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An Emerging Giant: Prospects and Economic Impacts of Developing the Marcellus Shale Natural Gas Play

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Executive Summary

Many Pennsylvanians are aware of the recent surge in natural gas leasing activity. The vast majority of citizens, however, do not fully appreciate the scale of change such development will unleash. This report educates the public on the current size, economic impacts, and future prospects of the Marcellus shale gas industry in Pennsylvania.

The Marcellus shale is the largest unconventional natural gas reserve in the world. While reserve estimates should be considered somewhat uncertain at this early stage, as each new Marcellus well is completed, estimates of recoverable reserves of at least 489 trillion cubic feet seem increasingly reasonable. The market and strategic value of the Marcellus Shale will no doubt grow as conventional natural gas reserves are depleted and our economy adjusts to a path with lower greenhouse gas emissions. Natural gas has considerably lower carbon content than petroleum and coal. The market share of natural gas in electric power generation continues to expand and opportunities for switching from petroleum to natural gas beckon in the transportation sector.

This study finds that the Marcellus gas industry in Pennsylvania generated $2.3 billion in total value added, more than 29,000 jobs, and $240 million in state and local taxes during 2008. With a substantially higher pace of development during 2009, economic output will top $3.8 billion, state and local tax revenues will be more than $400 million, and total job creation will exceed 48,000.

Advances in drilling technology and highly productive wells make the Marcellus play very attractive. This study finds that activity in the Marcellus will continue to expand. Natural gas production from the Pennsylvania Marcellus could rise to almost 4 billion cubic feet BCF per day by 2020. The direct spending by Marcellus producers to support drilling operations and the royalty and other payments to land owners will stimulate business activity throughout the economy and induce households and businesses to spend earnings on additional goods and services. This study finds that the Marcellus industry could be generating $13.5 billion in value added and almost 175,000 jobs in 2020. The present value of additional state and local taxes earned from Marcellus development between now and 2020 is almost $12 billion.

Governor Rendell recently proposed a severance tax on natural gas production. This study finds that this tax cannot be passed on to consumers and, therefore, drilling activity would decline by more than 30 percent and result in an estimated $880 million net loss in the present value of tax revenue between now and 2020. Severance tax revenue gains are more than offset by declining state and local income taxes resulting from lower drilling activity under the severance tax. The high level of drilling activity in Pennsylvania is a function of relatively lower taxes. This competitive advantage should be maintained as the Marcellus competes for capital and labor with other shale plays around the nation. Imposing a severance tax at this early stage of development could significantly inhibit the growth of the Marcellus gas industry in Pennsylvania. Proposals to regulate hydraulic fracturing under the federal Safe Drinking Water Act pose yet another serious threat to the development of the Marcellus Shale and other unconventional gas sources.

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I. Introduction

Before modern science, natural gas posed somewhat of a mystery to man. Lightning strikes would occasionally ignite natural gas seeping from the earth, creating flames, which fostered superstition. On Mount Parnassus around 1000-BC such a flame inspired the Greeks to build a temple that became home to a priestess known as the Oracle of Delphi who believed her prophesies were inspired by the flame. Around the same time, the Chinese devised a more practical application, moving natural gas in bamboo pipelines and burning it as a fuel. Ironically, China is the world's largest coal user today in part because of its limited supplies of natural gas.

In 1821, William A. Hart drilled a 27-foot deep well in Fredonia, New York, which is the first recorded instance of a well intentionally drilled to obtain natural gas. The resulting limited supplies of natural gas were used primarily for street lighting. In 1885, Robert Bunsen invented a burner that mixed air with natural gas. This "Bunsen Burner" demonstrated that natural gas could provide heat for cooking food and heating buildings. By the 1890's, cities began converting street lamps to electricity, which induced natural gas producers to develop these new markets.

After the discovery of oil in Titusville, Pennsylvania in 1859, large quantities of natural gas were produced in association with oil production. The iron and steel mills in Pittsburgh mixed this natural gas with gas produced from their coke-ovens. Other businesses and households also began to use this so-called "town" gas. The discovery of massive natural gas fields in the southwestern United States compelled entrepreneurs to develop pipeline technology to transport this gas to the large population and industrial centers in the Mid-West and Northeast.

Advances in oxy-acetylene and later electric arc welding technology allowed the joining of thin-walled, high strength, and large diameter steel pipe for long-distance gas transmission. With advances in ditching technology and gas compressors, the long distance gas transmission industry was born during the 1920s. Further technological improvements spurred the growth of this industry during the 1950s and 1960s. Today, the U.S. pipeline network, laid end-to-end, would stretch to the moon and back *twice*. This extensive network and "smoke-control-ordinances," such as those in Pittsburgh during the 1940s, enabled natural gas to displace coal once used in thousands of household, commercial, and industrial applications.

There was, however, recognition that optimization of pipeline operations would require gas storage so that pipelines could be operated under the same-conditions year round. Natural gas not consumed during the summer-season could be stored in underground reservoirs and withdrawn during the winter to meet cold weather demand. The United Natural Gas Company (National Fuel Gas Supply Corporation) developed the first natural gas storage facility near Warren, Pennsylvania using a depleted natural gas reservoir. As markets grew so did the demand for storage. Pennsylvania became a key provider of these storage services given its many reservoirs and its close proximity to major consuming areas.

During the 1970s the demand for natural gas collapsed with the closure of many integrated steel mills. Eventually, with society's growing demands for cleaner air and electricity, these lost markets were replaced with a growing use of natural gas in electric power generation. As these demands grew, the price of gas began to rise and gas producers began looking at new or unconventional supply sources. These unconventional supplies include methane from coal beds, tight-gas reservoirs, reservoirs under deep-water in the Gulf of Mexico, and more recently organic shale formations.

Deep beneath the rolling hills and mountains of Pennsylvania lies a layer of shale rock known as the Marcellus Shale. This geological formation was known for decades to contain significant amounts of natural gas but was never considered worthwhile to produce. Uneconomic resources, however, are often transformed into marketable assets by technological progress. This time-honored principle is once again at work as innovations in natural gas drilling have greatly enhanced the productivity and profitability of producing natural gas from shale deposits.

Many Pennsylvanians, especially those in the rural western and northern counties of the Commonwealth, are aware of the recent surge in leasing activity. The vast majority of citizens and even those directly affected by gas leasing and production do not fully appreciate the scale of change such development could unleash. The objective of this report is to educate the public on the current size, economic impacts, and future prospects of the Marcellus shale gas industry in Pennsylvania. The over-arching conclusion of this study is that developing the Marcellus to its full potential could significantly transform the Pennsylvania economy.

The Marcellus shale is the largest known shale deposit in the world and lies under much of the Appalachian basin from upstate New York, as far south as Virginia, and as far west as Ohio. While estimates of natural gas reserves should be considered imprecise at this early stage, Engelder (2009) finds that recent production data suggest recoverable reserves could be as large as 489 trillion cubic feet.

The discovery of the Marcellus Shale comes at a critical juncture for the economic and strategic position of the United States. Natural gas is widely viewed as a bridge between the age of oil and the next energy paradigm, perhaps based upon some combination of nuclear, solar, wind, and biomass resources. Just 10 years ago, many believed that imported liquefied natural gas (LNG) would be a pillar in this bridge. By developing domestic natural gas resources here in the United States, greater energy import dependency and higher trade deficits could be avoided. Liquid fuel imports also could be displaced if these new natural gas resources could be utilized in transportation.

Natural gas also will play a pivotal role in the transformation of our economy to achieve lower levels of greenhouse gas (GHG) emissions. Compared with coal and oil, natural gas has roughly 60 and 30 percent lower carbon emissions respectively. While a federal system for pricing GHG emissions does not yet exist, many states have enacted carbon permit trading and renewable energy portfolio standards. Given the intermittent nature of wind and solar energy electricity generation, spinning reserves would be required to balance system load and natural gas is often viewed as the most likely fuel to service these requirements. Moreover, natural gas could be co-fired in coal-fired power plants to reduce carbon dioxide emissions thereby enabling the continued use of coal for electricity generation.

The development of the Marcellus Shale will have significant economic impacts for the economy of Pennsylvania. Leasing, exploring, drilling, and developing these natural gas reserves will directly generate thousands of high-paying jobs and indirectly create many others as employment is stimulated in support industries and as workers spend these wages and households spend royalty income. The economic stimulus from natural gas development and production will increase gross state product, income, and tax receipts. Longer term, the analysis below suggests that the Commonwealth of Pennsylvania could become a significant net exporter of natural gas, which would provide additional economic stimulus by keeping money once spent on imported fuels within the state.

Natural gas development, however, is a very competitive business prone to sharp contractions in drilling activity from adverse swings in costs, prices and taxes. As a result, many states have adopted policies that promote development. As the Pennsylvania Marcellus shale industry develops, policy makers should keep in mind the trade-offs between any short-term gains from taxation or regulation with the long-term effects on industry development. A larger industry in the long run will be a far greater generator of government tax revenues than an industry stunted by high taxes or costly regulations.

The next section of this report provides a brief introduction to the Marcellus natural gas play, discussing the history of the play, experience from other shale gas plays, and a geographical overview of the extent of the formation. Section three of the report discusses the strategic significance of the Marcellus shale play, its potential contribution to east coast energy markets, and the potential market for Marcellus gas. The fourth section of this report then provides a primer on the natural gas development process, hopefully dispelling some of the myths and misconceptions of the environmental impacts of natural gas development. How gas development affects local economies is the focus of section five with an overview of the supply chain for natural gas development and how the functioning of these industries affects local economies.

The following sections estimate the economic impacts of the industry during 2008 and for the next decade. The emergence of the Marcellus gas industry in Pennsylvania is discussed in section six along with summary statistics on leasing, drilling, and development activity. The estimated economic impacts of the current Marcellus industry are presented in section seven. Based upon this assessment, projections of the future level of development and related economic impacts are presented in section eight. Possible impacts of taxation and regulatory policies are also evaluated. The report concludes with a summary of our major findings, an analysis of the net revenue impacts of a proposed severance tax, and a discussion of policies that affect the long-term health and vitality of the industry.

II. The Marcellus Shale Play

The Marcellus Shale is the source rock for much of the natural gas and oil produced throughout the region. In many instances, puffs of natural gas emanating from the Marcellus were observed during the drilling of the wells into the deeper Oriskany sandstones. While small-scale production of gas from shale in Pennsylvania is not new production from shale at levels that rival production from conventional sources is a recent phenomenon.

As recently as 2002 the United States Geological Survey in its "*Assessment of Undiscovered Oil and Gas Resources of the Appalachian Basin Province,*" calculated that the Marcellus Shale contained an estimated undiscovered resource of about 1.9 trillion cubic feet (TCF) of gas. Just five years later, Engelder (2009) estimates 2,445 trillion cubic feet of reserves in place with recoverable reserves amounting to 489 trillion cubic feet. This remarkable, almost unbelievable, increase in estimated reserves is due to technological advancements in horizontal drilling technology and techniques, multi-dimensional seismology, and the implementation of hydrofracturing.

Horizontal and deviated wellbore drilling, originally developed for offshore locations, allow the development of multiple wells from a single platform. These extended-reach wells, commonly referred to as horizontal wells, allow access to hundreds of feet of shale from a common wellbore.

Modern seismology also known as "reflective seismology" sends sound energy waves into the Earth, where the different layers within the Earth's crust reflect back this energy, which are then recorded over a predetermined time period (called the record length). The reflected signals are stored on magnetic tape, analogous to recording voice data using a microphone onto a tape recorder for a set period of time. Once the data are recorded onto tape, it then can be processed using specialized software from which seismic profiles can be produced. These profiles or data sets then can be interpreted for possible hydrocarbon reserves. Contemporary seismology uses the computational power of the modern computers to construct 3-dimensional images of subsurface structures. This technology was first applied to field development in the Gulf of Mexico and subsequently was used in New York for the development of gas from the Trenton-Black River Formation. Natural gas producers use this technology throughout the Appalachian basin to delineate the Marcellus shale formation.

Hydraulic fracturing developed in the 1940s is another key technology and has been used in thousands of oil and gas wells worldwide. The objective of hydraulic fracturing is to increase the exposure a well-bore has to the surrounding formation and to provide a conductive/highly permeable channel through which fluid and gas can flow easily to the well. After drilling and casing the well, the casing is perforated and a mixture of fluids is pumped down the well under high pressure. The pressure then causes the formation to crack, which allows the fluid to enter and extend the fracture. To keep these fractures open, a solid proppant is added to the fracture fluid. The proppant, which is typically silica sand, is transported into the fracture. The hydraulic fracture then becomes a high permeability conduit through which the gas that was locked in place in the reservoir is now able to flow into the well and to the surface. The use of these technologies is key in the development of the Marcellus gas shale play.

Natural gas production from shale deposits began during the 1980s with the development of the Barnett Shale play in the Fort Worth, Texas region. During 2008 this field alone produced 3.8 BCF per day. Just five years prior in 2003, it produced 0.8 BCF per day. This success sparked the development of several other shale plays, including Antrim in Michigan, Fayetteville in Arkansas, Haynesville in Louisiana, New Albany in Indiana, and the Woodford in Oklahoma among others. There are also significant shale deposits in British Columbia.

The Marcellus in the Appalachian region, however, is by far and away the largest and potentially the biggest prize. Even though the shale deposit in the Marcellus formation is about half as thick as the Barnett, the areal extent of the Marcellus is significantly larger (see Figure 1). The isobars in the following diagram indicate the thickest gas bearing layers within the shale.

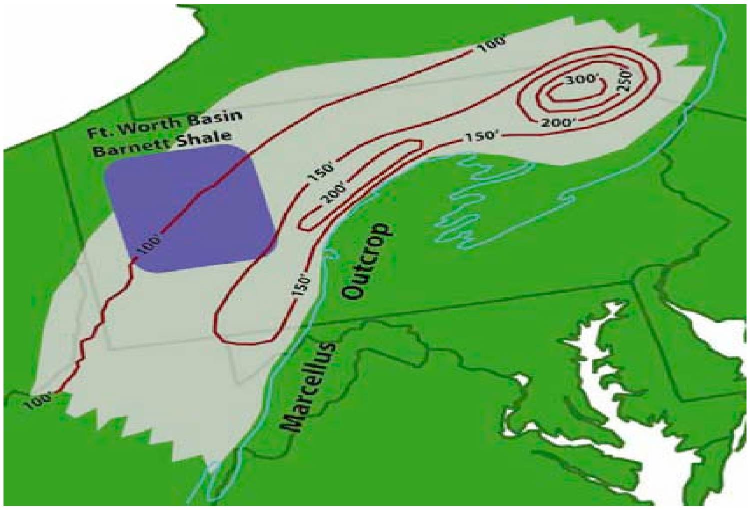

Figure 1: Extent of Marcellus Compared with Barnett Shale Formation

Based upon the extensive spending on lease and bonus payments since 2005, there is demonstrated commercial interest in the Marcellus Shale. The first Marcellus well went into production in 2005. Currently, the Marcellus industry appears to be in the transition from testing and evaluation to ramping up to large-scale commercial development.

The Marcellus Shale is a Middle Devonian-age black, low density, organically rich shale. Within Pennsylvania the average depth is about a mile with the southwestern and northeastern areas closer to the surface. Given these depths drilling costs are relatively high, so significant amounts of gas are required to financially break-even. Horizontal wells with hydraulic fracturing produce more gas than traditional vertical wells. Some horizontal wells employing "frac-jobs" have produced over 8 million cubic feet per day during early production.

After a few months to a year, production is considerably lower but can extend several decades. Producers drilled shallow shale-gas wells in upstate New York back in the 1920s that are still producing. Currently there is a mix of vertical and horizontal wells drilled in the Marcellus. There appears to be a growing consensus that the share of horizontal wells with frac-jobs will increase in the years ahead. If this does occur, water availability for fracing and most importantly disposal of the used water could be important factors affecting the growth of the Marcellus industry.

Another key factor affecting development is infrastructure. While most attention is drawn to the adventure of exploring and drilling for natural gas, the real yeoman's work occurs in the development of a network of thousands of miles of gathering lines and pipelines to carry this gas to consumers. Another important cog in this system is natural gas processing facilities. The Marcellus gas in southwestern Pennsylvania is "wet," with dissolved hydrocarbons such as propane, ethane, butane, and other heavier gases. These products must be removed so that "dry" gas or methane can be sold to gas transmission or distribution companies. While these by-products of dry gas production can be quite valuable, building a processing facility takes considerable time and incurs significant costs. Moreover, large volume production of these natural gas liquids, which appears likely, would require separate pipelines, rail facilities, or truck terminal facilities. Developing these transportation and processing networks takes time, in some cases, years.

While many citizens may view natural gas as yet another extractive industry that employs only roughnecks and drillers, the construction of supporting infrastructure is a very significant undertaking that requires thousands of suppliers of steel, machines, and equipment. These suppliers would have to ramp-up to meet this new demand by hiring thousands of workers, often in relatively high paying manufacturing and construction jobs. Pennsylvania experienced such an industrial boom during the last half of the 19^{th} century, leaving behind vast wealth that underpins great institutions, such as Carnegie Mellon University, which generate benefits for citizens today. Having a sizeable, home grown natural gas industry will once again allow Pennsylvania to revive its economy, create new jobs, and generate income and wealth for future generations. The Marcellus Shale also has significant strategic implications as the U.S. economy seeks domestic energy resources and attempts to reduce greenhouse gas emissions in the future.

III. Strategic Significance

Local, national, and global market forces will affect the development of the Marcellus Shale. The main factor affecting development is the market price for natural gas. Natural gas prices are very volatile and, as a result, most producers lock in a price using futures contracts. Historically, natural gas prices have always been below oil prices measured in heat equivalent units, known as British Thermal Units (BTUs). For example, from 1922 to 1992, the year when natural gas markets were largely deregulated, oil prices averaged three times the price of natural gas. In contrast, the ratio dropped to 1.5 from 1994 to 2008.

The relationship between natural gas and oil prices from 1994 to 2009 is displayed in Figure 2. During the 1990s real natural gas prices averaged about $3 per million BTUs (MMBTU). Since then average prices are more than $7 per MMBTU. Notice that both oil and natural gas prices trended upward until the summer of 2008. Since then oil prices are below $10 per MMBTU. Recently oil prices have been recovering during the spring of 2009. Real natural gas prices, however, have not yet recovered and are currently at levels last seen during 2002. One temporary factor is the sharp reduction in industrial gas consumption due to the recession. This pattern has been repeated in the past. Oil prices during 2006 and 2007 generally tracked upward and natural gas prices finally spiked during the summer of 2008 with the historic rise in oil prices. Nevertheless, apart from the oil price shock during the summer of 2008, natural gas prices have been drifting lower since 2005.

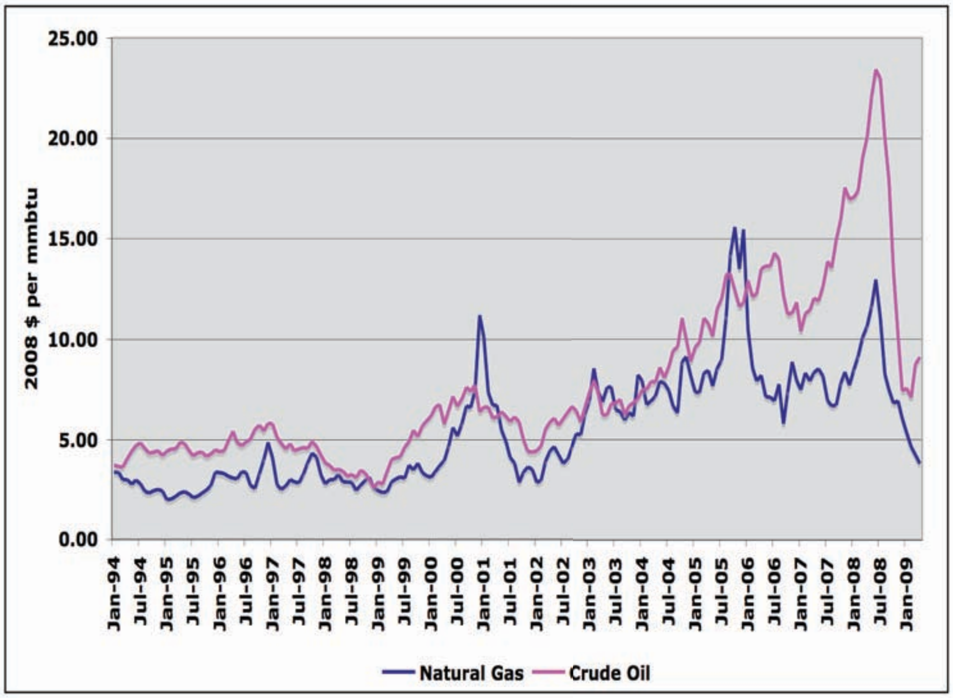

Figure 2: Natural Gas and Oil Prices in million BTUs, 1994-2009

Such a divergence between oil and natural gas prices has occurred in the past. Moreover, there are several factors contributing to a tenuous relationship. During the 1960s through 1980s natural gas competed with residual fuel in the boiler fuel and petrochemical markets. Residual fuel oil use in power generation is substantially lower today. Instead, natural gas competes with coal-fired electric power generation in many regions of the country. Since deregulation in the early 1990s, most new electric power generation capacity has been based upon natural gas. Lower capital costs and strategic environmental considerations have contributed to this increased reliance on natural gas in power generation. Indeed, most of the growth in natural gas consumption has come from the electric utility sector (see Figure 3). Another emerging competitor with natural gas is wind power. During 2008, wind captured 42 percent of new power generation capacity added in the U.S.

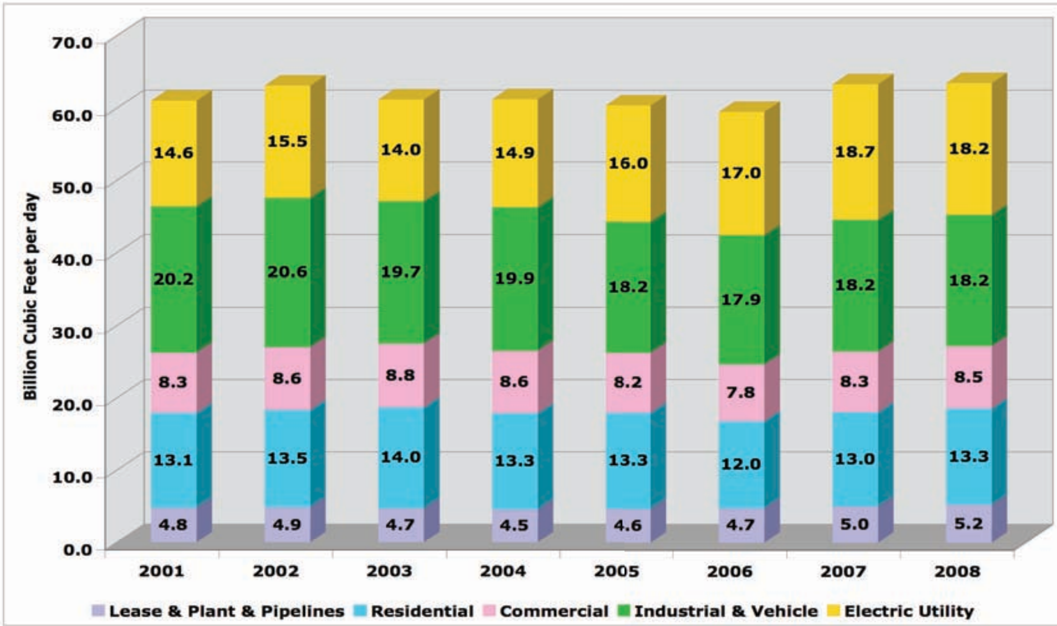

Figure 3: Composition of U.S. Natural Gas Consumption, 2001-2008

Another factor affecting market prices and the development of the Marcellus Shale is competition from other sources of natural gas. After reaching a peak in 1973 at 22.6 trillion cubic feet (TCF) U.S. natural gas production fell precipitously during the era of price controls in the 1970s, reaching a low of 16.8 TCF in 1983. Production then staged a steady recovery, reaching 20.6 TCF in 2001. Between then and 2005, however, U.S. natural gas production declined to 18.9 TCF. Expanding use of gas in power generation and declining production, contributed to rising prices during this period (see Figure 3). Since 2005 U.S. natural gas production has been on somewhat of a tear, rising to over 21.6 TCF in 2008, an increase of 8 percent from 2007.

Where is all this additional gas coming from? Wyoming and shale gas are the two primary sources of new supply. As Figure 4 below illustrates, Wyoming production increased almost 2 BCF per day between 2005 and 2008. Production from the Barnett Shale in Texas increased by 2.5 BCF per day over the same period. An additional BCF per day came from three other shale plays, including the Antrim in Michigan, Fayetteville in Arkansas, and Woodford in Oklahoma. Collectively these shale plays and Wyoming constituted almost 75 percent of the growth in U.S. domestic natural gas production from 2005 to 2008. This is an encouraging development for the future of natural gas in our nation's energy supply portfolio because it demonstrates the potential of unconventional sources of natural gas, such as tight sands and shale gas. These supplies will be critical as production from old, shallow conventional gas fields continue its inexorable decline.

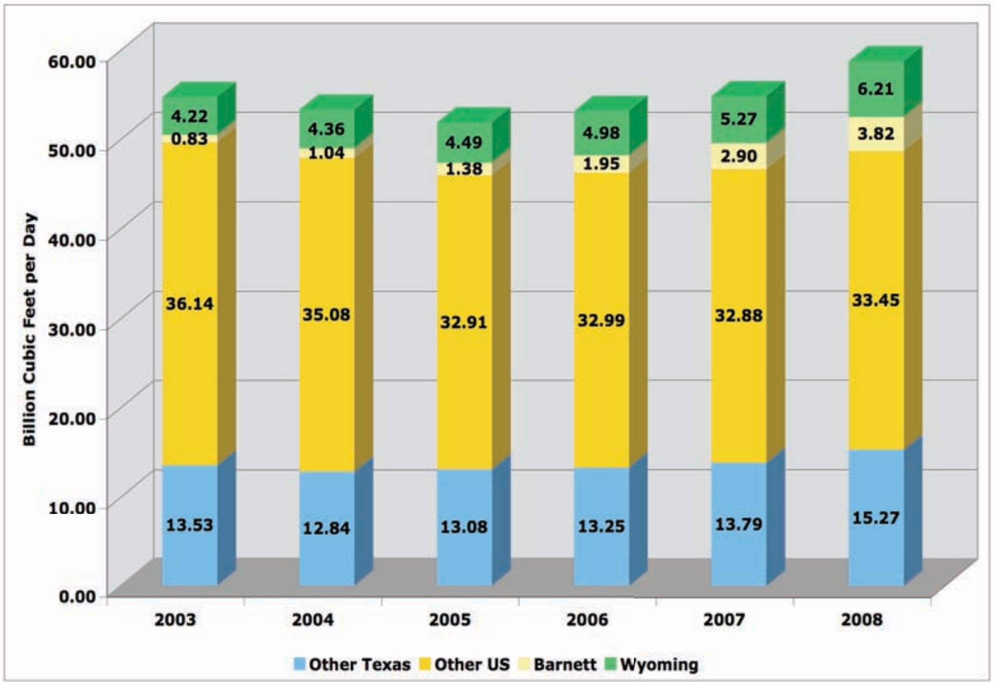

Figure 4: Regional U.S. Natural Gas Production, 2001-2008

Another implication of this supply picture is that several new sources of natural gas supply are emerging and likely will be in competition with the Marcellus play (see Figure 5). This suggests that small margins in relative costs may be important in determining the growth and vitality of these various sources of supply.

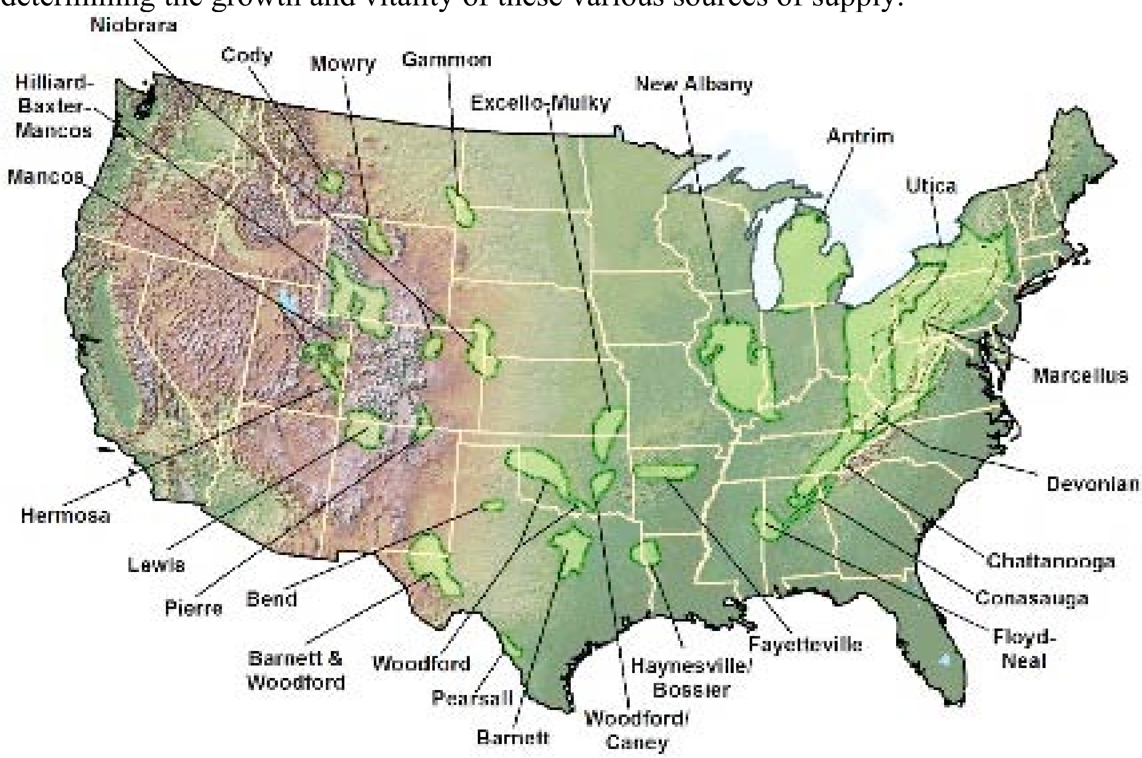

Figure 5: Domestic Competition with the Marcellus

Despite this supply-side competition, the Marcellus has some important advantages. The first competitive advantage is its proximity to a large regional natural gas market. Including Pennsylvania and its five bordering states, current natural gas consumption is 9.2 BCF per day (See Figure 6). There is also a considerable amount of coal-fired electric power generation in this region. In the unlikely event that all of this capacity was converted to natural gas, an additional 9 BCF per day of natural gas would be required. So within a 200-mile radius of the Marcellus, there is an existing and potential market of over 18 BCF per day. As we shall see below, Marcellus will likely become a significant supply source in future years, allowing plenty of room for market expansion.

Another important potential market for Marcellus gas is the transportation sector. Currently, there are about 130,000 vehicles running on primarily compressed natural gas, consuming only 2.7 BCF, which is slightly more than one-tenth of one percent of total natural gas delivered to consumers in the U.S. The most likely market niche for natural gas to make significant inroads is fleet vehicles, including buses, delivery trucks, taxis, and government vehicles. Given the delivery networks required to support these fleets with natural gas, high-density urban areas are the most likely candidates for market penetration. Here again is where the Marcellus has a unique advantage given its proximity to the Northeast corridor from Boston to Washington, D.C. with a population of over 55 million people. As these regions enforce regional or potentially federal greenhouse gas (GHG) emission controls policies, substituting natural gas for diesel or gasoline in these fleet vehicles may be a cost-effective solution to meet these tougher emission standards.

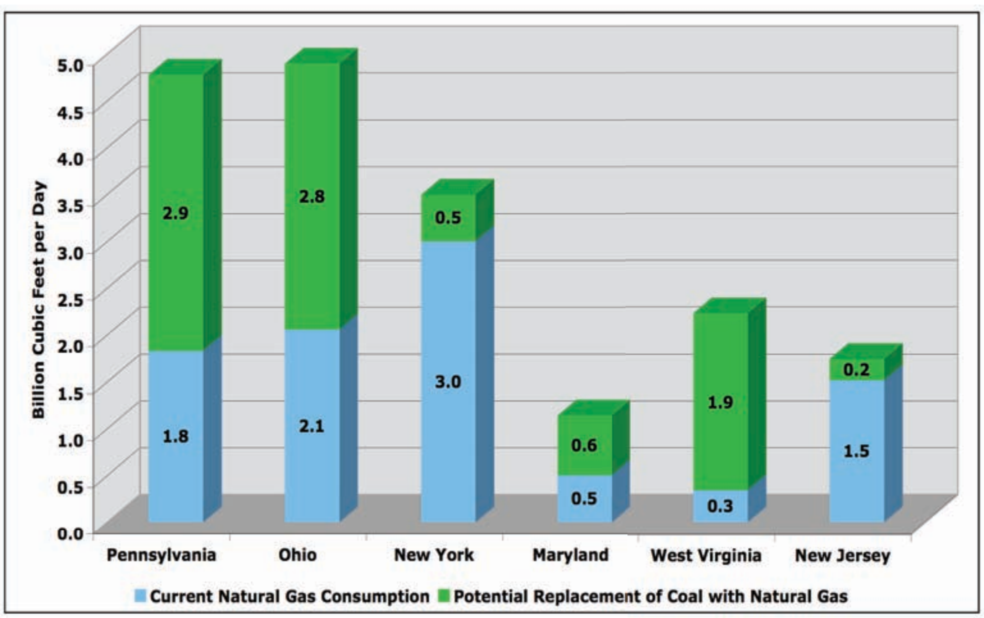

Figure 6: Current and Potential Markets for Marcellus Gas

This close access to a large market for natural gas translates into higher prices at the city gate. On average from 2003 to 2008, Pennsylvania city gate prices are almost 15 percent higher than the national average (See Figure 7).

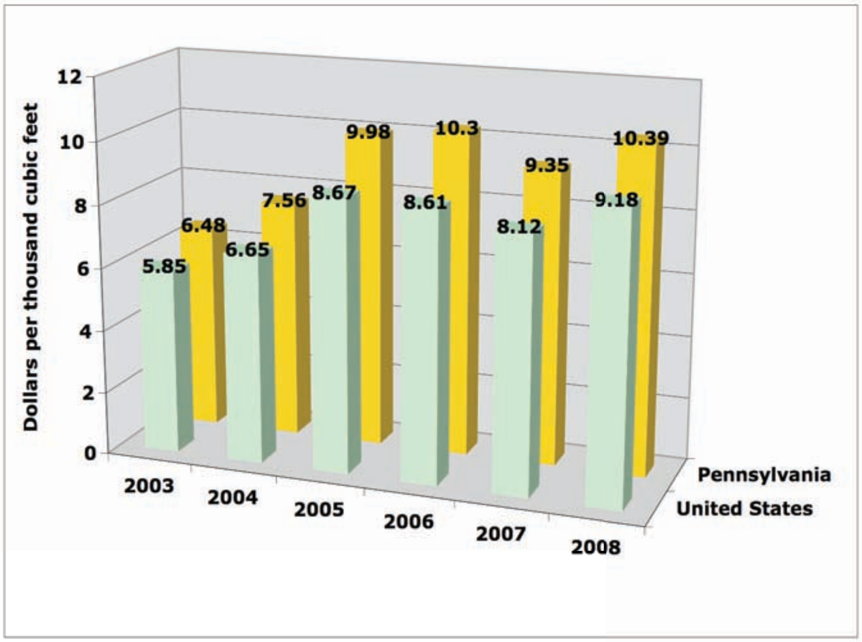

Figure 7: Comparison of City Gate Gas Prices, U.S. versus Pennsylvania

IV. Marcellus Shale Development

Developing natural gas from the Marcellus formation involves a sequence of activities from leasing land, exploring for suitable well sites, and drilling and completing wells, to constructing gathering pipelines and processing facilities. The time to complete each step differs. Leasing specific parcels can take several weeks and leasing operations occur continuously. Exploration also occurs regularly often during the warm summer months. Drilling can vary with market conditions and a typical drilling rig crew may take anywhere from 6 to 10 weeks to complete their work and to move on to the next drill site. Construction of gathering systems and processing facilities can take up to two years, depending upon a multitude of logistic, economic, and engineering considerations. This section describes these activities, illustrating how people with a wide variety of skills and expertise employ machines, supplies, and services from local economies to extract natural gas and deliver it to consumers.

Leasing

Once a natural gas production company decides to get involved in a particular gas field, access is established by leasing land from a landowner. In the Commonwealth of Pennsylvania, owning surface land does not automatically mean that you own the rights to the minerals below the surface. If one party owns the mineral rights below ground, but another owns the surface rights, by law, the surface landowner cannot prevent the other party from developing the subsurface property. As a result, natural gas companies must negotiate a combination of subsurface leases and surface right-of-ways in order to drill a well. Leases typically include an upfront bonus for leasing the property, and a share, or royalty of the gas that a well will produce. While the bonus may at times seem like a large sum of money, royalty payments have the potential to be the major income from leased land. Often times a well will produce millions of units of gas per day, and produce gas over a span of fifty years, so royalties can reach significant levels over time.

Exploration

Conventional oil and natural gas is produced from sandstone and limestone formations that have relatively high permeability, which is the rate at which fluids can move through rock. Sandstone is comprised of individual grains of sand cemented together. Voids are present between the grains and are interconnected throughout the formation, which allow fluids to pass with relative ease. Limestone possesses few voids between sediment grains but are often highly fractured contributing to high permeability. The Marcellus shale and all other shale formations have very low permeability compared with most conventional gas-producing rocks. Hence, they are considered unconventional sources for gas.

The Marcellus shale has been known for many years, and maps have been created that detail the location and thickness of the shale. All parts of the shale are not equal in terms of natural gas potential, so a company must do careful research before they spend millions of dollars on one well that may, or may not be a productive well. The Marcellus shale is a highly cracked, or fractured rock, and the interaction of a well and these fractures are paramount to the productivity of the well. Prior to developing a lease, companies perform a seismic survey to find areas with higher densities of these fractures.

During a seismic survey, specially equipped trucks vibrate the ground, generating sound waves that travel through the ground. Figure 8 shows a seismic vibrator truck used to generate the sound waves. Different rock types and features below the surface reflect these sound waves differently, and the reflected waves are detected at the surface by geophones and then processed by a computer to create a map of the subsurface. These maps are used to define areas where producers are most likely to drill a productive well.

Figure 8: Seismic Vibrator Truck

Drilling and Well Completion

The first step to drilling a well is to prepare a well pad for a drilling rig. Land is cleared, an area for the well is leveled off, and gravel roads are constructed. Landowners are compensated for any timber or farmland that is disrupted in the preparation process. After a well is completed, all surrounding land is returned back to its original state. Figure 9 shows a well site during drilling.

Figure 9: Well Site during Drilling

To drill the well, a large drilling rig rotates a steel pipe with a drill bit on the end, or in the case of a horizontal well, fluid is displaced through the stationary drill pipe through a drilling motor, which then causes the bit to rotate. In either case, as rock is crushed, a new length of pipe is connected to the one already in use and is pushed deeper into the hole. Currently, both vertical and horizontal wells are being drilled in the Marcellus shale. Vertical wells are drilled to a pre-determined depth. Horizontal wells also are drilled to a pre-determined vertical depth but then turned at an angle and drilled sideways for several thousand feet. While horizontal wells connect to more of the gas-bearing rock and are more productive wells, they cost 3-4 times the amount of money a vertical well costs. In both cases, a heavy-duty rig is required to support the weight of the steel pipe required in drilling a well that will be a mile or deeper in length. Figure 10 shows a typical drilling rig used for Marcellus shale wells.

Figure 10: Drilling Rig

Several measures are taken to ensure that the environment is protected during drilling. A well will penetrate the water table and continue downward for several thousand feet. As the well is drilled, steel pipe called casing is cemented in place to isolate the well from the surrounding area. In doing so, ground water supplies are protected and any contamination of sub-surface drinking water supplies is avoided. In addition to ground water, well drillers also make sure any fluids or chemicals used or produced during the drilling process do not contaminate lakes or streams on the surface. Every fluid on a well site is contained in a plastic lined pit or steel tanks so it can be recycled or properly disposed at sites with permits from the Department of Environmental Protection (DEP).

After the well is drilled to its final depth, another steel pipe is installed inside of larger ones above it and cemented in place. The drilling rig then leaves the site and a wellhead is installed on the surface (see Figure 11). This is a collection of valves that control the flow of the gas and allows it to be turned off completely if needed. It also allows equipment to enter the well safely to perform maintenance. Shaped-explosive charges are next used to perforate the bottom section of the steel pipe. This allows fluid to be pumped in and then gas to flow out of the pipe casing and to the wellhead at the surface.

Figure 11: Completed Wellhead Site

Once a well is drilled, the next step is to stimulate the well to produce more gas, which is accomplished with hydrofracturing (see Figure 12). The purpose of fracing a shale well is to try to intersect and connect as many of the natural fractures to the well as possible. Well designers exercise extreme care in well design to isolate any fluids used in the hydrofracturing process from any potable-sub-surface drinking water. Of the total volume of water used in the hydrofracturing process, approximately 1/3 of this water that is pumped down a well for fracing eventually comes back to the surface through the well. This water is collected in a plastic lined pit or large water tanks, and then is recycled or treated for disposal at a designated facility. No untreated water used in hydraulic fracturing is ever disposed to a stream or river. All water that is used in the stimulation process and collected at the surface is disposed of in DEP-regulated/permitted disposal sites that are located in the Commonwealth.

Figure 12: Well Site during Hydrofracturing

After the well is stimulated, water-holding tanks are installed onsite, the well is connected to a pipeline and the well site is then restored to its original condition. Figure 13 shows a finished well site with the well in the foreground to the right and a tank battery surrounded by a dike to protect against any spills should the tanks leak.

Figure 13: Completed Wellsite

Transporting, Processing and Sales

After the well is in production, the gas enters a pipeline and eventually arrives at its final destination for consumption. Sometimes the process is this simple but more often than not the gas must go through several additional steps before it can be sold. Gas that comes out of the well contains water vapor and other gases. Water vapor will condense to a liquid, reduce the operating efficiency of the pipeline, and reduce the marketability of the produced natural gas. The other gases will turn into petroleum liquids that will reduce the capacity of the pipeline so it carries less gas. For these reasons, wellhead gases are often processed onsite to remove water vapor or depending on the composition of the gas, is transported to a large facility that heats and cools the gas until nothing remains within the gas; but mostly methane (see Figure 14). The natural gas is then sold to a pipeline company, who in turn sells the gas to the consumer. Any liquid hydrocarbons that are separated are sold as feedstock to petrochemical plants and refineries, and in the case of the propane, marketed for domestic purposes such as space heating and cooking.

Figure 14: Natural Gas Processing Facility

V. Impacts on Local Economies

While the drilling rig may be the most widely associated symbol of natural gas development, there are many activities before and after drilling that generate significant economic impacts. Many people are required to identify lease properties, write leases, and conduct related legal and regulatory work. Seismic surveys also require manpower, local business services, and other provisions. Once a prospective site is identified, drilling begins and with it the need for services, labor, and other locally supplied activities. If natural gas is found in commercial quantities, infrastructure, such as well production equipment and pipelines are installed, which again stimulates local business activity. Finally, as production flows from the well, royalties are paid to landowners and taxes paid to local governments. These expenditures stimulate the local economy and provide additional resources for community services, such as health care, education, and charities (see Figure 15).

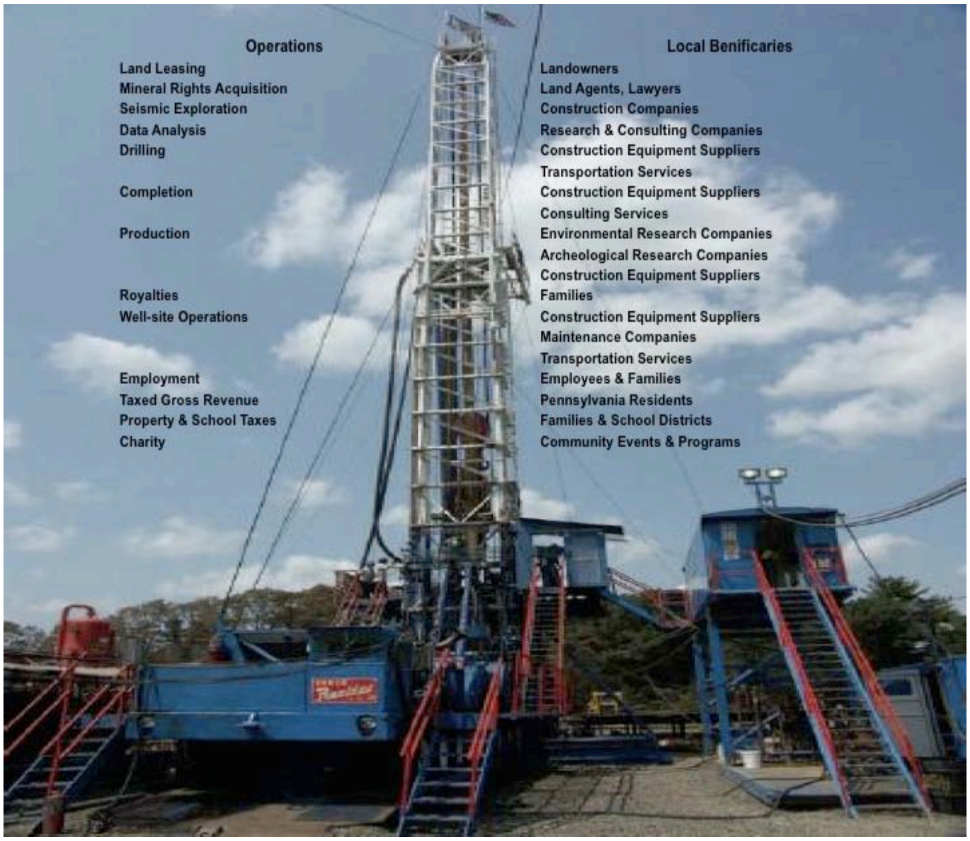

Figure 15: Natural Gas Development Activities and Local Beneficiaries

Expenditures at all stages of production generate indirect economic impacts as the initial stimulus from expenditures on natural gas development is spent and re-spent in other business sectors of the economy. For example, in developing mineral leases natural gas drilling companies employ the services of land management companies that in turn purchase goods and services from other businesses. These impacts are known as *indirect economic impacts*. The wages earned by these employees increase household incomes, which then stimulates spending on local goods and services. These impacts associated with household spending are called *induced impacts*. The total economic impacts are the sum of the direct, indirect, and induced spending, set off from the expenditures by Marcellus producers. These economic impacts are estimated by comparing gross output, value added, tax revenues, and employment in the local economy with and without Marcellus development.

Regional economic impact analysis using input-output (IO) tables and related IO models provide a convenient framework for measuring these economic impacts. Input-output analysis provides a quantitative model of the inter-industry transactions between various sectors of the economy and, in so doing, provides a means for estimating how spending in one sector affects other sectors of the economy and household disposable income. IO tables are available from Minnesota IMPLAN Group, Inc. based upon data from the Bureau of Economic Analysis in the US Department of Commerce.[1] This

[1] http://www.implan.com/index.html

project uses these tables to estimate the economic impacts from the Marcellus industry outlays for natural gas exploration, development, and production. This study also identifies the specific economic sectors affected by the stimulus generated from natural gas development.

VI. Emergence of the Pennsylvania Marcellus Gas Industry

The Marcellus gas industry appears to have entered the ramping-up phase of development. After relatively low levels of activity during 2006 and 2007 well completions jumped to a considerably higher level during 2008 with 308 wells drilled based upon statistics collected by the Department of Environmental Protection (DEP) (see Figure 16).

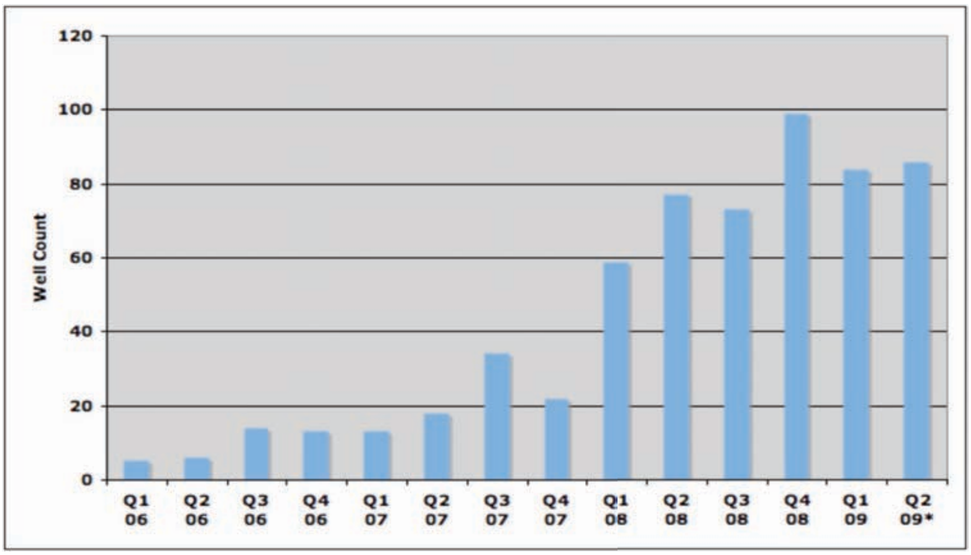

Figure 16: Marcellus Wells Drilled by Quarter, 2006-2009

During the first five months of 2009, drilling appears to be running about 22 percent above the same period in 2008. In contrast, gas drilling during the first quarter of 2009 for the entire U.S. is *down* 21 percent from year ago levels and 41 percent *below* the recent peak reached during the third quarter of 2008. So clearly Marcellus drilling activity is defying national trends. This dichotomy is often typical of natural gas plays in the early phases of development but more fundamentally reflects the high productivity and profitability of Marcellus wells.

Most of the Marcellus wells are in southwestern and northeastern Pennsylvania (see Figure 17). Forty-five firms have drilled at least one well in the Marcellus but the top ten have completed more than 78 percent of all wells. During 2007, 24 percent of all Marcellus wells were horizontal. The share of horizontal wells rose to 36 percent during 2008 and so far this year, 39 percent of all Marcellus wells are horizontal. This trend is expected to continue and will no doubt create additional demands for water and water disposal services.

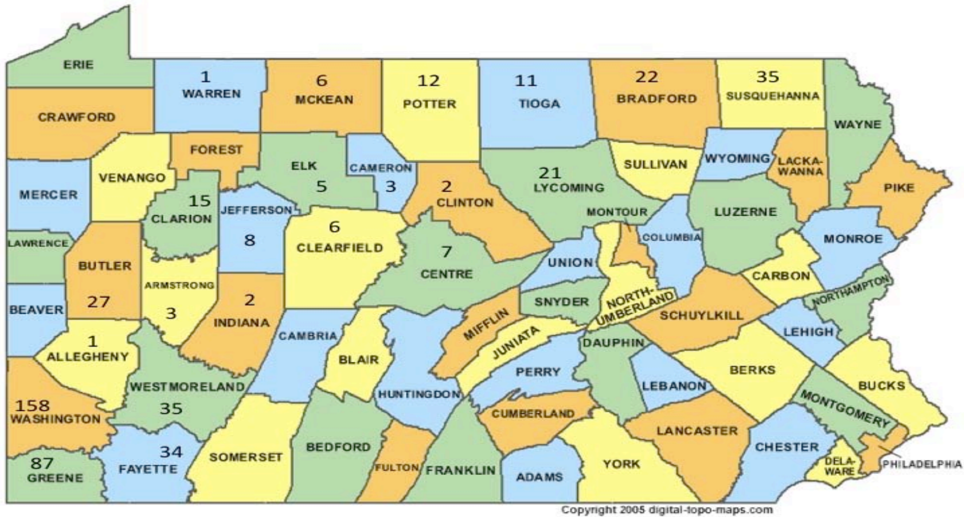

Figure 17: Marcellus Wells by County in Pennsylvania as of March 2009

To measure the level and composition of spending in the Marcellus gas industry, we conducted a survey. The seven firms that submitted data drilled 214 Marcellus wells during 2008.[2] Data from the DEP, however, indicate these same firms drilled 181 wells. After discussions with the survey participants and analysis of some of the differences between our survey and the DEP data, this study concludes that there is a reasonably good likelihood that current DEP data under-report Marcellus industry drilling activity. This finding is understandable given the dynamic growth in this industry with a rising number of new entrants. Consequently, the following analysis adjusts drilling activity upward by 18.2 percent, which is the difference between our sample of drilling activity and the well count reported by DEP for the firms responding to our survey. This approach yields an estimated 364 Marcellus industry wells drilled during 2008.

VII. Economic Impacts

The level of drilling activity will stimulate the Pennsylvania economy, creating additional income earned from workers in the Marcellus industry and those supporting it and generating yet more income from royalties and taxes. As discussed above, the economic impacts from this spending can be estimated using the IMPLAN input-output table for the economy of the Commonwealth of Pennsylvania. The Marcellus gas industry, however, is less than five years old, and is not included in the last update of the IO accounts for Pennsylvania. Accordingly, this study uses a technique proposed by Miller and Blair (2009) for introducing new industries into an input-output model of a regional economy.

This approach requires the direct estimation of purchases by the new industry from other businesses in the region. Our survey asked firms to report the location, dollar amount, and a description of purchases from all suppliers. The survey also requested data on payrolls and payments to land owners including lease and bonus payments and

[2] According to the Marcellus Shale Committee (2009), 36 firms are drilling in the Pennsylvania Marcellus.

royalties as well as taxes paid to governments. The locations of all these suppliers and income recipients were determined using the company profile databases Reference U.S.A. and Manta, which also provided the economic sector for each purchase.

Economic impact analysis requires that the spending introduced into the model be specified by economic sector to efficiently determine the direct, indirect, and induced impacts on all economic sectors in the region. For this reason, this study uses the North American Industry Classification System (NAICS), formerly known as the United States Standard Industrial Classification system. The NAICS numbering system is a six-digit code that classifies economic activities. Those codes were then bridged to the IMPLAN data sector scheme to run the impact analysis.

The data are classified into four categories: vendor purchases, state/local non-education spending, land-owner payments (i.e. royalties, lease bonuses, etc.), and payroll. The actual monetary amount that companies paid to land-owners was not entered into the economic model. Instead, that number was converted from household income to disposable income by calculating the disposable income to household income ratio for the study region. This ratio is determined by the sum of locally produced commodities, domestic imports, and foreign imports, divided by the total household income. For this study, the ratio was calculated using regional average household disposable income. The disposable income to household income ratio efficiently nets out taxes paid by households and savings and, therefore, reflects the amount of land payments or royalty payments recipients actually spend in Pennsylvania.

Industry wide, this study estimates total spending by Marcellus producers of over $3.09 billion during 2008. Not all of this spending occurred within Pennsylvania given that some supplies are imported from other regions and land income recipients may spend money outside the state. Our expenditure analysis, however, indicates that most of this spending or $2.95 billion occurred within Pennsylvania during 2008. Of this amount, over $855 million was spent on supplies, $2.0 billion in payments to landowners, $66 million on payrolls, and $2.3 million on taxes (See Table 1).

Table 1: Total Spending in millions of dollars

Sector	Amount
Payments to Suppliers	855.9
Payments to Landowners	2,021.9
Payroll	66.0
Taxes	2.3
Total Spending in Pennsylvania	2,946.1

These estimates are consistent with a recent survey by the Marcellus Shale Committee (2009) indicating that the Marcellus producers spent $4.7 billion from the beginning of the industry in 2005 through the end of the first quarter of 2009 with $2.5 billion on lease and bonus and other land payments and the remaining $2.2 billion on equipment and supplies. Our analysis of lease acquisition activity indicates that most of the leasing activity occurred during 2008 after producers reported data on production reflecting significant reserves.

The expenditures paid by Marcellus producers to companies during 2008 were researched to determine their respective locations. Identifying the location of firms in the Commonwealth allowed the determination of whether the Marcellus industry's direct spending was indeed within the local economy. The firms that were located within the Commonwealth were then organized by NAICS economic sectors. The Marcellus industry's regional "business-to-business" spending is displayed below in Table 2.

Table 2: Spending by Sector in Pennsylvania in millions of dollars

Sector	Amount
Ag, Forestry, Fish & Hunting	3.4
Mining	334.1
Utilities	4.0
Construction	259.0
Manufacturing	6.4
Wholesale Trade	141.1
Transportation & Warehousing	26.1
Retail Trade	21.5
Information	0.3
Finance & Insurance	0.4
Real Estate & Rental	0.6
Professional Services - Scientific & Technical	48.5
Administrative & Waste Services	6.8
Educational Services	0.9
Health & Social Services	0.9
Arts - Entertainment & Recreation	0.4
Accommodation & Food Services	0.5
Other Services	0.9
Total Purchasing	855.9

More than a third or $334.1 million was spent in the mining sector, which includes oil and gas well service companies and related suppliers. The next largest category of spending at $259 million is in the construction industry, which has been badly hurt by the downturn in the housing market during this recession. Ranked number three is wholesale trade at $141.1 million, which includes the buying and selling of the multitude of equipment, fuels, parts, and other supplies needed to supply drilling rigs, build pipelines, and construct processing plants. The Marcellus industry spent $48.5 million on scientific and technical professional services and administrative services. Developing natural gas is a knowledge intensive business that requires a high degree of skilled professional, legal, and business services. Spending in the transportation and retail trade sectors amounted to another $47.6 million. Acquisition of supplies from the agriculture, utilities, and manufacturing sectors amounted to $25.6 million. Apart from wholesale trade, the bulk of spending by Marcellus producers is in above average wage industries, such as mining, construction, and professional and administrative services.

The first set of estimated impacts reported in Table 3 involves gross output, which is equivalent to gross sales. The Marcellus gas industry provides a direct economic stimulus of $2.18 billion dollars to the local economy. This spending then leads to subsequent rounds of spending and re-spending by other firms on goods and services, which adds another $868 million to total state gross output. These direct and indirect business activities generate additional income in the region, which then *induces* households to purchase $1.177 billion in additional goods and services. The sum of these direct, indirect, and induced impacts is more than $4.2 billion.

Table 3: Impacts on Gross Output by Sector in millions of 2008 dollars

Sector	Direct	Indirect	Induced	Total
Ag, Forestry, Fish & Hunting	8.0	9.6	8.8	26.4
Mining (oil, gas, and minerals)	614.5	12.4	5.5	632.5
Utilities	24.1	26.3	30.9	81.3
Construction	458.1	12.7	9.5	480.3
Manufacturing	80.0	162.4	134.0	376.4
Wholesale Trade	293.4	56.9	61.3	411.6
Transportation & Warehousing	130.2	7.7	124.5	262.4
Retail Trade	50.3	53.6	31.9	135.9
Information	14.5	36.4	35.5	86.4
Finance & Insurance	37.9	92.0	105.0	235.0
Real Estate & Rental	99.6	77.4	192.8	369.8
Professional Services - Scientific & Technical	98.3	161.0	54.8	314.1
Management of Companies	0.0	47.9	13.6	61.5
Administrative & Waste Services	14.8	49.0	25.2	89.0
Educational Services	18.2	1.0	23.5	42.6
Health & Social Services	132.7	1.4	177.6	311.6
Arts - Entertainment & Recreation	10.8	3.4	15.3	29.5
Accommodation & Food Services	38.8	17.7	59.1	115.7
Other Services	32.2	22.7	48.3	103.1
Government & Other	11.6	16.4	20.3	48.4
Institutions	12.1	0.0	0.0	12.1
Total	2,180	868	1,177	4,226

So for every $1 that the Marcellus industry spends in the state, $1.94 of total economic output is generated. This estimate is considerably above the 1.34 multiplier found by Baumann et. al (2002) in their study of the impacts of oil and gas activities on the Louisiana economy. In a study of the economic impacts of the natural gas industry in New Mexico, Walker and Sonora (2005) assume an output multiplier of 1.43. The study by Snead (2002) finds an output multiplier of 1.55 for Oklahoma, which reflects the more developed oil service sector in that region. This study's higher multiplier probably reflects our detailed expenditure analysis based upon company accounting data, which provide a more accurate measurement of inter-industry purchases.

A more meaningful estimate of economic impacts is value added, which subtracts inter-industry purchases from gross output and measures the returns to labor and capital (see Table 4). Using this measure, the Marcellus gas industry in Pennsylvania directly added $1.1 billion to the economy of Pennsylvania, which then generated indirect and induced impacts that increased the total value added generated in the Commonwealth by $2.3 billion. In other words, the total economic impact of the Marcellus industry measured by valued added was $2.3 billion during calendar year 2008.

Table 4: Impacts on Value Added by Sector in millions of 2008 dollars

Sector	Direct	Indirect	Induced	Total
Ag, Forestry, Fish & Hunting	3.2	3.9	3.4	10.5
Mining (oil, gas, and minerals)	270.3	6.9	3.3	280.5
Utilities	15.6	15.7	19.9	51.2
Construction	207.0	6.6	5.0	218.6
Manufacturing	20.0	43.9	32.9	96.8
Wholesale Trade	191.0	37.1	39.9	268.0
Transportation & Warehousing	90.5	5.3	85.9	181.8
Retail Trade	25.2	29.0	16.0	70.1
Information	7.2	17.0	16.8	40.9
Finance & Insurance	18.8	48.7	52.8	120.3
Real Estate & Rental	68.6	55.3	134.8	258.7
Professional Services - Scientific & Technical	69.8	101.1	34.9	205.8
Management of Companies	0.0	28.3	8.1	36.4
Administrative & Waste Services	7.8	29.2	14.7	51.7
Educational Services	10.4	0.6	13.5	24.5
Health & Social Services	82.9	0.8	110.2	193.9
Arts - Entertainment & Recreation	6.5	1.9	9.1	17.5
Accommodation & Food Services	19.0	8.9	28.8	56.7
Other Services	16.2	12.0	24.7	52.9
Government & Other	5.8	10.4	9.9	26.1
Institutions	0.0	0.0	0.0	0.0
Total	1,135.8	462.8	664.4	2,263.0

Like the impacts on gross output by sector, the increases in value added by sector generated by the Marcellus industry are broad based. Value added generated in the mining, construction, wholesale trade, real estate, and professional service sectors all exceed $200 million. Health and social services, transportation and warehousing, finance and insurance, each generate more than $100 million in value added in response to the creation of the Marcellus gas industry. Likewise, utilities, manufacturing, retail trade, administrative, and accommodation and food services generate more than $50 million in value added. Overall, the Marcellus gas industry generates a rather widespread increase in value added across many sectors of the Pennsylvania economy.

This broad based increase in value added stimulates employment in the region. The Marcellus industry purchases of goods and services, their royalties to landowners, and tax payments directly create more than 14,000 jobs in Pennsylvania. Indirect and induced impacts create even more jobs so that total jobs created by the Marcellus industry is estimated at 29,284 (see Table 5). An estimated 3,998 jobs are created in transportation and warehousing, 3,795 in construction, 3,577 in health and social services, 2,154 in professional services, and 2,148 in mining. More than 800 jobs are created each in the manufacturing, retail, finance and insurance, and real estate sectors. Like our estimated impacts on gross output and value added, these diverse job gains reflect the widespread stimulus to the Pennsylvania economy from the supply chain required to develop Marcellus Shale gas.

Table 5: Employment Impacts in number of Jobs

Sector	Direct	Indirect	Induced	Total
Ag, Forestry, Fish & Hunting	65	97	98	259
Mining (oil, gas, and minerals)	2,101	34	13	2,148
Utilities	47	28	36	111
Construction	3,611	109	75	3,795
Manufacturing	162	418	280	860
Wholesale Trade	1,568	304	327	2,200
Transportation & Warehousing	1,900	120	1,979	3,998
Retail Trade	366	421	239	1,027
Information	49	120	120	290
Finance & Insurance	148	412	435	995
Real Estate & Rental	174	377	405	957
Professional Services - Scientific & Technical	528	1,231	395	2,154
Management of Companies	0	201	57	258
Administrative & Waste Services	200	773	382	1,355
Educational Services	266	15	362	643
Health & Social Services	1,569	11	1,997	3,577
Arts - Entertainment & Recreation	209	75	297	580
Accommodation & Food Services	694	305	1,068	2,066
Other Services	550	269	828	1,647
Government & Other	97	128	139	364
Institutions	0	0	0	0
Total	14,307	5,446	9,531	29,284

These employment impacts are within the range reported in the literature. The results of this study indicate that for every $1 million of output created by natural gas production in the Pennsylvania Marcellus, 6.9 jobs are created. This metric is within the range of employment multipliers of 3.0, 6.7, and 7.7 found by Walker and Sonora, Baumann et. al, and Snead et. al. respectively but more than the estimates reported by Perryman (2009).

The higher economic output and greater employment by the Marcellus gas industry generate additional tax revenues for federal, state and local governments. These impacts are reported below in Table 6. Total tax revenues increase more than $590

Table 6: Tax Impacts in millions of 2008 dollars

	Employee Compensation	Proprietary Income	Household Expenditures	Enterprises (Corporations)	Indirect Business Taxes	Total
Enterprises Transfers	-1.0					-1.0
Federal Non-Defense						
Corporate Profits Tax				59.4		59.4
Indirect Business Taxes						
Custom Duty					5.0	5.0
Excise Taxes					12.0	12.0
Fed Non-Taxes					6.0	6.0
Personal taxes						
Income Tax			118.3			118.3
Non-Taxes (Fines-Fees)						
Social Ins Tax - Employee	69.5	10.9				80.4
Social Ins Tax- Employer	72.9					72.9
Sub-total	142.4	10.9	118.3	59.4	23.0	354.0
State/Local Government						
Corporate Profits Tax				10.4		10.4
Dividends				12.4		12.4
Indirect Business Taxes						
Motor Vehicle					1.5	1.5
Other Taxes					22.4	22.4
Property Tax					72.9	72.9
S/L NonTaxes					4.5	4.5
Sales Tax					71.4	71.4
Personal taxes						
Estate and Gift Tax						
Income Tax			32.7			32.7
Motor Vehicle License			1.6			1.6
Non-Taxes (Fines- Fees)			4.6			4.6
Other Tax (Fish/Hunt)			0.7			0.7
Property Taxes			0.7			0.7
Social Ins Tax- Employee	0.5					0.5
Social Ins Tax- Employer	2.1					2.1
Sub-total	2.6		40.3	22.8	172.8	238.5
Total	144.0	10.9	158.6	82.1	195.9	591.5

million with the largest component coming from taxes on employee wages and households. Total state and local taxes increase more than $238 million. Taxes generated from indirect business taxes, such as excise taxes, property taxes, and sales taxes also constitute a significant part of the overall tax impacts.

The Allegheny Conference (2009) recently found that Pennsylvania's oil and gas industry in total generates $7.1 billion in economic impacts. Oil and gas producers drilled a total of 4,189 wells in Pennsylvania during 2008. Hence, according to their estimates every well drilled generates $1.7 million in economic impacts. In contrast, our study finds that each Marcellus well generates $6.2 million in economic impacts. This difference reflects the higher cost of Marcellus wells and the greater resource requirements for the supply chain.

VIII. Future Development Prospects

The economic impacts of the Marcellus industry are largely a function of drilling activity. In a competitive market, drilling activity depends upon profitability, often measured as the difference between revenues and costs. Given limited information of output and costs, a suitability proxy for profitability is the market price. Given only four annual observations on Marcellus drilling, this study uses times series data for the period 1993 to 2008 from the Barnett Shale. While Barnett and Marcellus have many geophysical and infrastructure differences, the relationship between drilling is largely an economic one, which in principle should be almost the same, especially since they are both shale plays with similar revenue and cost profiles.

Accordingly, this study estimates the following simple regression with ordinary least squares between drilling activity in the Barnett and the Henry Hub Price, which serves as a proxy for the rate of return from drilling.[3] This formulation is consistent with the organizational structure of the industry in which any individual producer is a *price-taker*. This means that producers cannot simply pass on their costs to consumers. The estimation results are as follows.

$$\ln(Drilling_t) = \underset{(2.93)}{1.61} + \underset{(7.84)}{2.70}\ln(Henry\ Hub\ \Pr ice_t) + error_t,$$

$$\mathrm{R}^2 = 0.825, DW = 1.79$$

The error term reflects random variation in factors affecting drilling other than the Henry Hub price. Since the variables are transformed into natural logarithms, the price coefficient is an elasticity. Our estimates indicate that for a one percent change in price, drilling increases 2.7 percent. The figures in parenthesis are ratios of the estimated coefficients divided by their standard errors. If the ratios are greater than two, the estimated coefficients are statistically significant from zero. The t-ratio on the Henry Hub price indicates that prices significantly affect drilling in the Barnett. The R^2 metric measures the degree to which the relationship explains the variation in drilling. The estimates above indicate that more than 82 percent of the variation in drilling is associated with variations in the Henry Hub price. The final metric is the Durbin-Watson statistic, which is a measure of the any time dependent patterns in the error terms. The estimated value of 1.8 suggests the absence of any temporal patterns in the estimated error term. Overall the estimated equation is surprisingly robust.

[3] Accurate data on the costs of drilling in the Barnett are not available.

To project future drilling activity for the Marcellus, the above equation must be calibrated with Marcellus drilling activity levels. This is accomplished by taking the difference between the prediction from the above equation and Marcellus drilling activity estimated for 2009. A recent survey conducted by the Marcellus Shale Committee (2009) of drillers' expectations for 2009 indicates that 621 wells will be drilled during 2009. The difference between the projection from the above equation and this estimate is then added to the above equation to project future Marcellus drilling given a forecast of the Henry Hub price.

Natural gas producers use the New York Mercantile Exchange (NYMEX) futures price to hedge future production. Hence, this study uses the futures prices from the NYMEX to forecast future drilling activity. Given proximity to eastern markets, Marcellus producers earn on average a $0.9 per MCF premium over what the Barnett producers receive, which is discounted relative to the NYMEX or Henry Hub price. Given these two assumptions, this forecast envisions prices averaging $5.4 per MCF during 2009 after a 2008 average of $8.9 per MCF during 2008, then rising to $6.7 per MCF in 2010, and gradually rising thereafter, reaching $7.5 per MCF by 2020.

Our simple model projects that over 1,000 Marcellus wells will be drilled during 2010 with a steady increase during the following ten years, reaching over 2,800 during 2020. Any sharp spikes in prices could increase drilling activity substantially. Likewise, a prolonged slump in prices could dampen activity substantially from these projected levels. While there are many reasons to be optimistic about future Marcellus activity, this projection has a methodological foundation and appears to be a reasonable middle ground, perhaps even conservative.

Natural gas production in any period is the sum of production from current and all previous vintages of producing wells. The production profile of typical shale wells entails a rather sharp initial decline in the production rate and after a few years a much slower rate of decline in production. This study uses a typical production decline curve from the Barnett Formation. Based upon our forecast of drilling activity, the projected natural gas production is plotted below in Figure 18.

Our estimates suggest that production from Marcellus wells during 2008 averaged around 40 million cubic feet of gas equivalents per day. Based upon our drilling projection for 2009, output should rise to about 170 million cubic feet per day and reach more than 550 MMCF per day during 2010. In 2012, the Marcellus alone will produce current natural gas consumption in Pennsylvania, which is current around 1,800 MMCF per day. By the year 2015, the Pennsylvania Marcellus could be producing upwards of 2,900 MMCF per day and almost 4,000 MMCF per day in 2020. In addition to the vagaries of drilling activity, production will be affected by the aforementioned factors, including regulatory policies, water issues, and infrastructure challenges.

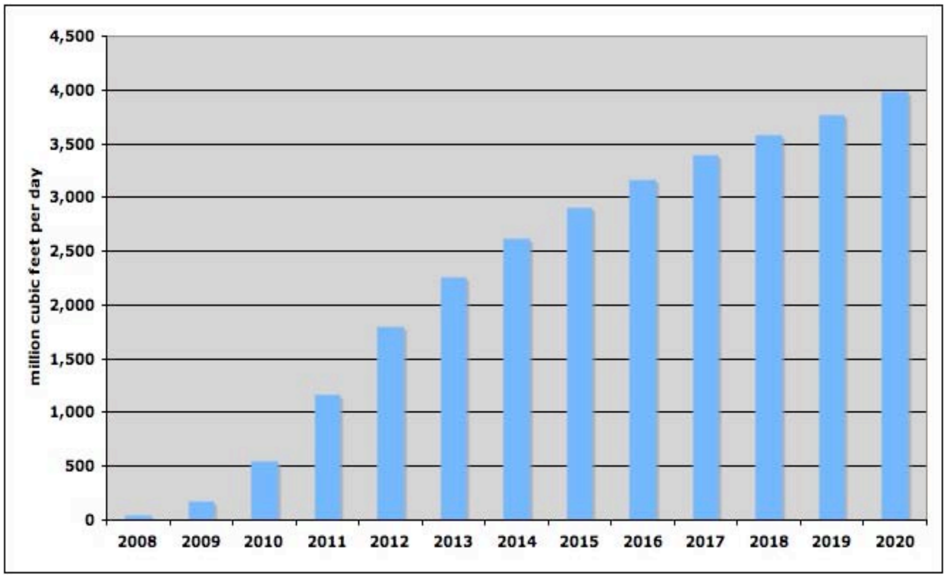

Figure 18: Forecast for Marcellus Natural Gas Production, 2009-2020

This level of future drilling and development activity will significantly stimulate the Pennsylvania economy. Estimates of these future economic impacts are summarized in Table 7. During 2009, the ramp-up in industry activity will generate more than 48 thousand jobs and more than $395 million in state and local taxes. In 2010 the total number of jobs created by the Marcellus industry could exceed 100,000. Valued added would exceed $8 billion in 2010. In 2015, gross output generated from the Marcellus industry could exceed $12 billion with employment of over 160,000 and over $1.3 *billion* in additional state and local taxes. In 2020, state and local taxes could exceed $1.4 *billion* and employment could exceed 174,000. In summary, if regulatory and tax policies remain supportive, the Marcellus gas industry could become a major employer and significant generator of tax revenue for the Commonwealth of Pennsylvania.

Table 7: Current and Future Economic Impacts

	Million 2008 dollars		Thousand
Year	Value Added	State & Local Taxes	Jobs
2008	2,263.0	238.5	29.28
2009	3,754.7	395.6	48.59
2010	8,271.8	871.6	107.04
2015	12,408.7	1,307.5	160.57
2020	13,500.2	1,422.5	174.70

Governor Rendell recently proposed the imposition of a severance tax on natural gas production. West Virginia has always been a high cost state in terms of business taxes. They have a corporate net income (CNI) tax of 8.9 percent, severance tax of 5 percent + 4.7 cents/MCF, and property tax that represents an effective tax of about 5 percent of oil and gas sales. In 2005, they added the 4.7 cent/MCF surcharge on the severance tax. Pennsylvania has no severance or property tax, so wellhead revenue is about 11 percent higher. Pennsylvania's 9.9 percent CNI is not paid by many companies and limited liability corporations (LLC)'s only pay at the 3.07 percent individual tax rate. Additionally, many companies have sufficient deductions that they pay no CNI tax. Natural gas prices began to increase in 2000 after 20 years in the doldrums; Pennsylvania drilling increased much more than West Virginia, presumably due to business climate, since West Virginia actually has more productive oil and gas properties and as much or more producing area. In 2005, there was another departure between drilling levels in Pennsylvania and West Virginia, this one possibly due to West Virginia increasing the severance tax. As Figure 20 illustrates, drilling activity in Pennsylvania exploded after 2000 while the gains in West Virginia were modest.

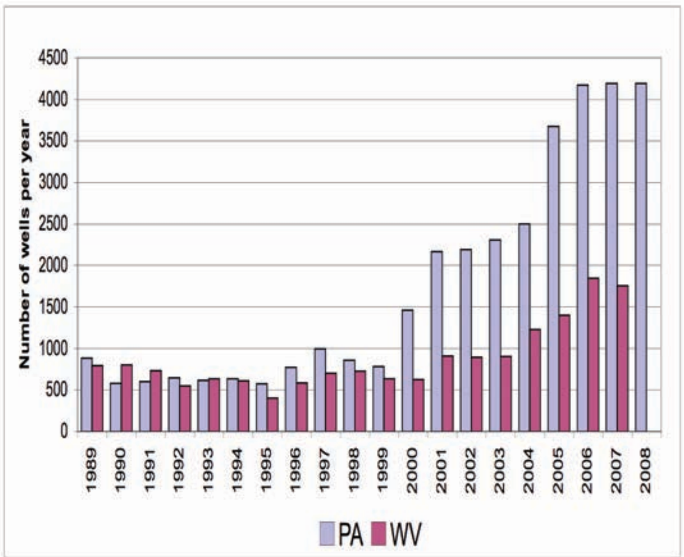

Figure 19: Comparison of Drilling Activity

The implication of this comparison is that the high level of drilling in Pennsylvania is in part due to its low tax and favorable business climate. Imposing a West Virginia style severance tax would result in substantially fewer wells drilled. For example, our calculations show that under such a tax the internal rate of return on Marcellus wells would decline at least 11 percent and result in more than a 30 percent reduction in wells drilled. This reduction in drilling activity suppresses state and local tax revenues from the baseline forecast. The revenue gains from severance taxes are offset by these losses in other state and local tax revenue. As a result, the imposition of a severance tax on oil and gas production in Pennsylvania leads to an overall net reduction in tax revenues in the state. In present value terms the net reduction is $880 million from 2009 to 2020.

Gas producers cannot pass on this tax increase to consumers because they operate in a highly competitive market place. If they did try to demand higher prices for their gas to compensate for a severance tax, their customers would stop buying from them and buy less expensive gas from another supplier. As other suppliers recognize this dynamic, they drive prices down to the competitive level, which is equal to the incremental costs of the last unit supplied to the market.

Other proposed taxes on oil and gas production would have similar effects. There is a pending bill in the Pennsylvania State House that would authorize county assessors to assess the value of oil and gas leases as real estate for local taxation. While there are no guidelines provided in the legislation as to how the assessment will be performed, a number of other states where property taxes are imposed take reported annual production and apply a formula to make a crude estimate of the NPV of remaining reserves. Property taxes applied to oil and gas properties in other states range from about 1 percent to 6 percent of gross production revenue. New York and West Virginia have property taxes that are equivalent to 4 percent and 5 percent of gross revenue. Once again, imposition of such taxes will reduce drilling activity, employment, and state and local tax revenues elsewhere. A low tax, pro-growth policy environment in the long-run, however, will generate more tax revenues for the state.

Imposing severance or property taxes on the Marcellus gas industry just as it is getting established will lead to tax losses for the state and could seriously undermine the future growth of the industry, especially given the possibility that producers could shift operations to developing promising shale formations elsewhere. The simple fact is that if you tax something you get less. In this case, you get less drilling and gas development.

The argument for using severance taxes to compensate for environmental and other external effects from natural gas development also ignores the unintended consequences on development activity. As our discussion above demonstrates, the environmental disruptions from natural gas production are minimal. Some have argued that large-scale development of the Marcellus will strain state and local services. Such problems have occurred out west, specifically in Wyoming. One significant difference is that Wyoming is very lightly populated with little infrastructure while Pennsylvania has a well-developed infrastructure and unemployed workers. Once again, the gains from development in terms of jobs and local tax revenues will likely exceed any adjustment costs or any transitory windfalls from taxing an infant industry, such as the Marcellus.

IX. Conclusions and Policy Implications

The birth of the Marcellus gas industry is an opportunity to create jobs and attract investment capital to the Commonwealth of Pennsylvania. This study finds that the Marcellus gas industry in Pennsylvania is in the *take-off* phase of development. Our measurements for 2008 indicate that the Pennsylvania Marcellus gas industry generates a total economic impact of $2.3 billion, 29,000 jobs, and $240 million in state and local tax revenue.

The future of the Pennsylvania Marcellus gas shale industry is bright. During 2009, our estimates indicate that the Marcellus industry will generate $3.8 billion in value added, over 48,000 jobs, and $400 million in state and local tax revenues. Over the next five years, the Marcellus industry will likely transform Pennsylvania into a net exporter of natural gas. In slightly more than 10 years, the Marcellus industry could be generating nearly 175,000 jobs annually and more than $13 billion in value added. Also, over this time frame, the present value of state and local tax revenues earned from Marcellus development is almost $12 billion.

Another finding of this study is that after the ramp-up phase of development, shale gas drilling activity is quite sensitive to rates of return. Governor Rendell recently proposed a 5 percent severance tax plus 4.7 cents for each thousand cubic feet of natural gas produced. Such a tax, however, would have unintended consequences.

Based upon the model developed in this study, this tax would reduce drilling activity by more than 30 percent. This would actually lead to an $880 million *reduction* in state and local taxes in present value terms from 2009 to 2020. Hence, a severance tax imposed on the Marcellus industry would result in a net loss in tax revenue to the state. Marcellus gas producers cannot simply pass this severance tax on to consumers. The Marcellus in one among several shale plays under development. Higher taxes or greater regulatory costs would induce producers to shift drilling activity to plays with more favorable terms. Over time, drilling accelerates as pipeline and gathering system infrastructure is better developed. Choking off the industry with a severance tax at this critical time would stunt this infrastructure development and limit future drilling activity. State policy makers would be wise to encourage the growth of this industry because it generates significant job creation, income, and tax revenue collections to the state.

An even more ominous proposal to the development of the Marcellus Shale and for that matter the domestic oil and gas industry is the proposal that hydraulic fracturing be regulated under the federal Safe Drinking Water Act. A study by HIS Global Insight, found that this policy would reduce gas production by 4.4 TCF, or 22 percent, and reduce oil production by 400,000-b/d, or 8 percent, by 2014. There is little question that this type of legislation would accomplish little in terms of protecting potable freshwater but would be disastrous in terms of the domestic oil and gas industry, raise prices for gasoline and natural gas, and ultimately derail any efforts to address the need to reduce carbon emissions.

Strategies and policies that encourage growth of the Marcellus gas industry will generate significant economic and environmental benefits for the Commonwealth of Pennsylvania. The potential of the Marcellus is enormous. Large-scale development would reshape the economic landscape of the state, transforming the Commonwealth to a net natural gas exporter while creating hundreds of thousands of jobs and generating billions of dollars in additional output, income, and tax revenues. The additional natural gas produced from the Marcellus would propel the economy forward while reducing greenhouse gas emissions. The Marcellus could very well turn out to be Pennsylvania's ace in the hole if pro-growth policies are pursued that unleash the entrepreneurial spirit of producers to develop this vital national treasure.

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