Submission to the Scientific Inquiry into Hydraulic Fracturing in the Northern Territory

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Brief Bio and Reason for this Submission

I have 30 years of experience as an educator and researcher in environmental health, Aboriginal and Torres Strait Islander health, epidemiology, toxicology, mental health and psychosocial wellbeing, with over 80 peer-reviewed publications in these areas. I have collaborated extensively with researchers at the Menzies School of Health Research in Darwin in Aboriginal mental health and empowerment studies. I have engaged with doctors, researchers, public health experts, Aboriginal people, veterinarians and community members in public presentations and government hearings on unconventional gas mining in NSW, South Australia, Western Australia, Queensland, as well as in Pennsylvania and New York State. With colleagues Bethmont and Ritchie, I recently completed a qualitative study on the psycho-social experiences associated with preparations for coal seam gas mining in a rural NSW community. In May 2017 I will be participating in a research methodology and planning workshop convened by CSIRO and University of Queensland that may lead to formal health studies in Queensland.

This submission was prepared in response to requests from a number of individuals and groups in the Northern Territory because of my expert knowledge of the current evidence of potential risks and impacts of unconventional gas mining. The paper draws heavily on two recent publications, *Health concerns associated with unconventional gas mining in Western Australia: A critical review* (Haswell 2017) available from Australian Policy Online (http://apo.org.au/node/74194) and *Health concerns associated with unconventional gas mining in rural Australia* (Haswell and Bethmont, 2016) in the peer reviewed journal, *Rural and Remote Health (*available at http://www.rrh.org.au/articles/subviewnew.asp?ArticleID=3825#cite_note-41*) .*

Adgate, Goldstein and McKenzie (2014) present a clear argument that unconventional gas mining poses risks to health, both directly and indirectly, and at the local, regional and global level. Thus, decisions on unconventional gas mining made by all Australian states and territories, and by other nations, affect us all.

As an Australian working intensively in this area, I offer this submission to the Northern Territory government to assist in the promotion and protection of environmental health and wellbeing at all of these levels. I have received no funding or commission for this submission.

Part 1. Overall Comments and recommendations on the Issues Paper

The NT government should be commended for this clear and comprehensive guide to submissions for this inquiry into unconventional gas mining within its jurisdiction. The Issues Paper reflects the long distance we have come in Australia in accepting that this industry poses a very wide range of significant complex and cumulative risks and impacts on the environment and to human health and wellbeing at local, regional and national levels.

The framework and approach described in the Issues Paper also acknowledges the need for voices from across the spectrum of disciplines, and diversity of perspectives from individuals and communities. This is also commendable.

The community will expect the Committee to honour this approach; from start to conclusion of the Inquiry, and for the NT Government to fully honour the findings in decision making.

This submission will first identify five key recommendations regarding the process and starting point (as judged from the submission guide) that need to be met or understood if the report is to have the rigour required to meet these needs (Part 1). It will then provide summaries of existing evidence regarding some of the key theme areas identified in the NT Issues paper (Part 2).

Part 1. Key Recommendations

1. Acknowledgement of both similarities and differences in types of unconventional gas mining and of the potential risks across the full lifecycle of gas exploration, preparation, production, processing and transportation.

It is very important that the scope of the Inquiry be precisely defined. If the words 'hydraulic fracturing' or 'fracking' are used, it is necessary to explain what is to be included or excluded. This is because "for the industry and in an engineering sense, 'fracking' is most often defined narrowly, meaning <u>only</u> 'hydraulic fracturing' – which is just one part of a very complex and multi-step process that finds, extracts, processes and delivers gas from unconventional sources for export or gas for domestic use. In sharp contrast to the engineering definition, communities tend to use the word 'fracking' to refer to the entire process that is used to produce unconventional gas, from start to finish" (Haswell, 2017).

In order to be fully transparent the Committee should fully present to the community in its report "the current evidence of risks and impacts across the entire life cycle of this industry on health and wellbeing of people and their environment. The risks, and their impacts should they occur, need to be clearly recognised as community-borne costs that need consideration in economic, social and health cost-benefit analyses" (Haswell, 2017).

The Issues Report provides useful, understandably brief, 'primer' regarding some aspects of unconventional gas mining operations. However, for subsequent reports, there is a need to be balanced and complete in background explanations. For example, it should be noted that while there are important differences between coal seam gas mining and shale gas mining, there are also many similarities. Noting the differences, for example depths and chemicals, without explaining the implications of them (with evidence provided) can be misleading.

For example, the social and mental health impacts of the two types of gas mining (job intensive construction cycle followed by years of low job high production activities) and stresses associated with living within the two types of gas fields are similar.

In addition, widespread physical changes to the landscape are similar. Gas in the coal seams and gas trapped in shale are widely dispersed; not concentrated like conventional gas reserves. Hence both types of gas production require multiple wells pads and access roads, heavy truck traffic, as well as compressor stations and pipelines, starting from a few and expanding to hundreds to thousands.

I strongly recommend the use of the following excellent figure from the Victorian Auditor-General's Report (2016) on unconventional gas mining to clearly and transparently identify the differences and similarities in potential risks associated with shale gas mining, and coal seam gas mining with and without hydraulic fracturing.

Potential risks of unconventional gas activities

Risk	Type of gas: Shale/ tight	Type of gas: CSG – Hyraulic fracturing	Type of gas: CSG – No fracturing	Potential impacts
Water resource risks				
• Water usage	✓	✓	x	Decreased groundwater quantity available for other uses
• Produced water	x	✓	✓	Pollute surface waters, groundwater, soils, food and livestock
• Flowback water	✓	✓	x	Pollute surface waters, soils, food and livestock
• Disposal of produced solids	✓	✓	x	Pollute soils, surface water and groundwater
Groundwater contamination from fracking				
• Fracking fluid leakage from poor well design, construction and integrity	✓	✓	x	Pollute groundwater—impact irrigation, stock and drinking water quantity and quality
• Chemical contamination from poor storage and surface spills of fracking chemicals	✓	✓	x	Pollute groundwater—impact irrigation, stock and drinking water quantity and quality
• Chemical contamination through leakage of fracking chemicals and flowback water into fracking cracks	✓	✓	x	Pollute groundwater—impact irrigation, stock and drinking water quantity and quality
• Natural gas released or disturbed by fracturing might seep into groundwater aquifers and other wells	✓	✓	✓	Pollute groundwater—impact irrigation, stock and drinking water quality and quality
• Disposal of used fracturing fluid, produced water or waste products	✓	✓	x	Pollute groundwater, surface water and other wells.
Air contamination from wells and infrastructure				
• Point source methane released from a well, leak in a pipeline or plant equipment	✓	✓	✓	Impact amenity and human health and climate change impacts
• Fugitive emissions from fractures and cracks in the ground	✓	✓	✓	Pollute groundwater quality and impact vegetation and climate change impacts
• Fracturing fluid can contain volatile organic compounds (VOCs) which can be released into the atmosphere	✓	✓	x	Impact amenity and human health
• Naturally occurring contaminants and radioactive materials in groundwater can be bought to the surface through drilling	✓	✓	✓	Pollute soils, surface water, stock and create prescribed wastes
• Drilling equipment and trucks produce emissions	✓	✓	✓	Impact amenity and human health
Landscape impacts from surface infrastructure or seismic surveys				
• Scale of footprint on landscape	✓	✓	✓	Impact landscape and biodiversity values, habitat fragmentation and community amenity, decreased land values
• Vegetation removal	✓	✓	✓	Impact biodiversity values, habitat fragmentation and soil quality
Seismic activity				
• Seismic activity from aquifer injection	N/A	✓	N/A	Impact landscape and biodiversity values
• Seismic activity from hydraulic fracturing	✓	✓	x	Impact landscape and biodiversity values
Operational activities				
• Noise	✓	✓	✓	Impact amenity and human health
• Dust	✓	✓	✓	Impact amenity and human health
• Increased infrastructure	✓	✓	✓	Impact amenity
• Increased traffic and population	✓	✓	✓	Impact amenity
Well integrity				
• Well leakage	✓	✓	✓	Pollute groundwater – impact irrigation, stock and drinking water quality
• Well blowouts	✓	✓	✓	Pollute surface and groundwater – impact irrigation, stock and drinking water quantity and quality
• Abandoned wells	✓	✓	✓	Pollute groundwater – impact irrigation, stock and drinking water quantity and quality
Depressurisation of the coal seam				
• Changes in pressures of adjacent aquifers	x	✓	✓	Impact groundwater availability
• Reductions in surface water flows in connected systems	x	✓	✓	Impact surface water availability
• Land subsidence over large areas	x	✓	✓	Impacts surface water systems, ecosystems, irrigation and grazing lands

Victorian Auditor General's Office. *Unconventional gas: managing risks and impacts.* (Internet) 2015. http://www.audit.vic.gov.au/reports_and_publications/latest_reports/2015-16/20150819-unconventional-gas.aspx (Accessed 13 August 2016), page 23.

2. Ensure adequate and independent expertise in public health, psychological/mental health and medicine is fully accessed and respected throughout the process

The Committee may face a number of challenges in reviewing the scientific evidence of impacts associated with the industry. It will be imperative that there is access to a variety of independent specialist knowledge in the scientific evidence review stage.

Sources of information, funding processes and incentives behind its provision must be carefully scrutinized in order to prevent personal and organizational interests. Opinions and beliefs expressed must be justified with valid evidence or logical argument.

Far too frequently, public health, psychological/mental health and medical expertise are 'missing from the table' (Goldstein et al., 2012) preventing optimum performance in :

- accessing the literature (knowing where and how to find the significant papers in theses disciplines);
- assessing the quality of the studies and likely consequences of their limitations;
- examining and understanding/communicating the findings of the studies;
- identifying gaps and uncertainties arising from the studies; and
- knowledge of related circumstances and risks that offer important and potentially relevant information to assist in interpretation and gap filling;
- reporting and advising on action on the findings.

Experts in engineering, safety science, environmental management and toxicology – while extremely important – should not be assumed to also have a comprehensive, in depth understanding of the impacts of disturbance of the environmental determinants of health and wellbeing on people's lives. Direct public and psychological health expertise is required.

Obviously, as the Committee would be fully aware, processes and culturally correct protocols regarding the gathering of perspectives with Aboriginal people also requires a very high level of accepted expertise and must be developed with Aboriginal leadership and a diversity of Aboriginal representatives. Given the high impact of the industry on Aboriginal people and communities, a valid consultation process will be paramount.

3. Ensure that up to date scientific literature is comprehensively accessed.

Research-based understanding and expert environmental health commentary on the health risks and impacts of unconventional gas mining continues to grow rapidly. Uncertainties in under-researched areas of concern with significant and potentially far-reaching impacts need to be taken very seriously. A lack of evidence should not be taken to mean a lack of importance to human health.

As stated in Haswell (2017; Executive Summary), "Providing a comprehensive, up-to-date and accurate answer to this question requires continuous attention to rapidly emerging evidence reported in the peer-reviewed literature. The number of papers on the topic of unconventional gas has risen rapidly from very few in 2012 to over 900 today as the pace and breadth of research has expanded dramatically across the United States. While gaps remain, most of the evidence from these studies has heightened, rather than reduced, concerns about potential negative impacts of unconventional gas mining on health and wellbeing".

It should be noted that shale gas mining has received a lot more attention in the health research literature because it is the dominant type of unconventional gas mining conducted in the United States. Gold and McGinty (2013) estimated that 15.3 million Americans live within a 1.6 km of one or more gas or oil wells that had been hydraulically fractured within a decade. Thus the direct significance of most research to date is clearer for shale gas mining than for coal seam gas mining.

Of particular importance in the unconventional gas mining and health literature is a comprehensive systematic review of 156 peer-reviewed publications published in December 2016 (Saunders et al., 2016). This milestone paper examines "the evidence of human exposures to harmful air and water pollutants, health impacts, seismic activity and climate impacts of unconventional gas mining. This review found multiple potential hazards to human health associated with mining and substantial gaps in understanding that prevented confirmation of the safety of the industry, and recommended no new developments in the United Kingdom until research demonstrated its safety".

Despite this large increase in publications, significant uncertainties remain and major questions remain unanswered. Some examples of insufficiently examined, but important, risks are exposure to chemicals in air and wastewater, including endocrine-disrupting chemicals, and mental health risks from psychosocial stress due to exposure to noise and loss of place and community cohesion (Haswell, 2017).

4. Clarify the topic area of 'Public health', in order to prevent under-recognition of the direct link between the health of the public and environmental impacts, for example on air, water, land, psychosocial health of communities, and economic inequality.

As public health impacts are used as a separate key theme, for clarity, it could be helpful to define this theme as the manner in which we predict, measure, evaluate and respond to changes in the health status of people and populations as a result of the industry. Losses of health, physical beauty, quiet and amenities impact negatively on quality of life, and raise needs for increased health services or increased burden on existing under-resourced health services, especially in remote areas. This appears especially important for meeting the needs of the community in coping with the psychosocial losses and mental health impacts of the industry (Hossain et al., 2013; Walton et al., 2014; Morgan et al., 2016).

I urge the Committee to give special consideration to immediate and long-term risks to children and young people, who have rarely been actively engaged or respected to the level commensurate with the degree to which their lives will be impacted by decisions made.

The Committee could help by providing further details regarding estimates of full numbers of wells and infrastructure (roads, compressor and processing stations, pipelines) that would be required for full development of the fields, according to a rough timeline. This can be assisting with photographs of similar areas in the United States, showing changes associated with fully mature gas fields. Appropriate predictions are needed, rather than 'see how we go'; in terms of likely water usage, placement and numbers of wells, and disruption of local living.

5. Place Climate Impacts as a key issue in its own right

I urge the Committee to consider the evidence and resulting impacts of greenhouse gas emissions from unconventional gas mining as a separate issue from air pollution for three reasons, ie. 1) climate change is an issue of overwhelming health, social and economic concern it demands specific focus, 2) greenhouse gases (methane and CO_2) impact on health very differently from other air pollutants, i.e. globally rather than locally; and indirectly rather than directly, and 3) because the cumulative impacts of greenhouse gas emissions on health and wellbeing will sustain for decades to hundreds of years; much longer than locally acting air pollutants. It is thus urgent that detailed consideration be given to the contribution of unconventional gas mining in the NT to climate change, especially as temperature rises are expected to be particularly severe for the NT.

This submission now provides some evidence-based summaries of information associated with six of the nine areas of risk identified in the NT Issues paper. Due to time limitations, some areas are less detailed than others.

Part 2. Brief review of evidence in some of the nine areas of risk

1. Water

Health studies have emphasized the health risks posed by potential exposure to chemicals capable of causing significant health impacts that may be released during unconventional gas operations via water and air. While significant concern has been raised about the large number and potential toxicity of the chemicals used in hydraulic fracturing and drilling muds, many researchers emphasise that the highly saline flowback waters containing naturally occurring chemicals are of substantially greater concern from an environmental and public health aspect (Colborn et al., 2011; Elliot et al., 2017; Vidic et al., 2013). The combination of chemicals and their resulting byproducts can accumulate and persistent indefinitely in the environment or be taken up by plants and animals and may enter the food chain.

Excerpts taken directly from Haswell (2017) on water risks associated with unconventional gas mining (shale gas) follows:

"Volatile organic compounds, including BTEX (Benzene, Toluene, Ethylene and Xylene), that occur naturally in the shale, and evaporate from the flowback wastewater after fracking and from flaring excess gas may pose health risks. Polyaromatic hydrocarbons (PAHs), heavy metals, naturally-occurring radioactive materials (NORMs) and a wide array of known and unknown chemicals used in drilling and hydraulic fracturing fluid, have the potential to damage the health of people who are exposed. Workers and community residents may become exposed through contact with water that has been contaminated through the handling of the large quantities of chemicals and wastewater involved (Esswein et al., 2014).

A study by Elliott et al. (2017) examined the carcinogenicity data on a total of 1177 chemicals in fracking fluids and wastewater (US EPA) and 143 chemicals identified in scientific papers reporting air pollutants that were published before 2016. The researchers found that over 80% of these chemicals were not evaluated for carcinogenicity. Among the 119 chemicals that were evaluated, 49 water and 20 air pollutants were possible, probable or known carcinogens and 20 were associated with leukemia/lymphoma, including benzene, 1,3 butadiene, cadmium, diesel exhaust and PAHs.

A second study by Elliott et al. (2017b) examined the reproductive and developmental toxicity of 1021 chemicals identified in fracturing fluid, wastewater or both. The researchers found that toxicity information was lacking for 781 (76%). Among the 240 that had been evaluated, 103 were known to have the potential for reproductive toxicity and 95 for developmental toxicity.

The comprehensive systematic literature review by Saunders et al. (2016) highlighted a major gap in our understanding of the interactions between the many chemicals in wastewater produced after hydraulic fracturing. Interactions are not considered in any risk assessments because there is still little to no understanding of this complex area.

Evidence of endocrine-disrupting activity in surface and groundwater in areas with unconventional gas mining raises concerns. These chemicals can interfere with endocrine function at very low concentrations without any signs or symptoms.

Balise et al. (2016) published a systematic review of 45 peer-reviewed publications examining the association between conventional gas extraction processes and the presence and potential impacts of endocrine-disrupting activity. The review concluded that there is moderate evidence for an increased risk of preterm birth, miscarriage, birth defects, decreased semen quality, and prostate cancer that could result from disruption of the estrogen, androgen, and progesterone receptors by chemicals associated with oil and gas production. The authors postulated that unconventional gas mining was likely to pose more risks to reproductive health than conventional gas operations given the many endocrine-disrupting chemicals involved in the hydraulic fracturing process.

Water security could be affected by the large amounts of water used in each hydraulic fracturing event (many times per well, many wells), contamination of aquifers rendering them unusable for human consumption, and in some places damage to the ecosystem that may reduce the quality of drinking water sources. These concerns would be particularly acute during times of water scarcity and could cause competition with agriculture uses.

A news release on the seminal US EPA report[1], "*Hydraulic Fracturing for Oil and Gas: Impacts from the Hydraulic Fracturing Water Cycle on Drinking Water Resources*", released in December 2016, follows:

EPA identified cases of impacts on drinking water at each stage in the hydraulic fracturing water cycle. Impacts cited in the report generally occurred near hydraulically fractured oil and gas production wells and ranged in severity, from temporary changes in water quality, to contamination that made private drinking water wells unusable.

As part of the report, EPA identified certain conditions under which impacts from hydraulic fracturing activities can be more frequent or severe, including:

- *Water withdrawals for hydraulic fracturing in times or areas of low water availability, particularly in areas with limited or declining groundwater resources;*
- *Spills during the management of hydraulic fracturing fluids and chemicals or produced water that result in large volumes or high concentrations of chemicals reaching groundwater resources;*
- *Injection of hydraulic fracturing fluids into wells with inadequate mechanical integrity, allowing gases or liquids to move to groundwater resources;*
- *Injection of hydraulic fracturing fluids directly into groundwater resources;*
- *Discharge of inadequately treated hydraulic fracturing wastewater to surface water resources; and*
- *Disposal or storage of hydraulic fracturing wastewater in unlined pits, resulting in contamination of groundwater resources.*

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[1] https://www.epa.gov/hfstudy

The report provides valuable information about potential vulnerabilities to drinking water resources, but was not designed to be a list of documented impacts.

Data gaps and uncertainties limited EPA's ability to fully assess the potential impacts on drinking water resources both locally and nationally. Generally, comprehensive information on the location of activities in the hydraulic fracturing water cycle is lacking, either because it is not collected, not publicly available, or prohibitively difficult to aggregate. In places where we know activities in the hydraulic fracturing water cycle have occurred, data that could be used to characterize hydraulic fracturing-related chemicals in the environment before, during, and after hydraulic fracturing were scarce.

[Author's note: A most important point in this extract is this final sentence:] *Because of these data gaps and uncertainties, as well as others described in the assessment, it was not possible to fully characterize the severity of impacts, nor was it possible to calculate or estimate the national frequency of impacts on drinking water resources from activities in the hydraulic fracturing water cycle."*

This conclusion makes it clear that, despite some 300,000 unconventional gas wells being drilled, hydraulically fractured and operating in the United States, the safety of the operation to drinking water resources is not demonstrated.

Further unknowns and uncertainties regarding water

At times, various 'solutions' to problems can actually cause further problems and may not be subject to research before implementation. For example, the siting of multiple wellheads on the same pad, and drilling multi-directionally may both reduce surface footprint. However, the wellheads may not be placed in optimal positions for the location of the 'sweet spots' of gas in each direction. This may mean longer distance drilling, and larger water requirements and greater pressures for hydraulic fracturing.

Furthermore, the reuse of flowback water after fracking for additional fracking (recycling) may result in increasingly high concentrations of hazardous chemicals, elevating risks in handling and ultimate disposal. According to Webb et al. (2014), recycling wastewater is not often used because of the increased concentrations of hazardous chemicals. An analysis by Parker et al. (2014) revealed multiple challenges in the treatment and management of fracking-affected water, which is also very expensive.

Any such proposed 'adaptive management' changes should be accepted only after extensive consideration of the potential complications and risks they may pose. Additionally, contamination risks to water in agricultural areas should also be seen as potential food safety concerns, as livestock and produce may be affected. Very little research has been done to investigate this possible concern".

2. Land

Excerpt from Haswell and Bethmont (2016):

"While the link between food safety and security and unconventional gas has received less research interest, it is a critical concern for farmers for whom livestock health and water rights are paramount, especially with increased droughts predicted in Australia and globally (Collins et al., 2014; Plattner et al., 2014). These concerns were highlighted in exceptionally drought-stricken California in 2015 where some farmers irrigated crops with unconventional oil wastewater (Freyman, 2015). The long-term safety of treated water in farming remains uncertain, as toxins may transfer into food chains (Bamberger and Oswald, 2015) and increased soil salinity may reduce productivity (Davies, Gore and Khan, 2016). Negotiations between water and energy sectors face conflicting views and complexity, increasing with climate change and population growth (Hussey et al., 2013). Prospects for successful coexistence between farming and UCG are further challenged by roads and mining infrastructure on agricultural land, pollution risks, livestock disturbance and economic uncertainties surrounding UCG (Freyman, 2014; Bamberger and Oswald, 2015; Davies et al., 2015; Hussey et al., 2013; Chen and Randall, 2013)".

4a. Air Emissions/ Greenhouse Gases promoting global warming

Unfortunately, early claims that the use of unconventional gas for energy will have positive impacts on greenhouse gas emissions in comparison to coal are no longer justified. The idea that gas makes a good 'bridging fuel' to assist the transition from coal to renewable energy sources is not validated. It is now clear that the impacts of gas emissions have been significantly underestimated for a number of reasons, including:

- Compared to what was initially expected, higher proportions of the extracted gas escapes as fugitive emissions (Howarth, 2014). This occurs for reasons of well-casing failures, or leaky pipes and infrastructure or, possibly, fracking-induced channels for gas flow from underground to surface.
- The recognition that methane's long-term impact on warming is 86 times more potent than carbon dioxide over 20 years (Voiland, 2016; NASA, 2014; IPCC 2013).
- The enormous impact of accidents involving well blowouts and leakage from methane storage sites, as exemplified by the 2016 Aliso Canyon disaster, but potentially occurring at many similar sites in future (Conley et al., 2016).
- Modelling has indicated that abundant supply of natural gas in the United States has competed against, rather than bridged to, renewable energies and delayed the urgently required transition to a decarbonized energy system required for limiting global warming (McJeon et al.,2014; Staddon and Depledge 2015).

4b. Air Emissions/ Pollutants with direct health impacts

Potential Exposure pathways

Air and water pollution are leading health concerns associated with unconventional gas extraction, due to the complex array of toxins emitted at each step and many potential mechanisms of human exposure. While initially the focus of most public health concern was on risks to water, the US experience to date has indicated that health risks associated with air pollution are at least as serious to the health of people living nearby as the risks mediated through water contamination (Finkel & Hays, 2013; Brown et al., 2014).

Adgate, Goldstein & McKenzie (2014) argued that a full analysis of potential public health hazards due to exposure to chemicals must include all steps of the extraction process, including site preparation and construction, materials transport, drilling, flowback and produced water collection and handling, hydraulic fracturing, gas production, storage and transport and decommissioning and monitoring of spent wells.

People may be exposed to air-borne pollutants directly, e.g. through diesel exhaust from the extensive truck movements, drilling, compressors and other machinery used in the process and from gases from the coal seam or shale deposits released during well completion and other phases (Petron et al., 2012; Adgate et al., 2014; Field, Soltis & Murphy 2014). Some of these gases mix and react in the atmosphere to form secondary pollutants, such as ground level ozone. Other exposure pathways involving inhalation of potentially harmful substances occur through the movement of volatile compounds from contaminated water into the air, and some toxins may return to contaminate soil and water bodies through subsequent rainfall, falling on waterways and livestock pastures.

Chemicals of health concern

A recent paper in Reviews of Environmental Health (Webb et al., 2014) details toxins associated with unconventional oil and gas operations of greatest concern – many of which can affect unborn and developing children at low doses. The authors state:

"Unconventional oil and gas (UOG) operations have the potential to increase air and water pollution in communities located near UOG operations. Every stage of UOG operation from well construction to extraction, operations, transportation, and distribution can lead to air and water contamination. Hundreds of chemicals are associated with the process of unconventional oil and natural gas production… Many of the air and water pollutants found near UOG operation sites are recognized as being developmental and reproductive toxicants; therefore there is a compelling need to increase our knowledge of the potential health consequences for adults, infants, and children from these chemicals through rapid and thorough health research investigation." (Webb et al., 2014, p 307)

The combination of chemicals in the produced fluid that become volatile varies according to the fracking fluid additives used and those naturally occurring in the coal seam or shale. Details of chemicals present in these fluids may not be known or are difficult to access from companies. Many have not been assessed for toxicity to humans or the environment (Colborn et al., 2011; McCarron & King 2014).

Toxins of greatest concern linked to gas extraction include volatile organic compounds (like benzene), poly-aromatic hydrocarbons, heavy metals and radioactive materials. These can affect the respiratory, endocrine, nervous and cardiovascular systems and some, notably benzene, can cause cancer (Colborn et al., 2011; ATSDR 2013). Diesel engines emit particulate matter, nitrogen oxides and volatile organic compounds and was recently classified as a Group 1 carcinogen by the International Agency for Research on Cancer (IARC 2014). Some materials have known toxicity, for example, silica, handled in very large quantities in the drilling and hydraulic fracturing processes, has the potential to pose serious risks to the respiratory health of exposed workers, causing silicosis decades later. There is also evidence of potent endocrine disrupting chemicals associated with the industry (Lloyd-Smith & Senjen 2013). Finally ground level ozone, that forms from mixtures of pollutants emitted during unconventional gas mining is also of significant concern and can travel large distances, acting at a regional level.

Risk assessments and health studies

An evaluation of potential impact associated with shale gas operations in the Barnett Shale region of the United States by Bunch et al. (2014) used routine measurements of a range of volatile organic compounds based on over 7500 assessments. These authors concluded that there was no evidence that any assessment compounds posed significant human health risks.

In contrast, health risk assessments of toxic air emissions conducted by McKenzie et al. (2012) suggested that people living within 0.8km of shale gas wells experience significantly increased risk of sub-acute non-cancer hazards (Hazard index [HI]=5), particularly those with neurological (HI=4), haematological (HI=3) and respiratory (HI=2) health impacts. This study also suggested a higher cancer risk to those living closest to the wells.

The latter risk assessment adds weight to frequent anecdotal reports and findings of a recent community study that found significantly higher prevalences of self-reported respiratory (39% vs 18%) and skin (19% vs 3%) conditions among people living within 1 km compared to those living more than 2 km from shale gas wells in Pennsylvania (Rabinowitz et al., 2015). People living near unconventional gas wells throughout the world, including near CSG gas wells in Tara, Queensland have anecdotally reported similar distressing symptoms, as well as headaches, nosebleeds and numbness and tingling sensations (McCarron 2013; McCarron & King 2014).

While no spatial health studies have been done in Australia, there have been two limited single timepoint studies. One by Queensland Health (2013) elicited low community participation and few reports of physical symptoms one-day clinic offered by a GP (former employee of the CSG company) and did not identify likely links between existing air emission data and symptoms reported at the clinic. In contrast, many community members reported a range of signs and symptoms potentially related to CSG activities in a house-to-house survey conducted by local GP, Dr Geralyn McCarron (2013). While their suggested results on the prevalence of physical symptoms were conflicting, both studies would be in agreement with Queensland Health's statement that:

"the available data were insufficient to properly characterise any cumulative impacts on air quality in the region, particularly given the anticipated growth of the industry. It is necessary to assess those impacts according to health-based standards which are relevant to long-term exposure" (Queensland Health 2013, p18).

A further step examining air quality and symptoms was taken in a study conducted by Macey et al (2014) in four US states where substantial oil and gas production activities had occurred. This involved community members receiving training and utilizing a grab air sampling procedure when individuals felt normal, and at times when they felt sick or sensed pollution from the nearby gas operations through taste or smell. This novel method enabled the community to enable the identification of numerous excursions above federal guidelines that were particularly frequent for air-borne toxins, notably formaldehyde, 1,3-butadiene, hydrogen sulfide, mixed xylenes and n-hexane, above health-based risk levels.

Importantly these measured exceedances had not been detected and/or reporting in routine air monitoring, raising questions about the sensitivity of existing data in ensuring protection of health. Indeed, atmospheric research in a variety of circumstances has revealed significant underestimations in emissions of methane and other hydrocarbons based on ground level measurements and modeled predictions (Petron et al., 2012; Brown et al., 2014, NASA, 2014).

Workers, and possibly people living very close to hydraulic fracturing operations, may also be exposed to unsafe levels of fine silica due to the large volumes of sand used, increasing the risk of silicosis (Esswein et al., 2014).

4. Public health

In this situation regarding assessing an industry as complex as unconventional gas mining that brings a wide array of potential and serious health risks as a result of environmental change or damage, public health should be understood in terms of all of the above themes (air, water, land and psychosocial risks). Public health studies on unconventional gas mining are gaining in maturity and rigour, and each year brings new understandings. These studies have an approach on how we measure the risks, assess the impacts and respond to the knowledge from studies of human health.

Brief review of studies measuring health Impacts

Studies attempting to measure health impacts of the industry remain relatively few but are increasing, and are mostly limited to physical health consequences. Some are described above in relation to air pollution. Negative health outcomes that have been found to occur more often in groups of residents with greater exposure to shale gas mining, compared with groups with lower exposure, include:

- Developmental problems during pregnancy and infancy – lower birth weight, small for gestational age, higher frequency of serious birth complications, specific birth defects (Casey et al., 2016; McKenzie et al., 2014; Stacy et al., 2015).

- Hospitalisations – for cardiovascular and neurological disorders and for those with existing asthma conditions (emergency department visits and inpatient stays) (Rasmussen et al., 2016; Jemielita et al., 2015).

- Symptoms – migraine headaches, chronic nasal and sinus irritation, fatigue, nausea, skin rashes, eye irritation, nosebleeds, and asthma worsening requiring medication changes (McCarron, 2013; Rabinowicz et al.,2015, Rasmussen et al., 2016) .

Risks for children

Since 2013, there has been an increasing focus on the likely vulnerability of developing fetuses and children to environmental hazards as compared to adults. The complex developmental processes that occur during gestation are exquisitely sensitive to chemicals and signals in the uterine environment. There is a growing understanding of the negative impacts of various exposures to the mother during pregnancy on birth outcomes, for example air pollution (PM2.5) and tobacco smoking on birth weight and preterm births, as well as alcohol and other drugs on brain development. Many of the chemicals involved in unconventional gas mining have reproductive and developmental toxicity.

A regional study involving 124,832 infants in Colorado that reported positive links between the incidence of congenital heart disease, and possibly neurotubular defects, and increasing numbers of shale gas wells within 10 miles (16kms) of residence in the infant’s birth year (McKenzie et al., 2014). Low birth weight, in contrast, was negatively correlated with numbers of wells. Insufficient time has elapsed from commencement of potential exposures through unconventional gas activities and longer-term health impacts, such as cancer and chronic disease, even in the United States.

Infants and children continue to face higher risks from toxic exposures due to their higher metabolic and respiration rates, their smaller body size and smaller and immature organs, including the liver, lungs and kidneys that deal with or store many toxins that enter the body. Children also experience greater exposure to toxins in the environment through outdoor play activities, compared to adults.

It is also very important to recognise that infant and child well-being is highly sensitive to psychosocial and community stressors, including noise, negative emotions expressed by others and witnessing aggression and conflict.

Despite this, only a small body of literature specifically examines potentially harmful exposures to air- and water-borne pollutants associated with unconventional gas mining for children despite revealing significant concerns (Webb et al., 2014; 2016; Elliott et al., 2017a, 2017b).

Understanding uncertainty in causative association – what adds strength to health impact studies

"Being ecological studies, the epidemiological evidence that is growing regarding the safety and risks posed by this industry will remain relatively weak in supporting a cause and effect relationship (Werner et al., 2015). However, the methodological difficulties are substantial, given the irregular nature of emission frequencies, the large number of pollutants potentially involved, the significant exposure to and impact of stress, the lack of reliable measurements of emissions and exposures, the lack of biomarkers of exposure, the many potential confounding factors and the non-specificity of health impacts resulting from possible exposures".

Thus while these findings are **associated** with unconventional gas activity geographically, it may be a long time before there is **proof** of either safety or risk. Research necessary to provide direct causal evidence of effects, such as randomized controlled trials, are unethical and unfeasible in this context. However, an increasing number of studies provide support for a **causative** relationship between the industry and elevations in these health concerns by demonstrating:

- Plausibility – there are logical links between the health problems being experienced and the kinds of chemicals and distressing experiences associated with living near industry operations.
- Dose-dependence – finding a higher frequency of problems with higher exposure (closer distance to wells, higher densities of wells, more intense gas production).
- Time relationship – showing that the increases in health problems began only after commencement of industry activities in the areas.
- Association still evident after allowing for other causes – for example, controlling for the potential contribution of smoking, socioeconomic status, community age profiles, legacies of other industrial activities in the area, etc.

Principles of public health : Precautionary Principle and unconventional gas mining

Good health is highly cherished. Australian citizens generally believe that their state and national governments make responsible decisions that protect their health above other considerations, even where there is uncertainty. Thus many people assume that the **precautionary principle** is being applied by government, i.e., that preventive action would be taken in the face of uncertainty; that the proponents of a proposed activity would be required to demonstrate its safety, not the community; that governments would explore a wide range of alternatives to possibly harmful actions; and that government would encourage public participation in decision making[2].

Bamberger & Oswald (2012) identified the rapid unconventional gas boom as an uncontrolled worldwide health experiment due to the incomplete disclosure of chemicals, combined with non-disclosure agreements in the US and in some cases in Australia. Finkel & Hays (2013) provides interesting historical and current context to activities conducted by the unconventional gas industry in interactions with communities and the US Environmental Protection Agency, emphasizing the risks of allowing the industry to go ahead without clear knowledge of risk. The effectiveness of regulations imposed on industries with the aim of increasing public safety have also been questioned. An interesting comparison between Kovats et al. (2014) and Hill (2014) highlights differing views on the potential versus the actual ability of regulation to protect human health from contaminants associated with shale gas mining. In a paper directed at the United Kingdom policy regarding the industry, Hay et al. (2015) urged governments to make policy decisions based on evidence of risk as well as measured effectiveness of harm reduction based on actual experience - and not on theoretical solutions that have not been demonstrated.

As a result of these and other concerns and lack of clear evidence of safety of the unconventional gas industry, many public health and medical organisations (including the Public Health Association of Australia (http://www.chiefscientist.nsw.gov.au/coal-seam-gas-review/?a=30027), the Climate and Health Alliance (www.chiefscientist.nsw.gov.au/coal-seam-gas-review/?a=29992) and the National Toxics Network (http://www.chiefscientist.nsw.gov.au/coal-seam-gas-review/?a=29853), collectively representing many doctors, public health practitioners, and allied health professionals, have expressed considerable concern about the lack of evidence of its safety to human health.

In submissions to the NSW Chief Scientist and Engineer's examination of the public health and safety of coal seam gas mining in 2013, these groups, as well as the Australian Medical Association, have publically called for application of the Precautionary Principle. This can be summarized as: *"When an activity raises threats of harm to the environment or human health, precautionary measures should be taken even if some cause and effect relationships are not fully established."* (1998 Wingspread Statement)

The Australian Medical Association stated simply, *"If in doubt, turn CSG off".* *https://ama.com.au/ausmed/if-doubt-turn-csg-ama*

The British Medical Journal recently published a joint letter with similar sentiments signed by 18 leading medical scientists, stating: *"The arguments against fracking on public health and ecological grounds are overwhelming. There are clear grounds for adopting the precautionary principle and prohibiting fracking"* (BMJ 2014).

t should be noted that many public health and medical organisations are calling on governments to apply the Precautionary Principle in this situation, and refrain from allowing

[2] (Kriebel D, Tickner J, Epstein P, et al. The precautionary principle in environmental science. Environmental Health Perspectives. 2001;109(9):871-876).

unconventional gas mining to occur in Australia until there is sufficient evident demonstrating that it is safe for people and the environment. Among these organisations are:

- Doctors for the Environment Australia[3]
- Public Health Association of Australia[4]
- Australian Medical Association[5]
- National Toxics Network[6]
- Climate and Health Alliance[7], which includes 28 professional health bodies, e.g. Australian Psychological Association, Australian Council for Social Services, Australian College of Nursing, Australian Research Alliance of Children and Youth.

The most extensive systematic literature review on the public health impacts of unconventional gas mining to date mentioned previously (Saunders et al., 2016) reported the following definition of the Precautionary Principle, updated from its original publication in 2001:

> *The Wingspread Declaration on the Precautionary Principle counsels that 'When an activity raises threats of harm to human health or the environment, precautionary measures should be taken even if some cause and effect relationships are not established scientifically. In this context the proponent of the activity, rather than the public, should bear the burden of proof' (Science and Environmental Health Network 2016).*

In concluding their review of 156 peer-reviewed publications on exposure pathways [air, water], seismicity, and health, economic and social and climate change impacts associated with unconventional gas mining, the authors [Saunders et al. (2016)] state:

> *As the available evidence does not enable a definitive public health judgment, a position shared by the US Centers for Disease Control (Centers for Disease Control and Prevention), we have a duty to pursue and assess that evidence while ensuring that, in the meantime, communities are not exposed to unacceptable risks. Several countries and North American states have banned, or imposed moratoria on, hydraulic fracturing including France, Bulgaria, Germany, Scotland, Wales, New York, Nova Scotia, Newfoundland, Quebec and New Brunswick (Finkel et al. 2015) … Considering the uncertainties surrounding the health, environmental, social, global warming potential and economic implications of unconventional gas within this internationally recognised framework, it would seem prudent to incentivize further research across all the domains of UNGD related impact, and delay any proposed developments until the products of this investment have been peer-reviewed and assessed.*

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[3] https://www.dea.org.au/topics/health-and-environment/unconventional-gas/

[4] https://www.phaa.net.au/documents/item/726
[5] https://ama.com.au/article/better-environmental-health-0
[6] http://www.ntn.org.au/wp/wp-content/uploads/2016/05/NTN-Unconventional-Gas-Report-April-2016.pdf
[7] http://www.caha.org.au/healthy_energy

5. Impacts on Aboriginal people and their culture

Time has not permitted the examination of this aspect. There is a serious lack of peer-reviewed publications on the views of Aboriginal people about unconventional gas mining.

6. Social impacts

"There are many avenues through which the unconventional gas industry can harm mental health and individual and community wellbeing (Hossain et al., 2013; Morgan et al., 2016; NSW Parliament, 2012). The **initial** phase impacts include distress and anxiety due to disagreements that split the community into those who support the industry and those who oppose it. In the '**boom**' phase tight-knit communities can feel inundated with strangers coming in, swamping unprepared health and mental health services. Crime may also increase. Such impacts are detrimental to the social cohesion and for some, the moral character, of the community. In the **post-construction** phase, jobs decline dramatically and housing demand drops. Production ramps up with drilling and fracking, with its 24-hour lights, noise, privacy invasion, odours, tree clearing and truck movements - causing some people to feel a deep sense of loss of control, loss of place and loss of peace and a feeling of being trapped and unable to escape. All of these phases present risks of depression, anxiety and increased use of alcohol and other drugs for coping" (Haswell 2017).

Haswell and Bethmont (2016) stated:

"…Upbeat accounts emerged during the construction phase of CSG mining in the Darling Downs, Australia. However, research has found uneven impacts on residents and uncertainty in how communities will cope with the post-construction phase (Rifkin 2015; Walton et al., 2014). A survey by Australia's Commonwealth Scientific and Industrial Research Organisation of 390 residents found that 48.5% felt their community was 'only just coping', 'not coping' or 'resisting' the industry. While 51.5% felt their community was adapting, just 11.4% of this group saw the change as 'into something different but better' (Walton et al., 2014).

The New South Wales Parliament Legislative Council Inquiry into Coal Seam Gas (2012) found widespread concern about CSG developments from rural, urban and indigenous communities. Some inquiry participants were concerned about poor behaviour by CSG companies and contractors, the pace of development and fear of loss of land and livelihood.

In southern Queensland, 239 landholders, community and service representatives attending workshops linked psychosocial, health service, housing and financial stressors and negative mental health impacts with coal and UCG mining (Hossain et al., 2013). Participants urged greater protection of mental health and increased health and psychological services in mining areas. Augmenting the Edinburgh Farming Distress Inventory to include stressors linked to CSG mining, Morgan et al (2016) demonstrated that mining concerns contributed to overall stress burdens and odds of experiencing depression and anxiety, felt most severely by farmers directly affected by mining activities.

The suicide of an Australian farmer in 2015 who, according to a family statement (Bender family, 2015), resisted pressure and experienced the consequences of UCG and underground coal gasification on his farmland for more than 10 years (adds gravity to the findings of these studies. This death stimulated a national Senate Select Committee Inquiry on Unconventional Gas Mining (Parliament of Australia, 2016) but, after an interim report, the Inquiry was suspended due to the 2016 Australian election.

There are particularly important concerns when considering the potential psychosocial and spiritual impacts of unconventional gas mining on Aboriginal people and communities. While there are no research publications to date, many Aboriginal and Torres Strait Islander people are leading efforts to protect the environment and health in the face of challenges from mining and climate change".

7. Economic impacts

The employment and economic benefits of UCG are often assumed to be substantial, but some research has contested this. For example, Chen and Randall (2013) modelled long-term economic net benefits in Australia and found that, under some plausible scenarios, the economic benefits from agriculture alone exceeded those from CSG. Costs to health and community wellbeing and other externalities were not included in the modelling.

It will therefore be imperative for the Committee to undertake a comprehensive, unbiased and realistic assessment of the economic impacts – both positive and negative - of the industry on individuals, local communities, regions and the Territory, to assist in its assessments. In order to achieve this, the Committee will need to:

1. "fully consider and discuss with the community the current evidence of risks and impacts across the entire life cycle of this industry on health and wellbeing of people and their environment. The risks, and their impacts should they occur, need to be clearly recognised as community-borne costs worthy of compensation and consideration in economic, social and health cost-benefit analyses.

2. equally scrutinize and make public the realistic short-, medium- and long-term economic benefits of the unconventional gas industry to enable accurate comparisons between its full likely costs and benefits. This should also be used to compare the cost-benefit ratios of unconventional gas mining with other potential state developments that may carry greater benefits with fewer potential health and environmental losses". (Haswell, 2017).

9. Regulatory framework

As stated by Haswell (2017):

"It is critical to also consider that risk management approaches are sufficient only where the technical capacity to alleviate all risks exists and is clearly and sufficiently demonstrated. Relying on risk management approaches also requires certainty that a sufficient level of regulation, monitoring, early detection, correction and preventative actions can be operationalised, paid for by appropriate bodies, and sustained over time. Experience documented in the US EPA Final Report regarding impacts of hydraulic fracturing in the United States shows that such a level of assessment, monitoring, detection and correction has not occurred, making it impossible to able to estimate on a wide scale how much contamination of water supplies has resulted from the industry. This raises serious questions about the extent to which people have been exposed to undetected contaminants in water they have consumed, and particularly to endocrine-disrupting chemicals that have the potential to affect human development and reproduction at very low concentrations.

Furthermore, the Physicians for Social Responsibility and Concerned Health Professionals of New York (2016) have compiled four extensive editions of "*Compendium of scientific, medical and media findings demonstrating risks and harms of fracking*" (Unconventional oil and gas extraction) in the United States. The authors argued that, based on this extensive experience, “regulations have not prevented significant harms; and that some harms are not preventable through regulatory opportunities”.

Even if risk management were theoretically possible, all governments should be asking whether their regulatory agencies have – and will continue to have - the capacity to adequately monitor and respond to the many potentially hazardous chemical, social, mental and physical health risks posed by large numbers of producing and depleted wells. The future security of these regulations will depend on the commitment of future government leadership to place the protection of human and environmental health above that of industry demands, where conflicts exist.

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