

COMMENT

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A drilling operation in Bradford County, Pennsylvania: one of the many places where shale rocks are fractured to release oil and gas.

Should fracking stop?

Extracting gas from shale increases the availability of this resource, but the health and environmental risks may be too high.

POINT

Yes, it's too high risk

Natural gas extracted from shale comes at too great a cost to the environment, say Robert W. Howarth and Anthony Ingraffea.

Natural gas from shale is widely promoted as clean compared with oil and coal, a 'win-win' fuel that can lessen emissions while still supplying abundant fossil energy over coming decades until a switch to renewable energy sources is made. But shale gas isn't clean, and shouldn't be used as a bridge fuel.

Shale rock formations can contain vast amounts of natural gas (which is mostly methane). Until quite recently, most of **PAGE 272** ►

COUNTERPOINT

No, it's too valuable

Fracking is crucial to global economic stability; the economic benefits outweigh the environmental risks, says Terry Engelder.

After a career in geological research on one of the world's largest gas supplies, I am a born-again 'cornucopian'. I believe that there is enough domestic gas to meet our needs for the foreseeable future thanks to technological advances in hydraulic fracturing. According to IHS, a business-information company in Douglas County, Colorado, the estimated recoverable gas from US shale source rocks using fracking is about 42 trillion cubic metres, almost **PAGE 274** ►

POINT: FRACKING: TOO HIGH RISK ▶ this gas was not economically obtainable, because shale is far less permeable than the rock formations exploited for conventional gas. Over the past decade or so, two new technologies have combined to allow extraction of shale gas: 'high-volume, slick-water hydraulic fracturing' (also known as 'fracking'), in which high-pressure water with additives is used to increase fissures in the rock; and precision drilling of wells that can follow the contour of a shale layer closely for 3 kilometres or more at depths of more than 2 kilometres (see 'Fracking for fuel'). Industry first experimented with these two technologies in Texas about 15 years ago. Significant shale-gas production in other states, including Arkansas, Pennsylvania and Louisiana, began only in 2007–09. Outside North America, only a handful of shale-gas wells have been drilled.

Industry sources claim that they have used fracking to produce more than 1 million oil and natural gas wells since the late 1940s. However, less than 2% of the well fractures since the 1940s have used the high-volume technology necessary to get gas from shale, almost all of these in the past ten years. This approach is far bigger and riskier than the conventional fracking of earlier years. An average of 20 million litres of water are forced under pressure into each well, combined with large volumes of sand or other materials to help keep the fissures open, and 200,000 litres of acids, biocides, scale inhibitors, friction reducers and surfactants. The fracking of a conventional well uses at

most 1–2% of the volume of water used to extract shale gas¹.

Many of the fracking additives are toxic, carcinogenic or mutagenic. Many are kept secret. In the United States, such secrecy has been abetted by the 2005 'Halliburton loophole' (named after an energy company headquartered in Houston, Texas), which exempts fracking from many of the nation's major federal environmental-protection laws, including the Safe Drinking Water Act. In a 2-hectare site, up to 16 wells can be drilled, cumulatively servicing an area of up to 1.5 square kilometres, and using 300 million litres or more of water and additives. Around one-fifth of the fracking fluid flows back up the well to the surface in the first two weeks, with more continuing to flow out over the lifetime of the well. Fracking also extracts natural salts, heavy metals, hydrocarbons and radioactive materials from the shale, posing risks to ecosystems and public health when these return to the surface. This flowback is collected in open pits or large tanks until treated, recycled or disposed of.

Because shale-gas development is so new, scientific information on the environmental costs is scarce. Only this year have studies begun to appear in peer-reviewed journals, and these give reason for pause. We call for a moratorium on shale-gas development to allow for better study of the cumulative risks to water quality, air quality and global climate. Only with such comprehensive knowledge can appropriate regulatory frameworks be developed.

We have analysed the well-to-consumer lifecycle greenhouse-gas

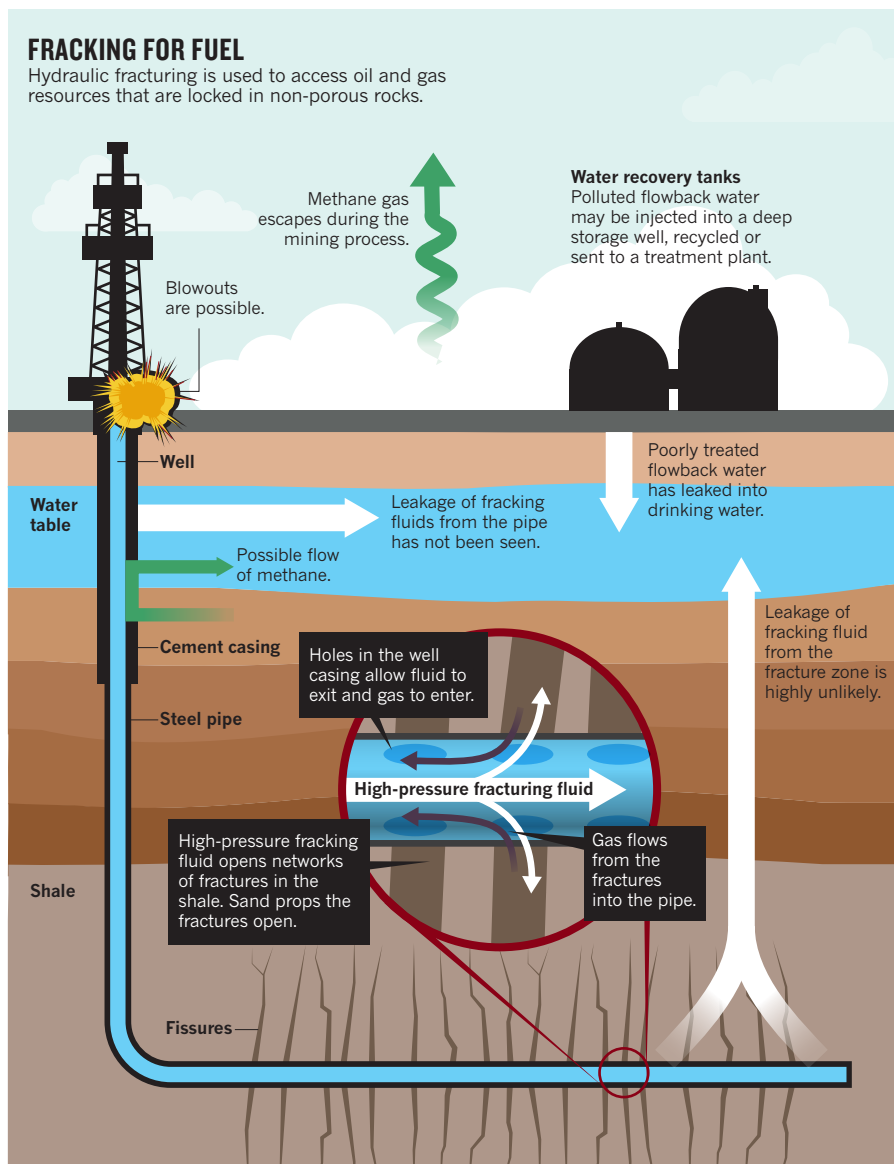
footprint of shale gas when used for heat generation (its main use), compared with conventional gas and other fossil fuels — the first estimate in the peer-reviewed literature². Methane is a major component of this footprint, and we estimate that 3.6–7.9% of the lifetime production of a shale gas well (compared with 1.7–6% for conventional gas wells) is vented or leaked to the atmosphere from the well head, pipelines and storage facilities. In addition, carbon dioxide is released both directly through the burning of the gas for heat, and to a lesser extent indirectly through the process of developing the resource.

Methane is a potent greenhouse gas, so even small emissions matter. Over a 20-year time period, the greenhouse-gas footprint of shale gas is worse than that for coal or oil (see 'A daunting climate footprint'). The influence of methane is lessened over longer time scales, because methane does not stay in the atmosphere as long as carbon dioxide. Still, over 100 years, the footprint of shale gas remains comparable to that of oil or coal.

When used to produce electricity rather than heat, the greater efficiency of gas plants compared with coal plants slightly lessens the footprint of shale gas³. Even then, the total greenhouse-gas footprint from shale gas exceed those of coal at timescales of less than about 50 years.

Methane venting and leakage can be decreased by upgrading old pipelines and storage systems, and by applying better technology for capturing gas in the 2-week flowback period after fracking. But current economic incentives are not sufficient to drive such improvements; stringent regulation will be required. In July, the US Environmental Protection Agency released a draft rule that would push industry to reduce at least some methane emissions, in part focusing on post-fracking flowback. Nonetheless, our analysis² indicates that the greenhouse-gas footprint of shale gas is likely to remain large.

Another peer-reviewed study looked at



private water wells near fracking sites⁴. It found that about 75% of wells sampled within 1 kilometre of gas drilling in the Marcellus shale in Pennsylvania were contaminated with methane from the deep shale formations. Isotopic fingerprinting of the methane indicated that deep shale was the source of contamination, rather than biologically derived methane, which was present at much lower concentrations in water wells at greater distances from gas wells. The study found no fracking fluids in any of the drinking-water wells examined. This is good news, because these fluids contain hazardous materials, and methane itself is not toxic. However, methane poses a high risk of explosion at the levels found, and it suggests a potential for other gaseous substances in the shale to migrate with the methane and contaminate water wells over time.

Have fracking-return fluids contaminated drinking water? Yes, although the evidence is not as strong as for methane contamination, and none of the data has yet appeared in the peer-reviewed literature (although a series of articles in *The New York Times* documents the problem, for example go.nature.com/58hxtot and go.nature.com/58koj3). Contamination can happen through blowouts, surface spills from storage facilities, or improper disposal of fracking fluids. In Texas, flowback fluids are disposed of through deep injection into abandoned gas or oil wells. But such wells are not available everywhere. In New York and Pennsylvania, some of the waste is treated in municipal sewage plants that weren't designed to handle these toxic and radioactive wastes. Subsequently, there has been contamination of tributaries of the Ohio River with barium, strontium and bromides from municipal wastewater treatment plants receiving fracking wastes⁵. This contamination apparently led to the formation of dangerous brominated hydrocarbons in municipal drinking-water supplies that relied on these surface waters, owing to interaction of the contaminants with organic matter during the chlorination process.

Shale-gas development — which uses huge diesel pumps to inject the water — also creates local air pollution, often at dangerous levels. Volatile hydrocarbons such as benzene (which occurs naturally in shale, and is a commonly used fracking additive) are one major concern. The state of Texas reports benzene concentrations in air in the Barnett shale area that sometimes exceed acute toxicity standards⁶, and although the concentrations observed in the Marcellus shale area in Pennsylvania are lower⁷ (with only 2,349 wells drilled at the time these air contaminants were reported, out of an expected total of 100,000), they are high enough to pose a risk of cancer from chronic exposure⁸. Emissions from drills, compressors, trucks and other machinery can lead to very high levels of ground-level ozone, as documented in parts of Colorado that had not experienced severe air pollution before shale-gas development⁹.

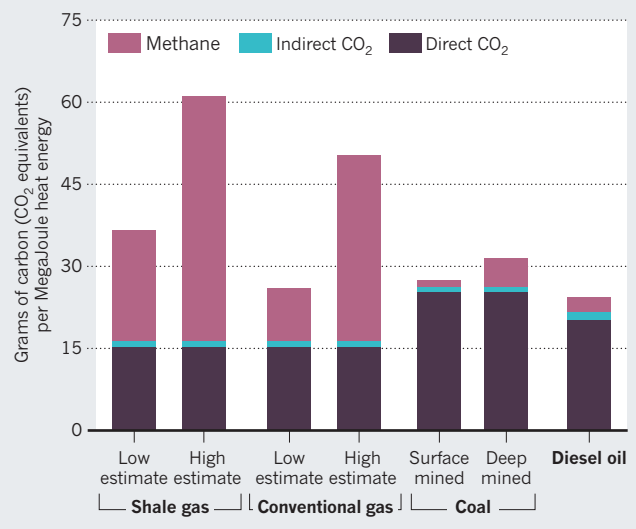
UNPROFITABLE PROGRESS

The argument for continuing shale-gas exploitation often hinges on the presumed gigantic size of the resource. But this may be exaggerated. The Energy Information Administration of the US Department of Energy estimates that 45% of US gas supply will come from shale gas by 2035 (with the vast majority of this replacing conventional gas, which has a lower greenhouse-gas footprint). Other gas industry observers are even more bullish. However, David Hughes, a geoscientist with more than 30 years experience with the Canadian Geological Survey, concludes in his report for the Post Carbon Institute, a non-profit group headquartered in Santa Rosa, California, that forecasts are likely to be overstated, perhaps greatly so³. Last month, the US Geological Survey released a new estimate of the amount of gas in the Marcellus shale formation (the largest shale-gas formation in the United States), concluding that the Department of Energy has overestimated the resource by some five-fold¹⁰.

Shale gas may not be profitable at current prices, in part because

A DAUNTING CLIMATE FOOTPRINT

Over 20 years, shale gas is likely to have a greater greenhouse effect than conventional gas or other fossil fuels.



production rates for shale-gas wells decline far more quickly than for conventional wells. Although very large resources undoubtedly exist in shale reservoirs, an unprecedented rate of well drilling and fracking would be required to meet the Department of Energy's projections, which might not be economic³. If so, the recent enthusiasm over shale gas could soon collapse, like the dot-com bubble.

Meanwhile, shale gas competes for investment with green energy technologies, slowing their development and distracting politicians and the public from developing a long-term sustainable energy policy.

With time, perhaps engineers can develop more appropriate ways to handle fracking-fluid return wastes, and perhaps the technology can be made more sustainable and less polluting in other ways. Meanwhile, the gas should remain safely in the shale, while society uses energy more efficiently and develops renewable energy sources more aggressively. ■

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COUNTERPOINT: FRACKING: TOO VALUABLE ▶ equal to the total conventional gas discovered in the United States over the past 150 years, and equivalent to about 65 times the current US annual consumption. During the past three years, about 50 billion barrels of additional recoverable oil have been found in shale oil deposits — more than 20% of the total conventional recoverable US oil resource. These ‘tight’ oil resources, which also require fracking to access, could generate 3 million barrels a day by 2020, offsetting one-third of current oil imports. International data aren’t as well known, but the effect of fracking on global energy production will be huge (see ‘Global gas reserves’).

Global warming is a serious issue that fracking-related gas production can help to alleviate. In a world in which productivity is closely linked to energy expenditure, fracking will be vital to global economic stability until renewable or nuclear energy carry more of the workload. But these technologies face persistent problems of intermittency and lack of power density or waste disposal. Mankind’s inexorable march towards 9 billion people will require a broad portfolio of energy resources, which can be gained only with breakthroughs such as fracking. Such breakthroughs should be promoted by policy that benefits the economy yet reduces overall greenhouse-gas emissions. Replacing coal with natural gas in power plants, for example, reduces the plants’ greenhouse emissions by up to 50% (ref. 1).

At present, fracking accounts for 50% of locally produced natural gas (see ‘US natural-gas production set to explode’) and 33% of local petroleum. The gas industry in America accounts for US\$385 billion in direct economic activity and nearly 3 million jobs. Because gas wells have notoriously steep production declines, stable supplies depend on a steady rate of new well completions. A moratorium on new wells would have an immediate and harsh effect on the US economy that would trigger a global ripple.

Global warming aside, there is no compelling environmental reason to ban hydraulic fracturing. There are environmental risks, but these

can be managed through existing, and rapidly improving, technologies and regulations. It might be nice to have moratoria after each breakthrough to study the consequences (including the disposal of old batteries or radioactive waste), but because energy expenditure and economic health are so closely linked, global moratoria are not practical.

The gains in employment, economics and national security, combined with the potential to reduce global greenhouse-gas emissions if natural gas is managed properly, make a compelling case.

NO NEED FOR PANIC

I grew up with the sights, sounds and smells of the Bradford oil fields in New York state. My parents’ small farm was over a small oil pool, with fumes from unplugged wells in the air and small oil seeps coating still waters. Before college, I worked these oil fields as a roustabout, mainly cleaning pipes and casings. Like me, most people living in such areas are not opposed to drilling, it seems. In my experience, such as during the recent hearings for the Pennsylvania Governor’s Marcellus Shale Advisory Commission, activists from non-drilling regions outnumber those from drilling regions by approximately two to one.

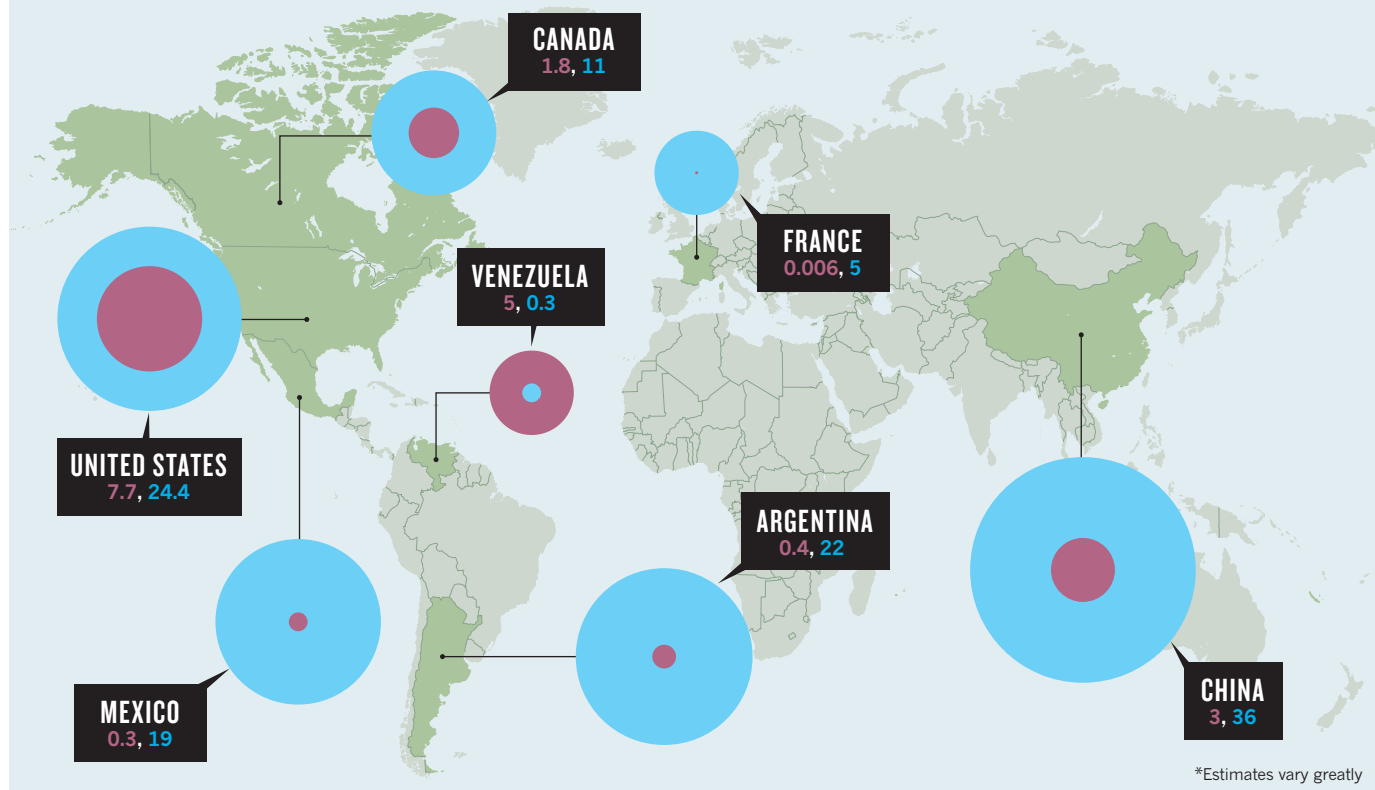
Modern, massive hydraulic fracturing is very different from that used decades ago. Larger pads are required to accommodate larger drill rigs, pumps and water supplies. People usually infer from this that modern techniques have a greater impact on the environment. This isn’t necessarily true. Although more water is used per well, there are far fewer wells per unit area. In the Bradford oil fields in the 1950s, a 640-acre parcel of land might have held more than 100 wells, requiring some 18 kilometres of roads, and with a lattice of surface pipelines. During the Marcellus development today, that same parcel of land is served by a single pad of five acres, with a 0.8-kilometre right-of-way for roads and pipelines.

Although ‘fracking’ has emerged as a scare term in the press,

GLOBAL GAS RESERVES

Using fracking to access shale gas would vastly increase gas resources in many countries. Russia and the Middle East are not included because their large reserves of easily accessible gas will render shale gas less important there.

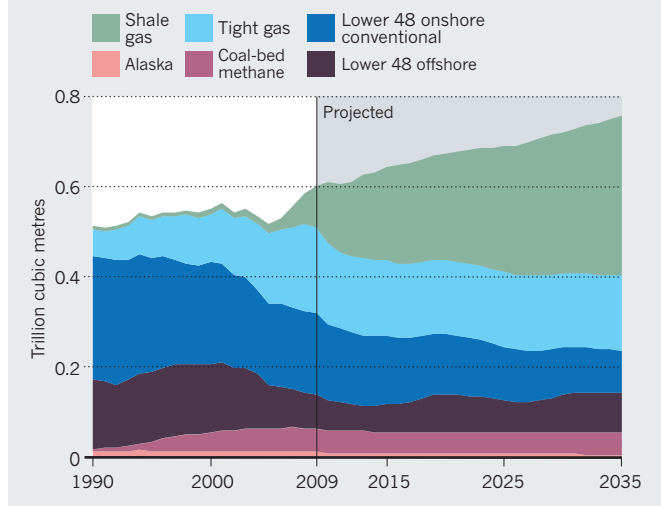
Proven gas reserves (trillion cubic metres) Technically recoverable shale gas resources* (trillion cubic metres)



SOURCE: EIA

US NATURAL-GAS PRODUCTION SET TO EXPLODE

Shale-gas output already matches production from offshore wells in the lower 48 states (mainland US states excluding Alaska). Gas (shale and tight) extracted by fracking is set to overtake all other sources.



hydraulic fracturing is not so strange or frightening. The process happens naturally: high-pressure magma, water, petroleum and gases deep inside Earth can crack rock, helping to drive plate tectonics, rock metamorphism and the recycling of carbon dioxide between the mantle and the atmosphere.

Oil and gas have their origins in muds rich with organic matter in low-oxygen water bodies. Over millions of years, some of these deposits were buried and 'cooked' in the deep Earth, turning the organic matter into fossil fuel and the mud to shale rocks. In many areas, natural hydraulic fracturing allowed a large portion of oil and gas to escape from the dense, impermeable shale and migrate into neighbouring, more porous rocks. Some of this fossil fuel was trapped by cap rock, creating the conventional reserves that mankind has long tapped. The groundwater above areas that host such conventional deposits naturally contains methane, thanks to natural hydraulic fracturing of the rock and the upward seeping of gas into the water table over long time periods.

More than 96% of all oil and gas has been released from its original source rocks; industrial hydraulic fracturing aims to mimic nature to access the rest. As in nature, industrial fracking can be done with a wide variety of gases and liquids. Nitrogen can be used to open cracks in the shale, for example. But this is inefficient, because of the energy lost by natural decompression of the nitrogen gas. Water is more efficient, because very little energy is wasted in decompression. Sand is added to prop open the cracks, and compounds such as surface-tension reducers are added to improve gas recovery.

UNDER CONTROL

Two main environmental concerns are water use and water contamination. Millions of gallons of water are required to stimulate a well. In Pennsylvania, high rainfall means that water is abundant, and regulations ensure that operators stockpile rainwater during the wet season to use during drier months (thus the injection of massive volumes of water in the Bradford oil fields for secondary recovery of oil, once the well pressure has fallen, flew under the radar of environmentalists for half a century). Obtaining adequate water for industrial fracking in dry regions such as the Middle East and western China is a local concern, but is no reason for a global moratorium.

Press reports often repeat strident concerns about the chemicals added to fracking fluids. But many of these compounds are relatively benign. One commonly used additive is similar to simethicone, which is also used in antacids to reduce surface tension and turn small bubbles in the stomach into larger ones that can move along more easily.

Many of the industrial additives are common in household products. Material safety data sheets for these additives are required by US regulation. Industry discloses additives on a website called FracFocus.org, run by state regulators.

Some people have expressed worries that fracking fluids might migrate more than 2 kilometres upwards from the cracked shale into groundwater. The Ground Water Protection Council, a non-profit national association of state groundwater and underground-injection control agencies headquartered in Oklahoma City, has found no instance in which injected fluid contaminated groundwater from below². This makes sense: water cannot flow this distance uphill in timescales that matter. This is the premise by which deep disposal wells, used to hold toxic waste worldwide, are considered safe. During gas production, the pressure of methane is reduced: this promotes downward, not upward flow of these fluids.

Gas shale contains a number of materials that are carried back up the pipe to the surface in flowback water, including salts of barium and radioactive isotopes, that might be harmful in concentrated form. According to a recent *New York Times* analysis, these elements can be above the US Environmental Protection Agency's sanctioned background concentrations in some flowback tanks. Industry is moving towards complete recycling of these fluids so this should be of less concern to the public. However, production water will continue to flow to the surface in modest volumes throughout the life of a well; this water needs to be, and currently is, treated to ensure safe disposal.

The real risk of water contamination comes from these flowback fluids leaking into streams or seeping down into groundwater after reaching the surface. This can be caused by leaky wellheads, holding tanks or blowouts. Wellheads are made sufficiently safe to prevent this eventuality; holding tanks can be made secure; and blowouts, while problematic, are like all accidents caused by human error — an unpredictable risk with which society lives.

“With hydraulic fracturing, as in many cases, fear levels exceed the evidence.”

Although methane coming up to the surface within the steel well pipe cannot escape into the surrounding rocks or groundwater, it is possible that the cement seal between the well and the bedrock might allow methane from shallow sandstone layers (rather than the reservoir deep below) to seep up into groundwater. Methane is a tasteless and odourless component of groundwater that can be consumed without ill effect when dissolved. It is not a poison. Long before gas-shale drilling, regulators warned that enclosed spaces, such as houses, should be properly ventilated in areas with naturally occurring methane in groundwater.

An alarm has been sounded too about the effect of escaped methane on global warming. The good news is that methane has a very short half-life in the atmosphere: carbon dioxide emitted during the building of the first Sumerian cities is still affecting our climate, whereas escaped methane from the fracturing of the Barnett shale in 1997 is more than half gone. Industry can and should take steps to reduce air emissions, by capturing or flaring methane and converting motors and compressors from diesel to natural gas.

Risk perception is ultimately subjective: facts are all too easily combined with emotional responses. With hydraulic fracturing, as in many cases, fear levels exceed the evidence. ■

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The author declares competing financial interests: details accompany this article online at go.nature.com/pjenyw.