

# THE IMPLICATIONS FOR HUMAN HEALTH AND WELLBEING OF EXPANDING GAS MINING IN AUSTRALIA

Onshore Oil and Gas Policy  
Background paper  
2019

***We acknowledge the Traditional Custodians of the many Lands we call Australia, and pay respects to Elders Past and Present, as well as emerging Aboriginal and Torres Strait Islander leaders.***

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Doctors for the Environment Australia (DEA) is an independent self-funded non-government organisation of medical doctors and students in all Australian States and Territories. Our members work across all specialties in community, hospital and private practice.

Since forming in 2001, we have been guided by our vision 'Healthy Planet, Healthy People'. We use compelling scientific evidence to demonstrate the important health benefits of clean air and water, biodiverse natural places, stable climates and sustainable health care systems.

We work to prevent and address the health risks-local, national, and global-caused by damage to our natural environment. We are a public health voice in the sphere of environmental health with a primary focus on the health harms from pollution, environmental degradation, and climate change.

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# Executive Summary

It is now recognised that the exploration and extraction of natural gas (methane) and oil from conventional and unconventional sources pose many potential direct and indirect risks to human health and wellbeing. As recently as 2013, there were few peer-reviewed publications available in the health science literature upon which to assess the potential local, regional and global health related impacts associated with these industries. Over the last six years, however, public health and environmental science researchers and doctors have published over 1500 papers, with a substantial body of research findings. This research comes mainly from the United States where rapid and expansive development of gas and oil fields has occurred in close proximity to residential areas.

This Paper presents a comprehensive review process that has been ongoing among Doctors for the Environment Australia's (DEA) unconventional gas group since 2013. It is informed by literature searches on PubMed, Scopus and the ROGER (Repository of Oil and Gas Energy Research) database, which have enabled DEA to make many evidence-based submissions to governments on the health implications of gas development proposals across Australia.

Of particular concern is the clear evidence of the substantial and rising greenhouse gas footprint of the expanding gas and oil industry that threatens global efforts to urgently reduce emissions. This is often underestimated through:

- Failure to consider the footprint of the entire lifecycle of gas production, processing, transport and use;
- Underestimation of the quantity and duration of fugitive methane emissions;
- Inappropriate application of climate-forcing potency of methane over a 100 year time timeframe (20 times more than CO<sub>2</sub>), rather than the more appropriate 20 year timeframe (86 times higher potency) given the already measurable health impacts of current rapid warming;
- Failure to consider the potential significance of large scale methane-emitting accidents (e.g. Aliso Canyon storage facility in California) and leakages that are difficult to stop quickly;
- Failure to incorporate the negative political influences and economic competition between abundant gas from large expansions and low emission renewable energies in the energy market.

In addition to greenhouse gas emissions, a second major concern to health associated with gas mining is the wide array of chemicals used in drilling and hydraulic fracturing, and released into the environment through airborne emissions and wastewater, and emitted from the high level of industrial activity (e.g. compressor stations, gas processing plants, on-site diesel-powered machinery and heavy vehicles) surrounding the production process.

Potential chemicals of concern within shale and coal seam gas mining wastewater include volatile organic compounds notably benzene, phenols, polycyclic aromatic hydrocarbons (PAHs), heavy metals, salt and technologically enhanced naturally occurring radioactive materials that may become concentrated through treatment processes.

Studies examining the potential toxicities of chemicals found in shale gas wastewater have reported that while many have not been evaluated, some are known carcinogens and/or have the potential for endocrine disruption and/or are associated with neurological, reproductive and developmental harm.

Many studies report evidence of pathways through which ground and surface water can, and in some cases has, been impacted by gas well activity, through spillage, injection procedures, spills or deliberate discharge of inadequately treated water and leakage from wastewater pits and ponds.

Potentially harmful substances emitted into the atmosphere during dewatering, gas production and processing, wastewater handling and transport include PM<sub>2.5</sub> and PM<sub>10</sub>, volatile organic compounds, hydrogen sulphide, formaldehyde, diesel exhaust and ground level ozone. Measuring concentrations and human exposures to these pollutants is complicated as levels vary widely over time and location, making it difficult to directly link airborne exposures to health impacts.

The review also found accumulating evidence of associations between residence close to gas mining activities and reports of poorer health, such as asthma exacerbations, sinus conditions and migraines, skin rashes, fatigue and headaches as well as hospitalisations for heart, neurological, respiratory, immune system diseases and some cancers. While most of these studies have been conducted in the US, exploratory hospital-based studies suggest that similar trends may be emerging between regions with and without coal seam gas mining in Queensland, Australia.

Increasingly consistent observations of higher frequencies of negative birth outcomes, such as low birth weight, extreme pre-term delivery, higher risk births and some birth defects, have been reported to occur in pregnancies spent closer (around 2 or 3 km) to gas mining activities, compared to pregnancies spent further away, or in the same area before commencement of gas mining activities.

Increased levels of stress, depression and sexually transmitted infections, aggression, criminal activity and traffic accidents have also been reported among those living near gas mining. These changes likely reflect psychological and social disturbance among individuals and whole communities. Australian researchers have found that stress and worries about coal seam gas mining may contribute significantly to mental health risks among directly affected farmers.

Of particular concern to Australian agriculture and remote communities is research showing an unpredicted but consistent rise in water footprint—up to 7.7 and 14 fold increases in water usage and waste used per well in semi-arid regions across the United States.

In summary, the review found growing evidence of direct health impacts as well as a clear potential for indirect impacts of gas and oil mining on essential environmental determinants of health. These concerns include risks to a stable climate, air quality, water quality, water security, food security, community cohesion and, in some locations, geological stability. The cumulative impacts of these industries on the wider requirements for good health and wellbeing are extremely concerning.

At a time when the dangers of climate change are becoming readily apparent through record-breaking heat waves, droughts, floods, forest fires and cyclones and increasing food and water security concerns, accelerating new and expanding existing gas developments is counterproductive to reducing greenhouse gas emissions. It is not possible to overemphasise the enormity of health, economic, security and environmental costs of an inadequate response to global warming.

**Doctors for the Environment Australia urge the Australian government to commit to a national energy plan that prioritises the urgency of climate change. Accordingly DEA urges a ban on new gas and oil developments, and heavy regulation of existing gas developments while vigorously promoting a coordinated transition to renewable energy.**

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# 1. Introduction

**Good health requires not merely the absence of disease, but also clean air, safe and sufficient supply of water and nutritious food, and a stable climate—the pillars of human health. Human activities, particularly since the Industrial Revolution, have both enhanced and diminished people’s continuing access to these fundamental requirements. Major global efforts mobilised by the United Nations Millennium Development Goals achieved improvements in human health and wellbeing. However it is recognised that these goals, and the economic developments of individual nations, were largely achieved at the expense of the environment. Global efforts are now guided by the Sustainable Development Goals, which aim to work in harmony with national commitments to the 2015 Paris Agreement on Climate Change (<https://www.un.org/sustainabledevelopment/repositioning-the-un-development-system/>) to achieve “Dignity, prosperity and peace on a healthy planet” by 2030.**

Much of the responsibility for achieving this vision lies at the level of individual nations who must make difficult decisions to secure a sustainable future for current and coming generations. According to the latest report released by the Intergovernmental Panel on Climate Change (2018), a major determinant of future health and prosperity is the speed at which the world can move away from fossil fuels—coal, gas and oil—and embrace the remarkable economic, environmental and health opportunities offered by renewable energies.

Australia is one of the world’s wealthiest nations, with one of the largest *per capita* global footprints and greenhouse gas emissions relative to its population. Even more importantly, Australia is among the world’s top exporters of coal and has a gas industry that is already the second, and appears to be aiming to be the first, largest liquid natural gas exporters in the world. Expansion of unconventional gas mining appears to be high on the agenda for Queensland, Northern Territory, Western Australia and possibly NSW; while conventional gas mining continues to expand in South Australia, Western Australia and the Northern Territory.

These plans carry enormous implications and risks for human health and wellbeing, both today and in the future.

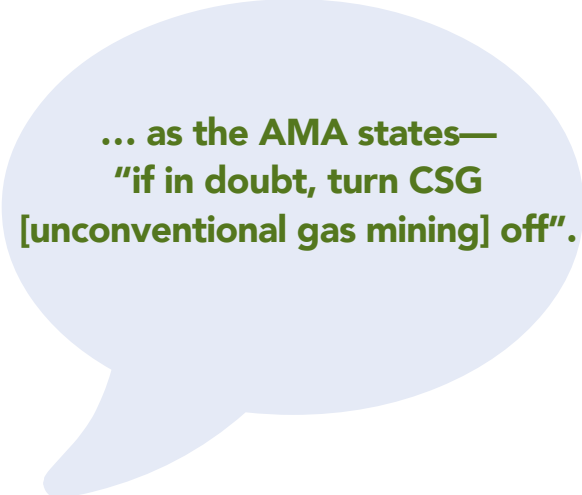
As recently as 2013, very little had been published on the environmental health risks and impacts associated with unconventional gas mining. By mid-2018, however, more than 1500 peer-reviewed

papers, reflecting rapidly expanding research efforts, were published which have collectively increased health concerns (see Repository of Oil and Gas Energy Research, Physicians and Scientists for Healthy Energy (<https://www.psehealthyenergy.org/our-work/shale-gas-research-library/>)).

Because of the complexities of unconventional gas mining, and the multiple chemical, physical and social stressors involved, a full analysis of potential public health hazards must include all steps of the process, starting from community awareness and reactions to development proposals, to 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. The broader implications of the industry on water, food and climate security have stimulated a wide and vigorous response around Australia and the world.

Based on extensive analysis of the literature, this Paper describes the current state of the evidence, which informs DEA's Oil and Gas Policy. The Paper first presents an overview of reviews and inquiries undertaken and the current situations of onshore oil and gas development in the states and territories in Australia. It then identifies and reviews evidence that supports the validity of concerns about potential and observed environmental health risks mediated through air, water, food and community disruption resulting from the various types of oil and gas mining. Finally a review of the evidence of direct health effects on communities is provided and followed

by a commentary on public health and medical opinion on the industry. Doctors and public health professionals largely support application of the precautionary principle—as the AMA states—“if in doubt, turn CSG [unconventional gas mining] off” (<https://ama.com.au/ausmed/if-doubt-turn-csg-ama>). The paper also includes an extensive reference list of cited studies and evidence upon which statements within this paper are based. Appendix 1 lists the submissions made to Australian governments by Doctors for the Environment Australia over the period 2011–2018.



**... as the AMA states—  
“if in doubt, turn CSG  
[unconventional gas mining] off”.**

## 2. Current Onshore Oil and Gas Development in Australia

**As indicated above, many Australian states and the Northern Territory are taking steps to develop a gas industry; mostly through unconventional gas mining. While conventional oil and gas resources have been extracted in Australia for decades, potentially extractable reserves requiring unconventional techniques for extraction far outstrip previous and current production levels.**

**States and Territories in Australia are taking various pathways in relation to current and future developments. A map of Australia detailing the various applications and granted oil and gas tenements, oil and gas wells and pipelines and based on government data is available from Energy and Resource Insights Australian Fossil Fuels Map (<http://data.erinsights.com/maps/fossilfuels-au.html>).**

Regarding state level decision-making on gas developments, as of March 2019:

- The Queensland government has embraced unconventional gas mining developments since 2005 without conducting any formal inquiries, nor funding independent research or comprehensive reviews of the now large literature examining the health impacts of the industry. By June 30, 2018, over 6,300 wells (1,634 drilled in a single year, 2014–15), plus ancillary infrastructure including 5000km of pipelines, compressor stations, three liquefaction plants and an export terminal were operating. Currently there are large and rapidly expanding coal seam gas developments in the Surat and Bowen Basins, with conventional gas production steady or in sharp decline. In February



**The Queensland government has embraced unconventional gas mining developments since 2005 without conducting any formal inquiries, nor funding independent research or comprehensive reviews...**

2019, the Queensland government formally approved a major expansion application allowing Arrow Energy to drill a further 2,500 coal seam gas wells in the Darling Downs and harvest an estimated 5000 petajoules of gas, with peak output expected in 2026. This has placed an additional 2,500km<sup>2</sup> to the existing 25,000km<sup>2</sup> under active gas production leases, mainly in the Darling Downs region. The government is also currently accepting proposals for oil shale developments. This review found no evidence that Queensland has conducted any formal independent public government inquiries or investigations into the evidence regarding health and environment risks and benefits associated with its coal seam gas mining policies, similar to those conducted by other states and territories prior to commencing approvals. However, a Senate Select Committee made numerous recommendations in an examination of coal seam gas mining within an investigation of certain aspects of Queensland Government related to Commonwealth Government Affairs in 2015 ([https://www.aph.gov.au/Parliamentary\\_Business/Committees/Senate/Certain\\_Aspects\\_of\\_Queensland\\_Government\\_Administration/Certain\\_Aspects\\_Qld\\_Admin/Report](https://www.aph.gov.au/Parliamentary_Business/Committees/Senate/Certain_Aspects_of_Queensland_Government_Administration/Certain_Aspects_Qld_Admin/Report))

- The NSW Chief Scientist and Engineer conducted an Independent Review of coal seam gas mining activities in NSW in 2014. This led to a reconsideration of the industry and a number of no-go areas and setbacks from residential areas. Many proposed projects did not proceed in the Illawarra, Gloucester, the north coast and Western Sydney.

Coal seam gas mining has progressed in the Narrabri and New England regions, but is projected to wind down in Camden, South Western Sydney. Currently, an application is under consideration by Santos to drill 850 coal seam gas production wells, mostly within the Pilliga Forest near Narrabri (<https://www.santos.com/what-we-do/activities/new-south-wales/gunnedah-basin/narrabri-gas-project/>).

- Victoria has banned unconventional onshore oil and gas mining and placed a moratorium on onshore conventional gas exploration until 2020 after conducting a Parliamentary Inquiry. However, offshore gas exploration is permitted using horizontal drilling into the seabed from onshore sites.
- South Australia is currently legislating an agreed 10-year moratorium on unconventional gas mining in the Southeast region (from 2018), following an inquiry conducted by the Natural Resources Commission. However conventional gas mining is proceeding in the state. Most of the state is under oil/gas exploration tenement grants and applications (Energy and Resources Insights, 2018) with extensive numbers of wells in the state's northeast along Queensland's border.
- The Northern Territory placed a moratorium on unconventional gas mining in 2016. An independent Scientific Inquiry into Hydraulic Fracturing of Onshore Unconventional Reservoirs in the Northern Territory handed down its Final Report to the government in April 2018. The report concluded that the industry could be made safe through 134 regulations. The NT government

accepted all recommendations and lifted the moratorium on 17 April, and is now proceeding with development applications. Most of the Territory is under gas exploration tenement grants and applications (Energy and Resource Insights, 2018), with little current activity to date.

- Western Australia imposed a state-wide ban on fracking in September 2017 following an initial Standing Committee Review. Its second Independent Scientific Inquiry into Hydraulic Fracturing Stimulation handed its final report to the government with 44 recommendations on 12 September 2018. The moratorium was lifted in November 2018 with 2% of the state potentially available for unconventional gas operations. Limited areas of Western Australia are under gas exploration tenement grants or applications. Off shore oil and gas production is under significant expansion in parts of the north and southeast.

- The Tasmanian government extended in March 2018 the current moratorium on the use of hydraulic fracturing for the purposes of shale gas and petroleum extraction until March 2025 (<http://www.mrt.tas.gov.au/portal/tasmanian-government-policy-statement-on-hydraulic-fracturing-fracking-2018>).

Crude oil production from conventional sources in Australia peaked at about 800,000 barrels a day in 2000, and steadily declined to a current monthly average of 240,000 to 290,000 barrels per day in 2018 (Trading Economics, <https://tradingeconomics.com/australia/crude-oil-production>). Over 90% of currently tapped conventional oil reserves are located off shore. While production of oil from onshore shale and tight deposits has been limited by prohibitive costs, the estimated potential of oil (and gas) from these unconventional sources may be substantial in Western Australia, Queensland and New South Wales (Geoscience Australia, 2018; <https://aera.ga.gov.au/#!/home>).



Decommissioned coal seam gas well, Pilliga Forest

Credit: Lock the Gate Alliance

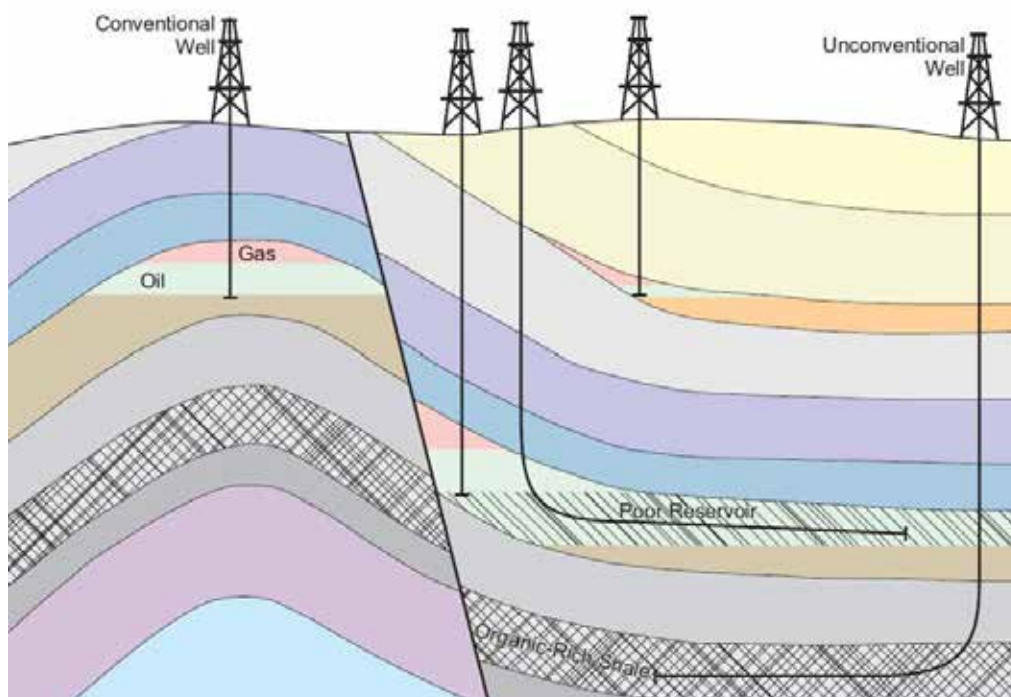
**A listing of Reports from major government inquiries is provided below:**

- NSW Chief Scientist and Engineer (2014). Independent Review of Coal Seam Gas Activities in New South Wales.  
<http://www.chiefscientist.nsw.gov.au/reports/coal-seam-gas-review>
- Northern Territory Scientific Inquiry into Hydraulic Fracturing in the Northern Territory (2018).  
<https://frackinginquiry.nt.gov.au/home>
- Parliament of Australia (2015). Select Committee on Unconventional Gas Mining, discontinued in May 2016.  
[https://www.aph.gov.au/Parliamentary\\_Business/Committees/Senate/Gasmining](https://www.aph.gov.au/Parliamentary_Business/Committees/Senate/Gasmining)
- Parliament of South Australia (2016). Unconventional Gas (Fracking) in the South East of South Australia. Final Report.  
<http://www.parliament.sa.gov.au/HOUSEOFASSEMBLY/BUSINESSOFTHEASSEMBLY/RECORDSANDPAPERS/TABLEDPAPERSANDPETITIONS/Pages/TabledPapersandPetitions.aspx?TPLoadDoc=true&TPDocType=1&TPP=53&TPS=2&TPItemID=147&TPDocName=Unconventional-Gas-Fracking-Final-Report-pdf.pdf>
- Parliament of Victoria, Environment and Planning Committee (2015). Inquiry into onshore unconventional gas in Victoria.  
[https://www.parliament.vic.gov.au/images/stories/committees/SCEP/GAS/Report/EPC\\_58-02\\_Text\\_WEB.pdf](https://www.parliament.vic.gov.au/images/stories/committees/SCEP/GAS/Report/EPC_58-02_Text_WEB.pdf)
- Rural Affairs and Transport Reference Committee (2011). Inquiry into management of the Murray Darling Basin—impact of mining coal seam gas.  
[https://www.aph.gov.au/Parliamentary\\_Business/Committees/Senate/Rural\\_and\\_Regional\\_Affairs\\_and\\_Transport/Completed\\_inquiries/2012-13/mdb/interimreport/index](https://www.aph.gov.au/Parliamentary_Business/Committees/Senate/Rural_and_Regional_Affairs_and_Transport/Completed_inquiries/2012-13/mdb/interimreport/index)
- Standing Committee on Environment and Public Affairs (2015). Implications for Western Australia of hydraulic fracturing for unconventional gas.  
[http://www.parliament.wa.gov.au/Parliament/commit.nsf/%28Report+Lookup+by+Com+ID%29/74E61E739E39E57748257EF9002150FE/\\$file/ev.fra.151117.rpf.042.xx.pdf](http://www.parliament.wa.gov.au/Parliament/commit.nsf/%28Report+Lookup+by+Com+ID%29/74E61E739E39E57748257EF9002150FE/$file/ev.fra.151117.rpf.042.xx.pdf)
- Western Australia government (2018). Independent Scientific Panel Inquiry into Hydraulic Fracture Stimulation in Western Australia: Final report  
[https://frackinginquiry.wa.gov.au/sites/default/files/final\\_report.pdf](https://frackinginquiry.wa.gov.au/sites/default/files/final_report.pdf)

# 3. The Mining Processes

**Easily accessible, concentrated land-based 'conventional' gas deposits have met domestic purposes for decades at costs well below the international market price. In recent years, new techniques have made it possible to extract methane present at low concentrations over widespread areas underground, and held tightly to shallow deposits of coal (coal seam gas), sandstone and limestone (tight gas) and deep shale deposits (shale gas).**

Unconventional gas mining refers the extraction of coal seam, tight and shale gas, which often require more invasive techniques, such as systematic dewatering of aquifers, horizontal drilling and hydraulic fracturing (Figure 1). Because the gas is widely dispersed across large areas, hundreds to thousands of wells spread across entire regions are required to maintain ongoing commercial viability. Oil may also be produced during this process in some areas. To date in Australia, most unconventional gas has been produced for export, not for domestic use.



**Figure 1:** This illustrates a single conventional well for a reservoir (left) and the unconventional wells, with horizontal drilling, for oil or gas containing strata (right)

Source: [https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/natural-gas-oil/petroleum-geoscience/conventional\\_versus\\_unconventional\\_oil\\_and\\_gas.pdf](https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/natural-gas-oil/petroleum-geoscience/conventional_versus_unconventional_oil_and_gas.pdf)

The need for multiple wells across large areas plus horizontal drilling and hydraulic fracturing are activities that differentiate conventional from unconventional oil and gas production. However, the distinction between conventional and unconventional gas is not always clear; and both operations often carry extensive land footprints (Figure 2).

The components of the mining process are briefly described below.

## Drilling procedures common to all unconventional and conventional gas and oil activities

Drilling is the standard mining process in which large drills, lubricated by special 'muds', penetrate the ground to reach the oil or gas. Muds are composed of lubricant and protective agents mixed



**Figure 2:** Tower for drilling horizontally into the Marcellus Shale Formation for natural gas in Lycoming County, Pennsylvania, USA

Source: Photo taken by Rurhfish 2009, GFDL, CC BY-SA Creative Commons License;  
[https://commons.wikimedia.org/wiki/File:Marcellus\\_Shale\\_Gas\\_Drilling\\_Tower\\_1\\_crop.jpg](https://commons.wikimedia.org/wiki/File:Marcellus_Shale_Gas_Drilling_Tower_1_crop.jpg)

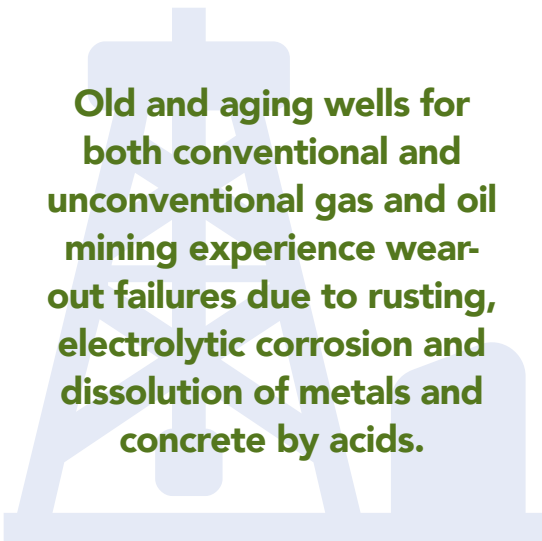
with other chemical additives. Muds with contaminants that return to the surface during drilling, if not re-used, may be buried in surface pits. Drilling also provides a long-term avenue for potentially harmful chemicals to migrate upwards and appear in local aquifers that have been drilled through. Handling and disposal of waste muds, drill cuttings and chemical additives pose risks to ground water, adjacent land and to the atmosphere through evaporation from waste-ponds.

Old and aging wells for both conventional and unconventional gas and oil mining experience wear-out failures due to rusting, electrolytic corrosion and dissolution of metals and concrete by acids. Failure of well integrity leads to long-term low-level fugitive emissions or contamination.

A study of well integrity by Bexte et al. (2008) found that “between 7% and 19% of more than 1000 wells drilled from 2005 to 2007 in western Canada had gas migration along the casing annulus, and 9% to 28% had gas leakage through surface casing vents”. Unintended natural gas migration along production wellbores, even for conventional gas, was described as a “chronic problem for the oil and gas industry ... as a result of poor primary cement jobs, particularly in gas wells”. U.S. Mineral Management Service data from the Gulf of Mexico indicates that “by the time a well is 15 years old, there is a 50% probability that it will have measurable gas build up in one or more of its casing annuli [rings]”.

A review of well barrier and integrity failures of unconventional and conventional oil and gas wells estimated that about four million on-shore wells had been drilled globally in 2014 (Davies et al., 2014). Analysis of 1144 violation notices issued from 3533 wells in Pennsylvania revealed cement and casing failures in 85 instances, and blowouts and gas venting in 6 cases between 2008 and 2011 (Considine et al., 2013). Other violations, comprising nearly 90% of notice issuances, included major and minor land spills, surface water contamination and site restoration (Davies et al., 2014).

A widespread lack of well monitoring and clear responsibility pathways for ‘orphaned’ wells, where the company that originally drilled the well no longer exists or transferred assets to another company, was also revealed (Davies et al., 2014). The authors concluded that their investigation confirmed that concerns regarding well integrity and barrier maintenance for conventional gas wells are equally necessary for the large and increasing numbers of unconventional gas wells.



**Old and aging wells for both conventional and unconventional gas and oil mining experience wear-out failures due to rusting, electrolytic corrosion and dissolution of metals and concrete by acids.**

## Hydraulic fracturing (fracking)

Extracting oil and gas from fossil fuel deposits may involve hydraulic fracturing of underground rock formations.

Additional to injection of lubricant and chemicals described above, hydraulic fracturing:

- utilises large volumes of local water reducing availability for local farmers and communities;
- necessitates drilling at multiple sites to achieve full access to the gas-bearing strata—resulting in hundreds of wells, requiring large areas of land and compounding the risks involved in each well;
- imposes a possible risk of reactivation of seismic activity due to the forceful injection and/or lubricating effect of hydraulic fracturing into geological fault lines, as observed in specific locations (Bau and Eaton, 2016; Yoon et al., 2017).

## Waste water production and management

Oil and gas wells often produce unwanted and variable amounts of water from the strata containing the fossil fuels or from fracking itself. This water may contain chemicals including naturally occurring radioactive materials, arsenic, mercury and volatile organic compounds—many of which can be harmful to human and animal life—as well as added chemicals used in the drilling and extraction process. These are further detailed in Section v.

One method of wastewater disposal, injection back into the ground, induced a 900-fold increase in seismic activity in Oklahoma (Ellsworth, 2013; Keranen et al., 2014). Recycling wastewater, i.e. using it repeatedly in hydraulic fracturing operations, is favoured in some jurisdictions, especially where water is scarce.

Other methods involve evaporation of wastewater from large holding ponds, spraying onto roads or nearby paddocks, and discharging into rivers, which disperses residual chemicals into the local environment. The impacts are concerning, but not fully understood (Davies et al., 2015).

Central wastewater treatment processes are used in the US and involve several steps, including separation and air and gas flotation to remove gels, dissolved gases, oil, sand, polymers and suspended solids, precipitation of metals, activated carbon filtration with aerobic degradation to remove organic compounds and reverse osmosis to remove salts (Butkovskyi et al., 2018; Water and Waste International <https://www.waterworld.com/articles/wwi/print/volume-28/issue-5/regional-spotlight-us-caribbean/fracking-wastewater-management.html>).

However, although there are many options being used, the actual safety of wastewater management remains unclear. Furthermore, there is no long term solution for the disposal of salt waste in inland areas, which when not managed well, may threaten the ecological health and productivity of rivers, soil and vegetation (Davies et al., 2015).

## Oil and gas processing

Crude oil and gas flowing directly from wells may contain toxic and equipment-damaging chemicals, such as acids, heavy metals (mercury and arsenic), and volatile organic compounds (such as benzene). These contaminants can be removed through a range of chemical and physical processes, for example by incineration (flaring), biofiltration and adsorption through acid gas treatment. These processes carry significant expense to industry, especially as they require constant application to multiple wells and gas infrastructure in order to be effective.

## Flaring and fugitive emissions

Burning off gas during oil or gas processing is often necessary to relieve well pressure during maintenance, during accidents, and for disposal of volatile organic compounds (Figure 3). However, carbon dioxide, carbon monoxide, nitric oxide, nitrogen dioxide and sulphur dioxide emitted by flaring may result in adverse environmental and health consequences, e.g. contribution to climate change, acid rain and respiratory illnesses. During extraction, processing and distribution of oil or gas, accidents, normal wear and tear and improperly constructed infrastructure all permit direct loss of methane gas into the atmosphere.



**Figure 3. Natural gas flaring**

Source: Photo by Tod Baker, ShareAlike 2.0 Generic (CC BY-SA 2.0); <https://www.flickr.com/photos/todbaker/9148692/in/photostream/>

## 4. Global impacts: Greenhouse Gas Emissions

**Human use of fossil fuels is the primary cause of both global warming and ambient air pollution, resulting from the release of greenhouse gases (carbon dioxide and methane) and other pollutants (particulate matter, nitrogen oxides and other gases) into the atmosphere during mining and combustion (IPCC, 2013; 2018).**

Atmospheric levels of methane, which accounts for an estimated 17– 25% of the increase in the trapping of heat in the atmosphere (causing global warming), have increased steady and substantially in the atmosphere since 2008. Worden and colleagues (2017) have demonstrated that oil and gas production is responsible for between 48% and 75% of the total methane emissions from all human activities, i.e. 12 to 19 of the total 25 terograms (trillion grams) released each year.

These pollutants cause direct and indirect impacts on human health. Climate change caused by increasing atmospheric greenhouse gas concentrations is described by the Lancet Commission on Climate Change and Health as the greatest health threat of the 21<sup>st</sup> Century, with unprecedented implications for human health and well being (Woodward et al., 2014; Watts et al., 2017).

Addressing both global warming and air pollution demands coordinated global efforts to rapidly transition away from the use of fossil fuels. The Paris Agreement emerged from the COP21 United Nations Framework Convention on Climate Change (UNFCCC) in 2015 with commitments from 175 countries to take responsibility for reducing greenhouse gas emissions and assist in limiting global warming to 2 °C, or preferably to 1.5 °C.

At the latest UNFCCC COP24 in December 2018, both the IPCC and the World Health Organisation focused specifically on the health, biodiversity and environmental benefits of limiting warming to 1.5oC. Furthermore, additional emphasis was given to the dual requirement for rapid reductions in both CO<sub>2</sub> and short lived climate pollutants (methane is the most important one) in order to success in controlling global warming. This is because of the high potency, even if comparatively short-lived, of methane, as it trap 86 times more heat energy in the atmosphere than CO<sub>2</sub> over 20 years, warming the atmosphere much more quickly than an equivalent amount of CO<sub>2</sub>.

In order to meet the minimum target limiting to 2 °C of global warming, McGlade and Ekins (2015) estimated that one third of oil reserves, half of gas reserves and over 80 per cent of current coal reserves must remain unused and warned that “any increase in unconventional oil production is incommensurate with efforts to limit average global warming to 2°C”. Seeking a target of 1.5oC in order to protect human health means that far more than half of the known gas and oil reserves will need to be left in the ground.

Despite this clear warning, exploration and exploitation of fossil fuel resources continue unabated and/or are expanding in Australia for both domestic consumption and for generating export revenue. In 2019, there are many reasons to be seriously concerned about the climate change implications of continued reliance on and expansion of gas production for energy purposes. Unfortunately, early claims that using unconventional gas for energy will have positive impacts on greenhouse gas emissions are no longer justified.



**RECOMMENDATION 1:  
Identify and promote actions  
to reduce both carbon  
emissions and air pollution,  
with specific commitments to  
reduce emissions of short-lived  
climate pollutants in Nationally  
Determined Contributions  
(NDCs) to the Paris Agreement.**

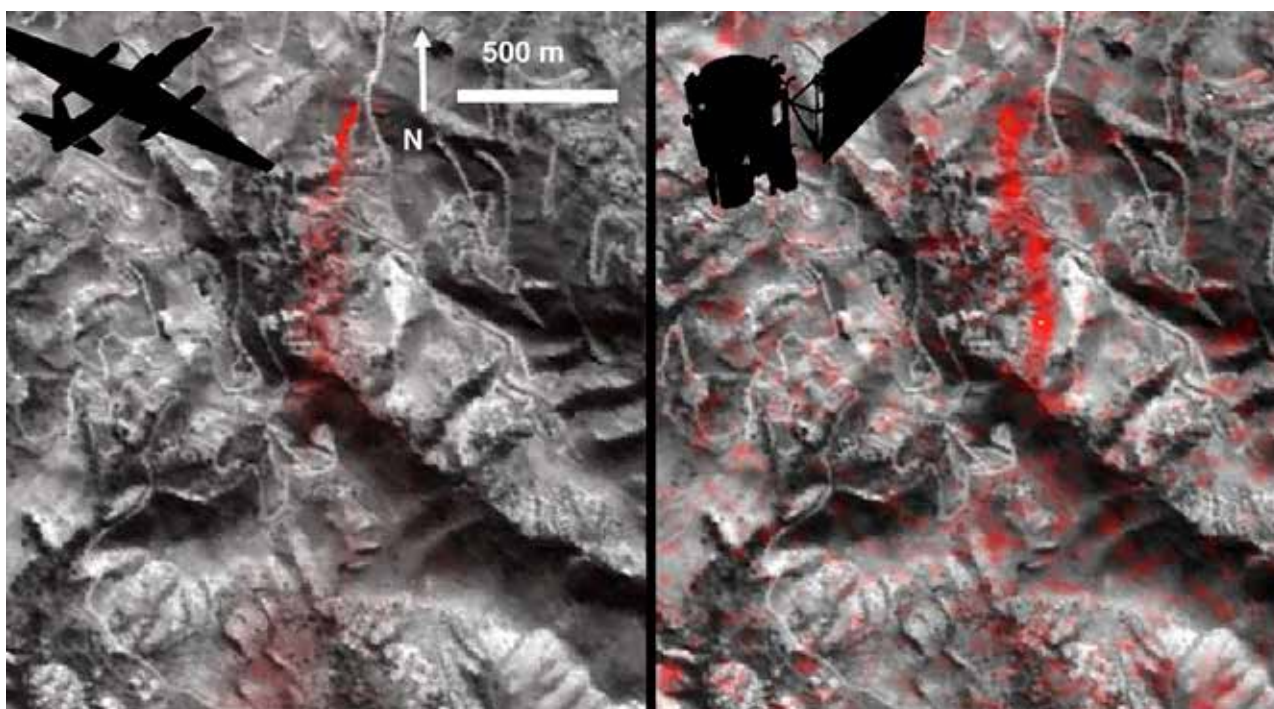
**(WHO COP24 Special Report on  
Health and Climate Change)**

When the entire life cycle of gas production, transportation and combustion is taken into consideration, fugitive (leaking) methane emissions that are not combusted to form CO<sub>2</sub> before release into the atmosphere, means that the claimed climate ‘advantage’ of gas over coal is greatly diminished (Staddon and Depledge, 2015; Voiland, 2016; IEA, 2018).

It is now clear that the impacts of gas emissions have been significantly underestimated for a number of reasons, for example:

- 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.
- Methane’s short-term impact on warming is 86 times more potent than carbon dioxide over 20 years (Voiland, 2016; NASA, 2014; IPCC, 2013; IEA, 2018), which is much more important to consider than the frequently used 100 year average potency of 25 (because it breaks down over time).

- Modelling suggests that abundant supply of natural gas in the United States has competed against, rather than bridged to, renewable energies and delayed urgent transitions to a decarbonized energy system to limit global warming (McJeon et al., 2014; Staddon and Depledge, 2015).
- The enormous impact of accidents involving well blowouts and leakage from methane storage sites, as exemplified by the 2016 Aliso Canyon disaster (Figure 4) and potentially occurring at similar sites in future (Conley et al., 2016).



**Figure 4.** NASA photograph showing for the first time a single point methane leak at Aliso Canyon in June 2016, three days after a major accident which led to the release of an estimated 97,100 metric tons of methane. Left hand side is from aircraft at 6.6 kilometer height, right hand side is a satellite image.

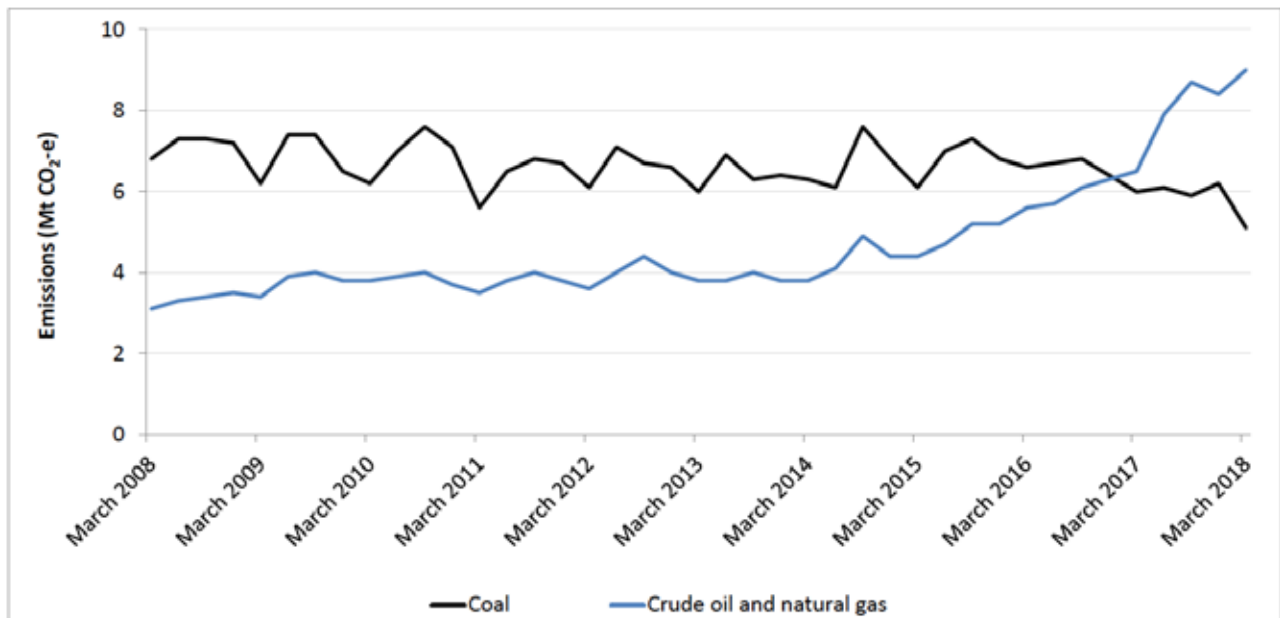
Source: NASA/JPL-Caltech/GSFC; [https://photojournal.jpl.nasa.gov/figures/PIA20716\\_fig1.jpg](https://photojournal.jpl.nasa.gov/figures/PIA20716_fig1.jpg)

Because the world's nations have failed to stabilise and sharply reduce greenhouse gas emissions over the last decade there is insufficient time left for a slow and gradual transition towards decarbonisation of energy supply. Hence even if a switch to gas did provide a significant reduction of CO<sub>2</sub> emissions as claimed, this reduction would not be sufficient to avoid exceedance of the 1.5 or 2° C carbon budget (IPCC, 2018).

The National Pollutant Inventory figures from Queensland, the only Australian state with a well-established unconventional gas mining industry, suggested that Queensland emitted 29% of Australia's total emissions in 2016; with fugitive emissions from gas fields being among the top 5 sources of emissions and steadily increasing by year (Commonwealth of Australia, 2018).

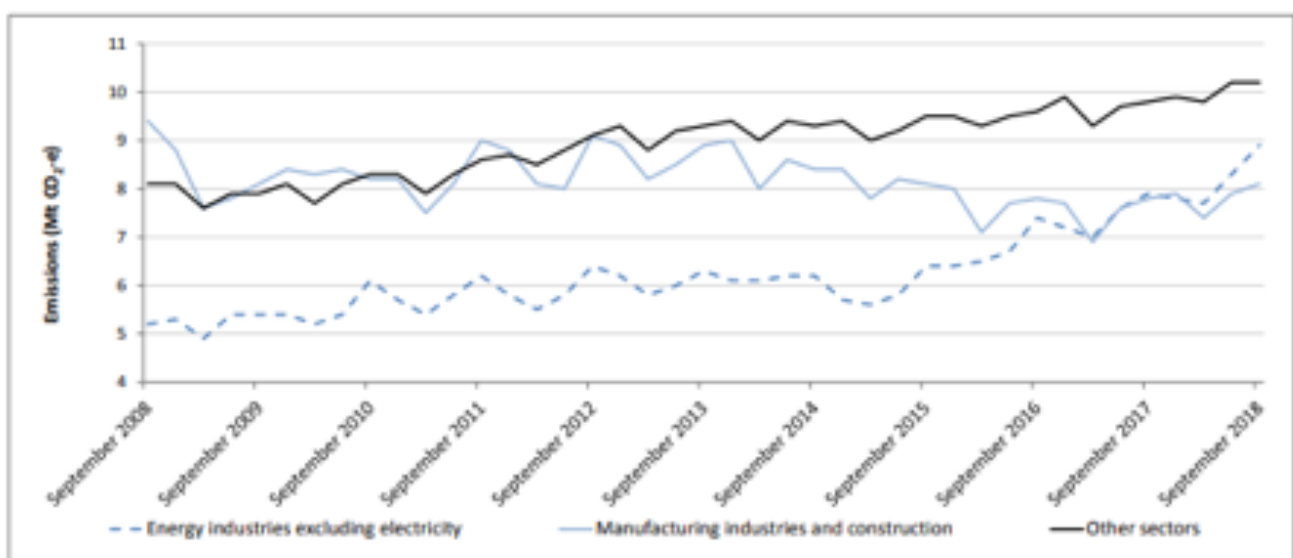
The September 2018 Quarterly report on Australia's National Greenhouse Gas inventory suggested that national fugitive emissions from gas and crude oil production more than doubled in

just four years, from 4 megatons of CO<sub>2</sub> equivalents in 2014 to approximately 9 megatons of CO<sub>2</sub> equivalents in 2018 and surpassing methane emissions from coal mining (Figure 5).



**Figure 5.** Fugitive emissions by quarter, sub-sector, unadjusted and trend emissions, Australia, September 2008 to September 2018.

Source: Department of the Environment and Energy; from the Quarterly Update of Australia's National Greenhouse Gas Inventory: September 2018, Commonwealth of Australia 2018, p 8.

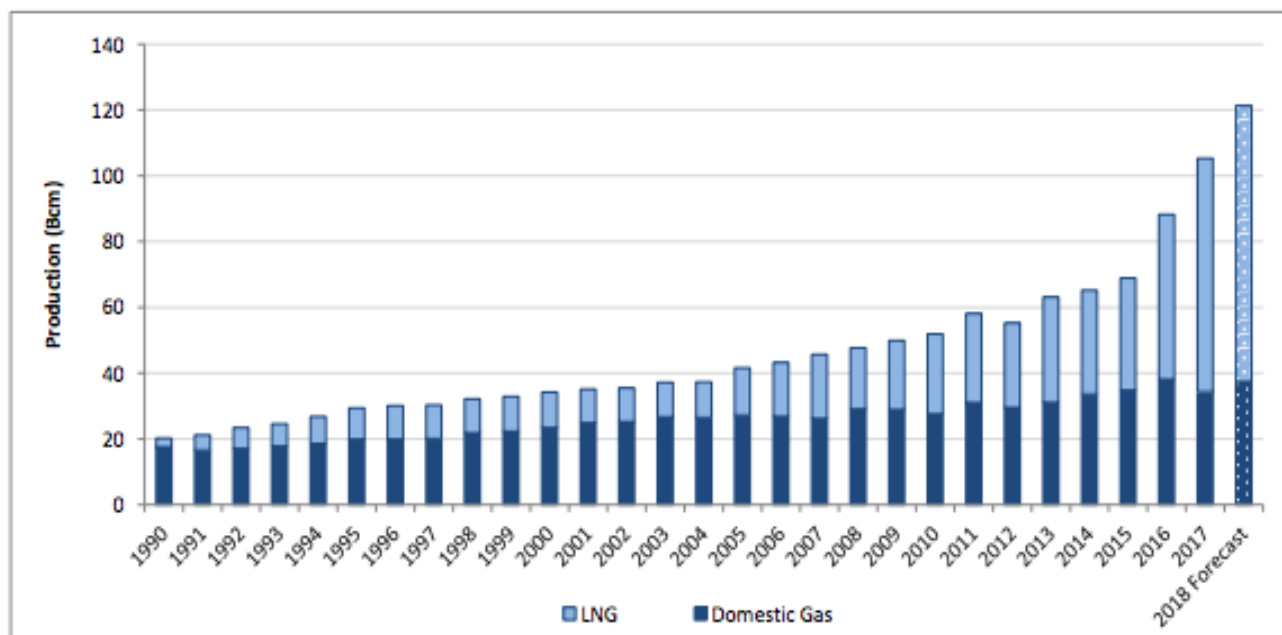


**Figure 6.** Stationary energy excluding electricity by sub-sector, quarterly, 'unadjusted' emissions, Australia, September 2008 to 2018.

Source: Department of the Environment and Energy; from the Quarterly Update of Australia's National Greenhouse Gas Inventory: September 2018, Commonwealth of Australia 2018, p 13.

According to the report “This was driven primarily by an increase of 19.7 per cent in LNG exports in 2018” (*Quarterly Update of Australia’s National Greenhouse Gas Inventory: September 2018, page 13*).

LNG production increases have mainly come from offshore developments in Western Australia, the Northern Territory and from Queensland’s coal seam gas developments, from approximately 25 billion cubic metres in 2014 to about 80 BCM in 2018 (Figure 7).



Sources: Department of Industry and Science (2018), Resources and Energy Quarterly

**Figure 7. Natural gas production, financial years, Australia, 1990 to 2017 and forecast data for 2018.**

Source: Quarterly Update of Australia’s National Greenhouse Gas Inventory: March 2018, Commonwealth of Australia 2018, p 13.

If other states and the Northern Territory pursue extensive shale gas mining industry developments, these upward trends are likely to amplify substantially in future years.

While these figures are concerning enough, they are mainly based only on reports and modelling, not actual measurements. A detailed analysis of potential greenhouse gas emissions from coal seam gas mining conducted by the Melbourne Energy Institute (LaFleur et al., 2016) identified multiple uncertainties

that could potentially yield significantly underestimated emissions figures.

LaFleur et al. (2016) questioned the adoption of a markedly low emissions factor (0.5% of fugitive emissions relative to total gas production), compared to that estimated in multiple studies in the United States suggesting much higher levels (2–17%). The authors highlighted a lack of confirmation by satellite or atmospheric measures and a lack of monitoring of all potential emission points where methane could be leaking in gas field operations.



### Much of Australia's gas production is predominantly geared towards export markets

Extensive monitoring is particularly important because it is known that shale gas mining can create 'super-emitting' points that emit extremely high quantities of methane, which must be identified for accurate measurement (and mitigation). Little is known about the variation in fugitive methane emissions between wells in coal seam gas mining. Furthermore, there is little understanding of potential 'migrating emissions' that may occur at considerable distances away from the well site. The authors stated that "there has been no comprehensive, rigorous and independently-verifiable audit of gas emissions" (Lafleur et al., 2016; p 7).

Another significant concern is that the current abundance of gas on the global market may not be acting as a bridging fuel towards renewable energies, but may instead be competing against the adoption of renewable energies, because of a belief that gas produces substantially fewer emissions than coal.

Like coal however, prices paid for gas do not include the many externalities—costs borne by communities—resulting from environmental loss, climate impacts, health loss and social conflicts and tensions between those gaining and those losing from developments in their midst.

In much of Australia, gas production is predominantly geared towards export markets; and the proportion exported may further increase with pipelines, processing facilities and access to shipping ports. Thus while some states are transitioning to low carbon domestic energy sources, the much larger contribution of Australian gas to the international market may be driving down prices, placing an economic deterrent against other nations' efforts towards decarbonisation and phasing out fossil fuel energy usage, as has been observed in the United States (McJeon et al., 2014; Staddon and Depledge, 2015).


# 5. Local and Regional Environmental and Public Health Risks and Concerns

**The following sections review the evidence regarding potential risks mediated via water, land and air pollution, as well as psychosocial impacts. A comprehensive database, ROGER (Repository of Oil and Gas Energy Research, was used to assist in accessing published papers for this section ([https://www.zotero.org/groups/248773/pse\\_study\\_citation\\_database](https://www.zotero.org/groups/248773/pse_study_citation_database))**

## Chemical Concerns: Overview

Research and assessment of health concerns associated with unconventional gas mining has been dominated by the use of a wide range of chemical additives and materials required for the procedure, plus the large number of naturally occurring chemicals brought to the surface within large quantities of wastewater generated at various stages. Many chemicals of both types have the potential to harm humans and the environment. Where data exists, it is clear that leaks and spills are common events in unconventional gas mining, although a lack of reporting prevents clear estimates of frequency of contamination of land and waters (Considine et al., 2013; Khan and Kordek, 2014; USEPA, 2016).

As of March 2019, 122 peer-reviewed publications on examining flowback and produced wastewater and 48 on chemical additives were listed on the ROGER database; with nearly all pertaining to shale and tight gas operations. Some examined potential impacts on health and are described below.



**...in contrast, there are few published studies on the composition of wastewater derived from coal seam gas mining in Australia or overseas.**

In contrast, there are few published studies on the composition of wastewater derived from coal seam gas mining in Australia or overseas. In Australia, the most significant work thus far has been done by National Industrial Chemicals Notification and Assessment Scheme (NICNAS) and is available here (<https://www.nicnas.gov.au/chemical-information/Topics-of-interest2/subjects/Chemicals-used-for-coal-seam-gas-extraction-in-Australia>; <http://www.environment.gov.au/water/coal-and-coal-seam-gas/national-assessment-chemicals/assessment-reports>).

However, it is important to acknowledge the limitations of this work. For example, only chemical additives (not naturally occurring chemicals present in wastewater) used in coal seam gas mining (not shale or tight gas mining) that were identified voluntarily by the industry (not mandated disclosure) were studied. Furthermore, the assessment focused solely on the (surface) above-ground handling of the chemicals, limiting information on environmentally mediated exposures to workers and communities.

Some findings of this work are discussed below.

## Water Concerns with potential health impacts

Harm to water resources through contamination and/or depletion is often cited as a primary concern in Australia, especially because most developments are planned or occurring in rural agricultural areas (Haswell and Bethmont, 2016).

### Introduced chemicals

Local disposal of produced water, muds or drill-debris, mediates the local dispersal of the chemicals they contain. Many of these have not been assessed for human health safety, while others are known to have detrimental human and/or environmental impacts.

As stated above, there has been very little peer-reviewed research investigating chemicals used in coal seam gas mining in Australia or elsewhere. The Australian government body, NICNAS (2017), conducted an analysis of 113 chemicals used in CSG mining. It is not clear if this represents all chemicals used, or a subsample or voluntarily disclosed chemicals used by companies, and which additional chemicals are now being used that were not in use when the study began.

NICNAS (2017) found that 44 chemicals out of the 113 examined were potentially harmful to workers in the case of exposure during an industrial accident. Twelve were found to have the potential to harm workers during mixing and dilution of highly concentrated chemicals if adequate protection methods were not used.



Flooded coal seam gas site, Nepean River, NSW

Source: Max Phillips

Considering public health, NICNAS identified that 40 chemicals used in CSG mining had the potential to harm the community should people become exposed to the chemical by swimming or drinking water contaminated by spills during transport or leakage from a waste water pond.

Companies are expected to abide by the *Environment Protection and Biodiversity Conservation Act 1999*, as well as state and national regulations and Codes of Practice in the handling and transport of dangerous goods. They are also expected to have emergency preparedness plans and reporting procedures in the event of an accident or leak.

A large number of chemicals are used in the hydraulic fracturing process for shale gas mining that may not have been

examined in the NICNAS study. These include surfactants, acids, bactericides, glycol and many substances not revealed under “commercial in confidence” agreements. In an August 2018 stakeholder update, NICNAS announced its intention to invite companies ‘to apply to protect a chemical’s identity as confidential business information (CBI). If approved we [NICNAS] will mask its identity by using a generic chemical name. These will be known as AICIS approved chemical names (AACNs) once the reforms come into effect’.

Thus it is not clear, as in some States in the United States, whether or not medical practitioners will be able to gain information needed for medical treatment of patients who may have been exposed to specific chemicals.

The greatest occupational health concern identified thus far in the United States for unconventional oil and gas workers is excessive exposure to silica—large quantities of ‘frac sand’ required for hydraulic fracturing (Occupational Safety and Health Administration (OSHA), 2012; Esswein et al., 2013; Esswein et al., 2014).

Independent research on the safety of chemicals used in shale gas exploration in Western Australia, South Australia and the Northern Territory is lacking; with no peer-reviewed publications available. In contrast, American researchers have published at least 49 peer-reviewed papers; many of which raised concerns about the chemicals used in shale gas operations in the United States.

Furthermore, little is published about the chemicals used in conventional gas mining, which does not involve hydraulic fracturing, but does use drilling muds and chemical additives, as well as conferring potential exposure to naturally occurring chemicals in air and wastewater (Balize et al., 2016).

From a human health perspective, there are significant concerns if chemicals enter the air, groundwater or aquifers, and, in the long term, have the potential to affect food and water safety for crops, humans and animals.

## **Naturally occurring chemicals**

There is significant concern about naturally occurring chemicals in the saline wastewater produced in unconventional gas mining (Colborn et al., 2011; Elliot et al., 2017; Vidic et al., 2013; Davies et al., 2015).

Volatile organic compounds, including BTEX (Benzene, Toluene, Ethylene and Xylene), which occur naturally in the shale, and evaporate from the flowback wastewater after fracking may pose health risks, as does the flaring excess gas. Benzene contamination of ground water was a frequent consequence of 77 surface spills that were reported in a 12-month period in a Colorado county with intense shale gas mining activity (Gross et al., 2013).

Polycyclic aromatic hydrocarbons (PAHs), heavy metals and naturally occurring radioactive materials (NORMs) have the potential to damage the health of people who are exposed. Radioactive materials, such as uranium, thorium, radium and their decay products, can be found in unconventional gas wastewater, and are concentrated and brought to the Earth’s surface in extraction and waste disposal process (US EPA, 2018; <https://www.epa.gov/radiation/tenorm-oil-and-gas-production-wastes>). The waste containing these materials is called TENORMS or technologically enhanced naturally occurring radioactive materials. If present at significant levels, workers and nearby residents may be at risk of exposure through air and water (Esswein et al., 2014; Geltman and LeClair, 2018).


A few studies have characterised constituents of wastewater produced during coal seam gas mining (Khan and Kordek, 2014). Untreated produced water contains high levels of sodium and bicarbonate, often with suspended solids, iron, silica and barium (Shaw, 2010; Alley et al., 2011; Khan and Kordek, 2014). Heavy metals, boron, fluoride, organic compounds and ammonia may also be present (Volk et al., 2011).

NICNAS and CSIRO commissioned important laboratory-based leaching experiments using samples from different sources of coal exposed to conditions roughly simulating those of hydraulic fracturing (Apte et al., 2017). Findings for a range of potentially hazardous metals, radioactive materials and organic compounding existing in the coal leachate were then compared where possible with existing water quality benchmarks for aquatic ecosystems and stock watering systems used in Australia. The authors highlighted the following inorganic chemicals released from the coal samples out of a total of 60 identified as priorities for further investigation: aluminium, arsenic, beryllium, boron, cadmium, chromium, cobalt, copper, gallium, lead, manganese, nickel, selenium, silver, thallium, uranium, vanadium, and zinc. Among the organic coal contaminants retrieved were phenols, cresols and low molecular weight total recoverable hydrocarbons. An additional 14 organic chemicals, including alkanes, alcohols, aldehydes and polycyclic aromatic hydrocarbons were also present, but their origin in the coal and/or in the added chemicals is unclear (Apte et al., 2017).

Concentrations of radionuclides, namely radium, thorium and uranium, were deemed below concern. However, the authors pointed out that these materials could potentially be concentrated during procedures, such as in crust formations in pipework, filters and on reverse osmosis membranes used in water treatment (Apte et al., 2017).

Concentrations of many additional chemicals found in the coal leachate, such as barium, could not be assessed due to a lack of guidelines or regulations available for drinking water or aquatic water systems (Apte et al., 2017). The authors called for additional research to extend these findings to actual hydraulic fracturing activities within coal seam gas mining.

Wastewater from both coal seams and shale strata is mildly to extremely saline. Treatment by reverse osmosis or other disposal methods produces enormous quantities of salt, creating a serious environmental hazard for both ecologically significant areas and agricultural regions, impacting on soil fertility (Khan and Kordek, 2014; Davies et al., 2015). Saline leakage from the water handling processes can also mobilise naturally occurring chemicals in soil, such as arsenic and uranium, transporting them into groundwater aquifers. One such incident caused by a leak in a wastewater holding pond liner in Santos' Pilliga Forest CSG operations has been reported (Carey et al., 2014).



**Treatment [of wastewater] by reverse osmosis or other disposal methods produces enormous quantities of salt, creating a serious environmental hazard for both ecologically significant areas and agricultural regions, impacting on soil fertility**

## Interactions between chemicals

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 from hydraulic fracturing. Interactions are not considered in risk assessments because there is still little or no understanding of this complex area. The use of experimental studies in animals and bioanalytical assays is recommended, progressing beyond identification of individual toxicological profiles constituents to better understand the potential negative consequences of exposure to unconventional gas wastewater (Khan and Kordek, 2014).

## Chemicals in wastewater with carcinogenic, neurological, reproductive and developmental toxicity

A study by Elliot et al. (2017b) examined the carcinogenicity data on a total of 1177 chemicals in fracking fluids and wastewater (US EPA) and 143 chemicals identified in scientific papers published before 2016 on air pollutants. 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.

Elliot et al. (2017a) also examined the reproductive and developmental toxicity of 1021 chemicals identified in fracturing fluid, wastewater or both. Information

on toxicity 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.

Evidence of endocrine-disrupting activity in surface and groundwater in areas with unconventional gas mining raises concerns (Kassotis et al., 2014; 2016; 2018). These chemicals can interfere with endocrine function at very low concentrations, sometimes without any overt signs or symptoms.

A systematic review of 45 peer-reviewed publications examined links between conventional gas extraction processes and the presence and potential impacts of endocrine-disrupting activity (Balise et al., 2016). Moderate evidence was found of an increased risk of preterm birth, miscarriage, birth defects, decreased semen quality, and prostate cancer that could result from disruption of the oestrogen, androgen, and progesterone receptors by chemicals associated with (mostly conventional) oil and gas production. The researchers postulated that unconventional gas mining posed more potential risks to reproductive health than conventional gas operations given the many endocrine-disrupting chemicals involved in the hydraulic fracturing process.

No studies have examined potential endocrine-disrupting chemical activity in wastewater from CSG extraction.

Webb et al. (2018) reviewed existing evidence regarding air and water pathways through which infants and children could potentially become exposed to and experience neurological and neurodevelopmental impacts associated with oil and gas mining

emissions. Five chemical groups were identified, including particulate matter, polycyclic aromatic hydrocarbons, volatile organic compounds, endocrine disrupting chemicals and heavy metals.

## Water security

Unconventional gas mining raises concerns for both water quality, as discussed above, and a sufficient and secure supply of water for drinking, food production and other human and ecosystem services (Entrekin et al., 2018; Rosa et al., 2018). Already many areas of the world, including the United States and Australia, face significant water stress, which will worsen as climate change progresses. A global analysis reported that 31–44% of shale deposits are located in areas of the world likely to be affected by water stress; 20% are in areas where groundwater is already depleted and 30% underlie irrigated lands (Rosa et al., 2018).

These authors warned of likely competition between unconventional gas production, food and other human uses of water.

Shale gas mining uses large quantities of water (4 to 24 million litres) in each hydraulic fracturing event (<https://www.appea.com.au/industry-in-depth/technical-information/water/water-volume/>), which can be applied many times per well across hundreds to thousands of wells in an area. Contamination of aquifers and surface waters may also render them unusable for human consumption.

It has recently been discovered that as shale gas and oil mining has expanded in the United States, the amount of water used per well to produce a unit of gas (water-use intensity) increased substantially (Kondash et al., 2018). This was associated with longer lateral drilling distances and increased intensity of hydraulic fracturing that occurred



Sydney Drinking Water Catchment, Nattai

Source: Lock the Gate Alliance

in 2014–2015, simultaneously with a reduction in drilling of new wells as oil and gas prices fell. High intensity production also resulted in an even greater increase in wastewater production per well. Examining water usage records across four shale gas mining regions in the United States, Kondash et al. (2018) reported increased water-use intensity (lower water efficiency) and waste water production across all areas. The increase was as high as 770% in water usage per well and 1440% in wastewater production in the Permian and Eagle Ford Basins, located in semiarid Texas and New Mexico over a five year time period.

These concerns are likely to be applicable to many areas of Australia where coal seam gas and shale gas deposits are found. Water stress is already experienced by local farmers and communities in existing developments in the Darling Downs, Queensland and Narrabri, NSW. Similarly water availability is a pressing challenge for farmers and communities near to proposed sites for exploration and mining in the Northern Territory and Western Australia.

## Evidence of harm to water resources

A seminal report by the U.S. EPA (2016), *“Hydraulic Fracturing for Oil and Gas: Impacts from the Hydraulic Fracturing Water Cycle on Drinking Water Resources”*, was released in December 2016. This long awaited report confirmed 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 has not been demonstrated.

The Executive Summary stated:

*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.

...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.

*"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."*

Experience to date suggests that the same circumstances are present in Australia. RMIT hydrogeologist and geochemist, Dr Matthew Currell, recently highlighted a serious lack of appropriate baseline data and insufficient resources available for monitoring and compliance to ensure that water resources can be sufficiently protected by Santos in their Narrabri operations (State Government Career, 2017: <http://state.governmentcareer.com.au/archived-news/water-warning-issued-for-csg-plans>; 2018: <https://www.smh.com.au/environment/sustainability/shocked-santos-csg-project-omissions-stoke-opponents-concerns-20180710-p4zqnk.html>). Currell provided detailed recommendations in a public

submission to the NT Hydraulic Fracturing Inquiry (<https://frackinginquiry.nt.gov.au/?a=424238>).

## Further unknowns and uncertainties regarding water

At times, '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, as fully demonstrated by Kondash et al. (2018) and discussed above, the wellheads may not be placed in optimal positions for the location of the 'sweet spots' of gas in each direction. This has meant longer distance drilling, and larger water requirements, greater pressures for hydraulic fracturing and greatly enhanced volumes of wastewater requiring safe handling. Effects can also occur at considerable distance from drilling, and can be difficult to trace back to the source of disruption.

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 are 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. There has been little research on these issues.

## Impacts on land use and food security concerns

Contamination of soils and competition for land use carries significant human health risks, especially when considering cumulative impacts of hundreds of wells over decades.

As stated by Haswell and Bethmont (2016), the link between food safety and security and unconventional gas has received less research interest, but 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., 2015; IPCC, 2013). These concerns were highlighted in exceptionally drought-stricken California in 2015 where some farmers irrigated crops with unconventional oil wastewater with unknown consequences (Freyman, 2014).

The long-term safety of insufficiently 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, 2015). Furthermore, irrigation of crops with saline wastewater can also mobilise heavy metals already present in the soil, such as cadmium and uranium (McLaughlin et al., 1994).

Negotiations between water and energy sectors face conflicting views and



Sorghum fields Spring Ridge, Liverpool Plains, NSW

Source: Max Phillips

complexity, increasing with climate change and population growth (Hussey et al., 2013). Prospects for successful coexistence between farming and gas mining are further challenged by roads and mining infrastructure on agricultural land, pollution risks, livestock disturbance and economic uncertainties surrounding unconventional gas mining (Freyman, 2014; Bamberger and Oswald, 2015; Hussey et al., 2013; Chen and Randall, 2013).

## Air Emissions with potential direct health impacts

### Potential Exposure pathways

Chemicals reach the atmosphere from flaring (Figure 3), venting, holding tanks, ponds, compressors and other infrastructure. 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 and Hays, 2013; Brown et al., 2014).

Residents living near gas wells and infrastructure and industry workers may be exposed to air-borne pollutants directly, e.g. through diesel exhaust from extensive truck movements, drilling, compressors and other machinery used in the process, flaring 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 and Murphy, 2014). Some gases form secondary atmospheric 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.

### Airborne chemicals of health concern

Webb et al. (2014) detailed the 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)

People living near unconventional and conventional gas operations may be at elevated risk of exposure to organic compounds (like benzene), poly-aromatic hydrocarbons, heavy metals and radioactive materials in the air as well as

water. These can affect the respiratory, endocrine, nervous and cardiovascular systems, and some have the potential to cause cancer, at sufficient levels of exposure (Colborn et al., 2011; Agencies for Toxic Substances and Disease Register, 2007; McKenzie et al., 2012).

Endocrine disrupting chemicals associated with the industry may also be airborne (Lloyd-Smith and Senjen, 2011). Bolden and colleagues (2018) reviewed 48 air quality studies associated with shale gas mining and identified 106 chemicals with endocrine disruption potential, including estrogenic and androgenic activity, chemicals capable of altering steroid formation.

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, potentially capable of causing exacerbations of asthma among residents.

Communities close to unconventional gas operations can experience a major increase in heavy vehicle traffic. This brings a loss of amenity, increased risk of traffic accidents among workers (Retzer et al., 2013) and residents (Graham et al., 2015; Blair et al 2017) and increased exposure to diesel engine exhaust (McCawley, 2017). Diesel exhaust from trucks and heavy machinery contains particulate matter, nitrogen oxides and volatile organic compounds and is classified as a Group 1 carcinogen by the International Agency for Research on Cancer (IARC, 2014). 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 (OSHA, 2012; Esswein et al., 2013).

## Studies measuring health risks and impacts associated with residence near gas wells

### Risk assessments and health studies

Many studies are now underway in the US to measure concentrations of potentially harmful chemicals in ambient air and water, assess likely levels of exposure to children and adults living in nearby communities to estimate their potential to cause or contribute to disease and compare disease frequencies among those close to and further from gas mining operations (McKenzie et al., 2012; Elliot et al., 2017a,b).

An evaluation of potential impacts 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 in over 7500 assessments. These authors concluded that there was no evidence that any of the assessed 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, particularly those with neurological, haematological and respiratory 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 prevalence for 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 the community of Tara in the Darling Downs region of Queensland, have anecdotally reported similar symptoms, as well as headaches, nosebleeds and numbness and tingling sensations (McCarron 2013; McCarron and King, 2014).

While no spatial community-level health studies have been done in Australia, there have been two limited single time-point studies. One by Queensland Health (2013) with low community participation and few reports of physical symptoms at a one-day clinic, 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 General Practitioner, Dr Geralyn McCarron (2013). While their results on the prevalence of physical symptoms were conflicting, the findings of both studies support 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).

**...in the Darling Downs, where increasingly extensive unconventional gas mining and production of coal seam gas has occurred to date, substantial rises in hospitalisation rates of... acute circulatory and... acute respiratory conditions between 2007 and 2014 [have been reported]...**

Also in the Darling Downs, Queensland, where increasingly extensive unconventional gas mining and production of coal seam gas has occurred to date, McCarron (2018) reported substantial rises in hospitalisation rates of 133% for acute circulatory and 142% rises in acute respiratory conditions between 2007 and 2014. Annual analysis of hospitalisations demonstrated that the rates were largely constant between 2007 and 2009, then climbed steeply from 2010 onwards; simultaneously with sharp rises in gas production and accompanying annual atmospheric emissions of nitrogen oxides, volatile organic compounds, PM2.5 and PM10, formaldehyde and sulphur dioxides that were reported by the companies and published in the National Pollutant Inventory. There is an urgent need to further investigate these coincidental increases in hospitalisations and pollution emissions (McCarron, 2018).

A further step examining temporality between air quality and symptoms was conducted in the US by Macey et al. (2014) in four US states with substantial oil and gas production. 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 identify 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 modelled predictions (Petron et al., 2012; Brown et al., 2014, NASA, 2014).

Workers 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).

Public health studies on unconventional gas mining are gaining in maturity and rigour, and each year brings new understandings (see reviews by Werner et al., 2015; Saunders et al., 2016; Hays and Shonkoff, 2016; Haswell and Bethmont, 2016). These studies collectively address the challenges on how to measure complex risks, assess impacts and

respond to knowledge from studies of human health.

Studies attempting to measure health impacts of the industry remain relatively few but are increasing, and are mostly limited to physical health consequences. To summarise, 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:

- Hospitalisations—for cardiological and neurological disorders and for those with existing asthma conditions (emergency department visits, inpatient stays) and for cancers, genitourinary presentations (kidney and urinary tract infections and urinary stones) and immune related diseases (Rasmussen et al., 2016; Jemielita et al., 2015; Werner et al., 2017; Whitworth et al., 2018; Denham et al., 2019).
- 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; Tustin et al., 2016).
- Sexually transmitted infections—increased incidence rates of chlamydia and gonorrhoea infections which are associated with changes in sexual behaviour that can be associated with mobile workers coming in to depressed areas (Mabey and Mayaud, 1997; Komarek and Cseg, 2017; Deziel et al., 2018).



Infants and children continue to face higher risks compared to adults from toxic exposures

## Special Risks to fetuses, infants and children

Of particular concern among research findings are studies that have identified developmental problems during pregnancy and infancy—lower birth weight, small for gestational age, higher frequency of preterm (especially severely pre-term) births and specific birth defects (Ma et al., 2016; Casey et al., 2016; McKenzie et al., 2014; Stacy et al., 2015; Currie et al., 2017; Whitworth et al., 2018; Hill et al., 2018).

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 (PM<sub>2.5</sub>) on birth weight and preterm births, as well as drugs on brain development. Many of the chemicals involved in unconventional gas mining have potential reproductive and developmental toxicity (Webb et al., 2014; 2016; Elliot et al., 2017a; 2017b).

Confirming previous studies suggesting an association between birth weight and exposure to unconventional gas mining

mentioned above, Currie et al. (2017) found a 25% increased risk of low birth weight infants among mothers living within 1 km of a hydraulically fractured well, and smaller but detectable elevated risks at 2 and 3 kilometres distance. Using these findings, it was estimated that 29,000 infants born in the United States each year were at increased risk of low birth weight; which has significant implications for their subsequent health.

Detailed studies by Hill (2018) controlled for a wide range of relevant maternal and geographical characteristics and examined birth weight outcomes of infants of mothers living within and beyond 2.5km of one or more shale gas wells in Pennsylvania. This work revealed a 7% increase in the frequency of low birth weights, a 5g reduction in the average full term birthweight and a 3% increase in preterm births for each well located closer than 2.5km. This affect was only observed for residence near active wells during gestation.

Further work has indicated that unconventional gas mining is also associated with increased risk and severity of preterm birth, especially when exposures to mining activity occurs in the first trimester of pregnancy (Whitworth et al., 2018).

A regional study involving 124,832 infants in Colorado 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 in this study.

Infants and children continue to face higher risks compared to adults from

toxic exposures after birth 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 exposure to toxins in the environment through outdoor play activities. Conversely it is also concerning if children do not feel safe to play outside, as lack of physical activity is also associated with poorer physical and mental health. It is very important to recognise that infant and child wellbeing is highly sensitive to psychosocial and community stressors, including noise, heavy traffic, negative emotions expressed by others and witnessing aggression and conflict (discussed below), and, potentially, fear of pollution.

Higher rates of childhood hematologic cancers among children living close to oil and gas developments compared to areas without such developments have been observed in areas producing shale gas in the United States (McKenzie et al; 2017). Similarly, higher hospitalisation rates for children with neoplasms (9% higher [95% CI 2–16%]) and blood/immune diseases (14% higher [95% CI 2–27%]) were reported by Werner et al. (2016) in the coal seam gas mining areas of the Darling Downs, Queensland compared to a rural agricultural area without coal or coal seam gas mining. Age-specific comparisons of hospitalisation rates revealed that living within areas with coal seam gas mining activity was associated with significant increases in hospitalisations for respiratory diseases among very young (0–4 years) and 10–14 year old children (ranging from 7–11% higher) and a 467% increase in blood/immune diseases among 5–9 year olds, when compared with children

in areas without coal seam gas mining activity (Werner et al., 2018).

Children living in areas where shale gas mining activities were introduced (by zip code) were found to experience a 25% increase in hospitalisations due to asthma (Odds ratio 1.25 (1.07–1.47)) within 3 months after commencement. In contrast, children living in comparison areas without of drilling activity did not experience a change in asthma hospitalisations (Willis et al., 2018).

Studies of longer-term impacts, such as cancers and chronic disease, are extremely limited to date because insufficient time has elapsed since commencement of potential widespread exposure to gas activities.

In summary, the relatively small literature specifically examining potentially harmful exposures to air- and water-borne pollutants and stressors associated with unconventional gas mining for foetuses, infants and children is consistently building evidence of significant concern in both the United States and Australia.

## **Social and mental health impacts**

There are many avenues through which the unconventional gas industry can harm mental health and individual and community wellbeing (Hossain et al., 2013; Ferrar et al., 2013; Powers et al., 2014; Kriesky, 2012; Morgan et al., 2016; NSW Parliament, 2012; Sangaramoorthy et al., 2017; Lai et al., 2017; Fisher et al., 2018; Hirsch et al., 2018). Prior to commencement, impacts may include distress, anxiety, fear of the unknown and social disharmony due to disagreements that split the community into those who

support the industry and those who oppose it (Moffatt and Baker, 2013; Hirsch et al., 2018). In the ‘boom’ phase tight-knit communities can feel inundated with strangers coming in, burdening health and other services (Hossain et al., 2013; Hirsch et al., 2018). Crime may also increase (Bartik et al., 2017; James and Smith, 2017). Such impacts are detrimental to the social cohesion and for some, the moral character, of the community (Moffatt and Baker, 2013; Sangaramoorthy et al., 2017; Lai et al., 2017; Fisher et al., 2018). In the post-construction phase, jobs may decline and housing demand drops. Production continues, 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, anger, powerless and loss of peace and a feeling of being trapped and unable to escape (Lai et al., 2017; Sangaramoorthy et al., 2017; Hirsch et al., 2018). All the phases may exacerbate the risk of depression and anxiety and suicidal ideation (Moffatt and Baker 2013; Morgan et al., 2016; Hirsch et al., 2018).

While the ‘boom’ phase may appear to bring positive social change, impacts on residents are uneven and most feel 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). Disturbance of place attachment as a result of unconventional

gas development may contribute to loss of wellbeing (Lai et al., 2017; Sangaramoorthy et al., 2017).

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.

A recent study by Casey et al. (2018) found a strong positive association between symptoms of depression and living in close proximity to greater numbers of unconventional gas wells in Pennsylvania.

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) found that concerns about CSG mining contributed to overall stress burdens and odds of experiencing depression and anxiety, especially among 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 unconventional gas mining and underground coal gasification

on his farmland for over 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. Doctors for the Environment Australia's submission to this inquiry can be found here ([https://www.dea.org.au/wp-content/uploads/Select\\_Committee\\_on\\_UG\\_Mining\\_Submission\\_03-16.pdf](https://www.dea.org.au/wp-content/uploads/Select_Committee_on_UG_Mining_Submission_03-16.pdf))

There are particularly important concerns when considering the potential psychosocial and spiritual impacts of unconventional gas mining on Aboriginal people and communities. Aboriginal people are highly overrepresented in the rural and remote areas where most developments are proposed, especially in the Northern Territory and Western Australia. Aboriginal people already experience substantially higher burden of morbidity, hospitalisation and mortality from the negative health conditions associated with exposure to unconventional gas mining, such as higher prevalence and severity of heart and respiratory tract conditions (including asthma and chronic obstructive airway disease), low birth weight, some cancers, mental health illnesses and traffic accidents. The environmental health conditions that Aboriginal people living remotely experience are often substandard, and water supplies difficult to monitor and maintain. While there are no specific research publications to date, a submission to the draft Final Report of the Scientific Inquiry into Hydraulic Fracturing in the Northern Territory by the Aboriginal Medical Services Alliance NT (AMSANT, 2018) concluded,

*"imposing fracking against the wishes of large sections of the Aboriginal community is likely to worsen health and wellbeing through increased community discord, and heightened levels of depression and anxiety with subsequent effects on physical health and wellbeing. Aboriginal health is connected to the health of the land and water- so threatening the physical environment directly affects Aboriginal wellbeing. Aboriginal people already suffer unacceptable rates of mental health issues and chronic disease. The benefits in terms of employment are likely to be limited and short term. AMSANT considers fracking to be an unacceptable risk to the health and wellbeing of Aboriginal people in the NT with the risks clearly outweighing the benefits".*

## **Inadequate and unproven regulatory framework**

For adequate protection of health and the environment, 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 operationalized, 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 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.

It should be noted that while fugitive emissions can be reduced during production, the processes are not cost effective for industries without a carbon pricing mechanism in place, and therefore continual legislation and monitoring is required to ensure compliance.

Furthermore, the Physicians for Social Responsibility and Concerned Health Professionals of New York (2015) 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".

Little has been published regarding the effectiveness of regulatory frameworks in Australia. This is despite significant reference to the ability of regulation to mitigate the many environmental, health and wellbeing concerns raised by the industry. For example, the Scientific Inquiry into Hydraulic Fracturing of Onshore Unconventional Reservoirs in the Northern Territory released in March 2018 concluded that, although there were significant risks and concerns associated with the industry, the application of 134 recommendations was deemed to be sufficient to ensure safety.

Even if risk elimination 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 depends on the commitment of future government leadership to place the protection of human health above that of industry demands, where conflicts exist.

## Interpreting these Studies

Understanding uncertainty in causative association—what adds strength to health studies?

There are many challenges hampering the ability to establish that gas mining is the cause of the higher frequencies of health problems associated with living close to mining activities (Werner et al., 2015). While many studies have demonstrated associations between unconventional gas activity and adverse outcomes, further research is necessary to provide more direct causal evidence of effects. For example the link between tobacco smoking and lung cancer took many years to be established. However, despite these difficulties, evidence is accruing, as studies are increasingly demonstrating for example:

- Dose-dependence—Many studies demonstrate higher frequencies of problems among those with higher likely exposure (closer distance to wells, higher densities of wells, more intense gas production);
- Time relationship—Many studies show that the detected increases in health problems began only after commencement of industry activities in the areas;
- Associations are still evident after considering 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.
- Plausibility—There are logical links between the health problems being experienced and the kinds of chemicals used based on their known properties and distressing experiences associated with living near industry operations;

## 6. Views of Professional Health Organisations

### 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 probably assume that the government would take preventive action would be taken in the face of uncertainty; that proponents of a proposed activity, rather than the community, are required to demonstrate its safety; that governments will explore a wide range of alternatives to possibly harmful actions; and that the government would encourage public participation in decision making (Kriebel et al., 2001).**

However, the unconventional gas boom has been described 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 (Bamberger and Oswald, 2012). Finkel and Hays (2013) provide 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 has 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 and *measured effectiveness* of harm reduction based on actual experience—and not on theoretical solutions that have not been demonstrated.

Many Australian public health and medical organisations including Doctors for the Environment Australia, the Public Health Association of Australia, the Climate and Health Alliance and the National Toxics Network, collectively representing many doctors, public health practitioners, and allied health professionals, have expressed serious concern about the lack of evidence of safety to human health.

Doctors for the Environment Australia (<https://www.dea.org.au/wp-content/uploads/2016/06/DEA-Position-Statement-Unconventional-and-Coal-Seam-Gas-Development-April-2015.pdf>) joins the Union of Concerned Scientists ([https://www.ucsusa.org/sites/default/files/legacy/assets/documents/clean\\_energy/climate-risks-natural-gas.pdf](https://www.ucsusa.org/sites/default/files/legacy/assets/documents/clean_energy/climate-risks-natural-gas.pdf)) and many other health and medical organisations, in concluding that actions taken to prolong the continued use of gas as an energy source, such as continued exploration, production of any new gas resources and the new development and expansion of unconventional gas

operations, pose unacceptable risks to the climate and hence, human health and wellbeing.

In its submission on the draft Final Report of The Scientific Inquiry into Hydraulic Fracturing in the Northern Territory, the Aboriginal Medical Service of the NT (AMSANT, 2018) emphasised that when uncertain risks are involved, “the choice of action should be the result of a participatory process” and unbiased information about the risks must be publicly available. AMSANT (2018) stated:

*There is also a critical distinction between being consulted and being able to engage and make one's views heard, especially when there is such a critical power imbalance between disadvantaged, impoverished populations and dominant economically and politically backed mining lobby groups and governments, particularly when, as pointed out by the report, the regulatory mechanisms are inadequate.*



DEA is a professional organisation of doctors and medical students—  
here meeting in Melbourne April 2017

In submissions to the NSW Chief Scientist and Engineer's examination of the public health and safety of coal seam gas mining in 2013 and in subsequent government submissions and communications, these groups, as well as the Australian Medical Association, have publically called for application of the Wingspread Declaration on the Precautionary Principle. This can be summarized as: *'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).

Coram, Blashki and Moss (2013) reviewed the comparatively small body of evidence that had accumulated at the time and argued, *"The uncertainty over the health implications of unconventional gas is greater than that surrounding any other energy choice, and suggests that adopting an attitude of precaution—such as that employed with the introduction of a new drug—is justified on the basis of health risks alone"*. The research conducted since that time has only added evidence of harm, not evidence of safety.

In her paper entitled, "Regulating Coal Seam Gas in Queensland: Lessons in an Adaptive Environmental Management Approach", Dr Nicola Swayne, cautioned: *"Most significantly, a truly adaptive environmental management approach must be able to embrace the hard decisions that go with "learning by doing" including the ultimate decision of ceasing CSG activities in Queensland in the face of significant information gaps and/or an unacceptably high risk of cumulative adverse impacts"*.

The British Medical Journal (2015) 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"*.

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, 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.*

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

# 7. Conclusion

**This paper has provided an extensive review of the evidence on the complex array of potential direct and indirect impacts on human health and wellbeing associated with the rapidly expanding gas and oil mining industries.**

While evidence is growing of wide ranging and serious risks to many basic environmental determinants of health (clean and secure supply of water, air and food), arguably the most important implication of continuing and expanding gas mining in Australia and globally is its carbon footprint. Substantial research has highlighted the gas industries' major contribution to fugitive methane and CO<sub>2</sub> emissions during clearing, exploration, production, storage, transportation and combustion with special concern regarding major accidents and poorly understood super-emitting wells. In Australia where there is no price on carbon, and no external auditing of gas emissions, it can be presumed that efforts to legislate, monitor and enforce will be difficult to commence and even more difficult, if not impossible, to sustain, with little optimism for success.

We conclude that for this reason alone, widespread development of new gas resources is a very dangerous gamble that humans should not be subjected to.

The accumulating evidence in other areas indicates that the many predictable concerns about, and impacts associated with, unconventional oil and gas mining are not only well founded, but also being increasingly measured and reported from various locations in the United States, Australia and elsewhere. These concerns include the wide range of potentially harmful chemicals being used which require transport, dilution and application; the large and increasing quantities of water used for gas extraction; the even

larger volumes of waste water produced which contains both introduced chemicals and those brought to the surface and into the atmosphere; stress experienced by many directly affected; the disruption of community life from social changes and loss of physical amenity; and alarming contributions to increased greenhouse gas emissions at this crucial time.

This review has reported research, which has helped characterise these risks, identify the potential avenues of entry of chemicals into the environment and of human exposure, and quantify increasing rates of symptoms and exacerbations of illnesses. Particularly concerning to health and medical professionals and affected communities are associations found in many studies between living close to gas operations and increased hospitalisation for a range of serious health problems, increased stresses impacting on physical, social and mental wellbeing, and increased risk of poorer birth outcomes.

We conclude that the safety of gas and oil mining to the environment and to people is not confirmed by current research. While no study is wholly conclusive on its own, when the evidence is considered comprehensively, it becomes clear that the industry places significant risks to the health of people, especially developing fetuses and babies, and to the environmental determinants of health (climate, water and food security) on which we depend.

The limitations of this work include the possibility that some research findings may have been missed, that study quality was not individually assessed, and that the economic impacts of the industry, which may have influenced health and wellbeing, were not considered. It is considered

likely that socioeconomic status will have advanced for some people, and declined for others, especially in Australia where landholders do not own the rights to underground minerals.

From these findings, we broadly recommend that in the short term, existing and already developed gas reserves should be used judiciously to assist in the rapid transition away from coal and gas fired power stations towards clean energy resources, i.e. wind, solar, hydroelectric energy where existing and agricultural biomass energy for extenuating circumstances.

However, as clearly demonstrated in the most recent Intergovernmental Panel on Climate Change report (IPCC, 2018) report, if we are to limit global warming to 1.5°C or even 2°C, the use of gas should curtail as quickly as possible, allowing renewable energies take over the powering of Australia and the world. To participate appropriately in this global urgency, Australia should urgently assist developing countries to transition away from gas power, instead of developing an industry that would continue to supply vast quantities of gas on the world market.

We point out that the cost and feasibility of such transitions has been repeatedly demonstrated through research across the world, including Australia (Diessendorf and Elliston, 2018; Brown et al., 2018; Institute for Energy Economics and Financial Analysis, 2018). Political will is a critical requirement. We urge the Australian government to take the necessary steps to lead Australia away from fossil fuel production and into a clean energy future that can support the health and well being of current and future generations all over the world.

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# Appendix

## Unconventional gas mining Doctors for the Environment Australia submissions to Governments 2011–2018

Independent Scientific Panel Inquiry into Hydraulic Fracture Stimulation in Western Australia 2018

March 2018

<https://www.dea.org.au/wp-content/uploads/2018/03/Inquiry-into-Hydraulic-Fracture-Stimulation-in-Western-Australia-2017-Submission-03-18.pdf>

Scientific Inquiry into Hydraulic Fracturing in the Northern Territory in Response to the Draft Final Report 2018

February 2018

<https://www.dea.org.au/wp-content/uploads/2018/02/Scientific-Inquiry-into-Hydraulic-Fracturing-in-the-NT-02-18.pdf>

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

October 2017

<https://www.dea.org.au/wp-content/uploads/2017/10/Supplementary-Submission-to-the-Scientific-Inquiry-into-Hydraulic-Fracturing-in-the-NT-10-17.pdf>

Narrabri Gas Project

May 2017

<https://www.dea.org.au/wp-content/uploads/2017/05/Narrabri-Gas-Project-Submission-Final-05-17.pdf>

Scientific Inquiry into Hydraulic Fracturing in the Northern Territory

April 2017

<https://www.dea.org.au/wp-content/uploads/2017/04/Scientific-Inquiry-into-Hydraulic-Fracturing-in-the-NT-Submission-04-17.pdf>

Jemena Northern Gas Pipeline EIS

October 2016

<https://www.dea.org.au/wp-content/uploads/2017/02/Jemena-Northern-Gas-Pipeline-EIS-submission-10-16.pdf>

Inquiry into Hydraulic Fracturing of Unconventional reservoirs onshore within the NT 2016 (ToR)

October 2016

[https://www.dea.org.au/wp-content/uploads/2016/10/NT\\_Inquiry\\_into\\_Hydraulic\\_Fracturing\\_of\\_Unconventional\\_Reservoirs\\_submission\\_10-16.pdf](https://www.dea.org.au/wp-content/uploads/2016/10/NT_Inquiry_into_Hydraulic_Fracturing_of_Unconventional_Reservoirs_submission_10-16.pdf)

Select Committee on Unconventional Gas Mining

March 2016

[https://www.dea.org.au/wp-content/uploads/Select\\_Committee\\_on\\_UG\\_Mining\\_Submission\\_03-16.pdf](https://www.dea.org.au/wp-content/uploads/Select_Committee_on_UG_Mining_Submission_03-16.pdf)

Inquiry into Unconventional Gas in Victoria

July 2015

<https://www.dea.org.au/wp-content/uploads/2017/04/Unconventional-Gas-VIC-submission-07-15.pdf>

Inquiry into Unconventional Gas (Fracking)—South Australia

January 2015

<https://www.dea.org.au/wp-content/uploads/2017/02/Inquiry-into-Unconventional-Gas-SA-01-15.pdf>

Review of Hydraulic Fracturing (Fracking) in Tasmania

December 2014

<https://www.dea.org.au/wp-content/uploads/2017/04/Review-of-Hydraulic-Fracturing-Fracking-in-Tasmania-12-14.pdf>

Certain Aspects of Queensland Government Administration related to Commonwealth Government Affairs

November 2014

<https://www.dea.org.au/wp-content/uploads/2017/03/Certain-Aspects-of-QLD-Government-Administration-Submission-11-14.pdf>

Presentation to the Planning and Assessment Commission regarding the Narrabri Coal Seam Gas Mining Project Australia

June 2014

<https://www.ipcn.nsw.gov.au/resources/pac/media/files/pac/projects/2014/05/dewhurst-gas-exploration-and-pilot-expansion-project-ssd6038/public-meeting--presentations-tabled/42-dr-melissa-haswell--doctors-for-the-environmentpdf.pdf>

Hydraulic Fracturing Inquiry Northern Territory Submission

May 2014

<https://www.dea.org.au/wp-content/uploads/2017/04/DEA-Hydraulic-fracturing-in-NT-inquiry-final.pdf>

Implications for Western Australia of Hydraulic Fracturing for Unconventional Gas

September 2013

<https://www.dea.org.au/wp-content/uploads/2017/04/WA-Inquiry-into-Hydraulic-Fracturing-UG-Submission-09-13.pdf>

Amendments to the NSW State Environmental Policy Plan (SEPP) on Mining, Petroleum Products and Extractive Industries Amendment (Resource Significance) 2013

August 2013

[http://dea.org.au/images/uploads/submissions/NSW\\_Mining\\_SEPP\\_Submission\\_08-13\\_.pdf](http://dea.org.au/images/uploads/submissions/NSW_Mining_SEPP_Submission_08-13_.pdf)

Draft significant impact guidelines: Coal seam gas and large coal mining developments—impacts on water resources

July 2013

[http://dea.org.au/images/uploads/submissions/CSG\\_and\\_large\\_coal\\_mining\\_impacts\\_on\\_water\\_resources\\_submission\\_07-13.pdf](http://dea.org.au/images/uploads/submissions/CSG_and_large_coal_mining_impacts_on_water_resources_submission_07-13.pdf)

NSW Government Planning Review—White Paper

June 2013

[http://dea.org.au/images/uploads/submissions/NSW\\_Planning\\_Review\\_White\\_Paper\\_submission\\_06-13.pdf](http://dea.org.au/images/uploads/submissions/NSW_Planning_Review_White_Paper_submission_06-13.pdf)

Management of the Murray Darling Basin—impact of mining coal seam gas

June 2011

[https://www.dea.org.au/wp-content/uploads/2017/05/MDB\\_CSG\\_Senate\\_submission\\_June\\_2011.pdf](https://www.dea.org.au/wp-content/uploads/2017/05/MDB_CSG_Senate_submission_June_2011.pdf)



THE IMPLICATIONS FOR HUMAN HEALTH AND WELLBEING OF EXPANDING GAS MINING IN AUSTRALIA