Impact Fees for Covering the Fiscal Costs of Oil and Gas Development

A Conservation Economics Institute Report

by

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Executive Summary

Impact fees have a long history in promoting sustainable community development by internalizing external costs such as the loss of open space and the increased truck traffic that compromises local public infrastructure. The rise in the popularity of impact fees coincides with a long-term decline in federal and state funding. The two basic approaches to setting impact fees are the average-cost pricing method that sets a flat connection fee and a marginal cost pricing system. The legal challenges to impact fees center on proportionality and the rational nexus test. The impact fee must be proportional to the increase in the costs associated with increased truck traffic, for example. And the impact fee revenue must be used to repair the roads. Impact fees represent a potential economic tool for collecting additional compensation to cover the fiscal and external costs to local taxpayers not covered by severance taxes, and property tax revenues and royalty payments.

When examining net fiscal impacts from oil and gas development, economists have primarily focused on marginal increases in staff time and salaries and road maintenance costs. When these costs are considered, net fiscal impacts for local governments can be positive, neutral or negative. Research has found the results vary widely with the pace and scale of oil and natural gas development, population density, and tax policy.

However, local governments incur additional fiscal costs that heretofore have not been considered in research on net fiscal impacts. A full accounting of the cumulative fiscal costs associated with oil and natural gas development include: 1) the additional costs of hiring inspectors, collecting baseline data, monitoring air and water quality; 2) planning, legal and research costs; 3) the legacy fiscal costs from orphaned and abandoned wells, plugged and reclaimed wells and pipelines; and 4) the change in property and home values. Internalizing all these fiscal costs is essential for promoting efficient and responsible oil and natural gas development.

While the impact fees to date are primarily for recovering road costs and paying for wastewater infrastructure, there is no reason impact fees cannot be extended to cover the fiscal costs of collecting baseline data on orphaned and abandoned wells and for paying for applied research for a better understanding of net fiscal impacts.

Impact fees can also be extended to cover public health, air and water pollution, as well as other environmental costs associated with oil and gas development. Therefore, it is reasonable and necessary to allow time for communities to budget in the costs to collect baseline data and design research methods that produce legally defensible estimates of the marginal fiscal, public health and environmental costs associated with oil and gas development.

Local governments exploring the use of impact fees would do well to keep legal concepts around proportionality and the rational nexus test in mind when designing methods and studies for estimating the costs associated with oil and gas development. This is true whether the research is for estimating impact fees for road costs, traffic congestion, public health costs, loss of property values, legacy fiscal costs or environmental externalities.

A review of the economic research indicates one of the largest fiscal costs are the legacy costs from old oil and natural gas wells. Studies find that: 1) well depth is positively correlated with reclamation costs; and 2) bonding requirements by federal and state agencies often fail to cover reclamation costs. For Colorado, with an estimated per well legacy cost of $11,000, taxpayers could be facing upwards of $500 million in legacy costs from the state's current inventory of over 50,000 oil and natural gas wells.

By taking responsibility for addressing the legacy costs from past drilling, the oil and natural gas industry will mitigate the environmental effects of abandoned wells, restore disturbed drill sites to productive agricultural and recreational uses, possibly enhance oil and gas recovery from future wells, and help retain its social license to operate.

Key Recommendations:

- Local governments should explore charging impact fees on oil and gas development to help cover all of the fiscal costs and negative externalities that are not currently covered by severance taxes, property taxes and royalty payments.
- The use of impact fees can be extended to cover the full accounting of costs, including the fiscal costs of collecting baseline data and paying for research, and the public health costs from air and water pollution.
- States should examine the costs and benefits of charging a per well impact fee to pay for the legacy fiscal costs associated with plugging and reclaiming orphaned and abandoned wells.
- Local and state governments would do well to keep legal concepts around proportionality and the rational nexus test in mind when designing fair and accurate impact fees.

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Introduction

In the last 20 years, the pace and scale of oil and natural gas drilling in the U.S. has increased. As oil and natural gas drilling, production and distribution move closer to human population centers, the potential for human health damages from air pollution increases (McKenzie et al. 2012, Garcia-Gonzales et al. 2019). Czolowski et al. (2017) estimate that 17.6 million Americans live within approximately 1 mile of at least one active oil and/or gas well. In Colorado, McKenzie et al. (2016) estimate that at least 378,000 Coloradans live within 1 mile of an active oil and gas well, with the number growing at a faster rate than the overall population. The increase in oil and gas drilling near communities has led to a growing list of complaints from local residents about air, water and noise pollution and the associated public health and environmental damages.

In addition to concerns over pollution and human health, a less obvious worry is the fiscal health of communities. While the oil and gas industry does generate severance and property tax revenue and royalty payments, one question rarely asked is whether the additional revenue covers the additional fiscal costs to communities and counties. What has been missing from the fiscal calculus is a full accounting of the direct and indirect costs to taxpayers associated with oil and gas development (Morton, Kerkvliet and Hjerpe 2015). A reasonable and necessary question to ask is: When all additional fiscal costs are properly counted, are the net revenues from oil and gas development positive, zero, or negative? As all businesses know, you can't just talk about revenue without talking about the costs associated with generating revenue. Gaining a better understanding of the net fiscal revenue from oil and gas is important since government revenue coming from oil and gas is viewed by Colorado stakeholders as the benefit with the highest level of agreement (Heikkila and Weible 2015).

A full accounting of the cumulative fiscal costs directly and indirectly related to oil and natural gas development is needed in order to accurately estimate net fiscal revenue. Local governments and stakeholders need a better understanding of the full accounting of fiscal costs involved in implementing responsible oil and gas development including: planning, legal and research costs, road and infrastructure costs, monitoring baseline data and enforcement costs, potential declines in property values, and the legacy fiscal costs from orphaned and abandoned wells.

Local governments have already turned to impact fees as a source of additional revenue to cover the road repair and maintenance costs from heavy truck traffic associated with oil and gas development. As the increase in fiscal costs to local governments become more apparent, we expect a growing interest in the use of impact fees. Revenue from impact fees may be needed to pay for the increase in fiscal costs not currently covered by royalty payments, severance taxes and the sales tax revenue generated by the oil and gas industry. Overall, our intent is to provide useful information for communities to make more informed decisions about the potential role of impact fees for promoting more efficient and responsible oil and gas development in Colorado and elsewhere.

We begin with a synthesis of the literature on impact fees used in promoting sustainable community development. We then review the emerging literature on net fiscal impacts to local governments from oil and natural gas development. We follow this with a more complete accounting of the fiscal costs from implementing efficient and responsible oil and gas development, with an in-depth look at the legacy fiscal costs passed forward to future generations when bonding requirements fail to cover the costs of plugging and reclaiming orphaned and abandoned oil and gas wells. We end with a summary and discussion on the potential role of impact fees for implementing more efficient and responsible oil and gas development.

Sustainable Community Development and Impact Fees

Sustainable community development can be defined as construction projects that do not impose external costs on third parties in the present or the future (Burge and Ihlanfeldt 2013). The authors define five categories of development-related external costs: non-conforming land use; decreases in open space amenities; congestion-related negative externalities;[1] compromised local public infrastructure; and degraded local environmental quality.

Recognition of these costs, combined with the challenge of passing new taxes, has led local communities and counties to turn to impact fees as revenue sources to pay for the direct and indirect costs of growth. The economic premise for impact fees is simple: development should pay the full marginal cost of providing facilities necessary to accommodate growth (Libby and Carrion 2004).

Based on past experiences, local governments have learned that the cost to taxpayers of providing a residential unit with new or expanded public facilities range from $20,000 to $100,000 or more per new home (Nelson et al. 2017). The question communities face is who should pay for the cost of growth: the new residents by using impact fees, or new and current residents through higher taxes (Libby and Carrion 2004)?

Given public sentiment against voting for higher taxes, impact fees which are set by local governments are now institutionalized as a financial tool for: 1) placing responsibility for the increase in marginal costs on developers and new residents rather than spreading the costs to existing residents; and 2) managing the scale of growth and the pace of development (Coutts et al. 2015).[2]

Texas adopted the first general impact fee enabling act in 1987 and since that time 29 states have also adopted impact fee enabling legislation (Mullen 2015). While most state acts are clear that impact fees should pay for the cost of improvements that are reasonably related to its impacts, not all of them are clear on what this means. According to (Mullen 2015):

> One of the things it should mean is that impact fees should not charge new development for a higher level of service than is provided to existing development. If the fees are based on a higher level of service

> provided to existing development in the community, other funding must be identified to remedy the existing deficiencies. This principle is expressed colloquially in the saying, "impact fees should not be used to pay for the sins of the past" (page 2).

Colorado's 2001 impact fee legislation included the following in this regard: "No impact fee or other similar development charge shall be imposed to remedy any deficiency in capital facilities that exists without regard to the proposed development." (Sec. 29-20-104.5(2), Colo. Rev. Stat.).[3] Facilities eligible for impact fees under current law in Colorado include: roads, water, sewer, stormwater, parks, fire, police, library, solid waste (Mullen 2015).

Impact Fees and Economic Efficiency

The rise in the popularity of impact fees coincides with a long-term decline in federal and state funding – as more and more fiscal responsibility is being passed to local governments (Bauman and Ethier 1987, Nelson et al. 2017). Impact fees have been used to help pay for the marginal increase in infrastructure costs, and to internalize the negative externalities associated with new home development (Nelson et al. 2017).

Impact fees empower local governments to correct for development-driven negative externalities while still retaining the benefits of the market pricing mechanism (Burge and Ihlanfeldt 2013). Examples of

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development negative externalities include increased traffic and congestion and loss of open space. Based on a review of the academic literature, Nelson and Moody (2003) conclude that paying for infrastructure with impact fees improves economic efficiency and ensures the direct and indirect benefits flow to those who pay them. According to the authors, the direct economic benefits include infrastructure investments, such as new roads, new schools, and new water and sewer extensions. Indirect benefits include improved predictability in the marketplace, knowing when and where infrastructure investment will occur, and equitable treatment of developers.

While impact fees began as small supplementary sources of revenue, they have become a much larger revenue source. The debate has also shifted from whether or not impact fees should be assessed to the methods used in the determining the appropriate level of fees (Nelson et al. 2017). The two basic methods for setting impact fees are the average-cost pricing method that sets a flat connection fee and a marginal cost pricing system (Carrion and Libby 2004). Marginal cost pricing method consists of several parts: 1) capital costs (e.g. new water treatment plant); 2) the costs of delivering the new service (e.g. the costs of connections or extensions); and 3) a charge for actual use based on the short-run costs of producing the service.

Chalfant (2018) documents the history of stormwater impact fees used to fund the operation, maintenance, and/or capital improvement of stormwater infrastructure by 1,600 local governments in 40 states since the mid-1960s. The most common method for calculating stormwater impact fees is based on the areal extent of impervious surfaces. This method uses a marginal cost basis for setting fees by estimating the amount of runoff generated from a parcel and approximates additional demands (i.e. marginal costs) placed on stormwater infrastructure and services.

Impact Fees and Legal Issues

A local government's authority to charge impact fees originates from the state's police power to regulate development for the public's health, safety, or general welfare, while the more restricted taxing power is for the express purpose of raising general revenue (Bauman and Ethier 1987). Despite their acceptance by public officials and community planners, impact fees remain controversial as they raise several constitutional issues including equal protection, due process, and the taking of private property without just compensation (Libby and Carrion 2004).

In general, impact fees may be permissible if they do not violate the “unconstitutional conditions” doctrine – i.e. government should not use its regulatory powers to coerce individuals or companies into giving up constitutional protections. A road impact fee, for example must bear an “essential nexus” to a legitimate public interest and be “roughly proportional” to the projected impact (Dundon 2017).

Impact fees to pay for housing development have a history filled with lawsuits from which an extensive body of case law has been developed (Mantz and Thomas 2012). With respect to the constitutionality of assessing impact fees, three nexus tests have emerged from case law (Libby and Carrion 2004):

> The reasonable relationship test is based on California exaction practices and requires that there is a reasonable connection between the fee charged to the developer and the needs generated by that development.
>
> The specifically and uniquely attributable test requires that the fee charged to the developer is attributable to that development.
>
> The rational nexus test states that there must be a proportionality between the amount charged to the developer and the type and amount of facilities demand generated by the development and that there be a reasonable connection between the use of the fees and the benefits produced for the new development (Libby and Carrion 2004; Page 2).

The primary legal challenge to date for impact fee programs has been passing the rational nexus test. Specifically, the rational nexus test requires a clear connection between new growth and the marginal (additional) costs; fees must be proportional to the marginal costs of providing the enhanced services, and the new development must benefit directly from the spending (Burge and Ihlanfeldt 2013).

Evans-Crowley (2006) provides an excellent overview of impact fees including legal concerns, methods and example calculations from the City of Albuquerque, New Mexico.   Albuquerque calculated impact fees for drainage, parks, public safety, and roadway facilities. The author concludes that the city's impact

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fee program met the rational nexus test by connecting impacts and benefits using appropriate methodology that links the impacts of new development with the needed infrastructure improvements.

For best success in the courtroom, local governments exploring the use of impact fees to pay for housing and commercial development would do well to keep proportionality and the rational nexus test in mind when designing methods for estimating fair and accurate impact fees.

Oil and Gas Development and Impact Fees

Local governments are on the front line in managing the fiscal costs, the noise and traffic congestion, loss of open space as well as the public health impacts associated with unconventional oil and natural gas development. Although oil and gas drilling can create jobs and income, it also creates challenges for local governments which bear substantial responsibility for public infrastructure, human services, public safety (Christopherson and Rightor 2012, Kelsey 2014, Zwick 2018). Many communities are simply unprepared to handle the fast pace and large scale of this industry (Haefele and Morton 2009, Krupnick et al. 2017).

In response to the increase in drilling for unconventional oil and gas, local governments have experienced an increase in spending (Weber and Harleman 2015). Recent research on fiscal costs has primarily focused on increased staff time and the increased costs for road repairs and maintenance.

Road Impact Fees

A review of the literature indicates that one of the largest marginal fiscal costs from oil and gas development to local governments are those related to increases in heavy truck traffic (Krupnick et al. 2017). Dundon (2017) reviewed studies on truck traffic from unconventional oil and gas development, and found estimates ranging from 1,184 to 3,399 truck trips per well. The costs associated with the increase in heavy-truck traffic - road damage, traffic accidents, congestion, air pollution, and safety concerns -- are well documented (Gilmore 2013, Abramzon et al. 2014, Graham et al. 2015, Patterson and Maloney 2016, Muehlenbachs et al. 2017).

Abramzon et al. (2014) estimated roadway damages based on a "consumptive use cost" from heavy truck traffic associated with shale gas development in Pennsylvania. The authors combined estimates of the total number of heavy truck trips required per well and roadway life and reconstruction costs by roadway maintenance class. The results indicate a roadway consumptive use fee from the additional heavy truck traffic of $13,000- $23,000 per well for all state roadway types, or $5,000-$10,000 per well if state roads with the lowest traffic volumes are excluded (Abramzon et al. 2014).

Often the roads most negatively impacted by heavy truck traffic are local and county roads outside of the federal or state system. These roads are typically built to handle smaller volumes of traffic (Dundon 2017).[4] In contrast, state and federal highways generally receive revenue from state gas taxes and the federal government, and are better constructed to withstand heavy truck traffic. Bottom line: Local governments that do not get a share of state and federal revenues have less money for road maintenance and repair.

Given these fiscal constraints combined with increasing costs, local governments have turned to impact fees as a source of additional revenue to cover increased marginal road costs associated with oil and gas development. Rio Blanco County in Colorado enacted an oil and gas impact fee of $18,000 per well to help cover road costs (Zwick 2018). Greeley, Colorado also charges an impact fee based on the estimated road costs associated with each well within city limits (Raimi and Newell 2017).

An engineering report completed for Boulder County (2011) estimated the additional wear and tear from the truck traffic associated with additional drilling directly cost taxpayers $33,000-$45,000 per well. Based on this study, Boulder County adopted an Oil and Gas Road Deterioration and Roadway Safety Fee, which is designed to recoup the incremental costs from oil and gas development to the County transportation system (Boulder County 2013).

Per Well Impact Fees and Effective Severance Tax Rates

In 2012, after public outcry over the environmental and public costs from drilling for unconventional natural gas, the state of Pennsylvania authorized an impact fee on each unconventional gas well. To account for past damage, the state applied the impact fee retroactively to all existing unconventional gas wells (Black et al. 2018).

Pennsylvania's per well impact fee is based in part on a well's annual production, with adjustments based on the type and age of well, and the price of natural gas.[5] The impact fee decreases in a stepwise fashion as the well ages over a 15-year period. Assuming natural gas prices between $3.00 and $4.99 per thousand cubic feet, in the first year a well is drilled, the impact fee is $50,000. In year 2 and 3 the fee is $40,000 and $30,000 respectively, and so on (Raimi and Newel 2014).[6] The fee for vertical wells is 20 percent of the amount for horizontal wells.

If the operator fails to pay the impact fee on time, new drilling permits are withheld, permits for existing wells are suspended and interest charges and monetary penalties may be imposed (Asif-Ehsan 2016). In addition to authorizing the state impact fee, Pennsylvania's legislature expanded the zone of presumed liability for well operators, required disclosure of fracturing fluids, increased civil fines, and made bond requirements higher and conditional on well-bore length (Black et al. 2018).[7]

Proceeds from Pennsylvania's impact fee are distributed to local governments and state agencies to provide for local infrastructure projects, emergency services, environmental initiatives such as recreation trails and open space and various other programs. Local governments receive funds based on the number of wells located within their boundaries or their proximity to jurisdictions where natural gas extraction takes place (Pennsylvania Independent Fiscal Office 2019).

In 2018, 56% of the Pennsylvania's impact fee revenue went to local governments, 37% went to the Marcellus Legacy fund, 4% went to commonwealth agencies, and 3% went towards conservation (Pennsylvania Public Utility Commission 2016, Pennsylvania Independent Fiscal Office 2019). The Marcellus Legacy Fund supports the remediation of abandoned wells and infrastructure investments. All counties can receive disbursements from the Legacy Fund, regardless of whether they contain wells (Weber and Harleman 2015).

Weber and Harleman (2015) document the value of Pennsylvania's impact fee as a revenue-sharing policy that helps local residents from bearing all of the external costs from shale development. The authors do not estimate whether the revenues to communities actually cover the increase in marginal fiscal costs from oil and gas development, but they do find that without the revenue from the per well impact fee, municipalities in high drilling areas would have exhausted their pre-drilling fund balances in less than three years.

It is important to note that Pennsylvania does not collect severance taxes. The Pennsylvania

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Independent Fiscal Office (2019) translated the impact fee into an annual average effective tax rate in order to quantify the implicit severance tax burden imposed by the impact fee in a given year.

An effective severance tax rate is computed by dividing total severance tax payments by the value of production. The value of production is estimated by multiplying total production by the market price of the oil or gas produced. Effective severance tax rates are particularly useful because they account for the tax incentives and deductions granted to oil and gas producers (Gerking et al. 2000). Effective severance tax rates are lower than statutory severance tax rates because they fully account for all applicable tax breaks and deductions granted the oil and gas industry.

In order to calculate the effective tax rate for Pennsylvania's impact fee, annual fee revenues are divided by the total value of unconventional natural gas production.[8] Between 2014 and 2018, the annual effective tax rate in Pennsylvania fluctuated between 2.2% and 6.3 % - with the price of natural gas being the dominant factor influencing the variations in the effective tax rate (Pennsylvania Independent Fiscal Office 2019). In comparison, Colorado has a much lower effective severance tax rate. Silbaugh (2018) estimates the effective severance tax rate in Colorado ranged from 2.1% in 2008 to a low of 0.2% in 2015.

Road Impact Fees and Legal Issues

While road and traffic impacts generated by development are well within the realm of permissible impacts local governments can address (Been 1991), impact fees have met with legal challenges when applied to the oil and gas industry. The legal issues with impact fees for oil and gas development are similar to the ones for impact fees for home and commercial development: proportionality and the rational nexus test. Is the impact fee proportional to the marginal increase in the direct and indirect costs associated with heavy truck traffic which occurs as part of oil and gas development? Will the impact fee revenue be used to repair the roads?

Dundon (2017) documents the efforts of the City of Arlington, Texas to impose a road damage fee based on the costs of road repairs due to oil and gas truck traffic. The road damage impact fee is calculated based on the replacement costs for asphalt and/or concrete road segments determined from current cost per square yard of road surface material, including installation and labor. Industry challenged Arlington's ordinance, but the road damage fee and permitting requirements remain.[9]

Net Fiscal Impacts from Oil and Gas Development

Industry's historical social license to operate is based in part on its economic contribution to local and state economies. In addition to jobs, oil and gas development directly and indirectly contributes revenue to local governments. Sources of direct revenue include: 1) ad valorem property taxes on oil and gas property and production; 2) portions of state severance taxes sent to local governments; and 3) lease bonuses and royalties from oil and gas development on public land. Indirect revenues include sales taxes from population growth and increased economic activity. (Raimi and Newell 2016).

The question at hand is whether the current sources of revenue are sufficient to cover the increase in fiscal costs in order to generate net positive or zero fiscal impacts for local governments? If not, how much additional revenue is needed to cover the costs to local governments of implementing efficient and responsible oil and gas development? Economic research examining the net fiscal impacts from oil and gas development have found mixed results.

Recent research on fiscal costs has primarily focused on increased staff time and salaries and the increased costs for road repairs and maintenance. Newel and Raimi (2018) combined surveys and analysis of local costs and revenues and found that 74% of local governments experienced positive net fiscal impacts, 14% reported neutral impacts, and 12% reported negative fiscal impacts. Results vary widely due to the pace and scale of activity, population density, and tax policy. In addition, there are fiscal costs such as declines in property value and legacy costs from abandoned wells, that Newel and Raimi (2018) did not consider. When the added fiscal costs are counted, the percentage of local governments that actually have positive net fiscal impacts may be lower. To improve future fiscal outcomes, the authors recommend that local officials plan for impacts, state policymakers re-examine revenue policies, and operators pursue collaborative agreements with local governments.

Krupnick et al. (2017) provide a comprehensive review of the economic literature on net fiscal impacts. The methods to assess local fiscal impacts in the studies reviewed include: 1) analyzing local and/or state revenue data, local and state laws, and methods of distributing revenues within various jurisdictions; 2) conducting surveys of local governments; 3) interviewing local officials; and 4) econometric analysis to estimate the effective tax rate. Their findings indicate that in general municipalities and counties are able to meet the increased demand for services and increased costs related to shale development, but that rapid development can cause problems.

Raimi and Newell (2017) examined the effects of lower oil prices on the fiscal conditions of local governments in five key regions (the Bakken, Denver-Julesburg, Eagle Ford, Marcellus, and Permian basins). In general, they found that fiscal conditions had generally improved. However, revenue volatility presents a major challenge for many local governments. The authors note: "…economic diversification is a priority for most local officials, achieving this goal will be difficult, particularly for rural communities that are or have become heavily dependent on the oil and gas sector."

Colorado Case Studies

In Colorado, Raimi and Newell (2016) examined the fiscal effects of oil and gas development for two Western Slope Counties: Garfield and Rio Blanco Counties; and two communities: Grand Junction and Rifle. Garfield and Rio Blanco counties rely heavily on taxes on oil and gas property, which includes surface equipment as well as the oil and gas produced (Raimi and Newell 2016, 2017). In these two counties, oil and gas properties provide more than half of county property tax revenues.

Garfield County has experienced a rapid increase in property tax revenues from oil and gas development creating large fiscal benefits. In contrast, the revenues in Rio Blanco County, including the increase in revenues from the County's per well impact fee, did not keep pace with the marginal increase in the costs of new service demands. Rio Blanco County officials estimate that needed road repairs would cost over $100 million -- more than twice Rio Blanco County's annual revenues (Raimi and Newell 2016).

The communities of Rifle and Grand Junction also had contrasting fiscal experiences. Rifle's limited infrastructure coupled with a rapidly growing population created fiscal challenges. As the drilling bust set in, many of the fiscal challenges subsided, but the rosy economic impact projections made during the drilling boom proved too optimistic. As a result, Rifle overbuilt its water and wastewater systems, saddling residents with large new capital costs (Raimi and Newell 2016). In contrast, Grand Junction has a more diverse economy and the new demands for service and new revenues associated with oil and gas industry were smaller relative to Rifle, but appears to have helped Grand Junction rebound from the recession of 2008-09.

On the Front Range of Colorado, Weld County and the City of Greeley have done quite well fiscally. Property taxes are the leading revenue source for Weld County, making up roughly half of annual revenues, with oil and gas constituting roughly two-thirds of countywide assessed value. Oil and gas development continue to have a net positive fiscal impact for Greeley (Raimi and Newell 2017).

The challenges for the Town of Eaton associated with Colorado's taxpayer bill of rights (TABOR) are worth highlighting. An increase in property tax valuations largely driven by oil and gas development triggered a decline in the property tax rate. However, when prices dropped and oil and gas valuations declined, the city would need unlikely voter approval to increase property tax rates to maintain a consistent level of revenue. Local officials estimate that because

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of the TABOR-lowered tax rate, Eaton has lost roughly $130,000 in annual revenues (Raimi and Newel 2017). To make fiscal budgeting matters worse, due to dropping prices, severance tax revenue for Eaton declined from a peak of $216,000 in 2015 to $113,000 in 2016. Similar declines in severance tax revenue occurred in other communities – underscoring the fiscal risks – especially for small communities -- from being too dependent of oil and gas revenues.

In other Colorado Front Range counties and communities examined by Raimi and Newell (2017), oil and gas development has had a limited fiscal impact because local governments along the Front Range do not rely heavily on oil and gas revenues and they represent a small part of fiscal budgets. Based on their interviews with local officials in Colorado's Front Range, Raimi and Newel (2017) reported local problems with workforce retention while at the same time an increase in the demand for law enforcement. Local officials also voiced concerns that the dense and growing network of oil and gas infrastructure, such as wellheads and pipelines could restrict future growth of residential and commercial property in the coming decades, leading to foregone property and incomes taxes from future development. In other words, the opportunity costs associated with oil and gas development need to be considered.

Recent research supports the concern voiced by local officials in Colorado as the fiscal impacts to local governments extend far from well pads to include pipelines. Simons et al. (2017) in a case study examining the fiscal impacts from a proposed pipeline route in Ohio concluded that the city of Green would disproportionately bear the burden of anticipated economic losses and reduction in tax revenue associated with the pipeline. The authors project over a 50-year period, the pipeline will cause fiscal losses of over $52 million, primarily from foregone property and income taxes from future development.

Lessons Learned

One of the lessons learned from Raimi and Newell's body of research is that the net fiscal impacts from oil and gas development are not uniform across counties or across communities in the state of Colorado. The variation in fiscal risks is especially relevant for small and geographically isolated communities with limited infrastructure experiencing rapid population growth. Collecting baseline data on pre-development conditions is important for understanding how local government finances might be impacted by development (Raimi and Newell 2016).

While Newel and Raimi (2018) largely focused on road maintenance costs and increased staff time, there are additional fiscal costs associated with implementing oil and gas development that should be counted. Obviously, more data collection and applied economic research is needed. What can be done to improve the fiscal outcomes for local governments? Can revenue be increased to reduce the fiscal risks to communities that take on long term debt to pay for infrastructure projects? Can the net positive fiscal impacts be increased to cover the long-term risks associated with the slower economic growth often associated with reliance of natural resource extraction (Kerkvliet and Morton 2017). And how much additional revenue is needed to cover the costs of implementing responsible oil and gas development?

In other words, current research showing net positive fiscal impacts is a necessary but not sufficient condition for implementing responsible oil and gas production. Given the growing evidence of increased road, capital and staff oversight costs from oil and gas development, it is important for state and federal agencies to begin reporting these additional fiscal costs and to start reporting net fiscal impacts.

A Full Accounting of Fiscal Costs from Oil and Gas Development

As research on net fiscal impacts moves forward, we offer several additional categories of costs worthy of consideration. A more complete and full accounting of the marginal fiscal costs associated with responsible oil and gas development include: 1) the additional costs of hiring inspectors, collecting baseline data, monitoring air and water quality; 2) planning, legal and research costs; 3) the legacy fiscal costs from abandoned wells (and pipelines); and 4) changes in property values. Table 1 provides a more complete accounting of the fiscal costs to local governments along with methods for estimating each cost.

One prominent fiscal cost from oil and gas development is the change in property value and property tax revenues for local governments. A review of the literature and methods for examining the change in property values associated with oil and gas development is covered in our companion report (Kerkvliet and Morton 2019). Below we will examine perhaps the largest fiscal costs: the legacy costs from inadequate bonding amounts to plug and reclaim abandoned and orphaned oil and gas wells.

Table 1. Fiscal Costs Associated with Oil and Gas Development

Fiscal Cost	Explanation	Methods to Estimate
Road costs	Increase in road maintenance costs from heavy truck traffic	Survey and interview local officials. Engineering models on road costs
Staffing costs	Salary costs of increased staff time	Survey and interview local officials.
Police and emergency services costs	Salary costs of increased time for police, fire and emergency services	Survey and interview local officials. Review county budgets.
Debt financing costs from capital investments.	The long-term risk and cost with financing investments in infrastructure.	Survey and interview local officials. Review county budgets.
Legacy costs	Plugging and restoration cost that exceed bonding requirements	Statistical models relating reclamation costs to well depth and other site characteristics to reclamation cost and bonding amounts
Monitoring and Enforcement costs	Cost to collect and monitor baseline data as well as the cost of inspections and enforcing regulations	Survey and interview local officials and experts. Review county budgets.
Research and Legal costs	Legal costs of hiring lawyers and the cost of research on impact fees.	Survey and interview local officials and experts. Review county budgets.
Fiscal externalities	Change in home values and tax revenue. Opportunity cost from loss of land use.	Hedonic studies, regression analysis, revealed preference, choice experiments, benefit transfer methods.
Pollution costs	Public health and climate change costs from carbon and methane pollution.	BenMAP software,[10] Carbon and methane leakage and emission rates multiplied by the social cost of carbon and methane.

What are Legacy Fiscal Costs?

Legacy fiscal costs are created when bonding amounts paid by oil and gas developers do not cover the costs of plugging and abandoning wells, environmental remediation and reclaiming well pads to natural conditions. Without sufficient bonding from operators, these legacy fiscal costs fall partially on taxpayers. The legacy fiscal costs apply to orphaned and improperly plugged abandoned wells,[11] in addition to the shut-in, inactive and active wells currently operating that will eventually stop producing profitable quantities of oil and gas.

The basic technologies for plugging and abandoning of oil and gas wells has not changed significantly since the 1970s. According to the National Petroleum Council (2011):

> The plugging and abandoning (P&A) of oil and gas wells that are no longer economically viable for production, or which have wellbore issues that require closure, has historically

> been conducted as an afterthought in the oil and gas production business. Production wells that can no longer be used must be plugged to prevent the oil and gas reservoir fluids from migrating uphole over time and possibly contaminating other formations and/ or fresh water aquifers. A well is plugged by setting mechanical or cement plugs in the wellbore at specific intervals to prevent fluid flow. The plugging process usually requires a workover rig and cement pumped into the wellbore. The plugging process can take two days to a week, depending on the number of plugs to be set in the well. The P&A work takes capital to complete and provides no return on the investment for the oil companies. Most wells are plugged at the lowest cost possible following the minimum requirements set forth by the oil and gas regulating agencies (page 6).

With respect to the risks currently present from older wells, the National Petroleum Council (2011) states the following:

> In areas where shale-gas reservoirs are being newly developed, plugging of older wells has become an issue due to the potential for stray gas to migrate from the shale formation to other formations that are open to the old wells in the area. The old wells can transmit gas from the formation to the fresh water or even the surface, thereby posing an environmental risk to the local area. Older wells are a risk if they are poorly plugged or not plugged across the shale production zone. Even if the older well has casing, the casing might not be adequately cemented across the shale production zones (page 16).

Addressing legacy costs from abandoned wells is an important environmental issue for local and state governments, as they can contaminate underground drinking water by acting as a conduit for drilling fluids or contaminated surface water (American Petroleum Institute 2001). In addition to surface water pollution, gas leaks along the cement casing cause methane pollution years after production has stopped and the well has been plugged and abandoned (Dusseault et al. 2000, Nowamooz et al. 2015).

Abandoned oil and gas wells that are improperly plugged or not plugged present a risk to current and future oil and gas development because they provide a potential pathway for unwanted gas and fluid migration to the surface (Pekney 2018). Upwardly migrating gas, known as stray gas, which is mostly methane, is not only a potent source of greenhouse gas emissions, methane represents an explosive hazard if not properly vented away from buildings, homes and drinking water wells (Mitchell and Casman 2011).

Abandoned wells leak oil, gas, and brines as well casings deteriorate over time, and the once depleted rock formations re-pressurize (Bishop 2013). In recent years, a flurry of studies found compelling evidence of methane pollution emitting from abandoned oil and gas wells and well pads (Etiope et al. 2013, Kang et al. 2014, Boothroyd et al. 2016, Townsend et al. 2016, Lyman et al. 2017, Pekney et al. 2018, Riddick et al. 2019, Schout et al. 2019) The air and water pollution from abandoned wells is covered more extensively in Appendix A.

In addition to air and water pollution, the opportunity costs of not reclaiming well pads and plugging abandoned wells include habitat fragmentation, declining wildlife populations (Weller et al. 2002), delays in re-establishing vegetation for grazing, increased spread of noxious weeds, increased erosion from well pads and roads, and the loss of other ecosystem services.

Background on Bonding

When companies drill an oil or gas well, they are required to post a bond to cover plugging, abandonment and reclamation costs of well pads and infrastructure. These bonds may be surety bonds, a third-party guarantee that an operator purchases from a private insurance company; or personal bonds accompanied by a financial instrument, such as a cashier's check or negotiable Treasury security (GAO 2010).

Bonds help decrease the fiscal risks to taxpayers from "bad actors" and companies going bankrupt. For federal public land the Bureau of Land Management (BLM) has authority to require a bond ranging from $10,000 for a single well to $25,000 for a statewide bond or $150,000 for a nationwide bond – no matter how many oil and gas wells a company has permitted and drilled. Federal bonding amounts have not been updated since the 1950s and 1960s (GAO 2010). The GAO (2012) raised concerns about the current bonding system being inadequate for reclamation needs, and Lee (2018) estimated that bonding amounts were woefully short of covering reclamations costs on federal land. Similar bonding

Credit: Cody Winters

problems have been found for private and state land. Without sufficient bonding, companies in financial stress have more to gain by abandoning a well than by reclaiming it (Weber et al. 2018).

Inadequate bonding is a concern as the nature of boom and bust drilling cycles tend to result in too many speculative wells being drilled which are later abandoned. Walsh (2017) examined the resulting "orphaned well crisis" in the Powder River Basin of northeastern Wyoming. During the boom period between 1998 and 2008, over 16,000 coalbed methane wells were drilled. By 2017, as the bust set in after prices dropped, more than 25 percent of these wells (4,149 wells) were orphaned as a result of industry bankruptcy and abandonment. The author notes that the increase in orphan wells has led to notable challenges primarily around stalled reclamation activities.

To be consistent with economic theory and the Polluter Pays Principle,[12] the costs of plugging and reclaiming well pads should be covered by the performance bond or some form of insurance purchased by the company operating the well. Bonding is justified based on economic efficiency and equity arguments. Weber et al. (2018) state the following:

> Motivation for bonding requirements includes an efficiency justification and an equity justification. First, bonding requirements encourage firms to consider at least some of the cost of reclamation in the decision to drill a particular well. Incorporation of reclamation costs increases efficiency by preventing the drilling of wells that would be economical if reclamation and bonding requirements were not in place. Second, when firms operating wells go bankrupt or dissolve, bonds provide funds for reclamation, reducing outlays for the state or affected landowners. Put differently, without bonds, greater costs would be shifted to parties that did not benefit economically from the well (Weber et al. 2018, page 7).

While there is strong consensus from economists that bonding requirements should reflect the actual cost of well reclamation, there is a paucity of historic research on the subject. As with the case for net fiscal impacts, in the last decade there is an emerging line of research that examines the adequacy of bonding by comparing revenues and costs. In this case, economists are comparing the actual costs of plugging and reclaiming oil and gas wells with the financial assurances provided by bonding. Based on the research completed to date, there is evidence of reclamation costs being much greater than bonding requirements – creating significant legacy fiscal costs for states and local governments (Anderson and Coupal 2009, Anderson et al. 2009, GAO 2010, Mitchell and Casman 2011, Weber et al. 2018, Ho et al. 2018a).

Results and Methods for Estimating Legacy Costs

Andersen and Coupal (2009) completed one of the first studies to estimate legacy costs since the recent drilling boom began. These economists established that a statistically significant relationship exists between reclamation costs and drilling depth of wells in the state of Wyoming. Their analysis used Wyoming Oil and Gas Conservation Commission data over a 10-year period (1997-2007) on well depth and the actual cost of reclaiming 255 abandoned oil and gas wells in 48 locations.

Drilling depth of a well was chosen to estimate reclamation costs on a per foot basis due to the strong statistical correlation between the total drilling depth and reclamation costs. Based on this statistical correlation, the authors estimated average reclamation costs of $10.01 per foot of well depth. Based on average well depth, the mean average reclamations costs in Wyoming equaled $27,555 per well.

In addition to setting bonding amounts equal to the actual cost of reclamation, the authors recommend requiring a cash bond at the start of development that is invested in an interest-bearing reclamation account (e.g. low-risk government securities) so that accrued interest is available to cover the increasing cost of reclamation over time (Anderson and Coupal 2009).

Consider the following example: if a state were to collect $10,000 at the time the well is drilled and earns 4% on that cash bond, by year 10 the state would have $14,233 to pay for reclamation. By year 20 it would have $21,068. The accumulated interest helps close the gap between actual reclamation costs and the reclamation costs estimated when the well is first drilled. Of course, reclamation costs might be rising faster or slower than the rate of interest, so the deficit may get bigger or smaller over time. Either way, investing a cash bond in an interest-bearing account will increase the amount of money available over time to pay for reclamation.

Anderson and Coupal (2009) also make the following observation:

> One final note concerning current reclamation policy is that it does not properly account for the loss of surface land values. Oil and gas producers pay severance taxes and royalty payments that are intended to account for the loss of sub-surface value of mineral resources, but they may not pay for the total loss of ecosystem services such as lost grazing allotments, wildlife uses, and aesthetic values. One way to account for these opportunity costs associated with oil and gas production is to increase bonding rates to reflect the loss of surface values (Anderson and Coupal 2009, page 7).

In follow-up research, Anderson et al. (2009) performed a statistical analysis of the cost of reclaiming 280 orphaned wells at 67 locations in Wyoming. The total cost of reclamation was dependent on three independent variables: the number of wells per location, the total well drilling depth per location, and the 30-year average of annual precipitation at the location. The results showed strong correlation with the three independent variables jointly explaining 95 percent of variation in total reclamation costs. On a per well basis, the regression predicts a fixed cost of $15,144 mostly comprised of road reclamation costs - which are not influenced by well depth. The variable costs indicate reclamation costs increase $4.80 for each additional foot drilled, and they decrease $5,277 in areas with higher precipitation.

Precipitation was chosen as an environmental variable influencing the costs of reclamation. In general, areas with higher average precipitation are likely to experience relatively more natural re-vegetation. An increase in natural vegetation can decrease the costs of re-establishing grazing conditions, for example, that existed prior to drilling. The authors predicted an average reclamation cost per well of $23,662. The per well reclamation cost was compared with the per well bonding amount estimated with state data from 220 wells in 25 locations. Subtracting the per well average bond of $10,180 from the cost per well gave an estimated shortfall of $13,482 per well. The shortfall of $13,482 per well was multiplied by the 60,403 wells active in 2009, to estimate a legacy cost of $814 million for the state of Wyoming (Anderson et al. 2009).

The authors conclude that the most effective system is one requiring a fixed bond amount per well plus an additional fee per foot of drilling depth. Their regression provides estimates of these parameters. The economic incentive that is ultimately required is to make defaulting on reclamation as costly as doing the actual reclamation (Anderson et al. 2009).

More recent studies have found similar results: 1) the depth of oil and gas wells is positively correlated with reclamation costs; and 2) bonding amounts required by federal and state agencies are inadequate for covering reclamation costs. Given the strong correlation between well depth and reclamation costs, economist have applied the results from Anderson et al. (2009) in other states.

Mitchell and Casman (2011) estimated the cost of reclaiming unconventional wells in Pennsylvania using Andersen et al. (2009) estimated per foot cost rounded to $10.50. They collected state data on total wellbore length of approximately 1000 unconventional wells. Based on an average wellbore length of 10,675 feet, the authors estimated the average reclamation cost for a single unconventional Marcellus shale gas well to be about $110,000.

Joyce and Wirfs-Brock (2015) using similar methods to Anderson et al. (2009) but with updated data, completed a regression model to estimate the reclamation cost as a function of well depth for wells drilled in Wyoming. New wells tend to be deeper than older wells leading to an estimated average reclamation cost of more than $100,000 per well.

Based on historic data, the authors determined that 3-4 percent of the wells drilled end up becoming orphaned wells. They combined these results to estimate the reclamation costs for future orphaned wells. To do this the authors developed scripts and ran 1000 computer simulations that randomly selected 3 percent of the 5,125 wells drilled between 2011 and 2015. Reclamation costs were estimated with their statistical model based on the depths of the wells chosen in each of the 1000 simulations. They estimated future reclamation costs from orphaning Wyoming's newest wells ranged from $15 to $19 million. While Joyce and Wirfs-Brock (2015) acknowledge there are many unknown factors, they conclude it will be difficult for Wyoming taxpayers to cover the reclamation costs under the state’s new bonding rules.

Lee (2018) used updated data and regression methods from Anderson et al. (2009) and Joyce and Wirfs-Brock (2015) to estimate $6.1 billion in reclamation costs for the 94,096 producing oil and gas wells on federal public land. These reclamation costs were compared to an analysis of BLM bond amounts (GAO 2010). In that report, the investigators found that oil and gas operators had posted bonds valued at $162 million for the 88,357 wells that existed at that time. Based on comparing the $6.1 billion in reclamation costs with the $162 million in bonds, Lee (2018) conclude that it appears likely that taxpayers face potential reclamation liability for wells on federal lands that exceeds the value of the bonds—possibly by a considerable amount.

Weber et al. (2018) collected reclamation data for more than 1,200 wells in Pennsylvania and found the actual costs of reclaiming a typical shale well at more than $90,000. Unfortunately, state policy requires a single shale well bond of $10,000. The authors conclude that bonding requirements for both unconventional (and conventional) wells in Pennsylvania are significantly less than actual reclamation costs.[13]

Ho et al. (2018a) developed a statistical analysis using data on plugging and reclamation costs, well depth and bonding collected from 13 state agencies. Similar to Anderson et al. (2009), the authors used a regression model to estimate plugging and abandonment costs of orphaned wells and compare them to bond amounts. The authors conclude that current state bonding requirements are insufficient to cover the average reclamation costs of orphan wells in 11 of the 13 states, including Colorado. Kansas and California were the only states with sufficient bonding.

Ho et al. (2018a) collected Colorado-specific data for the years 2006- 2015, and found the costs of plugging and reclaiming an orphan well ranged from $1,360 to $195,991. The average cost was $31,000, while the average bonding amount was only $20,000. The difference of $11,000 is an estimate of the legacy fiscal cost per well in Colorado. In comparison, Anderson et al. (2009) estimated a per well legacy fiscal cost for Wyoming of $13,482.

Table 2. Legacy Fiscal Costs – Plugging and Reclamation - Per Oil and Gas Well for Various States.

Reference	State	Plugging and Reclamation Costs Per Well	Bonding Amounts Per Well	Estimated Legacy Fiscal Costs Per Well
Anderson et al. 2008	Wyoming	$23,662	$10,180	$13,482
Ho et al. 2018	Indiana	$7,107	$2,500	$4,607
Ho et al. 2018	New York	$6,021	$5,000	$1,021
Ho et al. 2018	Arizona	$10,663	$3,000	$7,663
Ho et al. 2018	Pennsylvania	$9,820	$2,500	$7,320
Ho et al. 2018	Ohio	$11,029	$5,000	$6,029
Ho et al. 2018	Montana	$14,073	$5,000	$9,073
Ho et al. 2018	Colorado	$31,094	$20,000	$11,094
Ho et al. 2018	Michigan	$51,069	$25,000	$26,069

A review of recent economic research indicates that the legacy fiscal costs from orphaned wells represent substantial liabilities for taxpayers. Table 2 and 3 summarize the results from these studies with estimates of the per well legacy cost for various states. These fiscal legacy costs represent a significant fiscal cost that should be fully accounted for when discussing and estimating the net fiscal impacts from the oil and gas industry in Colorado and elsewhere.

Table 2 summarizes the per well plugging and reclamation costs as well as bonding amounts from recent literature. We combined the cost and bonding amounts to derive estimates of per well legacy fiscal costs for each state.

Table 3 summarizes the per well plugging and bonding amounts from recent literature. We combined the cost and bonding amounts to derive estimates of per well legacy fiscal costs for each state.

Discussion of Methods and Results

A straightforward method for estimating reclamation costs is based on the statistical relationship between well depth and plugging and reclamation costs. Estimated reclamation costs can then be compared to the available bonding to derive outstanding legacy costs. Although well depth is only one relevant factor affecting the reclamation cost, research has consistently found a strong correlation between well depth and reclamation costs (Anderson and Coupal 2009, Anderson et al. 2009, Ho et al. 2018a). Reflecting that relationship, many states require bond amounts based on the depth of the well (Lee 2018).

In general, deeper wells are not only more expensive to drill they are more expensive to plug and reclaim than shallow wells. Why would plugging and reclamation costs be higher for deeper wells? Ho et al. (2019), divide plugging and reclamation costs by the following categories: 1) the equipment costs such as the drilling rig, pulling unit, backhoe, and vacuum truck; 2) material costs for plugs such as cement or cast iron bridge plugs; 3) special services such as perforation or casing cuts; 4) fees for waste disposal; and 5) labor or supervision costs.

Table 3. Legacy Fiscal Costs – Plugging only – Per Oil and Gas Wells for Various States.

Reference	State	Plugging Cost Only Per Well	Bonding Amounts Per Well	Estimated Legacy Fiscal Costs Per Well
Ho et al. 2018	Kansas	$3,288	$2,795	$493
Ho et al. 2018	Illinois	$4,378	$1,500	$2,878
Ho et al. 2018	Texas	$9,756	$13,046	$0
Ho et al. 2018	Oklahoma	$15,239	$25,000	$0
Ho et al. 2018	California	$26,678	$25,000	$1,678

Using these cost categories, we offer the following explanations for why plugging and reclamation costs are greater for deeper wells. We suspect that equipment rental costs will be greater for deeper wells – as the time necessary to flush and plug the well will be longer than for shallow wells and will result in higher equipment rental costs. We expect that material costs will be greater for deeper wells as more cement will be needed to plug the well. Flushing and cleaning deeper wells before they are plugged produces more waste which in turn could increase waste disposal fees. Deeper wells that take longer to plug will require more hours of labor and supervision.

Ho et al. (2018a) found variation in plugging and abandonment costs and suggest that bonding would be more effective if the amounts are also varied by site factors that actually explain reclamation costs. In addition to well depth, location and annual precipitation, we recommend the following examples of environmental variables that may influence reclamation costs: soil type, distance to ground water, distance to water wells, bird and wildlife habitat, proximity to homes, schools, open space and natural areas.

Legacy Fiscal Costs are National in Scale

The legacy fiscal costs created by inadequate bonding for the timely plugging and reclamation of oil and gas wells is an under-reported but widespread problem in the U.S. The large number of unplugged or improperly plugged orphaned and abandoned wells provide ample evidence of substantial fiscal legacy costs. According to King and Valencia (2014):

> There have been over 4.3 million oil and gas wells and more than 15 million water wells drilled in North America…There is no question that un-plugged or improperly plugged oil and gas wells, dating from 1860's to 1930's and later, are a potential threat and, in some areas of early oil booms, unmarked wellbores still exist and pose a pollution pathway to aquifers from surface spills and a lesser risk from oil or gas well developments. This is a legacy issue… (page 1).

Part of the problem is a lack of a long-term vision and investment in research on the benefits from properly plugging and reclaiming abandoned and orphaned wells, including: 1) the benefits from reduced operational costs and/or increased production, especially in redeveloped, older fields; and 2) cost savings from avoiding future environmental costs (including litigation costs) associated with fluid or gas leakage (National Petroleum Council 2011).

In the eastern U.S. Bishop (2013) completed a comprehensive review of drilling data in the state of New York and found three-fourths of the state's abandoned oil and gas wells were never plugged. In addition, the author found that because the pace and scale of enforcement efforts did not keep up with the pace and scale of drilling, the number of unplugged oil and gas wells abandoned since 1992 has steadily increased.

Nationally, the scale of the legacy costs from past oil and gas drilling is quite large. Brandt et al. (2014)

estimate that approximately 3 million oil and gas wells are now abandoned across the United States which if unplugged or not properly plugged and sealed can cause environmental problems.

As discussed above, the cumulative fiscal legacy costs for states and local governments from inadequate bonding in the past and present include: 1) the costs of plugging and reclaiming orphaned well sites; 2) the cost to re-plug abandoned wells that were improperly plugged; and 3) the legacy costs of plugging and reclaiming wells that are currently shut-in, inactive and active wells when economic production stops for good.

In an attempt to reduce future legacy costs some states have updated their bonding requirements, most recently New Mexico. Similar to other states, New Mexico used well depth in establishing the bonding amount for a single well. New bonding amounts for each well on state or private land equal $25,000 plus $2 per foot of depth (State of New Mexico Oil Conservation Commission 2019).

New Mexico adopted a tiered blanket bonding structure covering all active wells on state and private land. Operators who have inactive or temporarily abandoned state or private wells are required to provide financial assurance in addition to the blanket bond for active wells. The state of New Mexico also established the maximum number of wells an operator is allowed to place in approved temporarily abandonment status (State of New Mexico Oil Conservation Commission 2019).

Estimating Legacy Fiscal Costs in Colorado

Legacy fiscal costs for state and private land must be addressed at the state-level, as the state of Colorado has the authority to set bonding amounts. Colorado's current inventory of oil and gas wells includes 39,266 producing wells, 9,628 shut in wells, and 1,486 wells temporarily abandoned (COGCC 2019).[14] Multiplying average reclamation costs of $31,000 per well from Ho et al. (2018a) by the total number of oil and gas wells (50,380) in Colorado, provides an approximation of the total reclamation costs ahead of $1.56 billion – some of which will be paid by industry. Unfortunately, the number of oil and gas operators declaring bankruptcy continues to increase (COGCC 2019).

One method for estimating future legacy costs in Colorado is to use the 3-4% orphan well rate found in Wyoming (Joyce and Wirfs-Brock 2015), apply that rate to the 50,380 oil and gas wells currently in Colorado, and multiply the estimated number of orphaned wells by the $31,000 per well reclamation costs estimated by Ho et al. (2018). Based on this method we estimate future legacy fiscal costs for orphaned wells in Colorado of $47 to $62 million.

A second method to estimate future legacy fiscal costs in Colorado utilizes Ho et al. (2018a) per well estimate of $11,000 for legacy fiscal costs as a result of inadequate bonding. Assuming the legacy costs applies to all wells, multiplying the $11,000 legacy cost by the total number of oil and gas wells provides an estimate of the large scale of future legacy fiscal costs from inadequate bonding policies. Assuming the legacy costs per well don't change in the future, the total legacy cost from Colorado's current inventory of 50,380 oil and gas well will be greater than $500 million.[15]

Colorado's current state bonding rules are in the process of being updated with a report due in the fall of 2019. The Colorado Oil and Gas Conservation Commission recently estimated that on a per well basis, the average cost to plug orphaned wells is 6 times greater than the amount of financial assurance held by the state. When the cost of environmental remediation and site reclamation are properly included, the total plugging and reclamations costs for orphaned wells are 14 times greater than the bonding amounts (Hickenlooper 2018).

Funding Options to Address Legacy Fiscal Costs

To address legacy fiscal costs in Colorado, state and local governments in Colorado should examine the benefits and costs of charging a per well impact fee on the current inventory of more than 50,000 oil and gas wells. Since orphaned and improperly plugged abandoned wells are a problem for industry, an industry-wide solution like a per well impact fee seems reasonable. To help fund the reclamation of abandoned and orphaned oil and gas wells, Pennsylvania charges fees on new oil and natural gas well permits amounting to $200 and $50 per well for the Orphan Well Plugging Fund and Abandoned Well Plugging Fund, respectively (Mitchell and Casman,

Credit: Steven Jenkins

2011). Since the Pennsylvania state legislature created the fund in 1992, 3,572 orphaned wells have been plugged (Weber et al. 2018).

Inadequate bonding for plugging and reclamation is not a new problem in Colorado. In 1990, the Colorado state legislature first authorized the Plugging and Reclaiming Orphan Wells (PROW) appropriation line item in the budget to plug and reclaim orphaned wells. In other words, for nearly 30 years, Colorado taxpayers have contributed tax revenue to help pay the legacy fiscal costs to reclaim oil and gas wells orphaned and abandoned by the oil and gas industry. For fiscal year 2019, the Colorado legislature dramatically increased the PROW appropriation from $445,000 in FY18 to $5,011,000 (COGCC 2018). While there are substantial public benefits from increasing appropriations for reclaiming orphaned wells, ideally the former owners of these oil and gas wells would be paying the full bill.

Colorado's $5 million PROW appropriation in FY19 is a prime example of the annual fiscal cost to taxpayers from having to pay for the legacy fiscal costs. These legacy costs should not be forgotten- but rather should be fully accounted for when estimating net fiscal impacts from oil and gas development.

Colorado is not alone in paying legacy costs. U.S. states use a variety of revenue sources to pay for the reclamation of orphaned oil and gas wells. Many states use revenue from enforcement penalties, fines, and forfeited bonds to cover reclamation cost, while a few have the funding built into their operating budget (Ho et al. 2018b). In addition, states use a variety of other economic tools to generate revenue to address legacy fiscal costs.

California has an idle well fee. Colorado imposes a mill levy on the market value of oil and gas produced. Louisiana charges a production fee. New Mexico utilizes a percentage of severance tax and forfeited bonds. North Dakota imposes a permit fee. Ohio has a tax on oil and gas production. Oklahoma has a voluntary excise tax of 0.01 percent of the gross value of oil and gas produced. Texas imposes production taxes and permitting fees, while Wyoming charges a conservation tax on oil and gas revenue, plus bond revocations, fines, and equipment sales (see Ho et al. 2018b).

Summary and Discussion

Impact fees have a long history in promoting sustainable community development by internalizing external costs such as the loss of open space and the increased traffic which compromises local public infrastructure. The rise in the popularity of impact fees coincides with a long-term decline in federal and state funding. The two basic approaches to setting impact fees are the average-cost pricing method that sets a flat connection fee and a marginal cost pricing system.

Impact fees represent a potential economic tool for collecting additional compensation to cover the fiscal costs and negative externalities to local taxpayers, that are not covered by severance and property tax revenues and royalty payments. Do revenues need to be increased to pay for these additional costs of implementing efficient and responsible oil and natural gas development? How does the net fiscal impact from oil and gas compare to the net fiscal impact from other industries? For example, what are the net fiscal costs to communities from pursuing cleaner and renewable sources of energy?

While the impacts fees to date are primarily for recovering road costs and paying for wastewater infrastructure, impact fees can also be extended to cover the fiscal costs of collecting baseline data on orphaned and abandoned wells and for paying for applied research for a better understanding of net fiscal impacts. Industry's court challenges to impact fees emphasize the importance of insuring baseline data is up-to-date and applicable. Baseline data are needed, for example so that local operators are not asked to pay for pre-existing road damage. Proper due diligence by local governments also requires collecting baseline data in order to successfully defend against legal challenges to impact fees.

Baseline data on public health and environment are also needed to determine marginal medical and environmental costs. If, for example, spills of wastewater or fracking fluid result in changes in pollutants being discharged in local streams, having baseline information on stream pollution prior to the spills will help verify and quantify the marginal damages.

Baseline data combined with appropriate research are necessary to accurately quantify the marginal costs and to accurately link the costs to individual operators. Paying careful attention to data and methods is required in order to establish the required "rough proportionality" between the operator and the impact fee imposed on that operator by the local government (Dundon 2017).[16]

Therefore, it is reasonable and necessary to allow local governments time to budget for data collection and research to produce legally defensible estimates of the marginal costs and damages from oil and gas development. The fiscal costs of collecting the necessary baseline data should also be included when examining the net fiscal impacts.

A review of the emerging economic research indicates one of the largest fiscal cost are the legacy costs from old oil and gas wells. To help address the legacy fiscal costs, the State of Colorado should examine the benefits and costs of charging a per well impact fee on the current inventory of more than 50,000 oil and gas wells. Abandoned wells are directly connected to past and current oil and gas development. And if the impact fees are used to specifically plug and reclaim orphaned and abandoned wells, industry can directly and indirectly accrue benefits.

The National Petroleum Council (2011) describes the economic benefits from investing in well-plugging technology.

> Well plugging is often seen by some operators as a cost that provides little benefit to the company bottom line. While in some instances that may be true, properly plugged wells can save the operators substantially through avoidance of lost production from fields that are candidates for high-technology recovery projects (NETL, 2010). Properly plugged wells can prevent cross-contamination from other zones in a production field. Proper well plugs can also

> prevent the loss of pressure in pressure maintenance water floods and CO2 floods. Both of those merits can result in higher oil and or gas production from the targeted reservoir…
>
> By advancing the technology of plugging wells, the overall cost of plugging can decrease. In addition, the newer plugging materials and methods can reduce the plugging failures along with the problems associated with leaking well plugs.[17]
>
> With the current development of numerous shale-gas basins in the US, the eventual plugging of all of those new gas wells is a concern. Most of those shale-gas wells are horizontal completions, which can pose an issue for plugging operations due to gas channeling and solids settling. If those wells are not plugged correctly, gas channeling can occur and the well could become a potential liability from gas leaking into the upper fresh water zones. Improved P&A practices in the shale-gas basin developments should allow more economical and sustainable development of US gas production (National Petroleum Council 2011, page 17).

Beyond a genuine desire to "do the right thing', by supporting an impact fee to address industry's fiscal legacy costs, the oil and gas industry will be taking responsibility for past damage and help retain its social license to operate. As oil and gas drilling has moved closer to populated areas and the damage becomes more visible, industry's social license to operate has come into question (Morton and Hjerpe 2017). The concept of social license to operates comes from increasing consumer awareness and stakeholder groups that exert influence beyond the traditional governmental roles (Berkhout 2014). Neglecting social concerns can have drastic negative impacts on performance (Ford et al. 2014).

In addition to a per well impact fee to help address the abandoned well problem, an impact fee could be charged annually to account for the ongoing environmental damage from abandoned wells. For example, a per well impact fee based on the social costs of methane could be charged based on the annual methane pollution from abandoned wells (see Appendix A). To estimate the environmental costs from methane pollution that can be avoided by properly plugging wells in Pennsylvania, Harleman (2018) used the social cost of methane estimated by Marten and Newbold (2015), combined with daily methane emissions from unplugged gas wells from Kang et al. (2016). A similar approach could be used to estimate impact fees for carbon dioxide and methane produced from old and new wells (see Appendix B on pollution taxes as an alternative to impact fees).

Impact fees can also be extended to cover public health, air and water pollution, as well as other environmental costs associated with oil and gas development. For example, the social cost of carbon could be used to estimate impact fees on other emission sources associated with oil and gas development. Gilmore et al. (2013) estimated the greenhouse gas emissions for shale gas water-hauling truck traffic at 70–157 tons of carbon dioxide equivalent per gas well. Based on a social cost of carbon dioxide of $41 per ton, Krupnick et al. (2017) use a back of the envelope calculation to estimate $782–$1,755 in damages per gas well from truck traffic associated with each well.

As impact fees are developed to cover public health and environmental costs, proportionality and rational nexus test will certainly be a point of legal contention. Therefore, it is reasonable and necessary to allow time for communities to budget in the costs to collect baseline data and design research methods that produce legally defensible estimates of the marginal public health and environmental costs. In addition, baseline health data could be collected for farm animals, wildlife and companion pets as an early warning indicator species for monitoring the overall health of the urban and rural environment (see Appendix C).

Credit: WildEarth Guardians

Local governments exploring the use of impact fees would do well to keep legal concepts around proportionality and the rational nexus test in mind when designing accurate methods and studies for estimating the costs associated with oil and gas development. This is true whether the research is for estimating impact fees for road costs, traffic congestion, public health costs, loss of property values, legacy fiscal costs or environmental externalities.

Endnotes

[1]Negative externalities are costs of economic activities not borne by those making decisions about those activities. Examples of negative externalities include increased traffic congestion, and the undesirable effects of air and water pollution, including degraded human health.

[2]Without having to increase taxes, local governments turned to their police powers to charge impact fees. In terms of the police power, most local governments have great discretion to regulate in order to protect the public's health, safety, and welfare (Nelson et al. 2017).

[3]Mullen (2015) provides the following summary of Colorado's impact fee legislation: "Senate Bill 15 was signed by the governor on November 16, 2001. Among other things, this bill created a new Section 104.5: Impact Fees, in Article 20 of Title 29, Colorado Revised Statutes, which specifically provides that: "Pursuant to the authority granted in section 29-20-104 (1) (g) and as a condition of issuance of a development permit, a local government may impose an impact fee or other similar development charge to fund expenditures by such local government on capital facilities needed to serve new development." Home-rule cities in Colorado had long assessed impact fees, but the authority of counties and towns to assess impact fees was less clear. While clarifying the authority issue, the enabling act has created some confusion about whether local governments can assess impact fees at time of building permit, or whether they must assess them at some earlier stage in the development process."

[4]As a point of comparison to heavy truck traffic associated with the oil and gas industry, Bai et al. (2010) estimated 3,700 - 4,400 truckloads needed per year for cattle shipments, which is close to the number of truck trips occurring over a matter of weeks and months during well development (Dundon 2017).

[5]Impact fees, like those in Pennsylvania, that use a sliding scale based on the market price have a downside. When markets are depressed, impact fee revenue based on low gas prices are less likely to cover fiscal costs – especially given the fixed costs on infrastructure and equipment. If the impact fee revenue is to plug and reclaim abandoned wells, lower prices will result in less revenue to address legacy costs in a timely manner.

[6]Horizontal wells in operating years four or greater that produce less than 90 Mcf (thousand cubic feet) per day are exempt. Plugged horizontal wells are exempt after remitting the fee in the first year. Vertical wells that produce less than 90 Mcf per day are exempt from the fee in any operating year (Pennsylvania Independent Fiscal Office 2019).

[7]PennFuture (2012) provides an easy-to-understand explanation of the new bonding requirements and other major provisions of Pennsylvania's Impact Fee Law (Act 13).

[8]The market value is equal to total production multiplied by the annual average regional spot price of natural gas net of post-production costs.

[9]In City of Arlington v. Texas Oil and Gas Association, No. 02-13-00138-CV (Ct. App. 2nd Dist. Texas, 2013), the primary challenge by industry was to a fee being charged to well developers for the training and equipping of City firemen on how to fight gas well fires, a charge that was never imposed on other industries and, in their view, amounted to an unlawful occupation tax under Texas Law. The city ultimately amended the ordinance and withdrew that fee, and the case settled. The road use permitting fees are still in force (Dundon 2017).

[10]The use of the BenMAP software to estimate public health costs is discussed in our companion report (Kerkvliet and Morton 2019).

[11]When companies go bankrupt, they create orphaned wells. Orphaned wells have not been plugged and reclaimed, and are not connected to a solvent company. In contrast, while abandoned wells may not be plugged or reclaimed, they are typically connected to a solvent company.

[12]The Polluter Pays Principle (PPP) simply says that oil and gas companies will pay all of the direct market and indirect non-market costs of producing oil and gas. Internalizing negative externalities is the main objective of PPP. Economists argue that only when negative externalities (i.e. non-market external costs like air and water pollution) have been fully incurred and internalized by decision makers will the socially optimal level of output occur. Under the Polluter Pays Principle, oil and gas producers will pay for the negative externalities occurring as part of their business operations. Payments are made in many forms, including royalties, severance taxes, compliance costs, pollution taxes, impact fees, assurances bonds, and direct in-kind services.

[13]Mitchell, A. and E. Casman. 2011 note that in some cases the costs for plugging and abandonment of a shale gas well in Pennsylvania have been substantially higher. They offer the following example: in 2010, Cabot Oil & Gas Corporation estimated that it spent $2,190,000 to properly abandon three vertical Marcellus Shale gas wells in Susquehanna County, Pennsylvania, about $700,000 per well.

[14]In 2017, based on an analysis of COGCC data by the Denver Post, there are 20,763 dry and abandoned wells, 15,739 abandoned wells that have been plugged, and an additional 14,857 abandoned wells that are neither dry or plugged https://www.denverpost.com/2017/05/01/oil-gas-wells-colorado-map/

[15]Data from the Energy Information Administration on drilling depths in the U.S. indicates a trend toward drilling deeper wells. If the positive correlation between increased reclamation costs with increased drilling depth holds in the future, reclamation costs will increase in the future. If bonding requirements or technology don't adjust to account for future increases in reclamation costs, the legacy costs could be greater than estimated here using reclamation costs from shallower wells.

[16]Dundon 2017 provides an excellent synthesis of studies estimating transportation impacts associated with oil and gas development and includes recommendations of methods for use by local governments.

[17]As an example of an innovative plugging technology, Shah and Sublette (2004) examined using fly ash from coal-fired power plants as a cementing material to plug wells in Oklahoma.

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Appendix A: Legacy Oil and Gas Wells and Methane Pollution: An Added Legacy Cost

Addressing legacy costs from abandoned wells is an important issue for local and state governments, as these wells can contaminate underground drinking water by acting as a conduit for drilling fluids or contaminated surface water (American Petroleum Institute 2001). In addition to surface water pollution, gas leaks along the cement casing cause methane pollution years after production has stopped and the well has been plugged and abandoned (Dusseault et al. 2000, Nowamooz et al. 2015).[18] Abandoned oil and gas wells that are improperly plugged or unplugged present a risk to current and future oil and gas development because they provide a potential pathway for unwanted gas and fluid migration to the surface (Pekney 2018). Upwardly migrating gas, known as stray gas, which is mostly methane, is not only a potent source of greenhouse gas emissions, it represents an explosive hazard if not properly vented away from buildings and drinking water wells (Mitchell and Casman, 2011).

Abandoned wells leak because well casings deteriorate over time, and once depleted rock formations re-pressurize with oil, gas, and brines (Bishop 2013). In recent years, a flurry of studies found compelling evidence of methane pollution emitting from abandoned oil and gas wells and well pads (Etiope et al. 2013, Kang et al. 2014, Boothroyd et al. 2016, Townsend et al. 2016, Lyman et al. 2017, Pekney et al. 2018, Riddick S. et al. 2019, Schout, G. J. Griffioen, S. Majid Hassanizadeh, G. de Lichtbuer, and N. Hartog. 2019). We will discuss the salient results from a few of these studies.

Kang et al. (2014) using static flux chambers found substantial methane pollution being emitted from abandoned oil and gas wells in Pennsylvania. The authors estimate that abandoned wells account for five to eight percent of annual methane emissions in the state. Three out of the 19 abandoned wells examined were high emitters with methane flow rates three orders of magnitude larger than the median flow rate. Riddick et al. (2019) documented methane pollution coming from abandoned oil and gas wells in West Virginia. The authors found that emission rates for active and abandoned wells can vary within the same geologic formation, with the highest levels coming from abandoned wells that were not plugged (Riddick et al. 2019).

Townsend et al. (2016) had similar results in their assessment of 138 abandoned wells in four active production areas in Wyoming, Colorado, Utah, and Ohio. The authors found 6.5 percent of the wells had measurable methane emissions and that methane emissions from plugged and abandoned wells were significantly lower than from unplugged wells ($p<0.001$). Eight of the 20 unplugged abandoned wells examined were positive sources of methane. Better information and more research are needed to identify the locations of high emitting abandoned wells, especially ones that have not been properly plugged.

Methane pollution coming from abandoned wells is not just a local issue, but a global one. Methane emissions from abandoned wells are not currently considered in any GHG emissions inventory. Townsend et al. (2016) conclude that leakage from abandoned wells could be a significant source of methane and one that might partially explain discrepancies between top-down and bottom-up estimates of methane emissions in oil and gas production areas (Pétron et al. 2012, 2014, Karion et al. 2013, Brandt et al. 2014). Kang et al. (2014) and Riddick et al. (2019) recommend additional research to accurately quantify methane pollution from abandoned wells nationally so they can be included in greenhouse gas emissions inventories. Overall, both the environmental hazard and complexities of detecting and quantifying gas leakage from cut and buried wells has been understudied (Schout et al. 2019).

Lyman et al. (2017) compared fluxes of methane and carbon dioxide from the soils on natural gas well pads to nearby undisturbed soils in eastern Utah. Fluxes from well pad soils were almost always greater than from undisturbed soils and were inversely correlated with distance from well heads. Evidence indicates the majority of emission fluxes (about 70%) were primarily due to subsurface sources of raw gas that migrated to the atmosphere, with the remainder likely from the re-emission of spilled liquid hydrocarbons.

With respect to soil fluxes of methane, Kang et al. (2014) notes that past research has connected abandoned wells to subsurface methane accumulations resulting in explosions, which can be a major concern in urban areas with oil and gas development or natural gas storage reservoirs. As drilling occurs in more populated areas, an increase focus and monitoring of the location and concrete integrity of abandoned wells and storage reservoirs is warranted.

Addressing environmental problems like methane leakage from abandoned wells will be a challenge because of the data uncertainty on the number, location, and abandonment state of legacy wells (Dilmore 2015). In addition, detecting methane leaks may not be obvious from surface observations alone. Concrete breaks down more rapidly in the deepest segments of abandoned wells. This is because temperature, pressure, and salt concentrations all tend to increase with the depth of the abandoned well - where the damage is most difficult to detect (Dusseault et al. 2000).

With respect to water pollution, maintaining well integrity to prevent methane leaks to groundwater is a cornerstone of environmental protection in all oil and gas drilling operations (Nowamooz et al. 2015). A loss of well integrity is important because it represents an uncontrolled release of fluids and gas which could pose a risk to groundwater supplies and air quality (Boothroyd, et al. 2016). Better information on the location and status of abandoned wells is needed to help mitigate both fire hazards and groundwater contamination (Townsend et al. 2016).

In one of the few detailed underground, subsurface investigations of methane leakage from a plugged and abandoned gas well, McMahon et al. (2018) collected hydrologic and geochemical data from 15 monitoring wells in the Piceance Basin in Western

Colorado. Their results indicate that a leaking gas well - plugged and abandoned in 1990 - contaminated shallow groundwater with thermogenic methane. Uncemented annular space behind production casing appears to be the likely migration pathway.

In order to understand the scale of risk to shallow groundwater from abandoned wells in Colorado, McMahon et al. (2018) examined drilling and plugging records to determine the number of wells drilled in the same timeframe as the gas well that contaminated the groundwater with methane. The authors found thousands of oil and gas wells drilled in the same timeframe – with "a majority of those wells in areas with relatively large depths to groundwater". These results emphasize the need for periodic inspection and assessment of abandoned wells long after they are plugged. Bishop (2013) recommends that effective state oil and gas regulatory programs must ensure that abandoned wells are properly plugged, periodically inspected and, when monitoring dictates problems, repair the plugged wells. With inadequate monitoring in the past, much of the evidence regarding local problems associated with abandoned oil and gas wells is anecdotal.[19]

The research from McMahon et al. (2018) also points to the critical importance of monitoring and the need for a continuous, long-term funding source to monitor abandoned wells long after production stops. Without the 15 monitoring wells, the abandoned natural gas well which was the source for the groundwater contamination in the Piceance Basin would have been more difficult to identify.

Sherwood et al. (2016) examined geochemical data collected from 1988 to 2014 in the Denver-Julesburg Basin and found dissolved methane in 593 of the 924 water wells sampled. Most of this methane was determined to be microbially generated, likely from shallow coal seams. Thermogenic gas was found in 42 of the water wells originating from oil and gas producing formations. The authors identified inadequate surface casing and leaks in production casing and wellhead seals in older, vertical oil and gas wells as stray gas migration pathways. Based on their results, wellbore barrier failure, not hydraulic fracturing per se, is the main cause of thermogenic stray gas migration.

Ingraffea et al. (2014) found the loss of well integrity to be more of an issue with unconventional gas wells than conventional wells. The authors assessed 32,678 producing wells and found that unconventional wells had six times the number of cement and casing issues compared to conventional wells. The increase risk of failure is also likely to increase with the age of the well (Boothroyd et al. 2016).

The potential risk to groundwater from hydraulic fracturing near abandoned wells is relatively unknown because few studies have investigated the impact of fracking on abandoned wells. Brownlow et al. (2016) examined the interaction between hydraulically fracturing and existing water wells (frac hits) in order to understand the potential risk to groundwater from upward leakage into overlying aquifers. The authors examined this potential in the Eagle Ford Shale play of south Texas, with attention paid to abandoned oil and gas wells converted into water wells. Their analysis showed abandoned wells have the potential to be intersected by multiple stimulated reservoirs, and risks for intersection increase if currently permitted horizontal wells in the Eagle Ford Shale are actually completed. The results of Brownlow et al. (2016) underscores the need to evaluate historical oil and gas activities in areas with modern unconventional oil and gas activities.

Given the emerging research on the methane pollution associated with unplugged, plugged, improperly plugged and abandoned wells, having sufficient bonding and economic incentives in place to insure timely plugging and reclamation as well as continued monitoring long after the wells have stopped producing economic quantities of oil and gas is pivotal for implementing more responsible oil and gas development.

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Endnotes

[18]Methane pollution from producing oil and gas wells is also a significant problem which can be addressed economically with impact fees (Morton and Hjerpe 2016).

[19]Weber et al. (2018) cites the following case. "As Royal Dutch Shell subsidiary East Resources was drilling a shale gas well in June of 2012, methane began to bubble out of nearby streams and the water well of a neighboring cabin overflowed, flooding the cabin. The unintended migration of methane seemingly caused by Shell's drilling culminated in a 30-foot geyser of water and natural gas erupting out of a nearby abandoned well for over a week. The abandoned well had been drilled as a gas well in 1932, and while Shell knew of the well's proximity to their operation, they assumed that it had been properly plugged. Shell asked local residents to evacuate their homes while they worked with well control specialists, a fire department, and state regulators to get the leak under control (Detrow, 2012)."

Appendix B. Pollution Tax as an Alternative to Impact Fees

Legal concerns about proportionality and the rational nexus test associated with impact fees may be somewhat mitigated if local governments propose pollution taxes and local citizens vote to support pollution taxes. Recognizing that local municipalities and individuals bear a disproportionate share of the environmental and human health costs associated with oil and gas development, Boulder City Council proposed a ballot measure for a pollution tax on oil and gas extracted within city limits (City of Boulder, Colorado 2018). Residents of the City of Boulder overwhelmingly voted to pass the ballot measure authorizing an oil and gas pollution tax of up to $6.90 per barrel of oil and up to $0.88 per thousand cubic feet (Mcf) of natural gas.

The pollution tax on oil and gas production was designed to cover the projected social costs of carbon pollution. The rational for the ballot measure is the following:

> Assigning an appropriate monetary value for these externalities will balance economic versus environmental and social interest and represent a portion of the true societal costs of oil and gas development. In the best-case scenario, there would be no oil and gas development within city limits, so no revenue would be collected from this tax. But if oil and gas development does take place, those profiting from these activities would pay a share of the societal costs (City of Boulder, Colorado 2018, page 258).

Boulder's pollution tax is derived from the EPA's estimate of the social costs of carbon – which quantifies the impact these emissions have on health, well-being, and quality of life in terms of dollars. The social cost of carbon was combined with estimates of carbon dioxide equivalents (CO2e) per barrel of oil and thousand cubic feet of natural gas.

While Boulder's pollution tax is not an impact fee, it does represent another economic tool with perhaps more flexibility for local governments than impact fees. Impact fees increased in popularity in part because of anti-tax sentiments. If local residents are willing to pass a pollution tax, some of the legal complications around proportionality and the rational nexus test associated with impact fees might be avoided. As noted by Boulder city staff:

> Because this is a tax, and not an impact fee, state law does not require the rate to directly correspond to the impact. Staff calculated the societal cost to show that the cost of the impacts is much higher than the proposed tax rate – but the tax rate itself was chosen to be a reasonable percentage of each fuels' sale price (City of Boulder, Colorado 2018, page 263).

Funds generated from the carbon pollution tax are dedicated to the costs created by oil and gas extraction operations with any remainder going to the general fund.

As discussed, staff for the City of Boulder combined an estimate of the social cost of carbon with estimates of carbon dioxide equivalents (CO2e) per barrel of oil and thousand cubic feet of gas. This calculation resulted in an estimated carbon tax of $46 per barrel of oil and $35 per thousand cubic feet (Mcf) of natural gas. Because the estimated tax rate of $35 per Mcf of gas represented 480% of the market price of natural gas, staff decided to use a "scaling factor" to make downward adjustments.

> If the city were to set the tax rate at the true social cost, it would be 40 percent and 480 percent of the sale price of oil and natural gas respectively. With that in mind, staff proposes a much lower rate, which represents only 15 percent and 2.5 percent of the social cost of these fuels. The scaling factors were chosen such that the proposed tax rate is roughly 12 percent of the sale price. Because the social cost of natural gas is higher relative to its sale price, it has a lower scaling factor (City of Boulder, Colorado 2018, page 263).

While perhaps using the scaling factor was a reasonable political approach, correcting market prices for negative externalities does not require that the pollution tax be less than the market price. When charged at the wellhead, the social costs of the methane pollution from oil and natural gas production may and indeed does appear to exceed the market price of natural gas.

The social costs of carbon and methane are calculated at a global scale – as climate change is a global phenomenon. Estimated costs range from local effects such as decreasing agricultural production to global effects such as rising sea levels. Given the large global damages estimated from methane pollution, having negative externalities greater than the market price of natural gas is not surprising.

Since the social cost of carbon and methane is calculated at the global scale, it does make sense for the City of Boulder to reduce the pollution tax lower to reflect just the local costs. But the full social cost of pollution tax could still be charged at the wellhead. If the full social cost of carbon and methane were charged as a pollution tax at the wellhead, the additional revenue collected could be allocated to other levels of government for mitigating the damages from climate change.

Consider the following option of charging the full social costs as a pollution tax at the wellhead – and then allocating the total tax revenue to local, state, federal and global accounts. For example, 12.5% of the pollution tax revenue could go to local communities, and an additional 12.5% could go to the state. The federal government could get 25% of the total revenue with the remaining 50% of the revenue going into a global climate change mitigation fund. Such a spatial allocation would be more representative of the distribution of local, national and global damages from climate change then if the local government captured the entire amount. If local governments adopt such an approach, a local, national and global mitigation fund could be established to provide financing for communities and countries that will be most impacted by rising sea level and more extreme weather patterns.

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Appendix C. Baseline Health Assessment of Farm Animals, Wildlife and Companion Pets

Conservation biologists pioneered the use of Management Indicator Species as a cost-effective approach for monitoring the overall health of forest ecosystems. The use of management indicator species has become a standard monitoring approach in ecological assessment and biodiversity conservation (Caro 2010, Bal et al. 2018). Populations of management indicator birds and wildlife species can be monitored to better understand the impacts from the habitat loss and degradation due to oil and gas operations. Selecting and monitoring non-human indicator species can also help communities understand the public health impacts of oil and gas drilling and production.

Communities near oil and gas drilling operations have become de facto laboratories for the study of environmental toxicology (Bamberger and Oswald 2015). Oil and gas drilling have increased in high population areas without a full assessment of the cumulative health risks to humans and animals from chemicals released by this industry. For these reasons, an epidemiological approach that analyzes the health effects on humans and animals in proximity to gas and oil extraction and processing has a great deal of potential for understanding possible risks (Bamberger and Oswald 2015).

Public health experts have recommended using farm animals and pets as “sentinels” of environmental and public health (Bamberger and Oswald 2014). Stahl (1997) defined animal sentinels as "any non-human organism that can react to...an environmental contaminant before the contaminant impacts humans". Utilizing nonhuman species as early warning systems for human health risk is not a new concept as it dates back to the miner's canary used to warn of high carbon monoxide concentrations in coal mines (Burrell and Seibert 1916, Schwabe 1984). With their rapid heart rates, canaries are more susceptible than humans to the effects of carbon monoxide poisoning or depletion of oxygen (Schmidt 2009). Though using animals as intentional sentinels fell out of favor in the 1960s, the large scale and fast paced drilling in the last decade has resulted in animals being “unintentional sentinels” (Whitley 2019).

Bamberger and Oswald (2012) identified possible exposure routes to oil and gas related chemicals using a case study approach to document health incidents experienced by humans and animals living near drill sites in six U.S. states (Colorado, Louisiana, New York, Ohio, Pennsylvania, and Texas). Their results for livestock documented reproductive problems (irregular cycles, failure to breed, stillbirths), neurological issues (seizures, incoordination, ataxia), gastrointestinal irregularities (vomiting, diarrhea), and dermatological problems (hair and feather loss, rashes). Adams and Kelsey (2012) found higher drilling activity associated with larger average declines in cow numbers. Pennsylvania counties with more than 150 wells experienced an 18.5 percent decrease in total milk production compared to an average increase of 0.9 percent in counties with no wells drilled.

Finkel et al. (2013) compared milk production, number of cows, and production per cow in Pennsylvania counties with significant unconventional drilling activity to neighboring counties with less drilling activity. Based on data from 1996 to 2006, the authors found a decrease in the number of cows and in milk production in counties with the most drilling. Counties with the most wells drilled during 2007 through 2011 uniformly had declines in total milk production ranging from –16.8 to –28.9 percent.

While correlation is not causation and these authors cannot fully explain their findings, given concern about the economic importance of livestock and dairy farming to America's agricultural economy, more investigation is warranted. Does the downward trend in milk production and cattle health continue over time as more wells are drilled? Are farmers being displaced by oil and gas drilling? These are important questions worthy of additional research. These results indicate economic reasons for collecting health data for farm animals. Recognizing the potential effect on our food supply through water and feed contamination resulting in chemical residues to be present in animal protein and milk, DeDonder et al. (2015) published a summary of the literature on the exposure of livestock to oil and gas chemicals.

In addition to farm animals, human epidemiologic studies should be complemented with similar studies conducted on companion species, such as pet dogs, cats, birds, horses. Companion animals can be used as proxies for monitoring human and ecosystem health of urban and rural environments. Companion pets share a common environment with people and have in the past provided valuable supplemental information relevant to human diseases. Communities could monitor the health of their companion animals as early warning indicator species of overall pet and human health.

Dogs have served as sentinel species for lead poisoning, toxic exposure to heavy metals, and for cancers associated with exposure to pesticides, asbestos and air pollution (Reynolds et al. 1994, and Hayes et al. 1995, Backer et al. 2001, Bischoff, Priest and Mount-Long. 2010, Reif 2011, Serpe et al. 2012.). Backer et al. (2001) used pet dogs as sentinels to illustrate the potential human health hazards from exposure to chemicals from Superfund sites. Bowser and Anderson (2018) completed a review of global research on the use of domestic dogs as sentinels for human infectious disease.

The advantages of using farm animals, birds and wildlife, and companion pets as early warning unintentional sentinels of potential human health risks include: 1) animals have shorter lifespans; 2) disease latency periods are also typically shorter in animals than in humans; 3) animals respond to many toxic insults in ways analogous to humans, and they can develop similar environmentally induced diseases by the same pathogenic mechanisms; 4) animals may be exposed to higher concentrations that produce overt toxicity by being enclosed in a corral; 5) animal studies are free from some of the confounders lifestyle and occupational risk factors that can make the results of human studies difficult to interpret; and 6) comparable exposure conditions under some circumstances, such as for people and their companion animals (National Research Council 1991, Van der Schalie et al. 1999, Backer et al. 2001, Rabinowitz et al. 2010, Reif 2011, Bamberger and Oswald 2014).

To gain a better understanding of possible risks from oil and gas operations, Slizovskiy et al. (2015) used a community health survey and found that reported health of dogs is significantly lower for people living within 1 km of a gas well compared to those living farther away. In addition to a health surveys, communities could work with university extension faculty, local veterinarians or a trusted organization like the Humane Society to establish a baseline assessment of the health of farm animals and companion pets. What is the pre-drilling baseline level of oil and gas related chemicals turning up in the blood samples for our cats? If such chemicals are present in farm animals and pets, it serves as an early warning sign of health problems for humans and other species.

Since cats and dogs typically don't worry about insurance premiums, and since humans bring their pets to the Humane Society to get blood tests done for other reasons, - we suspect that it will be easier and quicker to get a large sample population for a baseline analysis- than collecting baseline data on oil-gas chemicals in the blood on human subjects. What would be the additional cost of testing for oil and gas-related chemicals once a pet's blood sample is drawn?

Evaluating or monitoring the appropriate biological markers in companion animals, particularly pet dogs, could reduce some of the uncertainty associated with predicting human risk (Backer 2001). Monitoring the health of sentinel species can help screen, prioritize, and focus human health risk assessments and generate hypotheses for further evaluation (Van der Schalie et al. 1999). While health assessments based on data from human populations is preferable, collecting data and monitoring the health of indicator sentinel species contributes to the weight-of-evidence evaluations used for such assessments. In their review of the literature, Bowser and Anderson (2018) reinforced the value and need for greater collaboration between the human and veterinary medical sectors and ideally to have standardized shared database where human and animal health data could be entered and shared between health professionals.

In addition to the direct value of pets as sentinels for human health, Whitley (2019) recommends research on the indirect inherent value of human–animal relationships and the emotional costs associated with losing a pet. McHenry (2017) finds that people, especially women, are particularly concerned with how hydraulic fracturing impacts their family pets.

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