Environment and Society

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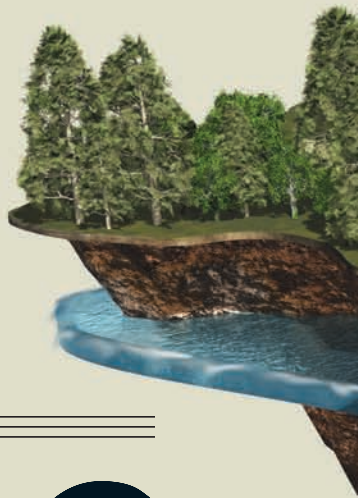


ENERGY

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.

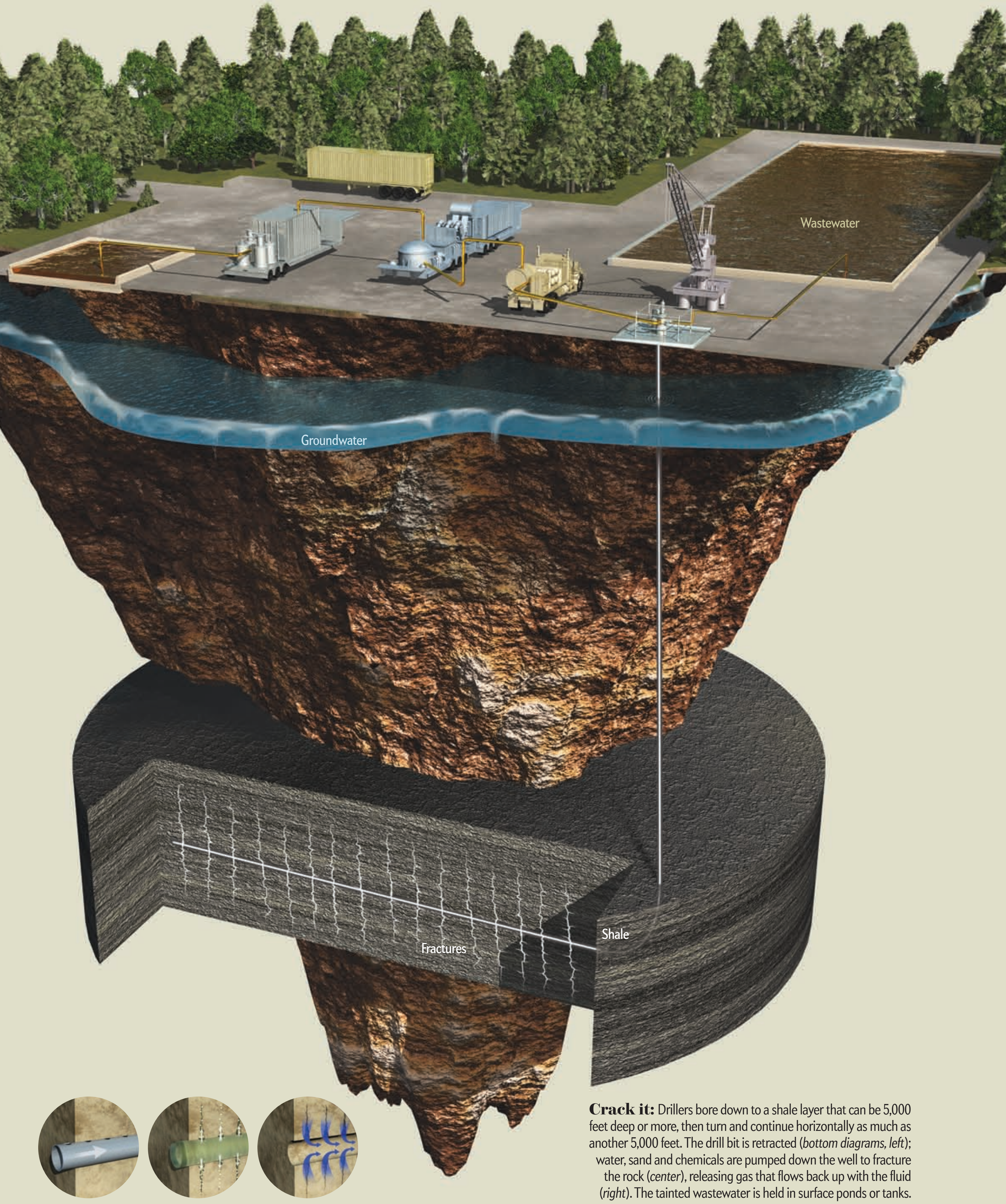
The basic technique of "hydraulic fracturing" has been used in conventional-style wells since the late 1940s. When a vertical well shaft hits a layer of shale, chemically treated water and sand are blasted down at high pressure to crack open the rock and liberate natural gas. Only recently, however, 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."

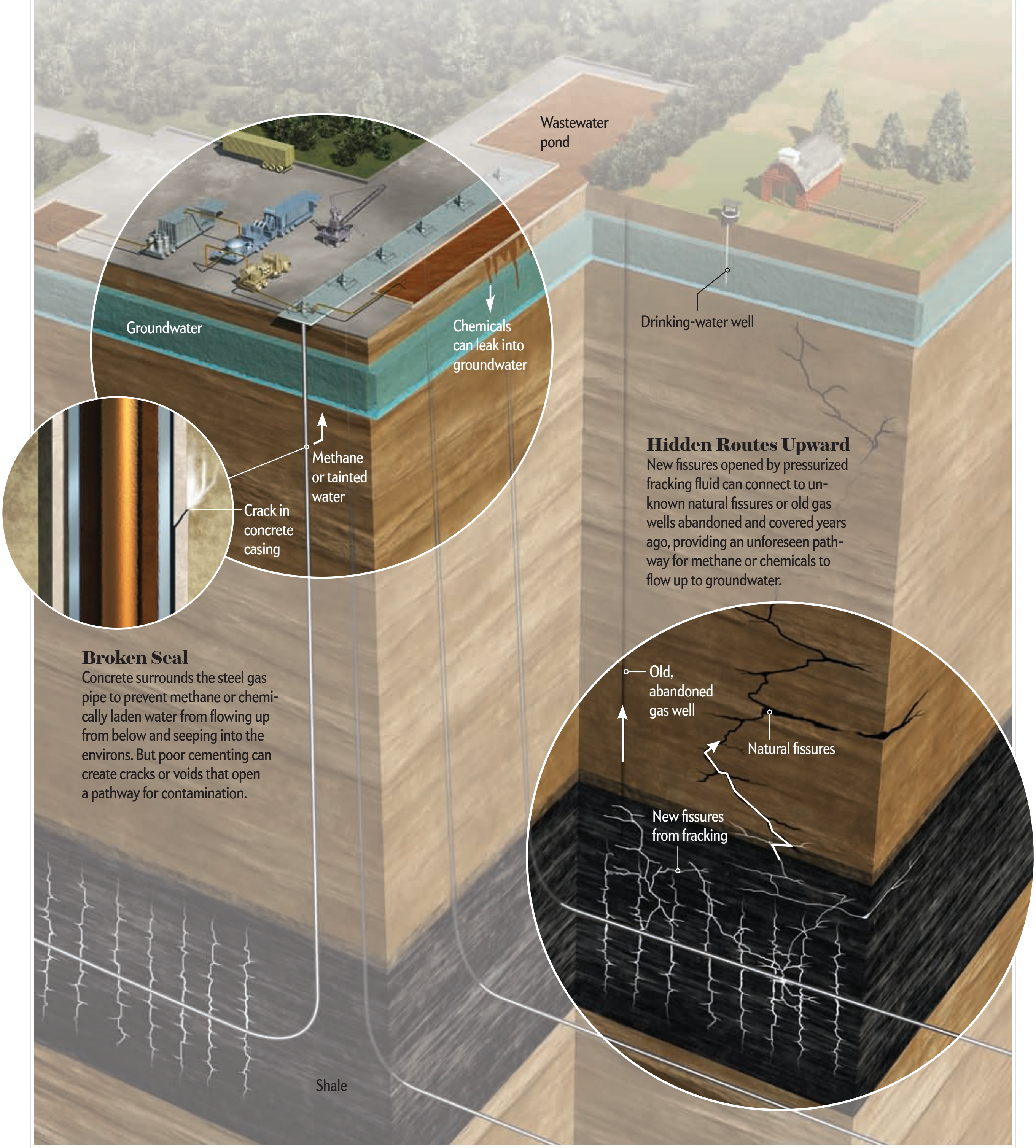
To show that fracking as *industry* defines it is the problem, you have to examine the alleged threat that is simultaneously the most publicized and yet the most uncertain—the idea that water blasts deep underground can directly contaminate drinking water, by creating unexpected pathways for gas or liquid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



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.

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.

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*

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 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

Environmental Protection Agency Draft Plan to Study the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources. EPA, February 2011. Available at www.epa.gov/research

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

failure

Fracking the Marcellus Shale

Hydraulic fracturing could help turn the U.S. into the Saudi Arabia of natural gas. But is it worth the environmental cost?

SHARE

Written by *Jason Zasky* Filed under *Business*, *Science & Technology*

Natural gas drilling in rural Pennsylvania.

"I've had drillers tell me they wish they had called it something else. It sounds so vaguely sexual and terrible," says journalist Seamus McGraw of the term "fracking," short for hydraulic fracturing, a technology that allows drillers to recover natural gas and oil from deep shale formations. Recent advances in this technology—when used in combination with directional drilling—now allow energy companies to extract natural gas from deposits that were considered inaccessible as recently as five or ten years ago. And these deposits—like those of the Marcellus Shale formation, which extends through the subsurface of much of West Virginia, Pennsylvania, and southwestern New York (and reaches into many other states)—could significantly reduce America's dependence on foreign oil *and* allow the U.S. to become a major exporter of natural gas.

But drilling in places like north-central Texas (the Barnett Shale), northwest Louisiana and deep east Texas (the Haynesville Shale), and Oklahoma (the Woodford Shale), may come at significant environmental cost, particularly in terms of water pollution. In his new book "The End of Country" (Random House), McGraw examines the impact gas drilling has had on the rural communities of Susquehanna County in northeastern Pennsylvania—in particular, Ellsworth Hill and Dimock Township. On the one hand, the influx of money from companies like Chesapeake Energy and Range Resources (which lease the land from locals) has provided a badly-needed jolt to the long-languishing local economy. On the other, the money has *changed* people, and the presence of outsiders and the environmental pollution has unnerved residents, many of them third- and fourth-generation farmers.

"One of my favorite lines from the drilling industry is: 'We don't use any chemicals that you don't have under your sink,' begins McGraw. "The problem is that you don't have 50,000 gallons of methanol under your sink," he continues, referring to one of the chemicals commonly used in fracking fluid, which is mixed with a million or more gallons of water and pumped under high pressure into shale formations to create fractures. In the following *Failure* interview, McGraw explains what it's like to visit a drill site, why it's so vital that the public understands the risks and benefits of *slick water fracking*, and how the environmental costs of drilling for natural gas could offset the benefits of moving away from coal and oil.

When were the gas deposits you write about in the book discovered?

The Marcellus Shale [named for a distinctive outcropping near the village of Marcellus, New York] was discovered in the 1840s. It was known that the shale's were gas-bearing from around the turn of the last century. But there was no technology to retrieve it. There was no way to drill down that deep and sufficiently fracture the shale's in order to release the gas. It wasn't until the middle of the last decade that the technology evolved to the point it became do-able.

And that's why there's so much excitement about the Marcellus Shale and other gas deposits at this moment in time?
As recently as the early 2000s, there was a real concern that we were going to have to go hat in hand to Russia within a decade or so and start buying gas from them. Of course, we knew we had large shale deposits, though we didn't know how rich they were. But beginning in the 1990s companies began to pursue some of these shale plays, particularly the Barnett. By 2005 they were starting to realize that not only did we have significant deposits, but we also had the technology. That changed the architecture of the debate. It was no longer: Are we going to run out of gas? It became: Is it worth the cost to get it? That's the debate we're about to have.

What are you referring to when you pose the question: Is it worth the cost?
I'm not really referring to money. There are serious, serious environmental downsides. The problems differ from region to region. In Texas and in parts of the arid west there is a real concern about whether there is sufficient water. There has been talk about shutting down wells because of the amount of water that is used. In the east one of the main problems is methane contamination. And there are serious challenges involved with water recycling.

The other challenge is human failure, and that happens fairly often. In Dimock, a little town which is ground zero for the debate, there was a spill of eight-thousand gallons of fracking fluid. Fracking fluid is 98 percent water and two percent chemicals, but two percent of hundreds of thousands of gallons is still a hell of a lot of chemicals. As I discuss in the book, for every million gallons of water injected into a well, anywhere between 200,000 and 400,000 gallons is regurgitated back to the surface, carrying with it not only the chemicals it included in the first place, but all the other noxious stuff that was trapped down there in the rock: iron and chromium, radium and salt—lots of salt.

The other danger involves methane drifting off into the atmosphere, either from the wellhead directly, via the pipelines, the compressor stations or at the end user. Unburned methane is one of the worst greenhouse gases, and methane contamination dramatically undercuts the claim that natural gas is a significantly cleaner alternative to coal or oil. Certainly gas burns more efficiently and more cleanly—50 percent cleaner than coal and 30 percent cleaner than oil—and there is the technology necessary to capture the methane. What is lacking is incentive. The industry—to its credit—is beginning to take on that challenge, but it is not their top priority.

Who developed hydraulic fracturing?
The company that pioneered it was Halliburton. It was originally done with foam, but the process of slick water hydraulic fracturing, which is what drillers are using now, came about by accident. In the mid-1990s there was a French engineer working for one of the smaller operations who screwed up and got the mix backwards. Rather than it being 75 percent foam and 25 percent water he made it 75 percent water and 25 percent foam. He phoned his boss and said, What do I do? His boss said, Don't tell anybody; let's see what happens.

The engineer blasted [the water] down there and it worked—and it worked more efficiently because it used less energy. The process has evolved since then, not always for the better.

What's it like at a drill site?
It's *loud*. You can't hear yourself think. You hear the sound of hammering like you've never heard before, you smell the stench of diesel, you see piles and piles of various additives, bags of cement, and pools of standing water that are used to keep the dust down. You also see the pools of water used to catch the fracking fluid when it comes back. It's a landscape that is dramatically changed over three to five acres.

How much oversight is there in Pennsylvania?
The state has done a remarkable job of developing regulations to keep pace with water disposal and developing responsible guidelines for water usage. We've made tremendous improvements in terms of regulation of the cementing of wells and the drifting of methane. But it's not enough. Quite frankly, we will never have enough cops on the beat in order to make sure drillers don't cut corners, and that they don't make boneheaded mistakes. And that if they do make boneheaded mistakes that they are responded to quickly, adequately, and effectively.

Help can come from the industry itself, but we have to make it in the industry's interest. Ever since "fracking" became the catch-all for all the ills in the world of drilling, you've had the drillers portrayed on the pro side as rugged individualist cowboys out there riding the range of America's energy frontier, [and on the con side] as mustache-twirling villains tying us all to the railroad tracks. But the corporations are neither good nor bad—they are amoral. They respond to the bottom line. What we need is to develop an energy policy that includes a series of taxes that generate the resources we need to help police this and develop it.

What environmental problems have been experienced by the residents of Ellsworth Hill and Dimock?
In Ellsworth Hill: noise pollution and light pollution, in an area where both are uncommon. Also, air pollution from the diesel burned. In Dimock, seven miles away, they've had fairly persistent and widespread methane contamination. And there have been similar problems elsewhere from methane migration. Then there have been spills of diesel fuel, and spills of chemicals. By and large these can be attributed to human error or carelessness.

I think the environmental dangers need to be balanced against continuing our dependency on the dirtiest and most deadly fuel in the world, which is coal. There's another balance we need to keep in mind too. Drilling is loud, dirty, and risky. But the people [in places like Dimock] understand something that the people who are not from the country don't understand, and that's that the land is your partner and adversary, and sometimes it's both at the same time. A lot of the people in these rural communities may believe the world is only four-thousand years old, but they have a better idea of how it works than a lot of the so-called sophisticates. You push the land as hard as you can, but you don't push it any further.

How has the drilling changed the communities you write about in the book?
Obviously you have people who have behaved badly. But that's rare. The truth is that many of the old farmers—and they are older people, by and large—have experienced hard luck for a long time. So they don't trust good fortune. There are a lot of people who have taken the (lease) money and are sitting on it because they don't believe it's here to stay. They have learned the hard way not to trust good luck.

The hard way. Depletion of conventional oil fields outside of OPEC is driving the mining of oil sands in Alberta, Canada.

Peak Oil Production May Already Be Here

Outside of OPEC's vast resources, oil production has leveled off, and it's looking like it may never rise again

FIVE YEARS AGO, MANY OIL EXPERTS SAW trouble looming. In 10 years or so, they said, oil producers outside the Organization of the Petroleum Exporting Countries (OPEC) would likely be unable to pump oil any faster (*Science*, 18 November 2005, p. 1106). Non-OPEC oil production would peak, no matter the effort applied. All the high-technology exploration and drilling, all the frontier-pushing bravado of the oil industry would no longer stave off the inevitable as OPEC gains an even stronger hand among the world's oil producers.

Five years on, it appears those experts may have been unduly optimistic—non-OPEC oil production may have been peaking as they spoke. Despite a near tripling of world oil prices, non-OPEC production, which accounts for 60% of world output, hasn't increased significantly since 2004. And many of those same experts, as well as some major oil companies, don't see it increasing again—ever. In their view, it's stuck on a flat-topped peak or plateau at present levels of production for another decade or so before starting to decline. "Stable [non-OPEC] production is the best we can hope for," says energy economist Robert Kaufmann of Boston University. "I have trouble seeing it increase more. It's a wake-up call."

Optimists remain. Some experts still see production from new frontiers, such as Kazakhstan, the deep waters off Brazil, and the oil sands of Canada, pushing production above the current plateau in the next few years. But time's running out to prove that newly discovered fields and new technology can more than compensate for flagging production from the rapidly aging fields beyond OPEC.

Running to stay in place

There's no debate about the reality of the 6-year-and-counting plateau of non-OPEC production. Output stagnated at about 40 million barrels a day beginning in 2004 after rising from an earlier plateau in the early 1990s, one induced by a low price for oil. But prices have been anything but low lately. They have gone from about $35 a barrel early in the past decade to double and nearly triple that. Normally, higher prices would encourage more production, but not this time. Since 2004, "there's been a tremendous increase in price, yet this is all we get for it, stable production," Kaufmann says. "It's quite stark."

The problem up to this point, all agree, has been increasing difficulties extracting conventional oil. That's the easiest oil to get at, oil that freely flows out of a well of its own accord or with a minimum of encouragement, such as pumping it out or pushing it out with water. Production of conventional oil from any one well or field typically increases, peaks, and then goes into decline. Larger producing regions behave the same way. Production from the United States, once the world's largest oil producer, peaked in 1970 as rising output from newly discovered fields failed to compensate for declines in old fields. Mexico's production peaked in 2004 as its huge, aging Cantarell field went into steep decline. North Sea production peaked in 1999, just 28 years after starting up.

The same pattern now seems to be emerging across much of the world. "We believe—and pretty much everybody else believes—that non-OPEC [conventional] production has plateaued," says oil analyst Michael Rodgers, a partner with PFC Energy in Kuala Lumpur. "Arguing that you're going to get continued and sustained growth of conventional oil is a very hard case to make." PFC Energy has just done a complete reassessment of the prospects for non-OPEC conventional production, he says. As in most oil outlooks, a country-by-country or even field-by-field survey of what producers are planning for the next 5 to 10 years was combined with an educated guess of how much oil remains to be discovered in each region.

That forecast of added production is balanced against how fast production from existing fields is declining. In the past decade, analysts have realized that rather than the 2% to 3% per year decline once assumed, production from existing fields is declining 4% to 5% per year. Some believe the depletion is even faster. The balance between added and declining production, in the PFC Energy assessment, is a plateau, though the plateau may undulate from year to year. "You

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bring on a [new] 100,000-barrel-a-day field," Rodgers says, "and somewhere else you've lost a 100,000-barrel-a-day field."

Tough oil to the rescue?

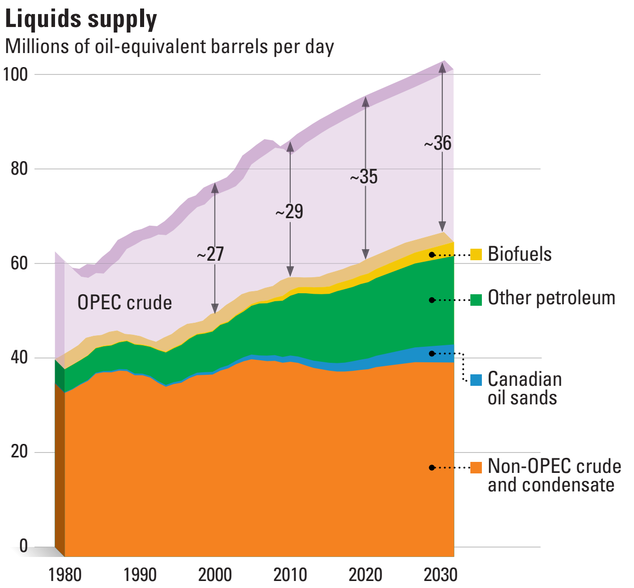
But what about unconventional oil, the hard-to-get-at oil that's only extractable using the latest in high technology? There's the oil beneath kilometers of seawater far offshore of the U.S. Gulf Coast, Brazil, and West Africa. It wasn't reachable until development of the necessary deep-water drilling and production technology. There is also the oil—more like tar—that is so viscous that steam must be piped underground to thin it before pumping it out. In Alberta, Canada, huge shovels just dig up the "oil sands" so it can be trucked to oil-extraction plants. And American drillers have lately taken to drilling into rock formations that would normally only dribble oil and fracturing the rock with high-pressure fluids in order to wrest worthwhile amounts from the rock. That's how drillers have been "fracking" stingy natural gas formations (*Science*, 25 June 2010, p. 1624).

Such unconventional oil is out there in abundance, everyone agrees, and more will be produced than in the past. However, some major oil companies as well as other analysts don't see unconventional oil boosting non-OPEC production much in the next 20 years. In their most recent annual energy outlooks to 2030, both ExxonMobil and BP—two of the world's largest independent oil companies—forecast that non-OPEC production will more or less hold its own, no better. "It's quite an accomplishment to keep non-OPEC supply flat level," says analyst Kyle Countryman, who as a member of ExxonMobil's energy and economics group in Dallas, Texas, helped put the outlook together. Adds his colleague, group manager Robert Gardner: "We're not optimistic we'll see a significant increase in unconventional liquids."

The problem with unconventional oil is that, by definition, it is hard to extract. "It's a matter of timing," Gardner says. "It depends on the pace of technology development." And even after the essential technology is developed, unconventional oil will still be difficult—as well as expensive—to extract, limiting the rate at which it can be produced. All in all, "technology matters, economics matters, but geology really does matter," says oil analyst David Greene of the U.S. Department of Energy's Oak Ridge National Laboratory in Tennessee. "Progress in technology is not fast enough to keep up with depletion" of oil reservoirs. Oil analyst Richard Nehring of Nehring Associates in Colorado Springs, Colorado, is more optimistic about prospects on oil's frontiers and how fast some kinds of unconventional oil can be brought online, but he still finds that "non-OPEC will be stable or at the very best slowly increasing" over the next couple of decades.

Optimism not dead

"We're a little more bullish about non-OPEC than some others," says Peter Jackson of Cambridge Energy Research Associates (CERA) in London. Along with the U.S. Energy Information Agency (EIA), CERA sees real promise in underdeveloped oil provinces such as offshore Brazil and Kazakhstan. Likewise, if prices stay high, unconventional oil will contribute substantially, both find, especially the Canadian oil sands. Beyond the next few years, "we're seeing a gradual increase in non-OPEC supply," Jackson says.



Running flat out. An ExxonMobil outlook has non-OPEC oil (orange plus blue) plateauing. Natural gas–derived liquids (green) and biofuels (yellow) will help, but OPEC (purple) must pitch in.

Such optimism has not always served forecasters well. In 2005, Jackson and his CERA colleague Robert Esser of the New York office predicted that "global oil production capacity is actually set to increase dramatically" up to 2010. It didn't; both OPEC and non-OPEC oil production remained steady. Likewise, in its 2005 outlook, EIA projected a jump in non-OPEC production by 2010 if prices were high, which they mostly were. But 2010 production was about 40 million barrels per day, right where it was in 2005.

So what if the pessimists turn out to be realists and non-OPEC producers can't answer the call for more oil? Demand will increase in this decade, mainly from developing countries like China and India as populations grow and incomes rise. That rising demand might be met by several sources. In decreasing order of reliability, production of another sort of petroleum liquid, natural gas liquids (NGLs), is expected to increase. NGLs are the lighter-weight hydrocarbons that condense from natural gas when it cools. The expected increase in global natural gas production—at least half of which would come from OPEC—would lead to increased production of NGLs.

A remaining hope. Some analysts see untapped oil fields in frontier areas, such as offshore Brazil (*above*), pushing up non-OPEC production.

OPEC would, it is fervently hoped outside of the cartel, be willing and able to boost its output of conventional oil. ExxonMobil has OPEC production rising from about 29 million barrels per day today to about 36 million barrels per day in 2030. That would increase OPEC's share of oil production even further, but Kaufmann, among others, expects that OPEC will see an opportunity to make more money from its oil by curbing production and driving prices up. That would tend to encourage production of liquid biofuels, but whether output could be ramped up quickly enough to bring relief remains unclear. The clearest outcome, according to Greene, is likely to be continued or even greater volatility in the price of oil with all the economic downsides that would entail.

Perhaps the most sobering outcome of a non-OPEC plateau might be reminding everyone that even planet-scale resources have their limits. And that when you are consuming them at close to 1000 gallons a second, the limits can catch you unaware. The next 5 years, assuming oil prices remain on the high side, should show who the realists are.

–RICHARD A. KERR