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Is fracking good for your health?

An analysis of the impacts of unconventional gas on health and climate

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TAI

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Synopsis

It's becoming increasingly clear that Australia needs to change the way it uses energy and many of those changes will be taking place over the next decade.

Our current reliance on coal is unsustainable, while Australia's considerable reserves of unconventional gas - tight, shale and coal seam gas (CSG) - are raising controversy after being flagged as part of a major expansion of the gas industry.

This report assesses existing research to address the question of whether unconventional gas should be endorsed as a major future energy source, based on its impacts on human health and the climate.

There is considerable lack of information and uncertainty around the health impacts of unconventional gas extraction. However, the potential health impacts associated with fracking chemicals used for extracting unconventional gas are serious. They include cancer, skin and eye irritation, respiratory problems, damage to the nervous system, cells and blood, endocrine disruption and reproductive problems.

The effects of climate change are likely to exacerbate certain health risks and the vulnerability of certain groups including the elderly, rural and indigenous communities, as well as future generations.

This report also considers the risks associated with water contamination caused by the fracking process and wastewater. It ranks the risks associated with wastewater as 'high', with the chemicals it contains found to be toxic. It sights cases in the US where wastewater accidents have affected livestock and soil tests showed high levels of materials which can be toxic to humans.

Australia has just been advised by the Climate Change Authority to boost efforts to cut greenhouse gas emissions, yet this paper finds that an expanded unconventional gas industry would be responsible for substantial levels of emissions. It is even possible that unconventional gas offers no climate benefits over coal. Gas also compares poorly to alternatives such as wind and solar.

Australia's role as a major exporter of gas also raises serious questions regarding our accountability for emissions in export countries and the effect of exports on markets for renewable energy. Given that the World Health Organisation has estimated that climate change is already responsible for over 150,000 deaths per year, this arguably creates a heavy moral burden for Australia. There are also serious doubts about the financial benefits gas exports will deliver everyday Australians.

This report finds that unconventional gas should not be endorsed from an environmental and human health perspective and states that the current case against further expansion of the industry is overwhelming.

Taking into account the evidence that exists for the health and climate impacts of unconventional gas, this does not represent the best option for Australia's energy future, either as a stepping-stone or a final destination.

Key findings

- Unconventional gas—CSG, shale gas and tight gas—is slated to play a major role in the expansion of Australia's gas industry, with the majority of future production to be exported. This expansion will be associated with climate and health effects that need careful consideration.
- There is substantial uncertainty over health impacts, with a noted lack of information, especially in relation to the nascent Australian shale gas industry.
- While the risk of water contamination by fracturing fluids cannot be dismissed, risks from wastewater are more concerning. Wastewater contains both fracturing fluids and naturally occurring contaminants, with many reported spills and accidents here and overseas.
- Risk pathways from air pollution, water use, soil degradation, and social impacts also exist. Land and water use are especially important pathways in Australia, with resource conflict already evident, and resources likely to be compromised for future generations.
- The proposed expansion of the industry will be responsible for substantial levels of GHG emissions, especially in comparison to viable alternatives.
- Uncertainty over the levels and impact of fugitive emissions make it unclear whether unconventional gas offers any climate benefits over coal, particularly given the climate impacts of methane are concentrated in a 20-year period—a critical time frame for serious effects of global warming.
- Australia arguably has a moral burden from the emissions caused by exported gas. Unconventional gas is also likely to displace renewables both in Australia and in export markets.
- The current state of knowledge does not offer reason for endorsing unconventional gas from the perspective of the environment or human health
- The evidence indicates a better path is a reduction in the use of such potentially harmful technologies and materials in favour of the demonstrably less harmful alternatives that are available.

Executive summary

Australia is facing a crucial decade for energy choices. It is increasingly clear that our current reliance on coal is unsustainable from the perspective of both climate and human health, while Australia's considerable reserves of unconventional gas—tight, shale and coal seam gas (CSG)—are poised to play a central role in a major expansion of the gas industry over the coming decades. However, while unconventional gas has been promoted as a relatively clean, safe, accessible and affordable energy source, the industry has attracted substantial criticism internationally, with critics highlighting the potential for serious health and environmental harms. It is then essential to address the question of whether unconventional gas can be endorsed on the basis of its impact on human and climate health.

The term 'unconventional gas' refers to types of gas that cannot be accessed using conventional vertical drilling methods. In Australia, the most commonly occurring are CSG and shale gas. CSG is kept trapped in coal seams by water pressure, while shale gas is found in fractures in organic-rich, low permeability shale reservoirs. Unconventional gas has only recently become a commercially viable energy source with the development of techniques such as horizontal drilling and hydraulic fracturing (fracking). Not all coal seams require fracking—only about 10% of current wells are fracked, with this figure estimated to rise to 30-40%[1]—whereas nearly all shale reservoirs require fracking.

A review of the international literature demonstrates the need for more objective research, especially regarding Australia's nascent shale gas industry. The shale gas industry in the US is more advanced than the unconventional gas industry in Australia and subsequently there is more data available regarding exposures and health outcomes in this context. However it is widely acknowledged that there are many gaps in our present knowledge, including reliable information on fugitive emissions, the industry's impacts on land and water, and the likely health outcomes from contamination events. The nature of exposures and the complexity of the pathways also means it is often is difficult to demonstrate direct causal links or predict long-term outcomes.

Despite these issues, it is possible to draw some conclusions based on existing evidence, and to highlight areas where the uncertainty over health and climate impacts is most problematic for making good decisions for Australia's future.

Concerns over the health implications of hydraulic fracturing recently led to over 100 medical practitioners requesting that the Obama administration halt construction of new LNG terminals on the basis that "[t]here is a growing body of evidence that unconventional natural gas extraction from shale (also known as 'fracking') may be associated with adverse health risks through exposure to polluted air, water, and soil".[2] There is substantial uncertainty regarding the human health implications of unconventional gas extraction, however there are many exposure pathways and known health hazards including the possibility of water contamination from fracturing chemicals and wastewater; air pollution; and decreased soil quality. Although there is a lack of clear evidence linking some exposures directly to negative health outcomes, there is an emerging consensus regarding the areas of most concern.

The potential for water contamination by the fluids used in fracking has been at the forefront of public debate. Approximately 18,500 kg of additives are injected in fracking one CSG well in Australia, with potential health impacts associated with fracking chemicals including cancer, skin and eye irritation, respiratory problems, damage to the nervous system, cells and blood, endocrine disruption and reproductive problems.[3] There are several areas of concern regarding pathways in unconventional gas developments including direct contamination, and contamination by stranded fluids and abandoned wells, although there is little by way of concrete evidence. However, while these risks cannot be dismissed, evidence suggests that naturally occurring contaminants such as heavy metals and naturally occurring radioactive materials (NORMs) in wastewater pose greater hazards, with wastewater treated and released in Australia found to contain boron, silver, chlorine, copper, cadmium, cyanide and zinc.[4] Additionally, the airborne pollutants associated with unconventional gas developments have serious health implications, especially if future developments in Australia take place in more densely populated areas. While levels of many such pollutants are lower than found in coal operations, evidence increasingly indicates that they can have effects at the population level in even very small quantities.

Along with direct implications for health, the environmental and social impacts of unconventional gas extraction can have indirect health effects. The potential economic and social benefits of these developments are questionable, and disruption of social cohesion and psychological impacts from social change are likely. This is especially true of Australian operations making use of fly-in-fly-out (FIFO) workers.[5]

Resource conflict between the gas industry and other industries over access to land and water, impacts on biodiversity, and long-term soil and water health are also likely to have implications for food security and environmental health. Modelling such impacts, especially over the long-term, is complex, but the potential impacts are more serious than many other energy sources, and especially salient in Australia given its heavy reliance on agricultural production.

While substantial uncertainty remains, it is clear that what amounts in some cases to an absence of concrete evidence of health harm cannot be interpreted as evidence that these risks do not exist. There is enough evidence for exposures from accidents and data on exposure levels to call into question the safety of the industry, and the potential health harms could be serious, far-reaching and possibly irreversible.

When making decisions that will affect future generations, careful attention needs to be paid to the broader picture, including long-term risks from abandoned wells, the cumulative nature of pollution, and how contaminants will interact with other future sources of contamination. The effects of climate change are likely exacerbate certain risks and the vulnerability of certain groups. The groups that are most likely to shoulder the burden of disease from such operations are the elderly and the young, rural and indigenous communities, and future generations.

The long-term implications make the impact of unconventional gas on climate health a particular concern. The climate impact of unconventional gas remains controversial, due to disagreement over levels of fugitive emissions; the global warming potential (GWP) of methane; and the most appropriate time period to be considered. The perception that gas is less damaging than coal is largely based on emissions from combustion, which are approximately half those of coal. However, levels of fugitive emissions and other non-combustion emissions from unconventional gas extraction can drive this figure up substantially, with several estimations suggesting it does not offer any, or only minor, benefits over coal in the short-term.[6,7] Furthermore, the comparison with coal obscures the high levels of greenhouse gas (GHG) emissions from unconventional gas in absolute terms, which are not sustainable under recent estimates of the world's carbon budget, as well as the fact these emissions are vastly higher than those accompanying renewable energy.

Australia's role as a major exporter of gas also raises serious questions regarding our accountability for emissions in export countries and the effect of exports on markets for renewable energy. Given that the WHO has estimated that climate change is already responsible for over 150,000 deaths per year[8], this arguably creates a heavy moral burden for Australia.

It is clear that any potential climate and health harms need to be taken into account in relation to the proposed benefits of the industry and alternatives available. It has been claimed that further exploitation of unconventional gas will improve access to a reliable and affordable source of energy, deliver downstream health benefits from reduced GHG emissions compared to current energy sources, and economic benefits to the nation and the local communities. However, many of these claims can be disputed. Gas exports are set to force gas prices up, a number of reports on the GHG impact of fugitive emissions have underlined the unsustainability of any form of fossil fuel from a climate perspective, and the need to reduce global reliance on fossil fuels may also mean that the industry is investing in stranded assets. The comparative framework employed also alters the perception of these benefits, with many only visible in comparison with coal. Gas compares poorly to alternatives such as wind and solar on almost all measurements. The technical and economic feasibility of a zero-carbon future for Australia has been demonstrated[9], making this a viable alternative against which the performance of unconventional gas needs to be measured.

Taking into account the evidence that exists for the health and climate impacts of unconventional gas, this does not represent the best option for Australia's energy future, either as a stepping-stone or a final destination.

1. Introduction

If the world is to avoid dangerous climate change, global GHG emissions need to be kept within an allowable "carbon budget" that equates to the amount of emissions that can be released into the atmosphere without exceeding a 2 degree temperature "guardrail". One of the ways to achieve this is to switch to less emissions intensive fuels. Gas has often been touted as a fuel that will allow us to safely make the transition to a low carbon future. Globally, gas produces just over 20% of energy supply, with unconventional gas (shale, tight and coal seam gas) poised to play a substantial role in projected future increases.[10] Australia's extensive reserves of unconventional gas put it at the forefront of this gas boom and will cement its role as one of the world's major gas exporters, with Australian LNG exports predicted to reach 70% of our production by 2035, on track to make us the 3rd largest gas exporter in the world.[11]

While the industry is committed to a substantial increase in its size, the development of unconventional gas reserves remains highly controversial. Concerns have been raised over the potential health harms wrought by hydraulic fracturing; the environmental impacts of unconventional gas extraction; and the possibility that the climate impact of fugitive emissions undermines its potential to reduce greenhouse gas emissions relative to coal. There are also important issues regarding social justice and the distribution of health burdens. At the same time as CSG extraction and the exploration of shale gas continues apace in Australia, the practice of hydraulic fracturing has been banned in countries including France and Bulgaria due to concerns over its impact on human and environmental health.[12]

The purpose of this report is twofold. The main aim is to provide an overview of the existing literature on the health impacts of unconventional gas in the form of a narrative summary based on a systematic review of available international literature. Secondly, it aims to review the claims concerning the supposedly relatively low emissions profile of unconventional gas. This is not a comprehensive analysis of all aspects of the unconventional gas industry: in particular, it does not consider the economic consequences in depth. The aim is to provide a clear picture of the current state of knowledge on some of its most significant impacts in order to be in a position to evaluate the claim that unconventional gas can play the role of providing a safe, clean energy choice for Australia. Given the scale of some of the proposed developments of unconventional gas reserves in Australia, providing an accurate assessment of the known or likely climate and health impacts is an important part of a thorough response to this issue.

The paper is structured as follows. Following an overview of unconventional gas operations in Australia and a brief summary of evidence, in section 3 we will argue that on current evidence there remains uncertainty over the likely health impacts of unconventional gas developments, however there is evidence for exposures to a range of health risks through water, air, soil and social and psychological pathways that warrant serious concern. In section 4, we will argue that unconventional gas is responsible for substantial GHG emissions in absolute terms, and there is considerable uncertainty over how much less GHG is produced by unconventional gas when compared to the emissions profile of coal. When the evidence for health and climate impacts are both taken into consideration, the case for expanding unconventional gas production is weak.

2. Overview of impacts of unconventional gas in Australia

2.1 Unconventional gas in Australia

Australia has considerable reserves of unconventional gas, especially CSG and shale gas. In total, Australia's estimated shale and CSG reserves total nearly four times the amount of conventional gas resources. Total resources of CSG are estimated at 258,888 petajoules (PJ).[13] While exploration for shale gas is less developed, it has been estimated that Australia has total reserves of approximately 435,600PJ.[11,13] In total, Australia's estimated shale and coal seam reserves total 694,488PJ, compared to economic, sub-economic and inferred conventional gas resources of 184,000PJ (see Table 1 below).[14]

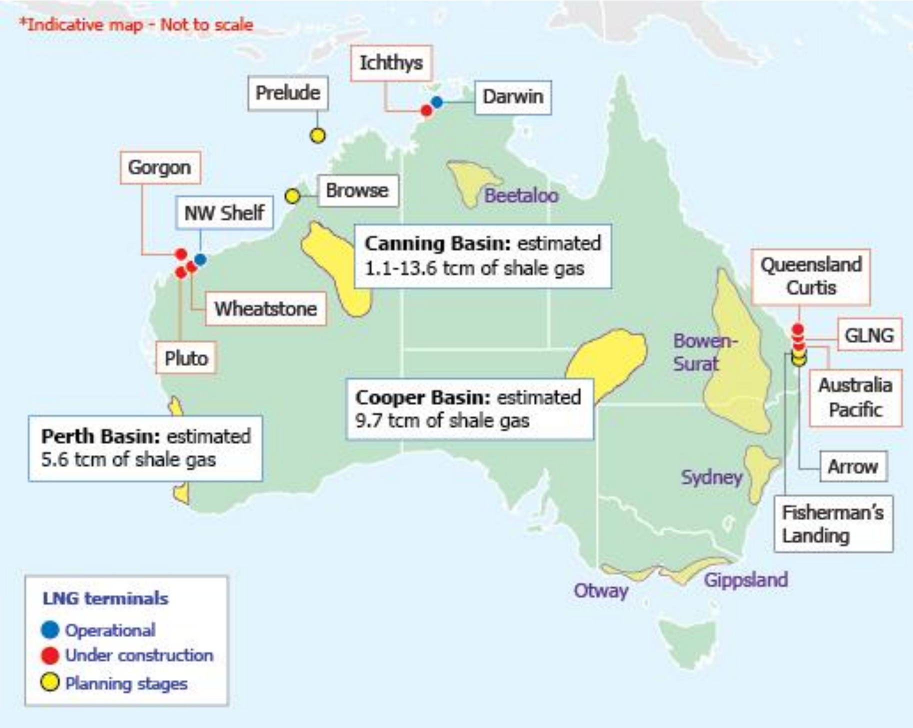
Currently, 437 million hectares of land—over half the land mass of Australia—is under some form of gas or coal licence.[15] CSG production has risen from about 2% of gas production in 2002-03 to 12% in 2011-12.[16] Most existing CSG operations are in Queensland and NSW, with explorations also underway in other states. Shale gas operations already exist in the Cooper Basin, and explorations are proposed or underway in the Perth, Canning and Beetaloo Basins[14] (see Figures 1 and 2 below).

Table 1: Australia's gas resources.

Resource category	Conventional gas (PJ)	Coal seam gas (PJ)	Tight gas (PJ)	Shale gas (PJ)	Total gas (PJ)
EDR	113,400	35,905	-	-	149,305
SDR	59,600	65,529	-	2,200	127,329
Inferred	~11,000	122,020	22,052	-	155,072
All identified resources	184,000	223,454		2,200	431,706
Potential in-ground resources	Unknown	258,888	Unknown	435,600	694,488
Resources identified, potential and undiscovered	184,000	258,888	22,052	435,600	900,540

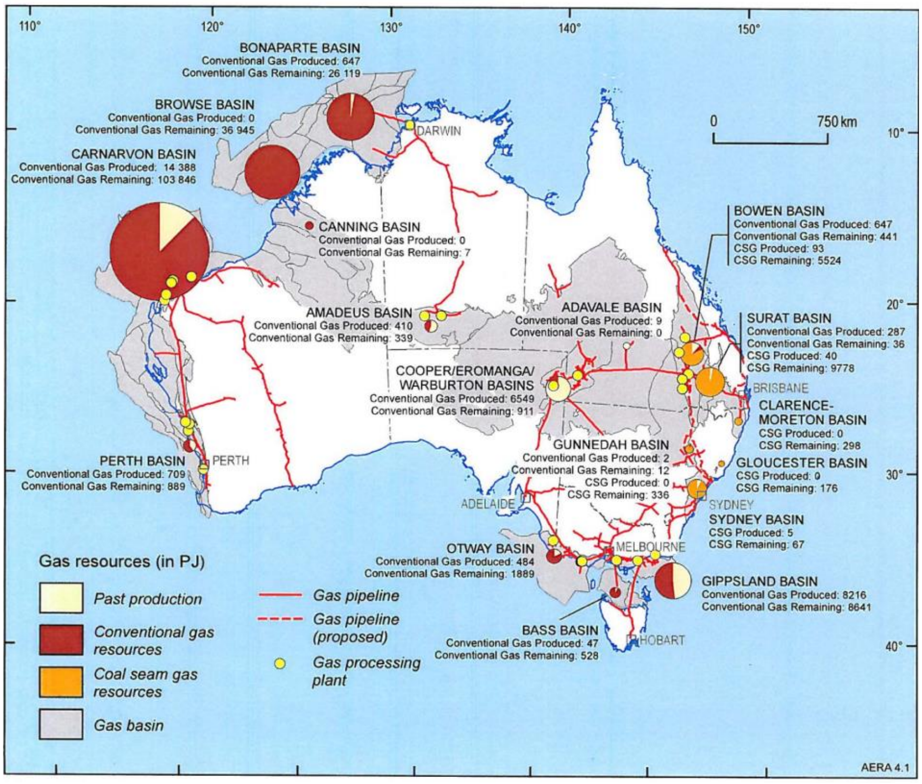
Source: Australian Gas Resources Assessment 2012; Geoscience Australia

Figure 1: Shale gas reserves.



Source: Interfax energy

Figure 2: Coal seam and conventional gas resources.

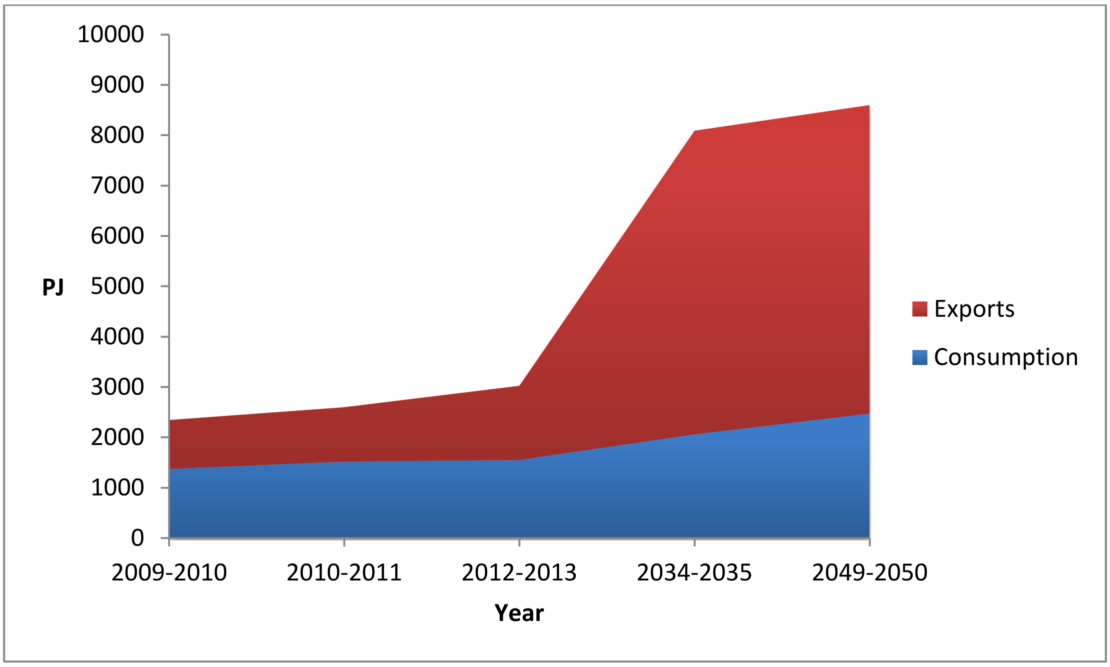


Source: Geosciences Australia

Australia currently exports 24 million tonnes of LNG, which is expected to more than triple by 2035[11] (see Figure 3 below). Currently, Australia is the world's fourth largest gas exporter, with projected increases expected to see it become the third largest exporter by 2035.

While the gas industry has stated that it was responsible for an estimated 150,000 new jobs in 2012[17], according to the ABS the mining industry *as a whole* directly employed 217,100 people in May 2011 or approximately 1.9% population, of which only 12,600 were employed in the oil and gas industry. In addition, over 80% of the oil and gas sector is foreign owned.[18] These figures call into question the direct benefits that the industry has for those living and working in Australia.

Figure 3: Outlook to 2050 for the Australian Gas market.



Data source: Bureau of Resources and Energy Economics 2011, 2012

2.2 Comparisons with US operations

There is substantially more information about the potential environmental and health implications of unconventional gas in the US than Australia. These findings cannot be directly translated to the Australian context as potential health and environmental outcomes are dependent on the details of individual operations—for example, weather patterns, density of well pads, proximity to areas of high population, and the nature of fracture formations.

There are several differences between CSG and shale operations that make direct comparisons of the industries problematic. In general, CSG drilling is considerably shallower, requires less fracturing and less water to fracture with, and the gas produced requires less processing. Some risks—in particular, the possibility of cross-contamination of aquifers—are higher with CSG, while shale gas is riskier for pathways connected to water use, the complexity of the chemicals required, and venting and flaring.[19] Shale gas wells also have a greater decline rate than CSG, leading to greater production costs.

In addition, shale gas reservoirs in the US and Australia have some important differences, such as the way in which they fracture (which might make operations more straightforward in Australia) and the organic matter and minerals they contain. More infrastructure is likely to be required in Australia, and many of these operations are likely to use fly-in-fly-out (FIFO) workforces.

Despite these differences, literature on US gas operations can provide important insights into the potential health and environmental harms from unconventional gas extraction generally.

2.3 Evidence for health and climate impacts

It is widely acknowledged that there is currently not enough evidence to conduct comprehensive health impact assessments of unconventional gas facilities, in large part due to a lack of data such as base-line pollution levels, and there is substantial disagreement about the levels of GHG emissions from these operations. However, an extensive review of the international literature enables some clear conclusions to be reached about the potential health and climate implications of unconventional gas extraction. The following subsections provide an overview of the evidence relating to health and climate impacts.

2.3.1 Health

There are many exposure pathways in unconventional gas extraction with potential impacts on health (see Table 2 below). While there is a scarcity of clear evidence regarding these risks and many remaining areas of uncertainty, there is some emerging consensus regarding the highest risk pathways and health hazards. Section 3 provides an overview of the evidence regarding water, air, land and social and psychological pathways.

Although the potential pollution of aquifers by fracturing fluids has been at the forefront of public debate and this risk cannot be dismissed, the evidence suggests that naturally occurring contaminants pose greater hazards to health. Heavy metals, naturally occurring radioactive materials (NORMs) and salts require a more sustained focus, especially in regards to Australia's nascent shale industry. Additionally, airborne methane has serious health implications, especially if future developments take place in more densely populated areas, with evidence increasingly indicating there is no 'safe' level of pollutants such as nitrous oxide (NOx), sulfur dioxide (SO_2), volatile organic compounds (VOCs) and particulate matter (PM) at the population level.[20,21]

Along with direct implications for health, environmental impacts of unconventional gas extraction can have indirect health effects. Land and water use and impacts on biodiversity can have implications for food security and environmental health. Modelling such impacts, especially over the long-term, is complex, but the potential impacts are more serious than many other energy sources. These also need to be considered against a background of potential climate change that may exacerbate certain risks.

The broader picture—including long-term risks from abandoned wells, the cumulative nature of pollution, and how contaminants will interact with other future sources of contamination and the effects of climate change[22] –has not received the attention it requires, with vulnerable groups such as the elderly and the young; rural and indigenous communities; and future generations likely to shoulder the majority of the burden.

The gas industry has highlighted the potential economic and social benefits of gas developments, however many of these are questionable, and negative effects on social cohesion and psychological impacts from social change are also likely. While any such effects are highly dependent on the nature of the individual operations, Australia's use of fly-in-fly-out (FIFO) workers in particular has raised concerns.[5]

The high degree of uncertainty makes an assessment of likely health outcomes difficult, especially in the absence of details about particular operations. Some of these uncertainties are the result of a lack of data, while others are intrinsic to the risk pathways themselves. However, it is clear that what amounts to an absence of concrete evidence for harm in some cases cannot be interpreted as evidence that these risks do not exist. Even when the relevant risks are low, the potential effects could be far-reaching and potentially irreversible.

Table 2: Summary of risk pathways, health exposures and evidence

Pathways	Exposures and health risks	Evidence
Water • contamination by fracturing fluids • cross-contamination of aquifers • wastewater • water use	Many potential health implications from chemicals Naturally occurring contaminants (heavy metals, NORMs) Degraded water quality Resource conflict	Direct contamination low risk, but unknowns regarding stranded fluids and abandoned wells. Lack of information about chemicals through relevant pathways and at low levels. Wastewater risks high, with several risk pathways and known health effects of contaminants.
Air • Airborne fracturing and drilling pollutants • Pollutants from infrastructure and transport • Airborne proppants and radioactive materials	Ground level ozone, NOx, SOx, diesel fumes, smog, silica, radon, methane, airborne fracturing chemicals.	Lower levels of several pollutants than coal production, but evidence from the US indicates severely compromised air quality. Even low levels of many pollutants associated with health impacts at population level. Methane is an explosive risk at relatively low levels. Silicosis a risk for workers
Land • Soil degradation • Food health • Biodiversity	Erosion, subsistence, soil contamination, food contamination, habitat fragmentation, increased fire risk.	Resource conflict already an issue. High levels of impact on biodiversity likely. Food contamination scares have already had impact.
Social & psychological • Conflict • Community disruption • Lack of decision-making • Visual amenity • Noise	Mental health, community well-being	Difficult to gauge impacts, though social disruption likely and FIFO workers associated with negative social outcomes. Little information on noise.

2.3.2 Climate

The perception of gas as relatively less damaging to the climate is largely based on the fact that gas fuelled power plants release approximately 40% less carbon dioxide (CO_2) emissions than coal powered stations, depending on the technology used.[23] However, this relatively clean reputation has been bought into question by reports on the GHG impact of fugitive emissions.[6,7,24] Furthermore, using coal—which is known for its high environmental burden— as a benchmark in such debates does not provide a clear comparative picture.

Section 4 considers the GHG emissions from unconventional gas as reported in a variety of sources, their comparison to other forms of energy and their relation to global and national carbon budgets. The climate impact of unconventional gas remains controversial, due to disagreement over figures for fugitive emissions (with estimates ranging from 0.1% – 9% of production), the Global Warming Potential (GWP) of methane, and the most appropriate time period to be considered. Under several estimations, unconventional gas does not offer any benefit over coal, especially in the short-term where the high GWP of methane raises the possibility of severe and irreversible damage.[25] Australia's role as a major exporter of gas also raises serious questions regarding our accountability for the combustion technologies that are employed in export countries and the effect of exports on markets for renewable energy.

The current status of knowledge suggests that unconventional gas cannot be simply assumed to be a cleaner alternative to coal, and highlights its poor climate profile compared to renewable energy.

2.3.3 Potential benefits of unconventional gas

There are numerous benefits that have been claimed for unconventional gas, many of which can impact on health. These include claims that it will improve access to a reliable and affordable form of energy, downstream health benefits from reduced GHG emissions compared to current energy sources, the comparatively few emissions of PM compared to coal, and economic benefits to the nation and the immediate community.

However, many of these claims have been disputed. It is highly likely that increasing gas exports will force gas prices up[26], and a number of reports on the GHG impact of fugitive emissions have called the relatively climate-friendly profile of the industry into question. The number of jobs generated by the industry appears to be substantially overstated, and a considerable majority of resources are foreign-owned.[18] The comparative framework used substantially alters the perception of these benefits, with many disappearing in relation to other viable energy alternatives.

2.3.4 Comparative assessment of unconventional gas and other energy sources

Any meaningful discussion of the impacts of unconventional gas extraction needs to consider the way in which these compare with the health and environmental consequences of other forms of energy production.

The commonplace use of coal or oil as a point of comparison[27,28] is based on the implicit assumption that any form of energy generation that reduces the negative effects on climate, health and the environment that result from the status quo should be considered a benefit. However, this can obscure the significantly lower risks represented by viable alternatives. It is technically possible for Australia's energy needs to be met using renewable technology[9], suggesting that this should be taken as a benchmark against which to measure costs to the environment and human health. In all reports identified that considered the health and environmental externalities from energy sources, gas performed worse than renewables.

2.4 The role of unconventional gas in Australia's energy future

While the debate over unconventional gas has been marked by conflicting information and a lack of clarity about the real risks and hazards, an overview of the available literature indicates the areas of greatest concern and those where more information is required. This puts us in a position to answer the question: *does unconventional gas represent a safe, clean energy option for Australia's future?* In particular, we can assess whether unconventional gas can be endorsed from the perspective of climate and human health.

Taking into consideration the current evidence that exists for the climate, health and environmental implications of unconventional gas extraction, the risks and uncertainties are of serious concern and clearly leave gas well behind other alternatives to coal. While some risks can be mitigated by the adoption of best practice models and industry regulation, there are at present too many unknowns and too many likely pathways of harm to claim that unconventional gas represents a safe, clean energy source. Pursuing this industry also risks 'technological lock-in', making it difficult to extract ourselves from commitments to gas and potentially threatening the emerging renewables market, both domestically and internationally. Furthermore, claimed benefits such as access to cheap and reliable energy are questionable.

It is clear that the evidence allows for the distinct possibility that unconventional gas extraction represents substantial hazards to health and well-being, and the burden of proof lies with its proponents to concretely establish claims for its safety for human and climate health. While some possible exposure pathways are low risk, the potential outcomes are serious and far-reaching. When taken in a broader context that includes economic costs, GHG emissions and the availability of other energy options, this firmly tips the scales against an endorsement of unconventional gas.

Summary Section 2: Overview

Unconventional gas—CSG, shale gas and tight gas—is slated to play a major role in Australia's considerable gas industry expansion, with the majority of future production to be exported

- *The proposed expansion of the industry will be responsible for substantial levels of GHG, especially when compared to viable alternatives such as wind and solar*
- *Uncertainty over the levels and impact of fugitive emissions make it unclear whether unconventional gas offers any climate benefits over coal*
- *There is substantial uncertainty over health impacts, with a noted lack of information, especially in relation to the nascent Australian shale gas industry.*
- *Potential risks from wastewater and long-term environmental hazards are particularly concerning, and risk pathways from air pollution, water use, soil degradation, and social impacts also exist*
- *Although beyond the scope of this report, many other proposed benefits of the industry are questionable*
- *The current state of knowledge does not offer reason for endorsing unconventional gas from the perspective of the environment or human health.*

3. Health implications of unconventional gas

The controversy over unconventional gas extraction, and in particular hydraulic fracturing, has largely been a response to its health implications. A strong protest movement has arisen in the US and Australia, highlighting concerns over the chemicals used in fracturing fluids, the potential for water pollution, and a lack of community consultation. At the same time, industry bodies have expressed frustration at what they claim is 'fear-mongering' and have pointed to the lack of strong evidence clearly connecting fracturing to negative health outcomes.

This section of the report looks at the evidence available for the health implications of unconventional gas extraction, reflecting a concern with both epidemiological and social determinants models of health. The pathways considered are *water, air, land* and *social/psychological* pathways, with the general risks from fracturing and drilling fluids considered briefly first.

There are high degrees of uncertainty accompanying the exposure risks from unconventional gas extraction, and these are magnified when considering questions about the likely health outcomes from such exposures. The complex pathways and confounding factors makes the establishment of direct, clear causal links unlikely, however there is an emerging consensus over the risks of most concern.[29]

Even where risks appear low, the possibility that unconventional gas extraction could cause considerable health harm cannot be entirely mitigated against given the potential role of human error. In addition, there are several unknowns concerning long-term implications and the interaction between risks and the impacts of climate change. The burden of proof lies with proponents of unconventional gas to provide concrete evidence for its safety, and this is far from established. All of these factors suggest that unconventional gas cannot be endorsed from the perspective of human and environmental health.

3.1 Drilling and fracturing chemicals

While concrete evidence for harms caused directly by drilling and fracturing chemicals is scarce, there is currently not enough information to endorse their safety in the context of unconventional gas extraction. While chemicals only make up a small percentage of fracturing fluids, the volume of fluids used (especially in shale fracturing) means that the quantities injected are not insignificant. The drilling of gas wells also uses chemicals that can pose health risks, with the potential for these chemicals to be "equally, if not more dangerous" than fracturing fluids.[30]

3.1.1 Identifying hydraulic fracturing chemicals

Most fracturing fluids are 90-99% water, although other base fluids can be used. Additives used include proppants (to prop open the fractures), antibacterial agents, stabilisers, lubricants, surfactants and materials to otherwise make the process more efficient. Not all listed chemicals will be used in all fracturing operations. Although these only make up 1-10% of fracturing fluids, the volumes used mean that this can total approximately 18,500 kg of additives per frack per well.[3]

The most comprehensive report on chemicals used in the US is the 2011 Committee on Energy and Commerce report[31], with a similar list produced for the Endocrine Disruption Exchange (TEDX) database.[32] In Australia, a report for the National Toxics Network (NTN - an NGO advocacy group) reviewed the Material Safety Data Sheets (MSDSs) provided by CSG companies to create a general list of chemicals used (see Table 3 below), and also identified further chemicals from a spill in Queensland.[3]

Table 3: Chemicals used in fracturing fluids in Australia.

Additive Type	Main Compound(s)	Purpose
Diluted Acid	Hydrochloric acid, muriatic acid	Dissolves minerals
Biocides	Glutaraldehyde, tetrakis hydoxymethyl phosphonium sulfate	Eliminates bacteria in water that produce corrosive products
Breaker	Ammonium persulfate/sodium persulfate	Delayed break gel polymer
Corrosion Inhibitor	n,n-dimenthyl formamidem methanol, naphthalene, naptha, nonyl phenol, acetaldehyde	Prevents corrosion of pipes
Friction reducer	Mineral oil, polyacrylamide	Reduces friction of fluid
Gel	Guar gum	Thickens water
Iron Control	Citric acid, thioglycolic acid	Prevent metal oxides
KCl	Potassium chloride	Brine solution
pH adjusting agent	Sodium or potassium carbonate	Maintains pH
Scale inhibitor	Ethylene glycol	Prevents scale deposits in pipe
Surfactants	Isopropanol, 2-Butoxyethanol	Affects viscosity of fluid
Crosslinker	Ethylene glycol	Affects viscosity of fracking fluid

Source: National Toxics Network

3.1.2 Health implications of fracturing chemicals

Industry bodies have claimed that the fluids they use are “readily degradable and are not considered harmful in the concentrations applied”.[1] However, there are many obstacles to providing a clear, accurate profile of the potential health effects of fracturing chemicals, making such claims unwarranted.[33]

Information about toxicity is usually garnered from publically available information from groups such as TEDX; MSDSs; government regulations (such as EPA guidelines); and other health bodies. Even when this information is available, it may not be directly relevant to the exposures accompanying the fracturing process and the chemical mixtures used, which presents a serious obstacle to conducting adequate health risk assessments. The nature of chemically induced illness—such as the mild, non-specific or long-term nature of symptoms—together with the fact that physicians might not be familiar with illnesses related to chemical agents also makes estimating the hazards difficult[30], and there is a lack of information about possible cumulative and interactive effects.

Based on the toxicity of some of the chemical additives used in Australia, the NTN notes potential health effects summarised in Table 4 below (other chemicals included in the table were found in an analysis of a sample of fluids had similar potential health implications, although BTEX compounds have since been banned from use in Queensland and NSW).

Table 4: Potential health implications of chemicals used in fracturing fluids in Australia.

Substances identified in Australian fracturing operations	Potential health effects
tetrakis hydoxymethyl phosphonium sulfate, naphthalene, ethoxylated 4-nonylphenol	Cancer
tetrakis hydoxymethyl phosphonium sulfate, ammonium persulfate/sodium persulfate, ethylene glycol, formamide	Skin and eye irritation
ammonium persulfate/sodium persulfate, ethylene glycol	Respiratory problems
menthol, isopropanol, formamide	Nervous system damage
naphthalene	Blood cell damage
ethylene glycol, ethoxylated 4-nonylphenol	Endocrine disruption
Formamide, ethylene glycol, 2-butoxyethanol	Reproductive problems
tetrakis hydoxymethyl phosphonium sulfate, naphthalene, ethoxylated 4-nonylphenol	Cancer

Based on data from National Toxics Network

In the US, it was found that several products used in hydraulic fracturing contained chemicals that were either known or possible carcinogens, or regulated under clean air and water acts.[31] In particular 2-butoxyethanol—also found in Australian operations—has several reported health effects, including hemolysis (destruction of red blood cells) and damage to the spleen, liver, and bone marrow. Another US report noted that 93% of the chemicals had some identifiable health effect (with not enough information on the remaining 7%), although not all of these will be found in Australian operations.[32] Nearly all of the chemicals had multiple potential health effects, with some difficult to trace back to chemical exposures.

Any exposure to fracturing chemicals is likely to be to heavily diluted forms, which suggests reduced health hazards. However, there are gaps in toxicity information, and some chemicals were detected by the US EPA at concentrations “high enough to pose a threat to human health under a state or federal water quality standard”.[34]

In addition, some fracturing chemical “remain dangerous even at concentrations near or below their chemical detection limits”[48], and could potentially inflict damage across generations.[30] In particular, chemicals that disrupt the endocrine system have been shown to have “effects at low doses that are not predicted by effects at higher doses”[35] with potential health effects at parts per billion. Furthermore, there is little research on the outcomes of chemical combinations, with “the potential for the shared toxic action of these contaminants, especially those affecting the same and/or multiple organ systems”.[32]

It cannot then simply be assumed that the use of such chemicals for household purposes, or the dilute form of likely exposures, renders them safe. The threat posed to human health will be considered in relation to the potential exposure pathways in sections 3.2 – 3.4 below.

3.1.3 Drilling chemicals

All gas drilling operations requires fluids to help the drilling process, with contents acting as "carrier fluids, anionic water-soluble polymers, activators, emulsifiers and neutralizers".[3] It has been suggested that exposure to drilling chemicals may explain symptoms such as respiratory disease and nausea that are reported prior to the commencement of hydraulic fracturing,[32] however evidence on 'downwinder's syndrome' in Australia is inconclusive (see section 3.3.5).[36] Some of the effects of these fluids will be considered via individual pathways below.

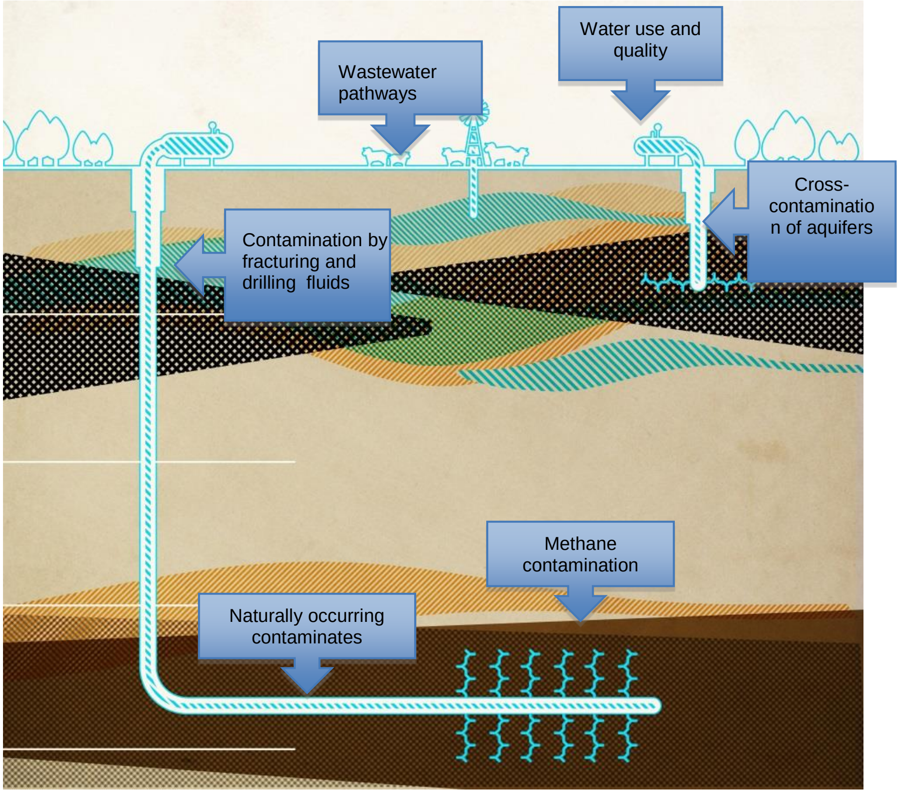
3.2 Water

Unconventional gas extraction involves intensive water use, which is especially of concern in Australia due to our reliance on water resources for food security—and our vulnerability to drought, a vulnerability that is likely to be exacerbated by climate change. The likely consequences of fracturing for water supply and quality has attracted considerable attention, with a major report on drinking water quality being undertaken by the US EPA and the Australian Government also undertaking an extensive investigation.

There are several intersecting pathways that will be considered here: the contamination of aquifers by fracturing and drilling fluids; methane contamination; cross-contamination; water use and wastewater (see Figure 4 below). Water can also affect health through atmospheric emissions from wastewater (considered in section 3.3), and soil pollution (considered in section 3.4.2).

While there are few confirmed instances of direct contamination by fracturing fluids or cross-contamination of aquifers, these risks cannot be dismissed—especially in light of the potential effect of seismic activity caused by the fracturing process and the impacts of climate change. The potential hazards of wastewater are even more concerning, with many potential risk pathways and a mix of fracturing fluids and naturally occurring contaminants (including radioactive materials) posing serious health concerns. Water use is a particularly salient issue in Australia, with resource conflict a likely result of the industry's expansion.

Figure 4: Potential water health pathways.



Source: adapted from Business Review Weekly

3.2.1 Chemical contamination of aquifers

The contamination of underground aquifers by fracturing and drilling chemicals, which may in turn be used as a source of drinking water or for irrigation, has been a source of particular public concern. The evidence suggests that direct contamination is a low risk in properly managed operations, though it cannot be dismissed entirely. There are also considerable knowledge gaps concerning the fate of stranded fracturing fluids and the potential for seismic activity caused by fracturing or the re-injection of wastewater to damage well casings.

While direct ingestion of fracturing fluids is unlikely, some of the chemicals employed are of concern, with 109 water soluable chemicals identified in US operations that could potentially make their way to vital organ systems through "immediate eye, nasal, dermal contact, and inhalation"[32], and eight chemicals regulated by the US EPA that may have an adverse effect on human health.[31] Although not all of these will be found in Australian operations, a thorough investigation into the soluability of these chemicals was not identified. Diesel contamination is also an issue, with the US EPA stating that the "use of diesel fuel in fracturing fluids poses the greatest threat"[37] to underground sources of drinking water, as they can contain toxic constituents. Diesel has not been detected as an additive in Australia, but is present in drilling operations.

Industry figures stress that adequate protective well-casing and regulatory frameworks can mitigate any risk, with one stating that: "The assertion that you cannot protect the environment and fracture natural gas wells is totally inconsistent with the reality"[38], and another asserting that, out of approximately 2 million fracturing events that have been undertaken, there have been no confirmed cases of contamination of aquifers from fracturing fluids.[39]

Some independent studies corroborate these claims. One comprehensive analysis acknowledged the presence of contamination risks but concluded they were manageable[40], with similar conclusions drawn by several other high profile studies.[41,42] The US energy secretary Ernest Moniz has stated that risks associated with shale gas "can be mitigated to acceptable levels through appropriate regulation and oversight", while risks of groundwater contamination could be reduced, if not eliminated, if "best practice case setting and cementing protocols are rigorously enforced".[43] The CSIRO also claim that groundwater contamination from CSG operations is a low risk, due in part to the low toxicity and dilution of chemicals, as well as the removal of fluids and the presence of aquitards, concluding that: "Hydraulic fracturing, when conducted correctly, is unlikely to introduce hazardous concentrations of chemicals into groundwater".[44] A 2004 US EPA report concluded that there was "little to no risk of fracturing fluid contaminating underground sources of drinking water during hydraulic fracturing of coalbed methane production wells".[37] However, this report attracted much criticism[34] and another report is due for release in 2014.

However, there are many case studies that indicate the contamination of water supplies in direct connection with hydraulic fracturing operations, with at least one confirmed instance in the US.[45] In Australia, BTEX chemicals were found in a fracturing operation, and benzene and toluene were discovered in the water in an underground coal gasification project.[3] A compilation of case studies from the US lists many additional unconfirmed instances, including a well containing "50 times the acceptable level of hexavalent chromium" and "elevated levels of arsenic, lead, chromium, butanone, acetone, carbon disulfide, and strontium" at a nearby location[46].

Several independent risk assessments have noted such contamination is a possibility, especially due to corroded well casings or improperly constructed wells.[47,48] For example, groundwater samples in Colorado were found to contain high levels of benzene, and in Wyoming an EPA investigation found increased levels of hazardous contaminants in drinking water wells connected to nearby fracturing operations.[49]

A comprehensive analysis of the risk of water contamination of the Marcellus Shale due to fracturing noted that "[t]he contamination risks and epistemic uncertainties associated with well casing failure…and migration of fluids through fractures…were *potentially substantial*" (p7– my italics)[50], though not as significant as the risks associated with wastewater disposal. A study incorporating an analysis of past incidents reached similar conclusions, noting some risks of underground water contamination by fracturing and drilling fluids, but higher risks from the storage and transport of fracturing and drilling fluids.[51]

Water pollution risks can also be exacerbated by seismic activity caused by fracturing. While the evidence strongly suggests that such seismic activity will not be of a level that would be felt above ground (see section 3.4.3), even small seismic events pose an additional risk to well casing integrity—as demonstrated by the event in the Preese Hall shale reservoir in the UK that led to gas company Cuadrilla suspending its activities.[52]

An area that has not received much attention is the risk associated with abandoned wells and stranded fracturing fluids. One report estimated that one in six abandoned wells was "releasing its contents to the surrounding area, including the surface" in the US[51], and it has been claimed that up to 85% of fluids may remain underground[53] (although considerably lower figures of around 20-40% are usually estimated[44]). These fluids can mingle with naturally occurring contaminants that can also be mobilised by the process (see section 3.2.4 for more discussion). While it has been theorised that such stranded fluids will not contaminate water because of the processes of dilution, adsorption and biodegradation[37,54], these claims are not based on empirical data, with concerns expressed that "as groundwater tables rise (post oil or gas development), the groundwater could mobilize these stranded fluids”.[34] The complexity and uniqueness of fracture formations, and the possibility that they extend past the target formations, makes it difficult to estimate these risks accurately.

3.2.2 Methane contamination

The available evidence regarding the presence of methane in drinking water is highly suggestive of contamination as a result of fracturing, although it is not always easy to ascertain the source of contamination. While the health hazards through this pathway do not appear to be serious, methane is dangerous through other pathways, and may be indicative of the presence of other dangerous gases. There were no studies found that specifically related to methane contamination in Australia.

One recent US report analysing groundwater from 68 wells showed evidence of methane contamination of drinking water systems connected to active drilling and extraction areas[55], likely due to increases connectivity of the fracture system. Another independent study based on sampled groundwater concluded there was the *possibility* of contamination by fugitive emissions due to fracturing because of connections between formations (Warner et al).[56]

Thermogenic methane (see Box 1) was also found by the Pennsylvania Department of Environmental Protection in relation to fracturing operations[49], and there are a number of other cases of elevated levels of methane that are likely to be tied to gas drilling activities.[55] These include a well drilled into tight sand that was not properly sealed, allowing gas to travel to an underground source of drinking water where “[t]he methane eventually built up until an explosion in a resident’s basement alerted state officials to the problem”.[57]

Box 1

Biogenic and thermogenic methane

The type of methane present is often used to determine the source of contamination.

Thermogenic methane is generated under pressure at depths over 1,000m.

Biogenic methane is formed from the decay of organic materials, is usually closer to the surface and can ‘naturally’ contaminate water.

The presence of thermogenic methane is often taken to suggest contamination from gas operations. However King (2012) has argued this can be a poor indicator as thermogenic methane can also migrate naturally.

Perhaps one of the most disputed results concerns the drinking water in Dimock, which featured in the documentary ‘Gasland’.[58] While it is clear the water contains substantial quantities of methane (with five of the 59 wells containing levels at which it is a potential explosive risk) there is a lack of consensus about its source.[59]

There is also dispute over the source of considerable quantities of methane bubbles that have been noted in the Condamine river in NSW. While methane was present in water in this area before CSG operations, the quantities and locations are strongly suggestive of these activities exacerbating its migration.[60]

While there remains some uncertainty about the risks, methane dissolved in drinking water “is not currently classified as a health hazard for ingestion”.[55] However, methane does have other serious health implications (see section 3.3.1) and has been claimed to indicate pathways through which other contaminants, including gases like radon, may travel.[3] As discussed further in section 4, methane also has a high GWP and any such leaks will have a significant negative effect on the climate.

3.2.3 Cross-contamination of aquifers

The cross-contamination of aquifers is one potential health pathway where CSG poses a greater risk than shale, as it often involves drilling past freshwater aquifers to the briny coal seams below. The distances and geological mechanisms involved in shale formations make such contamination more unlikely, with one author stating that there "is virtually zero chance of fracturing into a fresh water supply from a deep well".[54] However even in shale this risk cannot be dismissed.

The CSIRO report the risk of cross-contamination in coal seams in Australia as low, as "most of the inter-aquifer transfer will be of higher quality water into neighbouring coal measures as water flows from high to low pressure", although this might have the effect of "groundwater depression and reduced volume in fresh water aquifers".[44] However, there has been at least one occurrence of cross-contamination in Australia, where damage to a coal seam resulted in what the company described as 'relatively minor' leakage to a nearby aquifer[61], and one documented case where shale fracturing (in combination with a pre-existing network of faults) led to contamination after large quantities of fluids from the formation migrated over a kilometre before seeping out at the surface.[62]

Another report employing an interpretive modelling system to predict possible behaviours of fracture systems suggested the possibility of contamination, including speeding up the process whereby natural contaminants make their way to higher aquifers "from geologic time-scales to as few as tens of years".[56] While the modelling in this report has been criticised[63], the author notes that: "The evidence for potential vertical contaminant flow is strong, but there are also almost no monitoring systems that would detect contaminant transport as considered herein"[56], posing a major obstacle to sufficient regulation.

Such contamination might result in a loss of water for drinking or irrigation purposes, as well as carrying the potential for direct health effects. Apart from fracturing chemicals, heavy metals such as arsenic and naturally occurring radioactive materials (NORMs) found in some systems (discussed in further detail below) would be of particular concern.

3.2.4 Wastewater

The most likely water pathway through which unconventional gas extraction can impact human and environmental health appears to be wastewater.[29,50] For purposes of this report, 'wastewater' will be used to refer to fluids used for fracturing that return to the surface as well as the water produced from the reservoirs. Wastewater contains fracturing and drilling fluids, as well as other materials present in the fracture formation.

Naturally occurring contaminants including heavy metals and naturally occurring radioactive materials (NORMs) can be found in wastewater. While there is not sufficient information about such contaminants in Australian CSG and shale reserves, several reports have noted the presence of heavy metals in US shale reservoirs.[64,65]

Information about the potential health effects of naturally occurring contaminants through these pathways is limited. A systematic review identified "no research studies that directly examined the human health impact of metals exposure related to oil and gas exploration activities"[66], however there was a clear relationship between metals exposure in general and adverse health outcomes, with the potential for damage to be more extreme with exposure to more than one type of metal, with "environmental exposures to metals…associated with the following: autoimmune disease; cancer; cardiovascular disease; cognitive function; dermatiologic function; dermativologic toxicity; genotoxicity; hematology; metabolism; neurotoxicity; renal dysfunction; reproduction, fetal health and development; respiratory disease".[66] The health implications of the contaminants present in the Marcellus shale have also been treated in detail elsewhere, including barium (toxic to heart and kidneys); lead (potential effects on any system in the body, effects on neurological development at low concentrations); arsenic (all tissues); chromium (carcinogen); and benzene (leukemia).[51]

Of particular concern are NORMs such as uranium and radon, which can pose a health hazard through not only wastewater, but also through radon gas in the gas stream leading to radon decay elements depositing in pipes and other equipment[34], and through rock cutting waste—which have been shown to be "highly radioactive (25 times higher than surface background)"[67]—being spread over soil.

The level of NORM present differs substantially across shales. Some studies have shown radon and gamma rays "associated with, and emitted from, scale and impurities in equipment, gas streams, and pipelines…at levels that exceed certain "acceptable risk" measures"[68]; wastewater samples from the Marcellus Shale have been demonstrated to exceed radium-226 safety standards as much as 267 times[64]; and production waters from oil and gas in offshore facilities in Nigeria contained uranium, thorium and radon, with measurements of radiation levels at these sites far exceeding background levels.[69] Highly mobile radon gas has been singled out as especially problematic—it is the primary cause of lung cancer in non-smokers, and there is no known threshold below which it does not carry a risk.[70] Measurements of groundwater samples in New York State found radon at levels over proposed limits for drinking water.[51]

The problem seems particularly acute with the treatment of sludge and waste[34], with a waste truck recently refused entry into a landfill site in the US after setting off radioactivity alarms.[71]

Research has also demonstrated that interaction with oxidized drilling and fracturing fluids has the potential to release low levels of soluable uranium into wastewater, along with heavy metals such as lead and arsenic.[72] However, it has been argued that NORM management "is not unique to shale gas extraction"[54], with considerable experience with monitoring and handling from other industries.

There are many data gaps in this area making it difficult to estimate the level of risk, with no identified tests of radioactivity at intake plants downstream from busy drilling regions in the US since 2008[73], and no studies identified in Australia (although radon has been detected at elevated levels in a CSG site).[74]

Another potential source of naturally occuring contaminates are the organic compounds found in coal, which may be released by solvents interacting with naturally occurring hydrocarbons and ethanol leaching polycyclic aromatic hydrocarbons (PAHs).[39] However there is no conclusive evidence regarding this possibility. One analysis focusing on organic compounds in produced water samples from CSG operations in the US indicated the presence of "phenols, biphenyls, N-, O-, and S-containing heterocyclic compounds…(PAHs), aromatic amines, various non-aromatic compounds, and phthalates".[75] Although the compounds are potentially toxic, the authors note that the known toxic PAHs were absent, and "the human health effects of low-level, chronic exposure to coal-derived organic compounds in drinking water are currently unknown". This held true for other observed compounds, with low concentrations "likely preclud[ing] any acute human health or environmental effects".[75] No studies were found on organic compound contamination from coal in Australia.

Another study looked at the effects of boron—a known contaminant of drinking water that is very difficult to remove from wastewater, can affect reproduction and has suspected teratogenetic properties for humans. In addition to the effects of boron by itself, it can form complexes with heavy metals, with "[s]erious health and environmental problems…caused when these complexes pass to groundwater".[76] While the authors do not come to any firm conclusions regarding the health hazards, they note that there is a very narrow range between deficiency and toxicity of boron.

3.2.5 Health pathways from wastewater

The potential health risks from wastewater are strongly tied to the method of wastewater treatment and disposal, however the impacts are potentially significant.

An assessment of possible impacts of wastewater in New York state based on statistics from instances of wastewater leaks and spills concluded that 6% of gas projects in the area suffered 'serious mishaps', posing considerable pollution risks.[51] The risks and epistemic uncertainities associated with wastewater contamination were also identified in a comprehensive water risk assessment as "several orders of magnitude larger than the other pathways", a likelihood that a single shale gas well "would release at least 200 m^3 of contaminated fluids" in the case of an accident.[63]

There have also been many reported incidents in Australia, including over 30 water-related incidences such as spills and overflows of storage ponds in the first six months of 2011.[77]

The risks and nature of health implications accompanying such incidents are dependent on the different methods of treating wastewater.

Evaporation pits or ponds can leak or flood leading to pollution of water or soil, and emissions can also cause air pollution. While such pits have been banned for new developments in Queensland and NSW, there is no restriction on the use of open 'holding dams' to store produced water before treatment, which pose similar risks.[33] In a survey of the opinions of government, industry, university and NGO experts, "on-site pit or pond storage of flowback water and its potential leakage into surface water" was the risk pathway most selected.[29]

This risk can be greatly reduced through regulation and insistence upon best practice management, however past performance does not give reason for optimism and human error is always a possible factor. In the US, high concentrations of toxic materials including benzene, diesel range organics, and hydrocarbons were detected in ground water samples in the US[49], while a collection of case studies includes a home owner who noticed "her well water had an odor and black sediment" after drilling began, and "dramatic decreases in quantity, as well as poor quality, of both well and spring water" when the wastewater impoundment was constructed.[78] After the deaths of several animals (potentially from drinking wastewater that had been dumped), their child fell ill, exhibiting what their physician suspected were "symptoms were of toxicological origin". While the authors note that well water *did not* show increased levels of arsenic, this testing was done a year after the child developed symptoms.[78]

There have been cases where wastewater accidents have affected livestock, such as one accident resulting in a wastewater impoundment leaking into a into cow pasture. Soil tests showed high levels of materials including strontium, which can be toxic to humans and other animals. Farmers reported higher than usual levels of calves lost in the following two calving seasons, with 11 out of 17 calves lost in the second season after exposure.[78] The authors also describe two cases of water contamination that acted like natural control studies. In the first case, 21 cows exposed to a contaminated creek died and 16 did not produce offspring, while there were no health problems for those who were not exposed. In the second case, half of the cows exposed directly to wastewater died, with many of the survivors showing reproductive issues. No health problems were observed in those members of the herd not exposed.[78]

It is clear that such case studies have several critical limitations, however they are illustrative of the potential hazards of major accidents involving wastewater. Furthermore, the cause of such accidents is often human error, which cannot always be countered by best practice.

Two pathways related to the treatment and release of flowback water were identified as top risk priorities in a survey of risk pathways in shale gas extraction.[29] The successful treatment of wastewater faces several limitations, and wastewater plants cannot always properly treat fracturing fluids because of the concentration and nature of materials present. Reverse osmosis filtration is being developed and is employed in several plants in Australia, however it has limitations, with the National Water Commission (NWC) noting several chemicals associated with wastewater that are unable to be treated.[4]

Preliminary results from ongoing research found produced water from the Marcellus Shale development to be "a major contributor of total dissolved solids (TDS), including and most significantly bromides" to nearby rivers, with potential health implications:

> *These bromides can interact with the chemical treatment systems in public drinking-water systems, increasing the risk of brominated trihalomethanes (THMs) entering public water supplies. THMs are known to cause an elevated risk of birth abnormalities and certain types of cancer in people exposed over long periods.*[22]

A water test result from a proposed pipeline in the Pilliga found it to be "completely unlike freshwater" and requiring intensive treatment in order to be fit for use in agriculture or for human consumption.[79]

The introduction of sediment and increased turbidity to surface waters is another high risk to water quality, which could potentially affect food webs.[68] Turbidity is exacerbated by land clearing during the development of wells and associated infrastructure, with one report noting that "[s]ediment and contaminants associated with recovered wastewater will likely affect organism behavior and alter ecological interactions at sub-lethal levels" in the US[80], and another extrapolating from reports on annual sediment and typical disturbance from a gas well to argue that there would be considerable sediment load, with additional disturbance due to erosion.[51] Stormwater flows rated as a high priority risk pathway for expert groups[29], although this is not unique to the fracturing process.

Conversely, the NWC raises the possibility that treated wastewater that is too 'clean' could dilute naturally turbid systems, alter its temperature and its content of dissolved oxygen and nutrients, and change natural flow patterns.[4] There are also more mundane limitations to treatment, with reverse osmosis being very energy intensive, and not available to municipalities that lack the relevant infrastructure.[27]

Permits are sometimes given for wastewater to be released or re-used. There have been several cases in which such water contained potentially harmful chemicals, even after treatment. For example, an authorised release of treated water into the Condamine River in NSW included 22 chemicals over the limit of environmental guidelines—including boron, chlorine, cadmium, cyanide, and zinc—at levels potentially toxic to aquatic organisms.[77] Produced water is sometimes sprayed on roads for dust suppression, with the potential for fracturing chemicals and naturally occurring contaminants (such as thorium) to become airborne.[60]

Waste salt produced from fracturing remains a known issue, with estimates ranging from 7.8 to 154 million tonnes of waste salt over the next 30 years.[71] Currently, this is stored on site, injected into brine injection wells (see below), or released. However, an acceptable resolution to the issue of waste salts has yet been reached.

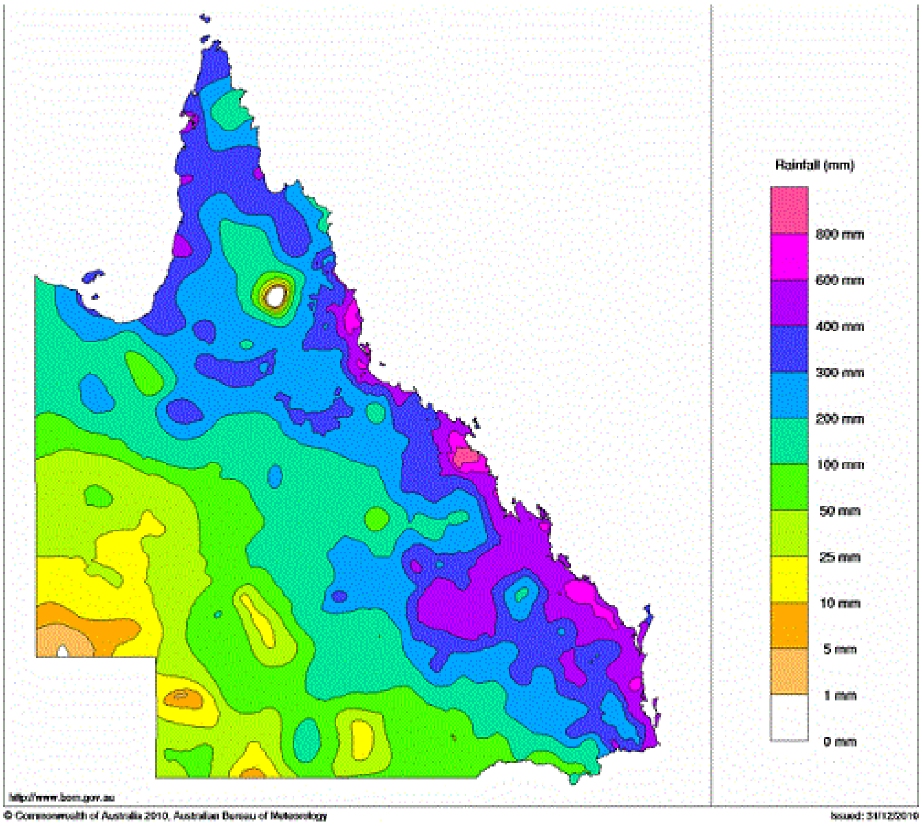
Risks to water also need to be evaluated in respect to the potential increases in extreme weather conditions predicted to accompany climate change. Many existing and proposed unconventional gas operations are located in areas that have already seen substantial flooding, with climate change likely to exacerbate drought and flood and so increase the risks associated with degraded water quality (see Figures 5 and 6 below).

There have been very few studies on the impacts of reinjection of hydraulic fracturing wastewater. One geologist noted that:

> *To-date, geophysicists and geochemists have found it impossible to agree on or be certain about the long-term stability and effectiveness of the few burial locations for nuclear waste that they have laboriously located worldwide. Why should the proponents of CSG production water reinjection, perform and fare any better?*[79]

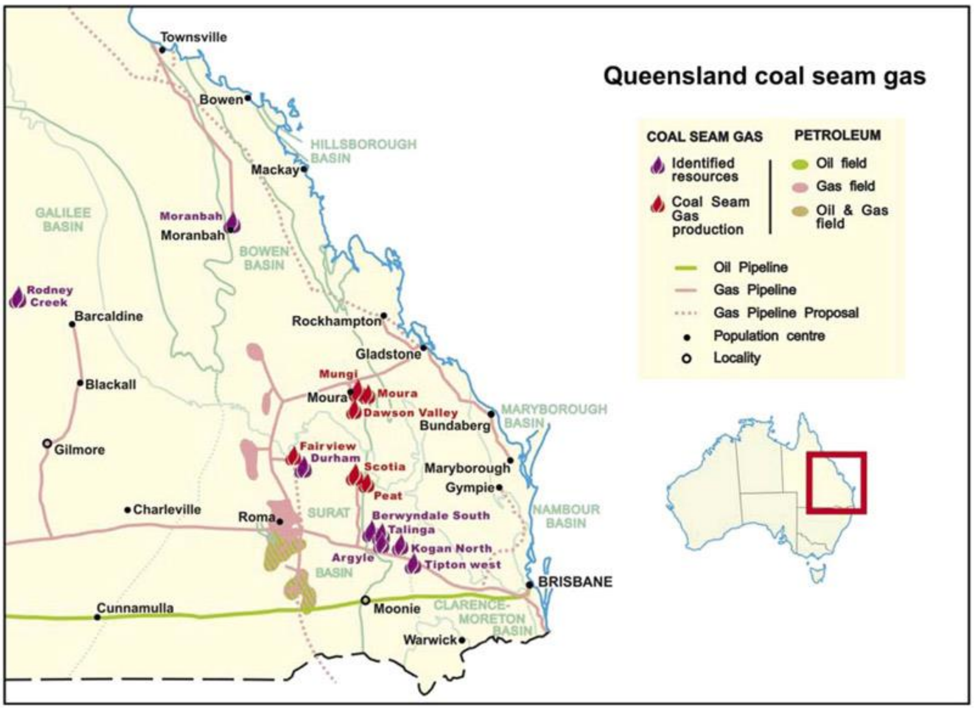
The NWC has also expressed concerns that the reinjection of treated wastewater into other aquifers has the potential to change the characteristics of those aquifers. Furthermore, injection of wastewater has been linked to seismic activity in the US (see section 3.4.3 for further discussion).[82]

Figure 5: Queensland rainfall, December 2010.



Source: National Climate Centre

Figure 6: Distribution of Queensland CSG.



Source: Petroleum Exploration Society of Australia

There have been a number of documented spills of wastewater in the US, with a report based on historical data predicting an accident rate of 1-2% in the New York State.[51] A collection of case studies includes a liquid gel spill that polluted a wetland and killed fish; another impacting seven drinking water wells with five having iron and manganese above established drinking water standards; 4,200 gallons of wastewater discharged in Pennsylvania; turbid discharges; diesel and fracturing fluid discharge; 250 barrels of diluted fracturing fluid that killed fish and other aquatic life; fracturing fluids overflowing wastewater pits; 1.4 million gallons of fluid leaking beneath a storage pit and making its way to a creek; and a case where a resident drank water that contained benzene after a spring had been contaminated.[46] Other accidents have seen companies fined in the US for failure to implement erosion and sedimentation control measures leading to turbid discharges, discharging of fracturing and drilling fluids into the ground, and overflows of wastewater pits.[62] In Australia, the NSW government is set to prosecute Santos over breaches of its production license leading to a spill of untreated water in the Pillaga state forest.[83]

While there is little by way of clear evidence regarding the health outcomes for these exposures, there is evidence of the lethal effect of direct exposure to fracturing fluids for livestock and serious effects from isolated incidents of human exposure. In one case, the release of fracturing fluids into a pasture killed 17 cows in one hour, and in another goats exposed to hydraulic fracturing fluids suffered reproductive problems for two years.[78] An emergency room nurse in Colorado nearly died after treating a patient who had been splashed with fracturing fluid from a spill on a gas rig.[84] While there are clear limitations to extrapolating from these cases and they are not indicative of risks in normal operations, they demonstrate the more extreme hazards.

3.2.6 Water use

Access to clean and plentiful water for drinking, agriculture and other uses is an essential aspect of environmental health. The process of hydraulic fracturing—especially shale gas—uses very large quantities of water, which can lead to conflict over resources.

Water use and management has been identified as "perhaps the most important natural resource management challenge confronting successful CSG exploration, production and decommissioning"[85], and this issue has been the focus of considerable attention in Australia, including a $200 million Australian Government reform package to build scientific understanding about the use of water for such projects.

These concerns become particularly salient when consideration is given to the effects of climate change. However, gaining accurate information about the cumulative risks is difficult, in part because of current data gathering tools, the complexity of modelling aquifers, the potential for cumulative impacts from multiple sites, and the long time periods over which such impacts emerge.[85]

Apart from potential conflict over resources, water use can also have secondary effects as less water becomes available for diluting contaminants.[80]

The amount of water used in unconventional gas extraction varies depending on the characteristics of individual operations, and there are conflicting estimates of the quantity projected for CSG activities in Australia (see Table 5 below). Fracturing of shale gas uses much higher quantities of water because of the depth of the formations and the pressure required to access the gas, however there is little produced water.

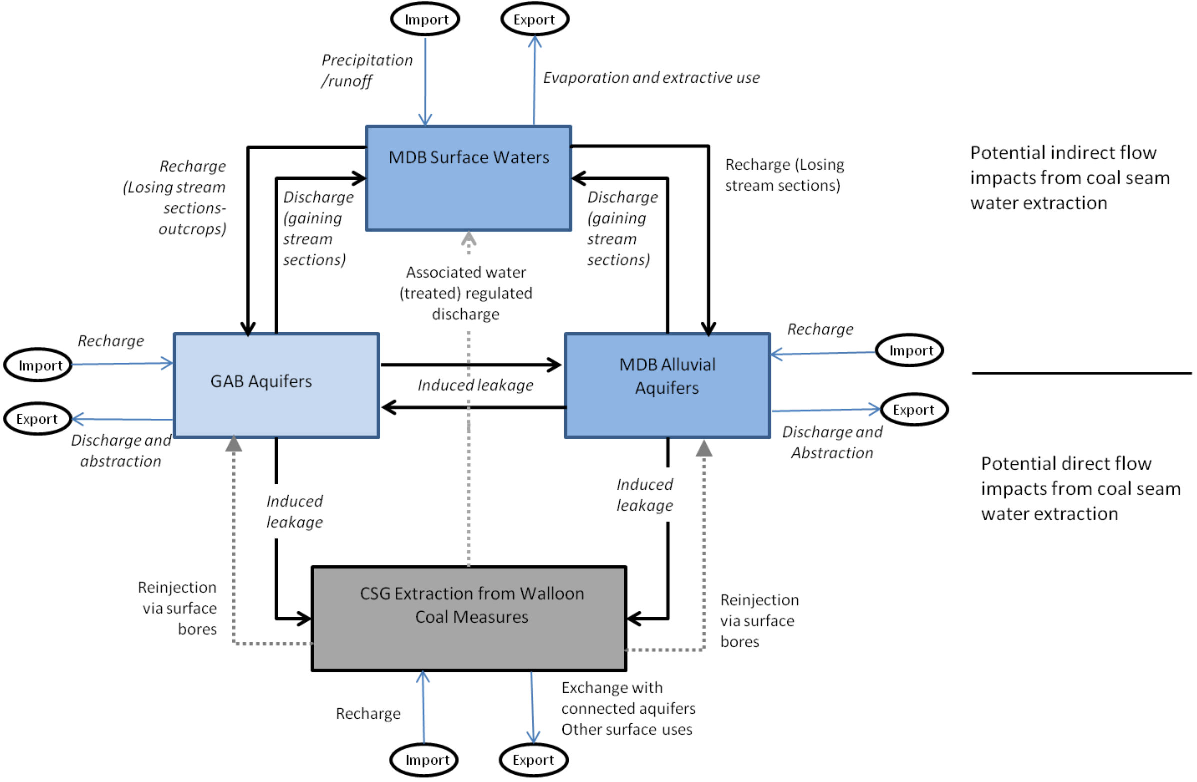
Table 5: Estimates of water use from unconventional gas operations

Source	Estimate	Notes
APPEA	90 GL a year	CSG industry-wide
National Water Commission	300GL a year	CSG industry-wide, compared to current total extraction from the GAB of approx 540 GL a year
Williams	468-914 GL a year likely range	CSG industry-wide, extracted from GAB systems
Queensland Water Commission 2011	126-281 GL a year	CSG industry-wide
Jenner and Lamadrid	276-397 GL a year	All shale gas, using estimate of 27,000 wells in 2011
Jenkins – The Energy Collective	511 GL a year	All shale gas, using estimate of 27,000 wells in 2011 Compared to agricultural use, which used approx 243 times more

While it is possible to recover 20-80% of the water used, and in some cases treat it for re-use[27], this still leaves a substantial amount of water loss. Moreover, the re-use of treated water may pose other hazards to be discussed in section 3.4.

Aside from direct withdrawal, there are other complex pathways by which unconventional gas operations can affect water flow. In CSG developments, the depressurisation of the coal seam can cause ‘drawdown’—changes to the water pressure in the geological strata due to the differences in water pressure this introduces—with estimates of between 3 and 65 meters by 2028 in different operations.[3] Figure 7 below shows some of the potential impacts of coal seam gas activities on water flows in the Walloon Coal Measures.[86]

Figure 7: Potential impacts of CSG water activities in the Walloon coal measures.



Source: Moran and Vink

The extensive water needs of hydraulic fracturing can result in conflict over resources, with the NWC noting that some surface and groundwater resources “may already be fully or over-allocated, including the Great Artesian Basin and Murray-Darling Basin”, and raising concerns about the effect that changes on pressure in adjacent aquifers will have on water availability and surface water flows in connected systems.[4] A recent comprehensive report on the impacts of CSG argued that it should be treated like any other resource-using activity, noting that extensive grazing was the most compatible form of agriculture, with potential problems arising from resource conflict with cropping and irrigated agriculture.[85]

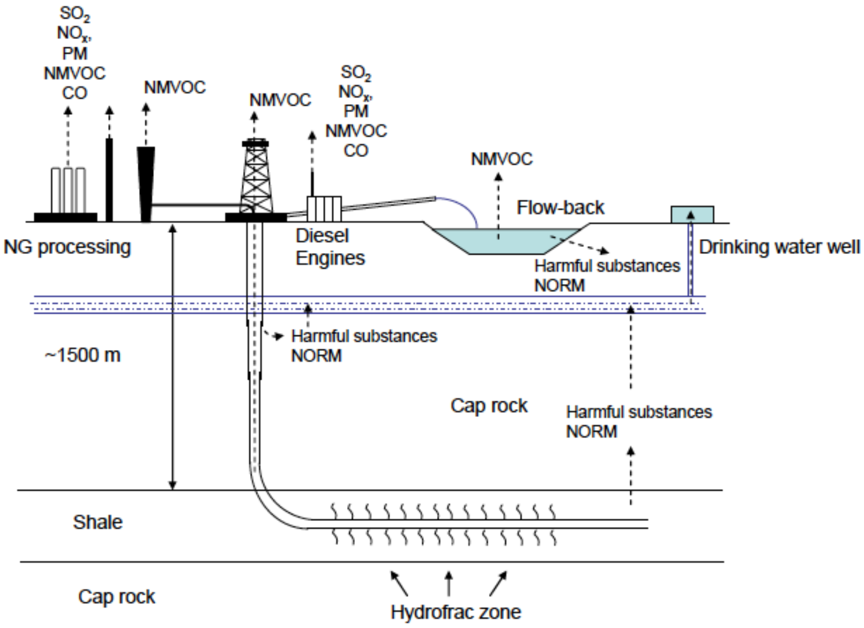
Despite widespread concern over impacts on water, industry figures and many government bodies have stressed the tight regulations surrounding water use—such as the recently introduced Commonwealth water trigger—and the detailed studies that have taken place—such as a cumulative water study which predicted no material impact on 20,500 water wells out of 21,000 that would be affected by CSG activities in Queensland.[39] The CSIRO notes that, whilst modelling large groundwater systems is challenging, “the general principles of hydrology are well understood”.[44]

3.3 Air

The impacts of unconventional gas are held to be less damaging than coal in relation to air pollution, especially because it is responsible for less damaging particulate matter (PM).[21] However, there are several pathways through which air pollution from unconventional gas extraction can affect health as illustrated in Figure 8 below: fugitive emissions from gas reservoirs; emissions from equipment used in the extraction process (including nitrous oxide (NOx), sulfur dioxide (SO_2), and volatile organic compounds (VOCs)); evaporation from wastewater ponds; emissions from spills and well blowouts; and flaring and venting. One ongoing study on the health implications of unconventional gas in the US suggests that air pollution is of more concern than water contamination.[50]

While exposure to emissions of many of these pollutants in current Australian developments is likely to be less than their US counterparts given the current location of gas operations and population density, it is becoming apparent that *any* level of such pollutants can have health implications at a population level.[20] Furthermore, the gas industry is fighting to scrap current 2km buffers that operate in some parts of Australia.[87]

Figure 8: Potential flows of air pollution emissions (along with water and soil pathways).



Source: Lechtenböhmer et al

3.3.1 Methane emissions

Coal seam and shale gas are predominantly made up of methane, which can escape as fugitive emissions in the course of extraction (see section 4). At low concentrations, methane is considered non-toxic. At high concentrations, it can cause nausea, vomiting, difficulty breathing, irregular heartbeat and flulike symptoms, and at very high concentrations it can displace oxygen and act as an asphyxiant.[88] The most likely immediate hazard is explosion, with methane forming an explosive mixture with air at levels exceeding 5%, and the most likely overall health pathway is through the formation of ground level ozone and smog.

Methane, along with other VOCs, can contribute to ground level ozone (O_3) in the presence of NO_x from equipment used in the drilling and fracturing process and in contact with sunlight. While there were no studies identified of ground level ozone levels in Australian operations, there are several reports of high ozone levels connected to US gas operations, with one linking high ozone levels in Wyoming to increased doctor visits[89], and another reporting ozone at levels 85% higher than US federal health standards in Utah in 2010-2011 (these levels have since fallen).[90] The amount of ozone created by gas extraction in the Barnett shale has been forecast using an air dispersion model, with predictions that regular emissions "may increase ambient ozone [in the area] by more than 3ppb", and possibly leading to additional ozone exceeding 10ppb about 16km downwind.[91] Ozone can damage animal and plant tissues at concentrations of 100 parts per billion (ppb), so while this does not represent a severe threat by itself, it can contribute to damaging levels.

Ground level ozone is known to be a respiratory irritant that can damage lungs. A meta-analysis of time-series studies found overall "strong evidence of a short-term association between ozone and mortality, with larger effects for cardiovascular and respiratory mortality, the elderly, and current-day ozone exposure".[92] The association of ground level ozone exposure with a range of health effects, including mortality, is also noted in other reports[66,93], and the damage that can be done is highlighted in another:

> *One highly reactive molecule of ground level ozone can burn the deep alveolar tissue in the lungs, causing it to age prematurely. Chronic exposure can lead to asthma and chronic obstructive pulmonary disease (COPD), and is particularly damaging to children, active young adults who spend time outdoors, and the aged.*[94]

Ozone has also been shown to damage trees and crops.[94]

When combined with particulate matter, ozone can also produce smog. This is a noted problem in the US, where gas-field ozone haze has created pollution of magnitudes close to that found in urban areas that can spread over 300 km past the gas production facilities.[91] One study calculated that, out of 21 counties in the US, the 5 counties responsible for the majority of natural gas and oil activities produced over 80% of the smog-forming compounds during peak production time.[95] Smog has many known health effects, especially relating to respiratory health, with too many to individually address here.

Methane is an explosive hazard at relatively low concentrations, and there have been several documented explosions as a result of shale gas extraction in the US. These include an explosion at a gas well that "sent seven injured workers to the hospital"; an explosion inside a home after methane from drilling operations got into the water system; a house exploding resulting in three fatalities; and incidents of evacuation due to the risk of explosion.[46] No reports were found in relation to Australian operations.

While it can be argued that such incidents are a result of poor practice, they remain a potential risk with serious consequences.

3.3.2 Wastewater and blowouts

In addition to emissions of methane, other compounds that exist in fractures and many fracturing chemicals have the potential to become hazardous air pollutants through evaporation from wastewater pits and well blowouts.

The risks associated with such emissions in the Australian context will depend on the nature of the wastewater disposal method, and no studies were identified that isolated atmospheric pollution from evaporative ponds alone. However, it has been noted that approximately 37% of chemicals used in US operations can become airborne, with nearly all of these having the potential to harm the eyes, skin, sensory organs, respiratory tract, gastrointestinal tract, liver, brain and nervous system, cardiovascular system and blood, or kidneys.[32] In particular, hydrogen fluoride is a "highly corrosive and systemic poison that causes severe and sometimes delayed health effects due to deep tissue penetration. Absorption of substantial amounts of hydrogen fluoride by any route may be fatal"[31], while lead, methanol, formaldehyde, hydrogen chloride, and ethylene glycol can also be hazardous.

Evaporative emissions may also result from well blowouts that occur when pressurised gas from the reservoir is not controlled, or from other accidents. There have been several such blowouts in the US, including one in which more than 130,000 litres of wastewater and gas erupted for 16 hours, and an incident where a tank and open pit used to store hydraulic fracturing fluid caught fire resulting in flames of over 30 meters high causing a "plume of black smoke visible for miles".[46]

There is no clear evidence about health effects directly attributable to emissions from these sources, although it is likely that they contribute to the 'cumulative risks' discussed below.

3.3.3 Emissions from drilling and infrastructure

The process of building infrastructure and drilling can result in air pollutants from mobile and stationary equipment, including NOx, SO_2, carbon monoxide, hydrocarbons, and PM with an aerodynamic diameter less than ten microns (PM_{10}).[67] Table 6 below shows some estimations of emissions in shale gas extraction in the US, although it should be noted this does not include emissions from the construction of infrastructure, which are likely to be higher in Australia given greater infrastructure and transport requirements.

Table 6: Typical emissions of air pollutants from stationary diesel engines used for drilling, hydraulic fracturing and completion.

	Emissions per engine mechanical output [g/kWh_{mech}]	Emissions per engine fuel input [g/kWh_{diesel}]	Emissions per natural gas throughput of well [g/kWh_{NG}]
SO2	0.767	0.253	0.004
NOx	10.568	3.487	0.059
PM	0.881	0.291	0.005
CO	2.290	0.756	0.013
NMVOC	0.033	0.011	0.000

Source: Lechtenbohmer et al

There is extensive data about exposure to these pollutants, including "clear evidence that nitrogen oxides, sulfur dioxide, and ozone exposures are significant contributors to respiratory disease" and "reasonably strong evidence for its contribution to cardiovascular illness as well"[66]; even small increases of PM increasing the risks for "respiratory disease; cardiovascular disease; fetal and neonatal health; childhood illnesses; [and] geriatric illness"[66]; and studies of low levels of occupational exposure to benzene suggesting its connection with acute myeloid leukemia at rates as low as 0.8ppm. However, there is no data specifically concerning exposure from gas fields, and "little meaningful information on chronic, low level, exposure in the general environment" in relation to VOCs.[66]

As noted previously, it is unlikely that gas developments in Australia will be as dense as the US, and Australia LNG claim that these emissions can be managed through equipment design and use, along with compliance with environmental management plans.[1] The possibility of substantially lessening such pollutants by using natural gas engines has also been raised.[27] These emissions are also substantially lower than those associated with coal plants.[20] However, current evidence suggests that even very low levels of such pollutants will have an impact at the population level.[21]

3.3.4 Flaring and venting

The processing of unconventional gas sometimes requires the flaring or venting of ‘associated’ gases, although this is far more common for shale than CSG (see Box 2). While flaring in CSG operations still occurs, Australia LNG states that the impacts are “predicted to be below limits set in the air quality objectives”.[1]

No studies specifically concerned with the health effects of flaring on humans were found, however a peer-reviewed study examining air quality around gas facilities in the US showed the presence of VOCs including methane, ethane, propane, and toluene along with PAHs potentially resultant from venting and flaring “at concentrations greater than those at which prenatally exposed children in urban studies had lower developmental and IQ scores”.[94] An extensive study on the effects of flaring from oil and gas operations on reproduction in cattle did not produce any clear pattern of association.[96]

Box 2

Composition of shale and coal seam gas

Australian CSG: 95% methane

Shale gas (estimated): 78.3% methane; 17.8% non-methane hydrocarbons; 1.8% nitrogen; 1.5% carbon dioxide; 0.5% hydrogen sulphide; 0.1% water

Source: Skone et al. 2011; US EPA 2011

No studies related to flaring and venting were identified in Australia. This is likely to become more of an issue as the shale industry develops.

3.3.5 Cumulative risks

Data from several sources demonstrate that gas developments are responsible for emissions of a complex mixture of pollutants. The contributions of different sources to health outcomes can be difficult to isolate, and so general air quality studies connected to particular operations can be more informative.

In Dish, Texas “high concentrations of carcinogenic and neurotoxin compounds in ambient air near and/or on residential properties” were found[97]; another report found that “pollutant emissions from natural gas drilling activities per day surpassed those produced by all of the vehicle traffic in the Dallas-Fort Worth region”[95]; and a Texan monitoring program found high levels of benzene in a number of sites in 2010.[46] A preliminary study of air quality around a gas site in the US detected NHMCs, VOCs, carbonyls, PAHs, formaldehyde, acetaldehyde and methylene chloride (which was attributed to its storage on site for cleaning purposes).[94] Although the authors caution that they could not be directly connected to gas operations, they have been associated with such operations and have multiple health effects, including many affecting the endocrine system.

One of the only high quality measurements of the health risks directly associated with air pollution due to unconventional gas developments estimated health hazards resulting from exposure to hydrocarbons for residents in Battlement Mesa, Colorado using air toxics data collected at various sites.[98] The authors estimated chronic and sub-chronic non-cancer hazard indices and lifetime excess cancer risks due to emissions for residents both less than and more than ½ mile from well sites. While incomplete information about the toxicity of some of the exposures made it difficult to make a complete assessment, the authors conclude that the ambient levels of benzene could increase cancer risks, with cumulative cancer risks from exposures estimated at "6 in a million for residents >1/2 from wells and 10 in a million for residents ≤1/2 mile from wells". In addition, levels of benzene, xylene and alkalines detected could also have other health impacts, and reported symptoms of headache, throat and eye irritation were "consistent with known health effects of many of the hydrocarbons evaluated".[98]

Apart from direct data linking air pollution from gas operations to health outcomes, there has been some reports of 'down-winder's syndrome'—a collection of symptoms including headaches, eye and throat irritation, nosebleeds, skin rashes, peripheral neuropathy, lethargy, nausea, reduced appetite and mental confusion that has been associated with gas-field activity.[51] However the evidence for this syndrome is inconclusive. While several doctors in Queensland had raised concerns about residents living near coal seam mining operations reporting symptoms consistent with gas exposure, Queensland health issued a statement that there was not "an unusual increase in patients with those symptoms".[99] A further study incorporating environmental monitoring concluded that there was no clear evidence associating reported symptoms with CSG emissions in Tara.[36]

Some limited case studies indicate exposure to benzene in residents close to gas operations in the US who reported health scares.[78] Livestock from the same area were also affected: a horse suffered from acute liver failure due to toxicity and neurological impairment that a veterinarian suspected was due to heavy metal poisoning; similar conditions were noted in two horses living next to a vertical well operation; and reproductive problems were found in other animals.

One draft study was identified (not yet peer-reviewed) that focused on the adverse effects of gas operations on infant health, comparing mothers in Pennsylvania within a 2.5km distance of a well permit (yet to have a gas operation) to those within 2.5km of an existing well, concluding that "exposure to NGD [natural gas development] increases the overall prevalence of low birth weight by 25 percent, increases overall prevalence of small for gestational age by 17 percent and reduces 5 minute AGPAR scores, while little impact on premature birth is detected".[100] Several potential causative pathways were identified, including noise, lights, emissions of pollutants and methane, drilling muds and fracturing fluids.

As with all risks of exposure details concerning weather patterns, density of wells and other factors are crucial to understanding their relevance to local operations, and information on air quality associated with gas operations is lacking in Australia. Compared to coal and oil, exposure to air pollution from gas fares reasonably well, with "[t]he total external costs…in the range of about 0.5–1 eurocents/kWh for most EU countries", although these figures do not take into account fugitive emissions.[101] However, they are clearly substantially greater than renewable energy sources.

3.4 Land

Any gas operation requires considerable amounts of land, which can have indirect health implications arising from impacts on other industries; decreased land quality; and impacts on biodiversity as well as more direct impacts through soil health. Given the additional stressors that are likely to occur due to climate change and Australia's reliance on its 'clean food' reputation, these risks are substantial, although they will vary significantly depending on the nature of the land that is used.

Apart from the well pads themselves (which are expected to be approximately 1 hectare each in size in the proposed QGC, Origin and Arrow facilities), unconventional gas operations require associated infrastructure including roads, compressor stations, power lines, pipelines, and waste treatment facilities, accommodation and facilities for workers, and a processing plant. It is estimated that a typical CSG footprint is 160km of roads and 6.1 parcels of land encompassed by road for every 100km2 development.[102]

3.4.1 Resource conflict

Loss of land can have a significant impact on agricultural production above and beyond the land directly used. A wheat producer calculated that the likely impacts for his property (including drainage patterns, erosion and safety zones) totaled 38 acres in 250, compared to the industry estimate of one acre in 250.[103]

An independent report notes such extended impacts, with wells often connected by a network of infrastructure.[85] This pattern “breaks up productive land and makes it hard to farm”, which can make “large scale irrigation impossible” and interferes with grazing. One farmer testified that:

> *The animals are not allowed to settle because there is a flared well every 405 metres across your land. But, all importantly, our cattle eat grass. Because of dust and disturbance to the grass the cattle cannot eat.*[103]

Arrow energy also acknowledges the possibility of disturbances to agriculture, noting reduced productivity; increased costs; crop losses; disturbance of stock; soil disturbance and loss of amenity, estimating that “2-3% of land associated with a typical production well spacing of 800m, which will equate to 65 ha will be disturbed by activities” in the Surat basin.[104] They also note that their activities occur on land in which there are 2,300 Indigenous cultural heritage places listed. Their proposal in respect to these is to meet their “duty of care obligations”.[104]

These impacts can be put into perspective by a comparison with the land-use intensity of solar, with one estimate suggesting that, if a solar facility occupied the area of land required by a well production pad (approximately 10,000 m^2), it would yield 400,000 kWh per year (equivalent to about 70,000 mT of natural gas).[67] Additionally:

> *In contrast to fossil energy extraction, the solar power plant generates electricity for more than 20 years. At the end of its life time the solar plant can be substituted by a new one without additional land consumption.*[67]

Another study compared the impacts of land-use for coal, shale gas and conventional gas, finding that natural gas uses about 200-300m$_2$/GWh (similar to solar over a 30 year time period), while land use for coal was as high as 950m$_2$/GWh.[27]

3.4.2 Land quality

Unconventional gas operations can degrade land through water seepage, erosion, subsistence.[105] While the direct impact of unconventional gas extraction on soil health does not receive a great deal of attention, the potential for soil health to effect food security also makes it important to consider.

The potential for soil erosion as a result of gas field infrastructure is noted in the impact statement for the Australian Pacific LNG project, with potential effects such as scarring, gullying of local drainage lines and negatively impacting downstream water quality. The company states they "recognise the significant risk of soil erosion and will implement appropriate measures to avoid or minimise erosion impacts".[1]

Only one study identified dealt with soil health exclusively, and this was in relation to drilling fluids only. Tests determined the effects of non-aqueous drilling fluid and synthetic base oil on soil health by measuring the amount of particular enzymes that are often used as a measure of metabolic activity of soil. The study found that the presence of drilling fluid actually *increased* the presence of these enzymes, with soil microbes using them as a source of nutrients "indicating that soil biota and soil health were not adversely affected at the concentrations used in this study".[106] However, this does not look at fracturing chemicals and materials released through fracturing.

Natural contaminants can also affect soil health, with salt is a major issue:

> *The salt could be spread onto adjacent agricultural land either by flood waters, wind or by seepage from even well constructed storages...the salt will be highly alkaline made up of sodium carbonate and bicarbonate mixed with sodium chloride salt. The environmental impacts of these mixed salts are substantially more complex than that of ordinary salt.*[103]

As noted in section 3.2.4, there are also risks associated with shale cuttings that have high levels of NORMs being spread over soil.

The reputation of Australia as a clean food provider means that the possibility of food contamination from soil is a major issue, with the potential for serious damage from even a single instance of contamination. For example, cadmium has been discharged from Queensland CSG activities and has several potential health effects:

> *Cadmium can infiltrate pastures and livestock via fertilisers; soil or water, especially downstream from mining....Cadmium accumulates in soil, where it can then be transferred to plants, animals and humans.... is concentrated in the kidney and liver(and, to a much lesser extent, muscle and milk) of livestock and humans…[h]igher soil chloride concentrations [found to be released from CSG operations] increase the release of cadmium from soil and uptake by plants.*[103]

While there is little concrete evidence of food contamination in Australia, even the perception of such contamination can have adverse effects on livelihoods, such as occurred when a BTEX scare in Queensland forced some properties into quarantine where some cattle were unable to be sold[103], and in Pennsylvania where cattle were similarly quarantined food chain after they had came into contact with drilling wastewater from a gas operation.[107] Public perception has also led to a major dairy company in New Zealand refusing to collect milk from any new farms that engage in 'landfarming'—the practice of spreading drilling waste on to farmland and creating new pasture on top—because of the cost of testing for petrochemical contaminants to provide reassurance to their consumers.[108]

3.4.3 Seismic activity

Hydraulic fracturing operations have been linked to seismic activity, although most studies suggest that these events would be of a magnitude too small to be felt (up to about magnitude 3).[54,109] However, this does not mean that they cannot have an effect, and there have been claims that larger quakes can be traced to fracturing.

In Lancashire near the Preese Hall shale gas drilling site (an area that generally has low seismic activity), magnitude 1.5 and 2.3 earthquakes were recorded, with the Geological survey suggesting they were connected to fluid injection and an independent study (commissioned by gas company Cuadrillo) also finding that it was highly probably the fracturing caused the event.[110]

In Arkansas, US there was a reported ‘swarm’ of earthquakes, with over 700 quakes over six months including an earthquake of magnitude 4.7 that caused minor damage and was felt across Arkansas as well as some parts of Missouri, Tennessee, Kentucky, Indiana and Oklahoma.[111] This area does contain geological faults and this activity was potentially a naturally occurring cluster. However, the possibility that they were related to hydraulic fracturing in nearby gas developments was not ruled out.

It is not only fracturing that can produce seismic activity. A series of 11 earthquakes over magnitude 2, along with 98 smaller ‘tremblers’, have been linked to the injection of waste-water in Youngstown. The largest quake was a magnitude 4 – strong enough to be clearly felt and result in minor damage.[82]

It is important to note that other energy sources, such as coal and geothermal, have a higher associated risk of causing seismic activity.[112] However, there are additional hazards from seismic activity in unconventional gas because of increased risk of damage to the well casings that serve as protection from water pollution and fugitive emissions.

3.4.4 Biodiversity

Environmental health can also be indirectly linked to human well-being. While this report does not provide a thorough investigation of environmental impacts of unconventional gas, it is worth noting the significant recognised impacts on ecosystems through habitat fragmentation, and long-term effects tied to land use and water quality. While these risks are not limited to unconventional gas operations, the substantial use of land for infrastructure and increased traffic for water and waste management make such risks significant, with habitat fragmentation noted as a high priority risk pathway for all expert groups consulted in an extensive survey.[29]

Fragmentation of habitat is recognised as extremely problematic, as it disrupts the connectedness that allows small, otherwise isolated populations to function as larger, more resilient ‘meta-populations’.[85] Among many other damaging effects—such as making it easier for invasive flora and fauna species to inhabit the areas[113]—this results in isolated populations that “may be subject to loss of genetic variability and inbreeding depression, and fixation of deleterious mutations” and more vulnerable to environmental events such as fire.[85]

In the US, there have been noted consequences of soil erosion and infrastructure associated with shale gas extraction for native animals: one study of the movements of mule deer found that the population dropped by 45% in one year, and they shifted towards “less-preferred and presumably less-suitable habitats”[114]; another study reported an 82% decline in the sage-grouse population within areas of expansive CSG production over a four year period[115]; and other studies noted the effects of oil and gas sites on grasslands which “persisted for more than 50 years following well site construction, and extended outward 20 m - 25 m beyond the direct physical footprint of PNG well infrastructure”.[116]

While recognising the potential for significant risk to ecosystems, industry bodies in Australia make the case that these can be mitigated through careful management.[1,104] However, calculating impacts on ecological system is an area of substantial uncertainty.

3.5 Social and psychological

The potential social and psychological impacts of unconventional gas developments have increasingly become a focal point of government and industry, and there have been calls to include more comprehensive treatment of these pathways in impact assessments.[22] While these are difficult to measure and heavily dependent on details of individual operations, the general social effects of resource booms have been well-studied, and studies on the effects of noise, visual amenity and environmental disruption can also provide insights.

3.5.1 Resource booms

Any form of resource boom can have a marked influence on wellbeing. However, these are not likely to be straightforward, and will be largely determined by the community and the nature of the development:

> *Positive effects might include less stress over finances, if increased demand for local business benefits the local economy, and increased access to social resources, services and infrastructure…For example, increased school enrollment can lead to more educational opportunity…Negative effects may include increased substance abuse, crime, sexually transmitted infection, demands on the education system beyond current capacity, interference with recreational activity and decreased social cohesion.*[66]

When asked “whether boomtown externalities are, on balance, positive or negative”, two-thirds of survey respondents from government, industry, academic and NGO thought boomtown effects were positive overall, although there was a sharp division between the attitudes of respondents from industry versus non-governmental organisations.[29]

While the potential for jobs and improved finances has been a major selling point for the expansion of the gas industry in Australia, it is not clear that such benefits will appear, and if so whether they will result in further entrenching inequality.

CSG operations have been predicted to bring 20,000 jobs and approximately $40 billion in taxes to Australia.[53] One study examining the social and economic impacts of mining generally in regional Australia found “mining activity had a positive impact on incomes, housing affordability, communication access, education and employment across regional and remote Australia”.[39]

However, other reports have noted potential adverse impacts, including impacts on other sectors, dependence on export, foreign ownership, increase in social inequality and negative effects of the high Australian dollar.[117] Another study noted that **“**the regional benefits of mineral wealth [might be] masking highly localised inequalities and disadvantage”.[85] Such outcomes have accompanied coal mining developments in the Bowen Basin, with non-resident workforces resulting in wealth leaving the town and flowing instead to regional centres; housing shortages and price spikes; and a finding that “none in the study were able to use the current mining boom to leverage other economic development opportunities that might provide additional insurance against welfare dependence”.[5]

Although a thorough examination of the economic effects is beyond the scope of this report, it is clear that, while there are some economic gains for some individuals and companies, claims for the economically beneficial nature of these developments should not be uncritically accepted.

There is significant controversy surrounding gas operations in Australia, with the establishment of several large advocacy groups (such as Lock the Gate, which involves over 160 groups), ongoing protests, and blockades—a pattern also found in the US, UK and other countries. In many cases this reflects the non-economic values of the communities, with “[i]dentities and affinities associated with activities and lifestyles such as ‘farming’, ‘rural life’ and ‘life on the land’ are powerful dimensions of the way in which communities perceive and understand CSG development and their potential impacts”.[85]

The potential for such conflict varies significantly with the nature of the operation and the way in which decisions are made[118], with the considerable variation in the way CSG companies work with landholders one sticking point.[85] The potential for conflict also appears exacerbated by the inequality that can arise from such developments, with landholders expressing concern that “most negative impacts are accrued locally, and may not be off-set by substantial positive impacts that accrue at larger regional scales”, and potential competition for resources such as water, housing and land.[85] Additionally, the capacity of local and regional governance to manage the changes wrought by development is a major issue.

Gas developments are often associated with considerable social changes to host communities due to an influx of workers, changes to the use of services and so on, with Australian LNG estimating a “cumulative peak of 6,300 construction workers could be required for all CSG projects by 2012”.[1]

Social issues such as violence and crime; sexually transmitted disease; suicide rates; and mental health problems have been associated with gas operations, however evidence regarding such effects is mixed, with a literature review noting evidence that “exposure to oil and gas activities can have serious negative social and psychological health implications. Conversely, there is some evidence that such industrial activities may be associated with positive social and psychological health outcomes”.[66] For example, while such developments have been associated with an increase in crime, they have also “been credited with a perceived decrease in local crime”, with other studies found no relationship between the two. There have also been conflicting reports regarding the impact of such activities on sexually transmitted diseases.[66]

It is apparent that the ratio of resident to non-resident work forces is of central importance, with social issues compounded by changing demographics that see these towns “increasingly dominated by ‘single’ males with limited education or training”.[5] A recent report discussing the effect of ‘fly-in, fly-out’ and ‘drive-in, drive-out’ (FIFO, DIDO) workers in Australia (a practice that is common in mining communities) noted many positive effects of these arrangements, however the authors concluded overall that this “work practice is eroding the liveability of some regional communities” and “exacerbating to an extreme level the divide between the cost of living in metropolitan and regional Australia”.[5] The negative effects noted by the majority of submissions from local governments and individuals included erosion of community identity, cohesion and safety; declining community engagement; and concerns over increased traffic accidents. In particular, the authors note the socially disruptive nature of these arrangements, which can often result in a “shadow population” with “serious and negative impact on the safety, image and amenity of communities”.[5]

However, there is also some evidence of improvements to local communities. A CEO of the APPEA noted that some companies have donated $1 million per week to local communities, including in one instance paying for an aero-medical evacuation facility that saved lives.[39] The FIFO report also noted that many companies make a “real effort to engage with communities through funding community infrastructure and sponsoring community events”, and that these arrangements potentially offered Indigenous Australians the opportunity for more engagement in the industry.[5]

3.5.2 Psychological

As with many mining operations, unconventional gas operations can affect psychological health. In addition to the direct effects on quality of life, poor psychological health can also exacerbate other health implications.

Mental health effects tend to be tied to the social effects noted above and the level of conflict associated with gas developments. Findings in this area face methodological difficulties and numerous confounding factors, making it difficult to draw any firm conclusions.[66] However, there have been many reports about “violence, predatory behaviour and high alcohol and drug use” in relation to FIFO workers, with the Australian Manufacturing Workers’ Union (AMWU) suggesting “that the social isolation experienced by FIFO workers can lead to alcohol and violence problems”, and other reports noting an increase in sexually transmitted and blood borne infections, mental health issues, fatigue related injuries and injuries related to high-risk behaviour (however it is also noted that some of these are related to the risk profile of young men generally).[5]

A recent study of the impacts of mining and CSG operations on the mental health of landholders and rural communities in southwest Queensland concluded that “the rural communities in this region are under sustained stress resulting from the incursion of the mining and coal seam gas industries. This has an impact on community mental health and well-being”, with additional strain put on community health services.[119] Similar issues have been noted in regards to coal mining expansion.[120]

It is clear that the visual impact of coal seam operations is of significant concern to many communities and advocacy groups. Apart from the impact of the well pads, drilling equipment, pipelines and infrastructure, there is the need for light when operations run during the night.

Changes to environment can in and of themselves have psychological effects. A study investigating the experiences of those suffering drought and mining using the conceptual framework of ‘solastalgia’ or “the distress that is produced by environmental change impacting on people while they are directly connected to their home environment”.[121] Those interviewed experienced loss to sense of place and “threats to personal health and wellbeing and a sense of injustice and powerlessness”.[121]

While it is difficult to ascertain the degree to which such psychological effects impact on well-being, and how this should fit into more objective measures of benefits and health burdens of energy generation, land-use that is extensive, particularly disruptive, or takes place in areas of cultural significance represents a potential pathway to ill-health, and can amplify some of the issues connected with other pathways.

Although a major focus of anti-wind farm activists, the significant levels of noise that can be generated by unconventional gas extraction by the use of compressors, site traffic and general operations has not attracted significant attention.[33,78]

However, there is some direct evidence relating to the low frequency noise of the kind caused by gas compressors, which can cause annoyance, stress, irritation, unease, fatigue, headache, adverse visual functions and disturbed sleep.[66] There is substantial research into measuring the levels of noise, predicting its effects and carrying out qualitative research to determine subjective experiences of noise in relation to wind farms which suggests some correlation with low frequency noise and annoyance.[122] There is no such body of work in relation to gas developments.

3.6 Distribution of health burdens

The distribution of health burdens is an important factor to take into account when considering the social justice implications of energy generation, and one that has been the subject of increasing focus in respect to environmental justice.

There were no studies identified that were solely concerned with the distribution of health burdens from unconventional gas operations or the demographics of those affected. However, some conclusions that can be drawn from the available literature and consideration of the locations of gas developments in Australia.

3.6.1 Workers

It is unclear exactly what the risks for workers in the Australian context will be for proposed gas developments.[123] A report on an increase in fatalities among oil and gas extraction workers in the US found that nearly half of the fatal injuries were caused by vehicle crashes and "workers being struck by machinery or equipment", with explosions accounting for 9%.[124] In many cases, these deaths were attributable to causes that could be mitigated through proper regulation and management.

Other potential health issues facing workers concern continuous exposures to toxic materials, airborne silica, radon, and risks associated with shift work. A Venezuelan study found that oil and gas workers had "chromosomal alterations due to continuous exposure to low levels of ionizing radiation".[66] The potential for silicosis resulting from the sand used as a proppant has been claimed as "the most significant known health hazard to workers", with 4 out of 5 air samples collected from 11 wells in 5 states exceeding the recommended exposure limits to for airborne silica.[123] Such exposure is associated with lung cancer, chronic obstructive pulmonary disease, autoimmune disease and chronic renal disease. While protective steps can be taken, workers can potentially be exposed to fracturing sand during moving, transporting, blending and refilling.

There are several studies demonstrating increased risk of cancer among shift workers who are exposed to light at night.[66]

3.6.2 Children and the elderly

Many of the potential health effects from unconventional gas extraction (such as exposures to NOx, SO_2, VOCs and PM) would have a disproportionate effect on the elderly, and children (because of their respiratory and metabolic rates, and developing systems).[66,125] The elderly may be more vulnerable to negative social effects and strains on health services.[66] The nature of some of the potential hazards also means that future generations would likely shoulder much of the health burden.

3.6.3 Rural and Indigenous communities

The nature and location of gas operations suggests that most of the effects will be felt by those living in rural, agricultural and Indigenous communities who are also "the very same communities who are already at most risk from the adverse effects of climate change".[103]

In the US context, several issues of environmental justice have been noted.[22] Different factors can intersect in these communities to increase their susceptibility to harm from chemical exposure:

> *For example, in local communities with oil and gas development where we have evidence that sexually transmitted infections have increased…how might this affect physiological or emotional stress levels, immune responses, and exposure to hazardous chemicals in air, water, or food?*[22]

There are also some positive health implications that may be experienced by local communities. However, careful attention needs to be paid to the character of the rural communities, the existing demographics and the potential intersection of health risks.

In Australia, unconventional gas extraction significantly impacts Indigenous communities because of the land on which gas resources lie. Reaction from Indigenous communities to coal seam gas developments has been extremely mixed.[126,127] As with other sectors of the Australian community, any benefits of economic development are also shadowed by the possibility for environmental and social damage.

3.6.4 Economic inequality

Some studies have demonstrated that the distribution of health impacts from energy generation "are disproportionately concentrated in disadvantaged areas".[128-131] Although such findings are only directly relevant to the areas where they have been carried out, the general susceptibility of those from low socioeconomic backgrounds to health harms suggests that any increase in health burdens will tend to effect this group disproportionately.

There is also some evidence that mining activities in Australia can lead to greater economic inequality, although this is dependent on many factors. One study found that:

> *Among men, inequality initially increases as mining employment in a region increases, but then sharply decreases; at high levels of mining activity, income inequality among men is lower than is typically observed in non-mining areas. Among women, income inequality increases with mining activity throughout its range. This suggests that income inequality is most likely to be a problem in locales with intermediate levels of mining activity and that it affects men and women quite differently.*[85]

In the case of unconventional gas resources, the high levels of foreign ownership alo suggest that the costs accrue to locals affected by gas developments, while most of the benefits are international.

3.6.5 Harms from export

Australia must also address the moral implications of our role as one of the world's largest exporters of gas. While the emissions from the combustion of exported gas are not included in our national inventory, it is arguable that countries have a *prima facie* responsibility for at least part of the harms caused by their exported emissions.

While it is beyond the scope of this report to address the health implications from the combustion of gas, it is clear that such emissions have serious short and long-term consequences for health. The WHO has suggested that climate change is already responsible for the deaths of 150,000 people annually[8], and the International Energy Agency has suggested that "only one third of the carbon contained in proven reserves of fossil fuels can be released into the atmosphere by 2050 if the world is to achieve its under 2°C goal".[132]

It is clear that the extraction and use of new fossil fuel resources needs to occur in a controlled and fair way, but there are currently no such constraints on our development of new gas resources.

Apart from concerns regarding the efficiency with which exported LNG is combusted, it is also likely that such exports will detract from emerging markets in renewable energy both domestically and internationally, increasing Australia's moral debt for the impacts of climate change.

Summary Section 3: Health implications of unconventional gas extraction

- *There are a range of exposure pathways through which unconventional gas extraction can impact on human health. In many cases, the likely harms are uncertain, however the role of human error means that even low risk events cannot be entirely dismissed and there are potentially serious health consequences.*
- *Potential impacts must be considered in light of the probable changes to be wrought by global warming, which will exacerbate many exposure pathways and further affect vulnerable communities.*
- *While exposure to fracturing fluids would be to dilute forms, the cumulative, interactive and low-dose effects are in many cases unknown. The risk of direct water contamination can be exacerbated by seismic activity, and there remain serious questions about abandoned wells and stranded fluids.*
- *Wastewater represents one of the highest risk exposure pathways and serious health hazards. Heavy metals, NORMs and other compounds can be mobilised through fracturing, many of which have acute health implications.*
- *While the character of current Australian operations makes air pathways somewhat lower risk than the US, the cumulative risks are potentially high, with many pollutants having health effects at a population level even in very low quantities.*
- *Land and water use are especially important pathways in Australia, with resource conflict already evident. Unconventional gas extraction can degrade land-quality through many pathways that may compromise resources for future generations.*
- *There is a high risk of significant impacts on ecosystems and biodiversity from gas developments, with the magnitude and nature of these impacts uncertain.*
- *Social and psychological pathways are highly dependent on the nature of unconventional gas operations and communities, however they can disrupt social cohesion. The burden of disease will mostly fall on rural populations and the vulnerable.*

4. Greenhouse gas emissions associated with unconventional gas

The current ecological and political climate has placed the impact of energy generation on climate change in the spotlight, with Australia committed to an unconditional 5% decrease of CO_2-e emissions from 2000 levels by 2020, and a 25% decrease conditional on a global deal to stabilize atmospheric GHGs to 450ppm.[133]

There are two related issues that are relevant to assessing the emissions profile of unconventional gas – the measurement of fugitive emissions and its overall level of emissions compared to other fuel sources. If only emissions from *combustion* are taken into account, gas appears a comparatively attractive option, with combined cycle gas-fired power plants estimated to produce about 40% of the CO_2-e emissions per megawatt hour (CO_2-e/MWh) of black coal-fired power plants, with an even greater advantage over lower rank coals.[23] However combustion emissions are not the full story, with the GHG potential of fugitive emissions a major concern for unconventional gas. These emissions, together with the impact of the unconventional gas industry on other forms of energy generation, have the potential to undermine any climate advantage claimed for unconventional gas over coal, with a recent government document stating that "fugitive emissions from shale gas raise questions about the effectiveness of gas as a 'bridging fuel' to a new, low-carbon energy sector".[19]

It is not just the amount of fugitive emissions that remains controversial, but also how these should be taken into account. CSG and shale gas are predominantly methane (CH_4), which is a considerably more potent greenhouse gas than CO_2. A widely accepted GWP for methane is 21-25 times that of CO_2 for a 100 year horizon, and 72 times greater on a 20 year horizon.[134] However, the interaction of methane with other emissions may also increase its greenhouse effect, with some authors claiming even higher GWP numbers.[135, 136]

The level of fugitive emissions assumed and how they are counted impacts considerably on the climate profile of unconventional gas in comparison with other energy sources. While there are a multitude of factors affecting such calculations, it has been estimated that fugitive emissions would need to remain below 2%-7% of total gas production to produce net climate benefits relative to coal across short and long-term time frames.[6,24,135,137-139]

Aside from fugitive and combustion emissions, unconventional gas extraction is responsible for other life-cycle emissions, and the development of gas-fired power stations has the potential to negatively affect renewables both domestically and in importing countries, which could substantially increase its negative climate impact.[7]

Several issues must then be considered that are relevant for ascertaining the comparative climate impact of unconventional gas—the levels of fugitive emissions, how such emissions are weighed, life-cycle emissions, and impacts on other energy sources.

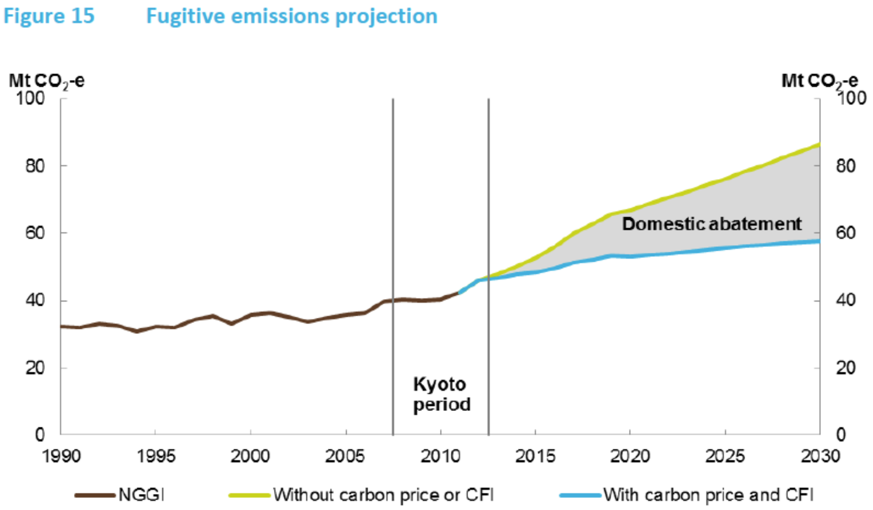
4.1 Emissions from unconventional gas

There are several potential sources of emissions accompanying well production, processing and distribution—some of which are classed as 'fugitive' or unintentional emissions, and some of which accompany normal gas operations. These include emissions from wastewater; the 'drilling-out' of plugs separating fracturing stages; venting and flaring; equipment leaks; gas processing; transport; storage and distribution.[6]

It is estimated that global fugitive emissions will increase from 1600 Mt to almost 2000 Mt CO_2-e per annum by 2030[140], in part due to the growth in unconventional gas, while it is projected that Australia's fugitive emissions will increase from an average of 42 Mt CO_2-e from 2008-2012 to 53 Mt CO_2-e in 2020 and 58 Mt CO_2-e by 2030 (*with* abatement from carbon pricing).[141] Figure 9 below shows the predicted increase in Australia's fugitive emissions to 2030.

There is no universally adopted method for deciding which sources of emissions to include, the data to use, or how to calculate final emissions, resulting in wide variance between estimates. In particular, estimations can vary substantially based on the amount of venting (releasing methane directly into the atmosphere) versus flaring (burning methane emissions, which reduces CO_2-e) that is assumed, and the amount of potential emissions that are assumed to be captured for processing. Little information currently exists about fugitive emissions in Australia, however there is reason to believe that fugitive emissions from CSG will be less than shale gas, due to the more straightforward extraction and treatment process.[44]

Figure 9: Australian fugitive emission projections.



Source: DCCEE

There are also several conflicting estimates regarding the level of fugitive emissions at which gas ceases to have a GHG advantage over new coal facilities across all time periods. A figure of 4.2%—representing the mean of existing estimates to be discussed further in section 4.2—will be used to organize some commonly cited estimates, with Australian estimates presented separately.

4.1.1 Fugitive emissions over 4.2% of gas production

One of the highest existing estimates of fugitive emissions is based on data compiled from different sources in the US in a study conducted by Howarth et al. This study estimated that, over its life cycle, "3.6 to 7.9% of the total production of the well is emitted to the atmosphere as methane"[6], resulting in a higher climate impact than coal over a 20-year period (to be discussed in section 4.2).

While these measurements have attracted criticism for assuming 100% venting and using data based on *potential* rather than *actual* emissions[142,143], another independent study detected even higher rates of fugitive emissions in Colorado and Utah using direct measurements and atmospheric modelling, finding leakage rates of approximately 4% (Colorado) and 9% (Utah) of the total production from these sites.[144] This suggests that estimates of 3.6 – 7.9% cannot be ruled out, at least under some operating conditions, and in fact there are even higher possible levels of fugitive emissions from unconventional gas extraction.

4.1.2 Fugitive emissions under 4.2% of gas production

Fugitive emissions figures from the US EPA are among those most commonly cited and used in comparing energy sources. Their major investigation into fugitive emissions from the US natural gas industry in 1997 estimated rates of 0.5 – 1.4%, however this was revised upwards in 2010 to approximately 2.2-2.4% of gas produced.[145]

Another study by O'Sullivan and Palstev looked at actual emissions from approximately 4,000 wells, noting that about 70% of *potential* emissions (included in Howarth et al's study) were captured, with a 50/50 mix of venting and flaring for the remainder.[143] This would bring the estimates of 3.6 – 7.9% by Howarth et al down to approximately 1.8 – 2.4% of gas produced, and represent a difference of over 1,000Mt of CO_2-e produced in the US (using a GWP of 25, taking an average of the production estimates from the reservoirs studied, and applying this to the approximately 25,000 wells in operation in the US).

Some high estimations also fail to take into full account technology that can reduce emissions, with the US EPA initiating an international Global Methane Initiative to "advance the abatement, recovery, and use of methane as a valuable clean energy source".[25] The EPA estimates that they can be reduced by 40%, with other estimates suggesting they can be lowered by up to 90%.[27] This would be financially attractive to industry, although the removal of the carbon tax in Australia would substantially reduce this incentive.

4.1.3 Australian sources

There is a lack of research into fugitive emissions from unconventional gas in Australia, with the CSIRO and the DCCEE currently collaborating on an investigation to improve available knowledge. However, the comparative simplicity of the extraction and processing of CSG compared to shale suggests that these emissions are likely to be much lower. While one industry figure puts fugitive emissions from CSG as low as 0.1% of total production[139], this seems highly unlikely, with the CSIRO giving a more realistic range of 1.3 – 4.4% of gas production.[23]

Researchers from Southern Cross University provided the first independent observation of GHG in the atmosphere of a CSG field in Australia, obtaining CH_4 and CO_2 concentrations in a CSG field in Tara, Queensland and comparative areas. Figures were not provided as a percentage of production, however:

> *The results clearly showed a widespread enrichment of both* CH_4 *and* CO_2 *within the production gas field compared to outside the gas field…Hotspots with concentrations of* CH_4 *as high as 6.89 ppm and* CO_2 *as high as 541 ppm were identified near Tara. For comparison, background atmospheric* CH_4 *outside the gas fields were lower than 2 ppm*[146]

They also noted radon levels were approximately three times higher in CSG dense areas than background levels, suggesting that this was diffusing through the soil. If methane were similarly diffusing, then "current methods of estimating fugitive emissions would underestimate greenhouse gas emissions".[74] While these results have not been peer reviewed, this suggests that current Australian estimates for CSG fugitive emissions may well be too low.

It is as yet unclear what emissions are likely from proposed Australian shale developments, although these will most likely be higher than CSG.

4.1.4 Life cycle emissions of greenhouse gases from unconventional gas

Life-cycle emission estimates take into account other sources of GHG emissions from gas developments, including those from combustion and infrastructure development, usually using a standard figure of combustion emissions of 57 kilotons a petajoule (kT/PJ) CO_2-e. These estimates vary considerably because of a number of factors, such as data used (including fugitive emission estimates); the assumed production quantities from the wells; the GWP figure used to convert levels of methane into CO_2-e emissions; and the efficiency of gas for electricity or heat generation.

It should be noted that the studies considered below take estimates of fugitive emissions from the low end, usually relying on US EPA figures of around 2%.

One such study of Marcellus shale gas (Jiang et al—using a fugitive emission rate of 2%; a mix of 76% flaring and 24% venting; and a GWP factor of 25) estimated "the development and completion of a typical Marcellus shale well results in roughly 5500t of [CO_2-e] emissions or about 1.8g CO_2-e/MJ of gas produced"[147], with total non-combustion emissions of 18kT/PJ. Another lifecycle analysis (Lechtenböhmer et al) provided a slightly higher estimated range of non-combustion emissions of 18 to 23kT/PJ from development and production, although the authors note that these could vary by up to a factor of ten depending on the methane production of the well.[67]

A further study (Broderick et al) noted several limitations in available data, basing their findings on the most accurate available non-peer reviewed data. The resulting estimate of non-combustion emissions was lower than others, amounting to 3.01 – 16.9g CO_2-e/MJ (equivalent to 3.10-16.9kT/PJ), totalling 60.01 – 73.9kT/PJ when 57g CO_2-e per MJ direct emissions are added.[62]

The variety of fugitive emission and life-cycle emissions estimates are presented in Table 7 below, including estimates of CO_2-e using both a 20 year (72 GWP) and 100 year (25 GWP) conversion factor.

Table 7: Summary of unconventional gas emission estimates.

Study	Fugitive emission % of total production	Fugitive emission per PJ	Fugitive emission CO2-e (GWP 25/ 72)/PJ	Notes
Fugitive emission estimates				
Petron et al 2012	1.68-7.7% Denver – likely estimate 4% Utah likely estimate 9%			Based on direct measurements and atmospheric modelling
Howarth et al	3.6-7.9%	450-770t /PJ*	11.3-19.3kT/ 32.5-55.5kT CO2-e/PJ	Based on estimates and compiled data.
O'Sullivan & Paltsev 2012		66.8 and 89.2t/PJ *potential* 15.9 and	1.7 and 2.2kT/ 4.8 and 6.4kT *potential* CO2-e/ PJ	Figures given per well. PJ rates calculated here using 2bcf/2.2PJ per well for Barnett and

Study	Fugitive emission % of total production	Fugitive emission per PJ	Fugitive emission CO2-e (GWP 25/ 72)/PJ	Notes
		21.3t/PJ *actual*	0.4 and 0.53kT/ 1.1 and 1.5kT *actual* CO2-e/PJ	6.5bcf/7.1PJ for Haynesville.
CSIRO	1.3-4.4%			Estimates for Australian CSG operations
US EPA	2.2 -2.4%	246t /PJ*	6.2kT/17.7kT CO2-e/PJ	Using US gas production data
SANTOS	0.1%			Estimate based on industry ‘accepted practice’
Hardisty et al	1.3-4.38%	160-230t /PJ*	4-5.8kT 11.5-16.5kT CO2-e/PJ [Parsons 17kT/PJ total emissions?]	Based on life-cycle analysis using Clark et al (2011) revised fugitive emissions estimates.
Life-cycle estimates				
Lechtenböhmer et al			18-23kT/PJ non-combustion emissions 75-80kT/PJ life-cycle	Standard estimate of *combustion* emissions for gas = 57kT/PJ
Jiang et al 2011	2%		18kT/PJ non-combustion emissions 63-75kT/PJ life-cycle	
Broderick et al 2011			0.14 – 1.63kT/PJ pre-production emissions 2.87 – 15.3kT/PJ fugitive emissions 60.01 – 73.9kT/PJ life-cycle	
Range of estimates	*0.1-9%*	*15.9 – 770t/PJ*	*0.33-16kT CO2-e/PJ (100 year)* *1.1-55.5kT CO2-e-PJ (20 year)*	

* calculations from Kember

4.2 Comparisons with other energy sources

While there is some consensus over the standard combustion emissions of gas, the considerable variation in estimates of life-cycle emissions translates to a wide disparity in its estimated climate impact compared to other forms of energy. It has been claimed that unconventional gas generates anywhere between 50% less to 20% more CO_2-e than new coal-fired power plants, depending on certain key assumptions such as the assumed efficiency of electricity generation[7,6,147]; the level of fugitive emissions; transport distances; and the GWP of methane. Comparisons are also made to different kinds of coal combustion technologies, with ‘subcritical’ coal being the most GHG intensive and ‘ultra-supercritical’ coal the least.

Variation in these assumptions also leads to different calculations of the level at which fugitive emissions would outweigh any climate benefits of unconventional gas over coal *across all time periods* (that is, including 20-year GWP). These range from approximately 2% fugitive emissions (lower than almost all the estimates discussed above) to 7% (higher than almost all the estimates discussed above). Although some commentators have disagreed with using 20-year GWP figures, the potential for irreversible and serious harms from climate change within this period makes this an important consideration.

Despite these substantial areas of disagreement, it is clear is that the climate profile of unconventional gas is worse than conventional gas and renewables, while its relationship to coal requires more detailed information about specific operations. This is especially in relation to the responsibilities that Australia has as a major exporter of gas. There are also further issues to be considered when assessing overall climate impact that will be returned to in section 4.3, such as the impact of the unconventional gas industry on other energy industries.

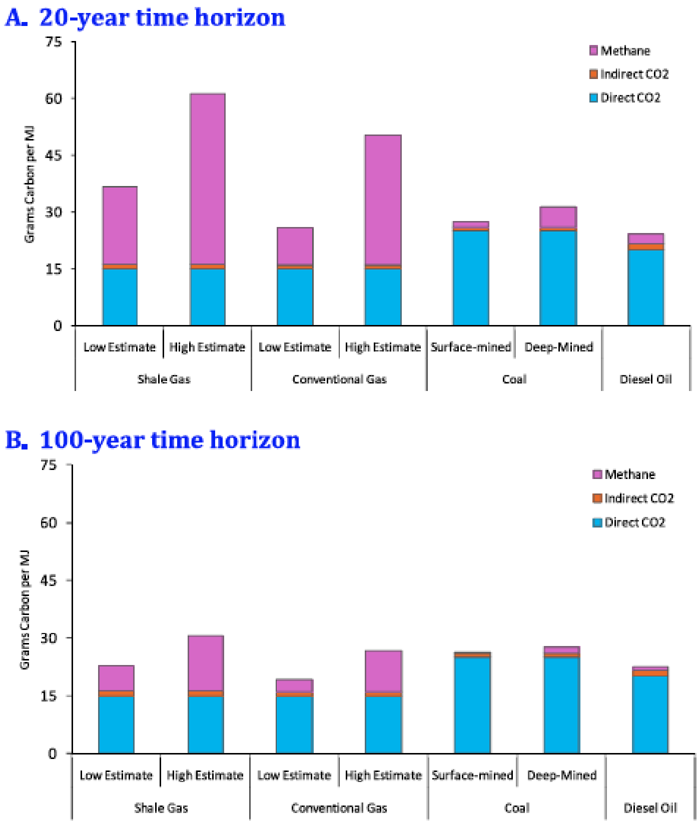
4.2.1 Comparisons with coal and conventional gas

Using the relatively high estimate of a 3.6 – 7.9% fugitive emission rate for unconventional gas and some other assumptions that have attracted controversy, Howarth et al argue that unconventional gas results in about 30- over 50% higher emissions than conventional gas, and would result in a GHG footprint 20% *higher than coal* over a 20-year period and roughly *equivalent to coal* over a 100-year period (see Figure 10 below).[6]

If these claims are borne out, this effectively discredits the claim that unconventional gas is a suitable stepping-stone or replacement for coal on grounds of climate impact. While Howarth et al do not provide a calculation of the percentage of fugitive emissions that would lead to breaking even with coal over all time periods, their conclusions suggest that these would need to remain well below 3.6%.

Howarth et al’s study has been criticized for focusing on the 20-year horizon; using a higher GWP figure than the standard (the authors used a GWP of 105 for the 20-year period, arguing this better reflected the interaction of methane and aerosols); using an unrealistic estimate of fugitive emissions; failing to take into account emissions reduction technology; and for making comparisons based on fuel combustion for heat generation rather than electricity generation (where gas has a higher efficiency). [142,143] This suggests a pessimistic interpretation that is unlikely to be found in Australian CSG operations. However, such estimates cannot be dismissed—especially in light of measurements of up to 9% fugitive emissions—and there is currently no information about the likely levels of fugitive emissions from Australian shale gas.

Figure 10: Comparison of shale gas, conventional gas, coal and diesel oil over a 20 and 100 year time period.



Source: Howarth et al 2011

By contrast, Jiang et al assumed a 10% higher efficiency for gas-fired electricity over coal in their estimation that non-combustion emissions of unconventional gas total 18kT/PJ, and claimed that the rate of fugitive emissions rate "would need to be 14% …before the overall life cycle emissions including those of electricity generation would be greater than coal….If we convert our data to the 20-year GWP the break-even point is reduced to 7%" (my italics).[147] This represents the highest available estimate of the level of fugitive emissions that would be required before gas was more GHG intensive in the short term. Under the estimates used, the authors claimed that unconventional gas produces between 20-50% *less* CO_2-e than coal, with a likely figure of 47% less than coal on a 100-year horizon[147]—a figure also approximated by another study using the same fugitive emission estimations.[148]

Box 3

Level of fugitive emissions at which gas has no GHG benefits over coal

Alvarez et al – 2%

Howarth et al – below 3.6%

Hardisty et al – 4%

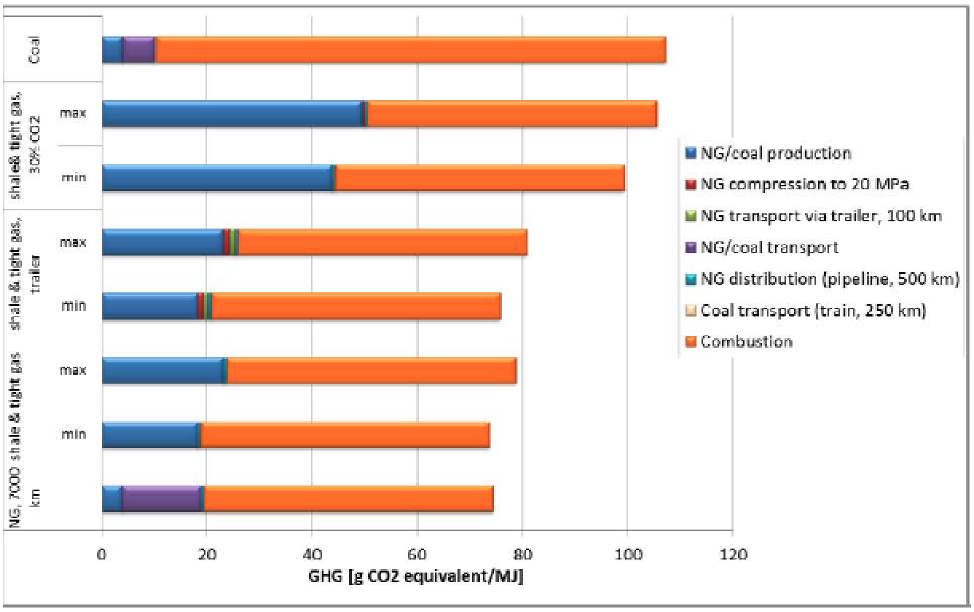
Jiang et al – 7%

(All estimates are for a 20-year period)

The study by Lechtenböhmer et al is more cautious in its conclusions, noting that the uncertainty in measuring emissions and the role played by other assumptions involved mean that GHG emissions from shale gas "are as low as those of conventional gas transported over long distances or as high as those of hard coal over the entire life cycle from extraction to combustion" (see

Figure 11 below).[67] Such a cautious approach seems more justified than estimates giving unconventional gas an across-the-board advantage over coal, especially if the potential for higher levels of fugitive emissions and lower efficiency combustion technology is taken into account.

Figure 11: Comparative emissions of shale and tight gas to conventional natural gas and coal.



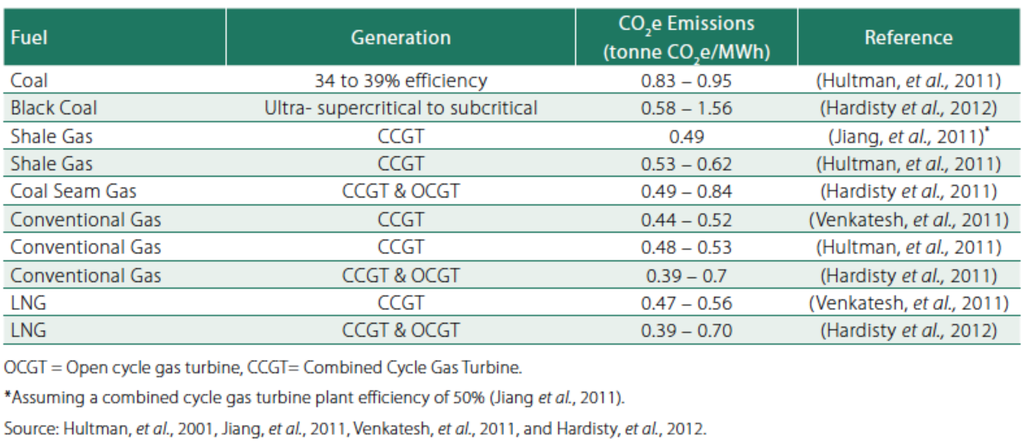
Source: own source

Source: Lechtenbohmer et al.

In the Australian context, a study conducted by Hardisty et al assuming best practice (including no venting, which is unlikely for Australian CSG) estimated CSG LNG was “approximately 13-20% more GHG intensive…than conventional LNG”.[7] Although it compared favourably to coal under many estimates, the authors note that methane leakages of 4% would, over a 20-year period, result in a GHG intensity of CSG-LNG generation “on par with sub-critical coal-fired generation”.[7] Given the CSIRO’s estimated range of 1.3 – 4.4% of total production[23], this is certainly a possibility. It is also important to note that these estimates do not take into account the affect of Australia’s exports where the combustion technologies are not likely to be as efficient, and is not necessarily representative of the emissions that might result from proposed shale gas operations on which there is currently no information.

A recent report from the Australian Council of Learned Academies (ACOLA) summarised some existing estimates of the GHG emissions from coal, unconventional gas and conventional gas (see Table 8 below). This table summarises some average to conservative estimates, and indicates the fact that some high estimates for unconventional gas exceed low estimates for coal (note that this is measured in tonnes CO_2-e/MWh and some assumptions are made regarding efficiency of energy generation that are not used in this report).

Table 8: Total life cycle emissions for electricity generation.



Fuel	Generation	CO_2e Emissions (tonne CO_2e/MWh)	Reference
Coal	34 to 39% efficiency	0.83 – 0.95	(Hultman, *et al.*, 2011)
Black Coal	Ultra- supercritical to subcritical	0.58 – 1.56	(Hardisty *et al.*, 2012)
Shale Gas	CCGT	0.49	(Jiang, *et al.*, 2011)*
Shale Gas	CCGT	0.53 – 0.62	(Hultman, *et al.*, 2011)
Coal Seam Gas	CCGT & OCGT	0.49 – 0.84	(Hardisty *et al.*, 2011)
Conventional Gas	CCGT	0.44 – 0.52	(Venkatesh, *et al.*, 2011)
Conventional Gas	CCGT	0.48 – 0.53	(Hultman, *et al.*, 2011)
Conventional Gas	CCGT & OCGT	0.39 – 0.7	(Hardisty *et al.*, 2011)
LNG	CCGT	0.47 – 0.56	(Venkatesh, *et al.*, 2011)
LNG	CCGT & OCGT	0.39 – 0.70	(Hardisty *et al.*, 2012)

OCGT = Open cycle gas turbine, CCGT= Combined Cycle Gas Turbine.

*Assuming a combined cycle gas turbine plant efficiency of 50% (Jiang *et al.*, 2011).

Source: Hultman, *et al.*, 2001, Jiang, *et al.*, 2011, Venkatesh, *et al.*, 2011, and Hardisty, *et al.*, 2012.

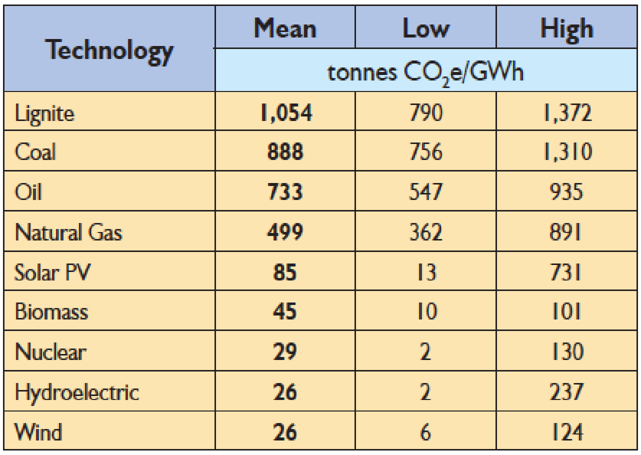
Source: ACOLA

4.2.2 Comparisons between gas and renewables

The discussion above has illustrated the substantial controversy that still exists over the GHG impact of unconventional gas versus coal and conventional gas. However, no such controversy exists for the relative impact of unconventional gas and renewables. Even the lowest estimates of CO_2-e emissions from unconventional gas are significantly higher than solar, wind and other such technologies. In addition, the life-cycle emissions from renewables largely come from the use of existing coal, gas and oil technologies in the manufacturing of parts, infrastructure and transport.

A table compiled using a wide range of existing estimates of different technologies by the World Nuclear Association gives some idea of the magnitude of differences (see Table 9 below). It should be noted that 'gas' here refers to conventional gas, so unconventional gas will produce higher quantities of CO_2-e than cited below.

Table 9: Comparison of lifecycle GHG emissions.



Technology	Mean	Low	High
	tonnes CO_2e/GWh		
Lignite	**1,054**	790	1,372
Coal	**888**	756	1,310
Oil	**733**	547	935
Natural Gas	**499**	362	891
Solar PV	**85**	13	731
Biomass	**45**	10	101
Nuclear	**29**	2	130
Hydroelectric	**26**	2	237
Wind	**26**	6	124

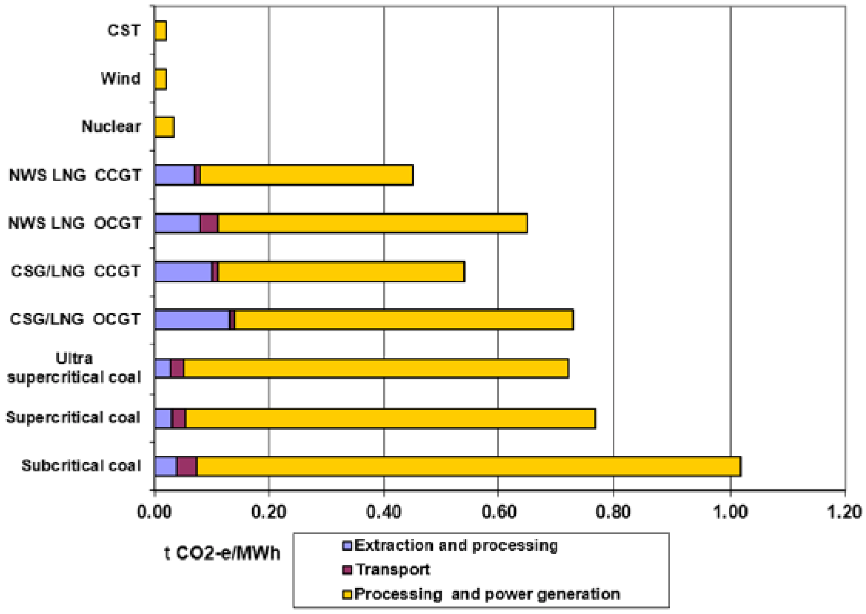
Source: World Nuclear Association.

This gap is even more significant if we consider that combustion technologies employed in export countries can significantly raise the GHG emissions of Australia's exported LNG, with Hardisty et al noting that:

> *When exported to China for electricity production, LNG was found to be 22-36 times more GHG intensive than wind and concentrated solar thermal (CST) power and 13-21 times more GHG intensive than nuclear power.*[7]

Figure 12 below compares emissions resulting from different electricity generation technologies likely for Australian exports with emissions from renewables, demonstrating the considerable differences in emissions (where CCGT, OCGT, ultra-supercritical, supercritical and subcritical refer to different energy generation technologies used for coal and gas).

Figure 12: Life-cycle emissions from Australian fossil fuel exports with renewable base-rates.



Source: Hardisty et al 2012

4.3 Assessing the climate impact of unconventional gas

There is a lack of consensus regarding many of the factors that determine the climate impact of unconventional gas that is accessed using hydraulic fracturing, including the measurement of fugitive emissions, the GWP of methane, the effects of emission reduction technology, and the consequences of exporting gas. Any comparison of the climate effect of different energy technologies will need to make justified assumptions about each of these issues, however there is strong evidence that the positive climate impact of unconventional gas has been substantially oversold.

Firstly it is important to note that, under any estimation, unconventional gas is responsible for considerable quantities of GHG in absolute terms at a time when these are of serious concern. The International Energy Agency recently stated that "Only one third of the carbon contained in proven reserves of fossil fuels can be released into the atmosphere by 2050 if the world is to achieve its under 2°C goal"[10]—a claim substantially at odds with Australia's push for massive expansion of its gas and coal industries.

These issues are compounded when the nature of methane in terms of its greenhouse effect is considered. While the figures used to establish the CO_2-e of methane for carbon-trading markets are currently 21 (100-year) and 72 (20-year), Howarth et al used weighting of 33 and 105 respectively[6,136], chosen because they better capture the interaction of methane with aerosols. Another source of controversy is the use of 20-year horizons as a basis for conclusions about relative climate impact. While the 20-year scale is often neglected, this is acknowledged as a critical period for mitigating serious climate change. There have been warnings over 'tipping points' that could occur in this period, such as melting permafrost, loss of ice-sheets, slowing of ocean circulation, or permanent changes in weather patterns.[134] The United Nations Environmental Program (UNEP) Climate and Clean Air Coalition (CCAC) have targeted short-lived climate pollutants (SLCPs) such as methane as "an urgent and collective challenge"[47], noting that "[c]utting SLCPs is a critical climate strategy for reducing near-term rate of global warming, particularly in regions most vulnerable to climate change".[149]

Although it is often argued that unconventional gas provides a viable way to lessen emissions compared to business-as-usual (a claim that is itself questionable, as demonstrated by the foregoing discussion), coal does not provide a good benchmark in this debate. Given the availability of other energy sources; the known climate and health harms of coal;[150] and Australia's obligations to reducing GHG emissions, it is more realistic to compare the emissions from unconventional gas with those attending emerging renewable options. Here the comparison is clear. Unconventional gas is responsible for emissions of a different scale than solar, wind, water or other technologies, no matter what assumptions are made in its favour.

Unconventional gas expansion can also harm other, less GHG intensive energy industries, especially when Australia's role as a major exporter is considered. It is quite possible that exports of Australian LNG will displace emerging markets in renewable energy in other countries, with one report noting that:

> *[T]he assumption that LNG exported to China, or any other Asian destination, would result in a coal-fired power station being taken off-line and replaced by a gas-fired power station is problematic. The International Energy Agency has recently suggested that…it is unlikely that LNG will displace coal in Asia.*[7]

It is also unclear what effect this will have on domestic markets, with signs that gas has displaced nuclear in the US, and indications that the current Australian government's pursuit of unconventional gas will come at the expense of commitments to the renewable industry.

It is clear from the foregoing discussion that the level of emissions and the overall impact of unconventional gas on climate change is a subject of ongoing controversy. It is important to take into account the emission reductions possible through the employment of new technologies, and to continue to base estimations on the broadest range of data available. However, the high short-term GWP of methane and the urgent challenges posed by climate change mean that many estimates are dangerously optimistic.

Summary Section 3: Greenhouse gas emissions

- *While there is some controversy over levels of emissions from unconventional gas vary considerably, these are vastly greater than renewables*
- *Estimates of fugitive emissions from unconventional gas range from 0.1% up to 9% of gas produced. Gas ceases to have GHG benefits over coal at levels of 2% - 7% fugitive emissions over a 20-year period, where short-term climate tipping points are a serious concern*
- *Unconventional gas can displace renewable energy markets domestically and internationally, adding to their overall climate impact*
- *The considerable uncertainty regarding emissions—especially in relation to the emerging shale gas industry in Australia—means that gas cannot be endorsed on the grounds of climate benefits even in relation to unsustainable coal use.*

5. Conclusion

The uncertainty surrounding the health and climate impacts of unconventional gas extraction highlights the careful consideration that needs to be given to the principles guiding future energy choices. Although there is a lack of concrete evidence regarding the link between some of the known exposures and negative health outcomes, this cannot be taken to suggest that such threats do not exist. Ultimately the assessment of whether there should be a continuation and expansion of the Australian unconventional gas industry depends on its emissions profile, general environmental impacts, health impacts, and community attitudes towards such operations.

The research on health introduces a clear cause for concern about a possible expansion of the industry. What the literature tells us is that there is considerable uncertainty concerning the likely impacts and their risk. However, although there is not the kind of clear health risks that are associated with products such as tobacco, the evidence that we have discussed has clear implications.

In terms of the most serious risks, wastewater represents a major source of concern. Heavy metals, NORMs and other compounds can be mobilised through fracturing, many of which have serious health implications in addition to those resulting from fracturing chemicals. While the risk of accidents can be mitigated by best practice, the track record of the industry in regards to accidental and deliberate releases of wastewater in Australia and the US does not suggest reason for optimism. Furthermore, no amount of best practice will ever remove the possibility of human error.

Fracturing fluids are generally becoming safer, and exposure would be to highly dilute forms through most pathways, however there is a lack of information regarding their likely health implications in the relevant quantities and exposure routes. In well-managed operations, the risk of direct contamination is low, however risks still exist which can be exacerbated by seismic activity, and there is uncertainty regarding cumulative, interactive and low-dose exposures for some chemicals, along with questions about abandoned wells and stranded fluids.

The cumulative risks associated with air pollution from unconventional gas extraction are potentially high, with studies in the US indicating substantially compromised air quality. The pollutants that are associated with these operations have been linked to several serious health outcomes, and many are suggested to have health effects at even very low amounts at a population level. While the character of Australian operations makes health issues from air pollution somewhat less concerning than their US counterparts, and some emissions can be reduced by equipment design, the gas industry’s argument that current 2km buffer zones should be scrapped could make this an area of increased concern.

Land and water use are important pathways in Australia, given our reliance on our ‘clean food’ reputation and the need for unconventional gas operations to share resources with farming and other practices. The amount of resources used by unconventional gas activities is substantial, and can have severe impacts on agriculture and irrigation activities in particular. Apart from direct use, unconventional gas extraction can cause erosion, subsistence, drawdown and unknown long-term impacts that may degrade these resources for future generations. The treatment of waste salt remains a known obstacle to environmentally sustainable practices. These impacts must also be considered in light of the likely changes wrought by global warming.

More indirectly, there is a high risk of significant impacts on ecosystems and biodiversity from gas developments. The magnitude and nature of these impacts is uncertain, however there are a number of identifiable risks including habitat fragmentation, increased risk of fire, increased opportunities for non-native species invasion and unknown effects of contaminants on food webs.

Social and psychological pathways are highly dependent on the nature of unconventional gas operations and communities. While operations can support local communities, large influxes of workers can disrupt social cohesion, with several reports illustrating the negative impact that such operations can have on residents, especially when FIFO workers are employed.

In addition to these very serious health risks we also need to note some more general points. As with any new or greatly expanded practice that may have a significant impact on our health we ought to demand a high level of assurance that there will not be unacceptable health risks. Given that so many of the risks that we have discussed pose a serious risk to health and have, in some cases, been actualised, we should not accept industry claims that the health risks are negligible enough to ignore. For instance, without convincing evidence concerning the management of wastewater, it is hard to conclude that expanded gas operations will be safe. Indeed, where a significant doubt exists concerning a health risk we should adopt a standard that is similar in some respects to the standards we employ when assessing new medical drugs for market release. Crucially, that the burden of proof ought to be on the proposers of the new practice to say with a high degree of certainty that the medicine or practice is safe. That kind of evidence does not currently exist in the case of unconventional gas mining.

A further set of concerns stem from the distribution of the health effects over the population and through time. While any resource boom will provide economic advantages for some, the question of how equitably these benefits are distributed is of concern. This is also true for the burden of disease more generally, with the location of the developments and nature of diseases meaning that this will mostly fall on rural populations and the vulnerable.

The impacts of unconventional gas developments are likely to be keenly felt by future generations. While we think that the risk of aquifer contamination is serious but ultimately relatively low, this risk cannot be ruled out in the future without an adequate (properly monitored and funded) system for ensuring that capped wells do not leak. If as some industry estimates predict 40,000 wells are drilled in Australia, all of these must be adequately sealed. Even if there is no immediate leakage this does not mean that there will not be potentially serious leakage in the future. This leaves a potential problem for future generations, which cannot be ruled out. Moreover, the costs are likely to be transferred to the public given the uncertainty of legal mechanisms for recovering the costs of such accidents from commercial entities that may have changed or ceased to exist.

When we add the possible health impacts to our concerns about the unfair distribution of health burdens, the disruption to communities and agriculture together with the huge increase in GHGs that a full expansion of the unconventional gas industry will entail, the current case against further expansion of the unconventional gas industry is overwhelming.

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