Chemical and Biological Risk Assessment for Natural Gas Extraction in New York

Ronald E. Bishop, Ph.D., CHO
Chemistry and Biochemistry Department
State University of New York, College at Oneonta

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Summary:

Over the last decade, operators in the natural gas industry have developed highly sophisticated methods and materials for the exploration and production of methane from unconventional reservoirs. In spite of the technological advances made to date, these activities pose significant chemical and biological hazards to human health and ecosystem stability. If future impacts may be inferred from recent historical performance, then:

- Between two and four percent of shale gas well projects in New York will pollute local ground-water over the short term. Serious regulatory violation rates will exceed twelve percent.

- More than one of every six shale gas wells will leak fluids to surrounding rocks and to the surface over the next century.

- Each gas well pad, with its associated access road and pipeline, will generate a sediment discharge of approximately eight tons per year into local waterways, further threatening federally endangered mollusks and other aquatic organisms.

- Construction of access roads and pipelines will fragment field and forest habitats, further threatening plants and animals which are already species of concern.

- Some chemicals in ubiquitous use for shale gas exploration and production, or consistently present in flowback fluids, constitute human health and environmental hazards when present at extremely low concentrations. Potential exposure effects for humans will include poisoning of susceptible tissues, endocrine disruption syndromes, and elevated risks for certain cancers.

- Exposures of gas field workers and neighbors to toxic chemicals and noxious bacteria are exacerbated by certain common practices, such as air/foam-lubricated drilling and the use of impoundments for flowback fluids. These methods, along with the intensive use of diesel-fueled equipment, will degrade air quality and may cause a recently described "down-winder's syndrome" in humans, livestock and crops.

- State officials have not effectively managed oil and gas exploration and production in New York, evidenced by thousands of undocumented or improperly abandoned wells and numerous incidents of soil and water contamination. Human health impacts from these incidents appear to include abnormally high death rates from glandular and reproductive system cancers in men and women. Improved regulations and enhanced enforcement may reasonably be anticipated to produce more industry penalties, but not necessarily better industry practices, than were seen in the past.

Overall, proceeding with any new projects to extract methane from unconventional reservoirs by current practices in New York State is highly likely to degrade air, surface water and ground-water quality, to harm humans, and to negatively impact aquatic and forest ecosystems. Mitigation measures can partially reduce, but not eliminate, the anticipated damage.

Introduction:

Natural gas production from hydrocarbon-rich shale formations is probably the most rapidly developing trend in onshore oil and gas exploration and production today. "In some areas, this has included bringing drilling and production to regions of the country that have seen little or no activity in the past. New oil and gas developments bring changes to the environmental and socio-economic landscape, particularly in those areas where gas development is a new activity. With these changes have come questions about the nature of shale gas development, the potential environmental impacts, and the ability of the current regulatory structure to deal with this development." (1)

Prominent features of shale gas development, which distinguish it from conventional gas extraction activity, are the use of horizontal drilling and high-volume hydraulic fracturing. While these technologies certainly lead to well projects which are orders of magnitude larger than traditional gas wells, and enable energy development companies to pursue projects in places which historically weren't commercially viable (such as New York's Southern Tier), gas exploration and production have never been free of risk. No attempt is made here to isolate horizontal drilling or hydraulic fracturing from any other processes used for gas extraction and transportation, inasmuch as the term "fracking" is understood by a majority of Americans as emblematic of the entire shale gas industry (2). Therefore, the objective is to evaluate risk related to the industry as a whole.

The working hypothesis of this work is that recent historical performance may be used to predict future performance of the gas industry. Data sources predominantly include official state, federal or industry reports.

Two components of risk imposed by the gas industry are evaluated here: incident frequency and impact. Frequency data are presented in Part 1, and chemical and biological aspects of impact are discussed in Part 2.

Part 1: Incidents of Contamination Related to Natural Gas Extraction

Official incident reports from various jurisdictions are cited below, but their evaluation requires appropriate context. One approach to context compares official gas industry incidents over any period to the total number of gas wells that ever existed in the report region. In the author's judgment, this approach fails to accommodate the facts that many gas wells were "spudded" prior to any official record-keeping (let alone incident reporting), and most reported gas well mishaps arguably occur during initial drilling and stimulation. This author's contextual approach is to compare incident reports to the total active gas wells operating in a jurisdiction at the close of the reporting period, and to offer the number of new gas well projects started in that period, where available, as an alternative comparison.

Data from Colorado indicated that 1549 spill incidents related to natural gas extraction activities occurred in the period from January 2003 to March 2008; the Congressional Sportsmen's Foundation estimated that 20% of these (310) impacted groundwater (3). The New Mexico Oil Conservation Division recorded 705 groundwater-contaminating incidents caused between 1990 and 2005 by the oil and gas industry (4). Compared to totals of 25,716 and 40,157 producing gas wells in Colorado and New Mexico, respectively (5), these data suggest that 6% of western region gas projects suffer serious mishaps, and that natural gas development in western states degrades groundwater quality at a rate of 1.2 to 1.8 incidents per 100 gas wells. Data from West Virginia lead to a generally similar conclusion of groundwater impacts from approximately 1.5% of active gas wells (5, 6), while Utah reported a violations rate of 11.5% without expressly indicating the extent of documented groundwater contamination (6).

The Pennsylvania Land Trust reported 1610 DEP violations in the Commonwealth between January 2008 and late August 2010, of which 1052 were judged likely to impact the environment (7). The Land Trust report appears to have included incidents related only to those gas wells which targeted the Marcellus shale formation. What fraction of the 57,356 active gas wells in Pennsylvania targeted that formation has not been reported (5), but 2010 records show that 20% of the DEP's gas well inspections were performed on Marcellus wells (9). Comparing 1052 serious incidents to an upper limit of 11,471 Marcellus wells, these data suggest that at least 9% of Pennsylvania's shale gas projects had negative impacts on their environment.

Pennsylvania's gas industry incident data are open to independent review since, responding to Act 15, signed into law by Governor Rendell in March, 2010 (8), the Department of Environmental Protection developed the DEP Oil and Gas Electronic Reporting website (9). **Table I** summarizes incidents from (a) all formations and (b) Marcellus shale formations for the period from January 2008 through November 2010.

Table I: Pennsylvania Gas Industry Inspections, Violations and Enforcements

Year	Formations	Inspections	Violations	Enforcements
2008	All	937	1447	662
	Marcellus	130	179	122
2009	All	1801	3159	693
	Marcellus	314	639	190
2010	All	1364	2486	662
	Marcellus	565	1105	280
Total	All	4102	7092	2017
	Marcellus	1009	1923	592

These records indicate that total violations and serious violations (enforcements) correlate well with the numbers of inspections, but Marcellus projects tended to generate violations and enforcements at rates that increased with the passing of time. Compared to a total of 57,356 producing gas wells in the Commonwealth, the data indicate a violations rate of 12.4% and an enforcements (serious violations) rate of 3.5%. Further, they suggest that industry operators became less compliant with regulations as the Marcellus shale projects advanced: more citations produced greater penalties, but not better practices.

Now, it could be argued that not all producing wells pose equal risk: that gas well projects which are under construction contribute greater hazards than completed wells. Compared to 19,997 total *new* gas well projects reported from January 2008 through November 2010 (10), the data in Table I indicate a serious (potentially groundwater-impacting) violations rate of 10.1%. Put another way, about one of every ten new gas well projects in Pennsylvania has run into serious trouble over the past three years. For a more detailed analysis of incident reports from Pennsylvania, Utah and West Virginia, the reader is referred to the work of Conrad Daniel Volz (6).

Statistics for New York's natural gas industry are somewhat more complex than those reported by the states just mentioned. Toxics Targeting, Inc., using data compiled by the New York State Department of Environmental Conservation (NYSDEC), brought to light 270 gas industry-related contamination incidents which had occurred in New York State since 1979 (11). This number, compared to a total of 6,680 active gas wells (5), points to a serious incident rate of 4.0%. However, a 1994 review conducted by the Interstate Oil and Gas Compact Commission (IOGCC) revealed that approximately 8.6 million barrels (360 million gallons) of oil and gas well brines were discharged directly onto farm fields, into streams, or onto roadways annually as late as 1993 (12). The scale of this intentional dumping (in the review panel's language: "no pit at the end of the pipe"), arguably for most of the industry's 170 years of operating in New York prior to 1993, appears to vastly outweigh the accidental releases identified by Walter Hang and his team (11). Analyses are currently underway to evaluate the scope of harm done to surface streams and shallow aquifers in the western counties where most of the discharges took place (13 – 20). Some possible human health impacts are presented in Part 2 of this article.

Short-term collateral damage from gas well development constitutes only part of this industry's hazard profile. In 1992, the US Environmental Protection Agency (EPA) estimated that of 1.2 million abandoned oil and gas wells in the U.S., 200,000 were leaking (21). This represents a 16.7% failure rate; one of every six abandoned wells is releasing its contents to the surrounding area, including the surface. A Canadian research team investigated the mechanisms for these failures, and determined that concrete shrinkage which leads to well casing fissures is essentially inevitable in a fifty-year time frame. They found that this cracking was especially severe at maximum depth, and exposure of steel casings to the hot (140 – 180 °F) brines there accelerated their breakdown, permitting subterranean gases and other fluids to re-pressurize the deteriorating wells (22). Wells in regions containing mobile geological faults, such as Upstate New York (23), are also subject to casing deformation and shear (24). According to the IOGCC panel report, New York has a "substantial abandoned wells problem", with more than 48 thousand undocumented or improperly abandoned oil and gas wells (12). Therefore, we may reasonably expect higher percentages of gas well casings to fail over time, especially longer than fifty years. The probability that a project scope of as few as ten modern gas wells will impact local ground water within a century approaches 100% certainty. Indeed, citizens of New York have already suffered extensive water pollution by this industry, as mentioned above, and health effects possibly related to exposure to this pollution are presented below.

Part 2: Chemical and Biological Hazards From Natural Gas Extraction

Drilling Additives:

Many chemical products are used in the development of a gas well. Some examples, along with their most common applications, are shown in **Table II**.

Table II: Additive Functions in Shale Gas Extraction

Additive Type	Examples	Purpose	Used In
Friction Reducer	heavy naphtha, polymer microemulsion	lubricate drill head, penetrate fissures	drilling muds, fracturing fluids
Biocide	glutaraldehyde, DBNPA, dibromoacetonitrile	prevent biofilm formation	drilling muds, fracturing fluids
Scale Inhibitor	ethylene glycol, EDTA, citric acid	prevent scale buildup	drilling muds, fracturing fluids
Corrosion Inhibitor	propargyl alcohol, *N*,*N*-dimethylformamide	prevent corrosion of metal parts	drilling muds, fracturing fluids
Clay Stabilizer	tetramethylammonium chloride	prevent clay swelling	drilling muds, fracturing fluids
Gelling Agent	bentonite, guar gum, "gemini quat" amine	prevent slumping of solids	drilling muds, fracturing fluids
Conditioner	ammonium chloride, potassium carbonate, isopropyl alcohol	adjust pH, adjust additive solubility	drilling muds, fracturing fluids
Surfactant	2-butoxyethanol, ethoxylated octylphenol	promote fracture penetration	drilling fluids, fracturing fluids
Cross-Linker	sodium perborate, acetic anhydride	promote gelling	fracturing fluids
Breaker	hemicellulase, ammonium persulfate, quebracho	"breaks" gel to promote flow-back of fluid	post-fracturing fluids
Cleaner	hydrochloric acid	dissolve debris	stimulation fluid, pre-fracture fluid
Processor	ethylene glycol, propylene glycol	strip impurities from produced gas	post-production processing fluids

Individual additives are typically used in multiple stages of the drilling process; most hydraulic fracturing additives are also used in drilling fluids (or "muds") (25). Rare exceptions include bentonite and barium sulfate, which are used almost exclusively in drilling muds and packer slurries, and hemicellulase enzyme, used solely in post-fracturing fluids. Even the chemicals used for post-production purification may also be used as solvents in drilling muds (25).

The majority of chemical products used by the gas industry have not been fully tested for human or environmental toxicity (26, 27). Of those which have, a minority (*e.g.,* bentonite, guar gum, hemicellulase, citric acid, acetic acid, potassium carbonate, sodium chloride, limonene, polyethylene glycol and mineral oil) pose no significant hazards to humans or other organisms as utilized in gas extraction processes.

Several other additive chemicals, including ammonia, methanol, ethanol, 2-propanol, 1-butanol, thioglycolic acid, acetophenone, sodium perborate tetrahydrate, diammonium peroxydisulfate and hydrochloric acid, are moderately or acutely toxic to humans or aquatic organisms when encountered in concentrated forms (28 – 37), but as used by the natural gas industry, they end up greatly diluted, and so impose relatively modest hazards (26). More significant issues with these chemicals would be anticipated from storage sites, trucking accidents while they are being transported to remote well sites via rural roads, and staging at well sites.

However, a few chemical products in widespread use, including in exploratory wells, pose significant hazards to humans or other organisms, because they remain dangerous even at concentrations near or below their chemical detection limits. These include the biocides glutaraldehyde, 2,2-dibromo-3-nitrilopropionamide (DBNPA) and 2,2-dibromoacetonitrile (DBAN), the corrosion inhibitor propargyl alcohol, the surfactant 2-butoxyethanol (2-BE), and lubricants containing heavy naphtha. Precisely because of the hazard these chemicals pose even when they are extremely diluted, they are considered in some detail in this section. (Note: CAS No. refers to a unique identifier assigned to every known substance by the Chemical Abstracts Service Registry.)

Glutaraldehyde:

Glutaraldehyde (CAS No. 111-30-8) is a biocide used widely in drilling and fracturing fluids. Along with its antimicrobial effects, it is a potent respiratory toxin effective at parts-per-billion (ppb) concentrations (38); a sensitizer in susceptible people, it has induced occupational asthma and/or contact dermatitis in workers exposed to it, and is a known mutagen (i.e., a substance that may induce or increase the frequency of genetic mutations) (38, 39). It is readily inhaled or absorbed through the skin. In the environment, algae, zooplankton and steelhead trout were found to be dramatically harmed by glutaraldehyde at very low (1 – 5 ppb) concentrations (40).

DBNPA:

2,2-Dibromo-3-nitrilopropionamide (DBNPA) (CAS No. 10222-01-2) is a biocide finding increasing use in drilling and fracturing fluids. It is a sensitizer, respiratory and skin toxin, and is especially corrosive to the eyes (41). In the environment, it is very toxic to a wide variety of freshwater, estuarine and marine organisms, where it induces developmental defects throughout the life cycle. In particular, it is lethal to "water fleas" (*Daphnia magna*), rainbow trout and mysid shrimp at low (40 to 50 ppb) concentrations, and is especially dangerous to Eastern oysters (42). Chesapeake Bay oysters are killed by extremely low (parts-per-trillion, ppt) concentrations of DBNPA, well below the limit at which this chemical can be detected.

DBAN:

Dibromoacetonitrile (DBAN) (CAS No. 3252-43-5) is a biocide often used in combination with DBNPA, from which it is a metabolic product (with the release of cyanide). Its human and environmental toxicity profiles are similar to that of DBNPA, except that DBAN is also carcinogenic (43). DBNPA and DBAN appear to work synergistically. In combination, the doses at which these biocides become toxic are significantly lower than when they are used separately. In other words, it takes much less of these chemicals to exert toxic effects when they are used together, although the specific degree of potentiation has not been publicly reported.

Propargyl Alcohol:

Propargyl alcohol (CAS No. 107-19-7) is a corrosion inhibitor that is very commonly used in gas well construction and completion. This chemical causes burns to tissues in skin, eyes, nose, mouth, esophagus and stomach; in humans it is selectively toxic to the liver and kidneys (44). Propargyl alcohol is a sensitizer in susceptible individuals, who may experience chronic effects months to years after exposure, including rare multi-organ failure (45). It is harmful to a variety of aquatic organisms, especially fathead minnows, which are killed by doses near 1 ppm (46).

2-BE:

2-Butoxyethanol (2-BE), also known as ethylene glycol monobutyl ether (EGBE) (CAS No. 111-76-2), is a surfactant used in many phases of gas exploration and extraction. It comprises a considerable percentage of Airfoam HD, commonly used for air-lubricated drilling (47). Easily absorbed through the skin, this chemical has long been known to be selectively toxic to red blood cells; it causes them to rupture, leading to hemorrhaging (48). More recently, the ability of EGBE at extremely low levels (ppt) to cause endocrine disruption, with effects on ovaries and adrenal glands, is emerging in the medical literature (49). This chemical is only moderately toxic to aquatic organisms, with harm to algae and test fish observed with doses over 500 ppm (48).

Heavy Naphtha:

Heavy naphtha (CAS No. 64741-68-0) refers to a mixture of petroleum products composed of, among other compounds, the aromatic molecules benzene, toluene, xylene, 1,2,4-trimethylbenzene and polycyclic aromatic hydrocarbons including naphthalene. It is used by the gas industry as a lubricant, especially in drilling muds. This material is hazardous to a host of microbes, plants and animals (50). Several of the mixture's components are known to cause or promote cancer. If released to soil or groundwater, several components are toxic to terrestrial and aquatic organisms, especially amphibians, in which it impedes air transport through the skin.

Flowback Fluids:

Irrespective of chemical additives used for drilling, Marcellus shale contains several toxic substances which can be mobilized by drilling. These include lead, arsenic, barium, chromium, uranium, radium, radon and benzene, along with very high levels of sodium chloride (51). These components make flowback fluids hazardous without any added chemicals, and are often among the analytes most easily measured by potential waste fluid treatment plant operators (**Figure 1**).

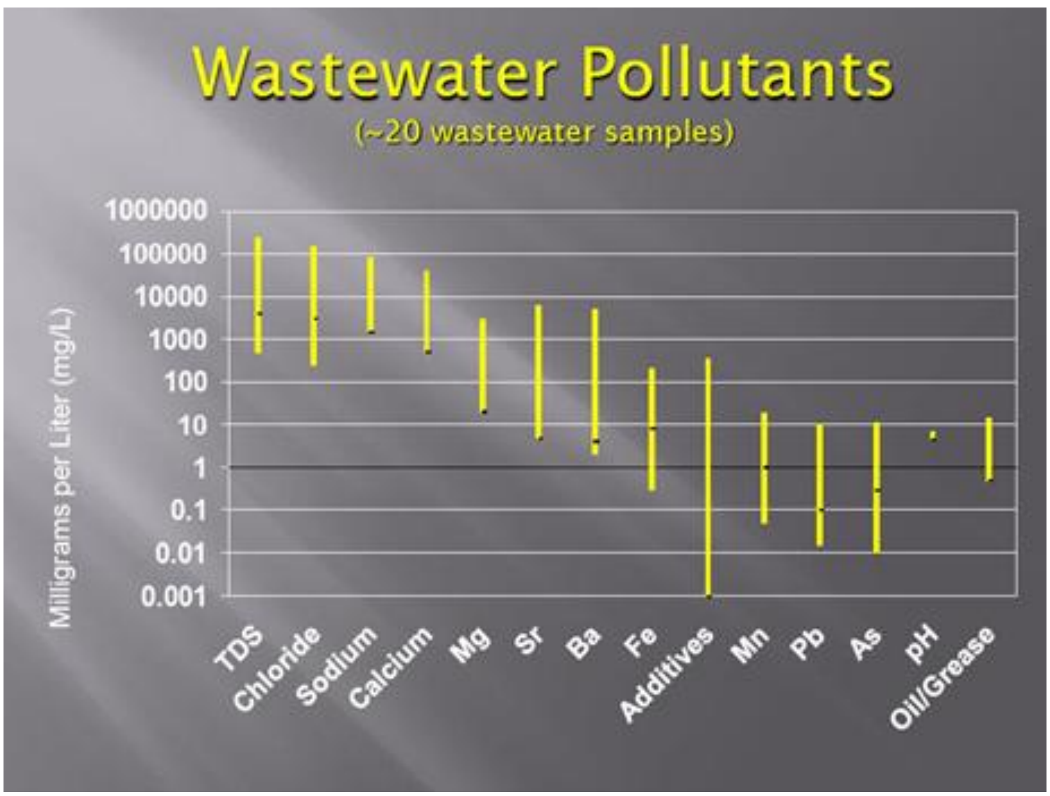

Figure 1: Wastewater Pollutants (52)

Because of to their significant toxicity at low (ppb) concentrations, and the fact that drill cuttings are often not removed, but rather are buried on-site, several of these flowback fluid and cuttings components (51) are discussed below: barium, lead, arsenic, chromium, benzene and technologically enhanced naturally occurring radioactive materials.

Barium (Ba):

Barium is a toxic heavy metal commonly found in Marcellus shale well flowback fluids (53). Exposure to soluble salts (not the sulfate), which may occur by ingestion, absorption or inhalation, may induce drops in tissue potassium levels, and by this mechanism it is selectively toxic to the heart and kidneys (54). Further, barite (barium sulfate), used as a weighting agent in drilling muds, reacts with radium salts in shale, forming radioactive scale on metal parts (such as the drill "string") which then are subsequently brought to the surface (25); in these reactions, barite is converted to more soluble (i.e. more toxic) barium salts.

Lead (Pb):

The poisonous nature of lead has been known for centuries, but its ability to impair neurological development in children at very low (1 ppb) concentrations makes it a toxicant of special concern. The most sensitive targets for lead toxicity are the developing nervous system, the blood and cardiovascular systems, and the kidney. However, due to the multiple modes of action of lead in biological systems, and its tendency to bio-accumulate, it could potentially affect any system or organs in the body. It has also been associated with high blood pressure (55).

Arsenic (As):

Arsenic, another component of black shale (51), has also been known as a poison for hundreds if not thousands of years. The most sensitive target tissue appears to be skin, but arsenic produces adverse effects in every tissue against which it has been tested, especially brain, heart, lung, the peripheral vascular system, and kidney (56). Arsenic is harmful below one part per trillion (ppt) in water, and is a confirmed carcinogen.

Chromium (Cr):

Chromium, also found in Marcellus shale (57), may be an essential nutrient required in extremely small doses (μg per day), but the biological system it supports is not currently known. Exposure to elevated doses by inhalation, ingestion, skin or eye contact may lead to respiratory, gastrointestinal, reproductive, developmental and neurological symptoms

(58). Sensitization-induced asthma and allergy have also been reported. However, at very low concentrations, particularly of potassium dichromate or strontium chromate (the hexavalent form, as found in shale rock) (59), the major hazard posed by chromium is as a carcinogen, especially in stomach and lung tissues (58).

Benzene:

Benzene, a known shale constituent (51), was briefly considered above as a component of heavy naphtha. In ppb concentrations, the primary hazard from this compound is due to its proven ability to cause acute non-lymphocytic leukemia (60).

Technologically Enhanced Naturally Occurring Radioactive Materials (TENORM):

The use of lubricants and "slickwater" additives along with hydraulic fracturing for oil and gas production have been shown to mobilize naturally occurring radioactive materials, including uranium- 238, radium-226 and radon-222 (61). This has been identified as one of the greatest challenges facing the American gas industry today (62). Of these, radon is of special concern because as a gas it is extremely mobile, and it is intensely radioactive (62). Exposure by inhalation or ingestion typically results in migration to the lungs, which are susceptible to damage from its nuclear decay; exposure to radon is considered the second leading cause of lung cancer after tobacco smoking (63). Radon was detected at levels above 300 pCi/L (a drinking water limit proposed by the USEPA), in a majority of groundwater samples collected in New York State by USGS investigators (18 – 20). However, whether the high levels of radon in drinking water may be related to past or present oil and gas development in those locales has not been studied.

4-NQO:

In addition to the above shale constituents, one chemical compound was consistently encountered in flowback fluids from Marcellus gas wells in Pennsylvania and West Virginia: 4-nitroquinoline-1-oxide (4-NQO) (64). This is one of the most potent carcinogens known, particularly for inducing cancer of the mouth (65). It is not used as a drilling additive and is not known to occur naturally in black shale; no studies have been published to date with respect to what chemical interactions account for its consistent presence in flowback fluids. However, it is dangerous at parts-per-trillion (ppt) concentrations, well below its levels reported in gas well flowback fluids (64).

Biological Contamination:

Rock strata beneath the earth's surface are populated by microscopic organisms, and the advent of air-lubricated drilling (without biocides) has introduced a risk of contaminating surface (fresh) water zones with bacteria and other microbes from deeper (brine) layers, where they often flourish. Of particular concern are sulfate-reducing bacteria, especially *Desulfovibrio desulfuricans*, a facultative anaerobe that thrives in fresh water where some sulfate (such as is present in pyrite or hematite) is available (66), (**Figure 2)** (67).

Figure 2: Biofilm of *Desulfovibrio desulfuricans* Growing on a Hematite Surface

These bacteria are especially prevalent and aggressive in oil and gas producing regions, where they avidly form living black, sticky films in water wells and other structures (68). There they produce hydrogen sulfide (H_2S), characterized by a "rotten eggs" smell. Rock strata rich in gas are often also rich in this bacterium, and exposure to hydrogen sulfide along with methane raises significant health concerns –neurological syndromes in humans and, in livestock, elevated birth defect rates and diminished herd health. At high concentrations, hydrogen sulfate is lethal (69).

The now-common use of air-lubrication (without biocides) while drilling the top one- to three thousand feet of gas wells (70) risks contaminating fresh water aquifers with sulfate-reducing bacteria from the deeper strata, but there is no clear evidence that this water well fouling mechanism is recognized by New York state regulators.

Transportation Infrastructure:

Gas well development requires the construction of well pads, access roads and pipelines. These structures, as well as the construction projects that produce them, pose significant environmental hazards from accelerated erosion (71, 72). A report for the USEPA determined an average annual sediment yield of 7.4 metric tons per hectare in Denton, Texas (73). After adjusting for the difference in average rainfall amounts in Denton, TX and New York State, and estimating one hectare (2.47 acres) as a typical land disturbance for a gas well pad, access road and pipeline (74), the sediment load for a New York gas well is expected to average 8.5 tons per year. Degradation of existing roads, culverts and bridges by excessive truck traffic also accelerates erosion and increases deposition of road dust into waterways (75). Organisms which are critical for maintaining stream water quality and are especially vulnerable to sediment runoff and siltation damage include filter-feeding macroinvertebrates (76) and bivalve mollusks, including the federally endangered dwarf wedgemussel (77, 78).

In addition to soil erosion issues, all-weather access roads also lead to the fragmentation of fields and forests (72, 79). One consequence is declining critical core populations of Allegheny woodrats, Henslow's sparrows, snowshoe hares, and plants such as tamarack and red spruce trees, and yellow lady slipper orchids, all of which require interior woodland habitats (79). Woodland amphibians, including marbled, blue-spotted and Jefferson's salamanders, which are species of special concern, are also sensitive to habitat fragmentation (80). As predator species (*e.g.* songbirds) decline, their food sources (insects) burgeon. Conversely, as important food sources (*e.g.* salamanders) decline, organisms dependent on them (snakes, turtles and birds) will suffer stress and decline.

Air Quality Impacts:

Gas well projects can generate uniquely severe air quality problems, as volatile organic compounds (VOC's) from flowback fluid impoundments, polycyclic aromatic hydrocarbons (PAH's) from incompletely-combusted fuel and fugitive methane emissions combine with nitrous oxides (NOx) from diesel exhaust (81) to form ground-level ozone. To paraphrase the pioneering work of Theo Colborn et al (82): "This ozone can burn the deep alveolar tissue in the lungs, causing its premature aging. Chronic exposure can lead to asthma and chronic obstructive pulmonary diseases (COPD). Ozone combined with [fine] particulate matter produces smog which has been demonstrated to be harmful to humans as measured by emergency room admissions during periods of elevation. Gas field ozone has created a previously unrecognized air pollution problem in rural areas, similar to that found in large urban areas, and can spread up to 200 miles beyond the immediate region where gas is being produced. Ozone not only causes irreversible damage to the lungs, it is similarly damaging to conifers, forage, alfalfa, and other crops commonly grown in the U.S." (82).

In addition to impacts from ground-level ozone, fugitive emissions of methane from wellheads, pipelines and storage facilities, along with combustion (primarily diesel) exhausts related to construction and pipeline pressurization, combine to put the total greenhouse gas emissions from shale gas extraction on par with greenhouse gas emissions from coal (83). Further, Robert Howarth's analysis suggests that "clean" natural gas exerts a greater "carbon footprint" than diesel oil when the intensive efforts required to extract gas from shale are taken into account (83). Therefore, the desirability of natural gas as a "transition fuel" is questionable when the resource must be extracted from unconventional reservoirs by energy-intensive means: it may be no better than coal.

Potential Health Effects:

Hazards that accompany the above chemicals and microbes and physical agents have to this point been considered individually. They clearly don't occur individually. No investigations of interactions among all these materials have been reported to date. However, this author has been contacted by officials with the National Institute of Safety and Occupational Health, Centers for Disease Control (NIOSH/CDC), who requested any information that might shed light on a group of clinical symptoms, presented by patients in southwestern Pennsylvania and the state of West Virginia, which is being tentatively identified as "down-winder's syndrome" (84). These symptoms, including irritated eyes, sore throat, frequent headaches and nosebleeds, skin rashes, peripheral neuropathy, lethargy, nausea, reduced appetite and mental confusion, were also reported in gas field health impact studies conducted by Wilma Subra in Texas (85) and Wyoming (86). These disparate observations are supported by a literature review of potential human health effects from gas drilling activities (87). In response, the Medical Society of the State of New York and the medical societies from Broome, Cayuga, Chenango, Chemung, Herkimer, Madison, Oneida, Onondaga, Oswego, Otsego and Tompkins Counties, and the Sixth District (Delaware and Tioga Counties), have all called for a moratorium on natural gas extraction using high volume hydraulic fracturing in New York State (88).

The proposed practice in New York of using open impoundments for large-scale capture of flowback fluids from gas wells may exacerbate the risk of this syndrome. Although most additives are greatly diluted in the drilling process, organic compounds (with the notable exceptions of DBNPA and DBAN) tend to be lighter than water; therefore they float to the surface of holding pits, where they concentrate to essentially 100% of the top layer. From there they volatilize or aerosolize into the air, from which they may be inhaled by neighbors and on-site industry workers. Partly for this reason, the states of

Colorado (89) and New Mexico (90) have prohibited the use of impoundments for flowback fluids.

As mentioned in Part 1, above, the oil and gas industry was responsible for substantial contamination of soil and water in New York, particularly in our western-most counties, from 1821 to at least 1993 (12 – 20). Among other possible health concerns, there is overwhelming evidence that industrial pollutants can cause or promote cancer in humans (91). As a preliminary approach to assessing potential human health effects from exposure to that environmental pollution, cancer mortality statistics were reviewed for Chautauqua, Cattaraugus and Allegany Counties. These three counties were selected because of their historically intensive gas industry activity, documented impairment of drinking water by industrial pollution sources, and distinctively rural character (to minimize influences from industries other than oil and gas). Based on nation-wide reports for 55 different cancer types from 1950 to 1994, women in this three-county area of New York were consistently in the top bracket for deaths caused by cancer of breast, cervix, colon, endocrine glands, larynx, ovary, rectum, uterus and vagina(92). Men from the same region were consistently in the highest statistical bracket for deaths caused by bladder, prostate, rectum, stomach, and thyroid cancers (92).

While it must be noted that county-wide cancer mortality statistics don't prove a connection between the elevated numbers of cancer deaths and gas industry pollution, the industry has also never been exonerated from a contribution to the unique profile of abnormally high cancer incidence and mortality in these counties. Clearly, much more investigative work needs to be done in this regard.

Conclusions:

As stated above, the working hypothesis for this risk assessment is that future impacts may be inferred from historical performance. Therefore, cumulative chemical and biological impacts from the gas industry in New York may be predicted for projects of any scope by combining incident statistics from Part 1 with related health and environmental impacts from Part 2. For example, from a development of 10,000 gas wells (a plausible estimate according to Anthony Ingraffea) (93), the sediment run-off into nearby waterways would amount to at least 80,000 tons per year. Such a development would reasonably be expected to generate about 1,200 citations for serious regulatory violations and at least 200 incidents of groundwater contamination in the short term. Over a century, about 1,600 leaking gas wells should be anticipated. If this scale of development takes place in a 2-county area, then significant spikes in emergency room visits for respiratory complaints and other aspects of "down-winder's syndrome" in those counties should be anticipated as well. Changes in human chronic disease profiles and impacts on domestic, aquatic and forest ecosystems would be more insidious and difficult to measure – but not necessarily less significant.

The record of New York State officials in managing gas industry impacts has historically been no better than those of officials in neighboring states, and may be much worse. Documenting harm and penalizing those in the energy industry who caused it have historically done little to mitigate that harm or prevent its re-occurrence. Therefore, there is no evidence that changes to the regulatory process will be adequate to protect New York's environment and citizens from damage caused by this industry. These conclusions essentially agree with those made by Hazen and Sawyer (94) and Fuller and Hetz (95).

It is hoped that this instrument will be found useful to public servants at every level in New York State, whether they serve in executive, legislative, judicial, health, safety, planning, education, or advocacy roles. Decisions we make today regarding whether or how to proceed with shale gas development here will have ramifications for generations to come.

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