shaleionaires. That is the name—complete with initial dollar sign—coined in 2010 for the newly rich farmers, ranchers, and other residents around the U.S. who have found that their homes and lands are sitting atop mammoth reserves of natural gas, in dinosaur-era shale rock a mile or more underground.

Geophysicists had known of its existence for decades, but petroleum engineers were long convinced that maybe only one or two percent of it might be recoverable. But in the last decade, technological developments have revolutionized the industry’s ability to tap shale reserves—half or more of which is now technically recoverable according to current estimates. That’s enough to power the nation for perhaps 90 years—figures that have revolutionized the industry’s commercial economics.

The result? Just as miners in the 19th Century rushed to Georgia, California, Australia, or Alaska intending to strike gold in Dahlonega, the Sierras, Victoria, or the Klondike, today oil and gas companies have been rushing to secure mineral-rights leases from individual land-owners in (just to name a few) Texas, Montana, North Dakota, Pennsylvania, and— the latest boom state right now—Ohio, to drill on or under their lands to tap the Barnett, Bakken, Marcellus, and now the Utica-Point Pleasant (Utica for short) shale “plays.” In Ohio alone, just 72 Utica shale wells had been drilled by May 2012—but even then the Ohio Department of Natural Resources was projecting 2,250 to be drilled by the end of 2015.

Some visionaries speculate a future when cars might run on natural gas instead of gasoline; others foresee the U.S. becoming a net exporter of liquefied natural gas instead of a net importer of oil. Galloping after the newly rich are others hoping to profit from supporting industries: not only drilling and road construction contractors and refinery workers, but also steel makers, machine shops, truckers, hoteliers and restaurateurs, bankers, work truck and luxury car dealers, real estate agents, and lawyers.

Yet, around the nation, citizen groups have also organized vocal “anti-fracking” protests and even outlawed shale gas extraction in some states and municipalities. What are gas shales? If they are a mile or two underground, how is the natural gas extracted? And why has hydraulic fracturing for shale gas become so controversial?

Philosopher’s Stone
Oil and gas shales began as sediments 150 to 400 million years ago—primarily clay-fine silts building up on the quiescent bottoms of ancient tidal flats or deep-water oceans, mixed with organic (carbon-based) material from algae and other prehistoric organisms that died and drifted down to the sea beds. As the oceans gradually filled in, both the layers of sediments and the organic materials became compressed and heated by the weight of materials accumulating above. Over the eons, the organic-rich sediments ended up 500 to 13,500 feet underground—and by the alchemy of slow geological pressure cooking, converted into rock bearing crude oil, methane, propane, butane, ethane, and other liquid and gaseous hydrocarbons that modern society values as gold: for power, yes, but also for plastics, fertilizers, and other chemicals.

Similar to shale formations seen at the earth’s surface, the gas shales are thin horizontal layers of black or dark brown rock, some structurally strong and ductile but others quite brittle—the ones you are not supposed to trust your weight to when rock-climbing because the layers easily separate and fracture under your feet. Because some of the
prehistoric seas were quite large, entire shale layers extend horizontally from 5,000 square miles (Barnett) to 95,000 (Marcellus), many underlying several U.S. states. Depending on location, however, a shale layer may be only 20 to 700 vertical feet thick. A few regions have overlapping shale layers: in eastern Ohio and western Pennsylvania, the Utica shale lies a couple thousand feet below the Marcellus.

Shale gas is often a dry gas consisting of perhaps 90% methane (CH\textsubscript{4}) and needing little refining. But some formations also produce valuable “wet” gas (various heavier hydrocarbons in liquid form) and/or oil. A single shale play (including the Utica) may hold several hydrocarbons, in liquid or gaseous form, either concentrated in different regions or mixed together. In conventional reservoirs, oil, gas, or the other liquids pool in a natural cavity sealed between layers of impervious rock. In shales, the hydrocarbon molecules literally saturate the structure of the rock itself, almost like water molecules saturate the matrix of a damp sponge. You can't just stick a straw in it—or drill a well to it—and expect liquids or gas to begin flowing. Thus, gas shales are considered “unconventional” reservoirs. And unconventional reservoirs require unconventional extraction technologies.

Enter horizontal drilling and multistage slickwater fracturing—the two key technologies most often cited as revolutionizing the industry's economics. Jump-started by the OPEC crisis in the 1970s, when researchers began developing methods for tapping shale oil and boosting the recovery rates of older oil fields, both technologies were advanced primarily through collaboration among the U.S. Department of Energy (DOE), the Gas Research Institute (GRI), and petroleum companies. By the late 1980s, they became commercially viable for oil; in the early 2000s, the methods were adapted for recovering natural gas.

**Drilling Sideways**

Quick but essential vocabulary alert: In the general press, and even in the business press, the term “hydraulic fracturing” is often used in a broad sense that encompasses the entire months-long enterprise of locating the
resources, drilling a well, fracturing the shale, extracting the hydrocarbons, and disposing of the fracturing waste. In the technical literature, the term “hydraulic fracturing” refers specifically and only to the literal fracturing of the shale rock after drilling and before extraction. Moreover, the technical literature shortens the term to “frac” or “fracing”—without either doubling the c or adding a k. With one important exception noted later, this article follows that narrower engineering usage.

Most schematic diagrams of rock strata and horizontal drilling show a vertical wellbore that turns at a neat 90-degree angle to form the horizontal lateral. Such diagrams can be misleading. Although short-radius turns can be made in particular formations for specific reasons, they pose technical challenges. Thus, many wells bore curve gradually, starting from a “kickoff point” perhaps several hundred feet above the “pay layer” of shale, until entering the reservoir at an angle. Such long-radius horizontal wells can be drilled with machinery used for drilling conventional vertical wells: the seemingly rigid drill pipe sections are flexible enough to be bent a few degrees off the vertical axis without incurring structural failure. Once in the shale pay layer, the drill bit then proceeds horizontally—or even along a complex trajectory if needed to circumvent an obstruction; such horizontal laterals routinely extend 2,500 to 5,000 feet, with some exceeding 12,000 feet. Guided in part by reference to earth’s magnetic field, operators up at the surface control the altitude and azimuth of the drill bit using several “geo-steering” or “geonavigation” methods along with fiber-optic sensors to measure position and downhole conditions. To maximize the flow of natural gas, the laterals are drilled more or less at right angles to the prevailing pattern of underground joints or faults in the shale (for example, in the Utica and Marcellus shales near the Ohio-Pennsylvania border, laterals are oriented generally north-northwest to south-southeast).
their full length all at once. Also, much study has revealed that certain patterns of fractures (e.g., clusters) increase productivity. Thus, the shale is fractured in isolated stages each maybe a few hundred feet long, each isolated from the other by a temporary plug, starting at the far end of a lateral and working back to the vertical wellbore; depending on local conditions, more than 20 stages may be used, with somewhere around 10 being common.

Although wells have been stimulated using gels, foams, diesel, kerosene, or even napalm, the revolutionary advance that enabled today's wells is “slickwater” fracturing: plain old freshwater mixed with additives to reduce friction, kill bacteria, inhibit corrosion or buildup of chemical scale, or other purposes. Each stage commonly starts with a flush of a 15% solution of hydrochloric acid to dissolve salt crystals and thereby open and connect natural fractures and to unplug pores clogged by drilling mud or casing cement. Then the wellbore is filled with a “slickwater pad” to facilitate the placement of the fracsand. The volume of sand poured down the well is slowly increased as the volume of fluid is decreased; the fracsand mesh size may also be increased so that smaller fractures deeper in the shale are first filled with finer grains and larger fractures closer to the wellbore are filled with coarser grains. Then that first stage is temporarily closed off from the rest of the lateral and the process repeated for the next nearer stage. After all the stages are completed, the full wellbore and equipment are flushed with freshwater to remove excess sand. As each stage generally takes 20 minutes to 4 hours to complete, the full hydraulic fracturing process (“fracing” without a k) for an entire well takes maybe a day or two (working 24/7). Depending on the shale play, a single well commonly consumes between 2 and 6 million gallons of water (4.5 million is typical in the Marcellus and Utica shale plays) and between 0.5 and 4 million pounds (up to 2,000 tons) of fracsand.

After the well has been fractured, some of the slickwater is absorbed by pores in the underground rock. But 5% to 50% of it returns as “flowback” over several days or weeks. This so-called “produced water” may have lower concentrations of any toxic additives (many of which have chemically converted to other substances or been absorbed by the rocks). In its round trip through the ancient seabed shale, however, the freshwater absorbs great concentrations of salts—sometimes returning from the wellbore as supersaturated brine up to 40% saline, 10 times saltier than seawater. It may also return with some concentration of naturally occurring radioactive materials (NORM) such as barium and strontium. Neither the great salinity nor the NORM can be handled by regular municipal sewage or water treatment plants, nor is it safe to release into waterways as is, nor to store in tanks to use for salting roads in winter ice and snow. In many shale plays, the millions of gallons of produced water is discarded: injected at high pressure into what are called Class II injection wells drilled to geological structures perhaps deeper underground than even the layers of shale. In arid regions such as Texas and the Great Plains, where freshwater is a precious and expensive resource, increasing research has been devoted to developing “closed-loop” systems that process and reuse the produced water in fracturing additional wells.

Highly Charged Epithet

Why has “fracking” (with a k) become such a highly charged epithet among a hefty portion of the general public? Shaleionaires around the nation notwithstanding, state and local governments (indeed, other nations) have enacted moratoria, passed regulations regarding the additives used in the slickwater, or prohibited venting or flaring (the intentional releasing of hydrocarbon gases into the air, a common practice in drilling). In Ohio, tougher regulations were enacted in July 2012 when earthquakes around Youngstown were associated with injecting produced water into nearby Class II injection wells. Questions about the effects of fracking on local drinking water have been raised in several recent popular movies.

Some articles and editorials in the oil and gas industry media express bafflement at public resistance. They point out that when burned as fuel, natural gas emits about half the carbon dioxide as coal and 30% less than fuel oil (carbon dioxide is a greenhouse gas strongly implicated in climate change).
change), and 80 percent less of the harmful ingredients that cause smog (including nitrous oxide, a greenhouse gas more powerful than carbon dioxide). Lower-carbon natural gas could be a route away from today’s coal and oil fossil fuels until renewable energy technologies such as solar and wind are commercially economic at national or global scale.

For generating electric power, natural gas provides both reliable day-and-night “baseload” energy (like coal, oil, and nuclear) as well as rapid response to quick changes in demand (unlike coal, oil, or nuclear). The natural gas is underfoot here at home, increasing the nation’s energy independence from foreign oil. The new abundance of natural gas has led to declining prices, reducing costs to consumers and businesses. Oil and gas jobs are pouring into regions that have long been economically depressed. State governments may benefit from severance taxes (excise taxes on resources “severed” from the earth). And horizontal drilling means far fewer wells are needed to drain an area than would be required when drilling vertically, because multiple wells can be sunk from a single pad and the laterals radiate out in different directions; fewer pads mean fewer roads built, pipelines trenched, or surface facilities installed—with perhaps less impact on wildlife habitats, agricultural resources, and surface bodies of water. What’s not to like?

**Critical Media**

“[F]or too many years, the [oil and gas] industry has mainly responded to attacks on shale gas operations by pointing out errors or omissions in critical media accounts,” observes Richard A. Liroff, executive director of the Washington, D.C.-based Investor Environmental Health Network; his article in the July 2012 *Journal of Petroleum Technology* was based on IEHN’s longer report *Extracting the Facts: An Investor Guide to Disclosing Risks from Hydraulic Fracturing Operations*. “Thoughtful companies recognize that this has not been a successful strategy for building public trust, and they are beginning to speak directly to the real risks associated with their operations. ...In the U.S., there have been numerous incidents of poorly constructed wells, equipment failures, degraded local and regional air quality, water contamination, strained community relations, and related government enforcement actions and private lawsuits. ... Bans and moratoria are denials of companies’ social license to operate—denials of public consent—arising from concerns about environmental and social risks.”

Here is where the above vocabulary alert becomes critical, and where a useful distinction can and should be made between “fracing” and “fracking.”

The topmost concern of the general public is the safety of drinking water aquifers. Oil and gas companies state there is no documented case of a fracture from hydraulic fracturing from a well deeper than 2,000 feet making its way through intervening rock to contaminate freshwater sands. This is entirely true for the strict, narrow engineering meaning of the process of “fracing” (without a k). Fractures rarely extend more than a few hundred feet away from the lateral; indeed, the goal is to keep fractures within the shale pay layer to avoid expending needless slickwater and sand or losing gas into a different layer of rock; moreover, thou-

sands of feet of intervening geology has been an effective seal for millions of years. However, Liroff (among others) points out that “drinking water contamination incidents have been associated with cementing failures” around the casing installed in the uppermost few hundred or 1,000 feet where the wellbore penetrates freshwater aquifers. To the non-engineering public, however, drilling a well is an integral part of the overall enterprise encompassed in the general and business press by the word “fracking” (with a k). Splitting hairs risks making companies look like lawyers arguing to acquit a perpetrator based on a legal technicality.

Another concern is the volume of freshwater and sand needed for fracing thousands of wells per year. Companies accurately point out that in regions such as Ohio and Pennsylvania where water abounds, quantities as large as 2 to 6 million gallons of freshwater per well are literally, well, a drop in the bucket of annual water use in the region by agriculture, businesses, and residences. Such large withdrawals over a few days can be problematic in local watersheds, however, especially in times of drought. Meantime, the boom in hydraulic fracturing has meant a monumental surge in demand for frac sand, leading to hundreds of square miles of open-pit mining of ancient sandstone formations in Wisconsin, Minnesota, Iowa, Texas and elsewhere, and raising concerns about risks of silicosis to workers and residents.

A third concern has been earthquakes associated with “fracking” (with a k, the enterprise broadly meant). Earthquakes in the middle of the continent—historically rare—have increased 11-fold between 2008 and 2011 compared with 1976–2007. Companies correctly point out that no earthquakes have been associated with “fracking” (meaning the specific process of hydraulic fracturing, although sensing microseisms—faint earth tremors—is an essential technique for mapping the development of fractures). However, earthquakes have indeed been associated with injection wells for disposal of produced water; a November 2011 quake in Oklahoma was a damaging 5.7 on the moment magnitude scale (now replacing the Richter scale) and felt in 17 states. Such induced seismicity is the focus of a 2012 National Research Council 300-page report and associated Congressional testimony.

**Deliberately Burned Off**

Other concerns are air emissions and safety risks of concomitant activities. In the Bakken shale of western North Dakota, valued primarily for its oil, over 240 million cubic feet of natural gas—the very product extracted from the Marcellus and Utica shales—is “flared,” or deliberately burned off into the air each day; because in the Bakken Play the gas is less valuable than the oil, no infrastructure has been built for gathering it for market. That enormous daily volume represents 30 percent of the natural gas produced in the state, annually amounting to enough to heat every U.S. household for three days. Safety concerns focus on truck traffic involved in building horizontal wells, with risks of accidents and spills of chemicals and produced water. A drilling rig and earth-moving equipment, thousands of tons of frac sand, thousands of gallons of additives, and millions of gallons of freshwater per well must be
trucked to each drilling site; moreover, the produced water that returns from the well must be trucked away to a recycling facility or to an injection well. On average, each well requires 1,000 to 1,500 truckloads. In water-rich locations such as Ohio, truck traffic is being reduced by piping the freshwater through temporary hoses laid through fields. Still, for drilling 2,000+ wells projected for 2015 for the Utica shale play, that is a lot of heavy-duty traffic on the hilly, winding two-lane roads with blind curves and little shoulder characteristic of eastern Ohio, especially in winter snow and ice.

Property rights issues are straining community relations. Three biggies are split estates, forced pooling, and setback distances. In a split estate, a current land-owner does not own mineral rights. Not only does that allow the mineral lease owner to drill horizontally under the land (paying a royalty or not, depending on the specific legal agreement), but it even may allow that party use of the surface of the land to retrieve the resources beneath—including legal right to drill an oil or gas well. In forced pooling, a land-owner who may not wish to lease mineral rights may be compelled to if enough immediate neighbors agree to lease theirs—effectively, eminent domain by majority rule. A setback distance is the minimum legal distance between a wellhead and a private residence. In Fort Worth, Texas, in the Barnett shale, the setback distance is 600 feet; in Pennsylvania (Marcellus), it is 200 feet; in Ohio (Utica), it is a mere 100 feet. Short setback distances can create complications for both a homeowner and a lender in obtaining or selling a mortgage, and may invalidate title insurance.

Although having nothing to do with the technology of hydraulic fracturing (“fracing”) per se, such legal issues surrounding shale gas recovery operations (“fracking”) have created a swirl of public distrust over perceived lack of full disclosure (at best) or trickery and coercion abetted by complicit legislators (at worst).

**Avoiding the Battlefield**

Thankfully, some leaders in the oil and gas industry are sounding a warning alarum that both environmental and social concerns must be taken seriously and acted upon responsibly. In two 2011 reports, the DOE’s Secretary of Energy Advisory Board expressed concern over “community disruption” and warned that “if action is not taken to reduce the environmental impact accompanying the very considerable expansion of shale gas production expected across the country—perhaps as many as 100,000 wells over the next several decades—there is real risk of serious environmental consequences causing a loss of public confidence that could delay or stop this activity.”

Not only is public trust at stake, but also investor trust, noted Liroff. The message of his entire IEHN report *Extracting the Facts* is: there is a strong business case to be made for earning free, prior, and informed community consent. He offers 12 core management goals that address environmental and social risks, and advocates a policy of “comply or explain.”

Another major petroleum industry consultant, George E. King of Apache Corp., in his 70-page 2012 review document *Hydraulic Fracturing 101*, constructs a detailed risk matrix of all activities involved in the full enterprise and advises, “...Given the concerns of the public, the best approach is to respond to the questions being asked ...Simplifying and reducing chemical additives along with reduction to total environmental impacts are seen as a large part of the social license to operate in the world. This is a problem to be addressed and solved, not ignored.”

Some oil and gas companies are getting the message. In April 2011, the Interstate Oil and Gas Compact Commission teamed with the Ground Water Protection Council to create a voluntary chemical disclosure registry *FracFocus* ([http://fracfocus.org/](http://fracfocus.org/)) for additives used in hydraulic fracturing; some 200 companies now participate. Others are developing “green” (non-toxic, biodegradable) alternatives to current additives.

A uniquely foresighted pro-active approach—which could serve as a model for other states—is being pioneered by Rich Cochran, CEO of the Western Reserve Land Conservancy in Ohio. The conservancy recognizes that some landowners dream of being windfall shaleionaires, and have every right to do what they want with their land within the law. Or they feel for non-monetary reasons that continuing to develop fossil fuels is right. Thus, the conservancy has launched an ambitious effort to cut through conflict to unite people to develop a shared vision (think master plan) for ensuring the preservation of the land overlying the Utica shale. “If this oilfield becomes a battlefield, we will all lose,” Cochran declared to the 600 oil and gas experts and community leaders at Crain’s Business 2013 Shale Summit in Cleveland on February 5, “because it is impossible to be deliberate, planful, cooperative and constructive. Everyone is angry. Things get destroyed. Nothing good happens.”

Ohio “is blessed with” three major world-class endowments that have sustained economic activity for 150 years, Cochran pointed out: prime nutrient-rich topsoils “glob-

*(continued on page 61)*
Executive Council Meetings
(Continued from page 7)

events to have been successful and that they should be continued at the conferences in 2014.

Engineering Futures Facilitators R. Della Rovere, F.A. Leon, C.G. Gorzkowski, Czebal, J.M. Nolan, J.R. Luchini, L.A. Matta, N.P. Gray, K. Schroeder Samuels, G.J. Morales, and R.W. Pierce were re-appointed for 2013-16, and Y.C. Chang was re-appointed for 2013-14. Wayne B. Paugh, Esq., FL Γ ’92; Stewart R. Baskin, FL E ’13; and Vanessa A. Scagliati, FL Θ ’09, as of July 1, were appointed as Engineering Futures Facilitators through June 2016.

M.M. Youssef, Ph.D., VA Γ ’94, and A.M. Richards, Ph.D., WA Α ’99, were appointed to the Advisor Recruitment and Development Committee to terms ending May 2014 and June 2015, respectively.

Councillor J.F.K. Earle reviewed a summary of the MindSET sessions conducted since August 2012 and presented an action plan to implement the teacher training component of the program. The proposal and funding were approved with a completion date of May 2014.

Councillor Piñ discussed the progress of the inaugural Young Engineers Organization in New York City. The Council expressed its continued support for the group and authorized Executive Director Gomulinski to provide the requested Headquarters assistance during this pilot year of the program.

A chapter proposal for a Greater Interest in Government project grant was declined because it did not meet the guidelines. The Council accepted the explanations from three chapters that held unapproved initiatives and agreed to waive the fines.

A new member benefit that provides numerous discounts and rewards was examined by the Council. Additional information about the benefit was requested, and action was tabled pending further review.

Executive Director Gomulinski presented an update on Headquarters staffing; several temporary employees and students have been hired for the spring and summer to support initiatives in digitizing Headquarters records; and the postings for the permanent full-time Major Gifts Officer and volunteer Director of Alumni Affairs were reviewed and accepted with minor adjustments.

The costs of the 2015 Convention bid were discussed, and the invitation of the MA Chapter to host the Convention in Providence, RI, was accepted. Plans to hold professional development sessions at the 2013 Convention in Ames, IA, were approved.

Mr. Gomulinski reviewed the status of the 2013 Alumni Giving Program; the reports from Major Gifts Officer S.D. Jennings-King were discussed; a proposal to conduct audits for 2013-15 was accepted; and a proposal to raise the initiation fee will be presented to the 2013 Convention. Several proposed changes to the Constitution and Bylaws were reviewed. The Council requested additional information be presented at the June Executive Council meeting before sending them to the Convention for review and action.

Shale Gas Recovery 101
(Continued from page 27)
ally rare but abundant here” for agriculture, freshwater resources that attract fishermen and tourism, and unfragmented wildlife habitats that boost exemplary birdwatching and trophy hunting. “Economic activity related to natural endowments like agriculture and wildlife recreation never goes away, while economic activity such as oil and gas always goes away,” he cautioned (the productivity of many shale gas wells declines by three-quarters in their first one to three years). “One is a golden goose, and the other is a one-time lottery winner... It would be so foolish to unwittingly destroy our golden goose to buy a one-time lottery winner, especially because we can do both if we make the right choice for ourselves and our children.” He included mayors, landowners, oil and gas engineers, government officials, conservationists, and others to collaborate in thoughtful planning of ways to guide oil and gas development to minimize unintended negative long-term consequences.

“When the wells are no longer producing,” Cochrane asked, “what choice will we have made for our grandchildren?”

Selected References
Only major references central to this print article are cited below (copy and paste the URLs for best results). More text with numbered, footnoted references appears online at:


Percentage of gas flared was 30% of Sept and Oct 2012 production of ~796,000 MCF/day = ~240,000 MCF/hour https://www.dnrc.nd.gov/algas/directorsc/oil/gas/2012-12-17.pdf


About the Author
Trudy E. Bell, M.A., (t.e.bell@ieee.org, www.trudyebell.com, @trudyebell) is senior writer for the University of California High-Performance AstroComputing Center and a contributing editor for Sky & Telescope magazine. She is a former editor for Scientific American and IEEE Spectrum magazines, and she has written a dozen books and nearly 500 articles. This is her 20th feature for The Bent.

Summer 2013 A THE BENT OF TAU BETA PI 61