Submission to the Scientific Inquiry into Hydraulic Fracture Stimulation in Western Australia

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This submission deals principally with the likely direct health consequences of lifting the present moratorium on fracking in Western Australia. It will principally address, therefore, the direct health aspects of the first term of reference (TOR1), endeavour to base its statements on credible scientific evidence (TOR2), and propose regulatory mechanisms to mitigate or minimise risks to health (TOR3 and TOR4) in the event that the present moratorium is lifted. This extensive, scientifically based review of the public health impacts of fracking – Saunders PJ, McCoy D, Goldstein R, Saunders AT and Munro A. *A review of the public health impacts of unconventional natural gas developments.* Environmental Geochemistry and Health 2018; 40:1-57 – and scientific papers to which it refers are the primary sources of the statements of scientific fact and opinion that I make. I will not individually reference the sources my statements. I will use the term "unconventional natural gas" (UNG) when referring to the industry that employs fracking as a production tool and the product of this industry.

There are also indirect health aspects of fracking consequent on its major contribution to greenhouse gas emissions. On present evidence these aspects will probably be locally and globally far more important than the direct health effects. Time has prevented me from including these health aspects in this submission. It is essential that the Inquiry has regard to them.

Hazardous exposures

Fracking fluids

An average fracking episode can inject 2-8million US gallons (7.5-30million litres) of a water-based fracking fluid into the drilled rock; 5% to 80% of the injected fluid (on average about 35%) can resurface as flowback following the fracking episode and may be accompanied by produced water (water originating in drilled/fracked rock). At best this resurfaced fluid is completely contained in tanks or open ponds prepared for the purpose but spills, leaks and other failures of containment are common. About a half of the spills are of flowback or produced water and nearly a half are from surface storage. Thus some degree of: outgassing of volatile components of fracking fluids into the atmosphere, therefore air pollution is inevitable; and entry into ground water, therefore pollution of drinking water is possible. Some direct contact of UNG workers with fracking fluid is also likely in every fracking operation.

In addition to fracking fluid, as much as 15% of the proppant (fine particles of high-silica quartz or ceramic injected to keep the fractures open) may be returned to the surface in the flowback, and workers on the site can be heavily exposed to it. The chemical composition of flowback can differ from that of the injected fracking fluid due to effects of high pressure, high temperature and salinity on the original chemical mixture. Flowback and produced water can contain naturally occurring radioactive materials and produced water can be highly saline.

More than 1,000 chemicals have been identified in fracking fluids or wastewater from fracking operations and a large number of them have not been adequately assessed for their potential toxicity to humans or to animals and plants. In many fracking operations worldwide the chemical composition of fracking fluids is not disclosed. In a review of 352 chemicals used in US natural gas operations, including UNG operations, 25% were found to be potentially carcinogenic, 75% had the potential to affect skin, eyes and respiratory and gastrointestinal systems, 40-50% the nervous, immune and cardiovascular systems and the kidneys, and 37% the endocrine system.

Polluted water

There are three potential routes for contamination of water by UNG operations: Stray gas contamination of aquifers; spills, leaks and inadequately treated wastewater; and accumulation of toxic or radioactive substances in soil or stream sediments near spill or disposal sites. Present evidence indicates that stray gas contamination of shallow aquifers and surface water, BTEX chemicals (benzene, toluene, ethylbenzene, and xylenes) in flowback spills contamination of surface waters and accumulation of radioactive isotopes in some spill or wastewater disposal sites do occur. Relevant chemicals have been identified, sometimes in excess, in some private water supply wells and public water supplies close to UNG operations but it has been difficult to confidently connect instances of water pollution to the UNG operations except in a few cases, principally due to lack of measurements of these chemicals before fracking began.

Polluted air

Volume and composition of emissions into the atmosphere in proximity to fracking operations vary depending on the stage in their life cycle: pre-production; production; transmission, storage and distribution; and well production end-of-life. Sources of hazardous air pollutants (HAPs) include use of large, diesel- or gas-powered machinery, truck traffic, outgassing of volatile compounds from fracking and flowback fluids; proppant injection; and venting (controlled release of gas into the atmosphere in the course of routine production operations) and flaring (controlled burning of gas in the course of routine production operations). HAP chemicals include PM (particulate matter), NOx (oxides of nitrogen), methane (commonest hydrocarbon constituent of natural gas) and other hydrocarbons, non-methane volatile organic compounds (other VOC, which include polycyclic aromatic hydrocarbons (PAHs) and sometimes benzene), respirable silica (silica particles so small that they can inhaled into the lungs and penetrate into the gas-exchange regions of the lungs), hydrogen sulphide (H_2S), sulphur dioxide (SO_2) and formaldehyde. Ozone, while not an emission as such, can be formed from the reaction of NOx and VOC in the presence of solar radiation.

The concentrations of many of these chemicals have been measured in air at various distances from fracking operations, levels of various chemicals have been reported to be above those specified in various air quality standards, but not consistently so. The research suggests that most of the pollutants found to be at increased concentrations in air have their origin in diesel or gas-powered machinery; e.g. 50% in one US study.

Of the specific chemicals or classes of chemicals listed above, Benzo[*a*]pyrene (a PAH found in diesel exhaust fumes among other sources), benzene, silica dust, and formaldehyde have been shown to cause cancer in humans (classified as a Group 1 agent by the International Agency for Research on Cancer (http://monographs.iarc.fr/ENG/Classification/List_of_Classifications.pdf). Fine particle (e.g. $PM_{2.5}$) air pollution has been shown to cause heart and lung disease in humans.

Direct health impacts

Evidence that links some measure of exposure to UNG operations to clinically diagnosed disease is very limited: Saunders et al (2018) identified five such studies and I have added two more that were published after Saunders et al completed their review, Currie et al (2017) and Whitworth et al (2017).

- Fryzek et al (2013) used Pennsylvania Cancer Registry data to compare incidence rates of childhood cancer in Pennsylvania counties from when the first well was drilled to 2009 with incidence rates in the same counties from 1990 to the year before the first well was drilled. Hydraulic fracturing (fracking) had been little-used in gas wells in these areas until the early 2000s. Before and after comparisons were made for all childhood (0-14 years of age) cancers, childhood leukaemia and childhood brain tumours by calculating indirectly standardised cancer incidence rate ratios (SIRs) for the before and after periods using national SEER cancer registry data for the standard rates so as to adjust for potential confounding by age (in 5 year age groups), sex and race. The SIRs were 0.94 (95% confidence interval 0.90, 0.99) for all cancers before drilling and 1.02 (0.98, 1.07) after drilling. Corresponding SIRs for leukaemia were 0.97 (0.88, 1.06) and 1.01 (0.92 to 1.11), and for brain tumours 0.89 (0.79, 0.99) and 1.13 (1.02, 1.25). Only the increase in incidence of brain tumours is, in conventional terms, statistically significant (because the lower 95% confidence bound of the after drilling SIR is greater than the upper 95% confidence bound of the before drilling SIR). The authors post hoc explanations for this apparent increase in incidence of brain tumours after drilling is not valid. It is true, though, that there is little evidence for a dose-effect relationship in the association between number of wells and brain tumour, but this may be a consequence of use of wells as a rather crude measure of exposure. Given that this study is an ecological study, however, confounding as a cause for the association cannot be ruled out. At most, therefore, this study raises an hypothesis that UNG development is associated with an increased risk of childhood brain tumour.

- McKenzie et al (2014) used the publically accessible Colorado Oil and Gas Information System to build a data set with latitude, longitude, and year of development (1996–2009) for all gas wells in rural Colorado. UNG development was the focus, which increased rapidly from 2000 and the study was limited to rural areas and towns of <50,000 people to minimise confounding of UNG exposures with urban air pollution. A retrospective cohort study was conducted based on the 124,842 live births in the study period, which was limited to singleton births and white births (<5% of the total were black). Birth outcomes studied included congenital malformations of the oral cleft, neural tube and heart, preterm birth, term low birthweight and term birthweight (continuous measure). Exposure was estimated from the inverse-distance weighted measure of number of UNG wells within 10 miles of mother's residence that existed in the birth year. Analyses were adjusted for maternal age, education, tobacco use, ethnicity, and alcohol use, parity at time of pregnancy and infant sex. Gestational age was also included in the analysis of term birth weight. Relative to a reference exposure of zero wells within 10 miles, risk of both neural tube defects and heart defects increased with proximity to wells in three successive categories of distance-weighted number of wells. For neural tube defects adjusted odds ratios (ORs) increased from 0.65 (95% confidence interval 0.25, 1.7) to 0.80 (0.34, 1.9) and 2.0 (1.0, 3.9) (p value <0.01); and, for heart defects, from 1.1 (0.93, 1.3) to 1.2 (1.0, 1.3) and 1.3 (1.2, 1.5) (p value <0.0001). In contrast both preterm birth and term birthweight tended to fall with increasing proximity (p value <0.0001 in each case). The positive results are weakened by lack of adjustment of key potentially confounding variables (such as folate intake) and the relatively crude exposure measure. Error in exposures measures, however, tends to weaken associations not to create them.

- Jemielita et al 2015 reported results of a cross-sectional ecological study that related rates of hospital inpatient separation (95,000 over the study period) in 25 diagnostic categories in 2007-11 to density of UNG operations across 67 zip code areas in three Pennsylvania counties. Number of wells and gas production grew substantially in this period. Four observations of this study are notable: relative to zip codes with no wells, risks for cardiology, neurology, endocrine and oncology separations became progressively higher across three categories of well density and had reasonably low p-values. The increment in risk in the third category was 27% (p-value <0.001) for cardiology, 19% (p-value <0.001) for neurology, 39% (p-value = 0.01) for endocrine and 82% (p-value = 0.02) for oncology. The authors considered that an association between well density and rate of separation was statistically significant if the p-value was <0.001, having applied a Bonferroni correction for the number of diagnostic categories studied. By using conditional fixed effects Poisson regression, the authors endeavoured to control statistically for all possible characteristics of the zip codes, both measured and unmeasured, that did not change during the period of observation. It is uncertain, however, whether this procedure can be taken to rule out operation of the "ecological fallacy" that limits the evidentiary value of ecological studies. While the results for endocrine and cardiology separations did not meet the Bonferroni correction's criterion for statistical significance, the were included above because they had the next lowest p-values of the remaining diagnostic categories and there are known carcinogens and endocrine disrupting chemicals used in UNG operations. These results raise reasonable hypotheses that risk of number of chronic disease categories is increased in people living near UNG operations.

- Stacy et al (2015) undertook in three counties of southwest Pennsylvania – Butler, Washington and Westmoreland – a somewhat similar but more rudimentary study to that of Casey et al (2016), the description of which follows. GIS coordinates, drilling commencement date and status of UNG well (active or other) were obtained; there were 509 active wells operating in the three counties in 2007-10. Information on all births in the counties was also obtained for the same period; 79.6% of all singleton births had geocoded addresses at the time of birth, a total of 22,273, and were included in the analysis. Neonate's sex, birthweight and gestational age were available in records, as were mother's age, education, pre-pregnancy weight (missing for 15%), race, "women, infant and children assistance (WIC)", prenatal visits, pre-pregnancy weight, and birth parity. Eighty nine percent of mothers had a least one active UNG well within a 10 mile radius of their residence; mothers outside this radius were excluded from the analysis because they were demographically very different from those inside. Exposure was measured as an inverse-distance weighted well count for each mother. Outcome variables were birth weight, "small for gestational age" and prematurity. All models were adjusted for gender of the child and mother's age, education, pre-pregnancy weight, prenatal care, smoking, gestational diabetes, WIC; African American and parity. In a multivariate linear regression analysis of the neonate's birthweight was significantly diminished for mothers living closest to active wells (p value = 0.02). In addition the risk of being small for gestational age increased with proximity to active wells with an odds ratio of 1.34 (95% CI 1.10, 1.63) for the highest proximity category. Prematurity was not consistently associated with proximity to wells. While this study is generally of good quality, there are deficiencies in the way its results have been reported. Those deficiencies, however, are unlikely to be misleading regarding the general tendency of the findings.

- Casey et al 2016, conducted a retrospective cohort study of neonates born in 2009-13 in the care of one large health service provider in central and north-east Pennsylvania. Study health outcomes were: term (≥37 week) birth weight, preterm birth (<37 weeks gestation), low 5-minute Apgar score (<7), and small for gestational age. An index of UNG development at the mother's residence (as recorded in 2013) was based on four exposure metrics representing phase of UNG development activity (UNGD): pads/m2, wells/m2, total well depth (m)/m2, and gas production volume m3/m2 (pad, drilling, stimulation, and production metrics, respectively), each of which was only included in the single exposure index if it overlapped temporally with gestation. To take account of residence, the overall metric based on these components for each development site was divided by the squared distance between the GIS coordinates of the site and the mother's home address and summed across sites. Statistical analysis models were adjusted for sex of the neonate, season of birth, maternal age, maternal race/ethnicity, primary care status, smoking status during pregnancy, pre-pregnancy BMI, parity, receipt of Medical Assistance, delivery hospital, distance to nearest major road, drinking water source (well vs municipal), community socioeconomic deprivation, greenness and, in a separate analysis, period of the birth (2009–2010 vs. 2011–2013). Birth weight models also included gestational age. In total, 10,496 neonates of 9,384 mothers were included in the analysis. Of the four primary outcomes, only preterm birth was associated with UNGD: Odds ratios (ORs) for preterm birth were 1.3 (95% confidence interval 1.0, 1.8), 1.6 (1.1, 2.4) and 1.9 (1.2, 2.9) for quartiles of exposure 2, 3 and 4 of UNGD respectively calculated with reference to a value of 1.0 for quartile 1. This is a high quality study, and the result is made more credible by the consistent increase in OR with increasing exposure. Exposure measurement is the study's greatest weakness, especially that it was based on mother's address in 2013 and not the actual location during gestation, which could have been different for a sizeable proportion of mothers. However, any bias in the findings due to exposure measurement error would be most likely to have biased the OR for preterm birth with higher exposure towards the null value (1.0). Any confounding between exposure and other possibly causal variables should have been dealt with given the number and careful selection of confounding variables included in the analysis.

- Currie et al (2017) is a further report on UNG exposure and perinatal outcomes based on data from the whole of Pennsylvania for 2004-13, thus completely overlapping both Stacy et al (2015) and Casey et al 2016. Perinatal outcomes data were obtained for 1.1 million live births from Pennsylvania certificates of live birth. UNG exposure data were obtained from the Pennsylvania DEP Internal Operator Well Inventory of all UNG wells that were active in 2014, most of which were fracked after 2009. The study sought to address four problems in previous literature: Its sample size is much larger; it uses an index of infant health outcomes to incorporate all the measures of infant health that are available in vital statistics data; and it tests for effects at various distances of maternal residence from UNG sites. In addition, confounding for health characteristics of the mother are addressed by comparing the health of fracking-exposed neonates with that of unexposed siblings born to the same mother. The paper and its methods and results are unconventional, complex and poorly written. It appears, however, to confirm the presence of effects of UNG exposure on perinatal outcomes: low birthweight was more prevalent in infants whose mothers lived within 3km of a UNG site during pregnancy and the authors' index of infant health outcomes indicated poorer health outcomes in these infants. [Currie J, Greenstone M, Meckel K. Hydraulic fracturing and infant health: New evidence from Pennsylvania. Science Advances 2017; 3(12): e1603021.]

- Whitworth et al (2017) conducted a retrospective birth cohort study in 158,894 women with a birth or foetal death between November 30, 2010 and November 29, 2012 in North Texas. They constructed three UGD activity metrics by calculating the inverse distance-weighted number of active wells within half, two and ten-miles of the mother's residence. Women were excluded if the nearest well was >20 miles away. Outcomes were preterm birth, small-for gestational age, foetal death and birthweight. Models of foetal death and birthweight were adjusted for maternal age, race/ethnicity, education, pre-pregnancy body mass index, parity, smoking, adequacy of prenatal care, previous poor pregnancy outcome, and infant's sex. Preterm birth models included all of the above except parity, and small-for-gestational age models included all except previous poor pregnancy outcome. Adjusted odds ratios for preterm birth were elevated for each tertile of exposure (relative to residence >10 miles away) within the three distance categories – half, two and ten miles. They were respectively 1.18 (95% confidence interval 1.08, 1.29), 1.21 (1.09, 1.33) and 1.14 (1.03, 1.25) for half a mile; 1.11 (1.04, 1.19), 1.16 (1.09, 1.24) and 1.14 (1.07, 1.22) for two miles; and 1.02 (0.96, 1.08), 1.13 (1.06, 1.20) and 1.15 (1.08, 1.22) for ten miles. The lack of increasing odds ratio with increasing tertiles of exposure in each case is somewhat against these associations being causal. [Whitworth KW, Marshall AK, Symanski E. Maternal residential proximity to unconventional gas development and perinatal outcomes among a diverse urban population in Texas. PLoS One 2017; 12(7): e0180966.]

None of these studies taken individually or together with others give certainty to any specific health outcome in people living in proximity to UNG operations. The most persuasive results are in support of poorer perinatal outcomes in babies born of mothers living near to UNG operations. However, the inconsistency in the poorer outcomes observed, specifically prematurity or low birthweight, weakens inferences that can be drawn from them.

Notwithstanding the current weakness of the evidence from human health studies that directly relate health outcomes with indices of exposure to UNG operations, there is sufficient evidence on which to apply the precautionary principle to these operations. That is *"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 fully established scientifically"*. The case for applying the precautionary principle is strengthened by the evidence of water and air pollution associated with UNG operations.

Clearly, if UNG development is to continue, more and better evidence on the hazard and risk to human health of UNG related exposure is required. While there is no present framework in WA within which such research could be conducted, the enablement and conduct of such research should be a requirement of any new UNG developments in WA. This would require at a minimum:

1. A period of at least 12 months measurement and recording by independent scientists of known and suspected hazards in air and water (ground water and superficial aquifers) in all areas of intended UNG development;
2. Continuous independent measurement and monitoring of these hazards once UNG development has begun;
3. Setting and strict observance of standards for concentrations of key hazards in air and water (both ground water and superficial aquifers) with specified mitigation actions required for any exceedances;
4. Full documentation of the identities and roles of all workers employed in UNG development and operations, the nature and amounts of their exposure to specified hazard including from continuous personal monitoring and other health-related characteristics that might modify or confound exposure to UNG hazards.
5. Full documentation and updating of documentation of residences and their occupants living within 16km of UNG developments and operations. Documentation would include health-related characteristics that might modify or confound exposure to UNG hazards.

6. A personal exposure monitoring program for all the occupants in (5) above.
7. A major ongoing longitudinal study of the exposure and health of workers and residents within 16km enabled by (4), (5) and (6) with periodic testing for short-term effects of major hazards and monitoring of long-term effects of all hazards by way of linking WA and, as necessary, national health records to the identities obtained in (4) and (5) and the personal monitoring results obtained in 4 and 5.

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Bruce Armstrong is an epidemiologist and public health physician whose career has encompassed research, academia and public service; the latter including Commissioner for Health for WA, Director of the Australian Institute of Health and Welfare, Director of Research and Registers at Cancer Council NSW, founding Chairman of the Sax Institute Sydney, Head of the University of Sydney's School of Public Health and inaugural Chairman of the NSW Bureau of Health Information. Bruce is recognised internationally for his research into the causes and prevention of cancer, having published over 650 papers in scientific books and journals. He has retired from full-time employment but continues to actively pursue his interests as an Emeritus Professor at the University of Sydney and an Adjunct Professor at the University of WA. Bruce was made a Member of the Order of Australia in 1998 for his work in cancer epidemiology and a Fellow of the Australian Academy of Science in 2000. He received the inaugural New South Wales Premier's award for Outstanding Cancer Researcher of the Year in 2006 and has been listed by Thomson Reuters in both 2015 and 2016 as among the ~3,000 most highly cited researchers based on their numbers of highly cited papers published in recent years. In 2017, the University of WA honoured Bruce with the award of the honorary degree of Doctor of Medicine.