(Almost) Everything You Wanted to Know about Fracking –
but were Afraid to Ask

Frank R. Smith
Retired professor of chemistry

Presentation to:
The Research Exchange Group on the Health Impacts of Fracking
May 6, 2015
My Introduction to Hydraulic Fracturing

An article by D’Arcy Jenish in the January 2012 Canadian Chemical News, titled “Fracking Furor”, attracted my attention, both for what it contained and what seemed missing. My letter was published in February 2012.
Later in 2012, through involvement with the organization Canadian Physicians for the Environment, I came to know about Fracking issues in New Brunswick. An emergency physician there, active in opposition to fracking, was helpful in guiding me to other sources of health-related information.
The Science and Politics of Fracking
Fracturing using horizontal drilling allows energy companies to penetrate rock formations many kilometres below the surface.
Protestors in New Brunswick staged anti-fracking protests last August, fearing that fracking would contaminate groundwater with chemicals.
LETTER TO THE EDITOR

Adding fuel to fracking

In last month’s story, “Fracking Furo: The Science and Politics of Fracking,” neither the politics nor the science was adequately reported. Salient facts about fracking from last April’s US House of Representatives Energy and Commerce Report, {http://democrats.energycommerce.house.gov/sites/default/files/documents/Hydraulic-Fracturing-Chemicals-2011-4-18.pdf} “Chemicals Used in Hydraulic Fracturing”, include:

• Between 2005 and 2009, 14 oil and gas service companies used 2,500 hydraulic fracturing additives containing 750 chemicals, a total volume (exclusive of water added) of 780 million gallons.
• In the same period, fracking used 93.6 million gallons of 279 products containing undisclosed chemicals.
• Some disclosed components used such as silica, salt, gelatin and citric acid seem harmless.
• Others, such as methanol, isopropanol and ethylene glycol are not harmless. Others, such as 2-butoxyethanol (2-BE), used as a foaming agent or surfactant, are easily absorbed in humans following exposure. Exposure to 2-BE can cause hemolysis (red blood cell destruction) and spleen, liver and bone marrow damage.
• Some chemicals used are or may be human carcinogens: diesel fuel, benzene, naphthalene and acrylamide. Others such as hydrogen chloride and hydrogen fluoride are toxic.

Published in Canadian Chemical News, February 2012
LETTER TO THE EDITOR

The Committee on Energy and Commerce remarks:

"Hydraulic fracturing has opened access to vast domestic reserves of natural gas that could provide an important stepping stone to a clean energy future. Yet questions about the safety of hydraulic fracturing persist, which are compounded by the secrecy surrounding the chemicals used in hydraulic fracturing fluids.

"Groundwater contamination doesn't necessarily come directly from injecting fracking chemicals deep into shale rock formations well below water aquifers but from waste water evaporation ponds and poorly constructed pipelines taking the waste water and chemicals to processing facilities."

Water contamination is not the only problem. In the town of Dimock, Pa., 13 water wells were contaminated with methane (one blew up) and the gas company, Cabot Oil & Gas, had to construct a pipeline to bring in clean water.

Some countries, like France and South Africa and provinces such as Quebec and Nova Scotia have banned or delayed permission to proceed with fracking.

Frank R. Smith, FCIC, Retired professor, Chemistry Department, Memorial University of Newfoundland

Published in Canadian Chemical News, February 2012
Fear of fracking: How public concerns put an energy renaissance at risk
Excerpts from article by Carrie Tait and Shawn McCarthy, Globe and Mail March 10th 2012

The public fear of fracking has come to encompass all the risks associated with development of shale gas and tight oil: from seepage of fracking fluids into aquifers, to methane in well water, to pollution from wastewater, and to earthquakes caused by re-injecting the wastewater underground.

A view is emerging that the most obvious and pressing threat comes from poor well construction, in which broken or ill-fitting cement well casings can allow methane gas and fluids to leak into drinking water.

Shale gas and tight oil development is booming in British Columbia, Alberta and Saskatchewan with little additional regulatory oversight, while Quebec has imposed a moratorium to review science.
The potent mixture behind fracking fluids
Excerpts from article by Carrie Tait, Globe and Mail March 10th 2012

Trican Well Service Ltd. uses guar bean gum as its preferred frack additive. Hydraulic fracturing companies use dozens of additives – plenty of which are harmful chemicals. Fracking is different from drilling, which precedes it.

Pumper trucks push frack fluid through a pipe connected to the wellhead and down the wellbore. Nitrogen is also used and pumped at extremely high pressures, mixing with frack fluid and causing the target rock layer to crack.

A typical fracture will be 1 cm wide, 30 m high, and 100m long, and comes with smaller splinters. As the fracture grows, sand is added to the frack fluid and into the cracks, typically 800-3500 m below the surface, and stretch horizontally 1,000 - 1,800 m.
The shaky state of fracking
Excerpts from article by Shawn McCarthy, Globe and Mail March 10th 2012

Last Christmas Eve, residents of Youngstown, Ohio, were shaken by a rare earthquake, followed by another a week later on New Year’s Eve.

Stanford University geologist Mark Zoback said the risks of seismic activity can be managed by not drilling injection wells in fault zones, monitoring seismic activity, and managing the flow of injections to avoid buildup. No injection-triggered earthquake has ever caused serious injury or significant damage.

Simon Fraser geologist John Clague said several minor tremors in northeastern B.C. have been caused by the re-injection of oil industry wastewater, notably around Encana Corp.’s Horn River operations. Just because past earthquakes have all been small doesn’t mean you couldn’t get a larger one,” he said.
Secrecy, safety

Last April, the U.S. House of Representatives energy and commerce committee reported on “Chemicals Used in Hydraulic Fracturing” in the U.S. and concluded that 2,500 fracturing products were in use. These contain 750 different chemical compounds, 650 of which are known or possible carcinogens or hazardous air pollutants (The Fear Of Fracking – Globe & Mail Report on Business, March 10).

Questions about the safety of the process are compounded by the secrecy surrounding the chemicals in the hydraulic fracturing fluids. Some fracking companies are injecting fluids containing unknown chemicals, about which they have limited understanding of the potential risks to human health – these products are “proprietary” or “trade secret” and have no MSDS (material safety data sheet) information.

Also, surely the very act of fracturing the rock below makes contamination of waters above more probable?

Frank R. Smith, Fellow of the Chemical Institute Of Canada, St. John’s

Published in the Globe and Mail, March 12th 2012
Refers to
## Comments on Chemicals Proposed by Black Spruce Exploration

<table>
<thead>
<tr>
<th>Additive Example</th>
<th>Effectiveness</th>
<th>Health Problems?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrochloric Acid HCl</td>
<td>Dissolves carbonates; initiates cracks.</td>
<td>Minor: stomach acid.</td>
</tr>
<tr>
<td>Glutaraldehyde CH₂(CH₂CHO)₂</td>
<td>Organic disinfectant – biocide.</td>
<td>Don’t inhale!!! TLV: 0.2 ppm</td>
</tr>
<tr>
<td>Ammonium persulfate (NH₄)₂S₂O₈</td>
<td>Aggressive oxidant, delays “breakdown” of the gel.</td>
<td>Hazardous with organics!</td>
</tr>
<tr>
<td>Potassium chloride KCl</td>
<td>A salt; stabilizer of gel.</td>
<td>Not toxic by ingestion; fertilizer.</td>
</tr>
<tr>
<td>Formic acid HCOOH</td>
<td>Reducing agent; inhibits pipe corrosion.</td>
<td>Don’t inhale!! TLV: 5 ppm Burns skin &amp; lungs.</td>
</tr>
</tbody>
</table>

See [http://www.blspexp.com/media/factsheets/factsheets.htm](http://www.blspexp.com/media/factsheets/factsheets.htm)  
TLV means Threshold Limit Value (not to be exceeded)
### Comments on Chemicals Proposed by Black Spruce Exploration

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<tr>
<th>Additive Example</th>
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<th>Health Problems?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Borates $\text{Na}_3\text{BO}_3$</td>
<td>Borate cross-linked gel increases viscosity. Reverse crosslink by altering pH.</td>
<td>Borax gentle, non-toxic cleaning agent.</td>
</tr>
<tr>
<td>Zirconates $\text{Na}_2\text{ZrO}_4$</td>
<td>Similar to borates.</td>
<td>TLV: $5\text{mg/m}^3$</td>
</tr>
<tr>
<td>Polyacrylamide $\text{CH}_2\text{-HC-C}=\text{O-NH}_2$</td>
<td>“Slicks” the water. Reduces friction between pipe and fluid.</td>
<td>Possible depolymerization to acrylamide: TLV: $0.3 \text{ mg/m}^3$ Dust irritates skin, eyes and CNS.</td>
</tr>
</tbody>
</table>

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<th>Effectiveness</th>
<th>Health Problems?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Guar bean gum</td>
<td>Thickens sand mix.</td>
<td>Used in ice cream</td>
</tr>
<tr>
<td>Citric acid</td>
<td>Prevents oxide pptn.</td>
<td>Lemon juice.</td>
</tr>
<tr>
<td>Lauryl sulfate, sodium</td>
<td>Prevents emulsion formation in fluid.</td>
<td>Toxic to aquatics.</td>
</tr>
<tr>
<td>Sodium hydroxide</td>
<td>As required; adjusts pH.</td>
<td>Formed from soap.</td>
</tr>
<tr>
<td>Sodium poly-carboxylate</td>
<td>Prevents scale deposits in pipe.</td>
<td>Household cleaning detergent.</td>
</tr>
<tr>
<td>2-butoxyethanol = butycellosolve = ethylene glycol monobutyl ether</td>
<td>Surfactant, used in cleaning agents.</td>
<td>Respiratory irritant, hemolysis!!; (eyes/skin) TLV: 50/25 ppm; flash point = 61°C.</td>
</tr>
</tbody>
</table>

See [http://www.blspexp.com/media/factsheets/factsheets.htm](http://www.blspexp.com/media/factsheets/factsheets.htm)
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COLORADO August 2008 Near-fatality – secrecy blamed

Cathy Behr, an emergency room nurse in Durango, Colo., had almost died after treating a wildcatter who had been splashed in a fracking fluid spill at a BP natural gas rig.

The hospital sounded alarms and locked down the ER. But a few days later Behr lay in critical condition facing multiple organ failure. Her doctors searched for details that could save their patient.

Behr’s doctor learned, weeks later, what ZetaFlow, a drill stimulation fluid, was made of, but he was sworn to secrecy by the chemical’s manufacturer, and could not tell his patient.

From http://www.propublica.org/article/buried-secrets-is-natural-gas-drilling-endangering-us-water-supplies-1113
At a Trican Well Service fracking site near Sundre, Alta., 45 personnel monitor all aspects of the operation with computers in the control trailer. The project involves hydraulically fracturing two oil wells drilled on the same pad. Each well descends about 2,000 metres deep, then extends horizontally another 1,500 metres into the targeted Cardium sandstone formation.

From Canadian Chemical News November, December 2014
Excerpts from report by M. Lowey, Canadian Chemical News, Nov-Dec 2014

“Tracking the Chemical Fracking Controversy”

At Trican Well Service’s operation near Sundre, about 120 km northwest of Calgary, 10 powerful pumper trucks, running full bore, generate more than 22,000 horsepower at 5,000 to 6,500 pounds per square inch (PSI), to frack:

Two wells about 2,000 metres deep, using 5.24 million litres of fresh water, 925 tonnes of sand, 100,000 cubic metres of N2 gas and 27,420 litres (0.52%) chemicals (16,950 litres claimed as non-toxic, biodegradable and non-bioaccumulating).

Details on next slides:
Excerpts from report by M. Lowey, Canadian Chemical News, Nov-Dec 2014
“Tracking the Chemical Fracking Controversy”

Details of chemicals provided by Trican Well Service Ltd.:

- A non-hazardous chemical stabilizer to stop clay particles in the rock formation from swelling and plugging up the well;

- A “green” friction reducer, a polymer that reduces friction of the water against the well pipe (called “slickwater” fracking), allowing more efficient pumping;

Note that the reporter was unable to publish the names of any of the chemicals.
Excerpts from report by M. Lowey, Canadian Chemical News, Nov-Dec 2014
“Tracking the Chemical Fracking Controversy”

Details of chemicals provided by Trican Well Service Ltd. contd:

- A biocide (naturally biodegradable within 24 hours) to kill bacteria in the formation that can cause sludge, corrosion or toxic hydrogen sulphide gas;

- A “green breaker,” a non-hazardous chemical that breaks the long molecular chains of the friction-reducing polymer after pumping stops, so the frac fluid flows back out of the well;

- A surfactant which helps the sand particles disperse evenly into the fractures.
From Canadian Chemical News November, December 2014
Note sign ‘1993’ denoting the family of chemicals contained therein.
Union of Concerned Scientists – Center for Science & Democracy
On July 25, 2013 a live webcast of the Lewis M. Branscomb Forum in Los Angeles, CA.

Science, Democracy, and Community Decisions on Fracking occurred.
Dr. Andrew Rosenberg, Director, Center for Science and Democracy, Union of Concerned Scientists, drew attention to the Louisville Charter and said that there are some places where we should not frack.
LOUISVILLE CHARTER FOR SAFER CHEMICALS

In May 2004, Louisville hosted a meeting of a network of groups and individuals whose common goal is to work together on chemical policies and campaigns to protect human health and the environment from exposures to unnecessary harmful chemicals.
Such principles are apparently unknown to the oil and gas companies engaging in fracking.
December 2014 marks the 30th anniversary of a grim milestone for the world’s chemical industry – the accidental release of methyl isocyanate gas from a pesticide plant in Bhopal, India, which killed about 4,000 people and compromised the health of thousands more.

In 1979, the Canadian Chemical Producers’ Association created the Guiding Principles of Responsible Care that addressed all aspects of chemical processing from research to disposal. About 60 national manufacturing associations have signed on, while major chemical companies have also endorsed the Responsible Care Charter. The book *Responsible Care: A Case Study* published by the International Union of Pure and Applied Chemistry explores how far Responsible Care has progressed over the course of three decades.
The Halliburton Loophole 2005

The U.S. Energy Policy Act of 2005 exempted the fracking industry from seven major federal environmental laws that simultaneously protect public health:

1. the Clean Water Act (CWA),
2. the Clean Air Act (CAA),
3. the Safe Drinking Water Act (SDWA),
4. the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA, otherwise known as the Superfund Act),
5. the Resource, Conservation and Recovery Act (RCRA),
6. the Toxic Release Inventory under the Emergency Planning and Community Right-to-Know Act (EPCRA),
7. and the National Environmental Policy Act (NEPA).

• In 2008, the EPA began sampling well water in Pavillion, Wyo., because of residents’ complaints.

• In 2009, families in Dimock, Pa., filed a federal lawsuit against an oil and gas company for allegedly contaminating their well water with methane.

• In 2010 the EPA designed a water study around these elements:
  • Analysis of data from companies about the ingredients in fracking fluids, fracking procedures and the health effects of fracking chemicals.
  • Computer modeling to understand whether fracking could contaminate water.
  • Lab studies of fracking fluids creating new compounds.
  • Toxicology assessments of fracking fluids.
  • Case studies, including retrospective research examining cases of reported water contamination at fracked sites.
  • Prospective, or baseline, studies in places where fracking had not yet happened.

EPA’s FAILURE

But after five years of fighting with the oil and gas industry, the agency may still be unable to provide a clear answer when a draft of the study is published this spring, based on internal EPA documents and interviews with people who have knowledge of the study.

"We won’t know anything more in terms of real data than we did five years ago," said Geoffrey Thyne, a geochemist and a member of the EPA’s 2011 Science Advisory Board, a group of independent scientists who reviewed the draft plan of the study. "This was supposed to be the gold standard. But they went through a long bureaucratic process of trying to develop a study that is not going to produce a meaningful result."
Harper’s Magazine March 2013
Anthony Ingraffea would say that a third innovation was necessary: Slickwater fracking.
“Bakken Business: The Price of North Dakota’s Fracking Boom”
Excerpted & edited from Richard Manning, Harper’s March 2013

Even the trivial effects seem not so trivial in multiplication. During the first year of a well’s life—the year of drilling, plugging, and fracking—will require 2,000 truck trips. The beat-up two-lanes and gravel roads that thread between wells handle at least 4 million trips a year. Farmers and ranchers living on these back roads no longer open windows in summer because of the dust. Roadside litter is now dependably punctuated with “trucker bombs”—plastic bottles filled with urine—rest stops on the prairie being few and far between. Trucks need drivers; roads need builders; fleets need mechanics; men need houses, which need carpenters; rigs need workers; the hundreds of new companies in the Bakken need accountants, flacks, lobbyists, surveyors, negotiators, paymasters; and all these need Wal-marts, Holiday Inn Expresses, ATV dealerships, gun shops, strip clubs, and greasy spoons.
“Bakken Business: The Price of North Dakota’s Fracking Boom”
Excerpted & edited from Richard Manning, Harper’s March 2013

“Our quality of life is gone,” a county commissioner named Dan Kalil testified last January to the North Dakota legislature’s Energy Development Committee. “It is absolutely gone.

My community is gone, and I’m heart-broken. I never wanted to live anywhere but Williston, North Dakota, and now I don’t know what I’m going to do.”

Williston, which in the 2010 census was recorded as having fewer than 15,000 people, built a total of 166 houses and apartments in 2009; this year (2013), planners expect to build about 2,300.

“All’s Well That Ends Wells”
In his report on the fracking boom in North Dakota [“Bakken Business,” Letter from Elkhorn Ranch, March], Richard Manning fails to mention the rapid falloff in the output of fracked wells — often as much as 80 percent over two years. The industry must constantly drill new wells to keep up production. The 673,000 barrels produced daily in the Bakken in January 2013 required more than 4,500 wells. To maintain that level, another 699 wells must be drilled next year, but there are plans for many more than that. At a certain point, diminishing returns set in; the Canadian energy geoscientist David Hughes gives the Bakken bubble ten years before it bursts. Saudi America this is not.

Ando Arike

Fig. 4 Typical production decline curves for US gas shales, from Iain C. Scotchman, “Exploration for Unconventional Hydrocarbons: Shale Gas and Shale Oil”, Chapter 3 in Fracking, Vol. 39, Issues in Environmental Science & Technology, eds. R.E. Hester & R.M. Harrison, shows this phenomenon.
1. Well head and frac tree with 'Goat Head'
2. Flow line for flowback & blending
3. Sand separator for flowback
4. Flowback tanks
5. Line heaters
6. Pump trucks
7. Pump truck
8. Sand hogs
9. Sand trucks
10. Acid trucks
11. Frac additive trucks
12. Blender
13. Frac control and monitoring center
14. Fresh water impoundment
15. Fresh water supply pipeline
16. Fuel tanks
17. Line heaters
18. Separator meter skid
19. Production manifold

Figure 4 A well site during a single hydraulic fracturing operation.
THE BEST FEATURES OF THE PRESENT SYSTEM

✓ We may (or may not) know the identities of chemicals used in fracking.

✓ We don’t know the relative amounts.

✓ Some may react together to nullify individual effects.

✓ Some may react together violently.

✓ Some may react with the steel pipes.

✓ Fire fighters use a system of numbers to identify like chemicals which behave similarly. (UN system or NA system)

An identity system for Fracking Chemicals is an urgent requirement.
Table 3  Truck visits over lifetime of six well pads.15

<table>
<thead>
<tr>
<th>Purpose</th>
<th>Per well</th>
<th></th>
<th>Per pad</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
<td>High</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Drill pad and road construction equipment</td>
<td>10</td>
<td>45</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drilling rig</td>
<td>30</td>
<td>30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drilling fluid and materials</td>
<td>25</td>
<td>50</td>
<td>150</td>
<td>300</td>
</tr>
<tr>
<td>Drilling equipment (casing, drill pipe, etc.)</td>
<td>25</td>
<td>50</td>
<td>150</td>
<td>300</td>
</tr>
<tr>
<td>Completion rig</td>
<td>15</td>
<td>15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Completion fluid and materials</td>
<td>10</td>
<td>20</td>
<td>60</td>
<td>120</td>
</tr>
<tr>
<td>Completion equipment (pipe, wellhead)</td>
<td>5</td>
<td>5</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Hydraulic fracture equipment (pump trucks, tanks)</td>
<td>150</td>
<td>200</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydraulic fracture water</td>
<td>400</td>
<td>600</td>
<td>2400</td>
<td>3600</td>
</tr>
<tr>
<td>Hydraulic fracture sand</td>
<td>20</td>
<td>25</td>
<td>120</td>
<td>150</td>
</tr>
<tr>
<td>Flow back water removal</td>
<td>200</td>
<td>300</td>
<td>1200</td>
<td>1800</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>4315</strong></td>
<td><strong>6590</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>... of which, associated with fracturing process:</em></td>
<td></td>
<td></td>
<td><strong>3870</strong></td>
<td><strong>5750</strong></td>
</tr>
<tr>
<td></td>
<td><strong>90%</strong></td>
<td><strong>87%</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


<table>
<thead>
<tr>
<th>Operation</th>
<th>Materials &amp; Equipment</th>
<th>Activities</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preparation for hydraulic fracturing</td>
<td></td>
<td>Rig down &amp; removal or repositioning of drilling equipment. Truck trips for temporary tanks, water, sand, additives and other fracturing equipment.</td>
<td>30-60 days per well, or per well pad if all wells treated in one mobilization</td>
</tr>
<tr>
<td>Hydraulic fracturing procedure</td>
<td>Temporary water tanks, generators, pumps, sand trucks, additive delivery trucks &amp; containers, blending unit, personnel vehicles, outbuildings, computerized monitors.</td>
<td>Fluid pumping and use of wire line equipment between pumping stages to raise &amp; lower tools used for downhole well preparation &amp; measurements. Computerized monitoring. Continued water and additives delivery.</td>
<td>2-5 days per well, including 40-100 hours actual pumping</td>
</tr>
<tr>
<td>Fluid return (flowback) &amp; treatment</td>
<td>Gas/water separator; flare stack, temporary water tanks, mobile water treatment units, trucks for fluid removal, personnel vehicles.</td>
<td>Rig down and removal or repositioning of fracturing equipment, controlled fluid flow into treatment equipment, lined pits, impoundments or pipelines; truck trips to remove fluid (if not otherwise).</td>
<td>2-8 weeks per well; may occur concurrently for several wells</td>
</tr>
<tr>
<td>Waste disposal</td>
<td>Earth moving equipment, pump trucks, waste transport trucks.</td>
<td>Pumping &amp; excavation to empty/reclaim reserve pits. Truck trips for waste transfer to disposal facility.</td>
<td>6 weeks per well pad</td>
</tr>
<tr>
<td>Well cleanup &amp; testing</td>
<td>Wellhead, wastewater tanks, flare stack. Earth-moving equipment.</td>
<td>Well flaring &amp; monitoring; truck trips to empty waste water tanks. Gathering line construction (if not otherwise).</td>
<td>0.5-30 days per well</td>
</tr>
</tbody>
</table>

AIR POLLUTION FROM TRANSPORT re HYDRAULIC FRACTURING

The likely health effects of intense diesel truck traffic associated with fracking are serious long-term harms. Truck traffic emits the following: CO, SO₂, NOₓ and non-methane volatile organic compounds (NMVOCs). Small particles are also emitted, particularly by diesel engines, and classified according to maximum particle size in micrometres: PM₁₀, PM₂.₅ and PM₁. Whereas carbon monoxide is short-term toxic, it is readily dissipated. NOₓ and VOCs in sunlight generate ozone O₃, an irritant. For those individuals with chronic lung disease, sulfur dioxide, nitrogen dioxide (part of NOₓ) and ozone each have their cumulative effects, resulting in increased mortality and morbidity, while small particles are possibly the most severe hazard to health. NMVOCs have specific effects, depending on their nature.

View Chai Jing’s Review: Under the Dome –concerning PM2.5 pollution. https://www.youtube.com/watch?v=T6X2uwIuQGQM
From a Discussion of the Faraday Division of the Royal Society of Chemistry: Satellite observations of nitrogen dioxide in tropospheric air over cities with heavy traffic and/or industrial activity.
AIR POLLUTION FROM TRANSPORT re HYDRAULIC FRACTURING

Road transport contributed 42% of NO\textsubscript{x}, 30% of PM\textsubscript{1}, 24% of PM\textsubscript{2.5} and 24% of VOCs in the U.K. in 2000.

It contributed 10% of PM\textsubscript{2.5} in the U.S.A. in 1999.

Diesels emit a greater mass of particulate matter per kilometre than gasoline engines.


Also see “Lives per Gallon: The True Cost of Our Oil Addiction” by Terry Tamminen, aide to former California Governor Arnold Schwarzenegger.

View Chai Jing Under the Dome – concerning PM2.5 pollution.
https://www.youtube.com/watch?v=T6X2uwlQGQM
Health Effects of Vehicle and Engine Emissions

- premature mortality
- chronic bronchitis
- hospital admissions
- respiratory & cardiovascular
- emergency room visits for asthma
- acute bronchitis in children
- upper and lower respiratory symptoms in children
- work loss days and restricted activity days
Origins of Petroleum: Oil and Natural Gas

Petroleum (including natural gas) originates from the organic remains of life at the bottom of the seas, millions of years ago, perhaps 500 million years.

This could have been marine plants and animals, including fish. They became buried in sediments, deprived of oxygen, and compressed and heated during geological time into rocks we call shales. This is the thermogenic origin of shale oil and gas.

Shales generally have a natural pattern of cracks or fractures.

If shales are even more heated and compressed by violent events, they metamorphose into slates.
SHALE GAS and ITS ORIGINS

Shale gas is predominantly methane. It may also contain small amounts of other gases: carbon dioxide, oxygen, nitrogen, hydrogen sulfide, argon, helium, neon and xenon and radon.

Biogenic or microbial processes at shallow depths and more normal temperatures can form shale gas. The gas is then predominantly methane and has a low $<<1\%^{13}C$ content.

Shale gas usually has a thermogenic origin. As well as methane, $CH_4$, other light hydrocarbons such as ethane $C_2H_6$, and propane $C_3H_8$ are present. The methane has about a $1\%^{13}C$ content and about 99% $^{12}C$ content.
HAZARDS of METHANE = NATURAL GAS CH₄

• Methane is not toxic, but appears to have physiological effects on people.

• Methane is extremely flammable and it may form explosive mixtures with air at 5 – 15% concentration.

• Methane is also an asphyxiant. Asphyxia may result if the oxygen concentration is reduced in an enclosed space to below about 16% by displacement, as most people can tolerate a reduction from 21 to 16%.

• Methane off-gas can penetrate the interiors of buildings near landfills.
<table>
<thead>
<tr>
<th>Component</th>
<th>Concentration Range: ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total dissolved (salt) solids</td>
<td>66,000 – 261,000</td>
</tr>
<tr>
<td>Sodium ions</td>
<td>18,000 – 44,000</td>
</tr>
<tr>
<td>Calcium ions</td>
<td>3000 – 31,000</td>
</tr>
<tr>
<td>Strontium ions</td>
<td>1400 – 6800</td>
</tr>
<tr>
<td>Barium ions</td>
<td>2300 – 4700</td>
</tr>
<tr>
<td>Chloride ions</td>
<td>32,000 – 148,000</td>
</tr>
<tr>
<td>Sulfate ions</td>
<td>0 – 500</td>
</tr>
<tr>
<td>Bromide ions</td>
<td>720 – 1600</td>
</tr>
<tr>
<td>Oil &amp; grease</td>
<td>10 -260</td>
</tr>
<tr>
<td>Total suspended solids</td>
<td>27 – 3200</td>
</tr>
</tbody>
</table>

Parts per million (ppm) means mg per kg of water (mg/L)


Composition of Sea Water

<table>
<thead>
<tr>
<th>Component</th>
<th>Concentration : ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium ions</td>
<td>138,000</td>
</tr>
<tr>
<td>Calcium ions</td>
<td>5100</td>
</tr>
<tr>
<td>Magnesium ions</td>
<td>16,500</td>
</tr>
<tr>
<td>Chloride ions</td>
<td>212,000</td>
</tr>
<tr>
<td>Sulfate ions</td>
<td>35,000</td>
</tr>
<tr>
<td>Potassium ions</td>
<td>5100</td>
</tr>
</tbody>
</table>

Parts per million (ppm) means mg per kg of water (mg/L)

Composition of Fresh Waters

<table>
<thead>
<tr>
<th>Component</th>
<th>Appr. Concn.: ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fresh water</td>
<td>Total Dissolved Salts</td>
</tr>
<tr>
<td>Fresh groundwater</td>
<td>Total Dissolved Salts</td>
</tr>
</tbody>
</table>
### Composition of ‘Produced Water’ from shale gas wells
Marcellus PA, US

<table>
<thead>
<tr>
<th>Component</th>
<th>Concentration Range: ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total dissolved (salt) solids</td>
<td>66,000 – 261,000</td>
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</tr>
</tbody>
</table>

*Parts per million (ppm) means mg per kg of water (mg/L)*


Figure 1-1
Possible source of Radon$^{222}$ (Rn) from radioactive decay of Uranium$^{238}$. Uranium$^{235}$ is a less likely source as it is comparatively rare. These elements are likely to be found in the company of igneous rocks.
Figure 1-2
Possible source of Radon$^{220}$ from radioactive decay of Thorium$^{232}$. These elements are likely to be found in the company of igneous rocks.
HEALTH HAZARDS IN HYDRAULIC FRACTURING
from Concerned Health Professionals of New York Report December 2014
A concise summary of the risks.

- Water usage.
- Wastewater disposal; difficult purification for potable use.
- Sand and silicosis among workers.
- Large volumes of hazardous chemicals: some left below water table.
- Large volumes of hazardous chemicals: direct escape to water table.
- Hazardous chemicals and employee health.
- Toxicity and radioactivity of “produced water”.

HEALTH HAZARDS IN HYDRAULIC FRACTURING
from Concerned Health Professionals of New York Report December 2014
A concise summary of the risks.

• Significant earthquakes associated with hydraulic fracturing.
• Landscape erosion.
• Flooding.
• Excessive truck traffic: water, sand and chemicals to the site.
• Noise pollution of the operation.
• Light pollution from the operation.
• Leakage from the well bore etc. of methane gas into the air.
• Leakage from the well bore of methane or hydrocarbon liquids, oils etc. into the water table.
• Blow off of methane and flaring pollution.

Fig. 6 Conceptualised illustration of pollutants, pathways and receptors associated with shale gas operations, from Ward, Stuart and Bloomfield, “The Hydrogeological Aspects of Shale Gas Extraction in the U.K. in Fracking, Vol. 39, Issues in Environmental Science & Technology, eds. R.E. Hester & R.M. Harrison.
Fig. 17 Possible risk scenarios for shallow and deep gas leakage from shale gas wells and their mitigation, from Iain C. Scotchman, “Exploration for Unconventional Hydrocarbons: Shale Gas and Shale Oil”, Chapter 3 in Fracking, Vol. 39, Issues in Environmental Science & Technology, eds. R.E. Hester & R.M. Harrison.
ROYAL SOCIETY of LONDON (and Royal Academy of Engineering)
Shale Gas Hydraulic Fracturing
Some of their Recommendations June 2012

• Guidelines should be clarified to ensure the independence of the well examiner from the operator.
• Well designs should be reviewed by the well examiner from both a health and safety perspective and an environmental perspective.
• The well examiner should carry out onsite inspections as appropriate to ensure that wells are constructed according to the agreed design.
• Operators should ensure that well integrity tests are carried out as appropriate, such as pressure tests and cement bond logs.

ROYAL SOCIETY of LONDON (and Royal Academy of Engineering)
Shale Gas Hydraulic Fracturing
Some of their Recommendations June 2012
• Operators should carry out goal-based risk assessments according to the principle of reducing risks to As Low As Reasonably Practicable (ALARP). The UK’s health and safety regulators and environmental regulators should work to develop guidelines specific to shale gas extraction.
• Operators should ensure mechanisms are put in place to audit their risk management processes.
• Risk assessments should be submitted to the regulators for scrutiny and enforced through monitoring and inspections.
• Mechanisms should be put in place to allow the reporting of well failures, as well as other accidents and incidents, between operators and shared to improve risk assessments and promote best practices across the industry.

LEAKY WELLBORES – A CANADIAN OPINION
Canada’s 500,000 Leaky Energy Wells: ‘Threat to Public’
By Andrew Nikiforuk, 5 Jun 2014, TheTyee.ca

A new University of Waterloo report warns that natural gas seeping from 500,000 wellbores represent "a threat to environment and public safety" due to groundwater contamination, greenhouse gas emissions and explosion risks wherever methane collects in unvented buildings and spaces.

Fourteen years ago, when Dr. M. Dusseault first wrote about the subject in a scientific paper titled "Why Oilwells Leak," he got no mail. Methane leakage from wellbores, pipelines, pumps and urban gas distribution systems have now become a hot button issue because they can undermine or reverse the greenhouse gas advantage that natural gas has over coal or oil.
LEAKY WELLBORES – A CANADIAN OPINION
Canada's 500,000 Leaky Energy Wells: 'Threat to Public'

Ten per cent of all active and suspended gas wells in British Columbia now leak methane. In addition, some hydraulically fractured shale gas wells in that province have become super methane emitters that spew as much as 2,000 kilograms (2 tonnes) of methane a year. That amount of methane would make an audible hiss at the wellbore or form a big bubble in a swamp, says report lead author Maurice Dusseault.

An average wellbore may leak about 100 kilograms of methane a year, or the same as a cow, but little data has been collected or accurately verified.

In Saskatchewan, about 20 per cent of all energy wells leak. In Alberta, regulators report chronic seepage from 27,000 wells.
My personal opinion about leaky wellbores in fracking

These devices are pressure vessels. All pressure vessels I have seen have gaskets, which seal better the higher the pressure applied.

The well bore designs are fundamentally flawed because of the parallel nature of the interfaces..

Furthermore, the marriage of steel and cement, two quite dissimilar materials, is asking for trouble when these are subject to considerable changes of temperature as season follows season. I believe the thermal expansion coefficients to be sufficiently different that the “joint” will not stay together as it is required to do to seal.
From the Summary of the Panel’s Response (10.1)

1. There has been no comprehensive investment in research and monitoring of environmental & health impacts.
2. Natural gas leakage from wells due to improperly formed, damaged or deteriorated cement seals is a long-recognized yet unresolved problem.
3. An undetermined risk to potable groundwater exists from the upward migration of natural gas and saline waters via complex underground pathways.
4. Gas and chemicals formed from reactions of the gas with natural constituents in aquifers may have longer term cumulative effects.
5. About 25%-50% of the water used in hydraulic fracturing flows back up the well to the surface and is potentially hazardous containing fracturing chemicals, hydrocarbons including benzene etc., unknown chemicals formed down the well by chemical interactions at high temperature & pressure, & constituents leached from the shale.

6. Shale gas development alters the land & local hydrology, probably over the long term & no comprehensive study has been done.

7. Hydraulic fracturing near active faults should be avoided; waste fluid injection can have larger seismic risks.

8. Health risks of shale gas development, which include risks to gas field workers & local residents from exposure to waste water & air pollution, are not well studied.
From the Summary of the Panel’s Response (10.1)

9. The net impact of shale gas globally on greenhouse gas emissions will depend significantly on the control of methane leakage.

10. The Canadian regulatory framework governing shale gas is not based on strong science & remains untested.

11. There can be advantages in the “go slow” approaches taken in the eastern provinces of Canada & in Europe, allowing additional data collection and integration of multidisciplinary expertise.

12. A science-based, adaptive, and outcomes-based regulatory approach is more likely to be effective than a prescriptive approach.
A Final Word (10.2)

More, well-targeted science is required to ensure that, ultimately, long-term public interests are well understood and safeguarded so that there is the opportunity to put in place the management measures required.