Subject: Cement Casing: The Weak Link of Fracking by R D Chapman , Moora , WA.

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I am a single parent of two teenagers and a homeowner in Moora. For the past 16 years I have been resident in Moora since arriving from Zimbabwe. I am a self employed mechanic involved predominately in the local agricultural industry. I am a permanent resident of Australia and will always be grateful to this nation and especially the local people of Moora for welcoming my family when we were forced out of Zimbabwe.

I knew nothing about fracking prior to 2015 until I was given a DVD called Fractured Country by a friend which highlighted the fracking industry in Queensland and the USA which I found most concerning and I was shocked to find out it was on our doorstep near Badgingarra - the Warro Gas field owned at the time by Latent Petroleum / Transerv energy.

Together with another concerned Moora resident; Marie Carter, we invited Jo Franklin, a representative, from Lock the Gate organisation, resident in Geraldton; to come and hold an information day at the Moora Rec. Centre with a morning and evening session . We had a small response and the Shire President at the time , Colin Gardiner , was the only shire council representative . He suggested we needed to hear the other side and that Stephen Keenihan from Latent Petroleum was holding a meeting at the community centre in Badgingarra in a few weeks after our presentation in Moora. This meeting was held in July/ August 2015 (I am uncertain of the exact date) and a small group of us from Moora attended. Stephen Keenihan introduced Dr Damian Barrett from CSIRO who gave us a long talk about how fracking is carried out and assured us that the CSIRO has tested the methods and integrity of the cement and bore casings thoroughly and that there was minimal risk of contamination to aquifers by bore failure due to the fracking process. He said the only risk of contamination was due to a spillage on the surface which would be easy to clean up.At the question time I was intrigued at what kind of hydraulic pressure was needed to crack highly compressed sandstone over thousands of years and four km. below the surface so I asked Dr Barrett " What is the hydraulic fracking pressure in PSI ? "

He was unable to even attempt to guess the answer and looked over to Stephen Keenihan who quickly answered " 1750 psi ". I doubted this answer as that is what some air compressors can deliver . On checking an Oil and Gas & Petroleum industry web site the next day the correct answer was 17000 - 22000 psi - a BIG difference. A major concern I had was that if CSIRO had tested the integrity of cement - sealing bore casings only months old; to seal against massive hydraulic pressure able to crack highly compressed sandstone over thousands of years; surely those pressure test figures would have been easy for Dr Barrett to recall and would have formed a major part of tests carried out by CSIRO ? Did any such testing take place or has CSIRO relied on assurances given to them by the Gas Industry ?

In approximately October of the same year Stephen Keenihan held another information meeting at the Dandaragan community centre where he explained about fracking on the same lines as Dr Barrett . He had a sample cross section of a bore casing with 3 bore casings fitting within eachother , each approx. 10mm thick steel and separated from eachother by cement approx. 75mm thick. Having had some experience of laying concrete and knowing the importance of eliminating air bubbles from freshly laid concrete to ensure it set hard , I found it hard to accept that pouring concrete 4000 metres down a space between 2 casings or the side of the bore hole which was less than 100mm wide would result in a perfect fill with no air pockets or even less likely no air bubbles. The sample he showed us was perfect but was easy to achieve on a vibrating table in a laboratory.

When asked how the risk of airpockets allowing hydraulic fluid to pass up between the casings or the outer casing and the side of the well hole and where small air bubbles in the cement would make it porous to fracking fluid at 22000psi ; he said they tested each sealed casing after a pour with a sonic instrument called a Log . It was gradually lowered down the casing and when an air pocket was detected it would be removed and a hole made through the casing at that point. The casing would be blocked/sealed below this point and then cement pumped in to fill the pocket. The plug would then be

removed and the hole in the casing welded closed. The log instrument would then be redeployed and the process repeated when the next airpocket was found. The question needs to be asked how long this process will take especially over a distance of 4000 metres and where time taken to get a well ready to frack is costing millions of dollars , how many shortcuts will be taken ? No amount of regulation can guarantee that when the pressure is on for a bore to be completed that the cementing process and testing afterwards will be done properly.
When asked by a local farmer, Grant Creigh ,what Latent Petroleum would do for him if his water bores became contaminated approx. 5 years after they had fracked on or near his farm, Stephen Keenihan said " You prove that we are responsible ". This made everyone realize that no farmer, no community and not even the WA state Govt. could take a multinational Gas/ Oil company which possibly turns over billions of dollars each year, to court and have a hope of winning a prolonged case where the evidence of the source of a contaminated water bore is hidden thousands of metres underground.
When asked if he realized that where Latent Petroleum were planning to drill after Warro., at what he called the Kolburn bore field was actually underneath the Watercorp bore supplying Moora and Dandaragan , surprisingly Stephen Keenihan was totally unaware of this fact.
When he was asked about the danger of earth tremors he said there had never been a recorded seismic activity in the Dandaragan / Moora region. He was corrected by a local farmer who farms in the Kolburn area, Ian Minty, who has experienced two earth tremors in his lifetime , including during the Meckering earth quake when he can remember the caravan he was in at the time rocking and shaking.
At the Warro gas field near Badgingarra , Latent Petroleum drilled and fracked four separate bores ,named Warro 3, 4 , 5 &6. On Warro 3&4 both bores had high volumes of water flow back and flooded to the extent they were abandoned. Latent Petroleum reported that they suspected deep undetected Aquifers had been breached during the fracking process by possibly a fault line. Yet at the meeting in Dandaragan Stephen Keenihan said that with 3D seismic surveys they could see any possible fault lines leading to aquifers. So how did 2 out of 4 bores fracked at Warro result in " unknown " aquifers being ruptured or is it the Yaragadee aquifer on which our district is so heavily dependant. In this one case with only 4 bores fracked there is a 50% failure rate. Apart from the gas company admitting something went wrong I am unaware of an Official enquiry and any testing of the Yaragadee aquifer close to these test bores to see if contamination has occurred. A question needs to be asked - if current regulations are so stringent how did this occur and why has no testing been done to find the cause of the flooding and try to seal the breach or plug the bore? Instead Latent Petroleum were allowed to continue to frack the remaining two bores Warro 5&6 which were successful. I feel that the Regulator should have prevented any further fracking after Warro 3&4 flooded and insisted on test holes being drilled into the Yarragadee aquifer near Warro 3&4 to make certain there was no contamination. In this instance this was probably the only wells being fracked in WA and the State regulating and monitoring body overseeing this industry has failed completely to carry out a full and proper investigation as to the cause and effect of this bore failure. What will happen if Fracking is allowed to proceed throughout WA and hundreds of wells are being fracked every month ? This is one example that shows me that if Gas companies are allowed to carry out full scale exploration and development of a fracked gas industry in WA any regulations to control this industry will not be worth the paper they are written on.
My concern for Moora and any other community including Perth which are dependant on an aquifer like the Yaragadee for their water source and deep below that aquifer are gas deposits which can only be extracted by fracking; what will happen to that community if one day during the lifetime of the gas bores - anytime from 1-50 years after fracking, that Watercorp on a daily water test of the water bore find toxic petrochemical contaminants and cease pumping to that community. How long would it take to replace the supply to a small community like Moora or Dandaragan and how would this occur . What about Perth ? Well I guess an easy decision for Perth in the short term would be to cut the Kalgoorlie pipeline at the expense of the eastern wheatbelt towns and farmers who are all so heavily reliant on this water source , not to mention closing down Kalgoorlie and the mining industry - absolutely not an option . In my view if any WA govt. were to allow a gas-fracking industry to proceed this scenario has to be considered . The option of trying to keep toxic water test results a secret and telling Water Corp to keep pumping to unsuspecting communities would have dire consequences . Before the WA Govt. allows any gas exploration using fracking to continue I believe for every single community , farm or intensive horticulture project dependant on underground water (which is everyone including Perth) , the WA Govt. with the Federal Govt. must Guarantee everyone a continuation of supply of clean water at a rate equal to current consumption with provision for increased consumption allowing for normal economic growth and expansion in the future. This guarantee must be detailed to show where the water will be sourced from (which cannot be a local bore in the same aquifer) and costed plus estimated time when this alternative water source will be connected . It should also provide for an interim temporary supply of water (at full usage rates prior to contamination) to the community , farm or orchard ie Moora Citrus . A simple connection to the Kalgoorlie pipeline system serving the wheatbelt east of the Great North highway is not acceptable as this is already oversubscribed and requires injection currently, of de-salinated water from Perth.

It is the fundamental right of every resident in WA and Australia to access to clean drinking water and that those sources of drinking water (including for arable or industrial use) are protected by Federal and State Governments. Should any Federal or State Government allow an activity , such as fracking or mining , which could possibly cause contamination or any loss of existing supply of clean water in any area within Australia; before allowing that activity to proceed ; that Government should give a guarantee residents in that area that the quality and volume of their water supply will not be affected and provide a costed plan to replace their water from another source should contamination or loss occur.This should include a short term replacement while the permanent replacement is constructed. The replacement plan should be implemented immediately once contamination or loss of existing volume of supply is found to have occurred. There should be no delays while the cause is investigated or Court proceedings to appropriate blame and liability to whichever party has caused the contamination or loss of volume of supply.
It is the responsibility of Government to assess the risk to water supply by any form of activity for which they may give approval. It is also the responsibility of Government to provide regulations to govern that activity and to ensure the regulations are fully implemented and adhered to. Should that activity , while adhering to all regulations implemented by Government , cause contamination or loss of volume of pre-existing supplies of water; it is ultimately the Government who allowed that activity to proceed who is liable and must honour their guarantee to replace any loss of supply of clean water.

Research sources for this Article

1 Cement Casing : The Weak Link of Fracking by Bernhard Debatin Nov 28 2011
2 Shale Gas : How Often Do Fracked Wells Leak by Andrew Nikiforuk Jan. 10 2013
3 Fluid Migration Mechanisms Due to Faulty Well Design And / Or Construction: An Overview And Recent Experiences In The Pennsylvania Marcellus Play
By Anthony R. Ingraffea, PH.D. , P.E. October 2012.
4 DESMOG - Fracked Well Failures
5 Assessment and risk analysis of Casing and Cement Impairment in Oil and Gas wells in Pennsylvania, 2000 - 2012.
Authors : Anthony R Ingraffea , Martin T Wells , Renee L. Santoro , Seth B.C . Shonkoff.
6 Information Summary on Unconventional Gas Development for WA Scientific Inquiry - by Bryan Whan - Chapter 5 - Well Integrity and Failure.

Article 1 Cement Casing : The weak link of Fracking .

Bernhard Debatin quotes an EPA Groundwater Investigation report of Nov. 9 2011, where " a pair of environmental monitoring wells drilled deep into an aquifer in Pavillion , Wyoming, contain high levels of cancer - causing compounds and at least one chemical used in hydraulic fracturing ."
" the chemical compounds the EPA detected are consistent with those produced from drilling processes , including one - a solvent called 2- Butoxyethanol (2 - BE) widely used in the process of hydraulic fracturing "
Another decisive result of this investigation is that methane found in the aquifers was " at near saturation levels (up to 19mg/l) " and has a " similar istopic signature to production gas"
This defeats the industrys claim that methane in the groundwater is merely a natural occurrence and not caused by fracking , since methane from shallower layers has a different chemical makeup.

Chris Mooney in his article " The Truth about Fracking (in the American Scientist , Nov. 11 , Vol. 305 , Issue 5 , p. 80 - 85) he states " Faulty cementing is the leading suspect in possible causes of contamination , and by the industrys definition is not part of fracking ."
Which means the industrys claim that fracking causes no contamination whatsoever is based on the arbitrary and in fact faulty definition that fracking is limited to an *event* some thousand feet below ground , but does not include the *process* of pumping pressurized chemicals , water , and gas up and down the well.

There is , in fact , growing concern among scientists about the lack of reliability of cement casings . The below quoted article in the American Scientists calls cementing the " weak link " of fracking.
Cementing is the obvious " weak link " , according to Anthony Gorody , a hydrogeologist and consultant to gas companies who has been a defender of fracking. Other scientists emphatically agree. "If you do a poor job of installing the well casing , you potentially open a pathway for the stuff to flow out ," explains ecologist and water resource expert Robert B. Jackson of Duke Universitys Nicholas School of Environment .

Although many regulations govern well cementing and although industry has strived to improve its practices , the problem may not be fully fixable.
"A significant percentage of cement jobs will fail ," Ingraffia says . " It will always be that way . It goes with the territory."
Dr Anthony Ingraffea holds the Dwight C. Baum Professorship of Engineering at Cornell Universitys School of Civil and Environmental Engineering. He got his doctorate in rock fracturing and directs the Cornell Fracture Group, which specializes in computational simulations fracturing. He contends that while cement failure has been a chronic and known problem , the industry is not willing to share any data about cement failures with regulatory agencies.

Update , Dec. 14 , 2011 :While the overall problem with cement casing remains the leading suspect for most cases of undergroundwater contamination , the case of Pavilion , Wyoming , is different : The EPA report clearly excludes cement failure (due to lack of cement traces in the water samples) and concluded that the contamination came directly from the fracking area through vertical fissures and cracks into the aquifer (see e.g. p. 20, 34, and 38f. of the report).
This in itself is a frightening finding because the industry has continuously insisted that such occurrences are impossible.

A question must again be asked why at Warro wells 3 & 4 in WA there has to date been no environmental monitoring wells drilled to test the Yaragadee aquifer for contamination and the source of flooding to both wells plus what caused the flooding after fracking. Does this mean that the regulations governing this industry in WA do not demand any investigation but rather allow for further fracking to continue with no hold until the cause of flooding to Warro 3 & 4 was ascertained and that there was no traceable contaminants in any freshwater aquifer ?

Article 2 :
SHALE GAS : HOW OFTEN DO FRACKED WELLS LEAK ?

Andrew Nikiforuk attributes the main source for this article is Cornell University Engineer , Anthony Ingraffea
(http://thetyee.ca/Series/2013/01/08/Fracking-Myths-And-Realities/) who has studied the non linear science of rock fractures for three decades.

Moreover industry studies show that five to seven percent of all new oil and gas wells leak . As wells age , the percentage of leakers can increase to a startling 30 or 50 per cent. But the worst leakers remain "deviated " or horizontal wells commonly used for hydraulic fracturing .

In fact leaking wellbores has been a persistent and chronic problem for decades.
Even a 2003 article in Oil Field Review
(http://www.slb.com/~/media/Files/resources/oilfield_review/ors03/aut03/p62_76.ashx), a publication of Schlumberger, reported that , "Since the earliest gas wells , uncontrolled migration of hydrocarbons to the surface has challenged the oil and gas industry.

Aging can affect leakage too. Old and decaying cement jobs largely explain why offshore oil wells in the Gulf of Mexico report leakage rates as high as 60 % after 16 years service. Abandoned wells can also become major pollution portals.
(http://www.nytimes.com/1992/05/03us/abandoned-oil-and-gas-wells-become-pollution-portals.html?src=pm)

The Norwegian Petroleum Safety Authority reports that 18% of its deep offshore oil and gas wells have integrity problems , while Australia struggles with chronic leaks from fractured coal bed methane wells.
Based on industry reports to regulators as opposed to independent audits , about 5% of Alberta s 300,000 oil and gas wells now leak (15000 leaking wells)
But 2009 study (http://www.spe.org/ejournals/jsp/journalapp.jsp?pageType=Preview&jid=EDC&mid=SPE-106817-PA) by Alberta scientists Stephan Bachu and Theresa Watson found that so called " deviated wells "
(the same kind right angling used for fracturing shale gas and tight oil formations) typically experience leakage rates as high as 60% as they age. Moreover high pressure fracturing increased the potential to create pathways to other wells, the atmosphere and ground water.
(http://www.ieghg.org/docs/wellbore/Wellbore%20Presentations/4th%20Mtg/19.pdf)

Leaking of toxic fracture fluids is also common because only 25 to 60 per cent of diluted chemicals and water used to blast open shale or coal formations are ever recovered (stated by Theresa Watson , now a member of Alberta s Energy Resources Conservation Board).

What 16,017 inspection reports said .

In 2012 Ingraffea and colleagues read through 16,017 inspection reports filed over the last four years. What they found (http://www.damascuscitizenforsustainability.org/wp-content/uploads/2012/11/PSECementFailureCausesRateAnalysisIngraffea.pdf) was a significant and steady rate of methane leaks at the well bore or what is known in industry jargon as " bubbling in the cellar "

In 2010 , 111 of 1609 wells drilled and fracked , failed and leaked.Thats a 6.9 % rate of failure. In 2012 , 67 out of 1014 wells leaked - a 7% rate of failure.

" We looked at violations and not comments ," adds Ingraffea . Quite often inspectors would note that a well was leaking like a sieve but that violation was pending. As a consequence the 7% figure represents a dramatic underestimate of methane leaks says Ingraffea.

Moreover , the 7% figure only includes leaks at the wellhead. It does not include leaks that sprouted up in stream beds , water wells , or ponds often 2,000 feet away from the well site after steady fracking operations.

Evidence is growing that toxic fluids used for hydraulic fracturing can also migrate into adjacent water bodies . A 2012 study in the journal Ground Water warned that hydraulic fracturing opens more pathways for the movement of both fluids and methane. And a recent study by the US Environmental Protection Agency in Pavilion , Wyoming, found that toxic fluids had contaminated local water supplies.

The scientific truth is irrefutable says Ingraffea: " Fluid migration from faulty wells is a well known chronic problem with an expected rate of occurrence." Inadequate well construction and monitoring remains a persistent industry problem.

The health implications are also serious . The migration of methane or fracking fluid has repeatedly contaminated groundwater across North America or polluted the atmosphere with methane , a potent greenhouse gas.

Article 3
Fluid Migration Mechanisms Due to Faulty Well Design And /Or Construction: An Overview and Recent Experiences in the Pennsylvania Marcellus Play

By Anthony R Ingraffea , PH.D., P.E
October 2012

1.0 Introduction : Loss of Well Structural Integrity.

An overall description of mechanisms by which oil and gas wells can develop gas and other fluid leaks can be found in Dusseault *et al* . (2000) . These mechanisms can be exacerbated with repeated pressurization of the casing , with open-annulus sections along the casing , and with high gas pressures encountering curing cement or entering such open hole sections.All of these exacerbating factors lead to more rapid occurrence and upward growth of circumferential fractures , essentially disbonding , in the rock- cement and/or the cement- casing interface.

The article includes diagrams showing how gas and fracking fluids can bypass cement seals to gain access to aquifers and the surface. Also shown are charts showing the frequency of occurrence of sustained casing pressure of wells in the outer continental shelf area of the Gulf of Mexico from the
United States Mineral Management Service and historical levels of drilling activity and sustained casing vent flow (SCVF) or gas migration (GM).

In their statistical analysis of information about nearly 315,000 onshore oil and gas wells Watson and Bachu (2009) state:
" Low cement top or exposed casing was found to be the most important indicator for SCVF/GM . The effect of low or poor cement was evaluated on the basis of the location of the SCVF/GM compared to the cement top ... the vast majority of SCVF/GM originates from formations not isolated by cement "

2.0 Prevalence of Fluid Migration From Faulty Wells.

The science on contamination of drinking water from shale gas drilling , fracking , and production , is recent , ongoing , and incomplete. A peer-reviewed , archival journal study from Duke University (Osborne,*et al.,* 2011) found apparent migration of substantial amounts of methane from gas wells to private water wells as far out as 1000m in the Marcellus play in Pennsylvania.
A more recent paper from the Duke University team (Warner, *et al* ., 2012) ... found in Pavilion , Wyoming , clear evidence that there had been migration of methane from gas wells to nearby drinking water wells - likely caused by deficient cement jobs . Inadequate well construction and, of course , spills have been implicated in many states in a large number of cases of migration of drilling related substances into nearby drinking water.
In the article Ingraffea states Gas industry sources have asserted that private water wells are often contaminated by naturally occurring methane. This is presented in an apparently analytical and confusing way , suggesting that it is common for methane to suddenly occur in private water wells and be unrelated to any gas well drilling. He continues ...
Such presentation fails nearly entirely to :
1 Distinguish between dangerous/hazardous levels of methane in water (7mg/L or more in PA), and much lower levels that are not generally taken to
be of concern.
2 It ignores the prevalence or likelihood of having a dangerous natural level of methane in drinking water.

3 It ignores any time line : has there been any change in the concentration of methane concurrent with the beginning of a nearby gas field.

In conclusion he quotes findings from water test results in the Delaware, Genesee, and St Lawrence River Basins; Southern Tier of NY and Alberta Canada , stating ...
None of these findings suggest, in any way, that dangerous levels of methane are at all common in rural private water wells. Thus a fairly strong implication is that , if and when methane does occur at high levels in water wells near gas drilling, it is likely due to some aspects of gas drilling , fracking and/or production operations themselves. This is consistent with both the Osborne,*et al., (2011)* study an the EPA Pavilion (2011) preliminary report. Exact migration mechanisms are not yet completely clear in each case , but the potential well failure mechanisms described in the previous section are often implicated.

3 .0 Recent Experiences in the PA Marcellus Play.

In this section Ingraffea deals with a review f the PA DEP Marcellus Violations database at http://www.depreportingservices.state.pa.us/ReportServer/Pages/ReportViewer.aspx?/Oil_Gas/OG_Compliance.

He gives a table shown in figure6 on methane concentration found in private water wells in Susquehanna County, PA. Of 2433 wells tested 89.5% had concentrations of methane < 0.5mg/L and 95.6% had concentrations of methane < 7.0 mg/L .
The data was obtained by searching the violations data base for all violations indicating that the well was leaking outside its production casing , the Violation Codes of which are detailed in table 1 on page 7. Ingraffea contends the results do not represent a true result. He continues...
All inspection reports for more than 6000 wells drilled to date in the Marcellus in PA were reviewed ; this is a more complete and revealing search than just filtering on certain violations. The inspection reports indicate that many failed wells were not issued violations . Rather they received " Violation Pending " comments ; or comments indicating that "squeezing", a cement repair procedure which would only be done if a well was leaking outside its production casing , had been done or was to be done; or comments that repairs were underway for a perforated casing; or comments that gas was detected at the wellhead at or above the LEL (lower explosive limit).
Finally it should be noted that a well that appears , at its wellhead , not to be leaking is not necessarily a sound well. It is well known that fluid migration can occur a significant distance away from the wellhead of a well that appears on inspection of only the wellhead to be of sound structural integrity.

4 . 0 Summary

The most recent experience with shale gas wells in the Pennsylvania Marcellus play reflects long term , world-wide industry data with respect to new wells with compromised structural integrity .

Operator - wide statistics in Pennsylvania show that about 6-7% of new wells drilled in each of the past three years have compromised structural integrity . This apparently low failure rate should be seen in the context of the full buildout in the Pennsylvania Marcellus of at least 100,000 new wells , and in the entire Marcellus , including New York , of twice that number. Therefore , based on recent statistical evidence , one could expect at least 10,000 new wells with compromised structural integrity. It is too early to discern wether the other industry experience with this technical problem , an increase in loss of integrity with old age, will also be reflected. However, at play in modern shale gas development are many of the key factors identified by industry researchers as having a negative influence on well structural integrity:
1 The need for deviated wells
2 Rapid development of a field
3 Presence of " shallow " high-pressure gas horizons
4 Disturbance of young cement due to adjacent drilling activities on the same pad.

It should be noted that if the total number of wells expected to be drilled in the Marcellus area ie 200,000 were to lose structural integrity similar to the statistics in this article on the wells in the Gulf of Mexico and onshore in Alberta Canada , with failure as high as 60 % after only 16 years, as many as 120,000 wells in the Marcellus could be leaking methane into ground water and the atmosphere by 2030. This % will steadily increase as these wells get older.

In the Australian context many gas wells will be drilled through fresh water aquifers and also highly saline aquifers(twice as concentrated as sea water) before reaching gas deposits. It is well known that steel and cement corrode rapidly in saline water. As steel oxidises (rusts) it expands with considerable force. This force will react on the cement encasing the steel bore casing causing it to fracture and disintegrate more rapidly and further assisted by chemical deterioration of the cement by salt water .Basically the bores as they deteriorated would become conduits for deep highly saline water under extreme pressure to travel upwards and infiltrate fresh water aquifers on which most rural communities are entirely dependant for their needs with no other source of supply in this dry continent. The USA has snowcapped mountains and large river systems and lakes which capture rainfall. We have nothing similar except large untapped river systems up north which no-one is allowed to dam when they flow once a year.
I quote from an example of one such leaking well in N Territory from Information Summary on Unconventional Gas Development for WA Scientific Inquiry prepared by Bryan Whan .In section 5.4 he gives an example :
"An example of the effect of corrosive water on cementing and casing is provided by deep oil exploration wells drilled in the Perdika / Great Artesian Basin in NT in the 1960 s . Now, some 50 years later , the steel casing has almost entirely corroded away , resulting in inter-aquifer contamination . This well required expensive rehabilitation works to stem artesian flow.This single bore cost the Northern Territory and Commonwealth Governments $500,000 to plug as the company responsible for the well was insolvent.This example highlights the issue of operator insolvency due to the boom and bust cycles of oil and gas development which complicate efforts to hold liable parties responsible and provide for timely environmental reclamation".
If this example is costed to 120,000 wells in the Marcellus basin in 50 years from now, at todays costing the USA taxpayer would have to foot a bill of $60,000,000,000 (sixty trillion dollars !) in 2058. Considering oil and gas companies are exempt from prosecution for contamination of underground and surface water thanks to indemnity given to them by the US Congress in the legislation nicknamed the Halliburton Loophole; it is the American taxpayer who will foot this bill. This is only in the Marcellus basin, what will be the total cost of plugging old wells throughout the USA and Canada at much higher costs in 50 years from now?

This same problem will exist for Australia if the gas industry is allowed to go ahead. Yes it is worth millions of dollars in royalties now but how much of that will have to be kept to repair all the damage at the end and our mining boom years show us that no reserves of royalties paid were kept for the future. Instead we sit with a
$ 40 billion dollar deficit. Imagine if we needed to find $ 60 trillion to seal the gas wells in WA at the end of the gas boom.

Article 4

DESMOG - Fracked Well Failures

This article is in the same vein as the previous article and draws from information given by Anthony Ingraffea but highlights the failures in the State Regulation of the gas industry in the USA and, gives numerous examples with references to sources.

For the past several years ,the shale gas industry has argued that oversight of fracking is getting tighter and that the amount of methane gas leaking from their wells is less than some have speculated.
In Pennsylvania the opposite is true , according to a white paper (http://catskillcitizens.org/learnmore/PSECementFailureCausesRateAnalysisIngraffea.pdf) delivered to New York state regulators by Cornell engineering professor , Anthony Ingraffea. Inspection data from the state indicate that over 150 Marcellus shale wells had severe flaws that have led to sometimes large leaks and yet operators of these wells were never issued violations by regulators for breaches of state law.
By failing to cite drillers when things go wrong , Pennsylvania environmental regulators have for the past 3 years obscured the rate at which the Marcellus wells leak, creating a falsely optimistic picture. Leaks at dozens of wells were described by state inspectors in their report notes , but violations were never issued.
If analysts relied on data about violations alone , it would seem that 6.2% of wells drilled in 2010 failed. In fact, the rate was 6.9% according to notes in inspection reports , leaving a difference of 0.7%. By 2011 a full 1% of well failures were going uncited. For the first half of 2012 the DEP s violation data showed a 7.2% of well failures, while a review of inspection reports shows an 8.9% failure rate for the full year . Put another way , Pennsylvania officials discovered that 76 Marcellus wells drilled in 2012 lost integrity but never cited drillers for these problems.
Why do these numbers matter ?
Roughly over 200,000 wells will be drilled across the entire Marcellus region over the next decades, so these percentages add up to a lot of escaping
gas.
The leak rate is also important because natural gas is so often portrayed as cleaner than coal with regards to climate change. Natural gas does have far lower emissions when burned , compared to coal . But when natural gas - also known as the greenhouse gas methane - is allowed to leak into the atmosphere unburned it has climate changing impacts that , depending on time frame , are 30 to 100 times more destructive than those from carbon dioxide.
The article describes gas leaks in the Chesapeake gas wells which contaminated water wells in Bradford County which resulted in water turning black and undrinkable.The DEP ordered the Chesapeake gas company to provide alternative supplies of water to dozens of families . A consent order from the cases settlement specifically describes notices of violations issued by the DEP to Chesapeake over failed gas wells. The company attempted , at times unsuccessfully, to repair the methane leaks . But no violations for these events appear in the states data on well failure rates.
Of great concern is the following report (http://public-accountability.org.wp-content/uploads/Fracking-and-the-Revolving-Door-in-Pennsylvania.pdf)which offers new insight into the relationship between the Regulators and the Gas Industry in Pennsylvania. The report describes in stark detail the coziness between the drilling industry and the people in Pennsylvania who are supposed to police it.
A revolving door between the natural gas industry and environmental spins quickly in the state. One person featured in the report is John Hanger , who directed the DEP under a democratic administration when the Marcellus boom first took hold in Pennsylvania. He was tasked with policing the industry , but under his watch the state was opened in new ways to drillers and major environmental problems emerged. Mr Hanger is now special counsel to a law firm that represents every segment of the fossil fuel industry, including the states oil and gas industry association, and is also running for governor.
"Twenty DEP employees have held jobs in the energy industry either before or after their agency jobs" the Public Accountability Initiative reported.
" Every Secretary of Environmental Protection since the DEP was created has had ties to the natural gas industry." And all three of the states recent governors have industry ties.
This report is an eye-opener in that it reveals that the gas industry has powerful influence from governors of states where they operate to staff in the DEP who are supposed to police their industry and protect the environment and have failed to do so to the advantage of the gas industry. It would be hard to assume the same tactics will not be used by the gas industry in Australia. As Cecil John Rhodes , mining magnate and governor of the Cape Province in South Africa once quoted " Every man can be bought , it is just to find out what he wants - as often it is not monetary ".
A prime example cited in the report is a Mr Krancer , director of the DEP in Pennsylvania in 2011 where :
A leaked memo revealed that he was requiring all violations to be approved by DEP headquarters instead of directly issued by field staff , as had been the norm previously. After the memo was publicized , Krancer recinded the policy. But the data indicates that enforcement may have been chilled as inspectors became less likely to issue violations for known problems on Krancer s watch.
Pennsylvania s drilling boom is often cited as a textbook example of how not to handle drilling.

The Pennsylvania auditor general is currently investigating Mr Krancers oversight of the shale gas industry. And at a state budget hearing , lawmakers grilled Mr Krancer about his agency s record. One lawmaker pointed out that nine of every ten Marcellus Shale violations in 2011 resulted in no fines.
Mr Krancer , however, argued that there is a logic to not penalizing drillers when they break the law.
" The idea of an issuance of a notice of violation is not to issue a fine," said Mr Krancer during the hearing. " The idea is to bring conduct which is potentially volatile to the attention of the operator so the operator can do something about it. "
So how is that theory working out?
Virtually all evidence coming from the state seems to show this type of oversight works better for the drillers than residents of the state. The data shows that operators have failed to " do something bout it ". Instead the opposite is true. Drillers have grown more likely to make mistakes as time goes on and recently drilled wells have a worse track record than those drilled years ago. But when accidents happen , state regulators , it seems , have simply been turning a blind eye.
Warro 3&4 at Badgingarra in WA are a prime example of failure by State regulators.

Article 5
Assessment and risk analysis of casing and cement impairment in oil and gas wells in Pennsylvania 2000 - 2012
Proceedings of the National Academy of Sciences.
This article provides a thorough investigation and analysis of records covering over 41,000 gas wells in the Marcellus basin, both conventional and unconventional to determine the elevated levels of methane in groundwater aquifers in Pennsylvania.
It draws the same conclusions as previous articles :" compromised structural integrity of casing and cement in oil and gaswells"
Of interest is that they found unconventional wells are six times more likely to leak. The article also finds that often reports of well failures by inspectors are not recorded as violations. They also found that certain geological formations were contributing to casing and cement failure. Another conclusion is that as wells age the percentage of failed casings rapidly increases.

Article 6
Information Summary on Unconventional Gas Development for WA Scientific Enquiry.
Prepared by Bryan Whan.
This is a comprehensive document dealing with all issues associated with the impact on community and environment by the unconventional gas industry.
Chapter 5 deals with well integrity and failure with numerous sources including from Australia.
It has examples from articles previously mentioned and others which all draw the same conclusion that casing and cement failure are common and increase as wells grow older . Bryan quotes the cost ($500,000) of sealing a 50 year old oil well in the Northern Territory and this , I feel, is a major consideration when looking at allowing this industry to proceed.

Conclusion.
I have completed this article in limited spare time as a single parent and only just in time ie. 19 March.
While writing after reading each article I was amazed that they told me of problems with cement and casing which my own common sense and limited experience had made me concerned when I heard what huge pressure is used in Hydraulic fracturing.
I hope the following points will be factored in to any decision to allow fracking.
1 The fundamental right of every resident in Australia to have the quality and current supply of clean water preserved and GUARANTEED against contamination by this industry.
2 For Government to consider where alternative sources of supply of water will come from in the event of contamination and that it be costed and financial measures put in place to do so before allowing fracking to proceed.

3 That if a decision is made to allow this industry to proceed , there will be a minimum 2 year period where all water sources in areas designated to be fracked will be tested at least 8 times at regular intervals and recorded.
4 That consideration is given for the cost of sealing every well at the end of its lifespan and that the money is paid up front by the gas company when drilling commences and is kept in Trust.

I do not want to see this industry start anywhere in WA or Australia as I see no benefits for us and the risks are too great to our Underground water resources. We have no mountains with snow melt or rivers flowing all year in WA and over most of Australia. Yes 4km underground sounds too deep to be of concern but the fact is that the well casing is the conduit for contaminants and gas all the way through saline and fresh aquifers to the surface.

Sincerely,
Roger Chapman.
Please note I am posting a copy of this presentation together with the articles from which I sourced my information.

INFORMATION SUMMARY ON UNCONVENTIONAL GAS DEVELOPMENT FOR WA SCIENTIFIC INQUIRY

Prepared by Bryan Whan for Lock The Gate Alliance December 2017

This document provides a summary of information that can be used for people wishing to prepare submissions to the WA Inquiry on fracking.

There is one clear message that arises from reviewing the literature for this document: **Fracking destroys the landscape and is not safe. The problems are not controllable, and regulations are simply not capable of preventing them.**

This view is not based on emotion, but rather a massive amount of high level, credible, peer-reviewed information, prepared by eminent people and organisations, and this is complemented by personal stories and experiences. While the industry claims it is credible, honest, transparent and consultative, in real life this is far from the true situation.

Extensive surveys conducted by 'Lock The Gate' clearly demonstrate the community does not want unconventional gas. It does not want the landscape destroyed, and it does not want to suffer the health and environmental problems associated with it. There is no reason to allow unconventional gas development. Contrary to what the gas companies claim, it does not add jobs, and it has little or no economic benefits to Australians. Even if it did generate jobs and economic benefits this cannot be justified compared to the damage it does to the landscape and the community.

1. GENERAL BACKGROUND

References (1.1, 1.2, 1.3, 1.4)

1.1 Unconventional Gas

Unconventional gas exploration and/or production is now taking place across Australia. Coal seam gas, shale gas and tight gas differ from conventional gas because they are more difficult to extract and cannot be developed with conventional processes. The gas is the same, the difference is how it is extracted from the ground.

The three main types of unconventional gas are:

- Coal seam gas (CSG), found in coal seams.
- Shale gas found in shale rocks.
- Tight gas found in low permeability sandstone rocks.

1.2 Difference between conventional and unconventional gas

Different extraction techniques are required due to the different geology of the reservoirs from which they are extracted.

Conventional gas

- Found in relatively large permeable rock reservoirs.
- The gas can usually be extracted relatively easily via vertical wells.
- Has been extracted in Australia for many decades.

Unconventional natural gas

- Found in less permeable deposits or spread more diffusely throughout the rock substrates.
- This gas is more difficult to extract and therefore requires more specialized (i.e. 'unconventional') extraction techniques and processes.
- The methods required for the extraction of unconventional gas include hydraulic fracturing (fracking), horizontal drilling, multiple drilling, and acidation.

1.3 Impacts on area

- Unconventional gas production is highly invasive. While conventional gas production generally requires single wells, shale and tight gasfields involve the industrialisation of entire landscapes as hundreds or even

thousands of closely spaced gas wells are required to extract commercially viable quantities of gas. Gasfields also require vast networks of access roads, gas pipelines, processing plants, compressor stations, and wastewater holding dams and treatment plants.

- Valuable agricultural and horticultural land is lost. Native forests and wild life are impacted.
- The presence of mining in the area will reduce surrounding land values. Experience elsewhere in Australia has shown that land owners have been refused bank finance due to uncertainty of the asset caused by the presence of wells on the property *(10.11, 10.12, 10.13*).

1.4 Unconventional gas techniques

- Involve using invasive 'unconventional' methods to crack rocks that hold methane gas deep underground.
- Techniques such as horizontal drilling and hydraulic fracturing (fracking) are used to extract methane from the shale and sandstone rocks.
- Fracking involves pumping large volumes of water, chemicals, radioactive tracers and sand into the ground at high pressure to release gas.
- Tight gas may also require acidation, which involves pumping acids into the well to dissolve the cements between rock grains.

Modern fracking techniques used for unconventional gas extraction are vastly different to older fracking methods used in WA's conventional oil and gas industries. These newer, more damaging fracking processes have only been in use since the 1990's and require vast quantities of water and chemicals, much higher pressures, and riskier horizontal drilling techniques. Modern fracking technology has never been deployed on a commercial scale in Western Australia.

1.5 Water use: *(1.4)*

Fracking is an extremely water-intensive practice.

- A single shale gas frack uses 11-34 million litres of water in the fracking fluids.
- Wells are often fracked on multiple occasions, sometimes up to ten times, multiplying overall water use.
- Some of this fluid returns to the surface as flowback, but most stays underground and is never recovered - estimates suggest 70% or more remains underground.

1.6 Wastewater: *(1.11)*

- Wastewater from gas operations includes flowback from fracking and 'produced' water that is present in the source rock. This produced water is brought to the surface during gas production. The wastewater may contain heavy metals, salts, radioactive materials and volatile organic compounds.
- The massive volumes of wastewater produced may be stored in large ponds, partially 'treated' and released into waterways or re-injected back underground - a process that can lead to earth tremors and earthquakes.

1.7 Shale and tight gas in Western Australia *(1.12, 1.13, 1.14)*

- WA could contain 280 trillion cubic feet of potential shale and tight gas resources.
- Gas companies are actively exploring for gas across the state, with the Kimberley, Mid West and South West regions currently being targeted for exploration and pilot production.
- Fracking for unconventional gas is already underway in WA, with around 12 exploration wells fracked in the past 11 years.
- The Department of Mines and Petroleum (DMP) has handed out exploration licences to gas companies that could end up fracking through our precious groundwater sources, including the Yarragadee North and South aquifers that supply Perth and the Southwest with drinking water.
- There are currently four gas exploration licences granted in the South West region that could open the door to widespread drilling through the Yarragadee aquifer. Currently there is a fracking ban covering the south west, peel and metro regions, but this ban is not protected by an act of Parliament and could be overturned without having to go back to the Parliament.
- Conservative estimates suggest that the Kimberley could see 41,720 gas wells and the Perth Basin more than 14,000 *(1.14)*

1.8 What is at risk?

A large swathe of Australia is covered in coal and gas leases & applications. Families and communities are suffering as a result. In parts of Queensland, the unconventional gas industry has impacted on the health of

families living close to mines and gasfields. These impacts are only just beginning to be recognised, although people have been providing anecdotal evidence of the impacts for many years *(1.15, 1.16)*.

In Queensland, the rate of change has seen prime agricultural regions transformed into industrial areas through coal seam gas *(1.3)*. 18,000 wells have been approved, and tens of thousands more are planned.

Invasive gas mining impacts include:

- Industrialization of whole regions with wells, roads, pipelines, and infrastructure.
- Contamination of ground and surface waters with toxic chemicals and methane.
- Loss of agricultural land and reductions in property values.
- Release of hazardous air pollutants from venting, flaring and wastewater evaporation.
- Depletion of water resources from well dewatering and use in fracking.
- Substantial greenhouse emissions from methane leakage.
- Serious health effects experienced in communities living near gasfields in the USA & Queensland.
- Fragmentation and destruction of native forests and critical wildlife habitat.
- Reduced quality of life for rural residents from industrialization of rural areas.
- Increased threat of seismic activity from fracking and wastewater re-injection.

1.9 Quick Facts on coal & gas *(1.17, 1.18, 1.19)*

- Australia gets little benefit from coal and gas production because 83% of the mining industry is foreign-owned.
- Mining is one of the smallest employers in Australia, employing only 2% of the population which is less than the arts and recreation services industry.
- Australia has plentiful supplies of 'conventional' or 'natural' gas and some of the best solar and wind resources in the world.
- Most gas is shipped overseas - Australia plans to become the biggest exporter of gas by 2020.
- On the east coast, exports of coal seam gas are driving up the cost of gas for consumers in Australia, because companies are increasing domestic prices to match overseas prices.

1.10 Successful actions *(1.20, 1.21)*

- The Government of Victoria has introduced legislation to ban fracking and unconventional gas exploration.
- Tasmania has instigated a moratorium on fracking, with a possible ban ahead.
- The Northern Territory promised a ban on unconventional gas exploration before the recent election, but has since indicated a ban will apply to fracking only.
- The Queensland Parliament passed a bill to restore the rights of landholders and communities to object to major mining projects.
- Numerous national, state and regional governments overseas have enacted bans or moratoriums.
- Many local councils across Australia have passed motions opposing unconventional gas development and calling for a moratorium.

The growing evidence of actual harm, and the potential environmental and health risks from shale gas development, has now resulted in decisive action from governments across the globe to halt the expansion of this industry. Internationally, jurisdictions with some form of ban or moratorium in place include Scotland, Wales, Germany, Bulgaria, Romania, the Netherlands, Northern Ireland, Wales, the Czech Republic, Luxembourg and France as well as the US States of New York, Maryland, Florida and Vermont and the Canadian Provinces of New Brunswick, Newfoundland, Nova Scotia and Quebec *(1.6, 1.7, https://keeptapwatersafe.org/global-bans-on-fracking/)*

1.11 A warning from Queensland

The impact on the land and the industrialisation unconventional gas production creates is neatly demonstrated in a series of 'Before and After' photos of various forest and agricultural areas in Queensland. *http://www.csgfreenorthwest.org.au/qlds_story (1.8)*.

1.12 The community does not want unconventional gas *(1.22)*

Across Australia there have been more than 450 communities who have declared themselves coal or gasfield free. In WA, we have close to 20 communities who have said they want to remain Gasfield Free. These communities include Brunswick, Stratham, Dandaragan, Greenough, Cervantes, North Boyanup, Moora, The

Vines, Forest Grove, Stirling Estate, Quedjinup, Swan Hills, Leeman-Greenhead, Jurien, Carnamah and Chittering.

Gasfield Free communities follow an extensive survey of residents who are asked house by house, street by street, whether they want to declare their communities Gasfield Free. When a community declares itself Gasfield Free it is making a powerful statement to the gas industry that the industry does not have a social licence to operate in the community

Representing a large sector of the rural community, the Country Women's Association of WA passed a motion at its 2017 Annual Conference calling for an end to fracking and unconventional gasfields in WA. This follows a similar ban passed by the NSW branch of the CWA earlier in the year. *(1.10)*

2. WHAT THE INDUSTRY CLAIMS – INDUSTRY CREDIBILITY

References (2.1, 2.2, 2.3, 2.4)

2.1 Claims made by the industry

The gas companies, the Australian Petroleum Production and Exploration Association (APPEA), and the WA Department of Mines, Industry Regulation and Safety claim that:

- Mining for unconventional gas is safe, and the risks are known and can be managed.
- The gas industry has a good track record of safe operations in SA, Qld, WA, NSW, and Victoria.
- The industry is transparent, consultative, and honest, and is committed to relationships built on trust and mutual respect.
- Gas mining will provide jobs and investment to boost the economy.

A thorough analysis of peer-reviewed evidence, as reviewed in this paper, clearly demonstrates these claims cannot be justified, and the industry lacks credibility in promoting these views.

Typical claims made by industry follow:

Jobs and economic benefits

- Development of Northern Territory's onshore natural gas resources will deliver 6300 new long-term jobs and generate up to $1b revenue over next 20 years.
- Using more natural gas would enhance Australia's ability to meet increasing energy needs while at the same time reduce greenhouse gas emissions.
- SANTOS has invested $15.4b throughout Australia - $8b in Qld with $1b in regional areas. More than 10,000 people have worked on the construction operation and many more suppliers and businesses have benefited.

Risks

- The risks are well known and can be managed.
- Numerous Australian and international reviews have found that the risks associated with hydraulic fracturing can be managed effectively with a robust regulatory regime.
- The most common well integrity risk is slow leakage of methane around the external casing, but the consequences of such leaks, although negative from a climate change perspective, do not threaten health because natural gas is not toxic, the frequency of substantial leaks is low, and the leakage rates are low as well.
- Origin Energy: Studies and decades of practical experience show the risk of groundwater and surface water contamination is very low.
- Santos: Numerous reputable independent reports and inquiries have found that the technical process of hydraulic fracturing to be safe and sustainable when accompanied by operational capability, good management processes, and a robust regulatory framework.

- The gas industry has a demonstrated track record of safe, sustainable operations in SA, Qld, NT, WA, NSW and Vic.
- Around Australia, thousands of wells have been drilled – and more than 1000 have been fracked – with no significant impact on the environment or groundwater resources. Some minor surface incidents have occurred, but none that have caused the type of environmental harm some people claim is inevitable. As with any industry, there are risks involved that must be managed and minimised.

- Today, companies can drill multiple horizontal well paths from a single surface location. Clustering wells onto a single surface location dramatically reduces the overall amount of surface land required for wells and related infrastructure.

Credibility of industry
- The industry is committed to ensuring the equitable treatment of all stakeholders, and it focuses on building relationships based on trust and mutual respect.
- Origin Energy: One of our overriding principles is to be open and transparent at all times. We always engage respectfully based on a dialogue of facts.
- Santos: We acknowledge that we must have a social licence to operate. Relationships are built on respect and openness.

Impacts on other industries
- Independent evidence from Queensland and South Australia shows the established industries have not been disadvantaged by the development of the natural gas industry.

Health complaints in Queensland
- Queensland Health found no clear link could be drawn between the health complaints of some residents and the local CSG industry. The Queensland Health report found that the nature of complaints meant there were multiple possible causes and explanations including faecal contamination in the water supply, the use of wood- fired heaters or open fires, and rainwater contaminated with bacteria, viruses or other organisms. These causes are not related to gas operations. The report noted the most prevalent reported symptoms are headache, transient (reversible) eye irritation, nosebleeds and skin rashes. These are common medical complaints,

2.2 Industry credibility? Personal stories and case studies *(2.21)*

While industry claims it is transparent, respects and consults with the landowners, and its operations are safe without any impacts, there is abundant evidence that suggests a very different story. This review provides abundant scientific evidence that refutes these claims. The following examples of personal stories also destroys the industry's credibility of claiming a policy of consultation, honesty and public interest.

Landowners on the Darling Downs, Queensland *(1.3 A fractured country, An unconventional invasion. http://www.lockthegate.org.au/our_films)*

- Families on the Darling Downs in Queensland have health problems through living close to the gas mining. They are no longer able to drink the water, with instances where gas was emitted from their water supplies. The presence of gas mining on their properties and the transformation of their prime agricultural land to an industrial zone which operates 24 hour a day has devastated their lives, and it has affected their mental as well as physical health. Their properties and livelihoods are ruined. The value of their properties has reduced drastically, preventing them from selling and moving on.
- Contrary to what the industry claims, these land owners recounted experiences on how they were treated with contempt by the gas companies.
- Personal stories from:
  - Brian Monk, Landowner, Kogan, Darling Downs, Qld
  - Ruth Armstrong, Mixed cropping farmer, Cecil Plains, Darling Downs Qld
  - Mabel Quakawoot, Bailai Elder, Gladstone, North Qld
  - Graham Gibson, Vigneron, Broke, Hunter Valley, NSW
  - Joe Hill, Angus cattle breeder, Miles, Darling Downs, Qld
  - Lee McNicholl, Beef producer, Dulacca, South West Qld
  - Ian Moore, Farmer, Jerry's Plains, Hunter Valley, NSW
  - Scott Lloyd, Farmer, Chinchilla, Qld
  - Marion Palmer, Landholder, Tara, Darling Downs, Qld
  - Debbi Orr, Landowner, Tara, Darling Downs, Qld
  - Geoff and Barbara Brown, Vigneron, Hunter Valley, NSW
  - David Quince, Farmer and Grazier, Tambar Springs, Liverpool Plains, NSW
  - Don Durrant, Farmer, Doubtful Creek, Northern NSW
  - Ben Marrjarr, Traditional Owner, Arnhem Land, NT
  - Megan Kuhn, Farmer, Bundella, North West NSW
  - Lesley MacQueen, Dairy Farmer, Lynchs Creek, Northern NSW
  - Wal Buckman, Farmer, Lynchs Creek, Northern NSW

- Paul Hobbs, Landholder, Lynchs Creek, Northern NSW

Megan Baker, Wilkie Creek Qld *(2.3)*

Megan's family suffered 5 years of negotiations and a legal battle with Arrow Energy, taking a huge toll on her family. The gas company dozed fences and introduced weeds, and vehicles would come and go all hours of the day and night. Stock were running everywhere because they could not be contained to one paddock due to the damage. They were forced out of production so eventually decided to sell the sheep flock.

Wayne Waker – Chinchilla, Queensland *(2.4)*

Wayne signed an access agreement for unconventional gas extraction by Origin Energy, but was given misleading information during negotiations. He was advised that coal seam gas would provide extra money and would have no impact. The company would 'just come in the front gate, conduct activities for a while, and then move on'. They cut about 10 holes in the boundary fences, drove over a 6 feet high fence and went where they liked – all without consultation. He has pipelines running through his property, and 10 high vents pumping out methane gas. The company had no principles, morals or scruples, and treated the landowner with contempt. Wayne gets headaches and sore eyes and is worried about long term health. His lifestyle and agricultural production have been ruined. His property is now not worth the original unimproved value.

Nood and Narelle Nothdurft – living in the heart of a gas field *(2.5)*

Their 860 acre farm was transformed into an industrialised gas field, with 4 processing plants and 7 gas wells. Within a 2.5km radius of their home there are 30 wells, 37 high point vents which vent methane 24/7/365, and hundreds of km of water and gas pipelines. There are 4 vents within 80m of their home with signs indicating the gas is flammable, explosive and dangerous. Gas company said it was only venting air, but FLIR camera images showed it was methane and VOCs. There is an unbearable noise generated from the gas infrastructure, with dust and methane emisions.

Their children suffer from incredible health problems – severs headaches, vomiting, metal taste in their mouths, sore limbs, nasal problems.

Neil Stanley's story – Kogan Qld *(2.6)*

In late 2009, QGC drilled a gas well on an important cultural heritage site near Kogan in western Queensland. The site, a Bora Ring used in initiation ceremonies, was well documented and well known. QGC has never been made accountable for desecrating the site.

Greg and Joanne Vines' story – Wallumbilla, Qld *(2.7)*

Greg and Joanne Vines battled gas giant Santos for nearly two years over the company's push to lay a second pipeline through the Vines' property in south-west Queensland for coal seam gas (CSG). The couple were worried about the weeds a trencher and vehicles would bring to their property as the machinery would have been in areas of parthenium infestation, a toxic plant that impacts heavily on pastoral production. Despite repeated requests the company was unable to provide the Vines with adequate documentation to prove the trencher was weed free. The Vines locked their gates in an attempt to keep the trencher off their land and protect their pasture business, but they were threatened with arrest on their own property and had their locked gates cut. Their fight with Santos has taken a heavy toll. Fracking and unconventional gas has changed their lives, for the worse. 'Blatant disregard for people'

USA experience

There is extensive experience from USA of farmers living in areas subject to fracking. Farmers can't use the water, which catches on fire, and it is possible to have explosions in the house if it is not kept open. There are immense health issues, and children are most susceptible. Some farmers have been bought out by the gas companies, but they must sign confidentiality agreements, so they can't talk openly. A clear conclusion is that agriculture and gas production cannot co-exist.

Negotiations with Kimberley traditional owners
(1.5 and 1.9 A fractured State, and an Excerpt from A Fractured State.
https://www.dontfrackwa.com.au/2017/12/18/afracturedstate/
https://www.facebook.com/frackfreewa/videos/1038894279581650/)

A traditional landowner, Mitch Torres, recounted her experience at a negotiation meeting with a gas company, where the company representatives mislead the indigenous people by saying the chemicals used in fracking were similar to those used in jelly beans. The indigenous participants had quite a different view about fracking when it was later explained correctly.

Misrepresenting tight gas as conventional

Gas companies have been known to misrepresent tight gas as 'conventional' in the past.

- Metgasco misrepresented the drilling planned at Bentley in NSW, obtaining an approval for conventional drilling, when it was in fact unconventional tight sands gas that is being sought.
- In South West WA, companies claim they are targetting conventional gas, when it is tight sandstone and limestone in the area. The company which originally applied for the gas licence over Capel, Boyanup and Dardanup was called 'Unconventional Resources Pty Ltd'. After community protest, they changed their name to Bunbury Energy.
- In the Mid West, the Waitsia field is being heralded as the biggest conventional gas find in about 40 years. But the company has admitted they would start with 20 wells in 50 square kilometres. There is also tight Gas in exactly the same spot, so it is possible they will develop that eventually too. They will have the land access by then.

Views of some people who work, or have worked, in the unconventional gas industry

While the leaders of the gas industry claim that fracking is safe, and the industry has credibility, it is significant the number of people who work or have worked in the industry who have different views. Unfortunately, many are unable to speak publicly for fear of losing their jobs. Concerns from those involved reinforces doubts about the credibility of the industry.

Some examples of people that we can name, who are experienced in the mining industry but are now critics of unconventional gas production, include:

- Jessica Shaw: Current State MP for Swan Hills, previously worked in resources and energy
- Peter Lindsay: Former CSG industry regulator, Qld Government (DERM) (1.26)
- Prof Anthony Ingraffea: Currently Cornell University, ex consultant and researcher with oil and gas industry

2.3 Industry credibility? Documentaries

A number of documentaries have been produced by reputable TV networks and production companies outlining the truth about unconventional gas production and its impacts.

- Lock The Gate: A fractured State *(1.5)*
- Australia's NOW Government – Fracking destroying our country *(2.8)*
- The Gas Rush: ABC's 4 Corners Feb 2010 *(2.9)*
- Undermined: Nine's 60 Minutes 14 May 2010 *(2.10)*
- Voices from Gasfields – it started with just one well *(2.11)*
- Food Security and Australia's Regional Way of Life: Coal Seam Gas: Alan Jones - National Press Club Address 19 October 2011 *(2.12)*
- Coal Seam Gas: Channel 10 'The Project' 21 Feb 2013 *(2.13)*
- Fracking an inconvenient truth 17 Aug 2013 *(2.14)*
- Exposing the real price of the US fracking industry *(2.15)*
- Water on fire – Marcellus shale reality *(2.16)*

3. BUSTING INDUSTRY MYTHS

References (1.2, 1.3, 3.1, 3.2, 3.3)

3.1 Myth: "We've been fracking for years without adverse consequences"

Response

- Fracking techniques, and the associated risks, have changed over time.
- In WA, hydraulic fracturing has mainly been applied to enhance production in *conventional* oil and gas reservoirs with vertical wells.
- Fracking for *unconventional* gas in WA only commenced in the last 15 years and only a handful of wells have been fracked in that time.
- Fracking for unconventional gas is vastly different to the techniques used in conventional gas extraction

- it involves high volume "slickwater" hydraulic fracturing with horizontal drilling, rather than vertical drilling for conventional gas..
  - it uses significant quantities of a large variety of chemicals
  - it requires massive volumes of water and produces large volumes of toxic wastewater
  - much higher pressures must be applied to the well to undertake a frack
  - The entire shale gas production process requires industrialisation of vast areas of land with ever-expanding networks of multi-well pads, gas and water pipelines, access roads, treatment plants, compressor stations, and toxic wastewater ponds.

3.2 Myth: "Fracking for shale gas is safer than for CSG"

The industry claims that the depth of shale gas deposits (typically 3-5km under the ground) means there is less risk to groundwater from fracking than when fracking for CSG, which is extracted from shallower coal seams which are closer to underground aquifers.

Response

- Shale gas wells are, if anything, more likely to fail than coal seam gas wells due to the greater pressures required to fracture shale (which is extremely hard) compared to fracturing coal seams.
- The greater pressure required places the well infrastructure under greater strain and therefore increases the chance of failure of well casing and integrity.
- As shale gas wells must pass through potable underground aquifers, well failure can lead to contamination of these water sources and upward migration of fracking fluids and gas.
- Because shale wells are generally deeper and longer, they are more difficult to construct, and with added complexity comes greater chance of failure.
- Fracking for shale gas also uses much larger quantities of water and chemicals than fracking for CSG, increasing the potential for depletion of water resources and chemical contamination.
- Whilst only a proportion of CSG wells need to be fracked (10-40%), *all* shale gas wells require fracking to extract commercial quantities of gas.

3.3 Myth: "Fracking can be done safely, if it is regulated appropriately"

Response

- There is growing evidence to show that even strict regulations are simply not capable of preventing harm.
- Industry studies and independent analyses indicate inherent engineering problems including uncontrolled and unpredictable fracturing, induced seismicity leading to an increase in earth tremors, plus well casing problems, infrastructure integrity issues and leaks that cannot be prevented despite apparent 'best practice' regulations.
- If a shale gas industry is established in the Kimberley and Mid-West regions, appropriate monitoring and compliance is unlikely due to resource constraints in Government Departments, the large number of production wells required and the remote locations of many of these wells.

3.4 Myth: "There's no real risk of wells leaking, as well casings are thick and made of concrete and steel"

Response *(3.4, 3.5, 3.6, 3.7)*

- 'World's best practice' well construction just isn't enough to stop wells leaking.
- A gas industry study last year in Pennsylvania found that more than 6% of gas wells leaked in the first year of operation, and up to 75% of existing wells could have some form of integrity failure.

3.5 Myth: "The chemicals used can be found in household products"

Response *(3.8)*

- While some chemicals can be found in home products, they may not be safe for humans and the environment if they make their way into water supplies, particularly in the large quantities used in fracking fluids and in various untested combinations with numerous other chemicals.
- Many fracking chemicals are known to be toxic and many others have not been assessed for their long-term impacts on the environment and human health. Fracking compounds used in Australia have been shown to include many hazardous substances, including carcinogens, neurotoxins, reproductive toxins, irritants/sensitisers, and endocrine disruptors. It is also worth noting that some of these chemicals are toxic even in extremely small concentrations.

3.6 Myth: "Only a small amount of chemicals is used in fracking"

Response

- While chemical additives make up only 0.5 - 2% of fracking fluids, it translates to very large *actual* quantities of chemical additives.
- A typical 15 million litre fracturing operation would use from 80 to 330 tons of chemicals.

3.7 Myth: "The gas industry will create local jobs"

Response *(3.9, 3.10)*

- The oil and gas industry is one of the smallest employers in Australia, employing less than 0.2% of the Australian workforce. (Just 22,000 out of a total workforce of around 12.5million. Bunnings employs 40,000 workers across its stores in Australia and NZ.)
- The majority of gas industry jobs are required for the short construction phase only.
- Local employment opportunities are minimal with the majority of skilled workers being fly-in-fly-out workers. Those employed locally are usually skilled workers poached from local industries that have spent years training them, leaving these industries short of labour and unable to compete with gas industry wage rates.
- In Queensland, with the 4 year construction phase of the CSG production gasfields in the Surat Basin now coming to an end, the gas 'boom-towns' of Dalby, Roma and Chinchilla are experiencing a crippling economic down turn with associated job losses and loss of revenue for local businesses.

3.8 Myth: "The gas industry will revive ailing rural economies"

Response *(3.11)*

The most advanced unconventional gas development in Australia, in Queensland's Darling Downs region, shows that gas development negatively impacts all sectors of local industry other than the gas industry itself.
While the industry employs some people, and some businesses profit by servicing the mining industry, overall it is a small, short term employer that drives up costs for local businesses and negatively impacts the community. People working in local businesses, agriculture, government and the community sector consistently believed CSG development and mining had led to a deterioration of the economy of the region.

3.9 Myth: "Unconventional gas will provide tremendous economic benefits"

Response

The gas industry has been prolific in putting out exaggerated claims about CSG's economic benefits while at the same time staying almost completely silent on the health and environmental risks. The economic benefits are likely to be relatively small, and a lot more work needs to be done to assess the health and environmental risks. There is little for Australia to gain by rushing into an expansion of unconventional gas operations.

3.10 Myth: "Unconventional gas will reduce greenhouse emissions"

Response

- Researchers have measured elevated levels of methane and other gases in Queensland gas fields.
- Methane is about 34 times as potent as a climate change-fueling greenhouse gas than carbon dioxide over a span of 100 years. Over 20 years, it's 86 times more potent. Of all the greenhouse gases emitted by humans worldwide, methane contributes more than 40 percent of all radiative forcing, a measure of trapped heat in the atmosphere and a measuring stick of a changing climate. *(3.4)*

4. CHEMICALS USED IN HYDRAULIC FRACKING

References (1.6, 4.1)

General summary

- Shale gas development uses fracturing fluids that contain organic and inorganic chemicals known to be health damaging.
- Chemicals are used in drilling and fracturing processes as corrosion inhibitors, biocides, surfactants, friction reducers, gels, and scale inhibitors.
- These chemicals include methanol, ethylene glycol, naphthalene, xylene, toluene, ethylbenzene, formaldehyde, and sulfuric acid, some of which are known to be toxic, carcinogenic, or associated with reproductive harm.
- Many of these compounds are considered hazardous water pollutants and are regulated in other industries.
- Fracturing fluids can move through the environment and come into contact with humans in a number of ways, including surface leaks, spills, releases from holding tanks, poor well construction, leaks and accidents

during transportation of fluids, flowback and produced water to and from the well pad, and run-off during blowouts, storms, and flooding events.
- Further, the mixing of these compounds under conditions of high pressure, and often high heat, may synergistically create additional potentially toxic compounds.
- Many of the chemical compounds used in the fracturing process lack scientifically based maximum contaminant levels, making it more difficult to quantify their public health risks.

5. WELL INTEGRITY AND FAILURE

References (1.3, 5.1, 5.2, 5.3, 5.4)

5.1 Do modern gas wells leak?

- There is growing evidence to show that even strict regulations are simply not capable of preventing harm and that 'world's best practice' well construction just isn't enough to stop wells leaking.
- Studies consistently show that oil and gas wells routinely leak, allowing for the migration of natural gas and potentially other substances into groundwater and/or the atmosphere. Recent research suggests that the act of fracking itself may induce pathways for leaks.
- According to Schlumberger, one of the world's largest companies specializing in fracking, about 5 per cent of wells leak immediately, 50 per cent leak after 15 years, and 60 percent leak after 30 years *(5.5).*
- Some incidents (as well as breaches of approval processes and conditions) have come to light only because of whistle-blowers within government departments and gas companies.

5.2 Well integrity failure risks

An industry paper in Oilfield Review 2003, published by Schlumberger *(5.5)*, admits:
- 'Techniques for locating, exploiting and transporting natural gas to our homes and industries have had huge advances since the early days. Despite these advances, many of today's wells are at risk. Failure to isolate sources of hydrocarbon either early in the well construction process or long after production begins has resulted in abnormally pressured casing strings and leaks of gas into zones that would otherwise not be gas-bearing'.
- 'Since the earliest gas wells, uncontrolled migration of hydrocarbons to the surface has challenged the oil and gas industry. Gas migration, also called annular flow, can lead to sustained casing pressure (SCP). The presence of SCP indicates that there is communication to the annulus from a sustainable pressure source because of inadequate zonal isolation. Annular flow and SCP are significant problems affecting wells in many hydrocarbon-producing regions of the world. By the time a well is 15 years old, there is a 50% probability that it will have measurable SCP in one or more of its casing annuli. However, SCP may be present in wells of any age'.

A 2014 study published in the Proceedings of the National Academy of Sciences of the United States of America provides a useful and more recent overview of the industry and scientific data produced to that date, specifically considering unconventional extraction.

The International Association of Hydrogeologists in 2015 noted in its submission to the Hawke Inquiry *(5.6)*:
- Deterioration and failure of improperly decommissioned wells will, over time, result in long term release of oil and/or gas into the environment. Pathways in the annulus may develop that would allow oil, gas, and brine to move vertically across geologic formations and contaminate groundwater. Substances dissolved in the brine may include those that occur naturally in the shale formations and others injected during the hydraulic fracturing process.
- Upwardly migrating gas, known as stray gas, represents an explosion hazard if not properly vented away from buildings and drinking water wells.
- The risk that annular pathways will develop increases over time as chemical, mechanical, and thermal stresses causes deterioration of well structures and components.
- Failure modes of improperly abandoned wells include the formation of cracks in the cement casing or packers, corrosion of steel production casing, faulty valves, and leaking temporary plugs or surface caps.

5.3 Frequency of well failure

- Estimates of well failure rates vary although the more conservative well failure rates found in the literature are between 4.6% and 8.9%.

- Davies *et al.* (2014) *(5.7)* reviewed reliable databases of well integrity from around the world and found that failure rates were highly variable from 1.9 to 75 per cent, with the Marcellus Shale well failure rate at 6.3 per cent, for example. They found a greater proportion of failure in injection wells (such as those required for hydraulic stimulation) when compared to production only wells (such as in traditional oil/gas fields). They concluded it is not possible to have zero per cent well integrity failure. They also noted that the amount of information retained by oil and gas companies and regulators was not sufficient for an exhaustive study, and were not released even if available.
- A 2009 study from Alberta, Canada of more than 315,000 oil, gas and injection wells of various ages, showed that 'injection wells' into which liquids or gases are pumped are 2-3 times more likely to leak than conventional 'production wells'. The same study found that horizontal or inclined wells are observed to have significantly higher failure rates than vertical wells. It is universally acknowledged that problems with casing centralisation and cement slumping in horizontal or inclined wells may contribute to the increased incidence of leakage.
- Data from Pennsylvania's Department of Environmental Protection (DEP) for 2000-2012 show over nine percent of shale gas wells drilled in the state's north eastern counties leaking within the first five years.
- According to state inspections of all 6,000 wells drilled in Pennsylvania's Marcellus Shale before 2013, six to ten per cent of them leaked natural gas, with the rate of leakage increasing over time. The rate was six per cent in 2010 (97 well failures out of 1,609 wells drilled); 7.1 per cent in 2011 (140 well failures out of 1,972 wells drilled); and 8.9 percent in 2012 (120 well failures out of 1,346 wells drilled) *(5.13)*. Wells with horizontal underground arms were four times more likely to fail than vertical wells in the same area.
- A 2011 report from Pennsylvania, USA, showed about 75% of groundwater wells sampled within 1 kilometre of gas drilling in the Marcellus shale were contaminated with methane from the deep shale formations. Isotopic fingerprinting of the methane indicated that the deep shale was the source of contaminations, rather than biologically derived methane.
- In 2016, an interdisciplinary team led by University of Colorado researchers found methane in 42 water wells in the intensely drilled Denver-Julesburg Basin where high volume, horizontal fracking operations began in 2010. Of the 42 affected wells, 11 had already been identified by state regulators as suffering from 'barrier failures' *(5.8)*.
- In 2014, University of Waterloo researchers warned that natural gas seeping from 500,000 wellbores in Canada represented 'a threat to environment and public safety' due to groundwater contamination, greenhouse gas emissions, and explosion risks. Ten percent of all active and suspended gas wells in British Columbia now leak methane, and some hydraulically fractured shale gas wells in that province have become 'super methane emitters', spewing as much as 2,000 kilograms of methane a year *(5.9, 5.10)*.
- In 2014, the Council of Canadian Academies identified inherent problems with well integrity as one of its top concerns about unconventional drilling and fracking. According to one expert panel, 'the greatest threat to groundwater is gas leakage from wells from which even existing best practices cannot assure long-term prevention.' Cement may crack, shrink, or become deformed over time, thereby reducing the tightness of the seal around the well and allowing the fluids and gases to escape into the annulus between casing and rock and thus to the surface *(5.11)*.
- In 2015, the New York State Department of Environmental Conservation stated 'there is a risk that well integrity can fail, especially over time, and questions have arisen about whether high-volume hydraulic fracturing can cause seismic changes which could potentially result in fracturing fluid migration through abandoned wells or existing fissures and faults. Thus, high-volume hydraulic fracturing could result in significant adverse impacts to water resources from well construction and fracturing fluid migration' (5.12).
- Professor Anthony Ingraffea (Cornell State University, and previously a consultant and researcher in the oil and gas industry) showed leaking gas wells in a video *(5.4)*.
  An analysis of industry literature showed:
  - In 340,000 oil and gas well in Canada, 15-16% of conventional wells leak and 65% of modern deviated wells leak.
  - 35% of 1.8million global wells leak – 5% in young wells and 35% in old wells.

  An analysis of public 75,000 inspection reports in Pennsylvania between 2000-2013 showed:
  - Leakage in old wells pre 2009 of 13% for unconventional wells and 20% for conventional wells.
  - Leakage in modern wells post 2009 were better, but still 12% in unconventional wells.

5.4 Incidents in Australia

- Peter Lindsay, a former CSG industry regulator in the Queensland Government (DERM) claimed that some of the infrastructure in Queensland is already failing *(1.3)*.
- An example of the effect of corrosive water on cementing and casing is provided by deep oil exploration wells drilled in the Perdika/Great Artesian Basin in NT in the 1960s. Now, some fifty years later, the steel

casing has almost entirely corroded away, resulting in inter-aquifer contamination. This well required expensive rehabilitation works to stem artesian flow. This single bore cost the Northern Territory and Commonwealth Governments $500,000 to plug as the company responsible for the well was insolvent. This example highlights the issue of operator insolvency due to the boom and bust cycles of oil and gas development which complicate efforts to hold liable parties responsible and provide for timely environmental reclamation.

- Spills have occurred in Australian CSG operations. A scalded area in NSW's Pilliga Forest has not recovered almost 10 years after a wastewater spill by Eastern Star Gas. Wastewater leaking from a pond in the Pilliga (on tenements that Santos bought from Eastern Star Gas) resulted in the contamination of groundwater with uranium and arsenic.
- There have been numerous reports of water contamination and health impacts by people living close to Australian CSG fields in Camden, NSW and on the Western Darling Downs in Queensland. They are similar in nature to reports in the United States.
- In Western Australia a well in the Whicher Range, east of Margaret River was fracked in 2004 using diesel as the fracking fluid as other fluids caused the clay soils to swell. The experimental technique failed and more than half of the 1.2M litres of diesel remains trapped down the well.

5.5 Long-Term Well Integrity and well abandonment

- Once production ceases wells are closed using cementing and capping.
- It is not possible to have a zero per cent well failure rate during production let alone post abandonment.
- Wells deteriorate with age, and they remain after they go out of production.
- If Regulations only apply to the title holder during production, the rest of the community, who do not get any financial benefit, will have to bear the costs of maintaining the wells forever.

6. IMPACTS ON WATER - Ground water and Surface water

6.1 Contamination of aquifers and surface water

Water and chemical use and wastewater production from unconventional gas mining places WA's vital water resources at risk from contamination and depletion.

There are numerous examples of peer-reviewed literature showing serious unconventional gas impacts on groundwater in the USA, regardless of the industry's insistence that there are no impacts. This should provide a warning to Western Australia that impacts do occur and are usually found by third parties *(5.2)*.

The gas industry claims that because shale and tight gas extraction involves deeper rock layers, they are safer than gas extraction from shallow coal seams. But according to a European Commission Report *(6.1)* there is an overall high risk of ground and surface water contamination resulting from fracking.

Aquifers can be contaminated by fracking:

- through water seeping from leaking wells
- from faults induced by fracking
- from surface spills of produced water involved in the fracking process
- contaminated water from the gas source per se. *(1.6, 6.2, 6.3, 6.4).*

After fracking at each well, the large volumes of hazardous flow back fluid must be stored and disposed of. Surface water pollution can occur:

- when there are accidental spills of fluids or solids at the surface
- when well blow outs occur
- through discharge of insufficiently treated waste water onto land surfaces or into waterways *(1.6, 6.2, 6.3, 6.4).*

Flowback fluids contain hazardous fracking chemicals as well as naturally occurring toxic substances released from target geological zones such as:

- methane
- BTEX (benzene, toluene, ethylbenzene, xylene)
- polycyclic aromatic hydrocarbons (PAHs)
- naturally occurring radioactive materials (NORMs)
- heavy metals and other volatile organic compounds (VOCs) *(6.5, 6.6, 6.7, 6.8).*

6.2 Contamination of ground water and drinking water in USA – Results of studies

- In the US state of Pennsylvania alone, more than 240 private drinking water wells have been contaminated or have dried up as the result of drilling and fracking operations over a seven-year period. There has been widespread drinking water contamination in 550 water samples throughout the heavily drilled Barnett Shale region in northern Texas *(6.9)*.
- In March 2016 a USA federal jury awarded two Dimock, Pennsylvania couples $4.24 million after finding an oil and gas company responsible for contaminating their well water during drilling and fracking activities *(6.31)*.
- The presence of a fracking-related solvent in private drinking water wells near drilling and fracking operations *(6.10)*.
- Elevated levels of methane have been found in groundwater discharging into a stream near fracking operations in Pennsylvania along with high levels of methane in nearby private water wells due to a defective casing *(6.11)*.
- Comparison of pre-drill and post-drill data on water quality found changes in water chemistry that coincided with the advent of drilling and fracking activities. Methane was also detected in most houses tested in this study *(6.12)*.
- 56 of the 143 well owners surveyed in south-western Pennsylvania in 2015 indicated changes in water quality or quantity. Chloride, sulphate, nitrate, sodium, calcium, magnesium, iron, manganese and strontium were commonly found, with 25 households exceeding the secondary maximum contaminate level for manganese. Methane was detected in 14 of the 18 houses tested. Since 2009, 65 horizontal wells were drilled within a 4 km radius of the community and each well was stimulated on average with 3.5 million gallons of fluids *(6.13)*.
- A 2016 study by Stanford University scientists determined that fracking and related oil and gas operations have contaminated drinking water in the town of Pavillion, Wyoming where residents have long complained about foul-tasting water *(6.14, 6.15)*.
- Analysis, in the journal *Environmental Science & Technology, 2017*, revealed 6,648 spills from the fracking industry from just four states - Colorado, New Mexico, North Dakota and Pennsylvania, in 10 years *(6.16)*. The researchers determined that up to 16 percent of fracked oil and gas wells spill hydrocarbons, chemically laden water, fracking fluids and other substances.
- Analysis of published data (Vengosh *et al.* 2014, *6.4*) showed evidence of stray gas contamination, surface water impacts in areas of intensive shale gas development, and the accumulation of radium isotopes and other contaminants in some disposal and spill sites.
- Recent research from the USA found higher levels of arsenic and other heavy metals, plus higher salinity, in water bores which were less than 3km from shale gas wells *(6.17)*. Other research has found increased methane concentrations in water bores closer to shale gas wells, creating an explosion hazard *(6.18)*.
- Studies from Duke University in the US have found high levels of radioactivity in a creek used for disposal of wastewater *(6.19)*.
- Using geochemical and isotopic tracers to identify the unique chemical fingerprint of Bakken region brines, a 2016 Duke University study found that accidental spills of fracking wastewater have contaminated surface water and soils throughout North Dakota where more than 9,700 wells have been drilled in the past decade. Contaminants included salts as well as lead, selenium, and vanadium. In the polluted streams, levels of contaminants often exceeded federal drinking water guidelines. Soils at spill sites showed elevated levels of radium *(6.20)*. Contaminants were observed in spill sites up to 4 years following the spill events, and it was concluded there is clear evidence of direct water contamination from fracking *(6.21)*.
- High levels of iodide, bromide, and ammonium were found in samples of wastewater from fracking operations in two US shale formations. The same chemicals were found when fracking wastewater was discharged into rivers and streams at three treatment sites in Pennsylvania and during an accidental spill in West Virginia *(6.22)*.

6.3 Experiences in Australia

- A review by Klohn Crippen Berger Free *(6.23)* for the Queensland Department of Natural Resources and Mines concluded that gas from CSG development can even occur in water bores that do not experience a water level decline from CSG development. These impacts have also been reported by numerous landholders who suffered bore impairment from excess gas.
- There have been numerous reports of water contamination and health impacts by people living close to Australian CSG fields in Camden, NSW and on the Western Darling Downs in Queensland. They are similar in nature to reports in the United States *(6.24)*.

- In Australia, Gavin Mudd from Monash University showed gas bubbling from the Condamine river. The industry claims this was not due to Coal Seam Gas (1.3)!
- Spills have also occurred in Australian CSG operations. A scalded area in NSW's Pilliga Forest has not recovered almost 10 years after a wastewater spill by Eastern Star Gas. Wastewater leaking from a pond in the Pilliga (on tenements that Santos bought from Eastern Star Gas) resulted in the contamination of groundwater with uranium and arsenic *(6.24).*
- In May 2013 some 240,000 litres of oil were spilled at a conventional well in Santos's Zeus field west of Thargomindah. Despite clear evidence, the Queensland environment department chose not to prosecute Santos for this breach of conditions *(6.24).*
- In the Northern Territory, Origin Energy has used unlined pits for the storage of waste water, and then has failed to responsibly remove all contaminants, leaving polluted water in areas that then flooded. Photos are available showing the state that a shale gas pad was left in after gas fracking activities stopped in 2015 *(1.6).*
- In Australia, during the exploration phase of coal seam gas development in NSW, there have been a number of recorded contamination events around the state. Santos' CSG operations in the Forest region of NW NSW recorded at least 20 coal seam gas waste water spills and continuing leaks from evaporation ponds. Santos' records show spills and leaks from all parts of the operations, from evaporation ponds, pipelines, the wastewater treatment facilities and at well sites *(6.25).*
- Eastern Star Gas was responsible for pollution offences in NSW. The EPA issued two penalty notices with fines of $1,500 each to Eastern Star Gas for discharging polluted water containing high levels of salt into Bohena Creek in March and November 2010 *(6.26).*
- In 2014, Santos was found guilty of polluting an aquifer in the Pilliga Forest *(6.27)* with radioactive uranium 20 times safe levels as well as toxic heavy metals *(6.28).*
- A spill in June 2011 in the Pilliga resulted in 10,000 litres of untreated toxic coal seam gas wastewater containing a mix of heavy metals (including arsenic, lead and chromium), salts and petrochemicals that killed vegetation and wildlife. Santos was found guilty in the NSW Land and Environment Court and fined $52,000 *(6.29).*

7. IMPACTS ON AIR

Unconventional gas mining and fracking will lead to large deliberate and fugitive emissions of methane, adding to climate change *(1.6).*

7.1 Gas emissions associated with fracking

- Damien Maher, a Senior Research Scientist with Southern Cross University, showed that methane levels surrounding gas mines were consistently higher – up to 3 times background values *(1.2).* It was previously shown that in the Condamine River area considerable atmospheric methane levels were associated with the CSG development in the Surat Basin area where fracking had occurred, evidenced by bubbling of methane in the Condamine River *(7.1).*
- It is increasingly being recognised that volatile chemicals used in the fracking process and the gases released pose health risks to workers and people living nearby. Volatile organic compounds and hydrocarbons (including the carcinogen benzene) are released during unconventional gas operations, from venting, holding tanks, ponds, compressors and other infrastructure. Some of these mix with nitrous oxides from diesel-fuelled machinery, creating ground level ozone – a significant respiratory irritant. (*Doctors for the Environment Australia*, *(7.2).*
- Emissions measured near gas wells include the BTEX compounds - benzene, toluene, ethylbenzene, and xylene – of which benzene is a contributor to lifetime excess cancer risk *(7.3).* Emissions of formaldehyde, hydrogen sulphide, acrylonitrile, methylene chloride, sulphuric oxide, and volatile organic compounds (VOCs) are recorded near gas drilling, and all have potential adverse health effects. Trimethyl-benzenes, aliphatic hydrocarbons, and xylenes may cause neurological effects, and can irritate the respiratory system and mucous membranes *(7.4).*
- A 2012 study detected 44 hazardous air pollutants at unconventional gas well sites *(7.5)*, whilst other recent USA studies *(7.6)* show that drilling and fracking emissions often contain strikingly high levels of benzene. The NYS Department of Health Public Health Review (the NYS Review) noted that 'studies provide evidence of uncontrolled methane leakage, emissions of other volatile organic chemicals, and particulate matter from well pads and natural-gas infrastructure as well as intermittently high dust and benzene concentrations'.
- Exposure to a range of harmful substances associated with unconventional gas operations constitutes a serious health hazard to those working on and living adjacent to or surrounded by unconventional gas development *(7.7).* Emissions can contribute to community odour problems and respiratory health impacts such as asthma.

- The Bakken shale emits 250,000 tons of ethane per year *(7.8)*. Emissions observed in this single region are 10 to 100 times larger than reported in inventories. Ethane is a gas that affects climate and decreases air quality.

7.2 Recorded Methane Venting in Australia (7.9, 7.10)

- An independent energy advisor, Tim Forcey, used an FLIR GF-320 infrared camera in the Queensland coal seam gasfields in 2017 to demonstrate substantial gas emissions from vents:
  - Continuous releases of methane from "high-point vents" on water-gathering pipelines
  - Intermittent releases of methane from other gas field equipment
  - Methane bubbling from the Condamine River and Wambo Creek.
- This report includes videos that amply demonstrate these emissions.
- Given the very large number of high point vents and other gas field equipment vents which are located throughout the Queensland CSG fields, if the scale of venting detected by the FLIR camera was replicated, it would represent a potentially vast, unmeasured contribution to global warming.

Arcadia Valley, Qld, in 2015, where flare stacks from wells looked to be just hundreds of metres apart.

7.3 Industry concerns

Industry reports illustrate the level of concern:

- The industry publication GasTips, World Oil Oilfield Review stated that between 7% and 19% of more than 1000 wells drilled from 2005 to 2007 in western Canada had gas migration along the casing annulus, and 9% to 28% of them had gas leakage through surface casing vents *(7.11)*.
- Unintended natural gas migration along production wellbores, even for conventional gas, has been a chronic problem for the oil and gas industry as a result of poor primary cement jobs, particularly in gas wells *(7.12)*.
- Brufatto et al (2003)cite USA Mineral Management Service data from the Gulf of Mexico indicating, 'By the time a well is 15 years old, there is a 50% probability that it will have measurable gas build up in one or more of its casing annuli *(7.13)*.
- Schlumberger, one of the world's largest companies specialising in fracking, published in its magazine as long ago as 1994: 'Older fields will continue to benefit from the expertise of the corrosion engineer and the constant monitoring required to prevent disaster *(7.14)*.

7.4 Climate change:

As climate change is widely considered the major global health threat of this century, fugitive emissions produced from the gas industry are an unacceptable health risk *(7.15)*.

Methane is a more powerful greenhouse gas than carbon dioxide – 86 times more powerful when considered over a 20-year timeframe and 34 times more over a 100-year timeframe.

A recent review by the Melbourne Energy Institute on methane fugitive emissions from unconventional gasfields in the USA *(7.16)* concluded:

- Actual measurements above USA gasfields have recorded fugitive emissions of up to 17% of production. For comparison, the unconventional gas industry in Australia claims that its fugitive emissions amount to only 0.1% of production *(7.17)*.
- 'Top down' methods of measuring fugitive emissions, such as satellite imagery and aerial borne surveys, have revealed methane emissions that are many orders of magnitude greater than emissions recorded from 'bottom up' surveys using ground measurements'.
- It is widely recognized that at more than about 3% leakage, gas is actually more polluting than coal when used to generate electricity *(7.18)*.

The Australia Institute showed that emissions from unconventional gas have been severely underestimated in Australia *(7.19)*. The current methodology for measuring greenhouse gas emissions from unconventional gas extraction is based on assumed and outdated methane emissions factors, rather than direct measurement of wells, pipelines and other gasfield infrastructure. The estimate used by the Australian Government is 0.058 tonnes of methane leaked per kilotonne of methane produced, or 0.0058%. This estimate is based on a historic USA emissions factor designed for measuring conventional gas emissions and is no longer used in the USA. Actual measurements by 16 peer reviewed research projects, using improved technology to take direct measurements from gas fields in the US, have ranged from 2-17% of production *(7.20)*.

The impact of these unaccounted-for methane emissions is seen in recent research showing that USA methane emissions have risen 30% in the last decade. The study used evidence from atmospheric observations to trace the largest rise of these emissions to the central part of the USA, where oil and gas extraction has expanded dramatically over the same time period (7.21).

The Melbourne Energy Institute reported that methane gas migrating to the surface due to coal seam dewatering and depressurisation for coal seam gas production was a potentially significant source of greenhouse gas *(7.22)*. It found that migration of methane along existing natural faults and fractures is possible and may increase with continued depressurization by unconventional gas mining. It noted that presence of free methane in water bores can be the direct consequence of depressurisation of the coal seams. The Melbourne Energy Institute also concluded that Australia may be dramatically under-estimating the fugitive methane emissions from unconventional gas.

Bista (2017) from Murdoch University *(7.23)* concluded that greenhouse gas emissions resulting from the development of Western Australia's five onshore gas basins would be equivalent to all other Australian emissions sources combined at 2014 levels each year for 20 years which is the general lifetime of a well. This paper concludes that onshore gas fracking without any control mechanism could not be considered as a transition fuel for climate change mitigation in Australia. Fracking emissions could be a highly significant source of greenhouse gas emissions nationally as well as globally.

8. IMPACTS ON LAND

8.1 Transformation of productive land into industrial landscape

The biggest impact on land is the transformation of entire regions of beautiful productive land into an industrial landscape. **It could be argued that this alone is reason to not allow unconventional gas mining.** While the industry claims that the footprint is relatively small, it does not take too much research to realise this is not correct. Much evidence is provided in this paper to support this. The industry will claim that new technologies involving multiple lateral drillings will reduce this footprint, but this is yet to be determined.

The background paper for the WA Inquiry claims that the footprint for unconventional gas will have a smaller footprint than coal seam gas *(8.1)*. It is not appropriate to assume that yet. Australia's former and present Chief Scientists, Professor Chubb and Dr Finkel, have both admitted that Australia's unconventional shale gas industry will have a larger footprint and require considerably more water than CSG. They have highlighted the absolute necessity to undertake detailed studies in an effort to understand the complications that could arise from this industry *(8.2, 8.3)*.

Gas wells on Condamine State Forest and farmland in Queensland, 2016.

8.2 Well Density

The high density of gas wells associated with unconventional gas mining and the impacts on the landscape have been summarised previously in this review – see sections 1.3, 1.8, 1.11, 1.12, 2.2

- In a few years, prime agricultural regions have been transformed into industrial areas through coal seam gas *(1.3)*. In Queensland, 18,000 wells have been approved, and tens of thousands more are planned.
- Estimates suggest that the Kimberley might soon be home to over 100,000 shale gas wells and the Mid West to over 25,000 shale wells *(1.12)*.
- The impact on the land and the industrialisation unconventional gas production creates is neatly demonstrated in a series of 'Before and After' photos of various forest and agricultural areas in Queensland. *A warning from Queensland: http://www.csgfreenorthwest.org.au/qlds_story (1.8)*

It is important to note that although conventional oil and gas production can have many of the same types of water resource and environmental impacts (spills, well integrity failure etc.), the well density in an unconventional oil/gas field, when compared to a conventional oil/gas field, is hundreds to thousands of times higher *(5.2)*.

Early in the development of the tight gas industry, hydraulic stimulation was done on vertical wells so a higher well density was required. However, since the development and reduced cost of horizontal drilling techniques, lower well densities are more typical with multiple wells starting from the same drilling site or pad. Although this reduces pad and well density in the landscape, it potentially puts greater pressure on the sites in terms of likelihood of impact due to the increased failure potential in the vertical portion of the well hole. Regardless, there are large increases in well density when compared to conventional oil and gas *(5.2)*.

8.3 Rehabilitation

It may not be possible to fully restore sites in sensitive areas following well completion or abandonment, particularly in areas of high agricultural, natural or cultural value (European Commission report, *8.4, 1.6*). Over a wider area, with multiple installations, this could result in a significant loss or fragmentation of amenities or recreational facilities, valuable farmland or natural habitats.

A recent USA study documents the failure of plant and soil systems disturbed by drilling and fracking activities to return to pre-drilling conditions following rehabilitation- even after 20 to 50 years *(8.5)*.

An interdisciplinary study published in *Science* 2015 demonstrated that the accumulating land degradation has resulted in continent-wide impacts of the unconventional gas industry in the United States, as measured by the reduced amount of carbon absorbed by plants and accumulated as biomass. This is a robust metric of essential ecosystem services, such as food production, biodiversity, and wildlife habitat, and its loss "is likely long-lasting and potentially permanent. The land area occupied by well pads, roads, and storage facilities built during this period is approximately three million hectares, roughly the land area of three Yellowstone National Parks *(8.6)*.

8.4 Fragmentation and Biosecurity

Ecological experts in Australia have identified that the considerable surface footprint of CSG infrastructure represents a serious threat to biodiversity fragmentation through direct clearing of bushland, loss of native vegetation, fragmentation of important remnant vegetation, spread of invasive species and increased fire risk *(8.7)*.

The sheer scale of gas wells and associated infrastructure, presents genuine risks for unique natural landscapes. In Queensland, farmers have reported serious invasions of weeds following CSG development. One cattle farmer has initiated legal action against a CSG company after he had to destock his property at Dalby after a sudden infestation of the noxious African lovegrass weed following CSG activities *(8.8)*.

Lawyers in Queensland representing farmers dealing with the CSG industry consider that weeds may ultimately be one of the biggest legacies of the CSG industry *(8.9)*, and have highlighted the weaknesses of biosecurity measures.

8.5 Seismic Activity

Evidence arising in the past 18 months has demonstrated links between fracking and waste fluid reinjection with increased seismicity and earthquakes.

- International researchers in 2016 concluded that the underground injection of waste water from oil drilling had contributed to earthquakes in California in 2005 by changing pressures along an active fault *(8.10).*
- An article in the Texas Journal of Oil, Gas, and Energy Law in 2016 exhaustively reviewed the literature on earthquake activity in areas of six states (Arkansas, Colorado, Kansas, Ohio, Oklahoma, and Texas) concluded that courts should impose strict liability for earthquake damage caused either by fracking itself or by the underground injection of fracking fluids *(8.11).*
- Emerging data summarised in Scientific American in 2016 suggests that pressure changes caused by fracking wastewater injection can migrate for years before encountering a geological fault and altering stresses in ways that allow for slippage *(8.12).* In spite of increasing scientific clarity about these mechanisms, regulators have been slow to respond.
- May 2016: In a study that has "far-reaching implications for assessment of induced seismicity hazards," a Canadian team of researchers determined in 2016 that hydraulic fracturing itself is linked to earthquake swarms in western Canada, in contrast to the central United States where disposal of fracking waste is the cause of most induced seismicity. Furthermore, lowering the volume of injected fluid may not be sufficient to prevent quakes *(8.13).*

The evidence is strong enough that the Oklahoma Supreme Court ruled unanimously that homeowners can sue the oil and gas industry for injuries or property damage resulting from earthquakes. The number of earthquakes of magnitude 3.0 or higher has skyrocketed in Oklahoma since the advent of the fracking boom, with fewer than two per year before 2009 and more than 1,100 predicted to occur in 2015 (8.14).

The Dutch government plans to compensate people whose homes and buildings were damaged in a 3.4 magnitude quake, blamed on extraction at Europe's biggest gas field. More than 900 homes and buildings were damaged, according to an association which collates reports from residents. Groningen, which houses the European Union's largest gas field, has been plagued by tremors which increased as gas production rose in the region through the 1990s. *(8.15)*

9. HEALTH IMPACTS

9.1 Claims made by industry and Governments have no credibility

The gas industry and Governments maintain that unconventional gas extraction is safe and 'clean'. There is a rapidly growing body of research that demonstrates this is far from the truth and that unconventional gas operations can have serious consequences for human and animal health.

Adgate, Goldstein and McKenzie (2014) *(9.1)* present a clear argument that unconventional gas mining poses risks to health, both directly and indirectly, and at the local, regional and global level. Thus, decisions on unconventional gas mining made by all Australian states and territories, and by other nations, affect us all.

There are numerous independent reviews involving many hundreds of peer-reviewed papers demonstrating the impacts of unconventional gas on human health.

9.2 Health impacts shown in over 80% of 700 peer-reviewed papers

Peer-reviewed scientific literature to 2016 involving more than 700 studies on the impacts of unconventional gas development show:
84% of public health studies indicate risks to public health
69% of water studies show actual or potential water contamination
87% of air quality studies indicate elevated air pollution.
(9.4, 9.4a Hays, J., Shonkoff, SB. (2016)

Other Sources:
Public Health Association of Aust: Submission to Inquiry into Hydraulic Fracturing in NT 2017 (9.2)
Doctors for Environment Australia: Submission to Inquiry into Hydraulic Fracturing in NT April 2017 (7.2, 9.3)
Chesapeake PSR (2016) The health effects of fracking. Fracking harms human health. Chesapeake PSR Physicians for social responsibility. Health and Energy Brief. Author – Gina Angiola, MD (9.6)

9.3 Saunders – 156 papers

A comprehensive review of 156 peer-reviewed publications (Saunders et al., 2016) (9.8) found multiple potential hazards to human health from exposures to harmful air and water pollutants associated with unconventional gas mining (9.7).

The major concerns identified are (9.9):

- There are direct local health concerns associated with living and working in close proximity to all steps of the unconventional gas mining process, not just the hydraulic fracturing ('fracking') component. These include potential exposures to air pollutants released during the whole process, including volatile organic compounds, fine silica, oxides of nitrogen, hydrogen sulphide, formaldehyde, ground level ozone and diesel fumes.
- Local communities may also face stress from an array of changes, including exposure to noise, lights, odours, and dust, as well as worries and fears about health, accidents, declining property values, increased traffic, industrialised landscapes, loss of community cohesion, post-construction job losses, local business loss, and changes to community character.
- Findings from various research studies have suggested associations between living close to unconventional gas operations and higher frequencies of negative health indicators, such as lower birth weights, more birth complications, more self-reported symptoms such as migraines, nasal and sinus problems and fatigue, and more hospitalisations due to heart, nerve and asthma conditions.
- At a local and regional level, unconventional gas activities near drinking water sources carry the potential for impacts on water quality.
- Dealing with wastewater from hydraulic fracturing safely remains a major challenge – each method and proposed new solution carries with it potential problems and complications.
- At a global level, there are grave concerns about the unconventional gas industry's contribution to climate change.

9.4 Compendium of Scientific, Medical, and Media Findings Demonstrating Risks and Harms of Fracking

Source: LTG Submission to NT Inquiry April 2017 (1.6)

The New York based health organization, the *Concerned Health Professionals of New York,* has compiled the *Compendium of Scientific, Medical, and Media Findings Demonstrating Risks and Harms of Fracking* (1.7, 1.6) - a fully-referenced compilation of the evidence for the risks and harms of fracking that brings together findings from the scientific and medical literature, government and industry reports, and journalistic investigation.

9.5 Studies by Physician organisations

Sources:

- *Chesapeake PSR (2016) The health effects of fracking. Fracking harms human health. Chesapeake PSR Physicians for social responsibility. Health and Energy Brief. (9.6)* Author – Gina Angiola, MD
- *Doctors for the Environment Australia: Submission to Inquiry into Hydraulic Fracturing in NT April 2017 (7.2)*

Recent studies in the peer-reviewed literature are of vital importance, both from a clinician's perspective and a policy perspective. These studies include:

- In October 2015, researchers at the Johns Hopkins Bloomberg School of Public Health and collaborating institutions analysed data from roughly 10,000 birth records in Pennsylvania and found a statistically significant association between maternal proximity to active fracking operations and premature births and high-risk pregnancies *(9.10, 9.11).*
- In July 2016, researchers at the Johns Hopkins Bloomberg School of Public Health and collaborating institutions analysed medical records of more than 35,000 asthma patients, ages five to 90 years old, and found a statistically significant association between proximity to active fracking operations and mild to severe asthma exacerbations *(9.12).*
- In August 2016, researchers at the Johns Hopkins Bloomberg School of Public Health and collaborating institutions analysed responses to questionnaires received from more than 7,000 adult primary care patients in central and northern Pennsylvania, and found statistically significant associations between proximity to active fracking operations and various combinations of migraine headaches, chronic rhinosinusitis and fatigue symptoms.
- In a further study from Pennsylvania, published in 2015, researchers examined health care use with fracking activity. They looked at well numbers and density and examined over 95,000 inpatient hospital records. They found that hydraulic fracturing as determined by well number or density had a significant association with cardiology hospital inpatient rates, and well density had a significant association with neurology hospital inpatient rates *(9.13).*

Other research teams have documented associations with serious illnesses, as well as pathways for disease development that may take many years or decades to become clinically apparent.
For example:

- In 2015, researchers at the University of Pennsylvania and Columbia University reported an increase in cardiac and neurologic hospitalizations in two Pennsylvania counties with active fracking operations, compared with a neighbouring county where such operations had been banned.
- In 2016, researchers working collaboratively with local residents near oil and gas operations in Wyoming reported combined results from environmental sampling and biomonitoring in one of the first studies of its kind. Toxicants and their metabolites, including BTEX6 chemicals known to damage multiple organ systems, were detected in air samples and in the urine of residents. Although most of the wells in this region are conventional vertical wells, the human health hazards from volatile organic compounds are present in all types of oil and gas development and production.
- In 2016, researchers documented endocrine-disrupting chemicals in surface waters near fracking wastewater disposal sites in West Virginia. Such chemicals can have potent effects on human development at exceedingly low concentrations during critical developmental windows. As part of their ongoing work, researchers now also have documented adverse effects on development and reproductive capacities of both male and female mice at concentrations that are relevant to real-life human environmental exposures.

Unconventional gas development affects human health and well-being not only through direct exposures to toxic chemicals in air, water and soil, but also through many stressors introduced into communities. These include excessive noise and light pollution, increases in traffic accidents and fatalities, increases in domestic violence, alcohol and drug use, crime and disruptions of family and community relationships.

Importantly, in order to make any meaningful decisions about the risk to public health from UGD, baseline studies need to be undertaken as well as comprehensive epidemiological studies of population health, with support for research on potential health effects of UGD independent of industry funding, including long term prospective health studies. Also, health surveillance of persons living and working near major UGD needs to be carried out, with full and transparent disclosure.

The Chesapeake PSR concluded that the science is increasingly clear. The health risks posed by fracking are real, significant and unacceptable. No regulatory framework has been shown to adequately protect public health or the environment.

9.6 Review by Concerned Health Professionals of New York & Physicians for Social Responsibility.

Sources:
- *Concerned Health Professionals of New York & Physicians for Social Responsibility. (2015, October 14) (9.14).*
- *Compendium of scientific, medical, and media findings demonstrating risks and harms of fracking (unconventional gas and oil extraction) (3rd ed.). http://concernedhealthny.org/compendium/*

Drilling and fracking emissions contribute to toxic air pollution and smog (ground-level ozone) at levels known to have health impacts.
- The New York State Department of Environmental Conservation determined that fracking could increase ozone levels in downwind areas of the state, potentially impacting the ability to maintain air quality that meets ozone standards.
- Air near gas wells in rural Ohio had levels of polycyclic aromatic hydrocarbons that surpassed those in downtown Chicago. They were also ten times higher than the levels found in rural areas without fracking operations, raising the lifetime risk of cancer for residents living near the well pads by 45 percent.
- Increased air pollution and smog formation poses a serious risk to all those already suffering from respiratory issues, such as children with asthma.

Public health problems associated with drilling and fracking, including occupational health and safety problems, are increasingly well documented.
- Health impacts among residents living near drilling and fracking operations include increased rates of hospitalization, self-reported respiratory problems and rashes, motor vehicle fatalities, trauma, drug abuse, and low birth weight among infants.
- Benzene has been detected in the urine of wellpad workers in Colorado and Wyoming.
- The National Institute for Occupational Safety and Health named oil and gas extraction industry workers among those at risk for silicosis, an incurable lung disease caused by exposure to silica dust, from the silica sand that is used extensively in fracking operations.
- Fatality rates among workers in the oil and gas extraction sector in North Dakota were seven times the national fatality rates in this industry, which itself has more deaths from fires and explosions than any other private industry. An increase in workplace deaths has accompanied the fracking boom in West Virginia.

Drilling and fracking activities can bring naturally occurring radioactive materials to the surface.

- Exposure to increased radiation levels from these materials is a risk both for workers and for residents.
- In Pennsylvania, radon levels in homes have been rising since the advent of the fracking boom, and buildings in heavily drilled areas have significantly higher radon readings than areas without well pads—a difference that did not exist before 2004.
- University of Iowa researchers documented a variety of radioactive substances including radium, thorium, and uranium in fracking wastewater and determined that their radioactivity increased over time; they warned that radioactive decay products can potentially contaminate recreational, agricultural, and residential areas.
- The New York State DEC's Findings Statement noted that naturally occurring radioactive materials (NORM) are brought to the surface in the cuttings, flowback water and production brine. The build-up of NORM in pipes and equipment has the potential to cause a significant adverse impact because it could expose workers handling pipes, for cleaning or maintenance, to increased radiation levels.

9.7 Medical health survey in the Tara region Queensland

Source: McCarron (2013). Symptomatology of a gas field. An independent health survey in the Tara rural residential estates and environs. geralynmcc@iinet.net.au (9.15)

This report documents an investigation during February and March 2013 by a concerned General Practitioner, in relation to health complaints by people living in close proximity to coal seam gas development in SW Queensland.

- Thirty -five households in the Tara residential estates and the Kogan/Montrose region were surveyed in person and telephone interviews were conducted with three families who had left the area. Information was collected on 113 people from the 38 households. Of these, 17 were children 5 years of age or less, 31 were children aged between 6 and 18, and 65 were adults aged between 19 and 82.
- 58% of residents surveyed reported that their health was definitely adversely affected by Coal Seam Gas, whilst a further 19% were uncertain. The pattern reported was outside the scope of what would be expected for a small rural community.
- In all age groups there were reported increases in cough, chest tightness, rashes, difficulty sleeping, joint pains, muscle pains and spasms, nausea and vomiting. Approximately one third of the people over 6 years of age were reported to have spontaneous nose bleeds, and almost three quarters were reported to have skin irritation. Over half of children were reported to have eye irritation.
- A range of symptoms were reported which can sometimes be related to neurotoxicity (damage to the nervous system), including severe fatigue, weakness, headaches, numbness and paraesthesia (abnormal sensations such as pins and needles, burning or tingling). Approximately one third of the all the 48 children to age 18 (15/48) were reported to experience paraesthesia. Almost all the 31 children aged 6-18 were reported to suffer from headaches and for over half of these the headaches were severe. Of people aged 6 years and over, severe fatigue and difficulty concentrating was reported for over half. Parents of a number of young children reported twitching or unusual movements, and clumsiness or unsteadiness.

No baseline air or water monitoring or baseline health studies were done prior to the Queensland Government permitting the widespread development of the CSG industry in close proximity to family homes. No ongoing health study or surveillance and no ongoing testing to monitor chronic exposure levels is in place. This is clearly unacceptable.

The rural residential estates near Tara are the most densely settled area in Australia to have seen intensive CSG development. Since 2008, the people of these estates have informed successive Queensland Governments of their health problems. Their reports of ill health have been trivialised and ignored.

The recent report released by the Queensland Government following their investigation into the health impacts near Tara was so inadequate and flawed that it has done little to alleviate concerns.

- The Queensland government undertook minimal non-systematic environmental sampling, and relied mainly on inadequate industry commissioned data.
- The investigation of patient symptoms was grossly underfunded and understaffed, with no medical staff actually visiting the site.
- Only 15 people were examined clinically.

Positive findings of volatile chemicals were dismissed, despite the fact they are potentially capable of causing health impacts, especially over long periods of time.

A 2018 paper by Dr. McCarron *(9.32)* suggests a link between the escalating rise in hospital admissions for circulatory and respiratory conditions and a massive increase in air pollutants from the unconventional gas

industry in south east Queensland. While recognising limitations on the data, partly due to anomalies in the data reported by industry and inadequate Government monitoring, it was concluded there was sufficient evidence to warrant full investigation.

9.8 Health Impacts Associated with Air and Water Pollution

Some of the public health effects of unconventional gas development that researchers have documented, outlined in the Compendium of Fracking Risks *(1.7)*, include:

- increased rates of hospitalization for cardiological complaints, cancer, skin conditions, and urological problems;
- increase in frequency of health symptoms reported by residents as distance between households and gas wells decreased; with rashes and upper respiratory problems more prevalent among persons living less than one kilometre from drilling and fracking operations;
- increases in commercial vehicle accidents;
- a sharp rise in ambulance calls and emergency room visits for drug related cases and oilfield related injuries and accidents;
- increase in infant deaths to six times the normal rate over three years;
- congenital heart defects, and possibly neural tube defects in newborns, associated with the density and proximity of natural gas wells within a 10-mile radius of mothers' residences;
- elevated rates of low birthweight among infants born to mothers living near drilling and fracking operations during their pregnancies;
- reductions in average birthweight and length of pregnancy as well as increased risk for low birthweight and premature birth associated with proximity to fracking operations *(9.16)*.

An array of chemicals capable of causing significant health impacts may be released during unconventional gas operations *(9.7, 9.17)* including:

- Volatile organic compounds, including BTEX (Benzene, Toluene, Ethylene and Xylene), that occur naturally in the shale, and evaporate from the flowback wastewater after fracking and from flaring excess gas
- Polyaromatic hydrocarbons (PAHs), heavy metals, naturally-occurring radioactive materials (NORMs)
- Endocrine-disrupting chemicals
- Nitrogen oxides
- Hydrogen sulphide from gas processing
- Formaldehyde (from the breakdown of escaping methane)
- Diesel fumes from extensive truck movements
- Ground level ozone, that forms from mixtures of pollutants and which is known to travel large distances.

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

The following are some health studies that have emphasized the health risks posed by potential exposure to chemicals that may be released during unconventional gas operations via water and air.

- USA experience has indicated that health risks associated with air pollution are at least as serious to the health of people living nearby as the risks mediated through water contamination (Finkel & Hays, 2013; Brown et al., 2014) *(9.7)*.
- While significant concern has been raised about the large number and potential toxicity of the chemicals used in hydraulic fracturing and drilling muds, many researchers emphasise that the highly saline flowback waters containing naturally occurring chemicals are of substantially greater concern from an environmental and public health aspect (Colborn et al., 2011; Elliot et al., 2017; Vidic et al., 2013). The combination of chemicals and their resulting by-products can accumulate and persistent indefinitely in the environment or be taken up by plants and animals and may enter the food chain *(9.7)*.
- A study by Elliott et al. (2017) examined the carcinogenicity data on 1177 chemicals in fracking fluids and wastewater (US EPA) and 143 chemicals identified in scientific papers reporting air pollutants that were published before 2016. Over 80% of these chemicals were not evaluated for carcinogenicity. Among 119 chemicals that were evaluated, 49 water and 20 air pollutants were possible, probable or known carcinogens and 20 were associated with leukemia/lymphoma, including benzene, butadiene, cadmium, diesel exhaust and PAHs *(9.7)*.
- A second study by Elliott et al. (2017b) examined the reproductive and developmental toxicity of 1021 chemicals identified in fracturing fluid and wastewater, and found that toxicity information was lacking for 781 (76%). Among the 240 that had been evaluated, 103 were known to have the potential for reproductive toxicity and 95 for developmental toxicity *(9.7)*.

- Toxins of greatest concern linked to gas extraction include volatile organic compounds (like benzene), poly-aromatic hydrocarbons, heavy metals and radioactive materials. These can affect the respiratory, endocrine, nervous and cardiovascular systems and some, notably benzene, can cause cancer (Colborn et al., 2011; ATSDR 2013) *(9.7)*.
- Diesel engines emit particulate matter, nitrogen oxides and volatile organic compounds and was recently classified as a Group 1 carcinogen by the International Agency for Research on Cancer (IARC 2014) *(9.7)*.
- Silica, handled in very large quantities in the drilling and hydraulic fracturing processes, has the potential to pose serious risks to the respiratory health of exposed workers, causing silicosis decades later. There is also evidence of potent endocrine disrupting chemicals associated with the industry (Lloyd- Smith & Senjen 2013). Ground level ozone, that forms from mixtures of pollutants emitted during unconventional gas mining is also of significant concern, and can travel large distances, acting at a regional level *(9.7)*.
- Anecdotal reports and findings of a community study found significantly higher reports of respiratory (39% vs 18%) and skin (19% vs 3%) conditions among people living within 1 km compared to those living more than 2 km from shale gas wells in Pennsylvania (Rabinowitz et al., 2015) *(9.7)*.
- People living near unconventional gas wells throughout the world, including near CSG gas wells in Tara, Queensland, have anecdotally reported similar distressing symptoms, as well as headaches, nosebleeds, numbness and tingling sensations (McCarron 2013; McCarron & King 2014) *(9.7)*.
- A study conducted by Macey et al (2014) identified levels of air-borne toxins above Federal guidelines in four USA States where substantial oil and gas production activities had occurred.
- Negative health outcomes have been found to occur more often in groups of residents with greater exposure to shale gas mining, compared with groups with lower exposure *(9.7)*:
  - Developmental problems during pregnancy and infancy – lower birth weight, small for gestational age, higher frequency of serious birth complications, specific birth defects (Casey et al., 2016; McKenzie et al., 2014; Stacy et al., 2015).
  - Hospitalisations – for cardiovascular and neurological disorders and for those with existing asthma conditions (Rasmussen et al., 2016; Jemielita et al., 2015).
  - Symptoms – migraine headaches, chronic nasal and sinus irritation, fatigue, nausea, skin rashes, eye irritation, nosebleeds, and asthma worsening requiring medication changes (McCarron, 2013; Rabinowicz et al.,2015, Rasmussen et al., 2016).
- Petroleum-based hydocarbons can break down underground in ways that promote the leaching of naturally occurring arsenic, a known human carcinogen that causes bladder, lung, and skin cancer, into groundwater *(9.19)*.
- Elevated levels of toxic BTEX (Benzene, Toluene, Ethylene, Glycene) chemicals in flowback water from fracked wells were detected at AGL's Waukivory CSG Project at Gloucester *(9.20)*. It is likely the chemicals were mobilized due to the fracking process. This well is now abandoned.
- In a 2013 US study, surface and groundwater near areas experiencing high levels of unconventional gas activity in Colorado were shown to contain endocrine-disrupting chemicals in concentrations high enough to interfere with the response of human cells to male sex hormones and estrogen. Exposure to endocrine-disrupting chemicals can increase the risk of reproductive, metabolic, neurological, and other diseases, especially in children and young organisms. *(9.33)*

9.9 Impacts on mental health, psychosocial wellbeing and community cohesion

There are many avenues through which the unconventional gas industry can harm mental health and individual and community wellbeing *(9.9)*.

- The initial phase impacts include distress and anxiety due to disagreements that split the community into those who support the industry and those who oppose it.
- In the 'boom' phase tight-knit communities can feel inundated with strangers coming in, swamping unprepared health and mental health services. Crime may also increase. Such impacts are detrimental to the social cohesion and for some, the moral character, of the community.
- In the post-construction phase, jobs decline dramatically and housing demand drops. Production ramps up with drilling and fracking, with its 24-hour lights, noise, odours, tree clearing and truck movements - causing some people to feel a deep sense of loss of control, loss of place and loss of peace and a feeling of being trapped and unable to escape.
- All of these phases present risks of depression, anxiety and increased use of alcohol and other drugs for coping.

Doctors for the Environment Australia note that 'water and air pollution, water shortages, permanent degradation of productive agricultural land and loss of livelihood and landscape all have mental health consequences for communities living in a gas field *(9.21)*.

A 2013 study involving 12 workshops established that CSG operations in south west Queensland placed rural communities 'under sustained stress' *(9.22).* Study participants reported that mining and CSG operations 'significantly impacted or exacerbated issues such as the health, social fabric and economy of the community', and the authors noted that local health services faced 'unsustainable pressure'.

A 2014 article in the Medical Journal of Australia noted that 'gas developments can have numerous and considerable social and psychological effects, which may exacerbate more direct health risks' *(9.23).*

A 2014 CSIRO study *(9.24)* noted that local farmers perceived the nature of CSG development in South West Queensland as an 'invasion' or 'occupation', whilst a previous study in Chinchilla found residents describing a 'tsunami of change' *(9.25).*

Interacting and engaging with CSG companies has also been reported as having a significant negative impact on farmer's wellbeing *(9.26).* The interactions between farmers and CSG companies resulted in issues of stress, conflict and disconnection.

Researchers assessed the contribution of coal seam gas extraction in Queensland to the global stress burden and mental health of Australian farmers.

A survey of 378 Australian farmers, predominantly from Queensland and NSW, published in Journal of Environmental Psychology *(9.27)* in 2016, found that farmers concerned about the impacts of coal seam gas on their health, community and the environment, were more likely to report symptoms of depression and decreased levels of wellbeing.

Schlumberger Oilfield Australia Pty Ltd was fined $162,500 after a worker at a Queensland drilling site was burned when exposed to unsafe levels of radiation *(9.33).*

9.10 Livestock health risks (9.28, 9.6)

There is considerable evidence from the USA that gas mining is detrimental to livestock and domestic animals. Twenty four case studies have been compiled of apparent harm to animals, mainly resulting from contamination of water wells, springs, ponds or creeks, some due to accidents or negligence, and others a consequence of normal operations. On seven cattle farms studied in the most detail, half the herd, on average, was affected by death or failure to breed.

In one case, of 60 cattle with access to a creek allegedly contaminated with fracking wastewater, 21 died and 16 failed to reproduce, while 36 cattle without access to the tainted water remained healthy.

In another case, of 140 cattle exposed to fracking waste, about half died and many others bore stunted or stillborn calves while 60 others in another pasture had no problems.

The Concerned Health Professionals of New York has compiled several other cases of affected livestock. For example, in Pennsylvania, one farmer whose cows were ex-posed to drilling wastewater in 2010 lost 8 out of 11 newborn calves. In Pennsylvania the number of dairy cows declined where fracking was prevalent – in counties with more than 10,000 dairy cows and more than 150 shale gas wells, dairy cow numbers declined by 16% between 2007 and 2010.

A 2012 case study in the USA also found serious evidence of harm to domestic stock from shale gas drilling waste contamination, including cattle deaths, stillbirths and reproductive problems (9.29).

9.11 Involvement of health experts (9.7)

Far too frequently, public health, psychological/mental health and medical expertise are 'missing from the table' in assessing the impacts of unconventional gas on health (Goldstein et al., 2012). Experts in engineering, safety science, environmental management and toxicology, while extremely important, should not be assumed to also have a comprehensive, in depth understanding of the impacts of unconventional gas on the health and wellbeing on people's lives. Direct public and psychological health expertise is required.

Precautionary principle

Many people assume that the precautionary principle is being applied by government, i.e. that,
- preventive action would be taken in the face of uncertainty
- the proponents of a proposed activity would be required to demonstrate its safety, not the community
- governments would explore a wide range of alternatives to possibly harmful actions
- government would encourage public participation in decision making.

In submissions to the NSW Chief Scientist and Engineer's examination of the public health and safety of coal seam gas mining in 2013, many public health organisations and the Australian Medical Association, called for application of the Precautionary Principle. The Australian Medical Association stated simply, 'If in doubt, turn CSG off' *(9.30)*.

The British Medical Journal recently published a joint letter with similar sentiments signed by 18 leading medical scientists, stating: 'The arguments against fracking on public health and ecological grounds are overwhelming. There are clear grounds for adopting the precautionary principle and prohibiting fracking' *(9.31)*.

Many public health and medical organisations in Australia are calling on governments to apply the Precautionary Principle in this situation, and refrain from allowing unconventional gas mining to occur in Australia until there is sufficient evident demonstrating that it is safe for people and the environment. Among these organisations are:

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

10. COMMUNITY

10.1 Impacts on the community

In the course of its work supporting landholders and communities facing the impacts of unconventional gas developments, Lock the Gate Alliance hears firsthand about the impact unconventional gas development is having on the livelihoods, health and well-being of Australian farming families living adjacent to and surrounded by gas activities. These harmful impacts include: intimidation, coercion and bullying by UG companies; intolerable noise and light pollution from flaring, traffic and UG infrastructure; contamination and depletion of water in farm bores; rivers bubbling with methane; bores running dry; stock losses associated with pipeline construction and water contamination; costly and time consuming interruptions to farming operations; huge trucks and heavy machinery on small local roads affecting lifestyle, safety and road infrastructure; dust impacts on pasture; increases in weed infestation; industry workers leaving mess from pipeline construction in farm paddocks; workers destroying fences and leaving gates open; properties not able to be sold; credit being denied; mental health impacts resulting from dealing with companies and the impacts of industry development; and physical health symptoms including respiratory ailments, headaches, rashes, nausea and vomiting, and nose, throat and eye irritations.

For many affected landholders, these impacts affect all facets of life and are making their living situation untenable. Personal testimonies of a number of affected landholders can be viewed in a series of short films compiled by the Lock the Gate Alliance talking about the impacts on them:
https://www.youtube.com/watch?v=4OG9JkzB_3M *(10.1)*

While the gas companies move on once the commercially viable gas has been extracted, the communities suffer long term *(1.3)*. The unconventional gas mining leaves massive damage, and the community must foot the bill. Yet the community did not want it.

Queensland's experience shows that reality does not match the unconventional gas industry's claims. Few benefits are realised outside the gas industry, and there are serious social and economic effects on local communities and existing businesses *(10.2)*.

10.2 Unconventional gas led to a degradation of public resources in QLD

A study conducted in the Darling Downs of Queensland between 2008 and 2013 by the industry-funded Sustainable Minerals Institute at the University of Queensland surveyed stakeholders from different sectors in the local community including the local business community, agriculture, local government, advocacy groups and environmental consultants, as well as the mining and unconventional gas industries *(10.3)*.

Far from mining and unconventional gas providing economic benefits, local businesses felt that it had reduced financial capital, human capital, infrastructure, social capital and natural capital. Local businesses had to compete with inflated gas industry wages in order to recruit and retain staff, and they experience increased rent

and competition for services. There were disruptions to farmers from the rollout of access roads, pipelines, water treatment plants and other infrastructure.

10.3 Community cohesion and wellbeing:

The Queensland and NSW experience has shown that when an unconventional gas industry is forced upon communities against their wishes, there is potential for significant conflict and social upheaval and disruption as a result *(1.6)*. Lock the Gate members and local community groups report a range of impacts on their mental and emotional wellbeing, including:

- A sense of injustice that they do not have the right to refuse access to companies for UG activities and that this industry is being forced on an unwilling population.
- Fear and anxiety about the impacts of the unconventional gas industry on their family's health and the quality of the air and water they rely upon.
- Concern about the impact of unconventional gas development on the economic viability of their farms and property values.
- A sense of anger and betrayal that governments are supporting industry rather than communities in the development of the unconventional industry.
- A sense of anger that the industry is being pushed ahead rapidly without proper consideration of the impacts and before proper scientific studies have been done and baseline data collected.

Doctors for the Environment Australia note that the lack of a veto right for landholders in relation to unconventional gas development, the stress involved in dealing with companies (often against their will), the lack of full information and disclosure on the realities of unconventional gas development, and the often underhanded tactics employed by companies contributes to a sense of powerlessness, betrayal and frustration amongst landholders and affected communities. The injustice and powerlessness contribute to distress and poorer mental health outcomes. Unconventional gas development can 'divide previously close-knit rural communities, increasing tension and disharmony'.

According to DEA, in eastern Australia, the stress and disruption caused to farmers has already been shown to force some of them to leave a CSG drilling area, allowing once productive lands to lapse into disuse. In the USA long-time residents are moving, unable to bear the changes the gas industry has wrought on their landscape and community.

A study on landholders in Queensland found that unconventional gas operations placed rural communities under sustained stress, with study participants describing significant impacts on the health, social fabric and economy of local communities (10.4).

10.4 Boom Bust impact

The scale of the 'bust' after the short unconventional gas construction period ends is severe, and long-term job opportunities are extremely limited. Queensland Treasury figures reveal that more than 10,000 fly-in-fly-out jobs have been lost in the Surat Basin since the CSG construction boom peaked in 2014. In June 2014 there were 14,490 non-resident jobs in the region, and by June 2016 that had reduced to just 3,820 jobs (10.5), similar to pre-CSG levels.

The gas industry frequently makes claims about delivering substantial flow-on jobs in regional communities, particularly in the services industry, and job multipliers are frequently used to derive large job estimates. However, research undertaken by CSIRO's Gas Industry Social and Environmental Research Alliance found that job spill-overs into non-mining employment in the Surat Basin were negligible (10.6).

10.5 Employment impacts (*The Australian Institute, 2017 7.19*)

- While gas companies continually spruik the promise of more jobs for local communities as a justification for unconventional gas development, the simple fact is that it is a relatively small employer in the long term.
- The majority of gas industry jobs are required for the short construction phase only, they are not ongoing, as modern gas fields are highly mechanized and need very few people to operate them. Local employment opportunities are minimal with the majority of skilled workers being brought in from elsewhere with fly-in-fly-out workforces.
- The industry has made some incredible claims about its capacity to employ. In 2012 it claimed it created 100,000 jobs whereas the Australian Bureau of Statistics showed there were only 9,372 additional jobs. A 2011 report prepared for Santos by Allen Consulting Group found that a potential coal seam gas development in Northwest NSW would increase employment opportunities in NSW by 'around 2,900 ongoing

full time positions', even though the project would only create about 30 gas industry jobs. Over 500 jobs would apparently be created in the public sector, at taxpayer expense *(10.7).*

- Far from creating many additional jobs, the coal seam gas industry has been found to reduce employment in certain sectors. The Office of the Chief Economist's 2015 Review into the Socioeconomic Impacts of Coal Seam Gas in Queensland reported that 1.8 agricultural jobs are lost for every CSG job created *(10.8).* Similarly, a study of Queensland's unconventional gas expansion by CSIRO's Gas Industry Social and Environmental Research Alliance found that for every 10 additional people employed in coal seam gas, 18 agricultural jobs were lost *(10.9, 10.10).*
- The Chair of the NT Fracking Inquiry claimed there could be 32,000 jobs created by fracking in the NT, yet the Australian Institute states there is a very high probability that no long term jobs will be created in the Northern Territory. Even the best case would be for only 500, but this was a very low probability. The Research Director of the Australian Institute criticised the inquiry chair, saying its own commissioned research had been ignored. *(10.19, 10.20)*

10.6 Property values and credit Availability

Rabobank, the world's leading specialist in food and agribusiness banking, stated risks from unconventional gas mining included reductions in farm productivity, efficiency, land values and credit availability. It also indicated that concurrent CSG mining and agricultural activities on agricultural land could result in problem loans or defaults (10.11).

In 2016 it was revealed that a Queensland family was unable to obtain a bridging loan using their property for equity, because the property had four coal seam gas wells on it. The Commonwealth bank stated that coal seam gas wells on the land make the security unacceptable for residential lending purposes *(10.12, 10.13).*

10.7 Insurance

Insurance companies have refused to insure against risks associated with unconventional gas extraction, both in Australia and in the USA. In the USA, homeowners can be confronted with uninsurable property damage for activities that they cannot control *(10.14).*

In the north west of NSW, farmers have been refused insurance cover for risks and contamination associated with unconventional gas extraction *(10.15).*

Landholders are concerned they may be liable for any negative impacts caused by hydraulic fracturing. In 2014, the NSW Chief Scientist released a report, which concluded that the CSG industry was markedly under-insured and that landholders were likely to bear a substantial risk as a result *(10.16).*

Meat and Livestock Australia has advised there is a genuine risk that landholders may ultimately be responsible for liabilities arising from unconventional gas activities if they lead to personal injury, property damage, or contamination *(10.17).*

The Rural Industries Research and Development Corporation cite a case study in Queensland where a landowner was advised by their supply chain partners that they would be liable for any contamination caused by coal seam gas activities. Neither the CSG company nor the insurer would agree to indemnify the landholder against that risk *(10.18).* Legal advice indicated:

- Gas companies are refusing to include provisions in access agreements to accept liability for any contamination that may occur.
- Gas companies in Australia are under-insured and do not have adequate insurance to cover the types of risks that CSG activities bring.
- Some graziers have reported that insurers have examined the risk to them of unconventional gas contamination and found it too high to offer insurance.

One must ask the obvious question: **Why don't the companies cover the liabilities if the process is so safe and free of risks?**

11. IMPACTS ON AGRICULTURE

11.1 Threat to agriculture in WA

Across Western Australia large areas of highly productive farmland are under threat from Unconventional Gas mining. This activity has the potential to severely disrupt virtually every aspect of agricultural production and potentially even remove the land from production.

11.2 Landholders will lose millions every year by hosting unconventional onshore gasfields

A 2016 CSIRO report found the alienation of productive farmland for CSG infrastructure in Queensland resulted in losses in gross economic returns of up to 10.9% *(11.1)*. The total losses to gross revenues varied between $1.32m and $3.29m per property and averaged $2.17 million.

The Lock the Gate Alliance notes that the methodology was estimating economic losses based solely on reduction in land area and did not attempt to quantify losses resulting from disruption to operations, dust generation, spills and leaks of wastewater or the spread of weeds. Therefore, total losses to landholders will undoubtedly be far higher.

12. LAND ACCESS

12.1 Land owners have no rights to prevent access by the mining company.

Landowners have no rights to veto gas development on their land. Petroleum leases are issued by the Department of Mines and Petroleum with no consultation or rights to object. The affected landowners, businesses or the community do not have to be notified, as has been the case with the current leases. If a landowner initially refuses access, the matter will be referred to a Magistrates court after three months to decide on appropriate compensation.

Leases are often issued first in state forests, and then expanded from there.

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SHALE GAS: HOW OFTEN DO FRACKED WELLS LEAK?

By Andrew Nikiforuk (http://www.resilience.org/resilience-author/andrew-nikiforuk/), originally published by The Tyee (http://thetyee.ca/News/2013/01/09/Leaky-Fracked-Wells/)

January 10, 2013

Pennsylvania-wellhead.jpg

Tight as a drum? Shale gas well head in Pennsylvania. Photo by Jeremy Buckingham MLC (http://www.flickr.com/photos/62459458@N08/7800489034/) via Creative Commons license.

When industry says hardly ever, that's a myth. It's a documented, chronic problem.

One of the boldest claims (http://www.capp.ca/getdoc.aspx?DocId=217568&DT=NTV) made by the shale gas industry goes like this: oil and gas companies have drilled and fractured a million oil and gas wells with nary a problem.

In other words fracture fluid or methane leaks are "a rare phenomenon."

But industry data disproves this dubious claim says Cornell University engineer Anthony Ingraffea, the main source for this series (http://thetyee.ca/Series/2013/01/08/Fracking-Myths-And-Realities/), who has studied the non-linear science of rock fractures for three decades.

Moreover industry studies clearly show that five to seven per cent of all new oil and gas wells leak. As wells age, the percentage of leakers can increase to a startling 30 or 50 per cent. But the worst leakers remain "deviated" or horizontal wells commonly used for hydraulic fracturing.

In fact leaking wellbores has been a persistent and chronic problem for decades. Even a 2003 article in Oil Field Review (http://www.slb.com/~/media/Files/resources/oilfield_review/ors03/aut03/p62_76.ashx), a publication of Schlumberger, reported that, "Since the earliest gas wells, uncontrolled migration of hydrocarbons to the surface has challenged the oil and gas industry."

Going up

Methane, by its very lightness, wants to go up. Where ever drillers have not properly sealed and cemented wellbores in deep shale rock, the gas will escape and move through rock fractures (existing or industry-made ones) into groundwater, stream beds, water wells and even the basements of houses.

Aging can affect leakage too. Old and decaying cement jobs largely explain why offshore oil wells in the Gulf of Mexico report leakage rates as high as 60 per cent after 16 years of service. Abandoned wells also can become major pollution portals (http://www.nytimes.com/1992/05/03/us/abandoned-oil-and-gas-wells-become-pollution-portals.html?src=pm).

The Norwegian Petroleum Safety Authority reports that 18 per cent of its deep offshore oil and gas wells have integrity problems, while Australia struggles with chronic leaks from fractured coal bed methane wells.

"Anything that ages starts to fail," explains Ingraffea. "I'm 65 and I've had a knee replaced."

How much of Alberta is leaking?

Based on industry reports to regulators as opposed to independent audits, about five per cent of Alberta's 300,000 oil and gas wells now leak. But a 2009 study (http://www.spe.org/ejournals/jsp/journalapp.jsp?pageType=Preview&jid=EDC&mid=SPE-106817-PA) by Alberta scientists Stephan Bachu and Theresa Watson found that so-called "deviated wells" (the same kind right angling used for fracturing shale gas and tight oil formations) typically experienced leakage rates as high as 60 per cent as they age. Moreover "high pressure fracturing (http://www.ieaghg.org/docs/wellbore/Wellbore%20Presentations/4th%20Mtg/19.pdf)" increased the potential to create pathways to other wells, the atmosphere and groundwater.

gas-migration-paths.jpg

The many ways methane can escape a natural gas well. Source: Alberta Energy Utilities Board.

Theresa Watson (http://www.ieaghg.org/docs/wellbore/Wellbore%20Presentations/4th%20Mtg/19.pdf), now a member of Alberta's Energy Resources Conservation Board, also disclosed that an increase in the number of water wells in heavily fractured oil and gas fields would increase "the likelihood that gas, due to migration through shallow zones, can accumulate in buildings."

Alberta's energy regulator does not yet keep track of leaking wells in a rigorous or transparent fashion but it does note in a 2011 Field Surveillance Report (http://www.ercb.ca/sts/ST57-2011.pdf) that leaks and methane migration are routine items of "high risk noncompliance" that companies voluntary disclose to the regulator. In Alberta the industry remains largely self-regulated.

Leaking of toxic fracture fluids is also common because only 25 to 60 per cent of diluted chemicals and water used to blast open shale or coal formations are ever recovered.

In a 2004 report the U.S. Environmental Protection Agency factually noted that "if fracturing fluids have been injected to a point outside of the well's capture zone, they will not be recovered through production pumping and, if mobile, may be available to migrate through an aquifer."

The failure rates of shale gas wells in heavily fractured jurisdictions with transparent regulation has now become a significant issue. During the shale gas rush in Pennsylvania more than 75 companies drilled thousands of wells and fractured rock formations throughout the state in 2007. Due to a rising number of accidents, spills and leaks, the Department of Energy started to compile and publish open public statistics.

What 16,017 inspection reports said

In 2012 Ingraffea and colleagues read through 16,017 inspection reports filed over the last four years. What they found (http://www.damascuscitizensforsustainability.org/wp-content/uploads/2012/11/PSECementFailureCausesRateAnalysisIngraffea.pdf) was a significant and steady rate of methane leaks at the wellbore or what is known in industry jargon as "bubbling in the cellar."

In 2010, 111 of 1,609 wells drilled and fracked failed and leaked. That's a 6.9 per cent rate of failure. In 2012, 67 out of 1,014 wells leaked — a seven per cent rate of failure.

"We looked at violations and not comments," adds Ingraffea. Quite often inspectors would note that a well was leaking like a sieve but that violation was pending. As a consequence the seven per cent figure represents a dramatic underestimate of methane leaks, says Ingraffea.

Moreover, the seven per cent figure only includes leaks at the wellhead. It does not include leaks that sprouted up in stream beds, water wells, or ponds often 2,000 feet away from the well site after steady fracking operations.

'That's a lot of leaking wells'

In 2009, Cabot Oil and Gas drilled 68 new Marcellus wells in Pennsylvania that the state's Department of Environmental Protection concluded resulted in extensive groundwater contamination for nearly a dozen families in the town of Dimock (http://stateimpact.npr.org/pennsylvania/tag/dimock/). State regulators cited the company seven times for "Failure to report defective, insufficient or improperly cemented casing within 24 hours or submit plan to correct within 30 days."

But this common problem will only get worse. Industry has proposed between 150,000 to 200,000 new wells to develop the Marcellus Shale in Pennsylvania, West Virginia and New York. Given current practices that means 10,000 to 20,000 new wells leaking methane into the atmosphere or groundwater and many more over their lifetimes. "That's a lot of leaking wells," says Ingraffea.

Evidence is also growing that toxic fluids used for hydraulic fracturing can also migrate into adjacent water bodies. A 2012 study in the journal Ground Water warned that hydraulic fracturing opens more pathways for the movement of both fluids and methane. And a recent study by the US Environmental Protection Agency in Pavilion, Wyoming, found that toxic fluids had contaminated local water supplies.

So what is it, myth or reality, when industry claims that leaks are rare?

The scientific truth is irrefutable says Ingraffea: "Fluid migration from faulty wells is a well-known chronic problem with an expected rate of occurrence." Inadequate well construction and monitoring remains a persistent industry problem.

The health implications are also serious. The migration of methane or fracking fluid has repeatedly contaminated groundwater across North America or polluted the atmosphere with methane, a potent greenhouse gas.

Part 4: How clean is natural gas? (http://www.resilience.org/stories/2013-01-11/shale-gas-how-clean-is-it)

Proceedings of the National Academy of Sciences
www.pnas.org
(/) > Current Issue (/content/111/30.toc) > vol. 111 no. 30
> Anthony R. Ingraffea, 10955–10960, doi: 10.1073/pnas.1323422111

Assessment and risk analysis of casing and cement impairment in oil and gas wells in Pennsylvania, 2000–2012

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Significance

Previous research has demonstrated that proximity to unconventional gas development is associated with elevated concentrations of methane in groundwater aquifers in Pennsylvania. To date, the mechanism of this migration is poorly understood. Our study, which looks at more than 41,000 conventional and unconventional oil and gas wells, helps to explain one possible mechanism of methane migration: compromised structural integrity of casing and cement in oil and gas wells. Additionally, methane, being the primary constituent of natural gas, is a strong greenhouse gas. The identification of mechanisms through which methane may migrate to the atmosphere as fugitive emissions is important to understand the climate dimensions of oil and gas development.

Abstract

Casing and cement impairment in oil and gas wells can lead to methane migration into the atmosphere and/or into underground sources of drinking water. An analysis of 75,505 compliance reports for 41,381 conventional and unconventional oil and gas wells in Pennsylvania drilled from January 1, 2000–December 31, 2012, was performed with the objective of determining complete and accurate statistics of casing and cement impairment. Statewide data show a sixfold higher incidence of cement and/or casing issues for shale gas wells relative to conventional wells. The Cox proportional hazards model was used to estimate risk of impairment based on existing data. The model identified both temporal and geographic differences in risk. For post-2009 drilled wells, risk of a cement/casing impairment is 1.57-fold [95% confidence interval (CI) (1.45, 1.67); $P < 0.0001$] higher in an unconventional gas well relative to a conventional well drilled within the same time period. Temporal differences between well types were also observed and may reflect more thorough inspections and greater emphasis on finding well leaks, more detailed note taking in the available inspection reports, or real changes in rates of structural integrity loss due to rushed development or other unknown factors. Unconventional gas wells in northeastern (NE) Pennsylvania are at a 2.7-fold higher risk relative to the conventional wells in the same area. The predicted cumulative risk for all wells (unconventional and conventional) in the NE region is 8.5-fold [95% CI (7.16, 10.18); $P < 0.0001$] greater than that of wells drilled in the rest of the state.

shale oil and gas (/search?fulltext=shale+oil+and+gas&sortspec=date&submit=Submit&andorexactfulltext=phrase)
casing integrity (/search?fulltext=casing+integrity&sortspec=date&submit=Submit&andorexactfulltext=phrase)
cement integrity (/search?fulltext=cement+integrity&sortspec=date&submit=Submit&andorexactfulltext=phrase)
onshore wells (/search?fulltext=onshore+wells&sortspec=date&submit=Submit&andorexactfulltext=phrase)
wellbore integrity (/search?fulltext=wellbore+integrity&sortspec=date&submit=Submit&andorexactfulltext=phrase)

Oil and natural gas production has increased substantially in the United States in recent years, predominantly due to innovations such as high-volume hydraulic fracturing and directional drilling in shale formations (1). Concurrent with this increase, concerns have mounted regarding effects of this oil and gas development process on groundwater quality, human health, public safety, and the climate, due, in part, to subsurface migration of methane and other associated hydrocarbon gases and volatile organic compounds. Economic development of gas and oil from shale formations requires a high well density, at least one well per 80 surface acres, over large continuous areas of a play. Osborn et al. (2) and Jackson et al. (3) identified a positive relationship between the concentration of thermogenic methane in private water wells in Pennsylvania and the proximity of those water wells to the nearest unconventional (i.e., Marcellus shale) gas production well. These studies also identified three possible mechanisms for explaining this relationship, and concluded that the most likely of these is subsurface migration from leaking gas wells. Other researchers have observed thermogenic and other subsurface-sourced methane in atmospheric concentrations high above background levels near conventional and unconventional gas development (4⇓–6), suggesting that leaking wells may also contribute to fugitive methane and other associated gas emissions, with clear climatic and air quality consequences (7).

Leaking oil and gas wells have long been recognized as a potential mechanism of subsurface migration of thermogenic and biogenic methane, as well as heavier n-alkanes, to the surface (7⇓⇓⇓–11). A leaking well, in this context, is one in which zonal isolation along the wellbore is compromised due to a structural integrity failure of one or more of the cement and/or casing barriers. Such loss of integrity can lead to direct emissions to the atmosphere through one or more leaking annuli and/or subsurface migration of fluids (gas and/or liquid) to groundwater, surface waters, or the atmosphere. Cement barriers may fail at any time over the life of a well for a number of reasons, including hydrostatic imbalances caused by inappropriate cement density, inadequately cleaned bore holes, premature gelation of the cement, excessive fluid loss in the cement, high permeability in the cement slurry, cement shrinkage, radial cracking due to pressure fluctuations in the casings, poor interfacial bonding, and normal deterioration with age (12). Casing may fail due to failed casing joints, casing collapse, and corrosion (13). Loss of zonal isolation creates pressure differentials between the formations intersected by the wellbore and the open barrier(s). The pressure gradient thus created allows for the flow of gases or other formation fluids between geological zones (i.e., interzonal migration) and possibly to the surface (14⇓–16), where it might manifest as sustained casing pressure (SCP) or sustained casing vent flow.

Annuli are often vented, as noted in inspection records, and may contribute to fugitive emissions from the well site. Low-pressure leaks may continue to be periodically bled off and monitored, although recent studies warn that bleeding pressure to zero may actually lead to gas migration (17). High-risk (e.g., rapid repressuring of the annulus following bleed down) leaks must be structurally remedied (i.e., cement squeeze, gel squeeze, use of packers, topping off cement). State regulations (Pennsylvania code 25 §78.86) mandate that wells with leaks that cannot be vented or adequately repaired be permanently plugged, which may reduce but not eliminate the interzonal flow of gases and liquids. Leaks that continue undetected or inadequately remedied may lead to the contamination of shallow aquifers, accumulation of explosive gases within and around residences and other structures, and emission of methane and other associated gases to the atmosphere.

Although not every instance of loss of zonal isolation will lead to such events, the incidence rate of cement/casing impairments and failures can provide some insight into the scale of current and future problems. However, the structural integrity failure rate of oil and gas well barriers continues to be a subject of debate. The rates most commonly cited (from 2 to >50%) are based upon industry reporting for offshore wells in the Gulf of Mexico (13, 14) and Canadian onshore (mostly conventional) wells (16). Watson and Bachu (16) note that wells drilled during periods of rapid development activity and/or wellbores deviated from vertical (e.g., horizontal wellbores) may be more prone to casing vent flow and/or gas migration away from the wellhead.

Due to the lack of publicly available structural integrity monitoring records for onshore wells from industry, more recent studies have used data from state well inspection records to estimate the proportion of unconventional wells drilled that develop cement and/or casing structural integrity issues. For instance, Considine et al. (18) analyzed Pennsylvania Department of Environmental Protection (PADEP) notice of violation (NOV) records for 2008–2011 and found that between 1% and 2% of wells had one or more potential structural integrity issues during that time period. Vidic et al. (19), using the 2008–2013 data from the PADEP database, found that 3.4% of all monitored unconventional wells drilled to date in Pennsylvania might have structural integrity failures based on NOVs related to cement/casing integrity. However, neither study adequately accounts for non-NOV indicators of cement/casing integrity impairment or temporal or spatial dimensions of such impairments.

Earlier work found that the NOV count alone does not account for all incidences of cement/casing failure (20). State regulatory agencies and the oil and gas industry monitor many of the wells showing signs of SCP or other indicators of cement and/or casing impairment. Remedial action is often attempted once or many times on a monitored well, but a NOV is not issued by the agency. Additionally, violation codes are sometimes entered incorrectly as non-cement/casing issues and later corrected in violation comments. By not accounting for these, previous assessments based on PADEP inspection records (18, 19) may underestimate the actual proportion of wells with cement and/or casing problems in Pennsylvania.

Failure to account for temporal dimensions of the data may also skew results. Previous studies on cement/casing impairment have noted that wells drilled during boom periods may be more susceptible to loss of zonal isolation because operators might cut corners in an attempt to increase the number of wells drilled over a short period (16). The increased risk of zonal isolation problems as wells age and the increased probability of identifying these issues with more inspections may also create a time lag between the date that drilling of the well commences (i.e., the spud date) and the entry of a cement/casing issue in the inspection records. This time lag is due to the fact that wells drilled in recent years have not been subject to the same duration of analysis or number of inspections as older wells. Thus, inspection records on newer wells are incomplete relative to those of older wells.

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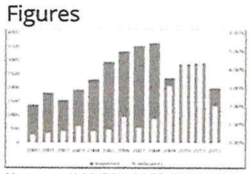
Figures



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Here, we offer an in-depth analysis of the complete inspection records, including NOVs, observations and corrections noted in the inspector comments, for 32,678 oil and gas production wells drilled in Pennsylvania between 2000 and 2012. We use a time-dependent risk analysis model to assess the cumulative risk of cement/casing problems for wells based on the historical occurrence of cementing/casing impairment events.

Results and Discussion

Comparison of state inspection and well spud reports (where the "spud" date is the start date of drilling) indicates a loss of well integrity in 1.9% of the oil and gas production wells spudded between 2000 and 2012. This value agrees well with some previous estimates in the literature; however, this superficial indication comes with important caveats and is an incomplete assessment. The data suggest large differences in structural integrity issues between well types, with unconventional wells showing a sixfold higher incidence of cement and/or casing issues relative to conventional wells statewide (Table 1 and *SI Appendix*, Table S14 (/lookup/suppl/doi:10.1073/pnas.1323422111/-/DCSupplemental/pnas.1323422111.sapp.pdf)). Even within the unconventional well category, a wide range (1.49–9.84%) of incident rates is observed among wells spudded during different time periods and in different regions. Unconventional wells spudded before 2009 in the northeastern (NE) counties of the state are associated with the highest occurrence of loss of structural integrity (9.84%). It can be argued that this subcategory reflects a small number of observed cases (61 wells) and the earliest industry experience in the Marcellus play, and thus should not be used as an indication of current practices. However, unconventional wells spudded in the NE region since 2009 (2,714 wells) show a similarly high rate of occurrence (9.18%).

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Table 1.

Percentage of wells showing loss of structural integrity by temporal (pre- and post-2009 spuds), geographic (non-NE and NE counties), and well type (conventional and unconventional) categories

As already noted, direct comparison of rates of loss of well integrity in young wells to those of much older wells is misleading. Assuming an increased risk of cement/casing issues as the materials (cement/casing) age, it must follow that the risk of structural integrity loss and likelihood of state inspectors identifying a cement/casing problem will increase through time as a well accumulates additional inspections. Thus, a well spudded 3 y ago, which will ideally have a 3-y record of inspections from which to draw observations, is more likely to have an indicator of cement/casing integrity loss noted in the inspection record than a similar well spudded only 1 y ago and associated with just one-third of the observation time. The effects of this temporal dependency can be seen in Fig. 1. Annual trends for wells spudded in 2010 and 2011 show rates of incidence similar to the cumulative unconventional rate reported in Table 1 (unconventional wells make up 57.5% and 66.3% of spuds in 2010 and 2011, respectively). However, wells spudded in 2012 and subject to an observation period ≤1 y appear to have a much lower incidence of cement/casing issues. This raises an important question: Are wells spudded in 2012 more sound than those spudded in previous years, or is the apparent decline in indicators in state inspection reports an artifact of an incomplete inspection history?

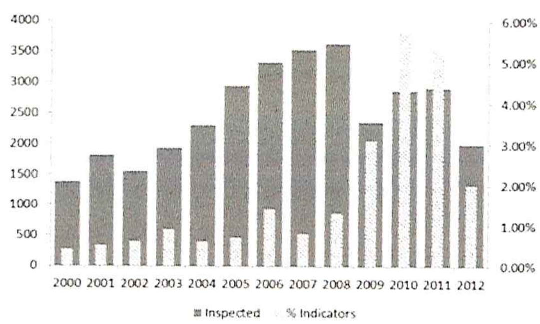

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Fig. 1.

Annual trends of indicators for wells spudded in the state of Pennsylvania, 2000–2012. The percentage of spuds with integrity issues reflects the number of unique wells spudded in a given year for which an indicator was found at any time within the inspection record (13 y). The rates of incidence noted in the inspection records for pre-2009 spuds hover around 1% for the several years before spiking in 2010. These trends may represent differences in state emphasis on locating leaking wells following widely publicized contamination events or actual increases in loss of structural integrity.

Note that incomplete inspection records may also occur in older wells that have not been regularly inspected through time. Inspection records for modeled wells indicate an average of 2.75 inspections per well statewide, despite nearly 71.6% of wells being >3 y old. Moreover, PADEP records indicate that of the more than 41,000 oil and gas production wells spudded between 2000 and 2013, 24% of conventional and 4% of unconventional well spuds have never received facility-level inspections or the relevant inspections are not included in the PADEP online database (8,703 wells in total). It should be noted that these wells might have received inspections under the client- or site-level category, which generally are carried out as part of large-scale contamination/gas migration investigations, but these types of inspections are not included in our analysis because the details of such inspections often do not include a full listing of wells of interest. Assuming that the

individual wells observed in these larger scale investigations did, in fact, receive facility-level inspections and are included in our analysis, we would expect a negligible impact from excluding client- and site-level investigations because the individual well inspections would have likely been flagged by at least one of the indicators before a large-scale contamination event. The impact of wells investigated in the client- and site-level inspections but not receiving a facility-level inspection (i.e., not included in this analysis) may be significant but cannot be assessed with the data available. Not all wells inspected in large-scale contamination investigations are found to be leaking and, although the count of impairment events from such wells could increase, the rate of impairment (the number of events per wells inspected) might not.

Hazard analysis captures such temporal dependencies through the nonparametric baseline hazard rates and hazard ratios of the inspection count variable, thus allowing us to predict what the incidence rate for wells might be if they were to acquire comparable observation times and inspection counts. Results from hazard modeling of temporal and geographic strata are given next.

Hazard Model: Temporal Strata. Wells spudded before 2009 make up almost 72% of the total wells modeled but just 31% of the total count of unique wells with documented cement/casing indicator events from the 2000–2012 modeled dataset. Unconventional wells make up 16.8% of the wells in this stratum. The first unconventional well in the modeled dataset has a 2002 spud date; however, unconventional drilling activity remained relatively low until 2009 (Fig. 2). Pre-2009 unconventional wells show a modest but statistically insignificant increase in hazard [1.07-fold greater risk relative to pre-2009 conventional wells, 95% confidence interval (CI) (0.18, 1.52); Table 2]. However, in the post-2009 stratum, risk of a cement/casing event is 1.58-fold [95% CI (1.45, 1.67); $P < 0.0001$] higher in an unconventional well relative to a conventional well spudded within the same time period (Table 2).

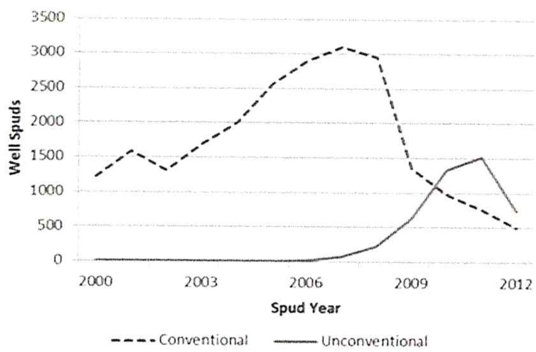

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Fig. 2.

Conventional and unconventional spud counts: 2000–2012 (Source: PADEP, 2013).

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Table 2.

Statewide data: Effects of model covariates for pre- and post-2009 well spuds

Fig. 3 shows estimated cumulative hazards for conventional and unconventional wells across the state for pre- and post-2009 strata, respectively. These figures are plotted in the units of the Nelson–Aalen estimator of the cumulative hazard function (i.e., the definite integral, from zero up to the indexed time, of the hazard function). These plots are used for visually examining differences in distributions in time-to-event data and are interpreted here as the fractional probability that a well will be identified as having a cement and/or casing problem at time *t*, assuming that the event has not occurred before time *t*. Wells spudded after January 1, 2009, show significantly higher ($P < 0.0001$) predicted hazards across comparable analysis times, regardless of well type, relative to pre-2009 well spuds [4.58 hazard ratio, 95% CI (3.84–5.47)].

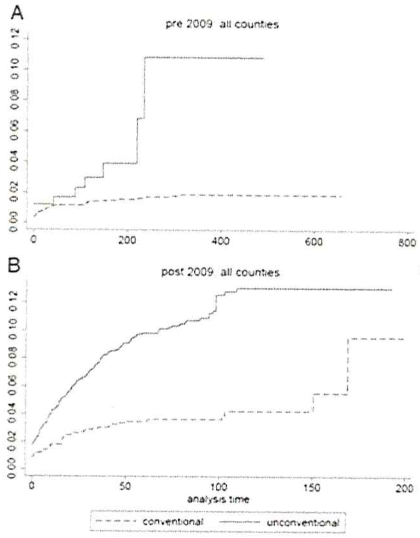

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Fig. 3.

Nelson–Aalen cumulative hazard for pre-2009 (*A*) and post-2009 (*B*) spuds by well type. The vertical axis is the fractional probability of an event occurring at a given analysis time.

It is unclear whether these temporal differences reflect more thorough inspections and greater emphasis on finding well leaks, more detailed note taking in the available inspection reports, or real changes in rates of structural integrity loss. The percentage of wells inspected in the first year has risen, from an average of 76% in pre-2009 spuds to 88.7% in the post-2009 spuds (*SI Appendix*, Table S3 (/lookup/suppl/doi:10.1073/pnas.1323422111/-/DCSupplemental/pnas.1323422111.sapp.pdf)), and this may partially account for the increase in documented cement/casing problems. Additionally, more than one-half (53.2%) of the nonevent wells (i.e., no indicator of loss of structural integrity found) lack inspector comments and other information necessary to determine whether a cement/casing issue ever occurred. These wells, by default, are modeled as nonevents. The majority of such wells (73%) were spudded before 2009. This lack of data for older wells may result in an underestimation of events in the pre-2009 stratum. As such, results from our modeling should be considered conservative.

Note that the full analysis time for the statewide dataset is 676 wk (13 y). Naturally, more recently spudded wells will have a shorter analysis time (1–208 wk for wells spudded since 2009). However, inspection records indicate that 52.9% of pre-2009 spuds have a <2-y inspection record, with an average of 2.4 inspections per well across the entire time period (*SI Appendix*, Table S4 (/lookup/suppl/doi:10.1073/pnas.1323422111/-/DCSupplemental/pnas.1323422111.sapp.pdf)). This suggests that the majority of these active, older wells are no longer being inspected. Continued annual inspections may increase the predicted cumulative risk of structural integrity issues for these wells beyond what is reported here, indicating, again, that results from our analysis are conservative. Each additional inspection in the pre-2009 stratum increases the risk of identifying a cement or casing problem by 17.7% [1.18 hazard ratio, 95% CI (1.15, 1.20); Table 3] relative to the hazards shown in Fig. 3. The effect of increased inspections on younger wells (post-2009 spuds) is smaller but statistically significant [1.06 hazard ratio, 95% CI (1.05–1.07); Table 3].

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Table 3.

NE counties data: Effects of model covariates

Hazard Model: Geographic Strata. The NE counties of the state (Bradford, Cameron, Clinton, Lycoming, Potter, Sullivan, Susquehanna, Tioga, Wayne, and Wyoming) make up just 11% of the total wells spudded (3,030 wells) but 54.7% of the state's unconventional wells and 88.8% of the cement/casing events in unconventional wells. There are 266 total structural integrity indicator events in the NE region, or ~52% of events statewide. The predicted cumulative hazard for all wells (unconventional and conventional) in the NE region is 8.5-fold [95% CI (7.16, 10.18)] greater than that of wells drilled in the rest of the state (Table 3). The log-rank test for this regional difference is extremely significant ($P < 0.0001$).

As with the statewide data, effects of covariates in the NE counties indicate significant increases in the risk of finding an indicator in the inspection records. Unconventional wells in the NE region are at a 2.7-fold higher risk relative to the region's conventional wells [95% CI (1.43, 4.95); Table 3]. Additional inspections in these counties have a similar effect on risk as that found for post-2009 spuds statewide [1.06 hazard ratio, 95% CI (1.05, 1.08); Table 3].

Figs. 4–6 reveal increased cumulative hazards for wells in the NE counties relative to other areas of the state, as well as increased cumulative hazards associated with unconventional wells ($P < 0.001$) and post-2009 spudded wells ($P = 0.005$) in the region. These figures, like Fig. 3, are plotted in units of the cumulative hazard function. Overall, NE wells show a risk of an identified integrity issue within the first 3 to 4 y (156–208 wk) of operation of ~20% (Fig. 4). The cumulative hazard for unconventional wells in the region is predicted to increase upward of 40% by year 7 of the analysis (364 wk; Figs. 5 and 6).

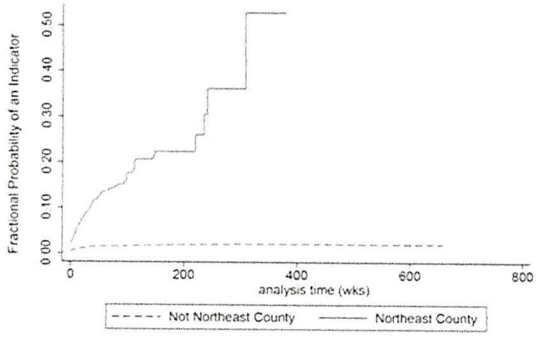

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Fig. 4.

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Nelson–Aalen cumulative hazard: NE vs. non-NE counties for combined conventional and unconventional wells. The vertical axis is the fractional probability of an event occurring at a given analysis time.

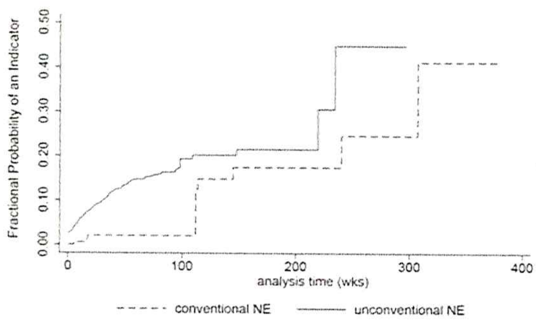

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Fig. 5.

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Nelson–Aalen cumulative hazard for NE counties by well type. The vertical axis is the fractional probability of an event occurring at a given analysis time.

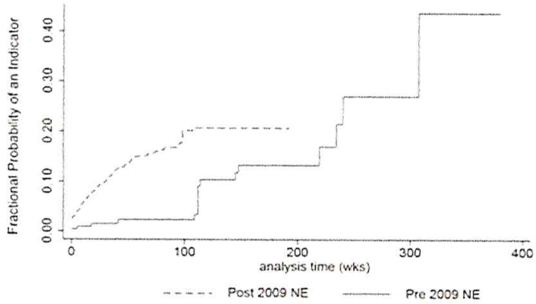

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Fig. 6.

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Nelson–Aalen cumulative hazard for NE counties by temporal strata. The vertical axis is the fractional probability of an event occurring at a given analysis time.

Conclusion

Pennsylvania state inspection records show compromised cement and/or casing integrity in 0.7–9.1% of the active oil and gas wells drilled since 2000, with a 1.6- to 2.7-fold higher risk in unconventional wells spudded since 2009 relative to conventional well types. Hazard modeling suggests that the cumulative loss of structural integrity in wells across the state may actually be slightly higher than this, and upward of 12% for unconventional wells drilled since January 2009. This wide range of estimates is influenced by significantly higher rates of impairment in wells spudded in the NE counties of the state (average of 12.5%, range: 2.2–50%), with predicted cumulative hazards exceeding 40% (Figs. 5 and 6).

These results, particularly in light of numerous contamination complaints and explosions (21⇓–23) nationally in areas with high concentrations of unconventional oil and gas development and the increased awareness of the role of methane in anthropogenic climate change (24), should be cause for concern. A recent investigative report of water contamination cases confirmed PADEP determination letters and enforcement orders

indicating that at least 90 private water supplies across the state were damaged due to subsurface gas migration between 2008 and 2012 (25). The NE region of Pennsylvania, in particular, has experienced several widely publicized methane migration cases related to loss of structural integrity of wells, including the Dimock, Susquehanna County [Commonwealth of Pennsylvania Department of Environmental Protection (DEP) Consent Order to Cabot Oil & Gas, December 15, 2010] and Towanda, Bradford County (Commonwealth of Pennsylvania DEP Consent Order to Chesapeake Appalachia LLC, May 16, 2011) groundwater contamination cases. PADEP records cite unconventional wells spudded between 2009 and 2010 in both of these cases. Incidence rates inferred from direct comparison of indicator counts and the number of wells inspected in these townships as of December 31, 2012, are 21.2% and 15.4%, respectively; however, hazard modeling predicts a cumulative 7-y hazard for similar wells in the region twofold higher (Figs. 5 and 6; $t = 364$).

Our aim in this study was to quantify the rate of barrier impairment in a population of modern on-shore oil and gas wells, and in doing so, we have noted significant temporal and spatial differences in risk of impairment. It is beyond the scope of this paper to explain these spatial and temporal differences. Various biasing effects might influence these differences and are the focus of our continuing study of this problem. Moreover, results presented here represent a snapshot in time of an evolving situation. This study presents the state of structural integrity loss in oil and gas wells over a 13-y period in the state of Pennsylvania as inferred from publicly available data, while also presenting a risk assessment model of future performance. It should be a priority to update and validate this model with well monitoring and evaluation data reported to the PADEP from the industry as they are collected. Finally, although this study discusses one possible primary mechanism of methane migration to groundwater aquifers and fugitive emissions to the atmosphere, more studies are needed to investigate the association between the structural integrity loss in oil and gas wells and the incidence of these unwanted events.

Methods

Database. The database created here is based upon spud reports from the PADEP Office of Oil and Gas Management website for conventional and unconventional gas, oil, combined gas and oil, and coal-bed methane wells spudded from January 1, 2000–December 31, 2012 (www.depweb.state.pa.us/portal/server.pt/community/oil_and_gas_reports/20297 (http://www.depweb.state.pa.us/portal/server.pt/community/oil_and_gas_reports/20297)). Spud reports provide data on well characteristics, including American Petroleum Institute (API) well identification, spud date, well type, production type, and well location (county, municipality, and geographic coordinate information). We exclude storage, injection, and undetermined purpose wells to focus exclusively on oil and gas production wells.

Compliance Reports. The compliance reports for oil and gas well inspections carried out over the same time period (www.depweb.state.pa.us/portal/server.pt/community/oil_and_gas_compliance_report/20299 (http://www.depweb.state.pa.us/portal/server.pt/community/oil_and_gas_compliance_report/20299)) are then cross-referenced with the well inventory by matching API identification codes. PADEP compliance reports provide data on inspection category (i.e., site, client, facility), inspection type (e.g., administrative review, drilling, routine), inspection date, violations issued, and comments noted by PADEP inspection staff regarding the inspection and/or violation(s) issued. We exclude client and site inspection categories, because these inspections generally reflect multiwell, large-scale compliance assessments and rarely identify individual wells. We also do not include construction (i.e., site clearing), asbestos program, Chapter 94, joint external/internal, Nuclear Regulatory Commission, and road-spreading inspection types. Construction inspections occur before well spudding, and thus are not relevant to well integrity. The remaining excluded inspection types are also considered not relevant to the study question. Excluded inspections accounted for <0.5% of total inspections carried out over the 2000–2012 time frame.

Indicators Search. Inspector comments indicate barrier remediation and/or ongoing monitoring of annular gas or pressure (indicators of impaired structural integrity) for numerous wells that were not issued an NOV. To ensure that we captured these wells, we filtered both the "Inspection_Comment" and "Violation_Comment" fields for the most common keywords associated with failure of primary cement/casing or common remediation measures. Keywords used in the filtering and their relevancy to impaired primary cementing and casings are presented in *SI Appendix*, Table S6 (/lookup/suppl/doi:10.1073/pnas.1323422111/-/DCSupplemental/pnas.1323422111.sapp.pdf). Keyword filter results are then human-read thoroughly to confirm an indication of impaired well integrity and to separate filter results that do not indicate an integrity issue (e.g., gas meter readings = 0, nonremediation perforations, "no visible bubbling"). A detailed discussion of the indicators and their temporal and geographic distributions is provided in *SI Appendix* (/lookup/suppl/doi:10.1073/pnas.1323422111/-/DCSupplemental/pnas.1323422111.sapp.pdf).

Violation codes provide a more direct indication of a potential well impairment. PADEP violation codes relevant to cement and casing integrity are listed in *SI Appendix*, Table S7 (/lookup/suppl/doi:10.1073/pnas.1323422111/-/DCSupplemental/pnas.1323422111.sapp.pdf). The compliance reports indicate multiple misentries in the original violation code noted by an inspector, which are later corrected in the "Violation_Comment" field. We assume that wells with any one of the violations or a combination of violations listed in *SI Appendix*, Table S7 (/lookup/suppl/doi:10.1073/pnas.1323422111/-/DCSupplemental/pnas.1323422111.sapp.pdf) and entered in either the "Violation_Code" or "Violation_Comment" field in inspection reports are indicative of a well with impaired cement and/or casing. We note that not all violations will result in groundwater contamination events. The relative importance of key violation codes and the temporal and geographic distributions of total violation counts are discussed in detail in *SI Appendix* (/lookup/suppl/doi:10.1073/pnas.1323422111/-/DCSupplemental/pnas.1323422111.sapp.pdf).

Hazard Analysis. The Cox proportional hazards model (26) is a semiparametric model that uses a multivariate regression technique to model the instantaneous probability of observing an event (i.e.,

occurrence of a cement/casing indicator in the inspection record) at time *t*, given that an observed case (i.e., a well) has survived to time *t* (i.e., has not experienced an inspection where a cement/casing indicator was found) as a function of predictive covariates (well type and total number of inspections received). All wells enter observation at $t = 0$, regardless of spud date, and observation continues until the last known date of inspection or the occurrence of a cement/casing indicator in a well's inspection history. Addition details and definitions of key model terms and concepts are provided in *SI Appendix* (/lookup/suppl/doi:10.1073/pnas.1323422111/-/DCSupplemental/pnas.1323422111.sapp.pdf).

Time of analysis of a well, as the dependent variable in the statistical model, cannot be a null or a negative value. Wells showing no record of inspection (8,703 wells) have null *t* values, and are therefore removed from the model dataset. We also found 5,223 wells, 100 of which were associated with comment or violation indicators, where the time since spud to first inspection was negative. Because construction/site clearing inspections were removed from the database in previous steps, we assume that either the spud dates or inspection dates for these wells were entered incorrectly; these data are also removed from the dataset. The impact of removing these inspections from the modeled dataset is negligible, because the overall impairment rate (1.9%) for these wells mirrors that of the statewide data. The resulting modeled statewide dataset contains 27,455 wells that are associated with 75,505 inspections.

Multiple inspections per unique well number are mined to return only a single set of entries per well: well characteristics (i.e., county, well type, spud date), event status (a binary code assigned to each well stating whether an indicator was found at any point in the life of the well: Y = 1, N = 0), date of first inspection, date of first mention of indicator if found, date of last inspection (for nonevent wells), and total number of inspections carried out.

An assumption of the Cox proportional hazards model is that the hazard ratio is constant over time. The validation of this assumption for the various models, using the Grambsch and Therneau test (27), is presented in *SI Appendix*, Table S1 (/lookup/suppl/doi:10.1073/pnas.1323422111/-/DCSupplemental/pnas.1323422111.sapp.pdf). The proportional hazards test for individual covariates passed for well type ($P = 0.06$) and inspection counts ($P = 0.09$) in the full dataset. The proportional hazards model assumption also holds for the pre/post-2009 analyses. Well type (i.e., unconventional, conventional) and inspection counts (i.e., number of times a well is inspected during the analysis time) are used as covariates in these models.

Temporal and geographic (i.e., county) strata are run in separate analyses. Interannual log-rank statistics were used to assess whether any groups of well spuds were statistically significantly different in terms of their predicted failure risk. We stratified the data accordingly to allow for separate regressions of temporal period (before January 1, 2009, and after that date). We also stratified the data by region to assess the relative geographic distributions [the NE counties (Bradford, Cameron, Clinton, Lycoming, Potter, Sullivan, Susquehanna, Tioga, Wayne, and Wyoming) compared with the rest of the state] of wells with indications of cement/casing problems. Log-rank tests (28) were used to assess geographic variation.

As robustness checks to the Cox proportional hazards model, parametric Weibull and Gompertz regression models (28) were also fit to the full data and the temporal and geographic strata, and the magnitude substantive conclusions did not change.

Footnotes

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Cement Casing: The Weak Link of Fracking

Posted on November 28, 2011 | 5 Comments

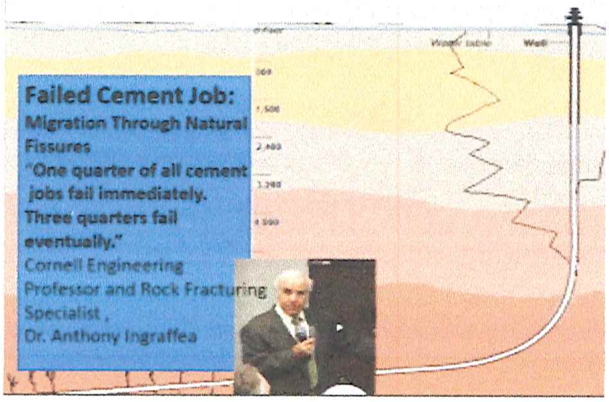
By Bernhard Debatin

Recently, the EPA confirmed that "a pair of environmental monitoring wells drilled deep into an aquifer in Pavillion, Wyo., contain high levels of cancer-causing compounds and at least one chemical commonly used in hydraulic fracturing." Although the EPA Groundwater Investigation of Nov. 9, 2011, only provided the raw data without interpretation, one can conclude that "the chemical compounds the EPA detected are consistent with those produced from drilling processes, including one — a solvent called 2-Butoxyethanol (2-BE) — widely used in the process of hydraulic fracturing." (ProPublica, NOv. 10, 2011).

Moreover, another decisive result of this investigation is that the methane found in the aquifers was "at near-saturation levels (up to 19 mg/L)" and has a "similar isotopic signature to production gas" (EPA Presentation). This defeats the industry's claim that methane in the groundwater is merely a natural occurrence and not caused by fracking, since methane from shallower layers has a different chemical makeup.

The importance of this EPA investigation cannot be overestimated. It officially confirms, for the first time, what local citizens and critical voices have said for years: That fracking chemicals can and will seep into the groundwater and result in severe contamination of our water resources.

The question remains why and how exactly the contamination is happening. The industry claims it is impossible because fracking is done at such a deep level that it is impossible for contaminated water to travel to shallow aquifers. However, in his article "The truth about Fracking" (in the *American Scientist, Nov. 11, Vol. 305, Issue 5, p. 80-85*), author Chris Mooney states: "Faulty cementing is the leading suspect in possible sources of contamination, and by industry's definition it is not part of fracking." Which means the industry's claim that fracking causes no contamination whatsoever is based on the arbitrary and in fact faulty definition that "fracking" is limited to the *event* some thousand feet below the ground, but does not include the *process* of pumping pressurized chemicals, water, and gas up and down the well.



There is, in fact, growing concern among scientists about the lack of reliability of cement casings. The above quoted article in the *American Scientists* calls cementing the "weak link" of fracking:

> *Cementing is the obvious "weak link," according to Anthony Gorody, a hydrogeologist and consultant to gas companies who has been a defender of fracking. Other scientists emphatically agree. "If you do a poor job of installing the well casing, you potentially open a pathway for the stuff to flow out," explains ecologist and water resource expert Robert B. Jackson of Duke University's Nicholas School of the Environment. Although many regulations govern well cementing and although industry has strived to improve its practices, the problem may not be fully fixable.* ***"A significant percentage of cement jobs will fail," Ingraffea says. "It will always be that way. It just goes with the territory."***

Dr. Anthony Ingraffea holds the Dwight C. Baum Professorship of Engineering at Cornell University's School of Civil and Environmental Engineering. He got his doctorate in rock fracturing and directs the Cornell Fracture Group, which specializes in computational simulations fracturing. He contends that while cement failure has been a chronic and known problem, the industry is not willing to share any data about cement failures with regulatory agencies.

It is obvious that the integrity of the casing and piping of fracking wells is crucial. Imposing strict controls and regulatory oversight of this particular aspect of fracking should not even be an issue of debate. It should be a basic precondition that anybody, including the industry, subscribes to in the name of the safety and well-being of everybody.

Update, Dec. 14, 2011: While the overall problem with cement casing remains the leading suspect for most cases of undergroundwater contamination, the case of Pavillion, WY, is different: The EPA report clearly excludes cement failure (due to the lack of cement traces in the water samples) and concluded that the contamination came directly from the fracking area through vertical fissures and cracks into the aquifer (see e.g. p. 20, 34, and 38f. of the report). This, in itself is a frightening finding because the industry has continuously insisted that such occurrences are impossible.

——————————————

Note:
Here, you can sign on to the Ohio Environmental Council's letter to the Ohio General Assembly asking for a moratorium on fracking

For the past several years, the shale gas industry has argued that oversight of fracking is getting tighter and that the amount of methane gas leaking from their wells is less than some have speculated.

In Pennsylvania, however, the opposite is true, according to a white paper (http://catskillcitizens.org/learnmore/PSECementFailureCausesRateAnalysisIngraffea.pdf) delivered to New York state regulators by Cornell engineering professor, Anthony Ingraffea. Inspection data from the state indicate that over 150 Marcellus shale wells in Pennsylvania had severe flaws that have led to sometimes large leaks and yet the operators of those wells were never issued violations by regulators for these breaches of state law.

By failing to cite drillers when things go wrong, Pennsylvania environmental regulators have for the past three years obscured the rate at which Marcellus wells leak, creating a falsely optimistic picture. Leaks at dozens of wells were described by state inspectors in their report notes, but violations were never issued.

If analysts relied on data about violations alone, it would seem that 6.2 percent of wells drilled in 2010 failed. In fact, the rate was 6.9%, according to notes in inspection reports, leaving a difference of 0.7%. By 2011, a full 1 percent of well failures were going uncited. For the first half of 2012, the DEP's violation data showed a 7.2% rate of well failures, while a review of inspection reports shows an 8.9% failure rate for the full year. Put another way, Pennsylvania officials discovered that 76 Marcellus wells drilled in 2012 lost integrity but never cited drillers for these problems.

Why do these numbers matter?

Roughly 100,000 new shale gas wells (http://www.frackcheckwv.net/2012/11/30/an-overview-and-recent-experiences-in-the-pennsylvania-marcellus-shale-play/) are expected to be drilled in Pennsylvania over the next decades, with twice that many across the entire Marcellus region – so these small percentages add up to a lot of escaping gas.

This puts water at risk. When gas wells have faulty casings or cement, they can contaminate drinking water supplies, both above ground and below, as contaminants seep from around the well bore into surrounding aquifers or at times escape into rivers, lakes and streams.

The leak rate is also important because natural gas is so often portrayed as cleaner than coal with regards to climate change. Natural gas does have far lower carbon dioxide emissions when burned, compared to coal. But when natural gas — also known as the greenhouse gas methane – is allowed to leak into the atmosphere unburned it has climate changing impacts that, depending on time frame, are 30 to 100 times more destructive than those from carbon dioxide.

While we know that the leaks from compressor stations, storage facilities and from pipelines carrying natural gas from wells to our homes and power plants are hugely consequential (http://cornellsun.com/node/46888), no one has studied whether leaks from gas wells themselves allow enough methane to escape to have meaningful climate change repercussions. Because of known gas leaks, there is already a lively argument over natural gas's climate change impacts, especially compared to the impacts of other fossil fuels. These additional leaks from the wells themselves urgently need more study if those arguments are to be resolved in an informed way.

The full inspection reports reveal that roughly nine percent of Pennsylvania's newest shale gas wells are already leaking. Experts say this rate is expected to get worse with time since the wells are newly drilled. As wells age, their casings corrode and cement linings will shrink, crack, and debond, causing even more methane to be released. Two large industry studies have reported that, over 30 years, and depending on the age of a well, 2 to 60 percent of oil and gas wells fail.

Not only are more shale gas wells leaking than previously believed, but the new data reveal a striking trend. Inspectors repeatedly found problems at Marcellus wells, and described the problems in their notes, but drillers were never cited for those violations. Since 2010, the PA DEP has grown increasingly unlikely to cite or penalize drillers when wells' protective casings and cement break down. In some cases, no violations were recorded by the DEP even in cases when residents' drinking water became contaminated and lawsuits followed.

To understand how these leaks impact real people, one need only talk to folks in Bradford County.

In February 2010, a resident of Towanda Township complained to Chesapeake Energy that his well water had turned black and undrinkable, legal documents show. Shortly after, two nearby ponds began to bubble, as did the Susquehanna River as it passed through Bradford County, PA. The bubbles were found to be methane gas that matched the gas produced by Chesapeake's nearby wells.

Before the year was out, over a dozen households in Bradford County had their drinking water supplies tainted by gas from Chesapeake gas wells whose casings or cement jobs had failed. The DEP ordered Chesapeake to fix their gas wells' problems and in some cases, the company paid for water deliveries or a replacement water well. A consent order from the case's settlement specifically describes notices of violations issued by the DEP to Chesapeake over the failed gas wells. The company attempted, at times unsuccessfully, to repair the methane leaks. But no violations for these events appear in the state's data on well failure rates.

Clearly, the amount of gas that leaks from these wells is only part of the story in Pennsylvania. The rest of the story has to do with how state regulators handle problems when they arise.

For that, it is worth looking to a report (http://public-accountability.org/wp-content/uploads/Fracking-and-the-Revolving-Door-in-Pennsylvania.pdf) issued recently by the Public Accountability Initiative, which offers new insight into the politics of drilling oversight in Pennsylvania. The report describes in stark detail the coziness between the drilling industry and the people in Pennsylvania who are supposed to police it.

A revolving door between the natural gas industry and environmentalists spins quickly in the state. One person featured in the report is John Hanger, who directed the Department of Environmental Protection under a Democratic administration when the Marcellus boom first took hold in Pennsylvania. He was tasked with policing the industry, but under his watch the state was opened in new ways to drillers and major environmental problems (https://www.nytimes.com/2011/02/27/us/27gas.html?ref=drillingdown&_r=0&gwh=03C29F8FCF4C2020CE29C7B15A097BBF) emerged. Mr. Hanger is now special counsel to a law firm that represents every segment of the fossil fuel industry, including the state's oil and gas

industry association, and is also running (http://www.witf.org/smart-talk/2013/02/radio-smart-talk-democrat-john-hanger-discusses-his-candidacy-for-governor.php) for governor.

These patterns have continued under the current Republican administration. Current DEP head Michael Krancer (//www.desmogblog.com/2012/11/26/pennsylvania-s-top-environmental-regulator-champions-drilling-industry-shale-conference) is former general counsel at a utility that relies on natural gas and a former partner at a law firm member of the Marcellus Shale Coalition, an industry lobby group.

"Twenty Department of Environmental Protection employees have held jobs in the energy industry either before or after their agency jobs," the Public Accountability Initiative reported. "Every Secretary of Environmental Protection since the DEP was created has had ties to the natural gas industry." And all three of the state's recent governors (//www.desmogblog.com/2013/02/05/ed-rendell-range-resources-obama-epa-texas-fracking-water-contamination-lawsuit) have industry ties.

When Mr. Krancer started his tenure as the director of the Pennsylvania DEP in 2011, he immediately found himself immersed in scandal after a leaked memo revealed that he was requiring all violations to be approved by DEP headquarters instead of directly issued by field staff, as had been the norm previously. After the memo was publicized, Krancer recinded the policy (http://www.post-gazette.com/stories/local/marcellusshale/dep-rolls-back-approval-process-for-shale-violations-296116/). But the data indicates that enforcement may have been chilled as inspectors became less likely to issue violations for known problems under Krancer's watch.

The Public Accountability Initiative report also offers new information about the Krancer scandal. One high level DEP staffer, John T. Hines, left the DEP in February 2012 for a job with Shell Oil Company. Mr. Hines, it turns out, was the author of the memo that required inspectors to clear any notices of violation they intended to issue with himself or another top DEP employee in Harrisburg.

Pennsylvania regulators have offered their state as a model for the rest of the country to follow, claiming that drilling is closely monitored.

"No other state has added more staff, done a more comprehensive strengthening of its rules or more aggressively enforced its rules than

Pennsylvania has," reads a fact sheet (http://www.elibrary.dep.state.pa.us/dsweb/Get/Document-84024/0130-FS-DEP4288.pdf) created by the DEP in 2011.

Shale industry officials have echoed this point.

"Pennsylvania has some of the strictest regulations in the country, further enhanced with the passing of Act 13, and a long history of regulating oil and gas," Energy in Depth Marcellus bloggers wrote (http://http://eidmarcellus.org/marcellus-shale/marcellus-shale-ambulance-chasers-on-the-loose-in-pennsylvania/8152/) last April.

Not everyone is convinced.

Pennsylvania's drilling boom is often cited as a textbook example of how not to handle drilling. Officials from states like Maryland (http://www.heathermizeur.com/content/timeout-debate-heats-annapolis) and New York have pointed to pollution and other issues that fracking caused in Pennsylvania as they consider holding off on shale gas extraction in their states. Robert F. Kennedy, Jr. recently told the Associated Press that he had convinced (http://http://abcnews.go.com/US/wireStory/ap-ny-fracking-held-cuomo-rfk-jr-talk-18636918) New York Governor Andrew Cuomo to keep New York's moratorium on shale extraction in effect until results come in from a study of fracking's health impacts in Pennsylvania.

The Pennsylvania auditor general is currently investigating Mr. Krancer's oversight of the shale gas industry. And at a state budget hearing (http://www.phillyburbs.com/news/local/courier_times_news/dep-secretary-krancer-hit-on-marcellus-shale-smallmouth-bass/article_446821c4-2d21-55d3-a497-d995674c994a.html?mode=jqm) on Friday, lawmakers grilled Mr. Krancer about his agency's record. One lawmaker pointed out that nine of every 10 Marcellus Shale violations in 2011 resulted in no fines.

Mr. Krancer, however, argued that there is a logic to not penalizing drillers when they break the law.

"The idea of an issuance of a notice of violation is not to issue a fine," said Mr. Krancer during the hearing. "The idea is to bring conduct which is potentially volatile to the attention of the operator so the operator can do something about it."

So how is that theory working out?

Virtually all evidence coming from the state seems to show that this type of oversight works better for drillers than residents of the state. The data shows operators have failed to "do something about it." Instead, the opposite is true. Drillers have grown more likely to make mistakes as time goes on and recently drilled wells have a worse track record than those drilled years ago. But when accidents happen, state regulators, it seems, have simply been turning a blind eye.

Image credit: [Map of PA by iQoncept (http://www.shutterstock.com/cat.mhtml?lang=en&search_source=search_form&search_tracking_id=13507A3E-853E-11E2-9389-12CDACE6966E&version=llv1&anyorall=all&safesearch=1&searchterm=pennsylvania+map&search_group=&orient=&search_cat=&searchtermx=&photographer_name=&people_gender=&people_age=&people_ethnicity=&people_number=&commercial_ok=&color=&show_color_wheel=1#id=117914764&src=2CE18C9A-853E-11E2-8E89-94BF37D0D1A0-1-0)] / [Shutterstock (http://www.shutterstock.com/)]

(mailto:?subject=Check out this story from DeSmogBlog&body=https://www.desmogblog.com/2013/03/05/pennsylvania-failing-sanction-drillers-fracked-well-failures%0D%0A%0D%0APennsylvania Failing to Sanction Drillers for Fracked Well Failures)

Physicians Scientists & Engineers for Healthy Energy

FLUID MIGRATION MECHANISMS DUE TO FAULTY WELL DESIGN AND/OR CONSTRUCTION: AN OVERVIEW AND RECENT EXPERIENCES IN THE PENNSYLVANIA MARCELLUS PLAY

BY

ANTHONY R. INGRAFFEA, PH.D., P.E.

OCTOBER, 2012

1.0 INTRODUCTION: LOSS OF WELL STRUCTURAL INTEGRITY

An overall description of mechanisms by which oil and gas wells can develop gas and other fluid leaks can be found in Dusseault *et al.* (2000). These mechanisms can be exacerbated with repeated pressurization of the casing, with open-annulus sections along the casing, and with high gas pressures encountering curing cement or entering such open-hole sections. All of these exacerbating factors lead to more rapid occurrence and upward growth of circumferential fractures, essentially disbonding, in the rock-cement and /or the cement-casing interface.

A schematic depiction of the phenomenon of gas, or additional fluid, migration upwards along a wellbore is presented in Figure 1a, for the simplest case of bypass by disbonding along the surface casing. Figure 2 is a close-up schematic showing other possible fluid pathways. Additional layers of casing and attendant cement interfaces, present in the defective wells in question, do not eliminate these phenomenon; they may, in fact, increase its likelihood. Figure 3 is a snapshot of yet another situation in which an intermediate casing annulus is left un-cemented, but open to a shallow gas source.

These phenomena are not rare in the oil and gas industry. Data on failure rates for cement jobs leading to sustained casing pressure and possible fluid migration into USDW can be found, for example, in Figure 4 from Brufatto *et al.* (2003), who state:

"Since the earliest gas wells, uncontrolled migration of hydrocarbons to the surface has challenged the oil and gas industry…many of today's wells are at risk. Failure to isolate sources of hydrocarbon either early in the well-construction process or long after production begins has resulted in abnormally pressurized casing strings and leaks of gas into zones that would otherwise not be gas bearing".

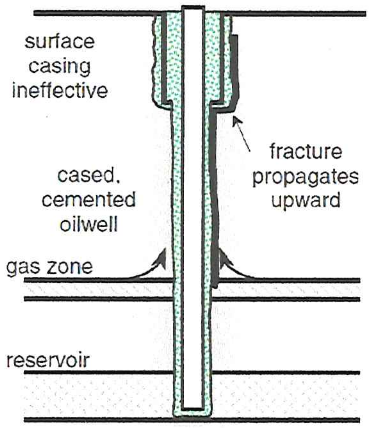


Figure 1. Simplified schematic showing phenomenon of upward gas migration along a casing string. From Dusseault *et al.*, 2000.

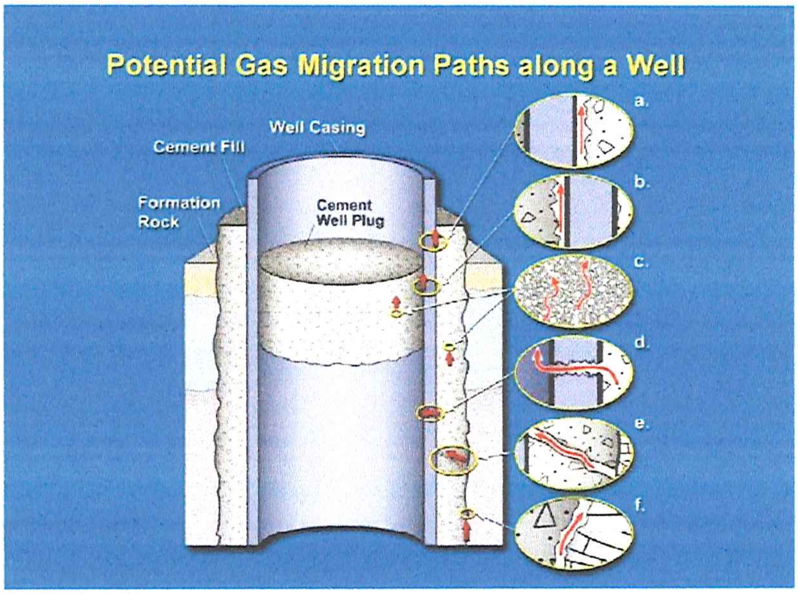


Figure 2. Schematic of details of possible fluid migration paths in and around a cased/cemented well.

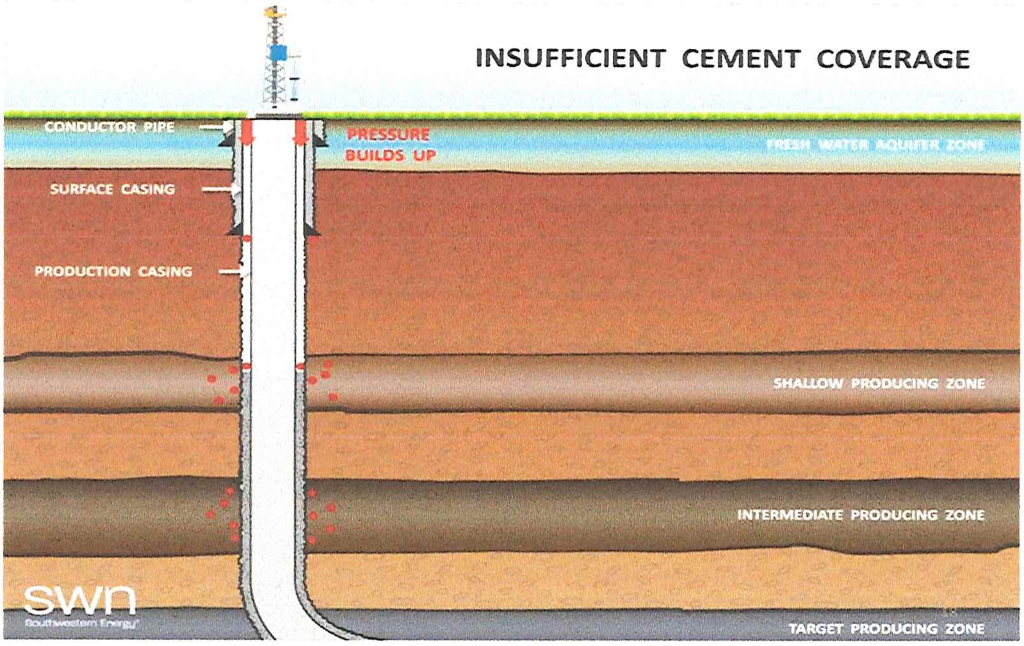
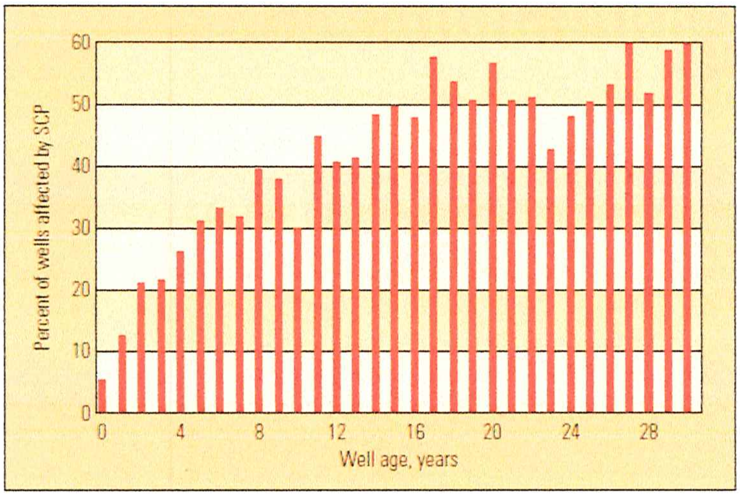


Figure 3. Depiction of entry of gas from a shallow source into an un-cemented annulus, leading to sustained casing pressure and migration of fluids into an USDW. From Boling (2011).



^ Wells with SCP by age. Statistics from the United States Mineral Management Service (MMS) show the percentage of wells with SCP for wells in the outer continental shelf (OCS) area of the Gulf of Mexico, grouped by age of the wells. These data do not include wells in state waters or land locations.

Figure 4. Data on frequency of occurrence of sustained casing pressure (SCP) in offshore wells. From Brufatto *et al.* (2003).

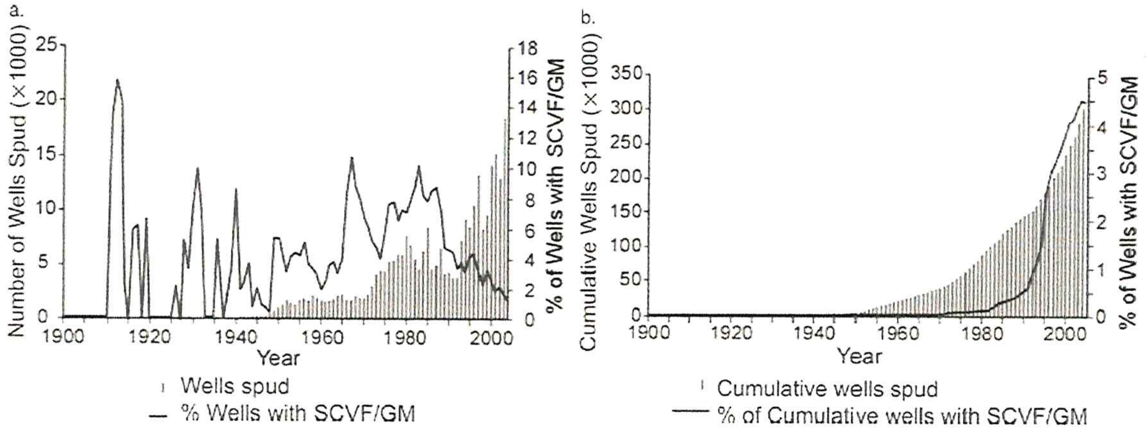


Fig. 8—Historical levels of drilling activity and SCVF/GM occurrence in Alberta: (a) by year of well spud and (b) by cumulative wells drilled.

Figure 5. Data on frequency of occurrence of sustained casing vent flow (SCVF) or gas migration (GM). From Watson *et al.* (2009).

In their statistical analysis of information about nearly 315,000 onshore oil and gas wells, Watson and Bachu (2009) state:

> "Low cement top or exposed casing was found to be the most important indicator for SCVF/GM. The effect of low or poor cement was evaluated on the basis of the location of the SCVF/GM compared to the cement top... the vast majority of SCVF/GM originates from formations not isolated by cement."

Figure 5 shows data gathered by Watson and Bachu that is consistent for young wells with that shown in Figure 4. Note that all these citations are from industry sources. It should be noted that, even with ongoing technological and chemistry improvements in cement and in cementing, loss of wellbore integrity is still common. For example, during 2011, Cabot drilled 68 new Marcellus wells in Pennsylvania, and was cited by PA DEP seven times for "Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days". Chesapeake Appalachia drilled 279 wells and was cited 24 times for the same violation. A summary of the incidence of well failure in the PA Marcellus since 2010 is presented in Section 3, below.

2.0 PREVALENCE OF FLUID MIGRATION FROM FAULTY WELLS

The science on contamination of drinking water from shale gas drilling, fracing, and production, is recent, ongoing, and incomplete. A peer-reviewed, archival journal study from Duke University (Osborne, *et al.*, 2011) found apparent migration of substantial amounts of methane from gas wells to private water wells as far out as 1000m in the Marcellus play in Pennsylvania. A more recent paper from the Duke University team (Warner *et al.*, 2012)

documented geochemical evidence for possible natural migration of Marcellus formation brine to shallow aquifers in Pennsylvania. Also, the U.S. Environmental Protection Agency (EPA, 2011) recently released a preliminary report from an on-going study in Pavilion, WY, that suggests that substances used in fracing might migrate into adjacent water-bearing strata. The study also found clear evidence that there had been migration of methane from gas wells to nearby drinking water wells - likely caused by deficient cement jobs. Inadequate well construction and, of course, spills have been implicated in many states in a large number of cases of migration of drilling related substances into nearby drinking water.

Along with these fairly direct evaluations of the migration of methane and other substances, industry sources have asserted that private water wells are often contaminated by "naturally occurring" methane. This is often presented in an apparently analytical but confusing way, suggesting that the appearance of methane in drinking water wells is sort of "common" and thus unlikely related to any gas well drilling. Such presentation fails nearly entirely to, first, distinguish between dangerous/hazardous levels of methane in water (7 mg/L or more in PA), and much lower levels that are not generally taken to be of concern. Second, it ignores the prevalence or likelihood of having a dangerous "natural" level of methane in drinking water. Third, it ignores any time line: has there been any significant change in the concentration of methane concurrent with the beginning of nearby gas field development?

The New York DEC's data (NYS rdSGEIS, pg. 4-39) make crystal clear that for a 2010 sample of water wells (n=46) in the "Delaware, Genesee, and St. Lawrence River Basins," presumably not near gas wells, just 2% of the wells had a dangerous level over 10 mg/L. One well had a level of 22 mg/L; the remaining wells then had an average level of 0.31 mg/L. This low percentage of "normal" risk has been confirmed repeatedly in studies in PA, Figure 6, in the Southern Tier of NY (1450 water wells, USGS, 2010), in Alberta, Canada (360,000 wells, Griffiths, 2007) and by both independent investigations and by testing by gas drillers (e.g., Boyer, *et al.*, 2011). None of these findings suggest, in any way, that dangerous levels of methane are at all common in rural private water wells. Thus, a fairly strong implication is that, if and when methane does occur at high levels in water wells near gas drilling, it is likely due to some aspects of gas drilling, fracing and/or production operations themselves. This is consistent with both the Osborn, *et al.* (2011) study and the EPA Pavilion (2011) preliminary report. Exact migration mechanisms are not yet completely clear in each case, but the potential well failure mechanisms described in the previous section are often implicated.

3.0 RECENT EXPERIENCES IN THE PA MARCELLUS PLAY

A previous review of the PA DEP Marcellus Violations Database at

http://www.depreportingservices.state.pa.us/ReportServer/Pages/ReportViewer.aspx?/Oil_Gas/OG_Compliance

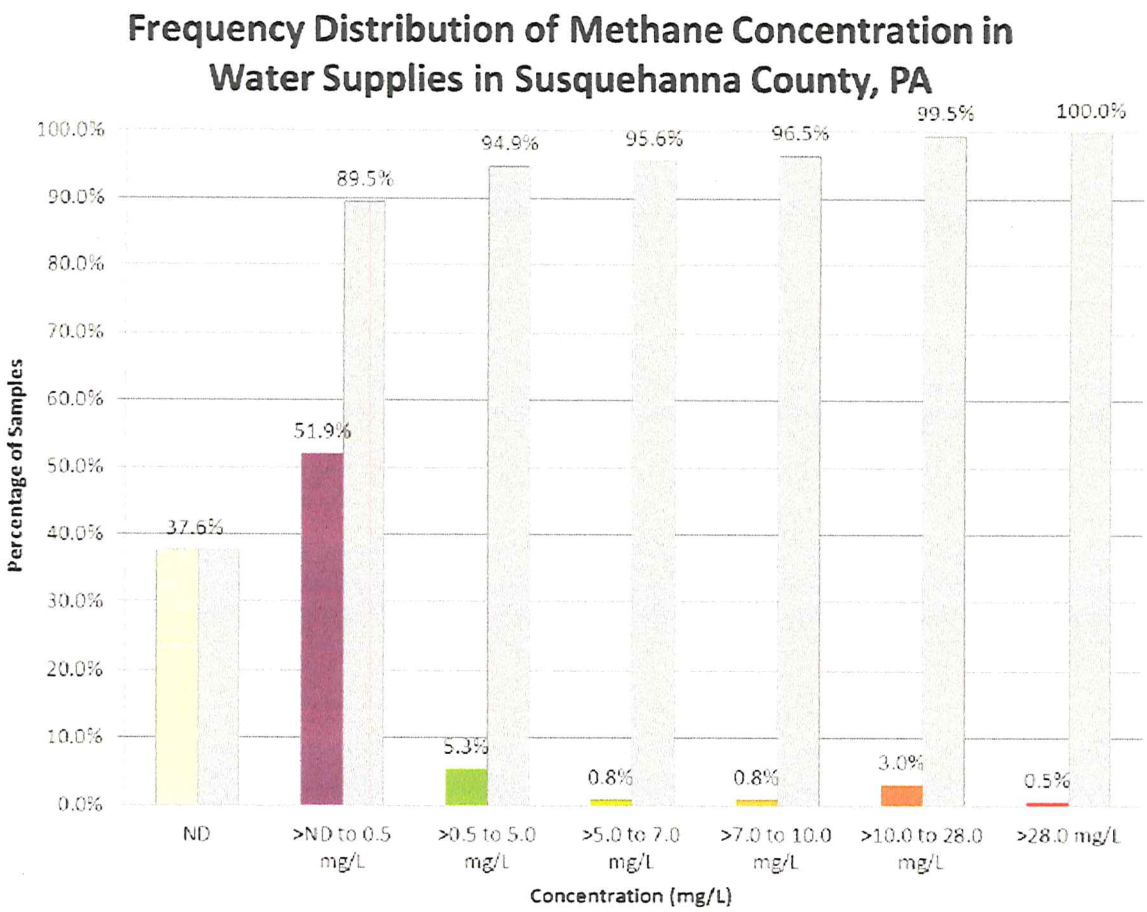


Figure 6. Data collected by PA DEP on methane concentration in private water wells in Susquehanna County, PA. 2433 water supplies were tested: 89.5% had concentrations of methane < 0.5 mg/L, 95.6% had concentrations of methane < 7.0 mg/L. Courtesy of Seth Pelepko, PA DEP.

resulted in the data shown in Figure 7. However, a recent re-review of this database revealed that the data shown in Figure 7 are inaccurate. That data was obtained by searching the violations database for all violations indicating that a well was leaking outside its production casing. Table 1 shows all the violation codes used by PA DEP to indicate that a well is leaking outside its production casing, why it might have occurred, and the consequences of such failure. These were the codes used to filter the entire violations database to identify wells with compromised structural integrity presented in Figure 7.

However, recently it has come to our attention that this filtering process results in a *lower-bound on the number of wells with compromised structural integrity.* That is, more wells have failed cement jobs than have been reported through the violations shown in Figure 7. All inspection

1,454 wells drilled in 2010.
90 well failures.
6.2% rate of failure.

1,937 wells drilled in 2011.
121 well failures.
6.2% rate of failure.

262 wells drilled in Jan/Feb 2012
19 well failures
7.2% rate of failure

Consistent with previous industry data, and not improving.

Figure 7. Preliminary results of survey of leaking wells in the Pennsylvania Marcellus play based on violations issued by the DEP. Violations data from http://www.depreportingservices.state.pa.us/ReportServer/Pages/ReportViewer.aspx?/Oil_Gas/OG_Compliance

Table 1. Violation Codes Used to Identify Wells with Violations for Figure 7.

78.73A - Operator shall prevent gas and other fluids from lower formations from entering fresh groundwater.
78.81D2 - Failure to case and cement properly through storage reservoir or storage horizon
78.83A - Diameter of bore hole not 1 inch greater than casing/casing collar diameter
78.73B - Excessive casing seat pressure
78.83GRNDWTR - Improper casing to protect fresh groundwater
78.83COALCSG - Improper coal protective casing and cementing procedures
78.85 - Inadequate, insufficient, and/or improperly installed cement
78.86 - Failure to report defective, insufficient, or improperly cemented casing
207B - Failure to case and cement to prevent migrations into fresh groundwater

reports for the more than 6000 wells drilled to-date in the Marcellus in PA were reviewed; this is a more complete and revealing search than just filtering on certain violations. The inspection reports indicate that many failed wells were not issued violations. Rather, they received "Violation Pending" comments; or comments indicating that "squeezing", a cement repair procedure which would only be done if a well was leaking outside its production casing, had been done or was to be done; or comments that repairs were underway for a perforated casing; or comments that gas was detected at the wellhead at or above the LEL (lower explosive limit).

Table 2 shows the comparison for each of 2010, 2011, and 2012 between the numbers of wells that had actually received violations, and those that were noted in inspection comments to be leaking but had not received violations.

Table 2. Additional Counts of Wells with Loss of Integrity Included in Figure 8.

2010	64 wells with violations, 47 additional wells with loss of integrity noted in Inspection Comments
2011	97 wells with violations, 45 additional wells with loss of integrity noted in Inspection Comments
2012 (Jan-Aug)	31 wells with violations, 36 additional wells with loss of integrity noted in Inspection Comments

Figure 8 contains the revised well failure rates, using both actual violations and inspection comments to identify leaking wells. The complete database supporting the results shown in Figure 8 is available on request to http://www.psehealthyenergy.org/CONTACT.

Finally, it should be noted that a well that appears, at its wellhead, not to be leaking is not necessarily a sound well. It is well known that fluid migration can occur a significant distance away from the wellhead of a well that appears on inspection of only the wellhead to be of sound structural integrity.

4.0 SUMMARY

The most recent experience with shale gas wells in the Pennsylvania Marcellus play reflects long term, world-wide industry data with respect to new wells with compromised structural integrity. Operator-wide statistics in Pennsylvania show that about 6-7% of new wells drilled in each of the past three years have compromised structural integrity. This apparently low failure rate should be seen in the context of a full buildout in the Pennsylvania Marcellus of at least 100,000 wells, and in the entire Marcellus, including New York, of twice that number. Therefore, based on recent statistical evidence, one could expect at least 10,000 new wells with compromised structural integrity. It is too early to discern whether the other industry experience with this technical problem, an increase in loss of integrity with well age, will also be reflected. However,

drilling, which shows an extremely low frequency of water wells with dangerous levels of methane, provided by industry sources, is credible.]

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