Air Impacts of Shale Gas Extraction and Distribution

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Introduction: In this review, we will summarize available data on the local and regional air impacts of unconventional natural gas development. Where possible we will focus on shale gas plays and studies published in peer reviewed scientific journals. We will point out specific gaps in scientific knowledge and suggest future studies that are needed. The presentation will be organized by shale gas life cycle segment (i.e., well development, production, distribution and storage). Within each of these compartments, we will address individual sources along with the atmospheric constituents known to be emitted. We will also present sample case studies where available.

Several atmospheric pollutants have been linked to the lifecycle of unconventional natural gas. These atmospheric species include hazardous air pollutants (HAPs) (i.e., BTEX - benzene, toluene, ethylbenzene, and xylenes) and other pollutants such as methane and ethane, hydrogen sulfide, sulfur dioxide (SO_2), ozone precursors (NOx and non-methane VOCs), silica and particulate matter. The aromatic hydrocarbons, BTEX, which are HAPs and/or carcinogens, can be emitted from several stages of the natural gas life cycle [1-4]. Methane can react with hydroxyl radicals in the atmosphere to create nitric acid and hydrogen peroxide [5] and has a higher global warming potential than CO_2 (not discussed in this report). Hydrogen sulfide and some non-methane hydrocarbons have been linked to nervous system, respiratory, and cardiovascular diseases and are trapped within the shale formations [4, 6, 7]. SO_2 from off-road diesel engines contributes to acid rain and can increase asthma symptoms in humans. Non-methane VOCs and NOx are important precursors to ozone production and can be emitted during well development and production stages of the natural gas life cycle [4, 8-10]. High atmospheric ozone concentrations, catalyzed by increased VOC abundance, can lead to respiratory problems particularly in children and older adults [11]. Exposure to airborne fine particulate matter (2.5 µm and smaller in diameter; $PM_{2.5}$) through diesel emissions on site and silica from proppant can lead to decreased lung function, asthma, and increased respiratory symptoms such as coughing and difficulty breathing [12] and in the case of silica can cause silicosis [13].

Attributing atmospheric emissions to particular segments of the shale gas life cycle can be quite difficult. For instance, emissions of species such as BTEX and hydrogen sulfide may originate at point sources during well development (e.g., drilling and fracturing) and at compressor stations, but access to individual well sites and facilities is often limited [1, 4]. On the other hand, emissions during transmission and storage can be diffuse and more difficult to pinpoint [2, 14]. Also, characterizing individual and community exposure to air pollutants is complex since contaminants can vary both spatially and temporally, based on proximity to point sources, magnitude, transport and dispersion of emissions [1, 2].

Combined, all natural gas systems are the highest emitters of methane of any anthropogenic sector in the United States [15]. However, these estimates are based on very limited measurement data and are instead modeled and calculated annually by EPA [15, 16]. The inherent uncertainties associated with this technique are demonstrated by an EPA implemented change in the calculation for estimated greenhouse gases from natural gas systems for the 2013 report [15]. This change, which does not use recent scientific studies to aid in its estimates, resulted in a 33% decrease of all methane emission estimates from natural gas systems in 2010 alone, and a reduction of between 15 and 33% for every year since 1990 [15, 16]. The inventory change emphasizes the need for measurements throughout the natural gas (not limited to shale gas only) life cycle to evaluate which calculation is correct and to reduce overall uncertainties surrounding the air impacts of shale gas extraction and distribution.

Well Development: The well development stage, also called material acquisition and preproduction, has had limited investigations that are reported in the literature [4, 17, 18]. During this stage, site preparation occurs, roads are constructed, the site is excavated and leveled, holding ponds and other infrastructure are constructed, and the equipment (e.g., drilling rig, compressors, separators, generators) is gathered. Vertical and horizontal drilling activities along with hydraulic fracturing (“fracking” or “fracing”) occur during this stage. The well is completed when drilling and hydraulic fracturing operations have been finished and equipment such as well casings, and measurement and control systems have been inserted for the well to begin production of natural gas [19]. During well completion a process called liquid unloading is performed to remove fluid from the wellbore so that the well can start flowing natural gas [19].

Potential atmospheric impacts vary throughout this stage and include extensive use of off road diesel powered equipment and trucks during construction of roads and clearing of the well pad. Emissions from diesel engines (particularly off-road diesel) are known to include $PM_{2.5}$, NOx, and SO_2 [20, 21]. Hydraulic fracturing during this life cycle stage has been shown to emit a number of pollutants [17]. During this process 1 - 5 million gallons of water, fracking fluid, and proppant (e.g., frac sand or silica sand) are used to create fractures in the shale rock for the natural gas to flow through. Onsite emissions during hydraulic fracturing can include exhaust from diesel and raw or processed natural gas powered engines for drilling rigs and pumps; dust/PM2.5 from loading and unloading proppant (e.g. frac sand), and from chemicals used during the fracturing process [17, 19]. These emissions can include methane, hydrogen sulfide, ozone precursors, and potentially volatile chemicals present in fracking fluid. However, these are temporary emissions and the well drilling is usually completed in a few weeks. Emissions during the well completion process, particularly during venting and flaring of the initial natural gas, can include methane, BTEX and other non-methane hydrocarbons, and can cause health effects for residents living within 800 m of wells [4]. The levels of these emissions can vary substantially among natural gas plays, for instance high levels of hydrogen sulfide can be present in natural gas (called “sour gas”) of the Jonah gas field in Wyoming while concentrations were below detection limits near the Barnett Shale formation in Texas [1].

Production: The production stage begins after well completion, once the salable natural gas begins flowing from the well. Emissions from this longer duration stage have been measured, but due to the diffuse nature of emissions, the data are quite inconclusive. Once production has begun, emission sources may include compressors or pumps that bring the produced gas up to the surface or up to pipeline pressure (engines are often fired with raw or processed natural gas), condensate tank vents, dehydrators, and natural gas processing and transmission fugitive emissions. During the production stage the natural gas is dried and many secondary (and often valuable) products are separated out [1]. For example, fluids that are brought to the surface at Barnett Shale natural gas well sites are a mixture of natural gas (methane), other gases, water, and higher hydrocarbon liquids ("condensates"). Some gas wells produce little or no condensate, while others produce large quantities. The mixture typically is sent first to a separator unit, which reduces the pressure of the fluids and separates the natural gas and other gases from any entrained water and hydrocarbon liquids. The gases are collected off the top of the separator, while the water and hydrocarbon liquids fall to the bottom and are then stored on-site in storage tanks. In particular, the condensate tanks at Barnett Shale wells are typically 10,000 to 20,000 gallons and hydrocarbon vapors from the condensate tanks can be emitted to the atmosphere through vents on the tanks. Condensate liquid is periodically collected by truck and transported to refineries for incorporation into liquid fuels, or to other processors. Emissions may occur at the well level (with a few storage tanks) or at the central collection stations (compressor stations), which process the gas from several wells. These compressor stations are often equipped with dehydration units, which use ethylene glycol to remove water from the natural gas. In addition to water, the glycol absorbent collects aromatic hydrocarbons, which can be emitted to the atmosphere when the glycol is regenerated with heat. Ozone precursors are also emitted during production which can make attainment of EPA ozone exposure limits difficult even in winter for some areas [8-10].

Distribution and Storage: Distribution and storage includes over 300,000 miles of pipeline throughout the United States [22]. Emissions during distribution and storage are mainly limited to fugitive methane emissions from an aging natural gas pipeline infrastructure and venting [14, 23]. In Boston alone a recent study found over 3300 methane leaks from the infrastructure there [14]. However, during this stage emissions from shale gas development are no different from natural gas sourced from conventional gas plays, because they mix in pipeline networks. This problem may be very widespread, and more information is needed to evaluate the importance and generality of these fugitive emissions.

Conclusions: Based on this examination of the air impacts of shale gas extraction and distribution, we have determined that actual measurement data on individual segments of the natural gas life cycle are critically lacking. Before the true benefits of this resource can be determined and useful regulations developed we must first fill these gaps in our understanding[2, 24, 25]. As demonstrated by discrepancies in the annual calculated EPA methane inventories for natural gas systems, large uncertainties exist in the estimate of methane emissions throughout the entire life cycle, therefore more targeted studies of atmospheric methane concentrations before, during and after drilling are needed. Although extensive natural gas infrastructure leaks have been identified, data on these fugitive losses is very limited; also more information is needed on the surface-atmosphere exchange of methane and the level of these fugitive losses in all areas. Further, due to limited data, we do not know how air emission signatures vary from formation to formation, comprehensive studies of all methane, VOCs, silica, hydrogen sulfide, and PM2.5 across all formations must be identified in order to develop informed regulations for these areas. One other important emission during hydraulic fracturing is silica[13]; however, little data exists on the emissions and potential occupational health impacts. The areas in need of measurement are extensive, and should be explored before further development of this resource occur to ensure the highest level of public safety and accurate public information in the near and distant futures.

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