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Submission to the Inquiry into Unconventional Gas (Fracking) in South Australia

The industrialisation of the rural landscape brought about by unconventional gas (UG) activities with its associated air and water pollution, would significantly damage the South Australian landscape without adding substantial economic or social benefits. As this submission will show, after a decade in Australia, the UG industry still does not have effective ways to deal with its waste water, its solid wastes (eg salts, drilling muds) or its impact on groundwater aquifers. As the federal government's National Pollutant Inventory demonstrates, the industry cannot control its toxic air emissions, which continue to escalate. While improved regulation may to some extent reduce the impacts of hydraulic fracturing (fracking/HF), which is an essential part of shale gas production, the global alert released in 2012 by United Nations Environment Programme acknowledged that that unintended impacts are inevitable and it is impossible to regulate the UG industry into safety.

'UG exploitation and production may have unavoidable environmental impacts. Some risks result if the technology is not used adequately, but others will occur despite proper use of technology. UG production has the potential to generate considerable GHG emissions, can strain water resources, result in water contamination, may have negative impacts on public health (through air and soil contaminants; noise pollution), on biodiversity (through land clearance), food supply (through competition for land and water resources), as well as on soil (pollution, crusting).'

- UNEP Global Environmental Alert System 2012

This submission will address the potential impacts of the use of hydraulic fracturing (HF) in unconventional gas exploration and production in South Australia based on experience elsewhere in Australia and overseas. It will examine the effects on air and water quality and human health. It will also address claims that HF fluids are 'harmless'.

Section 1.

Chemicals used and released in unconventional gas exploration and production

HF involves injecting wells at high pressure with water, proppants, radioactive tracers and chemical additives to fracture the formation and produce new cracks and pathways to help extract the gas.

While chemical additives make up less than 2% of the fracking fluid, this nevertheless translates to large quantities of chemical additive. An estimated 18,500 kilograms of HF products were used in one hydraulic fracturing of a CSG well in Australia with up to 40% (7400 kg) not recovered[1] and hence potentially contaminating the environment.
The volume of chemicals used in the 3 exploratory HF in the Buru Energy Shale project in West Australia was estimated at up to 47,000 litres of chemical additives.[2]

The European Parliament report estimates 16 tonnes of acute toxic substances were used to frack tight gas in Lower Saxony, Germany, [3] whereas the US industry fracfocus database shows that up to 100 tons of chemical can be added to fracking fluid used in shale gas production depending on depth and pressure requirements. A shale gas well may be 'fracked' a number of times to maintain commercial flows.

At a minimum, HF usually requires:

- biocide to prevent bacterial action underground (eg glutaraldehyde, THPS, DBNPA);
- clay stabiliser to prevent clay expanding on contact with water and plugging the reservoir (eg tetramethyl ammonium chloride);
- gelling agent to hold the proppant in suspension (eg mixtures of guar gum, diesel);
- gel stabiliser (eg sodium thiosulphate) and gel breaker (eg sodium persulfate);
- friction reducer to ease pumping and evacuation of fluid (eg polyacrylamide, mixtures of methanol, ethylene glycol, surfactants); and
- buffer fluids and crosslinking agents.

HF may also utilise corrosion inhibitors (eg formamide, methanol, naphthalene, naptha, nonyl phenol); scale inhibitors (eg ethylene glycols); iron control (eg citric acid, thioglycolic acid); pH adjusting agents (sodium or potassium carbonate) and various surfactants to affect fluid viscosity (eg isopropanol, 2-BE.) Large quantities of proppant are used for each fracturing, consisting of sand or manufactured sol-gel ceramic spheres based on alumino-silicates.

More than 750 chemical products containing 650 hazardous substances plus 279 products with trade secrets were identified by the US House of Representatives Committee on Energy and Commerce.[4] These include carcinogens (eg naphthalene), neurotoxins (eg isopropanol*),* irritants/sensitisers (eg sodium persulfate*)*, reproductive toxins (eg ethylene glycol) and endocrine disruptors [5] (eg nonylphenol). Some of the chemicals were found to be dangerous

[1] Coal Seam Hydraulic Fracturing Fluid Risk Assessment. Response to the Coordinator-General Requirement for Coal Seam Gas Operations in the Surat and Bowen Basins, Queensland. Golder Associates 21 October 2010

[2] Yulleroo-2 Hydraulic Fracturing Operations Environmental Management Plan Buru Energy Pty Ltd Kimberley Western Australia

[3] European Parliament Directorate General For Internal Policies, Economic & Scientific Policy Impacts of shale gas & shale oil extraction on the environment & on human health ENVI 2011

[4] US House of Rep. C'tee on Energy & Commerce, April 2011 Chemicals Used In Hydraulic Fracturing. http://democrats.energycommerce.house.gov/sites/default/files/documents/Hydraulic%20Fracturing%20Report%204.18.11.pdf

[5] WHO State of the Science of Endocrine Disrupting Chemicals (2013) notes there is often no threshold for EDC

at concentrations near or below chemical detection limits,[6] (eg glutaraldehyde, brominated biocides (DBNPA, DBAN), propargyl alcohol, 2-butoxyethanol (2-BE), heavy naphtha.)

A number of chemicals used in hydraulic fracturing have recently been identified as endocrine disrupters. These include ethylene glycol monobutyl ether, 2-ethylhexanol, ethylene glycol, diethanolamine, diethylene glycol methyl ether, sodium tetraborate decahydrate, 1,2-bromo-2-nitropropane-1,3-diol, n,n-dimethyl formamide, cumene, and styrene. [7]

A quick review of the health impacts associated with some HF chemicals demonstrate they are far from non-toxic and safe for human health or the environment. *The following information was compiled from publically available sources including International Program on Chemical Safety, INCHEM, www.inchem.org, US Agency for Toxic Substances & Disease Register, www.atsdr.cdc.gov, Material Safety Data Sheets and NICNAS literature. Health data for 560 HF chemicals is available for download at http://www.endocrinedisruption.com/chemicals.multistate.php*

*Sodium Persulfate - e*xposure via inhalation or skin contact can cause sensitization, i.e., after initial exposures individuals may subsequently react to exposure at very low levels of that substance. Exposure can also cause skin rashes and eczema. Sodium persulfate is irritating to eyes and respiratory system and long-term exposure may cause changes in lung function (i.e. pneumoconiosis resulting in disease of the airways) and/or asthma.

2-Butoxyethanol - high doses of 2BE can cause reproductive problems and birth defects in animals. Animal studies have shown exposure can cause hemolysis (destruction of red blood cells that results in the release of hemoglobin). The International Agency for Research on Cancer has not classified 2-butoxyethanol as to its human carcinogenicity as no carcinogenicity studies are available. 2BE was declared a Priority Existing Chemical under NICNAS due high mobility, low degradation and potential to contaminate aquifers.

Ethylene Glycol - known human respiratory toxicant, associated with increased risks of spontaneous abortion and sub-fertility in female workers, can irritate the eyes, nose and throat. It is a human respiratory toxicant, birth defects in animals. Ethylene Glycol is on the U.S. EPA list of 134 priority chemicals to be screened as an endocrine disrupting substance (EDC).

Methanol - a volatile organic compound, which is highly toxic to humans, causes central nervous system depression in humans and animals as well as degenerative changes in the brain and visual system. Chronic exposure to methanol, either orally or by inhalation, causes headache, insomnia, gastrointestinal problems, and blindness in humans and hepatic and brain alterations in animals. Methanol is highly mobile in soil. In water, the degradation products of methanol are methane and carbon dioxide. Methanol also volatilizes from water and once in air, exists in the vapor phase with a half-life of over 2 weeks. The chemical reacts with photochemically produced smog to produce formaldehyde and can also react with nitrogen dioxide in polluted air to form methyl nitrite. Methanol is listed as the most commonly used HF chemical by the United States House of Representatives Committee on Energy and Commerce. [8]

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effects and EDCs are likely to have effects at very low doses and may exhibit non linear dose response curves.

[6] Chemical and Biological Risk Assessment for Natural Gas Extraction in New York. Ronald E. Bishop, Ph.D., CHO, Chemistry & Biochemistry Dept, State University of New York, Sustainable Otsego March 28, 2011. www.sustainableotsego.org/Risk %20Assessment%20Natural%20Gas%20Extraction-1.htm

[7] Kassotis et al Estrogen and Androgen Receptor Activities of Hydraulic Fracturing Chemicals and Surface and Ground Water in a Drilling-Dense Region, *Endocrinology* doi: 10.1210/en.2013-1697 http://www.endo.endojournals.org

[8] Methanol was used in 342 of the 750 hydraulic fracturing products, and is a hazardous air pollutant and on the candidate list for potential regulation under the US *Safe Drinking Water Act* due to its risks to human health. See

Naphthalene - IARC *'possible human carcinogen'*, US *'reasonably anticipated to be human carcinogen'*. Chronic exposure of workers and rodents to naphthalene has been reported to cause cataracts and damage to the retina. Based on the results from animal studies, which demonstrated nasal and lung tumours in lab animals, US EPA and the International Agency for Research on Cancer (IARC) has classified naphthalene as a Group C, possible human carcinogen. Animal studies suggest that naphthalene is readily absorbed following oral or inhalation exposure. Although no data are available from human studies on absorption of naphthalene, the detection of metabolites in the urine of workers indicates that absorption does occur, and there is a good correlation between exposure to naphthalene and the amount of 1-naphthol excreted in the urine.

Glutaraldehyde - highly irritating to the eyes, skin and the respiratory tract of humans and laboratory animals. It has induced skin sensitization in humans and laboratory animals, and caused asthma in occupationally exposed people. In animal tests, glutaraldehyde by inhalation caused lung damage in rats and mice. DNA damage, mutations and some evidence of chromosome damage were found in mammalian cells in culture following treatment with glutaraldehyde. Data indicates that both algae and fish embryos may be particularly sensitive to long-term glutaraldehyde exposure.

Ethoxylated 4-nonylphenol - persistent, bioaccumulative, endocrine disruptor, which has been detected widely in wastewater and surface waters. NPE disrupt normal hormonal functioning in the body and can mimic the natural hormone estradiol and binds to the estrogen receptor in living organisms. Exposure to NPE changes the reproductive organs of aquatic organisms. Sexual deformities were found in oyster larvae exposed to levels of nonylphenol (NP) that are often present in the aquatic environment. A 2005 study found that exposure to NP increases the incidence of breast cancer in lab mice. Canada classified NPE metabolites as toxic. The European Union classifies nonylphenol as very toxic to aquatic organisms, which may cause long-term adverse effects in the aquatic environment. The intermediary chemicals formed from the initial degradation of NPE are much more persistent than the original compound.

Many HF chemicals have not been assessed for their long-term impacts on the environment and human health. In Australia, of the 23 identified as commonly used 'fracking' chemicals, only 2 (Sodium persulfate, 2-Butoxyethanol) had been assessed by the national regulator, National Industrial Chemicals Notification and Assessment Scheme (NICNAS) and neither for their use in UG.[9] The mixtures used in drilling and fracking fluids are also not assessed for toxicity or persistence. Mixtures can form new compounds when exposed to sunlight, water, air, radioactive elements or other natural chemical catalysts.

US industry self-reporting on 9,310 individual fracking operations between January 2011 and September 2012, noted cancer causing chemicals were used in one out of every three HF operations. While not all companies report and not all chemicals used in the process are disclosed because of 'trade secret' exemptions, industry did report that known carcinogens like naphthalene, benzyl chloride and formaldehyde were used in 34 percent of all HF operations.[10]

United States House of Representatives Committee on Energy and Commerce, Minority Staff, April 2011 Chemicals Used In Hydraulic Fracturing.
http://democrats.energycommerce.house.gov/sites/default/files/documents/Hydraulic%20Fracturing%20Report%204.18.11.pdf

[9] Lloyd-Smith, M.M & Senjen, Rye, Hydraulic Fracturing in Coal Seam Gas Mining: The Risks to Our Health, Communities, Environment & Climate, National Toxics Network Sept. 2011 www.ntn.org.au

[10] http://ecowatch.org/2013/cancer-causing-chemicals-fracking-operations/

Secrecy and Confidential Business Information makes regulation difficult
Proprietary data and trade secret regimes mean the disclosure of full formulations is usually not possible even by those who use the products. This can result in failure to adequately assess worker exposure and potential contamination to the environment.

The friction reducer, INFLO 150 commonly used in Australia including in shale gas in West Australia[11] is a pertinent example. It lists its active ingredients on the Australian material safety data sheet (MSDS) as:

Methanol (CAS 67-56-1) at 5-10%
Ethylene Glycol (CAS 107-21-1) at 10-30%
Oxyalkylated Alcohols (trade secret) 10-30%

Plus the following with no information on their identity or concentration:
Fatty Alcohol
Oxylalkylated Alkanolamine(s)
Silicone(s)
Surfactant(s)

On the US MSDS the surfactant is described as a fluorocarbon surfactants but it is still not specifically identified with a chemical abstract services (CAS) number. Fluorocarbon surfactants belong to a group of chemicals, perfluorocarboxylic acids (PFCAs) that can be extremely persistent, capable of long-range transport and are widespread throughout the environment and in wildlife. Many are found in human blood indicating bioaccumulation and concentrations in wildlife high on the foodchain, strongly suggest biomagnification. Some are known to have serious adverse health impacts, e.g. tumourigenic and immunotoxic impacts in laboratory animals. Discussions with the maker of hydraulic fracturing fluids such as Haliburton indicate that the company is not willing to provide full details of the formulation to either the users or government regulatory bodies.[12]

Drilling Chemicals
As the lifespan of an UG well according to the International Energy Agency is 5 to 15 years with output typically declining by between 50% and 75% in the first year of production, many new wells are required to be drilled to keep a gas field commercially viable. Hence, the impact of the large amounts of drilling fluid components need to be addressed in an assessment of the impacts of the UG industry

Drilling fluid components include:
- Viscosifiers to increase viscosity of mud to suspend cuttings (eg bentonite, polyacrylamide)
- Weighting agent (eg barium sulphate);
- Bactericides/biocides to prevent biodegradation of organic additives (eg glutaraldehyde);
- Corrosion inhibitors to prevent corrosion of drill string by acids and acid gases (eg zinc carbonate, sodium polyacrylate, ammonium bisulphate);
- Defoamers to reduce mud foaming (eg glycol blends, light aromatic and aliphatic oil, naptha);
- Emulsifiers and deemulsifiers to help the formation of stable dispersion of insoluble liquids in water phase of mud;
- Lubricants to reduce torque and drag on the drill string (eg chlorinated paraffins)

[11] Yulleroo-2 Hydraulic Fracturing Operations Environmental Management Plan Buru Energy Pty Ltd Kimberley Western Australia
[12] Views expressed by the Haliburton representative presenting at the Helsinki Chemical Forum, April 2014

- Polymer stabilisers to prevent degradation of polymers to maintain fluid properties (eg sodium sulfite);
- Breakers to reduce the viscosity of the drilling mud by breaking down long chain emulsifier molecules into shorter molecules (eg diammonium peroxydisulphate, hemicellulase enzyme)
- Salts (eg potassium chloride, sodium chloride, calcium chloride);

and in the case of drilling for shale gas:

- Shale control inhibitors to control hydration of shales that causes swelling and dispersion of shale, collapsing the wellbore wall (eg anionic polyacrylamide, acrylamide copolymer, petroleum distillates).

Drilling Muds, Cuttings and Waste Disposal

Drilling muds consisting of drilling fluid, weighting agents, and stabilizing materials need to be disposed of safely. The mud has come into contact with the coal and its contaminants, which mixing with the mud fluid are transported to the surface with the drilling muds. Trials undertaken in Queensland on a proposal for land spraying of drilling by–products identified environmental hazards associated with drilling by–products include potentially toxic additives, salt compounds, heavy metals, hydrocarbons, pH-control additives, and total suspended solids (TSS).[13] The report notes that concentrations of aluminium, boron, iron, manganese, molybdenum, vanadium and mercury exceeded the Australian and New Zealand Environment and Conservation Council (ANZECC) 2000) Guidelines[14] and detectable concentrations of petroleum hydrocarbons were observed in drilling muds. They concluded that the C6–C9 fraction, which include BTEX (benzene, toluene, ethyl benzene and xylenes) may pose a risk from an environmental and human health perspective. In June 2013, New Zealand milk giant, Fonterra, announced it would no longer accept milk from farms that accept CSG muds and drilling cuttings on their properties, citing both contamination concerns and the extra cost of testing the milk at about $80,000 per year.[15]

Section 2.

Air Pollution From Unconventional Gas Exploration And Production

The USEPA states that air toxics associated with oil and gas extraction activities can cause cancer and other serious, irreversible health effects, such as neurological problems and birth defects. [16] They state that the oil and gas industry is the largest industrial source of VOC emissions in the U.S. Once considered a summertime pollutant, ozone had now become a problem in winter in areas with significant natural gas production.

The US National Library of Medicine notes that operations at gas fields emit a wide range of pollutants including nitrogen oxides, volatile organic compounds (VOCs), carbon monoxide, sulfur dioxide, and particulate matter. Air emissions come from several sources in gas fields, including equipment engines, drilling rigs, pumpjacks, boilers, heaters, generators, combustion flares, storage tanks, injection pumps, dehydrators, vehicles, and oil and gas skimmers. They note that one of the major sources of air emissions at gas fields are compressor stations that move natural gas through pipelines and gas processing plants.[17]

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[13] Origin's EMP Landspraying While Drilling (LWD) Trial Program OEUP-Q8200-PLN-ENV http://www.aplng.com.au/pdf/Environmental_Management_Plan_Landspraying_While_Drilling_Trial_Program.pdf

[14] http://www.environment.gov.au/resource/australian-and-new-zealand-guidelines-fresh-and-marine-water-quality-volume-1-guidelines

[15] http://www.stuff.co.nz/taranaki-daily-news/news/8813978/Fonterra-rejects-new-landfarm-milk

[16] Reducing Air Pollution from the Oil and Natural Gas Industry EPA's Final New Source Performance Standards and National Emission Standards for Hazardous Air Pollutants, April 17, 2012 http://www.epa.gov/airquality/oilandgas/pdfs/20120417presentation.pdf

[17] http://toxtown.nlm.nih.gov/text_version/locations.php?id=150

The United Kingdom's Public Health Association also identified UG activities as sources of air pollution by primary pollutants such as oxides of nitrogen (NOx) and particulate matter (PM) and the precursors of secondary pollutants such as ozone (O3). They highlighted a diverse range of sources and air pollutants associated with the unconventional gas industry including:[18]

Carbon monoxide - CO is emitted during flaring and from machinery used in CSG. CO is poisonous if inhaled, inhibiting blood's ability to carry oxygen and can cause dizziness, unconsciousness, and even death.

Sulfur dioxide - CSG may contain traces of sulfur, which can be emitted during flaring or from equipment onsite. SO2 reacts with other chemicals to form acid rain and particulate pollution, which can damage lungs and cause respiratory illness, heart conditions, and premature death.

Hydrogen sulfide – H2S occurs naturally in some gas formations and can be released when gas is vented or flared, or via fugitive emissions. It is a toxic gas, which is lethal if inhaled at high concentrations.

Nitrogen Oxides - NOx are emitted from machinery and compressors as well as during flaring. NOx may react with volatile organic compounds to form ground-level ozone. Nitrogen dioxide can cause respiratory problems, heart conditions and lung damage,

Particulate Matter - Particulate matter can be emitted during construction, venting, flaring and transport operations. Chronic inhalation of PM_{10} and $PM_{2.5}$ may lead to respiratory problems, cancer or premature death.

Volatile organic compounds - VOCs can be emitted during drilling, flaring, from machinery and from produce water. Some are known to cause cancer in animals and humans and are key ingredients in smog linked to asthma.

Benzene, toluene, ethylbenzene, xylene - BTEX chemicals are naturally occurring in coal and gas deposits and found in associated groundwater.[19] Their short term health effects including skin, eye and nose irritation, dizziness, headache, loss of coordination and impacts to respiratory system. Chronic exposure can result in damage to kidneys, liver and blood system. Benzene is also linked with cancer and leukemia.[20]

Natural Gas - while the primary component of natural gas is methane, it typically contains other hydrocarbons such as ethane, propane, butane, and pentanes and in some cases, may also contain hazardous air pollutants such as BTEX, hexanes, hydrogen sulphide, and carbon dioxide. Fugitive emissions associated with leaks from pumps, flanges, valves, pipe connectors etc. can include methane with these other gases.

Gas Processing

Gas Processing, which is required to remove impurities before natural gas can be used as a fuel, produces by-products including ethane, propane, butanes, pentanes and higher molecular weight hydrocarbons, hydrogen sulphide, carbon dioxide, water vapour and

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[18] A Kibble, T Cabianca, Z Daraktchieva, T Gooding, J Smithard, G Kowalczyk, N P McColl, M Singh, S Vardoulakis and R Kamanyire Review of the Potential Public Health Impacts of Exposures to Chemical and Radioactive Pollutants as a Result of Shale Gas Extraction: Draft for Comment, PHE-CRCE-002 http://www.hpa.org.uk/Publications/Environment/PHECRCEReportSeries/PHECRCE002/
[19] http://www.ehp.qld.gov.au/management/coal-seam-gas/btex-chemicals.html
[20] Rinsky, R.A Benzene and leukemia: an epidemiologic risk assessment. *Environ Health Perspect*.1989 July 82:

sometimes helium and nitrogen. These are often vented to the atmosphere, providing an important point source of air pollution from the industry. Dehydration units based on the ethylene glycols eg triethylene glycol (TEG), diethylene glycol (DEG)[21] are a likely source of BTEX emissions, and compressor stations are a significant source of carbon monoxide and nitrous oxides as well as VOCs

Particulates and Silica
UG activities result in the formation and distribution of particulate pollution from a range of sources including diesel engines and the use of proppants in hydraulic fracturing. Up to 50,000 kg of proppants may be used per HF. These consist of either silica or manufactured ceramic polymer spheres based on alumino-silicates, which are injected as part of the fracturing fluid mixture and intended to remain in the formation to hold open the fractures once the pressure is released. Breathing silica can cause silicosis, and exposure to silica dust is a known cause of lung cancer and a suspected contributor to autoimmune diseases, chronic obstructive pulmonary disease and chronic kidney disease.[22]

The US National Institute for Occupational Safety and Health (NIOSH) recently released a Hazard Alert, identifying exposure to airborne silica as a health hazard to workers conducting hydraulic fracturing operations.[23]

NIOSH identified seven primary sources of silica dust exposure during hydraulic fracturing operations:

- dust ejected from thief hatches (access ports) on top of the sand movers during refilling operations while the machines are running (hot loading);
- dust ejected and pulsed through open side fill ports on the sand movers during refilling operations;
- dust generated by on-site vehicle traffic;
- dust released from the transfer belt under the sand mover;
- dust created as sand drops into, or is agitated in, the blender hopper and on transfer belts;
- dust released from operations of transfer belts between the sand mover and the blender; and
- dust released from the top of the end of the sand transfer belt (dragon's tail) on sand movers.

NIOSH acknowledges the serious lack of information on occupational dust exposure in the gas industry, including exposure to diesel particulates. Diesel exhaust is classified as a Group 1 carcinogen by the International Agency for Research into Cancer.[24]

Proppants based on ceramic polymers may also add to air pollution. According to Haliburton's patent[25] acrylic polymers, consisting of 85% of the human carcinogen, acrylonitrile are used for proppant spheres. Acrylonitrile has been detected in US air sampling of gas sites at high levels. Acrylonitrile is also a respiratory irritant, causing degeneration and inflammation of nasal epithelium. Levels of acrylonitrile in the five samples

[21] Reduce Emissions and Operating Costs with Appropriate Glycol Selection HAROLD O. EBELING, Latoka Engineering, L.L.C., Tulsa, OK LILI G. LYDDON, KIMBERLY K. COVINGTON, Bryan Research & Engineering, Inc., Bryan, Texas http://www.bre.com/portals/0/technicalarticles/Reduce%20Emissions%20and%20Operating%20Costs%20with%20Appropriate%20Glycol%20Selection.pdf
[22] NIOSH Hazard Review, Health Effects of Occupational Exposure to Respirable Crystalline Silica. National Toxicology Program [2012]. Report on carcinogens 12th ed. U.S. Department of Health and Human Services, Public Health Service.
[23] www.osha.gov/dts/hazardalerts/hydraulic_frac_hazard_alert.htm
[24] http://www.iarc.fr/en/media-centre/pr/2012/pdfs/pr213_E.pdf
[25] Halliburton Patent 7799744, Polymer-Coated-Particulates, www.docstoc.com/docs/58860687/Polymer-Coated-Particulates---Patent-7799744

exceeded the level set by USEPA for risk of increased noncancer health effects from long term exposure by 3 to 15 times.[26]

Flaring

Flaring (the burning off of natural gas from a new well) is a common practice in the gas fields and represent a direct release of pollutants to air. The USEPA has effectively banned gas flaring after January 2015 due to growing concerns over air pollution.[27] The practice of flaring means that air contaminants including hydrogen sulphide, methane, BTEX [28] and other contaminants associated with methane are released. Gas flaring is recognised as a significant source of soot, or black carbon, pollution in the Arctic, with new research indicating that flaring from oil and gas developments is the largest source of this pollutant, responsible for 42% of black carbon pollution in the Arctic.[29]

Fugitive emissions

Fugitive non-methane and methane emissions are not only an issue associated with abandoned wells but are associated with the complete gas exploration and production cycle, affecting both shale gas and CSG.

Australian research[30] measured atmospheric radon (Rn-222 and Rn-220) and carbon dioxide (CO_2) concentrations as a measure of fugitive emissions in the gas fields. The researchers suggest the presence of radon and CO_2 indicates the possible release of other gases, such as VOCs. They suggest that CSG activities such as the depressurisation by groundwater extraction from the coal bed strata change the geological structure and pressures, helping gases to seep through the soil and be released to the atmosphere. They reported a 3-fold increase in maximum radon ^{222}Rn concentration inside the gas field compared to outside with a significant relationship with the number of wells.

In their submission to the Australian government, they also reported hotspots with concentrations of methane (CH4) as high as 6.89 ppm and CO_2 as high as 541 ppm near Tara. Background atmospheric CH4 outside the gas fields were lower than 2ppm.[31] In a later study just published, the same researchers confirmed the widespread enrichment of both CH4 (up to 6.89 ppm) and CO_2 (up to 541 ppm) within the production gas field, compared to outside. The CH4 and CO_2 δ13C source values showed distinct differences within and outside the production field, indicating a CH4 source within the production field that has a δ13C signature comparable to the regional CSG.[32]

A US report by NASA researchers published October 2014, demonstrated that there is a 2,500-square-mile cloud of methane over the region, where the borders of Arizona, Colorado, New Mexico, and Utah intersect. The report states, "the source is likely from established gas, coal, and coalbed methane mining and processing." [33]

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[26] Citizen Investigation of Toxic Air Pollution from Natural Gas Development July 2011, Global Community Monitor, www.gcmonitor.org

[27] http://www.epa.gov/airquality/oilandgas/pdfs/20120417presentation.pdf

[28] http://www.med.upenn.edu/ceet/documents_user/MarcellusShale_Penning3.pdf

[29] Stohl, A., Klimont, Z., Eckhardt, S. et al. (2013). Black carbon in the Arctic: the underestimated role of gas flaring and residential combustion emissions. *Atmospheric Chemistry and Physics*. 13: 8833–8855. Also see http://ec.europa.eu/environment/integration/research/newsalert/pdf/349na5.pdf

[30] Douglas R. Tait, Isaac Santos, Damien Troy Maher, Tyler Jarrod Cyronak, & Rachael Jane Davis, Enrichment of radon and carbon dioxide in the open atmosphere of an Australian coal seam gas field *Environ. Sci. Technol.* http://pubs.acs.org/doi/abs/10.1021/es304538g

[31] Submission on National Greenhouse and Energy Reporting (Measurement) Determination 2012 - Fugitive Emissions from Coal Seam Gas. Submitted 19 October 2012 to Department of Climate Change and Energy Efficiency by Dr. Isaac Santos Southern Cross University, NSW Australia

[32] Damien T. Maher & Isaac R. Santos & Douglas R. Tait, Mapping Methane and Carbon Dioxide Concentrations and δ13C Values in the Atmosphere of Two Australian Coal Seam Gas Fields *Water Air Soil Pollut* (2014) 225:2216

[33] Kortet al, Four corners: The largest US methane anomaly viewed from space, *Geophysical Research Letters*

Earlier this year, Cornell environmental engineering professor Anthony Ingraffea released the results of a study of 41,000 oil and gas wells that were drilled in Pennsylvania between 2000 and 2012, and found newer wells using fracking and horizontal drilling methods were far more likely to be responsible for fugitive emissions of methane.[34]

Methane Leaks
Further evidence of fugitive emissions was evident in bubbling methane gas reported along a 5 kilometre stretch of the Condamine River in Queensland, Australia. The Queensland government's initial investigation [35] notes that four UG wells were within 5k radius of the gas seep but there was no evidence of fracking within 40 kilometres. Methane was measured at 80% of the lower explosive limit (LEL) (at river surface) equating to 4% gas in air. Another Queensland government study found 26 of 58 gas wells tested leaked methane; one above the lower explosive limit (LEL), 4 at or above 10% of the LEL and 21 with levels between 10-3000ppm. Similar figures were found in surrounding gas fields. [36]

Methane is a powerful greenhouse gas with a global warming potential much greater than that of CO2. The IPCC calculated that methane is 34 times stronger as a heat-trapping gas than CO2 over a 100-year time scale. The IPCC report also stated that over a 20-year period, methane has a global warming potential of 86-105 compared to CO2. Its release may also indicate ongoing releases of other gases toxic to human health.

Volatile Organic Compounds (VOCs)
Of particular concern in regards to the adverse impacts of air pollution are the VOCs, which are released at all stages of UG production. Raw natural gas contains many toxic non-methane hydrocarbons that surface with the methane and are released during venting and in fugitive emissions at all stages of natural gas production and delivery. Mobile and stationary equipment release VOCs, as well as NOx, CO and particulate matter through exhaust and evaporative emissions. Pit fluids and holding ponds are also a source of VOCs, including the break-down products and mixtures of chemicals that cannot be predicted. Volatile chemicals are used during cleaning and maintenance of well pads and equipment. Semi volatile chemicals are also injected underground during HF, a percentage of which eventually surfaces.

Many VOCs are toxic. Some are known to cause cancer in animals (eg methylene chloride), or in humans (eg formaldehyde) or are suspected human carcinogens (eg chloroform and bromodichloromethane). VOCs are also key ingredients in forming ozone (smog), which is linked to asthma attacks, and other serious health effects. VOCs help form fine particle pollution (PM2.5). VOC exposure may result in eye, nose, and throat irritation; headaches, visual disorders, memory impairment, loss of coordination, nausea, damage to liver, kidney, and central nervous system.[37] BTEX are components of drilling fluids and are natural VOCs released from the coal seam.

VOCs detected in Tara Queensland
While there has been no comprehensive monitoring of air pollutants in the Tara community near gasfields, industry and government sampling of ambient air around homes detected a

Volume 41, Issue 19
[34] Ingraffeaa et al, Assessment and risk analysis of casing and cement impairment in oil and gas wells in Pennsylvania, 2000–2012, *PNAS* vol. 111 no. 30
[35] Summary Technical Report - Part 1 Condamine River Gas Seep Investigation, December 2012 Version 1 State of Queensland, Department of Natural Resources and Mines, 2012. http://www.dnrm.qld.gov.au/mining/coal-seam-gas
[36] Investigation report, Leakage testing of coal seam gas wells in the Tara 'rural residential estates' vicinity, The State of Queensland, Department of Employment, Economic Development and Innovation, 2010. http://www.dnrm.qld.gov.au/__data/assets/pdf_file/0011/119675/tara-leakage-csg-wells.pdf
[37] http://www.epa.gov/iaq/voc.html

wide range of VOCs. These included many toxic VOCs, eg acetone, acrolein, alpha-pinene, benzene, benzothiazole, chloromemethane, cyclohexane, dichlorofluromethane, ethanol, ethyl acetate, ethylbenzene, 2-ethyl-1-hexanol, heptane, hexane, heptadecane, hexadecane, 2-methylbutane, methylcyclohexane, methylene chloride, methyl ethyl ketone, 3- methylhexane, 3 methylpentane, naphthalene, pentane, phenol, propene, tetradecane, tetrachlorethylene, 1,2,4,-trimethylbenzene, toluene, vinyl acetate, xylene, ethanol, phenylmaleic anhydride, methyl ethyl ketone.[38]

Toluene, a neurotoxin was detected in the air around at least eight Tara homes and in the air over a private bore. In the latter,[39] it was well above the ‘Chronic Reference Exposure Limits’ used by many states in the USA (eg California, Massachusetts, Michigan) for assessing the impacts of long term exposure.

Community sampling in the vicinity of gas activities over an eight hour period also detected ethanol and chlorofluorocarbons (CFCs).[40] Dichlorodifluoromethane, a potent CFCs, was detected in all samples.

In July 2014, State government sampling outside a family residence adjacent to the gasfields identified Acrolein at 9.6ppb, more than 100 times higher than acceptable chronic exposure standard.[41] The Texas annual criterion is 0.066ppb. Acrolein is an acute irritant of the eyes, nose, throat, lungs and skin and is reported to be used by the oil and gas industry as a biocide in drilling waters, as well as a scavenger for hydrogen sulphide and mercaptans. Flares are also a possible source of acrolein. Formaldehyde[42], as well as acetaldehyde was also detected.

Preliminary health investigation by Queensland health department concluded that there was some evidence that might associate some of the residents’ health symptoms to exposures to airborne contaminants arising from CSG activities. [43]

In a 2012 US study,[44] of shale gas drilling sites over a 12-month period, found 44 hazardous air pollutants with the highest percentage of detections occurring during the initial drilling phase. The study found a wide range of air toxics including methane, methylene chloride, ethane, methanol, ethanol, acetone, propane, formaldehyde, acetaldehyde and PAHs including naphthalene. They noted a great deal of variability across sampling dates in the numbers and concentrations of chemicals detected.

[38] Symptomatology of a gas field, An independent health survey in the Tara rural residential estates and environs - http://www.ntn.org.au/wp/wp-content/uploads/2013/05/Symptomatology-of-a-gas-field-An-independent-health-survey-in-the-Tara-rural-residential-estates-and-environs-April-2013.pdf

[39] Simtars Investigation of Kogn Water Bore (RN147705) -16 October 2012

[40] Australian Government National Measurement Institute, Report of Analysis of Air Canisters Low Level, Report No. RN900555 (2 Feb 2012), Report No. RN893233 (16 Dec 2011), Report No. RN893232 (16 Dec 2011) as reported in Lloyd-Smith & M, Senjen, R Halogenated Contaminants From Coal Seam Gas Activities, Proceedings of Dioxin 2012 Conference, Cairns, Australia.

[41] Submission to the Senate Select Committee on Certain Aspects of Queensland Government Administration related to Commonwealth Government Affairs, 17th November 2014 BY Dr Geralyn McCarron MB BCh BAO FRACGP

[42] Formaldehyde is a suspected human carcinogen. It can affect nearly every tissue in the human body, leading to acute (dermal allergies, asthma) and chronic (neuro-, reproductive, hematopoietic, genetic and pulmonary toxicity and cellular damage) health effects http://www.ehjournal.net/content/pdf/1476-069X-13-82.pdf

[43] Queensland Department of Health Report ‘Coal seam gas in the Tara region: Summary risk assessment of health complaints and environmental monitoring data’, March 2013

[44] Colborn T, Schultz K, Herrick L, and Kwiatkowski C. 2012 (in press). An exploratory study of air quality near natural gas operations. *Hum Ecol Risk Assess*

Human Health Risk Assessment of air emissions around US UG activities

A Human Health Risk Assessment of air emissions around US shale gas activities,[45] concluded that residents closest to well pads i.e. living less than 1/2 mile from wells, have a higher risks of respiratory and neurological effects based on their exposure to air pollutants; and a higher excess lifetime risk for cancer. The study took 163 measurements from fixed monitoring station, 24 samples from perimeter of well pads (130-500 feet from center) undergoing well completion and measured ambient air hydrocarbon emissions. Emissions measured by the fenceline at well completion were statistically higher ($p \leq 0.05$) than emissions at the fixed location station (including benzene, toluene, and several alkanes.) The assessment was based on the US EPA guidance to estimate non-cancer and cancer risks for residents living greater 1/2 mile from wells and residents living equal to or less than a 1/2 mile from wells. The study may have underestimated risks to human health as it did not measure ozone or particulates. USEPA methods may also underestimate health risks of mixed exposures. Sampling around UG activities in Australia have shown the presence of BTEX including benzene on which the cancer risk was primarily based (See VOCs in Tara, Queensland).

The National Pollutant Inventory Reports shows increase in toxic air emissions

The Australian government's National Pollutant Inventory (NPI) requires companies to self report their calculated emissions for a limited list of around 100 chemicals and heavy metals. Table 1 compares NPI reports from three Queensland based UG activities. Note two reports are concerned with the compressor station infrastructure required to treat the gas.

The NPI also indicates that toxic air emissions are increasing over time. Data submitted by QGC (British Gas) to the NPI[46] for their emissions in 2010 and in 2013 demonstrate clearly the escalation of air pollution. Particulate matter increased by 126 times from less than 16 thousand kilograms in 2010 to almost 2 million kilograms three years later. Carbon monoxide emissions were 17 times higher at over a million kilograms and the emission of total volatile organic compounds or VOCs had escalated 100 times to 262,000 kilograms in 2013. In 2013 QGC emitted 62,000 kilograms of formaldehyde into the air whereas none had been reported in 2010.

[45] Lisa M. Mckenzie, Roxana Z. Witter, Lee S. Newman and John L. Adgate, Human health risk assessment of air emissions from development of unconventional natural gas resources. *Science of the Total Environment* March 21, 2012

[46] 2011/2012 report for QGC PTY LIMITED, Windibri Processing Plant (PL201) and Compressor Stations - Condamine, QLD - http://www.npi.gov.au/npidata/action/load/individual-facility-detail/criteria/state/QLD/year/2012/jurisdiction-facility/Q012QGC002

Table 1

2011/2012 National Pollutant Inventory reports of Total Air Pollution for:
A) ARROW ENERGY (DAANDINE) PL, Daandine Gas Field - Dalby, QLD;
B) QGC P/L, Kenya Processing Plant and Compressor Stations – Tara, QLD; and
C) QGC P/L, Windibri Processing Plant & Compressor Stations-Condamine, Qld.

Substance	A) Arrow Dalby Air Total (kg)	B) QGC Tara Air Total (kg)	C) QGC Condamine Air Total (kg)
Arsenic & compounds	0.27		
Beryllium & compounds	0.013		
Cadmium & compounds	0.016		
Carbon monoxide	140,000	520,000	500,000
Chromium (III) compounds	3.1		
Copper & compounds	1.3		
Fluoride compounds	8.9	17,000	
Formaldehyde (methyl aldehyde)	13,000	47,000	42,000
Lead & compounds	1.6		
Mercury & compounds	0.0027		
Nickel & compounds	2.2		
Oxides of Nitrogen	210,000	840,000	850,000
Particulate Matter 10.0 um	13,000	2,700	8,300
Particulate Matter 2.5 um	73	2,700	8,200
Polycyclic aromatic hydrocarbons	0.044		
Sulfur dioxide	190	690	640
Total Volatile Organic Compounds	30,000	110,000	99,000
On-site long term waste storage		17,000	

Note: Air Total = Air Point + Air Fugitive

In 2013 the World Health Organization [47] declared that outdoor air pollution is carcinogenic. Particulate matter, as well as being a carcinogen has widespread adverse health impacts including heart attacks, strokes, diabetes, asthma, hypertension and renal disease amongst others.

Section 3.

Naturally occurring radioactive materials (NORMs)
NORMs are often present in high concentrations in gas-bearing shale, and may be brought to the surface via drill cuttings and other waste from the well. NORMs can be concentrated by human actions (i.e., drilling and processing ores) and this concentrated, technologically (human) enhanced naturally occurring radioactive material is called TENORM.

Uranium, thorium, radium-228 and radium-226 are found in both coal seams and shale.[48] The radioactive material can be released to the environment through disposal of drill cuttings/muds, flowback water and through air emissions. Radon-222 is the immediate decay product of Radium-226 and preferentially follows gas lines. It decays (through several rapid steps) to Pb-210, which can build up as a thin film in gas extraction equipment. The level of reported radioactivity varies significantly, depending on the radioactivity of the

[47] International Agency for Research on Cancer, press release no 221 17 Oct 2013 - http://www.iarc.fr/en/media-centre/iarcnews/pdf/pr221_E.pdf
[48] Fact Sheet FS-163-97 October, 1997 Radioactive Elements in Coal and Fly Ash: Abundance, Forms, and Environmental Significance, USGShttp://pubs.usgs.gov/fs/1997/fs163-97/FS-163-97.html

reservoir rock and the salinity of the water co-produced from the well. The higher the salinity the more NORM is likely to be mobilized. Since salinity often increase with the age of a well, old wells tend to exhibit higher NORM levels than younger ones.[49]

Both radon and radium emit alpha particles, which are most dangerous when inhaled or ingested. Radium is a known carcinogen[50] and exposure can result in increased incidence of bone, liver and breast cancer. When inhaled, radon can cause lung cancer, and there is some evidence it may cause other cancers such as leukemia.[51] Consuming radium in drinking water can cause lymphoma, bone cancer, and leukemias.[52] Radium-226 and radium-228 have half-lives of 1,600 years and 5.75 years, respectively. Radium is known to bioaccumulate in invertebrates, mollusks, and freshwater fish,[53] where it can substitute for calcium in bones.

Despite the increased rate of radon detected by the SCU study inside the gas fields, there has been little radionuclide analyses or testing for radon in the communities surrounding gas fields.

The disposal of radioactive water from shale gas production has proven a major challenge in the US.[54] While Barium and radium were substantially reduced in the treated effluents compared to concentrations in Marcellus Shale produced waters, Radium 226 levels in stream sediments (544–8759 Bq/kg) at the point of discharge were 200 times greater than upstream and background sediments (22–44 Bq/kg) and above radioactive waste disposal threshold regulations, posing potential environmental risks of radium bioaccumulation in localized areas of shale gas wastewater disposal[55]

In 2014, Santos NSW coal seam gas project was found to have contaminated aquifers with Uranium at 335 micrograms per litre, which is 20 times the Australian Drinking Water guideline of 17 ug/l. [56]

Section 4.

Risks to Water Resources

The European Commission identified potential risks from UG to ground and surface water as:

- leakage of drilling fluids from the well bore into near surface aquifers;
- poor cement jobs on well bore casing, or fracking pressure resulting in cracks in the well casing allowing leakage of fluids;
- contamination from flow back fluid;
- accidental spills of fluids or solids at the surface;

[49] http://www.world-nuclear.org/info/Safety-and-Security/Radiation-and-Health/Naturally-Occurring-Radioactive-Materials-NORM/#.UTlc2qXfCcM

[50] http://www.atsdr.cdc.gov/toxfaqs/tf.asp?id=790&tid=154

[51] NRC. Health effects of radon progeny on non-lung-cancer outcomes. In: Health Effects of Exposure to Radon, BEIR VI. Washington, DC:Committee on Health Risks of Exposure to Radon (BEIR VI), National Research Council, National Academies Press (1999). http://www.nap.edu/openbook.php?record_id=5499&page=118

[52] EPA. Radionuclides: Radium [website]. Washington, DC:Office of Radiation and Indoor Air, U.S. Environmental Protection Agency (updated 6 March 2012). http://www.epa.gov/radiation/radionuclides/radium.html#affecthealth

[53] Warner NR, et al. Impacts of shale gas wastewater disposal on water quality in western Pennsylvania. Environ Sci Technol 47(20):11849–11857 (2013); http://dx.doi.org/10.1021/es402165b.

[54] Brown, V., Radionuclides in Fracking Wastewater: Managing a Toxic Blend, *Environ Health Perspect;* DOI:10.1289/ehp.122-A50).

[55] .Warner NR, et al. Impacts of shale gas wastewater disposal on water quality in western Pennsylvania. *Environ Sci Technol* 47(20):11849–11857 (2013); http://dx.doi.org/10.1021/es402165b.

[56] Santos coal seam gas project contaminates aquifer, SMH 2014 http://www.smh.com.au/environment/santos-coal-seam-gas-project-contaminates-aquifer-20140307-34csb.html

- surface and subsurface blow outs;
- chemicals remaining in the underground from repeated fracking or naturally occurring contaminants finding their way from the producing zone to shallow or drinking water aquifers through fractures in the rock; and/or
- discharge of insufficiently treated waste water into surface water or underground.[57]

Contamination of groundwater
Australian UG company, Shenhua Watermark Coal acknowledge that drill holes may intersect with one or multiple aquifers potentially mixing groundwater from different strata or altering the groundwater chemistry through exposure to air, gas, drilling fluids or release of natural compounds.[58] They also note interconnection of aquifers within the borehole may impact on aquifer levels.

BTEX chemicals have been found in 5/14 monitoring wells in Queensland gas fields; benzene at levels 6 and 15 times Australian drinking water standard.[59] Toluene and methane were also found in private drinking water bore adjacent to gasfields.[60]

Treating Produced water does not remove all contaminants
Produced water is the term used by the industry to describe the waste water produced along with the gas. Produced water from both shale gas and CSG is contaminated with heavy metals, NORMs, fracking or drilling chemicals, volatile and semi volatile organic compounds and high concentrations of salts. For a typical shale gas well, daily produced water volumes range from 300 - 4,500 litres (80 to 1,200 gallons).[61] The amount of produced water from a CSG well varies between 0.1 - 0.8 megalitres (ML) per day.[62]

Produced water tends to be of high salinity and large quantities of salts are a by-product of CSG production.[63]

Produced water is either reinjected into aquifer formations, used for dust suppression on roads, reused for brick making, sent to holding ponds or partially 'treated' and released into waterways. The treatments to remove contaminants from produced water are limited by the chemicals they can remove, the energy needed and their economic costs. Reverse osmosis filtration has significant limitations and cannot remove many of the organic chemicals used in UG activities. Low molecular weight, non polar, water-soluble solutes such as the methanol and ethylene glycol are poorly rejected.[64]

In Queensland, the UG company, Santos claimed in their original environmental impact statement that they would treat the produced water to Australian standards before disposing of it in local waterways (Dawson Creek). However, Santos found that they were unable to treat the water to Australian standards. (Ammonia was 45 times guidelines, sulphate was 80 times guidelines, boron was 8 times guidelines and total suspended solids were twice

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[57] Potential Risks for the Environment and Human Health Arising from Hydrocarbons Operations Involving Hydraulic Fracturing in Europe. http://ec.europa.eu/environment/integration/energy/pdf/fracking%20study.pdf
[58] Shenhua Watermark Coal Pty Ltd, Review of Environmental Factors Exploration Drilling and Associated Activities -EL 7223 February 2011 GHD-RPT-EXP-DRL-007 [1] Revision 1
[59] Media Release 'Arrow advises of monitoring results' 26 August 2011
[60] Simtars Investigation of Kogen Water Bore (RN147705) -16 October 2012
[61] Bill Chameides, "Natural Gas, Hydrofracking and Safety: The Three Faces of Fracking Water," *National Geographic,* September 20, 2011
[62] CSG and water: quenching the industry's thirst, Gas Today Australia, May 2009
[63] Tim A. Moore, Coalbed methane: A review, *International Journal of Coal Geology* 101 (2012) 36–81
[64] Chemicals unable to be treated successfully include bromoform, chloroform, naphthalene, nonylphenol, octylphenol, dichloroacetic acid, trichloroethylene. See www.industry.qld.gov.au/documents/LNG/csg-water-beneficial-use-approval.pdf; http://www.aquatechnology.net/reverse_osmosis.html ;Stuart J. Khan Quantitative chemical exposure assessment for water recycling schemes, Waterlines Report Series No 27, March 2010 Commissioned by the National Water Commission

guidelines). In late 2012, they requested permission to dump this contaminated water and they were given permission by the Queensland government to pump 12-18 million litres per day of contaminated water into the Dawson Creek.[65]

In Australia, high levels of lead, mercury, chromium, hydrocarbons and phenols have been detected in produced water, seven months after a spill in the Pilliga Forest CSG gas field.[66] In 2011, bromine was detected in treated produced water released by Eastern Star Gas at six times background levels. Methane was also detected at 68 micrograms per litre (ug/l), whereas it was not detected in the upstream control sample.[67]

Flowback is contaminated

Flowback refers to the 15 - 80% of the hydraulic fluid mixture that returns to the surface. It contains some of the chemicals injected, plus contaminants from the coal seam like BTEX, polycyclic aromatic hydrocarbons (PAHs), NORMs) heavy metals and other volatile organic compounds (VOCs). Samples taken from the top of the well-head, a day after the well had been 'fracked', detected bromodichloromethane, bromoform, chloroform and dibromochloromethane, as well as benzene and chromium, copper, nickel, zinc.[68] Published studies from USA show that even after treatment, flowback water had dangerous levels of bromine and Radium 226. [69]

Evidence of Water Contamination in the US

In 2011, US EPA investigation of water contamination in 23 drinking water wells near natural gas extraction sites detected high concentrations of benzene, xylenes, gasoline range organics, diesel range organics, and other hydrocarbons in groundwater samples from shallow monitoring wells near pits indicated that they were a source of shallow ground water contamination. They concluded that compounds associated with hydraulic fracturing had contaminated the aquifer at or below the depths used for domestic water supply.[70] Elevated levels of dissolved methane in domestic wells generally increased with proximity to gas wells. A review of complaints in four US states, showed more than 100 cases of pollution being confirmed in Pennsylvania alone.

Methane in Drinking Water

US studies have shown that methane levels in drinking water are higher in areas with a high density of wells and methane levels increased over time coinciding with the increasing number of wells. Methane contamination of water was evident in 60 water wells near active gas wells in the US.[71] Contamination at 19 to 64 parts per million was above US federal government safety guidelines. The majority were situated one kilometre or less from a gas well. Wells more than a kilometre from active gas wells had only a few parts per million. In a follow up 2013 study, distance to gas wells was found to be the most significant factor. Water wells close to gas-drilling sites had methane levels more than six times higher than

[65] The Australian, Big Gas fills state coffers, http://www.theaustralian.com.au/national-affairs/big-gas-fills-state-coffers/story-fn59niix-1226678669963

[66] Flint, C & Hogan, N, THE TRUTH SPILLS OUT: A Case Study of Coal Seam Gas Exploration in the Pilliga, May 2012 Report for Northern Inland Council for the Environment The Wilderness Society Newcastle

[67] Analytical Results ES1118565, 25-AUG-2011 East West Enviroag Project No. EW110647

[68] Labmark Environmental Laboratories, Certificate of Analysis, Report 331850-W Composite: Roma Water Analysis, Mar 26, 2012 as reported in Lloyd-Smith & M, Senjen, R Halogenated Contaminants From Coal Seam Gas Activities, Proceedings of Dioxin 2012 Conference, Cairns, Australia.

[69] Valerie J. Brown, Radionuclides in Fracking Wastewater: Managing a Toxic Blend, *Environ Health Perspect;* DOI:10.1289/ehp.122-A50;.Also see Warner NR, et al. Impacts of shale gas wastewater disposal on water quality in western Pennsylvania. *Environ Sci Technol* 47(20):11849–11857 (2013); http://dx.doi.org/10.1021/es402165b.

[70] http://www.epa.gov/region8/superfund/wy/pavillion/EPA_ReportOnPavillion_Dec-8-2011.pdf

[71] Osborn, SG, A Vengosh, NR Warner, RB Jackson. 2011. Methane contamination of drinking water accompanying gas-well drilling and hydraulic fracturing. http://www.nicholas.duke.edu/cgc/pnas2011.pdf

more distant wells.[72] Methane was detected in private drinking water bores adjacent to Australian gasfields.[73]

Endocrine disrupting chemicals are commonly found in water near UG sites
In a 2013 stud,[74] surface and groundwater near sites experiencing high levels of unconventional gas activity in Colorado contained endocrine-disrupting chemicals and showed moderate to high levels of endocrine-disrupting chemical (EDC) activity. Samples taken from sites with little drilling showed little EDC activity. Exposure to EDCs can increase the risk of reproductive, metabolic, neurological, and other diseases, especially in children and young organisms.

Unsustainable water use
UG activities use very large quantities of water, which compete with human and agricultural needs for water, raising important water equity issues. Depending on the depth and permeability of the formation, shale gas requires between 7.7 - 38 megalitres / ML (2-10 million gallons) of water each time the well is hydraulically fractured.[75] UNEP reports a single fracking operation on a shale gas well may use between 11 and 34 million litres of water.[76] As wells may be fracked up to 10 times [77] and large amounts of water are also used in drilling processes (approx 1 million litres per well),[78] the combined impacts of the shale gas industry may lead to significant pressure on water resources particularly in areas already experiencing drought or drier than normal conditions.

Section 4.

Impacts on Human Health
There is growing evidence both in Australia and overseas of the impacts HF and UG activities have on health outcomes of residents living close to the gasfields and their infrastructure. Very similar situation have been reported by both US residents living adjacent to shale gas production and by Australian residents living adjacent to CSG fields. They also share the experience of air pollution with a comparable group of toxic air contaminants.

Reports of ill health from Queensland gasfields
In March 2013, Dr Geralyn McCarron, a Brisbane based GP conducted a health survey of residents living within or adjacent to the Queensland gas fields. Full details can be found in "Symptomatology of a gas field."[79] 35 households in the Tara residential estates and the Kogan/Montrose region were surveyed in person and telephone interviews were conducted with three families who had left the area. Information was collected on 113 people from the 38 households. 58% of residents surveyed reported that their health was definitely adversely affected by CSG, whilst a further 19% were uncertain.

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[72] Jackson et al, Increased stray gas abundance in a subset of drinking water wells near Marcellus shale gas extraction *PNAS* 2013 110 (28) 11250-11255
[73] Simtars Investigation of Kogen Water Bore (RN147705) -16 October 2012
[74] Kassotis et al Estrogen and Androgen Receptor Activities of Hydraulic Fracturing Chemicals and Surface and Ground Water in a Drilling-Dense Region, *Endocrinology* doi: 10.1210/en.2013-1697 http://www.endo.endojournals.org
[75] Kargbo D, William R & Campbell D, (2010) Natural Gas Plays in the Marcellus Shale: Challenges and Potential Opportunities, *Environmental Science & Technology*, Vol. 44, No. 15
[76] UNEP Global Environmental Alert Service: *Gas Fracking: Can we safely squeeze the rocks?*
[77] European Parliament, Economic & Scientific Policy Dept, *Impacts of shale gas and shale oil extraction on the environment and on human health.*
[78] WA Government: *Natural gas from shale & gas fact sheet: water use & management.*
[79] Symptomatology of a gas field, An independent health survey in the Tara rural residential estates and environs - http://www.ntn.org.au/wp/wp-content/uploads/2013/05/Symptomatology-of-a-gas-field-An-independent-health-survey-in-the-Tara-rural-residential-estates-and-environs-April-2013.pdf

In all age groups, there were reported increases in cough, chest tightness, rashes, difficulty sleeping, joint pains, muscle pains and spasms, nausea and vomiting. Approximately one third of the people over 6 years of age were reported to have spontaneous nose bleeds, and almost three quarters were reported to have skin irritation. Over half of children were reported to have eye irritation. Of particular concern were the symptoms that could be related to neurotoxicity (or nervous system damage), and the frequency with which these symptoms were reported in children.

Approximately a third of the all the children to age 18 were reported to experience paraesthesia (abnormal sensations such as pins and needles, burning or tingling). Almost all the children aged 6-18 were reported to suffer from headaches and for over half of these the headaches were severe. Of people aged 6 years and over, severe fatigue and difficulty concentrating was reported for over half. Parents of a number of young children reported twitching or unusual movements, and clumsiness or unsteadiness.

The people of the Western Downs gas fields had been reporting adverse impacts since 2008 when untreated CSG waste was sprayed on local roads under the auspices of 'dust suppression.' Health impacts such as rashes, nose bleeds, nausea and vomiting forced people to leave their homes in 2009.

Urine specimens from 16 people living in Queensland's gas fields were tested privately. Testing revealed a mixture of chemical contaminants including phenol, cresol, acetone, polycyclic aromatic hydrocarbons, methyl ethyl ketone, toluric acid, a metabolite of xylene and hippuric acid which is the metabolite of toluene. 13 people had mixtures of two or more chemicals in their urine. The chemicals that returned positives in urine samples were not chemicals routinely tested for in normal pathology laboratories. Their reference ranges relate only to occupational exposure to a single chemical toxin, and relate to adult workers whose exposure is limited to a typical 8 hour working day. There are no "normal" values or reference values for children exposed 24 hours per day, 7 days per week to a chemical cocktail. [80]

As previously highlighted, some chemicals are known to affect the endocrine system at extremely low levels with children and unborn babies the most vulnerable. In utero and early infancy chemicals can cause permanent brain damage at levels of exposure that would have little or no adverse effect in an adult.[81] In investigations into cancer clusters, mixtures of chemicals have been implicated where a single chemical would have been assumed to be safe at that level of exposure.[82]

The results of the survey carried out by Dr McCarron may have influenced the gas company, QGC decision two buyout six affected families.

A US Health Survey [83] investigated the extent and types of health symptoms experienced by people living near shale gas activities in Pennsylvania. Environmental testing was conducted on the properties of a subset of survey participants (70 people in total) to identify the presence of pollutants that might be linked to both gas development and health symptoms. Test locations were selected based on household interest, the severity of symptoms

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[80] Symptomatology of a gas field, An independent health survey in the Tara rural residential estates and environs - http://www.ntn.org.au/wp/wp-content/uploads/2013/05/Symptomatology-of-a-gas-field-An-independent-health-survey-in-the-Tara-rural-residential-estates-and-environs-April-2013.pdf

[81] Dr Philippe Grandjean MD & Philip J Landrigan MD, Neurobehavioural effects of developmental toxicity, *The Lancet Neurology*, Volume 13, Issue 3, Pages 330 - 338, March 2014 doi:10.1016/S1474-4422(13)70278-3 http://www.thelancet.com/journals/laneur/article/PIIS1474-4422(13)70278-3/abstract

[82] Zeliger HI, Unexplained cancer clusters: common threads. *Arch Environ Health*. 2004 Apr;59(4):172-6. http://www.ncbi.nlm.nih.gov/pubmed/16189988

[83] Gas Patch Roulette: How Shale Gas Development Risks Public Health In Pennsylvania, October 2012 Earthworks' Oil & Gas Accountability Project http://www.earthworksaction.org

reported, and proximity to gas facilities and activities. In total, 34 air tests and 9 water tests were conducted at 35 households in 9 counties. VOCs were detected in air including 2-Butanone, Toluene, Acetone, Chloromethane, Carbon tetrachloride, Benzene, Trichlorofluoromethane, Methylene Chloride, Dichlorodifluoromethane, n-Hexane, Tetrachloroethylene, 1,2,4-Trimethylbenzene, Ethylbenzene, Trichloroethylene, Xylene and 1,2-Dichloroethane**.** A range of symptoms were reported in the 108 surveys including nasal & throat irritation (60%), sinus problems (58%), eyes burning (53%), shortness of breath (52%), difficulty breathing (41%), severe headaches (51%), sleep disturbance (51%), frequent nausea (39%), skin irritation (38%), skin rashes (37%), dizziness (34%). The study suggest a strong association, with exposure to the shale gas emissions as the closer to gas facilities respondents lived, the higher the rates of symptoms they reported.

Vulnerable Populations are at risk

There are many children living in communities in close proximity to UG activities and are at special risk from air and water pollutants.

"Children are not little adults: they have special vulnerabilities to the toxic effects of chemicals. Children's exposure to chemicals at critical stages in their physical and cognitive development may have severe long-term consequences for health. Priority concerns include exposure to air pollutants, pesticides and persistent organic pollutants (POPs), lead, mercury, arsenic, mycotoxins and hazardous chemicals in the workplace." [84]

The unique vulnerability of children to hazardous chemicals is well recognized by WHO, UNICEF and UNEP [85] and newborns can be much more vulnerable than adults to the commonly-used chemicals, eg.,up to 164 times more sensitive to the organophosphate pesticides chlorpyrifos.[86] Children's bodies are still developing, their detoxification systems are immature and their protective biological barriers such as the blood-brain barrier are still developing.[87] They are also more at risk because they have higher respiration and metabolic rates than adults, they eat and drink more per bodyweight, and they live life closer to the ground, crawling, digging in dirt and putting objects in their mouths. Being unaware of chemical risks, children are less able to protect themselves from exposures and higher skin absorption rates may also result in a proportionally greater exposure.[88]

Maternal exposure to air pollutants; a risk to the foetus and baby

Maternal exposure to air pollutants is also very important as the placenta is not an effective barrier to chemical transfer from mother to the foetus, and toxins can be transferred through breast milk as well. The timing of chemical exposures is significant. Research has shown that babies and children experience particular "windows of susceptibility" in their development.[89] If exposures occur during critical times, it may contribute to health problems much later in life; for example, exposure to dioxin in utero can produce disabilities in

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[84] World Health Organisation (WHO), International Labor Office (ILO), United Nations Environment Program (UNEP) 2006. Helping to Protect Children from the Harmful Effects of Chemicals. International Program on Chemical Safety. http://www.who.int/ipcs/en/

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neurological function and learning ability well into childhood.[90] Similarly, early exposure to other endocrine disruptors can affect an individual's immune function or ability to reproduce. Early exposure to carcinogens can increase the risk of developing cancer later in life.[91]

Some VOCs like polycyclic aromatic hydrocarbons (PAHs) are endocrine disrupting chemicals and can cause adverse effects at very low-concentrations. Babies with elevated PAHs in their umbilical cord blood were much more likely to eventually score highly on the anxiety/depression scale than those with low PAH levels in cord blood. [92] PAHs have been detected in the air around Tara residences, where many children live. Importantly, US researchers have already observed a positive association between the density and proximity shale gas development, pregnant mothers residences and the prevalence of congenital heart defects and possibly neural tube defects in their newborns. [93]

Section 5.

Risks to Livestock

A 2012 report by Robert Oswald, a professor of molecular medicine at Cornell's College of Veterinary Medicine, and veterinarian Michelle Bamberger [94] highlighted many cases of illness, death and reproductive issues in cows, horses, goats, llamas, chickens, dogs, cats, fish and other wildlife, and humans which they related to exposure to gas drilling operations. However, they acknowledged "making a direct link between death and illness was not possible due to incomplete testing, proprietary secrecy from gas drilling companies regarding the chemicals used in hydrofracking, and non-disclosure agreements that seal testimony and evidence when lawsuits are settled."

The paper's authors interviewed animal owners in six states; Colorado, Louisiana, New York, Ohio, Pennsylvania and Texas, citing 24 cases where animals were potentially affected by gas drilling. Some of the case studies include:

- In Louisiana, 17 cows died within an hour of direct exposure to hydraulic fracturing fluid. A necropsy report listed respiratory failure with circulatory collapse as the most likely cause of death.
- A farmer separated his herd of cows into two groups: 60 were in a pasture with a creek where hydrofracking wastewater was allegedly dumped; 36 were in separate fields without creek access. Of the 60 cows exposed to the creek water, 21 died and 16 failed to produce calves the following spring. None of the 36 cows in separated fields had health problems, though one cow failed to breed in the spring.
- Another farmer reported that 140 of his cows were exposed to hydrofracking fluid when wastewater impoundment was allegedly slit, and the fluid drained into a pasture and a pond. Of the 140 cows, about 70 died, and there were high incidences of stillborn and stunted calves.

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[93] McKenzie et al., Birth Outcomes and Maternal Residential Proximity to Natural Gas Development in Rural Colorado, *Environ Health Perspect;* DOI:10.1289/ehp.1306722 http://ehp.niehs.nih.gov/1306722/)
[94] Michelle Bamberger & Robert E. Oswald, Impacts Of Gas Drilling On Human And Animal Health, *New Solutions*, Vol. 22(1) 51-77, 2012

Since the release of this report many more as yet unsubstantiated reports of impacts on farm animals have been recorded.

Conclusion

In conclusion, a recent literature review (August 2014) by Shonkoff, Hays and Finkel summarises the growing body of evidence of the adverse impacts of HF and UG. [95]

These findings included:

- The concentrations of chemicals detected in surface and ground water in areas with intensive natural gas development were in high enough concentrations to interfere with the response of human cells to male sex hormones and estrogen. (Kassotis et al. 2014);
- Fifty-two percent of the chemicals have the potential to negatively affect the nervous system, and 37% are candidate EDCs (endocrine disruptor chemicals) (Colburn et al 2011);
- Residents living <_0.5mile from wells were at a greater risk for health effects from exposure to natural gas development than those living > 0.5 mile from wells. (McKenzie et al. 2012);
- Many non-methane hydrocarbons (NMHCs), which were observed during the initial drilling phase, are associated with multiple health effects. (Colburn et al 2014);
- High photochemical ozone concentrations in the rural Upper Green River Basin in the winter, reporting readings of up to 140ppb, just less than double the U.S. EPA ozone concentration limit of 75ppb. (Schnell et al. 2009);
- Workers experience the most direct exposure; however, silica dust may also be an air contaminant of concern to nearby residents. Silicosis is a progressive lung disease in which tissue in the lungs reacts to silica particles. (Esswein et al.2013);
- Diesel PM (particulate matter) is a well-understood health damaging pollutant that contributes to cardiovascular illness, respiratory disease (eg lung cancer) (Garshick et al.) atherosclerosis and premature death.(Pope 2002);
- Insufficiently treated flowback and produced water that contain concentrations of contaminants associated with shale gas development entered local water supplies, even after treatment. They also found elevated levels of chloride and bromide downstream, along with radium -226 levels in stream sediments at the point of discharge, that were approximately 200 times greater than upstream and background sediments and well above regulatory standards (Warner et al 2013);
- The results of Alley et al. (2011) agree with other reports that samples of fracturing fluids, drilling muds, and flowback and produced waters in wastewater- surface containment ponds contain chemicals that, at elevated doses or certain concentrations have been associated with health effects ranging from skin and eye irritation to neurological and nervous system damage, cancer and endocrine disruption (Colborn et el 2011);
- An analysis of waste obtained from reserve pits indicated the potential for exposure to technologically enhanced naturally occurring radioactive materials and potential health effects from individual radionuclides (Rich and Crosby 2013);
- The researchers did observe a positive association between density and proximity of pregnant mothers to shale gas development and the prevalence of congenital heart defects and possibly neural tube defects in their newborns (McKenzie et al. 2014);

[95] Shonkoff SB, Hays J, Finkel ML. 2014. Environmental public health dimensions of shale and tight gas development. 122:787–795; http://dx.doi. org/10.1289/ehp.1307866

Australian guidelines and standards currently do not take into account of low-level, chronic exposure particularly to environmental contaminants that demonstrate endocrine and epigenetic impacts. To assess the full impacts of UG development, this is essential and would need to be addressed as a priority. Comprehensive environmental health impact assessments taking into account all exposure routes must be carried out before any approval is given for UG activities. Nevertheless, all the monitoring and regulatory safeguards put in place around unconventional gas exploration and production cannot remove the threat of adverse impacts to water and air quality and to the health of all South Australians. When so much is at risk, the most simple cost benefit analysis would suggest that this is an industry that represents far too great a risk to the environment, to agriculture and tourism.