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Research article

Increases in trade secret designations in hydraulic fracturing fluids and their potential implications for environmental health and water quality

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ABSTRACT

Hydraulic fracturing is an increasingly common method of oil and gas extraction across the United States. Many of the chemicals used in hydraulic fracturing processes have been proven detrimental to human and environmental health. While disclosure frameworks have advanced significantly in the last 20 years, the practice of withholding chemical identities as "trade secrets" or "proprietary claims" continues to represent a major absence in the data available on hydraulic fracturing. Here, we analyze rates of trade secret claims using FracFocus, a nationwide database of hydraulic fracturing data, from January 1, 2014 to December 31, 2022. We use the open-source tool Open-FF, which collates FracFocus data, makes it accessible for systematic analysis, and performs several quality-control measures. We found that the use by mass of chemicals designated as trade secrets has increased over the study time period, from 728 million pounds in 2014 to 2.96 billion pounds in 2022 (or a 43.7% average yearly increase). A total of 10.4 billion pounds of chemicals were withheld as trade secrets in this time period. The water volume used (and therefore total mass of fracturing fluid) per fracturing job has shown a large increase from 2014 to 2022, which partly explains the increase in mass of chemicals withheld as trade secrets over this time period, even as total fracturing jobs and individual *counts* of proprietary records have decreased. Our analysis also shows increasing rates of claiming proppants (which can include small grains of sand, ceramic, or other mineral substances used to prop open fractures) as proprietary. However, the mean and median masses of non-proppant constituents designated as trade secrets have also increased over the study period. We also find that the total proportion of all disclosures including proprietary designations has increased by 1.1% per year, from 79.3% in 2014 to 87.5% in 2022. In addition, most disclosures designate more than one chemical record as proprietary: trade secret withholding is most likely to apply to 10–25% of all records in an individual disclosure. We also show the top ten reported purposes that most commonly include proprietary designations, after removing vague or multiple entries, the first three of which are corrosion inhibitors, friction reducers, and surfactants. Finally, we report the top ten operators and suppliers using and supplying proprietary chemicals, ranked by mass used or supplied, over our study period. These results suggest the importance of revisiting the role of proprietary designations within state and federal disclosure mechanisms.

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1. Introduction

Hydraulic fracturing is an increasingly common practice in oil and gas extraction across the United States. This process injects a mixture of water, chemicals, and sand or other mineral grains into oil or natural gas wells at such high pressure that the geologic formation fractures, releasing oil and/or natural gas. Hydraulic fracturing has propelled the United States' increases in fossil fuel production over the last decade. However, environmental health research has increasingly linked hydraulic fracturing activity to a range of adverse public health outcomes (McDermott-Levy et al., 2013; Elliott et al., 2017), ecological impacts on aquatic environments (Brittingham et al., 2014; Folkerts et al., 2021), and risks to water quality, including drinking water sources (Osborn et al., 2011; Fontenot et al., 2013; Burton et al., 2014).

One major barrier to investigating these concerns is that fracturing fluids' full composition remains unknown. Some of the most common chemical constituents known to comprise fracturing fluid are: petroleum products, including petroleum distillates, diesel fuels, and naphthalene; acids, including hydrochloric and acetic acid; a range of biocides like glutaraldehyde and quaternary ammonium compounds; and inorganic oxidants, like potassium or magnesium oxide (e.g., Stringfellow et al., 2017). However, chemical identities are often withheld by either well operators or chemical suppliers as proprietary information, or trade secrets. (Here, we use the terms "trade secret" and "proprietary" interchangeably.) This withholding is pervasive; one previous study estimated that 84% of all disclosures from 2013 to 2014 withheld at least one record as proprietary (U.S. Department of Energy, 2014). Another found that 85–88% of studied disclosures withheld at least one record as proprietary, depending on reporting method (Trickey et al., 2020). These trade secret claims prohibit a comprehensive analysis of fracturing fluid composition. This presents implications for understanding the hydrogeologic processes within oil and gas wells, the fate and transport of these constituents, and managing potential surface water or groundwater contamination.

As far as we are aware, an aggregate analysis of proprietary designations in fracturing jobs by mass use and proportion (whether by individual fracturing job, state, or county) has not yet been performed at the national level. Therefore, this paper uses data published in the national database FracFocus.org (2023) and collated by the open-source tool Open-FF (Allison, 2022), discussed further below, to further analyze trade secret withholding across the United States from 2014 to 2022 and to investigate associated potential environmental implications. We investigate the use of proprietary claims by reported mass and proportion of total fracturing fluid, map their geographies of use, and trace the operators and chemical suppliers that most often report proprietary chemicals in fracturing jobs.

1.1. Hydraulic fracturing fluids and risks to water sources

The primary ingredient in fracturing fluid by mass is water, which commonly comprises over 85% of the fluid used in a fracturing job. The second-highest reported mass is usually a proppant. Proppants are small solid grains (traditionally sand) that are used to "prop" open fractures for oil and gas to flow back out rather than allow the fissures to close again. The remaining 0.5–2% of fracturing fluid includes a range of chemicals used as biocides, friction inhibitors, acidifiers, and surfactants, among other purposes.

Given that fracturing jobs regularly include tens of millions of gallons of water, individual chemical masses within fracturing fluid can represent large quantities even though chemical percentages are small, especially at regional or national scales. In 2022, the median percent by mass of ethylene glycol - a common chemical used in hydraulic fracturing that is also a core constituent in antifreeze - was 0.004% in a given fracturing job (Open-FF, 2022a), yet the median water volume used per fracturing job in 2022 was 16 million gallons. Therefore, the median mass of ethylene glycol used per fracturing job in 2022 was 6,036 pounds. This aggregates to approximately 14.3 million pounds (rounded) across 4,276 total disclosures in 2022 alone. Similarly, the median percent by mass of naphthalene, a toxicant also known as white tar, was only about 0.0005% of a given fracturing job in 2022 (Open-FF, 2022b). However, this equates to 754 pounds per fracturing job; nationally, this sums to 107,113 pounds across 666 total disclosures in 2022 alone. (See the Python code we used for these calculations linked in Section 2.2 below.)

Fracturing fluids have been shown to contaminate surface and groundwater, including drinking water sources, with a range of constituents such as benzene and other diesel-range organic compounds associated with demonstrated human and environmental health impacts (Drollette et al., 2015; Kahrilas et al., 2015; Elliott et al., 2017). This includes heavy metals, such as arsenic; radioactive species, such as radium; and aromatic compounds, such as the BTEX chemicals, associated with significant health effects including nervous system deficits, kidney damage, and pregnancy complications (Gross et al., 2013; Luek and Gonsior, 2017). In addition, at least 100 chemicals found in fracturing fluids are known or suspected endocrine-disrupting chemicals, which can affect child development, decrease fertility, and increase the incidence of cancer (Kassotis et al., 2014). However, environmental health researchers are unable to study the environmental prevalence or toxicological effects of any chemicals in fracturing fluids whose identities are withheld as proprietary.

Mechanisms of potential contamination include leaking or unlined wastewater pits or storage tanks (Burton et al., 2014; Chen and Carter, 2020), defective well casings or wellbore integrity (Ingraffea et al., 2014; Wisen et al., 2019), or surface spills (Gilmore et al., 2014; Patterson et al., 2017). Researchers have found evidence of fugitive gas migration along wellbores (Vengosh et al., 2014), showing the possibility of fluid migration along similar pathways (Gallegos et al., 2015; Llewellyn et al., 2015); others have found evidence of solute migration into drinking water aquifers (DiGiulio and Jackson, 2016). Similarly, a (2016) report by the US Environmental Protection Agency (EPA) found evidence that hydraulic fracturing could impact drinking water sources, particularly through surface spills, inadequate well integrity, or inadequately treated wastewater discharging into surface water.

The EPA also noted significant data gaps and uncertainties that limited their ability to fully assess hydraulic fracturing impacts. These included: a lack of comprehensive information on the precise location and depth of fracturing jobs or waste disposal; uncertainty over locations of drinking water sources; and incomplete information on all chemicals used, their potential transformation products, and the full composition of wastewater. In addition, the absence of local water quality data before and after a fracturing event precluded comparison of pre-and post-hydraulic fracturing water quality. The overlapping activities of multiple industries within a given location also often prevented isolated study of hydraulic fracturing impacts. A report by the California Council on Science and Technology (2017) noted similar data gaps, uncertainties, and lack of information as major barriers to a full investigation of the public health impacts of hydraulic fracturing.

This paper investigates proprietary designations as a major part of these data gaps. As also noted by these reports, and given the documented public and environmental health impacts of particular chemicals used in fracturing jobs alongside the variety of potential water contamination routes, a thorough analysis of proprietary designations in fracturing fluid is necessary to better understand possible risks to water sources. A better understanding of the use of proprietary designations for chemical identities would help constrain some of these unknowns by defining their scope, frequency, and change over time.

1.2. Trade secrets within FracFocus

A trade secret is defined as information that derives independent economic value from not being known *and* is subject to reasonable efforts to maintain its secrecy (Cieplak, 2016; Fink, 2018). Courts have largely held that fracturing fluids' composition represents a trade secret but rarely require the same registration or oversight requirements as, for instance, patents. Though trade secret laws for fracturing fluid vary widely (Fink, 2018), all states except California currently allow companies to designate chemical identities as proprietary information. (Even in California, there are mechanisms through which trade secret status can still be attained (SB 4 Oil and Gas: Well Stimulation, 2014)). In effect, companies have a significant amount of discretion regarding which substances they can label as "proprietary" given the absences of federal oversight and limited or no oversight at the state level.

Despite this widespread practice, few studies have analyzed trade secret withholding in depth. The Department of Energy (2014) studied aggregate rates of withholding across the United States using an early version of FracFocus.org, and Trickey et al. (2020) compared trade secret withholding across different chemical disclosure formats using a simple binary flag of "withholding" or "no withholding" per disclosure. There remains a need to study trends in trade secret designation in greater depth, including the aggregate mass of chemical records withheld, the proportion of use, geographies of use, reported purpose, and operators and suppliers most often associated with proprietary designations.

2. Materials and Methods

2.1. FracFocus and OpenFF

We worked with data from FracFocus.org (referred to here as FracFocus), a database run by the Ground Water Protection Council and supported by the oil and gas industry. FracFocus was initiated in 2011 as a voluntary mechanism to disclose chemicals used in fracturing jobs. Now, disclosure to FracFocus is required in 23 states, including most oil- and gas-producing states. Although FracFocus offers a depth of information on a well-by-well basis, including downloadable PDFs of each disclosure form itself, it does not include the tools to carry out systematic and cumulative analyses. In addition, researchers have repeatedly found flaws in FracFocus as a disclosure mechanism, including incomplete reporting, data gaps, and an inaccessible and difficult-to-use interface (Konschnik et al., 2013; Kinchy and Schaffer, 2018; Avidan et al., 2019). Nevertheless, FracFocus remains the most comprehensive data source available on chemical use in hydraulic fracturing.

To work with these data, we used Version 16 of Open-FF, a database using open-source code to resolve errors and inaccuracies within FracFocus data, making it more accessible, transparent, and useful. For each fracturing job, operators submit one disclosure form to FracFocus; Open-FF collates these data and enacts quality control measures. It also offers other analyses such as calculating the mass used for each chemical reported, including any proprietary chemicals, by using the percentage by mass for a given chemical (reported in a disclosure) and the total mass of the base fluid, which is usually water (Allison, 2022; see Underhill et al., 2023 for full description).

2.2. Using Open-FF to investigate proprietary designations

We defined proprietary claims as any part of a disclosure for which the Chemical Abstract Service (CAS) Number, a unique numeric identifier for every chemical substance, was entered as "proprietary," "trade secret," "confidential business information" or similar phrases (see Supporting Information for a full list of all phrases aggregated as "proprietary"). We then filtered for proprietary designations used in fracturing jobs beginning January 1, 2014 and ending December 31, 2022, because many FracFocus disclosures before 2014 had no chemical records or were of lower data quality. We removed one data point as an outlier because its mass was two orders of magnitude larger than any other data point, and the reported water volume in that facturing job was 10 times more than the typical use for that area and time period. This analysis does not distinguish between well types, even though different fracturing processes use different chemical combinations, which presents one constraint of this study.

In addition to CAS Number, FracFocus also contains a field entitled "Ingredient Name," which is a voluntary, write-in option where operators can further describe the ingredient. These ingredient names are often non-specific or vague, and can be inaccurate: for instance, silicate minerals are often proppants but not always. Some silicate minerals are actually used as *carriers* (which are added to a particular product to help it diffuse within the formation) but are mislabeled as proppants in FracFocus (e.g., Stringfellow et al., 2017). For these reasons, FracFocus explicitly recommends prioritizing CAS Number over Ingredient Name in each record. Therefore, even if a given IngredientName is included, Open-FF ignores this value in quantifying proprietary records. Nonetheless, even though the accuracy of FracFocus data itself limits this distinction's accuracy, the Ingredient Name field can provide additional information and a small window into the potential identity and function of chemicals labeled proprietary. Open-FF organizes these self-entered descriptors to account for misspellings or typos in the additional field "BG Ingredient Name; " we used BG Ingredient Name in this analysis to avoid as many inaccuracies as possible.

Additionally, we separated our analysis into proppants and non-proppants based on ingredient names because the relatively high masses of proppants can obscure the increases in chemicals used in smaller masses. Proppant technology in the last few decades has evolved: while quartz sand has traditionally been the most common conventional proppant, ongoing development of hydraulic fracturing technologies has also expanded to various synthetic proppants and proppant coatings. These coatings, often based on one or more polymer films, including epoxy resin or phenolic resin, can improve proppant performance, but can also be toxic (Liu et al., 2023). Surface coatings are an ongoing site of proprietary designations, as they continue to be developed by companies including Carbo Ceramics and Preferred (Rassenfoss, 2013). Therefore, proppant trade secrets are also an important direction of analysis.

We used Google Colab notebooks written in Python to analyze changes in chemicals designated as proprietary by mass, separating proppants from non-proppants, to better understand the trends in each category. The large variance in non-proppant chemical masses led us to use a log scale in related data analyses. In addition, because multiple chemicals can be withheld as proprietary, we analyzed the proportion of records *within* individual disclosures withheld as proprietary. We also mapped the percentage of all disclosures that withheld at least one ingredient by county to show geographic distribution across the United States, and analyzed the well operators and chemical suppliers who most often claimed proprietary chemicals from 2014 to 2022. For further methods description, interactive maps, and the Python notebooks we used to explore FracFocus data, see: https://github.com/vunderhill/Proprietary-Analysis.

3. Results: proprietary designations in Open-FF

3.1. Constituents designated as proprietary are increasing by mass

We find that 83% of disclosures in FracFocus include at least one proprietary designation from 2014 to 2022. The total mass of chemicals designated as proprietary used in fracturing operations in the United States from 2014 through 2022 is 10.4 billion pounds.

Proprietary designations, by mass used, have increased from 2014 to 2022. Overall, the total mass of proprietary chemicals used yearly increased from 728 million pounds in 2014 to 2.96 billion pounds (rounded) in 2022. Proprietary designations have increased alongside increases in median water volume used in a fracturing job and, therefore, the total mass of fracturing fluids. At the same time, the total number of fracturing jobs has decreased, from 27,662 fracturing jobs in 2014 to 12,797 in 2022 (see Table 1).

The increase in mass of proprietary records is also due to increasing

Table 1
Overall trends in size and number of hydraulic fracturing jobs. This table shows, by year, the following: the total mass of all records designated as proprietary, the median water volume and mass of fracturing jobs, and the total yearly number of fracturing jobs.

Year	Total Mass of Records Designated as Proprietary (pounds)	Median Water Volume per Fracturing Job (gallons)	Median Mass of Fracturing Job (pounds)	Total Number of Fracturing Jobs per Year
2014	727,958,100	2,553,312	25,492,660	27,662
2015	505,228,600	4,226,107	40,645,430	16,690
2016	385,332,800	6,492,049	63,532,780	9,635
2017	580,145,800	8,969,730	87,556,360	13,830
2018	1,202,173,000	10,145,904	98,130,660	16,929
2019	1,129,773,000	11,916,450	114,343,000	15,480
2020	967,044,300	14,297,934	139,223,300	8,043
2021	1,929,830,000	14,762,219	143,134,700	10,760
2022	2,962,242,000	15,976,736	155,529,000	12,797

rates of labeling proppants as proprietary (see Fig. 1). Proppants usually comprise the second-largest ingredient by percentage within fracturing fluid and are reported in masses that are orders of magnitude higher than other chemicals.

The masses of non-proppant proprietary designations have also increased over the study period (see Fig. 2). While some non-proppant proprietary records are simply described in the “Ingredient Name” field as “proprietary” or “non-hazardous ingredients,” others are named as specific chemicals. Among these chemicals are 1,4-dioxane, acrylamide polymers, and ethylene glycol. Petroleum distillates and hydrotreated petroleum distillates are also reported. Numerous other chemicals are listed as categories, with Ingredient Name entries such as “surfactant blend,” “proprietary emulsion,” or “polymer.”

The median mass of non-proppant proprietary chemical records has steadily increased from 275 pounds in 2014 to 1,689 pounds in 2022. Meanwhile, the mean mass of these chemicals has increased from 4,880 pounds in 2014 to 16,499 pounds in 2022. At the same time, the total *count* of these records has declined, from 149,141 records designated as proprietary in 2014 to 43,595 records in 2022. Therefore, even though median and mean masses of proprietary-designated records have increased, the change in total yearly mass of non-proppant proprietary designations over time is not statistically significant.

3.2. Proportion of disclosures including proprietary designations is also increasing

The percentage of all disclosures with at least one proprietary designation has also grown over the study time period. In 2014, 79.3% of all disclosures included at least one record that was designated proprietary; in 2022, 87.5% of all disclosures included at least one proprietary record. This is a statistically significant increase ($p = 0.004$) of 1.1% per year.

However, many disclosures designate more than one record as proprietary (see Fig. 3). Over our study time period, 17.4% of all disclosures had *no* proprietary designations. The largest fraction, slightly over one third (37.6%) of all disclosures, withheld between 10 and 25% of records as proprietary. Another quarter of all disclosures (24.3%) withheld between 25 and 50% of records as proprietary. A small percentage of all disclosures (0.8%) withheld over half of their records as proprietary.

3.3. Proprietary designations within disclosures by state and county

There is significant variation across states in the percentage of disclosures that withhold at least one record as proprietary (see Table 2). Alabama and Utah show the highest rates of proprietary withholding (92.9% and 91.9%, respectively). In comparison, states such as Alaska and Kansas have relatively low rates of proprietary withholding (49.4% and 46.6% respectively). California has the lowest proprietary withholding rate, with only eight total proprietary claims over the study period, rounded to 0.4%.

This variation is less clear at the county level (see Fig. 4). There are some clusters of high percentages of proprietary designations in Texas, southeastern New Mexico, eastern Colorado, North Dakota, and Pennsylvania. Some individual counties stand out: in Elk County, PA, 100% of the county’s 154 disclosures included at least one proprietary designation. In Jefferson County, OH, 92.5% of the county’s 332 disclosures included at least one proprietary designation. However, it is useful to pair this with the total number of disclosures in each county. Other counties, such as Aransas County, TX, report that 100% of all disclosures include a proprietary designation but have low total disclosures (Aransas County has 6 total disclosures). Conversely, many counties in Texas

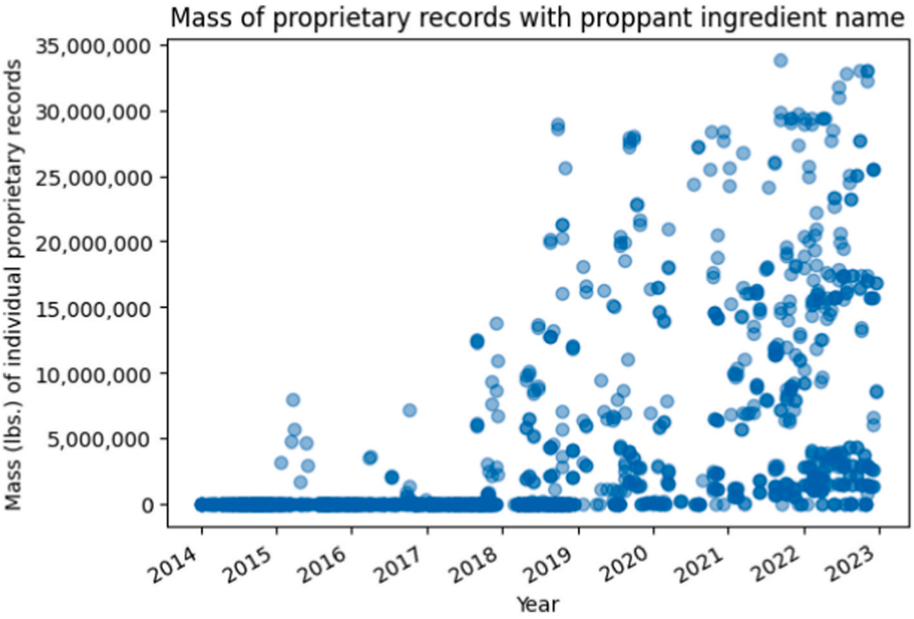
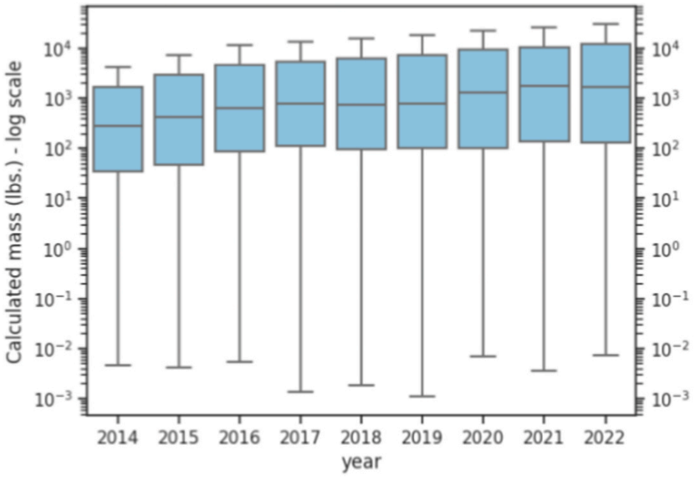
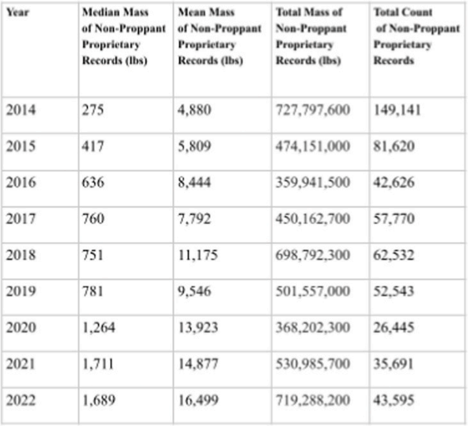


Fig. 1. Mass of proppant records designated proprietary. This figure shows the calculated mass, in pounds, of fracturing fluid constituents reported as proppants in the “Ingredient Name” field whose identities were withheld as proprietary in FracFocus from 2014 to 2022.





Year	Median Mass of Non-Proppant Proprietary Records (lbs)	Mean Mass of Non-Proppant Proprietary Records (lbs)	Total Mass of Non-Proppant Proprietary Records (lbs)	Total Count of Non-Proppant Proprietary Records
2014	275	4,880	727,797,600	149,141
2015	417	5,809	474,151,000	81,620
2016	636	8,444	359,941,500	42,626
2017	760	7,792	450,162,700	57,770
2018	751	11,175	698,792,300	62,532
2019	781	9,546	501,557,000	52,543
2020	1,264	13,923	368,202,300	26,445
2021	1,711	14,877	530,985,700	35,691
2022	1,689	16,499	719,288,200	43,595

Fig. 2. Mass of non-proppant records designated proprietary. This figure shows the calculated mass, in pounds, of fracking fluid constituents not reported as proppants in the "Ingredient Name" field whose identities were withheld as proprietary claims in FracFocus from 2014 to 2022. Note the log scale, used to best visualize values that range over multiple orders of magnitude.

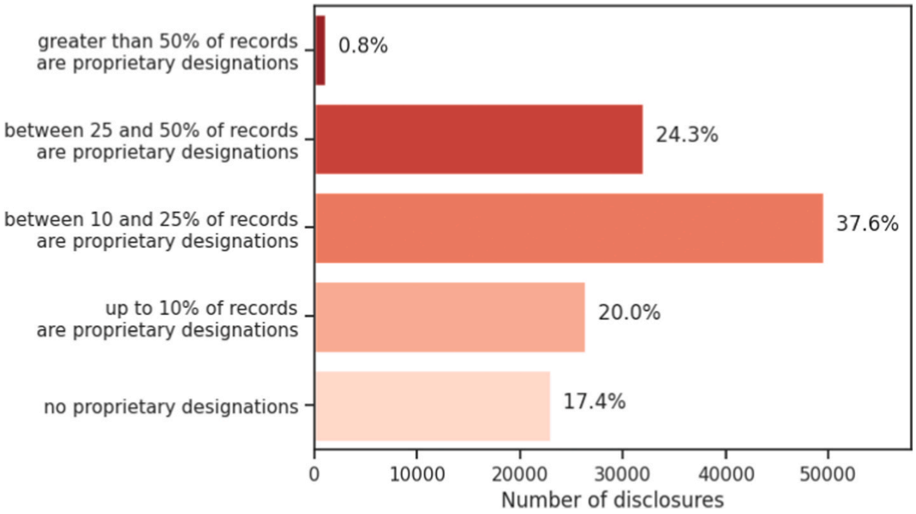


Fig. 3. Proportions of individual disclosures designated proprietary. This figure shows all disclosures in Open-FF from 2014 to 2022, sorted into five categories based on the percentage of records within each disclosure that are withheld as proprietary.

(including Reeves County and Howard County) stand out for having high total counts of disclosures, over 80% of which include at least one proprietary designation. We include interactive maps in the publicly available data files referenced in Materials and Methods that show individual counts by county for readers who want to investigate further.

3.4. *Most common purposes for chemicals designated proprietary*

It is also useful to better understand the purposes that most often use proprietary-designated chemicals; to do so, we further investigated these purposes and the most common *known* chemicals also associated with these purposes (see Table 3). We also investigated the organ and system effects associated with these chemicals, as documented by the US EPA's Integrated Risk Information System (IRIS) database, the National Institute for Occupational Health and Safety (NIOSH)'s guide to chemical hazards (NIOSH, 2021), and the National Oceanic and Atmospheric Administration (NOAA)'s database of hazardous materials called CAMEO Chemicals (Cameo Chemicals Version 3.0.0).

Among these purposes, "Corrosion inhibitor" was the most frequently reported use, with acid inhibitor and acid corrosion inhibitor also appearing in the top ten. Because many fracturing jobs include acidic treatments, which can damage steel and other metals, corrosion inhibitors aim to prevent the fracturing fluid from corroding the infrastructure of a fracturing operation (Finšgar and Jackson, 2014). These chemicals can irritate the eyes and skin in addition to affecting the nervous, respiratory, and renal (kidney) systems (NOAA, 2023).

Gellants and crosslinkers (numbers 5 and 9) increase the viscosity of injected liquid, while breakers (not shown in this list) reduce the viscosity of liquid extracted from a well. Surfactants reduce the surface tension of liquids, and friction reducers reduce the friction between fracturing fluid and the well formation itself, thus reducing the power needed to fracture the well. Finally, emulsions refer to a mixture of two liquids that usually aren't miscible; within a well, fracturing fluids can form emulsions with the oil, and non- and de-emulsifiers aim to break up those emulsions. Non-emulsifiers often include surfactants in order to support the separation of oil and water. Many of these compounds may affect development, skin, and eyes, along with nervous, digestive, respiratory, hematologic, and renal systems (see Table 3).

Many other entries in the "Purpose" field were vague, such as "Other Chemicals," "Other Ingredients," "See Trade Name(s) List," or "Hazardous and Non-Hazardous Ingredients." Others listed many purposes in the same row. In addition, like other fields in FracFocus, the Purpose

Table 2
Proprietary designations by state. This table shows all states with greater than 50 total disclosures, sorted from highest to lowest percentage of disclosures that include at least one proprietary record.

State Name	Disclosure Count	Proprietary Disclosures	Percentage of Proprietary Disclosures
Alabama	56	52	92.9
Utah	2,736	2,514	91.9
North Dakota	10,302	9193	89.2
New Mexico	8,257	7,360	89.1
Colorado	11,447	10,143	88.6
Texas	63,508	54,734	86.2
Louisiana	2,600	2,188	84.2
Ohio	2,625	2,155	82.1
Wyoming	3,514	2,749	78.2
West Virginia	2,450	1,828	74.6
Oklahoma	13,188	9,812	74.4
Pennsylvania	6,415	4,674	72.9
Virginia	469	330	70.4
Montana	352	241	68.5
Mississippi	134	83	61.9
Arkansas	827	483	58.4
Alaska	176	87	49.4
Kansas	451	210	46.6
California	2,253	8	0.4

field can include inaccuracies. For instance, Stringfellow et al. (2017) report that solvents and surfactants are often reported as corrosion inhibitors simply because they are used in formulating corrosion inhibitor mixtures - but they are not corrosion inhibitors themselves. This is often because the structure of FracFocus reports the purpose of the trade-named product, not the individual chemical records within that product.

3.5. Use of proprietary claims by operators and suppliers

Fig. 5 shows the top ten suppliers of chemicals designated proprietary from 2014 to 2022. The most common category was “Missing,” which accounted for 131,193 records. This category is excluded because it is an order of magnitude larger than the next-most frequently named supplier, Halliburton, and would skew the scale. We also excluded systems-approach disclosures from this analysis because they structurally disassociate suppliers from chemical records.

Halliburton, the largest supplier of fracturing fluids in the United States, claimed proprietary chemicals 25,531 times, representing 6.8% of all their disclosures. This small percentage reflects the large number of chemical records associated with Halliburton overall; therefore, even though they are named as the most frequent company claiming proprietary chemicals, this category still represents a small fraction of their overall supply. Furthermore, Halliburton and other companies’ use of proprietary chemicals is underestimated because, again, systems-approach disclosures structurally disconnect the link between the company and any proprietary chemicals used. Chemplex (18,878 or 9.9% of whose total supplied chemicals are designated proprietary) and FTSI (18,486 records or 13.9%) follow.

Fig. 6 shows the top 10 operators claiming proprietary chemicals from 2014 to 2022. Chesapeake Operating Company reported the most proprietary claims: 31,239 total, representing 91.4% of their total disclosures. Chesapeake is headquartered in Oklahoma City and works in the Eagle Ford, Haynesville, and Marcellus Shales. Chesapeake is followed by Pioneer Natural Resources (reporting 23,853 proprietary designations, or 96.7% of their total records), which works primarily in the Permian Basin, and XTO/ExxonMobil, with 20,686 proprietary records, or 86.3%.

This analysis is somewhat constrained because of the ways in which proprietary designations are reported and maintained. Though the designation of “trade secret” is applied by suppliers, chemicals included in fracturing fluid are reported by operators, who often don’t (or can’t) fully know what they are reporting.

4. Discussion

4.1. Consistency with previous studies

Our results are consistent with prior studies. A (2013) case study of the year and a half after Texas adopted a new disclosure law in 2011 also found that hydraulic fracturing companies claimed at least one trade secret in 82% of cases. A (2014) investigation by the Department of Energy (DOE) similarly concluded that 84% of disclosures included at least one trade secret. Similarly, we found that 83% of all disclosures from 2014 to 2022 report at least one proprietary claim. We also found that, for most counties, 75–100% of all disclosures include at least one proprietary claim. California is the only outlier. After 2014, California only has 8 proprietary claims due to 2014 state legislation prohibiting withholding chemical identities as proprietary. These 8 proprietary designations are either offshore fracturing jobs, or were begun in late December 2013 and ended on January 1st, 2014.

In addition, Trickey et al. (2020) offer the most detailed study of proprietary designations in FracFocus to date. They analyzed the effect of the systems approach on chemical withholding or disclosure from 2011 to 2018. The systems approach is a reporting format in which operators submit chemical constituents separately from trade names and functions. In other words, a disclosure using the systems approach reports all chemicals used in a separate section from the trade names used. At first, Trickey et al. found that the systems approach decreased

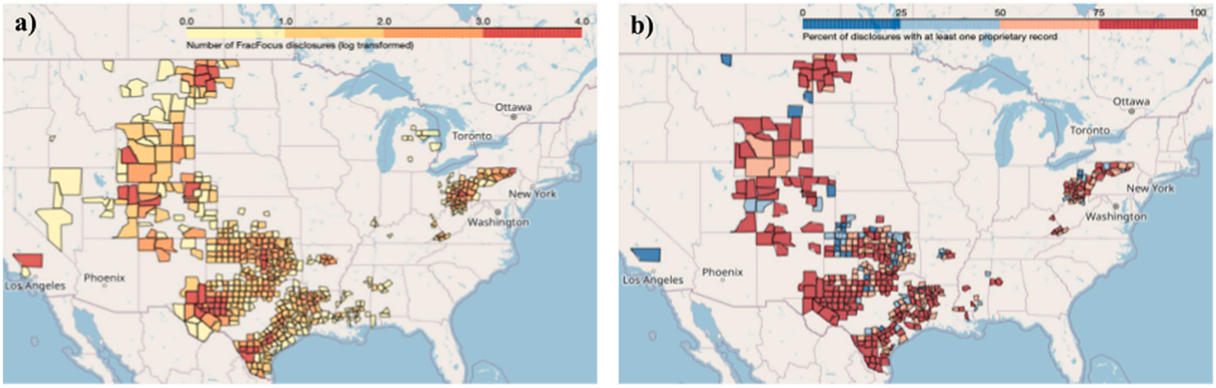


Fig. 4. Proprietary designations by county. Fig. 4a shows all counties with at least five total disclosures, coded by color according to how many total disclosures each county has reported from 2014 to 2022. Note the log scale for color. Fig. 4b shows all counties with at least five total disclosures, coded by color according to the county’s percentage of disclosures that include at least one proprietary record. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

Table 3

Most common purposes for proprietary records. This table shows the top ten named purposes, other than "missing" and "other ingredients," that most frequently include records designated as proprietary. We have removed vague or multiple purposes. It also names the most common known chemicals that are associated with each purpose, and the known organ and system effects for those chemicals according to the National Oceanic and Atmospheric Administration (NOAA), the US EPA, and the National Institute for Occupational Health and Safety (NIOSH). The compounds with associated health effects reported by these agencies are listed with an asterisk (*).

No.	Purpose	Top Chemicals	Organ System Effects	Citation
1	Corrosion Inhibitor	Methanol*, Isopropanol*, Propargyl alcohol*, Ethylene glycol*	Eyes or Optic Nerve, Central Nervous System, Respiratory System, Skin, Kidneys	NOAA, 2023
2	Friction Reducer	Hydrotreated light petroleum distillates*, Ammonium Chloride*, Alcohols, C12-16, ethoxylated*	Eyes or Optic Nerve, Central Nervous System, Respiratory System, Skin	NIOSH, 2021; NOAA, 2023
3	Surfactant	Methanol*, Isopropanol*, 2-Butoxyethanol*	Eyes or Optic Nerve, Central Nervous System, Skin, Digestive System, Respiratory System, and Hematologic System	NOAA, 2023; EPA, 2023
4	Scale Inhibitor	Methanol*, Ethylene glycol*, Ammonium Chloride*	Eyes or Optic Nerve, Central Nervous System, Skin, Digestive System, Kidneys, and Respiratory System.	NOAA, 2023; NIOSH, 2021
5	Crosslinker	Ethylene glycol*, Potassium hydroxide*, Potassium metaborate, Borax	Central Nervous System, Eyes or Optic Nerve, Skin, and Mucous Membranes	NOAA, 2023
6	Acid corrosion inhibitor	Ethylene glycol*, N,N-Dimethylformamide*, Methanol*, Isopropanol*	Urinary, Hepatic, Central Nervous System, Eyes or Optic Nerve, Developmental, Respiratory, and Digestive.	NOAA, 2023
7	Non- and de-emulsifiers	Methanol*, Solvent naphtha, petroleum, heavy aromatic*, alpha-Hexyl,omega-hydroxypoly(oxy-1,2-ethanediyl)	Central Nervous System, Eyes or Optic Nerve, Developmental, Skin, the Respiratory and Digestive Systems.	NOAA, 2023
8	Non-emulsifier	Methanol*, Isopropanol*, Nonylphenoxypolyethoxyethanol*	Eyes or Optic Nerve, Central Nervous System, Skin, Respiratory System, and Digestive System	NOAA, 2023
9	Liquid gellant	Hydrotreated light petroleum distillates, alpha-D-Galactopyrano-beta-D-mannopyranan*	Unknown	
10	Acid inhibitor	Methanol*, Propargyl alcohol*, Isopropanol*, Ethylene glycol*	Eyes or Optic Nerve, Central Nervous System, Skin, Respiratory System, Digestive System, Kidneys, and Mucous Membranes	NOAA, 2023

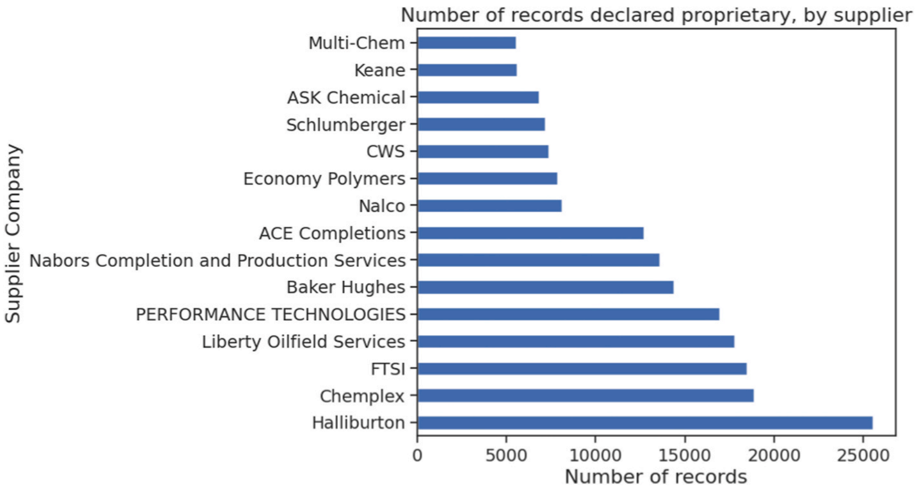


Fig. 5. Use of proprietary designations by supplier. This figure shows the top ten suppliers, ranked by number of individual records designated as proprietary, in Open-FF from 2014 to 2022.

withholding: following FracFocus' emphasis on a voluntary systems approach option in 2016, 93% of standard versions of reporting withheld an ingredient, compared with only 76% of systems approach disclosures. However, withholding increased over their study period, and by the end of their analysis at the end of 2018, systems approach forms withheld chemical identities *more* often (88%) than traditional forms (85%) did. These results are broadly consistent with those of our study; the minor discrepancies likely show differences in how each approach filtered proprietary claims. Trickey et al., for instance, consider CAS Number typos or Ambiguous ID records as proprietary withholding, while Open-FF only considers records that are explicitly "proprietary" or "trade secret."

4.2. Increases in mass and proportion

While most prior studies have used some version of a binary flag (proprietary/not proprietary) to report the number of disclosures using at least one proprietary designation, we also calculated mass and proportion of chemicals designated proprietary. This analysis shows that proprietary designations are increasing not only by frequency, as Trickey et al. show and we confirm, but also by mass. Importantly, increasing proprietary claims to withhold proppants' identities seems to be a large driver of total mass increases (see Fig. 1). The increase in proprietary proppants is likely because, as hydraulic fracturing has become a more mature technology, industry investments in proppant technology have also led to more proprietary proppant records. Rather than simply sand, these proppants now include ceramic, microbeads, and other minerals with a range of proprietary chemical coatings.

However, non-proppant proprietary claims have also increased over the study period (see Fig. 2). Our analysis shows that the mean mass of non-proppant constituents designated as proprietary has approximately quadrupled from 4,880 to 16,499 pounds, while their median mass (1,689 pounds) at the end of 2022 was 6.1 times greater than in 2014 (275 pounds). It is important to note that because we based this distinction on the reported Ingredient Name from the original FracFocus data, which is a voluntary category, some proppants are likely still

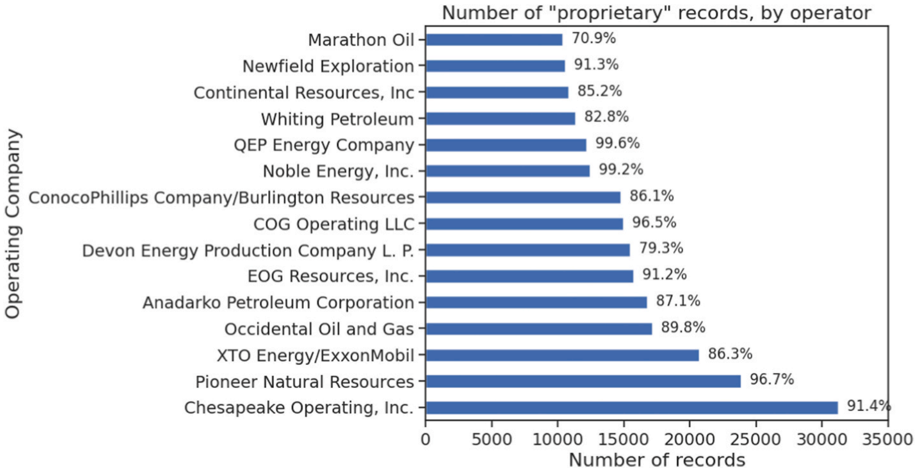


Fig. 6. Use of proprietary designations by operator. This figure shows the top ten operators, ranked by number of individual records designated as proprietary, in Open-FF from 2014 to 2022. It also shows the percentage of each operator's records that are designated as proprietary.

included in our "non-proppant" analysis. This is a structural limitation embedded in the FracFocus reporting system itself.

These increases are also likely due to increasing water volumes used in fracturing jobs and the resultant increases in total mass of fracturing fluid per job (see Table 1). In fact, the median volume of water used in fracturing jobs was about 6.3 times larger in 2022 than in 2014. This probably explains the increase in mass of records designated as proprietary, even as the total number of fracturing jobs has declined over our study time period; there were approximately half as many total fracturing jobs in 2022 as 2014. This suggests that, though fewer total records are designated as proprietary, they are being used in increasing masses alongside increasing water volumes.

Finally, it is important to note that one "proprietary" record might represent more than one chemical, which suggests that our analysis of proprietary claims by proportion may be, if anything, an underestimate.

4.3. *Other forms of ambiguity within disclosures*

While this analysis focused on formal trade secrets (records explicitly called trade secrets or proprietary), it also highlights other forms of ambiguity in FracFocus data. For instance, Open-FF also includes a category of records called "Ambiguous ID." These records are not explicitly claimed as trade secrets but include empty or "dummy" CAS numbers like 0000-00-0. The increased withholding of proppants seems to hold true here as well: 2,545 (or a total of 454 million pounds) of these "Ambiguous ID" records include descriptions such as "silica substrate" or "proppant." In addition, 4,428 (or a total of 152 billion pounds) of these Ambiguous ID records are likely water. However, it is unknown whether this water is produced, recycled, or fresh. Some Safety Data Sheets for oil wastewater from operators such as Devon or Chesapeake Energy report not only water but benzene and other hydrocarbons, hydrogen sulfide, and other dissolved minerals. If this produced water is re-used in fracturing jobs, these chemicals are likely not reported in the disclosure form itself but nonetheless constitute part of the fracturing fluid. For instance, a prior paper (Underhill et al., 2023) found a benzene spike in a group of disclosures from Texas in 2019. It inferred that this might reflect the disclosure of elements in wastewater that was being reused - but the disclosure of these constituents in produced water is not required and is not common.

The systems approach, discussed above, also represents one major form of ambiguity: because it structurally disconnects suppliers from the chemicals used in hydraulic fracturing, it makes certain forms of analysis (like supply chain investigation or comparison of different state regulatory structures on supplier behavior) unavailable. Though the DOE's FracFocus Task Force had originally advocated the systems approach to protect trade secret identity while still maximizing chemical disclosures, the analysis done by Trickey et al. (2020) shows that the systems approach has not, in fact, decreased chemical withholding.

Finally, FracFocus records include compounds listed by the Toxic Substances Control Act as "unknown, variable composition or biological" materials (UVCBs). Individual compounds within these substances do not necessarily require disclosure. Instead, they are reported under a single CAS number. The prevalence of these modes of ambiguity suggests that future research should investigate the environmental monitoring implications of multiple forms of non-disclosure in addition to explicit trade secrets.

4.4. *Implications for environmental health research and environmental management*

To date, environmental health and environmental management research on hydraulic fracturing has primarily addressed separate parts of the process individually. Researchers have investigated, for instance, the known additives used in fracturing fluid (Stringfellow et al., 2017; Hill et al., 2022) and characterized the chemical constituents of produced water (e.g., Chittick and Srebotnjak, 2017; Al-Ghouti et al., 2019). Public health research has reported on the probability of major health concerns based on spatial or temporal proximity to fracturing sites and stages of the fracturing process (e.g., Casey et al., 2016; McAlexander et al., 2020), and research within geochemistry has investigated the prevalence of hydraulic fracturing-related chemicals in the soil and water of impacted communities (McMahon et al., 2017).

However, toxicological studies that investigate the relationships *between* detrimental public health impacts and hydraulic fracturing chemical use - via exposure pathway analysis or forensic toxicology, for example - have been limited by data gaps. For instance, the EPA (2016) noted that they only had oral toxicity values for 8% of the 1,076 chemicals reported in fracturing fluids, and only 62% of the 134 chemicals reported in fracturing wastewater (Yost et al., 2016). Hydraulic fracturing is also exempt from the monitoring plans pursuant to the Safe Drinking Water Act's Underground Injection Control Program. Trade secrets (and other forms of data ambiguity discussed in section 4.3 above) contribute to these data gaps: their unknown status constrains the feasibility of forensic methods, assessment of exposure pathways, or monitoring for possible contamination routes because they prohibit full knowledge of what researchers should test *for*. Similarly, they inhibit modeling approaches to risk assessment or spatial probability. In terms of both water research and environmental management, this raises concerns over researchers' ability to understand the fate and transport of unknown potential toxicants through groundwater flow paths, compromised wellbores, or surface leaks.

Our use of the Ingredient Name field can contribute to bridging between these fields. Though it should be stressed again that Ingredient Name is a voluntary and open category, it can shed some light on what chemicals might be designated proprietary. For instance, 1,4-dioxane, often named alongside a proprietary designation, is a known carcinogen (Godri Pollitt et al., 2019). Other frequent "ingredient names" include acrylamide polymers, ethylene glycol, and petroleum distillates. Acrylamide polymers affect the nervous system and can cause degenerative nerve changes. They are classified as carcinogenic and mutagenic compounds (Tepe and Çebi, 2019). Ethylene glycol has numerous toxicological effects, including kidney damage (National Institute for Occupational Safety and Health, 2021). Finally, petroleum distillates and hydro-treated petroleum distillates are a class of substances defined by their mode of production, as all are distilled from crude oil. They are recognized as hazardous by OSHA, NIOSH, and other regulatory agencies (New Jersey Department of Public Health, 2011). Long-term exposure can harm the lungs, liver, and kidneys.

This is particularly important in light of the top ten purposes shown in Table 3. Corrosion inhibitors and surfactants are both known to commonly include quaternary ammonia compounds (QACs), which are particularly detrimental to aquatic environmental health (Stringfellow et al., 2017). In addition, surfactants, particularly anionic surfactants, are known to present hazards to aquatic and terrestrial environments, though the category is quite broad (Könnecker et al., 2011). Surfactants can also increase the mobility of other contaminants (Badmus et al., 2021). Our analysis suggests that the large - and increasing - use of proprietary designations represents an important issue to be addressed as environmental health researchers further investigate relationships between chemical use and ecological and public health impacts.

4.5. *Implications for produced water treatment and reuse*

These results also suggest implications for wastewater disposal, treatment, and reuse. There is increasing interest in reusing oil and gas wastewater, especially in arid regions, for uses including dust suppression and irrigation (Danforth et al., 2020; Cooper et al., 2022). Here, the presence of benzene and other hydrocarbons in produced water suggests the importance of full testing for produced waters' chemical constituents and reporting those results before further use. Researchers have worked to create locally specific characterizations of produced water, not only to better inform wastewater treatment methods, but also in anticipation of re-use. Trade secret chemicals could complicate the development of these treatment methods. For instance, the purposes shown in Table 3 suggest that some of these proprietary chemicals will have major implications for wastewater treatment and reuse.

The other two most common disposal techniques for produced water are underground injection or evaporation in surface ponds, each of which also carries risks of surface or groundwater contamination. Geochemists have shown that understanding possible contamination routes requires investigation of direct *and* indirect impacts (McMahon et al., 2019). For instance, radium (a constituent often high in produced waters) is usually thought to sorb directly onto barite minerals in the direct subsurface, thus becoming immobilized. However, studies have also found radium above federal Maximum Contaminant Levels downstream of wastewater treatment sites, evaporation ponds, or former spill sites, not because of direct contamination but because the highly saline produced water leads to desorption and mobilization of radium downstream (Akob et al., 2016; McDevitt et al., 2019). Indirect impacts due to ongoing chemical reactions downstream - whether within groundwater or surface water - may also be impacted by the function of chemicals whose identities are withheld as trade secrets (McLaughlin et al., 2020) or not reported through other forms of ambiguity.

4.6. *Conclusion and recommendations*

Our results show that trade secret designations have increased by mass reported and proportion of use over our study time period, 2014–2022. This increase has continued even as operators increasingly use the systems approach. These results suggest that, without an explicit ban on proprietary designations, the systems approach as a voluntary option does not actually reduce proprietary withholding.

While trade secret law varies widely across states, California is the only state that prohibits withholding chemical identities as trade secrets: all chemical constituents must be reported to the California Geological Energy Management Division (CalGEM), even if suppliers believe part of this information constitutes a trade secret. Accordingly, California has a 0.4% withholding rate from 2014 onward - the lowest percentage of any state. California's public disclosure website, WellSTAR, launched in 2016, replicates the systems approach; its database structurally separates additive names from chemical constituents, thus protecting the "recipe" of specific trade-name ingredients. Therefore, public health researchers, environmental management practitioners, and members of the public can access a full list of chemicals used in hydraulic fracturing in California without potentially compromising suppliers' trade secret information.

We join the Department of Energy's FracFocus Task Force (2014) and other researchers (e.g. Trickey et al., 2020) in recommending that other states enact bans on proprietary chemical claims while offering mechanisms such as the systems approach to facilitate full chemical disclosure. We further suggest that other states could also use regulatory structures similar to California's that presume chemical identities are *not* trade secrets unless proven otherwise. States should also provide clear challenge mechanisms for agencies, physicians, and members of the public for all proprietary claims.

CRediT authorship contribution statement

Vivian Underhill: Conceptualization, Methodology, Investigation, Writing - original draft, Writing - review & editing, Visualization, Supervision, Project administration. **Gary Allison:** Conceptualization, Methodology, Software, Validation, Formal analysis, Data curation, Visualization. **Holden Huntzinger:** Software, Formal analysis, Resources, Writing - review & editing. **Cole Mason:** Investigation, Conceptualization, Writing - review & editing. **Abigail Noreck:** Formal analysis, Writing - original draft. **Emi Suyama:** Formal analysis, Writing - original draft. **Lourdes Vera:** Validation, Writing - review & editing. **Sara Wylie:** Project administration, Writing - review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data and all code used is available at: https://github.com/vunderhill/Proprietary-Analysis

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvman.2023.119611.

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