ECONOMIC VALUE OF MARCELLUS SHALE GAS IN THE DELAWARE BASIN

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INTRODUCTION

Through modernization of horizontal drilling and hydraulic fracturing technology, natural gas has become a plentiful, inexpensive, and relatively clean-burning domestic resource that provides a quarter of U.S. electric power needs and promises to reduce reliance on foreign oil. The 350-million-year-old Marcellus Shale Formation covers 54,000 mi^2 in West Virginia, Ohio, Maryland, Pennsylvania, and New York. It is thought to be the third largest natural gas reserve in the world. Approximately 9% of the Marcellus shale lies in the upper third of the Delaware Basin in a watershed that supplies drinking water to 16 million people (5% of the U.S. population) in Delaware, New Jersey, New York, and Pennsylvania, including New York City and Philadelphia, the first and seventh largest metropolitan economies in the nation. Almost ¾ of the Marcellus shale lies in New York and Pennsylvania where drilling has generated thousands of jobs and billions of dollars of wages in Pennsylvania alone. In the Delaware Basin, Marcellus shale gas drilling is at the center of a contentious energy-water policy debate that pits gas companies, land owners, and rural towns interested in jobs versus environmental groups, water utilities, and fishermen concerned about the impacts of hydraulic fracturing on the quality and quantity of water supplies. Federal, state, regional, and local agencies are reviewing policies and standards to oversee Marcellus shale gas drilling. The Environmental Protection Agency oversees natural gas drilling, however, federal laws such as the Clean Water Act and Safe Drinking Water Act exempt portions of the hydraulic fracturing process from regulation. A drilling moratorium remains in the Delaware Basin after a November 2011 vote of the DRBC Commissioners was postponed. The governor of New York continues a ban on horizontal natural gas drilling pending approval of an environmental impact statement (EIS). Pennsylvania Act 13 established a 5% drilling fee and set horizontal drilling buffers. Buffers set by proposed DRBC and NYSDEC rules, recently enacted Pennsylvania Act 13, and drilling bans in four New York towns would exclude 2,363 mi^2 of the 4,940 mi^2 Marcellus shale region in the Delaware Basin from natural gas drilling, leaving 2,577 mi^2 (52% of the area) available for extraction. With buffers in place to shield sensitive water resources from hydraulic fracturing, the estimated economic value of 4.0 tcf of potentially recoverable Marcellus shale gas in the basin at the 2012 wellhead price is $425 million per year, or three times less than the value at the 2008 price. In the Delaware Basin, the annual economic value of natural resources ranges from $425 million for potentially recoverable Marcellus shale gas to $942 million for river

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recreation, $2.8 billion for drinking water, and $4.2 billion for forest ecosystems. The annual value of drinking water, forests, and recreation that depend on renewable resources in the Delaware Basin is higher than the value of potentially recoverable Marcellus shale gas, a nonrenewable resource. The Marcellus shale energy-water policy debate should be considered in the context that natural gas, water, forests, and river recreation are significantly valuable Delaware Basin resources. While Marcellus shale gas is a voluminous, inexpensive, and clean-burning domestic energy source, its extraction relies on the safe use of water for hydraulic fracturing. If natural gas is to be a key part of the nation's energy economy, then the most stringent Marcellus shale gas drilling standards should be adopted to protect the invaluable water resources of the Delaware Basin (and other watersheds like it) that support multibillion dollar drinking water, forest, and river recreation economies.

KEYWORDS

Marcellus shale gas, natural gas reserves, Delaware River Basin, regulations (federal, state, and local), job creation, water resources, ecosystem goods and services

INTRODUCTION

Natural gas is an inexpensive, plentiful, and clean-burning domestic resource that provides a quarter of the energy to the United States and emits less carbon emissions than other fossil fuels such as coal and oil. The 500-mile-long Marcellus shale formation under Ohio, West Virginia, Maryland, Pennsylvania, and New York holds the third largest natural gas reserve in the world, or enough to power the eastern United States for many years. Twin technological advances in hydraulic fracturing and horizontal drilling have kicked off a Marcellus shale drilling boom so feverish that Pennsylvania has been called the "Saudi Arabia" of natural gas.

Hydraulic fracturing requires large quantities of water pumped under high pressure to crack the shale and free the long-trapped gas from the pores of the sedimentary rock. This Marcellus shale "hydro-fracking" has led to concerns about potential overallocation of water supplies and pollution of forested drinking water, wild trout, and canoeing streams in the 13,000 mi^2 Delaware River Basin. The Marcellus shale lies under 4,900 mi^2 in the upper third of the watershed that supplies drinking water to over 16 million people (5% of the U.S. population) in Delaware, New Jersey, New York, and Pennsylvania, including New York City and Philadelphia, the first- and seventh-largest metropolitan economies in the nation.

The Delaware River Basin Commission is considering draft water quality regulations that would set buffers to protect the basin's water resources during Marcellus shale gas drilling (DRBC 2011). Water use is administered by the DRBC Compact of 1961, signed by President John F. Kennedy and the governors of Delaware, New Jersey, New York, and Pennsylvania—the first federal-state water accord. DRBC shale gas drilling regulations may be approved only by majority vote by the five Commissioners—the president and four governors.

Marcellus shale gas drilling in the Delaware Basin is at the center of a contentious energy-water policy debate. The Environmental Protection Agency (EPA) and U.S. Department of

FIGURE 1. The Delaware Basin depicting Marcellus shale (shaded) and drinking water intakes.

Energy (DOE) are preparing national shale gas drilling studies for consideration by the White House. The New York State Department of Environmental Conservation (NYSDEC) is considering a draft shale gas environmental impact statement that drew over 21,000 comments. The Pennsylvania Act 13 put new shale gas drilling buffers and a 5% drilling fee in place. Drilling opponents from environmental groups and New York City, which draws half of its drinking water from Catskill reservoirs in the basin headwaters, are pitted against proponents like the natural gas companies and small towns in rural Pennsylvania and the southern tier of New York who push for economic and jobs benefits. Studies from universities and the federal government estimate Marcellus shale gas drilling can provide hundreds of thousands of jobs and billions of dollars in benefits to the Pennsylvania and New York economy. Others are concerned about the temptation of short-term financial gain that will eventually evaporate in a boom and bust economy once the shale gas is gone.

Marcellus shale gas has considerable economic value but hydraulic fracturing is water-dependent and if not done safely, has the potential to diminish the significant drinking water, forest, river recreation, and other natural resources in the Delaware Basin that contribute $24 billion in annual economic benefits and over a half million jobs to the regional economy of Delaware, New Jersey, New York, and Pennsylvania (Kauffman 2011). Ecological economists classify natural gas and other fossil fuels as nonrenewable resources with finite stock value over a defined time frame, say 25 to 50 years (Daly and Farley 2011). Water is a renewable resource with infinite stock value over a perpetual lifetime (over 100 years), provided the supply is undiminished in quantity and quality. While a vigorous energy-water policy debate rages on, little is known about the potential economic value of nonrenewable Marcellus shale gas compared to the value of renewable water resources in the Delaware Basin.

OBJECTIVES

The objectives of this study are to review Marcellus shale gas policy and regulations considered by federal, state, local, and regional agencies and estimate the economic value of potentially recoverable shale gas in the Delaware Basin with protective buffers in place compared to the value of renewable water resources such as drinking water, forests, and river-based recreation.

THE DELAWARE BASIN

Authorized by a 1961 compact passed by President John F. Kennedy, Congress, and the governors and legislatures of Delaware, New Jersey, New York, and Pennsylvania, the DRBC manages water resources in four states, 25 congressional districts, 38 counties, and over 500 municipalities (Figure 1). The five Commissioners are a federal appointee and the four governors (DRBC 2011). The basin covers just 0.4% of the U.S. land mass yet supplies drinking water to 16 million people, or 5% of the nation's population. In 2010, over 8.3 million people lived in the Delaware Basin, which if counted as one entity would be the 12th largest state in the United States.

The Marcellus shale underlies parts of 13 counties in New York and Pennsylvania in the upper Delaware Basin where the population grew by 48,406 people (9.2%) from 524,935 in 2000 to 573,341 in 2010 (Table 1 and Figure 2). The population grew the most (over 9%) in the booming Pennsylvania counties of Monroe, Pike, and Wayne, which also happen to overlay the thickest Marcellus shale deposits. The population declined in the New York counties of Broome (–4.3%) and Delaware (–6.8%), which also contain thick shale deposits.

In 2012, 282,000 people were employed in the Marcellus shale counties in the Delaware Basin (Table 2). Unemployment rates in Broome and Delaware counties are near or just above the average rate in New York state (8.8%). Unemployment rates in the Pennsylvania counties (except for Wayne County) range from 9.3%–9.9% and exceed the state rate of 8.1%. Wayne County is situated over the thickest Marcellus shale deposits and has a relatively low unemployment rate of 6.6%. All counties except for Wayne County have unemployment rates that exceed the U.S. average of 8.2%. Broome and Delaware counties in New York and Carbon, Lackawanna, and Wayne counties in Pennsylvania have low median income compared to the state medians, while Pike and Monroe counties have high income that significantly exceeds the state norm.

TABLE 1. Population in the Marcellus shale region in the Delaware Basin (U.S. Census Bureau).

State/county	Area (sq mi)	2000 Population	2010 Population	Change	Change (%)
Broome	72	15,713	15,038	–675	–4.3%
Delaware	1101	28,030	26,111	–1,919	–6.8%
Greene	33	1,231	1,207	–24	–1.9%
Orange	59	17,722	19,887	2,165	12.2%
Sullivan	937	46,712	47,563	851	1.8%
Ulster	151	14,900	15,162	262	1.8%
New York	**2,352**	**124,308**	**124,969**	**661**	**0.5%**
Carbon	348	58,795	63,640	4,845	8.2%
Lackawanna	28	11,617	11,335	–282	–2.4%
Luzerne	45	17,916	17,491	–425	–2.4%
Monroe	543	138,690	166,209	27,519	19.8%
Pike	544	46,303	59,859	13,556	29.3%
Schuylkill	368	81,159	79,358	–1,801	–2.2%
Wayne	713	46,147	50,480	4,333	9.4%
Pennsylvania	**2,590**	**400,627**	**448,372**	**47,745**	**11.9%**
Delaware Basin	**4,942**	**524,935**	**573,341**	**48,406**	**9.2%**

FIGURE 2. Population change in the Marcellus shale region in the Delaware Basin, 2000–2010.

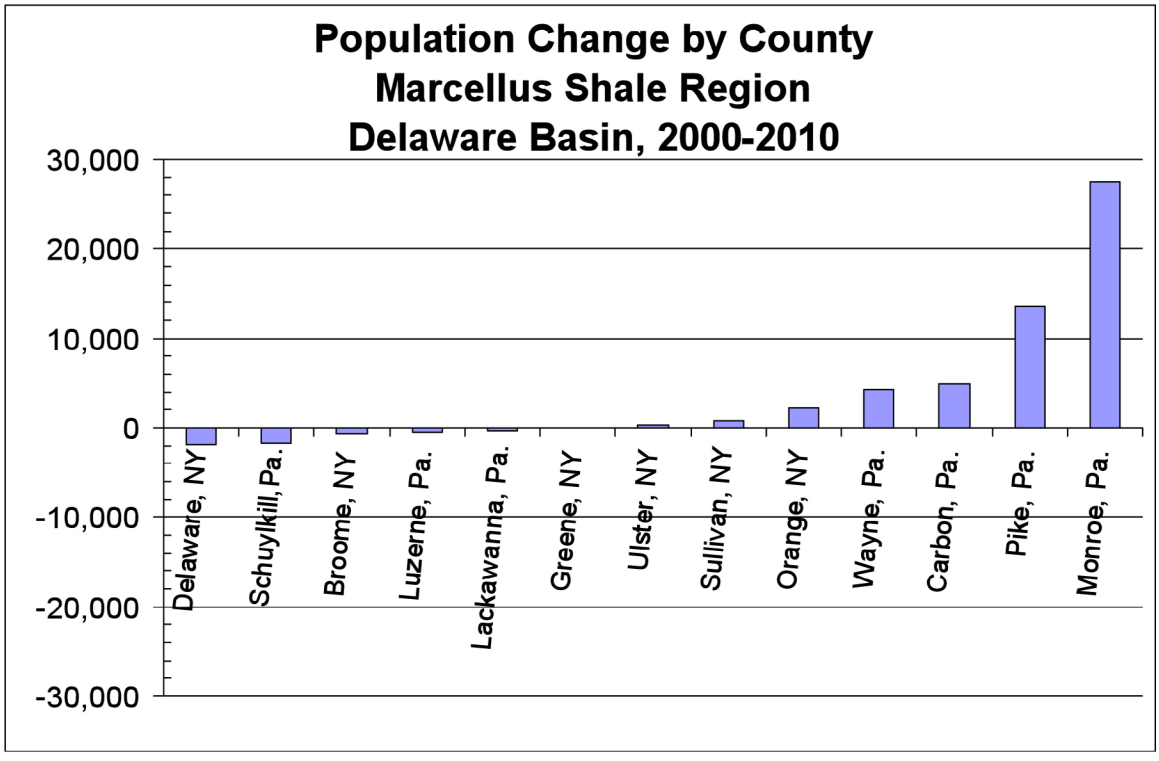


TABLE 2. Employment in the Marcellus shale region in the Delaware Basin (U. S. Bureau of Labor Statistics 2012).

State/county	2012 Employment by County	% of County in Basin	2012 Employment in Basin	Aug 2012 Unemployment (%)	% State Median Income
Broome	87,298	10%	8,730	9.0%	79%
Delaware	20,503	75%	15,377	8.7%	79%
Greene	22,303	5%	1,115	9.1%	
Orange	383,084	7%	26,816	8.7%	125%
Sullivan	32,947	94%	30,970	9.1%	79%
Ulster	81,827	13%	10,638	9.1%	101%
New York	**627,962**		**93,646**	**8.8%**	**100%**
Carbon	29,607	90%	26,646	9.5%	91%
Lackawanna	100,464	6%	6,028	9.3%	88%
Luzerne	149,692	5%	7,485	9.9%	81%
Monroe	76,661	88%	67,462	9.9%	110%
Pike	24,288	96%	23,316	9.7%	120%
Schuylkill	68,439	47%	32,166	9.7%	83%
Wayne	26,660	95%	25,327	6.6%	93%
Pennsylvania	**475,811**		**188,430**	**8.2%**	**100%**
Delaware Basin	**1,103,773**		**282,076**		
United States				**8.2%**	

NATURAL GAS

The United States has long been fueled by domestic sources of natural gas. In 1821, the first natural gas well in the United States was drilled to 27 feet in the Devonian shale near Fredonia, New York, along the southern shore of Lake Erie (PADCNR 2008). The first horizontal well was drilled in Texas in 1929 and it became a conventional practice during the 1980s. The United States has 25% of the world's shale gas reserves, more than Canada and Europe combined (Table 3). In 2010, the United States produced 4.8 tcf of shale gas or five times the output in 2006. Due to modernization of horizontal drilling and hydraulic fracturing technology, the Energy Information Administration (2012) projects U.S. shale gas production will increase from 4.8 tcf in 2010 to 13.6 tcf by 2035 and "become a net exporter of liquefied natural gas in 2016, a net pipeline exporter in 2025, and an overall net exporter of natural gas in 2021."

The EIA (2012) estimates that natural gas supplied 24% of U.S. electric power in 2010 and projects a 3% increase by 2035, along with a 6% increase in renewable energy and 6% decline in coal power over the same period (Table 4). The United States and North America produce 84% and 97% of each region's respective domestic natural gas needs. The United States has 1,744 tcf of potentially recoverable natural gas reserves, or

TABLE 3. World shale gas potential.

Region	Reserve (Tcf)	Reserve (%)
United States	4,000	25%
Canada	1,500	9%
Europe	1,000	6%
China and India	3,500	22%
Rest of World	6,000	37%
World	16,000	100%

enough to supply the country for almost a century at an annual production rate of 20 tcf (Groundwater Protection Council 2009). A trillion cubic feet (tcf) of natural gas is enough to heat 15 million homes and power 12 million vehicles in a year.

Natural gas is less expensive than other energy sources. The MIT Energy Initiative (2011) concluded that on a levelized basis, natural gas at 5.6¢/kW-hr and coal at 5.4¢/kW-hr are least-cost energy alternatives, lower than nuclear at 8.8¢/kW-hr and a tad more cost effective than wind at 6.0¢/kW-hr (Table 5). The EIA (2010) estimated that natural gas at $66/MW-hr has the lowest levelized cost of any power plant source scheduled to enter service by 2016 or almost half the cost of coal and nuclear (Table 6). Natural gas has the lowest capital construction cost of the power options at $17/MW-hr yet ranks among the highest costs in annual operation and maintenance at $49/MW-hr.

TABLE 4. Electricity generation by fuel type (EIA 2012).

Source	2010	2035
Natural Gas	24%	27%
Renewables	10%	16%
Coal	45%	39%
Nuclear	20%	18%
Oil	1%	1%

TABLE 5. Levelized cost of electricity (MIT 2011).

Source	2005 ¢/kWh
Coal	5.4
Natural Gas	5.6
Wind	6.0
Biomass	8.5
Nuclear	8.8
Wind + Gas Backup	10.0
Solar	19.3

Inexpensive natural gas is boosting the economy. More domestic natural gas consumption reduces reliance on foreign oil, with associated national defense benefits (National Sea Grant Law Center 2010). Low cost natural gas lowers nitrogen fertilizer production costs, which results in higher corn yield to make more ethanol in accordance with the 2007 Energy Independence and Security Act. In 2011, the price of natural gas was equivalent to $21 per barrel of oil, or 4 times less than the price of oil at $91 per barrel. Chemical firms such as Dow purchase low cost natural gas derivatives such as ethane to make plastic. Energy companies such as Exelon and PECO in Philadelphia have converted all but one of their thermoelectric power plants along the Delaware River from coal to cleaner natural gas due to the low price of gas from the nearby Marcellus shale fields. Natural gas prices dropped 12.6% in 2010, largely from Marcellus development, saving Pennsylvania consumers $633 million on their utility bills. In 2007, 33 states produced natural gas that generated $385 billion in economic activity

TABLE 6. Levelized cost ($2009) of power plants entering service in 2016 (EIA 2010).

Power Plant	Capital Cost ($/MW-hr)	O&M Cost ($/MW-hr)	Total Cost ($/MW-hr)
Natural Gas	17	49	66
Hydro	74	12	86
Wind Onshore	84	13	97
Geothermal	76	22	102
Coal	75	35	109
Biomass	55	57	112
Nuclear	90	23	114
Solar PV	195	16	211
Wind Offshore	209	34	243

and nearly 3 million jobs (DOE 2009). In August 2011, a Department of Energy advisory panel estimated natural gas production produced over 200,000 jobs in the United States.

Compared to other fossil fuels, natural gas is efficient and clean burning, producing 90 times less SO_2, 5 times less NO, and 50% less CO_2 than coal-fired power plants (GAO). In 2012, the DuPont Company converted the Wilmington Experimental Station, Edgemoor titanium dioxide plant, and its Wilmington global headquarters from fuel oil to natural gas, which will eliminate SO_2 emissions and reduce NO by 73% and CO_2 by 29%.

The EIA (2012) reported CO_2 emissions from U.S. energy sources dropped to the lowest levels in 20 years and declined by 9% since 2005. The EIA attributed a 2.4% decline in emissions during 2011 to slower economic growth coupled with a warm winter, decreased driving due to high gasoline prices, and increase in non-carbon emitting hydropower, wind, solar, and geothermal coupled with a switch from coal to natural gas consumption. In 2011, coal supplied 43% of electric power in the United States, down from 51% in 2005 while the natural gas share spiked from 14% in 2000 to 24% in 2011 due to increase in low cost gas fired power plants. Natural gas provides 26% of the energy consumed in the U.S. and 24% of emissions while coal provides 20% of consumption and 36% of emissions and oil accounts for 36% of energy consumption and 42% of emissions.

MARCELLUS SHALE

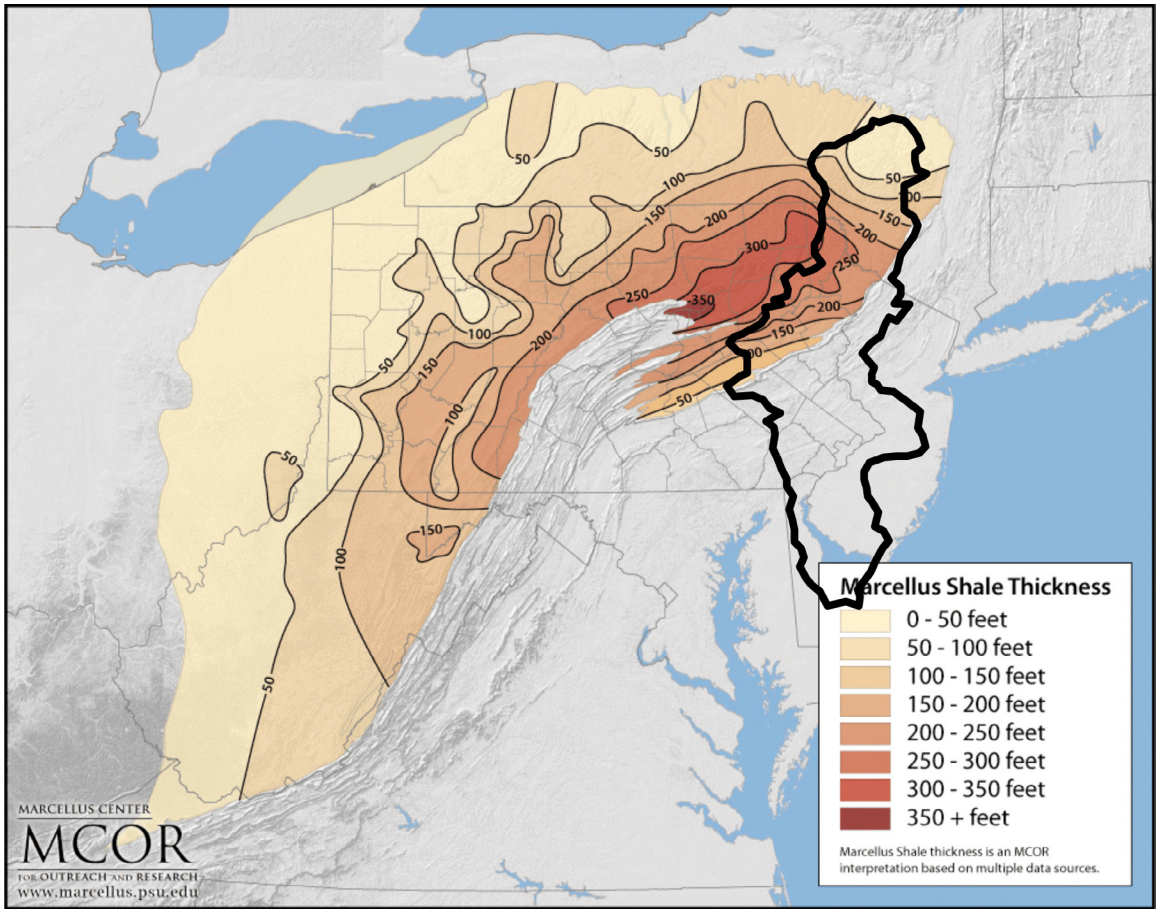
The 500-mile-long Marcellus Shale Formation covers 54,000 mi^2 and lies up to a mile and a half below Ohio, West Virginia, Maryland, Pennsylvania, and New York (Figure 3). Approximately 4,940 mi^2, or 9%, of the Marcellus shale occupies the upper 38% of the 13,000 mi^2 Delaware Basin in New York and Pennsylvania. The thickest black shale deposits (>250 ft) with potentially the highest gas yield are located along the Delaware River where Pennsylvania meets New York.

The Marcellus Shale is a brittle, low permeability (2%–7% porosity), fine-grained sedimentary rock in the Appalachian Basin that is easily cleaved into fracture. Based on stratigraphy, the Marcellus shale formed at the base of the Middle Devonian Hamilton Group over 350 million years ago when the ancient sea covered the Appalachian mountains (Soeder and Kappel 2009). About 250 million years ago, natural gas formed in the voids of organic muds (black shale) that were cooked and compressed under pressure in low-oxygen water conditions (PADCNR 2008).

Situated close to populous East Coast markets, the Marcellus shale is the third largest natural gas reserve in the world (NSGLC 2010). The EIA (2012) placed the volume of potential Marcellus shale gas at 141 tcf, less than an earlier estimate of 410 tcf. Coleman et al. (2011) from the USGS estimated that the mean recoverable Marcellus gas reserve is 84 tcf, enough to power the northeastern United States for 20 years. Engelder and Lash (2008) from Penn State University and SUNY at Fredonia calculated that 50 tcf of natural gas might be recovered from the Marcellus shale. Using data from Chesapeake Energy, Esch (2008) reported Marcellus shale gas yield could approach 363 tcf.

Range Resources Corp. drilled the first Marcellus shale gas well in Washington County, Pennsylvania in 2003 (PADCNR 2008). A 3,000 feet Marcellus well can recover 3 billion cubic feet of natural gas for 60 years. A Marcellus shale well may yield up to 4 billion cubic feet of gas, with an initial yield of 20% in the first 5 years and then constant production for the next 25 years. By 2010, 3,000 permit applications were submitted to PADEP and over

FIGURE 3. Marcellus Shale Formation (MCOR).



1000 wells were drilled in the Marcellus Shale in Pennsylvania. In 2010, three Marcellus shale wells were drilled in Wayne County in the Delaware Basin but extraction of natural gas cannot begin until the DRBC lifts its drilling moratorium (NSLC 2010).

HYDRAULIC FRACTURING

While Pennsylvania geologists have known that the Marcellus shale was a potential natural gas reserve for over 75 years, the modernization of hydraulic fracturing (and horizontal drilling) technology have opened up the fields to a drilling boom. The Congressional Research Service reported that advances in horizontal drilling and hydraulic fracturing technology have increased shale natural gas extraction in the United States with substantial economic benefits (Andrews et al. 2009). Hydraulic fracturing accounts for 50% of domestic natural gas production in the U.S.

Hydraulic fracturing requires pumping 3 to 5 million gallons of water, sand, and chemicals at high pressure to open fractures in the shale and free the natural gas (Wright et al. 2010, USDOE and NETL 2009). The wells are drilled horizontally using 100,000 gallons of water to depths over 5,000 ft, where the shale lies in fields 50 to 250 ft thick (McIlvaine and James

2010). A typical well in the Marcellus shale may be hydraulically fractured many times and require 3.8 million gallons per well or enough to fill eight Olympic swimming pools (Table 7). About 30% to 70% of the chemical-laden hydrofracturing water is recovered and treated before disposal to surface and groundwater. Around 1/5 of the fracking fluid flows back up the well to the surface in the first two weeks with more continuing to flow out over the lifetime of the well. These practices have "stirred environmental concerns" over excess water supply withdrawals and water pollution from the high total dissolved solids (TDS) fluid that flows back from the wellhead after the fracturing process (Soeder and Kappel 2009).

Hydraulic fracturing could cause water pollution from inadequate treatment and discharge of chemicals in the flowback water (Howarth et al. 2011). Hydraulic fracturing frees barium, sodium and calcium salts, metals, hydrocarbons, and radioactive isotopes from the Marcellus shale. The used water may contain total dissolved solids (TDS) that range from freshwater (500 ppm) to saline (over 5,000 ppm) levels. In the Marcellus shale, the used hydraulic fracturing flowback fluid is treated and discharged by wastewater treatment, recycling, or Class II injection wells (Table 8). Due to the high salt content of the Marcellus shale, many municipal wastewater treatment plants are not designed to treat the flowback liquid. Pennsylvania utilities are building central wastewater treatment plants with advanced reverse osmosis technology to treat the flowback water. Since 2004, hydraulic fracturing in the Marcellus shale has increased the amount of wastewater discharged by 570%, increasing the need for more wastewater treatment capacity to process the brine in the flowback water (Lutz, Lewis, and Doyle 2013).

Hydraulic fracturing fluid is composed of 99.5% water and 0.5% chemical additives (Groundwater Protection Council 2009). About 15,000 gallons or 80–300 tons of chemicals are used in the flowback water per well (Table 9). About 8 to 25 gallons of biocide are added per 1000 gallons of fracturing water (1% to 2% of the total flow) to kill bacteria and prevent pipe corrosion and H_2S production. The Occupational Safety and Hazard Administration (OSHA) requires that drilling companies post material safety datasheets (MSDS) onsite that list the chemicals in the hydraulic fracturing fluid.

TABLE 7. Water needs of natural gas well drilling and hydraulic fracturing operations (Groundwater Protection Council and All Consulting 2009).

Shale Gas	State(s)	Drilling Water per Well (gal)	Fracturing Water per Well (gal)	Total Water per Well (gal)
Barnett Shale	Texas	400,000	2,300,000	2,700,000
Fayetteville Shale	Arkansas	60,000	2,900,000	3,060,000
Haynesville Shale	Louisiana	1,000,000	2,700,000	3,700,000
Marcellus Shale	Penna., WV	80,000	3,800,000	3,880,000

TABLE 8. Wastewater treatment of hydraulic fracturing fluid in the Pennsylvania Marcellus shale (Groundwater Protection Council and All Consulting, 2009).

Wastewater Technology	Method
Class II Injection Wells	Commercial Noncommercial
Treatment and Discharge	Municipal Wastewater Treatment Commercial Wastewater Treatment
Recycling	On-site recycling for reuse in other fracturing projects

TABLE 9. Composition of hydraulic fracturing fluid (Groundwater Protection Council and All Consulting, 2009).

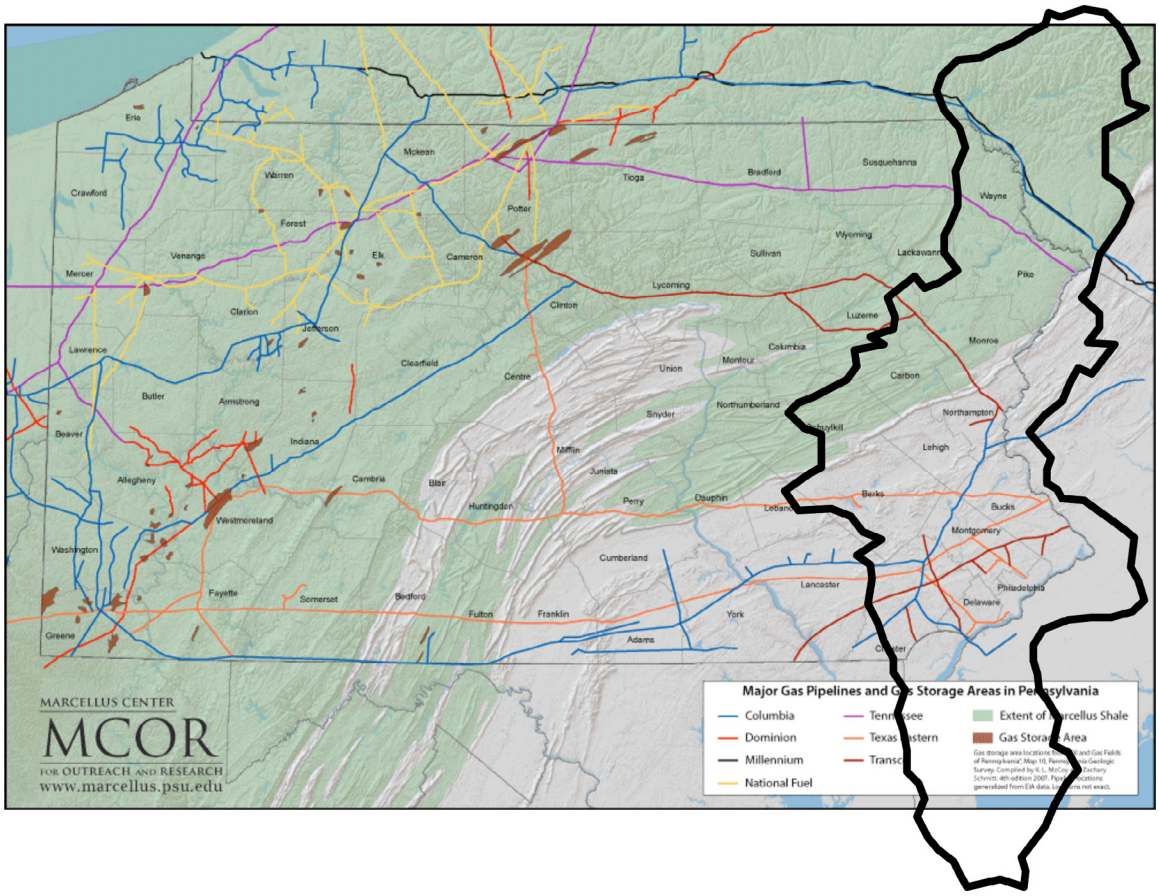
Constituent	%	Purpose
Water	99.510	Crack the shale under pressure and frees natural gas
Diluted acid (15%)	0.123	Hydrochloric or muriatic acid dissolves minerals and cracks rocks
Biocides	0.001	Glutaraldehyde eliminates bacteria that produce corrosive byproducts
Breaker	0.010	Ammonium persulfate allows a delayed breakdown of gel polymer chains
Corrosion inhibitor	0.002	N, n-dimethyl formamide prevents pipe corrosion
Crosslinker	0.007	Borate salts maintain fluid viscosity as temperature increases
Friction reducer	0.088	Polyacrylamide and mineral oil reduce friction between fluid and pipe
Gel	0.056	Guar gum or hydroxyethyl cellulose thickens water to suspend sand
Iron control	0.004	Citric acid prevents precipitation of metal oxides
KCI	0.060	Potassium chloride creates a brine carrier fluid
Oxygen scavenger	0.200	Ammonium bisulfate removes oxygen from the water to prevent pipe corrosion
pH adjusting agent	0.011	Sodium or potassium carbonate maintains other components such as crosslinkers
Propant	0.029	Silica and quartz sand allows the fractures to remain open so gas can escape
Scale inhibitor	0.043	Ethylene glycol prevents scale deposits in the pipe
Surfactant	0.085	Isopropanol used to control the rheological of the fracture fluid

PIPELINES

A network of 20 natural gas pipelines transport natural gas from the Marcellus shale fields to about 50 distribution companies in nearby east coast markets in Delaware, New Jersey, New York, Pennsylvania, and the northeastern United States (Figure 4). Proximity to the populous demand centers reduces transportation costs through the northeast pipeline network and lowers the price of gas sold to consumers and power plants. The dry natural gas from eastern Marcellus shale deposits is high quality (largely free of gas liquid, hydrogen sulfide, and water vapor) and needs little treatment before flowing through transmission lines. The Millennium pipeline in southern New York just above the Pennsylvania state line transmits natural gas from the Marcellus shale east to the population centers along the Atlantic seaboard. Tennessee Gas and Millennium pipelines run north and south of Wayne County to transport natural gas to eastern markets.

In November 2011, five companies filed applications with the U.S. Department of Energy to build terminals on the Hudson River, Delaware River, and Chesapeake Bay to export over 6 billion cubic feet of liquid natural gas (LNG), or 10% of U.S. production, from U.S. ports. This is a reversal from just five years ago when LNG terminals such as the Crown Point project on the Delaware River in Gloucester County, New Jersey were designed to import natural gas into the United States. The low price of Marcellus shale gas has prompted companies to propose reversing the flow of natural gas pipelines from the Gulf of Mexico to the northeast and convert these terminals for gas export. Exports may drive up prices for American natural gas consumers by reducing supply, however, increased natural gas exports could improve the U.S. economy by correcting the current trade imbalance where imports exceed exports. Natural gas exports are cost effective when oversea prices are high (such as in Japan where prices are four times higher than in the United States).

FIGURE 4. Natural gas pipelines (MCOR).



ECONOMIC IMPACTS

Over 70% of the Marcellus shale lies in New York and Pennsylvania, where researchers estimate that drilling could generate hundreds of thousands of jobs with several billion dollars in wages (Table 10).

Approximately 20% of the Marcellus shale lies under the southern tier and upstate New York. Weinstein and Clower (2009) from the University of North Texas concluded natural gas drilling in Broome County could generate $2.1 billion in annual revenues and produce 2,200 jobs. The New York State Department of Environment Conservation draft EIS (2011) estimates hydraulic fracturing in New York State could generate 46,808 direct and indirect jobs with peak earnings of $2.5 billion annually by year 30.

Over half of the Marcellus shale lies in Pennsylvania, where economic benefits are significant. The Joint Urban Studies Center (2008) calculated that oil and natural gas royalties paid to property owners totaled $200 million in 2006. From 2008–2011, Penn State University researchers concluded Marcellus shale gas drilling generated over 200,000 jobs, billions of dollars in wages, and around $2 billion dollars in state and local taxes in Pennsylvania (Considine et al. 2009, Considine et al. 2010, and Considine et al. 2011). Kelsey et al. (2009) from the Marcellus Shale Education and Training Center at Penn State Extension estimated shale gas development in Pennsylvania generated 23,385 jobs with $1.2 billion in wages in 2009. The Marcellus Shale Education and Training Center (2011) projected gas drilling in Pennsylvania could create up to 25,994 jobs in 2012 and 30,684 jobs by 2014. Near the Delaware

TABLE 10. Economic impact of Marcellus shale gas drilling in New York and Pennsylvania.

Author	State	Jobs	Wages ($ billion)	Output ($ billion)
Joint Urban Studies Center 2008	PA			$0.2
Weinstein and Clower 2009	Broome Co. NY	2,200	$2.1	
Considine et al. 2009	PA	29,284	$2.3	
Kelsey et al. 2009	PA	23,385	$1.2	$3.1
Considine et al. 2010	PA	200,000		$15.9
Considine et al. 2011	PA	156,000		$12.8
NYSDEC 2011	NY	46,808		$2.5
Marcellus Shale Education Center 2011	PA	25,994		

River in Wayne County, Pennsylvania where the Marcellus shale is thickest (150–250 ft), royalties in Wayne County could exceed $60 million annually for 1,200 wells on 200,000 acres. By September 2012, Pennsylvania collected $202 million from a 5% natural gas impact fee imposed by Act 13 signed by Governor Corbett in the spring of 2012.

Others are less optimistic about the long-term economic benefits of shale gas drilling. Kay (2011) from Cornell University expressed concern over boom and bust local economies that rely on extraction of natural gas which is a finite resource destined to disappear someday. Kinnaman (2011) pointed out that large uncertainties in these economic studies can lead to wide range in public response for or against shale gas extraction drilling and to reduce uncertainty calls for benefit-cost studies that compare environmental benefits with economic costs

ENERGY-WATER POLICY DEBATE

In the Delaware Basin, Marcellus shale gas drilling is at the center of a contentious energy-water policy debate that pits gas companies, land owners, and rural towns interested in jobs and revenue versus environmental groups, water utilities, ecotourism, and fishermen who have mobilized to protect water supplies. Water resources groups and citizens have raised questions about the environmental impacts of Marcellus shale gas extraction on watersheds in the Appalachian Basin (Soeder 2010). In 2010, filmmaker Josh Fox released *Gasland*, a documentary that warns against the environmental consequences of shale gas drilling and plays to fervent audiences that include Hollywood actors and upstate New York residents Mark Ruffalo and Deborah Winger. Since 2008, the PADEP has censured drilling companies almost 50 times for leaking well casings and documented at least 100 reports of hydrofracturing wastewater discharges flowing into waterways resulting in at least two fish kills. Osborn et al. (2011) from Duke University detected methane—but not hydraulic fracturing chemicals—in 85% of drinking water samples in New York State and Bradford and Susquehanna counties in Pennsylvania within 3000 feet of shale gas wells. To address these concerns, federal, state, regional, and local agencies have adopted or are considering policies to oversee Marcellus shale gas drilling in New York and Pennsylvania (Table 11).

Federal

The Environmental Protection Agency (EPA) and Department of Energy (DOE) oversee natural gas drilling at the federal level. With a final report due to Congress by 2014, EPA (2012)

TABLE 11. Chronology of natural gas drilling policies.

Year	Action
1988	EPA issues regulations that exempt oil and gas drilling wastes under Subtitle C of RCRA.
1990	Clean Air Act exempts minor oil and gas well emitters outside of areas more than one million people.
1997	U.S. Court of Appeals 11th Circuit orders EPA to regulate hydraulic fracturing under SDWA.
2005	Pres. Bush signs EPAct and exempts hydrofracturing chemicals (except diesel fuel) from SDWA.
2005	EPA modifies Clean Water Act to exempt natural gas drilling from NPDES stormwater permits.
2005	Congress exempts natural gas extraction from reporting environmental impacts under the NEPA process.
2008	Gov. Patterson bans Marcellus shale gas horizontal drilling in New York pending approval of SGEIS.
2009	NYCDEP releases EIA, opposes natural gas drilling in Catskill-Delaware drinking reservoir watersheds.
2010	Gov. Cuomo continues moratorium on shale gas drilling pending release of SGEIS by NYSDEC.
Mar 2011	Sen. Casey introduces FRAC Act to repeal 2005 EPAct exemption of hydrofrack chemicals in SDWA.
Apr 2011	DRBC receives 69,000 comments on draft Dec 2010 natural gas regs and holds 6 public hearings at 3 sites.
Jun 2011	NYS AG sues Corps, USFWS, NPS, USDOT, EPA for not preparing Marcellus shale EIS as per NEPA.
Aug 2011	Gov. Christie vetoes General Assembly bill to ban NJ gas drilling and recommends one year moratorium.
Sep 2011	NYSDEC draft SGEIS recommends drilling ban in New York City drinking water reservoir watersheds.
Sep 2011	EPA advises 9 natural gas companies to disclose information hydraulic fracturing. Chemicals.
Nov 2011	5 companies apply to DOE to build terminals to export 6 bcf of liquid natural gas from U.S. ports.
Nov 2011	DRBC issues revised draft shale gas regulations for vote by Commissioners Nov 21, 2011 in Trenton, NJ.
Nov 2011	Gov. Markell submits letter indicating Delaware will vote no on DRBC shale gas regulations.
Nov 2011	DRBC postpones Nov 2011 vote in Trenton on shale gas regulations as Delaware and New York oppose.
Dec 2011	NYSDEC extends public comments on natural gas drilling draft SGEIS by 30 days until Jan 11, 2012.
Jan 2012	NYSDEC receives 21,000 comments on draft SGEIS or 10 times received from prior environmental reg.
Feb 2012	Gov. Corbett signs Act 13 that set 5% natural gas drilling fee and more stringent drilling buffers.
Apr 2012	EPA finalizes standards to reduce 95% of VOC emissions during oil and natural gas drilling.
Sep 2012	PADEP collects $202 million from 5% natural gas drilling fee. WV imposes a 6% royalty.
Dec 2012	EPA releases progress report on 18 research studies about hydraulic fracturing impact on drinking water.

released a progress report in December 2012 that reviewed 18 research projects including a case study on the Susquehanna River Basin that will provide a nation-wide environmental study of hydraulic fracturing impact on drinking water. The U. S. Department of Energy (2011) Shale Gas Production Subcommittee recommended that natural gas drillers reduce air pollutants emissions of methane and ozone and protect water quality by measuring hydraulic fracturing water and establishing preservation zones at sensitive water resources areas. The DOE National Energy Technology Laboratory (NETL) is investigating the environmental impacts of Marcellus shale well drilling and hydraulic fracturing.

The EPA regulates shale gas drilling through the Clean Water Act, Safe Drinking Water Act, Clean Air Act, Resource Conservation and Recovery Act, Superfund Act, and National Environmental Policy Act. However, each of these environmental laws contains loopholes that exempt parts of the natural gas drilling or hydraulic fracturing process from federal regulation.

The Clean Water Act amendments of 1972, 1977, and 1987 require National Pollutant Elimination Discharge Elimination System (NPDES) permits for wastewater and stormwater discharges. The Oil Pollution Act of 1990 added Clean Water Act Section 311 to regulate oil and gas spill prevention and response planning. In 2005, the EPA modified the Clean Water Act to exclude oil and natural gas drilling from NPDES stormwater permit requirements unless there is a spill or water quality discharge violation. The EPA delegates NPDES permit authority to Pennsylvania and New York but retains authority over pretreatment of recovered hydraulic fracturing fluids. In October 2011, EPA announced a schedule to develop pretreatment standards for natural gas drilling and wastewater discharges.

The Safe Drinking Water Act of 1974 and amendments of 1996 established drinking water standards. In 1997, the U.S. Court of Appeals (11th Circuit) ordered the EPA to regulate hydraulic fracturing under the SDWA after a 1989 accident contaminated a residential well in Alabama (Holt and Glover 2011). In the Halliburton exemption pushed by Vice President Cheney, the Energy Policy Act of 2005 modified the SDWA to exclude public disclosure of oil and gas drilling hydraulic fracturing chemicals (other than diesel fuels). In 2011, Congress considered but never passed the Fracturing Responsibility and Awareness of Chemicals (FRAC) Act intended to reverse the 2005 Halliburton exemption and set minimum standards for underground injection of hydraulic fracturing fluids under the Safe Drinking Water Act (Marten Law 2011). In September 2011, the EPA requested that nine natural gas service companies voluntarily list the chemicals employed in hydraulic fracturing. In May 2012, the EPA maintained primacy over the underground injection program in Pennsylvania and New York and released draft guidance for class II wells that use diesel fuel during hydraulic fracturing.

The Clean Air Act of 1970 regulates air pollution to protect public health. The CAA Amendments of 1990 strengthened criteria for 180 chemicals but excluded minor oil and gas well emitters from oversight in urban areas with more than one million people. In April 2012, a suit filed in District of Columbia Circuit Court forced the EPA to finalize standards to reduce 95% of VOC emissions (benzene, hexane, and methane) from oil and natural gas drilling.

The Resource Conservation and Recovery Act (RCRA) of 1976 authorizes the EPA to control hazardous wastes from "cradle to grave". In 1988, EPA issued Subtitle C that exempted federal oversight of oil and gas drilling wastes under RCRA. These EPA exemptions remain but states may regulate oil and gas wastes under Subtitle D of RCRA.

The Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (Superfund Act) mandates clean up of abandoned hazardous waste sites and holds polluters

responsible for cleanup costs. The Superfund Act does not define natural gas as a hazardous waste, hence, shale gas drilling companies are exempt from clean up costs and regulations.

The National Environmental Policy Act of 1969 requires environmental impact statements (EIS) for projects under federal regulatory, funding, or administrative oversight. In 2005, Congress exempted natural gas and oil extraction from reporting on environmental impacts under the NEPA process.

The DOE's Federal Energy Regulatory Commission regulates construction and operation of natural gas pipelines under Section 7 of the Natural Gas Act and certifies compliance with U.S. Department of Transportation safety standards. FERC has no jurisdiction over pipeline safety but works with PENNDOT and NYSDOT on safety and security responsibilities.

New York

The New York State Department of Environmental Conservation (NYSDEC) regulates natural gas drilling through the Division of Mineral Resources and Oil, Gas, and Mining Regulatory Program. The NYSDEC imposed buffers that prohibit gas drilling near water bodies (50 ft), homes (100 ft), public roads (75 ft), and public water supplies (2,640 ft) and set minimum criteria for well spacing (1,320 ft) and water withdrawals (Lien and Manner 2010). Along with FERC, the New York Public Services Commission (PSC) oversees construction and operation of natural gas pipelines. New York City released an environmental impact assessment that detailed potential negative impacts of natural gas drilling on the Catskill-Delaware reservoirs and Delaware Tunnel and Aqueduct system that supply 50% of the drinking water to the five boroughs (NYCDEP 2009). In June 2011, the New York State Attorney General sued the U.S. Army Corps of Engineers, National Park Service, and U.S. Fish and Wildlife Service for failure to prepare an EIS for Marcellus shale drilling as per the National Environmental Policy Act (NEPA).

In 2008, Governor David Paterson issued an Executive Order that banned hydraulic fracturing and horizontal drilling in New York pending approval of a Supplemental Generic Environmental Impact Statement (NYSDEC 2011). By January 2012, the NYSDEC received over 21,000 comments on the draft SGEIS, or 10 times the comments received for any previous issue. The SGEIS recommends excluding hydraulic fracturing within: (1) New York City and Syracuse reservoir watersheds and a 4,000 ft buffer area around the watersheds; (2) primary aquifers and a 500 ft buffer; (3) Catskill and Adirondack State Forest Preserves and State Wildlife Areas already banned by the New York State Constitution; (4) 2,000 ft of public drinking water supplies; (5) 500 ft of private water wells; (6) 150 ft from streams; (7) 100-year floodplain; and (8) 1000 ft of subsurface water supply infrastructure such as aqueducts and pipelines.

During the summer of 2012, the governor floated a plan to continue the drilling ban in the New York City reservoir watersheds and Catskill Forest Preserve east of the Delaware River yet allow drilling to the west in Broome, Chenango, and Tioga Counties provided the southern tier towns pass resolutions in favor of the drilling. In September 2012, the NYSDEC Commissioner announced the governor would not approve the Marcellus shale SGEIS until the New York State Health Department completed a new study with hearings on the public health impacts of drilling.

By 2012, four Sullivan County towns in New York passed local zoning laws that ban natural gas drilling on 240 mi^2 of land in the Delaware Basin, including Tusten (49 mi^2), Lumberland (50 mi^2), Bethel (90 mi^2), and Highland (51 mi^2). The New York towns of Delaware, Hancock, and Fremont along the Delaware River passed resolutions in support of gas drilling.

In the Empire State, a 2011 Quinnipiac University poll found that 44% of residents support shale gas drilling for economic benefits compared to 43% against due to environmental concerns. The poll found that 23% of Republican, 55% of Democratic, and 44% of Independent voters oppose gas drilling. Approximately 45% of upstate, 43% of New York City, and 41% of suburban voters oppose drilling. Just over half of New York State voters support a natural gas drilling tax. In 2011, Pulse Opinion Research reported that east of the Delaware River 72% of Delaware County and 69% of Sullivan County respondents oppose hydraulic fracturing.

Pennsylvania

The Pennsylvania Oil and Gas Act of 1984 regulates hydraulic fracturing to permit "optimal development" of oil and gas resources in the state. The PADEP Division of Mineral Resources, Bureau of Oil and Gas Management oversees oil and gas exploration under Title 25 of the State Code, Chapter 78 Oil and Gas Wells, Chapter 95 Wastewater Treatment, and Chapter 102 Erosion and Sediment Control. The Pennsylvania Clean Streams Law of 1937 regulates mining wastes such as hydraulic fracturing. Since 2008, the Pennsylvania DCNR has issued natural gas leases on 700,000 acres of private forests and 139,000 acres of public forests. In February 2012, Governor Tom Corbett signed Act 13 that revised the Pennsylvania Oil and Gas Act of 1984 and set a 5% drilling fee to fund county/municipal services at a 60% share and a Marcellus Legacy Fund at a 40% share and prohibits horizontal drilling within 500 ft of buildings and individual wells, 1000 ft from water wells, surface water intakes, or water supplies, and 300 ft from streams and springs. In the Delaware Basin, drilling will be prohibited in the Delaware State Forest in Pike, Monroe, Northampton, and Carbon counties and Promised Land State Park.

Delaware River Basin Commission

In June 2010, the DRBC placed a moratorium on natural gas drilling in the basin pending approval of new regulations by act of the Commissioners. The DRBC (2011) published draft revisions to Article 7 of the Water Quality Regulations to protect the water resources in the Delaware Basin based on concerns that Marcellus Shale gas drilling may reduce flow in streams and aquifers and discharge hydraulic fracturing pollutants to ground or surface water. DRBC requires a permit for surface and groundwater withdrawals that exceed 100,000 gallons per day. In February 2011, the DRBC held six public hearings at three sites to review the draft shale gas regulations. By April 2011, the DRBC received 69,000 comments and scheduled a Commission meeting in Trenton to vote on the Marcellus shale regulations.

On November, 21, 2011, the five DRBC Commissioners representing the U.S. Army Corps of Engineers and governors of Delaware, New Jersey, New York, and Pennsylvania were scheduled to meet in Trenton and vote on Marcellus shale gas drilling regulations. The vote was postponed after the governors of Delaware and New York expressed concern and requested more time to review and strengthen the proposed water quality regulations to protect the basin's water supplies. While just two of the four basin states possess Marcellus shale gas reserves, each of the five Commissioners have vested interests in the outcome of the proposed DRBC shale gas regulations based on the viewpoints of their individual constituencies.

The President is represented on the DRBC by the Colonel in command of the Philadelphia District of the U. S. Army Corps of Engineers. The White House received a Department of Energy (2011) study that recommends strict controls on gas drilling to prevent pollution

and received a December 2012 progress report from the EPA on the water quality impacts of shale gas drilling with a final report due in 2014.

Delaware lies a hundred miles south of the shale gas line but has concerns about potential downstream impacts on the water supplies along the Delaware River near Wilmington. Drilling companies have contacted Pennsylvania wastewater utilities along the Delaware River just upstream from Delaware about the possibility of treating and discharging hydraulic fracturing fluid into the river. Major natural gas pipelines cross Delaware, including the sole conduit to the Delmarva Peninsula. Ports at Wilmington and a few thousand feet upstream in Marcus Hook, Pennsylvania are close to the Atlantic Ocean and are touted as future export terminals to ship liquid natural gas and ethane to the Gulf of Mexico and overseas to Japan and China.

Concerned about potential pollution of New York City's Catskill-Delaware water supply reservoirs, the governor of New York has continued a moratorium on shale gas drilling pending results of a Supplemental Generic Environmental Impact Statement (SGEIS). The New York Attorney General has sued to prevent the DRBC from issuing natural gas drilling regulations and argued that federal agencies are required to prepare an EIS under the National Environmental Policy Act. In September 2012, NYSDEC Commissioner announced that shale gas drilling would not be approved until the New York Health Commissioner completes a new study and holds hearings on the public health effects of hydraulic fracturing.

About half of the 54,000 mi^2 Marcellus shale lies under Pennsylvania, where the governor has touted the economic and jobs benefits of natural gas to the Commonwealth. While initially concerned about driving away drilling business, the Pennsylvania General Assembly passed Act 13 that imposed a 5% natural gas drilling fee that generated $202 million by September 2012. Local governments in Buckingham Township, Easton, Media, Philadelphia, and Phoenixville in Pennsylvania have banned shale gas drilling in the Delaware Basin.

Except for a small outcrop near the Delaware Water Gap, New Jersey has no Marcellus shale reserves, but stands to benefit from jobs for residents and companies who cross the river to work in the nearby Pennsylvania shale fields. Natural gas pipelines crisscross North Jersey and are positioned to ship the gas to metropolitan customers and terminals along the Hudson River. The governor of New Jersey has voiced concerns about potential impacts of hydraulic fracturing on downstream drinking water intakes along the Delaware River at Trenton and Delaware and Raritan Canal that feeds Princeton and New Brunswick. The New Jersey General Assembly passed a hydraulic fracturing ban in June 2011 but the governor vetoed the bill and replaced the ban with a one-year moratorium. Several basin towns in New Jersey have banned natural gas drilling, including Bethlehem, Byram, Delaware Township, Holland, and Trenton.

Water quality is good in forested Marcellus shale watersheds in the upper Delaware Basin in Pennsylvania and New York, with just 5% of 7,268 stream miles rated as impaired by the NYSDEC, PADEP, DRBC, and EPA (Table 12). DRBC antidegradation regulations protect 197 miles of the Delaware River and tributaries above Trenton as Special Protection Waters with exceptionally high scenic, recreational, ecological, and water supply values.

Article 7 of the draft DRBC (2011) water quality regulations seeks to minimize the impact to water resources from shale gas development through buffers and setbacks, monitoring of water use and wastewater treatment, management plans for leases over 3,200 acres, and financial assurances of $125,000 per natural gas well. Natural gas drilling will require up to 5 million gallons per well for hydraulic fracturing on 5-acre well pads near small headwater streams with excellent water quality in the Special Protection Waters of the Delaware Basin. Ground and surface water withdrawals for hydraulic fracturing could diminish the quality

TABLE 12. Stream water quality in the Marcellus shale region in the Delaware Basin.

Stream	Total (mi)	Impaired (mi)	Impaired (%)
EW1 West Branch (Cannonsville)	841	58	7%
EW2 East Branch (Pepacton)	1,017	25	2%
EW3 Mainstem (above Narrowsburg)	819	52	6%
LW1 Lackawaxen River	882	5	1%
NM1 Neversink-Mongaup	1,136	38	3%
UC1 Pennsylvania tributaries	1,012	15	1%
LV1 Lehigh River above Lehighton	660	29	4%
LV2 Lehigh River above Jim Thorpe	481	21	4%
SV1 Schuylkill River above Reading	420	102	24%
Total	7,268	345	5%

and quantity of these small, near-pristine headwater streams. Without protective buffers and standards, natural gas development in the headwaters of the Delaware Basin could cause forest loss, steep slope erosion, stream encroachment, and deleterious water supply and wastewater impacts. If regulations are adopted, the DRBC estimates that 18,000 horizontal wells may be drilled in the basin on 2,200 well pads on 2,000 acres. If hydraulic fracturing requires 5 mgd per well and 20% is flowback water (1 mgd), wastewater treatment capacity will be needed for 18 billion gallons of wastewater over 20 years.

DRILLING BUFFERS

If adopted, proposed DRBC water quality regulations would set buffers (Table 13) that exclude natural gas drilling from high value landscapes and special protection waters such as:

New York City Catskill reservoir watersheds that convey up to 800 mgd of drinking water from the east and west branches of the Delaware River through the 85-mile Delaware Aqueduct. Natural gas drilling is banned in the Cannonsville (455 mi^2), Pepacton (371 mi^2), and Neversink (92 mi^2) reservoir watersheds and a 4,000 ft reservoir buffer (80 mi^2).

Delaware Water Gap National Recreation Area (109 mi^2) managed by the National Park Service with 12 mi^2 in the Pennsylvania shale along 40 miles of the upper Delaware River.

Upper Delaware National Wild & Scenic River (107 mi^2) from "Ridge to Ridge" from RM 258-331 administered by National Park Service under National Wild & Scenic Rivers Act.

Stream buffers (300 ft) along 6,649 stream miles to exclude 755 mi^2 (15%) of the Delaware Basin shale from drilling or 342 mi^2 in New York and 413 mi^2 in Pennsylvania (Table 14).

Wetland buffers (300 ft) that exclude 340 mi^2 (7%) of the Delaware Basin shale from drilling including 81 mi^2 in New York and 260 mi^2 in Pennsylvania.

Setbacks from surface water supply intakes (1000 ft), water supply reservoirs (1,000 ft), public water systems (1,000 feet), private wells (500 feet), and steep slopes (>15%).

TABLE 13. Marcellus shale gas drilling buffers set by DRBC, New York, and Pennsylvania

Criteria	NYSDEC	PADEP	DRBC
New York City Catskill Reservoir Watersheds	w/4,000 ft buffer		Yes
Delaware Water Gap National Recreation Area			Yes
Upper Del. National Wild and Scenic River			Yes
State Land	Catskill Preserve	State Parks	
Primary Aquifer	w/500 ft buffer		
Water Body (Stream)	50 ft	300 ft	300 ft
Wetlands	100 ft	100 ft	300 ft
100-yr Floodplain	Yes	Yes	Yes
Occupied Homes	100 ft	500 ft	
Public Roads Buffer	75 ft	—	
Public Water Supply	2,000 ft	1000 ft	1000 ft
Private Wells	500 ft	500 ft	
Steep Slopes (>15%)			Yes
Financial Bond (per well)	$250,000	$2,500	$125,000

Sources: Lein and Manner 2010, PA Act 13, DRBC 2011.

TABLE 14. Stream and wetland buffers protected by proposed DRBC shale gas regulations.

Watershed	Stream Length (mi)	Watershed Area (mi^2)	300 ft Buffer (mi^2)	Watershed Protected (%)
EW1 West Branch (Cannonsville)	763	615	87	14%
EW2 East Branch (Pepacton)	1,017	840	116	14%
EW3 Mainstem (above Narrowsburg)	387	281	44	16%
NM1 Neversink-Mongaup	847	613	96	16%
New York	**3,014**	**2,349**	**342**	**15%**
EW1 West Branch (Cannonsville)	68	51	8	15%
EW3 Mainstem (above Narrowsburg)	384	242	44	18%
LW Lackawaxen River	887	597	101	17%
NM1 Neversink-Mongaup	199	140	23	16%
UC1 Pennsylvania tributaries	675	486	77	16%
LV1 Lehigh River above Lehighton	669	451	76	17%
LV2 Lehigh River above Jim Thorpe	406	354	46	13%
SV1 Schuylkill River above Reading	348	269	40	15%
Pennsylvania	**3635**	**2,590**	**413**	**16%**
Total	**6,649**	**4,940**	**755**	**15%**

Protective buffers set by proposed DRBC and NYSDEC rules, recently enacted PADEP Act 13, and drilling bans by four New York towns would exclude 2,363 mi^2 or 48% of the 4,940 mi^2 Marcellus shale area in the Delaware Basin from natural gas drilling (Table 15). Buffers would exclude 1,645 mi^2 (70%) of New York's and 718 mi^2 (28%) of Pennsylvania's Marcellus shale area from drilling in the basin (Figure 5). With protective buffers, 30% of New York's and 72% of Pennsylvania's gas shale area in the Delaware Basin would remain for natural gas drilling

TABLE 15. Buffers that would exclude Marcellus shale gas drilling in the Delaware Basin.

Buffers	NY (mi^2)	PA (mi^2)	DRB (mi^2)
New York City Reservoirs			
Cannonsville watershed	445		445
Pepacton watershed	371		371
Neversink watershed	92		92
4000 ft buffer	80		80
Delaware Water Gap National Recreation Area		12	12
Upper Delaware National Wild and Scenic River (RM 258-330)	46	62	108
Stream Buffer (300 ft wide along 6,649 stream miles)	342	413	755
Wetland Buffer (300 ft wide)	81	260	340
Catskill Forest Preserve	427		427
State Park, Forest, and Game Lands	104	67	171
NYS Towns with Drilling Bans	240		240
Total Drilling Buffers	2,228	814	3,042
Total Drilling Buffers (excluding Overlaps)	1,645	718	2,363
Marcellus Shale Region	2,350	2,590	4,940
Available for Natural Gas Drilling (with buffers)	705	1,872	2,577
% Available for Natural Gas Drilling (with buffers)	30%	72%	52%

ECONOMIC VALUE

Marcellus Shale Gas

The Marcellus shale lies under 4,940 mi^2 (38%) of the Delaware Basin, including 2,350 mi^2 in New York and 2,590 mi^2 in Pennsylvania. The USGS (Coleman et al. 2011) estimated the 54,000 mi^2 Marcellus Shale Formation in Ohio, West Virginia, Maryland, Pennsylvania and New York holds a mean volume of 84 tcf of potentially recoverable natural gas within a range of 43 tcf (95th percentile) to 144 tcf (5th percentile). Given that the Delaware Basin covers 4,940 mi^2 (9.1%) of the Marcellus shale, the scaled mean volume of shale gas in the basin is 7.6 tcf, within a range of 3.9 tcf (95th percentile) to 13.1 tcf (5th percentile). These estimates may vary depending on the Marcellus shale thickness, which increases to the northeast toward the New York/Pennsylvania border from 50 ft thick near Stroudsburg to over 250 ft under Wayne County.

During 2012, the Energy Information Administration reported the annual natural gas wellhead price was $2.68 per 1000 cubic feet, down three-fold from $7.97 per 1000 cf in 2008 (Table 16). At the 2012 price, the mean value of potentially recoverable natural gas from the Marcellus shale in the Delaware Basin (without buffers) is $20.4 billion, within a range of $10.4 billion at the 95th percentile to $35.1 billion at the 5th percentile (Table 17). Assuming a recovery period of 25 years, the annual wellhead value of Marcellus shale gas in the basin is $815 million (mean), within a range of $418 million ($95^{th}$ percentile) to $1.4 billion (5th percentile). Without buffers, the mean value of potentially recoverable natural gas in the basin from Pennsylvania ($9.6 billion or $386 million/yr) is just less than the value in New York ($10.7 billion or $429 million/yr).

If proposed DRBC and NYSDEC rules are adopted and PADEP Act 13 standards and drilling bans in four New York towns are enforced, buffers will exclude 2,363 mi^2 (48%) of

FIGURE 5. Protective buffers in the Marcellus shale region of the Delaware Basin (Pinchot Institute).

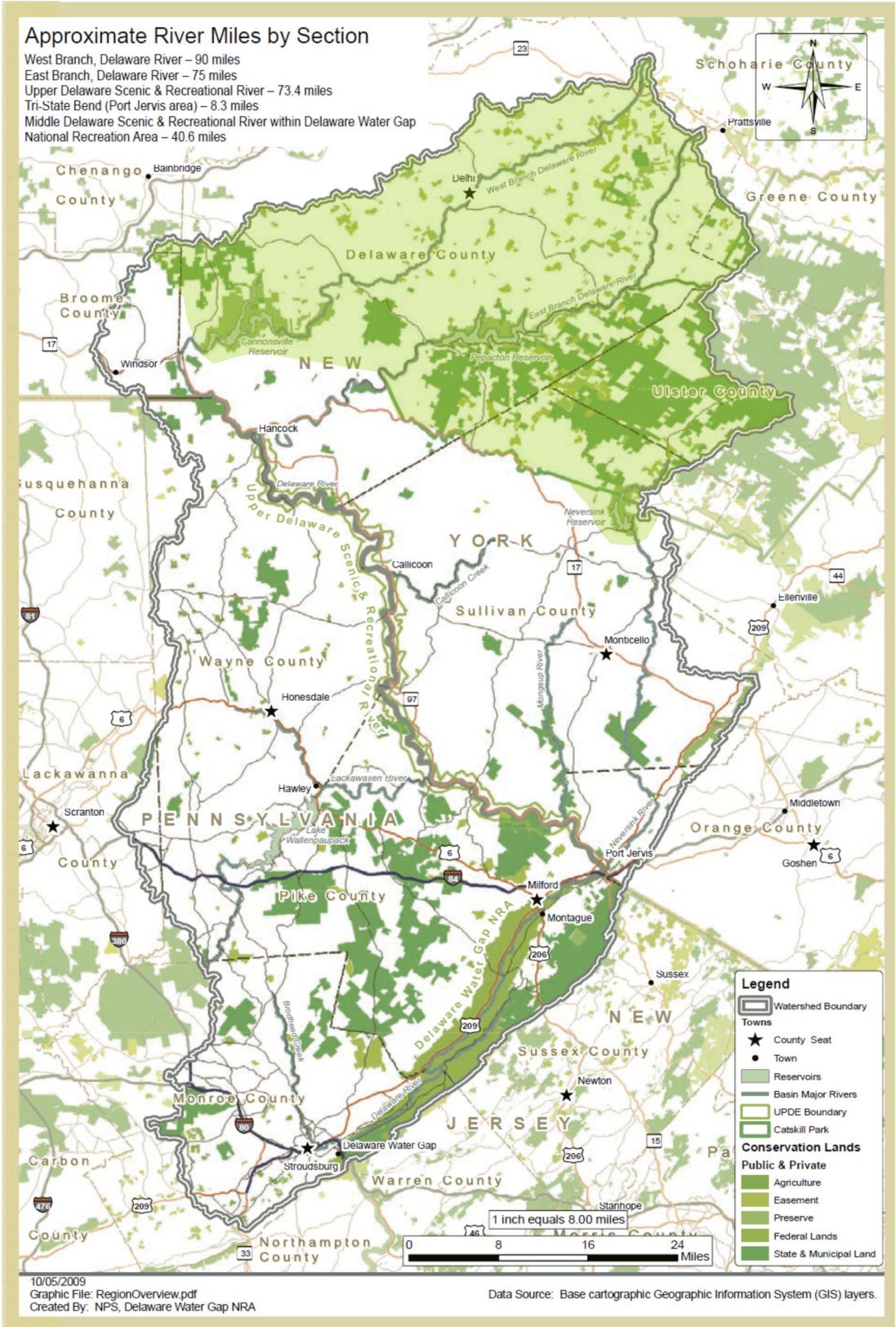


TABLE 16. Wellhead price of natural gas in the United States from 2008–2012 (EIA).

Year	Wellhead Price ($/1000 cf)
2008	$7.97
2009	$3.67
2010	$4.48
2011	$3.95
2012	$2.68

TABLE 17. Wellhead value (2012) of Marcellus shale gas in the Delaware Basin.

State/Basin	Marcellus Shale Area (mi^2)	Wellhead Price[1] ($/1000 cf)	Natural Gas Vol.[2] (tcf)	Total Value ($ million)	Annual Value[3] ($ million/yr)
95th Percentile					
Pennsylvania	2,350	$2.68	1.9	5,092	204
New York	2,590	$2.68	2.0	5,360	214
Delaware Basin	4,940	$2.68	3.9	10,452	418
Mean					
Pennsylvania	2,350	$2.68	3.6	9,648	386
New York	2,590	$2.68	4.0	10,720	429
Delaware Basin	4,940	$2.68	7.6	20,368	815
5th Percentile					
Pennsylvania	2,350	$2.68	6.2	16,616	665
New York	2,590	$2.68	6.9	18,492	740
Delaware Basin	4,940	$2.68	13.1	35,108	1,404

1. EIA 2012. 2. Scaled from USGS 2011. 3. Based on 25 year natural gas recovery period.

Marcellus shale area in the Delaware Basin from natural gas drilling, leaving 2,577 mi^2 open for extraction including 705 mi^2 in New York and 1,873 mi^2 in Pennsylvania. With buffers that would exclude 48% of the Marcellus shale from drilling in the Delaware Basin, the mean volume of Marcellus shale gas available for drilling in the basin declines to 4.0 tcf, within a range of 2.0 tcf (95th percentile) to 6.8 tcf (5th percentile). With buffers, the estimated mean value of potentially recoverable natural gas at the 2012 price is $10.6 billion ($425 million/yr), within a range of $5.4 billion ($218 million/yr) at the 5th percentile to $18.3 billion ($733 million/yr) at the 95th percentile (Table 18 and Figure 6). With buffers in effect, the potentially recoverable value of Marcellus shale gas in the Delaware Basin is $425 million/yr at the 2012 wellhead price, or three times less than the value at the 2008 price, or $1.3 billion/yr (Table 19 and Figure 7, 8, and 9).

Drinking Water

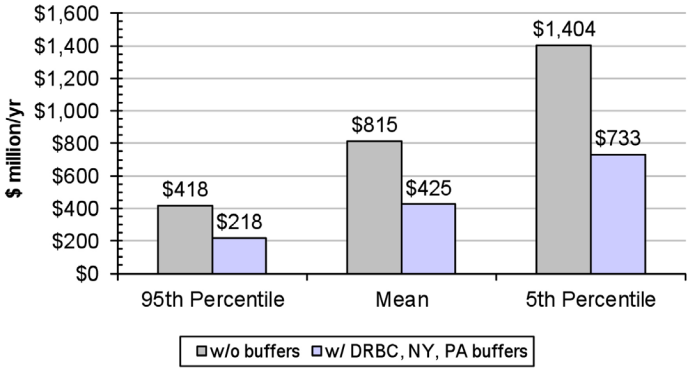
The Marcellus shale in the Delaware Basin lies upstream from intakes that provide 1.6 bgd of drinking water to New York City, Philadelphia, Stroudsburg, Allentown, Easton, Trenton, and cities in Delaware, New Jersey, New York, and Pennsylvania (Table 20). The value of public drinking water in the Delaware Basin ranges from $684 million/yr for untreated water

TABLE 18. Wellhead value (2012) of Marcellus shale gas in the Delaware Basin with buffers.

State/Basin	Marcellus Shale Area (mi^2)	Buffer Area (mi^2)	Available Shale (mi^2)	Natural Gas Vol.[1] (tcf)	Available Gas Vol.[2] (tcf)	Total Value[3] ($ mil)	Annual Value[4] ($ mil/yr)
95th Percentile							
Pennsylvania	2,590	718	1,872	1.9	1.4	3,680	147
New York	2,350	1,645	705	2.0	0.6	1,608	64
Delaware Basin	4,940	2,363	2,577	3.9	2.0	5,452	218
Mean							
Pennsylvania	2,590	718	1,872	3.6	2.6	6,973	279
New York	2,350	1,645	705	4.0	1.2	3,216	129
Delaware Basin	4,940	2,363	2,577	7.6	4.0	10,625	425
5th Percentile							
Pennsylvania	2,590	718	1,872	6.2	4.5	12,010	480
New York	2,350	1,645	705	6.9	2.1	5,548	222
Delaware Basin	4,940	2,363	2,577	13.1	6.8	18,314	733

1. Scaled from USGS 2011.
2. w/ DRBC, NYSDEC, PADEP buffers.
3. At 2012 wellhead price of $2.68/1000 cf (EIA 2012).
4. Based on 25-year recovery period.

FIGURE 6. Annual wellhead value (2012) of Marcellus shale gas reserves in the Delaware Basin.



to $2.8 billion/yr for treated water (Table 22). The value of drinking water is based on the product of the water supply and unit price and annualized for 365 days per year. The New Jersey Water Supply Authority (2011) established a price of untreated water supplies in the Manasquan system at $1.168/1000 gal. The mean price of treated water based on a survey of water rates in Delaware, New Jersey, Pennsylvania, and Maryland is $4.78/1000 gal (Corrozi and Seymour 2008).

Forests

Construction of drilling pads and service roads for Marcellus shale gas drilling could reduce forested land in the headwaters of the Delaware Basin. Over 3,200 mi^2 (or 2/3) of the Marcellus

TABLE 19. Wellhead value of Marcellus shale gas in the Delaware Basin with/without buffers.

Year	Available Marcellus Shale (mi^2)	Available Natural Gas[1] (tcf)	Annual Wellhead Price[2] ($/1000 cf)	Natural Gas Value ($ mil)	Annual Natural Gas Value[3] ($ mil/yr)
w/o buffers					
2008	4,940	7.6	$7.97	60,572	2,423
2009	4,940	7.6	$3.67	27,892	1,116
2010	4,940	7.6	$4.48	34,048	1,362
2011	4,940	7.6	$3.95	30,020	1,201
2012	4,940	7.6	$2.68	20,368	815
with buffers[4]					
2008	2,363	4.0	$7.97	31,880	1,275
2009	2,363	4.0	$3.67	14,680	587
2010	2,363	4.0	$4.48	17,920	717
2011	2,363	4.0	$3.95	15,800	632
2012	2,363	4.0	$2.68	10,625	425

1. USGS 2011.
2. EIA 2012.
3. Assumes 25 year recovery period.
4. w/ DRBC, NY, and PA buffers

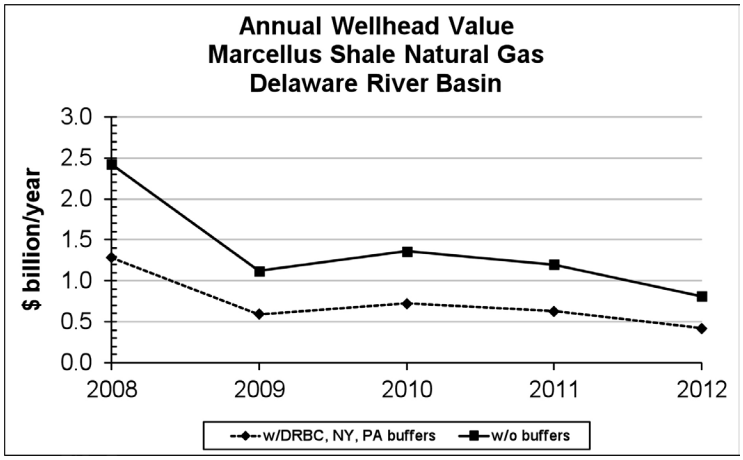


FIGURE 7. Annual value of Marcellus shale gas in the Delaware Basin with and without buffers.

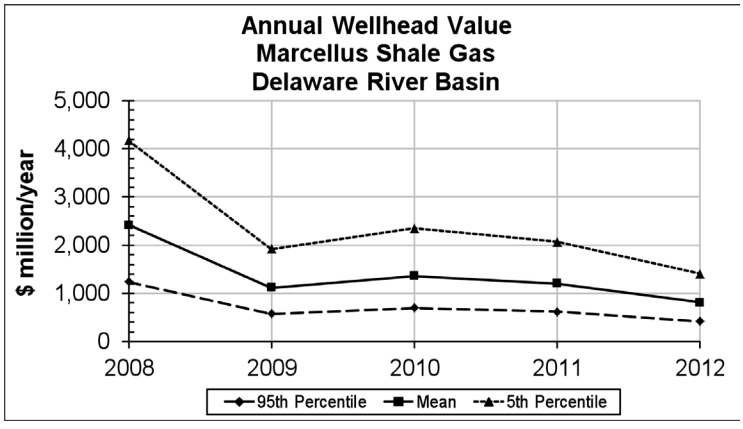


FIGURE 8. Annual value of Marcellus shale gas in Delaware Basin without buffers (2008–2012).

FIGURE 9. Annual value of Marcellus shale gas in the Delaware Basin with buffers (2008–2012).

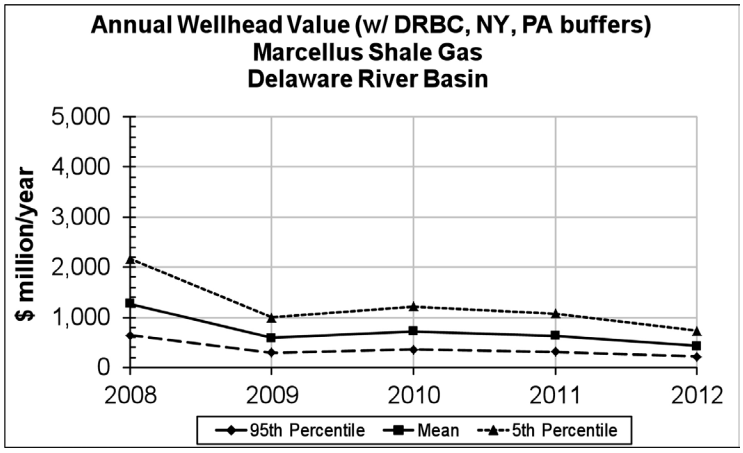


TABLE 20. Public water supply intakes in the Delaware Basin (DRBC 2010)

Water Purveyor	Supply (mgd)	Water Purveyor	Supply (mgd)
United Water Delaware	18.5	North Penn Water	8.6
Wilmington	20.0	Easton	7.1
Newark	2.2	Schuylkill Co. Authority	5.1
Delaware	**40.7**	Pottstown Water Auth.	4.6
Del. & Raritan Canal	100.0	Easton Suburban Water	4.5
NJ American Western	39.4	Schuylkill Co. Authority	4.4
Trenton	26.1	Muhlenberg Twp.	4.3
Camden	10.9	Lehigh County	4.3
Merchant.-Pennsauken	6.1	PA American Nazareth	4.1
Willingboro MUA	4.6	Hazelton	4.1
NJ American Mt. Holly	4.5	Allentown City	4.0
Aqua NJ Phillipsburg	3.5	Northampton Boro.	3.7
Bordentown	2.2	East Stroudsburg	3.7
Burlington City	1.4	PA American Yardley	3.2
Florence Twp.	1.2	Morrisville	2.9
Gloucester City	1.0	Falls Twp.	2.7
New Jersey	**200.9**	Northampton Bucks	2.5
New York City	**800.0**	Milford	1.9
Philadelphia	287.8	Tamaqua MWA	1.9
Aqua PA Main System	102.2	Lehighton MWA	1.8
Bethlehem	15.7	Brodhead Cr. Auth.	1.7
Allentown	15.5	South Whitehall Twp.	1.7
North Wales Water	15.1	Emmaus Munic. Water	1.5
Bucks Co. Water/Sewer	15.0	Wyomissing Boro	1.4
Reading Area Authority	14.3	Schuylkill Haven Boro.	1.4
PA Amer. Norristown	10.1	**Pennsylvania**	**562.8**

TABLE 21. Value of public drinking water in the Delaware Basin.

State	Supply[1] (mgd)	Untreated[2] ($/yr)	Treated[3] ($/yr)
Delaware	41	17,479,120	71,532,700
New Jersey	201	85,690,320	350,684,700
New York	800	341,056,000	1,395,760,000
Pennsylvania	563	240,018,160	982,266,100
Delaware Basin	**1,605**	**684,243,600**	**2,800,243,500**

1. DRBC 2010.
2. Untreated water @ $1.168/1000 gal.
3. Treated water @ $4.78/1000 gal.

shale region in the Delaware Basin are covered by vast forests that protect the quantity and quality of rivers that provide drinking water to 16 million people in four states and support a multi-billion dollar boating, fishing, hunting, and tourism recreation economy. Forests in Marcellus shale watersheds provide shade for coldwater streams with reproducing native brook trout, which is the state fish of New Jersey, New York, and Pennsylvania.

Forests provide substantial ecosystem goods and services such as carbon sequestration, clean air, stormwater/flood control, clean water, erosion/sediment control, water temperature, recreation, and fish/wildlife habitat benefits that range from $837/ac to $13,543/ac in 2010 dollars (Table 22). The Conservation Fund estimated the ecosystem services value of forests in Cecil County, Maryland is $12,033/ac (Weber 2007). The U.S. Forest Service (Nowak et al. 2008) concluded that forests in Delaware provide benefits from carbon storage ($827/ac), carbon sequestration ($29/ac), air pollution removal ($266/ac), building energy savings ($56/ac), and avoided carbon emissions ($3/ac), for a total value of $2,037/ac. Costanza from the University of Vermont prepared a study for the NJDEP (2007) that estimated the value of New Jersey forests at $1,714/ac. The Audubon Society estimated the economic value of forests in Massachusetts at $984/ac (Breunig 2003). Ingraham and Foster (2008) from the University of Maryland and the Nature Conservancy estimated the eco-value of forests in the National Fish and Wildlife Refuge System at $845/ac. The Wilderness Society (Kreiger 2001) concluded forest ecosystem services from climate regulation, water supply, water quality, and recreation benefits totaled $392/ac.

TABLE 22. Forest ecosystem services values.

Source	Organization	Location	Value ($/ac/yr)	Value[1] ($2010/ac/yr)
Weber 2007	Conservation Fund	Maryland	12,033	13,543
Nowak et al. 2008	U.S. Forest Service	Delaware	$2,037	2,161
Costanza for NJDEP 2007	Univ. of Vt., NJDEP	New Jersey	1,714	2,036
Breunig 2003	Mass Audubon	Massachusetts	984	1,207
Ingraham & Foster 2008	Univ. of Maryland	Nat'l. Wildlife Refuge	845	896
Kreiger 2001	Wilderness Society	United States	641	837

1. Adjusted to $2010 based on change in Consumer Price Index (CPI).

TABLE 23. Forest ecosystem services in the Marcellus shale region of the Delaware Basin.

Watershed	Forests (ac)	Low Estimate ($/ac/yr)	UVM/NJDEP ($/ac/yr)	High Estimate ($/ac/yr)	Low PV $2010	UVM/NJDEP PV $2010	High PV $2010
EW1 E.B. Del. R.	318,662	837	2,036	13,543	266,720,094	648,795,832	4,315,639,466
EW2 W.B. Del. R.	486,782	837	2,036	13,543	407,436,534	991,088,152	6592,488,626
EW3 Pt. Jervis	267,961	837	2,036	13,543	224,283,357	545,568,596	3628,995,823
NM1 Neversink R.	468,104	837	2,036	13,543	391,803,048	953,059,744	6339,532,472
New York	**1,541,509**	**837**	**2,036**	**13,543**	**1,290,243,033**	**3,138,512,324**	**20,876,656,387**
LW1 Lackawaxen	66,075	837	2,036	13,543	55,304,775	134,528,700	894,853,725
UC1 Pocono Mt.	78,310	837	2,036	13,543	65,545,470	159,439,160	1,060,552,330
LV1 Upper Lehigh	25,143	837	2,036	13,543	21,044,691	51,191,148	340,511,649
LV2 Middle Lehigh	191,472	837	2,036	13,543	160,262,064	389,836,992	2,593,105,296
SV1 Schuylkill	154,983	837	2,036	13,543	129,720,771	315,545,388	2,098,934,769
Pennsylvania	**515,983**	**837**	**2,036**	**13,543**	**431,877,771**	**1,050,541,388**	**6,987,957,769**
Total (3,215 mi^2)	**2,057,492**	**837**	**2,036**	**13,543**	**1,722,120,804**	**4,189,053,712**	**27,864,614,156**

The annual ecosystem services value of forests (3,215 mi^2) in the Marcellus shale region of the Delaware Basin is $4.2 billion within a range of $1.7 billion as a low estimate to $27.9 billion as a high estimate (Table 23). Forests in New York (2,409 mi^2) and Pennsylvania (806 mi^2) are worth $3.1 billion and $1.1 billion, respectively. The value transfer technique employed here involves selecting data from published literature from other watersheds and applying the per acre values to land use areas computed by GIS from NOAA Coastal Services Center land cover data. NJDEP (2007) data are used for value transfer to the Delaware Basin since New Jersey forest ecosystems are similar in habitat, climate, and geology.

A typical shale gas drilling footprint disturbs 9 acres per well or 3 acres for the well pad and 6 acres for roads, pipelines, and impoundments (Johnson et al. 2010). If DRBC and NYSDEC drilling bans were lifted, 20,000 natural gas wells could be drilled in the Delaware Basin in New York and Pennsylvania by 2030, which would disturb 180,000 acres (280 mi^2) (10%) of the forests in the Marcellus shale region with a loss in forest ecosystem services of $366 million.

Instream Use

In the Delaware Basin, the annual instream value of wastewater disposal and recreation, fish, wildlife uses in Marcellus shale streams is $79 million including $43 million in New York and $36 million in Pennsylvania (Table 24). Frederick et al. (1996) from Resources for the Future

TABLE 24. Value of instream uses in Marcellus shale watersheds in the Delaware Basin.

Watershed/USGS Gage	D.A.[1] (mi^2)	D.A. (ac)	Median Runoff (in)	Median Runoff (ac-ft)	WW Value[2] ($/ac-ft)	Rec. Value[2] ($/ac-ft)	Instream Value ($ million)
EW1 W.B. Del. R. Hale Eddy, NY	595	380,800	23	729,867	2	8	7.3
EW2 E.B. Del. R. Fishs Eddy, NY	784	501,760	25	1,045,333	2	8	10.4
EW3 Del. R. Port Jervis, NY	1,384	885,760	29	2,140,587	2	8	21.4
NM1 Neversink R. Godeffroy, NY	307	196,480	23	376,587	2	8	3.8
New York	**3,070**	**1,964,800**		**4,292,373**	**2**	**8**	**42.9**
LW1 Lackawaxen Rowland, PA	589	376,960	32	1,005,227	2	8	10.1
UC1 Brodhead Cr. Minisink, PA	259	165,760	34	469,653	2	8	4.7
LV1 Lehigh R. White Haven, PA	290	185,600	35	541,333	2	8	5.4
LV2 Lehigh R. Walnutport, PA	599	383,360	32	1,022,293	2	8	10.2
SV1 Schuylkill R. Berne, PA	355	227,200	32	605,867	2	8	6.1
Pennsylvania	**2,092**	**1,338,880**		**3,644,373**	**2**	**8**	**36.4**
Delaware Basin	**5,162**	**3,303,680**		**7,936,747**	**2**	**8**	**79.4**

1. Drainage area above USGS stream gage.
2. Frederick et al. 1996 converted to $2010 based on change in CPI.

concluded median instream use values ranged from $1/ac-ft for wastewater disposal to $5/ac-ft for recreation/fish/wildlife, in 1994 dollars. In 2010 dollars, based on the change in the Consumer Price Index, instream use values are $2/ac-ft for wastewater disposal and $8/ac-ft for recreation/fish/wildlife. The annual instream value of waste disposal and recreation/fish/wildlife uses in Marcellus shale watersheds is determined by the unit value ($/ac-ft) for instream uses multiplied by median annual runoff (ac-ft) as determined from USGS stream gages.

Water Quality

Willingness to pay (WTP) for good water quality in Marcellus shale watersheds in the Delaware Basin is $7.6 million for boating, $7.6 million for fishing, and $64.6 million for swimming, or $79.8 million for total use support. Parsons et al. (2003) from the University of Delaware measured the economic benefits of improved water quality for recreational users in six northeastern states and found annual WTP per person for good water quality ranged from $8.25 for boating, $8.26 for fishing, and $70.47 for swimming in 1994 dollars. Adjusting to 2010 dollars based on change in the CPI, WTP per person is $13.20 for boating, $13.22 for fishing, and $112.75 for swimming. Total WTP for good water quality is calculated by multiplying the individual WTP by the population of 573,341.

Paddling Recreation

Canoeing, kayaking, and rafting drive a significant recreation economy along the Lehigh, Schuylkill, and Delaware rivers in the Marcellus shale region. In the Mid-Atlantic census division (NY, NJ, PA), the Outdoor Industry Association (2006) estimated paddling recreation is practiced by 11% of the population (3,356,000 participants) and supports $356 million in gear retail sales, $1.6 billion in trip related sales, and 22,844 jobs. Given the Marcellus shale region in the Delaware Basin covers 4,700 mi^2, or 4.4% of the area of the three states (109,332 mi^2), paddling recreation is practiced by 147,664 participants and supports $86 million in gear retail and trip sales and 1,005 jobs in the basin.

River Recreation

Cordell et al. (1990) from the U.S. Forest Service and National Park Service estimated that 367,4000 river recreation participants at the Upper Delaware River and Delaware Water Gap generated 448 jobs and $20.3 million in total economic output in 1986 dollars, which adjusting for change in the CPI is $41.2 million in 2010 dollars. Downstream, 34 liveries along the Delaware, Lehigh, and Schuylkill rivers lease canoes, kayaks, and rafts to 204,000 visitors and realize earnings of $10.2 million per year, assuming a daily rental fee of $50 per person.

Fishing, Hunting, and Bird/Wildlife Watching

In New York and Pennsylvania, the U. S. Fish and Wildlife Service (2008) estimated the annual economic value of fishing, hunting, birding and wildlife/bird watching recreation was $9.2 billion in $2006 based on trip expenditures for food and lodging, transportation, and equipment. If the Marcellus shale region in the Delaware Basin covers 2,338 mi^2 (4.3%) of New York's and 2,362 mi^2 (5.2%) of Pennsylvania's land area, then the scaled value of fishing, hunting, and wildlife recreation is $364 million/yr, or $138 million/yr in New York and $226 million/yr in Pennsylvania (Table 25).

TABLE 25. Value of fishing, hunting, and wildlife recreation in the Delaware Basin.

Recreation Activity	NY by state[1] ($M)	PA by state[1] ($M)	NY in basin[2] ($M)	PA in basin[2] ($M)	Del. Basin ($M)
Fishing	**926**	**1,291**	**40**	**67**	**107**
Trip Related	585	299	25	16	41
Equipment/other	341	993	15	52	66
Hunting	**716**	**1,609**	**31**	**84**	**114**
Trip-related	202	274	9	14	23
Equipment/other	514	1,335	22	69	92
Wildlife/Bird Watching	**1,568**	**1,443**	**67**	**75**	**142**
Trip Related	696	325	30	17	47
Equipment/other	872	1,118	37	58	96
Total	**3,209**	**4,343**	**138**	**226**	**364**

1. USFWS 2008. 2. Scaled by ratio of shale area in basin to state area in NY (4.3%) and PA. (5.2%).

Shad Fishing

A 1986 study of shad fishing along the Delaware River reported anglers spent $1.6 million or $3.2 million in $2010 during 63,000 trips over a nine-week season based on an average expenditure of $25.40 per trip for gasoline, food, lodging, and tackle (Pennsylvania Fish and Boat Commission 2011). The average angler was willing to pay $50 per day for shad fishing or $102 per day when adjusted to $2010. For 63,000 angler days, the annual economic value of the Delaware River shad fishery was $3.2 million in $1986, or $6.5 million adjusted to $2010.

Wild Trout Fishing

New York City reservoir releases and excellent water quality in forested Catskill watersheds combine for a thriving cold water fishery along the Beaverkill and East Branch, West Branch, and main stem of the Delaware River in New York. Wild trout fishing in this area contributed almost $18 million in annual business revenue, over $29 million in economic activity, and almost 350 jobs with $3.6 million in wages (Maharaj, McGurrin, and Carpenter 1998).

Delaware Water Gap and National Recreation Area

Stynes (2011) from Michigan State University estimated that the National Park system along the upper Delaware River drew 5,592,229 recreation visits in 2010, with total visitor spending of $160 million generating 2,198 jobs and $61 million in wages. The Delaware Water Gap National Recreation Area hosted 5,285,761 recreation visits in 2010, with total visitor spending of $151 million generating 2,087 jobs and $58 million in wages. The Upper Delaware Wild and Scenic River had 306,468 recreation visits in 2010, with total visitor spending of $9 million generating 111 jobs and $3 million in wages.

Skiing

In the Pocono Mountains of Pennsylvania, nine ski areas withdraw 1 mgd from the Delaware Basin for snowmaking on 1,005 skiable acres at Alpine Mountain, Bear Creek, Big Boulder,

Camelback, Blue Mountain, Jack Frost, Elk Mountain, Ski Big Bear, and Ski Shawnee. The Pennsylvania Ski Areas Association (2009) estimated the economic value at 23 ski resorts statewide was $832 million which scales to $325 million at the nine ski areas in the Delaware Basin. The nine Delaware Basin ski resorts earned aggregate annual revenues of $88 million from 1.9 million ski visits based on a mid-week lift ticket rate of $45 per day.

DISCUSSION AND CONCLUSIONS

Through modernization of horizontal drilling and hydraulic fracturing technology, natural gas has become a plentiful, inexpensive, and relatively clean-burning domestic resource that provides a quarter of U.S. electric power needs and promises to reduce reliance on foreign oil. The 350-million-year-old Marcellus Shale Formation covers 54,000 mi^2 in West Virginia, Ohio, Maryland, Pennsylvania, and New York and is thought to be the third largest natural gas reserve in the world. Marcellus shale drilling has been so feverish that Pennsylvania has been called the "Saudi Arabia" of natural gas. Approximately 9% of the Marcellus shale lies in the upper third of the Delaware Basin in a watershed that supplies drinking water to 16 million people (5% of the U.S. population) in Delaware, New Jersey, New York, and Pennsylvania, including New York City and Philadelphia, the first and seventh largest metropolitan economies in the nation.

Marcellus shale gas provides economic benefits. Power companies and Fortune 500 companies are converting coal and oil fired power plants along the Delaware River to natural gas due to the low cost and cleaner emissions. The shale fields are linked by a network of 20 natural gas pipelines to distribution companies who wish to build liquid natural gas export terminals on the East Coast. Almost 3/4 of the Marcellus shale lies in New York and Pennsylvania, where drilling has generated over a quarter million jobs, 2 billion dollars in wages, and around $2 billion dollars in state and local taxes in Pennsylvania alone. Some are concerned that the boom and bust economies that rely on natural gas extraction will disappear someday and the large uncertainties shown in economic studies can lead to wide swings in public response for or against shale gas drilling

In the Delaware Basin, Marcellus shale gas drilling is at the center of a contentious energy-water policy debate that pits gas companies, land owners, and rural towns interested in jobs versus environmental groups, water utilities, and fishermen concerned about the impacts of hydraulic fracturing on the quality and quantity of water supplies. A coalition of drilling opponents drawn from environmental groups, movie stars, and New York City, which draws half of its drinking water from basin reservoirs, vie against proponents such as the natural gas companies and small towns in rural northeastern Pennsylvania and the southern tier of New York who push for economic and jobs benefits. In New York, 44% of residents support shale gas drilling while 43% oppose hydraulic fracturing along the Delaware River in Delaware County and Sullivan County.

Federal, state, regional, and local agencies are reviewing policies and standards to oversee Marcellus shale gas drilling. The Environmental Protection Agency and Department of Energy oversee natural gas drilling, however, federal laws such as the Clean Water Act and Safe Drinking Water Act exempt portions of the hydraulic fracturing process from regulation. A

drilling moratorium remains in the Delaware Basin after a postponed November 2011 vote of the DRBC Commissioners representing the U.S. Army Corps of Engineers and governors of Delaware, New Jersey, New York, and Pennsylvania to consider draft Marcellus shale drilling regulations. Proposed DRBC regulations would set buffers to exclude natural gas drilling from high value waters such as New York City Catskill reservoir watersheds, Delaware Water Gap National Recreation Area, Upper Delaware National Wild and Scenic River, and streams and wetlands (300 ft buffer). The governor of New York continues a ban on horizontal natural gas drilling pending approval of an EIS that received 21,000 comments and until the State Health Department completes hearings on the public health impacts. In 2012, the governor of Pennsylvania signed Act 13 that established a 5% drilling fee and set horizontal drilling buffers around wells, water intakes, water supplies, and streams.

Buffers set by proposed DRBC and NYSDEC rules, recently enacted Pennsylvania Act 13, and drilling bans in four New York towns would exclude 2,363 mi^2 (or 48%) of the 4,940 mi^2 Marcellus shale region in the Delaware Basin from natural gas drilling leaving 2,577 mi^2 (52% of the area) available for extraction including 1,873 mi^2 (72% remaining) in Pennsylvania and 705 mi^2 (30% remaining) in New York. With buffers in place to shield sensitive water resources from hydraulic fracturing, the estimated economic value of 4.0 tcf of potentially recoverable Marcellus shale gas in the basin at the 2012 wellhead price is $425 million per year, or three times less than the value at the 2008 price ($1.3 billion per year).

In the Delaware Basin, the annual economic value of natural resources ranges from $425 million for potentially recoverable Marcellus shale gas to $942 million for river recreation, $2.8 billion for drinking water, and $4.2 billion for forest ecosystems (Table 26). The Delaware Basin downstream from the shale region provides up to 1.6 bgd of treated drinking water with an annual market value of $2.8 billion to cities such as New York City, Philadelphia, Allentown, Easton, Trenton, and Wilmington. Over 2/3 of Marcellus shale watersheds in the Delaware Basin are covered by vast forests that provide annual ecosystem services worth $4.2 billion—$3.1 billion in New York and $1.1 billion in Pennsylvania. Up to 10% of the forests may ultimately be disturbed by shale gas drilling with a $366 million loss in ecosystem services. In the Marcellus shale region in the Delaware Basin, the annual value of river-based recreation for tourism, boating, fishing, hunting, wildlife viewing, swimming, and skiing is $942 million. The combined annual value of drinking water, forests, and recreation that depend on renewable resources in the Delaware Basin is higher than the value of potentially recoverable Marcellus shale gas, a nonrenewable resource (Figure 10).

The Marcellus shale energy-water policy debate should be considered in the context that natural gas, water, forests, and river-recreation are significantly valuable Delaware Basin resources. While Marcellus shale gas is a voluminous, inexpensive, and relatively clean-burning domestic energy source, its extraction relies on the safe use of water for hydraulic fracturing. If managed carefully, renewable water resources in the Delaware Basin can be tapped in perpetuity. If natural gas is to be a key part of the nation's energy economy, then critical safeguards for Marcellus shale gas drilling standards should be adopted to protect the invaluable water resources of the Delaware Basin (and other watersheds like it) that support multibillion dollar drinking water, forest, and river recreation economies.

TABLE 26. Economic value of resources in the Marcellus shale region of the Delaware Basin.

Economic Value	2010 ($ million)	Sources
Marcellus Shale Gas[1] (4.0 tcf @ $2.68/1000 cf)	425	Coleman et al. 2011 (USGS), EIA 2012
Drinking Water (1,605 mgd @ $4.78/1000 gal)	2,800	DRBC 2010, NJWSA 2011, Corrozi & Seymour 2008
Forests (2,057,492 ac @ $2,036/ac)	4,189	NJDEP 2007
River Recreation	942	
Instream Use (7.9 million ac-ft @ $10/ac-ft)	79	Frederick et al. 1996 (Resources for the Future)
Boating, Fishing, Swimming (WTP = $139/person)	80	Parsons, Helm, and Bondelid 2003 (Univ. of Del.)
Paddling-based Recreation (147,664 participants)	86	Outdoor Industry Association 2006
Delaware Water Gap Recreation (267,000 visits)	41	Cordell et al. 1990 (USFS and National Park Service)
Canoe/Kayak/Rafting (204,000 trips, $50/trip)	10	Canoe and Kayak Liveries 2012
Fishing (11-18 trips/angler, $53/trip)	107	U. S. Fish and Wildlife Service 2008
Hunting (16 trips/hunter, $50/trip)	114	U. S. Fish and Wildlife Service 2008
Wildlife/Bird-watching (8-13 trips/yr, $27/trip)	142	U. S. Fish and Wildlife Service 2008
Shad Fishing (63,000 angler trips, $102/trip)	6	Pennsylvania Fish and Boat Commission. 2011
Wild Trout Fishing	29	Maharaj, McGurrin, Carpenter 1998 (Trout Unlimited)
Del. Water Gap Natl. Rec. Area (5.6 million visits)	160	Stynes 2011 (MSU for National Park Service)
Skiing (9 resorts, 1.9 million ski visits, $45/day)	88	Pennsylvania Ski Areas Association 2009

1. Potentially recoverable shale gas at 2012 wellhead price assuming 25 year extraction period.

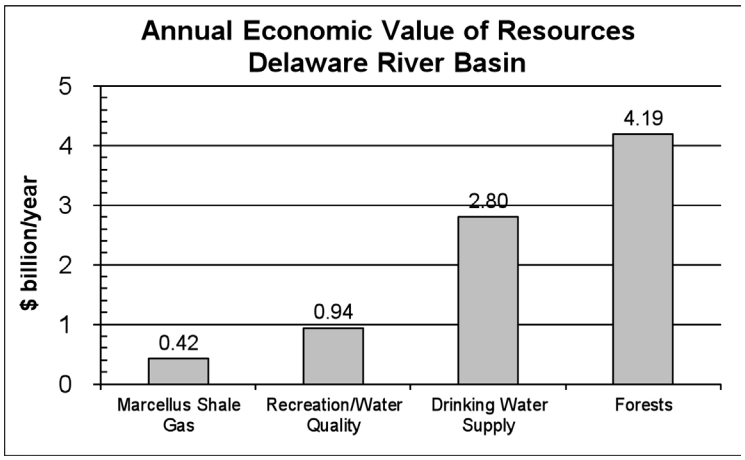


FIGURE 10. Annual economic value of nonrenewable/ renewable resources in the Delaware Basin.

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