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ARTICLE *in* ENVIRONMENTAL SCIENCE & TECHNOLOGY · NOVEMBER 2011

Impact Factor: 5.33 · DOI: 10.1021/es2021796 · Source: PubMed

Environmental Science & Technology

POLICY ANALYSIS

pubs.acs.org/est

Economic Incentives and Regulatory Framework for Shale Gas Well Site Reclamation in Pennsylvania

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ABSTRACT: Improperly abandoned gas wells threaten human health and safety as well as pollute the air and water. In the next 20 years, tens of thousands of new gas wells will be drilled into the Marcellus, Utica, and Upper Devonian shale formations of Pennsylvania. Pennsylvania currently requires production companies to post a bond to ensure environmental reclamation of abandoned well sites, but the size of the bond covers only a small fraction of the site reclamation costs. The economics of shale gas development favor transfer of assets from large entities to smaller ones. With the assets go the liabilities, and without a mechanism to prevent the new owners from assuming reclamation liabilities beyond their means, the economics favor default on well-plugging and site restoration obligations. Policy options and alternatives to bonding are discussed and evaluated.

The emergence of technologies for economic recovery of natural gas from tight shale formations across the U.S. is responsible for a resurgence in domestic natural gas production. Even though the national average wellhead price has dropped by more than two-thirds in three years, shale gas production continues to increase. The Marcellus shale formation underlies numerous Appalachian states and is considered to be the largest gas-bearing shale formation in the U.S. Rapid development of this resource, evidenced by thousands of new wells in the region since the first well in 2004, is charting a new course for natural gas supply and utilization in the Northeast. In Pennsylvania, where there are more drilled wells than any other Appalachian state, this development already dwarfs past oil and gas booms in areal extent and production

■ ECONOMIC, ENVIRONMENTAL, AND HUMAN HEALTH RISKS OF IMPROPERLY ABANDONED SHALE GAS WELLS

Disturbance of the surface environment and subsurface geological strata is a necessary outcome of shale gas development in Appalachia. Surface disturbance is caused by the construction of well pads, impoundments, access roads, and pipelines. Reclamation of the disturbed surface occurs in two stages. Shortly after a well begins production the size of the well pad is reduced and the impoundment is removed. Full reclamation does not occur until after a well is abandoned (permanently taken out of production) because site access is necessary for routine maintenance and removing produced water (brine that comes up with gas).

If a well site is not properly reclaimed after abandonment, the well pad and access roads may cause permanent changes to the natural environment. The deterioration of erosion control features increases siltation, which results in the loss of nutrient-rich topsoil and increased sedimentation of nearby surface waters, impairing natural habitats of aquatic species.[1−3] Compared to natural forest clearing occurrences (e.g., fire), the recruitment, growth, and mortality rate of native plant species at reclaimed oil and gas well sites in boreal forests was found to be significantly worse.[4] Without restoration of topsoil and proper revegetation, the regeneration of natural habitat will be delayed and the environmental impacts of forest fragmentation, including loss of biodiversity and introduction of invasive species, will be exacerbated. The adverse effects of forest fragmentation on the nesting success of migratory birds have been documented,[5] and the impacts extend to other plant and animal species dependent on shade, humidity, and tree canopy protection characteristic of deep forest environments in the region.[6,7] The construction of well pads, water impoundments, and access roads is projected to disturb 129 000−310 000 acres of forested land in Pennsylvania.[6] In northern Pennsylvania forests, where largest blocks of public forests exist, the potential for lasting forest fragmentation and associated environmental impacts could negatively affect economic interests related to timber management, game, and tourism.[7]

To reach the Devonian Shale formations, wellbores transect a mile or more of geologic strata, including fresh and saline aquifers and shallow gas-bearing formations. Shale gas wells will need to be plugged to prevent environmental damage

Received: June 27, 2011
Accepted: October 10, 2011
Revised: October 4, 2011

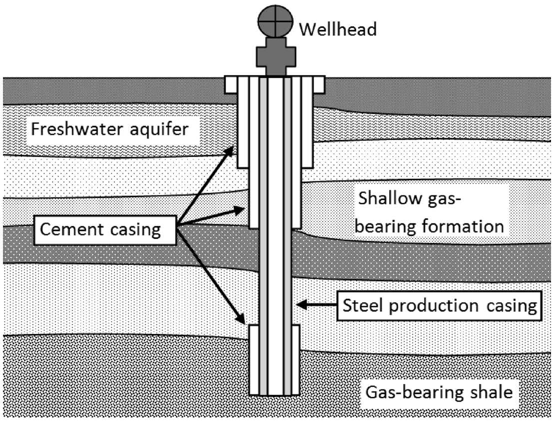

Figure 1. Simple representation of shale gas well anatomy. Layers of cement and steel casing are used to isolate production zones from freshwater aquifers. To properly close a shale gas well, the wellhead and steel production casing are removed and cement plugs are installed to prevent fluid movement in the wellbore and annulus. This diagram is not drawn to scale.

caused by the disturbance of the subsurface, namely the movement of oil, gas, and brine to the surface and between geologic formations connected by the wellbore. General plugging procedures in most states, including Pennsylvania, begin with the removal of steel production casing, which extends from the surface to producing formations, for scrap value. Next, a series of cement plugs will be installed in the wellbore to isolate freshwater and saline aquifers and gas producing formations.[8] (Figure 1)

Unplugged wells may provide a direct pathway to the environment for fluids in the wellbore,[9] which results in ecological harm, property damage, and surface and groundwater contamination. Additional pathways in the annulus (an industry term for the space between two concentric objects, such as between the wellbore and casing or between casing and tubing) may develop that would allow oil, gas, and brine to move vertically across geologic formations and contaminate groundwater. Substances dissolved in the brine may include those that occur naturally in the shale formations (some radioactive) and others injected during the hydraulic fracturing process (some toxic). Also upwardly migrating gas, known as stray gas, represents an explosion hazard if not properly vented away from buildings and drinking water wells.[10−12]

The risk that annular pathways will develop increases over time as chemical, mechanical, and thermal stresses causes deterioration of well structures and components. Failure modes of improperly abandoned wells (defined here as nonproducing wells not in compliance with Pennsylvania plugging requirements or inactive status rules) include the formation of cracks in the cement casing or packers, corrosion of steel production casing, faulty valves, and leaking temporary plugs or surface caps.[9,13−17] Properly performed, the plugging process reinforces existing casing and seals and prevents fluid movement in the wellbore, which may retard the deterioration of vital well components and structures. Therefore, prompt plugging once a shale gas well becomes uneconomic may reduce the risk of negative environmental and human health impacts,[13,14] while also avoiding additional plugging costs that may be incurred if the mechanical integrity of a casing has been compromised.[18] However, the risk of failures leading to fluid migration pathways still exists after a well has been plugged and increases with time.[9,14−16]

The impacts and remediation costs resulting from gas migration and groundwater contamination due to failures at unplugged and improperly abandoned gas wells is well documented in Pennsylvania and elsewhere.[10,12,19−21] Property values can be negatively affected if gas wells contaminate groundwater used for drinking.[22−24] Moreover, the presence of an improperly abandoned gas well may prevent landowners from using their property for other purposes.[25] Stray gas, which is mostly methane, is also a potent source of greenhouse gas emissions.[26]

■ THE SAUDI ARABIA OF NATURAL GAS AND THE SWISS CHEESE OF APPALACHIA

Approximately 350 000 conventional oil and natural gas wells have been drilled in Pennsylvania since the 1859 discovery of oil in Titusville. [11] Many of these legacy wells that are no longer producing oil or gas were never plugged. Some leak gas, oil, and/or brine into freshwater aquifers and the surface environment.[27,28] To remedy this situation, Pennsylvania's Oil and Gas Act of 1984 required all wells from which economic benefits were accrued after 1979 to be plugged according to the latest standards and the well sites reclaimed by their owners. To promote compliance with this statute and cover the cost in the event of owner insolvency, a bonding requirement was established. In 1985, Pennsylvania started plugging oil and gas wells lacking a legally responsible owner, known as orphan wells, and supported these activities with fees on new oil and natural gas well permits ($200 and $50 per well for the Orphan Well Plugging Fund and Abandoned Well Plugging Fund, respectively), monies collected for regulatory violations, and grants distributed by Pennsylvania's taxpayer-funded Growing Greener program.[29] From 2007 to 2008, the most recent years for which data are available, a total of $1,066,000 in Growing Greener grants were awarded to reclaim orphan and abandoned wells. [30,31] Before the current shale gas boom, the Pennsylvania Department of Environmental Protection (PADEP) estimated that at 2004 funding rates it would take around 160 years to plug all the existing orphan wells in the Commonwealth.[11]

■ COSTS OF SITE RESTORATION AND SHALE GAS WELL CLOSURE

Pennsylvania's 1984 Oil and Gas Act defines a natural gas operator's drinking water, site restoration, and well closure responsibilities. Once a well is abandoned, the owner has 12 months to properly plug it and restore the well pad to its previous condition. Restoration of the production well pad (which typically covers 1−3 acres[32]) may involve regrading of land, removing access roads and impoundments, restoring top soil, planting native flora, or other necessary restoration required for compliance with Pennsylvania's Clean Streams Law of 1937. Operators must also remove all equipment used in the production of gas as part of the well abandonment process. This equipment includes the production casing (innermost steel casing that extends down to the production zone), Christmas tree (a grouping of pipes, valves, and fittings used to control the flow of gas from a well), dehydrator, compressor, and tank battery.

The cost to plug a deep shale gas well has not been formally estimated by the PADEP, however, it is understood that the cost to plug a well depends primarily on its measured depth (full length of wellbore including horizontal portions). Plugging costs increase when the condition of the wellbore is poor or access to the site is difficult. For orphan oil and gas wells in Southwestern Pennsylvania, the PADEP estimates the total cost to plug and restore the site of a well approximately 914 m (3000 feet) in depth averages $60,000, but per well reclamation costs have also exceeded $100,000.[18] Reclamation costs of wells drilled into the Devonian Shale (Marcellus, Utica, and Upper Devonian), which range from 1524 to 2744 m deep, will be greater because costs are strongly correlated with depth. Using reclamation data from 255 orphan wells in Wyoming, Andersen and Coupal (2009) estimated the relationship between reclamation costs and depth.[33] They estimated that total reclamation costs (well plugging, site restoration, and equipment removal) were approximately $34.45 per meter ($10.50 per foot). They also noted that economies of scale exist when more than one well is on each well pad, which is the norm for wells in the Marcellus Shale. Summarizing data from approximately 1000 individual well completion reports catalogued by the Pennsylvania Department of Conservation and Natural Resources,[34] the average measured depth of hydraulically fractured shale gas wells completed in Pennsylvania during 2010 was approximately 3254 m (10 675 feet). Thus, for a single well, at $34.45 per meter, the average reclamation cost for a well in the Marcellus Shale will be in the vicinity of $100,000. However, in some cases the costs for plugging and abandonment of a shale gas well in Pennsylvania have been substantially higher. For instance, 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.[35]

PENNSYLVANIA BONDING REQUIREMENTS ON PRIVATE LANDS DO NOT INCENTIVIZE RECLAMATION

Issues of operator insolvency due to the boom and bust cycles of oil and gas development complicate efforts to hold liable parties responsible and provide for timely environmental reclamation. In theory, requiring that operators post bonds prior to drilling bolsters traditional liability rules by incentivizing compliance.[36] In Pennsylvania, bonded monies are released one year after the PADEP deems regulatory requirements associated with reclamation have been satisfied. If the level of bonding is set less than the associated reclamation costs, companies could be tempted to pursue strategies that avoid their liabilities.

Oil and gas bonding requirements vary across states and on federal lands, but most have established minimum bonding levels (blanket or for individual wells).[25] In general, the dollar amount of state and federal bonds for oil and gas wells often do not reflect expected reclamation costs. The full effect of this imbalance has not yet been felt because oil and gas wells may have long life spans (up to 50 years, which can be prolonged further on paper via regulatory allowances), and bonding requirements are relatively new.[36]

Pennsylvania's experience with bonding of coal mining sites may be indicative of what to expect. From 1985 to 1999, bonds for surface mining permits covering approximately 10% of total acreage were forfeited.[37] Since the cost to reclaim a mine in most cases was higher than the amount bonded, funding to bring abandoned mine lands into compliance has generally been inadequate.[37−39] In 1986, only 33% of acreage covered by forfeited bonds had been reclaimed, according to a U.S. General Accounting Office study. The discrepancy was attributed to inadequate funding from forfeited bonds and legal delays in bond forfeiture.[39] Following a lawsuit and increased Federal scrutiny thereafter, Pennsylvania modified its regulatory framework related to the reclamation of abandoned mine lands.[38] Pennsylvania now requires mine operators to perform site-specific estimation of reclamation liabilities to ensure posted bonds cover the full cost of reclamation.[40]

Today, shale gas operators in Pennsylvania must post either a bond of $2500 for each well or a blanket bond of $25,000 to cover all the wells they drill in the state. This is the same dollar amount required in 1984, despite statutory provisions that empower the Environmental Quality Board to adjust the level of bonding to match projected reclamation costs every two years. A bond of $2500 is inadequate to cover the costs to plug a deep shale gas well and restore the land (approximately 100−700 thousand dollars). The inadequacy of the blanket bond is even more pronounced, as many operators are expected to drill thousands of wells. For example, Chesapeake Energy, operating in a joint venture with Statoil, plans to drill up to 17 000 shale gas wells in Appalachia over the next 20 years.[41]

The Oil and Gas Act prohibits private landowners from securing financial assurances from the operator independent of Pennsylvania regulations. The situation is different on Pennsylvania's state-owned land. Pennsylvania includes a condition in all of its lease agreements for drilling in state forests that requires operators to submit additional individual well bonds. The dollar amount required scales with the measured depth, so operators in state forests are required to post bonds of $50,000−100,000 per well drilled.[42]

It is important to note that the substantial bonds required in drilling leases in state forests did not preclude a successful lease auction, proceeds of $128 million far exceeded original expectations of $60 million.[43] This suggests that bonds in the $100,000 range are not prohibitive for large exploration and production companies, though they may be an obstacle for smaller concerns.

TRANSFERRING ASSETS SHIFTS ENVIRONMENTAL LIABILITY

Over the next two decades, drilling rates of 1000 or more new shale gas wells per year are projected, as production from Pennsylvania's Marcellus Shale is expected to reach approximately 110 million cubic meters (4 billion cubic feet) of natural gas per day by 2015.[44,45] To sustain such high levels of production, the shale gas industry needs to constantly drill and complete new wells because gas production rapidly declines in the first few years of production.

Figure 2 shows a type curve published by a Marcellus Shale operator, EQT Production.[46] A type curve is a gas production curve modeled from initial and historic production data and reservoir characteristics. The precipitous decline in production rate of gas is typical of deep shale gas wells in Pennsylvania and elsewhere. (Refracking is a process that can be used to increase production in a declining well. Because there are no reliable data published on this practice in Appalachia it is excluded from this analysis.)

Industry economics are dominated by high initial gas production rates. For a typical well, assuming a constant price of $176.6 per thousand cubic meters of gas ($5/Mcf) and a $5.3 million cost to drill and complete a new well,[46] the internal rate of return (IRR) asymptotes near 79% after the seventh year, after which production revenue dwindles compared to that of the initial years. Assuming a 10% discount rate, 81% of the net present value (NPV) of gross revenue would be realized in 10 years. Compared to the potential revenue from gas sales, the present value of long-term shale gas liabilities, which are discounted

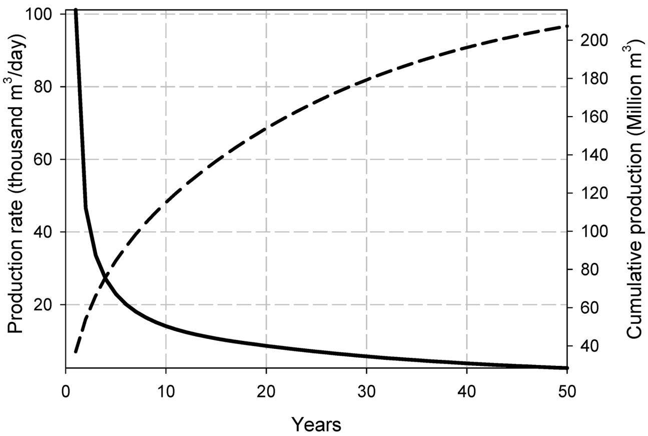

Figure 2. Expected gas production rate (solid line) and cumulative production curve (dashed) for EQT Production's Marcellus Shale operations.[46].

40−50 years, has negligible impact on near-term accounting. The problem of failing to internalize reclamation liabilities emerges when the liabilities begin to exceed the current asset value.

The steep decline in production may drive divestment of shale gas assets by primary exploration and production companies well before the expected closure of a shale gas well. The transfer of marginally producing assets to smaller independent operators or surface owners is common practice in the oil and gas industry.[47−49] Sometimes surface owners take ownership of a marginally producing well for household use. In such cases, the Oil and Gas Act permits oil and gas asset transfers as long as the prospective owner satisfies the applicable bonding requirements. In Pennsylvania, there exists no formal regulatory mechanism to prevent fully bonded owners from assuming shale gas assets with reclamation liabilities substantially above their own financial means. Large liabilities covered by limited resources could lead to large-scale insolvency, similar to the situation that spawned Pennsylvania's pervasive abandoned acid mine drainage and orphan well problems.[50]

In Pennsylvania and other U.S. states, individual and blanket bonds may be satisfied using a number of financial instruments and often do not even require monies to be transferred. Requiring only the demonstration of assets is common, especially for large operators. When an operator cannot demonstrate sufficient assets to cover liabilities, third party backing, usually in the form of a surety bond, may be obtained for a percentage of the bond's face value. Since surety companies or banks underwriting the bond are liable if an operator is unable to perform reclamation, bond rates are set according to an individual operator's risk of insolvency.[36]

Today's low bonding levels make it possible for hundreds of independent operators satisfy the Pennsylvania's blanket bonding requirements.[51] These operators are capable of producing marginal amounts of oil and gas economically, which allows them to maximize potential economic benefits by extending the productive lifetime of oil and gas wells.[52] The ability to transfer well ownership to independent operators benefits the industry, but a potential consequence of increasing bonding minima could be that smaller operators may face steep risk premiums or not qualify for third party backing and be excluded from participation.

Primary exploration and production companies rely on divestment of existing assets to fund new drilling operations. Blocking independent operators from the market may force these companies to temporarily abandon their uneconomic wells and apply for inactive status instead. In Pennsylvania, nonproducing wells may be granted inactive status for a period of five years, but to be granted an annual extension the operator only has to declare regulatory compliance and the capacity to produce gas in the future from the inactive well. Inactive status and similar provisions in other states grant operators the ability to temporarily abandon a gas well until technology advances or favorable gas prices improve the economics of production, though in practice the decision to reopen a well is expected to be dominated by reclamation and other liabilities.[13]

Inactive status could be used to defer the costs of reclamation indefinitely. According to PADEP records, almost 17 000 conventional oil and gas wells did not report or produce oil or gas for three consecutive years (2007−2009), and were listed as active at the end of 2009.While it may be the case that many of the operators of these wells simply failed to report production, poor compliance with reporting requirements prevents the PADEP from enforcing plugging requirements or administering the inactive status program. In 2009 alone, only 38% of the Commonwealth's conventional oil and gas wells reported production, which indicates a majority of the wells drilled in Pennsylvania may represent environmental liabilities as opposed to a source of revenue.[53] Incentives (fines) are needed to improve compliance with production reporting requirements, though reporting alone will not close this loophole.

The delay between production and reclamation temporally separates revenue generation from the future liabilities. Others have recognized this undesirable trend and instituted remedies. Growth in the number of nonproducing (idle) wells in Alberta and Saskatchewan led these two Canadian provinces to implement a Licensee Liability Rating Program as a measure of insolvency risk and to minimize state financial exposure to orphan wells. The program requires individual operators to provide financial assurance equivalent to the difference between the operators' assets (active wells and assets) and liabilities (inactive wells and abandoned assets).[54,55] Some U.S. states offer tax breaks to promote marginal well production, while others require additional bonds or levy annual fees for inactive wells to incentivize new production or plugging, and to fund compliance monitoring. [25,52]

■ REGULATORY POLICY AND FINANCIAL ASSURANCE OPTIONS

When bonding requirements are smaller than expected liabilities, there is a financial incentive to not comply with reclamation requirements. Individual well bonding requirements that match reclamation costs would remedy this situation, especially with the blanket bonds, where misalignments with reclamation costs can be huge. Eliminating the blanket bond would be a common sense first step for Pennsylvania. However, simply increasing the bond requirement to match reclamation costs may not be the best alternative because more operators will need to obtain third party backing. In theory, reliance on third party backing favors operators that manage assets and liabilities effectively since the underwriting firms would assess the risk of insolvency of individual operators. However, the same may not be true for third party backers. Insolvency of these financial firms is a real concern and the effects may be large.[36,56]

Furthermore, bonds are inherently inflexible to changes in the cost of performing reclamation, to the economics of gas extraction when wells start to lose pressure, and the way financial risk is shared in the industry. This is problematic if reclamation costs deviate dramatically from the average. For instance, following methane migration into the aquifer supplying drinking water to 14 households in Dimock, Pennsylvania, the estimated costs for individual water filtration units and supply replacement via permanent pipeline were approximately \$8,000 and \$800,000 per household, respectively.[57,58] Underwriting firms will only market surety bonds when the amount and term of liability are strictly defined,[36] so bonds are not well suited to cover uncertain liabilities. Bonds would also fail to provide funding for maintenance and monitoring of plugged and abandoned wells and the potential environmental issues that may arise postreclamation. After the release of a bond, recovery of additional environmental costs would require aggrieved citizens or the State to pursue civil action. The State may also block the issuance of new permits to operators with outstanding reclamation liabilities, but for operators without ongoing interests in Pennsylvania, this enforcement mechanism will be limited.

■ ALTERNATIVES TO BONDS

To pay for the long-term treatment of acid mine discharges, coal mine operators in Pennsylvania may establish trust accounts under contract with the State. Funding requirements are based on operator estimates of the present value of capital costs and operating expenses of pollution control projects, which depend on the inflation rate and the expected growth of the trust account. As irrevocable beneficiaries of the trust, the State will reimburse coal mine operators one year after the performance of work, or in the case of nonperformance, the State may use accumulated funds to do the work.[59]

If reclamation trust accounts were to be used for the shale gas industry, it would be the responsibility of the operator to determine current (time zero) reclamation costs as part of the drilling permit and the responsibility of the state to approve that figure. If fully funded trust accounts were tied to individual wells rather than pooling them, timely plugging would become independent of the solvency of the last operator.

For the mining industry, trusts are designed so that they will be fully funded one-year after production ends. The size the trust is estimated from eq 1, which shows the calculation for the present value of reclamation costs.

$$\mathrm{PV} = \left[\frac{\mathrm{RC}}{(1 + [E - I])^{t}}\right] \times (1 + \mathrm{Vol}) \qquad (1)$$

Where RC = estimated cost of reclamation in current dollars, E = expected annual return on investments in trust, I = inflation rate, Vol = volatility premium, proportional to amount invested in stock market, and t = time in years, duration of production

For the shale gas industry, the contract between the State and individual operator would specify the firm responsible for managing the trust account and investment strategy. An inflation rate of 3.1%, bond yield of 5.25%, and market return of 11.2% are recommended by the PADEP for eq 1. At most, 80% of the trust may be invested in stock. A 20% volatility premium is required for the portion of the trust invested in stock.[59] It is the responsibility of the PADEP to ensure an operator's inflation, bond yield, and market return assumptions reflect current conditions. This contract would also detail the irrevocable rights held by the State to claim monies held in the trust.

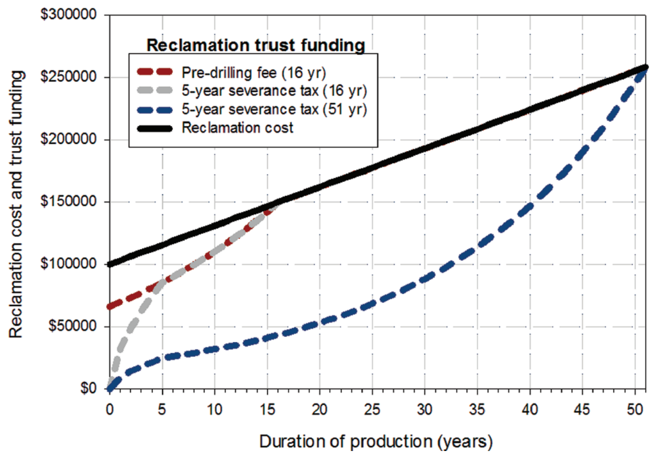

Figure 3. Comparison of financial assurance mechanisms for funding a reclamation liability costing \$100,000 at time zero. Assumptions: gas is produced according to the EQT Production type curve (Figure 2); the inflation rate is 3.1%; and monies invested in the trust have an assumed annual return of 5.25%, following PADEP guidance for bond yields.[59] The "no risk" cash bond option is not shown as it is equal to the cost of reclamation. The funds collected by a predrilling fee and severance tax collected for five years are contrasted. Delayed collection options run the risk of collecting insufficient funds for reclamation of the well if the number of productive years is less than the number of years used to determine present value of reclamation costs. At any given year, the funding shortfall is measured as the difference between the projected reclamation cost line and the respective delayed option line.

We compare three potential mechanisms to fund well reclamation costs estimated using eq 1: cash bond, severance tax on gas production, and a discounted predrilling fee. The properly sized cash bond represents a "no risk" scenario for Pennsylvania because operators would be required to deposit the full cost of reclamation as a precondition for drilling permit approval. Compared to the other forms of bonding allowed by the PADEP, the State Treasurer would manage the bonded monies and the risks associated with operator or third-party default or insolvency would be eliminated. A severance tax on gas production would gradually collect and reinvest monies to reach the future value of reclamation. Pennsylvania's Governor, Tom Corbett, opposes levying taxes on the natural gas industry, but has supported a one-time, per well fee to pay for local impacts of the natural gas industry. To fund a reclamation trust via a discounted predrilling fee, we assume that the fee would need to be assessed in an amount equal to the present value of expected reclamation costs at the time of well closure. The severance tax and predrilling fee represent delayed funding mechanisms, so the annual growth and security of the trust as well as the productive lifetime of a shale gas well are important variables. The cost to perform reclamation is compared to funds accrued in a reclamation trust by a severance tax (calculated for two different anticipated well lifespans) and a predrilling fee in Figure 3. To fully fund a reclamation trust by year 16, a predrilling fee of \$65,975 and a severance tax of \$0.87/TCM (\$0.25/Mcf) collected for five years would need to be assessed. A severance tax of \$0.15/TCM (\$0.004/Mcf) on the first five years of production would be assessed if full funding of the trust is not required until year 51. The cash bond option is not graphed because it is equivalent to the inflated reclamation cost each year. The options are fully

dx.doi.org/10.1021/es2021796 | *Environ. Sci. Technol.* XXXX, XXX, 000–000

funded when they intersect the reclamation cost line. If the well is abandoned before the reclamation trust is whole, the difference between the accumulated funds and the inflated reclamation costs will be the shortfall.

No empirical evidence exists to suggest the economic lifetime of a shale gas well will reach generic industry predictions of 40−50 years. Well productivity and the economics of shale gas production have equal weight in an operator's decision to keep a well open. The use of unrealistic expectations of well economics has implications for the application of delayed funding mechanisms and risks underfunding reclamation trust accounts. Figure 3 shows that even if a 15-year lifetime is assumed (reclamation costs discounted from year 16), the difference between the reclamation cost and the funding levels in the trust are substantial for wells abandoned sooner. For the purpose of estimating reclamation costs, it would be wise for Pennsylvania to require that reclamation costs by funded within 10 years, regardless of the actual life span of the well.

Actual production will deviate from industry type curves. Figure 4 shows the cumulative production from horizontal shale gas wells in Pennsylvania that began producing gas from January 2010 through July 2011 compared to the EQT Production type curve (Figure 2).

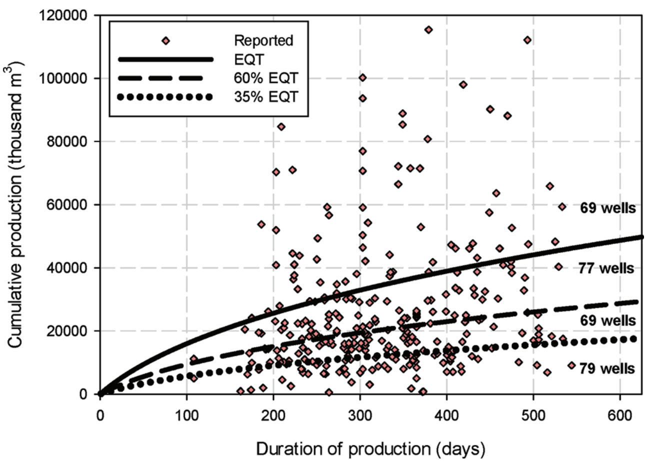

Figure 4. Reported cumulative production of 294 individual horizontal Marcellus Shale gas wells that began producing after 1/1/2010.[51] Three continuous cumulative production curves are modeled: EQT Production's type curve (Figure 2), a 60% EQT, and 35% EQT. Cumulative production predicted by the 60% EQT and 35% EQT curves is exceeded by 50% and 75% of horizontal Marcellus Shale gas wells, respectively.

While nearly a quarter of the wells exceeded the EQT curve, half of the wells produced less than 60% of the EQT curve and 25% of the wells produced 35% or less of the EQT estimate. The variability in cumulative production indicates that industry type curves should not be used to set the terms of financial assurance policy. If a 5-year severance tax is calculated from EQT Production's type curve and applied to the cumulative production of all the wells in Figure 4, independent of the tax rate, the amount of money collected in a trust would only be 62% of the target funding level, assuming that excess funds are returned to the operator.

■ THE IMPACT OF THESE REGULATORY OPTIONS ON THE INDUSTRY BOTTOM LINE

From the point of view of industry finances, the different funding mechanisms have similar impacts on the internal rate of return (IRR) of a producing well, even if total production is low. Table 1 contrasts the IRRs resulting from implementation of (1) the current bond requirement ($2,500), (2) a cash bond equivalent to the reclamation cost, (3) a predrilling fee, and (4) a 5-year severance tax. We assume 50 years of revenue from production, but use a 10-year funding timeline to minimize the risk of underfunding the reclamation trust.

Though these are rough calculations based on simple assumptions, Table 1 shows that levying a predrilling fee and small severance tax on the first five years of production would quickly fund a trust account with minimal impact on the project's IRR. From the industry point of view, paying the full cost of reclamation in an up-front bond is the least attractive alternative. However, actual implantation of any financial assurance requires an industry-wide evaluation of financial assumptions

■ RISKS TO THE STATE

From the State's point of view, there is a risk that the well will become uneconomic prior to year 10, especially if production is much less than EQT Production's type curve. If this occurs, the shortfall of the 5-year severance tax would be greatest.

The problem of underperforming wells or dry holes, however, is not adequately addressed, and unless the "no risk" cash bond is employed, it is expected that both delayed funding options will result in inadequate funding of the reclamation trust account. In the coal industry, operators are required to make underfunded trust accounts whole either by direct payments into the trust or supplementary bonds. If regulations are strictly enforced to prevent dry holes and uneconomic wells from being granted

Table 1. Gross Revenue IRRs Incorporating the Implementation Cost of Financial Assurance Mechanisms[a]

reclamation cost	gas production curve model	IRR with current bond	IRR with "no risk" cash bond	IRR with predrilling fee	IRR with 5-year severance tax
$100,000	EQT	78.7%	76.7%	77.1%	78.1%
	60% EQT	34.3%	33.2%	33.5%	33.8%
	35% EQT	13.2%	12.7%	12.8%	12.9%
$700,000	EQT	78.7%	65.6%	68.4%	74.3%
	60% EQT	34.3%	27.6%	29.0%	30.7%
	35% EQT	13.2%	10.2%	10.8%	11.0%

[a] Drilling and completion cost of $5.3 million and $176.6/TCM ($5/Mcf) price of gas is assumed. The pre-drilling fee and 5-year severance tax are calculated to fully-fund the reclamation trust by year 11. Two target reclamation costs are contrasted, $100,000 and $700,000. The pre-drilling fees are $76,000 and $535,000 for targets of $100,000 and $700,000, respectively. A severance tax rate of $1.01/TCM ($0.029/Mcf) is required for reclamation cost of $100,000 and the EQT production curve. The rate increases to $20.01/TCM ($0.57/Mcf) for reclamation cost of $700,000 and the 35% EQT production curve. TCM = thousand cubic meters. Mcf = thousand cubic feet.

inactive status, the risk of these wells becoming State liabilities decreases.

The risk of underfunded reclamation trusts due to dry holes or otherwise underperforming wells could be reduced if individual operators pooled monies in a reclamation trust. In this case, the severance tax would need to be based on the value of the pooled trust, aggregate production data, and total reclamation liability. To prevent operators from shirking environmental responsibility and ensure the State has adequate resources in case of insolvency, adjustments to the severance tax rate may be necessary so that pooled funds cover the sum of expected reclamation costs.

PADEP may readjust trust funding levels for the mining industry to reflect changes in pollution control costs of plus or minus 10%.[59] However, regulatory inertia or poor oversight pose a threat to the achievement of adequate funding levels, as demonstrated by the lack of adjustment in oil and gas well bonding levels for more than a quarter-century. In theory, the potential for a downward adjustment of the required funding level incentivizes operators to invest in new technologies (or enhanced "pollution control") to lower the cost of reclamation and to have excess funds returned.[60]

DISAGGREGATING ENVIRONMENTAL ACCIDENTS FROM WELL SITE RESTORATION AND CLOSURE

While bond forfeiture is commonly associated with operator failure to perform site restoration and plug abandoned wells, the intent of current bonding system for oil and gas wells is much broader. At any point during the productive life of a well, noncompliance with the Oil and Gas Act or an order of the PADEP may be grounds for bond forfeiture. Restoration of water supplies impacted by nearby shale gas operations is an example.

The formation of a competitive bond market requires that liabilities be well-defined in amount and time. Therefore, neither bonds nor trust accounts are the appropriate tool for environmental accidents that occur during production. A remedy could be for Pennsylvania to adopt financial assurance rules that separate expected liabilities from uncertain events such as casing failure or other environmental accidents. Requiring active operators to obtain liability insurance for uncertain events is a partial solution. Insurance companies would need to quantify potential risks and determine an efficient way to pool risk across multiple wells or operators. However, in the absence of a responsible operator, the State or affected citizen is likely to bear the cost in the event of an environmental issue postreclamation.

CONCLUSION

The financial assurance mechanisms that Pennsylvania uses to ensure compliance with Pennsylvania's Oil and Gas act of 1984 are outdated and allow ownership transfers to entities less likely to be able to cover the expected costs of reclamation. Without strict enforcement of gas production reporting requirements, the PADEP will be unable to monitor compliance with plugging requirements and prevent abuse of the inactive status program. Timely plugging and abandonment should be the goal of PADEP policy because the long-term environmental and human health risks of shale gas development will increase over time and with the risk of operator insolvency. However, increasing the bonding requirements to fully cover reclamation costs, which is within the PADEP's mandate, will not address well-known limitations of environmental bonds and may limit participation in shale gas development to larger companies. Alternative mechanisms to ensure operators pay for future reclamation costs include a cash bond, a predrilling fee, and a severance tax. If operators were to deposit the full cost of reclamation in the form of a cash bond, the risk of underfunding will be lowest. Taxing gas production to fund an individual-well trust account for future reclamation poses no additional barrier to operator entrance. This approach may force the State to assume the risk of reclaiming dry holes unless wells are pooled and a severance tax adjustable to funding levels in the trust, total reclamation liabilities, and aggregate production is developed. Comparing all three mechanisms, we found that generating funds directly from the revenue stream during the most lucrative years of gas production has the lowest impact on an operator's IRR. Though the industry generically predicts wells to operate for 40−50 years, reliance on these assumptions to define the terms of financial assurance increases the risk of underfunding and cannot be justified. Separate handling of reclamation and accidental environmental liabilities would promote the development of a competitive bond market if the current system is kept in place.

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ACKNOWLEDGMENT

We are grateful to W. Michael Griffin (CMU), Joel Tarr (CMU), Roma Sidortsov (Vermont Law School), and Susan Ghoweri (PADEP) for their valued advice and perspective. This work was funded by the Climate Decision Making Center (SES-3045798) and by the Center for Climate and Energy Decision Making (SES-0949710), both through cooperative agreements between the National Science Foundation and Carnegie Mellon University; and by the Gordon and Betty Moore Foundation (Award Number 1625) in support of the Carnegie Energy Research Initiative.

NOMENCLATURE

BCF, billion cubic feet
Mcf, thousand cubic feet
TCM, thousand cubic meters
PADEP, Pennsylvania Department of Environmental Protection
IRR, internal rate of return
NPV, net present value

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