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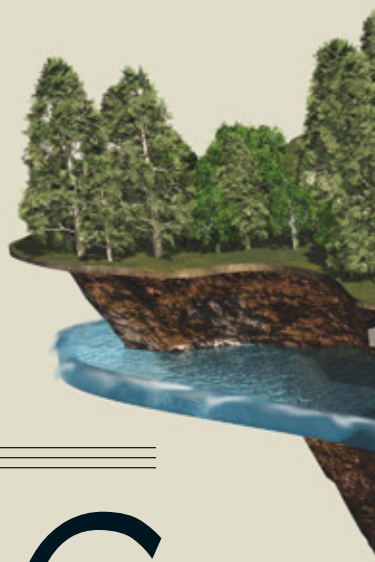


ENERGY

THE TRUTH ABOUT FRACKING

Fracturing a deep shale layer one time to release natural gas might pose little risk to drinking-water supplies, but doing so repeatedly could be problematic

By Chris Mooney

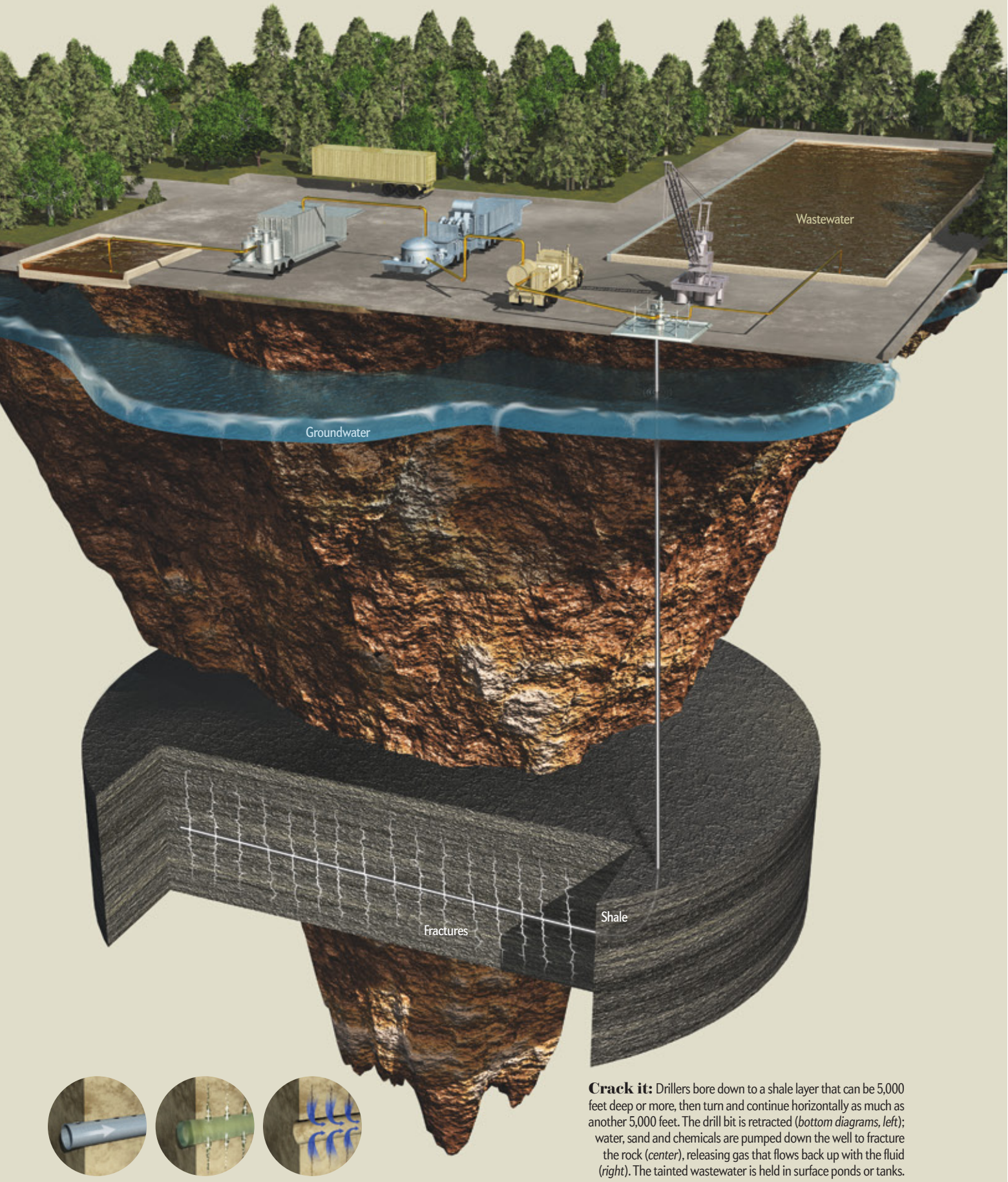
IS FRACKING POLLUTING OUR DRINKING WATER? The debate has become harsh, and scientists are speaking out.

Anthony Ingraffea, an engineering professor at Cornell University and an expert on the controversial technique to drill natural gas, has had much to say, especially since he attended a March meeting in Arlington, Va., hosted by the U.S. Environmental Protection Agency. There he met scientists from top gas and drilling companies: Devon Energy, Chesapeake, Halliburton. All had assembled to help the agency determine whether fracking, accused of infusing toxic chemicals and gas into drinking-water supplies in various states, is guilty as charged. The answer lies at the center of escalating controversy in New York State, Pennsylvania, Texas and Colorado, as well as Australia, France and Canada.

The basic technique of "hydraulic fracturing" has been used in conventional-style wells since the late 1940s. When a vertical well shaft hits a layer of shale, chemically treated water and sand are blasted down at high pressure to crack open the rock and liberate natural gas. Only recently, however, has the technique been combined with a newer technology called directional, or horizontal, drilling—the ability to turn a downward-plodding drill bit as much as 90 degrees and continue drilling within the layer, parallel to the ground surface, for thousands of additional feet. The result has been a veritable Gas Rush. Sequestered layers of methane-rich shale have suddenly become accessible. The U.S. is estimated to have 827 trillion cubic feet of this "unconventional" shale gas within reach—enough to last for de-

IN BRIEF

If fracking is defined as a single fracture of deep shale, that action might be benign. When multiple "fracks" are done in multiple, adjacent wells, however, the risk for contaminating drinking water may rise. If fracking is defined as the entire industrial operation, including drilling and the storage of wastewater, contamination has already been found. **Advanced tests,** such as putting tracer chemicals down a well to see if they reappear in drinking water, could ultimately prove whether fracking is safe or not. **Some regulators** are not waiting for better science; they are moving toward allowing fracking on an even wider scale.



Crack it: Drillers bore down to a shale layer that can be 5,000 feet deep or more, then turn and continue horizontally as much as another 5,000 feet. The drill bit is retracted (*bottom diagrams, left*); water, sand and chemicals are pumped down the well to fracture the rock (*center*), releasing gas that flows back up with the fluid (*right*). The tainted wastewater is held in surface ponds or tanks.

Illustrations by Don Foley

cades—although industry e-mails published by the *New York Times* in June suggest the resource may be more difficult and expensive to extract than companies have been claiming.

The chief hurdle is that unlike fracking of vertical wells, horizontal fracking requires enormous volumes of water and chemicals. Huge ponds or tanks are also needed to store the chemically laden "flowback water" that comes back up the hole after wells have been fractured.

As Ingraffea sat in the room, he watched industry scientists dismiss the idea that fracking has caused polluted water wells and flammable kitchen faucets. After all, the logic goes, the shale layers can be a mile or more deep, separated from shallow aquifers by thousands of feet of rock—precisely why they have been so difficult to tap until now. Fracking may be powerful, but it's not *that* powerful—not enough to blow open new fissures through that much rock, connecting horizontal well bores (called "laterals") to groundwater near the surface.

"I saw beautiful PowerPoint slides depicting what they think is actually happening," says Ingraffea, who previously worked with the global gas supply company Schlumberger but has emerged as a leading scientific critic of the gas rush. "In every one, the presenter concluded it was highly improbable." Yet, Ingraffea explains, these analyses considered only single "fracks"—one water blast, in one lateral, one time. To maximize access to the gas, however, companies may drill a dozen or more vertical wells, closely spaced, at a single site. They may frack the lateral for each well in multiple segments and perhaps multiple times.

"You've got three spatial dimensions and time" to consider, Ingraffea says. He doubts a single lateral frack can connect the shale layers to the surface. Still, he adds, "if you look at the problem as I just described it, I think the probabilities go up. How much? I don't know."

GUILT BY DEFINITION

THE SCIENTISTS and regulators now trying to answer this complex question have arrived a little late. We could have used their research *before* fracking became a big controversy. The technique is the cause of political conflict in New York, where the Department of Environmental Conservation recently unveiled a plan to give drilling companies access to 85 percent of the state's portion of the Marcellus and Utica Shale formations. Fracking would not be allowed in the New York City or Syracuse watersheds, because those water supplies are unfiltered between source and citizen.

The department based its go-ahead on reviews of various studies and says it plans to tightly regulate any drilling work. The actions essentially replace a previous statewide ban on fracking, despite the fact that the EPA is only midway through a major safety study due in preliminary form in late 2012. The department, unwilling to wait for the EPA's science, was set to issue its final regulations in October, open to public comment until early December.

The push to drill in New York before the EPA's results are ready is forcing experts to try to determine which charges against fracking hold some weight and which need new research to address. The answers to this deeply confused issue ultimately depend on competing definitions of "fracking."

If fracking is taken to refer to the entire process of unconventional gas drilling from start to finish, it is already guilty of some serious infractions. The massive industrial endeavor demands a staggering two to four million gallons of water for a single lateral, as well as 15,000 to 60,000 gallons of chemicals; multiply those quantities by the number of wells drilled at one site. Transporting the liquids involves fleets of tanker trucks and large storage containers.

Then the flowback water has to be managed; up to 75 percent of what is blasted down comes back up. It is laden not only with a cocktail of chemicals—used to help the fracking fluid flow, to protect the pipe and kill bacteria, and many other purposes—but often with radioactive materials and salts from the underground layers. This toxic water must be stored on-site and later transported to treatment plants or reused. Most companies use open-air pits dug into the ground. Many states require the bottoms of the pits to be lined with synthetic materials to prevent leakage. Some also require the pits to be a sufficient distance from surface water. The problem is that even when proper precautions are taken, pit linings can tear, and in heavy rains the pits can overflow. Under the proposed New York rules, only watertight tanks will be allowed to store flowback water, and runoff precautions must be made.

All these processes can cause accidents. "This is not a risk-free industry," explains Terry Engelder, a hydraulic fracturing expert at Pennsylvania State University who has generally been a proponent of the process but has occasionally criticized companies involved. Indeed, a series of *New York Times* exposés have documented the possible contamination of major Pennsylvania river basins such as the Susquehanna and Delaware because of inadequate handling of flowback water. In Pennsylvania, household taps have gone foul or lit on fire, and companies have been cited and fined. Most recently, the state's Department of Environmental Protection fined Chesapeake almost $1 million for contaminating 16 families' water wells with methane as a result of improper drilling practices.

These kinds of impacts can be blamed on fracking if the term refers to the whole industrial process—but not necessarily if it means just the underground water blast that fractures the rock after the drilling is done. Even the people most steeped in the issues can differ on this basic matter. "There's a real vulnerability in having chemicals at these kinds of volumes out there, but it's more an industrial kind of threat, rather than a threat from fracking itself," argues Val Washington, a former deputy commissioner of New York's Department of Environmental Conservation. But Cornell's Ingraffea sees it differently: "I just wish the industry would stop playing the game of 'fracking doesn't cause the contamination.' You've got to drill to frack. It's a matter of semantics and definition that they're hiding behind."

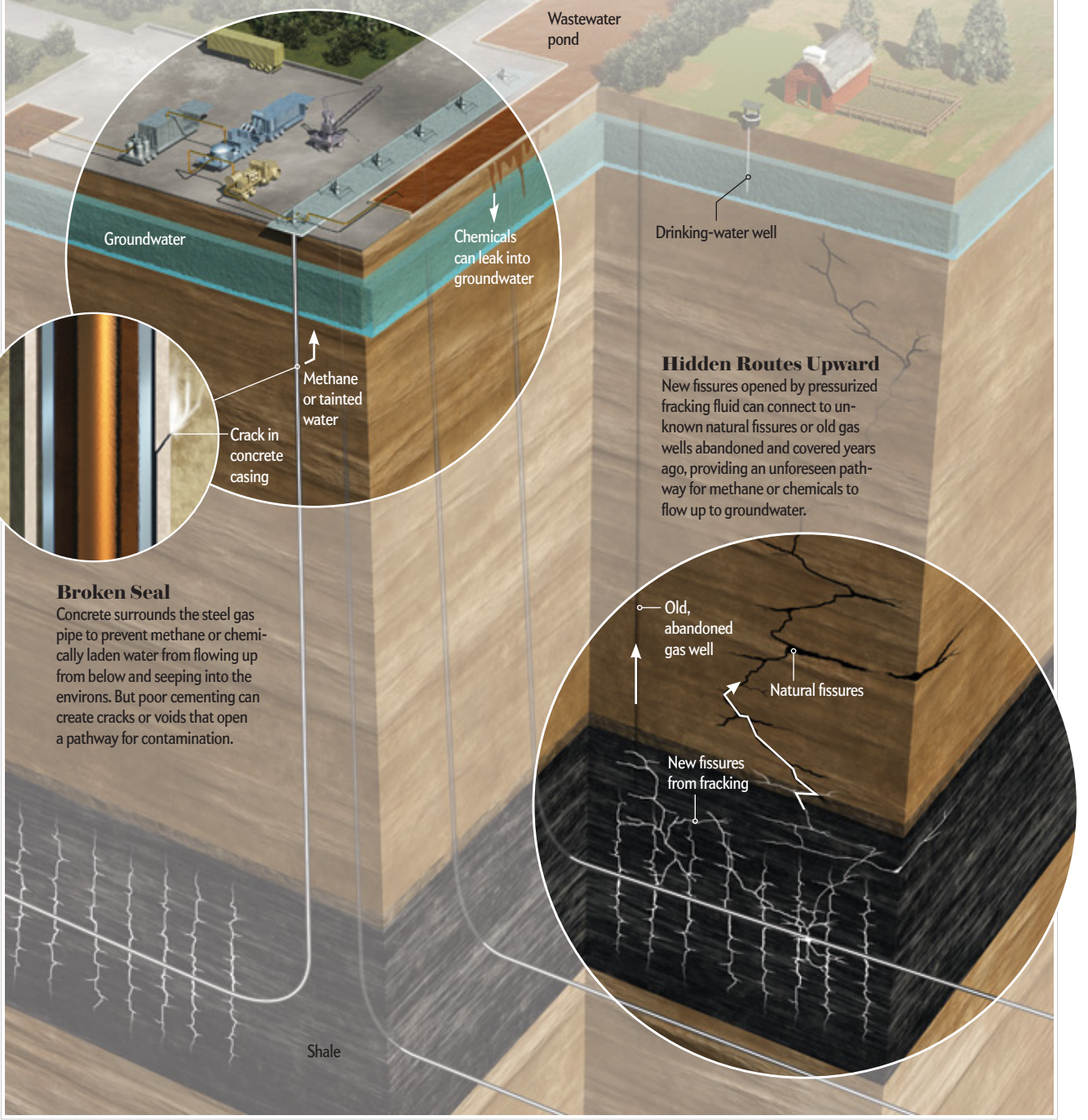
To show that fracking as *industry* defines it is the problem, you have to examine the alleged threat that is simultaneously the most publicized and yet the most uncertain—the idea that water blasts deep underground can directly contaminate drinking water, by creating unexpected pathways for gas or liquid to travel between deep shale and shallow groundwater.

CONCRETE CULPRIT

TO SEE HOW COMPLEX this issue is, consider an EPA enforcement action in 2010 against Range Resources, a Fort Worth–based gas company that plumbs sites in Texas's famed Barnett Shale. The EPA claimed that two residential drinking-water wells near

Risks to Drinking Water

Once a drill pad and wastewater pond are established, a driller may sink a dozen wells or more to fully tap the shale gas. Three spots may have the greatest potential to contaminate groundwater. Chemical-laden wastewater ponds can leak or overflow (*center*), which happened in Pennsylvania in September because of flooding by Tropical Storm Lee. Concrete that encases the vertical pipe can crack (*inset, left*), and new fissures opened by the fracking can connect to natural fissures or old wells (*inset, right*).



Broken Seal

Concrete surrounds the steel gas pipe to prevent methane or chemically laden water from flowing up from below and seeping into the environs. But poor cementing can create cracks or voids that open a pathway for contamination.

Hidden Routes Upward

New fissures opened by pressurized fracking fluid can connect to unknown natural fissures or old gas wells abandoned and covered years ago, providing an unforeseen pathway for methane or chemicals to flow up to groundwater.

two of the company's gas wells were contaminated with methane of deep, "thermogenic" origin. That kind of gas originates in shale layers, unlike "biogenic" methane, which is produced by microbes in pockets closer to the surface, where aquifers typically are. The EPA also claimed that one of the wells contained chemicals sometimes used in fracking—such as benzene—and was delivering flammable water.

The EPA ordered the company to provide clean water to the injured parties, to determine if any other nearby wells were contaminated, and to take other steps. Range Resources fought back strongly—disputing in court the claim that it bore any responsibility, noting the "long horizontal and vertical distances" involved. As of mid-September, the legal battle was in a U.S. Court of Appeals. Crucially, however, even if the EPA is correct that Range Resources is at fault, that does not mean fracking deep in the ground caused the problem. The agency asked the company to determine which "gas flow pathways" were involved—and many are possible. Gas could have migrated all the way up from the fracked shale through some unknown route. Or a faulty cement job on the vertical part of the well, much closer to the surface, could have done the trick.

Faulty cementing is the leading suspect in possible sources of contamination, and by industry's definition it is not part of fracking. On the way down, any well has to pass through the near-surface layers that contain groundwater, and it could also pass through unknown pockets of gas. Drillers fill the gap between the gas pipe and the wall of the hole with concrete so that buoyant gas cannot rise up along the outside of the pipe and possibly seep into groundwater. A casing failure might also allow the chemical flowback water, propelled by the pressure released when the shale is cracked, to leak out.

Cementing is the obvious "weak link," according to Anthony Gorody, a hydrogeologist and consultant to gas companies who has been a defender of fracking. Other scientists emphatically agree. "If you do a poor job of installing the well casing, you potentially open a pathway for the stuff to flow out," explains ecologist and water resource expert Robert B. Jackson of Duke University's Nicholas School of the Environment. Although many regulations govern well cementing and although

Tough sell: Strict regulations might be key to winning over citizens who fear unsafe drilling practices, such as demonstrators in Albany, N.Y., who supported a state ban.

MIKE GROLL *AP Photo*

industry has strived to improve its practices, the problem may not be fully fixable. "A significant percentage of cement jobs will fail," Ingraffea says. "It will always be that way. It just goes with the territory."

Contamination because of bad cementing has been a long-standing problem in traditional vertical wells, which were fracked at times, too. According to former DEC deputy commissioner Washington, "we've got a lot of wells in western New York that have been producing oil and gas for decades. And fracking was the way to get the gas out of these really hard shales; that has been going on for maybe 20 years." What is different now with horizontal drilling, she says, is that "because of the depths of the gas and the combination of fracking and directional drilling, instead of 80,000 gallons of water it is now millions of gallons per fracking operation," with the big increase in chemicals that go along with it.

UNSAFE AT ANY DEPTH?

POOR CEMENTING accounts for a number of groundwater contamination cases from unconventional gas drilling—including the $1-million Chesapeake violation. "Methane migration is a problem in some areas. That's absolutely correct," Engelder says. The question is whether any *other* causes exist. If the groundwater problem really turns on cementing, you might argue that fracking as industry defines it gets a pass, and tougher regulations are needed to scrutinize companies as they drill—precisely what New York State now proposes.

The most intriguing work on possible gas migration is described in a recent paper by Jackson and his colleagues in the *Proceedings of the National Academy of Sciences USA*. It holds something for environmentalists and industrialists alike. When the hotly debated paper came out, as Jackson jokes, the responses ranged from "you saved my life" to "get a life."

Jackson's team analyzed samples from more than 60 private drinking-water wells overlying the Marcellus Shale in northeastern Pennsylvania and the Utica Shale in upstate New York. Methane existed in 51 of the wells, but wells closer to drilling sites contained considerably more of it. Chemical analyses determined that much of the methane was of the deep, thermogenic kind rather than the biogenic kind of microbes nearer the surface.

None of the samples contained fracking fluids, however, or salty brines consistent with deep shale layers. Jackson therefore thinks the likeliest cause of the contamination was faulty cementing and casing of wells. He notes another possibility: fracking may create at least some cracks that extend upward in rock beyond the horizontal shale layer itself. If so, those cracks could link up with other preexisting fissures or openings, allowing gas to travel far upward. Northeastern Pennsylvania and upstate New York are "riddled with old abandoned wells," Jackson observes. "And decades ago people didn't case wells, and they didn't plug wells when they were finished. Imagine this Swiss cheese of boreholes going down thousands of feet—we don't know where they are."

Yet if methane is getting into drinking

water because of unconventional gas drilling, why aren't the fracking chemicals? Here Jackson and Engelder can only hypothesize. When methane is first released from the rock, enough initial pressure exists to drive water and chemicals back up the hole. That flow subsides rather quickly, however. Thereafter, although gas has enough buoyancy to move vertically, the water does not.

Still, if hydraulic fractures could connect with preexisting fissures or old wells, the chemicals could pose a groundwater risk. Fracking "out of zone" can happen. Kevin Fisher, an engineer who works for Pinnacle Technologies, a Halliburton Service firm, examined thousands of fractures in horizontal wells in the Barnett and Marcellus Shale formations, using microseismic monitoring equipment to measure their extent. Fisher found that the most extreme fractures in the Marcellus Shale were nearly 2,000 feet in vertical length. That still leaves a buffer, "a very good physical separation between hydraulic fracture tops and water aquifers," according to Fisher.

Other engineers read the same kind of evidence differently. In British Columbia, Canada, regulators catalogued 19 separate incidents of "fracture communication"—new wells that ended up connecting with other wells in ways that were not expected. In one case, the communication occurred between wells that were more than 2,000 feet apart. As the British Columbia Oil and Gas Commission warned operators, "Fracture propagation via large scale hydraulic fracturing operations has proven difficult to predict." The agency added that fracture lengths might extend farther than anticipated because of weaknesses in the overlying rock layers.

None of this constitutes evidence that fracturing a horizontal shale layer has directly polluted an aquifer. EPA administrator Lisa Jackson recently stated that no such case has been documented, although she added that "there are investigations ongoing." Absence of evidence is not evidence of absence, however; each site is different. The *New York Times* and the Environmental Working Group recently revealed an alleged contamination case from 1984, which suggested that a fracked well in West Virginia may have intersected with an old, abandoned well nearby, leading to drinking-water pollution. Industry contests the validity of the case.

MORE SCIENCE, TOO LATE?

IMPLICATING OR ABSOLVING fracking, no matter how it is defined, will require more data. That's where the EPA study comes in. The agency is examining a variety of ways in which drilling could contaminate water supplies—from unlined and leaky storage pits, to faulty well cementing, to the possible communication of deep fractures with the surface. The EPA will examine five alleged cases of groundwater contamination to determine the cause, including two in Pennsylvania. The agency will also monitor future drilling activities from start to finish at two additional sites. It will also use computer modeling to simulate what is going on deep underground, where no one can watch.

Ingraffea's advice is to develop a powerful model that can iterate a scenario of multiple wells, multiple fracks, and gas and liquid movements within a cubic mile of rock—over several weeks of drilling. "You're going to need really big supercomputers," he says, to determine the possibility of contamination. "You show me that, and I'll tell you where I stand between 'snowball's chance in hell' and 'it's happening every day.' " At a minimum, Ingraffea says, such models would reveal "circumstances in which gas migration is more possible, more plausible, than other situations."

That kind of model may be difficult to find. The current standard used in academia to simulate underground reservoirs—and the one that the EPA plans to use—is called Tough 2, but Ingraffea says it is not "commercial-grade." Big corporations use their own models, and in his view "the best and the brightest in terms of people, software, instrumentation and data are all in the hands of the operators and the service companies." Ingraffea worries that Tough 2 "would have a tough time handling all the faults and joints and fracture propagation" in detail fine enough to determine whether a discrete new pathway for unwanted flow would emerge.

In the meantime, Gorody and Jackson agree that the EPA should monitor chemistry in drinking-water wells before and after drilling begins at new sites. Chemicals found only after drilling starts would significantly weaken the common industry argument that water was naturally contaminated before drilling arrived but that the residents just didn't notice.

Geoffrey Thyne, a petroleum geologist at the University of Wyoming's Enhanced Oil Recovery Institute, has another suggestion for sorting out the fracking puzzle: make companies put an easily identifiable chemical tracer into their proprietary fracking fluid mixture. If it turns up where it's not supposed to, that would be a smoking gun. Thyne says introducing a tracer would be "relatively easy," although he adds that "in general, industry does not view this suggestion favorably." The EPA says it is "considering" the use of tracers. The agency also says that much of the information it has received about the chemicals used in fracking has been claimed as "confidential business information" by the companies involved, and therefore the EPA has not made it available to the public. Legislation could change that situation.

Study by the EPA and others may bring clarity to complex, conflicting claims. But new insight may come too late. Fracking "has never been investigated thoroughly," says Amy Mall, a senior policy analyst with the Natural Resources Defense Council. "It's a big experiment without any actual solid scientific parameters guiding the experiment." Yet New York seems convinced that tight regulations will be enough to protect its citizens.

Residents opposed to fracking in New York, Pennsylvania and other states display a common lawn sign: the word "FRACK" in white letters against a black background, with a red circle and line through the word. The irony is, although it is very possible that gas companies have been guilty of carelessness in how they drill wells and dispose of waste, fracking technology itself may be exonerated. The yard signs would be wrong, yet the fears would be right. SA

MORE TO EXPLORE

Methane Contamination of Drinking Water Accompanying Gas-Well Drilling and Hydraulic Fracturing. Stephen G. Osborn et al. in *Proceedings of the National Academy of Sciences USA*, Vol. 108, No. 20, pages 8172–8176; May 17, 2010. www.nicholas.duke.edu/cgc/pnas2011.pdf

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Revised Draft Supplemental Generic Environmental Impact Statement on the Oil, Gas and Solution Mining Regulatory Program. New York State Department of Environmental Conservation, September 2011. www.dec.ny.gov/energy/75370.html

SCIENTIFIC AMERICAN ONLINE

For the latest news on fracking, see ScientificAmerican.com/nov2011/fracking