Physicians and Scientists for Global Responsibility

New Zealand Charitable Trust

Hydraulic Fracturing

Hydraulic fracturing is commonly referred to as *fracking* or *hydrofracking*

Controversy surrounds the increasing use of hydraulic fracturing to access resources of petroleum oil hydrocarbons. PSGR sets out what is involved in the technology and its variants and the potential for adverse effects on the human and physical environments.

Oil well is a general term applied to drilling a vertical or lateral bore into Earth's surface crust to locate and extract petroleum oil hydrocarbons[1], which usually include natural gas. Modern fracking is commonly done on lateral wells, several of which can be initiated from a single vertical bore.

When well drilling is used in conjunction with hydraulic fracturing, fractures can be enlarged or extended in rock strata that allow natural oil and gas resources to be extracted which are largely inaccessible to vertical well drilling alone. This significantly increases the efficiency of resource extraction.

The first identifiable *frack job* was done in about 1947. Since the late 1990s, improved fracking techniques have been used to establish commercially viable wells worldwide. The US Environmental Protection Agency (EPA) estimates there are now 35,000 wells fracked each year in the United States alone.[i]

While a statistically small number of these wells have been proven to have resulted in health-threatening environmental damage, there is no excuse for ignoring them. Instead, Physicians and Scientists for Global Responsibility urges much greater attention be paid to their prevention at all levels of government, industry, and public investment. In doing so, the objective for New Zealand should be a long as opposed to short term, balanced, approach of resource development and environmental preservation. A necessary step in this direction is open recognition of such problems and the creation of the political will to face them.

1 Petroleum oil hydrocarbons - where are they found?

Rock fractures occur naturally and play a part in Earth’s dynamic processes. Fractures are formed, for example, by seismic and/or magma activity, thermal contraction, natural steam, and stress fields near the surface following volcanic eruptions. Understanding how these rock fractures work is essential for effective exploitation of natural resources such as groundwater, geothermal water, and petroleum oil hydrocarbons.[ii]

---

[1] Hydrocarbons also include natural gas liquids; e.g. ethane, propane, butane, iso-butane, and natural gasoline.

Some hydrocarbons are held in natural fractures, some in pore spaces, and some are adsorbed; that is, gathered as a gas or liquid or dissolved substance in a condensed layer on organic material.

Most often wells that are fracked are fracked for natural gas. Natural gas is typically found in porous sandstone, limestone and dolomite[2], and oil shale[3] and coal beds.

Oil shale has insufficient permeability for traditional well drilling and has generally been seen as an unconventional[4] source rock that is not accessible or commercially viable. With technology advances, oil shale is being targeted as accessible using hydraulic fracturing.

Oil shale basins are found on all continents with the possible exception of Antarctica. The depths of the basins vary. Some surface or shallow accessible oil shale is mined *in situ* or underground using the room-and-pillar method. Fracking is used where traditional methods are not suitable due to the depth of the shale. In the US, the Marcellus Shale lies approximately 1.8 kilometres deep, Eagle Ford 1.2 to 4.3 km and the Haynesville Shale 3 km. The Karoo Shale in South Africa is 2 to 4.5 kilometres deep.

> **World Shale Gas Resources: An Initial Assessment of 14 Regions Outside the United States**
> US Energy Information Administration (EIA)
> www.eia.gov/analysis/studies/worldshalegas/
>
> **Gas Well Drilling and Development, Marcellus Shale**
> Susquehanna River Basin Commission, 2008
> www.srbc.net/whatsnew/docs/Marcellusshale61208ppt.PDF;
> www.marcellus.psu.edu/resources/maps.php.
>
> **Characteristics of continental oil shale and oil shale resources in China**
> Petroleum and Basin Analysis Unit, Jilin University, China, 2008
> www.ceri-mines.org/documents/28thsymposium/presentations08/PRES_11-3_Zhaojun-Liu.pdf.

1.2 Global reserves of recoverable shale gas and oil

According to the US Energy Information Administration, the largest reserves of recoverable shale gas are in China, followed by the United States. Argentina lies third at around 774 trillion cubic feet (tcf).

Australia has 396 tcf of technically recoverable shale gas resources. There is concern as to how it will affect aquifers on which Australia heavily relies, and a temporary moratorium is currently in place in eastern New South Wales State.[iii]

---

[2] Dolomite is a carbonate mineral composed of calcium magnesium carbonate CaMg(CO3)2.
[3] Shale is a fine-grained, clastic sedimentary rock composed of mud that is a mix of flakes of clay minerals and silt-sized particles of other minerals, especially quartz and calcite. Shale is characterized by breaks along thin laminae or parallel layering or bedding less than one centimetre in thickness, called fissility. Mudstones are similar in composition but do not show the fissility.
[4] The International Energy Agency also lists unconventional oil sources as oil sands-based synthetic crudes and derivative products, coal-based liquid supplies, biomass-based liquid supplies, and liquids arising from chemical processing of natural gas.

A chart of 'Proven reserves of natural gas'[iv] shows New Zealand has 33,980,000,000 cubic metres (1,199,992,400,000ft³) as of 1 January 2012; 0.02% of the global total and low in terms of global reserves.

International Energy Agency – multiple items on http://www.iea.org/

1.3 Hydrocarbons in New Zealand

1.3.1 Taranaki Basin

Over 400 on- and off-shore exploration and production wells have been drilled in the Taranaki Basin, an area of about 330,000 km^2.[v] Currently, the Taranaki Basin reportedly supports 33 oil and/or gas wells between 1.5 to 4 kilometres deep, with further wells under development or on the drawing board for the near future. (See 6.)

Sediments in the Basin run from approximately 200 metres deep to more than 6000 metres / 6 kilometres deep. The hydrocarbon source rocks are Palaeocene and Cretaceous coal rocks and shales. Drilling targets are primarily sandstones. The Kapuni is as deep as 4000 metres / 4 kilometres; the generally shallower Moki, Mount Messenger and Urenui are at depths of 1,000 to 3,000 metres / 1 to 3 kilometres.

Fact File: Taranaki Basin
New Zealand Ministry of Economic Development
http://www.nzpam.govt.nz/cms/pdf-library/petroleum-basins/Taranaki%20Basin%20Fact%20File.pdf

Taranaki's wells produce 100% of New Zealand's current hydrocarbon output, approximately 130,000 BOE/day[5] (55,000 barrels/day of crude oil and 460 MMCF/day[6] of natural gas). Reports claim the recent application of horizontal drilling in the region (fracking) is initially producing approximately 2.5 times the average rate for comparable vertical wells.

The rate of exploration is increasing. The New Zealand Energy Corporation's Copper Moki-3 Well was drilled through the Urenui and Mount Messenger formations to the deeper Moki formation and has been flowing from natural reservoir pressure out of the Mt Messenger formation since 2 July 2012. It has a measured depth of 3,167 metres / 3.167 km and true vertical depth of 2,633 metres / 2.633 km. NZEC plans to drill up to 12 additional exploration wells in 2012.[vi]

1.3.2 East Coast Basin

There are around 300 oil or natural gas seeps identified in the region. During 2011 and 2012, an estimated 20 exploratory wells were to be drilled into unconventional shale formations.[vii]

The Kawakawa Anticline reportedly presents as much as 2,000 feet of fractured oil shale at relatively low depths. Late Cretaceous and Palaeocene marine shales are the primary source

[5] BOE/D Barrels of Oil Equivalent - Oil producers refer to production by the number of cubic feet of natural gas, and/or by the barrels of oil equivalent, they produce per day.
[6] MMCF/day Million Cubic Feet per Day.

rocks, and investigations have revealed other source rock potential in, for example, sandstone, limestone, mudstones, marl, turbidite and terrigenous organic matter in the area.

Oil companies claim the East Coast Basin is an excellent geological environment for fractured shale exploration and compare it favourably to the Bakken Shale in Montana and North Dakota, and the Liassic Shale in France.[viii]

> **Fact File: East Coast Basin,** Ministry of Economic Development
> http://www.nzpam.govt.nz/cms/pdf-library/petroleum-basins/East%20Coast%20Basin%20Fact%20File.pdf
>
> **Assessment of Undiscovered Oil Resources in the Devonian-Mississippian Bakken Shale Formation, Williston Basin Province, Montana and North Dakota, 2008,** http://geology.com/usgs/bakken-formation-oil.shtml
>
> **Shale Oil Potential of the Paris Basin, France**
> Adapted from oral presentation at AAPG International Conference and Exhibition, Milan, 23-26 October 2011, posted 9 January 2012
> www.searchanddiscovery.com/documents/2012/10384monticone/ndx_monticone.pdf

1.3.3 Western Southland Basin

The Western Southland region comprises numerous small basins, on- and off-shore. Drilling has taken place on-shore around the Waiau basin for coal-seam-gas and a recent significant discovery was reportedly found in the Goodwin-1 exploration well near Ohai.[ix]

The Western Southland Basin has thick successions, thick coals, oil shales and seeps. On-shore drilling around the Waiau Basin, Blackmount district, and Ohai has explored for coal-seam-gas[xxiii] which involves hydraulic fracturing.

> **Fact File: Western Southland Basins**
> http://www.nzpam.govt.nz/cms/pdf-library/petroleum-basins/Western%20Southland%20Basins%20Fact%20File.pdf

1.3.4 Other Petroleum Basins in New Zealand

Petroleum oil hydrocarbon systems also exist in the following Basins: Reinga/Northland; Whanganui/King Country and Waikato; West Coast; Raukumara; Pegasus; Canterbury and Great South Basin.

The following discoveries have been made: Kawau gas-condensate; Galleon gas-condensate; Kora oil; Kauhauroa gas; Karewa gas.

Developments are taking place in the following Fields: Kapuni gas-condensate; Mangahewa gas-condensate; Maui gas-condensate; MacKee oil and gas; Maari-Manaia oil; Tawn gas-condensates; Pohokura gas-condensates; Tui Area oil.

NZ Petroleum Basins
www.nzpam.govt.nz/cms/pdf-library/petroleum-publications-1/2010%20NZ%20Petroleum%20Basin%20Report-WEB.pdf

Geochemical study of 10 oils from several New Zealand basins
Zink and Sykes 2010
http://gns.cri.nz/Home/Our-Science/Energy-Resources/Oil-and-Gas/Products/Geochemical-study-of-10-oils-from-several-New-Zealand-basins

Briefing - Out Of Our Depth: Deep-sea oil exploration in New Zealand, East Coast Basin November 2011
www.greenpeace.org/new-zealand/Global/new-zealand/P3/publications/climate/2011/Greenpeace%20Deep%20Sea%20Oil%20Briefing.pdf

More at: http://www.gns.cri.nz/Home/Search?cx=000739735540594332840%3A7p51qeexgyk&cof=FORID%3A9%3BNB%3A1&ie=UTF-8&q=oil&sa=Search

2 Hydraulic Fracturing - fracking

Fracking is an induced pressurization process which opens up and enlarges fractures in targeted rock layers. The fractures allow natural resources to flow or migrate to well bores, or in some circumstances these channels may also reach into aquifers and near surface waters and environments and become accessible. While statistically small in number, such situations have cast doubt on the common use of fracking without significant assurances of its safety in these regards.

A fracked well bore could be about 130 mm to 900 mm in diameter, and can be drilled up to several kilometres deep. Once the required depth is reached, laterals are bored which on average extend horizontally up to one kilometre. In the Barnett Shale basin, Texas, laterals reach up to 1.5 kilometres, and in the Bakken Shale formation, North Dakota, 3 kilometres.

Opening fractures is generally accomplished by water injected under high pressure. The water contains proppants and chemicals, usually referred to as fracking fluid. Primarily, fracking fluid is forced into pre-existing fractures in the targeted rock. In some cases, explosives are used in the opening of a drill casing along the laterals. Fracking fluid, pumped into the bore, helps keep the fractures open.

Research on ‘super fracking’ is looking at how to create deeper fractures in rock layers to release more of a targeted resource.[x] A method of fracking multiple laterals sequentially is patented[xi] (US7441604, issue date 28 October 2008). These laterals extend from a main lateral vertical well oriented penetratingin the producing zone.

In 2009, there were reportedly over 493,000 active natural-gas wells across 31 states in the United States; about 90% having used fracking technology at some point in their development.[xii]

N.B: Fracking is also used to stimulate groundwater wells, to inject waste fluids deep underground, to extract heat for electricity from geothermal resources, to precondition rock for mining, and other applications.[iii]

Hydraulic Fracturing Research Study
www.epa.gov/owindian/tribal/pdf/hydraulic-fracturing-fact-sheet.pdf.

Unconventional Gas Shales: Development, Technology, and Policy Issues
Anthony Andrews et al, Congressional Research Service, October 2009,
www.fas.org/sgp/crs/misc/R40894.pdf.

See how fracking is done:
www.youtube.com/watch?v=lB3FOJjpy7s&feature=related.

Search for fracking items on
www.scientificamerican.com/search/?q=fracking&x=10&y=1.

Natural Gas Extraction – Hydraulic Fracturing
US Environmental Protection Agency
www.epa.gov/hydraulicfracturing/.

3 The fracking process

Fracking is most often applied to a new well, but some wells are fracked repeatedly to extract as much oil or natural gas as possible. The process can include scouring with acid, injecting fracking fluids,[xiii] and flushing with water after fracking has taken place.

Hydraulic Fracturing Fluids, Chapter 4, EPA 816-R-04-003,
www.epa.gov/ogwdw/uic/pdfs/cbmstudy_attach_uic_ch04_hyd_frac_fluids.pdf

3.1 Acid

Acid is regularly flushed down a new well to dissolve rock debris and scour fractures prior to the injection of fracking fluid. Most commonly used is:

Hydrochloric acid: Hydrogen chloride is a common synonym for hydrochloric acid. Hydrochloric acid is a colourless, non-flammable aqueous solution or gas.

Toxicity: Hydrochloric acid is corrosive to the eyes, skin, and mucous membranes. Inhalation may cause coughing, inflammation and ulceration of the respiratory tract, chest pain, and pulmonary oedema. Exposure in the mouth may cause corrosion of the mucous membranes, oesophagus and stomach, with nausea, vomiting, and diarrhoea. Skin (dermal) contact may produce severe burns, ulceration, and scarring.

Other acids commonly used are:

Acetic Acid: Acetic acid (also known as ethanoic acid) is a colourless organic liquid compound. Undiluted it is called glacial acetic acid. It is a component of vinegar and under food additive code E260 is an acidity regulator and condiment; approved for usage in the EU, US, Australia and New Zealand. Concentrated acetic acid is corrosive; handling requiring specially produced resistant gloves. Concentrated, it becomes flammable if the ambient temperature exceeds 39 °C / 102 °F.

Toxicity: Dilute acetic acid, in the form of vinegar, is harmless. Concentrated acetic acid can cause skin burns, permanent eye damage, and irritation to the mucous membranes. Ingestion of stronger solutions can cause severe damage to the digestive system, and a potentially lethal change in the acidity of the blood.

Formic Acid: Formic acid, also known as methanoic acid, occurs naturally in bee venom and ant stings.

Toxicity: Formic acid has low toxicity and is used as a food additive. The principal danger is from skin or eye contact with concentrated liquid or vapours. Formic acid is readily metabolized and eliminated by the body; however, the formic acid and formaldehyde produced as metabolites of methanol are responsible for the optic nerve damage causing blindness seen in methanol poisoning. Chronic exposure to humans may cause kidney damage and the development of a skin allergy that manifests upon re-exposure to the chemical.

Muriatic acid: Muriatic acid is an aqueous solution of hydrogen chloride gas (HCI). It is completely solvent in aqueous solution. Muriatic acid gas is colourless to slightly yellow, corrosive, non-flammable, heavier than air. Exposed to air, muriatic acid fumes are dense white. When Muriatic acid is in contact with water, it forms hydrochloric acid. Mixed with oxidizing agents it produces chlorine gas which is toxic.

Toxicity: Muriatic acid is irritating and corrosive to living tissue. Exposure can cause breathing difficulties, a blue colour of the skin, accumulation of fluid in the lungs, swelling and spasms of the throat and suffocation, and can be fatal.

3.2. Fracking fluids

Acid scouring usually takes place prior to fracking. Fracking fluid is then injected at high pressure into the well bore. Generally, fracking fluid is primarily water, chemicals and a proppant (e.g. sand or ceramic particulates). It may contain compressed gases, such as nitrogen, carbon dioxide (CO^2) and air, gels and foams, and radioactive components to allow tracing and measuring.

Reportedly, over 50 types of fluids can be used as fracking fluids. Fracking fluids can be oil-, methanol- or a combination of water and methanol-based.

Methanol Use in Hydraulic Fracturing Fluids
Prepared for the Methanol Institute
http://methanol.org/Environment/Resources/Environment/Methanol-Fracking-Fluid-White-Paper-Aug-2011.aspx

Fracking involves two main types of water-based fluids - slickwater and crosslink gel. A friction reducing agent is added to slickwater. With the crosslink gel system, guar[7] is added to increase viscosity. This helps carry more proppant and keep the proppant from settling. As

[7] The Guar bean or cluster bean (Cyamopsis tetragonoloba) is an annual legume and the source of guar gum.

the fracking continues viscosity reducing agents such as oxidizers and enzyme breakers may also be added to deactivate the gelling agents and encourage flowback; fracking fluid returned to the surface.

Other fracking fluids include:

- Tallow-waste from beef processing, claimed as 100% non-toxic, water table friendly, http://www.prlog.org/11743014-eco-friendly-fracking-fluid-set-for-debut.html

- Liquefied petroleum gas (LPG), which carries sand or ceramic particles to prop open the fractures, but no chemicals. LPG is claimed as almost 100 percent recoverable. http://www.helioza.com/Directory/Business/Energy-and-Environment/Green-Natural-Gas-Fracking-1.php

The chemicals added vary with specific geological situations, to protect wells, and to ease the operation (see 3.2.2). They typically comprise up to around 2.5% of fracking fluids and the composition may change as the fracking operation proceeds.

Once the fracking is finished, a well is generally flushed with water under pressure, perhaps with a friction-reducing chemical added.

The volume of fracking fluid recovered varies. Recovered fluid may contain hydrocarbons, heavy metals, salts, and naturally occurring radioactive material (NORM) acquired during fracking.[xiv]

3.2.1 Water

Water-based fracking fluids are the most commonly used.

The volume of water required for fracking is vast. A Research Study by the US EPA says 50,000 to 350,000 gallons – 189,271 to 1,324,894 litres - of water may be required to fracture one well in a coal bed formation, and 2,000,000 to 5,000,000 gallons – 7,570,824 to 18,927,059 litres - of water may be necessary to fracture one horizontal well in a shale formation.[xv]

A distinction is made between low- and high-volume hydraulic fracturing:

- Low volume fracking is used to stimulate high-permeability reservoirs and a single well may use up to 300,000 litres of fracking fluid to do this.[iii]

- With high-volume fracking, used in the completion of tight gas and shale gas wells, a single well may use up to 11,000,000 litres of fracking fluid per well to achieve the required results. Historically, the petroleum industry has considered gas locked in tight impermeable shale as uneconomical to develop. With advances in fracking techniques, and in directional well drilling and reservoir stimulation, these resources are now being targeted. The United States Geological Survey estimates 200 trillion cubic feet of natural gas may be technically recoverable.[iii]

Fresh water used in fracking fluids may originate from aquifers, municipal water supplies, catchment areas, rivers or lakes. In 2010, the American Petroleum Institute advised non-potable water be used for fracking whenever practicable[xvi] [xvii] and the oil industry claims it will use non-potable water sources over potable sources.[xviii] However, industry representatives are on record as saying non-potable water can contain contaminants and that fresh is best. Non-potable sources include: deep saltwater aquifers; brackish water; seawater; treated wastewater; power plant cooling water; rainwater collection ponds and run off; and/or recycled flowback water.

The source will relate to the volume of water and the quality requirements, regulatory and physical availability, and formation characteristics.

3.2.2 Chemicals

Fracking fluid composition varies from water and sand to complex polymeric substances with multiple chemical additives. Chemicals typically comprise up to around 2.5% of the total fracking fluid. During an average well life, that percentage may approach 400,000 litres of added chemicals, potentially including some toxic chemicals such as benzene, ethylene glycol (antifreeze) and radioactive isotopes.

> **Benzene** is a colourless, flammable liquid with a sweet odour that evaporates quickly when exposed to air. Benzene is used mainly as a solvent. It is a component in gasoline, diesel fuel and aviation fuel.
>
> **Toxicity**: Benzene is a Class A carcinogen, its carcinogenicity limiting most non-industrial applications. Exposure can result in the development of leukaemia, anaemia, a low white blood cell count, a low blood platelet count, and also in drowsiness, dizziness, headaches, irregular heartbeats, loss of consciousness, and may harm reproductive organs. Exposure to eyes and skin can cause tissue injury and irritation. Drinking water contaminated with high levels of Benzene can cause stomach irritation, vomiting, convulsions, rapid heartbeats and death.

The chemical components appearing most often in fracking products (2005 – 2009)[xix] were:

> **Methanol (Methyl alcohol)**: a light, volatile, colorless, flammable liquid with a distinctive odour; used as an antifreeze, solvent, fuel, and as a denaturant for ethanol, and for producing biodiesel via transesterification reaction. Methanol is ubiquitous (everywhere) in the environment.
>
> Toxicity: Methanol is an air pollutant and threatens drinking water sources. It can enter the body by ingestion, inhalation, or absorption through the skin, and can be fatal. Symptoms may include central nervous system depression, headache, dizziness, nausea, lack of coordination, confusion, leading to unconsciousness and death.
>
> **Isopropanol (Isopropyl alcohol, Propan-2-ol)**: a colorless, flammable chemical compound with a strong odour.

Toxicity: Isopropanol poisoning can occur from ingestion, inhalation, or absorption. Symptoms of toxic effects include flushing, headache, dizziness, central nervous system depression, nausea, vomiting, anesthesia, and coma.

Crystalline silica – quartz (SiO2): commonly known as Feldspar, is a naturally occurring anhydrous, inorganic, igneous rock; a complex aluminum silicate containing varying amounts of sodium, potassium, and calcium with crystalline silica levels of six to 10%.

Carcinogenicity: Repeated, prolonged inhalation of silica dust may cause delayed silicosis or pneumoconiosis. Classified in Group 1, Carcinogenic to Humans.

Ethylene glycol monobutyl ether (2-butoxyethanol): an organic foaming agent and sufactant (solvent), a colorless liquid with a sweet, ether-like odour; a butyl ether of ethylene glycol. It is a relatively nonvolatile with modest surfactant properties.

Toxicity: Moderate exposure to 2-butoxyethanol can result in irritation of mucous membranes of the eyes, nose and throat. Heavy exposure via respiratory, dermal or oral routes can lead to hypotension, metabolic acidosis, destruction of the red blood cells, pulmonary edema and coma, damage to the liver, spleen and bone marrow.

Ethylene glycol: an organic compound used as an automotive antifreeze. In its pure form, it is an odorless, colourless, syrupy, sweet-tasting liquid,

Toxicity: Ethylene glycol is moderately toxic, the major danger due to its sweet taste attracting children and animals to drink large quantities. Upon ingestion, ethylene glycol oxidizes to glycolic acid which is in turn oxidizes to oxalic acid, which is toxic. Ethylene glycol and its toxic byproducts affect the central nervous system, followed by the heart, then the kidneys. Ingestion can be fatal.

Sodium hydroxide (lye and caustic soda): widely used, including in detergents, soaps and drain cleaner. Pure sodium hydroxide, a white solid, is hygroscopic and readily absorbs CO_2 from the air. It is soluble in water, ethanol and methanol.

Toxicity: Solid sodium hydroxide or solutions of sodium hydroxide may cause chemical burns, permanent injury or scarring on tissue. It may cause blindness if it contacts the eye. Disolved in water, sodium hydroxide is highly exothermic (releases heat) and may cause heat burns or ignite flammables in this form.

Also used are Diesel, Formaldehyde, Napthalene, Sulfuric Acid and Lead[xvii]; all are carcinogic.

For a detailed list of fracking chemicals see 'Chemicals used in Hydraulic Fracturing': http://democrats.energycommerce.house.gov/sites/default/files/documents/Hydraulic%20Fracturing%20Report%204.18.11.pdf.

Its conclusion reads: "This analysis . . . shows that between 2005 and 2009, the 14 leading hydraulic fracturing companies in the United States used over 2500 hydraulic fracturing products containing 750 compounds. More than 650 of these products contain chemicals that are known or possible human carcinogens, regulated under the (US) Safe Drinking Water Act, or listed as hazardous air pollutants."

Under the US Energy Policy Act of 2005 gas drilling and extraction are exempt from requirements in the underground injection control programme of the Safe Drinking Water Act. Exemptions also apply in the Clean Air and Clean Water Acts.[xx]

> **Fracking chemicals, their uses and hazards** as used in Australia.
> The Australian Petroleum Production & Exploration Association, 1 November 2010
> http://www.appea.com.au/images/stories/mb_files/APPEA_fraccing_chemicals.pdf

3.2.3 Proppants

Because of natural pressures at the depths drilled, fracking fluids contain porous proppants to fill the fractures and help keep them open. Materials used include resin-coated sand, man-made ceramics, and/or other particulates.

Current research is looking at improving the proppants used. One example is nanotechnology[8] research which has produced high strength ceramic proppants,[xxi] nano-sized material which retains 20 times its weight of simulated formation fines.[xxii]

> **N.B**. Regulation of nanotechnology is almost nonexistent worldwide. Limited though toxicological studies on engineered nanoparticles are it appears that as a class they are more toxic than conventional forms of the same compound. Nanoparticles cannot be easily monitored. We do not know what would happen to manufactured nanoparticulates in fracking fluid when released into the environment: groundwater, soil or atmosphere. Studies have shown that they can move in unexpected ways through soil and carry other substances with them. We do not know if nanoparticles persist and accumulate in the environment or what may happen ecologically. Recent evidence from hydroponic plant studies[xxiii] suggests manufactured nano-materials (MNM) are taken up and processed by plants, varying with the plant and the type of MNM. We do not know if being absorbed by soil may reduce bioavailability or whether nanomaterials could harm soil bacteria, the engine of the ecosystem and food chain. Airborne nanoparticles could potentially travel vast distances.
>
> In terms of human health, a study[xxiv] published in the European Respiratory Journal looked at women workers exposed to nanoparticles in an inadequately vented workplace in China. Seven became seriously ill and two died. Autopsies found nanoparticles in the brains of the dead women. We know that nanoparticles can pass through epithelial surfaces (skin, gastrointestinal, conjunctiva) and the endothelial barriers lining blood vessels, and can be inhaled and pass through the blood-brain barrier.

---

[8] Nanotechnology refers to techniques used to engineer structures, materials and systems that operate at a scale of 100 nanometres (nm) or less. One nm measures one-billionth of a metre. It takes ten atoms of hydrogen side-by-side to equal one nm, a DNA molecule is about 2.5 nm wide, a red blood cell 5000 nm, a human hair head 60,000-80,000 nm thick, and the head of about 1 million nn across.

Eur Respir J 2009; 34:559-567 doi: 10.1183/09031936.00178308, 'Exposure to nanoparticles is related to pluerual effusion, pulmonary fibrosis and granuloma', Y Song, X Li and X Du. http://erj.ersjournals.com/content/34/3/559.full.pdf+html

PSGR 'Science Watch' in *Organic New Zealand* on Nanotechnology (September/October 2010 Vol 69 No 5 and November/December 2010 Vol 69 No 6).
www.psgr.org.nz/index.php?option=com_content&view=article&id=43:nanotechnology&catid=28:letters-to-government&Itemid=41
www.psgr.org.nz/index.php?option=com_content&view=article&id=66:letter-to-councils-2008&catid=26:letters-to-nz-councils&Itemid=41
www.psgr.org.nz/index.php?option=com_content&view=article&id=84:letter-to-councils-and-dhbs-2011&catid=26:letters-to-nz-councils&Itemid=41

Sand containing gamma-emitting isotopes may also be used to trace and measure fractures. Naturally occurring radium may contaminate flowback fracking fluid.

Radium (Ra)[xxv]. All isotopes of radium are highly radioactive. Radium is found in virtually all rock, soil, water, plants, and animals at low levels. Geologic processes can concentrate it. Radium and its salts are soluble in water. Exposure to radium can result where there is an elevated level of radium in the surrounding rock and soil, and where it is released into the air from the burning of coal or other fuels.

Toxicity: Radium emits alpha and gamma radiation, exposing individuals externally to gamma rays, or can be inhaled or ingested with contaminated food or water. Long-term exposure increases the risk of developing serious conditions such as bone cancer, lymphoma, and diseases affecting blood formation, usually taking years to develop.

Strategically placed geophones also allow tracing of micro seismic activity created by hydraulic fracturing.[xxvi]

Coalbed fracture treatments can use up to 145,150 kilograms / 320,000 pounds of proppant and shale gas wells more than 1,814,369 kilograms / 4 million pounds of proppant per well.[xxvii]

Long Term Stability of Proppants Exposed To Harsh Shale Reservoir Conditions
Society of Petroleum Engineers, January 2011, ISBN 978-1-55563-321-9
www.onepetro.org/mslib/app/Preview.do?paperNumber=SPE-140110-MS&societyCode=SPE

4 Impact of exploratory work and site establishment for fracked wells

Well exploratory work and site establishment will impact on communities and the environment. For example, wells on the Marcellus Shale may be spaced 16 wells per square mile / 259 hectares, and a town could contain up to 1500 wells.[xix]

For visual impact on environment see
Photographs of Marcellus Shale Drilling in the Pennsylvania State Forest
http://www.lhup.edu/rmyers3/marcellpix/marcelluspictures.htm;
http://www.marcellus-shale.us/MARCELLUS-AIR.htm

4.1 Well sites

Fracked wells with horizontal laterals can require industrial-sized pad sites, ranging up to 15 acres / 6 hectares, and involve the associated establishing and running of such a site, including storage buildings and access roads.[xxviii]

4.2 Manufacture, transport and storage

The chemicals used in fracking fluids are manufactured, transported, and stored near a well to be fracked. Each stage presents risks to handlers and the environment with many of the chemicals being toxic, carcinogenic, and/or highly flammable.[xxix]

4.3 Transport

A tanker truck may carry 5460 gallons / 20,668 litres. If a well requires two million gallons / 7,570,824 litres of freshwater, the truck will make 366 trips to carry the fresh water and up to 292 trips to remove the wastewater removal for a single fracking. In Pennsylvania, the Department of Environmental Protection estimates that one horizontal Marcellus well requires 1000 truck trips during drilling and fracking to establish a well.

> **Drilling 101**
> http://shaleshock.org/drilling-101/.

5 Waste fracking fluid

The chemicals in fracking fluid potentially present dangers to underground water systems and subsurface biota and, by migrating to the surface through natural fractures, they endanger surface water, soil biota and the greater environment. Waste fracking fluids would be classified as consumptive[9] water, that is freshwater originally part of the natural cyclic pool, but not returned directly to a natural source after use. Although most consumptive water is recycled indirectly it is almost always contaminated, whether it has been used for agriculture, industry or the populace.

Recovered fracking fluid is generally held in lined or unlined surface pits and steel tanks, spread over land, disposed of through Municipal or other facilities, or re-injected deep into unused or specially drilled wells.[i, xxx] Fracking wastewater can contain chemicals which are toxic and/or carcinogenic. Many fracking chemicals are associated with skin, eye and respiratory problems, harm to the gastrointestinal system, and with affecting the brain and nervous system.[xxxi]

N.B: The US EPA has plans to publish proposed minimum standards for wastewater sent to sewage treatment plants by 2014. It has not yet proposed guidelines on the underground disposal of wastewater.

---

[9] The US Geological Survey defines consumptive use as “that part of water withdrawn that is evaporated, transpired, incorporated into products or crops, consumed by humans or livestock, or otherwise removed from the immediate water environment.” http://watercenter.unl.edu/Downloads/ResearchInBrief/MartinWaterUse.pdf.

5.1 Subsurface microbial communities

Anaerobic iron and sulphate degrading bacteria breed in fracking fluids and cause corrosion of pipes and clog proppants.[xxxii] Biocides are added to fracking fluids to kill or inhibit growth of bacteria and microorganisms.

Biocides in anti-fouling paint on sea-going vessels impacted adversely on marine eco-systems.[xxxiii] Biocides range from very biodegradable to non-biodegradable. Bacterial resistance to biocides has been reported and scientific evidence indicates the active molecules in them may contribute to the increased incidence of antibiotic resistant bacteria.[xxxiv] Even relatively low concentrations of biocides harm fish. A biocide known to be used in fracking fluids, dibromonitrilopropionamide, affected the growth of juvenile rainbow trout.[xxxv]

Examples of biocides[xxxvi] are:

> **Brominated salicylanilides** (US Patent No 3532747) have antibacterial and antifungal functions.
>
> Toxicity: No substantive data available.
>
> **Mercaptans -** a group of sulphur-containing organic chemical substances, used in the production processes of some pesticides, pharmaceuticals and petroleum products, and to add a sulphur smell to natural gas.
>
> Toxicity: Little is known about the dangers of Mercaptans.
>
> **Quaternary ammonium compounds** are positively charged polyatomic ions of the structure NR4+ with R being alkyl or aryl groups; the R groups may be connected. Common uses include disinfectants, surfactants, fabric softeners, antistatic agents, and wood preservation.
>
> Toxicity: Can be inhibitory or toxic at certain concentrations; toxicity increases with increasing chain length of alkyl group.
>
> **Compounds of copper and arsenic**: Copper arsenate is a blue/bluish-green powder that is insoluble in water and alcohol, and soluble in aqueous ammonium and dilute acids. Copper arsenate is an insecticide used as an herbicide, fungicide, and a rodenticide, and as a poison in slug baits.
>
> Toxicity: As a dust it irritates the eyes, skin and respiratory tract. Ingestion may cause headaches, nausea, vomiting, diarrhoea, abdominal pain, muscle spasms. Prolonged exposure may cause central and peripheral nervous system damage.
>
> Environmental toxicity: Copper arsenate can be hazardous in aquatic environments and low concentrations potentially toxic to fish. In soils, it can lead to increased bioaccumulation and be detrimental to plants and invertebrates.

Recently approved for use in fracking, drilling and completion fluids, is a pH-neutral biocide (hypochlorous acid),[xxxvii] claimed as “green”.

Scientists do not know how much or how far biocides could affect subsurface organisms. Subsurface microbial communities comprise 50 percent of Earth's biomass and are responsible for geological phenomena, degrading wastes, and producing energy. Scientists have discovered microbial life at depths of four to five kilometres. Little is yet understood about the importance of these unique organisms and substantive research does not appear to have looked at how fracking fluids deposited on or below ground might affect biota.

See Dark Life: Biology, http://www.deepscience.org/contents/dark_life.shtml

5.2 Landfarming (disposing of fracking wastewater on land surfaces)

Land farming of drilling wastes: Impacts on soil biota within sandy soils in Taranaki (Year 1 of 3) Technical Report 2011-35
http://www.trc.govt.nz/assets/Publications/state-of-the-environment-monitoring/environmental-monitoring-technical-reports/894052w2.pdf

The above report concludes: "...it appears that there may be some statistically significant differences in soil characteristics and soil biota between untreated control areas and areas with synthetic-based muds applied (from wells), for carbon, nitrogen and phosphate levels, and microbial respiration and biomass in particular." Further research was recommended.

5.3 Disposal through Municipal facilities

The Municipal Authority of McKeesport in Allegheny County, Pennsylvania, accepts 80,000 gallons / 302,833 litres per day of fracking wastewater. This is mixed with treated sewage and discharged into the Monongahela River upstream from Pittsburgh. The fluids may contain sodium and calcium salts, barium, oil, strontium, iron, numerous heavy metals, soap, radiation and other components. This combination becomes brine wastewater. The saltiness of brine wastewater creates high levels of total dissolved solids (TDS). When discharged into rivers used for drinking water, a high TDS situation causes problems for drinking water treatment plants.[xxxviii] Bromide has been found in rivers in Pennsylvania and scientists are endeavouring to establish whether it is associated with hydraulic fracturing.[xxxix]

America's Most Endangered Rivers™ Report: 2010 Edition, #9 Monongahela River, Pennsylvania and West Virginia, Threat: Natural Gas Extraction
http://www.americanrivers.org/our-work/protecting-rivers/endangered-rivers/2010-endangered-monongahela.html

5.4 Injecting fracking wastewater into wells relating to seismic activity

A method of disposing of fracking wastewater is to inject it into disused or specially drilled re-injection wells. There is reportedly at least one re-injection well operating in Taranaki, New Zealand.[xl]

Dr Rosemary Quinn of New Zealand's GNS[10] Science has said[xli]:

[10] GeoNet Science maintains a geological hazard monitoring system in New Zealand to detect, analyse and respond to earthquakes, volcanic activity, large landslides, tsunami and the slow deformation that precedes large earthquakes. See http://www.geonet.org.nz/quakes/all for immediate updates of seismic activity.

"There is a large body of published data that indicates that seismic activity caused by fluid injection (for solution mining, hydrocarbon production, geothermal energy generation, hazardous and non-hazardous waste disposal purposes for example) cause small seismic events i.e. less than or equal to magnitude (ML) 3.9. The seismic activity associated with hydraulic fracturing is generally less than magnitude 2.0, with the magnitude and number of events depending on local geology, the pressure and duration of the fluid injection, and the injection-rate. The small-size of earthquakes induced by hydraulic fracturing (compared to those generated by other activities) is partly due to the fact that fluid injection is for shorter duration (days as opposed to weeks or years) than for other activities.

"This induced seismic activity will probably be minor compared to natural background seismicity. In New Zealand, for example, GeoNet records about 18,000 magnitude 2.5 and larger events in an average year. At the lower end of this scale, most people are unaware that anything is happening – a passing truck generates as much if not more vibration – so the effects of seismic activity that are typically induced by hydraulic fracturing would be hard to separate from the background level of seismicity.

"The fact that we experience natural earthquakes does not mean that we should be complacent: hydraulic fracturing operations need to be designed and monitored to ensure that they do not present undue risk to people and resources. The minimum pressures and flow-rates required to achieve the desired outcome should be used. If that is done, it is very unlikely that hydraulic fracturing operations will result in any noticeable seismic impact."

US Geological Survey reports have been documented of earthquakes caused by fluids injected into deep wells for waste disposal and secondary recovery of oil.[xlii]

Fracking has been blamed for tremors during shale gas drilling at the Preese Hall Well near Blackpool, England.[xliii] On 1 April and 27 May 2011, two earthquakes of magnitude 2.3 and 1.5 were felt in the area. In November 2011, the well operators, Cuadrilla Resources Limited, submitted a synthesis report to the Department of Energy and Climate Change. The report examined seismological and geomechanical aspects of the seismicity in relation to the hydraulic fracture treatments.

> **Preliminary report for Cuadrilla Resources**
> 13 January 2012 Seismik
> http://og.decc.gov.uk/assets/og/ep/onshore/5071-annex-g.pdf

Columbia University seismologists linked earthquakes up to magnitude 4.0, hitting Youngstown, Ohio, during 2011, to a fracking waste well.[xliv]

> **Fracking by-products may be linked to Ohio Quakes**
> **Recorded interview with John Armbruster, a seismologist with Lamont-DohertyEarth Observatory**
> http://www.npr.org/player/v2/mediaPlayer.html?action=1&t=1&islist=false&id=144633252&m=144633557.
> As text www.npr.org/2012/01/03/144633252/fracking-byproducts-may-be-linked-to-ohio-quakes.

An Assessment of the Effects of Hydraulic Fracturing on Seismicity in the Taranaki Region
GNS Science Consultancy Report 2012/50 February 2012
www.trc.govt.nz/assets/Publications/guidelines-procedures-and-publications/hydraulic-fracturing/gns-seismic-feb2012.pdf

5.5 Groundwater contamination from fracking fluids

In some circumstances, oil, gas and fracking fluids can migrate when induced fractures intersect natural vertical fault systems.[xlv] They can also become laterally and vertically mobile in geological circumstances where cap rocks and other types of geological barriers are not present or are removed by natural events such as earthquakes. In either case the result can be contamination of ground surface waters.

At the Manutahi wells in Taranaki, New Zealand, the distance between fresh water and fracking was reported at 257 metres[xlvi] raising public concern (see 7.1).

Communities near fracked wells experience illnesses they associate with contaminated drinking water. Over a period of nine months, the *New York Times* reviewed over 30,000 pages of documents regarding contamination and wastewater. The documents were obtained "through open records requests of state and federal agencies and by visiting various regional offices that oversee drilling in Pennsylvania. Some of the documents were leaked by state or federal officials." The most significant documents can be view on www.nytimes.com/interactive/2011/02/27/us/natural-gas-documents-1.html#document/p416/a9943.

A study of methane in groundwater found higher concentrations near fracked wells, the isotopic signatures being consistent with fracked shale origins.[xlvii] Samples taken from monitoring wells established by the US EPA contained fracking chemicals, methane, benzene, phenols, acetone, toluene, naphthalene, and diesel fuel. It says diesel in fracking fluids poses a serious threat to drinking water sources.[xlviii] [xlix]

The US EPA has requested information on a voluntary basis from nine principal natural gas service companies regarding the chemicals used in hydraulic fracturing fluids. The collected data is to be part of a broad scientific study Congress directed the Agency to conduct to determine whether hydraulic fracturing has an impact on drinking water and the health of communities living in the vicinity of wells applying hydraulic fracturing.[l]

See Final Plan to Study the Potential Impacts of hydraulic Fracturing on Drinking Water Resources
Jeanne Briskin, EPA Office of Research and Development, November 2011
www.epa.gov/hfstudy/Webinar-for-Study-plan-release-11-10-11.pdf.
A first report of findings is to be released in 2012, a second report in 2014.

Evaluation of Impacts to Underground Sources of Drinking Water by Hydraulic Fracturing of Coalbed Methane Reservoirs Study (2004)
http://water.epa.gov/type/groundwater/uic/class2/hydraulicfracturing/wells_coalbedmethanestudy.cfm

5.5.1 Pavillion, Wyoming – an example

In 2008, residents of Pavillion, Wyoming, began complaining about adverse tastes and smells from their drinking water, drawn from nearby wells.[li]

> **Health Consultation - Evaluation of Contaminants in Private Residential Well Water, Pavillion, Wyoming, Fremont County**
> Prepared by the Agency for Toxic Substances and Disease Registry 31 August 2012
> www.atsdr.cdc.gov/hac/PHA/Pavillion/Pavillion_HC_Well_Water_08312010.pdf

The above Report states: "There are an estimated 211 active gas wells, 30 plugged and abandoned wells, 20 wells identified as 'shut in' and 37 former pits associated with the natural gas exploration" in the area under examination. The EPA sampled three shallow groundwater monitoring wells near three oil and gas well sites. Significant quantities of petroleum hydrocarbons were identified in these wells. "Individual petroleum constituents identified above levels of concern in monitoring wells included: benzene (390 µg/L maximum), cyclohexane (140 µg/L maximum), and methylcyclohexane (140 µg/L). Methane, propane, and ethane" were detected dissolved in water. "Sodium and sulfates were elevated." TICs were identified including adamantane and 1,3 dimethyl adamantane. Also detected were a foaming agent, diesel fuel, toluene, ethylbenzene, xylene, naphthalene, and isopropanol. All these chemicals may be used in fracking fluids.

As a result of the study, local residents were warned not to drink their water, and to ventilate their homes while showering or washing clothes to prevent an explosion from the methane.

> **Investigation of Ground Contamination near Pavillion, Wyoming**
> A Draft Report from the Environmental Protection Agency
> http://www.epa.gov/region8/superfund/wy/pavillion/EPA_ReportOnPavillion_Dec-8-2011.pdf

The above Report states: "A lines of reasoning approach utilized at this site best supports an explanation that inorganic and organic constituents associated with hydraulic fracturing have contaminated ground water at and below the depth used for domestic water supply." In addition "although some natural migration of gas would be expected above a gas field such as Pavillion (Wyoming), data suggest that enhanced migration of gas has occurred to ground water at depths used for domestic water supply and to domestic wells." The Report also notes that, "alternative explanations were carefully considered."

5.5.2 Remaining questions on drinking water safety

If fracking fluid wastewater is processed by an industrial level processing plant, questions arise about the chemicals that remain in the processed drinking water. Despite the chemical content of fracking fluids being generally no greater than 2.5%, the amount of chemicals used to frack one well once is in the hundreds of thousands of litres[lii] and these pose potential risks. In addition, flowback and produced water may contain hydrocarbons, heavy metals, salts, and naturally occurring radioactive material (NORM).[xiv]

5.6 Leakage and spills of fracking fluids

Problems can arise from the failure of well-bore casing and cement. The Chesapeake Energy well in Bradford County, Pa., blew near the surface and spilled many thousands of gallons of fracking fluid over containment walls, through fields, personal property and farms.[liii]

Spills occur during the injection of fracking fluids and during the capture and disposal of the flowback.[liv] Surface spills of fracking fluid or the chemicals in them can occur during handling and transport;[lv] e.g. a spill extended 56 to 64 kilometres / 35 to 40 miles on a highway near Hughesville, Pa., after one of a dozen 100-gallon containers on a trailer leaked an undetermined amount of fracking fluid.[lvi]

Wastewater may be stored in surface pits which can potentially leak or overflow and can pollute groundwater and surface water. Wastewater may be disposed of on the surface, reused in another well, re-injected underground, or transported to a treatment facility. Each activity carries the risk of spills, leaks, earthquakes (in the case of underground injection) and threats to groundwater and surface water.[li]

5.7 Air pollution

Chemicals used in fracking fluid are detectable in air samples taken near fracked wells.[lvii] Condensate tanks and the flaring of wells are significant sources of volatile organic compounds (VOC's) and nitrogen oxide, which react with sunlight to form ozone. Other chemicals detected in the air near the wells include trimethylbenzenes, aliaphatic hydrocarbons, and xylenes.

Ambient air studies in Colorado, Texas, and Wyoming, show "direct and fugitive air emissions of a complex mixture of pollutants from the natural gas resource itself as well as diesel engines, tanks containing produced water, and on site materials used in production, such as drilling muds and fracking fluids (CDPHE, 2009; Frazier 2009, Walther 2011, Zielinska et al 2011). ... This complex mixture of chemicals and resultant secondary air pollutants, such as ozone, can be transported to nearby residences and population centres (Walther 2011; GCPH 2010)."[lviii]

The escape of fracking emissions is highest when the wells are under construction. The higher the density of wells drilled, the greater the potential air pollution.[lix] [lx]

Until 2012, well operators have been required to burn off or flare gas emissions. In April 2012, guidelines issued by the US EPA require petroleum companies from 2015 to capture the by-products of fracking, methane and other pollutant gases. Operators will be required to use "green completion" technologies on new fracked wells. The claim is that this proposal will avoid some of the emissions entering the atmosphere and cut smog-forming emissions by 25% through existing technologies that capture escaping gas and prevent the release of 3.4 million tons of methane. The EPA likens this to taking eleven million passenger cars off the road[liii] and estimates that half of all fracked oil and gas wells already comply with the new rules.[lxi]

> **Ozone Mystery** (posted 7 February 2012; 5.24 mins
> http://www.youtube.com/watch?v=exStZnGfBzY&lr=1&ob=0

Ozone ($O3$) or trioxygen, is a triatomic molecule, consisting of three oxygen atoms. It is present in low concentrations throughout Earth's atmosphere (0.6 parts per million). The portion of the stratosphere with a concentration of ozone from two to eight ppm, the so-called ozone layer, prevents damaging ultraviolet light from reaching Earth's surface.

Toxicity: Near ground level, ozone can damage plant tissue above concentrations of about 100 parts per billion. It can irritate the respiratory system, aggravate asthma and chronic lung diseases like emphysema and bronchitis, inflame and damage the lining of the lungs, and damage the cells that line the lungs. Repeated damage may potentially result in permanent problems.

Natural Gas and Polluted Air, video, 7 minutes, New York Times
http://video.nytimes.com/video/2011/02/26/us/100000000650773/natgas.html?ref=drillingdown

Human Health Risk Assessment of Air Emissions from Development of Unconventional Natural Gas Resources, 19 March 2012, Lisa M. McKenziea, Roxana Z. Wittera, Lee S. Newmana, John L. Adgatea, Colorado School of Public Health, University of Colorado, Anschutz Medical Campus, Aurora, Colorado, USA
www.erierising.com/human-health-risk-assessment-of-air-emissions-from-development-of-unconventional-natural-gas-resources/

5.8 Noise pollution

At the well site, primary sources of noise during drilling and development stages are equipment, diesel engines and vehicle traffic. Hydraulic fracturing equipment includes: a slurry blender; high pressure, high volume pumps; monitoring equipment; tanks for storage of proppants and chemicals; high pressure treating iron; chemical additive unit; low pressure flexible hoses; gauges and meters.[iii] Fracking operations also require transport for water and chemicals.

The highest noise levels occur with drilling and flaring of gas. Heavy vehicle movement and drilling can result in frequent-to-continuous noise; drilling continuing 24 hours per day until the bore reaches the depth of the formation sought. Wells also generate noise during all production processes.[lxii]

Beyond the well pad, blasting for sand and gravel required for construction may occur within a practical distance, with associated vehicle traffic transporting the material.

During production, compressor stations are required for around each one hundred wells to raise the gas pressure in gathering lines to that of larger pipelines. These stations are permanent and “extremely noisy”, running 24-hours a day.[lxiii]

Noise-producing activities near residential areas can potentially exceed the US EPA guidelines where sound becomes unwanted if it interferes with normal activities such as sleeping and conversation, or when it disrupts or diminishes quality of life. A Colorado-based noise consultant[lxiv] has put ambient noise levels in residential areas as low as 35 dBA[11] during the night, sometimes lower. Noise standards of 45 dBA LEQ or lower at night are used by many US jurisdictions covering oil and gas operations. As ambient noise conditions increase, the allowable noise level increases. In Alberta, Canada, the Energy and Utilities Board has a sliding scale noise standard whereby acceptable noise levels vary with the ambient noise. The highest allowable level in a residential area is 56 dBA at night, applying where there are greater than 160 dwellings in a quarter-mile radius.

Noise measurements are normally taken outdoors at a set distance from or at the property line of the receiver (receptor-based noise standards) or at a set distance from the noise source (source-based standards). Researchers have measured noise levels at 115 dBA at the source, to over 55 dBA at 550 metres / 1800 feet to 1067 metres / 3500 feet from an oil well.

A study[lxv] in La Plata County, Colorado, listed noise levels for various oil and gas activities:

Typical compressor station	50 dBA at 115 metres from property boundary			
Pumping units	50 dBA	"	"	"
Fuel and water trucks	68 dBA at 152 metres from source			
Crane for hoisting rigs	68 dBA	"	"	"
Concrete pump used during drilling	62 dBA	"	"	"
Average well construction site	65 dBA	"	"	"

The US Bureau of Land Management [lxvi] also published noise levels:

Well drilling	83dBA at 15.24 metres/50 feet from the source				
Pump jack operations	82 dBA	"	"	"	"
Produced water injection facilities	71 dBA	"	"	"	"
Gas compressor facilities	89 dBA	"	"	"	"

N.B. Estimates of noise attenuation at distances greater than 15.24 metres / 50 feet can be made by reducing noise levels by a factor of 6 dBA for each doubling of distance. The actual noise levels experienced by a receptor will depend on the distance between the receptor and the equipment, topography, vegetation, and meteorological conditions such as wind speed and direction, temperature and humidity.

6 Current situation New Zealand oil and gas operations (see also 1.3)

Commercial fields operate on- and off-shore in Taranaki. Their output accounts for 100% of New Zealand's current production of crude oil and natural gas.

Exploratory drilling has begun on the East Coast Basin, in the North Island. A recent TV One report said there may be 1000 wells on the Coast within the next decade or two.[lxvii]

Current or proposed drilling for 2011/2012 includes: on-shore exploratory drilling around the Waiau Basin, Blackmount district, and Ohai in Southland for coal-seam-gas[lxviii]; deep-water test drilling in the Canterbury Basin 65km off the coast from Dunedin[lxix]; 40 exploration

[11] The 'A' represents A weighting; dBA is the A-weighted decibel level applied to an electrical signal in a noise-measuring instrument as a way of simulating how the human ear responds to a range of acoustic frequencies.

wells, multiple 2D seismic surveys and initial production testing of coal seam gas resources in the North and South Islands[lxx].

In December 2012, TAG Oil Limited announced New Zealand Petroleum and Minerals had awarded the company four onshore exploration blocks (Petroleum Exploration Permit [PEP] numbers 54873, 54876, 54877 and 54879) located in the Taranaki Basin. The announcement said: "Extensive TAG controlled proprietary 3D seismic coverage over three of the four new permits - PEP's 54876, 54877, and 54879 - initially add at least ten shallow, low-risk drilling prospects plus numerous leads identified on 3D seismic in close proximity to the producing Cheal oil field. ... Our new oil and gas production facility expansion and associated pipelines in this area unencumber all production, transportation and marketing of TAG's oil and gas, including any new discoveries from these newly awarded lands."[lxxi]

On 19 March 2013, the company reported its Cheal infrastructure expansion project in the Taranaki region has been completed, giving it the capacity to fully commercialize its wells onshore in the Taranaki Basin.[lxxii]

TAG expects drilling of its first East Coast Basin wells to commence in late March/April 2013. It will use conventional vertical drilling techniques similar to those used in its Taranaki Basin operations. TAG claims independent assessments have concluded that there are approximately 14 billion barrels of undiscovered original oil within less than a fifth of TAG's total land holdings on the East Coast.[lxxiii]

There are reportedly 75 existing and pending on-shore gas drilling licences covering an equivalent of 36% of the South Island and 33% of the North Island (March 2012).[lxxiv] Any well could require fracking.

> **Ministry of Economic Development - Current Wells in New Zealand 2011**
> www.nzpam.govt.nz/cms/xls-library/petroleum-facts-figures/Current_Wells.xls/view

> **New Zealand Petroleum Basins**
> www.nzpam.govt.nz/cms/pdf-library/petroleum-basins/East%20Coast%20Basin%20Fact%20File.pdf

The New Zealand government has issued permits for deep-sea oil exploration at six major offshore sites, located off the East Cape and Bay of Plenty, Stewart Island, and Raglan on the West Coast of the North Island. Three deep-sea Basin sites are identified around the North Island: Northland, Taranaki and the Raukumara Basins, off East Cape. A further three are located around the South Island: the West Coast, Great South, and the Canterbury Basins. These deep-sea sites are detailed in:

> **Greenpeace Report detailing New Zealand's oil and gas fields**
> www.greenpeace.org/new-zealand/Global/new-zealand/P3/publications/climate/2011/Greenpeace%20Deep%20Sea%20Oil%20Briefing.pdf

6.1 Taranaki Basin (see also 1.3.1)

The Taranaki Basin's sediments extend from approximately 200 metres deep to more than 6000 metres / 6 kilometres. The Kapuni is as deep as 4000 metres / 4 kilometres; the generally shallower Moki, Mount Messenger and Urenui are at depths of 1000 to 3000 metres / 1 to 3 kilometres. The application of horizontal drilling has yielded results, initially producing approximately 2.5 times the average rate for comparable vertical wells.

Copper Moki-3 is a New Zealand Energy Corporation (NZEC) well drilled through the Urenui and Mount Messenger formations to the deeper Moki formation. It has a measured depth of 3167 metres and true vertical depth of 2633 metres. NZEC plans to drill up to 12 additional exploration wells in 2012.[lxxv]

6.2 East Coast Basin (See also 1.3.2)

The geological strata of the East Coast Basin have been folded and faulted due to oblique subduction of the Pacific Plate under the Australian Plate. There are around 300 known oil or natural gas seeps in the Basin. Unconventional shale formations are believed to be the source rocks for the basin's hydrocarbon system.

In 2011 and 2012, an estimated 20 exploratory wells were to be drilled; some may be fracked. TAG Oil seeks unconventional resource potential in the Waipawa black shale and Whangai shale rock formations. The Whangai Formation is a poorly bedded, siliceous or slightly calcareous mudstone 300 to 600 metres thick throughout much of the onshore East Coast Basin.[lxxvi] It has been geochemically linked to multiple onshore oil and gas seeps, pointing to its potential as an unconventional reservoir. The Formation is heavily fractured, providing increased reserve potential and natural pathways for resources.

The New Zealand Energy Corp (NZEC) holds three onshore permits for the Basin and says, "technical work suggests a total of 22.3 billion barrels of OOIP (Oil in place). An independent engineering firm has issued a best estimate for 478 million barrels of prospective (recoverable) resource in unconventional targets using a conservative 2% recovery rate, and 126 million barrels of prospective resource in conventional targets using a 9% recovery rate."[lxxvii]

Geological Structure of the East Coast, North Island, New Zealand
H N C Cutton, Institute of Geological and Nuclear Sciences
www.nzpam.govt.nz/cms/pdf-library/petroleum-conferences-1/1991-petroleum-conference-proceedings/cutten-747-kb-pdf

New Zealand Ministry of Economic Development: Energy
Listed on www.med.govt.nz/sectors-industries/energy/strategies

Rural Taranaki horrified by fracking risk
Video from Campbell Live, TV 3, 24 April 2012
http://www.3news.co.nz/Rural-Taranaki-horrified-by-fracking-risk/tabid/367/articleID/242319/Default.aspx

7 Water sources

Potentially, most water sources can be used in fracking fluids (see 3.2.1. and 7.1.3).

Underground freshwater aquifers supply much of the drinking water required by human populations globally. High draw-off rates are causing aquifers to shrink; e.g. under the Sahara Desert[lxxviii], and under cities like Beijing, Bangkok[lxxix] and under the Canterbury Plains in New Zealand.

Withdrawing water from surface sources can potentially lower flow rates and damage stream ecosystems.

> **Undermined**
> 60 Minutes, 14 May 2012
> http://sixtyminutes.ninemsn.com.au/article.aspx?id=1052462

7.1 New Zealand water sources and potential contaminations

New Zealand has around 200 generally shallow aquifers, the depth making them vulnerable to pollutants, especially from agricultural chemicals. Of particular concern in regard to fracking wells would be the aquifers in the petroleum basins of Taranaki, Poverty Bay, Hawke's Bay, the Canterbury Plains and Southland.[lxxx]

7.1.1. Taranaki

Taranaki has four main aquifers around 0.5km deep.[lxxxi] TAG Oil's wells are 1.4-1.8 kilometres deep, horizontal drilling reaching out up to 1km.[lxxxii] At the Manutahi wells the distance between fresh water and fracking has been reported as 257 metres.[lxxxiii] (See also 5.5.) This has raised public concern and media attention.

Sixty fracking events on 33 wells have been reported for Taranaki (as at April 2012). At the Mangahewa well, Todd Energy used 1.5 million litres of water from the Municipal supply with an estimated 600,000 litres of returned fluids.[viii]

Since 2004, Taranaki Regional Council (TRC) has been monitoring eight observation bores. Mean groundwater levels for 2005-2008 at all sites compared to mean historical levels, except at Motunui, North Taranaki, and Manutahi, South Taranaki, where both showed a minor decline.[lxxxiv] South Taranaki District Council says water will continue to be scarce in its district and conservation must continue as sources "approach the limits of consents issued" by TRC.[lxxxv]

TRC says water around fracked wells is not contaminated, but local residents blame their increase in ill health on drinking water contaminated by fracking chemicals.[lxxxvi] In September 2012, following requests from members of the public, South Taranaki District Council (STDC) had water tested for fracking contaminants, including BTEX (benzene, toluene, ethylbenzene, and xylenes). A letter from STDC to PSGR dated 21 November 2012 read:

"We draw water for our Kapuni water treatment plant predominately from the Kapuni stream and a borehole on the treatment plant which is some 420m deep."

If BTEX levels (or any other chemical) are detected at "more than 50% of the maximum acceptable values (MAV)" STDC "are required to formally monitor these elements and report on them to the Drinking Water Assessor (DWA). Toluene, Ethyl benzene and Xylene also have an aesthetic MAV" and "for these chemicals the odour would be noticeable in the drinking water at levels much lower than those that pose a risk to health."

At the Kapuni water treatment, STDC "use a S::CAN spectrolyser" which "can detect a huge variety of chemicals". The instrument is configured to measure benzene and report any positive reading through STDC's telemetry system which sends an alarm to the operations team if the level reaches the MAV. The instrument is being reconfigured to detect 50% of the MAV. "Since 2 March 2012, when this was set up, we have detected no benzene in the water."

In samples taken from the river at Kapuni and the Kapuni site borehole on 17 February 2012, all tests were "below the limit of detection for the chemicals (less than $0.005 g/m^3$ or 5 parts per billion). A second sample was taken on 12 September 2012 and the results were all below detection limits for BTEX. In addition the total petroleum hydrocarbons were measured and these were all below the detection limits too." STDC are considering drawing water from a subsurface level of the Kapuni Stream. "As petroleum products float on the water surface, this would go some way to mitigating the risk of unwanted chemicals entering the water supply in the unlikely event of any pollution of the river."

7.1.2. Water sources elsewhere in New Zealand

Fracking onshore could potentially put at risk the aquifers on which Christchurch, Napier, Hastings, and Palmerston North heavily rely; reservoirs established over millennia.[lxxxvii] Draw-off from Canterbury's aquifers is already greater than recharge.[lxxxviii] Poverty Bay's aquifers do not hold large quantities of water. Speaking of "water take consents in relation to fracking", Dennis Crone, Team Leader of Water Conservation, Gisborne District Council said, "No application for this area will be allowed that is likely to degrade any aquifer for water quality or recharge ability."

Questions arise. How does draw-off at high volumes impact ecologically on ground and surface water? What remains for users downstream? What impact has transporting just one million gallons/3,785,412 litres of fresh or wastewater, which the EPA estimates at 200 truck trips?[lxxxix]

7.1.3. Alternative water sources

Non-potable water could be used for fracking fluids: deep saltwater aquifers; brackish water; seawater; treated wastewater; power plant cooling water; rainwater collection ponds and run off; and/or recycled flowback water. The source would relate to the volume of water and quality requirements, and regulatory and physical availability. In 2010, the American Petroleum Institute advised non-potable water be used for fracking when practicable,[xc] [xci] but the industry is on record saying non-potable water can contain contaminants; fresh is best.[xcii]

8 Climate change

The petroleum industry claims fracking gas will ease the oil crisis and benefit climate change, that natural gas burns more cleanly than oil and coal, and gas power stations produce up to 50% less greenhouse gases (GHG) than coal stations.[xciii] This viewpoint has its detractors.

In 2012, the US Department of Energy announced CO_2 emissions for the early months of the year had reached a 20-year low, a reduction of some 20%. Reports accompanied the announcement claiming this is largely the result of increased use of natural gas.[xciv]

Dr Lawrence Cathles of the Department of Earth and Atmospheric Sciences at Cornell University is considered one of the world's most independent and quantitatively strong geomechanics scientists. He and his research team claim data shows the advantage of natural gas applies whether it comes from a shale gas well or a conventional gas well.

"Scientifically the prescription for reducing green house emissions is clear: substitute gas for coal while minimizing methane emissions using proven and available technology, and then move toward low carbon energy sources as quickly as technically and economically feasible."[xcv]

> Cathles LM (submitted) Assessing the greenhouse impact of natural gas, G^3, http://www.geo.cornell.edu/eas/PeoplePlaces/Faculty/cathles/Natural%20Gas/Cathles-%20Assessing%20GH%20Impact%20Natural%20Gas.pdf

9 Fracking – where to in New Zealand?

Reports say Taranaki Regional Council and other New Zealand councils are modifying their regulatory practices to introduce improvements.[xcvi]

Public concerns range from the potential effects on human health and the environment, to questions over profits: will they stay in the region where drilling takes place, will they go to central government, or will they end up in the pockets of the overseas' companies operating the wells. Ownership of oil and gas by iwi is also an issue.

'Fracking free' regions are appearing and a moratorium has been called for. In her interim report on hydraulic fracturing, the Commissioner for the Environment, Dr Jan Wright, states that she does not think a moratorium is justified at present.

Significant comments in her report include:

> "The Ministry for the Environment has not provided any guidance to councils specifically on fracking." Such guidance is urgently required, particularly when considering drilling offshore.
>
> The current approach in the oil and gas sector in New Zealand "involves a high degree of reliance on a company being motivated to 'do the right thing' by consumers, by workers, and by the environment." There are "problems with this approach in high risk industries."

> "In New Zealand, to a considerable extent, companies appear to be not only regulating themselves, but monitoring their own performance. Companies are required to provide (often highly technical) information to councils, to New Zealand Petroleum & Minerals, and to the High Hazard Unit[12]. However, this is no guarantee that the information is always being understood and used to enforce best practice – or even good practice."
>
> "Increasing public understanding of the technology should help address some concerns. . . . But ultimately what is needed is trust – trust that government oversight is occurring and that regulation is not just adequate but enforced and seen to be so."

N.B. Questions arising from the interim findings will be explored and discussed in phase two of Dr Wright's investigation.

Access www.pce.parliament.nz/assets/Uploads/Fracking-interim-web.pdf to download Dr Wright's interim report.

Meanwhile, government sees New Zealand as a net oil and gas exporter by 2030 and offers financial inducements to push oil exploitation.[xcvii] It sees an economic future built largely on oil and gas. Questions arise, says Ms Wright, "whether the same effort is going to be put into preparing for the impacts it may have. The scale and speed of change that could occur requires forethought now. . . . We can and must learn from other countries about what can go wrong."

Physicians and Scientists for Global Responsibility New Zealand Charitable Trust urge the application of the precautionary principle in regard to hydraulic fracturing.

This would require the establishment of independent peer-reviewed published research into:

- the possible effects of hydraulic fracturing within the context of New Zealand's unique and unstable geological structures;
- the immediate and long-term physical impacts of fracked wells on their immediate environs, including aquifers, and on the wider New Zealand environment;
- hydraulic fracturing and its potential for adverse effects on the human environment;
- the impacts on vital industries such as agriculture, tourism, and exports;
- the impacts of limiting fracking on potential geothermal power developments and exports.

The precautionary principle would also require the establishment of comprehensive regulations and effective oversight of those regulatory requirements.

[12] Formed after an announcement on 17 August 2011 by the Minister of Labour, New Zealand's High Hazard Unit is primarily to enforce health and safety legislation in the mining, petroleum and geothermal sectors: http://www.dol.govt.nz/services/highhazards/.

It would also require public education on hydraulic fracturing and public submissions on applications to use the technology or its variants.

Only after such research, regulation and public consultation should decisions be made on establishing further well fracking operations in New Zealand using this technology and/or its variants. PSGR believes their expansion should be limited, highly researched and regulated to preserve and protect the unique qualities of the New Zealand environment for future generations.

April 2013
www.psgr.org.nz

This material on hydraulic fracturing has been drawn from many sources by consensus with the Trustees of PSGR.

The geoscience material in this document has been reviewed by Peter Malin PhD. Dr Malin has an extensive background in crustal seismology and geophysics.

Find out more...

What you need to know about natural gas production presented by environmental health analyst Dr Theo Colborn, www.endocrinedisruption.com/chemicals.video.php.

European Parliament Report 2011, http://europeecologie.eu/IMG/pdf/shale-gas-pe-464-425-final.pdf

Marcellus Shale, www.marcellus.psu.edu/resources/maps.php; www.srbc.net/whatsnew/docs/Marcellusshale61208ppt.PDF;

Fracking, www.scientificamerican.com/search/?q=fracking&x=10&y=1.
US Environmental Protection Agency, www.epa.gov/hydraulicfracturing/.

60 minutes, Dangers of Shale Gas Fracking, www.youtube.com/watch?v=iNl6sx059bE

60 Minutes, Meet the Frackers, http://ondemand.tv3.co.nz/60-Minutes-Meet-The-Frackers/tabid/59/articleID/5752/Default.aspx

Fracking New Zealand, http://fracknz.org/fracking-library/

The Ecologist,
www.theecologist.org/tv_and_radio/ecologist_film_unit/1074609/fracking_hell_the_environmental_costs_of_the_new_us_gas_drilling_boom.html

Gasland, an award winning film www.gaslandthemovie.com/whats-fracking

How Many People Can Live on Planet Earth? Commentator Sir David Attenborough. www.forbiddenknowledgetv.com/videos/depopulation/how-many-people-can-live-on-planet-earth.html.

The Real Cost of Water We Use: Peter Gleick, Pacific Institute. www.youtube.com/watch?v=ORNuY-NdwkA. More videos listed on this site

Download a map of Safe Drinking Areas in any country,
www.mapsofworld.com/thematic-maps/safe-drinking-water.htm

International Energy Agency,
www.iea.org/weo/docs/weo2011/WEO2011_GoldenAgeofGasReport.pdf

Impacts of shale gas and shale oil extraction on the environment and human health, European Parliament Directorate-General for Internal Policies 2011, http://europeecologie.eu/IMG/pdf/shale-gas-pe-464-425-final.pdf

Fracking in New Zealand, The Listener, issue 3740, 14 January 2012, www.listener.co.nz/current-affairs/fracking-in-new-zealand/

Fracking: give us the facts, The Listener, issue 3753, 10 April 2012, http://www.listener.co.nz/commentary/editorial/fracking-give-us-the-facts/

FAQ about fracking - New Zealand Ministry of Economic Development, www.nzpam.govt.nz/cms/petroleum/overview/frequently-asked-questions-about-fracking

Fracking Free Ireland - http://frackingfreeireland.org/global-fracking/

The Real Cost of Water We Use: Peter Gleick, Pacific Institute, www.youtube.com/watch?v=ORNuY-NdwkA.

Chemical used in fracking,
http://democrats.energycommerce.house.gov/sites/default/files/documents/Hydraulic%20Fracturing%20Report%204.18.11.pdf

Memorandum: Multi-Agency Collaboration on Unconventional Oil and Gas Research
US Environmental Protection Agency, 13 April 2012,
http://www.epa.gov/hydraulicfracture/oil_and_gas_research_mou.pdf

Regulation of Hydraulic Fracturing Under the Safe Drinking Water Act,
http://water.epa.gov/type/groundwater/uic/class2/hydraulicfracturing/wells_hydroreg.cfm

Fracking and Freshwater – fissures of uncertainty,
New Zealand Freshwater Sciences Society,
Newsletter Number 50 October 2011 ISSN 1177-6906,
http://freshwater.science.org.nz/pdf/Newsletter_2011_for_web.pdf

References:

[i] US Environmental Protection Agency (2011a), 'Draft plan to study the potential impacts of hydraulic fracturing on drinking water resources' (EPA/600/D-11/001). Washington, D.C. http://water.epa.gov/type/groundwater/uic/class2/hydraulicfracturing/upload/hf_study_plan_110211_final_508.pdf
[ii] www.cambridge.org/gb/knowledge/isbn/item5634881/?site_locale=en_GB
[iii] http://uk.reuters.com/article/2012/04/17/uk-energy-shale-regulation-idUKBRE83G0ML20120417
[iv] http://en.wikipedia.org/wiki/List_of_countries_by_natural_gas_proven_reserves 1.3
[v] http://www.nzpam.govt.nz/cms/pdf-library/petroleum-basins/Taranaki%20Basin%20Fact%20File.pdf last updated 16 October 2012.
[vi] www.newzealandenergy.com.
[vii] www.newzealandenergy.com/Operations/East-Coast-Basin/default.aspx
[viii] www.mta.org.nz/n2608.html
[ix] http://www.southlandnz.com/BusinessinSouthland/OilGasMinerals/OnShoreExploration.aspx
[x] http://en.wikipedia.org/wiki/Hydraulic_fracturing
[xi] http://www.google.com/patents/US7441604
[xii] www.sourcewatch.org/index.php?title=Fracking
[xiii] http://www.propublica.org/special/hydraulic-fracturing
[xiv] http://www.nrdc.org/water/fracking-drinking-water.asp
[xv] Hydraulic Fracturing Research Study www.epa.gov/owindian/tribal/pdf/hydraulic-fracturing-fact-sheet.pdf; www.convertunits.com/from/50000+gallon/to/litre
[xvi] www.betweenlinesblog.com/tag/fracking/
[xvii] http://water.epa.gov/type/groundwater/uic/class2/hydraulicfracturing/upload/hf_stu dy_plan_110211_final_508.pdf
[xviii] www.energyfromshale.org/fracking-fracturing-water-supply; www.pennvirginia.com/operations/Fracturing/default.aspx
[xix] http://democrats.energycommerce.house.gov/sites/default/files/documents/Hydraulic%20Fracturing%20Report%204.18.11.pdf
[xx] http://en.wikipedia.org/wiki/Hydraulic_fracturing
http://cleanwater.org/page/fracking-laws-and-loopholes
http://www.ewg.org/reports/Free-Pass-for-Oil-and-Gas/Oil-and-Gas-Industry-Exemptions
[xxi] www.ryderscott.com/pdfs/presentations/2011/05-2011%20RSC%20Conference_Can%20Nanotechnology%20Provide%20a%20New%20Approach_Barron_Updated.pdf; www.rigzone.com/news/article.asp?a_id=109634
[xxii] www.bakerhughes.com/news-and-media/resources/article-archive/nanotechnology
www.bakerhughes.com/assets/media/articles/4c7d564ffa7e1c1310000009/file/guestedsept.pdf.pdf&fs=1964557
[xxiii] 'Soybean susceptibility to manufactured nanomaterials with evidence for food quality and soil fertility interruption', 2012 www.pnas.org/content/early/2012/08/14/1205431109?utm_source=HEADS-UP+24-30+AUGUST++2012&utm_campaign=SMC+Heads-Up&utm_medium=email
[xxiv] Y Song, X Li and X Du, 'Exposure to nanoparticles is related to pleural effusion, pulmonary fibrosis and granuloma', Eur Respri J 2009; 34; 559-567, http://erj.ersjournals.com/cgi/content/short/09031936.00178308v1
[xxv] http://www.epa.gov/rpdweb00/radionuclides/radium.html
[xxvi] http://en.wikipedia.org/wiki/Proppants_and_fracking_fluids
[xxvii] http://www.epa.gov/ogwdw/uic/pdfs/cbmstudy_attach_uic_ch03_cbm_practices.pdf
[xxviii] http://shaleshock.org/drilling-101/
[xxix] http://slowdownfracking.wordpress.com/2012/01/16/production-of-fracking-chemicals/
[xxx] www.trc.govt.nz/assets/Publications/guidelines-procedures-and-publications/hydraulic-fracturing/fracking-report-feb2012.pdf
[xxxi] www.safewater.org/PDFS/knowthefacts/Fracking.pdf
[xxxii] http://poseidonsciences.scienceblog.com/30/this-fracking-problem-chasing-the-solution-to-this-controversial-mining-issue/
[xxxiii] www.tandfonline.com/doi/abs/10.1080/08927019609386283
[xxxiv] http://ec.europa.eu/health/ph_risk/committees/04_scenihr/docs/scenihr_o_021.pdf
http://ec.europa.eu/health/opinions/en/biocides-antibiotic-resistance/l-2/4-mechanisms.htm.
[xxxv] http://scienceindex.com/stories/2095194/The_chronic_aquatic_toxicity_of_a_microbicide_dibromonitrilopropionamide.html.
[xxxvi] http://composite.about.com/library/glossary/b/bldef-b659.htm
[xxxvii] www.businesswire.com/news/home/20120110005568/en/EPA-Aproved-Fracking-Fluid-100-Green
[xxxviii] http://www.marcellus-shale.us/drilling_wastewater.htm
[xxxix] http://www.loe.org/blog/blogs.html?seriesID=1&blogID=32
[xl] http://freshwater.science.org.nz/pdf/Newsletter_2011_for_web.pdf
[xli] http://www.gns.cri.nz/Home/News-and-Events/Media-Releases/Commentary-on-fracking.
[xlii] www.phila.gov/water/pdfs/QA_Iodine131.pdf
[xliii] www.reuters.com/article/2011/11/02/us-gas-fracking-idUSTRE7A160020111102
[xliv] http://newsdirect.nma.com.tw/SingleItem.aspx?asset_id=OEM_20120104_OINT_004
[xlv] http://frackingofamerica.com/
[xlvi] www.justice.net.nz/_r/img/uploads/2011/12/Just-Facts-Fracking.pdf

xlvii www.news.cornell.edu/stories/March12/FrackingAnimals.html
xlviii www.scientificamerican.com/article.cfm?id=epa-finds-fracking-compound-wyoming-aquifer. www.epa.gov/region8/superfund/wy/pavillion/EPA_ReportOnPavillion_Dec-8-2011.pdf
xlix http://cleanwater.org/page/fracking-laws-and-loopholes
l www.empoweredmunicipality.com/epa-requesting-info-on-fracking-chemicals
li http://thewaterwatch.wordpress.com/2012/04/18/fracking-confusion/
lii http://www.marcellus-shale.us/drilling_wastewater.htm
liii http://www.huffingtonpost.com/2011/04/20/pennsylvania-fracking-spill-gas-blowout-2011_n_851637.html
liv http://frackingofamerica.com/
lv www.sciencedaily.com/releases/2010/10/101025172926.htm
lvi http://www.workers.org/2010/us/fracking_1021/.
lvii http://sciblogs.co.nz/griffins-gadgets/2012/03/20/fracking-wells-and-air-emissions/
lviii http://cogcc.state.co.us/library/setbackstakeholdergroup/Presentations/Health%20Risk%20Assessment%20of%20Air%20Emissions%20From%20Unconventional%20Natural%20Gas%20-%20HMcKenzie2012.pdf
lix http://www.deq.utah.gov/locations/uintahbasin/index.htm
lx http://www.businessweek.com/news/2012-03-19/fracking-wells-air-emissions-pose-health-risks-study-finds
lxi http://www.ft.com/cms/s/0/10cbafb8-899a-11e1-85b6-00144feab49a.html?ftcamp=published_links/rss/companies_us/feed//product#axzz1sWmG3aQb
lxii http://teeic.anl.gov/er/oilgas/impact/drilldev/index.cfm
lxiii http://shaleshock.org/drilling-101/
lxiv McGregor, H.N. (Engineering Dynamics, Inc., Englewood, CO). Propagation of Noise from Gas Compression Facilities Located in Mountainous Terrain. (COGCC Noise Stakeholder Meeting Handout).
lxv http://www.earthworksaction.org/issues/detail/noise_resources#.UMpa86wufSM; La Plata County, Colorado; 2002, La Plata County Impact Report. pp. 3-98.
lxvi Bureau of Land Management, October 2000, Draft RMPA/EIS for Federal Fluid Minerals Leasing and Development in Sierra and Otero Counties; pp 4-29.
lxvii http://tvnz.co.nz/national-news/east-coast-literally-leaking-oil-and-gas-4688478/video
lxviii www.southlandnz.com/BusinessinSouthland/OilGasMinerals/OnShoreExploration.aspx
lxix www.odt.co.nz/news/business/164016/anadarko-committed-test-drilling
lxx www.contrafedpublishing.co.nz/Energy+NZ/Issue+11+Summer+2009/LM+ups+its+CSG+s takes.html
lxxi TAG Oil Ltd, 'TAG Awarded Taranaki Exploration Acreage', Vancouver, B.C. 11 December 2012.
lxxii TAG Oil's Cheal Infrastructure Expansion Complete, Paving Way for Continued Oil & Gas Production Growth in Taranaki, Vancouver, B.C. – March 19, 2013, media@tagoil.com.
lxxiii TAG Oil Ltd, 'TAG Oil and Apache Corporation Conclude East Coast Basin Farmout Agreement', Vancouver, B.C. 31 January 2013
lxxiv www.reubenhunt.org.nz/images/Fracking%20in%20New%20Zealand%20and%20Canterbury. pdf
lxxv (www.newzealandenergy.com.)
lxxvi www.tagoil.com/whangai.asp
lxxvii www.newzealandenergy.com/Operations/East-Coast-Basin/default.aspx
lxxviii www.economist.com/node/17199914
lxxix www.wired.com/science/planetearth/magazine/16-05/ff_peakwater?currentPage=all
lxxx www.mfe.govt.nz/environmental-reporting/freshwater/groundwater/; www.es.govt.nz/media/7768/soe-groundwater-technical-report.pdf; www.nzpam.govt.nz/cms/petroleum/petroleum-basins
lxxxi www.energystream.co.nz/sites/energystream.co.nz/ files/users/u127/TRC%20fraccing%20report%202011.pdf www.trc.govt.nz/assets/taranaki/publications/state-of-environment/soe09/images/ch4_table1_large.jpg
lxxxii www.gisborneherald.co.nz/article/?id=2515
lxxxiii www.justice.net.nz/_r/img/uploads/2011/12/Just-Facts-Fracking.pdf
lxxxiv www.trc.govt.nz/assets/Publications/technical-reports/environmental-monitoring-technical-reports/611946.pdf
lxxxv www.southtaranaki.com/uploaded_files/water/savingwaterathome.pdf
lxxxvi http://www.massivemagazine.org.nz/blog/2012/03/19/fracking-the-deeper-you-dig-the-darker-it-gets/
lxxxvii The Geology of NZ, Economic and applied geology http://data.gns.cri.nz/geoatlas/text.jsp?Page=20,
lxxxviii www.waterrightstrust.org.nz/water-is-running-out
lxxxix www.earthworksaction.org/issues/detail/hydraulic_fracturing_101
xc www.betweenlinesblog.com/tag/fracking/
xci http://water.epa.gov/type/groundwater/uic/class2/ hydraulicfracturing/upload/hf_study_plan_110211_final_508.pdf
xcii http://www.independentmail.com/news/2011/jun/30/fracking-gives-texas-another-oil-boom-huge-water-c/
xciii http://en.wikipedia.org/wiki/The_New_York_Times_Magazine
xciv Natural Gas Boom Drops US Emissions to 1992 Levels; CO_2 emissions in US drop to 20-year low, AP, 16 August 2012 http://www.heatisonline.org/contentserver/objechandlers/index.cfm?ID=8310&method=full
xcv www.geo.cornell.edu/eas/PeoplePlaces/Faculty/cathles/Natural%20Gas/Response%20to%20Howarth%27s%20Reply%20Distributed%20Feb%2030,%202012.pdf
xcvi www.trc.govt.nz/assets/taranaki/environment/water/ngaere-gw-results-feb2012.pdf
xcvii www.newzealandenergy.com/Why-New-Zealand/default.aspx
Ends/