets in the northeastern U.S. and the expansion of the region's Millennium Pipeline, which will facilitate continued profitable distribution of natural gas to consumers. In the economically depressed times of 2008, the state underwent a 'Gas Rush' where the pace and scale of drilling increased as companies drilled hundreds of wells in Dimock Township, PA (Wilson 2012). Concurrently, residents started to complain about drinking water contamination, noise from truck traffic and other industrial equipment, and unexplained illnesses considered to be associated with drilling activities (Wilson 2012). A review of literature on community-level activities in response to these risks from the impacted states of Pennsylvania, and to a lesser extent New York, is presented below.

Community Voices: Watershed Monitoring Groups in Pennsylvania

In the Marcellus, community watershed monitoring groups are a predominant form of community response promoting citizen oversight and industry accountability in oil and gas development activities. Watershed monitoring groups are organized volunteers that, in most cases, gather water samples from rivers and streams to test for indicators associated with the signatures of chemicals used in the fracking process (Jalbert, Kinchy and Perry 2013). Reports of surface spills, dumping of inadequately treated wastewater from HF, and subsurface methane migration have communities worried about their water quality. Group participants place a high importance on protecting their watershed's biodiversity and preventing pollution. Pennsylvania has approximately 500 community watershed groups (Lee 2005). A recent study found that currently 24 organizations in NY and PA are monitoring the effects of shale gas development by gathering baseline data in anticipation of development (Kinchy et al. 2013).

Monitoring groups are organizing to fill knowledge gaps through citizen-organized surface and groundwater monitoring projects (Pennigrowth et al. 2013; Stedman et al. 2009; Kinchy and Perry 2011). A common theme among volunteer groups is the general distrust of private and governmental regulators to produce valid, unbiased water quality data. Groups may be initiated by activists or grassroots community organizations that receive support from scientific experts such as universities and/or training from capacity-building groups; and they may be funded by public entities such as state or federal agencies or receive private foundation funding. In any case, the

[4] 'Shale gas play' is used in the oil and gas industry to refer to a geographic area above a shale layer that has been targeted for exploration and development of natural gas. An area comes into play when it is recognized that there is significant economic quantities of gas to be developed.

emergence of watershed monitoring groups focusing on HF risks in the Marcellus addresses apparent knowledge gaps and public needs in a way that some may consider more legitimate and credible than agency or industry reporting.

Studies examine how such water-focused grassroots organizations use accessible technology and participatory democratic processes to affect public policy (Stedman et al. 2009; Jalbert 2011; Pennigrowth et al. 2013; Liss 2011). For example, Jalbert (2011) draws attention to "Culturally Situated Sensing," a method of collaboratively designing water monitoring instruments with input directly from citizen users. This is seen as a democratic and participatory design method to integrate contextually appropriate user needs by allowing technologies to vary with the user's diverse technical expertise, available resources, and local conditions. In this way, watershed monitoring projects become more useful to non-scientists and conducive to scaling up. These studies are less interested in the monitoring data and more concerned with questions of the how, what, where, when, and who of HF impacts to water resources.

Pennigrowth et al. report on a nonprofit, the Community Science Institute (CSI), that partners with community volunteers to perform regular sampling of more than 50 streams in the Marcellus and Utica Shale regions of upstate New York (2013). These samples are sent to a lab for testing, and water quality data is placed on a public database. CSI houses this database as a tool for community-based risk assessment. In this way, stakeholders empower themselves to understand local water resources and educate themselves on how to manage water resources sustainably. Importantly for other initiatives, Pennigrowth et al. highlight key elements of successful CSI-volunteer partnerships (159). What this article does not address is the question of validity of scientific findings gathered by citizen scientists. It also does not examine if and how community-based watershed monitoring initiatives have tangible impacts on industry management practices or with state and local policy-makers.

This gap is addressed by Kinchy and Perry through an analysis of the effectiveness of volunteer data collection models (2011). How will the data collected by volunteers be used by industry or regulators? The authors' thorough critique of watershed monitoring groups points out that the Pennsylvania Department of Environmental Protection (PA DEP) would not use the data for enforcement purposes. The DEP cites lack of resources to incorporate citizen gathered data, yet formally encourages citizens to participate in volunteer monitoring programs. Potential impacts of such activities on industry behaviors are also ambiguous, but the authors suggest that initiatives will have a deterrent effect on companies if the following conditions are met: "(1) volunteer observations are widely considered to be strong and credible evidence that particular industry actors have caused pollution, and (2) there are strong and enforceable penalties for causing pollution" (2011:335). Indeed, the shift of regulation responsibilities to citizens may have the reverse effect of letting governmental agencies "off the hook" while volunteer efforts have no tangible contract with the state to ensure data is used toward policy change.

Stedman et al. analyzes whether community-based environmental management in general improves both community well-being and the environment. Their study finds that watershed organizations are effective means for "building local leadership, enhancing the skills of rural residents, and making valuable connections with other communities facing similar water-resource and rural-development issues" (Stedman et al. 2009). Important for future research in this vein is whether community-based environmental management improves healthy ecosystems alongside these indicators of community well-being (Stedman et al. 2009) in Colorado. In addition, future research may examine the nature of land and mineral property ownership and its relationship to the dynamics of the watershed monitoring groups.

Landowner Coalitions in the Marcellus Shale Region

Landowner coalitions in the Marcellus Shale Region are grassroots organizations formed to collectively bargain with natural gas companies in order to influence environmental, economic, and community impacts of UNGD (Jacquet and Stedman 2011). These community responses, like the watershed monitoring projects, are motivated in part by a lack of trust for and transparency from oil and gas companies (Liss 2011). Steeped in past experiences, most community members participating in community-based organizations do not have confidence that experts, who are potentially funded by industry or government, and regulatory agencies will anticipate all possible risks from this new technology (Kinchy and Perry 2011). One group of landowners in northeastern Pennsylvania employed a collective bargaining style of negotiation and ultimately built trust and confidence with a natural gas company, effectively leveling the information playing field, increasing their economic benefits and ensuring adequate protection of their environment (Liss 2011). Landowner coalitions are sitting down at the table with companies to strategically plan, sign formal agreements, and ultimately ensure that they have a voice in what happens on their lands.

Focus on Colorado: Community Voices and Academic Research Agendas

Oil and gas related civic engagement is taking shape across Colorado. The increased pace and scale of UNGD has caught citizens and policy makers alike scrambling to make informed decisions that address community concerns and simultaneously provide sustainable access to energy and ecosystem services. Cities along the Front Range, such as Lafayette, Fort Collins, Broomfield, and Boulder, developed local ordinances and memorandums with the aim of mitigating potentially harmful air and water quality risks (Appendix I). Cities like Longmont, Broomfield, and Fort Collins have banned fracking within city limits and now face a lawsuit from the state. Local community groups perceive that city governments are not doing enough to address the potential health and environmental impacts related to UNGD, exacerbating tensions between the state, local governments, and citizens. The content analysis of community-based groups presented below demonstrates that along the Front Range, Western Slope, and in southern Colorado there is an increase in the number of community groups disenchanted with local and state governments responses. Eleven of the 15 grassroots, citizen-initiated groups highlighted in the analysis have organized within the last five years and focus almost exclusively on risks associated with oil and gas development.

Despite the numerous grassroots organizations forming across Colorado—from Citizens for a Healthy Fort Collins in the north to Citizens for Huerfano County in the south—there has been only one published study to date that documents a case in Delta County, Colorado where residents organized in response to proposed lease sales on BLM lands (Carre 2012). Carre's research shows how grassroots mobilization, efficient use of technology, and proactive mechanisms can affect public policy. After BLM notified Delta County of a pending natural gas lease sale encompassing 30,720 acres, community members responded by asking BLM for public hearings, an environmental impact study (EIS), and a moratorium on drilling until a study was completed. Carre documents the legal processes harnessed by communities to protect what they view as a threat to their health and lifestyle through a complex institutional arrangement between state and federal agencies, elected officials, and community members. While this is the only peer-reviewed research on community responses in Colorado, other natural gas-related research agendas are taking shape across the state.

A statewide National Science Foundation-funded network of researchers is currently examining the effects of natural gas development on water and air resources by analyzing tradeoffs between local, regional, and national costs and benefits in environmental, social, and economic domains (http://airwatergas.org). The team is comprised of five researchers from the University of Colorado-Boulder and 22 researchers from research institutions throughout the state including Colorado School of the Mines, National Oceanic and Atmospheric Administration, Colorado School of Public Health, the National Renewable Energy Laboratory, Colorado State University, and out-of-state researchers from Cal Poly and University of Michigan. In the second year of a five-year project, the network is employing a social-ecological systems approach to integrate both quantitative and qualitative assessment of the health risks, both chemical and non-chemical, associated with water and air exposure from natural gas development. The project aims to have broader impacts through education and outreach activities including: dissemination of best management practices in collaboration with stakeholders, communication about scientists and scientific activity for a broad public, and collaboration with Indian tribes and other under-represented groups disproportionately affected by natural gas development.[5]

Civil and Environmental Engineering professor Ken Carlson from Colorado State University and former Colorado Governor Bill Ritter are leading a project on water quality impacts of natural gas development along the Front Range of Colorado. They've partnered with Colorado Department of Natural Resources, the Colorado Oil and Gas Conservation Commission, the EPA, Western Resource Advocates, and Noble Energy to establish a regional monitoring network that would provide real-time measurement of water quality in dense oil and gas development areas. The project will use GIS technology and an accessible user interface to provide real-time data to the public (Ritter and Carlson 2013). This research is, in part, a response to citizen activism questioning the potential risks associated with increased pace and scale of UNGD in Colorado.

Where We Are Now: Active Community Groups in Colorado

Across Colorado from urban centers to rural mountain towns and the eastern plains, concerned citizens are organizing their communities to hold industry and governments accountable (Table 1). The groups are diverse geographically, politically, and strategically: some aim to ban fracking completely, others pass moratoriums, and others call for regulated and responsible industry practices. This section discusses findings from a descriptive content analysis of 30 national and state environmental organizations, regional community alliances, and grassroots organizations responding to oil and gas development in Colorado. Along Colorado's Front Range there has been a relatively recent emergence of grassroots organizations, or local groups of self-organized citizens active in their communities, concerned by the risks associated with HF. Organized

[5] For more information see their website: http://airwatergas.org

communities in the south and along the Western Slope began confronting oil and gas development in the late 1980s with an increase in grassroots organizations seen in the late 1990s. Despite differences in geography and inception, all have in common a concern with the risks of oil and natural gas development in their communities.

Content analyses of organizations' websites show different levels of involvement from grassroots to state and national scales. The grassroots groups along the Front Range are focused on working within their city limits. They have names such as: community alliance, citizen alliance, and community council. Some names clearly communicate their goals against fracking: 'Don't Frack Broomfield' and 'No Fracking in Colorado Springs'. Instead of focusing on a single resource, most grassroots groups are interested in an integrated approach that focuses on multiple resources: air quality, water quantity and quality, rivers, and drinking water. Grassroots groups use Facebook as an organizing and outreach tool and network with umbrella organizations at the state and national level (see "Scale of Operation" in Table 1). The grassroots organizations along the Front Range are not formal, legal organizations like some in southern Colorado and on the Western Slope. The groups in southern Colorado are more likely to have some of the following characteristics: legal status (501c3); capacity to work with policy makers; activities reach a larger number of stakeholders and/or broader geographic area; and more than one paid staff member. The southern Colorado groups with these characteristics include: Citizens for a Healthy Community, Huerfanos Against Fracking, Save the Thompson Divide Coalition, Community Alliance of the Yampa Valley, and Grand Valley Citizen Alliance.

The Community Alliance of the Yampa Valley and the Grand Valley Citizen Alliance work with Western Colorado Congress (WCC), an umbrella organization of five grassroots groups on the Western Slope. Four of these grassroots organizations are working on oil and gas issues and are part of the community group database and content analysis. WCC facilitates trainings and leadership development as part of their mission to organize people "to increase their power over decisions that affect their lives. WCC's community groups and members work together to create healthy, sustainable communities, social and economic justice, environmental stewardship and a truly democratic society" (http://wccongress.org/wcc/). Their programs include food systems, public land conservation, uranium mining, and a focus on oil and gas issues. Based on their website, they prioritize working to improve regulations for oil and gas operations. For example, WCC supports the following regulations: increased setback distances, longer public comment periods, protection of local government power to regulate industry, and comprehensive investigation of public health impacts before drilling. WCC makes no mention of moratoriums or bans. Within the four affiliated groups, two of them (Grand Valley Citizen's Alliance and Community Alliance of the Yampa Valley) are the longest-standing, established in 1997 and 1999, respectively. The Grand Valley Citizen's Alliance organized specifically to address the increasing scale of fossil fuel extraction in their communities, and may have useful insights from almost 20 years of experience to share with community groups along the Front Range.

Table 1. List of organizations responding to oil and gas development in Colorado. Groups are identified by scale of operation and geographic region.

Name	Website	Scale of Operation	Geographic Region
Clean Water Action Colorado	http://www.cleanwateraction.org/co	State and National	-
Colorado Conservation	http://www.coloradoconservationvoters.org	State	-
Sierra Club Rocky Mountain Chapter	http://rmc.sierraclub.org+B33	Regional	-
Save Colorado from Fracking	http://savecoloradofromfracking.org	State	-
Rocky Mountain Clean Air Action	http://rmcleanair.blogspot.com	State; Regional	-
Western Resource Advocates	www.westernresourceadvocates.org	Mountain West	-
WildEarth Guardians	http://www.wildearthguardians.org/site/PageServer	National	-
Earth Works	http://www.earthworksaction.org/issues/detail/peoples_oil_gas_summit_2010#.UYpuBbW7J-k	International	-
Park Rangers for Our Land	http://parkrangers.org/uncategorized/rangers-band-together-to-protect-national-parks-from-oil-and-gas-drilling	National	-
Earth Guardians	http://www.earthguardians.org	National	-
Mothers for Sustainable Energy	www.mothersforsustainableenergy.com	National	-
Western Organization of Resource Councils (WORC)	http://www.worc.org	National	-
Protect Our Colorado	http://www.protectourcolorado.org	State	-
Environment Colorado	http://www.environmentcolorado.org	State	-
Western Colorado Congress	http://wccongress.org/wcc	Regional	Western Slope
Citizens for a Healthy Community	www.citizensforahealthycommunity.org/	County	Western Slope
Longmont ROAR	http://longmontroar.org	Regional	Front Range
Erie Rising	http://www.erierising.com	Regional	Front Range
Huerfanos Against Fracking	http://www.huerfanofrack.com	County	South
Greeley Communities United	n/a	Local	Front Range
Citizens for a Healthy Fort Collins	http://www.healthyfoco.com	Local	Front Range
Save Thompson Divide Coalition	http://savethompsondivide.org	Regional	Western Slope

Name	Website	Scale of Operation	Geographic Region
Don't Frack Broomfield	http://ourbroomfield.org	County	Front Range
San Juan Citizen Alliance	http://www.sanjuancitizens.org/	Regional	Southwest
No Fracking in Colorado Springs	https://www.facebook.com/NoFrackingInElPasoCountyColorado	County	Front Range
Community Alliance of the Yampa Valley	http://cayv.org/index.html	Regional	Northwest
Grand Valley Citizen's Alliance	www.grandvalleycitizensalliance.org	County	Western Slope
Ridgeway-Ouray Community Council	http://www.roccnet.org	Regional	Western Slope
WCC of Mesa County	http://www.mesacountycoloradowcc.org	County	Western Slope
Protect Our Loveland	http://protectourloveland.com	City	Front Range
East Boulder County United	http://www.eastbocounited.org	City	Front Range
Boulder County Citizens for Community Rights	http://bococcr.org	County	Front Range

Interestingly, many of the grassroots groups highlighted in this study organized in direct response to oil and gas operations. Eleven of the 15 grassroots groups recently began activities, from 2008-2013, and are focused almost exclusively on oil and gas development. Eight of the 11 are located on the Front Range. Grand Valley Citizen Alliance in Garfield County organized 19 years ago to address concerns with the quantity and spacing of wells (unclear if this is natural gas or shale oil). The San Juan Citizen Alliance in Durango started on oil and gas issues in 1989 when they worked to mitigate surface impacts from coal bed methane development.

Of interest is the diversity of activities groups employ to have their voices heard: overt forms of protest, petitions to ban fracking in city limits, Health Impact Assessments (HIAs), citizen science and air quality, and participation in town hall meetings. Groups organizing to protect public lands focus resources on increasing the quantity and quality of public comments on Resource Management Plans (RMPs). Further examination is needed of how younger grassroots groups are positioning themselves with longer-established groups and forming statewide coalitions as they gain time and experience within their respective community initiatives.

Positions on fracking are complex and vary across groups. An example from the Erie Rising website states:

> "We believe the onus lies squarely with the gas companies and our elected officials to prove that natural gas drilling and mining by fracturing is safe and does not pose a real or imminent threat to our children, our health or our environment. We are seeking scientific studies and other information to prove we are not at risk from this activity. We pledge that, in the absence of that proof, we will take action to keep it

> out of our community and away from our schools until such proof is available" (Erie Rising 2013).

This statement exemplifies some underlying congruencies in the grassroots activism taking shape across the Front Range. Citizens have a general lack of trust toward regulators, governments, and companies associated with UNGD. At the same time that companies and engineering consulting firms claim there is no evidence of groundwater contamination linked to HF (Flewelling et al. 2013), reports document toxic levels of Benzene emanating from a gas plant in Parachute, Colorado (Finley 2013), and unregulated discharge of toxic waste into the South Platte River from overturned storage tanks during severe floods in 2013 (Pearce 2013). On their websites, citizen groups on the Front Range include less language referring to land preservation and environmental conservation and instead highlight environmental safety related to health of families. Community groups would rather see companies make use of the precautionary principal (that is, in absence of scientific consensus that fracking is not harmful, the burden of proof of no harm falls on the companies carrying out fracking activities) to prevent potentially harmful externalities, and will continue to actively struggle against UNGD until such proof is provided (Erie 2013). A bigger question looms in the background: Is it possible to bring community groups, industry, and governments together in order to facilitate socially, economically, and ecologically sustainable development of energy resources in a way that addresses the potential risks and externalities communities experience? More operationally, what are the social, economic, and environmental indicators required to answer this question? Considering research agendas at CU-Boulder, CSU, and the community initiated HIAs, there is evidence that such indicators are receiving attention. The challenge is to bridge these indicators with the experience of impacted communities. The arena is wide open for collaboration between sectors/stakeholders to address differing values and expectations for responsible energy development.

This descriptive overview of community groups has not addressed important questions concerning race, gender, and socio-economic status of stakeholders. This would include all those involved, from the industry workers and impacted community members to state regulators and company executives. What are the hidden power dynamics at play and how can they be balanced, or should they be balanced? What are the demographics of the citizens participating in these groups? What past experiences have influenced their participation in organized resistance? To learn more about 'where we are now' and possible trajectories for more sustainable national energy development, an on-the-ground research agenda will be a necessary next step. Working in that direction, Figure 4 shows community responses to oil and gas development in Colorado in relation to the percentage of the county-level workforce employed by the industry.

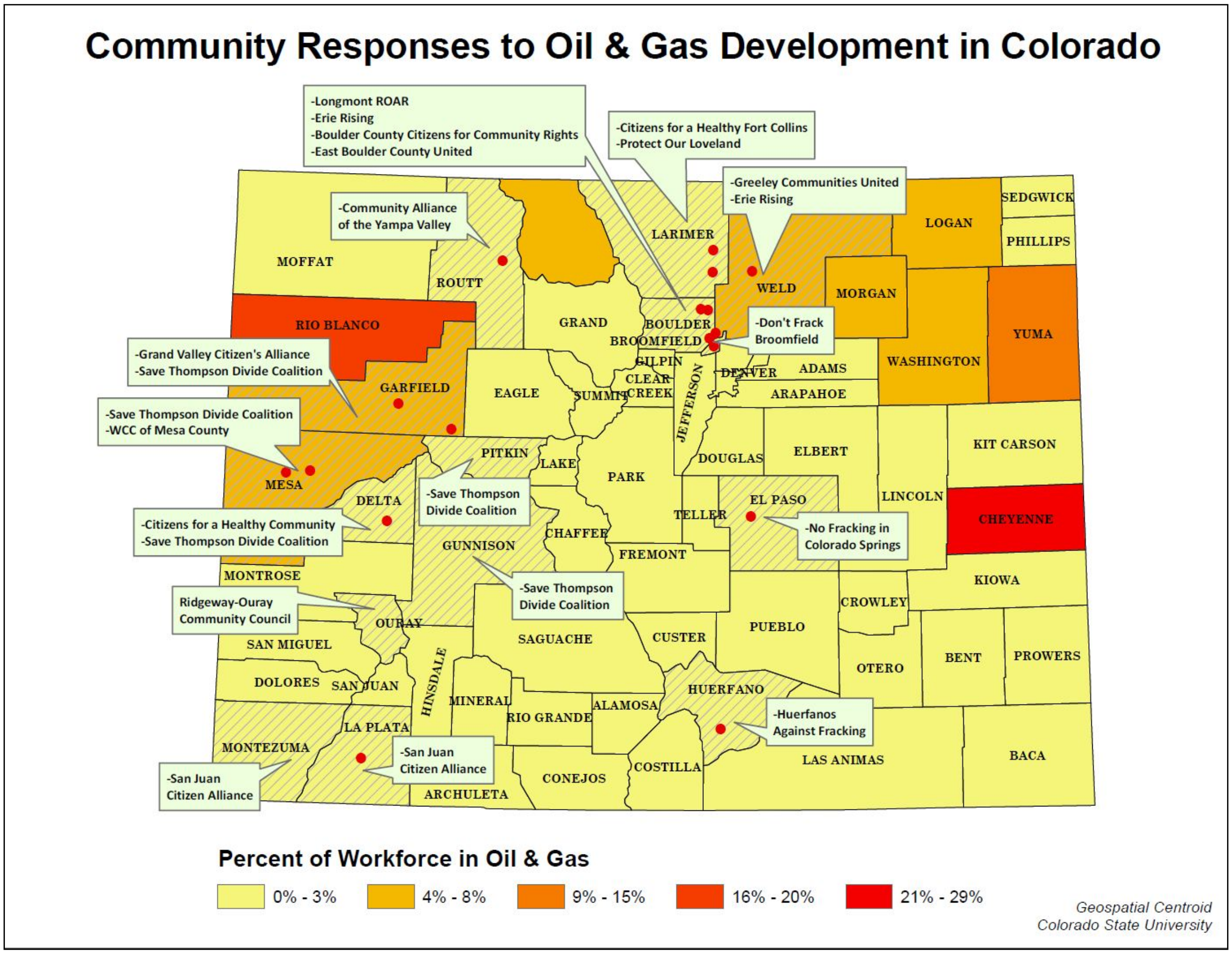


Figure 4. Colorado counties colored by percent of workforce in oil and gas. Grassroots groups labeled are present in 15 counties across the state as markated with the red dots.

Logan, Washington, Morgan, Yuma, and Cheyenne counties have high percentages of the workforce in oil and gas with no organized community responses. In contrast, on the Western Slope in Mesa, Garfield, and Rio Blanco counties, there is a high percentage of the workforce in the industry as well as multiple organized community groups. What might explain these differences, and why are they important? This intersection of socio-economic factors, grassroots organizing, and environmental impact will be integral to finding viable policy solutions to oil and gas conflicts. In the following sections, the broader context within which communities operate is examined. The report reviews Colorado's history with hydrocarbon resource extraction, the federal government's energy nationalization agenda, other contemporary governance mechanisms, economic benefits and challenges, and air and water-related risks of UNGD.

Brief Overview of Energy Extraction in Colorado: What's New With UNGD?

The history of fossil fuels extraction in Colorado sheds light on the overall context within which local communities are responding. While UNGD has only become significant in Colorado over the last decade, the state has a legacy of coal and oil extraction. Dating back to the late 1800s and throughout the early 1900s, coal fields have been located and extracted in 30 Colorado counties (Scamehorn 2002). In northern Colorado, the two principal fields were the Boulder-Weld and Colorado Springs. In the south, Las Animas and Huerfano counties were home to lucrative coal fields. Counties that are home to contemporary natural gas extraction were historically on the fore of coal production in the late 1800s to the early 1900s. Geographically, large coal fields outline the Rocky Mountains from the east and west. Oil and gas deposits are sprinkled along the Front Range as well as the Western Slope in the Piceance Basin and the San Juan Basin located in southwest corner of the state (Figure 6). Coal remains the second most consumed energy source in Colorado following natural gas (Figure 5) (EIA 2011a).

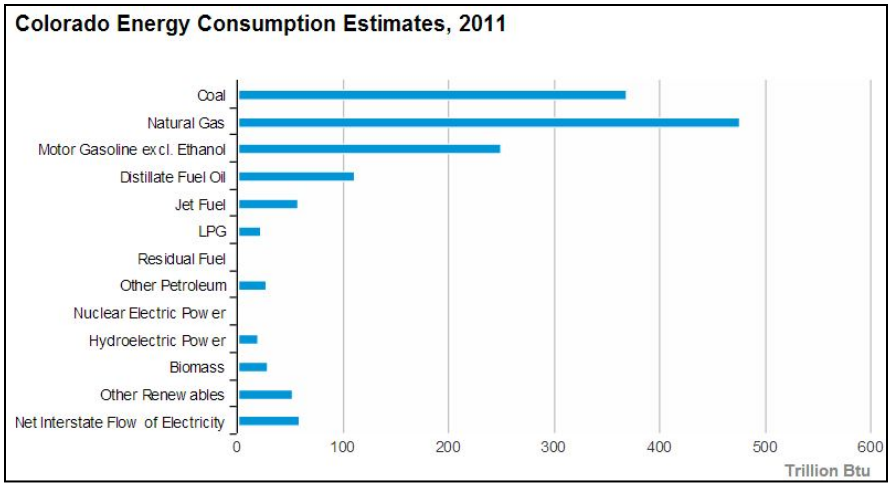


Figure 5. Colorado energy consumption estimates
Source: Energy Information Administration, State Energy Data System

The interest in the development of native fossil fuels has been historically and contemporarily framed within concerns over national security. Beginning with the Civil War, each new war brought renewed interest in excavation of oil in the name of national defense (Victor and Hayes 2006; Hanson and Limerick 2009). For example, fueling ships and war planes during World War I and II prompted presidents to set aside naval petroleum and oil shale reserves in Colorado and Utah to ensure a secure oil supply (Hanson and Limerick 2009). These reserves were the baseline of federal encouragement of research and policies supporting the national development of fossil fuels (discussed in the next section).

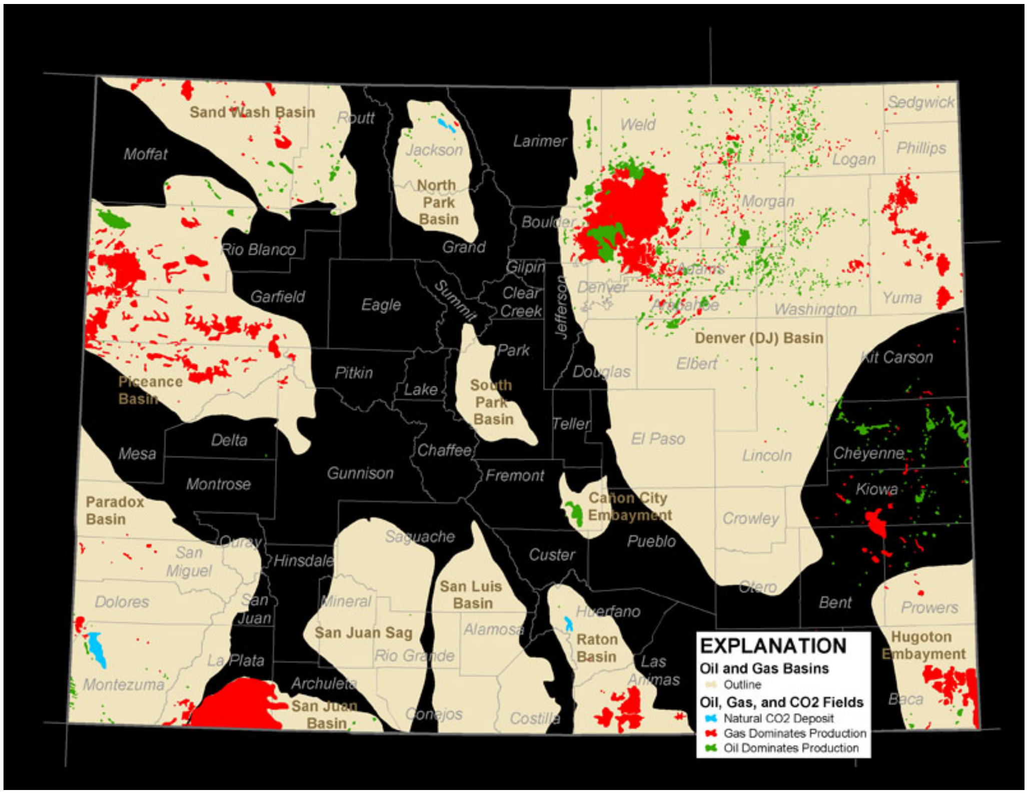


Figure 6. Oil, gas, and CO_2 fields in Colorado.
Source: Colorado Department of Natural Resources, Colorado Geological Survey

Within the Rocky Mountain region, fossil fuel extraction quickly became a staple of economic development during boom times—or periods of rapid growth and increased investment in extraction activities and regional consumption. The energy industry brought the Union Pacific Railroad to Colorado both to fuel trains and to transport coal to urban industrial centers. Colorado became the lead coal producer of the intermountain West in the 1880s and 1890s (Schamehorn 2002). Oil shale development followed coal and by the early 1920s, "oil fever" had consumed the western slope of the Rocky Mountains (Hansen and Limerick 2009). Northwest Colorado is home to some of the richest oil producing shale, located in the Green River formation.

On the brink of the 1920s oil rush, following energy development for battleships during World War I, Congress passed the Mineral Leasing Act of 1920 (MLA). For a small royalty payment, the MLA made fossil fuel-bearing lands in the public domain available for development. Some prospectors had filed their claims before the passage of the MLA under lax regulation and during the federal push for energy development to fuel the war effort (Hansen and Limerick 2009). These claimants were able to secure private ownership of the oil shale lands, which in turn has given the energy industry a permanent presence in the Western Slope's public lands (Hansen and Limerick 2009).

Times of prosperity and abundance of oil and coal extraction were followed by dramatic decreases in economic activities, also referred to as "busts." Because energy resources are market commodities, when the market crashes, local communities dependent on synthetic fuel extraction find themselves out of work. In the late 1920s and again in the 1930s, oil and coal booms ended in busts (Schamehorn 2002; Hansen and Limerick 2009). The oil boom returned in the 1970s, reinstating Denver as the energy capital of the Rocky Mountain States with a claim of more than 2,000 oil, gas, and synthetic-fuel enterprises until the recession took hold along with another bust in the 1980s (Scamehorn 2002). Remnants of abandoned buildings and houses across Colorado's ghost towns are physical evidence of the outcomes of market-dependent boom and bust cycles.

In the 21st century, coalbed methane—unconventional natural gas produced from coalbed seams underground—accounted for over 40% of Colorado's natural gas production and almost 30% of all U.S. coalbed methane production in 2009 (EIA 2009). Today, coalbed methane production is active in the San Juan and Raton basins, and future development is expected in northwest Colorado's Piceance Basin (Figure 2), which holds the second-largest proved reserve in the nation (EIA 2009). Importantly, coalbed seams were the first source of methane made profitable through horizontal drilling and hydraulic fracturing, the same technologies that were later modified and applied to shale gas extraction.[6] Shale gas development is only the most recent evolution of fossil fuel mining in Colorado, across the U.S., and throughout the world. Most countries have some quantity of proven natural gas reserves, with the largest quantities in China, Argentina, Algeria, North America, and Russia (USDOE 2013).

What is new for Colorado is the pace, scale, proximity to urban communities, and technical advancements that accompany increased shale gas production. Furthermore, the changing socioeconomic and political composition of the state has been felt by long-time residents and studied by scholars as the rapidly expanding "New West" (Booth 1999;Travis 2007; Winkler 2007; Robins et al. 2009). The U.S West has relied on resource extraction as its economic base for nearly 150 years. Over the past two decades, however, primary commodity production such as timber, agriculture, and grazing have experienced a combination of price collapses, improvements to technologies, and regulations that have led to organizational and institutional changes in states such as Colorado (Power 1996). Revenue declines in extractive industries have made way for new sectors, such as service and consumption economies. People move to Colorado not to work in agriculture or mining but for the lifestyle, outdoor recreation, and amenities, factors that relate to a particular quality of life (Robbins et al. 2009). In this New West, with service and consumption economies accelerating, extractive industries have to compete with amenity economies. The potential environmental and cosmetic effects of oil and gas development means companies are faced with heightened grassroots organizing, perhaps indicating changing assumptions about what constitutes quality of life.

Nevertheless, Colorado remains a key producer of natural gas, ranking sixth for marketed production of natural gas, ahead of the Marcellus shale play region (EIA 2011). An increase in drilling permits and production quantities started to take off in the first months of 1999 (Weber 2012). Statewide annual drilling permits increased from 1,010 to 8,027 between 1999 and 2008, leveling out in 2012 due to low market price (Figure 7). Despite the fluctuations in numbers of permits, gas production has continued to steadily increase from 1.98 bcf/day[7] in 1999 to 4.72 bcf/day in 2012 (Figure 8). At a national level, the increase in permits followed Mitchell Energy's first successful commercial shale gas extraction within the Barnett Shale in Texas in 1998 (Trembath 2012). At a state level, the overall increase in natural gas extraction coincided with a

[6] For more information on coalbed methane production in the intermountain west see Bryner (2002).
[7] bcf/day = billion cubic feet of gas per day. One billion cubic feet (bcf) of natural gas is enough to meet the needs of approximately 10,000 - 11,000 American homes for one year.

decrease in permit activity on the western slope and a concentration of activity in Weld County, Colorado. The following section describes the state's important role in facilitating oil and gas development in Colorado.

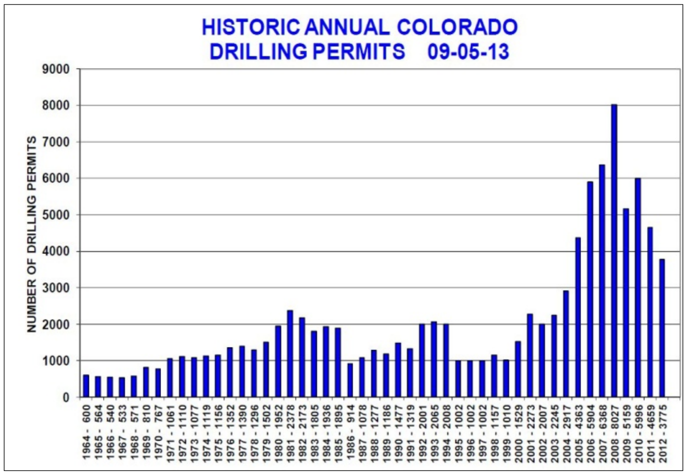


Figure 7. Historical annual Colorado drilling permits.
Source: COGCC 2013

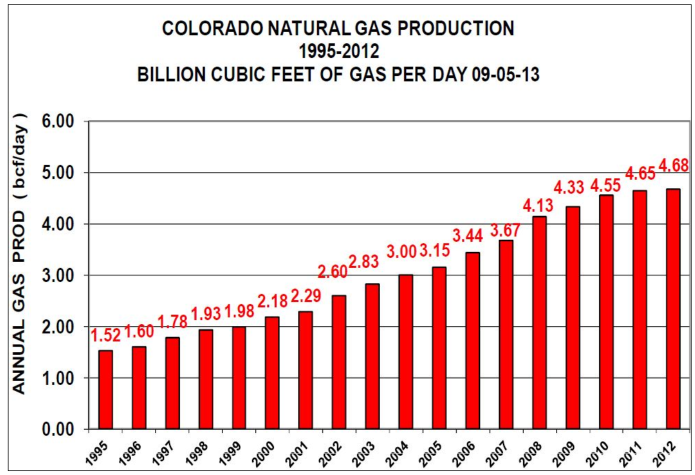


Figure 8. Colorado natural gas production.
Source: COGCC 2013

Rules and Regulations: The Role of the State

State agencies play important roles that define the social and environmental arena in which oil and gas companies operate. In 2012-2013 state agencies passed important regulations that ultimately allowed the dramatic increase in UNGD to take place (Appendix II). Three state agencies are charged with overseeing oil and gas production activities in Colorado. The Colorado Department of Public Health and Environment (CDPHE) is responsible for air and water quality. They issue permits for the discharge of wastes into surface waters and groundwater, and they regulate air quality near drilling sites. The State Engineer's Office must approve industrial consumptive use for the large quantities of water necessary for hydraulic fracturing. However, the primary authority in the regulation of UNGD activities is the Colorado Oil and Gas Conservation Commission (COGCC).

The COGCC is charged with enforcement of both environmental and health regulation, as well as efficient exploration and production of oil and gas resources (http://cogcc.state.co.us/). The Colorado General Assembly in 1951 passed the Colorado Oil and Gas Conservation Act, establishing the COGCC as the primary state agency responsible for regulating oil and gas in Colorado (C.R.S. §34-60-101). The COGCC permits wells (including their design, location, spacing, operation, and abandonment) as well as environmental activities (including water management and disposal, air emissions, underground injection, wildlife impacts, surface disturbance, and worker health and safety).

The COGCC board is made up of nine commissioners. Seven are appointed by the Governor and confirmed by the Senate, and the other two positions are filled by the executive director of the Department of Natural Resources and the executive director of the CDPHE. Monthly public hearings are held in Denver and in locations experiencing oil and gas activity around the state. Legally, the state gets the final word on policy, trumping local city council votes. In the following section, UNGD production in the U.S, and specifically in Colorado, is situated within the larger national energy context.

History of a Technology: Federal Policies, Organizations, and Public–Private Partnerships

While the magnitude of community responses confronting an accelerated pace and scale of production has increased over just the last five years, research and development of natural gas extraction processes has been advancing over the last century with federally-funded support. The emergence of UNGD in Colorado rests in a broad context of federal policies, tax supports and regulations, infrastructures, and the collaboration of both private and public entities that began in the early 1900s. Technological advances of HF and horizontal drilling techniques have ensured the economic viability of UNGD, and would not have been possible without the millions of dollars invested after the passing of each new energy-promoting legislation. Post-1970 investments in national energy security often followed international oil embargos from Organization of the Petroleum Exporting Countries in 1967 and again in 1973. The long-term impacts of this intentional federal energy agenda continue to unfold at the local level in communities affected by energy extraction. Such impacts are discussed below.

The history of policies and organizations contributing to this agenda goes back to 1815, when the first shale processing plant was established in Canada. This was followed by the first U.S. boom in the 1910s in preparation for World War I. The highly significant Synthetic Liquid Fuels Act of 1944 preceded the first HF technique performed by Standard Oil in Grant County, Kansas. By 1949, Halliburton Oil Well Cementing Company (HOWCO) was granted exclusive license for the new HF process (Montgomery and Smith 2010). However, HF did not become economically viable for commercial sale until the late 1990s (Figure 9). This section focuses on the U.S. federal policies and institutions promoting the excavation of natural gas during the 1970s and the second Arab oil embargo.

The mid 1970s marked the rise of the federally-funded Morgantown Energy Research Center (MERC) as a leader in natural gas research and development. In 1967, the initiation of the Eastern Gas Shales Project brought oil and gas companies together with MERC to map gas-bearing rock formations and reserves beneath the Appalachians (Mershon and Palucka 2012). Shared expenses for public-private collaborations followed with field experiments testing different fracturing techniques.

On the other side of the country, attention turned to the mountain west and the introduction of a sister project. The Western Gas Sands Project brought HF research and technology to Colorado in the late 1960s and early 1970s. The initiative organized the western states to examine the energy potential of dense sandstone rocks. Around the same time, coalbed deposits were beginning to be considered a viable source of natural methane gas. The Western Gas Sands Project housed MERC engineers to carry out testing of horizontal drilling technologies. By 1976, MERC engineers patented their directional drilling in coalbed methane, a horizontal drilling method that allowed for large amounts of methane collection at a reasonable cost (Mershon and Palucka 2012). By 1977 MERC's umbrella agency, the U.S. Department of Energy (DOE), successfully demonstrated massive HF in shale, revolutionizing natural gas as a priority energy source.

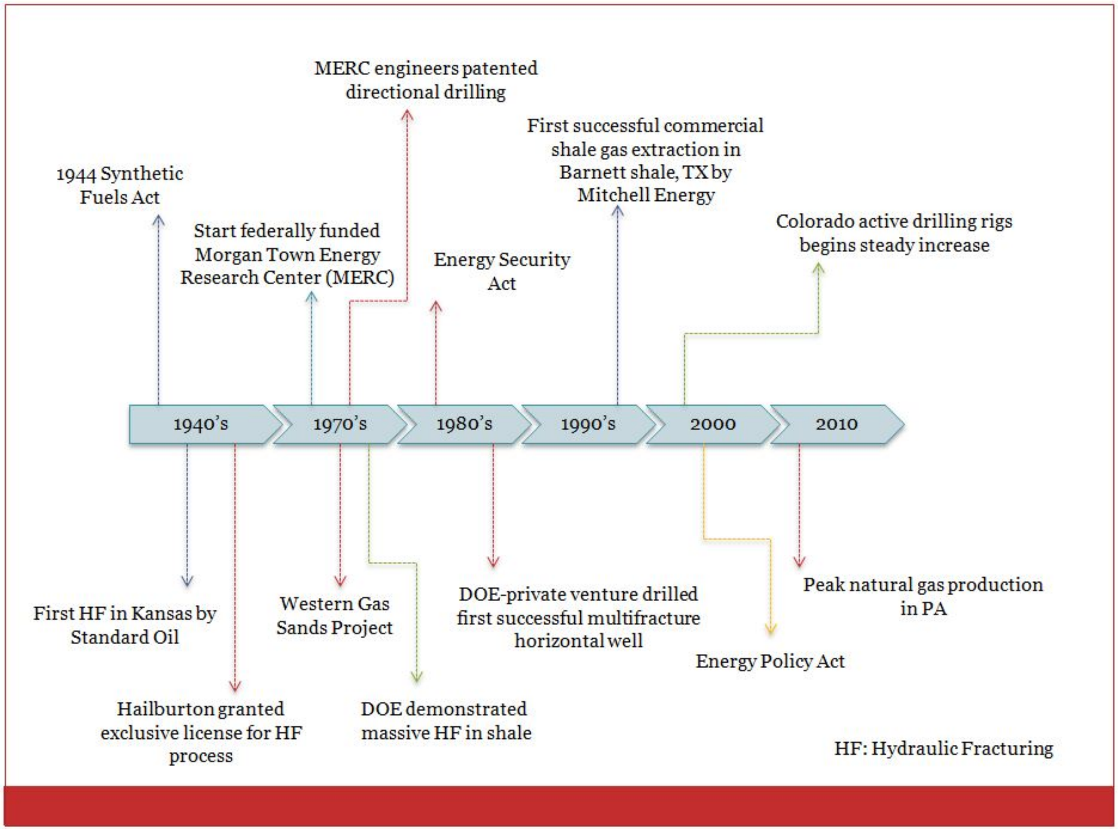


Figure 9. Historical timeline of federal policies, organization, and partnerships relevant to advancing increased pace and scale of unconventional natural gas development

In the 1980s, federal policies focused on nationalizing energy production and disseminating the HF technology. Specifically, the 1980 Energy Security Act signed by former president Jimmy Carter gave tax credits ($0.50/million BTUs) to companies extracting unconventional gas, and also introduced the Intangible Drilling Cost Expensing Rule that typically covered more than 70% of the well development costs at that time (Mershon and Palucka 2012). The Energy Security Act guaranteed billions of dollars for the creation of a Synthetic Fuels Corporation that would provide loans, price guarantees, and other financial incentives to stimulate natural gas development (Scamehorn 2002). This boost prompted companies such as Exxon, Chevron, Union Oil, and Conoco to explore Colorado's Western Slope. However, by 1982, expectations of national energy security dropped with prices for foreign gasoline. Private industries had received federal research funding, but once that support stopped, companies did not have incentives to continue excavation operations (Scamehorn 2002). The Synthetic Fuels Corporation proved unsuccessful for national energy security initiatives. Still, the stage was set for energy companies to develop economic opportunities and technical capabilities for *in situ* fracturing methods applied to oil shale.

By 1986 a DOE-private venture had drilled the first successful multifracture, horizontal well in

West Virginia. It took until 1998 for Mitchell Energy to harness the horizontal drilling method in the Barnett Shale in Texas, achieving the first successful commercial shale gas extraction (Trembath 2012). Mitchell Energy had built on MERC's directional drilling technology patented for use in coalbed methane and applied a drilling technique called "slick water fracture," innovating a combination of water, sand, chemical inputs, and proppants that effectively brought HF into commercial market competition (Trembath 2012).

HF technologies received a boost when President Bush signed The Energy Policy Act of 2005, effectively exempting fluids used in the natural gas extraction process of hydraulic fracturing from protections under the Clean Air Act (1970), Clean Water Act (1972), Safe Drinking Water Act (1974), and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) (1980) (Kosnik 2007). The Energy Policy Act excused companies drilling for natural gas from disclosing the chemicals involved in HF operations that would normally be required under federal clean water laws. The loophole is commonly known as the "Halliburton loophole" since former Halliburton CEO Dick Cheney was reportedly instrumental in its passage (Kosnik 2007). The disclosure exception has been an ongoing concern for community groups worried about potential and water contamination. It further works against citizen calls for transparency from industry and government. In this policy context, the next section reviews the academic and governmental literature on associated economic, air quality, health, and water-related risks attributed to UNGD.

Risks Associated with UNGD: What Does the Research Tell Us?

Research on environmental, economic and health risks of UNGD is full of controversy. Contradictory information, findings, and perspectives leave communities and industry alike sifting through conflicting arguments. This section aims to clarify the confusion with a review of economic benefits and challenges of UNGD, followed by a lifecycle analysis (LCA) that aims to quantify and compare cradle-to-grave air emissions of coal and conventional energy sources. LCAs do not address the social effects of UNGD on communities. Research addressing socio-psychological and community change as well as public health outcomes are addressed. However, gaps in the literature need to be filled with research in Colorado and other states that captures on-the-ground experiences of people living in industrialized oil and gas communities.

To systematically document "where we are now," this review cites peer-reviewed journals and governmental reports that are organized into an article database by topic. Articles documenting ground and surface water risks find linkages between surface spills and subsurface methane migration[8] with water contamination. There are still very few peer-reviewed studies that include the full lifecycle of water (Dale et al 2012; Grubert and Kitasei 2010). The current landscape of HF is examined, and gaps in understanding the potential risks associated with this industry are reviewed.

[8] Methane migration occurs when methane is released through the fracking process and migrates through underground pathways or fractures to shallow groundwater. The methane has the potential to contaminate drinking water and may pose an explosion hazard in confined spaces.

This review is reflective of the uncertainty within which policy-makers and the public make decisions. An example of arguments between academic and industry scientists illustrates the controversial nature of research related to UNGD. The public often perceive that political interests shape the presentation of facts, contributing to their mistrust of research on the potential social and environmental impacts of UNGD. While the focus of this report is on Colorado, there are few peer-reviewed studies about the state's shale plays. For this reason, research from the Marcellus region is examined, which was the first large scale application of HF and horizontal drilling technologies after its testing period in the Barnett shale in Texas.

Economic Analyses

Economic benefits of UNGD include employment, severance taxes, public leases, public royalties, and property taxes. Existing studies on monetary impacts of oil and gas utilize an economic input-output analysis. This linear method is widely embraced since it lends itself to rapid calculations and flexibility in calculating the effects of changes in demand (Miller and Blair 2009). The underlying aim of this method is "to estimate the level of overall economic activity associated with increased regional production or sales of particular services or products (such as shale gas), calculating the difference from what would otherwise be expected if the increases did not occur" (Kinnaman 2011:1248). Such input-output analyses measure changes in the level of product and service sales and how that translates into new employment and wages (refer to Input-Output models, Miller and Blair 2009). The economic indicators quantified by these models, such as jobs and income, are particularly relevant for citizens that want to assess the tradeoffs of oil and gas operations in their communities.
Kay (2011) explains the logic behind Input-Output models application to oil and gas development:

> "With each well, industry capitalizes on its earlier exploration and leasing expenditures by purchasing some of its drilling-related goods and services from local businesses and workers; eventually local expenditures pertaining to well production, reclamation and well closure will follow. Each producing well also prompts delivery of a stream of payments to government in taxes and of royalties to local landowners who (depending on assumptions) spend some or all of that money locally. Each of these infusions of funding in turn stimulates increased economic activity, or 'multiplier' effects on spending, in industries outside the gas extraction sector itself" (2011:4).

The idea is that the increase in UNGD will benefit the regional economy and the communities within that region through stimulating individual and corporate spending in the region. These expenditures can be calculated on a per well basis.

Limitations of Input-Output Studies:

The peer-reviewed literature on economic impacts of oil and gas development focuses on critiques of economic analysis reports that use the input-output model. They cite external costs not included in the market price but absorbed by society and the environment (Kinnamon 2011; Christopherson and Rightor 2012); inaccurate assumptions (Barth 2013; Bess and Ambargis 2011; Lazarus et al. 2002); the need for consideration of temporality, or long-term impacts (Christopherson and Rightor 2012; White 2012; Headwaters 2011); and the utilization of borrowed data from other regions that do not accurately represent local conditions (Kinnamon 2011). Authors also see a need to distinguish consulting reports released under academic institutional affiliations from peer reviewed economic research in order to provide accurate estimates of the economic impact of shale extraction (Barth 2012; Kinnaman 2011). Below is a detailed summary of each of these limitations.

Assumptions

Models have several built-in parameters that rely on underlying assumptions. In particular, those that indicate the proportion of goods and services in every economic sector that will be purchased and supplied locally can lead to inaccurate estimates for a given industry (Barth 2013; Kay 2011; Bess and Ambargis 2011). Also, input-output analysis assumes that all populations have identical spending patterns (Barth 2013). These assumptions end up overstating the estimated economic impact since new workers are often transient and goods and services are not always supplied locally. Kinnaman points out that these limitations could be corrected by including better assumptions of when and where households spend economic gains, as well as clarifying the process used to determine where suppliers to the industry and royalty-earning households are located (2011).

Christopherson and Rightor (2012) argue that the most important assumptions affecting the results from these models are those regarding the pace, scale, and geographic distribution of drilling activity. As described above, the pace and scale of national oil and gas production dramatically increased with the economic viability of horizontal drilling and hydraulic fracturing technologies. The physical geography of recoverable shale deposits means that economic analysis must be context-dependent within affected city and county economies. Input-output models become problematic in this case due to the lack of available regional data, sometimes necessitating the borrowing of data from other industries and regions, which may not be accurate for gas drilling in the region of study (Barth 2010).This difficulty is compounded by the other limitations and is particularly significant in the case of the Marcellus shale, where impacts are likely to be different and unevenly distributed across urban and rural localities (Kay 2011). Again, Kinnaman (2011) offers a direction by suggesting development of a more appropriate econometric model in order to estimate well drilling as a function of current price and other relevant variables.

Externalities

Externalities are costs or benefits that result from an activity that affects an uninvolved person or groups of people that did not choose to incur that cost or benefit. Negative externalities are often overlooked in input-output models, suggesting that the full costs of oil and gas developments to communities and societies as currently calculated are not accurate (Barth 2013). Examples of negative externalities in connection with shale gas development include water, air, and land contamination; public health impacts; wear and tear on roads and other infrastructure; and costs to communities due to increased demand for services such as police, regulatory oversight, firefighting, first responders, and hospitals (Barth 2013).

Christopherson and Rightor (2012) add to this list:

- types of jobs that become available, who gets them, and for how long;
- housing impacts—low income families displacement cumulative impacts;

- rise in local expenditures on basic needs;
- impacts on other industries such as agriculture and tourism and
- the negative externalities of an undiversified income base.

Another cost of natural gas extraction is the nuisance, noise, and loss of privacy to the owners of the property hosting the drill pads (Kinnaman 2011). These researchers argue that any study that wants to produce accurate results must also quantify these externalities in their analysis.

Temporal Aspects Such as Boom-Bust Cycles

Resource-dependent economies, or economies that rely on the extraction and export of primary resources, have been widely shown to be less economically resilient over the long-term (Weber 2012; James and Aadland 2011; Headwaters Economics 2011; Sachs and Warner 1995; 2001; Stevens 2003). Although it is a bold statement, it has yet to be effectively countered in the literature related to natural gas. The continued acceptance of extraction economies has been largely attributed to the weakened competitiveness of other sectors such as tourism and agriculture. The rapid expansion of material and institutional resources quickly retracts when operations change resources (such as from coal to natural gas extraction) or locate to a more lucrative geographic location. Commodity prices on the market are the most influential driver of the amount of exploration and drilling that occurs within Colorado (Headwaters 2012).

But the economic effects of growth in a natural resource industry can vary by commodity, context, and market price. In Colorado, a study out of CU-Boulder's Leeds School of Business utilized an input-output model to estimate the economic impacts of the oil and gas industry on the state from 2010. According to this report, employment totaled more than 43,800 jobs, contributing to nearly $3.2 billion in employee income to Colorado households in 2012, 2.6% of total Colorado salary and wages. For public revenues, the industry contributed $572 million derived directly from severance taxes, public leases, public royalties, and property taxes (Wobbekind et al. 2012).

A recent report released from Headwaters Economics (a bi-partisan, non-profit independent research group) reported similar numbers for 2010 and shows how volatility in the oil and gas industry's employment, personal income, and share of the state's gross domestic product have decreased since 2008 (2012). During the recent recession, the industry lost jobs at a faster rate than almost all other industries, and today it makes up for less than 1% of total statewide employment (Headwaters Economics 2012). Economic benefits and challenges are experienced directly by involved communities.

Lifecycle Analyses of Air Emissions

While some research focuses on a single pollution source (Fleweling et al. 2013; Ferrar et al. 2013), lifecycle approaches compile scientific data from all stages of a product's life, from 'cradle-to-grave.' Scientists evaluate the potential impacts of energy and materials associated with identified inputs and discharges (Hoffman and Schmidt 1997). Policymakers can inform their decisions by comparing the tradeoffs between energy portfolio options, such as coal and other conventional energy sources versus natural gas. Much of the scientific debate around lifecycle approaches deals with the scientific validity, as well as arguments over methodologies, namely components or processes included or omitted from complete lifecycle analysis. The EPA uses this standard definition of a Lifecycle Analysis (LCA):

> "A process to evaluate the environmental burdens associated with a product, system, or activity by identifying and quantitatively describing the energy and materials used, and wastes released to the environment, and to assess the impacts of those energy and material uses and releases to the environment. The assessment includes the entire life cycle of the product or activity, encompassing extracting and processing raw materials; manufacturing; distribution; use; re-use; maintenance; recycling and final disposal; and all transportation involved. LCA addresses environmental impacts of the system under study in the areas of ecological systems, human health and resource depletion. It does not address economic or social effects" (Hoffman and Schmidt 1997:52-53)

An inclusive lifecycle analysis applied to natural gas development includes (Howarth 2012; Venkatesh et al. 2011):

- Upstream emissions – those that occur during well completion and production at the well site
- Midstream emissions – those that occur during gas processing
- Downstream emissions – transmission pipelines and storage and distribution systems
- End use – those that occur from power generation

The baseline data used in the following emission studies draw on those published by the EPA and the Argonne National Laboratory. The LCAs are broadly based in a complex, multi-disciplinary context. This context yields inconsistencies that make any concise conclusions about the environmental risks of UNGD extremely challenging and lead to debate and disagreement among scientists, governments, public and industry.

Air Emissions

Research on the health impacts of greenhouse gas (GHG) emissions related to UNGD covers measurements and projections of Volatile Organic Compounds (VOCs)[9] in the Marcellus and Niobrara shale. Table 2 provides a summary overview of the literature examined on air emission LCAs. While some findings claim shale gas releases fewer VOCs than conventional sources, studies nevertheless show significant potential impacts to human health and climate change. In 2011, numerous studies estimated methane emissions specifically from "downstream" release points such as pipelines, storage, and natural gas distribution systems over the lifecycle of a well (EPA; Jiang et al.; Hultman et al.; Ventakesh et al.; Burnham et al.; Stephenson et al.; Howarth et al.). Other studies focus on "upstream" and "midstream" release points (EPA 2011; Hultman et al. 2011; Weber and Calvin 2012).

[9] Volatile Organic Compounds (VOCs) are federally regulated organic chemicals that are harmful to human and ecosystem health. VOCs include benzene, methane, carbon dioxide, and greenhouse gases.

Table 2. Summary of lifecycle analyses of greenhouse gas emissions (GHG) from conventional and shale gas. Analysis includes type of LCA model, the model's system boundaries, the type of fuel researched and the main findings.

Article	Life Cycle Model	System Boundary	Fuel Pathways	Main Findings
Burnham et al. 2012 - Argonne National Laboratories	Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET)	Well Infrastructure - Natural Gas Recovery - Processing - Transmission and Distribution – End Use	SG*, CG*, coal, and petroleum	SG burns cleaner than CNG, coal, and petroleum
Howarth et al. 2011 - Cornell University	Full Life Cycle Methane Emissions	Up, mid, and downstream over lifecycle of well for 20 and 100- year time horizon	SG, CG, coal	SG emissions significantly larger than CG and coal
EPA 2011	IPCC Guidelines for National Greenhouse Gas Inventories	Exploration, exploitation, conversion, transmission and distribution, fuel use	SG, CG	SG has almost double emissions as CG
Hultman et al. 2011 - University of Maryland	Not Standardized	Production Process and Fugitive Emissions, Electricity Generated for End User	SG, CG, coal	For electricity generation SG emissions marginally higher than CG Coal emissions are 56% that of SG
Ventakesh et al 2011 - Carnegie Mellon	Lifecycle Assessment (LCA)	Production, Processing, Transmission, Distribution, and Combustion	SG/CG, coal	NG instead of coal for power generation contribute to highest emissions reduction
Stephenson 2011 - Shell Global Solutions	WtW: Well to Wire	Well Drilling to Power Station	SG, CG	SG Emissions Higher than CG
Skone 2011 - National Energy Technology Laboratory	Lifecycle Assessment (LCA) (EPA)	Raw material acquisition and transport, energy conversion, product delivery (not end use)	SG, CG, coal	No significant difference between SG and CG, both substantially lower than coal
Dale et al. 2013 - University of Pittsburg	Lifecycle Assessment (LCA) - Including GHG Emissions, Energy Consumption, Water Consumption	From well pad construction and drilling to delivery (not end use)	SG, CG	No significant difference between SG and CG water consumption or GHG emissions

Using a Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) approach, Burnham et al from Argonne National Laboratories show that UNGD burns cleaner than coal (2012). They find that shale gas life-cycle emissions are 6% lower than conventional natural gas, 23% lower than gasoline, and 33% lower than coal. However, they caution that the range in values for shale and conventional gas overlap, so there is statistical uncertainty as to whether shale gas emissions are indeed lower than conventional gas (2012). Other studies comparing conventional to UNGD find little difference between the two when measuring GHG emissions. In one study, Dale et al (2013) use a lifecycle assessment tool to measure GHG emissions, energy, and water consumption under conventional and UNGD operating practices in the most resource-comprehensive analysis to date for the Marcellus region. GHG emissions of UNGD are similar to conventional operations, lower than conventional fossil fuels, and higher than unconventional oil sources in the Marcellus shale region. Interestingly, this research makes the case for reducing environmental impacts by centering efforts on efficient midstream processes, combustion, and use rather than well development practices.

Other studies integrate decadal projections to find that the UNGD footprint is overall greater than that for conventional gas or oil when viewed on any time horizon and principally over a time span of 20 years (Howarth et al 2011). According to Howarth et al, the footprint of shale gas is at least 20% greater and perhaps more than twice as great over 20 years in comparison to coal (2011). This research emphasizes the long-term projections of UNGD as significant in lifecycle analysis with a focus on fugitive emissions.[10] In 2012, Howarth et al. carried out an extensive analysis of the lifecycle approaches. At the crux of these LCA findings is the debunking of arguments promoting natural gas as a cleaner burning bridge fuel (EPA 2011; Hultman et al. 2011; Skone 2011; Dale et al. 2013).

Socio-Psychological Health Concerns and Air Emissions

Diverging from the LCA approach, the few published studies specific to Colorado highlight potential health risks and harmful VOC emissions related to oil and gas development from the wellhead (Table 3). Mckenzie et al. (2012) estimate health risks for exposures to air emissions from a UNGD project in Garfield County. The Colorado School of Public Health conducted this study as an HIA requested by the Garfield County Board of County Commissioners to address citizen concerns about health impacts of natural gas development and production in the Battlement Mesa Planned Unit Development. They find that residents living less than a half mile from wells are at greater risk for health effects from UNGD than others. According to their study, subchronic exposures to air pollutants that occur during well completion activities present the greatest potential for negative health effects. The measured health index is driven primarily by exposure to trimethylbenzenes, aliphatic hydrocarbons, and xylenes, all of which have neurological and/or respiratory effects. McKenzie et al (2012) also calculated higher cancer risks for residents living nearer to wells as compared to residents residing further from wells.

[10] Fugitive emissions are methane leaks from equipment, pipelines, and venting and flaring activities.

Table 3. Findings of regional air quality studies in Colorado (2012-2013)

Study	Findings	Supporting Institution	Location
McKenzie et al. 2012	• Residents living less than a half mile from wells are at greater risk for health effects from UNGD than others • Higher cancer risks for residents living nearer to wells as compared to residents residing further from wells	Colorado School of Public Health	Garfield County
Colorado Department of Public Health and the Environment (CDPHE) 2012	• Concentrations of high risk carcinogenic chemicals within acceptable limits as defined by the EPA • Do not account for potential risks due to exposure from multiple chemicals at the same time	CDPHE commissioned by city of Erie	Erie
Petron et al. 2012	• Estimated VOCs from oil and gas have been highly underestimated • Oil and gas operations are a significant source of ozone precursors	NOAA	Weld County

In another health study, the city of Erie, Colorado commissioned a study by the CDPHE that found concentrations of the high risk carcinogenic chemicals, namely benzene, were within acceptable limits as defined by the EPA (CDPHE 2012). In this same report, researchers comment that "the current state of the science is unable to estimate the potential risks due to exposure from multiple chemicals at the same time, which may be higher" (CDPHE 2012:i).

Gilman et al. (2013), researchers from the Cooperative Institute for Research in Environmental Sciences at UC Boulder and NOAA laboratories, examine how VOCs (propane, benzene, and ethane) associated with oil and gas development operations can be clearly differentiated from other sources. Gilman's team builds on the Petron et al. (2012) study that shows the differentiation between combustion emissions, such as from automobiles, and the venting emission leaks from raw natural gas together with the emissions from oil and gas storage tanks. Based on this finding, Petron et al. argue that the estimated VOCs from oil and gas have been highly underestimated in Weld County. Gilman et al. confirm these findings and make the case that emissions from oil and natural gas operations are a significant source of ozone precursors just north of Denver in the Wattenburg Field (2013).

Other hard-to-monitor public health concerns include the socio-psychological impacts on communities in oil and gas rich counties. Research from the Marcellus region documents community experiences through research integrating self-reported survey research (Saberi 2013) and ethnographic studies with quantitative data to assess the chronic symptoms experienced by people living near gas facilities in Pennsylvania (Perry 2012). This qualitative methodology can help health practitioners and policymakers be better equipped to treat residents and employees of the natural gas industry that believe their health has deteriorated as a result of exposure to natural gas development (Perry 2013; Saberi 2013). Steinzor et al. (2013) and Saberi (2013) add that environmental exposure history and health surveys coupled with environmental testing can identify links between shale gas development and health concerns. Such methods shed light on local resident's experiences through in-depth ethnographic accounts, while simultaneously creating channels for communities to participate as stakeholders in energy extraction conversations.

Perry (2012) uses ethnography to record rapid social and economic change affecting daily lives and community dynamics in Bradford County, an agricultural community in Pennsylvania. Perry situates residents' experiences in their social history to facilitate understanding of quality of life changes as experienced by the landowners. These changes are framed in relation to the cultural significance of place, home, and family, and importantly what they tell us about the sociocultural and psychological impacts of rapid energy development (Perry 2012). For example, her results show that traffic issues and road damage such as traffic noise, dust, and the increased volume of over-sized vehicles traveling dirt and gravel roads are the issues of greatest concern related to the gas industry's presence in Bradford county.

Focus group and ethnographic research methods found this as the most constant source of aggravation, stress, and fear, and the most significant change. Also, in a cultural sense, roadways are "part of a genealogical landscape, where roads and hills are named after families who owned the most land on that road or hill; 'special places' are denoted because they were where family memories and histories were made, and the entire landscape is identified by parcels of land, or a particular township with stories of a particular family who has lived, or did live there, for generations" (Perry 2012:86). Roadways in the county signify family land and the "arteries of rural community life that were being destroyed and transformed sometimes literally overnight" (86). From a long-term cultural perspective, Perry poses a thought-provoking question: "How does rapid landscape change, from agricultural and forested to industrial, impact the resiliency and health of a rural community, when for centuries that landscape has been defined by the lives and deeds of family ancestors and the promise or potential of future generations making a living from that land?" (89)

Water Quality and Use

Research specific to risks on water resources focus on the subsurface, such as potential groundwater contamination (EPA 2011; 2013; Myers 2012; Osborn et al 2011; Gross et al 2013; Warner et al 2012; USGS 2012) through identified subsurface pathways (Osborn et al 2011; Rozell and Reaven 2011; Warner et al 2012) and methane as well as other stray gas migration and contamination related to natural gas development (Holzman 2011; Jackson et al 2013; Osborn et al 2011; Robinson 2012). Although methane gas occurs naturally in the area's aquifers, studies show that the chemical "fingerprint" of methane found in shallow water wells overlying shale gas basins was identified to be the same as the natural gas extracted from deep shale layers (Jackson et al 2013; Vengosh et al 2013).

Multiple forms of surface water events have been documented over the last three years. They include wastewater disposal as the highest risk of contamination (Rozell and Reaven 2011; Ferrar 2013). Elevated sediment runoff from pipelines and roads, alteration of streamflow as a result of water extraction, and contamination from introduced chemicals or the resulting wastewater are also identified as contributing to surface water contamination (Entrekin et al 2011). Surface spills from stored wastewater and fracking chemicals are shown to elevate benzene levels in groundwater (Gross et al 2013). Also, research highlighting people's experiences in Bradford County, Pennsylvania (in 2010 and into 2011) shows that large plastic containers for holding water, called water buffalos, were purchased by gas companies after the "landowner complained of undrinkable well water or the PA DEP made a determination that the well water was contaminated by high levels of methane or other substances after drilling or fracturing of a nearby gas well…" (Perry 2012:87).

It should be noted that while this research is out of the Marcellus shale region, geologies have different physical properties from basin to basin. The research in Pennsylvania is informative, but it does not denote the same environmental impacts in the Niobrara in Colorado. Non-peer-reviewed industry reports and articles all overwhelmingly portray no negative environmental externalities of UNGD. The gap in literature on water-related risks is filled by studies examining community-based involvement in watershed monitoring and accountability addressed in the first section of this report.

Research is needed to document the full lifecycle of water use in UNGD. The few studies that exist are incomplete. Grubert and Kitasei (2010) of Worldwatch Institute find that UNGD has less overall impact on freshwater resources than coal since natural gas power plants generally use less water per unit of electricity generated than coal power plants (2010). Dale et al. find no significant change in water usage across self-reported operator data when comparing conventional and UNGD in the Marcellus region (2013). They suggest a more focused research effort on excessive withdrawals from specific bodies of water or during specific times rather than total quantity used during the hydraulic fracturing process itself.

The Controversy

A contentious debate exists between scientists questioning each others' methods and the validity of findings regarding risks for air and water. The literature measuring GHG emissions and air quality associated with oil and gas wells, for example, shows university academics (Howarth et al 2011; Cathles et al. 2011) finding UNGD to be more harmful to the environment than conventional energy sources. At the same time, consultancy agencies and politicians (Levi 2013) attempt to debunk such claims. In the case of water, the above-cited article from Osborn et al. drew a particularly large number of comments because they documented systemic evidence linking HF associated with UNGD to groundwater contamination in the Marcellus and Utica shale formations (2011).

Responses to Osbourne et al. included statements from the following sources: a Halliburton employee along with hired hydrology consultants under the name Flewelling et al (2013); Richard Davies, Director of Durham Energy Institute and previous Senior Exploration Geologist for ExxonMobil (2011); Saba and Orzechowski, both from an engineering consulting firm (2011); and Schon, who studied Geological Sciences at Brown University before beginning work with Exxon-Mobil (2011). All of these responses attempt to invalidate the findings of Osborn et al. and their conclusions that link hydraulic fracturing to contaminated groundwater.

Osborn et al. (2011b) addressed all the concerns listed previously, and there have been no further responses to the authors. Does this indicate that Osborn et al. has "won" the debate? How do we know if groundwater contamination is a valid risk? Osborn et al. received so many questions that they developed an FAQ guide: Responses to Frequently Asked Questions and Comments About the Shale-Gas Paper by Osborn et al. (Jackson et al. 2011).

It should be noted that the objections to Osborn et al.'s study come from both consulting firms and industry scientists, while the Osborn et al. team includes a professor of hydrogeology from Cal Poly Pomona, geochemistry and biochemistry Ph.D.s, and professors of geochemistry and water quality from Duke. On the one side we have academics—professors and Ph.D.s from universities—and on the other, scientists from industry and hired consulting firms. Hired scientists may have an intimate knowledge of the shale layers and access to information from companies that universities lack, and have directly worked on the HF process. Still, the public often has an extreme distrust of industry and even agency regulators and scientists, as exhibited in the first section of this report.

To further complicate the controversy, the federal government is well aware of the risks involved with shale oil and gas extraction, and is reported by the U.S Government Accountability Office (GAO) to Congress:

> "According a number of studies and publications we reviewed, shale oil and gas development pose risks to water quality from contamination of surface water and groundwater as a result of spills and releases of produced water, chemicals, and drill cuttings; erosion from ground disturbances; or underground migration of gases and chemicals" (GAO 2012:39)

However, the GAO also states that underground migration of gases and chemicals pose a risk of contamination to water quality, but there are insufficient baseline data for groundwater, without which it is difficult to determine if adverse effects were the result of oil and gas development, natural occurrences, or other activities (GAO 2012).

EPA studies on potential contamination also do not clarify the issues. To date, three separate EPA water quality studies were closed without conclusive findings. In March 2012, the EPA stopped an investigation of methane in drinking water in Parker County, Texas after the geologist hired by the regulator confirmed that the methane was from gas production. In late June, the EPA dropped another study of possible contamination of drinking water in Pavillion, Wyoming despite its earlier findings of carcinogens, hydrocarbons, and other contaminants in the water (EPA 2011). The Wyoming study was handed to the state and will be funded by EnCana Oil&Gas USA, the company drilling in the area studied in EPA's 2011 research.

The 2011 EPA report on the Pavillion study finds:

> "33 abandoned oil and gas waste pits – which are the subject of a separate cleanup program – (was) indeed responsible for some degree of shallow groundwater pollution in the area. Those pits may be the source of contamination affecting at least 42 private water wells in Pavillion. But the (deep) contamination, the agency concluded, had to have been caused by fracking."

The third and possibly most controversial study was halted in July 2012 in Dimock, Pennsylvania. After its closure, an internal EPA PowerPoint presentation compiling 4.5 years of data collected from 11 wells around Dimock concluding that "methane and other gases released during drilling apparently cause significant damage to the water quality" (EPA 2012). The presentation also concluded, "methane is at significantly higher concentrations in the aquifers after gas drilling and perhaps as a result of fracking and other gas well work." A study published by Duke scientists indicates that drinking water wells near natural gas production in northeastern Pennsylvania, including Dimock, are at greater risk of methane contamination than those farther away (Jackson et al. 2013).

Confusion over conflicting scientific reports from federal and state agencies, academic researchers, and rebuttals from industry about potential risks have created an atmosphere of public mistrust, raising doubts regarding the real versus perceived risks of UNGD. Public trust of science has multiple explanatory factors including political values, ideology, support for government regulations, trust in government, and demographics (Brewer and Ley 2013). Conflicting information communicated through media, science, and governmental reports related to UNGD often leave the public to validate information based on their perception of the credibility of the conveyer (Ren and Levine 1991; Brewer and Ley 2013). Also, funding sources need to be transparent, and ideally should not come from companies that have high economic stakes in findings of the research. When this occurs, it is common for political interests to shape the presentation of facts to fit different models of reality (Jasanoff 1987; Pielke 2007). This has the potential to lead to further public mistrust of science since citizens are not able to distinguish science from evidence-gathering influenced by political values and beliefs.

Conclusion

The purpose of this report has been twofold: to document community responses to natural gas development in Colorado and Pennsylvania, and to compile peer-reviewed research that examines the socio-ecological risks associated with UNGD. The combination of external (or non-local) decision-maker actions, potential social and environmental risks, and the visible infrastructure of industrial activities (such as tanks, trucks, and well heads) have fueled a statewide movement of local grassroots organizations. In some cases, newly radicalized citizens and already established environmental organizations have connected to build nationwide coalitions. Although occupying different contexts, citizen groups in Colorado may learn from experiences in Pennsylvania's Marcellus region where community groups are working to hold the oil and gas operations accountable to local voices and concerns.

While this report highlights avenues for citizens to have a voice, evidence from the Marcellus shows that some residents experiencing the negative consequences of UNGD have little say in whether, where, and how shale gas development takes place (Kelsey et al. 2012). Also, in many cases, landowners and farmers receive substantial royalty payments for UNGD on their properties, and although they have to bare the industrial activities and potential risks, they are benefiting. At the same time, others are not interested in the payments. During an informal conversation with a Paonia farmer, she expressed discontent over the influx of natural gas activities and lack of consultation with the local residents. She commented, "We didn't ask for a natural gas pipeline outside our house."

Future research might explore: correlations between environmental inequalities, land, and mineral ownership patterns (Kelsey et al. 2012); how collective action in the oil and gas context differs or is similar to collective action relating to other natural resources; political traditions that favor state government control over rules and regulations related to oil and gas development (Davis 2012); and the complications associated with land use policies such as split estate (Duffy 2005; Davis 2012). This would build on research showing that oil and gas development has historically taken place in economically depressed, rural regions where disadvantaged populations have few opportunities to participate in decision-making (Malin 2013). The complexity of the Colorado case could be highlighted by comparing the social, environmental, and economic contexts and implications of oil and gas development on the Front Range with Western Slope communities. Such a multi case, ethnographic analysis would provide robust evidence and compelling findings.

This report documents the most recently published social and environmental risks associated with UNGD. It presents conflicting LCAs exploring whether UNGD offers a reprieve from climate change-contributing GHG emissions when compared to conventional fossil fuels such as coal. Qualitative methodologies carried out in Pennsylvania show that residents in industrial zones experience harmful socio-psychological and in some cases health risks due to proximity to oil and gas operations. Regional air quality studies in Colorado find that oil and gas operations are a significant precursor to VOCs and that residents within one-half mile of operations are at greater risk of health effects, including cancer. While we have not reached the point of having sufficient peer-reviewed research on water quality in Colorado, this literature review indicates sufficient evidence of water contamination from oil and gas development in Pennsylvania. In Colorado, this report has shown that accidents, such as the Parachute Creek spill and spills following the September 2013 floods, will occur.

References

Alvarez, R. a, Pacala, S. W., Winebrake, J. J., Chameides, W. L., & Hamburg, S. P. (2012). Greater focus needed on methane leakage from natural gas infrastructure. *Proceedings of the National Academy of Sciences of the United States of America*, *109*(17), 6435–40. doi:10.1073/pnas.1202407109

American Petroleum Institute. (2009). *Hydraulic Fracturing Operations — Well Construction and Integrity Guidelines. API Guidance Document HF1 First Edition*. Washington, DC.

Barth, J. M. (2010). *Unanswered Questions About The Economic Impact of Gas Drilling In the Marcellus Shale: Don't Jump to Conclusions*.

Barth, J. M. (2013). The economic impact of shale gas development on state and local economies: benefits, costs, and uncertainties. *New solutions : a journal of environmental and occupational health policy : NS*, *23*(1), 85–101. doi:10.2190/NS.23.1.f

Bess, R. and Z. O. Ambargis, "Input-Output Models for Impact Analysis: Suggestions for Practitioners Using RIMS II Multipliers," 50th Southern Regional Science Association Conference, New Orleans, Louisiana, March 23-27, 2011.

Booth, D.E. 1999. ''Spatial Patterns in the Economic Development of the Mountain West.'' Growth and Change 30(3):384–405.

Boxall, P. C., Chan, W. H., & McMillan, M. L. (2005). The impact of oil and natural gas facilities on rural residential property values: a spatial hedonic analysis. *Resource and Energy Economics*, *27*(3), 248–269. doi:10.1016/j.reseneeco.2004.11.003

Brewer, P. R., & Ley, B. L. (2012). Whose Science Do You Believe? Explaining Trust in Sources of Scientific Information About the Environment. *Science Communication*, *35*(1), 115–137. doi:10.1177/1075547012441691

Burnham, A., Han, J., Clark, C. E., Wang, M., Dunn, J. B., & Palou-Rivera, I. (2012). Life-cycle greenhouse gas emissions of shale gas, natural gas, coal, and petroleum. *Environmental Science & Technology*, *46*(2), 619–27. doi:10.1021/es201942m

Carre, N. C. (2012). Environmental Justice and Hydraulic Fracturing : The Ascendancy of Grassroots Populism in Policy Determination. *Journal of Social Change*, *4*(1), 1–13. doi:10.5590/JOSC.2012.04.1.01

Christopherson, Susan and Rightor, N. (2012). How shale gas extraction affects drilling localities: Lessons for regional and city policy makers. *Journal of Town & City Management*, *2*, 1–20.

Colborn, T., et al. (2011). Natural Gas Operations from a Public Health Perspective. *Human and Ecological Risk Assessment*, *17*, 1039 – 1056.

Colorado Department of Public Health and Environment. (2012). *Air Emissions Case Study Related to Oil and Gas Development in Erie, Colorado*.

Colorado Oil and Gas Commission (COGCC). Colorado Weekly & Monthly Oil & Gas Statistics. 06-07-13. Retrieved July 02, 2013, from http://cogcc.state.co.us/

Colorado Oil and Gas Commission (COGCC). (2013). COGCC Colorado Weekly & Monthly Oil & Gas Statistics. *9-15-13.* Retrieved from http://cogcc.state.co.us/

Considine, T., R. Watson, R. Entler, and J. Sparks. (2009). "An Emerging Giant: Prospects and Economic Impacts of Developing the Marcellus Shale Natural Gas Play." in *The Pennsylvania State University, Department of Energy and Mineral Engineering*.

Considine, Timothy J., Robert Watson, and Seth Blumsack. (2011). "The Pennsylvania Marcellus Natural Gas Industry: Status, Economic Impacts and Future Potential." University Park, PA: The Pennsylvania State University, Dept. of Energy and Mineral Engineering.

Dale, A. T., Khanna, V., Vidic, R. D., & Bilec, M. M. (2013). Process Based Life-Cycle Assessment of Natural Gas from the Marcellus Shale. *Environmental science & technology*. doi:10.1021/es304414q

Davis, C. (2012). The Politics of "Fracking": Regulating Natural Gas Drilling Practices in Colorado and Texas. *Review of Policy Research*, *29*(2).

Davis, C., & Hoffer, K. (2012). Federalizing energy? Agenda change and the politics of fracking. *Policy Sciences*, *45*(3), 221–241. doi:10.1007/s11077-012-9156-8

Duffy, R. J. (2005). Political Mobilization, Venue Change, and the Coal Bed Methane Conflict in Montana and Wyoming. *Natural Resources Journal*, *45*, 409–440.

EIA Colorado State Profile and Energy Estimates http://www.eia.gov/state/analysis.cfm?sid=CO. October 2009. Accessed July 2, 2013.

EIA Rankings: Natural Gas Marketed Production, 2011 http://www.eia.gov/state/rankings/?sid=CO#series/47. Accessed July 31, 2013.

EIA Colorado Energy Consumption Estimates, 2011a http://www.eia.gov/state/seds/seds-data-complete.cfm?sid=CO#Production. Accessed August 21, 2013

"Annual Energy Outlook 2012." Washington, D.C.: U.S. Energy Information Administration, U.S. Department of Energy. Accessed July 2, 2013.

Entrekin, S., Evans-White, M., Johnson, B., & Hagenbuch, E. (2011). Rapid expansion of natural gas development poses a threat to surface waters. *Frontiers in Ecology and the Environment*, *9*(9), 503–511. doi:10.1890/110053

EPA. (2011) Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2009. Accessed April 14, 2012. U.S. Environmental Protection Agency, Washington DC. http://epa.gov/climatechange/emissions/usinventor-yreport.html

EPA. (2012). Isotech - Stable Isotope Analysis: Determining the origin of methane and its effect on the aquifer. PowerPoint Presentation.

Erie Rising. Website. http://www.erierising.com/#sthash.VWZzi8Zo.dpuf. Accessed 8/6/2013.

Ferrar, K. J., Michanowicz, D. R., Christen, C. L., Mulcahy, N., Malone, S. L., & Sharma, R. K. (2013). Assessment of Effluent Contaminants from Three Facilities Discharging Marcellus Shale Wastewater to Surface Waters in Pennsylvania. *Environment and Society*, *47*, 3472−3481.

Finley, B. (2013). Benzene levels in Parachute Creek near gas plant spill double again. *The DenverPost*. Retrieved from http://www.denverpost.com/ci_23689092/parachute-creek-benzene-levels-double-again

Flewelling, S. a., Tymchak, M. P., & Warpinski, N. (2013). Hydraulic fracture height limits and fault interactions in tight oil and gas formations. *Geophysical Research Letters*, *40*(April), n/a–n/a. doi:10.1002/grl.50707

United States Government Accountability (GAO). (2012). *Information on Shale Resources, Development, and Environmental and Public Health Risks*.

Gilman, J. B., Lerner, B. M., Kuster, W. C., & de Gouw, J. a. (2013). Source signature of volatile organic compounds from oil and natural gas operations in northeastern Colorado. *Environmental science & technology*, *47*(3), 1297–305. doi:10.1021/es304119a

Goodwin, S., Carlson, K., Douglas, C., & Knox, K. (2012). Life cycle analysis of water use and intensity of oil and gas recovery in Wattenberg field , Colo . *Oil & Gas Journal*, *Exploration & Development* (May), 48–58.

Gopalakrishnan, S., & Klaiber, H. A. (2012). Is the Shale Boom a Bust for Nearby Residents? Evidence from Housing Values in Pennsylvania. *SSRN Electronic Journal*. doi:10.2139/ssrn.2117932.

Gross, S. a., Avens, H. J., Banducci, A. M., Sahmel, J., Panko, J. M., & Tvermoes, B. E. (2013). Analysis of BTEX groundwater concentrations from surface spills associated with hydraulic fracturing operations. *Journal of the Air & Waste Management Association*, *63*(4), 424–432. doi:10.1080/10962247.2012.759166

Grubert, E., & Kitasei, S. (2010). *How Energy Choices Affect Fresh Water Supplies: A Comparison of U. S . Coal and Natural Gas*. Worldwatch Institute.

Hanson, J. L., & Limerick, P. (2009). *What Every Westerner Should Know About Oil Shale : A Guide to Shale Country*. Boulder.

Headwaters Economics. (2011). *Fossil Fuel Extraction and Western Economies*. Bozeman, Montana.

Headwaters Economics. (2012). *The Status of Colorado's Oil and Gas Industry: Activity Continues to Reflect Colorado's Overall Share of Nation's Fossil Fuel Reserves* (pp. 1–15). Retrieved from http://headwaterseconomics.org/wphw/wp-content/uploads/colorado_energy_analysis.pdf

Hoffman, L., & Schmidt, A. (1997). *Life Cycle Assessment: A guide to approaches, experiences and information sources*.

Holzman, D. (2011). Methane Found in Well Water Near Fracking sites. *Environmental Health Perspectives*, *119*(7). doi:10.1073/pnas.1100682108.2.

Howarth, R. W., Santoro, R., & Ingraffea, A. (2011). Methane and the greenhouse-gas footprint of natural gas from shale formations. *Climatic Change*, *106*(4), 679–690. doi:10.1007/s10584-011-0061-5

Howarth, R. W., Santoro, R., & Ingraffea, A. (2012). Venting and leaking of methane from shale gas development: response to Cathles et al. *Climatic Change*, *113*(2), 537–549. doi:10.1007/s10584-012-0401-0

Howarth, R. W., Santoro, R., & Ingraffea, A. (2012). Venting and leaking of methane from shale gas development: response to Cathles et al. *Climatic Change*, *113*(2), 537–549. doi:10.1007/s10584-012-0401-0

Hyne, N. J. (2012). *Nontechnical Guide to Petroleum Geology, Exploration, Drilling, & Production*. PennWell Books.

Hultman, N., Rebois, D., Scholten, M., & Ramig, C. (2011). The greenhouse impact of unconventional gas for electricity generation. *Environmental Research Letters*, *6*(4), 049504. doi:10.1088/1748-9326/6/4/049504

IHS Inc. 2012. "The Economic and Employment Contributions of Unconventional Gas Development in State Economies." Washington, D.C.: Prepared by IHS, Inc. for America's Natural Gas Alliance (ANGA).

Grubert, E., & Kitasei, S. (2010). *How Energy Choices Affect Fresh Water Supplies: A Comparison of U.S. Coal and Natural Gas*.

Jackson, R. B., Osborn, S. G., Warner, N. R., & Vengosh, A. (2011). Frequently Asked Questions and Comments About the Shale Gas Paper by Osborn et al. Nicholas School of the Environment and Earth Sciences: Duke University. doi:10.1073/pnas.1100682108.1

Jackson, R. B., Vengosh, a., Darrah, T. H., Warner, N. R., Down, a., Poreda, R. J., … Karr, J. D. (2013). Increased stray gas abundance in a subset of drinking water wells near Marcellus shale gas extraction. *Proceedings of the National Academy of Sciences*, 1–6. doi:10.1073/pnas.1221635110

Jacquet, J., & Stedman, R. (2011). Natural Gas Landowner Coalitions in New York State: Emerging Benefits of Collective Natural Resource Management. *Journal of Rural Social Sciences*, *26*(1), 62–91.

Jalbert, K. (2011). *Culturally Situated Sensing: Peer Innovation and Citizen Sensing in Native American Communities*.
Jalbert, K., Kinchy, A. J., & Perry, S. L. (2013). Civil society research and Marcellus Shale natural gas development: results of a survey of volunteer water monitoring organizations. *Journal of Environmental Studies and Sciences*, (November).
Jasanoff, S. S. (1987). Contested Boundaries in Policy-Relevant Science. *Social Studies of Science*, *17*(2), 195–230.
Kay, D. (2011). Working Paper Series: The Economic Impact of Marcellus Shale Gas Drilling What Have We Learned? What are the Limitations?
Kelsey, Tim, Metcalf, Alex and Salcedo, R. (2012). *Marcellus Shale: Land Ownership, Local Voice, and the Distribution of Lease and Royalty Dollars*.
Kinchy, Abby J and Perry, S. (2011). Can Volunteers Pick Up the Slack? Efforts to Remedy Knowledge Gaps about the Watershed Impacts of Marcellus Shale Gas Development. *Duke Environmental Policy and Law Reform*, *22*, 303–339.
Kinchy, A., Jalbert, K., Perry, S., & Parks, S. (2013). *WATERSHED KNOWLEDGE MAPPING PROJECTS: list of participating monitoring organizations* (pp. 1–2).
Kinnaman, T. C. (2011). The economic impact of shale gas extraction: A review of existing studies. *Ecological Economics*, *70*(7), 1243–1249. doi:10.1016/j.ecolecon.2011.02.005
Kosnik, Renee Lewis MSEL, L. (2007). *The Oil and Gas Industry's Exclusions and Exemptions to Major Environmental Statutes*.
Lazarus, W., Platas, D. E., & Morse, G. W. (2002). IMPLAN's weakest link: production functions or regional purchase coefficients?. *Journal of Regional Analysis and Policy*, *32*(1), 33-48.
Lee, B. D. (2005). "Pennsylvania Community Watershed Organizations: Form and Function." PhD dissertation, School of Forest Resources, Pennsylvania State University, University Park, PA.
Levi, M. A. (2013). Reply to "Reply to 'Comment on "Hydrocarbon emissions characterization in the Colorado Front Range - A Pilot Study"' by Michael A. Levi" by Gabrielle Pétron et al. *Journal of Geophysical Research: Atmospheres*, *118*(7), 3044–3046. doi:10.1002/jgrd.50299
Lipscomb, C., Wang, Y., & Kilpatrick, S. (2012). Unconventional Shale Gas Development and Real Estate Valuation Issues. *The Review of Regional Studies*, *42*, 161–175.
Liss, J. (2011). Negotiating the Marcellus : The Role of Information in Building Trust in Extractive Deals. *Negotiation Journal*, (October 2011), 419–446.
Malin, S. (2013). There's no real choice but to sign: neoliberalization and normalization of hydraulic fracturing on Pennsylvania farmland. *Journal of Environmental Studies and Sciences*, 1–11. doi:10.1007/s13412-013-0115-2
Marcus, P. (2013, July 29). "Fractivists" target chief oil&gas regulator. *The Colorado Statesman*. Retrieved from http://www.coloradostatesman.com/content/994284-%3Ffractivists%3F-target-chief-oil-gas-regulator
Mershon, S., & Palucka, T. (2012). *A Century of Innovation: From U.S. Bureau of Mines to the National Energy Technology Laboratory*.
McKenzie, L. M., Witter, R. Z., Newman, L. S., & Adgate, J. L. (2012). Human health risk assessment of air emissions from development of unconventional natural gas resources. *Science of the Total Environment*, 79–87. doi:10.1016/j.scitotenv.2012.02.018
Miller, R. E., & Blair, P. D. (2009). *Input-output analysis: foundations and extensions*. Cambridge University Press.
Myers, T. (2012). Potential contaminant pathways from hydraulically fractured shale to aquifers. *Ground water*, *50*(6), 872–82. doi:10.1111/j.1745-6584.2012.00933.x

Nelson, B. P. H., & Santus, S. L. (2011). *Gas, Oil, and Water Production from Wattenberg Field in the Denver Basin, Colorado*. Reston, VA.
Osborn, S. G., Vengosh, A., Warner, N. R., & Jackson, R. B. (2011). Methane contamination of drinking water accompanying gas-well drilling and hydraulic fracturing. *Proceedings of the National Academy of Sciences of the United States of America*, *108*(20), 8172–6. doi:10.1073/pnas.1100682108
Osborn, S. G., Vengosh, a., Warner, N. R., & Jackson, R. B. (2011b). Reply to Saba and Orzechowski and Schon: Methane contamination of drinking water accompanying gas-well drilling and hydraulic fracturing. *Proceedings of the National Academy of Sciences*, *108*(37), E665–E666. doi:10.1073/pnas.1109270108
Pearce, M. (2013, September 19). Environmental toll compounds the troubles in flooded Colorado. *Los Angeles Times*. Retrieved from http://articles.latimes.com/2013/sep/19/nation/la-na-colorado-floods-20130920
Penningroth, S. M., Yarrow, M. M., Figueroa, A. X., Bowen, R. J., & Delgado, S. (2013). Community-based Risk Assessment of Water Contamination from High-volume Horizontal Hydraulic Fracturing, *23*(1), 137–166.
Perry, S. L. (2013). Using Ethnography to Monitor the Community Health Implications of Onshore Unconventional Oil and Gas Developments: Examples from Pennsylvania's Marcellus Shale. *New solutions : a journal of environmental and occupational health policy : NS*, *23*(1), 33–53. doi:10.2190/NS.23.1.d
Perry, S. L. (2012). Development, Land Use, and Collective Trauma: The Marcellus Shale Gas Boom in Rural Pennsylvania. *Culture, Agriculture, Food and Environment*, *34*(1), 81–92. doi:10.1111/j.2153-9561.2012.01066.x
Pétron, G., Frost, G., Miller, B. R., Hirsch, A. I., Montzka, S. a., Karion, A., … Tans, P. (2012). Hydrocarbon emissions characterization in the Colorado Front Range: A pilot study. *Journal of Geophysical Research*, *117*. doi:10.1029/2011JD016360
Pielke, R. (2007). *The honest broker: making sense of science in policy and politics*. Cambridge: Cambridge University Press.
Power, T.M. 1996. Lost Landscapes and Failed Economies: The Search for a Value of Place. Washington, DC: Island Press.
Renn, O., & Levine, D. (1991). Trust and credibility in risk communication. In R. E. Kasperson & P. J. M. Stallen (Eds.), Communicating risks to the public (pp. 175-218). Norwell, MA: Kluwer Academic.
Renner, R. (2009). Spate of gas drilling leaks raises Marcellus concerns. *Environmental science & technology*, *43*(20), 7599. doi:10.1021/es9025563
Ridder, B., & Carlson, K. (2013). Regional Real-time Monitoring of Oil and Gas Operations.
Robbins, P., Meehan, K., Gosnell, H., & Gilbertz, S. J. (2009). Writing the New West: A Critical Review. Rural Sociology, 74(3), 356-382.
Rozell, D. J., & Reaven, S. J. (2012). Water pollution risk associated with natural gas extraction from the Marcellus Shale. *Risk analysis : an official publication of the Society for Risk Analysis*, *32*(8), 1382–93. doi:10.1111/j.1539-6924.2011.01757.x
Rubino, J. (2012, December 13). With Disputes on hand, anti-fracking forces remain civil at Boulder County hearing. *Daily Camera*. Boulder, CO. Retrieved from http://www.dailycamera.com/ci_22186936/boulder-county-fracking-vote-protests
Saba, T., & Orzechowski, M. (2011). Lack of data to support a relationship between methane contamination of drinking water wells and hydraulic fracturing. *Proceedings of the National*

Academy of Sciences of the United States of America, *108*(37), E663; author reply E665–6. doi:10.1073/pnas.1108435108
Saberi, P. (2013). Navigating Medical Issues in Shale Territories. *New Solutions*, *23*(1), 209–221.
Sachs, J. D. and A. M. Warner, "The Curse of Natural Resources," European Economic Review 45 (2001): 827:838, doi: 10.1016/S0014-292(01)00125-8.
Sachs, J. D. and A. M. Warner, "Natural Resource Abundance and Economic Growth," National Bureau of Economic Research Working Paper 5398 (1995).
Santoro, R.L., Howarth, R.H., and Ingraffea, A. R. (2011). *Indirect Emissions of Carbon Dioxide from Marcellus Shale Gas Development: A Technical Report from the Agriculture, Energy, & Environment Program at Cornell University*. Ithaca.
Scamehorn, L. (2002). *High Altitude Energy*. Coulder, Colorado: University Press of Colorado.
Skone, T. (2011). *Life Cycle Greenhouse Gas Inventory of Natural Gas Extraction, Delivery and Electricity Production*. Washington, DC.
Stedman, R., Lee, B., Brasier, K., Weigle, J. L., & Higdon, F. (2009). Cleaning Up Water? Or Building Rural Community? Community Watershed Organizations in Pennsylvania. *Rural Sociology*, *74*(2), 178–200. doi:10.1111/j.1549-0831.2009.tb00388.x
Steinzor, N., Subra, W., & Sumi, L. (2013). Investigating Links Between Shale Gas Development and Health Impacts Through a Community Survey Project in Pennsylvania. *New solutions : a journal of environmental and occupational health policy : NS*, *23*(1), 55–83.
Stevens, P., 2003. Resource impact: curse or blessing? A literature survey. J. Energy Lit. 9 (1), 1–42.
Throupe, Ronald L., Robert Simons, and Chen Huo. (2012) "An Exploration of Hydro 'Fracking' and Real Estate Effects." Unpublished paper presented at the American Real Estate Society Annual Meetings, St. Petersburg, FL, April 18-22.
Travis, W. R. (2007). *New geographies of the American West: land use and the changing patterns of place*. Island Press.
Trembath, A. et. a. (2012). *WHERE THE SHALE GAS REVOLUTION CAME FROM: Government's Role in the Development of Hydraulic Fracturing in Shale*. Retrieved from http://thebreakthrough.org/energy.shtml
U.S. Department of Energy (USDOE). (2013). *Technically Recoverable Shale Oil and Shale Gas Resources: An Assessment of 137 Shale Formations in 41Countries Outside the United States*. Retrieved from http://www.eia.gov/analysis/studies/worldshalegas/pdf/fullreport.pdf
U.S DOE. (2013). *Modern Shale Gas Development in the United States: An Update* (pp. 1–79).
Venkatesh, A., Jaramillo, P., Griffin, W. M., & Matthews, H. S. (2011). Uncertainty in life cycle greenhouse gas emissions from United States natural gas end-uses and its effects on policy. *Environmental science & technology*, *45*(19), 8182–9. doi:10.1021/es200930h
Victor, D. G., Jaffe, A. ., & Hayes, M. H. (2006). *Natural Gas and Geopolitics From 1970 to 2040*. Cambridge University Press.
Warner, N. R., Jackson, R. B., Darrah, T. H., Osborn, S. G., Down, A., Zhao, K., … Vengosh, A. (2012). Geochemical evidence for possible natural migration of Marcellus Formation brine to shallow aquifers in Pennsylvania. *Proceedings of the National Academy of Sciences of the United States of America*, *109*(30), 11961–6. doi:10.1073/pnas.1121181109
Weber, J. G. (2012). The effects of a natural gas boom on employment and income in Colorado, Texas, and Wyoming. *Energy Economics*, *34*(5), 1580–1588. doi:10.1016/j.eneco.2011.11.013
White, N. E. (2012). A Tale of Two Shale Plays. *The Review of Regional Studies*, *42*, 107–119.
Winkler, R., D.R. Field, A.E. Luloff, R.S. Krannich, and T. Williams. 2007. ''Social

Landscapes of the Intermountain West: A Comparison of 'Old West' and 'New West' Communities.'' Rural Sociology 72(3):478–501.
Wobbekind, Richard, Lewandowski, Brian, E. (2011). *ASSESSMENT OF OIL AND GAS INDUSTRY ECONOMIC AND FISCAL IMPACTS IN COLORADO IN 2010*. Boulder.
Zaffos, J. (2013, September 2). Front Range drilldown. *High Country News*. Paonia. Retrieved from http://www.hcn.org/issues/45.15/front-range-drilldown/view

Appendix I

Appendix I. Fracking related Measures passed across the Front Range of Colorado in 2013

City	Measure	Percent Votes
Lafayette	Question 300: Ban	60%
Fort Collins	Issue 2A: 5-Year Fracking Moratorium	56%
Broomfield	Question 300: 5-year Fracking Suspension	50% (20 vote margin)
Boulder	2H: 5-year Moratorium on Drilling and Fracking	78%

Appendix II

Appendix II. 2013 state regulations proposed in Colorado. Source: COGCC Rules and Regulations: Definitions. May 1, 2013

Topic	Description	Pass?	Bill or Rule Number
Setbacks	A Buffer Zone Setback (1,000 feet), Exception Zone Setback (500 feet), within one thousand (1,000) feet of a High Occupancy Building Unit, or within three hundred fifty (350) feet of a Designated Outside Activity Area, as referenced in Rule 604	Yes	HB 13-1278
Spills	"If one barrel or more of oil or exploration and production waste is spilled outside of berms or other secondary containment, the spill shall be reported within twenty-four hours after the discovery of the spill, to: (a) the commission; and (b) the entity with jurisdiction over emergency response within the local municipality"	Yes	HB 13-1278
Baseline Water Samples	> Initial baseline samples and subsequent monitoring samples shall be collected from all Available Water Sources, up to a maximum of four (4), within a one-half (1/2) mile radius of a proposed Oil and Gas Well, Multi- Well Site, or Dedicated Injection Well. If more than four (4) Available Water Sources are present within a one-half (1/2) mile radius of a proposed Oil and Gas Well, Multi-Well Site, or Dedicated Injection Well	Yes	
Chemical Disclosure	The Rule requires disclosures to FracFocus within 60 days of the conclusion of a hydraulic fracturing treatment, and in no case more than 120 days following the commencement of a hydraulic fracturing treatment.	Yes	205A
Baseline Water Samples: Wattenburg Exemption	Requirement of oil and gas companies in the Greater Wattenburg Area to abide by the same groundwater testing regimes as the rest of the state	No	HB 1316
Reorganization of COGCC Comission	Change the mission of the COGCC and reorganizes the makeup of the nine-member commission	No	HB 1269
Oil and Gas Accident Fines	To increase fines for spills and other environmental mishaps	No	HB 1267