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Consulting Engineer

Expert Report

by
Anthony R. Ingraffea, Ph.D., P.E.

In the matter of:

R v Joziet Khimba et al.
Burnley Magistrates Court

Prepared for:
KELLYS SOLICITORS
9 St Georges Place
Brighton BN1 4GB

November 5, 2017

1.0 Personal Background

I am the Dwight C. Baum Professor of Civil and Environmental Engineering, Emeritus, at Cornell University. I hold a PhD in Civil Engineering from the University of Colorado, Boulder, an MS in Civil Engineering from the New York University Polytechnic School of Engineering, and a BS in Aerospace Engineering from the University of Notre Dame. I am a licensed Professional Engineer in the states of Texas, Colorado, and New York.

I have expertise in rock mechanics, rock fracture, hydraulic fracturing for well stimulation, design of high pressure gas pipelines, computational mechanics, experimental rock mechanics, oil/gas well drilling and cementing, and oil/gas well integrity. During the period from 1977-2004, I performed paid consultancy and sponsored research for the oil/gas industry and the federal government, including EXXON, Amoco, Schlumberger, the Gas Technology Institute, the New York Gas Group, and the U.S. Department of Energy.

I have published more than 315 technical journal articles, proceedings papers, and reports during my career. I have written 5 book chapters on computational and experimental geomechanics and hydraulic fracturing. Since 2006, I have been the Co-Editor-in-Chief of *Engineering Fracture Mechanics*, the premier journal in the field of fracture mechanics, which publishes many papers on hydraulic fracturing and rock fracture mechanics. I have won the highest American honor for fracture mechanics, the George Irwin Medal of the American Society for Testing and materials:

"The award, given by ASTM Committee E08 on Fatigue and Fracture, honors Ingraffea's pioneering and outstanding contributions to the advanced computational simulation of fatigue and fracture processes and the resulting improved understanding necessary for practical applications of fracture mechanics to the assessment of integrity in engineering structures."

I have also twice (1978, 1991) won the National Research Council/U.S. National Committee for Rock Mechanics award for outstanding research in rock mechanics, the latter specifically for research into hydraulic fracturing.

My professional résumé is attached as Appendix A. My deposition and trial testimony is summarized in Appendix B.

2.0 Retention

In October 2017, I was retained by Kellys Solicitors to provide expert consulting services in this matter. I was asked to opine on the impacts of the expansion of fossil fuel development in the United Kingdom, both local and global.

Specifically, I have been asked to provide expert opinion concerning:

1. The process of slick water hydraulic fracturing and horizontal drilling for shale gas extraction including the impact on the water table.
2. The negative impacts of these processes that have been documented in the United States/globally.
3. The negative impacts that could be experienced in the UK.

3.0 Opinions

This matter involves the use of the necessity defense in light of the greater harms and imminent threats posed by the expansion of fossil fuel development in the United Kingdom, in particular the unconventional development of shale gas.

On the basis of the following discussions in this report, the documents and publications I reviewed, my education, experience, and training, I provide my opinions as follows. I reserve the right to prepare additional reports should additional information become available as this matter proceeds.

OPINION 1: To a reasonable degree of engineering certainty, I assert that the development of shale gas in the UK will require spatially-intense, heavy industrial operations at a much larger scale than conventional natural gas development.

OPINION 2: To a reasonable degree of engineering certainty, I conclude that the process of slick water hydraulic fracturing and horizontal drilling for shale gas extraction will negatively impact the water table and air quality in the UK.

OPINION 3: To a reasonable degree of engineering certainty, I assert that the process of unconventional shale gas development in other countries has had scientifically documented unwanted impacts on the local environment and on human health.

OPINION 4: To a reasonable degree of engineering certainty, I assert that these negative impacts experienced in other countries will also occur in the UK.

OPINION 5: To a reasonable degree of engineering certainty, I assert that development of shale gas in the UK will exacerbate climate change.

4.0 Unconventional Shale Gas Development: The Root Cause of Up-Scaling of Conventional Development Processes and Increased Spatial Intensity

There is a root cause for why the unconventional development of shale gas is a heavy industry, and requires an up-scaling of conventional development processes and increased spatial intensity: ultra-low permeability of shale rock. Unlike conventional mineral formations containing natural gas, shale rock has permeability, the ability for fluids to move through the rock, of typically less than 10 nano-darcies (Sakhaee-Pour and Bryant, 2012). This is about a thousand times less permeable than traditional gas-bearing sandstones. If shale is so stingy with its hydrocarbons, how can they be produced?

Some shale formations contain large amounts of shale gas and other hydrocarbons trapped in the *shale rock* itself. Such formations can be made to produce these hydrocarbons if they have migrated into and very near naturally existing cracks, joints, bedding planes and faults, discontinuities, in the *shale rock mass*. For example, Figure 1 shows a surface exposure of many *layers of shale rock* in a *shale rock mass*. Note the many such discontinuities in the rock mass. Over many millions of years, the hydrocarbons actually being produced in the shale through bio-thermo-mechanical processes can migrate from within the shale rock and occupy these discontinuities. This process and its timeline are depicted in Figure 2.



Figure 1. A surface exposure of a typical naturally fractured shale rock mass.

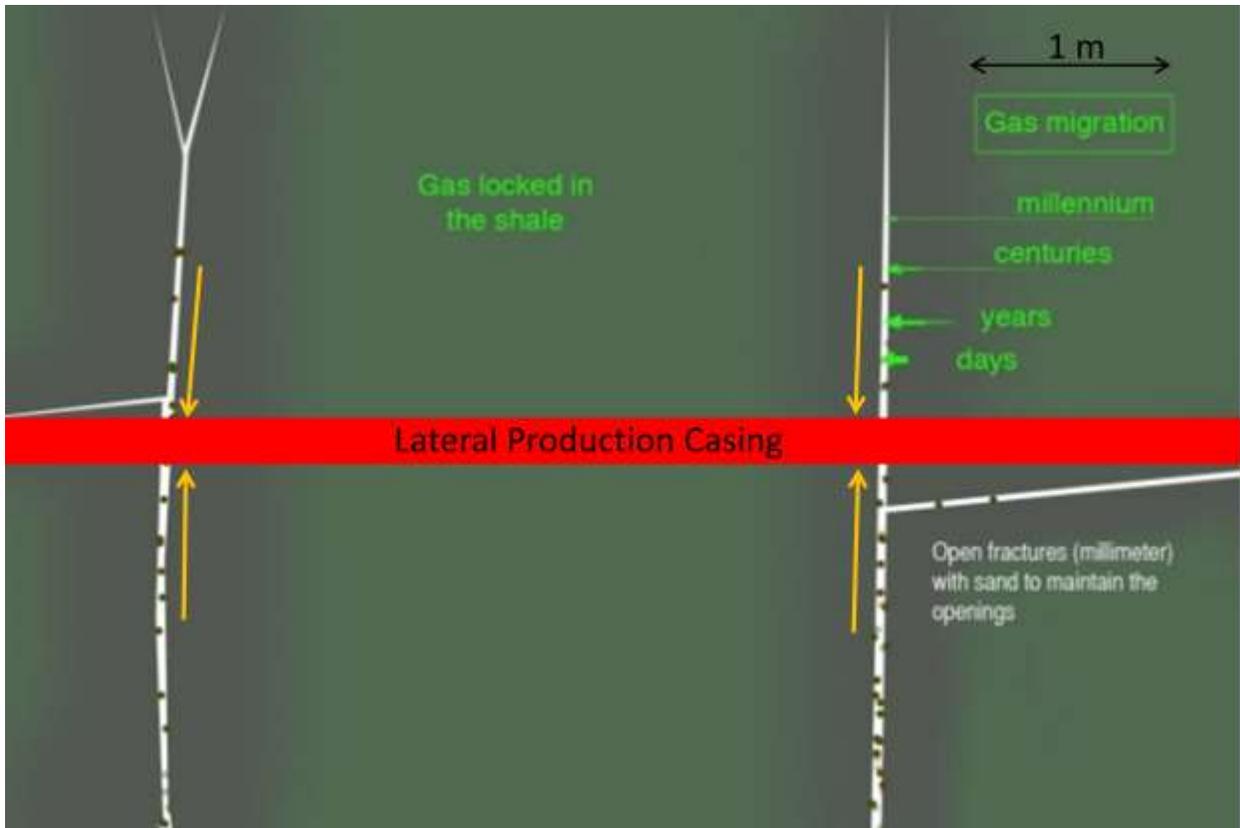


Figure 2. Depiction of how gas can be accessed in a shale rock mass through migration.
 Courtesy of Prof. Marc Durand.

To extract natural gas and other hydrocarbons trapped in the shale, unconventional, heavy industrial methods, in this instance vertical/horizontal drilling, clustered multi-well pads, and high-volume “hydraulic fracturing”, must be employed to access as many of the discontinuities in the shale rock mass so that hydrocarbons will flow from the rock mass to the well. It is a misnomer to use “hydraulic fracturing” as a description of this process, since little actual new fracturing is done. Rather, the purpose of “hydraulic fracturing” in this instance is merely to widen, interconnect, and prop open as many pre-existing discontinuities as feasible.

Proof that shale wells initially access the readily available hydrocarbons stored in and very near the natural discontinuities, and then quickly decline in production as implied by Figure 2, is shown in Figure 3. Such steep declines require that *many wells be continuously developed* to maintain contracted supplies of the targeted hydrocarbon. This overall approach which accounts for near-impermeability and the need to access as many natural discontinuities as feasible, is depicted in Figure 4. This figure shows a clustered, multi-well pad arrangement of

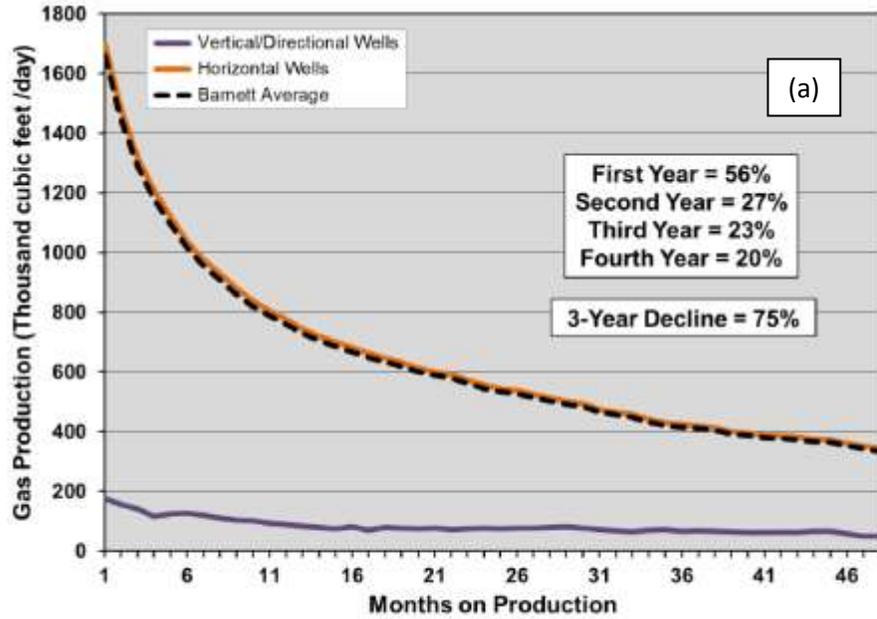


Figure 3-11. Average decline profile for gas wells in the Barnett play.¹⁷
 Decline profile is based on all shale gas wells drilled since 2009.

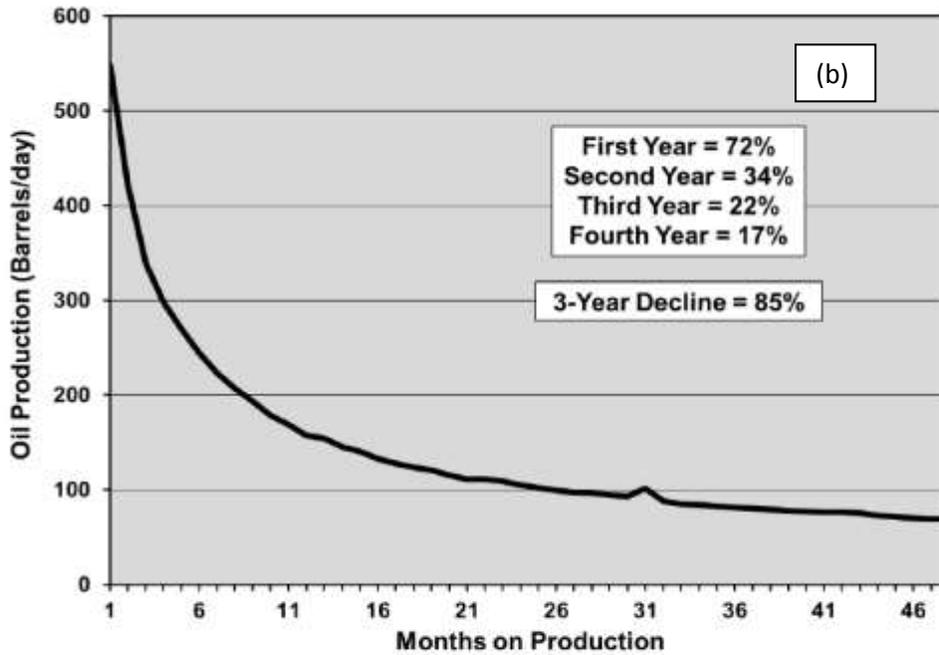


Figure 2-13. Average decline profile for horizontal tight oil wells in the Bakken play.²⁵
 Decline profile is based on all horizontal tight oil wells drilled since 2009.

Figure 3. (a) Typical decline curve for shale gas. Data from DRILLING INFO; From Hughes, <http://shalebubble.org/drilling-deeper/> (b) Typical decline curve for shale oil. Data from DRILLING INFO; From Hughes, <http://shalebubble.org/drilling-deeper/>

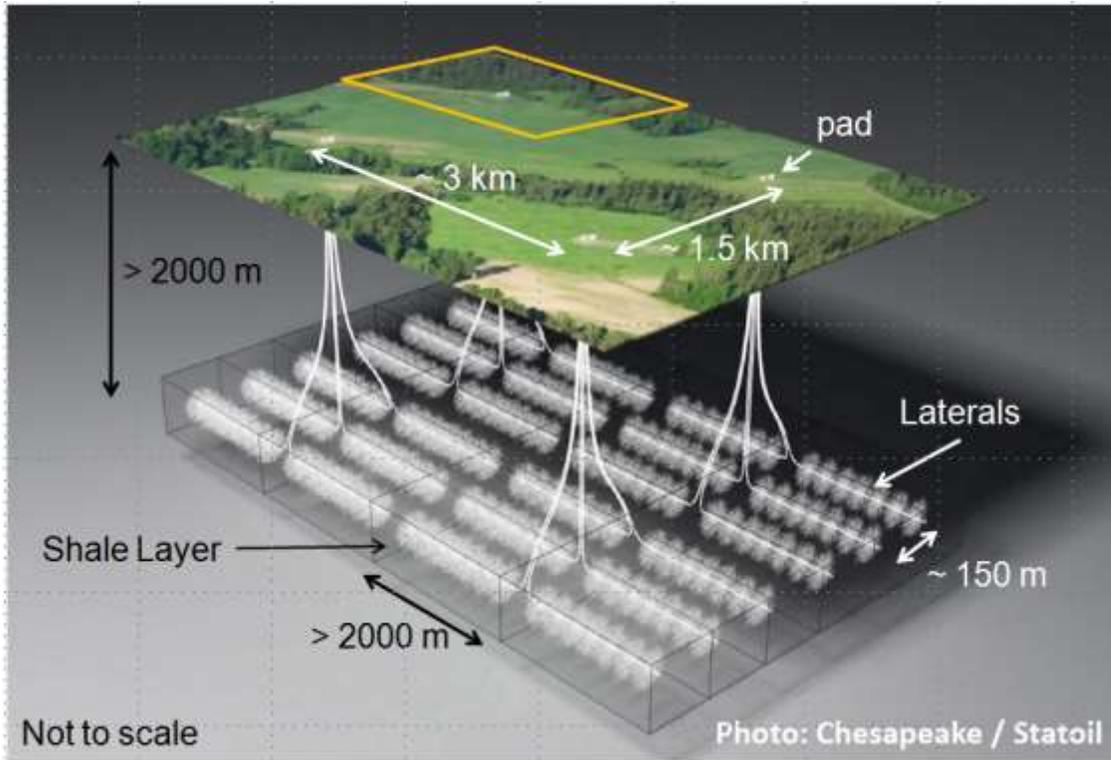


Figure 4. Depiction of overall shale hydrocarbon development approach, idealized.

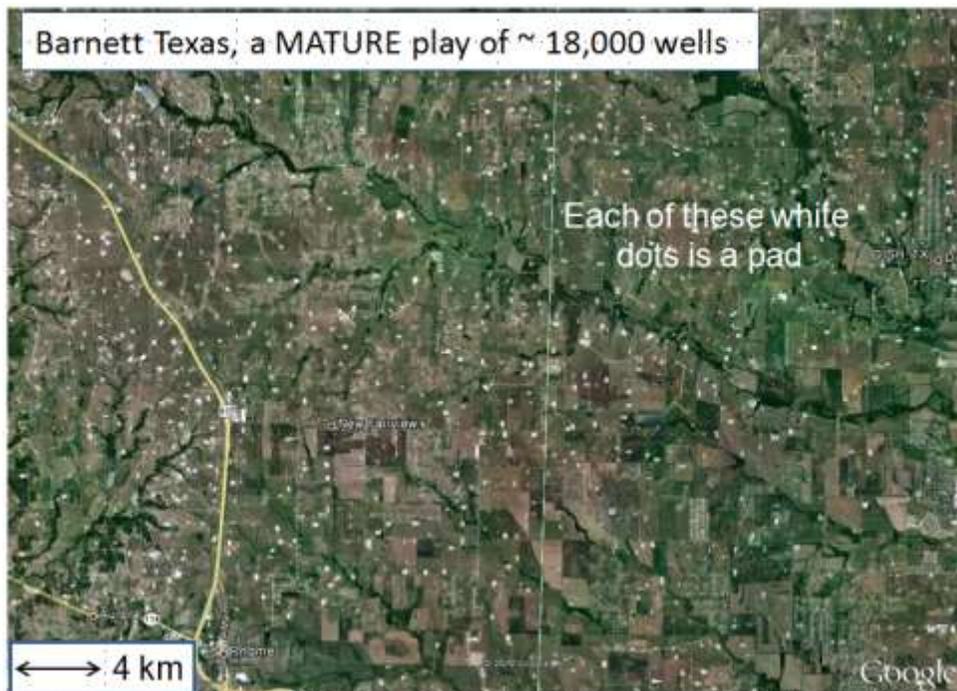


Figure 5. Google Earth view of actual spatially intense development of a shale gas play, the Barnett in Texas. Each white dot in photo is a multi-well pad.



Figure 6. Translation of the spatially intense development of a shale gas play, depicted in Figure 5, onto the region of proposed development near Blackpool. Each yellow rectangle is an extraction area for a pad (red square). Multi-well development with long laterals (red lines) shown from a few of the extraction areas.

wells with both vertical and lateral segments, and closely spaced long laterals stimulated by high-volumes of injected fluid and proppant.

In effect, getting hydrocarbons out of a shale formation requires a massive “scaling-up” of industrial operations: more wells, longer wells, more stimulation fluids, more solid and liquid waste, more traffic, more attendant infrastructure, and longer timelines. As will be described in the next section, this “state-of-the-practice” approach requires a myriad of operations typical of heavy industry, incompatible with a rural residential setting, with much higher risk of unwanted impacts on the local environment, and extremely untimely with respect to the climate change problem.

5.0 Unconventional Shale Gas Development: Typical Operations

The process of producing natural gas from shale involves a series of operations before and after stimulation, “hydraulic fracturing”, all of which are industrial in nature, many of which have the potential to impact public health the environment, and climate change. The following are the principal operations and some of their associated impacts:

1. The initial phase of shale gas development involves construction of access roads and well pads in an arrangement like that shown in Figure 4. A well pad must provide a stable base for large rigs, trucks, pumps, diesel engines, storage tanks, separation units and other equipment needed to drill, complete and operate the well. The size of a well pad depends on the number of wells that will be put on the pad. Figure 7 shows most recent data on the number of wells per pad in the Marcellus play in Pennsylvania. Data show a trend towards an ever-increasing number of wells per pad, so one can expect that the numbers shown in Figure 7 are low-end snapshots in time.

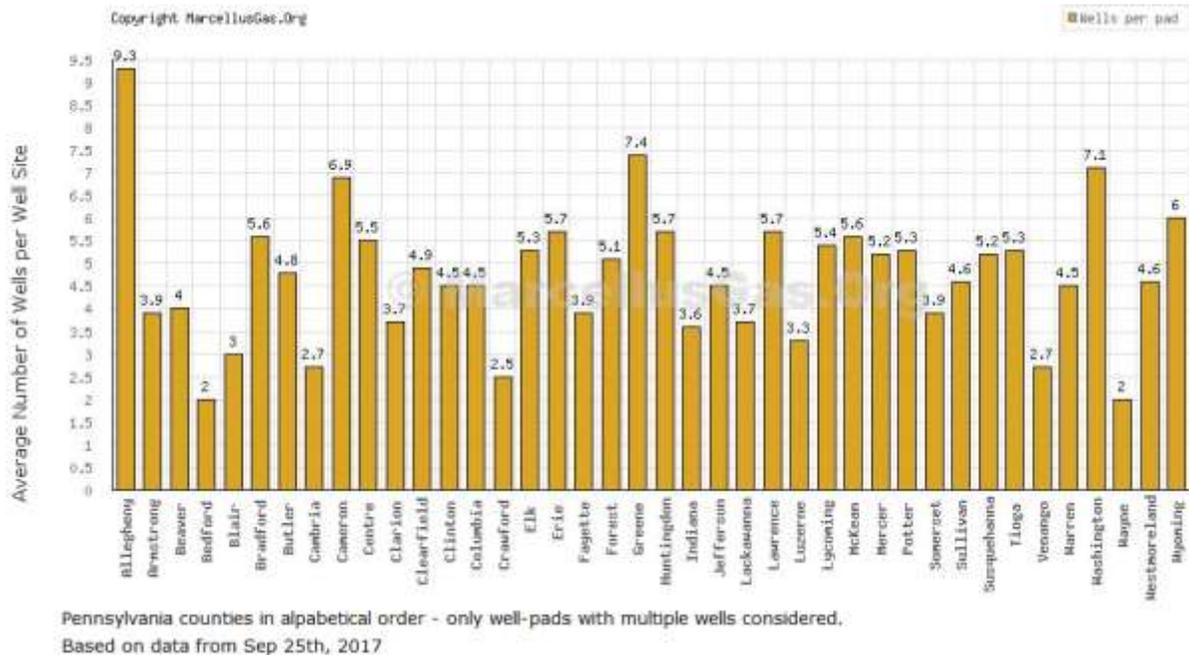


Figure 7. Average number of wells per pad in Pennsylvania by county. Data from <https://www.marcellusgas.org/graphs/PA#avgpad>

2. Construction of the access road and well pad involves the operation of large, heavy

machinery to excavate/backfill, grade and compact the site, transport and place large quantities of gravel on the ground, install an impermeable barrier, and potentially construct a large, lined impoundment for storage of water to be used in hydraulic fracturing. See Figure 8 for examples of pad construction activities. Each well pad, with associated roads and impoundments, consumes about five to fifteen acres of land.

3. Once the site has been prepared, equipment must be transported to the site and unloaded. Before the horizontal drill rig is assembled and powered up, another smaller rig will be brought on site to drill the starter hole and vertical section of the well. Rigs are transported using specialized heavy trucks. Portions of the vertical well section may be drilled using air, while other portions will be drilled using fluids or mud. The mud may be water-based, oil-based or synthetic based fluids, all of which must be stored on site. Drilling the vertical well produces at least 750 tons of drill cuttings per hole. Depending on the drilling technique and depth of wellbore, the cuttings may contain contaminants such as pyrite, which with air and water generate acid mine drainage, high concentrations of chlorides, and other toxic constituents associated with the drilling mud. Drill cuttings must be processed (solids separated from liquids), stored, transported away from the site by heavy truck, and managed as a residual waste. Figure 8(A) shows a multi-well pad in southwest Pennsylvania during the drilling operation.
4. Thousands of feet of steel pipe, some as drill string others as casing, must be transported, again using heavy trucks, onto the site to drill and line the well. A typical Marcellus shale gas well needs about 6,000 m of drill string, and 8,000 m of casing or different diameters.
5. Cementing operations are used on-site to fill the annulus after a casing string has been run, to seal a lost circulation zone, or set a plug before directional tools are used to push off from the vertical section of the well. A cementing crew uses special trucks, mixers and large hydraulic pumps to displace drilling fluids and place cement in the wellbore. Dry materials are ordinarily stored in silos on-site prior to mixing, see Figure 8(A).

6. The large drill rig used to construct the horizontal portion of the wellbore must be transported in pieces to the site and assembled. The horizontal drilling occurs for another 2 kilometers, or more, farther than the vertical portion of the well. The major components of the rig include mud tanks and pumps, the derrick, drawbacks, the rotary table, the drill string, power generation equipment -large electric, diesel or gas powered engines that drive turbines - and a variety of auxiliary equipment. During

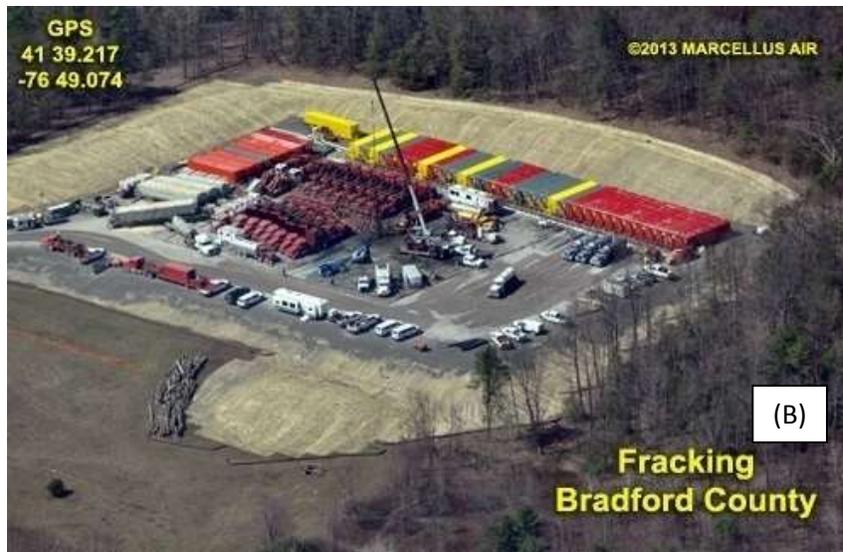


Figure 8. (A) Typical Marcellus shale gas multi-well pad during drilling operation. (a) Drill rig; (b) Unlit but venting flare stack; (c) Air compressors; (d) Main high-pressure air line; (e) Flow line; (f) Separator unit; (g) Water tanks. (B) Typical Marcellus shale gas multi-well pad during stimulation operation.

drilling of the horizontal section another 750 to 1,000 tons of drill cuttings will be generated, depending on the length of the borehole. Drill cuttings from the horizontal section of the well contain various toxic contaminants, including benzene and naturally occurring radioactive materials such as R-226 and R-228. The drill cuttings must be stored, transported using heavy trucking, and managed as a residual waste.

7. Well completion refers to the process of perforating the horizontal portion of the well casing, cement and rock with shaped charges to create communication between the discontinuities in the formation and the wellbore, and stimulation of the reservoir to create high permeability pathways for the gas and oil to flow into the wellbore, as described in Section 4.0, above.
8. Stimulation via “hydraulic fracturing” requires large volumes of liquids – on average 20 million gallons per well in Pennsylvania - to be transported to the well pad either by custom-constructed pipeline, or by using 18-wheel, 2,000 liter tanker trucks. The fracking liquid is pumped down the well under high pressure in order to increase the “effective permeability of the shale rock mass”. *The scale-up required for shale gas wells is readily seen when one considers that the volume of stimulating liquid needed is about 100-times more in an unconventional shale gas well than in a typical non-shale well.* Use of all this water and the concomitant large volume of liquid waste-water has documented environmental and health impacts. **An exhaustive compilation (currently 35 publications) of the peer-reviewed publications concerning water use and quality impacts from shale development can be found at: https://www.zotero.org/groups/248773/pse_study_citation_database/items/collectio nKey/Q7GFAPNU**
9. During stimulation, dozens of pump trucks and containers must be brought onto the well pad. The water is mixed with proppant, either sand or ceramic beads, and a suite of chemicals before being injected into the well. The proppant and chemicals must be brought to, and stored on, the well pad. *Typically, about 600 kg of proppant are used for each meter of stimulated lateral.* Therefore a typical well with a 2 kilometer long

lateral will require about 1,200,000 kg of proppant to be transported to each well. *On a 5-well pad, that would be about 6 million kg of proppant delivered by truck.* Figure 8(B) shows a multi-well pad in southwest Pennsylvania during the stimulation operation.

10. Once stimulation is completed, the internal pressure of the rock formation causes fluid to return to the surface through the wellbore, which is known as "flowback" or "produced water." This cleans the well bore and formation of debris and stimulation fluid. The flowback contains the injected chemicals and naturally occurring materials, including brines, metals, hydrocarbons and radionuclides. Additional equipment such as separators, sand traps and tanks are used to capture and process the gas and condensate. The flowback, typically a few million liters, must be initially stored on-site and then taken off-site using heavy 18-wheel, 2,000-liter tanker trucks for management as a residual waste.
11. When drilling and completion are complete, drilling and stimulation equipment is removed from the site. There remains equipment needed for production such as separator units and condensate tanks, both of which emit GHG's. Maintenance vehicles must visit the site, and drill rigs will return to add new wells to the pad, or to re-fracture existing wells. The existing wells must be tied into pipelines and other infrastructure to convey the gas to market. This infrastructure includes compressor stations, processing plants, and heavy equipment depots. These all require additional land use, and compressor stations and processing plants are point-source emitters of air/noise/light pollution.
12. Shale gas development causes noise pollution for persons residing near the well and along the truck routes that service the well pad. The most intensive noise from well pads will last about a month per well, and will recur when new wells are added, or when wells are reworked. The increased truck traffic associated with well development will impact residents throughout the township. Increased noise pollution can contribute to stress and result in physical effects associated with excess stress such as annoyance, irritation, fatigue, headache, unease, and disturbed sleep.

A number of recent peer-reviewed papers have addressed the issue of noise from shale gas development activities. Figure 9, taken from Hays *et al.* (2017), depicts the potential non-auditory health outcomes of environmental noise exposure.

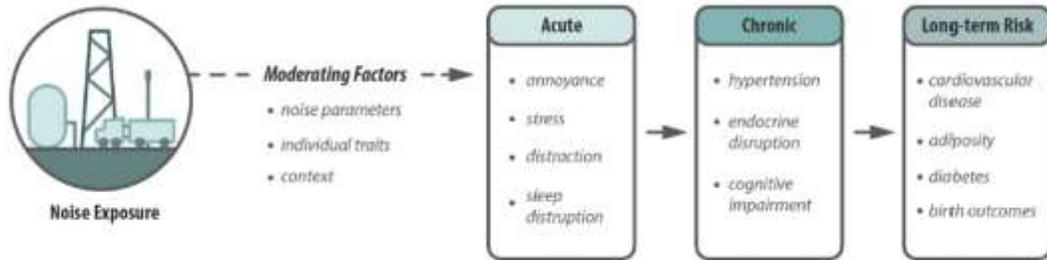


Figure 9. Potential non-auditory health outcomes of environmental noise exposure.

This figure is adapted from Shepherd *et al.* (2010) and depicts the relationships between exposure to noise and primary and secondary health effects. Non-physical effects of noise are also mediated by psychological and psycho-physiological processes (Shepherd *et al.*, 2010). The dashed lines indicate the physical effects of noise and the solid lines indicate the non-physical effects. Annoyance and sleep disturbance act as mediators between predisposing factors and secondary health effects, such as quality of life or cardiovascular disease.

Hays *et al.* evaluate the available literature specific to noise from unconventional oil/gas development (UOGD) and conclude the following:

“...both the nature and duration of noise are relevant to potential health outcomes. Many of the noise levels associated with UOGD are transient in nature and only occur during certain development activities. For instance, some activities, such as well pad preparation, drilling, and hydraulic fracturing will only be encountered prior to the completion of a well. Certain adverse health outcomes usually only result from long-term noise exposure and may be less of a concern with most development activities. On the other hand, some sources, such as compressor stations, produce chronic noise that will continue for years after wells are put out of production. *Although noise levels may fall under municipal and industrial noise limits, data indicate these limits may not be low enough to protect public health.*”

13. Shale gas development causes air pollution of various types from many sources.

Development of a shale gas well typically requires *thousands of heavy diesel truck trips per well installed*, which damages roads, and impacts the health of residents, especially in highly populated areas. Trucks typically run on diesel engines, as do the engines that provide electricity to the drill rig and other auxiliary equipment. Diesel-powered vehicles and equipment account for nearly half of all nitrogen oxides (NO_x) and more than two-thirds of all particulate matter (PM) emissions from United States transportation sources. PM is comprised of hundreds of chemical elements, including sulfates, ammonium, nitrates, elemental carbon, condensed organic compounds, and carcinogenic compounds and heavy metals such as arsenic, selenium, cadmium and zinc.

A recent peer-reviewed journal article (Anirban and Adams, 2016) evaluated air pollution impacts from shale gas development in Pennsylvania, both retrospectively and prospectively. Its approach and principal findings were (*emphases mine*):

“This paper describes an air emissions inventory for the development, production, and processing of natural gas in the Marcellus Shale region for 2009 and 2020. It includes estimates of the emissions of oxides of nitrogen (NO_x), volatile organic compounds (VOCs), and primary fine particulate matter (≤ 2.5 μm aerodynamic diameter; PM_{2.5}) from major activities such as drilling, hydraulic fracturing, compressor stations, and completion venting. The inventory is constructed using a process-level approach; a Monte Carlo analysis is used to explicitly account for the uncertainty. Emissions were estimated for 2009 and projected to 2020, accounting for the effects of existing and potential additional regulations. ***In 2020, Marcellus activities are predicted to contribute 6–18% (95% confidence interval) of the NO_x emissions in the Marcellus region, with an average contribution of 12% (129 tons/day). In 2020, the predicted contribution of Marcellus activities to the regional anthropogenic VOC emissions ranged between 7% and 28% (95% confidence interval), with an average contribution of 12% (100 tons/day).*** ...The development and production of this gas may emit substantial amounts of oxides of nitrogen and volatile organic compounds. These emissions may have special significance because Marcellus development is

occurring close to areas that have been designated nonattainment for the ozone standard. Control technologies exist to substantially reduce these impacts. PM2.5 emissions are predicted to be negligible in a regional context, but *elemental carbon emissions from diesel powered equipment may be important.*”

Particulate matter irritates the eyes, nose, throat, and lungs, contributing to respiratory and cardiovascular illnesses and even premature death. Diesel exhaust has been classified a potential human carcinogen by the U.S. Environmental Protection Agency (EPA) and the International Agency for Research on Cancer. Diesel emissions of nitrogen oxides contribute to the formation of ground level ozone, which irritates the respiratory system, causing coughing, choking, and reduced lung capacity. **An exhaustive compilation (currently 93 publications) of the peer-reviewed publications concerning air pollution from shale and tight gas development can be found at:**
https://www.zotero.org/groups/248773/pse_study_citation_database/items/collectionKey/FX6WTII3

14. Shale gas development causes light pollution, see Figure 10. As with excess noise, the constant illumination of shale gas pads can contribute to stress among those living in areas exposed to constant artificial light from the well pad.
15. Increased heavy traffic caused by shale gas development will have both local and cumulative impacts because of the multiple projects that will be ongoing in the zoned districts, all of which will contribute to traffic due to construction, drilling, transport of wastewater, transport associated with hydraulic fracturing, as well as an overlap of development phases on different well pads.
16. Shale gas development may cause surface and groundwater contamination. Numerous polluting substances are transported to and from well pads, stored on well pads, and used in association with shale gas development. The mismanagement of these substances would result in surface or groundwater contamination from spills,

leaks or accidents. To date, *the Pennsylvania Department of Environmental Protection (PADEP) has received over 4,000 formal complaints concerning potential water impacts from shale gas development in the state.* In the last year, the PADEP has received about one new complaint for each new shale gas well drilled in the state (PublicHerald, 2017). The PADEP has determined that, to date, 293 incidents have been proven to be attributed to shale gas development (PADEP, 2017). **An exhaustive compilation (currently 184 publications) of the peer-reviewed publications concerning water pollution from shale and tight gas development can be found at:** https://www.zotero.org/groups/248773/pse_study_citation_database/items/collectionKey/DCS54HV7



Figure 10. Flaring at night near a home in southwest Pennsylvania.

17. Faulty well construction, such as a bad cement job, can cause groundwater contamination that will affect private water wells, such as that experienced by the residents of Dimock,

Pennsylvania. In a comprehensive evaluation of PADEP inspection and violations records for over 41,000 gas and oil wells drilled between 2000 and 2012, Ingraffea et al. (2014) found that *risk of faulty well construction was about 50% higher in unconventional wells*. They also found that loss of well integrity occurred in over 6% of the unconventional wells developed in the state during that time period.

18. In addition to well-pads, compressor stations and natural gas processing stations are major industrial operations needed to accompany shale hydrocarbon development. Figure 11 shows a typical compressor station in operation and a typical processing plant (under construction) in southwest Pennsylvania. Air, noise, and light pollution and their impacts on human health accompany the continuous operation of such infrastructure.

Compressor stations consist of large reciprocating engines, operating at thousands of horsepower, which compress gas in order to transport it through transmission pipelines. Compressor station engines emit nitrogen oxides, volatile organic compounds, particulate matter, carbon monoxide, and other pollutants. When vented, compressor stations emit volatile organic compounds and methane.

Gas processing plants separate natural gas from other longer-chained hydrocarbons and contaminants produced from shale gas wells so that the natural gas complies with pipeline specifications, and the higher order hydrocarbons can be marketed. Processing plants may include fractionators and de-ethanators. Shale gas processing emits greenhouse gases, as well as toxic air pollutants such as benzene, formaldehyde and hexane. Shale gas wells, compressor stations, and processing facilities have a greater impact on more vulnerable populations, such as school-aged children. Air pollutants from all forms of shale gas development may interfere with brain development of children and more easily accumulate in their bodies as children cannot metabolize toxins at the same rate as adults. Pollutants and impacts from shale gas development may also lead to an increased rate of development of asthma and other respiratory diseases in children. **An exhaustive compilation (currently 120 publications) of the peer-reviewed publications concerning human health impacts from shale and tight gas development can be found at:**



Figure 11. (a) Three Brothers Compressor station in Smith Township. Lat 40;19;40.698. Long 80;23;25.236 (b) New processing plant under construction in Smith Township. Lat 40;25;3.402. Long 80;20;44.951 Photos courtesy of Bob Donnan.



Figure 12. (a) Burnoff at Mark West processing plant, Houston, Pa. Photo courtesy of Bob Donnan. (b) Blowdown at Teel compressor station, Dimock, Pa. Video courtesy of Ron Teel.

https://www.zotero.org/groups/248773/pse_study_citation_database/items/collectionKey/FX6WTII3

Unlike the noise and light emissions from pads, air pollution from compressor stations and processing plants are continuous for as long as such are in operation. Planned and unplanned “blowdowns” and “burnoffs” from such facilities can be dramatic and require

emergency evacuations from residences near these heavy industrial sites, Figure 12.

6.0 Conclusion

Unconventional development of shale hydrocarbons, anywhere in the world, is a heavy industry that requires substantial scaling-up of development and production operations when compared to conventional development, and requires much more spatially intense siting of well pads. In Section 5, above, repeated reference was made to an archive of peer-reviewed literature on the impacts of tight gas development: https://www.zotero.org/groups/248773/pse_study_citation_database/items. This is a one-of-a-kind archive, called ROGER (Repository for Oil and Gas Energy Research, which began operations in 2014 and daily surveys the scientific/environmental/medical literature for new additions. The archive is divided into the categories shown in Figure 13.



Figure 13. Categories of potential impacts in the ROGER archive.

It is crucial for the people, the government, and regulatory bodies in the UK to know that when the shale gas “revolution” began about 20 years ago, *there were only 6 peer-reviewed publications over all of these categories*. In other words, little was questioned or known about potential and actual impacts in each category. Ignorance was implicitly used as an excuse to unleash development in many states and provinces. Figure 14 shows the history of peer-reviewed publications in these categories up to the end of 2016. Note that research has been growing almost exponentially; over 60% has been published since Jan 1, 2015; over 1,280 publications are now in the archive. Ignorance is no longer an excuse for thorough study of all of the potential impact categories by regulatory and legal entities. It is now known that unwanted potential and actual impacts occur in each of these categories. For example, in a peer-reviewed paper Hays and Shonkoff (2016) evaluated the findings in three categories in this archive from 2009 to 2015. In the air quality category, they found that 87% of the publications indicated elevated air pollutant emissions and/or atmospheric concentrations; in the human health category, they found that 84% of the publications indicated public health hazards, elevated risks, or adverse health outcomes human health; in the water quality category, they found that 69% of the publications indicated potential, positive association, or actual incidence of water contamination.

Any assertion that the UK would have regulations and enforcement that would belie such scientifically supported statistics is ludicrous. Shale gas development is shale gas development, in the UK, in U.S., or elsewhere. After nearly 50,000 shale gas wells developed in the U.S., the process has been honed to an art, more intense and larger in all respects than its early instantiation. Every state and province in which it is occurring, or in which it is being proposed, claims to have the “toughest regulations”.

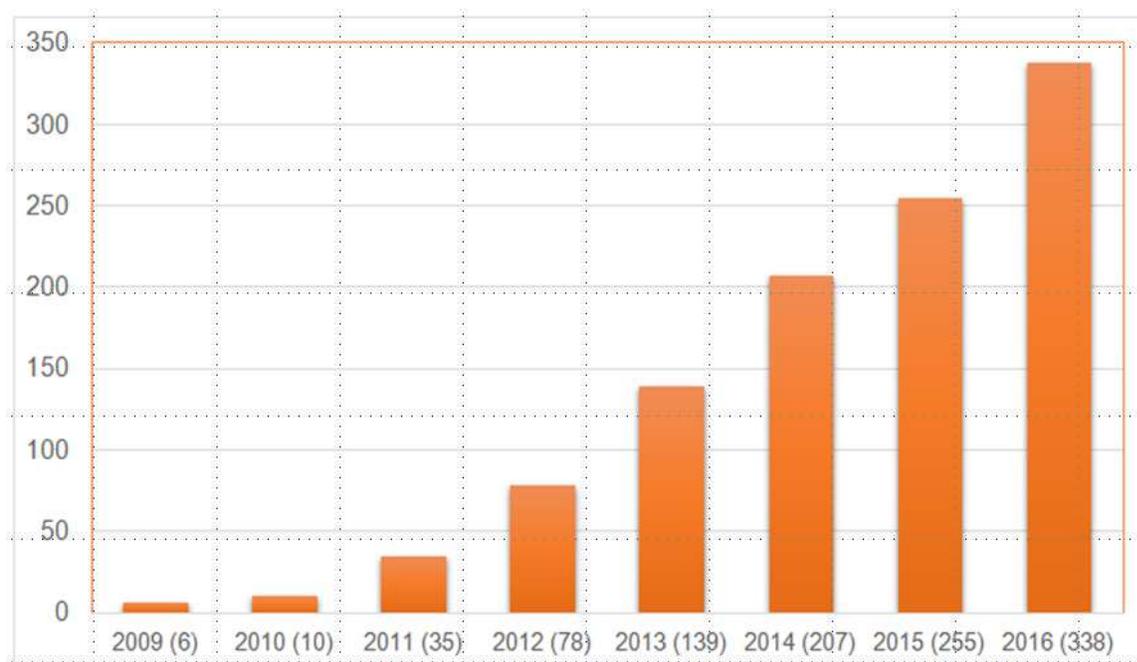


Figure 14. History of number of peer-reviewed publications in the impact categories shown in Figure 13.

Finally, in the category of climate and the question of the negative impacts that could be experienced in the UK, it is now clear that any increase in the production and use of fossil fuels exacerbates climate change. Figure 15 is from a 2012 paper in *SCIENCE* by Shindell et al.. At the time it appeared, it contained the most up-to-date predictions of global warming via simulation, for 4 possible scenarios (the 4 colored curves all starting from the actual record, the squiggly black line). It also showed error bars for each of the predicted scenarios, the four vertical bars on the right. The "zero", the basis for relative temperature change, was the average of the yearly measurements between 1890-1910. So, by 2009 a relative temperature increase of about 0.8 degrees C had been recorded. The red dots are NOT part of the original chart from Shindell. One dot has been added each year based on new measurements as reported by NASA GISS (available at <https://data.giss.nasa.gov/gistemp/graphs/>). Note that there are 3 red dots almost on top of each other for 2011, 2012, 2013.

As one can see in Figure 15, the scenario called REFERENCE (meaning no significant change in GHG emission rates going forward worldwide) is the most alarming, putting us at 2 degrees C warming between about 2030 and 2070 (one must use the error bars to see this, using the dotted

purple straight lines). But the trend in the dots shows warming at a much faster rate than that worst case scenario for the period of 2009-2016: in other words, the simulations done 7-8 years ago, were inaccurate, in the worst possible way--they were overly conservative. The red dots for 2015-2016 fall above the error estimate for those years.

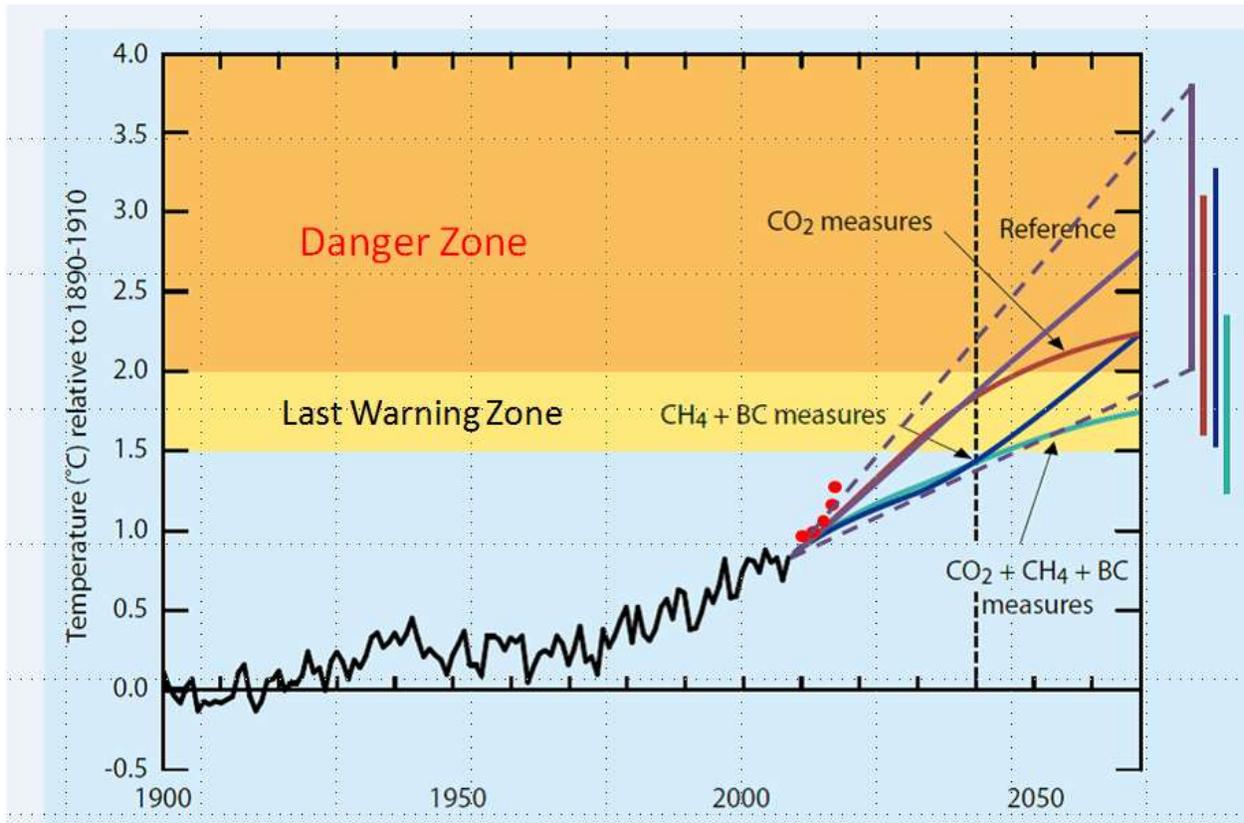


Figure 15. Shindell et al. (2012). Simultaneously mitigating near-term climate change and improving human health and food security. *Science* 335: 183-189.

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APPENDIX A

CV of Dr. Ingraffea

APPENDIX B - Deposition and Trial Testimony

B-1 Depositions

Nolan Scott Ely et al. Plaintiff v. Cabot Oil & Gas Corporation Defendant, Case No. 3:09-cv-02284-MCC, United States District Court, Middle District of Pennsylvania, July 15, 2015.

Robert Andrews et al v. Antero et al. Defendants, Civil Action No. 14-C-3000. Circuit Court of Ohio County, West Virginia, June 12, 2015.

Cody Murray et al. Plaintiffs v. EOG Resources; Fairway Resources et al. Defendants, Cause No. 342-284983-16, District Court, Tarrant County, Texas, May 24, 2017.

B-2 Trial

Nolan Scott Ely et al. Plaintiff v. Cabot Oil & Gas Corporation Defendant, Case No. 3:09-cv-02284-MCC, United States District Court, Middle District of Pennsylvania, February, 2016.

James Cromwell et al. Defendants v. State of New York, Docket Nos. 15120561, 16010030,15120476,15120478,15120477,16010031.Wawayanda Town Court, Orange County, New York, April, 2017