DELAWARE RIVERKEEPER NETWORK™

February 22, 2022

VIA eCOMMENT
Environmental Quality Board
Rachel Carson State Office Building
16th Floor, 400 Market Street
Harrisburg, PA 19101-2301

Re: Comment of Delaware Riverkeeper Network and Maya K. van Rossum, the Delaware Riverkeeper, on Proposed Rulemaking 25 Pa. Code Ch. 261a Exclusion for Identification and Listing Hazardous Waste at MAX Environmental Technologies, Inc. Bulger and Yukon Facilities

Dear Environmental Hearing Board,

The Delaware Riverkeeper Network and Maya K. van Rossum, the Delaware Riverkeeper, (collectively, "DRN") submit this comment in opposition to the Environmental Quality Board's ("EQB's") proposal to amend Chapter 261a to conditionally exclude the wastewater treatment sludge filter cake derived from EPA Hazardous Waste No. F039 (multi-source leachate) generated at MAX Environmental Technologies, Inc. Bulger and Yukon facilities from the list of hazardous wastes found in 40 CFR § 261.31 ("proposed rulemaking"). The proposed rulemaking is based on a lack of information about the presence of toxic and radioactive substances, particularly those that are highly likely to be present in materials discarded by the energy industry, including drill cuttings from the oil and gas industry. The proposed rulemaking must not be finalized without further analysis of the effects of delisting on human health and the environment.

Pennsylvania's Constitution guarantees to the people "a right to clean air, pure water, and to the preservation of the natural, scenic historic and esthetic values of the environment. Pennsylvania's public natural resources are the common property of all the people, including generations yet to come. As trustee of these resources, the Commonwealth shall conserve and maintain them for the benefit of all the people."[1] "[A]ll agencies and entities of the Commonwealth government, both statewide and local, have a fiduciary duty to act toward the corpus [of the trust] with prudence, loyalty, and impartiality."[2] Thus, EQB is bound by

[1] PA. CONST. art. I, § 27.
[2] *Pa. Envtl. Def. Found. v. Commw. ("PEDF II")*, 161 A.3d 911, 931 n.23 (Pa. 2017)

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the Environmental Rights Amendment as a Commonwealth entity, and must "refrain from permitting or encouraging the degradation, diminution, or depletion of public natural resources, whether such degradation, diminution or depletion would occur through direct state action or indirectly, *e.g.*, because of the state's failure to restrain the action of private parties."[3] EQB must ensure that the record in support of the proposed rulemaking comprehensively considers the environmental effects of the requested delisting, in order to ensure that its action in finalizing the rule is constitutionally permitted.[4]

The energy industry, and the fracked gas industry in particular, uses hundreds of chemicals in the drilling and extraction process. Not all of these chemicals are identified by the industry, and are often labeled as "trade secrets," thus preventing regulators and the public from evaluating risks associated with their handling, reuse, or disposal. Many of the chemicals that have been identified, however, are toxic.[5] It has also recently been exposed that per- and polyfluoroalkyl substances ("PFAS") have been used in fracking operations in Pennsylvania, including in the drilling process.[6] Despite this widely-available information about the risks of frack waste, EQB proposes to delist the sludge filter cakes from the Bulger and Yukon facilities based on a truncated analysis of only eight "constituents of interest."

Given that both the Bulger and Yukon facilities accept wastes from the fracking industry, it is illogical for the EQB to conclude that there is not a "reasonable basis to believe that factors (including additional constituents) other than those for which the waste was listed could cause the waste to be a hazardous waste."[7] There *is* such a reasonable basis, and thus the EQB cannot finalize the proposed rulemaking without "determin[ing] . . . that such factors do not warrant retaining the waste as a hazardous waste."[8] If the EQB cannot determine whether the filter cakes are toxic due to a lack of information about chemicals used in oil and gas operation, then the filter cakes must remain F039 listed hazardous waste.

The proposed rulemaking also fails to account for naturally occurring radioactive materials ("NORM"), which are then modified by human activity (technically enhanced NORM or "TENORM"). Exposure to TENORM can cause cancer and other harmful effects including alteration of DNA. Drill cuttings are wastes brought to the surface during the drilling process of oil and gas operations. As PADEP acknowledged in its 2015 TENORM Report, "[b]ecause landfills accept natural gas industry wastes such as drill cuttings and treatment sludge that may contain TENORM, there is a potential for leachate from those

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[3] *Robinson Twp. v. Commw.*, 83 A.3d 901, 957 (Pa. 2013); *PEDF II*, 161 A.3d at 933.

[4] *Robinson Twp. v. Commw.*,83 A.3d at 952 ("The failure to obtain information regarding environmental effects does not excuse the constitutional obligation because the obligation exists *a priori* to any statute purporting to create a cause of action.").

[5] Elliott, et al., *A systematic evaluation of chemicals in hydraulic-fracturing fluids and wastewater for reproductive and developmental toxicity*, J. of Exposure Sci. & Envtl. Epidemiology 27, 90–99 (2017) (Attachment A)

[6] Horwitt, Dusty, Physicians for Social Responsibility, Fracking with "Forever Chemicals" (July 2021) (Attachment B); Editorial, *Fracking in Pennsylvania used toxic 'forever chemicals' as Pa. officials maintain willful ignorance*, Phila. Inquirer, Aug. 5, 2021, https://www.inquirer.com/opinion/editorials/fracking-pennsylvania-pfas-toxic-chemicals-water-20210805.html

[7] 40 C.F.R. § 260.22(a)(2).

[8] *Id*.

facilities to also contain TENORM."[9]. Accordingly, the 2015 TENORM Report contained specific recommendations for landfills that handle oil and gas wastes such as drill cuttings:

- Evaluate and, if necessary, modify the landfill disposal protocol for sludges/filter cakes and other solid waste-containing TENORM.
- Conduct additional radiological sampling and analyses and radiological surveys at all facilities that treat leachate from landfills that accept waste from [oil and gas] operations to determine if there are areas of contamination that require remediation; if it is necessary to establish radiological effluent discharge limitations; and if the development and implementation of a spill policy is necessary.
- Add total RA (Ra-226 and Ra-228) to the annual suite of contaminants of concern in leachate sample analyses.[10]

Because TENORM varies greatly based on the soil and rock formations, it cannot be assumed that all "drill cuttings" contain a uniform (or even roughly uniform) level of radioactivity. Because the proposed rulemaking contains no discussion or evaluation of radioactivity at all, allowing the delisted wastes to be disposed of in Subtitle D landfills poses an unacceptable risk to human health and the environment. Prior to delisting, the EQB must determine (a) whether the waste is radioactive and to what degree (which may vary over time), and (b) if so, how to dispose of the waste to protect the people's environmental rights and the public natural resources.

In sum, the rulemaking as proposed cannot be finalized without further evaluation of the waste's toxic and radioactive properties. In light of the energy industry wastes disposed of at the MAX Environmental Technology Inc. facilities, the sludge filter cakes must continue to be treated as hazardous wastes until the EQB has sufficient information to conclude that disposal in a Subtitle D landfill will not violate federal law or the Pennsylvania Constitution.

Sincerely,

Kacy C. Manahan
Senior Attorney
Delaware Riverkeeper Network

[9] PA DEP TENORM Study Report at § 1.4.1.2.
[10] PA DEP TENORM Study Report at § 9.2.3.

Attachment A

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ORIGINAL ARTICLE

A systematic evaluation of chemicals in hydraulic-fracturing fluids and wastewater for reproductive and developmental toxicity

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Hydraulic-fracturing fluids and wastewater from unconventional oil and natural gas development contain hundreds of substances with the potential to contaminate drinking water. Challenges to conducting well-designed human exposure and health studies include limited information about likely etiologic agents. We systematically evaluated 1021 chemicals identified in hydraulic-fracturing fluids ($n = 925$), wastewater ($n = 132$), or both ($n = 36$) for potential reproductive and developmental toxicity to triage those with potential for human health impact. We searched the REPROTOX database using Chemical Abstract Service registry numbers for chemicals with available data and evaluated the evidence for adverse reproductive and developmental effects. Next, we determined which chemicals linked to reproductive or developmental toxicity had water quality standards or guidelines. Toxicity information was lacking for 781 (76%) chemicals. Of the remaining 240 substances, evidence suggested reproductive toxicity for 103 (43%), developmental toxicity for 95 (40%), and both for 41 (17%). Of these 157 chemicals, 67 had or were proposed for a federal water quality standard or guideline. Our systematic screening approach identified a list of 67 hydraulic fracturing-related candidate analytes based on known or suspected toxicity. Incorporation of data on potency, physicochemical properties, and environmental concentrations could further prioritize these substances for future drinking water exposure assessments or reproductive and developmental health studies.

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Keywords: developmental toxicity; hydraulic fracturing; reproductive toxicity; shale; unconventional natural gas; wastewater

INTRODUCTION

Unconventional oil and natural gas development has expanded substantially in the United States in the past decade. Concerns exist about the potential health risks associated with related environmental hazards including exposure to water pollutants.[1,2] Between 2000 and 2013, approximately 8.6 million people were served by a drinking water source located one mile from an unconventional well.[3] Evaluation of relationships between environmental hazards from unconventional natural gas development and risk of adverse human health outcomes is hindered in part by challenges in the exposure assessment. Some of these challenges include incomplete disclosure of the identity and concentrations of chemicals used in unconventional natural gas development,[4,5] the wide range in structures (e.g., organic, inorganic, and radioactive) and physicochemical properties (e.g., log K_{ow}) of chemicals used or produced during development,[6–8] geographic differences in the types of compounds used or produced, the complexity of the dispersion through soil and water, temporal variability in emissions and potential exposures over the life course of a natural gas well,[2] and limited environmental measurements of potentially health-relevant chemicals.[9]

Unconventional natural gas development involves the extraction of gas from previously untapped deposits in deep rock formations using new applications of directional drilling technologies and hydraulic fracturing.[10] After a well is drilled, first vertically and then horizontally into the rock, large quantities of "fracturing fluids", consisting of water, chemicals, and sand (or ceramic beads), are injected under high pressure to create fissures in the rock ("hydraulic fracturing") that release natural gas.[2] Typically, about 15–30 million liters of fluid are used for each well, of which approximately 1–2% consists of chemical additives representing a substantial volume (e.g., 150,000–600,000 liters of chemicals per well over its lifetime).[2] Over 1,000 substances have been identified in fracturing fluids or hydraulic-fracturing wastewater, including solvents, heavy metals, aromatic hydrocarbons, and naturally-occurring radioactive materials, but the exact composition of fracturing fluids remains unknown because chemicals and their concentrations may be classified as confidential business information.[4] Vast amounts of wastewater are generated during unconventional oil and natural gas development. After fracturing, about 30% of injected fluids rapidly return to the surface up through the well as "flowback" (within 1–4 weeks).[11] Over time, "produced" water containing a potentially more harmful mix of the injected fluids along with mobilized naturally-occurring compounds such as heavy metals and radioactive materials slowly resurfaces.[11,12] Flowback and produced wastewater are stored in large open pits (or increasingly commonly in storage tanks) until treatment, reuse, or disposal

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offsite.[11] Possible pathways of potential water contamination due to unconventional natural gas development include faulty or deteriorating well casings, equipment failure, surface spills of fracturing fluids or wastewater on-site or from tanker trucks transporting these liquids, migration of chemicals from fractures to shallow aquifers, leakage from wastewater pits, and unauthorized discharge and release of inadequately treated wastewater into the environment.[1,3,11,13–20] The current evidence suggests that activities at the surface are more likely to contribute to groundwater and surface water contamination; however, the impact of each of these potential pathways on water quality remains difficult to evaluate because of limited data.[3,13,20,21]

Several environmental monitoring studies have suggested that unconventional natural gas development may contaminate ground water[15,19,21,22] and surface water,[23,24] potentially leading to drinking water contamination.[3] These publications have focused primarily on measurements of methane, metals, major cations and anions, and parameters indicative of water quality, such as total dissolved solids, color, or odor.[15,19,23,25] Although these measurements may provide markers of contamination due to hydraulic fracturing, they do not necessarily include measurements of health-relevant chemicals.

Monitoring studies of health-relevant chemicals are emerging.[6,21,26,27] For example, a study commissioned by the West Virginia Department of Environmental Protection examined 13 samples of flowback water and found contamination in excess of drinking water standards with benzene in 10 (77%) samples and with selenium and with toluene each in 3 (23%) samples.[28] In addition, ground and surface water samples collected in a region with intense unconventional natural gas development and known spills in Colorado had greater estrogen and androgen receptor activities based on reporter gene assays in human cell lines, compared with samples from reference areas.[29] More field-based monitoring studies, particularly at residences, are needed to better understand human exposures to chemicals related to unconventional natural gas development.

The biological plausibility for examining the health effects associated with human exposure to hydraulic-fracturing derives mainly from the known or suspected toxic effects of involved chemicals and processes.[29,30] It has been postulated that exposure to known or possible human teratogens from drinking water may occur (e.g., toluene and benzene).[31] McKenzie et al.[32] observed an association between increasing proximity and density of natural gas wells within a 10-mile radius of maternal residence and congenital heart defects.[32] They also observed a decreased risk of pre-term birth and term low birthweight. Further, Stacy et al.[33] observed a decrease in birthweight and an increase in small for gestational age incidence with increasing proximity and density of natural gas wells.[33] As noted by these authors,[32,33] incorporation of environmental sampling or individual exposure measurements and information on migration of potential environmental pollutants could substantially improve upon this non-specific, proximity-based exposure assessment. However, conducting a well-designed sampling campaign is challenging, given the wide variety of potential target pollutants and the limited information available to identify which pollutants have the highest probability of exposure or health impact.

The primary objective of this analysis was to conduct a systematic, screening-level evaluation for potential reproductive and developmental toxicity of chemicals identified in hydraulic-fracturing fluids and wastewater to support prioritization for use in future human exposure studies and health assessments. We used reproductive and developmental toxicity data from a well-recognized source as a first step to triage the vast array of potential environmental contaminants for which information about potential human health effects is otherwise unavailable or insufficient. We focus on reproductive and developmental toxicity because these effects may be early or "signal" indicators of human exposure to environmental hazards due to the relatively short disease latency and vulnerability of the exposed population.[34,35] A secondary objective was to further classify compounds linked to reproductive and developmental toxicity by determining which had current or proposed water quality standards or guidelines as indicators of potential for occurrence in drinking water and current or emerging sampling or removal technologies. Third, we compiled the log octanol–water partition coefficient and the frequency of disclosure of fracturing fluid constituents as additional information that could be used to inform the exposure potential of hydraulic-fracturing chemicals.

METHODS

Classification of Reproductive/Developmental Toxicity

In 2012, the U.S. EPA released a draft progress report on their overall project designed to assess the potential impacts of hydraulic fracturing on drinking water resources using available data and modeling techniques.[4] We obtained the names and Chemical Abstracts Service Registry Numbers (CASRNs) for 1021 chemicals included in the appendix of the report that were used in hydraulic-fracturing fluids ($n = 925$); measured in flowback or produced water ($n = 132$); or both ($n = 36$) across numerous wells and locations.[4] Sources of information included federal and state well permit and construction records, industry-provided data such as the web-based chemical disclosure registry FracFocus,[36] the published literature, and other industry and government reports.

We then searched the REPROTOX information system for reproductive and developmental toxicity data using the CASRNs. REPROTOX is a widely used, publically-available online database of the adverse reproductive and developmental effects of >5000 agents, including medications and environmental chemicals, and is maintained by the Reproductive Toxicology Center (Washington, DC, USA).[37] Results from both animal and human studies from original research articles and toxicity studies reported in drug labeling are cited, reviewed for data quality and strength of the evidence, and summarized in standard formats by subject-matter experts. REPROTOX entries include a succinct statement ("Quick Take") of the direction of animal and human evidence of reproductive or developmental toxicity and a lengthier summary of results from relevant studies.

We designated chemicals as having "no information available" overall if they were either: not present in the database ($N = 644$) or were present but lacked any toxicity data (e.g., only information on chemical properties or product use was available) ($N = 137$). For chemicals with some toxicity information available ($n = 240$), we reviewed the evidence separately based on the toxicity end point (reproductive or developmental) and data source (animal or human) (Figure 1). For each end point and data source, we separately determined whether the evidence supported an association ("possibly associated") or did not support an association ("possibly not associated"). This determination was made by first consulting the Quick Take ($n = 148$). If the Quick Take was absent or did not provide an assessment specific to the data source or end point ($n = 92$), then we assigned the chemical toxicity classification based on the summary. In making these summary-based assignments, we applied exclusionary criteria consistent with the rationale provided in other REPROTOX entries. We excluded results from studies for which methods were unavailable or unclear, studies not following standard toxicity guidelines, studies in which the chemical of interest was evaluated as part of a mixture of other compounds, studies for which only an abstract was available, and those defined as case studies (typically a report of a high exposure incident for <5 individuals). If any studies meeting our criteria reported positive associations, then we classified the chemical as "possibly associated" to create a more inclusive list of candidate analytes.

We then summarized the evidence across animal and human sources for each toxicity end point. Chemicals were considered to be "possibly associated" when either human or animal data suggested an association. We classified chemicals as "possibly not associated" when both evidence from human and animal data did not support an association or when toxicity information from either animal or human studies did not support an association and toxicity could not be assigned based on the other data source. Finally, we evaluated the evidence jointly for both reproductive and developmental toxicity end points, and determined whether chemicals were possibly associated or possibly not associated with either or both endpoints. We calculated frequencies and percentages of

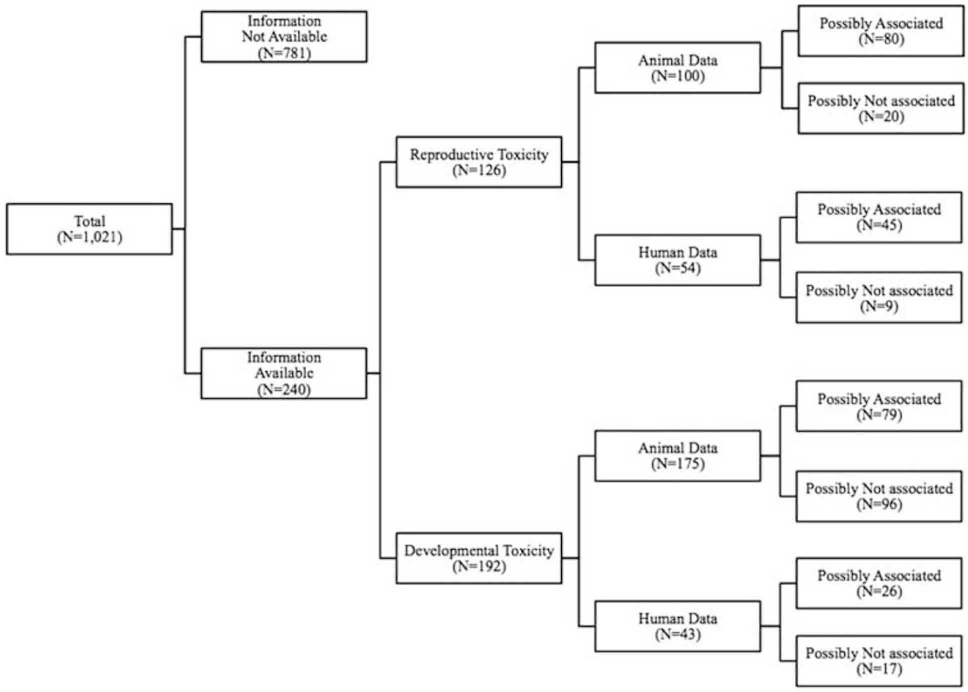

Figure 1. Reproductive and developmental toxicity data available for hydraulic-fracturing chemicals in the REPROTOX information system and possible association with toxicity. Numbers of subcategories under "Information Available" may not add up to the total, as toxicity information may be available for both endpoints, and/or both animal and human data.

hydraulic-fracturing fluid and wastewater chemicals in each of these categories.

Determination of Water Quality Standards

Next, we determined whether the hydraulic-fracturing chemicals linked to reproductive or developmental toxicity based on our REPROTOX evaluation had established drinking water standards or guidelines. First, we assessed which chemicals had a Maximum Contaminant Level (MCL), which is a legally enforceable public water system standard under the National Primary Drinking Water Regulations of the Safe Drinking Water Act. The presence of an MCL indicates that there is a validated sampling methodology, evidence of adverse human health effects, and a reference concentration against which to compare future measurements.[38] Second, we determined whether the substance had either a Maximum Contaminant Level Goal (MCLG) or an EPA oral Reference Dose (RfD). An MCLG is the contaminant concentration in drinking water at or below which no harm would be anticipated to occur. It can serve as a health-based reference concentration. It does not, however, consider sampling techniques or feasibility of removal and is not legally enforceable. An oral RfD is the amount of a compound that can be ingested daily over a lifetime without appreciable risk of harm.[39] It can be converted into a drinking water reference concentration by assuming a 70-kg adult ingests 2 L of water per day and that there are no other sources of exposure, yielding a comparable interpretation as an MCLG. Third, we noted the presence of chemicals on the EPA's Contaminant Candidate Lists (CCLs).[40] CCLs include unregulated contaminants identified for evaluation for future drinking water standards and were published in 1998 (CCL 1), 2005 (CCL2), 2009 (CCL 3), and in a draft form in 2015 (CCL4). The presence on a CCL indicates that a compound has been proposed for regulation due to occurrence or hazard information, but has no enforceable limit because the sampling or measurement methodology is still under development, a feasible removal technique is lacking, a safe level has not been determined, the compound is infrequently present in municipal water systems, or a regulatory decision is in progress.[38,41]

Octanol–Water Coefficient

Information on physicochemical properties could be used to predict the likelihood of chemicals being present in drinking water. Therefore, we estimated the log octanol–water partition coefficient (log K_{ow}) using EPI Suite™, a Windows-based tool developed by the EPA for estimating physicochemical properties of environmental organic compounds.[42] Log K_{ow} is used as a relative indicator of the tendency of an organic compound to adsorb to soil. Log K_{ow} values are generally inversely related to aqueous solubility and directly proportional to molecular weight.[43] Chemicals that are hydrophilic (log $K_{ow} < 0$) tend to be more mobile in water, whereas chemicals that are more hydrophobic (log $K_{ow} > 4$) tend to associate with organic matter and soil. The log K_{ow} also provides some indication of toxicokinetics. Chemicals with a log K_{ow} of 2–4 tend to absorb well through the skin, and those with log K_{ow} of 5–7 tend to bioconcentrate in organisms.[43]

Disclosure Frequency of Fracturing Fluid Chemicals

We identified which fracturing fluid constituents were frequently disclosed based on a short list of frequently reported chemicals provided on the FracFocus website,[36] a voluntary disclosure website of the oil and gas industry. In addition, we indicated which chemicals were listed in at least 10% of all disclosures reported to the FracFocus website, as compiled by the EPA.[3]

RESULTS

Of 1021 identified hydraulic-fracturing chemicals, 781 (76%) lacked reproductive and developmental toxicity information (Figure 1, Table 1). Of the 240 chemicals with available information, 126 chemicals had reproductive toxicity data available, and 192 had developmental toxicity data available (Figure 1, Table 1). The majority of evidence available to determine toxicity came from animal data. For reproductive toxicity, 100 chemicals had animal data compared with 54 chemicals with human data (Figure 1). For developmental toxicity, 175 chemicals had animal data, while 43 had human data available (Figure 1).

Of 126 chemicals with reproductive toxicity data, 103 (82%) chemicals were possibly associated with adverse reproductive effects, while 23 (18%) were classified as possibly not associated (Table 1). Of 192 chemicals with developmental toxicity information, 95 (49%) were possibly associated with developmental toxicity and 97 (51%) were possibly not associated. A total of 41

Table 1. Reproductive and developmental toxicity of disclosed hydraulic-fracturing chemicals ($n=1021$).[a]

	Total	*Fracturing fluids*	*Wastewater*
	N (%)	*N (%)*	*N (%)*
Any reproductive and developmental toxicity information	$n=1021$	$n=925$	$n=132$
Toxicity information available	240 (24%)	194 (21%)	73 (55%)
Toxicity information unavailable	781 (76%)	731 (79%)	59 (45%)
Reproductive toxicity information available[b]	$n=126$	$n=99$	$n=43$
Possibly associated[c]	103 (82%)	79 (80%)	39 (91%)
Possibly not associated	23 (18%)	20 (20%)	4 (9%)
Developmental toxicity information available[b]	$n=192$	$n=156$	$n=57$
Possibly associated[c]	95 (49%)	72 (46%)	38 (67%)
Possibly not associated	97 (51%)	84 (54%)	19 (33%)

[a]All chemicals were obtained from the US Environmental Protection Agency hydraulic-fracturing progress report (2012). Only chemicals with available Chemical Abstracts Service Registry Numbers ($n=1021$) were screened for reproductive and developmental toxicity. [b]Some chemicals have both reproductive and developmental toxicity information available; and therefore, numbers do not add to total with toxicity information available. [c]A total of 41 chemicals were possibly associated with both endpoints; therefore, the total # of chemicals possibly associated with at least one endpoint is 103+95 − 41 = 157.

chemicals were possibly associated with both endpoints. Toxicity information was available for a greater proportion of wastewater constituents (55%) compared with fracturing fluid chemicals (21%) (Table 1). A greater percentage of wastewater chemicals compared with fracturing fluid chemicals with toxicity data were possibly associated with reproductive toxicity (91% compared with 80%) and with developmental toxicity (67% compared with 46%).

Information about the 157 chemicals associated with at least one toxicity end point is presented in Table 2. Of these, 95 were constituents of fracturing fluids, 38 were detected in wastewater, and 24 in both. A total of 67 had a current federal water quality standard (MCL: $n=23$), or had a reference value that could be used as a water quality guideline (MCLG: $n=23$, RfD: $n=48$), or were proposed for a federal water quality standard (CCL: $n=24$). Several chemicals had more than one of these indicators. For example, the 23 chemicals with MCLGs all had MCLs. Examples of fracturing fluid constituents associated with reproductive or developmental effects with a water quality standard or guideline included: 1,2-propanediol, acrolein, bisphenol-A, and chlorine dioxide. Examples of chemicals in the wastewater linked to adverse reproductive or developmental effects with a water quality standard or guideline included: metals (e.g., arsenic, cadmium, lead, and mercury); polycyclic aromatic hydrocarbons (e.g., benzo(a)pyrene); volatile organic compounds (e.g., benzene and toluene); and other organics (e.g., di(2-ethylhexyl) phthalate and dibutyl phthalate). Reproductive or developmental outcomes were the basis for 3 out of 23 chemicals with an MCLG/MCL: benzo (a)pyrene, chlorine dioxide, and di(2-ethylhexyl) phthalate. A reproductive or developmental outcome was the basis for 9 of 48 chemicals with an oral reference dose, though four of these were structurally related: acrylic acid, borax, boric acid, boron, boron sodium oxide, carbon disulfide, chlorine, methyl ethyl ketone, and phenol.

The 157 chemicals possibly associated with reproductive or developmental toxicity included a wide variety of inorganic and organic structures (Table 2). The 94 chemicals with log K_{ow} values had estimates ranging from −13.17 (ethylenediaminetetraacetic acid tetrasodium salt) to 8.39 (di(2-ethylhexyl) phthalate). A total of 40 had $\log K_{ow} < 0$, indicating high mobility in water, 16 chemicals had a log K_{ow} in the 2–4 range, indicating tendency for dermal absorption, and 6 had log K_{ow} of 5–7, indicating ability to bioconcentrate. There were 119 fracturing fluid constituents possibly associated with reproductive and/or developmental toxicity (Table 2). Of these, 18 were reported to be frequently disclosed.

DISCUSSION

Based on our systematic evaluation of 1021 chemicals in hydraulic-fracturing fluids or wastewater, the substances and processes used in unconventional natural gas development indicate the potential for reproductive and developmental health risks. However, the majority of chemicals (76%) had undetermined toxicity due to insufficient information. Thus, we were able to evaluate reproductive and/or developmental toxicity for only 24% of chemicals. Of 240 chemicals with sufficient information available, 157 (65%) were possibly associated with reproductive and/or developmental toxicity. The 67 chemicals found to be possibly associated with reproductive or developmental toxicity and with a current drinking water standard, health-based guideline, or proposed for a drinking water standard included a range of compounds, such as metals, solvents, pesticides, polycyclic aromatic hydrocarbons, and volatile organic compounds. These 67 compounds could represent a starting point for consideration in future drinking water exposure assessments or reproductive or developmental health studies of unconventional oil and natural gas development. Effect levels, concentrations in environmental media, and physicochemical properties of the compounds could be incorporated to further prioritize this list for future health studies.

Because of the large number of known and potentially unknown chemicals used and produced in unconventional oil and natural gas development, a major challenge to conduct efficient and well-designed human exposure assessments is the lack of a clear target list of chemicals. The health effects of unconventional natural gas development have yet to be elucidated; thus, putative etiologic agents are not known. Therefore, biological and environmental measurements of health-relevant chemicals are limited, and a way to select priority chemicals for sampling is needed. Ideally, selection of target analytes would be based on a combination of human toxicity and exposure levels. However, in light of the paucity of data on environmental concentrations of hydraulic fracturing-related compounds, we prioritized chemicals based primarily on toxicologic potential for one related set of outcomes. This systematic and transparent approach could be updated to incorporate tap water sampling data as it becomes available. In addition, incorporation of environmental fate and transport parameters of these compounds would help predict the likelihood of these compounds entering drinking water sources.

Some previously published studies have characterized toxicological properties of chemicals used in unconventional oil and natural gas development with a focus on the fracturing fluid constituents. Stringfellow et al.[8] compiled inhalation and oral

Table 2. Characteristics of hydraulic-fracturing chemicals possibly associated with reproductive and/or developmental toxicity ($n = 157$).

CASRNs	*Chemical name*	*Source*	*Evidence for toxicity (animal/human)*		*MCLG/MCL (mg/l)*	*Contaminant candidate list*[a]	*Oral reference dose (mg/kg/day)*	*Estimated log K_{ow}*[b]
			Reproductive toxicity[c]	*Developmental toxicity*[d]				
Existing or proposed water quality standard or health guideline (n = 67)								
71-36-3	1-Butanol	FF	+/o	+/o	—	CCL 3	0.10	0.84
111-76-2	2-Butoxyethanol[e]	FF	+/o	o/o	—	—	0.1	0.57
109-86-4	2-Methoxyethanol	FF	+/o	+/o	—	CCL 3	—	− 0.91
95-48-7	2-Methylphenol	WW	+/o	o/o	—	CCL 1, 2	0.05	2.06
108-39-4	3-Methylphenol	WW	+/o	o/o	—	—	0.05	2.06
75-07-0	Acetaldehyde[e]	FF	o/o	+/+	—	CCL 3	—	− 0.17
67-64-1	Acetone	FF, WW	+/o	− /o	—	—	0.9	− 0.24
98-86-2	Acetophenone	FF, WW	+/o	o/o	—	—	0.1	1.67
107-02-8	Acrolein	FF, WW	o/o	+/o	—	CCL 3	0.0005	0.19
79-06-1	Acrylamide	FF	+/+	− /o	0/TT	—	0.002	− 0.81
79-10-7	Acrylic acid	FF	+/o	− /o	—	—	0.5[f]	0.44
309-00-2	Aldrin	WW	o/o	+/o	—	CCL 1	0.003	6.75
7429-90-5	Aluminum	FF, WW	o/o	+/o	—	CCL 1, 2	—	NA
62-53-3	Aniline	FF	o/o	+/o	—	CCL 3	—	1.08
7440-36-0	Antimony	WW	+/o	− /o	0.006/0.006	—	0.0004	NA
7440-38-2	Arsenic	FF, WW	+/+	o/o	0/0.010	—	0.0003	NA
71-43-2	Benzene	FF, WW	+/+	− /+	0/0.005	—	0.004	1.99
50-32-8	Benzo(a)pyrene	WW	o/o	+/o	0/0.0002[g]	—	—	6.11
80-05-7	Bisphenol A	FF	+/+	+/+	—	—	0.05	3.64
1303-96-4	Borax[e]	FF	+/+	+/o	—	—	0.2[f]	NA
10043-35-3	Boric acid[e]	FF	+/+	+/o	—	—	0.2[f]	NA
7440-42-8	Boron	WW	+/+	o/o	—	CCL 1, 2	0.2[f]	NA
1330-43-4	Boron sodium oxide[e]	FF	+/+	+/o	—	—	0.2[f]	NA
7440-43-9	Cadmium	WW	+/+	o/o	0.005/0.005	—	0.0005/0.001	NA
75-15-0	Carbon disulfide	WW	o/o	+/o	—	—	0.1[f]	1.94
7782-50-5	Chlorine	FF, WW	+/+	+/+	—	—	0.1[f]	NA
10049-04-4	Chlorine dioxide[h]	FF	+/+	+/+	0.8/0.8[g]	—	0.03	NA
67-66-3	Chloroform	WW	+/+	− /o	0.07/0.070	—	0.1	1.52
74-87-3	Chloromethane	WW	+/o	− /o	—	CCL 3	—	1.09
7440-47-3	Chromium[i]	WW	+/o	+/o	0.1/0.1	—	0.003	NA
7440-48-4	Cobalt	WW	o/o	+/o	—	CCL 3	—	NA
7440-50-8	Copper	FF, WW	+/+	+/o	1.3/1.3	—	—	NA
98-82-8	Cumene	FF, WW	+/o	o/o	—	—	0.1	3.45
57-12-5	Cyanide, free	WW	o/o	+/o	0.2/0.2	—	—	− 0.69
117-81-7	Di(2-ethylhexyl) phthalate	FF, WW	+/ −	+/ −	0/0.006[g]	—	0.02	8.39
84-74-2	Dibutyl phthalate	WW	+/+	+/+	—	—	0.1	4.61
75-09-2	Dichloromethane	WW	o/+	− /o	0/0.005	—	0.006	1.34
60-57-1	Dieldrin	WW	o/o	+/o	—	CCL 1	0.00005	5.45
84-66-2	Diethyl phthalate	WW	− /o	+/o	—	—	0.8	2.65
106-89-8	Epichlorohydrin	FF	+/o	− /o	0/TT	—	—	0.63
100-41-4	Ethylbenzene	FF, WW	o/o	+/o	0.7/0.7	—	0.1	3.03
107-21-1	Ethylene glycol[e]	FF, WW	+/o	+/o	—	CCL 3	2	− 1.20
75-21-8	Ethylene oxide	FF	+/+	+/o	—	CCL 3	—	− 0.05
50-00-0	Formaldehyde	FF	+/+	− /+	—	CCL 3	0.2	0.35
7439-92-1	Lead	FF, WW	o/+	o/+	0/TT	—	—	NA
58-89-9	Lindane	WW	+/o	− / −	0.0002/0.0002	—	0.0003	4.26
7439-96-5	Manganese	WW	o/o	+/o	—	CCL 1	0.14	NA
7439-97-6	Mercury (inorganic)	WW	o/o	o/+	0.002/0.002	—	—	NA
67-56-1	Methanol[e]	FF, WW	o/o	+/o	—	CCL 3	2	− 0.63
78-93-3	Methyl ethyl ketone	WW	+/o	+/o	—	—	0.6[f]	0.26

Table 2. (Continued).

CASRNs	*Chemical name*	*Source*	*Evidence for toxicity (animal/human)*		*MCLG/MCL (mg/l)*	*Contaminant candidate list*[a]	*Oral reference dose (mg/kg/day)*	*Estimated log K_{ow}*[b]
			Reproductive toxicity[c]	*Developmental toxicity*[d]				
7439-98-7	Molybdenum	WW	+/+	−/o	—	CCL 3	—	NA
872-50-4	N-Methyl-2-pyrrolidone	FF	+/o	o/o	—	CCL 3	—	−0.11
91-20-3	Naphthalene[e]	FF, WW	o/o	+/o	—	CCL 1	0.02	3.17
7440-02-0	Nickel	WW	o/+	+/o	—	—	0.02	NA
72-55-9	p,p'-DDE	WW	+/+	+/+	—	CCL 1, 2	—	6.00
108-95-2	Phenol	FF, WW	+/o	−/o	—	—	0.3[f]	1.51
85-44-9	Phthalic anhydride	FF	+/o	+/o	—	—	2	2.07
91-22-5	Quinoline	FF	o/o	+/o	—	CCL 3	—	2.14
7782-49-2	Selenium	WW	o/o	+/o	0.05/0.05	—	0.005	NA
7440-24-6	Strontium	WW	o/+	o/+	—	CCL 3	—	NA
100-42-5	Styrene	FF	o/+	+/−	0.1/0.1	—	0.2	2.89
127-18-4	Tetrachloroethylene	WW	o/+	−/−	0/0.005	—	0.006	2.97
108-88-3	Toluene	FF, WW	o/o	o/+	1/1	—	0.08	2.54
7440-62-2	Vanadium	WW	+/o	o/o	—	CCL 1, 2, 3	—	NA
1330-20-7	Xylenes	FF, WW	+/o	−/o	10/10	—	0.2	3.09
7440-66-6	Zinc	FF, WW	o/+	o/o	—	—	0.3	NA
7646-85-7	Zinc chloride	FF	+/−	+/−	—	—	0.3	NA
No existing or proposed water quality standard or health guideline (n = 90)								
71-23-8	1-Propanol	FF	o/o	+/o	—	—	—	0.35
57-55-6	1,2-Propanediol	FF, WW	−/−	+/+	—	—	—	−0.78
111-90-0	2-(2-Ethoxyethoxy)ethanol	FF	+/o	o/o	—	—	—	−0.69
110-80-5	2-Ethoxyethanol	FF	+/o	+/o	—	—	—	−0.42
2682-20-4	2-Methyl-3(2H)-isothiazolone	FF	+/o	−/o	—	—	—	−0.83
106-44-5	4-Methylphenol	WW	+/o	o/o	—	—	—	2.06
26172-55-4	5-Chloro-2-methyl-3(2H)-isothiazolone	FF	+/o	−/o	—	—	—	−0.34
57-97-6	7,12-Dimethylbenz(a)anthracene	WW	o/o	+/o	—	—	—	6.62
107-13-1	Acrylonitrile	WW	o/o	+/o	—	—	—	0.21
7446-70-0	Aluminum chloride	FF	+/o	o/o	—	—	—	NA
12125-02-9	Ammonium chloride[e]	FF	o/o	+/−	—	—	—	NA
10025-91-9	Antimony trichloride	FF	+/o	−/o	—	—	—	NA
1309-64-4	Antimony trioxide	FF	+/o	o/o	—	—	—	NA
68131-74-8	Ashes, residues	FF	o/+	+/o	—	—	—	NA
80-08-0	Benzamine, 4,4'-sulfonylbis-	FF	o/o	o/+	—	—	—	0.77
100-51-6	Benzyl alcohol	WW	o/o	o/+	—	—	—	1.08
7440-70-2	Calcium	WW	+/+	+/−	—	—	—	NA
1305-62-0	Calcium hydroxide	FF	o/o	o/+	—	—	—	−0.87
1333-86-4	Carbon black	FF	+/o	o/o	—	—	—	NA
124-38-9	Carbon dioxide	FF, WW	o/o	+/o	—	—	—	0.83
471-34-1	Carbonic acid calcium salt (1:1)	FF	o/o	+/−	—	—	—	−2.12
1066-30-4	Chromium(III) acetate	FF	+/o	+/o	—	—	—	−0.98
7758-98-7	Copper sulfate	FF	o/o	+/o	—	—	—	NA
7447-39-4	Copper(II) chloride	FF	+/+	+/o	—	—	—	NA
91-64-5	Coumarin	FF	o/o	o/+	—	—	—	1.51
50-99-7	D-Glucose	FF	o/o	+/+	—	—	—	−2.89
3252-43-5	Dibromoacetonitrile	FF	o/o	+/o	—	—	—	0.47
7173-51-5	Didecyldimethylammonium chloride[e]	FF	+/o	−/o	—	—	—	4.66
111-42-2	Diethanolamine	FF	+/o	o/o	—	—	—	−1.71
111-46-6	Diethylene glycol	FF	+/o	−/o	—	—	—	−1.47
111-77-3	Diethylene glycol monomethyl ether	FF	+/o	o/o	—	—	—	−1.18
627-93-0	Dimethyl adipate	FF	o/o	+/o	—	—	—	1.39

Table 2. (Continued).

CASRNs	Chemical name	Source	Evidence for toxicity (animal/human)		MCLG/MCL (mg/l)	Contaminant candidate list[a]	Oral reference dose (mg/kg/day)	Estimated log K_{ow}[b]
			Reproductive toxicity[c]	Developmental toxicity[d]				
1119-40-0	Dimethyl glutarate	FF	+/o	o/o	—	—	—	0.90
63148-62-9	Dimethyl polysiloxane	FF	+/o	−/o	—	—	—	8.16
64-17-5	Ethanol[e]	FF	o/+	o/+	—	—	—	−0.14
141-43-5	Ethanolamine	FF	+/o	−/o	—	—	—	−1.61
60-00-4	Ethylenediaminetetraacetic acid	FF	o/o	+/o	—	—	—	−3.86
64-02-8	Ethylenediaminetetraacetic acid tetrasodium salt[e]	FF	o/o	+/o	—	—	—	−13.17
139-33-3	Ethylenediaminetetraacetic acid, disodium salt	FF	o/o	+/o	—	—	—	−11.70
10028-22-5	Ferric sulfate	FF	o/+	o/o	—	—	—	NA
75-12-7	Formamide	FF	o/o	+/o	—	—	—	−1.61
79-14-1	Glycolic acid	FF	+/o	+/o	—	—	—	−1.07
5470-11-1	Hydroxylamine hydrochloride	FF	o/o	+/o	—	—	—	NA
7439-89-6	Iron	FF, WW	o/+	o/o	—	—	—	NA
7720-78-7	Iron(II) sulfate	FF	o/+	o/o	—	—	—	NA
67-63-0	Isopropanol[e]	FF, WW	o/o	+/o	—	—	—	0.28
7439-93-2	Lithium	WW	o/+	o/+	—	—	—	NA
7439-95-4	Magnesium	WW	o/+	o/o	—	—	—	NA
7786-30-3	Magnesium chloride	FF	o/+	o/o	—	—	—	NA
7791-18-6	Magnesium chloride hexahydrate	FF	o/+	o/o	—	—	—	NA
1309-42-8	Magnesium hydroxide	FF	o/+	o/o	—	—	—	NA
1309-48-4	Magnesium oxide[e]	FF	o/+	o/o	—	—	—	NA
119-36-8	Methyl salicylate	FF	+/o	+/o	—	—	—	2.60
110-91-8	Morpholine	FF	o/o	+/o	—	—	—	−0.56
68-12-2	N,N-Dimethylformamide[e]	FF	o/o	+/o	—	—	—	−0.93
110-26-9	N,N'-Methylenebisacrylamide	FF	+/o	o/o	—	—	—	−1.52
7786-81-4	Nickel sulfate	FF	o/+	+/o	—	—	—	NA
25154-52-3	Nonylphenol (mixed)	FF	o/o	+/o	—	—	—	5.99
10028-15-6	Ozone	FF	+/o	+/+	—	—	—	NA
79-21-0	Peracetic acid	FF	+/o	o/o	—	—	—	−1.07
7447-40-7	Potassium chloride	FF	+/+	o/−	—	—	—	NA
7778-50-9	Potassium dichromate	FF	+/o	+/o	—	—	—	NA
7681-11-0	Potassium iodide	FF	o/o	o/+	—	—	—	NA
14808-60-7	Quartz	FF	+/o	o/o	—	—	—	NA
81-88-9	Rhodamine B	FF	o/o	+/o	—	—	—	1.85
7631-86-9	Silica	FF, WW	+/o	o/o	—	—	—	NA
2492-26-4	Sodium 2-mercaptobenzothiolate	FF	+/o	−/o	—	—	—	−0.48
532-32-1	Sodium benzoate	FF	o/o	+/o	—	—	—	−2.27
7647-15-6	Sodium bromide	FF	+/o	−/−	—	—	—	NA
151-21-3	Sodium dodecyl sulfate[e]	FF	o/o	+/o	—	—	—	1.69
7681-52-9	Sodium hypochlorite	FF	+/+	+/+	—	—	—	NA
7681-82-5	Sodium iodide	FF	o/o	o/+	—	—	—	NA
7631-99-4	Sodium nitrate	FF	+/o	o/o	—	—	—	NA
7632-00-0	Sodium nitrite	FF	+/o	o/o	—	—	—	NA
11138-47-9	Sodium perborate	FF	+/−	o/o	—	—	—	NA
54-21-7	Sodium salicylate	FF	o/+	+/o	—	—	—	−1.49
10476-85-4	Strontium chloride	FF	o/+	o/+	—	—	—	NA
7440-28-0	Thallium and compounds	WW	o/+	o/+	—	—	—	NA
68-11-1	Thioglycolic acid[e]	FF	+/o	−/o	—	—	—	0.03
62-56-6	Thiourea	FF	o/o	+/o	—	—	—	−1.31
7440-31-5	Tin	WW	o/o	+/o	—	—	—	NA

Table 2. (Continued).

CASRNs	Chemical name	Source	Evidence for toxicity (animal/human)		MCLG/MCL (mg/l)	Contaminant candidate list[a]	Oral reference dose (mg/kg/day)	Estimated log K_{ow}[b]
			Reproductive toxicity[c]	Developmental toxicity[d]				
7772-99-8	Tin(II) chloride	FF	o/o	+/o	—	—	—	NA
7440-32-6	Titanium	WW	+/o	o/o	—	—	—	NA
13463-67-7	Titanium dioxide	FF	+/o	o/o	—	—	—	NA
126-73-8	Tributyl phosphate	FF	+/o	+/o	—	—	—	3.82
112-27-6	Triethylene glycol	FF	+/o	−/o	—	—	—	−1.75
112-24-3	Triethylenetetramine	FF	o/o	+/o	—	—	—	−2.65
150-38-9	Trisodium ethylenediaminetetraacetate	FF	o/o	+/o	—	—	—	−13.15
57-13-6	Urea	FF	o/o	+/o	—	—	—	−1.56
7732-18-5	Water[e]	FF	o/+	o/o	—	—	—	NA

Abbreviations: CASRNs, Chemical Abstract Service Registry Numbers; CCL, Contaminant Candidate List; FF, fracturing fluid; MCL, Maximum Contaminant Level; MCLG, Maximum Contaminant Level Goal; NA, not applicable; WW, wastewater. [a]CCLs are lists of unregulated contaminants prioritized for evaluation for future drinking water standards and were published in 1998 (CCL 1), 2005 (CCL2), 2009 (CCL 3), and in a draft form in 2015 (CCL4). [b]Estimated log K_{ow} values were obtained from EPI Suite.[42] Log K_{ow} values for most inorganic compounds are not applicable (NA). [c]+, evidence supports a positive association between chemical and reproductive toxicity; −, evidence supports an inverse association between chemical and reproductive toxicity; o, evidence does not support an association. [d]+, evidence supports a positive association between chemical and developmental toxicity; −, evidence supports an inverse association between chemical and developmental toxicity; o, evidence does not support an association. [e]Chemicals in fracturing fluids disclosed in >10% of oil or gas wells, according to FracFocus and/or EPA, 2015 for 18 out of 119 chemicals detected in fracturing fluids (FF). [f]The critical endpoint was a reproductive or developmental outcome for 9 chemicals, out of 48 chemicals with an oral reference dose. [g]Potential long-term health effects of exposure above MCL was associated with reproductive or developmental outcomes for 3 out of 23 chemicals with an MCLG/MCL. [h]Maximum Residual Disinfectant Level Goal (MRDLG) and Maximum Residual Disinfectant Level for chlorine dioxide. [i]Oral reference dose for chromium applies to chromium (VI).

acute toxicity values (i.e., lethal dose-50) for 81 hydraulic-fracturing chemical additives and found that 13 (16%) chemicals exhibited low or moderate toxicity; 25 (31%) lacked mammalian toxicity data, and the remainder ($n = 43$, 53%) were considered as non-toxic.[8] Wattenberg et al.[44] characterized the acute and chronic toxicity for 168 constituents of hydraulic-fracturing fluids commonly used in North Dakota, and found that 24 of the 168 (14%) constituents were associated with reproductive and developmental toxicity.[44] This is similar to our observation that 119 (12%) of all 961 constituents of fracturing fluids reviewed were associated with either reproductive or developmental toxicity. They also reported sparse data for commonly used fracturing chemicals with 59% and 35%, respectively, lacking chronic and acute toxicity information.[44] Kahrilis et al.[45] specifically examined the toxic effects of biocides used in fracturing fluids and identified five chemicals that exhibited reproductive or developmental toxicity.[45] We also identified two of these five substances (chlorine dioxide and didecyldimethylammonium chloride) as being possibly associated with reproductive or developmental toxicity; we did not evaluate the other three (bronopol, dazomet, and tributyltetradecylphosphonium) because they were not present in the REPROTOX database, possibly because of limited available data. Based on publically-available toxicity databases, material safety datasheets, and scientific publications, Colborn et al.[30] identified 353 chemicals used during natural gas operations with more than 75% linked to at least 1 of 12 health endpoints (e.g., respiratory effects and cancer).[30] In addition, a US House of Representatives report[46] found that 9 of 750 chemicals used in oil and gas hydraulic fracturing in 2005–2009 had MCLs which they applied as a proxy for toxicity.[46]

An improved understanding of the fate and transport of chemicals used or produced in unconventional natural gas development could help predict the exposure potential. We included the log K_{ow} as one physicochemical property predictive of mobility in the environment. Other investigators have compiled more detailed physicochemical properties on a subset of fracturing fluids to predict fate and transport.[8,45] For example, Rogers et al.[47] developed a screening framework for prioritizing 659 constituents of fracturing fluids likely to be present in groundwater using mobility and persistence characteristics and frequency of disclosure, and identified 15 chemicals of interest.[47] Three of these chemicals had a health-based standard and were also identified as candidate analytes using our toxicity-based framework: acrylamide, ethylbenzene, and xylenes. Combining our toxicity-based approach with a chemistry-based framework could inform the design of future studies.

Our analysis includes a systematic and transparent review of more than >1000 chemicals found in both fracturing fluids and wastewater. Gaps in our knowledge of the toxicities of chemicals related to hydraulic fracturing highlight the need to improve our understanding of the potential adverse health effects associated with these compounds. Although a single oil or natural gas well will not be associated with >1000 compounds, each well could yield a complex mixture of tens or hundreds of substances[44] that may lead to enhanced toxicity compared with the evaluation of single chemical compounds in isolation. Our observation that a greater proportion of chemicals in wastewater were linked to reproductive and developmental toxicity compared with fracturing fluids was consistent with previous findings suggesting wastewater produced by unconventional oil and natural gas activities may be more toxic than the fracturing fluids themselves. This may be in part because a greater proportion of wastewater chemicals had available toxicity information, and null toxicology studies may be more likely to remain unreported. Nevertheless, additional focus may be needed to study not only what chemicals go into the well, but also what chemicals and by-products are generated during natural gas operations.

Given the wide range of potential compounds associated with unconventional natural gas development and the paucity of exposure measurement data, we applied a screening-level evaluation of reproductive and developmental toxicity of these chemicals to narrow the list to those chemicals with a higher potential for public health impact. Several uncertainties were present in our analysis. Fracturing fluid chemicals classified as confidential business information under the Toxic Substances Control Act could not be included.[4] In addition, the list of >1000 substances was obtained by the EPA several years ago and different formulations may be in use over time. We relied on one publicly available database to classify the 1021 chemicals for reproductive and developmental toxicity and did not perform a comprehensive literature review for each chemical. Therefore, the absence of a listing in REPROTOX does not necessarily mean an absence of health hazard information. The REPROTOX® database is updated on an agent-by-agent basis, and the literature summaries may not include the most current information on specific chemicals. Also, publication bias may occur, in which null or negative findings are not published. However, comparisons of REPROTOX against other public reproductive toxicity databases have revealed that REPROTOX has a high consistency with other sources.[48] We erred on the side of being more inclusive with our list, to avoid eliminating a potentially health-relevant compound. We included compounds possibly associated with reproductive or developmental toxicity and did not conduct a traditional risk assessment approach that considered the dose at which the compounds elicited an effect. We used frequency of disclosure based on the FracFocus website as an indicator of prevalence or potential exposure. However, this information source only applies to compounds in fracturing fluids, the list is not complete, reporting is voluntary, and does not provide any information on naturally-occurring compounds mobilized from the gas extraction process that may be present in wastewater.

We used current and proposed water quality standards as indicators of occurrence, toxicity, and sampling and removal methodologies. One paradox worth noting is that hydraulic fracturing chemicals were exempted from complying with the EPA Safe Drinking Water Act under the Energy Policy Act of 2005.[49]

Although drinking water contamination has been identified as an important potential source of exposure associated with hydraulic fracturing, other public health concerns in relation to unconventional natural gas development include air pollution, greenhouse gas emissions, noise pollution, seismic activities and social stressors.[1,50] Quantification of these potential exposures remains vital for evaluation of the public health impact of unconventional oil and natural gas extraction.

CONCLUSION

Though data are limited, numerous constituents of fracturing fluids and wastewater have been linked to reproductive and/or developmental toxicity. Therefore, carefully designed, rigorous exposure, and epidemiologic studies are urgently needed to investigate public health uncertainties and form a scientific basis for appropriate evidence-based policies. The 67 chemicals we identified as possibly associated with either reproductive or developmental toxicity with a current or proposed federal drinking water standard or health-based guideline represent a feasible starting point for evaluation in future drinking water exposure studies or human health studies particularly with respect to these outcomes. Further prioritization could be achieved with the inclusion of environmental measurements from specific geographic regions of interest, as those data become available, in addition to information on physicochemical properties and toxicologic potency.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Attachment B

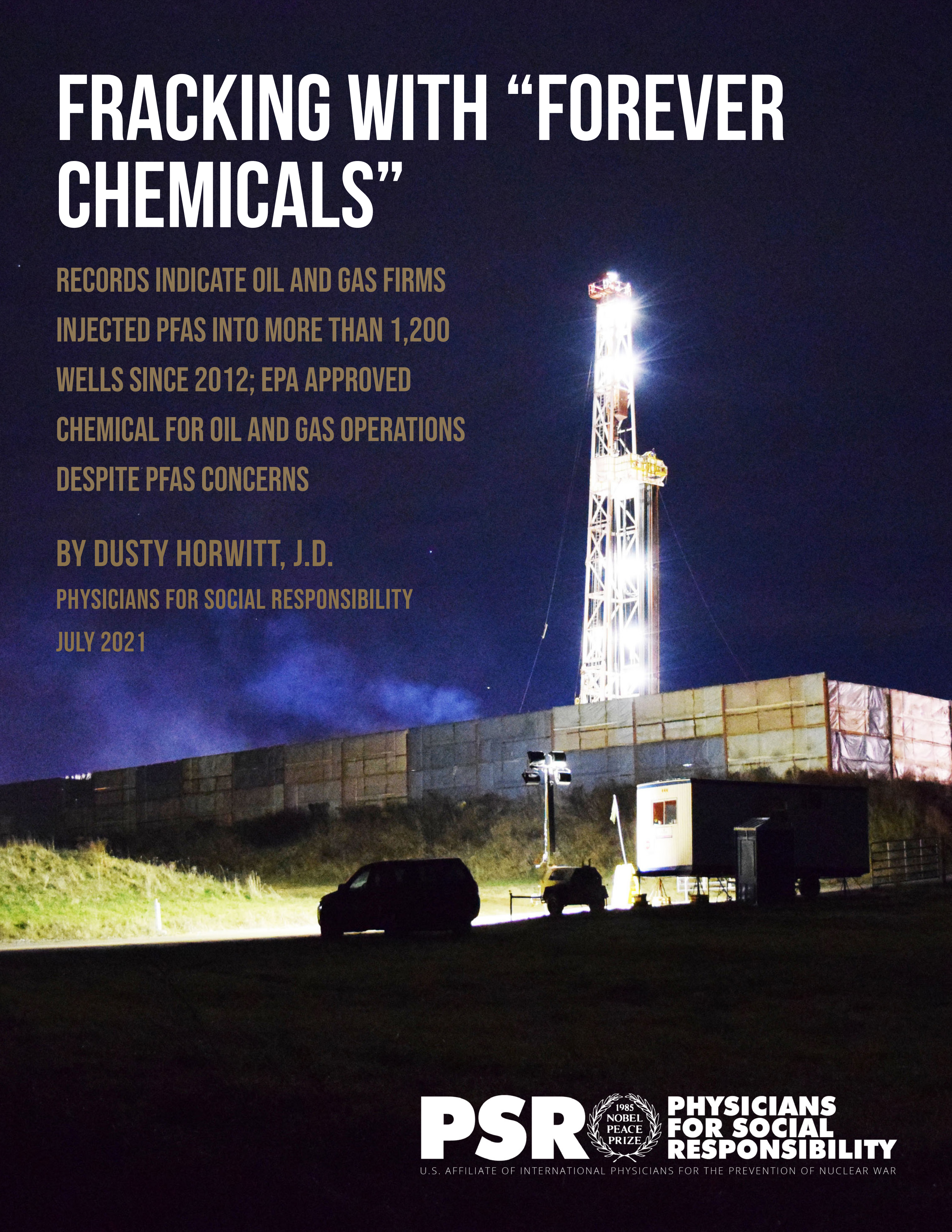
FRACKING WITH "FOREVER CHEMICALS"

RECORDS INDICATE OIL AND GAS FIRMS INJECTED PFAS INTO MORE THAN 1,200 WELLS SINCE 2012; EPA APPROVED CHEMICAL FOR OIL AND GAS OPERATIONS DESPITE PFAS CONCERNS

BY DUSTY HORWITT, J.D.

PHYSICIANS FOR SOCIAL RESPONSIBILITY

JULY 2021



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EXECUTIVE SUMMARY

Evidence suggests that oil and gas companies including ExxonMobil and Chevron have used per- and polyfluoroalkyl substances (PFAS), or substances that can degrade into PFAS, in hydraulic fracturing ("fracking") for oil and gas in more than 1,200 wells in six U.S. states between 2012 and 2020. The lack of full disclosure of chemicals used in oil and gas operations raises the potential that PFAS could have been used even more extensively than records indicate, both geographically and in other stages of the oil and gas extraction process, such as drilling, that precede the underground injections known as fracking.

PFAS have been linked to cancer, birth defects, pre-eclampsia, and other serious health effects. Toxic in minuscule concentrations, they accumulate inside the human body and do not break down in the environment – hence their nickname, "forever chemicals." PFAS were widely used for decades in non-stick cookware, stain-resistant carpeting, fire-fighting foam and other products before their highly toxic characteristics became public around the year 2000. Chemical manufacturers Dupont and 3M had known about these chemicals' environmental and health risks as early as the 1960s and '70s but failed to sound the alarm.

Evidence related to the use of PFAS in oil and gas operations has not been previously publicized. The apparent use of PFAS in these operations adds an especially hazardous class of chemicals to the list of harmful substances associated with oil and gas extraction and is another potential route of exposure to PFAS. In recent years, a growing number of states have set limits on PFAS pollution in water as researchers have discovered hundreds of sites where PFAS from a variety of sources have polluted groundwater. In addition, fire departments are disposing of firefighting foam that contains PFAS. "Fire departments are scrambling to get rid of firefighting foam with PFAS in it because EPA says it's toxic," said Silverio Caggiano, who retired in June 2021 as Battalion Chief with the Youngstown, Ohio Fire Department and is a hazardous materials expert who has trained with fire-fighting foam that contains PFAS. "So if it's too dangerous for us to use, why should oil and gas companies get to use it?"

> "There is evidence from human and animal studies that PFAS exposure may reduce antibody responses to vaccines [citations omitted] and may reduce infectious disease resistance."

Industry records indicating PFAS use in fracking in Arkansas, Louisiana, Oklahoma, New Mexico, Texas, and Wyoming came to light as part of Physicians for Social Responsibility's investigation of the U.S. Environmental Protection Agency's review of three new chemicals proposed in 2010 for use in oil and gas drilling and/or fracking. According to records obtained under a Freedom of Information Act request, EPA regulators worried that the chemicals could break down into products similar to PFOA, the most infamous PFAS, whose use has been largely discontinued in the U.S as part of an agreement between chemical makers and EPA. The regulators were also concerned that the degradation products of the three chemicals could be associated with severe health effects including male reproductive toxicity and tumors.

Despite these concerns, EPA approved the chemicals for commercial use, and EPA records show that one of the chemicals was used commercially for unspecified purposes at least as late as 2018. Records further indicate that the chemical was initially imported for commercial use by Dupont, a company that has agreed to pay hundreds of

EXECUTIVE SUMMARY [CONTINUED]

millions of dollars to settle injury claims related to PFOA pollution. EPA records included only a generic name for the chemical: fluorinated acrylic alkylamino copolymer. More specific identifiers were withheld as trade secrets.

PSR searched for the chemical in FracFocus, a database run by non-governmental organizations where companies operating in more than 20 states disclose well-by-well fracking chemical use. While we did not find the chemical with the name that EPA had approved, we did find other chemicals with related names that had been injected into more than 1,200 wells, the most common of which was "nonionic fluorosurfactant" and various misspellings. Evidence suggests these chemicals are likely PFAS and/or PFAS precursors (substances that could break down into PFAS).

In light of these findings, PSR recommends the following:

- **Health assessment.** EPA and/or states should evaluate through quantitative analysis whether PFAS and/or PFAS breakdown products associated with oil and gas operations have the capacity to harm human health. All potential pathways of exposure should be examined, including inhalation, ingestion, and dermal contact.

- **Testing and tracking**. EPA and/or states should determine where PFAS and chemicals that may be PFAS have been used in oil and gas operations and where related wastes have been deposited. They should test nearby water, soil, flora, and fauna for PFAS.

- **Funding and cleanup.** Oil and gas and chemical firms should be required to provide adequate funding for environmental testing and evaluation, and should PFAS be found, for cleanup. If water cleanup is impossible, the companies responsible for the use of PFAS should pay for alternative sources of drinking water.

- **Public disclosure.** Echoing recommendations by Pennsylvania's Attorney General in 2020, governments should require full public disclosure of drilling and fracking chemicals before each oil or gas well can be developed. EPA and/or states should inform communities potentially exposed to PFAS about PFAS contamination risks so that the communities can take actions such as water testing and treatment.

- **Moratorium on PFAS use for oil and gas extraction.** Until testing and investigation are complete, EPA and states should not allow PFAS or chemicals that could break down into PFAS to be manufactured, imported, or used for oil and gas drilling or fracking.

- **Limits on drilling and fracking.** The use of PFAS and of chemicals that break down into PFAS in drilling and fracking should prompt governments to prohibit drilling, fracking, and disposal of related wastewater and solid wastes in areas that are relatively unimpacted by oil and gas pollution, and to increase protections in already-impacted regions. When doubt exists as to the existence or danger of contamination, the rule of thumb should be, "First, do no harm."

"If water cleanup is impossible, the companies responsible for the use of PFAS should pay for alternative sources of drinking water."

RECORDS INDICATE PFAS WERE USED IN FRACKING FOR OIL AND GAS

PSR has unearthed evidence suggesting that per- and polyfluoroalkyl substances (PFAS) and/or PFAS precursors (substances that could degrade into PFAS) have been used for hydraulic fracturing ("fracking") in more than 1,200 oil and gas* wells in six U.S. states, creating risks for oil and gas workers and the public through multiple potential pathways of exposure. The lack of full disclosure of chemicals used in oil and gas operations raises the potential that PFAS could have been used even more extensively than records indicate, both geographically and in other stages of the oil and gas extraction process, such as drilling, that precede the underground injections known as fracking. The apparent use of PFAS in oil and gas production has not been previously publicized and raises concerns about toxic exposures.

PFAS are a class of chemicals known for having several valuable properties, including being slippery, oil- and water-repellant, and able to serve as dispersants or foaming agents.[1] The first PFAS to be sold commercially was discovered by a chemist at Dupont and patented as Teflon. Beginning in 1949, it was used in thousands of products, from nonstick cookware to waterproof clothing to plastics to dental floss.[2] Other PFAS have been used in food packaging, fire-fighting foam, and in 3M's widely used fabric protector, Scotchgard.[3] PFAS have been called "perfluorinated chemicals," "polyfluorinated compounds," or PFCs, though the term currently preferred by the U.S. Environmental Protection Agency (EPA) is PFAS.[4] PFAS' nickname "forever chemicals" is rooted in their manufacture, in which hydrocarbon chains of carbon and hydrogen atoms are mixed with hydrofluoric acid. The fluorine atoms in the acid replace the hydrogen atoms in the hydrocarbon chains, forming a bond between fluorine and carbon that is among the strongest in chemistry and barely exists in nature. The result: chemicals that are extremely resistant to breaking down in the environment.[5]

As early as the 1960s and 1970s, researchers inside Dupont and 3M became aware that PFAS were associated with health problems including cancers and birth defects, had accumulated inside virtually every human being, and persisted in the environment.[6] Many of these facts, kept internal by the companies, came to light after attorney Rob Bilott filed lawsuits in 1999 and 2001 against Dupont for causing pollution in and around Parkersburg, West Virginia with PFOA, a type of PFAS used to make Teflon.[7] In December 2011, as part of Dupont's settlement of the 2001 lawsuit, a team of epidemiologists completed a study of the blood of 70,000 West Virginians and found that there was a probable link between PFOA and kidney cancer, testicular cancer, thyroid disease (over- or under-production of hormones by the thyroid gland), high cholesterol, pre-eclampsia (a potentially dangerous complication during pregnancy characterized by high blood pressure and signs of damage to another organ system, most often the liver and kidneys), and ulcerative colitis (a disease causing inflammation and ulcers in the large intestine or colon).[8] Mounting evidence of PFAS's risks has led ten states to develop guidelines for concentrations in drinking water of PFOA and other types of PFAS.[9] One of these states is Michigan, which set standards in 2020 for drinking water and cleaning up groundwater for PFOA and six other forms of PFAS. (The state acted because EPA had not enacted federal drinking water standards for PFAS.) Michigan's maximum allowable level of PFAS is no more than eight parts per trillion for PFOA.[10] By extension, these standards indicate that one measuring cup of PFOA could contaminate almost 8 billion gallons of water, six times the 1.3 billion gallons of water used each day by New York City, or the amount of water needed to fill almost 12,000 Olympic-sized swimming pools at about 660,000 gallons per pool.[11]

PFAS/Fracking Link Began with Investigation of EPA Chemical Approval

PSR found evidence suggesting that PFAS have been used for hydraulic fracturing ("fracking") in the course of an investigation into EPA's approval of chemicals proposed for use in oil and gas drilling and fracking. In fracking, energy companies inject into oil and gas wells a mixture of up to tens of millions of gallons of water, sand, and chemicals at high pressure to fracture underground rock formations,

*Gas, the principal component of which is methane, is also known as "natural" gas, "fossil" gas and "fracked" gas unlocking trapped oil and gas. The chemicals serve a variety of purposes including killing bacteria inside the wellbore, reducing friction during high-pressure fracking, and as gelling agents to thicken the fluid so that the sand, suspended in the gelled fluid, can travel farther into underground formations.[12]

In 2020, PSR examined documents disclosed by EPA in response to a Freedom of Information Act (FOIA) request that asked EPA to disclose its health reviews and regulatory determinations for new chemicals proposed for use in oil and gas drilling and fracking.[13] We discovered documentation of chemicals proposed to be imported for use in drilling and/or fracking. They were identified by EPA case numbers P-11-0091, P-11-0092, and P-11-0093.[14] And EPA agency regulators worried in writing that these chemicals could degrade into PFOA-like substances.

The relevant documents were created by EPA in accordance with the Toxic Substances Control Act (TSCA), which requires among other provisions that chemical manufacturers or importers submit applications, called "premanufacture notices," in order to receive permission to use new chemicals commercially or to use existing chemicals commercially for new purposes.[15] This system of new-chemicals review is supposed to protect the public from chemical pollution, but it has been heavily criticized over the years as inadequate, including by Congress' investigative arm, the Government Accountability Office (GAO). The GAO has consistently included EPA's program regulating toxic chemicals on its list of federal government programs at highest risk of waste, fraud, abuse, and mismanagement.[16]

PMN2010P3

SANITIZED SUBMISSION

PMN Page 3

Part I -- GENERAL INFORMATION					
Section A – SUBMITTER IDENTIFICATION					
Mark (X) the "Confidential" box next to any subsection you claim as confidential					
1a.	**Person Submitting Notice (in U.S.)**				Confidential
Name of Authorized Official	(first) XXX		(last) XXX		X
Position	XXX				
Company	XXX				
Mailing Address (number & street)	XXX				
City	XXX	State		Postal Code XXX	
email	XXX				
b.	**Agent (if Applicable)**				Confidential
Name of Authorized Official	(first)		(last)		

Figure 1. "Sanitized" premanufacture notice for chemicals with EPA case numbers P-11-0091, P-11-0092, P-11-0093 showing that the chemicals' submitter withheld its own name as confidential. The term "sanitized" means that confidential business information has been withheld from the public version of the document.

Reviewing the EPA's documents was challenging because TSCA allows companies to withhold from the public virtually all the data they submit to EPA in their premanufacture notices. Companies can shield the information from the public by designating it as confidential business information or CBI.[17] In this case, the submitter marked multiple details as CBI, including the chemicals' names, structure, use, production volume, and unique numeric identifiers known as Chemical Abstracts Service (CAS) numbers that scientists consider the best way to identify chemicals.[18] When companies withhold specific chemical identifiers from their premanufacture notices, they must provide a generic or less specific name for their chemical(s) so that the public can have some idea what chemical EPA is assessing.[19] Here, a single generic name was listed for all three chemicals: "fluorinated acrylic alkylamino copolymer."[20] Similarly, manufacturers or importers must list a generic use when the specific use is deemed confidential.[21] Here, the generic use was listed as "oil and water repellent and release agent."[22] Even the company's name was withheld as confidential,[23] leaving the documents riddled with redactions and blank spaces, as may be seen in figures 1 and 2. PSR was, however, able to determine the original submitter's likely identity by digging deeper into EPA data disclosed as required by TSCA.

Despite the confidentiality, EPA's health and ecological hazard assessment and consent order regulating the chemicals P-11-0091, P-11-0092, and P-11-0093 show that the agency was concerned about their health and environmental impacts.

The agency's concerns were based in part on the potential that the chemicals might degrade into substances similar to one of the most infamous PFAS in modern chemistry, PFOA.[24] Unfortunately, EPA's assessment and consent order were themselves heavily redacted before being released in response to a FOIA request, preventing a full understanding of EPA's concern. In its consent order, EPA stated:

> EPA is concerned that these perfluorinated degradation products may be released to the environment from incomplete incineration of the PMN [premanufacture notice] substances at low temperatures. EPA has preliminary evidence, including data on other [REDACTED], that suggests that, under some conditions, the PMN substances could degrade in the environment. EPA has concerns that these degradation products will persist in the environment, could bioaccumulate or biomagnify, and could be toxic (PBT) to people, wild mammals, and birds based on data on analog chemicals, including PFOA and [REDACTED]. The presumed perfluorinated degradants for these PMN substances include [REDACTED].[25]

PMN2010P5A

SANITIZED SUBMISSION

PMN Page 5a

c. Please identify which method you used to develop or obtain the specified chemical identity information reported in this notice (check one).				CBI
Method 1 (CAS Inventory Expert Service - a copy of the identification report obtained from CAS Inventory Expert Service must be submitted as an attachment to this notice) [X]	IES Order Number	152725-1	**Method 2** (other source) [ ]	
Enter Attachment filename for Part I, Section B, 2. c.		CAS - Inventory Expert Service (2010) #1 (public).pdf		[ ]
d. The currently correct Chemical Abstracts (CA) name for the polymer that is consistent with TSCA Inventory listings for similar polymers.				[X]
XXX				
CAS Registry Number (if a number already exists for the substance)		XXX		

Figure 2. "Sanitized" premanufacture notice for chemicals with EPA case numbers P-11-0091, P-11-0092, P-11-0093 showing that the chemicals' submitter withheld the chemicals' Chemical Abstracts Service registry numbers – the surest identifier for a chemical's identity – as confidential.

The acronym PBT stands for (P) persistent, (B) bioaccumulative, and (T) toxic.[26] EPA did not answer a question sent via email by PSR about the circumstances in which the substances described in the premanufacture notice might be incompletely incinerated.

In discussing PFOA, to which EPA regulators had likened the degradation products of the three chemicals, the regulators added that

> toxicity studies on PFOA indicate developmental, reproductive and systemic toxicity in various species. Cancer may also be of concern. These factors, taken together, raise concerns for potential adverse chronic effects in humans and wildlife."[27]

EPA also expressed significant health concerns in its health and ecological hazard assessment. The agency wrote:

> For the potential incomplete incineration/environmental degradation product, based on the test data for the analogue [REDACTED], concerns are liver toxicity, blood toxicity, and male reproductive toxicity....There is also

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concern for immunosuppression and oncogenicity based on data for [REDACTED].[28]

On November 29, 2011, the undisclosed company that had requested the approval of the three new chemicals began importing one of the chemicals for commercial use, the one known by EPA case number P-11-0091, according to a document filed with EPA.[29] (The related chemicals, P-11-0092 and P-11-0093, have not been used commercially.[30]) An additional EPA record shows that chemical P-11-0091 may have been used in oil and gas wells, among other uses, at least as recently as 2018.[31]

Search of Fracking Database Indicates Use of PFAS in Oil and Gas Operations

To determine if the chemical known as P-11-0091 had been used in oil and gas operations, PSR searched for "fluorinated acrylic alkylamino copolymer," the chemical's generic name, in a publicly available online database of well-by-well fracking chemical disclosure maintained by FracFocus, a nongovernmental organization run by the Groundwater Protection Council and the Interstate Oil and Gas Compact Commission. The database, which began operating in 2011, contains records on the hydraulic fracturing chemicals used in thousands of wells across the nation. Twenty-five states require or allow reporting of hydraulic fracturing chemicals to the database.[32] Companies in states in which reporting to FracFocus is not required can, and sometimes do, report hydraulic fracturing chemical use voluntarily to FracFocus. The database can be searched for chemicals used across multiple wells.[33]

While PSR did not find any uses of "fluorinated acrylic alkylamino copolymer," we did find chemicals with related names had been used to fracture more than 1,200 wells primarily in Texas but also in Arkansas, Louisiana, Oklahoma, New Mexico, and Wyoming between 2012 and 2020. The most frequent use occurred prior to 2016. Chemicals with related names included:

- fluorinated benzoic salts
- Fluoroalkyl Alcohol Substituted Polyethylene Glycol
- fluoro surfactants – proprietary
- meta-Perfluorodimethylcyclohexane
- Perfluoro-1,3-dimethylcyclohexane
- nonionic fluorosurfactant (and multiple misspellings of the same term)

A variety of evidence shows that these chemicals are or could be PFAS and/or PFAS precursors. EPA lists two of the chemicals, meta-Perfluorodimethylcyclohexane and Perfluoro-1,3-dimethylcyclohexane, in the agency's "Master List of PFAS Substances."[34] According to two chemical experts, both of whom are authors of multiple peer-reviewed articles about chemicals related to oil and gas production,[35] all of the chemicals are PFAS or could degrade into PFAS. The two experts are Zacariah Hildenbrand, a research professor in Chemistry and Biochemistry at the University of Texas at El Paso, and Kevin Schug, Shimadzu Distinguished Professor of Analytical Chemistry at the University of Texas at Arlington.[36] In addition, Wilma Subra, who has a master's degree in chemistry and is a recipient of a John D. and Catherine T. MacArthur Foundation "Genius" Grant for her work helping to protect communities from toxic pollution, identified all of the chemicals as potentially PFAS. Subra, based in Louisiana, has spent decades working to reduce and remediate pollution from oil and gas operations.[37] And yet another expert, Linda Birnbaum, a board-certified toxicologist and former director of the National Institute of Environmental Health Sciences, informed PSR that all of the chemicals are likely to be PFAS.[38]

Are any of these chemicals in the FracFocus database the "fluorinated acrylic alkylamino copolymer" approved by EPA? Each of the four chemical and health experts said that was a possibility. However, it is impossible to know conclusively without having the precise identifier, known as a CAS number, both for the EPA-approved chemical and for the chemicals listed in the FracFocus records. CAS numbers are unique numeric identifiers assigned to each chemical by the American Chemical Society. They are the most accurate way to identify chemicals, because a chemical can have multiple names or trade names but only one CAS number.[39]

Major Oil and Gas Companies Likely Used PFAS and/or PFAS Precursors

According to the publicly available data in the FracFocus database, more than 130 oil and gas companies reported using the chemicals that, according to experts and EPA's list of PFAS substances, are or could be PFAS and/or PFAS precursors. These companies include some of the most prominent producers of oil and gas. Among them:

- XTO Energy Inc., a subsidiary of ExxonMobil, one of the world's largest oil and gas producers, disclosed using one of the chemicals, nonionic fluorosurfactant, in 78 wells in New Mexico, Oklahoma, and Texas between 2013 and 2019.

- Chevron Corp., another major producer, reported using nonionic fluorosurfactant in 38 wells in New Mexico and Texas in 2013 through 2015.

- Anadarko Petroleum Corp., reported using nonionic fluorosurfactant in eight wells in Texas in 2013-2014. Anadarko was the co-owner, along with BP, of the Macondo well that spewed millions of gallons of oil into the Gulf of Mexico in 2010.[40]

- EOG Resources, Inc., one of the largest oil producers from shale deposits in the U.S.,[41] reported using fluoroalkyl alcohol substituted polyethylene glycol in 99 wells in New Mexico and Texas from 2012-2014 as well as nonionic fluorosurfactant in one well in Texas in 2014.

- Encana Corp., once one of Canada's largest oil companies, disclosed the use of nonionic fluorosurfactant in four wells in Texas in 2014-2015. Encana moved its corporate headquarters to the U.S. in 2020 and changed its name to Ovintiv.[42]

The table below shows a sampling of wells fractured by these five companies and the estimated maximum amount, in pounds, of chemicals that may be PFAS used in each well. Each chemical in the table comprises a tiny percentage of the total amount of hydraulic fracturing fluid injected into each well – in one case as small as 0.00016 percent of the total.[44] However, because oil and gas companies can inject millions of gallons of hydraulic fracturing fluid into each of their wells, small percentages can add up to hundreds of pounds of chemicals or more. When chemicals are as

Examples of Apparent PFAS Chemicals and/or PFAS Precursors Utilized in Hydraulic Fracturing

Company	Well Number	State	County	Year	Potential PFAS Used in Well	Estimated Maximum Amount (lbs)
XTOEnergy/ExxonMobil	35-019-26303	OK	Carter	2019	Nonionic Fluorosufactant	17.60
XTOEnergy/ExxonMobil	35-019-26301	OK	Carter	2019	Nonionic Fluorosufactant	27.41
Encana (Ovintiv)	42-461-39585	TX	Upton	2015	Nonionic Fluorosurfactant	31.98
EOG Resources, Inc.	30-025-42387	NM	Lea	2015	fluoroalkyl alcohol substituted polyethylene glycol	114.63
EOG Resources, Inc.	30-025-42386	NM	Lea	2015	fluoroalkyl alcohol substituted polyethylene glycol	120.07
Encana (Ovintiv)/Athlon	42-173-36707	TX	Glasscock	2014	Nonionic Fluorosurfactant	324.87
Chevron	42-105-36572	TX	Crockett	2014	Nonionic Fluorosurfactant	25.25
Chevron	42-105-39233	TX	Crockett	2014	Nonionic Fluorosurfactant	23.23
Anadarko	42-105-40668	TX	Crockett	2013	Nonionic Fluorosurfactant	108.10
Anadarko	42-105-40818	TX	Crockett	2013	Nonionic Fluorosurfactant	8.94

Table 1. The estimated maximum amount of chemicals that may be PFAS, in pounds, used by five different oil and gas companies to hydraulically fracture selected wells in New Mexico, Oklahoma and Texas between 2013 and 2019. For a detailed explanation of the calculations in the table, see the endnote.[43]

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toxic as PFAS can be, even small quantities could cause extensive contamination through multiple pathways. "There's a potential for [PFAS] to contaminate a huge amount of water or soil or sediment if it were to spill on the surface," said chemist Subra in a telephone interview, noting that the amounts of potential PFAS in the table could pose a risk. "It doesn't take much to be present in those media to be a threat to health."[45]

In most cases, the declared uses of the chemicals in FracFocus were not much more specific than the generic name offered. Hundreds of uses were listed as some type of surfactant, including "fluoro surfactant" and "water recovery surfactant."[46] According to EPA:

> surfactants are substances that lower the surface tension of a liquid, the interaction at the surface between two liquids (called interfacial tension), or that between a liquid and a solid. Surfactants may act as detergents, soaps, wetting agents, degreasers, emulsifiers, foaming agents and dispersants.[47]

FracFocus also reflected a handful of other uses, including the use of "meta-Perfluorodimethylcyclohexane" as a tracer. It was injected in four wells in Sublette County, Wyoming in 2015 and 2016.[48] Tracers are used to help oil and gas companies infer information about underground formations.[49] EPA documents disclosed in November 2020 show that PFAS have been proposed for use as tracers.[50]

PFAS May Have Been Used for Decades in Oil and Gas Operations

Two sources suggest that the use of PFAS in oil and gas operations dates back decades and involves the use of the chemicals in a range of extraction techniques. The authors of a paper published in 2020 in the peer-reviewed journal *Environmental Science: Processes and Impacts* found that more than 50 PFAS have been used or proposed to be used to extract oil and gas, based on public records dating to 1956 that include patents, journal articles, and databases. The authors cautioned that they were not able to verify the information they found, but the records indicate that PFAS have been used to extend underground fractures, to increase the permeability of underground formations, to make the surfaces of underground oil-bearing reservoirs water- and oil-resistant, and as foaming agents.[51]

In a 2008 paper in *The Open Petroleum Engineering Journal*, two authors, including at least one from Dupont, wrote that:

> while fluorosurfactants have been used in gas and oil exploration for four decades, the increased demand for petroleum and the greater understanding of the benefits of fluorosurfactants have led to growing acceptance for fluorosurfactants throughout the petroleum industry.[52]

The authors did not explicitly say that fluorosurfactants were PFAS, but they wrote that "the use of fluorosurfactants is a recent but growing trend due to (i) the exceptional hydrophobic and oleophobic nature of the perfluoroalkyl and perfluoroalkyl ether groups…"[53] Thus, at least some of the fluorosurfactants mentioned in the article appear to be PFAS. Furthermore, the article indicated that use of fluorosurfactants was growing and, referring to them as an "emerging technology," said that fluorosurfactants showed promise in a variety of extraction techniques including fracking, drilling, and waterflooding.[54] Like the authors in the 2020 paper in *Environmental Science: Processes and Impacts*, the authors noted that they relied mostly on patents and laboratory models "vs actual oil and gas recovery experiments."[55]

OIL AND GAS CHEMICALS CAN POSE SERIOUS HEALTH RISKS

Shedding light on the use or possible use of PFAS in oil and gas extraction is important because, for years, people living near oil and gas operations have experienced contaminated water and serious illnesses that they believe are related to the chemicals associated with these activities.[56] During the 2000s, these concerns intensified as oil and gas companies moved into more heavily populated areas to drill so-called unconventional formations such as coalbed methane and shale.[57] To reach the new deposits, the companies have used hydraulic fracturing, often combined with horizontal drilling.[58]

As previously discussed, chemicals are injected into oil and gas wells as an integral part of the fracking process. They are also used during drilling, which precedes fracking. During drilling, companies bore deep holes in the earth; these holes typically pass directly through groundwater. Chemicals can be injected in this stage of the process to help keep the drill bit cool and to lift rock cuttings out of the well,[59] and at this point in the process, no protective structures are in place to keep those chemicals from entering groundwater. Following drilling and fracking, a portion of the water, sand and chemicals injected into oil and gas wells during fracking, as well as naturally occurring contaminants such as carcinogenic benzene[60] and radium,[61] flow out of the well in the form of wastewater.[62] Wastewater can reach volumes of millions of gallons per well.[63]

Use of PFAS in oil and gas operations would add a highly potent substance to an already long list of toxic chemicals associated with oil and gas extraction. In 2016, EPA published a study of fracking and drinking water that identified 1,606 chemicals used in fracking fluid and/or found in wastewater. While the agency found high-quality information on health effects for only 173 of these chemicals, that information was troubling. EPA found that "health effects associated with chronic oral exposure to these chemicals include carcinogenicity [for both benzene and radium], neurotoxicity, immune system effects, changes in body weight, changes in blood chemistry, liver and kidney toxicity, and reproductive and developmental toxicity."[64] Chemicals used in the drilling stage can also pose health risks, including developmental toxicity and the formation of tumors, according to EPA regulators.[65] A disclosure form filed with the state of Ohio, perhaps the only state to require disclosure of drilling chemicals, shows that Statoil, Norway's state oil company since renamed Equinor, has used neurotoxic xylene in drilling.[66]

The lack of high-quality health testing data for the other 1,400-odd chemicals identified by EPA does not necessarily mean that they are safe; it might simply mean that they have not been adequately tested. The federal Toxic Substances Control Act (TSCA) has likely contributed to these gaps because it has not required health testing for new chemicals. According to Congress' investigative arm, the Government Accountability Office, chemical manufacturers have often avoided such testing, and EPA often has not asked for it despite having the authority to do so.[67] Congress updated TSCA in 2016 to strengthen EPA's authority to ask for health testing,[68] but according to the Environmental Defense Fund, the Trump administration EPA failed to use this improved authority.[69] Separately, EPA noted that its list of chemicals associated with fracking was likely incomplete because chemical manufacturers treat many chemicals used in oil and gas drilling as trade secrets, as permitted by TSCA.[70]

A new health concern related to PFAS and its use or possible use in oil and gas operations is that the chemicals could compromise the effectiveness of vaccines for COVID-19. The U.S. Centers for Disease Control and the Agency for Toxic Substances and Disease Registry issued the following statement in June 2020:

> CDC/ATSDR understands that many of the communities we are engaged with are concerned about how PFAS exposure may affect their risk of COVID-19 infection. We agree that this is an important question….CDC/ATSDR recognizes that exposure to high levels of PFAS may impact the immune system. There is evidence from human and animal studies that PFAS exposure may reduce antibody responses to vaccines [citations omitted], and may reduce infectious disease resistance [citation omitted]. Because COVID-19 is a new public health concern, there is still much we don't know. More

Figure 3 shows an example of a spill of fracking fluids. The photo is from the U.S. Environmental Protection Agency and shows a fire on June 28-29, 2014 at the Eisenbarth Well operated by Statoil (since renamed Equinor) in Monroe County, Ohio. The photographer is not listed.[74] According to an EPA report, trade secret fracking chemicals along with other chemicals were spilled because of the fire. Fluids that may have contained the trade secret chemicals ran off the well pad into a tributary of the Ohio River. An estimated 70,000 fish died.[75]

research is needed to understand how PFAS exposure may affect illness from COVID-19.[71]

Multiple Potential Pathways to Human Exposure

EPA and others have identified multiple pathways through which people could be exposed to the chemicals associated with oil and gas extraction including, potentially, PFAS. The agency indicated that any chemicals used during the first stage of the drilling process would be highly likely to leach into groundwater because during this stage, drilling passes directly through groundwater zones[72] before any casing or cement is placed in the well to seal it off from surrounding aquifers.

EPA found that during the fracking phase that follows drilling, exposure pathways could include:

- spills of fracking fluid that seep into groundwater;
- injection of fracking fluid into wells with cracks in the casing or cement, allowing the fluid to migrate into aquifers (much of the fracking fluid can remain underground);

- injection of fracking fluids directly into groundwater;
- underground migration of fracking fluids through fracking-related or natural fractures;
- intersection of fracking fluid with nearby oil and gas wells, and
- spills of wastewater after the fracking process is completed, and inadequate treatment and discharge of fracking wastewater to surface water supplies.[73]

Additional potential pathways of concern involve wastewater. These include intentional dumping of fracking wastewater into waterways,[76] spreading wastewater on roads to suppress dust or melt snow and ice,[77] and the use of wastewater for irrigation of agricultural crops.[78] In addition to these intentional uses, underground leaks can occur from underground injection wells into which well operators have pumped billions of gallons of drilling and fracking wastewater for disposal.[79] This injected wastewater is intended to remain in underground formations permanently but has been known to leak and pollute groundwater.[80] In addition, drilling and fracking chemicals can become airborne at oil and gas sites through various routes[81] including by volatilizing from huge ground-level pools of wastewater[82] or from tanks that store condensate, a naturally-occurring liquid associated with gas.[83]

The toxic and secret chemicals used in drilling and fracking can also pose a risk not only to people living near oil and gas production wells in relatively rural areas but also to people living near wastewater disposal sites, especially underground injection wells;[84] in densely populated areas with oil and gas drilling, such as Los Angeles;[85] and in urban areas downstream from fracking or wastewater disposal activity.[86] In 2019, New Jersey governor Philip D. Murphy called for a ban on fracking and the disposal of fracking wastewater in the Delaware River Basin, a multi-state watershed that provides drinking water for more than 13 million people and encompasses parts of Pennsylvania that could be drilled for gas.[87] "As noted by the Environmental Protection Agency in its 2016 report on the impact of fracking on water resources," Murphy wrote:

> the ability of regulatory agencies to assess the full impacts of fracking wastes on public health and the environment is hampered by the prevalence of confidentiality claims that prevent disclosure of the chemical constituents of fracking fluids...Therefore, prohibiting all fracking activity in the Basin is vital to avoid injury and preserve the waters of the Basin and protect public health.[88]

In February 2021, the Delaware River Basin Commission, of which Murphy is a member, banned fracking in the Basin, citing in part the risks of chemicals associated with the process.[89] The decision made permanent a de facto moratorium on fracking that the commission had maintained for more than 10 years.[90] The commission said that by September 30, 2021 it would propose amendments to its rules regarding the importation of fracking wastewater into the basin and export of freshwater from the Basin.[91]

Evidence of Harm to Human Health from Oil and Gas Operations

Residents living near oil and gas operations have increasingly reported illnesses that they believe are related to chemical exposures, while expressing frustration about the secrecy surrounding many of the chemicals used by the oil and gas industry.[92] In 2020, Pennsylvania's Attorney General issued a report based on a criminal grand jury investigation of oil and gas drilling pollution in the Keystone State, where drilling for gas in shale formations has surged over the past 15 years.[93] That surge has vaulted Pennsylvania into the number two spot among gas-producing states (Texas is number one)[94] and brought thousands of Pennsylvanians into contact with gas drilling and its impacts. Based on testimony from over 70 households, the attorney general found that

> Many of those living in close proximity to a well pad began to become chronically, and inexplicably, sick. Pets died; farm animals that lived outside started miscarrying, or giving birth to deformed offspring. But the worst

> was the children, who were most susceptible to the effects. Families went to their doctors for answers, but the doctors didn't know what to do. The unconventional oil and gas companies would not even identify the chemicals they were using, so that they could be studied; the companies said the compounds were "trade secrets" and "proprietary information." The absence of information created roadblocks to effective medical treatment. One family was told that doctors would discuss their hypotheses, but only if the information never left the room.[95]

In addition to these and other self-reported or anecdotal reports, peer-reviewed studies of people living near oil and gas operations provide scientific evidence of illnesses and other health effects. A 2019 study in the journal *Environment International* examined 3,324 babies born in Colorado between 2005 and 2011 and found that, compared with control groups, congenital heart defects were 1.4 and 1.7 times more likely in babies born to mothers in areas of medium and high unconventional gas drilling, respectively.[96] A 2018 study in the *Journal of Health Economics* found that babies born between 2003 and 2010 to Pennsylvania mothers living near a functioning shale gas well had a higher incidence of low birth weight compared to babies born of mothers living near a permitted well that had not yet gone into production.[97] Low birthweight is a leading contributor to infant death in the United States.[98] A 2017 study in *PLOS One* of Coloradans between birth and 24 years old diagnosed with cancer between 2000 and 2013 found that those between the ages of five and 24 were more than four times more likely to live in areas of heavy oil and gas drilling, compared to controls.[99] In 2019, Pennsylvania-based FracTracker Alliance conducted a meta-analysis of 142 health studies published between 2016 and 2018 focusing on health impacts of unconventional oil and gas development (UOGD). The analysis concluded, "The results of this study indicate that a variety of health impacts in every major organ system are being experienced by individuals living near UOGD." Specific health effects included cancer, early infant mortality, pre-term birth, and poor infant health.[100] The Southwest Pennsylvania Environmental Health Project,[101] and PSR and the Concerned Health Professionals of New York,[102] have likewise compiled the substantial and growing number of scientific studies that have found serious health effects associated with oil and gas drilling.

Disadvantaged Communities Bear Disproportionate Oil and Gas Exposure Risks

"Fenceline" communities – people living adjacent or close to oil and gas operations – often bear a disproportionate risk of exposure to drilling and fracking chemicals. And although drilling and fracking take place in the majority of U.S. states, not everyone shares in that risk equally. Rather, oil and gas infrastructure and associated chemicals are frequently located in or adjacent to poor, underserved, and marginalized communities, indigenous communities, and communities of color.[103] For example, a 2019 analysis conducted in Colorado, Oklahoma, Pennsylvania, and Texas found strong evidence that minorities, especially African Americans, disproportionately lived near fracking wells.[104] A separate study focusing on West Virginia, Ohio, and Pennsylvania found that in Pennsylvania, a higher concentration of unconventional gas wells are located in lower-income communities, and that localized clusters of vulnerable populations are exposed to high levels of well density in all three states.[105] A study of census tract data in western Pennsylvania shows that among nearly 800 gas wells, only two were drilled in communities where home values exceeded $200,000.[106] And a study published in 2018 found that oil and gas wastewater injection wells in Ohio were disproportionately located in rural, lower-income areas.[107]

Various population sectors are more vulnerable than others to harm from chemical exposure. This includes pregnant women; the young, whose vital organs are still in development; people with preexisting medical conditions; the elderly; and those who live where pollutants from multiple sources combine to create a high cumulative load of toxic exposures.[108] Where vulnerable populations also have limited access to health care, their health risks are magnified. In short, the health disparities that already exist in U.S. society combine with proximity to oil and gas operations to impose a disproportionate health burden on the poorest, the sickest, the young, the elderly, and people of color.

Also at high risk are oil and gas field workers and waste handlers and first responders. Industry workers who may handle or otherwise be exposed to fracking-related chemicals may not have the personal protective equipment needed to shield them from exposure, much less the training necessary to take protective or remedial measures.[109] The same is true for first responders called to an emergency at a site of oil and gas operations. Confidential business information or trade secret claims may hide from them the identity and effects of the chemicals they may be exposed to, leaving them unable to determine how potentially dangerous chemicals should be handled or contained.[110]

Other Experts Voice Concern about Exposure to PFOA-like Substances

The possibility that people could be unknowingly exposed to PFAS in oil and gas extraction is of concern to other specialists, including experts in toxic exposure and other scientists. Toxicologist David Brown, who has investigated health effects associated with unconventional gas drilling with the Southwest Pennsylvania Environmental Health Project, has suggested two likely pathways to human exposure for PFAS chemicals that could occur in oil and gas extraction: 1) through air, when gas is burned off during flaring, or 2) through the use of contaminated groundwater for bathing, cooking, drinking or washing laundry, which would allow chemicals in the water to be ingested or to be inhaled if the chemicals were to volatilize (evaporate or disperse as a gas) inside the home. “Anything injected down the well will come back up,” said Brown, who also served on a panel that advised the state of Massachusetts Department of Environmental Protection Office of Research and Standards on development of drinking water standards for PFAS. “People will get exposed.” He added that the risks could be significant. “PFAS compounds are sequestered in the body for long periods after ingestion, leading to long-term but undefined health risks. Individuals and communities need to be aware of the presence of such chemicals so that they can take protective action.”[111]

Silverio Caggiano, who retired in June 2021 as Battalion Chief and hazardous materials expert with the Youngstown, Ohio Fire Department, expressed dismay that the federal government and state governments would act to protect firefighters and the public from PFAS in some ways, but leave them at risk in other ways. He noted that both EPA and the U.S. Fire Administration, a division of the Federal Emergency Management Agency, have issued warnings and initiatives to discontinue the use of old Aqueous Film Forming Foam (AFFF), used to fight fires for years, and to dispose of it properly because it can contain PFAS.[112] Yet at the same time, government agencies have failed to acknowledge the potential use of PFAS in association with oil and gas wells. “Fire departments around the country are scrambling to extract any of this older AFFF from their inventories,” he said,

> yet when firefighters and first responders are called to a frac well incident, the governments both state and federal act as if this chemical danger doesn’t exist on-site. It makes one wonder who the EPA would cite for contamination if a fire department used old PFAS-containing AFFF to put out a well fire that had PFOA-style chemicals on-site. These games have to end. The jobs of firefighters are dangerous enough without the continuous shell game the chemical industry and regulators play with toxic chemicals.[113]

Robert Delaney, a geologist who until his retirement in November 2020 led an initiative for the Michigan PFAS Action Response Team to address contamination of PFAS at U.S. Department of Defense sites in the state, said that communities should be very concerned about the use of PFAS in oil and gas drilling. Delaney spent 36 years working in natural resource protection for the state of Michigan and first warned state officials about the looming problem with PFAS in 2012, though unrelated to oil and gas extraction.[114] PFAS, he said,

> disperses all over, it doesn’t break down, and the levels at which it is dangerous are so, so low. It becomes an enormous problem. I call it a nightmare contaminant. I used to think that benzene, TCE (trichloroethylene), polyvinyl chloride were the really nasty ones to deal with, and then I saw these.[115]

HEALTH RISKS [CONTINUED]

Delaney also noted that cleaning up water contaminated with PFAS is expensive if any significant volume is involved, because the water must be run through activated carbon, the same material in Brita filters. The amount of activated carbon needed would be vast and could cost millions of dollars, as it has in the ongoing effort to remove PFAS from drinking water at Michigan's Wurtsmith Airforce Base. And after the activated carbon fills up with PFAS and any additional contaminants in the water, it must be disposed of somewhere. "Part of the problem is landfills won't take it because they don't know how much liability they're taking on" if PFAS waste were to contaminate the landfill, Delaney observed.

As of 2020, Michigan was trying to clean up groundwater at 137 sites that exceed its new standards for PFAS pollution. "There are a lot of sites in Michigan because we are looking," Liesl Clark, director of the Michigan Department of Environment, Great Lakes and Energy told the Detroit Free Press. "If other states were doing the same sorts of work, they would be finding a similar challenge — and some states are."[116]

Carol Kwiatkowski, former Executive Director of The Endocrine Disruption Exchange, the first organization to catalogue the health effects of chemicals used in oil and gas drilling and fracking, said in an email to PSR that

> current efforts to address the problem of PFAS contamination focus on waste incineration or filtering of drinking water. Neither process is 100% effective, nor do they clean up the PFAS that have polluted large river systems or the air. In other words, there is no effective way to remove them.

Kwiatkowski, who is currently Science and Policy Senior Associate at the Green Science Policy Institute, added that "the most effective solution is to stop their use and production as quickly as possible, except for uses where they are absolutely necessary, for example in medical equipment."[117] PSR concurs.

EPA OK'D PFAS-RELATED CHEMICALS FOR OIL AND GAS DESPITE RISKS

For years, attorney Bilott, environmentalists, and even the state government of Michigan have raised concerns that EPA was not adequately protecting the public from PFAS pollution.[118] EPA's approval of three chemicals for use in oil and gas operations that regulators believed could degrade into PFOA-like substances raises additional concerns about the agency's commitment to protecting people and the environment from dangerous substances.

By the time EPA regulators reviewed the chemicals P-11-0091, P-11-0092, and P-11-0093 in 2010, the agency would have had a firm basis for concern about chemicals that could degrade into PFOA-like substances. It was already well-known that PFOA and PFOS (used to make Scotchgard) were extremely harmful. In 2004, Dupont had settled Bilott's lawsuit alleging PFOA-related harm for $70 million, plus promises to pay for water filtration and the scientific study that in 2011 found serious health impacts related to PFOA.[119] In 2005, EPA reached a then-record $16.5 million settlement with Dupont after accusing the company of violating TSCA by failing to disclose information about PFOA's toxicity and presence in the environment.[120] In 2006, EPA invited Dupont, 3M and six other companies to join a "stewardship" program in which the companies promised to achieve a 95 percent reduction of emissions of PFOA and related chemicals by 2010, compared to a year 2000 baseline. The agreement also required the companies to phase out manufacture and use of PFOA by 2015.[121] In 2021, EPA says on its website that the companies reported that they had accomplished the goals either by exiting the PFAS industry or by transitioning to alternative chemicals.

Manufacture and importation of PFOA itself has ceased, though there could still be some PFOA use from existing stocks, and it could be contained in imported items.[122] However, since the announcement of its PFAS stewardship program in 2006, EPA has allowed multiple new PFAS to be used commercially.[123] And in 2015, a group of more than 200 scientists raised health and environmental concerns that the new short-chain PFAS designed to replace PFOA and PFOS may not be safer for health or the environment.[124] These "replacement" substances may include the parent chemical or the breakdown products discussed in this report.

Dupont Was the Likely Importer of Chemical P-11-0091

Beyond the health risks of PFOA, EPA should have been troubled by the likely importer of the new chemicals proposed for use in oil and gas operations: Wilmington, Delaware-based Dupont. This tentative identification is based on the EPA-issued "accession number" that was issued for the chemical P-11-0091 that went into commercial use. When EPA receives a notice (called a "notice of commencement") that a chemical is going to be imported or manufactured for commercial use and the chemical's identity is hidden from the public as confidential business information, the agency assigns the chemical an accession number. This number allows the public to find the chemical on the TSCA inventory, a list of existing chemicals in commerce, without learning the chemical's specific identity.[125] The accession number also allows the public to search for data about the chemical submitted by chemical manufacturers and importers every four years under TSCA's Chemical Data Reporting rule. These data provide EPA and the public with some information about the use of chemicals in commerce in each of the four years preceding the submission year.[126]

Using the accession number – 277420 – that was issued to chemical P-11-0091, PSR searched online data filed in 2016 that provided information on use of this chemical during each of the years 2012 through 2015. The company listed as having imported or manufactured the chemical from 2012 through 2015 was Wilmington, Delaware-based Chemours. There was, however, a puzzling discrepancy: The Chemours company did not exist until July 1, 2015, when it was created by Dupont as a spinoff company that would manufacture "performance chemicals."[127] Under that timeline, Chemours could not have been reporting on its own chemicals until the second half of 2015. What company, then, was manufacturing or importing the chemical from 2012 until mid-2015?

We believe there is an explanation to be found under EPA reporting guidance. The guidance provides that when a manufacturing division of a company is separated from a parent company to become an independent entity, yet continues to manufacture or import the same substances it did previously, it retains the responsibility for reporting the manufacture or importation of those substances over a four-year reporting period, including the manufacturing or importing that it did while a unit of the parent company.[128] According to at least two different articles in a chemical industry trade publication, Chemours took over what used to be Dupont's performance chemical business – one that included fluorochemicals,[129] a class that would encompass the chemical with case number P-11-0091 and/or its PFOA-like breakdown products. As the successor of the division of Dupont that manufactured or imported fluorochemicals, Chemours in 2016 would have had a duty under EPA's guidance to report fluorochemicals under its own name that were previously made or imported by Dupont in 2012, 2013, 2014, and for the first half of 2015. The chemical with case number P-11-0091 and accession number 277420 apparently qualified as one of these chemicals.

An alternate explanation could be that Chemours was reporting a chemical previously made by or imported by a company other than Dupont that had merged with, or been acquired by, Chemours. In this scenario, EPA's guidance states that if the other company had ceased to exist following the merger or acquisition, Chemours would have had the duty to report on behalf of the previously separate company.[130] However, Chemours' Form 10-K filed with the U.S. Securities and Exchange Commission in 2016 does not reflect any mergers and acquisitions involving Chemours in the first half-year of its existence (the second half of 2015).[131] It is therefore likely that it was Dupont and not some other company that originally sent notice to EPA in November 2011 that it was importing chemical P-11-0091. It is also likely that Dupont continued to import or manufacture the chemical through at least July 2015, when Chemours became a separate company.[132] In February 2021, PSR wrote to Dupont via FedEx delivery service and to Chemours via certified U.S. mail, sharing details of our investigation and asking the companies, among other things, whether Dupont was the original importer of chemical P-11-0091. PSR did not receive a response from either company.)

The likely scenario that Dupont originally imported and/or manufactured the chemical P-11-0091 should concern the public because Dupont has a history of harming people and polluting the environment with PFOA while withholding knowledge of PFOA's risks.[133] As is discussed above, the company in the past failed to communicate to the public the risks of PFOA, and widespread pollution occurred before people and regulators could act to protect themselves. PSR is concerned that a similar result could occur with chemical P-11-0091.

Dupont's likely involvement with chemical P-11-0091, and Chemours' documented involvement, also raise concerns about significant financial damages. In creating Chemours as a separate company, Dupont made Chemours responsible for hundreds of millions of dollars of what was previously Dupont's liability related to PFOA.[134] In 2019, Chemours sued its own parent company, alleging that Dupont had understated how much liability Chemours would be responsible for. Chemours has already paid hundreds of millions of dollars to settle PFOA-related damage claims against Dupont,[135] and Dupont itself has agreed to pay hundreds of millions of dollars to settle such claims. Could significant financial damages be associated with chemical P-11-0091 as well?

EPA Regulation of the Chemical Was Lax

One fact is clear: EPA's regulation of chemical P-11-0091 and the two related chemicals that did not go into commercial use was lax. Despite the agency's own finding that these chemicals could break down into PFOA-like substances, EPA did not issue any requirement that follow-up testing be performed to see if the breakdown of the chemicals took place. Neither did the agency call for tracking to determine where the chemicals were being used, or if these substances were contaminating the environment as the agency had feared. Nor did it require that use of the chemicals be prohibited within a certain distance of drinking water sources, homes, or schools.

EPA told the nonprofit organization Partnership for Policy Integrity in 2016 that it does not track where new chemicals are used when they are reviewed and regulated under TSCA and lacked the staff to test for the new chemicals near water supplies.[136] PSR asked EPA whether the agency tracked where chemical P-11-0091 was used, but EPA did not respond. Indeed, there are no regulations or statutes that systematically require EPA to report the locations where a chemical is used after it is approved for commercial use. The chemical data reporting system requires reporting in some cases of the location of facilities where chemicals are manufactured or imported, but not the locations of end uses.[137] There is no indication that EPA tracked the end uses of chemical P-11-0091. In its consent order, EPA did require the importer to conduct certain tests if the company reached certain production volume or importation thresholds. (These thresholds were redacted.) EPA also required the importer to limit impurities in the chemicals to certain levels, provide EPA yearly reports on impurities in the chemicals, and maintain certain records.[138] EPA also said that the company would "annually analyze the starting material, [REDACTED] for perfluorooctanoic acid (PFOA)."[139]

EPA's Decision to Approve Chemicals May Have Relied on Dubious Assumptions

Why did EPA approve the chemicals P-11-0091, P-11-0092, and P-11-0093 for commercial use despite its health concerns? The agency offered no explicit reason, but one indication appears in the consent order the agency issued in 2011: EPA wrote that it believed, based on testing data for redacted substances, that the three chemicals would be less likely than PFOA to bioaccumulate in people.[140]

EPA also said that testing data on redacted substances "indicate a different and less toxic profile for [REDACTED] (a presumed environmental degradant of the PMN substances) than for PFOA."[141] It is unclear whether the agency was correct, but without careful testing, there is no guarantee that newer chemicals will be safer than the toxic chemicals they replace. The Chicago Tribune has investigated the use of flame retardants, for example, and has found that after toxic flame retardants such as PCBs and PBBs were replaced in the 1970s by substitute chemicals such as PBDEs, the replacement chemicals were found to have toxic problems of their own. Some of these replacements are now being phased out – in favor of yet another generation of flame retardants that have also been associated with health problems.[142]

Even after suggesting that the new chemicals were less of a health and environmental risk than PFOA, EPA expressed misgivings about approving the substances for commercial use. EPA wrote:

> However, based on: (1) the persistence of [REDACTED]; (2) potential intermediate fate products; and, (3) the possibility or likelihood that this substance may be used as a major substitute for some uses of PFOA, EPA believes more information is needed on the toxicity of [REDACTED] and possibly other environmental degradants, and the fate and physical/chemical properties of [REDACTED]-derived or related polymers in the environment.[143]

The agency added, "EPA expects the PMN substances or the degradants to be highly persistent"[144] and that "there is high concern for possible environmental effects from the potential persistent degradation product [REDACTED]."[145]

To address these concerns, EPA recommended multiple additional tests: reproductive and long-term toxicological testing in rats, a chronic toxicity/carcinogenicity test in rats, and an avian reproduction test in mallard ducks. However, these tests were not required.[146] PSR has asked EPA for the results of any of these health tests, if indeed they were completed, as well as health testing data submitted with the importer's premanufacture notice that was not included in the release of public records. While we received health testing data for unidentified substances that may be for chemical P-11-0091 (the chemical identity was redacted), we did not receive any documents showing completion of the tests for reproductive and long-term toxicological testing, chronic toxicity/carcinogenicity, or avian reproduction. The health testing data PSR received did not appear to show alarming results but also did not appear to test for degradation products of the chemicals – despite the fact that the degradation products of chemical P-11-0091 were the focus of EPA's concern.

Another potential – and unstated – reason for EPA's approval of the chemicals is that EPA generally assumes in its new-chemical reviews that oil and gas chemicals never leak, spill, migrate underground, or are otherwise released into the environment accidentally. This assumption is not explicitly stated. Rather, it is apparent in a set of documents that EPA has used for decades to predict exposures to chemicals used in oil and gas drilling and hydraulic fracturing. As analyzed by Partnership for Policy Integrity in a 2016 report, the documents reveal that the agency assumes that any releases of chemicals into the environment will be intentional and controlled, such as disposal of chemical-tainted wastewater into injection wells that EPA assumes will never leak, and the use of wastewater for agriculture.[147] The only exception we are aware of to the agency's assumption that all releases of chemicals will be intentional and controlled was in a 1994 document which said that "several of the surfactants such as alcohol ethoxylates and alkyl phenol ethoxylates, as well as organic in situ crosslinkers such as formaldehyde, are sufficiently volatile to result in air emissions from their use." The same document says, however, that "releases to water are assumed to be negligible."[148] It is a dubious assumption.

EPA's longstanding assumption that accidental releases of chemicals are essentially nonexistent is contradicted by data from EPA itself. As early as 1987, the agency documented unintended releases of drilling mud, fracking fluid, and wastewater in a report to Congress on oil and natural gas wastes.[149] The EPA highlighted spills associated with fracking in its 2016 report on fracking and drinking water.[150] Also in 2016, in a tacit admission that its assumption was unrealistic, EPA told Partnership for Policy Integrity that it had planned to develop a new exposure scenario that accounted for leaks and spills of fracking chemicals.[151] In addition, other public sources show that leaks and spills are common in oil and gas operations. For example, Cabot Oil and Gas Corp., Range Resources Corp., and Noble Energy Inc., have told investors that blowouts, leaks, and/or spills are common risks in oil and gas operations.[152] PSR is not aware that EPA has adopted an updated set of assumptions, but in any event, in 2011, EPA generally did not consider accidental releases of oil and gas chemicals as a pathway of exposure. Making this assumption could have enabled EPA to conclude that human exposure to the chemicals would be limited and thus that there would be minimal harm even from an extremely toxic chemical. This perspective could have influenced the agency's decision to approve the three chemicals. PSR has asked EPA why it approved the chemicals and if the agency's unrealistic exposure assumptions played a role, but as of end-June 2021, has not received a response.

LOCATING WHERE PFAS CHEMICALS HAVE BEEN USED: AN ONGOING CHALLENGE

As previously stated, PSR was able to locate oil and gas wells where PFAS or potential PFAS were used, at least some of which might be chemical P-11-0091. But confidentiality claims and other hurdles make it extremely difficult for the public to know for certain where this particular chemical or other oil and gas chemicals associated with PFAS have or are being used. As is discussed above, people can search for wells in which fracking chemicals were used through the nongovernmental organization FracFocus.[153] In addition, California operates its own searchable database for fracking chemicals.[154] The most accurate way to search for chemicals through these databases is by CAS number.[155] Other ways to search are by specific chemical name or trade name, but these are less accurate because a single chemical can have multiple names or trade names, and people conducting a search might be looking under the wrong name. Yet in many cases, as is the case with chemical P-11-0091, all these searches are impossible because the chemical's CAS number, specific chemical name, and trade name are redacted as trade secrets.

Exemptions under state rules provide several additional ways for oil and gas companies or chemical makers to shield from public scrutiny the use of oil and gas chemicals. For example, state rules typically allow well operators to withhold chemical identities from the public as trade secrets, just as chemical manufacturers or importers are allowed to do under federal law. So even if a chemical importer decided to remove CBI protection from the chemical's identity under federal law, a well operator could still assert that the identity was a trade secret under state rules.[156] State rules also typically do not require chemical manufacturers or importers to disclose their chemicals at all.[157] There is some evidence that manufacturers and importers may not provide all their fracking chemical identities to well operators or owners, who bear the burden of public disclosure under state rules.[158] In any case, if chemical manufacturers do not disclose fracking chemicals to well operators or owners, these actors cannot disclose the chemicals to the public.[159] Finally, most state rules do not require public disclosure of chemicals used in the drilling process that precedes fracking. Therefore, if the chemical P-11-0091 were used for drilling as opposed to fracking, there would be no obligation to disclose the chemical publicly under most state rules. Ohio may be the only exception, although Ohio allows well operators to withhold the identities of drilling chemicals as trade secrets.[160]

It may be possible to locate where PFAS chemicals have been used by relying on provisions added to TSCA by Congress in 2016. But even under those provisions, there remain challenges. Some of the added provisions in TSCA enable state and tribal governments, health professionals and first responders to obtain confidential information about chemicals. The provisions also allow disclosure in situations "pursuant to discovery, subpoena, other court order, or any other judicial process otherwise allowed under applicable Federal or State law."[161] In many of these cases, entities would have to keep the information to themselves and could use it only for limited purposes such as medical treatment,[162] but there is no explicit prohibition on making the information public as part of judicial processes and in other situations.

However, even if officials were to obtain a PFAS chemical's specific identity, especially its CAS number, there is no guarantee that they could require chemical manufacturers or importers to disclose where the chemical had been used. And even if they could, disclosure after an accident has occurred makes it unlikely that first responders will obtain the information in time to provide appropriate treatment to persons who have been exposed to a dangerous substance. Furthermore, as Youngstown, Ohio Fire Department Battalion Chief Caggiano told Partnership for Policy Integrity in 2019, post-incident disclosure deprives first responders of the ability to plan for a hazardous materials response or prevent serious spread of a dangerous pollutant.[163] In addition, there is no guarantee that a chemical's CAS number – if obtained through TSCA – would appear in fracking chemical disclosure records, even if the chemical had been used in oil and gas wells. Exemptions previously discussed would enable oil and gas well operators to withhold such information from these state-level disclosures.

Finally, compliance with terms of the updated TSCA

LOCATING [CONTINUED]

might be an issue. Reporter Eliza Griswold wrote in her 2019 Pulitzer Prize-winning book, Amity and Prosperity, about residents of western Pennsylvania who had sued well owner Range Resources after suffering health impacts and the deaths of animals that they believed were caused by Range's drilling operations near their homes. The residents requested from Range, among other pieces of information, the full list of chemicals used nearby. Range failed to provide the plaintiffs with a full list despite a court order that was in effect for several years. Range's lack of compliance was likely due in part to the fact that Range did not know some of the trade secret chemicals used by its subcontractors. A judge declined to sanction Range for failing to comply with the order. The inability to obtain the chemical identities made it more difficult for the residents to establish that Range had harmed them and may have influenced two residents to sign a confidential legal settlement that, Griswold wrote, "left both of them feeling angry and defeated."[164] As is suggested by this example, it is possible that oil and gas companies may be unable to comply with some of the provisions of TSCA requiring disclosure of confidential chemical identities. EPA, state government officials, and courts may have to force other companies in the supply chain, particularly chemical manufacturers, to provide this information

RECOMMENDATIONS

Considering the evidence that PFAS substances and/or PFAS precursors are being used in oil and gas wells; given EPA's concerns that a chemical the agency approved for commercial use could degrade into PFOA-like substances that would be toxic, persist in the environment, and bioaccumulate in people's bodies; and in light of the potential that people might be unknowingly exposed to these highly toxic substances, PSR recommends the following:

- **Health assessment.** EPA and/or states should evaluate through quantitative analysis whether PFAS and/or PFAS breakdown products associated with oil and gas operations have the capacity to harm human health. All potential pathways of exposure should be examined, including inhalation, ingestion, and dermal contact.

- **Testing and tracking.** EPA and/or states should determine where PFAS and chemicals that may be PFAS have been used in oil and gas operations and where related wastes have been deposited. They should test nearby water, soil, flora, and fauna for PFAS.

- **Funding and cleanup.** Oil and gas and chemical firms should be required to provide adequate funding for environmental testing and evaluation, and should PFAS be found, for cleanup. If water cleanup is impossible, the companies responsible for the use of PFAS should pay for alternative sources of drinking water.

- **Public disclosure.** Echoing recommendations by Pennsylvania's Attorney General in 2020, governments should require full public disclosure of drilling and fracking chemicals before each oil or gas well can be developed. EPA and/or states should inform communities potentially exposed to PFAS about PFAS contamination risks so that the communities can take actions such as water testing and treatment.

- **Moratorium on PFAS use for oil and gas extraction.** Until testing and investigation are complete, EPA and states should not allow PFAS or chemicals that could break down into PFAS to be manufactured, imported, or used for oil and gas drilling or fracking.

- **Limits on drilling and fracking.** The use of PFAS and of chemicals that break down into PFAS in drilling and fracking should prompt governments to prohibit drilling, fracking, and disposal of related wastewater and solid wastes in areas that are relatively unimpacted by oil and gas pollution, and to increase protections in already-impacted regions. When doubt exists as to the existence or danger of contamination, the rule of thumb should be, "First, do no harm."

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[147] Dusty Horwitt. Toxic Secrets. Partnership for Policy Integrity (April 7, 2016). Accessed Oct. 17, 2020) at http://www.pfpi.net/wp-content/uploads/2016/04/PFPI_ToxicSecrets_4-7-2016.pdf. The report analyzed the following documents: Organization for Economic Cooperation and Development, Emission Scenario Document on Chemicals Used in Oil Well Production (Mar. 19, 2012), at 19. Accessed online November 25, 2020 at http://www.oecd-ilibrary.org/content/book/9789264220966-en. U.S. Environmental Protection Agency. (1994). Generic Scenario: Application of Chemicals in Enhanced Oil Recovery Steam Stimulation, Steam Flooding, and Polymer/Surfactant Flooding, Final Draft. U.S. Environmental Protection Agency. (1991). New Chemical Scenario for Drilling Muds. U.S. Environmental Protection Agency. (1991). New Chemical Scenario for Oil Well Treatment Chemicals.

[148] U.S. Environmental Protection Agency. (1994). Generic Scenario: Application of Chemicals in Enhanced Oil Recovery Steam Stimulation, Steam Flooding, and Polymer/Surfactant Flooding, Final Draft (on file with PSR).

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[156] Dusty Horwitt. Hydraulic Fracturing Chemical Disclosure: Can the Public Know What's Going Into Oil and Natural Gas Wells? Chapter in Environmental Issues Concerning Hydraulic Fracturing, Kevin A. Schug and Zacariah Hildenbrand, Eds. (Elsevier 2017), at 76-87.

[157] See, e.g., Pennsylvania's rules at 58 Pa.C.S. § 3222.1 (b)(9) and 58 Pa.C.S. § 3222.1 (d)(2)(ii).

[158] Eliza Griswold. Amity and Prosperity. Farrar, Straus and Giroux (2018), at 259-261 (reporting that well operator Range Resources likely did not know some of the chemicals that its subcontractors were using and that some of the chemical identities were known by a chemical manufacturer, ProTechnics, that refused to reveal some of them). Permittee Range Resources – Appalachia, LLC's Amended Responses and Objections to Appellant's Request for Production of Documents and Request for Admission. Filed with Commonwealth of Pennsylvania Environmental Hearing Board (April 24, 2013) (Range Resources, a well operator, stated in this document that "Some [chemical] manufacturers include very little information about the actual components of a particular product [in Material Safety Data Sheets provided to users of their chemicals]. As a result, Range is currently in the process of seeking additional information from manufacturers that have failed to provide enough information about their products in the MSDS." Range provided specific examples.) (on file with PSR). U.S. House of Representatives Committee on Energy and Commerce, Minority Staff. Chemicals Used in Hydraulic Fracturing (April 2011), at 2, 12 (finding that "in many instances, the oil and gas service companies [that conduct hydraulic fracturing] were unable to provide the Committee with a complete chemical makeup of the hydraulic fracturing fluids they used. Between 2005 and 2009, the companies used 94 million gallons of 279 products that contained at least one chemical or component that the manufacturers deemed proprietary or a trade secret. Committee staff requested that these companies disclose this proprietary information. Although some companies did provide information about these proprietary fluids, in most cases the companies stated that they did not have access to proprietary information about products they purchased 'off the shelf' from chemical suppliers. In these cases, the companies are injecting fluids containing chemicals that they themselves cannot identify.") (on file with PSR).

[159] See, e.g., Petitioners' pleading filed in Robinson Twp. v. Commonwealth, Docket No. 284 MD 2012 (June 9, 2014), at 11 FN6. United State House of Representative Committee and Energy and Commerce, Minority Staff. Chemicals Used in Hydraulic Fracturing (April 2011) (on file with PSR).

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[161] 15 USC 2613 (d).

[162] 15 USC 2613 (d) (4-7).

[163] Telephone interview with Silverio Caggiano (July 12, 2019).

[164] Eliza Griswold. Amity and Prosperity (2018), at 259-263, 302-304.

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