FIGURING OUT FRACKING WASTEWATER

Scientists are analyzing the liquid that comes from fracking wells to determine the **BEST WAYS TO TREAT IT**

CELIA HENRY ARNAUD, C&EN WASHINGTON

ALMOST 3 MILLION GALLONS of concentrated salt water leaked in early January from a ruptured pipeline at a natural gas drilling site near Williston, N.D. The brine, a by-product of the oil and gas extraction method known as hydraulic fracturing, spilled into two creeks that empty into the Missouri River, according to news reports. Although a state health official said the salty water was quickly diluted once it reached the Missouri, the spill—large by North Dakota standards—raised questions about the contents of the brine.

Accidental spills like this one occur with some frequency, so scientists would like to understand the contaminants they release into waterways and elsewhere in the environment. Their findings could help officials guide the cleanup of sites or mitigate damage.

For every well they drill, fracking operators pump 3 million to 5 million gal of water thousands of feet underground. There, the water opens fissures in the rock, allowing natural gas and oil to seep out of shale geologic formations. The water gets mixed with additives such as sand and surfactants to form fracking fluid, which is used to optimize the amount of fuel extracted.

But what goes down comes up. Shortly after the water gets injected, it flows back out of the well. The well releases water over its lifetime, larger volumes in the early stages and smaller quantities later on. The early-stage water—the so-called flowback—still contains many of the additives from the fracking fluid. As oil and gas production continues, water from the geologic formation mixes with the fracking fluid, bringing with it brine and other substances from underground. This "produced water" can be many times saltier than seawater—the salinity varies with the mineral content of the geologic formation. The flowback and produced water together make up fracking wastewater.

Operators have limited options for dealing with fracking wastewater. In Pennsylvania, for example, operators used to be able to take it to sewage treatment facilities that could clean it up and discharge it into creeks or rivers. Because of regulations the state adopted in 2012, that option is no longer available. Now, companies transport it to sites where the wastewater gets injected into wells thousands of feet below the surface and sequestered there. Alternatively, they can store it and treat it as needed for reuse in subsequent fracking operations.

Even though these deep-well-injection and recycled-water holding ponds appear to contain the wastewater, as was the case in North Dakota, accidents happen. "The concern is, if there's a spill or accident, it would be important to know what's in the wastewater," says Radisav D. Vidic, an environmental engineer at the University of Pittsburgh who studies wastewater treatment methods. Leaks could affect the water quality of nearby rivers, he adds.

But figuring out the composition is no easy task. The fracking wastewater is a complex mixture of organics, metals, and radioactive materials. Some of these substances get put into the water as fracking fluid additives, some are formed during degradation or transformation reactions, and some come from the underground geologic formations. Many researchers are working to identify these components and their relative concentrations.

THE GREAT UNKNOWN

The biggest question is the organic fraction of the wastewater. Part of the challenge is that oil and gas companies protect their fracking fluid recipes as closely guarded trade secrets (see article on page 13). Plus, drilling operators sometimes tweak the ratios of fluid additives on the fly to improve extraction efficiency. Without knowing what went down the well, it's hard for researchers to know what chemicals they should search for in wastewater.

"You will only find what you're looking for," says Thomas Borch, a chemist at Colorado State University who is studying the degradation of organics in fracking wastewater. "That's why we need to understand the degradation pathways of all these compounds."

Borch and his colleague Jens Blotevogel, an engineer also at Colorado State, are focused on biocides in fracking wastewater (*Environ. Sci. Technol.* 2015, DOI: 10.1021/es503724k). Companies add these compounds to fracking fluid to kill microbes that might produce corrosive acid or form well-clogging biofilms.

"We decided these biocides would be one of the higher-priority chemical groups because they are inherently toxic," Borch says. In their initial studies, they homed in on glutaraldehyde. According to the database at the FracFocus website—where some oil and gas companies disclose their fluid additives—it's the most commonly used biocide.

"We are asking what happens to biocides after they have been injected into these wells," Borch says. "How fast are the biocides being broken down? Are they being broken down to intermediate compounds that we need to be concerned about? How persistent are they?" If scientists can learn what happens to biocides deep within fracking wells, they can better predict what types of compounds will surface in the flowback or produced water, he adds.

Borch and Blotevogel are doing detailed studies in reactors at high temperatures and pressures to learn how these variables, as well as salt content and pH, influence the degradation kinetics of biocides. They are also looking at the effect of the shale itself, because it can act as a sorbent for many of the compounds in the fracking fluid. They find that glutaraldehyde polymerizes under the high-temperature and high-pressure conditions expected in a well. Thus, they need to look for dimers, trimers, or even longer molecules instead of glutaraldehyde in the fracking wastewater.

In addition to their work on biocides, Borch and Blotevogel are collaborating with E. Michael Thurman and Imma Ferrer at the Center for Environmental Mass Spectrometry at the University of Colorado, Boulder, to identify some of the unknown organic components in fracking wastewater. This group discovered that ethoxylated surfactants, including polyethylene glycols and linear alkyl ethoxylates, are major components of flowback (*Anal. Chem.* 2014, DOI: 10.1021/ac502163k). Drilling companies add these surfactants to reduce the surface tension of fluid in the well and improve recovery of oil and gas.

The researchers have developed a database of the surfactants they've found with high-resolution mass quadrupole time-of-flight mass spectrometry. "We can list all the surfactants we've seen by molecular formula and accurate mass," Ferrer says.

"The concern is, if there's a spill or accident, it would be important to know what's in the wastewater."

She and Thurman are willing to provide access to the database to other researchers.

The duo isn't stopping with surfactants. Thurman and Ferrer are also using high-resolution mass spectrometry to analyze other unknown organic components in fracking wastewater, such as biocides and gelling agents. Going forward, use of this type of high-accuracy technique will be key to identifying the organic unknowns in fracking samples, they contend. "Any time your research is going to have a large environmental and economic impact you have to be absolutely certain that you're identifying the correct compound," Thurman says.

Jenna Luek and coworkers at the University of Maryland Center for Environmental Science agree. Using ultra-high-resolution Fourier transform ion cyclotron resonance mass spectrometry to analyze samples of wastewater from fracking sites in North Dakota and Colorado, they've been able to demonstrate just how complex the organic portion of fracking wastewater can be.

"There is a huge diversity of chemicals in the produced water," Luek says. "We have identified more than 10,000 mass spec

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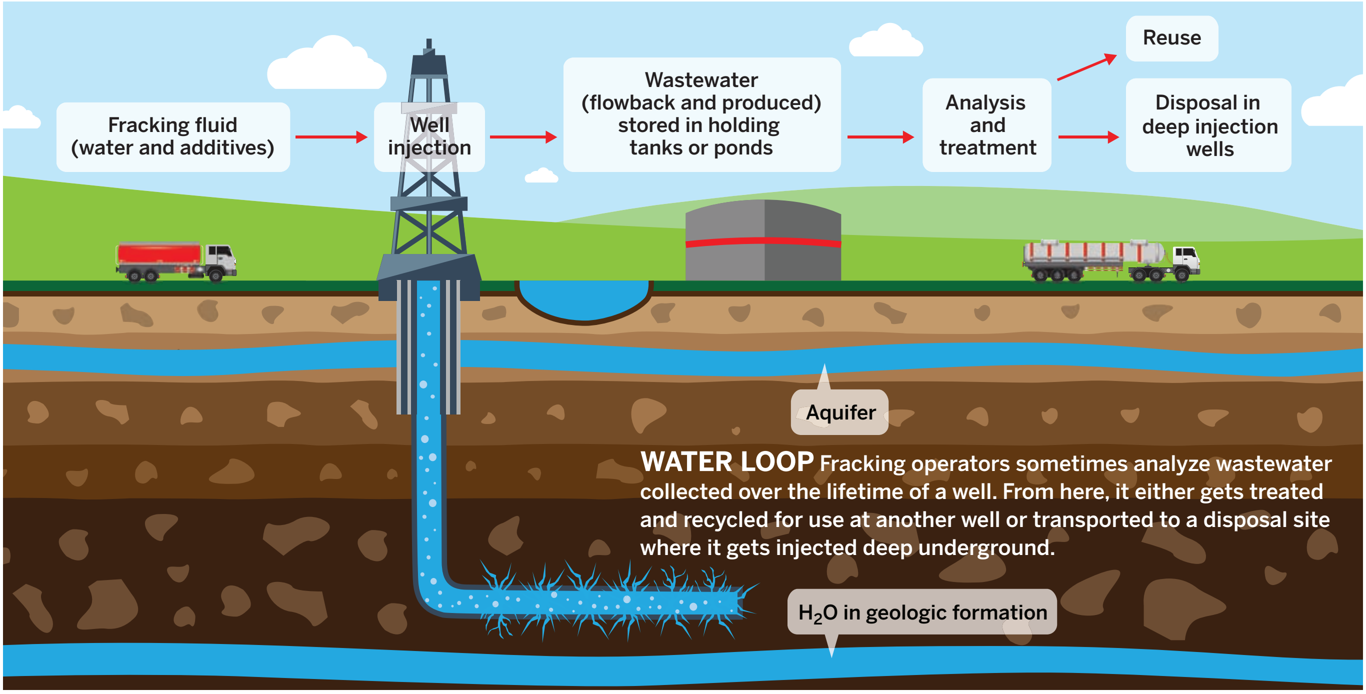


WATER LOOP Fracking operators sometimes analyze wastewater collected over the lifetime of a well. From here, it either gets treated and recycled for use at another well or transported to a disposal site where it gets injected deep underground.

SHUTTERSTOCK/C&EN

peaks, which can be assigned more than 2,500 chemical formulas."

Still others are grappling with the unknown organic content of fracking wastewater. Andrew R. Barron and Samuel J. Maguire-Boyle of Rice University have analyzed in detail the organic fraction of produced water from three fracking sites, each in a different shale formation (*Environ. Sci.: Processes Impacts* 2014, DOI: 10.1039/c4em00376d). They used gas chromatography with mass spectrometry detection.

"Shale oil tends to have very low composition of aromatics, but it was interesting that we actually saw less than you would imagine," Barron says. Produced water has an aromatic odor, he says. "It smells like xylenes."

But the Rice researchers didn't find xylenes. Although they detected other aromatic and asphaltene compounds, they found far more aliphatic hydrocarbons, mostly linear and branched alkanes and alkenes with chain lengths ranging from C_3 to C_{44}. All these components come from the geologic formations underground and are probably remnants from the fuel being extracted.

This variation in the produced waters complicates cleanup efforts. "If you're going to clean this water up and reuse it, you're never going to have one method that's absolutely perfect," Barron says.

To better understand treatment options, Karl G. Linden, an engineering professor at UC Boulder who collaborates with Thurman and Ferrer, has undertaken a comprehensive analysis of flowback water from a well in Colorado (*Sci. Total Environ.* 2015, DOI: 10.1016/j.scitotenv.2015.01.043). He and his group have also been exploring the compounds that make up the wastewater's smell, looking for more than 180 volatile and semivolatile organic chemicals typically found in water affected by conventional oil and gas production.

Unlike Barron and Maguire-Boyle, Linden's team found xylenes at detectable levels. Of the other volatile compounds, only acetone and 2-butanone were present in significant amounts. These compounds may have been added to the fracking fluid as solvents or they may have been produced by microbes as degradation by-products.

The researchers found fewer than 10% of the semivolatile compounds they were looking for. They also found a high concentration of dissolved organic matter. Knowing what's in the water allows Linden to propose tailored treatment options. For that particular well in Colorado, his group suggested that removal of iron and the suspended solids followed by disinfection was appropriate treatment for water that would be recycled and used at a new well.

THE LESS UNKNOWN

Although little is known about the organic contaminants in fracking wastewater, researchers have a firmer grip on its inorganic components. They reflect the metals and ions contained within the geologic formations underground, rock that is well characterized before drilling. Some of those constituents can be used to distinguish among flowback waters from wells in different locales.

The team of Avner Vengosh, an environmental geochemist at Duke University, uses elements such as boron and lithium to track where wastewater goes after leaks or spills. "We are trying to establish geochemical and isotopic fingerprints," Vengosh says, to follow fracking fluid's movement in the environment.

Using thermal ionization mass spectrometry, Vengosh and coworkers showed that fracking flowback water is characterized by distinctive isotope ratios of boron and lithium and that these are much different from the ratios in the small amounts of underground water that gets unearthed from conventional oil and gas wells (*Environ. Sci. Technol.* 2014, DOI: 10.1021/es5032135). With knowledge of a formation's geochemistry, such signatures could be used to trace spills or leaks back to particular fracking sites.

Vengosh and coworkers have also found elevated iodide, bromide, and ammonium in fracking and conventional oil and gas wastewater (*Environ. Sci. Technol.* 2015, DOI: 10.1021/es504654n). Iodide and bromide are common components of the brines found in geological formations. But the ammonium was a surprise. It was not previously known to be associated with oil and gas wastewater, Vengosh says.

"The level of ammonium in the produced water from different formations is highly correlated with chloride," Vengosh says. That suggests that the ammonium and chloride are associated with each other in the geologic formations rather than being added to the fracking fluid during drilling operations.

They found concentrations of ammonium up to 420 mg per L. In the event of spills, "ammonium would be very toxic to the ecosystem at the levels we're talking about," Vengosh says.

Aside from the ammonium, the high levels of bromide and iodide are of interest because these substances are difficult to remove from water, says William A. Mitch, an engineer at Stanford University who collaborates with Vengosh. At drinking water plants, they can lead to the formation of harmful brominated and iodinated disinfection by-products.

Mitch and Vengosh wanted to know at what dilutions fracking wastewater would be a concern if it got into drinking water supplies. Mitch diluted fracking wastewater from operations in Pennsylvania with water from the Ohio and Allegheny Rivers and then analyzed the products formed during processes, such as chlorination or chloramination, used to disinfect drinking water.

At dilutions as low as 0.01% fracking wastewater, the by-products formed during chlorination shifted toward brominated and iodinated by-products (*Environ. Sci. Technol.* 2014, DOI: 10.1021/es5028184). "When drinking water plants use these rivers for drinking water supplies, they run the danger that during disinfection these halides will become incorporated into the organic matter and make potential carcinogens," Mitch says.

Such concerns aren't merely hypothetical. Pennsylvania formerly allowed sewage treatment plants to accept, treat, and discharge wastewater from fracking operations. Jeanne M. VanBriesen, an environmental engineer at Carnegie Mellon University, conducted a three-year study of anion concentrations, including bromide, at drinking water intake points along the Monongahela River in Pennsylvania (*Environ. Sci. Technol.* 2013, DOI: 10.1021/es402437n).

"We documented significantly higher levels of bromide in the source water than were typical of inland source waters," VanBriesen says. "You typically see bromide in source

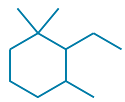
WHAT'S IN THERE? **The water released from fracking wells is a complex mixture of inorganic, radioactive, and organic materials. Here are just a few things researchers have found.**

Inorganics[1]
Ten most abundant elements
Na, K, Li, Mg, Ca, Sr, Fe, Si, P, S

Aliphatic hydrocarbons[1]
(components of petroleum)
C_5–C_{44} linear, branched, and cyclic hydrocarbons

Dodecane

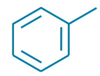
Phytane



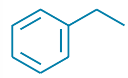
2-Ethyl-1,1,3-trimethylcyclohexane

Naturally occurring radioactive material[3]
Ra-226

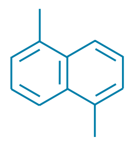
Aromatic hydrocarbons[1]
(components of petroleum)



Toluene

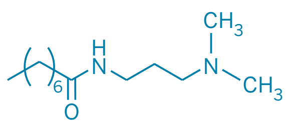


Ethylbenzene



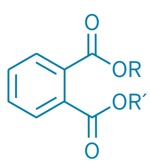
1,5-Dimethylnaphthalene

Surfactants[2]
(added to the fracking fluid by operators)



Cocamidopropyl dimethylamine

Resins and asphaltenes[1]
(likely from drilling fluids)



Fatty acid phthalate esters

Inorganic ions[2]
Cl^-, Br^-, NH_4^+

pH (dependent on geologic formation)[2]
6.8

SOURCES: 1. *Environ. Sci. Processes Impacts* 2014, DOI: 10.1039/c4em00376d.
2. *Sci. Total Environ.* 2015, DOI: 10.1016/j.scitotenv.2015.01.043.
3. *Environ. Sci. Technol.* 2014, DOI: 10.1021/ez5000379

COURTESY OF KARL LINDEN

waters of drinking water plants that are near the ocean.” At the same time she was working on the Monongahela River, the Pittsburgh Water & Sewer Authority found elevated bromide in the Allegheny River.

In April 2011, the Pennsylvania Department of Environmental Protection requested that shale gas drillers stop sending their produced water to treatment facilities that discharge into surface waters. When VanBriesen sampled after that request, she saw a significant decrease in the amount of bromide. That voluntary ban became mandatory in 2012.

On the basis of her findings, VanBriesen suggests fracking wastewaters shouldn’t be discharged back into the environment. “They are going to have unintended consequences because of their concentrations of bromide and iodide,” VanBriesen says. “People are always saying to me, ‘You’re not talking about much bromide.’ It’s still enough to have a negative impact.”

THE RADIOACTIVE UNKNOWN

In the event of a fracking wastewater leak, scientists don’t worry just about unknown organic compounds or briny inorganics. They also sweat the naturally occurring radioactive material within the fluid. This radioactive material, which comes from underground geologic formations, typically ends up in solids that get filtered out of the wastewater.

“The concern I have at the moment is that most naturally occurring radioactive-material-loaded waste is basically discharged into landfills,” Pitt’s Vidic says. “What happens with the [radioactive material] that gets deposited in the landfill? Is it going to leach out? How much of a health hazard is it going to cause for people working at a landfill?”

Much of the naturally occurring radioactive material is radium. To measure radium content, scientists typically add $BaCl_2$ and H_2SO_4 to a sample to coprecipitate the radioactive element out as $Ba(Ra)SO_4$. But Michael K. Schultz, an associate professor of radiology at the University of Iowa, and colleagues have found that the method doesn’t work well with fracking wastewater (*Environ. Sci. Technol. Lett.* 2014, DOI: 10.1021/ez5000379).

“The concentration of barium is so high, roughly a billion times more than the radium-226 concentration,” Schultz explains. “It turns into an unworkable situation when you literally have 9,000 mg per L barium in solution.” Plus, the high salinity of the Marcellus Shale flowback water samples his team analyzed makes the radium more soluble and less suited to a precipitation method.

Schultz and coworkers compared several methods and found that direct measurement of radium by a method called high-purity germanium gamma spectroscopy is the best option. But the detector for that technique costs about $100,000. State regulatory laboratories typically can’t afford one, he says.

Vidic and coworkers have shown that a cheaper method also works—inductively coupled plasma-mass spectrometry—to analyze high-salinity wastewater samples (*Environ. Sci. Technol.* 2015, DOI: 10.1021/es504656q). The Ra-226 concentration they measured with ICP-MS matched the results they obtained with gamma spectroscopy.

The levels of radium in fracking wastewater are high enough to be of concern, Schultz says. And there are other, “daughter” elements that form during radium decay to worry about.

In a closed system, such as a holding tank or covered landfill, “you can’t get away from the daughters,” Schultz says. “The total radioactivity goes up by a factor of about six in 15 days in a closed system because of the in-growth of radon and other short-lived decay products.”

But at least one state thinks there’s no cause for alarm. In January, Pennsylvania released the results of a two-year study on the potential for radiation exposure from oil and gas development. The study concluded that the public and workers have little risk of radiation exposure.

These analyses have increased what is known about fracking wastewater, but each study captures a snapshot of only one part of the process. Linden of UC Boulder hopes to assemble a more comprehensive picture.

He wants to track how the fracking wastewater changes over the lifetime of a well. He spent more than 18 months trying to convince drilling companies to let him work with fracking wastewater over time. Now, he’s found a partner. A small oil and gas company, which he declines to name, is allowing his group to follow a fracking operation from beginning to end. He and his collaborators can sample at each step in the process and take as much water as they want back to the lab.

“It’s a really amazing opportunity. I don’t think many people get the chance to be at a well site for six months and take as many samples as they want,” he says. “Our problem is to figure out how to narrow it down so we don’t go crazy with data.”

With any luck, their data and those from other studies will give people a head start the next time there’s a 3 million-gal fracking wastewater spill. ■

DISCLOSURE DEBATE

Uneven state requirements and trade-secret protections hinder release of data on **CHEMICALS IN FRACKING FLUID**

JESSICA MORRISON, C&EN WASHINGTON

A BREW OF STATE ACTIVITY, federal inaction, industry interests, and environmental concerns is bubbling over in response to public demands for more information about the chemicals used in hydraulic fracturing. Fueling the debate is the oil and gas industry's refusal to reveal the identity of the substances in fracking fluids.

Fracking, an unconventional oil and gas recovery method, involves injecting large volumes of fluid deep underground to break up tight rock formations to extract hydrocarbons. Composed of about 90% water, 10% proppant—sand or other particulate matter—and less than 1% assorted chemical additives, the fracking fluid that oil and gas drillers use varies in composition depending on the recovery method and underlying geologic formations.

The concern over the chemicals in this fluid has grown in recent years as fracking has become more popular. The extraction technique has boosted the U.S. production of natural gas by nearly 40% in the past decade. Even as the price of natural gas tumbled in 2014, fracking is expected to continue its growth to account for more than 75% of natural gas production by 2035, according to industry projections.

Fracking's contributions to job creation and U.S. energy independence have been significant, experts say. The fast-moving industry has blossomed in the Great Plains and in some parts of the Northeast.

As the public's call for environmental protections and information about what substances are getting injected into the ground has grown louder, some states have created their own rules to force the industry to reveal more information about fracking chemicals. In the absence of federal guidance, however, these disclosure rules have varied in scope and efficacy from state to state.

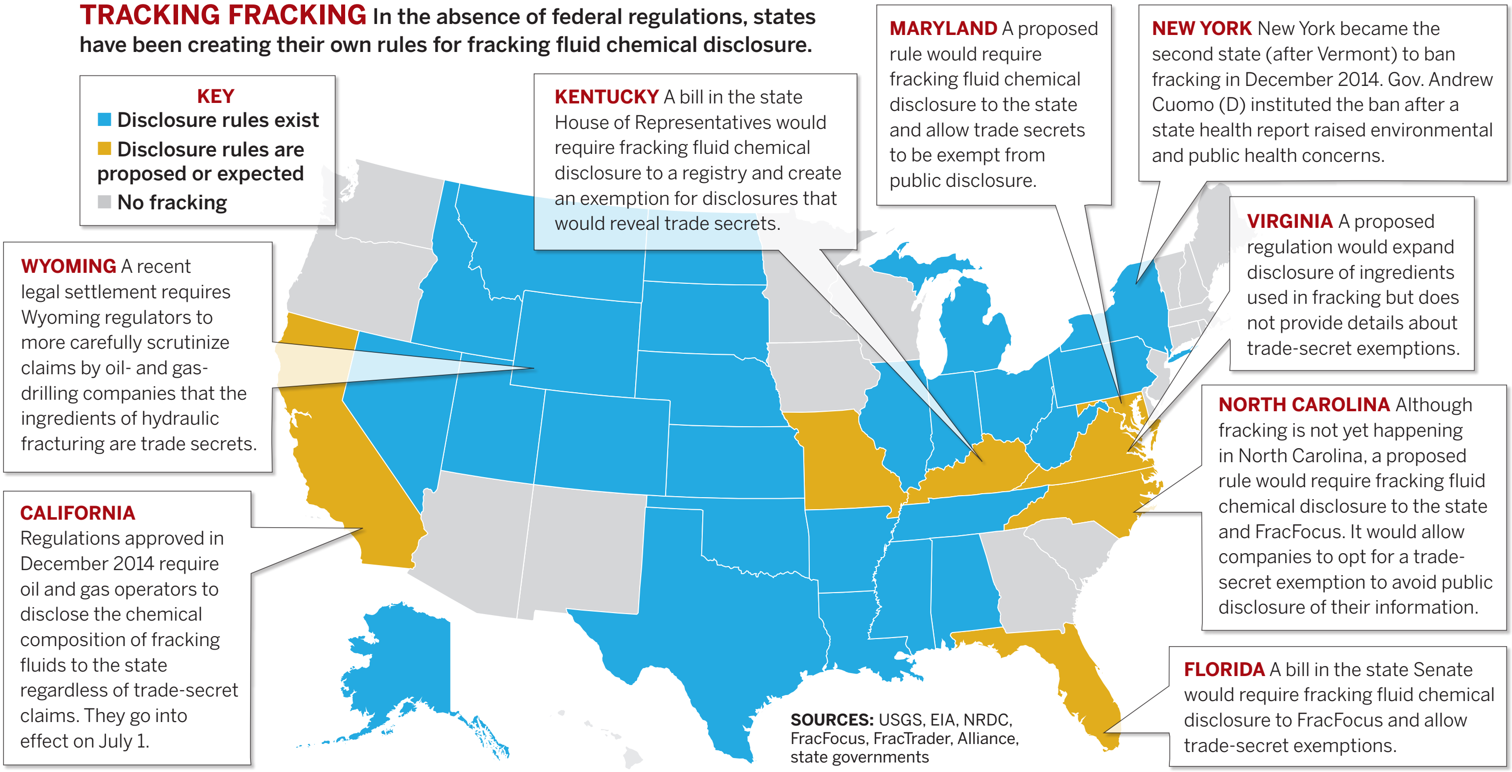
In 2010, Wyoming became the first state to require disclosure of fracking fluid additives. Since then, some 30 states have adopted rules or are in the process of doing so. But those actions are not enough to satisfy advocates for openness. That's because with few exceptions, state rules exempt industry from having to publicly disclose chemicals it claims are trade secrets.

These exemptions are, in most states, easily obtained, rendering disclosure rules largely ineffective for informing the public, says Matthew McFeeley, an attorney with the Natural Resources Defense Council, an environmental group. Opting out of disclosure can be as simple as marking a checkbox or writing "trade secret" on a form, he says.

"In many states, the trade-secret rules are so lax that there's essentially no oversight," McFeeley adds. "Companies are allowed to claim them with no justification or factual substantiation."

The situation is changing, albeit incrementally, McFeeley points out. In a recent settlement between the Wyoming Oil & Gas Conservation Commission and a handful of environmental groups, state regulators agreed to adopt stricter standards for scrutinizing trade-secret claims. Meanwhile, a California law that takes effect later this year will require industry to disclose to the state all fracking fluid chemicals, including those that might be held as trade secrets elsewhere. And lawmakers in Florida, Kentucky,

TRACKING FRACKING **In the absence of federal regulations, states have been creating their own rules for fracking fluid chemical disclosure.**



Maryland, North Carolina, and Virginia are considering fracking fluid disclosure legislation that would impose varying degrees of constraint on trade-secret exemptions.

Because some states are doing more than others, the nation has a patchwork of inconsistent disclosure rules, says Amanda Frank, a policy analyst with the Center for Effective Government. The watchdog group advocates for government transparency and accountability and was a petitioner in the Wyoming lawsuit.

Progress is being made in states like Wyoming, Frank says. "But we really need a strong federal action so that everyone is protected."

WHEN DRILLING OPERATORS inject fracking fluid into wells, that fluid comes back up as wastewater, carrying with it additives as well as naturally occurring metals, hydrocarbons, and radioactive substances from geologic formations (see page 8). This wastewater is typically reused for drilling or injected and sequestered deep underground at other sites.

To protect rivers, lakes, streams, and groundwater from contamination with fracking fluid, environmentalists might argue for federal regulations by the Environmental Protection Agency under the Clean Water Act or Safe Drinking Water Act. But Congress included a provision in the Energy Policy Act of 2005 that forbids EPA from regulating fracking fluids. This part of the 2005 law is nicknamed the Halliburton loophole because it was inserted reportedly at the urging of then-vice president Dick Cheney, a former executive at energy giant Halliburton. Attempts in Congress to reverse the policy through amendments to the law have so far been unsuccessful.

The loophole "was a point of controversy in committee and on the House floor," says Greg Dotson, vice president for energy policy at the Center for American Progress. He was the lead environmental and energy staffer for then-Rep. Henry A. Waxman (D-Calif.) when the Republican-controlled House of Representatives was debating the Energy Policy Act of 2005. Lawmakers offered several amendments in opposition to the loophole, though none was adopted. However, the House did agree to a provision limiting the use of diesel fuel for fracking.

Diesel fuel remains the only chemical restricted in fracking fluid under federal law. Drillers must obtain a permit under the Safe Drinking Water Act prior to injection of diesel fuel.

But there is ongoing activity regarding fracking fluids on the federal level. In the coming months, EPA is expected to release the results of a study it launched in 2011 to scrutinize the potential impacts of fracking on drinking water resources. This work will include a toxicity assessment of more than 1,000 chemicals used in fracking fluids between 2005 and 2011, the agency says. Also, EPA last May issued a notice that it was considering a possible regulation under the Toxic Substances Control Act to require disclosure of chemicals and mixtures used in fracking.

Although it could put up a fight, the industry says it is prepared to comply with stricter disclosure regulations.

"We change the level or depth of information that we provide to authorities whenever there is a change in regulation," says Nicholas Gardiner, strategic business manager for product enhancement at Halliburton.

Last year, Halliburton spent $601 million to research and develop the products and technologies it sells to oil and gas drillers. Part of that budget went to its fracking operation, which would include work on its carefully guarded injection fluids. If Halliburton were to publicly disclose the entire composition of its fracking fluids, this would tip off its competitors and hurt its bottom line, the company argues.

"There are some chemicals that we're not going to disclose 100%," Gardiner tells C&EN. "Those are the ones that we claim as trade secrets." Halliburton protects its fracking products with patents when possible, Gardiner adds.

Known additives, such as ethylene glycol and glutaraldehyde, act to prevent mineral deposits and microbial fouling, respectively, in the wells. Other chemicals help clear debris or protect steel casings (C&EN, May 12, 2014, page 31).

"While there are very few chemicals that we claim trade secret on," Gardiner says, "those tend to be the ones that the customers want to use because they provide a differentiated result."

In March of last year, Halliburton competitor Baker Hughes announced that it would fully disclose the chemical additives in its fracking fluids, without detailing specific product formulations. The decision came as a Department of Energy task force recommended a new approach to chemical disclosure on the website FracFocus, the nation's voluntary, industry-backed fracking chemical disclosure registry. The approach to disclosure favored by the task force—and soon to be implemented by FracFocus—would protect companies' trade secrets by listing chemical constituents without disclosing which commercial additive products contain them.

Halliburton is moving toward a similar type of reporting, Gardiner says. But full disclosure by the company is unlikely, he adds. Halliburton announced its intention to purchase Baker Hughes last fall, but the merger has yet to be finalized.

Although advocates for chemical disclosure applaud this progress, researchers argue that it's not providing them with enough information.

"In many states, the trade-secret rules are so lax that there's essentially no oversight."

Data are "not really provided in a meaningful way for researchers to use," says Dustin Mulvaney, assistant professor of sustainable energy resources at San Jose State University in California. He says it took more than 100 hours of research time to sift through chemical data from a few thousand wells. "The voluntary nature of FracFocus makes the data quality somewhat questionable," he adds.

Still, the compounds in fracking fluids are not regulated, and disclosure of chemical identities does not address gaps in data about the environmental characteristics and toxicity of these substances, says William T. Stringfellow, an environmental engineer and director of the Environmental Measurements Laboratory at Lawrence Berkeley National Laboratory.

"Is the chemical biodegradable? What's the water solubility? Does it have a toxicology profile?" Stringfellow asks. Without this information, it is difficult for researchers to carry out the risk assessments of fracking fluid chemicals that the public is clamoring for, he adds.

To estimate the real risk these additives pose, he says, "we need full disclosure of the information in an organized and complete manner." ■