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THE ECONOMIC OPPORTUNITIES OF SHALE ENERGY DEVELOPMENT

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Executive Summary

Directional drilling and hydraulic fracturing have unlocked vast new reserves of natural gas in the United States. Development of these resources is now well under way in Pennsylvania and West Virginia. Unlike their neighbors to the south, however, New York residents are not directly benefiting from natural gas development as the result of a government-imposed moratorium, itself a response to environmental concerns surrounding hydraulic fracturing. This study analyzes the economic and environmental impacts of shale gas drilling in New York and finds the net economic benefits to be significantly positive. Specifically:

- An end to the moratorium would spur over $11.4 billion in economic output.
- Some 15,000 to 18,000 jobs could be created in the Southern Tier and Western New York, regions which lost a combined 48,000 payroll jobs between 2000 and 2010.*
- Another 75,000 to 90,000 jobs could be created if the area of exploration and drilling were expanded to include the Utica shale and southeastern New York, including the New York City watershed. (This assumes a regulatory regime that protects the water supply but permits drilling to continue.)
- Localities and the state stand to reap $1.4 billion in tax revenues if the moratorium is allowed to expire.

This study also reviews the public records of environmental violations reported by the Pennsylvania Department of Environmental Protection over the period 2008–10. It then quantifies the impact of these violations on land, water, and air resources. The costs of these environmental impacts are then estimated on the basis of the value of the environmental amenities at stake. Our main finding is that the cost of these environmental impacts is far smaller than the economic benefits that drilling can provide.

- The typical Marcellus shale gas well generates about $4 million in economic benefits.
- The economic damage resulting from the environmental impacts of a typical shale gas well comes to $14,000.

The expected environmental costs are so low because the probability of an environmental event is small, and those that do occur are minor and localized in their effects.

Those environmental problems that have arisen in connection with hydraulic fracturing in no way call into question the soundness of that procedure. In reality, they result from improper drilling and well-casing technique and defective formulation of cement. Such errors and flaws allow wells to penetrate shallow gas deposits, permitting the gas within them to escape and enter groundwater supplies. Marcellus gas resides far below these deposits and any aquifers. More stringent design standards should be adopted, and more active regulatory oversight should be exercised. These steps would reduce the incidence of such problems.

Our findings suggest that the current shale gas drilling moratorium imposes a significant and needless burden on the New York State economy. In short, the economic benefits of developing shale gas resources in New York State are enormous and could be growing, while the environmental costs of doing so are small and could be diminishing if the moratorium is lifted and if proper policies are put into place.

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*Based on third quarter data from the Quarterly Census of Employment and Wages, maintained by the New York State Department of Labor. Posted at http://www.labor.ny.gov/stats/lsqcew.shtm.

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INTRODUCTION

Improved drilling and production technologies have unlocked large reserves of oil and natural gas in the United States that were once thought to be uneconomic to produce. Companies can now drill miles into the earth and then drill horizontally several thousand feet, directly through the "sweet spot" of "unconventional" formations, such as shale deposits and tightly packed sands. Directional drilling with hydraulic fracturing has unlocked reserves large enough, if fully developed, to satisfy U.S. demand for decades, and possibly centuries, to come. A similar but less dramatic expansion of recoverable oil reserves is under way in "oily" shale plays such as the Bakken field in western North Dakota, the Eagle Ford shale play in south Texas, and possibly the Utica shale in eastern Ohio that may extend into New York State.

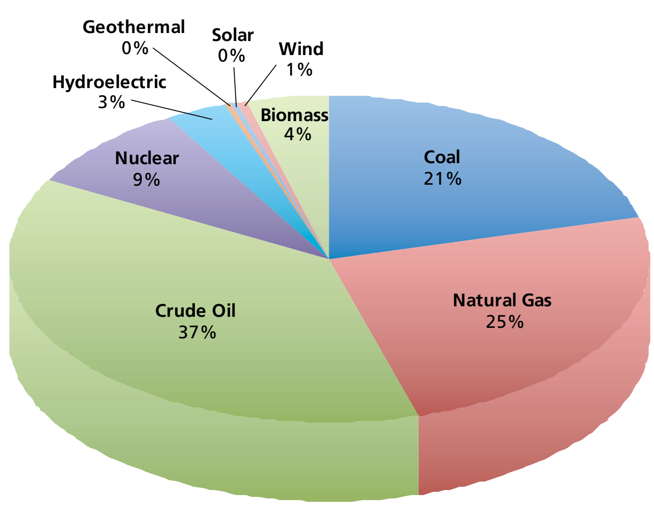
As is not true of conventional oil and gas wells, shale energy output declines steeply during the first few years of production. As a result, operators must be continually drilling new wells. If the market price is strong, the large initial output generates high rates of return and continuous incentives to keep drilling. This is one reason that regional economies with shale plays are enjoying a boom in job creation, tax revenues, and income growth. Like manufacturing and unlike the traditional oil and gas business, shale production can offer to localities and regions a stream of revenues that doesn't quickly dry up.

Because some shale plays now under development, such as the Marcellus, are within the densely populated northeast and within a day's drive of major metropolitan areas, such as New York City, concerns are being raised about not only the noise and other nuisances that drilling and hydraulic fracturing create, but the threat it might pose to drinking water.

During hydraulic fracturing, a sand, water, and chemical solution containing particles known as proppants is injected into the horizontal segments of the wells a mile or farther under the surface. The injected water is subsequently removed through the well bore, but the proppants remain within the fractures that they helped induce to keep them open, thus increasing the permeability of the reservoir. Hydraulic fracturing transports the proppants to their destinations and hence is critical to the success of shale energy production. Due to concerns that spent "frack" water might contaminate drinking-water supplies, New York State has adopted such low limits on how much water can be used per well that it effectively imposes a moratorium on shale gas drilling. This study assesses whether the economic benefits resulting from the access to shale gas provided by this technique justify incurring certain unavoidable environmental costs.

The next section provides an overview of shale energy and the role that it might play in our nation's energy future. A primer on how shale energy is produced follows. The next part of the study contains a discussion of the technology of shale drilling and its accompanying economic impacts. The study then conducts a detailed analysis of records on environmental violations associated with developing the Marcellus natural gas play in Pennsylvania. On the basis of this analysis, the impacts of Marcellus development on forests, water, and air are estimated. These impacts are translated into economic values based upon estimates reported in the literature on the economic valuation of environmental externalities. Calculating the net environmental damage incurred by shale gas drilling involves weighing the damages incurred by drilling against the improvement in air quality resulting from the displacement of coal-fired generation by natural gas. The net damage is then set against the economic benefits of shale gas drilling. The analysis is expressed on a per-well basis, which allows the estimation of a comprehensive economic-environmental benefit-cost ratio for a typical Marcellus shale gas well. The study then uses these estimates to determine the net benefit of the effective moratorium on shale gas drilling in New York State. The final section provides an overview of the main findings and discusses the policy implications of the analysis.

Figure I. Shares of Total Energy Consumption by Source, 2009



Source: Energy Information Administration

THE EMERGENCE OF SHALE ENERGY

The U.S. economy remains overwhelmingly dependent upon fossil fuels, with 83 percent of domestic energy consumption supplied by them. Oil, with 37 percent, leads and is followed by natural gas, with 25 percent, and then coal, with 21 percent (see Figure 1). Nuclear energy supplies 9 percent of total consumption, with biomass and hydroelectricity providing 4 percent and 3 percent, respectively. Wind and solar energy provided only 0.74 percent and 0.11 percent of total energy consumption, respectively, during 2009 (see Figure 1). While solar and wind energy production has been growing briskly in recent years, this growth has been dependent upon the continuation of federal and state subsidies. Even if the subsidies are continued, production from these sources would probably fail to grow even as rapidly as total energy demand, and these sources would almost certainly fail to grow their share of total production by displacing conventional fossil fuels.

The electricity industry is now the single largest user of natural gas and will likely expand consumption significantly in future years to meet higher demand for electricity and as the result of replacing aging coal-fired power plants. Since natural gas contains only about a third as much carbon as coal, such a transition could significantly reduce greenhouse gas emissions.

These additional demands for natural gas have been increasingly supplied by shale gas production. Total U.S. average annual shale gas production increased by over 65 percent from 2007 to 2008, exceeding 2,152 billion cubic feet (BCF), which is 10.7 percent of total U.S. production (see Table 1). Shale production increased another 48 percent during 2009, to 3,182 billion cubic feet, which is over 15 percent of U.S. dry gas production. Texas, led by the Barnett field, is the largest shale gas producer, with 1,789 BCF, followed by the Fayetteville shale in Arkansas with 527 BCF, the Haynesville shale in Louisiana with 293 BCF, and the Woodford shale in Oklahoma with 249 BCF. The Marcellus shale in West Virginia and Pennsylvania produced approximately 148 BCF during 2009. With the exception of the Antrim shale in Michigan, production is increasing rapidly in all shale plays. As conventional natural gas deposits deplete, the role of shale gas in the U.S. natural gas supply will increase.

Shale resources also contain crude oil and petroleum liquids. The Marcellus shale in Appalachia is emerging as a major producer of natural gas liquids such as propane and butane. These fuels are a critical input in petrochemical industries. The Bakken shale play in North Dakota is also increasing production rapidly. For example, crude oil production from North Dakota rose from 127,070 barrels per day in September 2007 to 341,384 barrels per day in

Table I. Shale Gas Production by State in Billion Cubic Feet, 2007–2009

	2007	2008	2009
Arkansas	94	279	527
Louisiana	1	23	293
Michigan	148	122	132
North Dakota	3	3	25
Oklahoma	40	168	249
Pennsylvania	5	20	81
West Virginia	5	17	67
Other	18	17	19
Texas	988	1,503	1,789
Total shale gas production	1,303	2,152	3,182
Total U.S. dry gas production	19,266	20,159	20,580
Shale share	6.8%	10.7%	15.5%

Pennsylvania and West Virginia based upon survey by Considine, Watson, and Blumsack (2010).
All other state data from U.S. Energy Information Administration.

September 2010. The Eagle Ford shale play in south Texas and the Niobrara play in eastern Wyoming are also promising. Production from these new oil-producing areas could reverse the long-term decline in U.S. oil production.

While potential recoverable reserves of shale oil amount to roughly 10 billion barrels, shale natural gas reserves are immense: there are hundreds or even thousands of trillion cubic feet. As a result of these newly found reserves, the Potential Gas Committee (2008) estimated that the total natural gas resource base for the United States is 1,836 trillion cubic feet.

PRODUCING ENERGY FROM SHALE FORMATIONS

Horizontal drilling and hydraulic fracturing technologies enabled the opening of these immense shale energy reserves. Horizontal drilling involves vertically drilling down to the shale-bearing strata, often 5,000 to 12,000 feet below the surface, and drilling horizontally to establish lateral well sections that may be up to a mile in length. This approach allows greater surface contact with the energy-bearing shale layer. Producers then inject water under high pressure into the well, which cracks the rock and increases the permeability of the reservoir. Companies are constantly increasing the speed and efficiency of these operations.

The first step in drilling a well is to install a well pad to support a drilling rig. Land is cleared, an area for the well is leveled off, and gravel roads are laid. After a well is completed, all surrounding land is restored and replanted.

Two types of wells can be employed (see Figure 2): a vertical well in which a large drilling rig rotates a steel pipe with a drill bit on the end; and a horizontal well in which a drilling motor pushes fluid through a stationary drill pipe, causing the bit to rotate. In either case, as the well is drilled, a new length of pipe is connected to the one already in use so that the latter can be pushed deeper into the hole. Currently, both vertical and horizontal wells are being drilled in most shale plays. Both types of wells are drilled to a predetermined vertical depth, but the latter then makes a turn, permitting it to be drilled sideways for several thousand feet. While the cost of a horizontal well is three to four times that of a vertical well, they are much more productive because they have far more contact with the gas-bearing rock.

Figure 2. Schematic of Horizontal Drilling in the Barnett Shale

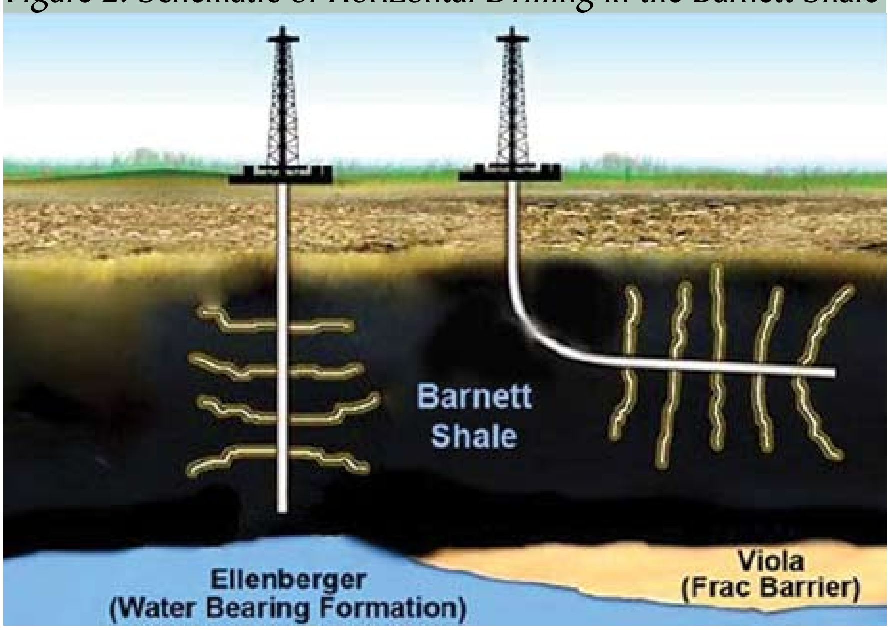
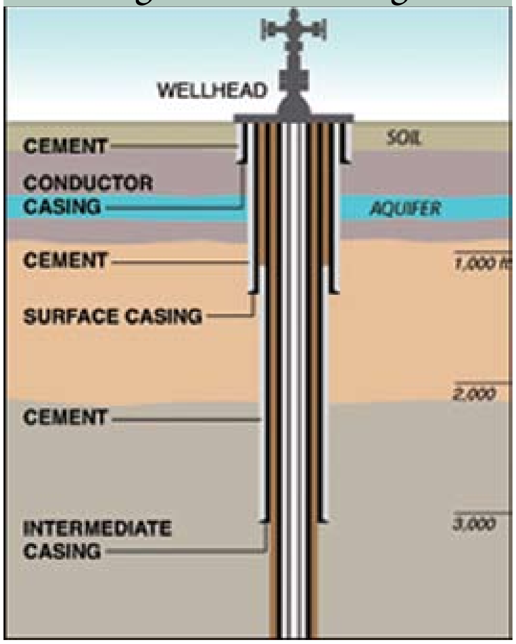


Figure 3. Well Casing



Standard drilling practice includes several measures intended to protect the environment. Oil and gas wells penetrate the water table, extending several thousand feet below potable water supplies. As the well is drilled, steel pipe called casing is inserted into the well bore and then cemented into place to form a barrier that protects subsurface groundwater from contamination. Well drillers are also responsible for ensuring that any fluids or chemicals used or produced during the drilling process and the completion processes do not contaminate surface waters such as streams, rivers, or lakes. In Pennsylvania, all fluids on a well site are contained within plastic tarpaulins, plastic-lined pits, or steel tanks, permitting these fluids to be recycled or transported to permitted well-disposal sites.

After the well is drilled to its final depth, another steel pipe is installed inside of larger ones above it and cemented into place. The drilling rig then leaves the site, and a wellhead is installed on the surface. This is a collection of valves, often referred to as a Christmas tree, that controls the flow of gas and allows it to be turned off completely if necessary. The Christmas tree also allows equipment for performing maintenance to enter the well safely. Shaped explosive charges are next used to perforate the bottom section of the steel pipe. Doing so allows fluid to be pumped in and then gas to flow out of the pipe casing and to the wellhead at the surface. The resulting well is a set of pipes within pipes known as casing strings (see Figure 3). The point where one casing string ends and another extends is known as the "shoe." Most companies use multiple strings of casings of varying lengths, diameters, and grades. We will see below that when natural gas from shallow deposits migrates from shallower formations, from which they can migrate into water strata, casing design is often responsible.

Once drilling is complete, hydraulic fracturing, which stimulates the well to produce more gas by intersecting and connecting as many of the natural fractures to the well as possible, can occur.

THE ECONOMIC RIPPLE EFFECTS OF SHALE DRILLING

The continuity of drilling effort and the economic activity that it generates set shale resource development apart from other energy development activities. Developing coal mines, wind turbines, hydroelectric resources, and solar energy involves significant job creation during construction. Once the facilities are in place, however, their operation requires relatively few workers. In contrast, the labor-intensive aspects of shale gas development accelerate over time and can persist for decades, if the reserves in place are large enough.

Transportation costs are high for key materials used in exploration, drilling, and the construction of gas-processing plants and pipelines. Therefore, support industries, including well support, steel, sand and gravel, concrete, trucking, and scientific and engineering services, often arise locally. Most of these support activities are not easily outsourced to foreign suppliers. And in regions with private mineral rights, shale gas development requires lease and bonus payments to landowners, who in turn pay taxes and spend this income on local goods and services. While the footprint of a shale well site is small, the shale deposits occupy an extensive geographical area, necessitating the leasing of large tracts of land.

Economic-impact studies have been conducted for the Barnett, Fayetteville, Haynesville, and Marcellus shale gas plays. These studies employ input-output models to estimate the direct, indirect, and induced impacts on regional value added (the regional equivalent of contribution to the nation's gross domestic product), employment, and tax revenues. "Direct impacts" constitute the purchases by natural gas companies from other sectors of the economy. "Indirect impacts" refer to the supply chain. For example, a natural gas company contracts with a drilling supply company, which then hires workers and other companies to supply it with materials, equipment, and services. "Induced impacts" constitute the rounds of transactions throughout the economy set off by the spending of workers, hired directly or indirectly, on goods and services. Induced impacts also result from landowners' spending of lease, bonus, and royalty payments.

A summary of the total employment impacts, which include direct, indirect, and induced impacts, found in these studies appears below in Table 2. The Perryman Group (2008) found that Barnett drilling activity generated 132,497 jobs. A study by Loren and Associates (2009) found that the Haynesville shale generated more than 57,000 jobs, almost the same number found by Considine, Watson, and Blumsack (2010) for the Marcellus play. A study by Collins and Deck estimates that development of the Fayetteville shale in Arkansas could generate more than 9,600 jobs. Each of these studies employs input-output models to estimate these impacts.

To accompany the analysis of the environmental impact of developing the Pennsylvania Marcellus shale, which is discussed in the next section, the economic benefits that its development is expected to yield are given below, in Table 3. The total economic output generated by a typical Marcellus well is $5.46 million, which can be considered the gross economic benefit before any deductions for environmental damage. In addition, economic activity associated with Marcellus development generates over $2 million in federal, state, and local taxes, plus 62 jobs per well.

The key question is whether the cost of the environmental impacts exceeds these economic benefits. To answer that question, we assess the environmental track record of the shale gas industry operating in Pennsylvania and estimate the economic cost of its impact on the environment. Such an analysis provides an estimate of the net benefit-cost ratio for shale gas drilling.

ENVIRONMENTAL IMPACTS AND RISKS

The extraction, processing, and transportation of natural gas all affect the environment. However, expansion of the supply of natural gas permits the displacement of more polluting

Table 2. Estimated Job Gains from Shale Gas Development by Basin

State	Shale Play	Year	Job Gains
Arkansas	Fayetteville	2008	9,683
Louisiana	Haynesville	2009	57,637
Texas	Barnett	2008	132,497
Pennsylvania and West Virginia	Marcellus	2009	57,357

Table 3. Economic Benefits from Developing the Pennsylvania Marcellus Shale

	Thousands of 2010 Dollars per well			
	Direct	**Indirect**	**Induced**	**Total**
Value Added	2,792	1,166	1,502	5,460
Taxes				2,036
	Number of Jobs per well			
Employment	31	12	19	62

Source: Calculations based upon Considine, Watson, and Blumsack (2010) forms of energy. Estimating the net environmental impacts, therefore, requires comparing the upstream negative environmental externalities associated with gas development with the downstream positive externalities created by switching to natural gas. The net economic benefit or change in social welfare would be the sum of the costs of this net environmental impact and the benefits derived from the stimulus to local economies. However, even confining economic benefits to those that are local, the positive externalities from substitution of fuels are unavoidably more than local in nature.

A well-developed methodology is discussed by Koomey and Krause (1997) for estimating environmental externality costs, involving these general steps:

- Identifying *insults* to the physical and human environment;
- Charting *pathways* that convert the insults to stresses;
- Estimating the physical or social *consequences* of the stresses; and
- Valuing the environmental and social *costs* of the stresses.

The first three steps collectively can be referred to as environmental-impact assessment and can be accomplished with varying degrees of accuracy or confidence. As a result, most studies estimating environmental externalities specify a degree of uncertainty. A similar approach is adopted below.

Some upstream negative externalities of natural gas production are unavoidable. They involve the clearing of land for well pads and pipelines; local congestion due to truck traffic; and noise and dust. Lease and bonus payments to landowners or direct outlays by companies to repair infrastructure damage caused by gas drilling activity compensate for most of these impacts. Nonetheless, the sheer presence of gas wells has effects on the ecosystem.

Environmental hazards associated with natural gas production are infrequent but can lead to contamination of local water supplies and impairment of air quality. Perhaps the most publicized environmental risk arises from the use and disposal of fluids used in hydraulic fracturing. The New York State Department of Environmental Protection, in its 2009 analysis of the potential impacts of natural gas drilling on the New York City watershed, raised the possibility that water from hydraulic fracturing could migrate from the gas-bearing layers, which are 5,000 feet below the surface, up to water tables less than 500 feet from the surface. The presence of 4,500 feet of rock above the hydraulic fractured zone makes such an eventuality unlikely. Indeed, it has never happened in over 60 years of hydraulic fracturing. Vaughan (2010) argues that water-supply contamination from so-called stray gas occurs more often from failures in well design and construction, breaches in spent hydraulic-fracturing water-containment ponds, and spills of leftover natural gas liquids used in drilling. To determine the frequency of environmental incidents, a detailed examination of the environmental violations reported in the Pennsylvania Marcellus appears in the next section. This provides a basis for estimating the environmental impacts of shale gas drilling and for conducting an economic valuation of the technique's social benefit-cost.

ENVIRONMENTAL VIOLATIONS IN THE PENNSYLVANIA MARCELLUS

Well designers exercise extreme care to isolate any fluids used in the hydraulic fracturing process from any potable subsurface drinking water. About one-third of the total volume of water injected during hydraulic fracturing returns to the surface, while the rest remains in the shale formation. This produced water is collected in a plastic-lined pit or large water tanks at the well site, and then is either recycled for other hydraulic fracturing jobs or treated for disposal at a designated permitted facility.

Pennsylvania has permitted the disposal of treated drilling wastewater into surface waters for decades. To accommodate this, brine-treatment facilities were constructed throughout Pennsylvania in counties where oil and gas production have taken place since the 1800s. To augment this capability, municipal treatment facilities such as the one in Bellefonte, Pennsylvania, took wastewater, treated it, mixed it with sewage waste, and disposed of it into several streams of the Commonwealth.

On August 21, 2010, the Pennsylvania Department of Environmental Protection issued a regulation that requires new or expanding dischargers of wastewater to meet the total dissolved solids (TDS) standard of 500 milligrams per liter. This action did not satisfy the environmental community, which insisted that the DEP ban all oil- and gas-field waste discharge into surface waters. In most instances, the major companies working in the Marcellus region had already moved to end the disposal of wastewater into surface waters and were instead transporting wastewater to Ohio for disposal. Indeed, a recent report by *The Wall Street Journal* (April 25, 2011) indicated that the major companies are moving to end oil- and gas-field waste disposal into surface waters.

The Bureau of Oil and Gas Management in the Pennsylvania Department of Environmental Protection (PADEP) oversees the exploration, development, and recovery of fossil fuels. If at least one of its more than 35 regulations relating to health and safety is not met, the PADEP issues a notice of environmental violation. To simplify the analysis, this study aggregates these violations into eight categories on the basis of the description of the violation and any comments that the inspector makes. Inspectors check off a particular violation from a menu of them but are free to add additional information going beyond the description of the violation in the form of a comment. If the violation comment was inconsistent with the violation description, we scrutinized the violation more closely and, in some instances, reclassified it. If, for example, a violation was administrative but its accompanying comment reported a spill, we would categorize the event as a spill.

Four of the eight violation categories can be called severe: major spills; cement and casing violations; blowouts and venting; and stray gas. These present the greatest threat to human health and safety. Major spills are spills of over 100 gallons of hazardous chemicals, fuel, or produced drilling fluids. Major spills are expensive to remediate and can cause long-term damage, depending on where or when they occur. Cement and casing violations typically involve a well casing that is not properly cemented into place because of poor or inadequate cement displacement and/or poor cleanup of the well bore prior to cement displacement.[1] These problems can allow gas to migrate into freshwater or can allow gas pressure to build up. Blowouts and venting are incidents in which a gas well is dangerously and uncontrollably

Table 4. Number of Environmental Violations in the Pennsylvania Marcellus Shale

	2008	2009	2010	2008–2010
Wells drilled	170	710	1,259	2,139
Serious violations				
Cement and casing	2	6	64	72
Blowouts and venting	0	0	8	8
Major spills	0	48	8	56
Stray gas	0	10	6	16
Subtotal	2	64	86	152
Other violations				
Erosion	84	111	155	350
Other spills	2	120	204	326
Water	10	61	126	197
Administrative	81	283	535	899
Subtotal	177	575	1,020	1,772
Grand total	179	639	1,106	1,924

Table 5. Incidence of Environmental Violations in the Pennsylvania Marcellus Shale				
	Count per 100 wells			
	2008	**2009**	**2010**	**2008-2010**
Serious violations				
Cement and casing	1.2	0.8	5.1	3.4
Blowouts and venting	0.0	0.0	0.6	0.4
Major spills	0.0	6.8	0.6	2.6
Stray gas	0.0	1.4	0.5	0.7
Subtotal	1.2	9.0	6.8	7.1
Other violations				
Erosion	49.4	15.6	12.3	16.4
Other spills	1.2	16.9	16.2	15.2
Water	5.9	8.6	10.0	9.2
Administrative	47.6	39.9	42.5	42.0
Subtotal	104.1	81.0	81.0	82.8
Grand total	105.3	90.0	87.8	89.9

discharging gas. Stray gas is the movement of natural gas through subsurface formations strata into freshwater or other near-surface strata. The movement of natural gas into these near-surface strata can pollute drinking water, and movement to the surface can contaminate wetlands. Consequently, these incidents are classified as severe.

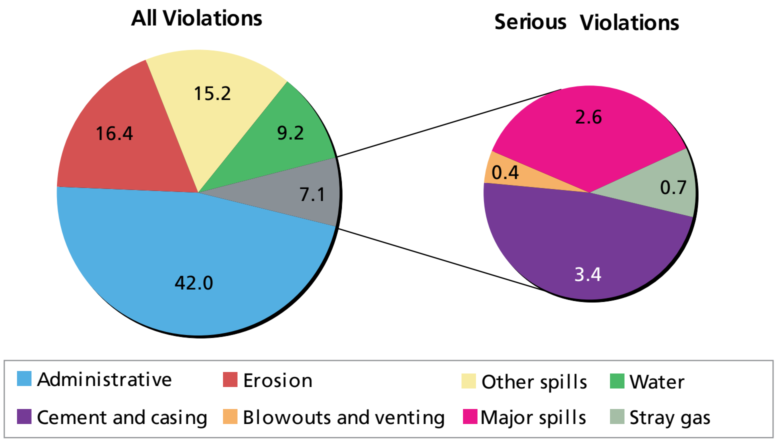
The other four categories are erosion, chemical spills, water spills, and administrative violations that do not have a direct impact on human health or safety. Erosion violations, resulting from spills of freshwater or overflows of drilling-pit waste after rainfalls, disturb soil or sediment. Spills of toxic chemicals are generally small, involving one or two gallons of liquid, such as fuel that has leaked from trucks. Water violations often are the result of illegal dumping or spills that enter streams. However, discharges into surface waters involving fewer than so many parts per million, depending on the chemical, are legal. Administrative violations typically result from errors in paperwork.

The number of environmental violations over the past three years appears in Table 4. In that period, there were 1,924 environmental violations. Of these, 7.9 percent were serious, with 3.7 percent involving cement and casing, 0.4 percent involving blowouts and venting, 2.9 percent involving major spills, and 0.8 percent involving stray gas. The plurality of violations are administrative in nature: 46.7 percent. Erosion, other spills, and water violations constitute 18.2, 16.9, and 10.2 percent of violations, respectively.

The number of violations increased with the number of wells drilled. To correct for this, the incidence of environmental violations per 100 wells drilled appears in Table 5. While the incidence of violations connected to cement and casing and blowouts and venting increased in 2010 over 2008 and 2009, the incidence of stray gas and major spills declined. While administrative and erosion violations are down, other spill and water violations increased between 2008 and 2010.

In summary, for every 100 wells drilled, as indicated in the data over the past three years, about seven incur serious environmental violations, with most of these incidents involving cement and casing problems or leading to major spills (see Figure 4).[2] For every 100 wells drilled, 42 are administrative in nature and 41 involve less serious violations involving water, small spills, and events leading to soil erosion. The key question surrounding these environmental violations is the impact that they have on the environment. The next section addresses this question.

Figure 4. Environmental Violations per 100 Wells Drilled in Pennsylvania Marcellus, 2008–10[3]



ENVIRONMENTAL-IMPACT ANALYSIS OF GAS DRILLING

Pennsylvania is home to four river basins: the Potomac, Delaware, and Susquehanna; and the Allegheny-Monongahela-Ohio river system. The state's mineral extraction industries, such as coal mining, and heavy industries, such as steel, have impaired water quality in those bodies. The citizens of the Commonwealth, therefore, do not welcome any further reduction in water quality that could result from the activities of some new industry.

The citation of violations is intended to deter companies from activities that harm the environment. The records of these violations provide a basis for estimating their environmental impact. The next three subsections discuss specific incidents caused, respectively, by stray gas, spills, and blowouts. A discussion of drilling's impact on air quality and the ecosystem follows.

Stray Gas: The most noteworthy case of stray gas occurred in Dimock, a small town in Susquehanna County, Pennsylvania, with a population of just over 1,300 and a per-capita income of about $15,000, according to the U.S. Census Bureau. When Cabot Oil and Gas began to lease land, according to Bateman (2010), many landowners were enthusiastic about the chance to earn an up-front signing bonus plus production royalties. Some local residents did express concern about the risk of environmental damage, but Cabot assured these residents that there would be little impact, since it had hydraulically fractured hundreds of gas wells without precipitating a major environmental incident.

The source of water for residents of Dimock living near the gas wells is backyard wells. In 2008, residents began to complain about the quality of the water coming out of their faucets. In January 2009, it was alleged that one of these water wells exploded.[4] The residents sued Cabot Oil and Gas in September 2009, alleging that Cabot allowed methane and metals to seep into drinking-water sources. In September 2010, Legere (2010a) reported that a private engineering firm indeed found toxic chemicals as well as methane in the water. This incident drew national attention.

On December 16, 2010, residents of Dimock Township reached a financial settlement with Cabot Oil and Gas in the amount of $4.185 million for contamination of 19 residential water wells, representing twice the assessed valuation of the properties (see Smith 2010). Cabot also agreed to pay the PADEP $1.07 million in penalties. An analysis by the PADEP, however, found that the methane in the well water probably came from plants and animals, not the Marcellus formation, which is more than a mile below the water wells' deepest point. Regardless of origin, how did the methane get into the water?

In fact, the stray gas issue is a public-safety issue rather than a water-quality issue. While water-treatment systems can remove methane and accompanying metals, migration of natural gas into buildings poses a serious risk of explosion. The stray gas problem can be mitigated by proper construction of gas wells.[5] These methods, however, cannot eliminate the problem of stray gas because there are many sources of stray gas other than deep shale formations: not only shallow gas reserves and decaying plants and animals but septic fields and unplugged orphan wells. To keep gas from these sources from contaminating the water supply, all water wells in Pennsylvania should meet certain construction standards. The government has not imposed such standards because of strong opposition from rural communities and the agricultural industry.

Quantification of the volume of gas that has migrated in a particular incident is difficult because it does not appear in the environmental violations database, nor does the volume of water that was affected appear there. Water also migrates into larger bodies, diluting gas concentrations and thus mitigating their effect on human health. Of the 16 cases in Pennsylvania of stray gas resulting from drilling, five directly caused contamination of the aquifer, and three resulted in contamination of local water wells. Regarding the rest, it is no known whether a water source had been affected or an inspector made a comment on the incident. Assuming that 20 households are affected by each incident of stray gas, that each of them uses 69.3 gallons of water per day, and that the contamination persists for one year, then 8,094,240 gallons of water would be affected by the typical stray gas.[6]

Cement and casing violations generally do not have a direct environmental impact. The method that this study uses to quantify the impact of such violations involved calculating the amount of water affected by stray gass and uncontrolled flows of fluids and then dividing this number by the number of casing and cement violations. This method implies 915,000 gallons of fluid spilled.

Spills of Fuels and Produced Water: Opportunities for spills are rife, given the massive amounts of freshwater that must be transported to the well during production and the massive amounts of wastewater that must be removed from it. In Washington County, Pennsylvania, Gresh (2010) reported, the PADEP fined Atlas Resources $97,350 for allowing used hydraulic fracturing fluids to overflow a pit and contaminate a high-quality watershed. (It was rainfall, not overfilling by the operator, that caused the pit to overflow.) Spills like this are uncommon and usually less serious, and the fine reflects those facts.

One kind of serious spill results from truck accidents. If a large truck carrying chemicals or wastewater crashes, spillage is likely. In Dimock Township, Legere (2010b) reports, a truck spilled about 100 gallons of diesel fuel after skidding down an icy hill and crashing. No one was injured, the spill was cleaned up, and the residual contents of the truck were contained. Though spills like this are not frequent, they are cleaned up quickly when they do occur, so as not to impede traffic.

The main impact of these spills is a reduction in water quality and, in some cases, fish kills. For example, Dilemuth (2009) reported that a temporary, above-groundwater transfer-line connection failed, discharging about 250 barrels (10,500 gallons) of partially recycled flow-back and freshwater into a small, unnamed tributary to Brush Run on private property in Hopewell Township. The company said that the water, which contained about 1 percent chloride salt, killed 200 to 300 minnows, but other fish species living in the tributary survived. Helen Humphreys, a spokeswoman for the state Department of Environmental Protection, said that species including crawfish and frogs also were observed to be injured or dying. DEP officials inspected about four-tenths of a mile of Brush Run in the area of the spill. Brush Run is a high-quality stream under Pennsylvania law, meaning that its purity and function as a habitat warrant special protection.

It is easy to keep track of spills exceeding 100 gallons because they have to be reported. The average major spill released 761.8 gallons of fluid, and did so on the drill site. The total water volume of spills from 2008 to 2010 was 42,661 gallons.

Blowouts: The PADEP calls any uncontrolled flow of fluids from a well bore a blowout. These events involve the rapid release of methane and produced water, most often due to equipment failure or flaws in the design of the well. In Clearfield County, Pennsylvania, on June 3, 2010, a natural gas well operated by EOG Resources discharged natural gas and propelled fluid 75 feet into the air. Puko (2010) reported that it was 16 hours before the incident was brought under control and venting ceased. The fluids that were blown out of the gas well were, for the most part, collected in an earthen capture pit constructed by EOG. Some fluids exited or bypassed the pit and contaminated a nearby stream, requiring the evacuation of nearby campers. The incident did not, however, threaten the integrity of the wellhead or cemented casing string, the steel pipe encased in cement. The cause of the incident, which was typically small and localized in its impact, was the failure of a subcontractor to put proper pressure barriers in place. EOG Resources incurred over $400,000 in fines.

Well blowouts and the uncontrolled flow of fluids alarm the public and, under extreme circumstances, can pose risks to public safety. This incident and other similar events in the Marcellus suggest that industry drilling practices were, at the time, inadequate to control the high pressures and flow rates encountered in developing the Marcellus shale. The Commonwealth codified these changes in its recently revised oil and gas regulations.[7] With time and experience, the industry and the Commonwealth have strengthened operational protocols.

The PADEP's data on environmental violations do not include the amount spilled in an event. To determine the volume of the fluid spilled, this study examines the Clearfield County well incident, in which 35,000 gallons of fluid were spilled during the 16-hour period necessary to bring the well under control. Assuming that this volume represents an average spill, multiplying it by the average duration of each event, which is recorded, yields an estimated 305,000 gallons leaked.

Air-Quality Impacts: Drilling for shale gas affects air quality through a variety of channels. Methane, a potent greenhouse gas, leaks from pipelines, wells, and other facilities. The activities of drilling, processing, and transporting natural gas to consumers consume fuel and release emissions. Jaramillo (2007) estimates the volumes of upstream emissions of air pollutants generated by the natural gas industry, which are reported above, in Table 6. These emissions occur during the continuous operation of the gas industry. Hence, for every million British Thermal Units (BTUs) of natural gas consumed, on average 17.7 pounds of greenhouse gases are emitted upstream.

Table 6. Upstream Air Emissions from Natural Gas Drilling without Hydraulic Fracturing

	Natural Gas (lbs / mmbtu)		
Emission	**Min**	**Mean**	**Max**
GHG* (CO_2 equivalent)	15.3	17.7	20.1
Sulfur dioxide	0.006	0.018	0.03
Nitrous oxides	0.009	0.0155	0.022

Source: Jaramillo (2007)
*Greenhouse gases

Jaramillo's study was based on estimates for industry-level emissions during the late 1990s, before the widespread use of hydraulic fracturing. To avoid overlapping Jaramillo's estimates of upstream emissions, this study estimates air emissions from hydraulic fracturing. A typical hydraulic fracturing job employs ten 1,400 horsepower (HP) engines. The engines have eight pumps running at all times, with two held in reserve.

On the basis of industry interviews, this study postulates 15,000 gallons as the amount of diesel fuel that the typical hydraulic fracturing job consumes. Assuming that these engines are no more than ten years old and using emission factors derived by Nelson (2010), this study estimates that a typical hydraulic fracturing job, defined as a single well bore in a given formation, emits 300,237 pounds of greenhouse gases, 1,722 pounds of nitrous oxides, 176 pounds of particulates under ten microns in size, and 545 pounds of carbon monoxide (see Table 7).[8] These could be considered high estimates. More detailed fieldwork measuring emissions for various configurations of equipment would have to be done before highly accurate estimates of emissions can be attained. The objective here is simply to provide a basis for comparing the cost of the environmental impacts incurred by shale gas drilling with the economic benefits that it provides.

Table 7. Air Emissions from a Typical Hydraulic Fracturing Job

Emission	lbs / job
Greenhouse gases (CO_2 equivalent)	300,237
Nitrous oxides	1,772
Particulate matter (under ten microns)	176
Carbon monoxide	545

For downstream emissions, this study computes average emission factors using data reported by the U.S. Environmental Protection Agency and the U.S. Energy Information Administration on emissions and fuel consumption in electric power generation. Since the analysis below will compare burner-tip emissions from natural gas with those from coal, the latter are also reported in Table 8.

Forest Impacts: Pennsylvania has extensive woodlands and forests that provide a variety of ecosystem benefits and recreational services. Some experts worry that natural gas drilling will lead to forest segmentation—woodlands punctuated by open field plots—which could have deleterious impacts on flora and fauna. The size of these impacts would be directly proportional to the amount of land that is permanently disturbed. Since nearly all pipelines are installed along access roads or existing rights-of-way that serve multiple uses, the amount of land permanently disturbed is equal to the land required for each well site, which is estimated to equal 3.5 acres.

Perspective on Impacts: This study estimates that the serious environmental violations recorded contaminated 9,356,901 gallons of water. Using similar methods described above, this study estimates the other violations to have contaminated slightly over 400,000 gallons of water. In sum, almost 10 million gallons of water have been contaminated by environmental violations. Although that number sounds large, it is not large in relationship to the size of the industry and its activities. Drilling a well requires 50,000 to 100,000 or more gallons of fluid; hydraulic fracturing, 4 to 5 million gallons of fluid. The total amount of water spilled in a typical incident amounts to less than half of this. Annual water use by all Pennsylvania households, by comparison, exceeds 300 billion gallons (62,800 gallons per household). What's more, natural gas entering aquifers can harm them only when it is trapped and its concentration builds up; if it is able to bubble up and escape into the atmosphere, no lasting damage is done.

VALUATION OF ENVIRONMENTAL IMPACTS

Koomey and Krause (1997) observe that the environmental valuation literature combines two approaches to valuation: estimating the value of direct damages; and estimating the costs of abatement, also known as the revealed preference approach. Observing the costs of abatement in the case of shale energy production, however, can be exceedingly difficult. Most firms do not directly track environmental abatement costs. The costs of production design adaptations intended to meet environmental regulations are commingled with other well-construction costs. Moreover, if obsolete preferences in pollution control are still embodied

Table 8. Air Emissions from Coal and Natural Gas Drilling in Electric Power Generation

	Emission Factors (lbs / mmbtu)	
Emission	**Coal**	**Natural Gas**
Carbon dioxide	215.0632	130.5527
Sulfur dioxide	0.6682	0.0007
Nitrous oxides	0.2135	0.1014
Particulate matter (under ten microns)	0.01168	0.00110
Carbon monoxide	0.02227	0.00428
Mercury	2.73823E-09	0

in current regulations, valuations of abatement costs based on them would be misleading. For these reasons, direct-damage cost estimation is the approach that this study has adopted.

An extensive empirical literature exists on the value that people place on the availability of clean water. Egan et al. (2008) find that households are willing to pay $192 per year for water mostly free of the pollutants listed in Table 8. Steinnes (1992) found that households living along lakeshores were prepared to pay $298 per year to maintain the purity of their lake water. Carson and Mitchell (1993) is another effort to measure the value of clean water. They try to measure the willingness to pay for water suitable for boating, fishing, and swimming and find values of $341 per household. Leggett and Bockstael (2000) studied the effects of water quality on residential land prices and derived values closer to the lower estimates of Whittington et al. (1994). The mean of these estimates is $211 per household in 2010 dollars, with a minimum value of $111 and a maximum value of $341 (see Table 9).

The values implied by the Dimock incident are roughly a thousand times higher than the value that households are reported in the literature to place on clean and usable water. Even if an imputed household service value for water[9] was added to the environmental service values, the resulting value is unlikely to come close to the values implied by the settlement. Nevertheless, we will consider in our analysis below the values implied in the Dimock case.

The value of forest-ecosystem benefits has attracted the attention of many scholars. Pearce (2001) conducted a survey of 34 valuation studies. A summary of his findings updated to 2010 dollars appears in Table 10. These services contain four main components: recreational value ($241 per acre); watershed value ($60 per acre); climate benefits ($739 per acre); and existence value ($86 per acre).[10] The sum of these average service values is $1,127, comprising a range in values of $398 to $1,855 per acre.

In addition to affecting water and land, natural gas development sends gases and matter into the atmosphere. This study uses estimates from a survey conducted by Newell (1998) that are reported in Table 11. The mean CO2 emissions value, based on the damages incurred from its impact on the environment, is equivalent to $12 per ton. Sulfur dioxide, nitrous oxides, and particulate-matter emissions under ten microns (PM10) have unit values far higher than the CO2 emissions value, given their greater immediate impact on human health and ecosystems. The toxic air pollutant mercury poses the highest estimated damages, with a mean value of $1,130 per pound. The ranges reported in Table 11 reflect uncertainties about impacts and economic values. With these values, the value of all the emissions generated by the production of natural gas from shale resources can be calculated.

Table 10. Estimates of Forest Ecosystem Values

	2010 Dollars per acre		
	Minimum	**Average**	**Maximum**
Recreation value	121	241	362
Watershed value	0	60	151
Climate benefits	271	739	1,207
Existence values	36	86	136
Total	398	1,127	1,855

Based upon Pearce (2001)

Table 9. Estimates of the Value of Clean Water

		Dollars per Household per Year	
Study	**Year**	**Nominal Dollars**	**2010 Dollars**
Carson and Mitchell (1993)	1993	241	341
Egan et al. (2008)	2008	188	192
Leggett and Bockstael (2000)	1996	86	115
Steinnes (1992)	1992	206	298
Whittington et al. (1994)	1994	80	111

Table II. Estimates of the Economic Value of Damages from Air Emissions			
	2010 Dollars per Pound		
Emission	**Min.**	**Mean**	**Max.**
Greenhouse gas (CO_2 equivalent)	0.003	0.006	0.012
Sulfur dioxide	1.784	7.733	21.413
Nitrous oxides	0.357	1.844	5.948
Particulate matter (under ten microns)	1.784	7.495	21.413
Carbon monoxide	0.000476	0.000476	0.000476
Mercury	565.077	1,130.155	1,695.232

Source: Newell (1998)

Unlike water and land impacts, which occur only when a well is drilled, air emissions occur over the entire course of production. Hence, it makes sense to measure environmental impacts from producing and consuming natural gas over the entire life of a well. This study uses the Marcellus production decline curve used by Considine, Watson, and Blumsack (2010) to estimate the value of effects on the atmosphere on the basis of the amount of shale gas produced each year, multiplied by the respective emission and the dollar cost of damage. These calculations are performed over the assumed 30-year life of a typical Marcellus well and translated into present-value terms, assuming a discount rate of 3 percent.

The last component of the environmental-impact valuation involves the environmental damages *avoided* by replacing coal with natural gas, which contains considerably less carbon and less of criteria air pollutants (nitrous oxides, sulfur dioxide, and particulate matter) than coal and petroleum do. Horvath (2010) argues that the greenhouse gas footprint of shale drilling is not as small as many believe. Exclusive focus on greenhouse gas emissions, however, can be misleading in view of the wide dispersion of other, more harmful, pollutants, such as sulfur dioxide and particulates.

COMPARING BENEFITS AND COSTS

With estimates for the environmental impacts and their valuation in hand, it is possible to make a comparison of the benefits and costs of shale energy development in Pennsylvania. The economic benefits stated in terms of value added are based on the estimates developed by Considine, Watson, and Blumsack (2010) and are expressed on a per-well basis. The environmental costs are estimated on the basis of the impacts and values discussed above.

While the drilling rig may be the most widely recognized symbol of natural gas development, many economically significant activities precede drilling or occur after it. They include identifying properties to lease, drafting leases, and performing related legal and regulatory work. In addition, specialists are needed to conduct seismic surveys, which depend on the provision of local business services. Once a prospective site is identified, drilling begins and, with it, the need for services, labor, and other locally supplied activities (e.g., local excavators are hired to clear land and build roads; and sand and gravel companies are contracted to supply materials). If natural gas is found in commercial quantities, infrastructure such as well-production equipment and pipelines is installed—in many cases, by local workers who, in turn, spend their wages on locally provided goods and services. As gas flows from the well, royalties are paid to landowners and taxes paid to local governments. The expenditures that they make with the proceeds help stimulate the local economy, as the money introduced by shale gas development repeatedly changes hands.

Input-output (IO) analysis allows construction of a quantitative model of transactions among various sectors of the regional economy with which one can estimate how spending in one sector affects other sectors of the economy and household disposable income.[11] This project uses these IO tables to estimate the economic impacts of the Marcellus industry outlays for natural gas exploration, development, and production. This study also identifies the particular economic sectors affected by the stimulus generated from natural gas development.

To provide some range for the economic benefits, this study uses various combinations of direct, indirect (business-to-business), and induced (business-to-consumer and consumer-to-business) economic impacts. It does so to compensate for some of the vagaries associated with economic-impact analysis that uses input-output models. The minimum economic benefits are just the direct impacts of Marcellus spending on the Pennsylvania economy, amounting to $2.8 million per well, an undeniably lower-bound estimate. What this means is that a Marcellus well adds value, including wages, payments on capital, and taxes, of $2.8 million. Indirect impacts arising from the stimulation of the supply chain come to almost $4 million per well. The maximum economic benefit is the sum of these two figures plus the value of the induced impacts arising from the economic stimulus created by households spending wages, lease and bonus payments, and royalties derived from Marcellus development and production. This roughly $5.5 million value is most likely on the low side because Considine, Watson, and Blumsack (2010) did not consider the positive effects on the economy of an expanded supply of natural gas and thus lower prices, and then the impact of these low prices on attracting new industry to the region.

Additional economic benefits accrue if the natural gas produced from Marcellus shale displaces Appalachian coal. For example, the economic value of the average avoided air emissions from coal is over $17,000 per well. According to estimates made by Epstein et al. (2011), additional benefits result from avoided environmental damages and community health impacts that amount to over $29,000 per well. These environmental benefits, however, constitute less than 2 percent of total benefits, which are mostly generated by the economic activity resulting from the development and production of shale gas.

The environmental costs of a typical Marcellus well appear in Table 12. The impacts of upstream natural gas emissions and those from the diesel engines powering hydraulic fracturing have economic values of about $2,800 and $7,200, respectively. The value

Table 12. Summary of Economic Benefit-Cost Analysis

	2010 Dollars per well		
	Minimum	**Average**	**Maximum**
Economic value added	2,791,549	3,957,746	5,459,859
Environmental benefits of coal displacement:			
Avoided air pollution	4,420	17,132	50,061
Avoided community health impacts from coal	14,555	29,111	43,666
Subtotal	18,976	46,243	93,727
Economic and environmental benefits	2,810,525	4,003,989	5,553,586
Environmental costs:			
Air impacts from upstream life-cycle emissions	1,089	2,796	7,173
Air impacts from diesel use during hydraulic fracturing	2,091	7,245	20,329
Water pollution using household values	102	193	312
Forest disruption	1,394	3,943	6,493
Subtotal	4,676	14,178	34,307
Economic and environmental net benefits	2,805,849	3,989,811	5,519,279
Without benefits from avoided health impacts from coal	2,791,294	3,943,569	5,425,552
Using Dimock settlement to value water-pollution damages	2,699,878	3,787,941	5,193,317
Without health impacts from coal and using Dimock settlement	2,685,322	3,758,830	5,149,651

assigned to water emissions comes to less than $200 per well drilled. Forest loss is valued at slightly less than $4,000 per well. In sum, total environmental costs are slightly greater than $14,000 per well.

Clearly, the economic benefits of shale gas drilling far outweigh the environmental costs. Including the very high water values implied by the Dimock settlement and excluding the environmental benefits of avoided health impacts from coal mining do nothing to undermine this conclusion. Hence, efforts like the New York moratorium to restrict shale drilling reduce overall societal welfare.

This study provides a retrospective accounting of the environmental impacts of gas drilling in Pennsylvania. Prospective environmental compliance costs have not been modeled in any way. To point out the relatively small environmental costs associated with shale gas drilling is in no way to suggest that there is little need for environmental regulation. Indeed, these low costs most likely reflect intense regulatory scrutiny. At the same time, there is reason to think that, small as these costs are, they will become progressively smaller, as new technology further mitigates the effects of drilling on the environment. The following section examines current industry practices and identifies best practices under prevailing technology as well as new approaches in controlling the environmental impacts of natural gas production.

INDUSTRY PRACTICE AND REGULATORY POLICY ISSUES

Since 2008, more than 2,000 Marcellus wells have been drilled in Pennsylvania; about 100 rigs are currently drilling this formation. The sudden creation of a multibillion-dollar industry of well development, including drilling and completion activities and major infrastructure construction—of pipelines, dehydration systems, gas-processing facilities, and compressor stations—had a range of environmental impacts, which caught state regulators by surprise. All these activities affected domestic water wells, surface water, and rural or secondary roads. This section discusses the environmental issues created, the response by regulators and industry, and the implications for regulatory policy.

Water Issues: Analysis by both the PADEP and industry of the kinds of incidents referred to above resulted in changes in both the Commonwealth's oil and gas regulations and industry practices. Key to the protection of subsurface water is casing methods and cement composition. Commonwealth oil and gas regulations have, since the 1980s, required that the principal subsurface water-protection string, the surface casing, be encased in cement, from the seat of the casing, the casing shoe, to the surface. Penetration of shallow pockets of high-pressure gas during the drilling of the Marcellus shale has resulted in the infiltration of natural gas into the annulus (the void between two pipes when one is inside the other). This pressurized gas has sometimes bypassed the surface casing shoe and entered sands holding potable water. Installation of a cemented intermediate casing string can solve the problem. A cemented casing string provides additional backup to the surface casing, which, as noted, is the primary water-protection string.

The presence of natural gas in subsurface water is viewed by the Commonwealth as a safety issue, given the nontoxic nature of methane gas. However, chemicals used in the drilling and stimulation of Marcellus shale wells are toxic and sometimes spill. Accordingly, Marcellus shale operators surround the well site with impermeable tarpaulins. Moreover, operators undertake extensive testing of water wells before commencing any operations, since an operator can escape liability by proving that a water supply was polluted before the well in question was drilled or altered.

Moving wastewater off-site is another hazardous task. Historically, wastewater was trucked off-site to EPA-certified treatment facilities. Marcellus shale operators either recycle the wastewater or transport it out of state by truck or rail for eventual disposal in permitted disposal wells. To recycle the water, many operators move it through aboveground pipelines. The pipe used is typically made of aluminum and is the type used in irrigation. Breakage can occur at a joint or union, spilling wastewater onto the ground.

Although trucks, too, can have accidents, the Pennsylvania Bureau of Forestry (BOF) requires all wastewater leaving the site to be removed by truck. On some sites, it is stored in metal tanks.

Well Safety and Construction Standards: The drilling and completion of oil and gas wells in Pennsylvania has been going on since 1859. The cable-tool rigs that were first used were succeeded by rotary drilling, just as nitroglycerine was used for stimulation before hydraulic fracturing came along. With Marcellus shale development, the complexity of drilling and completion technology increased significantly. Adding to it are the large flows of gas in the Marcellus shale itself and the high pressures to which gas is subjected. Appalachian basin drilling standards were not suited to these new realities, and incidents of the type discussed above occurred.

In response, Marcellus shale operators have equipped the wellheads with safety features, such as blowout-preventer (BOP) stacks. The PADEP now requires the presence of an individual certified in well-control technology during these operations.

The primary concern of the industry is the safety of its employees on the rig floor. Also important are protecting the wellhead equipment necessary to control the well, preventing a catastrophic event such as a wild well, protecting the on-site drilling and completion equipment, and keeping the surrounding area free of contaminants. Some organizations specializing in well control now have operations in Pennsylvania and are available to help out if an event should occur.

Increased Traffic on Secondary Roads: Roughly 1,000 truckloads of material are required to drill and complete a Marcellus shale well. Many of these wells are located in rural areas where the road infrastructure is inadequate to support such additional traffic. The industry has, however, repaired damaged roads and upgraded many secondary roads to make them stronger, safer, and generally better able to handle large trucks carrying heavy loads.

In addition, the industry has made efforts to minimize reliance on trucks. Much of the freshwater is now moved onto location via surface irrigation pipe. Wastewater that is to be moved to out-of-state disposal wells is often transported by rail, with the remainder kept on site and recycled.

Drilling wastes are minimized through the use of air for the vertical section of the well. Air drilling of the well's vertical section minimizes drilling wastes and thus the impact of drilling on potable-water strata near the surface. Furthermore, many operators are now using recyclable oil-derived drilling fluids. To recover as much drilling fluid as possible, drilling contractors utilize a sophisticated system of shale shakers and centrifuges. The residual solids are then transported to a permitted solid-waste site for final disposal. Pennsylvania State University's Material Science group, in concert with the PADEP, is developing technology that will recycle these solids into proppants that can subsequently be used in hydraulic fracturing.

Erosion and Sedimentation: Many notices of environmental violation received by industry refer to erosion of pits and impoundment areas and to sedimentation within them. In many instances, these conditions result from construction flaws. The breeching of these pits leads to the movement of the liquid pollutants that they hold into streams or other environmentally sensitive areas. In response, the PADEP's Bureau of Oil and Gas Management has announced that it would be permitting far fewer drilling pits.

To avoid the problems associated with drilling pits, the industry has moved into something called closed-system drilling. Drilling wastes, both solid and liquid, are collected in steel pits rather than lined earthen pits, the previous format. One purpose of these impoundment areas is to collect the large volumes of freshwater used in hydraulic fracturing. Another is to receive wastewater collected after stimulation and during production. It is then recycled for use in subsequent hydraulic fracturing operations. An adequate replacement for these impoundment areas has not yet been devised.

IMPLICATIONS FOR NEW YORK STATE

New York State regulations limiting the amount of water that may be used in hydraulic fracturing have imposed an effective

Has Lax Regulation Tainted Pennsylvania Rivers?

The New York Times article "Regulation Lax as Gas Wells' Tainted Water Hits Rivers" (Urbina, 2011) portrays a natural gas industry operating in Pennsylvania without government supervision and, as a result, generating large amounts of water pollution. The findings of this study do not support this view. While water pollution can result from gas drilling, such events are very small and infrequent, and the effects are highly localized.

Produced water from hydraulic fracturing does contain small amounts of radioactivity, but the levels are not high enough to harm human health unless directly ingested in large quantities. The Marcellus shale formation outcrops or reaches the surface near Marcellus, New York. As a road tour of the northeastern United States would demonstrate, travelers encounter numerous road cuts that expose black layers of rock or shale to the atmosphere. These exposures are not a public health issue because the level of ambient radiation that they release is very small.

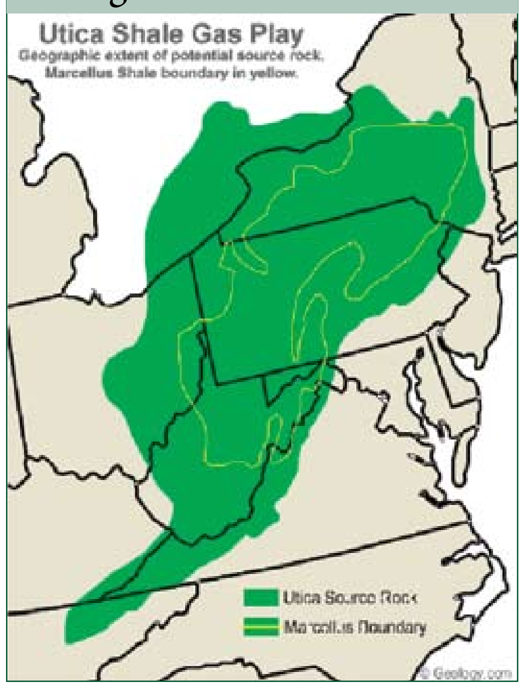
While the article is correct that produced water was discharged into Pennsylvania rivers, it was highly diluted by the rivers' huge volumes of water. Hence, the radiation exposure of those consuming that water was virtually nonexistent. According to the PADEP, the water containing the discharges still met federal drinking-water standards.

These issues, however, have been rendered moot by a regulation issued by the PADEP in January 2010 that bans the disposal into streams, lakes, and rivers of any wastewater containing over 500 milligrams per liter (mpl) of total dissolved solids (see Napsha, 2010). As a result, natural gas drilling companies are either recycling their produced water or disposing of it in deep EPA-certified wells.

While the PADEP was at first unprepared for the scale of the Marcellus drilling boom, regulation was hardly lax before this January 2010 regulation was issued. Pennsylvania has a long tradition of protecting its waters. In the past two years, the PADEP has added staff and updated its regulations. The natural gas industry in Pennsylvania is now operating under water-quality standards more stringent than those imposed on many other sectors of the economy.

moratorium on the development of the Marcellus and other shale gas resources in the state, including the Utica shale (see Figure 5). In 2008, Governor David A. Paterson imposed an administrative freeze on high-volume hydraulic fracturing. He also directed the state's Department of Environmental Conservation to expand the scope of the Generic Environmental Impact Statement to include high-volume hydraulic fracturing. That first moratorium has been succeeded by two others.

Figure 5. The Utica Shale



In the wake of British Petroleum's Deepwater Horizon blowout disaster in the Gulf of Mexico, the New York Senate passed a bill in August 2010 that suspended natural gas drilling in the entire state until its environmental impacts were fully understood. This action represents the first time that any legislature in the United States had specifically passed legislation to ban high-volume hydraulic fracturing. Although the stated intention of the bill's sponsors was to confine the reach of the bill to high-volume hydraulic fracturing alone, its loose wording would have banned all gas drilling in the state. To prevent this from happening, Paterson quickly vetoed the bill, but then issued Executive Order No. 41, which barred the issuance of new drilling permits until the release of the final draft of the Supplemental Generic Environmental Impact Statement, expected on June 1, 2011. These policies impose costs on the New York State economy equal to the forgone value that would have been added by income and tax revenues generated by development of the Marcellus shale and other shale gas resources, including the Utica shale but for the ban. If the ban were lifted, New Yorkers near the Pennsylvania border could expect the same level of drilling activity, which is substantial, now taking place on the other side of it.

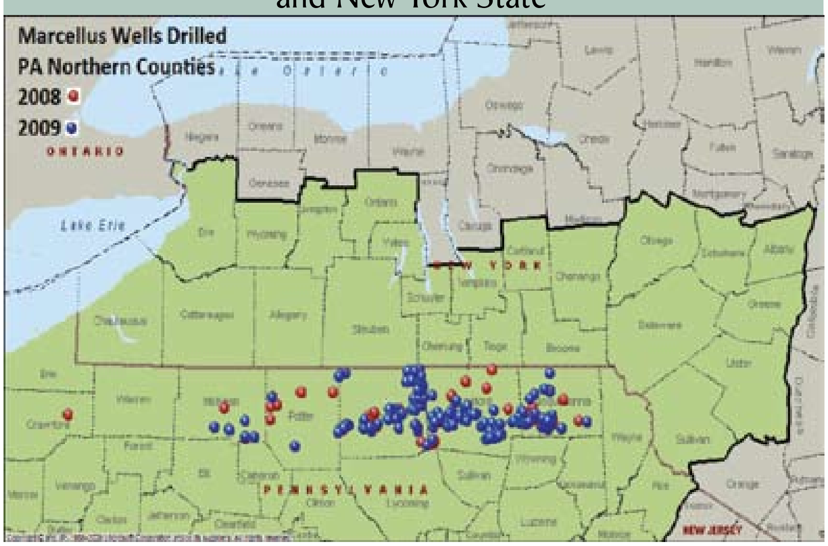
During 2008, 52 Marcellus wells were drilled in five counties in northern Pennsylvania: McKean, Potter, Tioga, Bradford, and Susquehanna. The number of Marcellus wells drilled in the same five counties during 2009 was 296. A map of this dramatic expansion of activity and its proximity to New York is displayed in Figure 6. The New York counties due north of this zone include, from west to east: Allegheny, Steuben, Chemung, Tioga, and Broome. Natural gas development is already taking place in Steuben and Chemung but from a much deeper resource called the Trenton Black River formation.

As the Marcellus extends northward into New York State, it comes closer to the surface, making it less attractive to drilling companies to exploit. Therefore, drilling would probably be concentrated in the southern half of the New York border counties mentioned above. For this and other reasons, according to New York State's Department of Environmental Protection, the maximum number of wells drilled in that area in any single year would be 500.

The reluctance of some companies to drill Marcellus wells in Delaware County, which contains a portion of New York City's watershed, is another constraint. Chesapeake Energy, for example, announced in 2010 that it would not drill in this area. Similar concerns may explain why there is no Marcellus drilling in Wayne County, Pennsylvania, which is within the Delaware River watershed. Any Marcellus development in New York would most likely be restricted to the state's southern tier, west of Broome County.

The Utica shale is another promising natural gas resource extending into New York. In Pennsylvania, the Utica formation lies below the Marcellus, but in New York, portions of the Utica extend north of the Marcellus, where it could be exploited. On the other hand, there is no evidence to date that the New York Utica shale is productive. Range Resources, a drilling company, completed and tested a horizontal Utica well

Figure 6. Northern Pennsylvania Marcellus Drilling and New York State



in western New York, but the results are confidential. Range's only comment is that it plans to drill additional Utica wells. Hence, prospects for the Utica shale in New York are promising, but there is simply no evidence of commercial prospects that would justify its inclusion in the scenarios developed below. Leasing activity in the Utica shale in northeastern Ohio, however, is rather intense, given the prospects of rich deposits of oil and natural gas liquids, especially in Start County. If it is determined that the liquids-rich portion of the Utica extends into western New York and the drilling moratorium is lifted, development of the Utica in New York could be very active and prolific.

Nevertheless, the safer assumption is that the Marcellus shale will be the first formation to be developed, if horizontal drilling with hydraulic-fracturing is allowed in New York. A hypothetical trajectory of future drilling appears in Table 13. In the first year, 42 wells would be drilled, climbing to 314 wells four years later, then leveling off at 340 wells in 2020. Horizontal drilling's share is based on the observed ratio in northern Pennsylvania. Total spending under this scenario would start out at $172.6 million; increase 11-fold, to $1.9 billion by 2015; and reach $2.2 billion in 2020 (see Table 13).

The economic benefits forfeited as the result of New York's restrictions on drilling (or, to put it more positively, the economic value of such activity if it should be carried out) are presented in tables 13-18. The value added that such activity would create is displayed in Table 14 and comes to $1.7 billion. This sum reflects direct, indirect, and induced effects.

Table 13 gives figures for only three distinct years. Assuming a 3 percent discount rate, the accumulated value added from 2011 to 2020 would come to over $11.4 billion. There would be more than 15,000 additional jobs in 2015 (see Table 15). And local and state tax revenues would have grown by over $214 million in 2010 dollars by 2015. The value, employment, and tax revenues that would be added by Marcellus industry spending for 2011, 2015, and 2020 are displayed in Tables 16, 17, and 18.

If the moratorium is maintained, New York residents not only pay an opportunity cost, in present-value terms, of over $11.4 billion in lost economic output from 2011 to 2020; they lose state and local tax revenues of $1.4 billion and employment levels of 15,000 to 18,000 jobs.

Under the second scenario, in which the development potential is greater, value of the lost output increases to $15.8 billion, and 20,000 to 27,000 jobs are lost, as is $2 billion in state and local tax revenue. As the above

Table 13. Projected Marcellus Activity in New York (2011, 2015, 2020)

	Millions of Current Dollars		
	2011	2015	2020
Total spending	172.6	1,899.9	2,209.9
Lease and bonus	66.6	502.2	502.2
Exploration	5.9	68.9	73.8
Drilling and completion	78.2	918.5	984
Pipeline and processing	19.1	224.5	240.5
Royalties	0	152.3	373.5
Other	2.9	33.5	35.9
	Assumed Number of Wells*		
Horizontal	14	304	330
Vertical	28	9	10
Total	42	314	340
	Gas Equivalents of Million Cubic Feet per Day		
Production	0.1	487.6	952.1

*Authors' assumptions

Table 14. Projected Value Added in New York by Sector for 2015

	Millions of 2010 Dollars			
Sector	**Direct**	**Indirect**	**Induced**	**Total**
Ag., forestry, fishing, and hunting	1.4	1.1	0.8	3.3
Mining	226.7	4.5	1.2	232.3
Utilities	12	13.6	12.5	38.1
Construction	157	3.7	2.7	163.4
Manufacturing	9.4	24.7	10.8	44.8
Wholesale trade	138.1	28.2	22.7	189.1
Retail trade	55.2	3.8	48.4	107.4
Transportation and warehousing	20.5	15.6	7.5	43.6
Information	7.6	27	19.3	53.9
Finance and insurance	14.9	58.5	63.5	136.9
Real estate and rental	68.1	49.5	106.4	224
Professional/scientific and tech services	42.3	84.7	23.1	150.1
Business management	0	21.5	4.4	25.9
Administrative and waste services	6.9	27.1	11.5	45.5
Educational services	21.6	0.4	10.1	32.1
Health and social services	44.4	0.6	67	112.1
Arts/entertainment and recreation	4.8	2.2	6.1	13.1
Hotel and food services	13	5.5	16.5	35
Other services	12.8	6.4	16.6	35.8
Government and misc.	5.2	6.8	6.3	18.4
Total	862	385.3	457.5	1,704.8

Table 15. Projected Employment Impacts in New York for 2015

	Number of Jobs			
Sector	**Direct**	**Indirect**	**Induced**	**Total**
Ag., forestry, fishing, and hunting	33	33	22	88
Mining	1,232	14	2	1,248
Utilities	32	22	19	73
Construction	2,154	49	37	2,239
Manufacturing	61	182	70	313
Wholesale trade	925	189	152	1,266
Retail trade	887	63	836	1,786
Transportation and warehousing	266	202	97	566
Information	34	107	85	226
Finance and insurance	57	215	267	540
Real estate and rental	154	227	213	593
Professional/scientific and tech services	271	730	182	1,183
Business management	0	100	21	120
Administrative and waste services	125	463	198	786
Educational services	445	9	236	691
Health and social services	701	6	1,051	1,758
Arts/entertainment and recreation	110	41	130	281
Hotel and food services	323	138	429	890
Other services	319	106	410	835
Government and misc.	67	95	82	244
Total	8,196	2,992	4,540	15,727

Table 16. Projected Value Added in New York by Sector (2011, 2015, 2020)

	Millions of 2010 Dollars		
Sector	**2011**	**2015**	**2020**
Ag., forestry, fishing, and hunting	0.3	3.3	3.8
Mining	19.8	232.3	249.2
Utilities	3.5	38.1	44.8
Construction	14	163.4	175.7
Manufacturing	4	44.8	51.1
Wholesale trade	16.4	189.1	207
Retail trade	9.9	107.4	125.9
Transportation and warehousing	3.9	43.6	48.9
Information	4.9	53.9	62.9
Finance and insurance	12.5	136.9	158.6
Real estate and rental	21	224	268.3
Professional/scientific and tech services	13.2	150.1	166.5
Business management	2.3	25.9	28.8
Administrative and waste services	4.1	45.5	51.6
Educational services	3.1	32.1	40.6
Health and social services	10.6	112.1	135.3
Arts/entertainment and recreation	1.2	13.1	15.7
Hotel and food services	3.3	35	42.1
Other services	3.4	35.8	42.9
Government and misc.	1.7	18.4	21.6
Total	153	1,704.8	1,941.2

Table 17. Employment Impacts in New York by Sector (2011, 2015, 2020)

	Number of Jobs		
Sector	**2011**	**2015**	**2020**
Ag., forestry, fishing, and hunting	8	88	101
Mining	106	1,248	1,338
Utilities	7	73	85
Construction	191	2,239	2,408
Manufacturing	28	313	354
Wholesale trade	110	1,266	1,386
Retail trade	165	1,786	2,101
Transportation and warehousing	50	566	633
Information	21	226	264
Finance and insurance	49	540	627
Real estate and rental	55	593	710
Professional/scientific and tech services	104	1,183	1,312
Business management	11	120	134
Administrative and waste services	70	786	892
Educational services	67	691	867
Health and social services	166	1,758	2,119
Arts/entertainment and recreation	26	281	338
Hotel and food services	84	890	1,069
Other services	79	835	1,004
Government and misc.	22	244	285
Total	1,419	15,727	18,027

Table 18. Prospective Tax Impacts in New York by Sector (2011, 2015, 2020)

Millions of 2010 Dollars

	2011	2015	2020		2011	2015	2020
State and local taxes				**Federal taxes**			
Dividends	1.9	21.5	24.6	Social Security employee contribution	4.8	53.6	60.8
Social Security employee contribution	0.1	0.6	0.7	Social Security employer contribution	4.2	47.3	53.7
Social Security employer contribution	0.2	2.5	2.9	Excise tax	0.6	6.9	7.9
Indirect Taxes				Custom duty	0.3	3.2	3.7
Sales tax	4.6	50.6	58.3	Non-taxes	0.5	5.3	6.1
Property tax	5.6	62.3	71.7	Corporate profits tax	2.4	26.8	30.6
Motor vehicle license	0.1	0.6	0.7	Personal income tax	8.6	96.2	109.1
Other taxes	0.9	10.2	11.7	Total federal tax	21.4	239.3	271.9
Non-taxes	0.2	1.7	2				
Corporate profits tax	1.4	15	17.2				
Personal Taxes							
Income	3.6	40.3	45.7				
Non-taxes (fines or fees)	0.7	7.4	8.4				
Motor vehicle license	0.1	0.7	0.8				
Property tax	0.1	0.6	0.7				
Other taxes (fish/hunt)	0	0.2	0.2				
Total state and local tax	19.3	214.3	245.5				

analysis demonstrates, the moratorium offers hardly any offsetting environmental benefits.

These losses in potential output, tax revenues, and employment from the drilling moratorium could turn out to be gross underestimations because New York State may be sitting on a far larger resource than the Marcellus shale—namely, the Utica shale, for which leasing activity is currently under way in eastern Ohio, on the strength of promising exploratory drilling.

If portions of the Marcellus shale under the New York City watershed as well as the Utica shale were developed, the number of wells drilled would, of course, be considerably greater. Assuming that the entire area developed in New York were equivalent in size to the areas now under development in Pennsylvania, the lost economic gains from the current moratorium would be roughly five times larger, or almost $80 billion, plus a total of 100,000 forgone jobs and over $10 billion in forgone tax revenues. Ending the moratorium would offer the collateral benefit of permitting exploratory drilling, which would allow estimates of the full scope of gas resources to become more precise.

SUMMARY AND CONCLUSIONS

The development of unconventional natural gas and oil resources is well under way throughout the United States and the world on account of the arrival of two technologies: directional drilling and hydraulic fracturing. The application of these technologies represents a paradigm shift in oil and gas development, sweeping out the model of intensive initial development followed by a long period of production, and ushering in natural gas manufacturing, which requires unremitting drilling activity to add new wells that can replace rapidly depleting older ones. Given the magnitude of these unconventional resources and wells' high initial output, such drilling and production activity is likely to continue for decades, creating jobs and driving growth in commercial activity, personal income, and tax revenue for years.

The environmental impacts of unconventional oil and natural gas development have received a great deal of public scrutiny. This study carefully reviewed the public records of environmental violations reported by the Pennsylvania Department of Environmental Protection for the period 2008–10. Of a total of 1,924 violations, 152 were serious, involving 72 cement and casing violations, 8 blowouts, 56 major spills, and 16 cases of stray gas. This study discusses some of these incidents in detail, including their impact on land and water. This study also quantifies the impacts of natural gas development on air emissions. The values of these environmental impacts are then estimated on the basis of estimates of the value of environmental amenities reported in the economic literature. Our main finding is that the value of these environmental impacts is far smaller than the economic benefits of the activities that caused them. A typical Marcellus shale well generates about $4 million in economic benefits while generating only $14,000 in economic damages from environmental impacts.

It goes without saying that drilling companies should do all they can to avoid environmental violations; but in any industry, accidents occur. In developing the Marcellus shale in Pennsylvania, the industry has taken steps to avoid these events, and when a violation has taken place, it has remediated the pollution and made efforts to compensate those harmed by the incident.

The Pennsylvania Marcellus industry is experiencing significant and justifiable scrutiny by both the state DEP and private environmental-interest groups. Many of the latter oppose natural gas development under any circumstances and have pressured both state and federal government agencies to bring it to a halt. They seem to overlook the fact that gas burns cleaner than many other fuels and that extracting it from the earth is far less invasive than, for example, coal mining. Despite the opposition of such groups, Pennsylvania and the industry are working together to develop regulations and protocols that will minimize drilling's environmental footprint and any long-term impacts that it might have.

New York State currently has in place a moratorium on shale gas development. Our analysis of Marcellus development in Pennsylvania suggests that environmentally safe development is possible in New York. Our study finds the net economic and environmental benefits from shale gas development to be considerable, suggesting that the current moratorium is far costlier than its proponents, or even its opponents, realize.

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Endnotes

1. Cement displacement refers to the space between the earth or one casing and the well casing.

2. Spills occur above the surface. Casing violations result in impacts below the surface, such as migration of natural gas into water tables.

3. Note the numbers reported here do not sum to 100. These data are counts per hundred wells drilled.

4. Subsequent investigations of this incident have called into question whether the incident actually occurred.

5. During September 2010, the PADEP investigated the appearance of natural gas bubbles rising out of the ground along the banks of the west branch of the Susquehanna River near Wyalusing. The investigation attributed this problem to natural gas wells drilled by Chesapeake Energy nearby. The company has moved to remediate these wells.

6. American Water Works Association, http://www.drinktap.org/consumerdnn/Home/WaterInformation/Conservation/WaterUseStatistics/tabid/85/Default.aspx.

7. E.g., the well pressures for the Marcellus are far higher than previously experienced in the Appalachian basin. Corrective procedures needed to be implemented and eventually codified into standards and regulations.

8. Many vintages of diesel pumps are used in the field. These machines are run so hard that they often do not last much longer than ten years. The EPA data feature emissions factors for various vintages of diesel engines. Older engines generate more pollution per unit of running time.

9. Household service value pertains to the value of water for cleaning, consumption, washing, and other utilitarian purposes.

10. "Existence value" refers to the notion that the presence of clean water has intrinsic value. E.g., we all derive benefit from knowing that Yellowstone National Park exists, even if we never visit it.

11. Wassily Leontief was awarded the Nobel Prize in Economic Sciences in 1973 for developing input-output analysis, which allows an empirical representation of the interrelationships among sectors of the economy. E.g., natural gas production requires steel, concrete, and other materials and services. Steel, e.g., then requires iron ore, labor, and coal to produce. An input-output model provides a consistent accounting of all these interrelated transactions. IO tables are available from Minnesota IMPLAN Group, Inc., based upon data from the Bureau of Economic Analysis in the U.S. Department of Commerce, http://www.implan.com/index.html.

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