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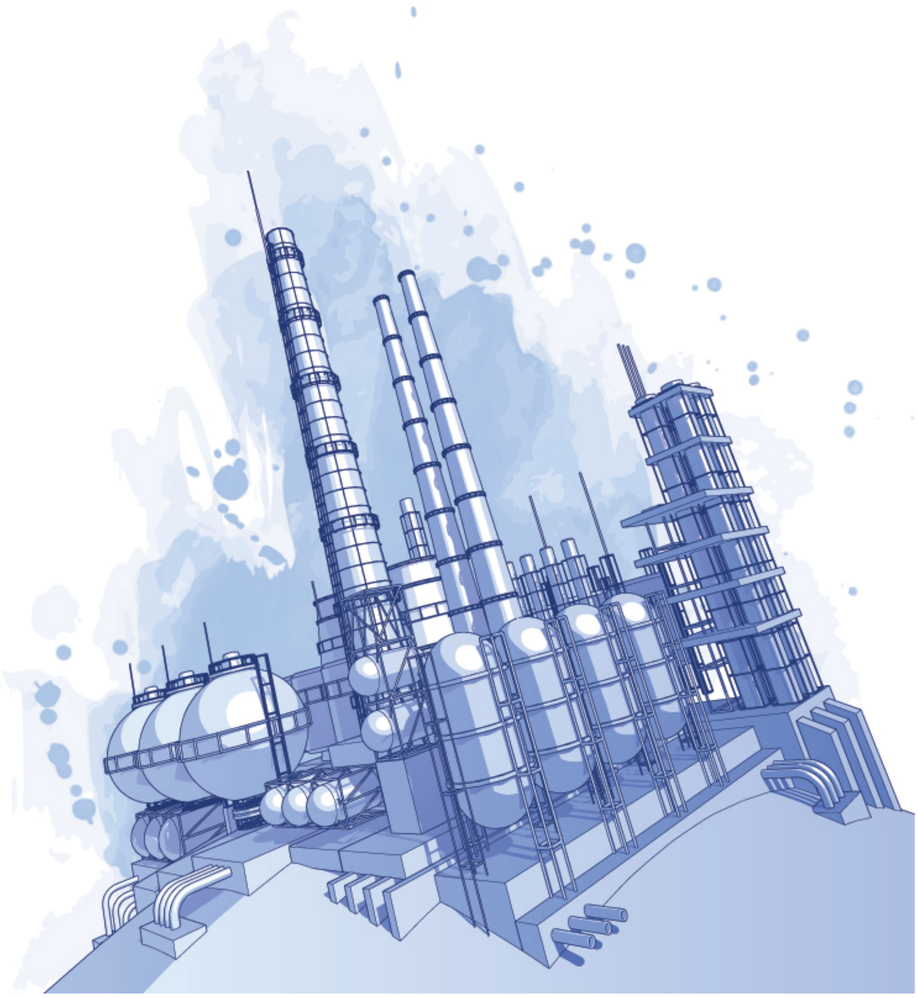
Unconventional Gas Exploration and Production: Human Health Impacts and Environmental Legacy



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This report is intended to be a living document and will be updated as new important information is released.

Summary

The industrialisation of the rural landscape brought about by unconventional gas (UG) activities with its associated air and water pollution can significantly damage the environment and put at risk the health of communities and associated agricultural industries.

Despite many years of operation, the UG industry, including shale and coal bed methane / coal seam gas, still does not have effective ways to deal with its contaminated wastewater, solid wastes and its impact on groundwater aquifers. As the Australian 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) and other activities of the UG industry, the global alert released in 2012 by United Nations Environment Programme acknowledged that it is impossible to regulate this industry into safety and unintended impacts are inevitable.

'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

In 2015, the New York Department of Health published the findings of their inquiry[1] into unconventional gas and high-volume hydraulic fracturing (HVHF). It concluded that: '*Overall weight of the evidence from the cumulative body of information demonstrates that there are significant uncertainties about the kinds of adverse health outcomes that may be associated with HVHF, the likelihood of the occurrence of adverse health outcomes, and the effectiveness of some of the mitigation measures in reducing or preventing environmental impacts which could adversely affect public health.*'

The Inquiry noted that an evaluation of the studies revealed critical information gaps and confirmed these needed to be filled to more fully understand the connections between risk factors such as air and water pollution and public health outcomes among populations living in proximity to HVHF shale gas operations. The Department of Health determined that until the science provides sufficient information to determine the level of risk to public health, HVHF should not proceed in their state.

The Inquiry's major findings are summarised as:

- Air impacts that could affect respiratory health due to increased levels of particulate matter, diesel exhaust, or volatile organic chemicals.
- Climate change impacts due to methane and other volatile organic chemical releases to the atmosphere.
- Drinking water impacts from underground migration of methane and/or fracking chemicals associated with faulty well construction.
- Surface spills potentially resulting in soil and water contamination.
- Surface-water contamination resulting from inadequate wastewater treatment.
- Earthquakes induced during fracturing.
- Community impacts associated with boom-town economic effects such as increased vehicle traffic, road damage, noise, odour complaints, increased demand for housing and medical care, and stress.

1.0 Chemicals used and released in unconventional gas exploration and production

Toxic

In Australia, a wide range of chemicals are used and released in unconventional gas exploration and production. These include drilling fluids, fracking fluids, wastewater treatment chemicals and industrial cleaners. They are also many volatile and semi-volatile compounds released to air and water as fugitive emissions. Some are the product of industrial UG uses and UG wastes and others are the naturally occurring toxic substances released from the coal seams or shale rock.

Hydraulic fracturing (HF) used in coal seam gas, shale and tight gas production, 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 still translates to large volumes of chemical additive. For instance, an estimated 18,500 kilograms of HF products were used in a single coal seam gas (CSG) HF in Australia with up to 40% not recovered.[2]

The European Parliament report[3] estimates 16 tonnes of acute toxic substances were used to frack tight gas in Lower Saxony, Germany. The US industry fracfocus database reports up to 100 tons (approx. 90 tonnes) of chemical can be added to fracking fluid used in shale gas production depending on depth and pressure requirements. A well can be 'fracked' a number of times throughout its life-time.

At a minimum, HF usually requires:

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

HF can 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 proppants are used for each fracturing, consisting of sand or manufactured sol-gel ceramic spheres based on alumino-silicates, for example in one shale gas trial HF in Australia, approximately 45,400kg of proppant (Terraprop Plus) was used.[4]

The US House of Representatives Committee on Energy and Commerce identified more than 750 chemical products used in HF containing 650 hazardous substances plus 279 products with trade secrets.[5] These included carcinogens (eg naphthalene), neurotoxins (eg isopropanol*)*, irritants/sensitisers (eg sodium persulfate*)*, reproductive toxins (eg ethylene glycol) and endocrine disruptors [6] (eg nonylphenol). Some of the chemicals were found to be dangerous at concentrations near or below chemical detection limits, (eg glutaraldehyde, brominated biocides), propargyl alcohol, 2-butoxyethanol (2-BE) and heavy naphtha.[7]

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.[8]

The independent scientific assessment (2015) undertaken at the request of the California State Government acknowledged that operators have unrestricted use of many hazardous and uncharacterized chemicals in HF and acid treatments and that the use of these chemicals underlies all significant potential direct impacts of well stimulation in California.' The assessment acknowledged that no agency has systematically investigated the possible impacts and noted the environmental characteristics of many chemicals remain unknown: '[We] *lack information to determine if these chemicals would present a threat to human health or the environment if released to groundwater or other environmental media.'* [9]

1.1 Endocrine Impacts of UG Chemicals

Chemicals used in HF have been identified as endocrine disrupting compounds (EDCs). 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.[10] Many chemicals associated with unconventional oil and gas (UOG) can block or antagonise hormone receptors, particularly androgen and estrogen receptors (antiestrogens, antiandrogens).[11] Prenatal exposure to anti-androgenic EDCs like ethylene glycol, can lead to delayed sexual development, birth defects such as hypospadias and other problems. Prenatal exposure to ethylene glycol-methyl cellosolve (ethylene glycol monobutyl ether, 2-Methoxyethanol) can lead to reproductive damage, congenital birth defects, intrauterine growth restriction and death, while perinatal exposure to toluene can reduce serum testosterone in rats. Perinatal exposure to EDCs has been shown to cause permanent changes in the brain and effect behaviour, obesity, fertility, cancer and result in other adverse health outcomes in laboratory animals depending on the timing of exposure.

Some impacts may be inherited and passed through epigenetic[12] changes that may not become apparent for many years.[13]

1.2 Health Impacts of Chemicals Used in Hydraulic Fracturing in Australia

A review of the health impacts associated with HF chemicals used in Australia demonstrate they are toxic to human health or the environment. The following information was compiled from publically available sources.[14]

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

Ethylene Glycol **-** a scale inhibitor and solvent; is known human respiratory toxicant and can also irritate the eyes, nose and throat. Exposure is associated with increased risks of spontaneous abortion and sub-fertility in female workers and birth defects in animals. Ethylene Glycol is an endocrine disrupting substance (EDC).

2-Butoxyethanol (2BE, ethylene glycol monobutyl ether, EGBE) - a surfactant and solvent; high doses of 2BE can cause reproductive problems and birth defects in animals. Animal studies have also shown it can destroy red blood cells. There are no carcinogenicity studies available for 2BE and it was declared a Priority Existing Chemical by Australian regulators due to its high mobility, low degradation and potential to contaminate aquifers.

Nonylphenol Ethoxylate - a surfactant; NPE is a persistent, bioaccumulative, endocrine disruptor, which has been detected widely in wastewater and surface waters. NPE can mimic the natural hormone, estradiol and binds to the estrogen receptor in living organisms. Nonylphenols (NP) are formed from the environmental degradation of NPEs. NP can cause the feminisation of aquatic species, decrease male fertility, and decreases survival in young fish. Sexual deformities were found in oyster larvae exposed to NP and it is linked to increases in breast cancer in mice. Canada classified NPE metabolites as toxic. The European Union classifies NP as very toxic to aquatic organisms, which may cause long-term adverse effects in the aquatic environment.

Methanol - a corrosion inhibitor; methanol is volatile organic compound (VOC), which is highly toxic to humans. It 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 and can volatilizes from water. Once in air, its half-life is over 2 weeks. The chemical reacts with photochemically produced smog to produce formaldehyde. Methanol was listed as the most commonly used HF chemical by the United States House of Representatives Committee on Energy and Commerce. [15]

Sodium Persulfate - used as a gell breaker; *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 can cause changes in lung function resulting in disease of the airways and/or asthma.

Tetrakis hydroxymethyl)phosphonium sulfate (THPS) - a biocide; is toxic to microorganisms with acute toxicity values for algae less than 1 milligram per litre. Repeated skin exposure to THPS can result in severe skin reaction and cause skin sensitization.[16] It has shown mutagenic potential (in vitro) and cancer potential in rats. No exposure information is available for either humans or organisms in the environment and little is known about the effects of the break down products of THPS

***Naphthalene** – a* friction reducer; is classified by the International Agency for Research on Cancer (IARC) as a *'possible human carcinogen'* and by the US EPA as *'reasonably anticipated to be human carcinogen*' based on nasal and lung tumours in lab animals. Chronic exposure of workers and rodents to naphthalene causes cataracts and/or damage to the retina. Naphthalene metabolites have been found in the urine of workers.

1.3 Chemicals Not Assessed

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 have been assessed at all by the National Industrial Chemicals Notification and Assessment Scheme (NICNAS) and neither for their use in CSG.[17] While the Australian government states it is in the process of addressing this, their assessment which was due in 2015 will not consider impacts on deep groundwater or air and is hampered by the lack of toxicological data. Nor will the mixtures used in drilling and fracking fluids be assessed for toxicity or persistence. Chemical mixtures may form new compounds when exposed to sunlight, water, air, radioactive elements or other natural chemical catalysts.

1.4 Secrecy and Confidential Business Information

Proprietary data and trade secret regimes mean that the disclosure of full formulations is usually not possible even by those who use the products. An example of this is the material safety data sheet (MSDS) for a commonly used friction-reducing chemical, INFLO 150. The Australia MSDS lists its active ingredients as:

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

The following are also listed but with no details on Chemical Abstracts Service Registry Number (CASRN), they cannot be identified.

- Fatty Alcohol, Oxylalkylated Alkanolamine(s), Silicone(s), Surfactant(s)

The US MSDS for INFLO 150 provides a little more information describing the surfactant as a fluorocarbon surfactant but still does not provide a distinct 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. While little toxicology data is available for the majority of the PFCAs, some are known to have serious adverse health impacts.

The 2015 Californian assessment recommended that all operators should report the unique Chemical Abstracts Service Registry Number (CASRN) identification for all chemicals used in HF and acid stimulation, and the use of chemicals with unknown environmental profiles should be disallowed.[18] Despite this, discussions with the legal representative of Haliburton, maker of HF fluids stated that the company is not willing to provide full details of the formulation to either the users or government regulatory bodies.[19]

1.5 Drilling Impacts

Whether or not a UG well is fracked, the industry still results in significant chemical usage and releases. According to the International Energy Agency, the lifespan of an UG well is 5 to 15 years with output typically declining by between 50% and 75% in the first year of production. As a result 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 needs 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)
- 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).

Some drilling chemicals, such as silica or crystalline quartz, bentonite clay and cristobalite are known to be carcinogenic with the primary malignancy associated with exposure through inhalation. [20]

1.6 Drilling Muds, Cuttings and Wastes

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 are transported to the surface with the drilling muds.

Trials undertaken in Queensland on a proposal for land spraying of drilling byproducts identified environmental hazards including release of potentially toxic additives, salt compounds, heavy metals, hydrocarbons, pH-control additives, and total suspended solids

(TSS).[21] 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[22] and detectable concentrations of petroleum hydrocarbons were observed in drilling muds. They concluded that the C6–C9 fraction, which include benzene, toluene, ethyl benzene and xylenes (BTEX) may pose a risk from to the environment and to human health.

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.[23]

2.0 Chemical Pollution Risks to Water

Potential risks to ground and surface water have been identified as:

- leakage of drilling fluids from the well bore into near surface aquifers;
- 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;
- 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.[24]

2.1 Contamination of Groundwater

Australian industry has acknowledged that drill holes can 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.[25] BTEX chemicals were found in 5 out of 14 monitoring wells in Arrow's Queensland gas fields with benzene at levels 6 and 15 times Australian drinking water standard.[26] Toluene was found in a private drinking water bore adjacent to Queensland gas fields.[27]

In 2014, Santos coal seam gas project in the Pilliga Forest, New South Wales was found to have contaminated aquifers with uranium at 335 micrograms per litre; 20 times the Australian Drinking Water guideline of 17 ug/l.[28]

US EPA investigation of ground water contamination

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.[29]

US EPA Report Assessment of Potential Impacts of Hydraulic Fracturing for Oil and Gas on Drinking Water Resource

The US EPA 2015 report[30] on groundwater contamination confirmed specific instances when fracking *"led to impacts on drinking water resources, including contamination of drinking water wells."* The report notes that spills occurred between January 2006 and April 2012 in 11 states and included 151 cases in which fracturing fluids or chemicals spilled on or near a well pad but due to the methods used for the EPA's characterization of spills, these cases were likely a subset of all fracturing fluid and chemical spills during the study's time period. The study notes that the relatively small number of contamination incidents included in the report might be due the lack of pre- and post-fracking data about drinking water resources; the dearth of long-term studies; and *"the inaccessibility of some information on hydraulic fracturing activities and potential impacts,"* most likely held by UG companies.

Methane in Groundwater

Methane was detected in private drinking water bores adjacent to Queensland gasfields.[31] 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.[32] 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 study, the 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 more distant wells.[33]

2.2 Produced Water

Produced water is the term used by the industry to describe the wastewater produced along with the gas. Produced water from both CSG and shale gas is contaminated with heavy metals, naturally occurring radioactive materials (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).[34] The amount of produced water from a CSG well varies between 0.1 - 0.8 megalitres (ML) per day.[35] Large quantities of salts are a by-product of CSG production, as produced water tends to be highly saline.[36] Produced water is often 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 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 by reverse osmosis filtration.[37] As the costs and difficulties of dealing with large quantities of wastewater grow, Australian UG companies are trialing reinjection into aquifer formations, despite the risks of seismic events, as experienced in the US.

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. However, the company found that they were unable to treat the water to Australian standards and in late 2012, requested permission to dump its contaminated water. They were given authorisation by the Queensland government to pump 12-18 million litres per day into the Dawson Creek.

In Australia, high levels of lead, mercury, chromium, hydrocarbons and phenols have been detected, seven months after a spill of produced water in the Pilliga Forest CSG gas field.[38] 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.[39]

In 2014, BTEX was detected in the water from two of four CSG wells and an aboveground water storage tank at the AGL CSG project in Gloucester in New South Wales. Five samples included BTEX, one at concentration of 555 ppb.[40] The New South Wales EPA suspended AGL's CSG Waukivory Project.

2.3 Flowback

Flowback refers to the 15 - 80% of the hydraulic fluid mixture that returns to the surface after fracking. 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 wellhead, a day after the well had been 'fracked', detected bromodichloromethane, bromoform, chloroform and dibromochloromethane, as well as benzene and chromium, copper, nickel, zinc.[41]

An assessment of the impacts of hydraulic fracturing for shale and tight gas in West Australia's drinking water supply areas by the West Australian Department of Health notes that there were 96 substances found in the flowback fluids that were not used in hydraulic fracturing fluid; of these 96 substances, 28 were found to be listed by regulatory agencies as known or suspected carcinogens.[42]

Published studies from USA show that even after treatment, flowback water had dangerous levels of bromine and radium-226.[43]

Australian company, AGL was criticised after its contractor, Transpacific transported 600,000 litres of flowback from its NSW Gloucester projects to be discharged into Hunter Water's network. [44] Hunter Water had previously advised both companies it would not accept the discharge after it was informed that the flowback water would contain 450 litres of the biocide, Tolcide (active ingredient THPS). AGL then made arrangements to send its flow backwater to WORTH Water Treatment Plant in Windsor, however the company rejected more CSG wastewater.

AGL ended its trial of using CSG wastewater for irrigation after regulators found it left behind unacceptably high levels of salt and heavy metals. The EPA reviewed the monitoring data from the irrigation trial and, based on this review, would not support a continuation of the trial. AGL is currently transporting its contaminated waste over 1000 km to the plasma arc facility in Brisbane.

2.4 Wastewater Contamination in the US

Researchers from Duke University found elevated levels of chloride and bromide downstream from Treatment Facility in south-western Pennsylvania, which was treating UG effluent. Bromide can combine with naturally occurring organic matter and chlorine disinfectant to form drinking water contaminants called trihalomethanes, which are associated with liver, kidney, and nervous system problems. The researchers reported highly elevated concentrations of bromide over a mile downstream from the plant, which indicated a potential future burden for drinking water treatment facilities downstream.

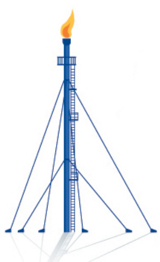
Radium-226 levels was detected in stream sediments at the point of discharge, that were approximately 200 times greater than upstream and background sediments and well above regulatory standards.[45]

Endocrine Disrupting Chemicals in Wastewater
In a 2013 US study,[46] surface and groundwater near areas experiencing high levels of unconventional gas activity in Colorado were shown to contain endocrine-disrupting chemicals (EDC) with moderate to high levels of EDC activity. The concentrations of chemicals detected in surface and ground water were in high enough concentrations to interfere with the response of human cells to male sex hormones and estrogen. 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.

2.5 Unsustainable Water Use

UG activities use very large quantities of water that compete with human and agricultural needs for water, raising important water equity issues. This is clearly acknowledged by the UG industry. Australian UG company Santos notes, '*The drawdown of ground water heads within coal seam gas aquifers is a necessary process and an unavoidable impact associated with the depressurisation of the coal seam.'*[47] There can be significant losses in pressure both within the aquifer, and/or in the overlying and underlying aquifers. Santos predicted for their Queensland CSG fields within the Bowen Basin, groundwater drawdown of 7 to 25 metres by 2028. Significant drawdown of farm bores has already been experienced in the region.

3.0 Air Contaminants Released from Unconventional Gas Exploration and Production



Data from the Australian government's National Pollutant Inventory (NPI) shows the UG industry is a significant source of air pollutants with releases of particulates (PM_{10}, $PM_{2.5}$), nitrogen oxides and VOCs. According to the NPI data, the quantities emitted are increasing. Air toxics associated with UG activities can cause serious, irreversible health effects, including cancer, neurological problems and birth defects.[48] In 2013, the World Health Organisation[49] declared that outdoor air pollution is carcinogenic.

There are many sources of toxic air pollutants in gas fields and related infrastructure, including high point vents, equipment/engines, drilling rigs, boilers/heaters, generators, flares, storage tanks, injection pumps, dehydrators, vehicles and gas skimmers. Major sources of air pollutants are the compressor stations that move natural gas through pipelines and gas processing plants.[50]

The following priority pollutants have been identified with some forming precursors of secondary pollutants such as ozone.[51]

Nitrogen Oxides **-** NO_x are emitted from machinery, compressors and flaring. NO_x can react with VOCs to form ground-level ozone, which is linked to asthma attacks and other serious health effects. Nitrogen dioxide can cause respiratory problems, heart conditions and lung damage.

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

Sulfur dioxide - SO_2 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 - H_2S 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

Volatile Organic Compounds **-** VOCs are present during all stages of UG activities including drilling, flaring, from equipment/machinery, hydraulic fracturing, flowback and holding ponds. Semi volatile chemicals are injected underground during fracking, a percentage of which eventually surfaces. Some VOCs cause cancer in animals (e.g. methylene chloride), in humans (e.g. formaldehyde) or are suspected human carcinogens (e.g. chloroform, bromodichloromethane). 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.[52] Some VOCs like formaldehyde and styrene are endocrine disrupting chemicals (EDCs).[53]

Sampling of air around homes near gasfields has detected a wide range of VOCs many of which are toxic. [54] Community sampling around Queensland gas activities also detected dichlorodifluoromethane, a potent chlorofluorocarbon (CFCs) which damages the ozone layer.[55]

A more detailed discussion of testing, results and impacts from UG on the Queensland Tara Estates is available later in this brief.

BTEX (benzene, toluene, ethylbenzene, xylene) **-** BTEX chemicals are naturally occurring VOCs released from coal deposits and are also found in associated groundwater.[56] Drilling, fracking and removal of produced water release BTEX from the coal seam. Their short-term health effects include skin, eye and nose irritation, dizziness, headache, loss of coordination and impacts to respiratory system while chronic exposure can result in damage to kidneys, liver and blood system.

Benzene - causes leukemia, non-Hodgkin's lymphoma and also affects the immune system. It may also cause chromosomal aberrations and mutations in human and animal cells. [57] It has been linked to birth defects[58] and sperm abnormalities. [59] The WHO identified exposure to benzene as a major public health concern. They note that benzene is a well-established cause of cancer in humans with IARC classifying benzene as carcinogenic to humans (Group 1).

Polycyclic Aromatic Hydrocarbons - PAHs are a group of very toxic volatile compounds.
They are a significant air pollutant associated with unconventional gas production. Research[60] indicates that people living or working near active natural gas wells may be exposed to pollutants at higher levels than the US EPA considers safe for lifetime exposure. High levels of PAHs were found across the study area with levels increasing closest to the wells.

3.1 Particulates and Airborne Silica

Particulate matter (PM) is released during construction of the infrastructure, venting, flaring, engines and diesel exhaust and via silica based proppants. Exposure to respirable crystalline silica can cause silicosis, lung cancer, autoimmune diseases, pulmonary disease and chronic kidney disease.[61]

The US National Institute for Occupational Safety and Health (NIOSH) released a Hazard Alert, identifying exposure to airborne silica as a health hazard to workers conducting hydraulic fracturing operations.[62] They identified a range of sources of silica dust exposure during HF operations. While workers experience the most direct exposure, silica dust may also be an air contaminant of concern to nearby residents.[63] NIOSH acknowledges a 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 IARC.[64]

Chronic inhalation of PM_{10} and $PM_{2.5}$ can cause respiratory problems, cancer, heart attacks, strokes, diabetes, asthma, hypertension, renal disease or premature death. PM also provides an effective pathway for other contaminants such as heavy metals and radioactive substances into the broader environment. The Australian government acknowledge that there is no threshold for PM at which health effects do not occur [65] yet, UG companies are not required to report emissions of either $PM_{2.5}$ or PM_{10} unless they exceed a threshold of 400 tonnes per year, or 1 tonne per hour.

3.2 Synergy Between Particulates and Air Pollutants

Particulate matter (PM) travels deep into the lung and crosses directly into the bloodstream carrying with it other toxic chemicals. The surface area of the particle drives a synergistic response, producing greater than an additive response.[66] Together, the mixture is even more dangerous to health than the added individual risks and importantly, there is no evidence of a safe level of exposure to the combined air pollutants or a threshold below which no adverse health effects occur.

3.3 Gas Processing - a Key Source of Air Pollution

Gas processing is needed to remove impurities before natural gas can be used. It produces many by-products, which are often vented to the air e.g. ethane, propane, butanes, pentanes, higher molecular weight hydrocarbons, hydrogen sulphide, carbon dioxide. A 2015 study using hourly measurements from Photochemical Assessment Monitoring Stations in the Baltimore, MD and Washington, DC areas, observed that daytime ethane concentrations have increased significantly since 2010, growing from 7% of total measured nonmethane organic carbon to 15% in 2013. They noted this trend appears to be linked with the rapidly increasing natural gas production in upwind neighbouring states.[67]

Flaring
The USEPA has banned gas flaring (the burning off of natural gas from a new well) in most cases since January 2015 due to growing concerns over air pollution[68]. There are no restrictions on UG flaring in Australia. Flaring releases hydrogen sulphide, methane, BTEX [69] and is recognised as a significant source of soot or black carbon pollution.[70]

3.4 Australian UG Industry Reports to the National Pollutant Inventory

Australia is one of the few countries where the UG companies are required to self-report their emissions to land, air and water to the government's National Pollutant Inventory (NPI).[71] The data submitted each year represents their calculated estimated emissions for a limited list of around 100 chemicals and heavy metals. The data show many thousands of tonnes of toxic chemicals are annually being released to air by the UG industry and the figure is increasing.

The NPI data confirms that the processing of coal seam gas is also major and increasing source of air pollution in Australia.

Emissions of particulate matter (PM) from the QGC's Kenya Processing Plant (ATP620) and Compressor Stations near Tara, have consistently risen over the last 5 years.

Table 1: QSG's Kenya Processing Plant (ATP620) and compressor stations, Queensland

EMISSIONS	2011-2012	2013 - 2014	2014-2015
Particulate matter (PM)	54 tonnes	342 tonnes	1,113 tonnes

Other emissions from the Kenya facility have also increased significantly.

Table 2: QGC's Kenya Processing Plant

EMISSIONS	2013-2014	2014-2015
NOx	710 tonnes	1,300 tonnes
CO	410 tonnes	1,000 tonnes
Total VOCs	89 tonnes	180 tonnes

While QGC's Windibri Processing Plant and Compressor Stations in 2014-15, reported a drop in total PM emissions from 1,316 tonnes to 495 tonnes, it reported a significant increase in total VOCs rising from 91 tonnes in 2013-14 to 160 tonnes in 2014-2015. As well it released 62 tonnes of the carcinogen formaldehyde.

Large increases in pollutants released from the gasfields are also evident.
QGC's Ruby Jo gas field in Tara, Queensland, reported emissions :

Table 3: QGC's Ruby Jo Gas Field, Queensland

EMISSIONS	2012-2013	2014-2015
CO	80 tonnes	1,600 tonnes
NOx	230 tonnes	810 tonnes
PM	30 tonnes	1902 tonnes
VOC	69 tonnes	110 tonnes

In South Australia, Santos Merrimelia Gas in Leigh Creek, have significantly increased their emissions of CO and NOx over the last three reporting periods .

Table 4: Santos Merrimelia Gas, Leigh Creek, South Australia

EMISSIONS	2012-2013	2013-2014	2014-2015
CO	32 tonnes	850 tonnes	1,900 tonnes
NOx	220 tonnes	580 tonnes	1,200 tonnes

Curtis Island QLNG plant, a significant point source

The Curtis Island QLNG plant an export facility in northern Queensland, reported to the NPI for the first time for 2014-2015 reporting year. The facility released 4,800 tonnes of deadly carbon monoxide, 4,300 tonnes of nitrous oxides, 620 tonnes of volatile organic compounds, 190 tonnes of formaldehyde, 29 tonnes of acetaldehyde, and 1.7 tonnes each of Benzene and Toluene (methylbenzene). It also released 546 tonnes of particulate matter. It was third largest emitter in Gladstone.

Table 5: Curtis Island QLNG Plant, Queensland

EMISSIONS	2014-2015
Carbon monoxide	4,800 tonnes
Nitrous oxides	4,300 tonnes
Volatile organic compounds	620 tonnes
Formaldehyde	190 tonnes
Acetaldehyde	29 tonnes
Benzene	1.7 tonnes
Toluene (methylbenzene)	1.7 tonnes

Cumulative Air Pollution Load

The numerous gasfields and infrastructures in a single region may add up to significant cumulative releases. For example, in the Leigh Creek, South Australia region where Santos has 23 oil and gas facilities and activities reporting to the NPI in 2014-15 including significant amounts of volatile toxic compounds. NPI figures reflect the steady growth in cumulative air emissions from UG activities across regions.

3.5 Australian Research on Fugitive Emissions

Fugitive non-methane and methane emissions are an issue usually associated with abandoned wells but are evident over the complete gas exploration and production cycle. Research conducted at Australia's Southern Cross University[72] measured atmospheric radon (^{222}Rn and ^{220}Rn) and carbon dioxide (CO_2) concentrations as a measure of fugitive emissions in the Queensland gas fields. The researchers found 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. They suggest the presence of radon and CO_2 indicates the possible release of other gases, such as VOCs. They argue 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.

In a submission to the Australian government, the same researchers reported hotspots with concentrations of methane (CH_4) as high as 6.89 ppm and CO_2 as high as 541 ppm near Tara. Background atmospheric CH_4 outside the gas fields were lower than 2ppm.[73] In a follow up study, they confirmed the widespread enrichment of both CH_4 and CO_2 within the production gas field, compared to outside. The CH_4 and CO_2 values showed distinct differences within and outside the production field, indicating a CH_4 source within the production field had a signature comparable to the region's CSG.[74]

Methane Leaks

Further evidence of fugitive emissions can be seen in the bubbling methane gas reported along a five kilometre stretch of the Condamine River in Queensland, Australia. The Queensland government's initial investigation [75] notes that four CSG wells were within five kilometre 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 LEL, 4 at or above 10% of the LEL and 21 with levels between 10-3000ppm. Similar figures were found in surrounding gas fields.[76]

Methane is a powerful greenhouse gas with a global warming potential much greater than that of CO_2. The IPCC calculated that methane is 34 times stronger as a heat-trapping gas than CO_2 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 CO_2.

3.6 Naturally Occurring Radioactive Materials

Naturally Occurring Radioactive Materials or NORMs, like uranium, thorium and their progeny radium-228 and radium-226 are found in both coal seams and shale.[77] The level of reported radioactivity varies significantly, depending on the radioactivity of the reservoir rock and the salinity of the water co-produced from the well. The higher the salinity, the more NORMs are likely to be mobilised. Since salinity often increase with the age of a well, old wells tend to exhibit higher NORM levels than younger ones.[78]

Radon and Radium

UG activities such as drilling, fracking, removal of produced water, earthworks and transport result in radioactive substances being remobilized and relocated either via waste water, 'bonding' with dust particulates or via resuspension in air. Direct particle fallout, as well as washout from rain provides an effective pathway for these contaminants to find their way into the wider environment including surface water and onto rooftops and into domestic water tanks.

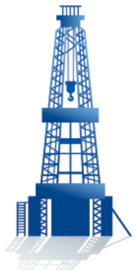
Both radon and radium emit alpha particles, which are most dangerous when inhaled or ingested. Radium is a known carcinogen[79] and exposure can result in increased incidence of bone, liver and breast cancer. Consuming radium in drinking water can cause lymphoma, bone cancer, and leukemia.[80] Radium also emits gamma rays, which raise cancer risk throughout the body from external exposures. 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,[81] where it can substitute for calcium in bones.

Radon is an inert gas, so it doesn't react with other elements and usually separates from produced water along with methane at the wellhead. When inhaled, radon can cause lung cancer, and there is some evidence it may cause other cancers such as leukemia.[82]

A US analysis of waste obtained from reserve pits used in unconventional natural gas mining confirmed elevated beta radiation readings. Specific radionuclides present included ^{232}Thorium decay series (^{228}Ra, ^{228}Th, ^{208}Tl), and ^{226}Radium decay series (^{214}Pb, ^{214}Bi, ^{210}Pb). The research indicated the potential for exposure to technologically enhanced naturally occurring radioactive materials and potential health effects from individual radionuclides.[83]

In 2014, a Santos coal seam gas project in the NSW Pilliga Forest 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. [84] As much uranium is in the form of Uranium-238, its detection above drinking water levels should have prompted immediate testing for radionuclides in the groundwater, which are far more harmful to living organisms. Unfortunately, testing for radioactivity did not occur.

4.0 Implications for Human Health



There has been no comprehensive assessment of the health implications of UG air pollutants to residents or workers in Australia. A US based human health risk assessment of air emissions concluded residents closest to well pads i.e., living less that half a mile from wells, have higher risks for respiratory and neurological effects based on their exposure to air pollutants; and a higher excess lifetime risk for cancer. [85]

Children living in close proximity to UG activities are at particular risk from air pollutants, due to their unique vulnerability to hazardous chemicals[86] Children's exposure to chemicals at critical stages in their development may have severe long-term consequences for health. WHO has expressed a priority concern around children's exposure to air pollutants [87]

4.1 Maternal Exposure

Maternal exposure to air pollutants carries significant risks as the placenta is not an effective barrier to chemical transfer from mother to the foetus. Toxins can also be transferred from mother to baby through breast milk. The developing fetus and baby is particularly sensitive to environmental factors with '*critical windows of vulnerability'* during prenatal and early postnatal development, during which chemical exposures can cause potentially permanent damage to the growing embryo and fetus.[88] Early exposure to carcinogens can also increase the risk of developing cancer later in life.[89] In utero and in early infancy, pollutants can cause permanent brain damage at levels of exposure that would have little or no adverse effect in an adult.[90]

A 2015 study [91] demonstrates that the higher a baby's prenatal exposure to PAHs, the more serious the impact on the brain and the greater the behavioural and developmental problems. The findings suggest that prenatal exposure to PAH air pollutants contributes to slower processing speed and attention-deficit/hyperactivity disorder symptoms. Importantly, the damage is not isolated to prenatal stages.

A large study from Colorado found that children born in areas with the highest number of gas wells had a 30% increased rate of congenital heart defects compared to children born in areas with no gas wells within 10km. [92] A 2015 retrospective cohort study using electronic health record data on 9,384 mothers linked to 10,946 neonates between January 2009 to January 2013 showed that prenatal residential exposure to unconventional natural gas development activity was associated with two adverse pregnancy outcomes; preterm births and high risk pregnancies, adding to evidence that unconventional natural gas development may impact health.[93] An earlier study from Cornell University concluded that babies born within 2.5km of a gas well had lower birth weight and more health problems than babies who were born within 2.5km of a well that was planned but had not been drilled.[94]

4.2 Unconventional Gas and Chemical Mixtures

A 2015 review [95] of more than 100 scientific, peer-reviewed publications on unconventional oil and gas (UOG) chemicals and their impacts found that research points to potential adverse health outcomes from mixtures of these chemicals. The review suggests there is strong evidence of endocrine disrupting chemical mixtures having additive effects. In light of the potential for environmental release of UG chemicals that can disrupt hormone receptor systems, it is desirable to assess the complex hormonally active environmental mixtures when assessing the health impacts of UG chemicals and releases.

The WHO framework for assessing mixtures[96] provides example situations where a risk assessment for combined exposure to multiple chemicals might be necessary such as the emissions of multiple substances from a common source as in the case of fracking or drilling; the presence of multiple substances in surface waters; exposure to multiple pollutants in the atmosphere; and exposure to a formulated multicomponent chemical product (e.g., HF fluid products). The potential impact of co-occurrence of, and concomitant exposure to, multiple chemicals should always be taken into account in problem formulation for any risk assessment. The WHO concluded that lack of data on exposure or even the key components and their combined hazards does not obviate the need to introduce risk management measures to reduce exposure.

4.3 Case study - Darling Downs / Tara, Queensland

The people of the Western Downs gas fields had been reporting adverse impacts since 2008 when untreated CSG waste was sprayed on local roads for 'dust suppression.' In 2009, residents reported health impacts such as rashes, nosebleeds, nausea and vomiting which forced people to leave their homes. In 2013, the Queensland Government released its Health Report into residents' complaints, which acknowledged that there was *'some evidence that might associate some of the residents' symptoms to exposures to airborne contaminants arising from CSG activities.'* [97]

Air Pollutant Testing
Despite the knowledge of the significant releases in the Tara region, there has been no comprehensive monitoring of air pollutants. However, single point sampling of ambient air around Tara homes by industry and government has detected a wide range of VOCs many of which are toxic. These include acetone, acrolein, alpha-pinene, benzene, benzothiazole, chloromemethane, cyclohexane, dichloroflurомethane, 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.[98]

In sampling undertaken by Australian gas company, QGC [99] (the ERM Report) in response to residents' complaints, only 13 air samples were collected in all. A single sample was taken at five Tara properties with two samples at each of the remaining four properties.

Benzene
While many VOCs were detected in the air, the ERM Report concluded that apart from the benzene exceedance, there were no other exceedances of the air quality screening criteria. Yet, in the case of 26 chemicals, the health criterion was below the detection level used by the laboratories. For example, US EPA Regional Screening Levels for 1,1,1,2-

tetrachloromethane is 0.33 µg/m3, whilst the limit of detection used by the different labs varied between 8.3 µg/m3 and 12 µg/m3, well above the health criteria. The report acknowledges that it cannot be categorically stated that concentrations in the samples were also below the relevant criteria value.

In the case where benzene was detected above health risk criteria, it was dismissed stating that 'benzene was not a compound that is found in CSG and therefore could not be attributed to CSG activities.' This was in contrast to statements found on the website of the Queensland Government's Department of Environment and Heritage Protection where it states that: *"BTEX compounds (benzene, toluene, ethylbenzene, xylene) are found naturally in crude oil, coal and gas deposits and therefore they can be naturally present at low concentrations in groundwater near these deposits".*[100] Benzene had already been detected in monitoring bores at an Arrow Energy fracking operation[101] in Queensland. The dismissal of benzene exceedances was unacceptable when other BTEX chemicals such as toluene, a neurotoxin, had been found in the air around a number of Tara homes and in the air above a resident's water bore. [102] The level of toluene in air above the bore was measured at 0.33ppm but was dismissed as below levels of concern. Yet, it was above the 'Chronic Reference Exposure Limits' used for long term exposure by California, Massachusetts, Michigan states in the USA.[103]

Inadequate Monitoring
The total ERM monitoring period was only nine days and clearly inadequate. The methodology resulted in testing limits of reporting for some chemicals that were substantially higher than the reference air quality criteria. The monitoring was not designed to identify short-term peaks or troughs in air concentrations. In order to assess air contaminants, sampling is needed over an extended period of time. This was demonstrated in a 2012 study on air pollution associated with unconventional gas activities. The twelve month study[104] detected 44 hazardous air pollutants at gas drilling sites including a wide range of air toxics, e.g., CH_4, methylene chloride, ethane, methanol, ethanol, acetone, and propane, formaldehyde, acetaldehyde, PAHs / naphthalene. Most importantly, the authors noted a great deal of variability across sampling dates in the numbers and concentrations of chemicals detected. Notably, the highest percentage of detections occurred during the initial drilling phase, prior to hydraulic fracturing on the well pad.

Community Testing
The Queensland Government facilitated some *adhoc* sampling for VOCs in air at the Wieambilla Estate in Tara in response to ongoing community concerns. They provided Summa canisters[105] with a 1-minute sampling period and passive diffusion samples to residents for use when appropriate. Again many VOCs were detected and while most were below relevant guidelines and the criteria used, the number and type of compounds was diverse.

Summa canister sampling found the following VOCs: hexane, propene, chloromethane, dichlorodifluromethane, methylene chloride, ethanol, acetone, methyl ethyl ketone, acrolein, vinyl acetate. Vinyl acetate exceeded the annual criteria in one case.

Passive samplers also found the following VOCs: pentane, hexane, heptane, tetradecane, hexadecane, heptadecane, cyclohexane, 2-methylbutane, 3-methylpentane, 3-methylhexane, methylcyclohexane, tetrachloroethylene, 2-ethyl-1-hexanol, ethyl acetate, benzene, toluene, xylene, ethylbenzene, 1,2,4-trimethylbenzene, phenol, benzothiazole, naphthalene, alpha-pinene.

Benzene was detected at 0.6 ppb; above the US EPA recommendations of 0.4ppb, which over a lifetime could cause a risk of one additional cancer case for every 100,000 exposed persons.[106] The benzene result was simply dismissed as an *'outlier'.*

In community sampling around UG activities over an eight-hour period, ethanol and chlorofluorocarbons (CFCs) were detected.[107] Dichlorodifluoromethane, a potent ozone depleting chlorofluorocarbon (CFC) was detected in all 3 air samples.

In July 2014, small suite of tests were undertaken by the Queensland State government around e a Tara family residence which identified Acrolein at 9.6ppb, more than 100 times higher than acceptable chronic exposure standard.[108] The US 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[109] was also detected.

Despite the increased rate of radon detected inside the Queensland gas fields, there has been little radionuclide analyses or testing in the Tara communities surrounding gas fields. However, limited independent testing has detected worrying levels of beta and alpha radioactivity in Tara residents' water tanks. This represents a significant concern for the children, as they are far more vulnerable to radioactivity than adults with sensitivity to radiation being highest early in life.[110] Particulate pollution provides an effective pathway for radioactive substances into the broader environment, and it is hypothesized that through resuspension of radioactive substances and washout from rain as well as direct particle fallout onto roofs and tanks, this has resulted in the detection of radioactivity in the water and sediment of Tara residents' water tanks.

An assessment of the scope and severity of the Tara region's air pollution is not possible from a review of the data sets that are available or from industry's reports of the estimated air releases. However, both the real world experience of serious particulate pollution and the consolidation of available information, does paint a worrying picture of the region's air quality and its possible impacts. This requires both an urgent investigation and precautionary management responses to protect human and environmental health.

Tara Residents' Observed Symptoms

The physical and social impacts on the affected residents have been substantial but the Queensland Government's Health Report[111] into residents' complaints was cursory and included little clinical investigation. The report concluded that it was unable to determine whether any of the health effects reported by the community were clearly linked to exposure to CSG pollutants. This was not a surprising finding and but one that is common in cases of chronic chemical exposures and suspected health effects, especially when no baseline health or environmental data was available. The report did however acknowledge that there was 'some evidence that might associate some of the residents' symptoms to exposures to airborne contaminants arising from CSG activities.'

In response to the Queensland government report which did nothing to allay community concern, in February-March, 2013 a Brisbane based GP, Dr Geralyn McCarron conducted a health survey of residents within the Western Downs gasfields. Her findings were published in the Australian and New Zealand Journal of Public Health.[112] Full details are also available in her report, "Symptomatology of a gas field."[113] Thirty-five 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. Over half (58%) the residents surveyed reported that their health was definitely adversely affected by CSG, whilst a further 19%

were uncertain.

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.

Urine specimens from 16 people living in Queensland's gasfields 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, a metabolite of toluene. Thirteen 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. The associated reference ranges relate only to occupational exposure to a single chemical toxin and to adult workers whose exposure is limited to a typical 8hour 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.

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

5.0 New South Wales Chief Supervising Scientist Report

The Chief Scientist and Engineer's Independent Review of CSG Activities in New South Wales, [114] (CSS report) recommends CSG only go ahead if there is *'appropriate engineering and scientific solutions in place to manage the storage, transport, reuse or disposal of produced water and salts.'* Professor Fell notes in the CSS report *"the problem of disposal of treatment concentrates remains the elephant in the room."*[115] He stressed that for the large plants the quantity of salts to be disposed of is substantial and while they are currently being stored in brine ponds awaiting resolution of the disposal issue, this storage is potentially environmentally hazardous.

The CSS report also notes that '*fracking fluids remain a potentially high threat to human health'* and Professor O'Kane, lead author of the report is quoted as saying fracking should be banned if the risk to human health can't be known for sure. [116] The CSS report acknowledges that we are no closer to knowing those risks. It found there were health risks at all stages of CSG extraction with exposures via water, soil and air pollution. The report listed possible adverse health outcomes as respiratory, cardiovascular, genitourinary and digestive diseases, skin problems, some types of cancer, injuries, hormonal disruption, fertility and reproductive effects.

The CSS report acknowledges there is a need to better understand the nature of the risks of pollution or other environmental damage from CSG, as well as the capacity and cost of mitigation and/or remediation e.g., for abandoned wells. It stressed the need for a better understanding of the industry impacts to better manage cumulative impacts of the industry.

6.0 State Government Response

Australian governments are increasingly concerned about the impact that unconventional gas has and may have on the environment and regional communities. In 2013, the NSW Government announced CSG exclusion zones to make certain residential areas ‘off limits’ to new coal seam gas activity. CSG exclusion zones came into force in October 2013 for existing residential areas in 152 local government areas in NSW, and the North West and South West Growth Centres of Sydney. The exclusion zones banned new CSG activity within a two-kilometre buffer around existing and future residential areas and within the mapped critical industry clusters. In January 2014, the Government introduced CSG exclusion zones for additional future residential growth areas and seven rural villages across NSW, and the equine and viticulture critical industry clusters in the Upper Hunter. [117]

The NSW Gas Plan also established a one-off buy-back of petroleum exploration licences (PELs) for titleholders across the state. This provides an opportunity for holders of PELs to surrender their titles. To date, the NSW Government has bought back and cancelled 15 PELs under the program and is extending the deadline for the buy-back of coal seam gas licences. The Government has reduced the footprint of CSG across the state from more than 60 per cent to 11 per cent.[118]

A moratorium on fracking has been in place in the state of Victoria since August 2012 and Tasmania has announced it will extend its moratorium on fracking for another five years to protect its premium produce reputation. Government inquiries are underway in the other states of South Australia and West Australia.

7.0 Conclusions

Currently, Australian guidelines and standards currently do not take into account low-level, chronic exposure to environmental contaminants even those that demonstrate potential endocrine and epigenetic impacts. To fully assess the impacts of UG development, this would need to be addressed as a priority. Nevertheless, monitoring and regulatory safeguards for unconventional gas exploration and production cannot remove the threat of adverse impacts to water, air quality and to human health. Repeatedly, research and real world experience has pointed to evidence of the adverse impacts of this industry. 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 people, to agriculture and to the environment.

Endnotes

[1] New York State Department of Health, Public Health Review of Hydraulic Fracturing For Shale Gas Development, 2/13/2015 http://www.health.ny.gov/press/reports/docs/high_volume_hydraulic_fracturing.pdf
[2] 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
[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] Buru Energy, Yulleroo-2 Hydraulic Fracturing Operations Environment Management Plan
[5] US House of Rep. Committee 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
[6] WHO State of the Science of Endocrine Disrupting Chemicals (2013) notes there is often no threshold for EDC effects and EDCs are likely to have effects at very low doses and may exhibit non linear dose response curves.
[7] 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
[8] http://ecowatch.org/2013/cancer-causing-chemicals-fracking-operations/
[9] Birkholzer, J.T., et al An Independent Scientific Assessment of Well Stimulation in California Executive Summary An Examination of Hydraulic Fracturing and Acid Stimulations in the Oil and Gas Industry, July 2015
[10] Kassotis et al (2013) Estrogen and Androgen Receptor Activities of Hydraulic Fracturing Chemicals and Surface and Ground Water in a Drilling-Dense Region, *Endocrinology* http://www.endo.endojournals.org
[11] Webb et al (2014) Unconventional oil and gas operations: developmental and reproductive effects. *Rev Environ Health* 2014; 29(4): 307–318
[12] Epigenetics refers to heritable changes in gene expression (active versus inactive genes) that does not involve changes to the underlying DNA sequence (source: http://www.whatisepigenetics.com/fundamentals/)
[13] Webb et al 2014
[14] See 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
[15] 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 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
[16] NTP Study Reports, Abstract for TR-296 - Tetrakis(hydroxymethyl)phosphonium sulfate (THPS) (CASRN 55566-30-8) and Tetrakis(hydroxymethyl)phosphonium chloride (THPC) (CASRN 124-64-1
[17] 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
[18] Birkholzer et al 2015
[19] Views expressed by the Haliburton representative presenting at the Helsinki Chemical Forum and responding to questions from the attendees, April 2014
[20] Hydraulic Fracturing for Shale and Tight Gas in Western Australian Drinking Water Supply Areas: Human Health Risk Assessment. Public Health Division Department of Health Western Australia June 2015
[21] 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
[22] http://www.environment.gov.au/resource/australian-and-new-zealand-guidelines-fresh-and-marine-water-quality-volume-1-guidelines
[23] http://www.stuff.co.nz/taranaki-daily-news/news/8813978/Fonterra-rejects-new-landfarm-milk
[24] 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
[25] 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
[26] Media Release 'Arrow advises of monitoring results' 26 August 2011
[27] Simtars Investigation of Kogen Water Bore (RN147705) -16 October 2012
[28] 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
[29] http://www.epa.gov/region8/superfund/wy/pavillion/EPA_ReportOnPavillion_Dec-8-2011.pdf
[30] United States Environment Protection Agency, Assessment of the Potential Impacts of Hydraulic Fracturing for Oil and Gas on Drinking Water Resources, Office of Research and Development, Washington, D.C. External Review Draft | EPA/600/R-15/047a | June 2015 | www.epa.gov/hfstudy
[31] Simtars Investigation of Kogen Water Bore (RN147705) -16 October 2012
[32] Osborn, SG, A Vengosh, NR Warner, RB Jackson. (2011) Methane contamination of drinking water accompanying gas-well drilling and hydraulic fracturing. *PNAS* Vol. 108 /20 http://www.nicholas.duke.edu/cgc/pnas2011.pdf

[33] 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
[34] Bill Chameides, "Natural Gas, Hydrofracking and Safety: The Three Faces of Fracking Water," *National Geographic,* September 20, 2011
[35] CSG and water: quenching the industry's thirst, Gas Today Australia, May 2009
[36] Tim A. Moore, Coalbed methane: A review, *International Journal of Coal Geology* 101 (2012) 36–81
[37] 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
[38] 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
[39] Analytical Results ES1118565, 25-AUG-2011 East West Enviroag Project No. EW110647
[40]http://www.agl.com.au/~/media/AGL/About%20AGL/Documents/How%20We%20Source%20Energy/Gloucester%20Document%20Repository/Fact%20Sheets/20150302__Fact%20Sheet%20GGP%20%20%20BTEX_V3.pdf
[41] 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.
[42] Hydraulic Fracturing for Shale and Tight Gas in Western Australian Drinking Water Supply Areas: Human Health Risk Assessment. Public Health Division, Department of Health WA June 2015
[43] Valerie J. Brown, Radionuclides in Fracking Wastewater: Managing a Toxic Blend, *Environ Health Perspect;* DOI:10.1289/ehp.122-A50
[44] http://www.smh.com.au/environment/water-issues/agls-irrigation-trial-using-csg-waste-water-found-to-be-unsustainable-20150416-1mmf82.html
[45] Warner, NR et al. (2013) Impacts of shale gas wastewater disposal on water quality in western Pennsylvania. *Environ. Sci. Technol.* 47(20), 11849-11857.
[46] Kassotis et al (2013) 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
[47] Groundwater (Deep Aquifer Modelling) for Santos GLNG Project – Environmental Impact Statement 31/3/2009 http://www.santosglng.com/media/pdf41108/P2_Groundwater%20(Deep)%20FINAL%20PUBLIC.pdf
[48] 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
[49] 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
[50] http://toxtown.nlm.nih.gov/text_version/locations.php?id=150
[51] 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/
[52] http://www.epa.gov/iaq/voc.html
[53] US National Library of Medicine http://toxtown.nlm.nih.gov/text_version/chemicals.php?id=65
[54] These include 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. See 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
[55] 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.
[56] http://www.ehp.qld.gov.au/management/coal-seam-gas/btex-chemicals.html
[57] http://www.atsdr.cdc.gov/toxprofiles/tp3-c6.pdf
[58] http://www.ncbi.nlm.nih.gov/pubmed/20923742
[59] http://www.environmentalhealthnews.org/ehs/newscience/benzene-linked-to-sperm-abnormalities
[60] Paulik et al., Impact of natural gas extraction on PAH levels in ambient air. *Environ Sci Technol*. 2015 Apr 21 ;49(8):5203-10. doi: 10.1021/es506095e. Epub 2015 Apr 9.
[61] 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.

[62] www.osha.gov/dts/hazardalerts/hydraulic_frac_hazard_alert.htm
[63] Seth B.C. Shonkoff, Jake Hays,and Madelon L. Finkel, (2014) Environmental Public Health Dimensions of Shale and Tight Gas Development, *Environ Health Perspect*; Vol 22: 8 DOI:10.1289/ehp.1307866
[64] http://www.iarc.fr/en/media-centre/pr/2012/pdfs/pr213_E.pdf
[65] http://www.npi.gov.au/resource/particulate-matter-pm10-and-pm25
[66] David Brown, Beth Weinberger, Celia Lewis and Heather Bonaparte, Understanding exposure from natural gas drilling puts current air standards to the test. *Rev Environ Health* 2014; DOI 10.1515/reveh-2014-0002 http://www.fraw.org.uk/files/extreme/brown_lewis_2014.pdf
[67] Vinciguerra, T., et al Regional air quality impacts of hydraulic fracturing and shale natural gas activity: Evidence from ambient VOC observations, *Atmospheric Environment* 110 (2015)
[68] http://www.epa.gov/airquality/oilandgas/pdfs/20120417presentation.pdf
[69] http://www.med.upenn.edu/ceet/documents_user/MarcellusShale_Penning3.pdf
[70] 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
[71] http://www.npi.gov.au
[72] 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
[73] 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
[74] Damien T. Maher & Isaac R. Santos & Douglas R. Tait, (2014) Mapping Methane and Carbon Dioxide Concentrations and δ13C Values in the Atmosphere of Two Australian Coal Seam Gas Fields *Water Air Soil Pollution* 225:2216
[75] 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
[76] 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
[77] 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; Note in 2014, Santos 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. See 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
[78] http://www.world-nuclear.org/info/Safety-and-Security/Radiation-and-Health/Naturally-Occurring-Radioactive-Materials-NORM/#.UTlc2qXfCcM
[79] http://www.atsdr.cdc.gov/toxfaqs/tf.asp?id=790&tid=154
[80] 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
[81] Warner et al. 2013
[82] 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
[83] Rich AL, Crosby EC. Analysis of reserve pit sludge from unconventional natural gas hydraulic fracturing and drilling operations for the presence of technologically enhanced naturally occurring radioactive material (TENORM). *New Solut.* 2013;23(1):117-35.
[84] 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
[85] 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
[86] World Health Organization / Children's Environmental Health. http://www.who.int/ceh/en/
Also see IFCS Children and Chemical Safety Working Group. 2005. Chemical Safety and Children's Health: Protecting the world's children from harmful chemical exposures - a global guide to resources, October.
[87] 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/
[88] Olin, S. R. & B. R. Sonawane. 2003. Workshop to Develop a Framework for Assessing Risks to Children from Exposure to Environmental Agents, September 2003. *Environmental Health Perspectives* 111/12: 1524-1526
[89] Barton, H. A., V. J. Cogliano, L. Flowers, L. Valcovic, R. W. Setzer & T. J. Woodruff. 2005. Assessing Susceptibility from Early-Life Exposure to Carcinogens. *Environ. Health Perspectives. 13(9): 1125–1133*

[90] 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

[91] Peterson et al, Effects of Prenatal Exposure to Air Pollutants (Polycyclic Aromatic Hydrocarbons) on the Development of Brain White Matter, Cognition, and Behavior in Later Childhood *JAMA Psychiatry*. Published online March 25, 2015. doi:10.1001/jamapsychiatry.2015.57 http://archpsyc.jamanetwork.com/article.aspx?articleid=2205842

[92] 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/)

[93] Casey, J.A. et al, Unconventional Natural Gas Development and Birth Outcomes in Pennsylvania, USA *Epidemiology* 2015

[94] Hill, E. (2013). The impact of oil and gas development on infant health in colorado. Cornell Dyson School Working Paper

[95] Christopher D. Kassotis, Donald E. Tillitt, Chung-Ho Lin, Jane A. Mcelroy, and Susan C. Nagel. Endocrine-Disrupting Chemicals and Oil and Natural Gas Operations: Potential Environmental Contamination and Recommendations to Assess Complex Environmental Mixtures. *Environmental Health Perspectives*, 2015 DOI: 10.1289/ehp.1409535

[96] M.E. Meek et al. Risk assessment of combined exposure to multiple chemicals: A WHO/IPCS framework *Regulatory Toxicology and Pharmacology* 60 (2011) S1–S14

[97] Queensland Government's Health Report, *'Coal seam gas in the Tara region: Summary risk assessment of health complaints and environmental monitoring data, March 2013'*

[98] 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

[99] Queensland Gas Company Environmental Health Assessment Report Tara Complaint Investigation Report, January 2013 Final REF: 0181432R01 (known as the ERM Report)

[100] http://www.ehp.qld.gov.au/management/coal-seam-gas/btex-chemicals.html.

[101] Media Release 'Arrow advises of monitoring results' 26 August 2011

[102] Simtars Investigation of Kogan Water Bore (RN147705) -16 October 2012

[103] http://oehha.ca.gov/air/chronic_rels/pdf/108883.pdf ; Also see http://environment.gov.ab.ca/info/library/6659.pdf

[104] 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*

[105] Summa canister is a stainless steel vessel which when the valve is opened allows the surrounding air to fill the canister and achieve a representative sample. The valve is then closed and the canister is sent to a laboratory for analysis

[106] http://www.anapolschwartz.com/practices/benzene

[107] 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.

[108] 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

[109] 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

[110] http://www.who.int/ceh/capacity/radiation.pdf

[111] Queensland Government's Health Report, *'Coal seam gas in the Tara region: Summary risk assessment of health complaints and environmental monitoring data, March 2013'*

[112] MacCarron, G. Symptomatology of a gas field 2013 Unconventional Natural Gas Development: Economic Salvation or Looming Public Health Disaster? *Australian and New Zealand Journal of Public Health* 2014.

[113] 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

[114] http://www.chiefscientist.nsw.gov.au/__data/assets/pdf_file/0005/56912/140930-CSG-Final-Report.pdf

[115] Discussion Paper for Office of NSW Chief Scientist and Engineer, Water Treatment And Coal Seam Gas Prepared by Emeritus Professor Chris Fell, Fell Consulting Pty Ltd, 15 September 2014

[116] www.abc.net.au/news/2014-06-03/ban-fracking/5495786 June 2014,

[117] http://www.planning.nsw.gov.au/en/Policy-and-Legislation/Mining-and-Resources/Coal-Seam-Gas

[118] http://www.resourcesandenergy.nsw.gov.au/landholders-and-community/coal-seam-gas/community/information-on-petroleum-titles/buy-back-scheme