

Economic Costs of Unconventional Natural Gas Drilling and Transmission in Maryland:

Concepts, Preliminary Estimates, and Policy Implications

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Summary

What are the full costs of investing in natural gas drilling, production, and transmission? This paper seeks to identify some of the “hidden costs,” those that usually do not have price tags attached. Other studies already completed or underway may provide some of the needed information to establish the full costs of unconventional natural gas development (UNGD) in Maryland, but key information gaps remain.¹ To help fill these gaps, this report focuses on certain external costs of Maryland’s existing and potential natural gas system. An external cost is one that is not borne by industry and so is not in the pricing structure for the product. Using data, techniques and assumptions described below, we have developed estimates for a subset of the external costs that could be expected for two extraction scenarios in Garrett County, for the compressor station in Myersville, and for construction and operation of the Columbia pipeline in Baltimore and Harford Counties.

Table 1, below, summarizes the scope of costs considered in this study by type of cost and geography. These represent what may be a small fraction of the total economic costs of UNGD and transmission in Maryland. Details on the estimation methods, the estimates themselves, and recommendations for further study and policy formation are described in the body of this working paper.

¹ Garrett County officials are in the process of commissioning one study that would address several important classes of the costs of drilling and extraction. Those include impacts on property value and damage to the recreation and tourism industry (Blaisdell 2016). While there is some inevitable overlap—concerns about health impacts could drive changes in local housing markets, for example—we do not wish to duplicate that effort here. Instead, our focus is on vectors of cost that are outside the scope of existing and planned future studies.

Table 1: External Costs of UNGD Addressed in this Study

Cost Vector	Potential UNGD Sites in Garrett County	Compressor Stations	Transmission Lines
Public Health	✓	✓ Case Study: Myersville	
Motor Vehicle Accidents	✓		
Social Cost of Carbon	✓		
Lost Ecosystem Services	✓		✓ Case Study: Columbia Pipeline

Using the best available information and conservative assumptions where data are not available, we estimate the following costs in these categories:

- Public health impacts include medical treatment costs and impacts on quality (and length) of life due to exposure to air pollution associated with hydraulic fracturing and natural gas compression stations. There are still few studies documenting the rate of health impacts occurring in communities already affected by UNGD and transmission.² Therefore, our estimates for Garrett County are limited to certain costs associated with just two conditions for which sufficient data are available: asthma exacerbations, and adverse birth outcomes.
 - Estimated costs for these two examples range from \$3,309 to \$6,712 per year depending on how much gas is extracted and on the density of wells at drilling sites. These low numbers reflect several factors, including the the small number of illnesses examined (asthma exacerbations and adverse birth outcomes), the lack of information about the full cost of these two illnesses (e.g., the cost of people missing work or children missing school due to asthma exacerbations), and the low population density in the study area.

² The Health Effects Institute has assessed the state of knowledge regarding health and other impacts of the natural gas industry. Its 2015 Strategic Research Agenda is designed to improve understanding about adverse effects of UNGD so that effects can more effectively be avoided or minimized and, we would add, so that the full economic cost of natural gas can be compared to the benefits (HEI Special Scientific Committee on & Unconventional Oil and Gas Development in the Appalachian Basin, 2015).

- Public health impacts are borne directly by those afflicted (and their families and insurers) and, more broadly, by society as a whole, when resources are spent treating preventable illnesses rather than on more productive things.
- Costs of increased rates of motor vehicle accidents, including the costs of emergency response and acute medical care, as well as the cost of any long-term disability that may occur.
 - Estimated costs are \$922,502 per year.
 - These costs are borne by individuals involved in the accidents, by emergency services agencies (municipal and volunteer) who must respond to and clean up after accidents, insurance companies, and other people tied up in traffic and losing productive time while accident scenes are cleared.
- Costs of road damage due to an increase in general traffic volume and heavy truck traffic.
 - These costs range from \$3.9 million to \$55.5 million per year depending on how much gas is extracted.
 - Road damage costs fall on state and municipal governments (and therefore taxpayers), and on all drivers whose vehicles sustain greater damage and wear out a little faster due to driving on damaged roads.
- The social cost of the carbon equivalent of natural gas extraction and use.³ Natural gas extraction, storage, and transmission results in methane emissions, which are 25 times more potent as a greenhouse gas than CO₂ (U.S. EPA, 2016). Using (burning) natural gas also results in CO₂ emissions. The damage done by these emissions of CO₂ and CO₂ equivalents are part of the total economic costs of UNGD and transmission in Maryland.
 - These costs range from \$12.0 million to \$36.3 million per year of production, depending on how much gas is extracted.
 - Greenhouse gas emissions exacerbate a global problem, and its costs are borne by people worldwide.
- The lost value of ecosystem services from areas cleared and converted to well pads and associated infrastructure (access roads, fracking fluid spills, and leaks) and the Columbia pipeline's construction corridor and right-of-way. These services include water supply and water purification, recreational value, aesthetics, food and fiber production, and others. Natural gas infrastructure

³ The Social Cost of Carbon is defined as “the economic damages associated with a small increase in carbon dioxide (CO₂) emissions...in a given year”(U.S. EPA, 2016).

affects these values through the conversion of more ecologically productive land uses such as forests and fields, to less productive uses, like well pads and pipeline corridors. Lost ecosystem service productivity will be felt (or paid) in many forms, including higher costs for water purification by municipalities or individual households, lower crop, forage, and timber production, or higher costs in time and travel expense for recreational experiences.

- Estimated costs for the Columbia pipeline would be \$517,000 per year during a limited construction period and \$264,000 during each year of operation.
- For UNGD sites in Garrett County, lost ecosystem service value ranges from \$808,722 to \$14.1 million, depending on the amount of gas extracted, the clustering of wells on well pads, and the amount of land consumed by each well pad and its associated infrastructure.
- Depending on the ecosystem service in question, different people will suffer the economic losses. For example, homeowners and municipal governments will lose home value and property tax revenue due to lost aesthetic value. Lost aesthetic and recreational value will affect tourists and the businesses that serve them. Tourist will incur greater transportation costs and/or have less-satisfying, lower-value experiences as they bypass the Marcellus region and go instead to second-choice locales, and the businesses will see sales fall. And when the landscape is less capable of filtering and otherwise regulating water on its own, municipal water supply systems, private well owners, and commercial and industrial water users could end up spending more to treat water before use and/or seeing farm and other productivity drop (Finkel, Selegan, Hays, & Kondamudi, 2013).⁴

Table 2, summarizes these costs on an annual basis.

⁴ It is true that one person's cost is another person's revenue, and traditional economic measures like gross receipts or contributions to gross state product may actually increase as a result of the damage done by unconventional natural gas development and transmission. Hospitalizations for asthma exacerbations, installation of residential water treatment systems, and even funerals for people killed in motor vehicle accidents are sales. But from a societal standpoint, these expenditures also represent a waste of resources on fixing or dealing with the consequences of problems-resources that could be more productively employed elsewhere in the local, regional, or global economy.

Table 2: Estimated Annual Costs Associated with Unconventional Natural Gas Development and Transmission in Maryland.

Cost Category		Annual Costs (2015\$)
Public Health Effects (Excess Asthma Exacerbations and Low Birth Weight Children)	Drilling, Lowest Impact: 25% Extraction (150 wells), & Higher Well Clustering	\$3,309
	Drilling, Highest Impact: 75% Extraction (450 wells), Low Well Clustering, & Larger Well Pads	\$6,712
	Myersville Compressor Station	Cost of illness not available
Motor Vehicle Accidents	Drilling, due to higher traffic volume in Garrett County	\$922,502
Road Damage	25% Extraction (150 wells)	\$3.9 to \$17.9 million
	75% Extraction (450 wells)	\$12.1 to \$55.5 million
Social Cost of Carbon (Equivalent)	25% Extraction (150 wells)	\$12.0 million
	75% Extraction (450 wells)	\$36.3 million
Ecosystem Services Forgone	Drilling, Lowest Impact: 25% Extraction (150 wells) High Well Clustering, & Compact Well Pads	\$808,722
	Drilling, Highest Impact: 75% Extraction (450 wells) Low Well Clustering, & Larger Well Pads	\$14.1 million
	Columbia Pipeline Construction Corridor (short-term effect) ³	\$517,152
	Columbia Pipeline Permanent Right of Way	\$264,199 per year forever
Total⁵		\$17.9 to \$107.1million

⁵ The grand total excludes the value of ecosystem services forgone during pipeline construction, which are a one-time cost, not a cost that recurs annually.

Other costs beyond the scope of this study may also be significant. These include:

- **Accident Storage Facility:** Health effects of leaks from the underground natural gas storage facility at Accident have not been assessed. The massive leak of stored gas from the similar Aliso Canyon facility near Los Angeles has raised questions about health effects of short- and long-term exposure to gas leaks. The Accident Storage Field can hold 18.3 billion cubic feet (Bcf) of natural gas in porous rock. It consists of 84 wells and a compressor station and is classified as a major source of “fugitive emissions”⁶ of pollutants (Spectra Energy, 2016; Engage Mountain Maryland, 2015). These emissions could result in ongoing health care costs and lost productivity for people living nearby. In the event of a major leak or explosion, there would be additional health-related costs as well as the added costs of evacuation, emergency services, and temporary housing for those affected.
- **Additional Health Effects:** Statistical evidence of associations between UNGD and various illnesses is expanding rapidly, and future versions of this working paper could add the treatment and other costs associated with those illnesses. A very recent (August 2016) study, for example, has established that drilling activity is associated with chronic rhinosinusitis, migraine headache, and fatigue (Tustin et al., 2016). Further work is necessary to determine the expected cost of these conditions under potential drilling scenarios in western Maryland as well as the incidence of such effects for people living near gas transmission infrastructure, such as compressor stations.
- **LNG Export:** Costs associated with liquefied natural gas (LNG) export facilities borne by nearby communities (e.g. Lusby, MD) or the public at large have not been assessed. These would include the loss of ecosystem services on and around the facility, as well as public health effects due to leaks and spills, explosions or fires, and toxic emissions.
- **Slower Transition to a Sustainable Energy Future:** Beyond the social costs of carbon, extending reliance on fossil fuels would delay achievement of Maryland’s mandated greenhouse gas reduction goals. To the extent that achieving those goals would generate benefits above and beyond avoiding the costs of carbon emissions—examples include job creation and regional competitiveness in the clean energy sector—delay or failure in achieving them would add to the costs of UNGD in the state (Maryland Commission on Climate Change, 2015).
- **Property Values:** We do not assess impacts on property value due to the Columbia Pipeline or due to UNGD in Garrett County.⁷

⁶ Fugitive emissions are emissions from pumps, valves, and other points in a system that are not designed to release material into the environment. They are in contrast to point sources of emissions, like vents or smokestacks, that are designed to transmit pollutants into the environment.

⁷ As of October 2016, Garrett County is in the process of commissioning a study that will consider and estimate costs associated with changes in property value and with effects on the recreation and tourism industry.

- **Garrett County Economy:** We do not address impacts on other industries, such as recreation and tourism, or on retiree- or other amenity-driven in-migration to Garrett County, which would be expected with the advent of UNGD in the county.⁵
- **Social Disruption:** Changes to familiar landscapes and fears of health and environmental risks associated with UNGD are further effects of UNGD and transmission (Sangaramoorthy et al., 2016). The effects of such stress on people would include changes in their well-being as reflected with their personal satisfaction with living where they do, or changes in their productivity as workers, caregivers, students, and volunteers. Some of these changes may be manifest in market transactions, such as lost wages or less spending in the community, and the balance will be a reduction in individual welfare, or “utility” to use the economists’ term. smeans that can show up as health effects, as

Background: Good Policy on Natural Gas Requires a Consideration of the Full Costs of Drilling and Transmission

Maryland committed by legislation to adopt regulations for natural gas drilling and extraction within the state before a two-year moratorium on drilling expires in October 2017. Draft regulations proposed in January 2015 sought to address “potential impacts to public health, safety, the environment and natural resources from [high-volume hydraulic fracturing, or] HVHF in the Marcellus Shale in Maryland” (Maryland Department of the Environment, 2015). In these draft regulations, the Maryland Department of the Environment identified positive and negative economic effects of the regulations including the costs of road improvements to local government, compliance costs borne by the oil and gas industry, higher property values and tourism spending in Garrett and Allegany Counties (where the regulations would better protect natural resources), and the benefits of improved health and safety for those counties’ residents.

While it is important that MDE has raised the issue of external costs of HVHF, there are several important problems with the way MDE approached the question in 2015. These are:

1. MDE did not consider Maryland’s existing and planned infrastructure for storing and transmitting natural gas along with the added effects of drilling. Facilities such as the Accident Storage Field, the new compressor station in Myersville, the Columbia Pipeline in Baltimore and Harford Counties, and the conversion of the Cove Point facility to handle the export of liquified natural gas (LNG) are examples of the downstream impacts of drilling not covered by MDE’s regulatory framework.

2. MDE's list of economic effects leaves out certain important costs of drilling, including the cost of emergency services and of injuries due to motor vehicle accidents.
3. MDE's descriptions of the means by which drilling costs (or regulatory benefits would) accrue to people were very general or vague, which weakens the draft regulation as a useful guide to what those costs might be.
4. MDE declared that none of the economic impacts of its proposed regulation, whether negative or positive, would have a magnitude that is determinable. At the same time however, MDE states that "the largest economic impact will be to oil and gas exploration and production companies that work in Maryland." If the costs and benefits of environmental regulation are truly "indeterminable," then one cannot identify any particular cost or benefit as "the largest."

We maintain that most, if not all, of these costs can at least be estimated. Stakeholders should therefore withhold judgement regarding the relative magnitude of costs and benefits of drilling and its regulation until estimates have been developed and considered.

5. MDE's regulatory framework was introduced after a study process that explicitly omitted the climate impacts of investing in gas infrastructure in Maryland. Given the urgency of climate actions to reduce greenhouse gas emissions and Maryland's relative leadership among states in addressing greenhouse gas emissions, this represents a significant gap in the 2015 regulatory framework.

MDE's limited approach is of serious concern because societal economic costs are a feature of the entire natural gas system. Those costs are imposed in many specific ways, and it is possible to obtain reasonable estimates of those costs as a partial guide to decisions about whether, how much, and what kind of natural gas drilling and other activity to allow in the state.

To its credit, MDE commissioned an *Impact Analysis of the Marcellus Shale Safe Drilling Initiative* (Regional Economic Studies Institute (RESI), 2014). The study lists many types of negative impacts associated with drilling, and it references the experience of other regions where health, motor vehicle accidents, and other impacts have been documented. While the RESI study provides a qualitative assessment, it does not attempt a quantitative estimate of how large the costs of drilling might be.

As the RESI authors note, it is difficult to quantify the economic effects of potential future environmental damage. There are many unknowns, including how many wells there could be, where wells would be drilled, how many wells would be drilled in a given location, what land uses would be disrupted or destroyed, and how many people would be affected. Many of the same unknowns, however, plus some others, such as the number of workers would who come from Maryland as opposed to other states, what wages they would earn, and what the price of natural gas might be years in the future,

would also make estimating positive economic impacts of UNGD more difficult. The RESI study is not so reticent, however, regarding potential positive impacts. As a result, the public, MDE and other decision-makers, and stakeholders are faced with an unanswerable question: how can we determine whether the benefits of UNGD outweigh the costs when all we know are estimates of the benefits?

Also to MDE's credit, in 2014, it commissioned a study from the Maryland Institute of Applied Environmental Health (MIAEH) at the University of Maryland School of Public Health. This report, titled *Potential Public Health Impacts of Natural Gas Development and Production in the Marcellus Shale in Western Maryland*, assigned a ranking to likely public health effects.

MIAEH's study confirmed that UNGD in western Maryland would very likely be harmful to the health of Maryland residents. In 7 out of 8 areas, the research team found there would be a high or moderately high likelihood of negative public health impacts; UNGD will likely harm local air quality, the healthcare infrastructure, worker health, and community cohesion (due to increases in crime, traffic, substance abuse, and STDs.); it is also likely to have negative public health impacts through harm to water quality, excessive noise, and cumulative effects from all of the above (Maryland Institute for Applied Environmental Health (MIAEH), 2014, Table 6-1, p.xx).

What are the costs associated with health effects and with other societal economic impacts that MDE has failed to assess? The purpose of this report is to make that question a little more answerable. We examine and estimate the dollar value of some costs of natural gas drilling and transmission infrastructure that have not been assessed by MDE.

Our estimates, while based on reasonable scenarios about UNGD operations and using appropriate secondary data and estimation techniques, should be considered a first approximation of the costs considered. We intend for this study to serve less as a definitive estimate of the costs of UNGD in Maryland and more as a stimulus for a comprehensive review of the effects that could occur if the moratorium is lifted and as existing and planned transmission infrastructure comes online. This information should be valuable in determining whether a regulatory regime can adequately protect Maryland's collective interests.

Scope of Inquiry

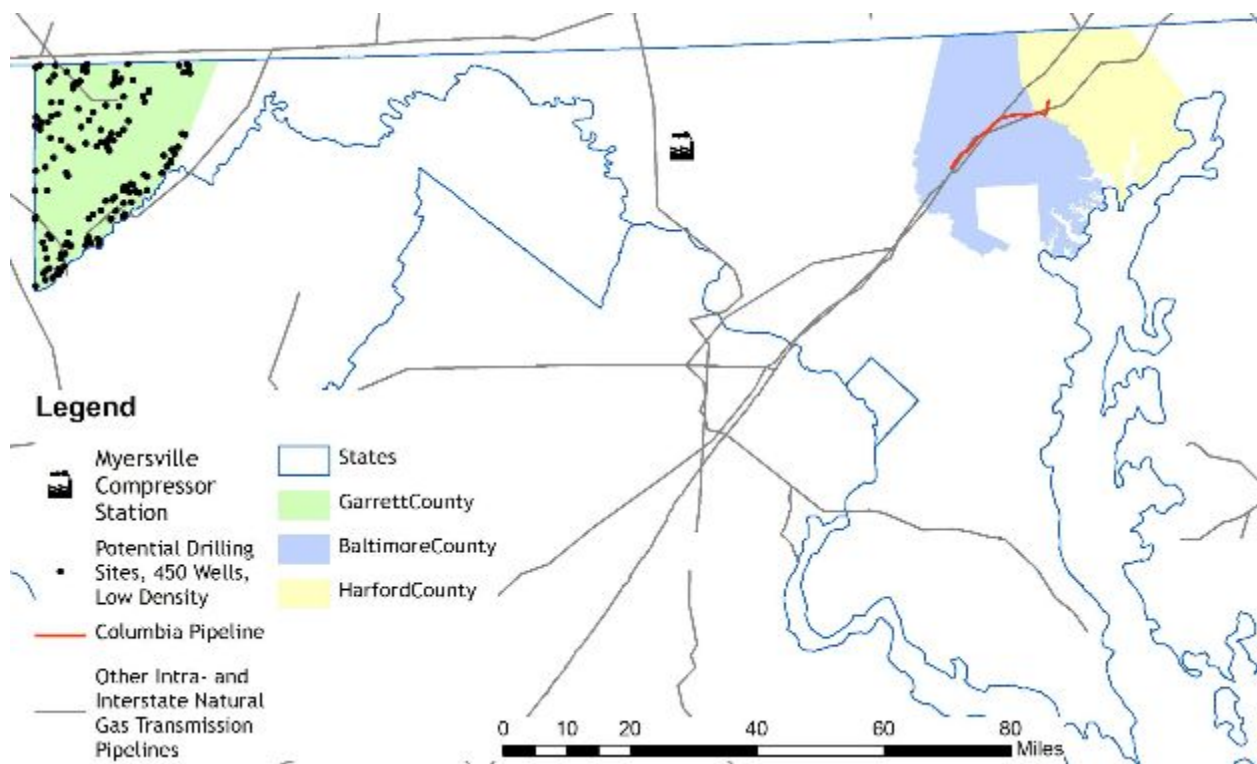
This report cannot provide a comprehensive review of all the economic effects of natural gas extraction and transmission in Maryland. Before and during Maryland's drilling moratorium, a number of studies have examined or are examining potential benefits and costs of unconventional drilling and shale gas extraction in western Maryland. These include: Regional Economic Studies Institute (RESI) 2014; Garrett County

Impact Study 2016; Maryland Institute of Applied Environmental Health, 2014. These studies provide important information for decisionmakers, but some gaps remain.

Given the focus of other studies on more traditional economic impacts (e.g., jobs, income, property value), we focus here on key vectors of costs that might otherwise be overlooked: health, safety, and lost ecosystem services due to environmental effects of shale gas extraction and transmission. (Please see Table 1, above.)

Our geographic focus is selective: on Garrett County, where we estimate costs associated with potential natural gas drilling; on the area surrounding the Dominion Transmission compressor station near Myersville, and on the area directly impacted by the Columbia pipeline (see Figure 1).

Figure 1: Geographic Focus: Garrett County (drilling), Myersville (compressor station), Baltimore & Harford Counties (Columbia pipeline)



Garrett County Drilling Scenarios

For purposes of providing illustrative estimates of potential health- and ecosystem-services-based effects of UNGD in Garrett County, we have developed scenarios for where in the county drilling could possibly occur with assumptions about how much land would be converted from current uses to well pads and associated industrial development. We have built these scenarios on three sets of information:

1. The results of a spatial (GIS) analysis by the Garrett County Planning Department (Carpenter, 2016) that identified areas where drilling could possibly occur, given proposed drilling regulations and local ordinances and after subtracting wellhead protection areas, caves, state-owned land, drinking water reservoirs, and others. For our analysis, we considered only those remaining areas greater than seven acres in size. (See item 3 on this list.)

These winnow the total Garrett County acreage available for well pads, impoundment ponds (to hold water and fracking fluids), and access roads to under 9,000 acres spread across 202 sites.

Larger sites (greater than 80 acres in size) were considered to be capable of supporting more than one production unit (typically 40 acres). Thus, an 80-acre site was counted as capable of accommodating one or two well pads and associated infrastructure; a 350-acre site could have up to eight pads (with 30 acres to spare); and so on.

2. Two general scenarios covered in the RESI study: a 25% extraction scenario, for which RESI estimates 150 wells would be required; and a 75% extraction scenario requiring 450 wells.
3. Results of a recent Shippensburg University analysis of land use change due to UNGD operations in Bradford County, Pennsylvania. Jantz et al. (2014) provide a range for well pad clustering—that is, the number of wells that would be drilled from a single well pad—as well as ranges for how much space the pads and other infrastructure consume. For both well pad clustering and area for infrastructure, we considered low and high scenarios corresponding to one standard deviation above and below the authors' reported means.

Combining the second and third sets of information, we have eight possible scenarios (two levels of production, times two levels of well clustering, times two sizes for infrastructure). For the purposes of our estimation, we chose sites at random from the full list of 202 available sites. For each scenario, we selected sites and counted possible wells (taking into account multiple pads per site and the degree of well clustering) until we reached the number of wells required for the 25% and 75% extraction scenario.

Differences in well-pad size are ignored for the health costs estimation because it is the distance from the well pad and/or the number of wells drilled on each pad that matter, not the size of the pad. Land consumption for well pads and other infrastructure matters for the estimation of lost ecosystem service value, however.

Table 3 summarizes these scenarios along with the number of sites required and the number of acres that would be converted in each scenario. The scenarios highlighted in grey represent the lower and upper extremes in terms of number of sites and acres

converted. Figure 2 shows the location of the randomly selected sites in the four primary scenarios.⁸

If UNGD is eventually permitted in Garrett County the actual results will be different. Sites will not be chosen at random and individual site characteristics will determine how many pads and wells would be developed and drilled on each site and how much land would be consumed for drilling infrastructure.

Table 3: Well Sites, Wells, and Land Consumption for Low (25%) and High (75%) Extraction Scenarios.

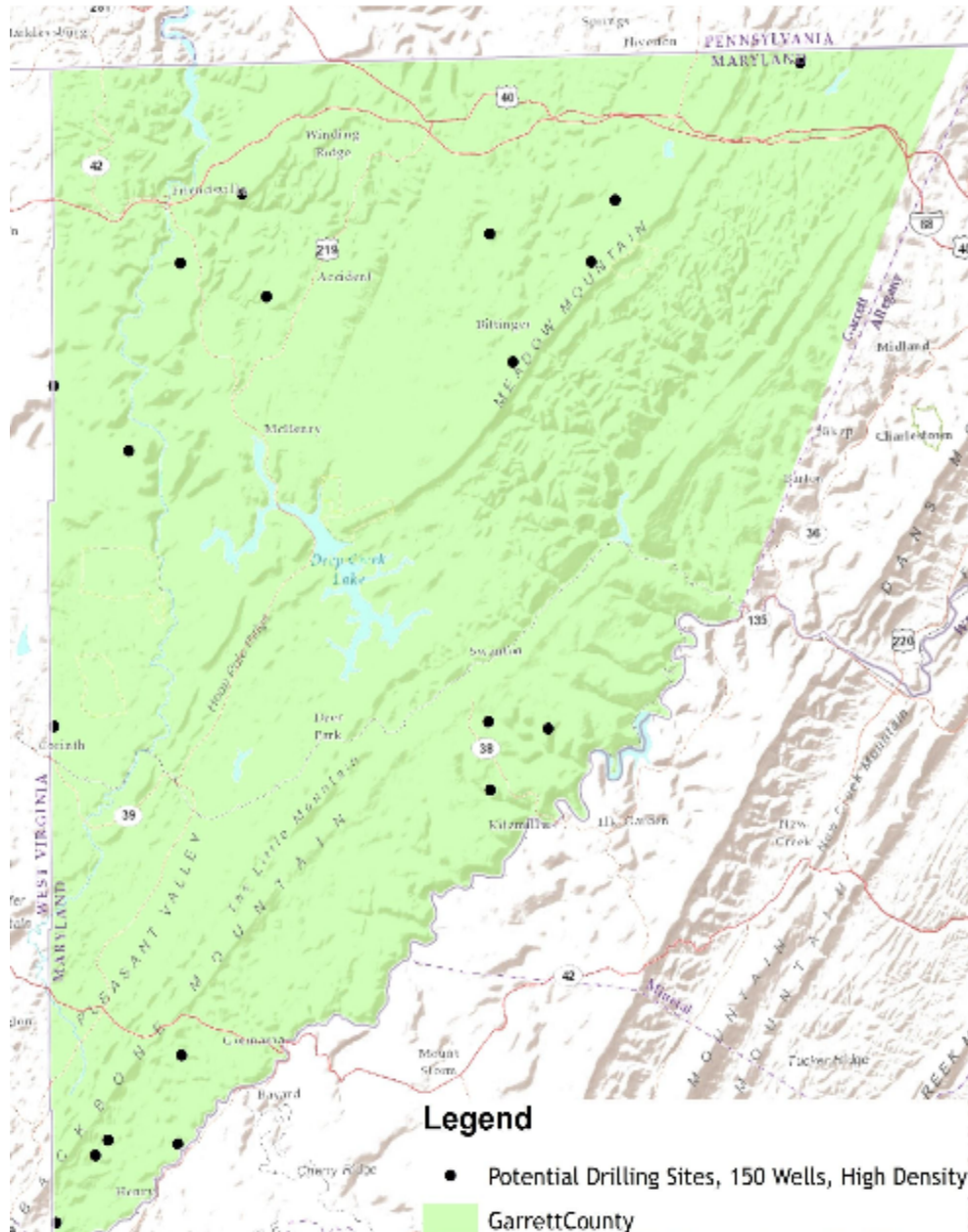
	Lower Well Clustering (more sites needed)		Higher Well Clustering (fewer sites needed)	
	<i>Compact Well Pads</i>	<i>Larger Well Pads</i>	<i>Compact Well Pads</i>	<i>Larger Well Pads</i>
Less Extraction (150 wells)	48 sites 150 wells 537 acres	48 sites 150 wells 952 acres	19 sites 154 wells ^a 158 acres	19 sites 154 wells ^a 279 acres
More Extraction (450 Wells)	144 sites 452 wells ^a 1,618 acres	144 sites 452 wells ^a 2,870 acres	43 sites 441 wells ^b 451 acres	43 sites 441 wells ^b 800 acres

Notes: a. The number of wells is in part a function of the number of acres in individual, randomly selected sites, and so the total differs from the target of 150 or 450. In these cases the last site selected put the total number of wells over the target.
 b. In these cases, the next site we could have selected could have accommodated 56 wells, and we chose to stop 9 wells short of 450 rather than overshoot by 47 wells and inflate cost estimates.

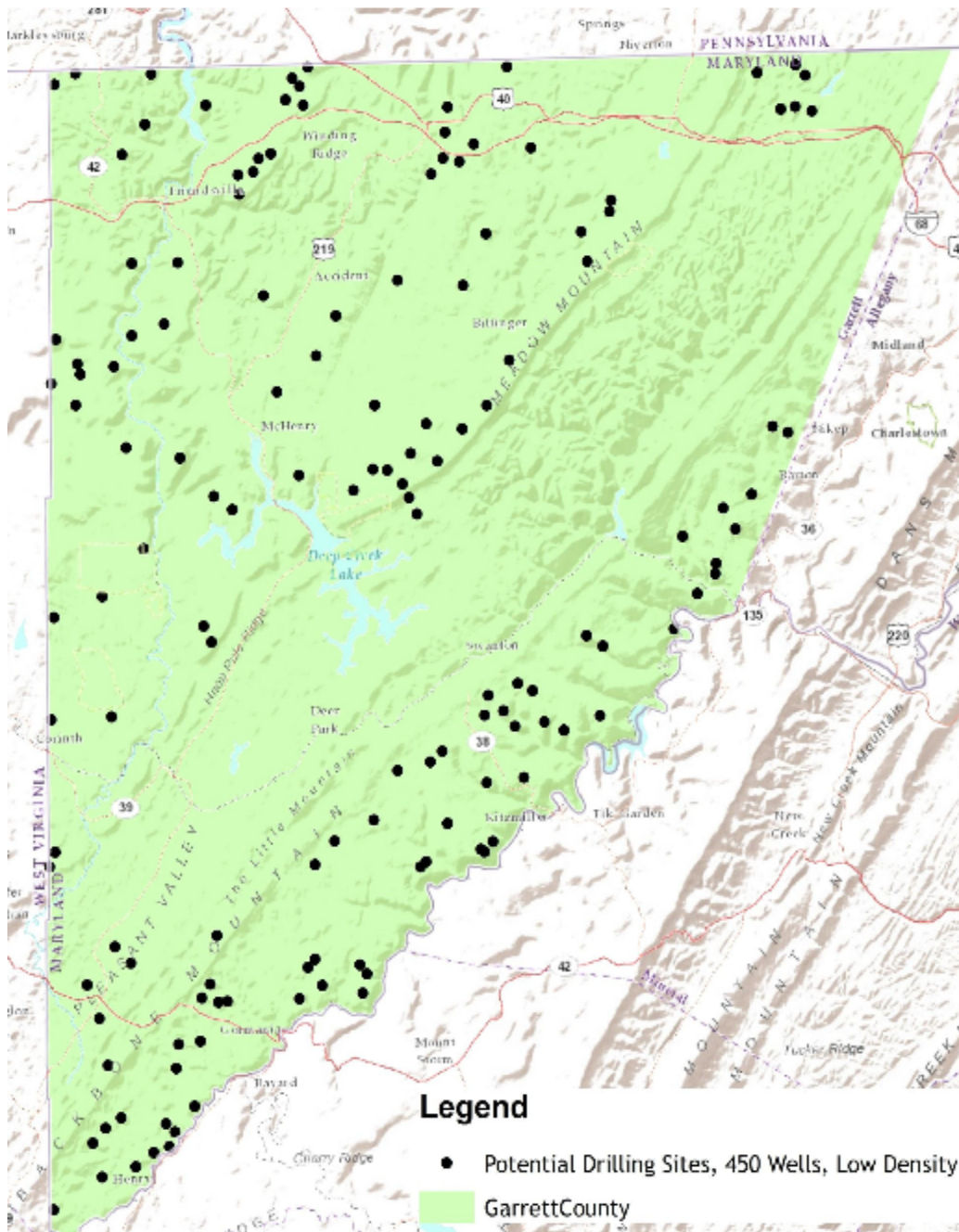
⁸ Each primary scenario has two secondary scenarios for compact and larger well pads, respectively.

Figure 2: Location of Drilling Sites in Garrett County
 Sites are selected at random from all sites to construct lowest (A) and highest (B, next page) impact scenarios, based on the total number of wells and the degree of well clustering.

A. Lowest Impact Scenario: 150 wells, high well clustering



B. Highest Impact Scenario: 450 wells, low well clustering



Vectors of Cost

Public Health. The total health related costs of UNGD would include the cost of treating various acute and chronic conditions suffered by residents near UNGD sites and

near compressor stations (Phillips, 2015) plus the cost of lost productivity in the form of time off of work or, in the case of premature death, lost working years.

While several studies point to associations between various maladies and exposure to air, water, noise, and other pollution from UNGD sites, only a few have reported results that can be applied to this case study. We only include those illnesses for which quantitative estimates of the incidence of illness in proximity to UNGD and transmission sites are available and for which applicable cost-per-case information is available. Consequently, our health cost estimates are limited to the acute cost of asthma exacerbations and the lifetime costs of negative birth outcomes (low birthweight especially) for persons living near UNGD sites.

We also estimate the number of people who may experience various health effects associated with air and other emissions from compressor stations, but due to a lack of information about the severity of those effects (and therefore no basis for assumptions about treatment costs) we do not take the next step of assigning dollar-value figures to the compressor station effects.

Motor Vehicle Accidents (MVAs): UNGD is associated with more frequent and sometimes more severe traffic accidents. MVA costs include the cost of emergency services, medical care costs, lost productivity (including lost working years for crash fatalities), legal and insurance administration costs, property damage, and other costs (National Highway Traffic Safety Administration, 2015).

Lost Ecosystem Services: Natural gas drilling and transmission will affect the function of ecosystems in several ways. Air and water emissions from the drilling process tax the natural capacity of the environment to assimilate those and other wastes. Unassimilated waste can reduce the productivity of other natural systems and also have negative effects on agriculture, recreational, aesthetic, and other human values. More directly, UNGD includes the construction and operation of pipelines, which entails the conversion of land from more natural to less natural uses. Standing forests, for example, produce more natural benefits (commonly called “ecosystem services”) than the shrub and scrub that replace the forest after a pipeline is built. Similarly, well pads, service roads and other industrial land uses are not as good at limiting erosion, processing waste, sequestering and storing carbon, providing space for recreation and aesthetic enjoyment, or for growing crops as the farm fields, forests, and other wild areas they replace.

It is these latter impacts on ecosystem service values that we consider in the present study. We estimate the amount of land that would be converted due to the Columbia pipeline under construction in Baltimore and Harford Counties and due to potential UNGD in Garrett County. Following the well-established “benefits transfer method” we compute the dollars’ worth of 10 ecosystem services, from aesthetics to water supply, that would be lost due to these projects.

Public Health

People who live near fracking sites, storage facilities, export facilities, and compressor stations are exposed to air pollution associated with a host of acute and chronic illnesses. Along with the natural gas itself, gas industry processes emit volatile organic compounds, diesel exhaust, nitrogen oxides, sulfur oxides, particulate matter, polycyclic aromatic hydrocarbons, metals, and hydrogen sulfide. These are known air toxins and exposure may cause illnesses and health problems for residents living near drilling facilities (Witter et al., 2008).

Chemicals used in the fluids for hydraulic fracturing have been linked to cancer, brain damage, respiratory disease, endocrine disruption, and other health impacts with relatively high economic costs (Barth, 2011). (The full range of possible health effects depends on the mixture of chemicals used by each company, deemed a trade secret, which prevents a full assessment of possible risks from exposure.)

Methane emissions (unburned) are also an issue at transmission and storage facilities, such as the Myersville compressor station and the storage facility at Accident. According to Zimmerle et al. (2015) storage and transmission account for one third of all methane emissions, with compressor stations emitting the largest share within the storage and transmission system.

The costs of natural-gas-related pollution include direct healthcare costs and indirect costs due to reduced productivity. Dutzik, Ridlington, and Rumpler (2012) estimate that “air pollution from drilling Arkansas’ Fayetteville Shale in 2008 likely imposed [overall] public health costs greater than \$10 million in 2008” (p. 18). Nationwide, EPA has estimated the value of clean air within the U.S. at \$22.2 trillion over a two-decade period and that the benefits of reduced ozone pollution over a single decade were \$409 billion (Kerkvliet & Culver, n.d.).

This pollution can be particularly damaging for people in vulnerable demographic groups, namely children, pregnant women, and the elderly, who may be particularly susceptible to health effects from exposure to pollution from natural gas facilities.

We consider the public health implications—numbers of illnesses and their economic costs—of drilling sites and of the Myersville Compressor station in turn.

Public Health and Unconventional Natural Gas Drilling

As the fracking boom continues, more and more literature suggests negative associations between the drilling process and public health impacts. Public officials in Maryland need to seriously consider the potential effects of fracking on its citizens as evidenced by lessons learned in other communities in the Marcellus and across the

nation. These impacts range, but are not limited to, elevated air impacts from increased levels of particulate matter, diesel exhaust, and other volatile organic chemicals, to surface and groundwater quality concerns (Banerjee, 2015).

Similarly, researchers at Johns Hopkins University found that radon, the second-leading cause of lung cancer worldwide and number one cause of lung cancer for nonsmokers, increases in homes near fracking (Casey et al., 2015).

Water pollution also creates a new suite of direct and indirect impacts for people living near drilling and associated infrastructure. People living closer to a fracking well face a higher risk of groundwater and drinking water well contamination (Meng, 2014). Pennsylvania's Department of Environmental Protection (PDEP) reported about 240 private water supplies were contaminated by oil and gas operations over a seven-year period (Legere, 2014), and a study examining methane in well water found that concentrations rose sharply with proximity to fracking sites (Holzman, 2011).

NASA found that leaks from fracking production significantly contribute to overall methane emissions in the U.S. (RT International, 2016). Methane is much more potent than carbon dioxide as a greenhouse gas; it has a global warming potential of up to 84 times that of carbon dioxide, depending on the time frame considered (Pachauri, Mayer, & Intergovernmental Panel on Climate Change, 2015). On the local level, drilling operations in Pennsylvania potentially release plumes of methane up to 1,000 times the EPA expected rate (Clark, 2014). Communities living in drilling areas with higher methane concentrations are more at risk for developing respiratory, cardiovascular, and neurological long-term health problems. This is in part due to concentrations of toxic chemicals released along with the methane, according to Ed Avol, a USC professor of clinical medicine who is studying the effects of the Porter Ranch gas leak (Vuong, 2016).

Long exposure to fracking chemicals and dust puts gas industry workers at particular risk of acute and chronic illness. The National Institute for Occupational Safety and Health (NIOSH) found that workers in the UNGD industry are exposed to unsafe levels of respirable crystalline silica dust (OSHA-NIOSH, 2016). Constantly being exposed to silica, which comprises 99% of hydraulic fracturing sand, leads to a greater risk of silicosis, a lung disease with no cure.⁹

This report does not quantify all public health costs of increased exposure to hazards such as silica and water contamination or health threats due to methane. Instead we apply recent research for two health effects, excess asthma exacerbations and adverse

⁹ We do not count the cost of occupational illness in this report because those and other costs borne by fracking companies and their employees are not "external" to the fracking industry. At least in concept, the costs stemming from elevated workplace hazards faced by gas industry workers would be reflected in the cost of company-provided health insurance, in the cost of compliance with occupational safety and health requirements, and in workers' wages. We would speculate, however that these costs only partially mitigate or offset the costs to workers and their families.

birth outcomes, to the drilling scenarios for Garrett County to provide an example of what some of the public health costs of UNGD might be.

Asthma Exacerbations

Asthma is one of the most common and costly diseases in the U.S. (Center for Disease Control and Prevention, 2016), and a recent study of asthma sufferers in the Marcellus Shale region of Pennsylvania suggests that UNGD makes treating the disease even more costly. Rasmussen et al. (2016) finds that people with asthma who live closer to UNGD sites have significantly higher rates of “asthma exacerbations” evidenced by trips to emergency departments, hospitalizations, and orders for oral corticosteroid medication. The authors were able to establish this relationship by examining the specific location of well pads and the timing and extent/intensity of drilling activity, the home addresses of known patients, and various other factors that may contribute to asthma exacerbations.

For our analysis of possible health impacts in Garrett County, we do not have the same level of detail about drilling activity. This is because no UNGD wells currently exist. Nor do we have information about the addresses of known asthma patients or their other risk factors. However, we do have information about asthma prevalence and total population in Census blocks (a relatively small geographic area—there are 2,520 Census blocks in Garrett County). Based on our drilling scenarios, we also have the location of possible UNGD sites and an estimate of the number of wells that could be drilled on each one. With some further simplifying assumptions, namely that the influence of complicating factors will be similar for people living in different block groups, it is possible to project the cost of certain asthma exacerbations based on the relationships established by Rasmussen et al. We restrict our projections to emergency department visits and hospitalizations, for which estimates of the cost per exacerbation specific to Garrett County are available (Maryland Asthma Control Program, 2011).¹⁰

As a measure of proximity, we use a version of the “pad preparation” metric from Rasmussen et al. (2016). Pad preparation is related to asthma exacerbations through the air emissions from truck traffic to and from UNGD sites and particulates made airborne due to the excavation, construction, and other activity at the sites. Our pad preparation metric is based on the distance in meters from the geographic center of each Census block group to the geographic center of each potential drilling site in the four primary drilling scenarios. Thus,

$$\text{Pad Preparation Metric for Census block } j = \sum_{i=1}^n \frac{1}{d_{ij}^2},$$

where d is the distance between each Census block j and each well site i .

To restrict our estimates to the wells that would most likely affect people living in the Census blocks, we only included potential sites within 10,000 meters (about 6.2 miles)

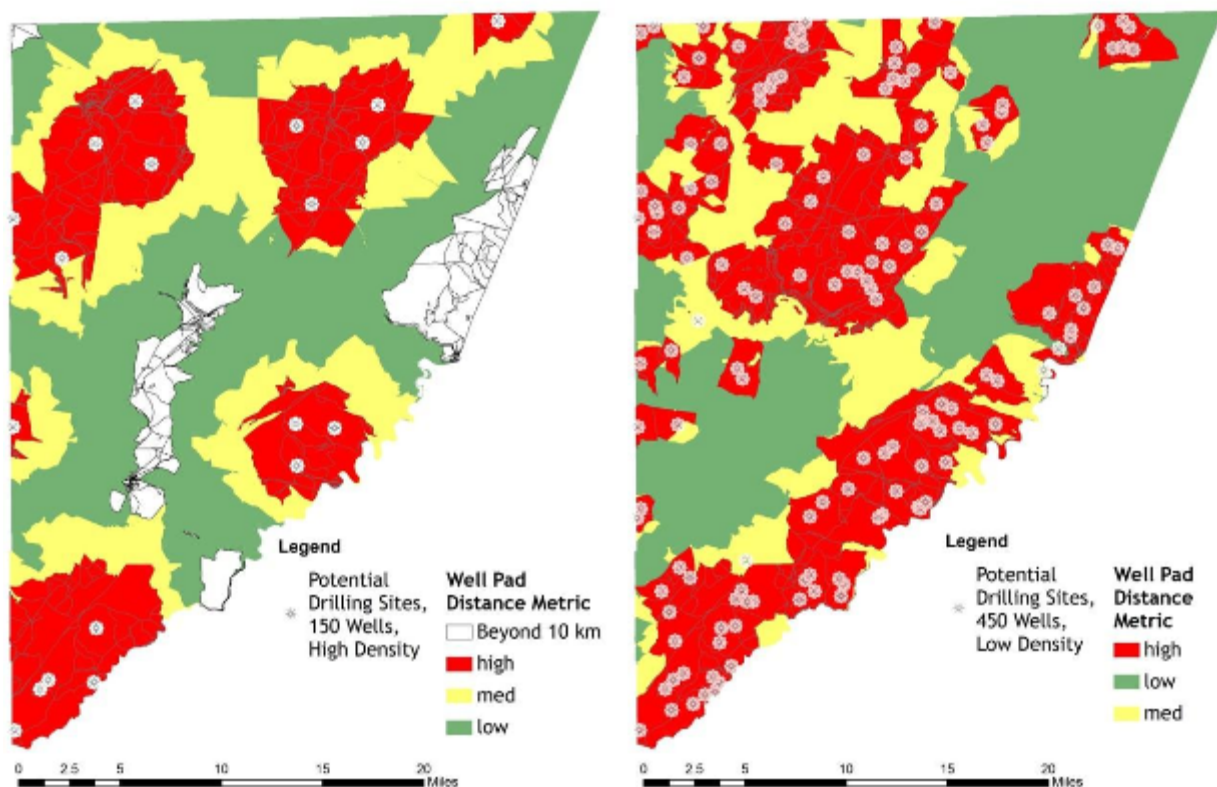
¹⁰ This leaves out the costs of oral corticosteroids (OCS), for which identifying the link between UNGD activity and the need for the additional OCS is more complicated than our information allows us to establish.

of the geographic center of each Census block in this calculation. Census blocks are then assigned to low, medium, and high exposure categories, based on the quartile rank of the pad preparation metric. Low blocks have distance metrics in the bottom two quartiles (50%) of all blocks; medium blocks are in the third quartile, and high blocks have distance metrics in the top quartile. (i.e. closest to potential UNGD sites). Figure 3 displays the classification of Census blocks for the lowest and highest impact scenarios.

After estimating the number of adults (18 years and older) with asthma in each Census block, we estimate the background rate of asthma exacerbations (emergency department visits and hospitalizations) for those asthma patients (U.S. Census Bureau, 2015; Maryland Asthma Control Program, 2011; Rasmussen et al., 2016). Next, we apply odds ratios from Rasmussen et al. (2016) to estimate the number of additional asthma exacerbations that could be experienced by asthma patients living in “low,” “medium,” and “high,” exposure areas each year. Finally, we apply an inflation-adjusted cost per exacerbation to obtain an estimate of the annual cost of those exacerbations. Figure 3, below, shows the distance metric for Census blocks in the lowest and highest UNGD scenarios.

Figure 3: Distance Metrics for Census Blocks under Lowest and Highest UNGD Scenarios.

The “lowest” scenario (left) assumes 150 wells at a high well density per pad, and therefore has the least number of well pads and the fewest people exposed of any scenario. The “highest” scenario (right) assumes 450 wells with relatively few wells per pads. Note that the distance from potential well sites is measured to the geographic center of each Census block within 10 km, and some sites near the edge of or even within some Census blocks may still be some distance from the center of such blocks.



Projected annual costs for additional asthma exacerbations range from \$2,044 under the 150-well, high-well-clustering scenario (the least-impact scenario) to \$2,257 under

the 450-well, low-well-clustering scenario (the greatest-impact scenario). These estimates do not include the cost of lost wages or other measures of reduced productivity that could accompany the direct medical treatment costs.

The figures presented here could be overestimates or underestimates of the true cost of asthma treatment due to UNGD in Garrett County. The estimates may be high given that all well sites in the scenarios will not be developed at the same time or operated in every year. Incorporating the timing of potential build-out would add another dimension to the scenarios (already characterized by number of wells and number of sites) and multiply the number of scenarios that would have to be considered. On the other hand, we have covered only exacerbations associated with well pad development. Additional exacerbations would be expected when wells are drilled (“spudded”), stimulated (fracked), and as they produce natural gas (Rasmussen et al., 2016).

A more complex model that incorporated timing, all phases of UNGD, more specific data on the location of existing asthma patients, and other conditions that could contribute to asthma exacerbations would yield more precise estimates of the cost of asthma exacerbations. Our aim here, however, is to illustrate a general path toward a more complete accounting of the costs of UNGD. In the event that UNGD is permitted in western Maryland, it would be prudent to gather specific baseline health data from all locations potentially affected, to monitor public health over time, and to use a portion of proceeds from natural gas development (collected through severance taxes or other means) to compensate victims of UNGD-related health effects.

Table 4: The Cost of Additional Asthma Exacerbations Due to Potential Unconventional Natural Gas Development in Garrett County.

UNGD Scenario (Wells and Well Density)	Distance Metric Level (for Census Blocks)	Adults (>18 yo) with Asthma	Exacerbation Outcome (Emergency Department Visit or Hospitalization)	Background Number of Exacerbations	Excess Exacerbations based on Distance Metric ^a	Cost of Excess Exacerbations ^b (2015\$)	Total of Excess Costs for Scenario, all Census Blocks
150 wells at low density	Low	824	Emergency	2.79	1.48	\$332	\$2,241
	Medium	304	Emergency	1.03	0.79	\$178	
	High	330	Emergency	1.12	0.41	\$93	
	Low	824	Hospitalization	0.37	0.1	\$739	
	Medium	304	Hospitalization	0.14	0.05	\$388	
	High	330	Hospitalization	0.15	0.07	\$512	
150 wells at high density	Low	730	Emergency	2.48	1.31	\$294	\$2,044
	Medium	323	Emergency	1.1	0.84	\$189	
	High	269	Emergency	0.91	0.34	\$76	
	Low	730	Hospitalization	0.33	0.09	\$655	
	Medium	323	Hospitalization	0.15	0.05	\$412	
	High	269	Hospitalization	0.12	0.05	\$417	
450 wells at low density	Low	795	Emergency	2.69	1.43	\$320	\$2,257
	Medium	318	Emergency	1.08	0.83	\$186	
	High	345	Emergency	1.17	0.43	\$97	
	Low	795	Hospitalization	0.36	0.09	\$713	
	Medium	318	Hospitalization	0.14	0.05	\$406	
	High	345	Hospitalization	0.16	0.07	\$535	
450 wells at high density	Low	857	Emergency	2.91	1.54	\$345	\$2,223
	Medium	273	Emergency	0.93	0.71	\$160	
	High	328	Emergency	1.11	0.41	\$92	
	Low	857	Hospitalization	0.39	0.1	\$768	
	Medium	273	Hospitalization	0.12	0.05	\$348	
	High	328	Hospitalization	0.15	0.07	\$509	

Notes: a. The odds ratio used to calculate exacerbations (from Rasmussen et al., 2016) included children, but available information on the base rate of reported asthma prevalence for Garrett County includes only adults (18 years and older).
 b. Cost estimates are from a profile of asthma in Garrett County (Maryland Asthma Control Program, 2011). The average cost per emergency room visit in 2009 due to asthma in Garrett for adults (>18 yo) was \$203. The average cost per hospitalization in 2009 due to asthma in Garrett for adults (>18 yo) was \$6,935. Both costs adjusted to 2015\$.

Birth Outcomes and Unconventional Natural Gas Development

Low birth weight (LBW) is strongly associated with infant mortality and developmental problems in childhood, as well as with greater risk of developing various diseases in adulthood (Wilcox, 2001). Maternal exposure to benzene while pregnant, for example, increases the odds of low birth weight (LBW) (Zahran, 2012), and many other measured chemicals associated with drilling (SO₂, NO_x, and VOCs) have been linked to low birth weight. Hill (2013) compared birth outcomes in areas around permitted (and later operating wells) and found “a statistically significant increase in low birth weight of 1.36 percentage points [25% higher than the background rate] and a reduction in term birth weight of 49.58 grams, on average” (p .24).

Following the methods in Hill (2013) we estimate the additional number of LBW babies due to UNGD per year in Garrett County, Maryland. The first step is to estimate the number of live births for the population living in Census blocks that are within 2.5 km of the potential well sites in our four primary scenarios (U.S. Census Bureau, 2015). The background rate of LBW in Garrett County is 10.56% of live births (Maryland State Department of Health and Mental Hygiene, 2014). If UNGD increases that rate by 25% (Hill, 2013), an additional 2.64% of live births would be LBW. Multiplying that percentage by the number of live births gives us the small number of LBW births that could result from UNGD in Garrett County (Table 5). According to Hill (2013), a conservative estimate of lifetime healthcare and special education costs, plus decreased earnings, comes to \$96,500 per LBW birth. Multiplying this figure by the expected number of LBW births per year yields an estimate of the annual LBW-related additions to the expected external cost of UNCD in Garrett County.

Due to the small number of people who live near the well sites in our scenarios, one would expect only one additional low birth weight outcome, at worst, every 22 years, on average. (The 450 wells at low density scenario has an elevated incidence of LBW of 0.045 babies per year.) The annual expected costs are similarly small, ranging from \$1,265 in the 150-well, high-well-density scenario, to \$4,454 in the worst case scenario just mentioned. This is not to say, of course, that the effects on the small number of children affected and on their families and communities will not be profound. It does suggest, however, that including compensation and mitigation funds from severance taxes or other fees paid by the energy industry for such families would be reasonable.

Table 5: Expected Health Care, Special Education, and Lifetime Earnings Costs of UNGD-Related Increases in Low Birth Weight Outcomes in Garrett County

UNGD Scenario (Wells and Well Density)	Annual Live Births per year within 2.5 km of a Well Pad	Baseline LBW Births per year	Additional LBW Births per year due to UNGD	UNGD's Annual Addition to lifetime LBW-related Costs (2015\$)
150 wells at low density	1.06	0.112	0.028	\$2,740
150 wells at high density	0.49	0.052	0.013	\$1,265
450 wells at low density	1.72	0.182	0.045	\$4,454
450 wells at high density	0.97	0.102	0.026	\$2,521

Public Health and Compressor Stations (Myersville, Maryland)

To bring fracked gas to market, the industry must transport the gas from the well via pipelines which require compressor stations every 50 to 100 miles (Energy Information Administration, 2007). The negative effects of compressor stations can include noise and air pollution from everyday operations plus periodic “blowdowns,” or venting of gas in the system to reduce pressure. As a recent study by the New York Department of Environmental Conservation indicates, pollution around compressor stations is common and severe. The five-state study found that “more than 40 percent of the air samples from compressor stations exceeded federal regulations for certain chemicals like methane, benzene, and hydrogen sulfide” (Lucas, 2015). The study also found high rates of illnesses such as nosebleeds and respiratory difficulties among people living near the stations.

Emissions from compressor stations are implicated in a long list of maladies. According to Subra (2015), individuals living within 2 miles of compressor stations and metering stations experience respiratory impacts (71% of residents), sinus problems (58%), throat irritation (55%), eye irritation (52%), nasal irritation (48%), breathing difficulties (42%), vision impairment (42%), sleep disturbances (39%), and severe headaches (39%). In addition, some 90% of individuals living within 2 miles of these facilities reported experiencing odor events (Southwest Pennsylvania Environmental Health Project, 2015). Odors associated with compressor stations include sulfur smell, odorized natural gas, ozone, and burnt butter (Subra, 2009). Finally, compressors emit constant low-frequency noise, which can cause negative physical and mental health effects (Lockett, Buppert, & Margolis, 2015; Boyle, 2014).

In Frederick County, 3,255 people live in Census blocks that have their geographic center within 2 miles of the existing Dominion Transmission compressor station in Myersville (U.S. Census Bureau, 2015). Based on the percentages in Subra, this would mean there are 2,930 people experiencing odor events, 2,311 people experiencing respiratory impacts, 1,888 people experiencing sinus problems, and 1,269 people experiencing sleep disturbances and/or severe headaches.

Motor Vehicle Accidents and Road Damage

Motor vehicle accidents (MVAs) are a leading cause of injury and death among gas field workers. Workers in the gas industry are 8.5 times more likely than all private wage and salary workers to experience a fatality in the workplace (Retzer et al., 2013). The added truck traffic and increased passenger vehicle traffic from temporary workers and fracking vehicles increases the rate of motor vehicle accidents for the existing population in gas-producing regions (Graham et al., 2015).

It is not just oil and gas workers who are affected. Counties where drilling occurs may experience up to 23% higher vehicle crash rates and up to 65% higher heavy truck crash rates (Graham et al., 2015). In West Virginia, some counties with extensive UNGD have seen a 40% increase in traffic fatalities, while the rest of the state has seen an 8% decline in traffic fatalities. In Pennsylvania, traffic fatalities in drilling counties rose by 4% while the rate fell by 19% in other Pennsylvania counties (Cassidy, 2014).

There are four factors that may increase the risk and cost of motor vehicle accidents if fracking is permitted in Maryland. First there will simply be more vehicles on the roads. Much of the added traffic will consist of heavy and light-duty truck traffic directly related to UNGD activities. UNGD requires about 2,300 to 4,000 truck trips per well (Cassidy, 2014). Under the 25% extraction scenario, Allegheny and Garrett Counties would see 22,595 more heavy truck trips, on average, each year. For light duty trucks, there would be an average annual increase of 7,903 trips. In the 75% extraction scenario, the average annual increases would be 67,785 heavy duty truck trips and 23,708 light duty truck trips (Regional Economic Studies Institute, 2014).

The second factor is the extent to which much of the additional traffic will be due to driving by workers from outside the community who are less familiar with local roads. This could mean a higher rate of MVA than would be expected from a simple increase in driving by long-time local residents.

Third, gas field workers typically work long hours, and the rules governing required rest for truckers carrying water, pipe, and other supplies to well sites are looser than for truckers servicing other industries. Consequently truckers and gas field workers may be

more fatigued while operating vehicles on the job or on the way to their homes or temporary lodgings (Urbina, 2012; Olson, 2016).

Fourth and finally are the effects of damage to local roads not designed to take the punishment brought by heavy trucks carrying fracking fluids and drilling equipment or the additional traffic volume associated with fracking. Unless state and county crews can keep up with the damages and upgrade roads to prevent further damage, poor road conditions can lead to further accidents.

No matter the cause, motor vehicle accidents translate into a variety of costs. According to the National Highway Traffic Safety Administration (2015), accidents result in medical care costs, lost productivity (including lost working years for people killed in crashes), costs for emergency services, costs of legal representation and insurance claims administration, costs of damage to property, costs of congestion on roadways in the aftermath of accidents, and costs of environmental/natural resource damage caused by spilled fuel and hazardous cargo.

Table 6. Cost of Motor Vehicle Accidents Per Year Due to Fracking in Garrett County

	Total Crashes	Fatal Crashes	Injury Crashes	Property Damage Crashes
Motor Vehicle Accidents 5-year average, 2010-2014	498	6	164	328
Fatalities and Injuries, 5-year average, 2010-2014		7	241	
Additional Accidents per year due to UNGD	23.2	0.3	7.6	15.3
Additional Fatalities & Injuries to UNGD		0.3	11.2	
Cost per Crash (Adjusted to 2015\$) ^a		\$1,656,297	\$45,509	\$7,354
Incremental Cost of UNGD-related Accidents (Annual, 2015\$)	\$922,502	\$462,699	\$347,497	\$112,307

Note: a. The cost for each type of crash is obtained from the National Highway Traffic and Safety Administration (2015) report titled *The Economic and Societal Impact of Motor Vehicle Crashes, 2010*.

To develop an estimate of what these costs might be if UNGD comes to Garrett County, we begin with the annual average number of motor vehicle accidents (fatal crashes, injury crashes, and property-damage-only crashes) in the county. Garrett County currently experiences 0.931 MVAs per million miles travelled (Maryland Center for Traffic Safety Analysis, 2015). Graham et al. (2015) finds that MVA rates increase by 5% in areas with active fracking operations. For Garrett County, that would increase the MVA rate to 0.975 accidents per million miles travelled or 23.2 additional accidents per year during UNGD. Assuming the same proportion of crash types, there would be 0.3

additional fatal crashes, 7.6 additional injury crashes, and 15.3 additional property-damage-only crashes, on average, each year.

After adjusting per-accident costs for inflation and multiplying by the numbers of accidents, we calculate the total cost of UNGD-related MVAs to be \$922,502 per year (see Table 6). Fatal crashes account for the largest share of these costs, followed by injury, and then property-damage-only crashes.

Increases in vehicle traffic volume are not only a catalyst for additional accidents, they also produce strains on existing transportation infrastructure. The large volume of heavy truck traffic associated with drilling degrades local roads and warrants an examination into the costs of the physical deterioration. Heavier vehicles cause exponentially more road damage (Abramzon et al., 2014). The estimated cost of road-reconstruction associated with a single horizontal well in the Pennsylvania portion of the Marcellus Shale formation ranges from \$13,000 to \$23,000, however, because the state will negotiate with drilling companies to rebuild visibly damaged small roads, the conservative estimate is \$5,000 to \$10,000 per well (Abramzon et al., 2014). Using those lower bounds and the total number of wells needed during the potential extraction period in Garrett County (Regional Economic Studies Institute, 2014), it would cost either Garrett County or the state of Maryland, \$3.9 to \$17.9 million if 25% of the total potential recoverable shale gas is extracted between 2017 and 2026 or \$12.1 to \$55.5 million if 75% of the total is extracted (Regional Economic Studies Institute, 2014).

In other areas of the Marcellus Shale region, some counties with heavy drilling activity are also seeing a spike in 911 calls or incidents (Detrow, 2011). Many of these calls are attributed to heavy trucks causing congestion and accidents involving large rigs, tractor trailers, dump trucks, and trucks with hazardous materials. Before drilling, 911 calls typically dealt with two-car accidents (Detrow, 2011).

While any traffic accident includes the need to address the risks posed by hazardous materials (fuel and fluids), the addition of trucks carrying hazardous materials, such as fracking chemicals and wastewater, increase both the likelihood of accidents requiring hazardous materials response and, potentially, the severity of any hazardous materials incidents. For responders, not knowing what chemicals, compounds, or other volatile materials are present at the scene present an inherent risk to the safety and well-being of those individuals. As Rand Moyer, a trucker now unable to work due to illness he believes was caused by exposure to fracking wastewater, stated “We weren't told what we were dealing with. We weren't given MSDS sheets (material safety data sheets) or any training on any of this stuff” (Moyer, 2016).

Emergency responders would likely have hazardous materials training and protective clothing (neither of which were provided to Mr. Moyer). However, not knowing what chemicals have spilled from a vehicle complicates everything from how to contain the

spill and how to determine a safe evacuation distance, to what to do with absorbents, other equipment, and supplies exposed to the spilled substances.¹¹

Adding the costs of motor vehicle accidents to increased road maintenance UNGD would cost between \$4.8 and \$18.8 million if 25% of the total potential recoverable shale gas is extracted between 2017 and 2026 or \$13.1 and \$56.4 million if 75% of the gas were to be extracted.

Social Cost of Carbon

The concept of clean natural gas is a misnomer. The increased urgency at all levels of government to mitigate climate change impacts and limit greenhouse gas emissions means that understanding the true cost of UNGD development is more important than ever. The social cost of carbon, ranging from \$12 to \$108 per metric ton, carbon dioxide equivalent (CO₂E), gives policy makers a tool to examine and quantify the economic harm of carbon (U.S. EPA, 2016). We use the EPA's methods to predict the social cost of carbon annually in western Maryland if 25% or 75% of the total potential recoverable shale gas is extracted between 2017 and 2026.

Table 7. Social Cost of Emissions of Carbon (and Carbon-Equivalents) due to UNGD in Western Maryland

	Natural Gas Extraction (Average bcf/year)	Net CO ₂ Emissions (MT CO ₂ E/year)	Annual Social Cost using 5% discount rate ^a (2015\$)
25% Extracted	18	957,548	\$12,039,245
75% Extracted	53	2,883,586	\$36,255,326

Note: a. This means that the cost of today's emissions of carbon (or carbon equivalents) in future years are discounted at 5%. Thus, for example, a \$10,00 cost experienced 5 years in the future would be valued at \$10,000/(1.05)⁵ today.

Under the 25% scenario, the RESI study estimates 175 bcf of natural gas would be extracted in Western Maryland over a 10 year period (Regional Economic Studies Institute). Using EPA estimates where 1 bcf is equivalent to 54,717 metric tons of CO₂ (U.S. EPA, 2016), under this scenario we would expect an average net CO₂ increase of about 957,500 metric tons of carbon a year for the 10 year period costing \$12.0 million a year. Under the 75% scenario, we would expect an average net CO₂ increase of about

¹¹ The principal author is a former firefighter certified in hazardous materials operation, and some of this material is based on personal experience.

2,883,586 metric tons of carbon a year for the 10 year period costing \$36.3 million a year.

Maryland's Greenhouse Gas Emission Reduction Act of 2016 aims for a 40% reduction of MMtCO₂E, or a reduction of 57 MMtCO₂E by 2030 (Aburn, 2016). If UNGD is permitted in western Maryland, the 25% scenario would increase emissions by about 2% of the target; under the 75% recovery scenario, emissions would increase by about 5% of the total. UNGD would make it that much harder to meet the state's target reduction.

Forgone Ecosystem Services

The idea that people receive benefits from nature is not at all new, but “ecosystem services” as a term describing the phenomenon is more recent, emerging in the 1960s (Millennium Ecosystem Assessment, 2003). “Benefits people obtain from ecosystems” is perhaps the simplest and most commonly heard definition of ecosystem services (Reid et al., 2005). Other definitions abound, including the following from Gary Johnson of the University of Vermont. It is helpful both because it emphasizes that services are not necessarily things—tangible bits of nature—but rather, they are the effects on people of the functions of bits of nature:

Ecosystem services are the effects on human well-being of the flow of benefits from an ecosystem endpoint to a human endpoint at a given extent of space and time (Johnson, 2010).

This definition also makes clear that ecosystem services happen or are produced and enjoyed in particular places and at particular times.

Shale gas extraction and related infrastructure will affect the flow of benefits from Maryland ecosystems and to Maryland residents and visitors. Well pads, fracking fluid holding ponds, gathering lines, and new transmission lines entail the conversion of land from one use to another.

Because different land uses are associated with different levels of ecosystem service production, changing the land use/land cover means changing the ecosystem services output. Forestland, cropland, urban open space, and other relatively natural areas produce ecosystem service value at a much higher rate than the barren ground and industrial facilities of pipeline construction corridors and fracking well pads. While the portion of the construction zone that becomes the permanent right-of-way would eventually be revegetated and function as shrub/scrub or grassland, that portion will not be as productive as the forest, urban open space, and other land uses taken for the pipeline. Thus the advent of hydraulic fracturing in western Maryland and the expansion of gas transmission infrastructure in the east will reduce the benefits people obtain from ecosystems.

While few of these ecosystem services are traded at a *market price* (food, some recreational opportunities, and water supply are exceptions), all of them have *economic value*. It is possible to estimate these values in various ways; we chose the well-established benefits transfer method, or “BTM,” here. According to the Organization for Economic Cooperation and Development, BTM is “the bedrock of practical policy analysis,” particularly in cases such as this when collecting new primary data is not feasible (OECD, 2006, p. 253).

BTM takes a rate of ecosystem benefit delivery calculated for one or more “source areas” and transfers or applies that rate to conditions in the “study area.” As Batker et al. (2010) state, the method is very much like a real estate appraiser using comparable properties to estimate the market value of the subject property. It is also very much like using an existing or established market or regulated price, such as the price of a gallon of water, to estimate the value of some number of gallons of water supplied in some other place or period of time. The key is to select “comps” (data from source areas) that match the circumstances of the study area as closely as possible.

Typically, values are drawn from previous studies that estimate the value of various ecosystem services from similar land cover or ecosystem types. Also, it is benefit (in dollars) per-unit-area-per-year in the source area that is transferred and applied to the number of hectares or acres in the same land cover/biome in the study area. So, for example, if data for the source area includes the value of forest land for recreation, one would apply per-acre values from the source area’s forest to the number of acres of forestland in the study area. Furthermore, it is important to use source studies that are from regions with underlying economic, social, and other conditions similar to the study area.

Following these principles as well as techniques developed by Esposito et al. (2011), Esposito (2009), and Phillips and McGee (2014, 2016), we employ a four-step process to evaluate the short-term and long-term effects of unconventional gas drilling in Garrett County and the Columbia Pipeline in Baltimore and Harford Counties on ecosystem service value. In summary, the steps for estimating ecosystem service value and potential losses are:

1. Assign land and water in the study to one of 10 land uses based on remotely sensed (satellite) data in the National Land Cover Dataset (NLCD) (U.S. Geological Survey, 2014). This provides the array of land uses for estimating baseline or “without drilling” and “pre-pipeline” ecosystem service value.

Figure 4 shows the land cover for all of Garrett County along with the potential drilling sites and those sites selected for the 450-well, low-density scenario. Land conversion per pad (including the pad itself and associated infrastructure) is 7.16 acres for compact well pads and 12.70 acres for larger well pads (Jantz et al., 2014). Figure 5 depicts the acreage in each land cover type that would be converted in the various 150- and 450-well scenarios. Figure 6 shows the baseline acreage, by land cover type, that will be converted for the 75-foot Columbia

pipeline construction corridor and the 50-foot pipeline right-of-way.

2. Re-assign or re-classify land and water to what the land cover would most likely be if drilling is permitted, during pipeline construction, and during later and ongoing operation of the pipeline. For drilling sites and the pipeline construction zone during construction¹², the “with drilling” or “with pipeline” land use is barren land. For the pipeline right-of-way, land that was in forest before pipeline construction returns to shrub/scrub, and pre-pipeline cropland returns as pasture/forage. Other acreage is assumed to revert to its baseline cover type after construction is completed.
3. Multiply acreage by per-acre ecosystem service productivity (the “comps”), in dollars-per-acre-per-year form, to obtain estimates of ecosystem service value under the baseline scenario and under the “with-drilling” and “with-pipeline” scenarios. For the pipeline, separate estimates are obtained for the construction corridor and for the right-of-way.

For many combinations of land use and ecosystem service there are multiple estimates of ecosystem service productivity (\$/acre/year) available from existing studies. Our reported estimates below reflect the ecosystem service value computed using the lowest of the available productivity values. Our estimates should therefore be considered a conservative estimate of ecosystem service value forgone due to drilling or the pipeline.

4. Subtract baseline ecosystem service value (ESV) from ESV in the “with-drilling” or “with-pipeline” scenarios to obtain estimates of the ecosystem service costs imposed annually during the drilling, pipeline construction, and pipeline operations periods.¹³

¹² For simplicity we assume that the pipeline construction corridor will remain barren for a full two-year period. We recognize that revegetation will begin to occur soon after the trench is closed and fill and soil are returned, but it will still be some time until something like a functioning ecosystem has actually been restored.

¹³ Further details on these techniques as applied to pipeline corridors be found in Phillips, S., Wang, S., & Bottorff, C. (2016). *Economic Costs of the Mountain Valley Pipeline: Effects on Property Value, Ecosystem Services, and Economic Development in Virginia and West Virginia* (p. 51). Key-Log Economics LLC. Retrieved from http://keylogeconomics.com/wp1/wp-content/uploads/2016/05/EconomicCostsOfTheMVP_TechnicalReport_FINAL_20160516.pdf

Figure 4: Land Cover in Garrett County, Maryland, with Potential UNGD Sites and Sites Randomly Selected for the 450-Well, Low-Density Scenario

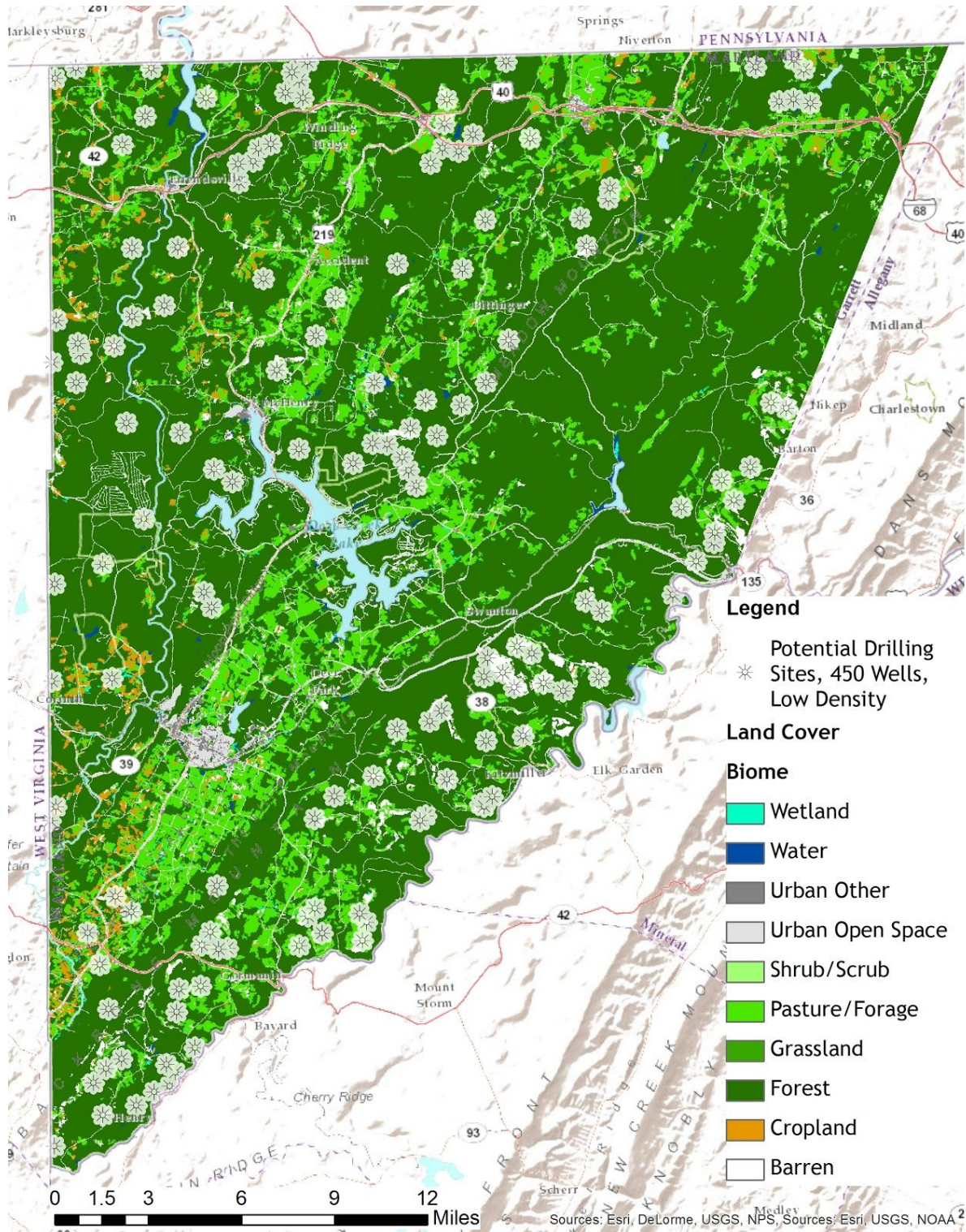


Figure 5: Land Use Conversion in the 150-Well and 450-Well Scenarios

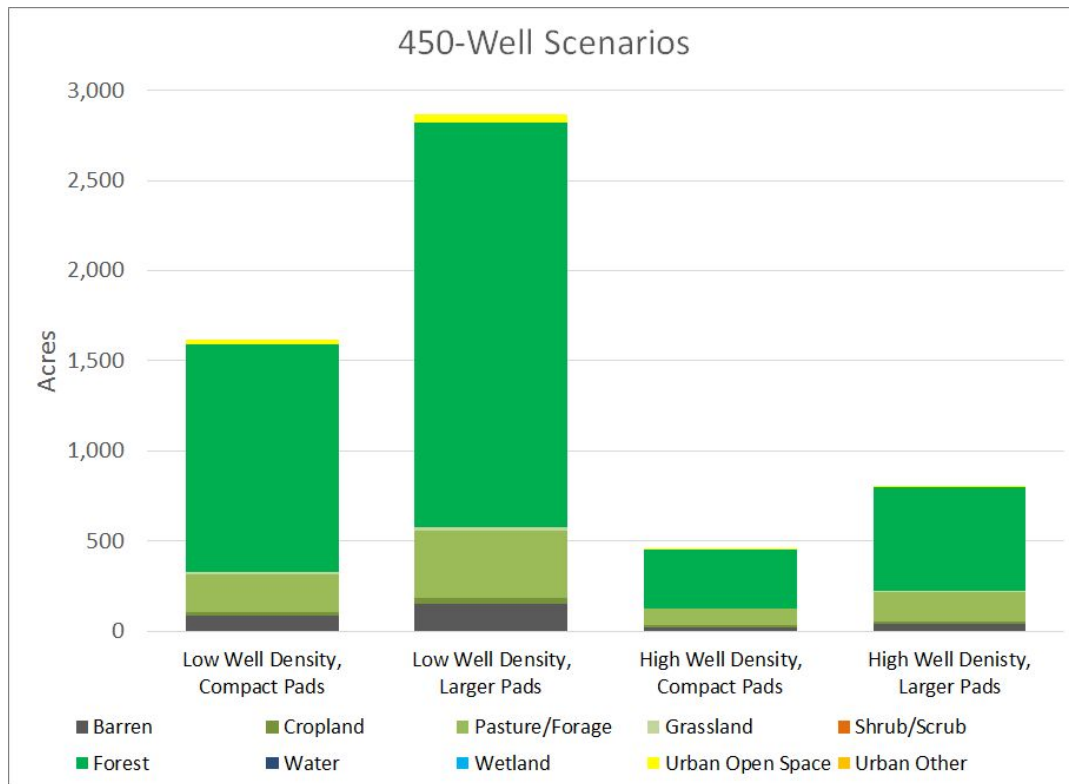
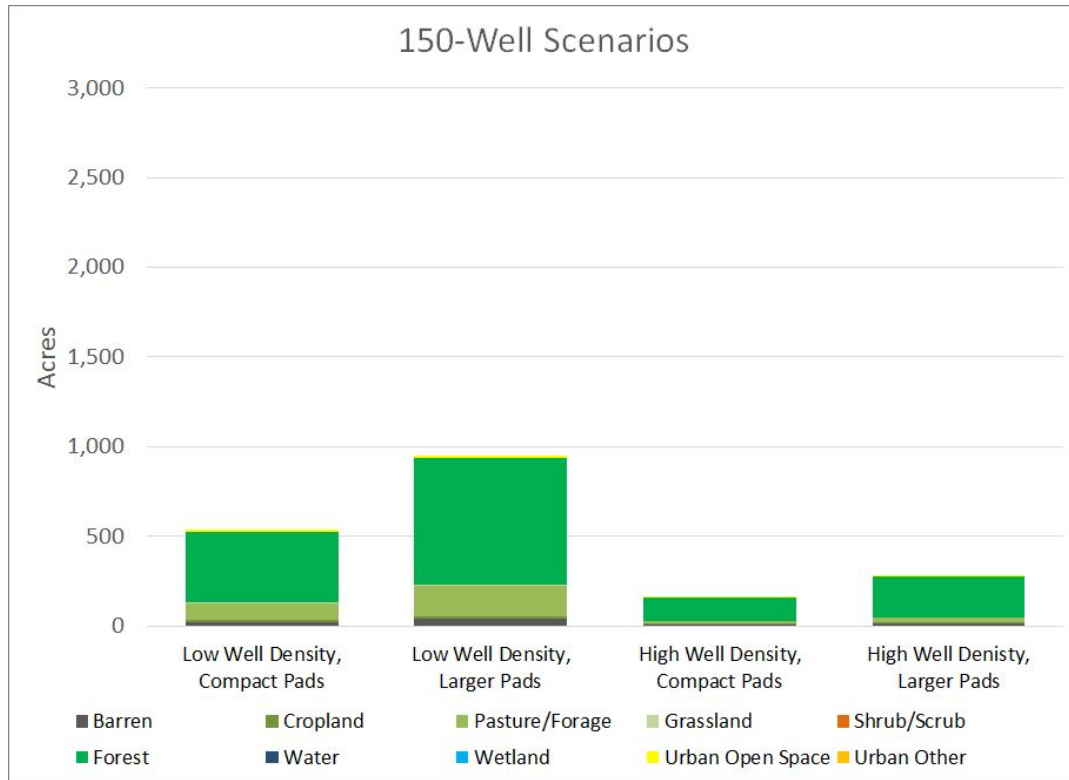
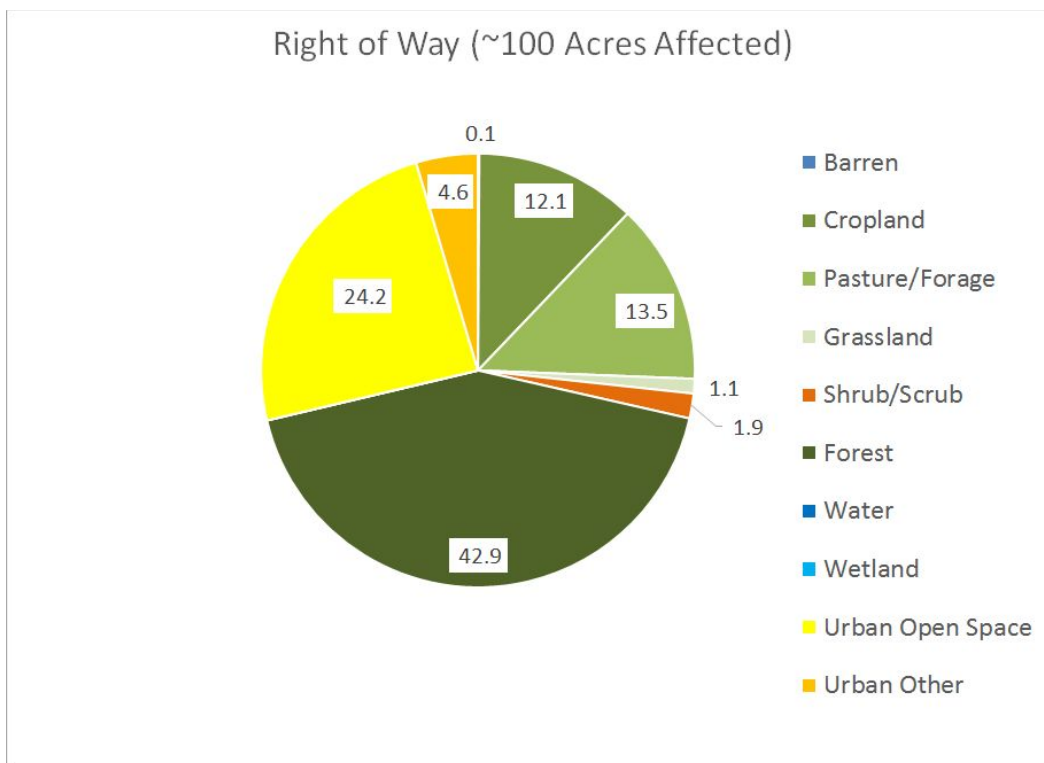
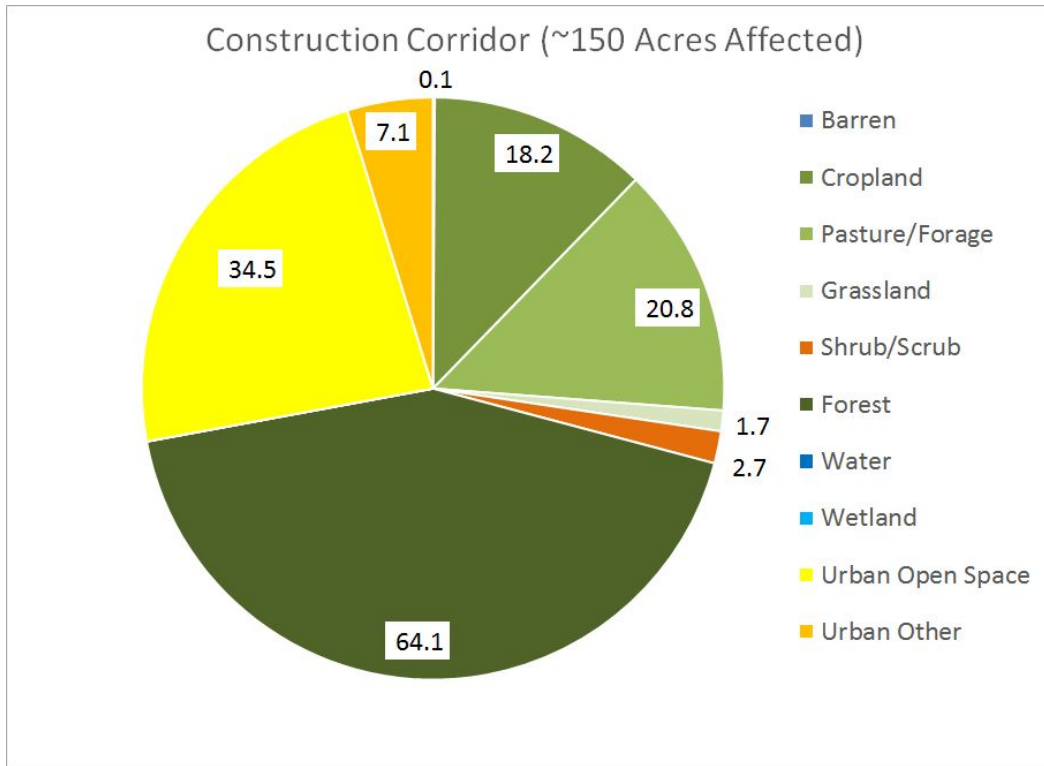


Figure 6: Baseline Land Cover in the Columbia Pipeline Construction Corridor and Right-of-Way



Ecosystem Service Value Estimates

Potential UNGD Sites

Relative to the baseline or “no drilling” scenario, converting land in Garrett County from its current uses to well pads and related infrastructure would cost between \$809,000 (for 150 wells at high density on compact pads) and \$14.1 million per year (for 450 wells at low density on large pads). In all scenarios, and because the vast majority of the affected acreage is currently in forest, most of this loss value is due to losses of forest land. Lost land classified, pre-drilling, as urban open space, as cropland, or as pasture/forage are the next largest in terms of lost ecosystem service value.

Forests provide high aesthetic value that shows up in housing prices and value for the tourism industry; they slow down rainwater and wind during extreme weather, and they filter particulates and other pollutants out of the air.

Tables 8 and 9 present full results for the eight scenarios defined by number of wells, degree of well clustering, and the size of well pads.

Columbia Pipeline Construction Corridor and Right-of-Way

Construction of the Columbia pipeline will cause an estimated loss of \$517,000 worth of ecosystem service value per year during construction. For the right-of-way (ROW), the annual loss would be \$264,000 per year. The annual loss for the ROW is smaller for two reasons. First, the ROW is two thirds the width of the construction corridor (50 vs 75 feet), and the one third of the construction corridor that does not become permanent ROW is assumed to eventually return to its pre-construction land cover, which will be much more productive than the barren construction zone. Second, all of the land that becomes part of the permanent ROW will return to some productive land cover, typically to its pre-construction land cover. (The exceptions are cropland and forests, as noted in step 2 of the method described above.)

As with the potential UNGD sites in Garrett County, it is the loss of forest acreage and the loss of aesthetic value that make up the largest share of total ecosystem service value lost to the the Columbia pipeline. Table 10 displays the full estimation results. Two seeming anomalies to point out have to do with the net increases in ecosystem service value for pasture/forage and shrub/scrub land in the ROW. This has to do with the range of available per-acre values that are transferred to the acreage in question. Pasture/forage has a higher per-acre aesthetic value, according to the available “comps”, than does cropland. Cropland that becomes pasture/forage after construction therefore produces more aesthetic value, and the gain in aesthetics more than makes up for other losses, such as in food production. For forestland that becomes shrub/scrub after construction, the picture is bit different. While forestland typically (and at higher ends of the range for our “comps”) is more productive for erosion control than shrub/scrub, it does happen that the minimum value for erosion control by an acre of shrub/scrub is higher than the minimum value for erosion control by an acre of forest. Because so

many acres of forest turn into shrub/scrub post construction, the gain in erosion control value overshadows other losses of air quality, climate regulation, and other services for which forestland is, even at the low end of the dollars-per-acre range, more productive.

Table 8: Annual Ecosystem Service Value Lost in 150-Well Scenarios, by Land Use and Ecosystem Service, (2015\$ using minimum per-acre values)

	Lower Well Clustering (2 wells/pad)		Higher Well Clustering (7 wells/pad)	
	Compact Well Pads (7.16 ac)	Large Well Pads (12.70 ac)	Compact Well Pads (7.16 ac)	Large Well Pads (12.70 ac)
By pre-UNGD Land Cover Classification:				
Barren	-	-	-	-
Cropland	(2,536)	(4,497)	(600)	(1,065)
Pasture/Forage	(17,657)	(31,319)	(2,593)	(4,599)
Grassland	(371)	(658)	(371)	(658)
Shrub/Scrub	-	-	-	-
Forest	(2,466,073)	(4,374,180)	(803,763)	(1,425,669)
Water	(55)	(97)	-	-
Wetland	-	-	-	-
Urban Open Space	(24,829)	(44,041)	(1,396)	(2,475)
Urban Other	-	-	-	-
Total	\$ (2,511,520)	\$ (4,454,791)	\$ (808,722)	\$ (1,434,465)
By Ecosystem Service:				
Aesthetic Value	(1,788,117)	(3,171,659)	(578,456)	(1,026,033)
Air quality	(148,671)	(263,705)	(48,369)	(85,794)
Biological Control	(2,632)	(4,668)	(606)	(1,074)
Climate Regulation	(34,279)	(60,801)	(8,074)	(14,321)
Erosion Control	(3,199)	(5,674)	(744)	(1,319)
Protection from Extreme Events	(320,746)	(568,921)	(103,694)	(183,926)
Food Production	(2,151)	(3,815)	(387)	(686)
Pollination	(82,457)	(146,257)	(26,611)	(47,200)
Raw materials	(9,766)	(17,323)	(3,183)	(5,646)
Recreation	(580)	(1,029)	(173)	(306)
Soil formation	(2,839)	(5,036)	(863)	(1,531)
Waste Treatment	(5,295)	(9,392)	(1,519)	(2,694)
Water Supply	(18,876)	(33,481)	(6,150)	(10,908)
Water flows	(91,913)	(163,030)	(29,895)	(53,026)
Total	\$ (2,511,520)	\$ (4,454,791)	\$ (808,722)	\$ (1,434,465)

Table 9: Annual Ecosystem Service Value Lost in 450-Well Scenarios, by Land Use and Ecosystem Service, (2015\$ using minimum per-acre values)

	Lower Well Clustering (2 wells/pad)		Higher Well Clustering (7 wells/pad)	
	Compact Well Pads (7.16 ac)	Large Well Pads (12.70 ac)	Compact Well Pads (7.16 ac)	Large Well Pads (12.70 ac)
	By pre-UNGD Land Cover Classification:			
Barren	-	-	-	-
Cropland	(5,291)	(9,384)	(2,536)	(4,497)
Pasture/Forage	(38,669)	(68,588)	(17,101)	(30,332)
Grassland	(2,042)	(3,622)	(371)	(658)
Shrub/Scrub	(5)	(9)	-	-
Forest	(7,841,754)	(13,909,256)	(2,005,279)	(3,556,849)
Water	(55)	(97)	(55)	(97)
Wetland	(2,170)	(3,848)	-	-
Urban Open Space	(65,556)	(116,280)	(3,959)	(7,022)
Urban Other	-	-	-	-
Total	\$(7,955,541)	\$(14,111,085)	\$(2,029,299)	\$(3,599,455)
By Ecosystem Service:				
Aesthetic Value	(5,671,003)	(10,058,902)	(1,449,081)	(2,570,297)
Air quality	(472,621)	(838,309)	(120,681)	(214,056)
Biological Control	(6,850)	(12,150)	(2,397)	(4,252)
Climate Regulation	(102,596)	(181,980)	(20,553)	(36,456)
Erosion Control	(8,315)	(14,748)	(2,916)	(5,172)
Protection from Extreme Events	(1,018,291)	(1,806,187)	(258,763)	(458,978)
Food Production	(4,846)	(8,596)	(2,087)	(3,702)
Pollination	(260,636)	(462,301)	(67,315)	(119,399)
Raw materials	(31,081)	(55,131)	(7,941)	(14,086)
Recreation	(1,762)	(3,125)	(484)	(858)
Soil formation	(8,633)	(15,314)	(2,376)	(4,214)
Waste Treatment	(14,931)	(26,484)	(4,633)	(8,217)
Water Supply	(60,017)	(106,454)	(15,350)	(27,227)
Water flows	(293,958)	(521,405)	(74,723)	(132,540)
Total	\$(7,955,541)	\$(14,111,085)	\$(2,029,299)	\$(3,599,455)

Table 10: Annual Ecosystem Service Value Lost to the Columbia Pipeline Construction Corridor (for two years) and Permanent Right-of-Way by Land Use and Ecosystem Service, (2015\$ using minimum per-acre values)

	Construction Corridor	Right-of-Way
By Pre-Pipeline Land Cover Classification		
Barren	-	-
Cropland	(6,623)	(4,403)
Pasture/Forage	(4,512)	2,615
Grassland	(370)	-
Shrub/Scrub	(194)	3,119
Forest	(397,146)	(265,529)
Water	-	-
Wetland	-	-
Urban Open Space	(86,251)	-
Urban Other	(22,057)	-
Total	\$ (517,152)	\$ (264,199)
By Ecosystem Service		
Aesthetic Value	(322,387)	(189,530)
Air quality	(25,111)	(14,376)
Biological Control	(766)	(99)
Climate Regulation	(45,931)	(2,084)
Erosion Control	(1,149)	724
Protection from Extreme Events	(62,049)	(34,198)
Food Production	(3,607)	(1,049)
Pollination	(13,562)	(8,563)
Raw materials	(1,573)	(1,052)
Recreation	(19,139)	88
Soil formation	(602)	(306)
Waste Treatment	2,052	(1,891)
Water Supply	2,032	(2,032)
Water flows	10,134	(9,830)
Total	\$ (481,657)	\$ (264,199)

Conclusion and Recommendations

Without a full accounting for costs, it is impossible to know whether UNGD and transmission are beneficial for the people of Maryland, but to date, no such accounting has been attempted.

This brief analysis provides a starting point for counting some of the costs, but more comprehensive, in-depth analysis will be required as the state considers whether to permit UNGD in the Marcellus Shale in western Maryland and how to manage and ensure mitigation of the impacts of natural gas infrastructure elsewhere in the state.

For the limited subset of impacts considered here, estimated annual costs range from \$17.9 million to \$107.1 million. Some subset of these costs would persist indefinitely, while others would fade as UNGD activity inevitably declines.

Even from these limited estimates, one cannot escape the conclusion that UNGD and natural gas transmission impose significant external costs that must be considered before concluding that either the extraction or the transmission of natural gas is worth initiating or continuing.

This study does not cover potential economic benefits of UNGD and transmission, as those have been at least partially covered in other works. Our goal was, instead, to begin to provide information about the costs to be considered alongside benefit estimates.

Without consideration of the economic costs, too much drilling and too much transmission will occur and that will be to the detriment—physically, aesthetically, AND economically—of the people of Maryland.

To address this situation fully, decisionmakers including MDE and the Maryland Legislature should take (at least) the following two steps:

- Commission an independent, comprehensive review of all of the benefits and all of the costs of UNGD and transmission in Maryland, including the categories covered in this brief analysis as well as others beyond its scope. It should not fall to local governments and small nonprofit organizations to ensure that the societal costs of the state's potential actions are adequately considered.
- Institute a program of rigorous, continuous monitoring of natural gas leaks and other air and water quality impacts associated with natural gas storage and transmission infrastructure, and beef up public health monitoring and reporting in areas near drilling sites and other infrastructure. This would provide baseline and ongoing data on which to base improvements in regulation, compensation mechanisms, and other policy interventions going forward.

No human activity is without impact, and UNGD and gas transmission is certainly no exception. By taking the steps listed here, the State of Maryland would make a solid

move in the right direction toward ensuring that the costs of energy production, transmission and use are minimized and mitigated.

Works Cited

- Abramzon, S., Samaras, C., Curtright, A., Litovitz, A., & Burger, N. (2014). *Estimating The Consumptive Use Costs of Shale Natural Gas Extraction on Pennsylvania Roadways*. Retrieved from <http://repository.cmu.edu/cgi/viewcontent.cgi?article=1065&context=cee>
- Aburn, T. (2016, April). *The Greenhouse Gas Emission Reduction Act of 2016*. Retrieved from <http://mde.maryland.gov/programs/Marylander/Documents/MCCCPresent04182016.pdf>
- Banerjee, N. (2015, May 15). Why Did NY Ban Fracking? The Official Report Is Now Public. Retrieved May 19, 2015, from <http://insideclimatenews.org/news/15052015/why-did-ny-ban-fracking-official-report-now-public>.
- Barth, J. (2011). *North American Shale Gas Plays: More Unanswered Questions*. JM Barth & Associates, Inc. Retrieved from http://www.catskillcitizens.org/barth/more_unanswered_questions.pdf
- Boyle, M. D. (2014). *Monitoring and Assessment of Residential Exposure to Noise Associated with Natural Gas Compressor Stations in West Virginia* (Masters). University of Maryland, College Park, Maryland.
- Carpenter, D. (2016, February 24). Fracking Constraint Analysis, Take 3. Garrett County Department of Planning & Land Management.
- Casey, J. A., Ogburn, E. L., Rasmussen, S. G., Irving, J. K., Pollak, J., Locke, P. A., & Schwartz, B. S. (2015). Predictors of Indoor Radon Concentrations in Pennsylvania, 1989–2013. *Environmental Health Perspectives*, 123(11). <http://doi.org/10.1289/ehp.1409014>
- Cassidy, M. E. (2014, September 11). Here They Come Again! The Impacts of Oil and Gas Truck Traffic. Retrieved May 13, 2016, from <https://www.fractracker.org/2014/09/truck-counts/>
- Center for Disease Control and Prevention. (2016, March 1). Asthma's Impact on the Nation. Retrieved August 19, 2016, from https://www.cdc.gov/asthma/impacts_nation/asthmafactsheet.pdf
- Clark, P. (2014, April 14). Unexpected loose gas from fracking. Retrieved August 18, 2016, from

<https://www.washingtonpost.com/apps/g/page/national/unexpected-loose-gas-from-fracking/950/>

Detrow, S. (2011, July 11). Emergency Services Stretched in Pennsylvania's Top Drilling Counties. Retrieved from <https://stateimpact.npr.org/pennsylvania/2011/07/11/emergency-services-stretched-in-pennsylvanias-top-drilling-counties/>

Dutzik, T., Ridlington, E., & Rumpler, J. (2012). *The Costs of Fracking: The Price Tag of Dirty Drilling's Environmental Damage* (p. 49). Environment North Carolina Research & Policy Center. Retrieved from http://pennenvironmentcenter.org/sites/environment/files/reports/The%20Costs%20of%20Fracking%20vPA_o.pdf

Energy Information Administration. (2007). *Natural Gas Compressor Stations on the Interstate Pipeline Network: Developments Since 1996* (Special Report) (p. 12). Energy Information Administration, Office of Oil and Gas. Retrieved from https://www.eia.gov/pub/oil_gas/natural_gas/analysis_publications/ngcompressor/ngcompressor.pdf

Engage Mountain Maryland. (2015, June 25). Above And Under The Accident Dome! Retrieved August 19, 2016, from <http://www.engagemmd.org/>

Esposito, V. (2009). *Promoting ecoliteracy and ecosystem management for sustainability through ecological economic tools*. (Doctoral). University of Vermont. Retrieved from <https://library.uvm.edu/jspui/handle/123456789/193>

Esposito, V., Phillips, S., Boumans, R., Moulaert, A., & Boggs, J. (2011). Climate change and ecosystem services: The contribution of and impacts on federal public lands in the United States. In *Watson, Alan; Murrieta-Saldivar, Joaquin; McBide, Brooke, comps. Science and stewardship to protect and sustain wilderness values*. (pp. 155–164). Merida, Yucatan, Mexico.: USDA Forest Service, Rocky Mountain Research Station. Retrieved from http://www.fs.fed.us/rm/pubs/rmrs_p064/rmrs_p064_155_164.pdf

Finkel, M., Selegan, J., Hays, J., & Kondamudi, N. (2013). Marcellus Shale Drilling's Impact on the Dairy Industry in Pennsylvania: A Descriptive Report. *New Solutions*, 23(1), 189–201.

Graham, J., Irving, J., Tang, X., Sellers, S., Crisp, J., Horwitz, D., ... Carey, D. (2015). Increased traffic accident rates associated with shale gas drilling in Pennsylvania. *Accident Analysis & Prevention*, 74, 203–209. <http://doi.org/10.1016/j.aap.2014.11.003>

HEI Special Scientific Committee on, & Unconventional Oil and Gas Development in the Appalachian Basin. (2015). *Strategic Research Agenda on the Potential Impacts of*

21st Century Oil and Natural Gas Development in the Appalachian Region and Beyond. Health Effects Institute.

- Hill, E. L. (2013). *Shale Gas Development and Infant Health: Evidence from Pennsylvania* (Working Paper No. WP2012-12). Retrieved from <http://ageconsearch.umn.edu/bitstream/128815/2/Cornell-Dyson-wp1212.pdf>
- Holzman, D. C. (2011). Methane Found in Well Water Near Fracking Sites. *Environmental Health Perspectives*, 119(7), a289. <http://doi.org/10.1289/ehp.119-a289>
- Jantz, C. A., Kubach, H. K., Ward, J. R., Wiley, S., & Heston, D. (2014). Assessing Land Use Changes Due to Natural Gas Drilling Operations in the Marcellus Shale in Bradford County, PA. *The Geographical Bulletin*, 55(1), 18.
- Johnson, G. W. (2010, March). *AIRES*. Presented at the Gund Institute AIRES Workshop, University of Vermont, Burlington, Vermont.
- Kerkvliet, J., & Culver, N. (n.d.). Assessing Costs Associated with Impacts to Air Quality. The Wilderness Society. Retrieved from <http://wilderness.org/sites/default/files/Economic%20Impacts%20of%20Air%20Pollution.pdf>
- Legere, L. (2014, February 9). DEP releases updated details on water contamination near drilling sites. Retrieved August 17, 2016, from <http://powersource.post-gazette.com/powersource/policy-powersource/2014/09/09/DEP-releases-details-on-water-contamination/stories/201409090010>
- Lucas, D. (2015, July 6). Officials To NYS: Take A Second Look At Pipelines. Retrieved July 14, 2015, from <http://wamc.org/post/officials-nys-take-second-look-pipelines>
- Luckett, B., Buppert, G., & Margolis, J. M. (2015, April 28). SELC ACP Comment, FERC DOCKET NO.: PF15-6-000,20150428-5504(30537222). Southern Environmental Law Center; Appalachian Mountain Advocates; Center for Biological Diversity.
- Maryland Asthma Control Program. (2011). *Asthma in Garrett County*. Department of Health and Mental Hygiene, Family Health Administration, Center for Maternal and Child Health. Retrieved from http://phpa.dhmh.maryland.gov/mch/Documents/asthma_control/Profile_Garrett.pdf
- Maryland Commission on Climate Change. (2015). *Maryland Commission on Climate Change, Final Report Prepared for: Larry Hogan, Governor, State of Maryland and the Maryland General Assembly* (p. 25). Annapolis, MD: Maryland Commission on Climate Change.

- Maryland Department of the Environment. (2015). Proposed Regulation: Oil and Gas Resources. *Maryland Register*, 94–116.
- Maryland Highway Safety Office, & Maryland Motor Vehicle Administration. (2014, July 25). Maryland Statewide Crash Summary. Retrieved July 12, 2016, from http://www.mva.maryland.gov/safety/_docs/StatewideBR-12Aug12-13.pdf
- Maryland Institute for Applied Environmental Health (MIAEH). (2014). *Potential Public Health Impacts of Natural Gas Development and Production in the Marcellus Shale in Western Maryland: Prepared for the Maryland Department of the Environment and the Maryland Department of Health and Mental Hygiene* (p. 173). College Park, Maryland: University of Maryland, School of Public Health. Retrieved from <http://www.marcellushealth.org/>
- Maryland State Department of Health and Mental Hygiene. (2014). Maryland Vital Statistics Annual Report. Retrieved August 15, 2016, from http://dhmh.maryland.gov/vsa/Documents/14annual_revised.pdf
- Meng, Q., & Ashby, S. (2014). Distance: A critical aspect for environmental impact assessment of hydraulic fracking. *The Extractive Industries and Society*, 1(2), 124–126. <http://doi.org/10.1016/j.exis.2014.07.004>
- Millennium Ecosystem, & Assessment Panel. (2005). Ecosystems and Human Well-Being. Retrieved August 21, 2016, from <http://www.millenniumassessment.org/documents/document.356.aspx.pdf>
- Millennium Pipeline Company, LLC. (2016). *Eastern System Upgrade, Draft Resource Report 5: Socioeconomics* (p. 32). Millennium Pipeline Company, LLC.
- Moyer, R. (n.d.). Shalefield Stories: Randy Moyer. Retrieved May 13, 2016, from <http://www.shalefieldstories.org/randy-moyer.html>
- National Highway Traffic Safety Administration. (2015, May). The Economic and Societal Impact Of Motor Vehicle Crashes, 2010 (Revised). Retrieved August 5, 2016, from <https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812013>
- OECD. (2006). Benefits Transfer. In *Cost-Benefit Analysis and the Environment* (pp. 253–267). OECD Publishing. Retrieved from http://www.oecd-ilibrary.org/environment/cost-benefit-analysis-and-the-environment/benefits-transfer_9789264010055-18-en
- Olsen, L. (2014, September 16). Fracking boom increases “triple tragedies” on Texas highways. *Houston Chronicle*. Retrieved from

- <http://www.houstonchronicle.com/news/science-environment/article/Fracking-boom-increases-triple-tragedies-on-5760588.php>
- OSHA-NIOSH. (n.d.). Worker Exposure to Silica during Hydraulic Fracturing. Retrieved March 4, 2016, from https://www.osha.gov/dts/hazardalerts/hydraulic_frac_hazard_alert.html
- Pachauri, R. K., Mayer, L., & Intergovernmental Panel on Climate Change (Eds.). (2015). *Climate change 2014: synthesis report*. Geneva, Switzerland: Intergovernmental Panel on Climate Change.
- Phillips, S., & McGee, B. (2014). *The Economic Benefits of Cleaning Up the Chesapeake: A Valuation of the Natural Benefits Gained by Implementing the Chesapeake Clean Water Blueprint* (p. 32).
- Phillips, S., & McGee, B. (2016). Ecosystem Service Benefits of a Cleaner Chesapeake Bay. *Coastal Management*, 241–258. <http://doi.org/10.1080/08920753.2016.1160205>
- Phillips, S. (2015, May 4). New study links gas drilling to water contamination in NE Pa. Retrieved from <http://stateimpact.npr.org/pennsylvania/2015/05/04/new-study-links-gas-drilling-to-water-contamination-in-ne-pa/>
- Rasmussen, S. G., Ogburn, E. L., McCormack, M., Casey, J. A., Bandeen-Roche, K., Mercer, D. G., & Schwartz, B. S. (2016). Association Between Unconventional Natural Gas Development in the Marcellus Shale and Asthma Exacerbations. *JAMA Internal Medicine*. <http://doi.org/10.1001/jamainternmed.2016.2436>
- Regional Economic Studies Institute (RESI). (2014). *Impact Analysis of the Marcellus Shale Safe Drilling Initiative, Revised* (p. 212). Towson, Maryland: Towson University. Retrieved from http://www.mde.state.md.us/programs/Land/mining/marcellus/Documents/RESI_Marcellus_Shale_Report_Final.pdf
- Reid, W. V., H. A. Mooney, A. Cooper, D. Capistrano, S. R. Carpenter, K. Chopra, and M. B. Zurek. (2005). Millennium ecosystem assessment, ecosystems and human well-being: Synthesis. Washington, DC: Island Press
- Retzer, K. D., Hill, R. D., & Pratt, S. G. (2013). Motor vehicle fatalities among oil and gas extraction workers. *Accident Analysis & Prevention*, 51, 168–174. <http://doi.org/10.1016/j.aap.2012.11.005>
- RT International. (2016, August 16). Fracking leaks a major factor in US methane “hot spot” – NASA. Retrieved August 17, 2016, from <https://www.rt.com/usa/356198-fracking-hot-spot-nasa/>

- Spectra Energy. (2016). Accident Storage Field [Corporate]. Retrieved August 19, 2016, from <http://www.spectraenergy.com/>
- Subra, W. (2009, December). Health Survey Results of Current and Former DISH/Clark Texas Residents. Earthworks. Retrieved from http://www.earthworksaction.org/files/publications/DishTXHealthSurvey_FINAL_hi.pdf
- Summary on Compressor Stations and Health Impacts. (2015, February 24). Southwest Pennsylvania Environmental Health Project. Retrieved from <http://www.environmentalhealthproject.org/wp-content/uploads/2012/03/Compressor-station-emissions-and-health-impacts-02.24.2015.pdf>
- The Associated Press. (2011, October 26). Gas-drilling boom brings more crime, carousing to some towns. *PennLive.com*. Retrieved from http://www.pennlive.com/midstate/index.ssf/2011/10/gas-drilling_boom_brings_more.html
- The Maryland Center for Traffic Safety Analysis. (2015). The National Study Center for Trauma and EMS-Garrett County Report. Retrieved August 15, 2016, from <https://somvweb.som.umaryland.edu/NSCTrauma/NSCData.aspx>
- Tustin, A. W., Hirsch, A. G., Rasmussen, S. G., Casey, J. A., Bandeen-Roche, K., & Schwartz, B. S. (2016). Associations between Unconventional Natural Gas Development and Nasal and Sinus, Migraine Headache, and Fatigue Symptoms in Pennsylvania. *Environmental Health Perspectives*. <https://doi.org/10.1289/EHP281>
- Urbina, I. (2012, May 14). For Oil Workers, Deadliest Danger Is Driving. *The New York Times*. Retrieved from <http://www.nytimes.com/2012/05/15/us/for-oil-workers-deadliest-danger-is-driving.html>
- U.S. Census Bureau. (2015, July 6). TIGER/Line with Data [Data]. Retrieved August 5, 2015, from <http://www.census.gov/geo/maps-data/data/tiger-data.html>
- U.S. EPA, C. C. D. (2016, June 12). Social Cost of Carbon [Overviews & Factsheets,]. Retrieved June 12, 2016, from <https://www3.epa.gov/climatechange/EPAactivities/economics/scc.html>
- U.S. EPA. (2016, May). Greenhouse Gas Equivalencies Calculator [Data & Tools]. Retrieved August 21, 2016, from https://www.epa.gov/sites/production/files/widgets/ghg_calc/calculator.html#results

- U.S. Geological Survey. (2014). *NLCD 2011 Land Cover (2011 Edition, amended 2014) - National Geospatial Data Asset (NGDA) Land Use Land Cover*. Sioux Falls, SD: U.S. Geological Survey. Retrieved from <http://www.mrlc.gov/nlcd2006.php>
- Vuong, Z. (2016, January 26). USC researchers look at long-term health effects of Porter Ranch gas leak. Retrieved August 18, 2016, from <https://news.usc.edu/91098/usc-researchers-to-study-long-term-health-effects-of-porter-ranch-gas-leak/>
- Wilcox, A. J. (2001). On the importance—and the unimportance— of birthweight. *International Journal of Epidemiology*, 30(6), 1233–1241. <http://doi.org/10.1093/ije/30.6.1233>
- Witter, R., Stinson, K., Sackett, H., Putter, S., Kinney, G., Teitelbaum, D., & Newman, L. (2008). *Potential Exposure-Related Human Health Effects of Oil and Gas: A Literature Review (2003-2008)* (Literature Review). Natural Resources Defense Council. Retrieved from http://docs.nrdc.org/health/files/hea_o8091702b.pdf
- Zimmerle, D. J., Williams, L. L., Vaughn, T. L., Quinn, C., Subramanian, R., Duggan, G. P., ... Robinson, A. L. (2015). Methane Emissions from the Natural Gas Transmission and Storage System in the United States. *Environmental Science & Technology*, 49(15), 9374–9383. <http://doi.org/10.1021/acs.est.5b01669>