National assessment of chemicals associated with coal seam gas extraction in Australia

Overview

The National assessment of chemicals associated with coal seam gas extraction in Australia was commissioned by the Department of the Environment and Energy and prepared in collaboration with NICNAS and CSIRO.

Australian Government
Department of the Environment and Energy
Department of Health
National Industrial Chemicals Notification and Assessment Scheme

Assessment overview

It is important to understand what coal seam gas extraction means for human health and the environment. Coal seam gas extraction is closely regulated by state and the Commonwealth governments, which legally require protective measures to be in place to safeguard health and the environment. While the exact requirements vary by jurisdiction, this regulatory framework applies to all aspects of the industry, including the handling and use of chemicals throughout the extraction process.

To increase the knowledge base about chemicals used in the industry and in recognition of the scientific and community interest in the risks of this chemical use, the Australian Government commissioned the *National assessment of chemicals associated with coal seam gas extraction in Australia* in June 2012.

The Assessment examined 113 chemicals used by companies in Australia between 2010 and 2012 in drilling and hydraulic fracturing for coal seam gas, to develop a stronger understanding of the risks these chemicals could pose to the health of workers, the public and the environment. Industry reports that 59 of the 113 chemicals that were being used in coal seam gas extraction in 2010-12 were still being used in 2015-17.

The focus of the Assessment was solely on the above-ground (surface) handling of chemicals – it did not consider potential risks from chemicals entering deeper groundwater through drilling or fracturing operations. The Australian government has since commissioned additional research into deeper groundwater that found the risks to be very low. This is consistent with international studies that had shown that the greatest risk to human health or the environment from chemicals used in coal seam gas extraction is from spills or releases of chemicals during surface activities such as transport, handling, storage and mixing of chemicals. It is important to note that not all wells require fracturing and not all chemicals are used at all sites. Most of the chemicals are also commonly used in other industries. Some are used in homes.

The Assessment looked at scenarios in the coal seam gas extraction process where workers, the public and the environment could come into contact with the chemicals. The scenarios considered all parts of the extraction process including the activities listed above. Spills, leaks and accidents were the main release events identified in the scenarios. Worker scenarios also examined direct handling of the chemicals.

The Assessment took a very conservative approach, consistent with best practice, to ensure any pre-mitigation risks are not overlooked. It examined worst case scenarios and did not take into account all the safety and handling precautions that are taken to protect people and the environment from industrial chemical use. In reality, these precautions are required by law and significantly reduce any likelihood of potential harm occurring.

The Assessment found that the greatest pre-mitigation risk of harm to public health or the environment was in the event of a large-scale transport spill. Because they work with chemicals in more concentrated forms, the main pre-mitigation risks to coal seam gas workers is from industrial accidents and handling chemicals while maintaining equipment or mixing and blending. Even in this case, applying the required safety and handling precautions such as wearing protective equipment and promptly notifying and cleaning up spills, reduces the risk significantly.

Australia has a strict regulatory regime for coal seam gas operations that requires safety and handling precautions to prevent spills and promptly control, report and remediate them if they occur. Strict work, health and safety regulations are in place to protect workers. Comprehensive national standards apply to the handling and transport of chemicals for all industries, including the coal seam gas industry.

The Assessment has provided regulators and companies with an additional level of information directly relevant to the coal seam gas industry. This is new knowledge and information that will enable more targeted risk management actions and practices for the safe management of chemicals in coal seam gas operations.

What did the Assessment look at?

The Assessment looked at 113 chemicals used for drilling and hydraulic fracturing for coal seam gas in Australia within a sample time period from 2010 to 2012. At the time of the research, all coal seam gas operations were in NSW and Queensland. Each chemical was assessed for its potential risks to workers, the public and the environment in scenarios specific to the coal seam gas extraction process. Chemicals used in drilling and hydraulic fracturing can change over time, so not all of the 113 chemicals assessed would necessarily still be in use. For example, industry reports that 59 of the 113 chemicals that were being used in coal seam gas extraction in 2010-12 were still being used in 2015-17.

The focus of the Assessment was solely on the above-ground handling of chemicals. This was identified as a priority for research as international studies had shown that the greatest risk to human health or the environment is from spills or releases of chemicals during surface activities such as transport, handling, storage and mixing of chemicals.

As its focus was on surface handling, the Assessment did not assess potential risks from chemicals entering deeper groundwater, mixtures of chemicals, geogenics (chemicals in the coal seam or rock that are mobilised by the fracturing process), fugitive emissions and ambient air, shale or tight gas extraction, potential effects on agriculture or the food chain, or the individual risks of chemicals used at particular sites.

The Department of the Environment and Energy commissioned CSIRO to conduct further research on how chemicals used in coal seam gas extraction might move from deeper groundwater to other parts of the environment, how long this movement might take, and what the concentrations of chemicals might be at receiving environments such as water bores and streams. The research found that chemicals remaining underground after hydraulic fracturing are unlikely to reach people or ecosystems in concentrations that would cause concern. This conclusion is based on natural dilution and degradation that reduce concentrations to negligible levels. Risks are therefore likely to be very low. The results of this research are available on the Department's website.

How was the Assessment done?

The Assessment was a complex, multi-agency Australian Government project. It is made up of 14 reports and reviews.

Who was involved?

The Assessment was a collaborative effort of technical experts from the National Industrial Chemicals Notification and Assessment Scheme (NICNAS), the Commonwealth Scientific and Industrial Research Organisation (CSIRO), and the Department of the Environment and Energy.

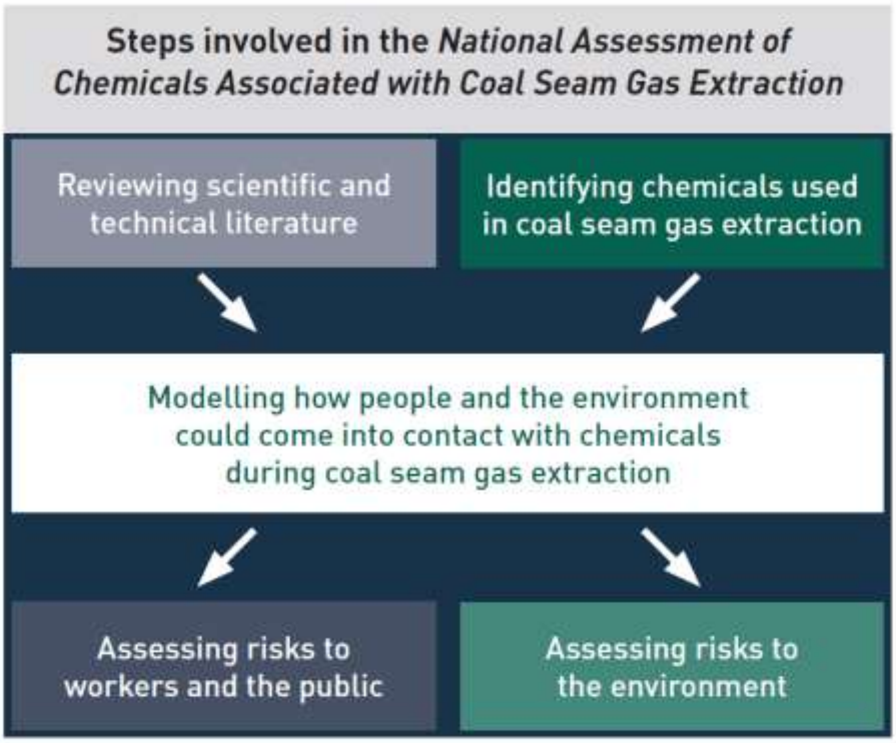
The Assessment drew on technical expertise in risk assessment, chemistry, toxicology, ecotoxicology, hydrogeology, hydrology, geology and natural resource management.

The Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (IESC) provided independent advice and critical review at key points in the development of the Assessment.

Experts from Australia, the United States Environmental Protection Agency and Health Canada reviewed the Assessment and found it and its methods were consistent with international practice and unlikely to underestimate risks.

What was involved?

The Assessment involved reviewing the scientific and technical literature and knowledge base, identifying the chemicals in use, developing new models and methodologies, and assessing the human health and environment risks of using the chemicals in coal seam gas extraction. Some of the methods had to be developed specifically for the Assessment. These methods can be applied in future risk assessments of chemicals proposed for use in coal seam gas extraction.



Preparatory steps

Several preparatory steps were needed before the human health and environmental risks of chemicals used in coal seam gas extraction could be assessed.

Reviewing scientific and technical literature

The first step in the Assessment was to review the scientific and technical literature about coal seam gas extraction to collate what was already known about how chemicals are used in the process and the potential risks to human health and the environment.

NICNAS, CSIRO and the Department of the Environment and Energy conducted the literature reviews.

The reviews covered five topics:

- how people could come into contact with chemicals during coal seam gas extraction, human health risk assessment methods, and regulation of chemicals—see the Human health implications review for details
- how chemicals could enter the environment during coal seam gas production, how they could move through the environment and how they might affect the environment—see the Environmental risks review for details
- integrity of coal seam gas wells and how fractures grow in coal seams after hydraulic fracturing—see the Hydraulic fracture growth and well integrity review for details
- what chemicals occur naturally in coal seams and how they may be mobilised following hydraulic fracturing—see the Geogenic contaminants review for details
- potential contamination of shallow groundwater by chemicals used in drilling and hydraulic fracturing—see the Leakage to shallow groundwater review for details.

See the Summary literature review for an overview of the literature reviews.

Identifying chemicals used in coal seam gas extraction

The second step in the Assessment was to identify 113 chemicals used in coal seam gas extraction in Australia between 2010 and 2012 from a survey of industry and publicly reported information on chemicals used in coal seam gas extraction.

During this phase of the Assessment, researchers also gathered information about how the chemicals were used during the coal seam gas extraction process and in what quantities.

See the Identification of chemicals report for more details.

Modelling how people and the environment could come into contact with chemicals during coal seam gas extraction

The third preparatory step was to develop models to show how chemicals might move from where they are released (most likely during an accidental leak or spill) to where humans and the environment could come into contact with them.

To do this, scientists identified the physical pathways the chemicals could travel along—for example, being washed off a surface into a stream or soaking into the soil and travelling through shallow groundwater.

The modelling stage also involved predicting the concentrations of chemicals that people or the environment could come into contact with, if the chemicals were released. These predictions were designed to overestimate the concentrations. For example, as some chemicals move through shallow groundwater they can 'stick' to soil particles, considerably reducing the concentration of chemical that humans or the environment might come into contact with, but the models did not take this into account. This 'conservative' approach is standard international best practice and ensures that any risks are not overlooked.

The models are described in detail in the:

- Human and environmental exposure conceptualisation report
- Environmental exposure conceptualisation report
- Predicted environmental concentrations report.

Before the human health risk assessment was performed, NICNAS assessed whether each of the chemicals was harmful (hazardous) to human health in its pure, concentrated form. This hazard assessment involved reviewing international studies and laboratory results in international and national databases.

Fifty-seven of the 113 chemicals were identified as harmful in their pure, concentrated form. This is because a risk arises only if humans come into contact with a chemical and at a high enough concentration to cause harm. For example, concentrated hydrochloric acid can be harmful if swallowed, spilled on the skin, splashed into the eye, or if people breathe the vapours. A chemical that is harmful in its pure, concentrated form may not necessarily cause harm when used in coal seam gas extraction at lower concentrations. State regulatory controls and industry practices on the use of drilling and hydraulic fracking chemicals are used to ensure that these risks are minimised. The Assessment went on to look at these chemicals in specific scenarios in the coal seam gas extraction process to identify the risks to human health. A risk arises only if people could come into contact with a high enough amount to cause harm. For example, the public is unlikely to come into contact with concentrated hydrochloric acid used for coal seam gas extraction and is therefore not at risk of harm. Coal seam gas workers, on the other hand, may handle concentrated hydrochloric acid and companies are required by law to take precautions against their workers coming into contact with it.

Results of the human health hazard assessment are detailed in the Chemicals of low concern and the Human health hazards of chemicals reports.

NICNAS also identified what the largest dose of a chemical could be before it would cause harm to human health. This dose (the 'largest harmless dose') was used later in the risk assessment.

Human health risk assessment

Assessing risks to workers and the public

NICNAS undertook the human health risk assessment. The first step in the risk assessment was to develop scenarios informed by the scientific literature and on-ground experience (through the industry survey), which defined how workers or the public might come into contact with chemicals used in coal seam gas extraction.

For workers, these scenarios involved skin contact, or breathing dusts or chemical vapours or contact with spills during the transport, storage and handling of chemicals. The Assessment looked at risks to workers when involved in:

- transporting and storing chemicals
- mixing or blending chemicals to produce formulations
- injecting fluid formulations into the well
- cleaning and conducting other maintenance activities
- transporting and storing waste water (otherwise known as flowback and produced water)
- an industrial accident resulting in contact with a chemical.

The general public are very unlikely to come into direct contact with chemicals as they are not involved in the day-to-day coal seam gas extraction process. It is generally only through large-scale accidental spills or leaks that are not detected and cleaned up that people could come into contact with the chemicals.

The Assessment looked at risks to the public in the following events:

- a bulk spill occurs during transport of a chemical to a well site and it is not notified to the authorities, closed off to the public, or cleaned up, then a chemical enters surface water (such as a river) that is used for drinking, washing or swimming
- a bulk spill occurs at a work site from a surface storage tank or pond and it is not detected, notified or cleaned up, then a chemical enters shallow groundwater or surface water that is used for drinking, washing or swimming
- a long-term underground leak occurs from a waste water storage pond and it is not detected, notified or cleaned up, then a chemical enters shallow groundwater or surface water that is used for drinking, washing or swimming.

These scenarios were formed using very conservative assumptions. Importantly, these scenarios did not assume that legislated and standard precautions designed to protect people from chemicals were in place. These kinds of conservative assumptions are standard practice for this type of pre-mitigation assessment. For example, the scenarios did not consider that workers would be wearing personal protective equipment when handling potentially harmful chemicals though workplace health and safety laws require the use of such equipment. Similarly, the distances from the source of the chemical to where the chemical could enter the environment were considered to be shorter than they are likely to be in reality.

The second step in the risk assessment was to calculate the dose of a chemical a person might take in under each scenario. These doses are likely to be overestimated because the predicted concentration models overestimate the concentrations of chemicals and the scenarios do not take into account standard precautions which are applied to protect people from chemicals.

The final step in the risk assessment was to compare the dose a person might receive in the different scenarios to the largest harmless dose. If the dose a person might receive was much smaller than the largest harmless dose, the chemical was considered unlikely to be harmful to human health. If this wasn’t the case, the chemical was considered to be potentially harmful to human health under the scenario.

For some chemicals there was not enough information to calculate the largest harmless dose. For these chemicals, risk was assessed by analysing the scientific literature and applying expert judgement on the chemical's potential to harm human health.

The risk assessment methods and findings are described in detail in the Human health risks report.

Environmental risk assessment

Assessing risks to the environment

The Department of the Environment and Energy undertook the environmental risk assessment using two methods. The method used was based on the level of information that was available for the chemical.

For chemicals with only basic information available, the risk assessment was done by compiling evidence from the international scientific literature to support an expert judgement on the chemical's potential to harm the environment. This approach considered the behaviour of the chemicals in the environment and what harm they could cause to water- and land-based animals and plants. It also considered how chemicals were used in coal seam gas extraction, factoring in the most likely ways for chemicals to be released during the extraction process and protective measures to prevent and limit spills and leaks.

Chemicals with more information available were assessed using a different method. Scenarios were developed to show how chemicals might enter a water body such as a river, pond or lake. Potential harm to the environment was assessed by determining what effect the chemicals could have on aquatic organisms in the water body, including algae, invertebrates and fish. As with the human health risk assessment, the scenarios were informed by the scientific literature and the industry survey in the preparatory steps.

The risks to the environment were assessed for the following scenarios:

- a chemical spills during transport from a storage warehouse to the well site and the spill is not detected, notified or cleaned up
- a chemical spills from storage at a storage facility and the spill is not detected, notified or cleaned up
- a chemical spills from storage at the well site and the spill is not detected, notified or cleaned up
- a chemical spills during use and handling at the well site and the spill is not detected, notified or cleaned up
- waste water containing a chemical spills during use or management of the waste water and the spill is not detected, notified or cleaned up
- waste water containing a chemical leaks from storage pond or tank and the leak is unreported
- waste water containing a chemical is reused for dust suppression
- waste water containing a chemical is reused for irrigation.

The second step in this method of risk assessment used the predicted concentration models and the above scenarios to calculate the concentrations of a chemical that the aquatic animals and plants might come into contact with. In keeping with the very conservative approach taken in this assessment, the models were designed to overestimate the concentration of a chemical that animals and plants might come into contact with.

The final step in this method of risk assessment was to compare the concentrations of chemicals that animals and plants might come into contact with under different scenarios to the largest harmless concentration. If the concentration animals and plants might come into contact with was smaller than the largest harmless concentration, the chemical was considered unlikely to cause harm to the environment. Otherwise, the chemical was considered to be potentially harmful to the environment.

This method used a staged approach with increasingly detailed consideration applied to those chemicals that were more likely to be a potential concern for the environment. Chemicals found to be safe were screened out at an early stage. The first stage used generic assumptions about extraction sites and worst case scenarios for the quantities of chemicals potentially entering the environment. Two more stages of testing were more specific to the conditions of actual extraction sites and the quantities of chemicals likely to be in use.

For some of the chemicals assessed using this method there was not enough information about the ways and quantities in which the chemicals were used to perform more detailed assessments. These chemicals were assessed only at the earliest, most conservative tier of testing.

Both methods of assessing risks to the environment, and their findings, are described in detail in the Environmental risks report.

What did the Assessment find?

The Assessment identified 113 chemicals used in drilling and hydraulic fracturing for coal seam gas in Australia between 2010 and 2012. Not all of these chemicals were used at any one site and hydraulic fracturing is not necessary at many coal seam gas wells.

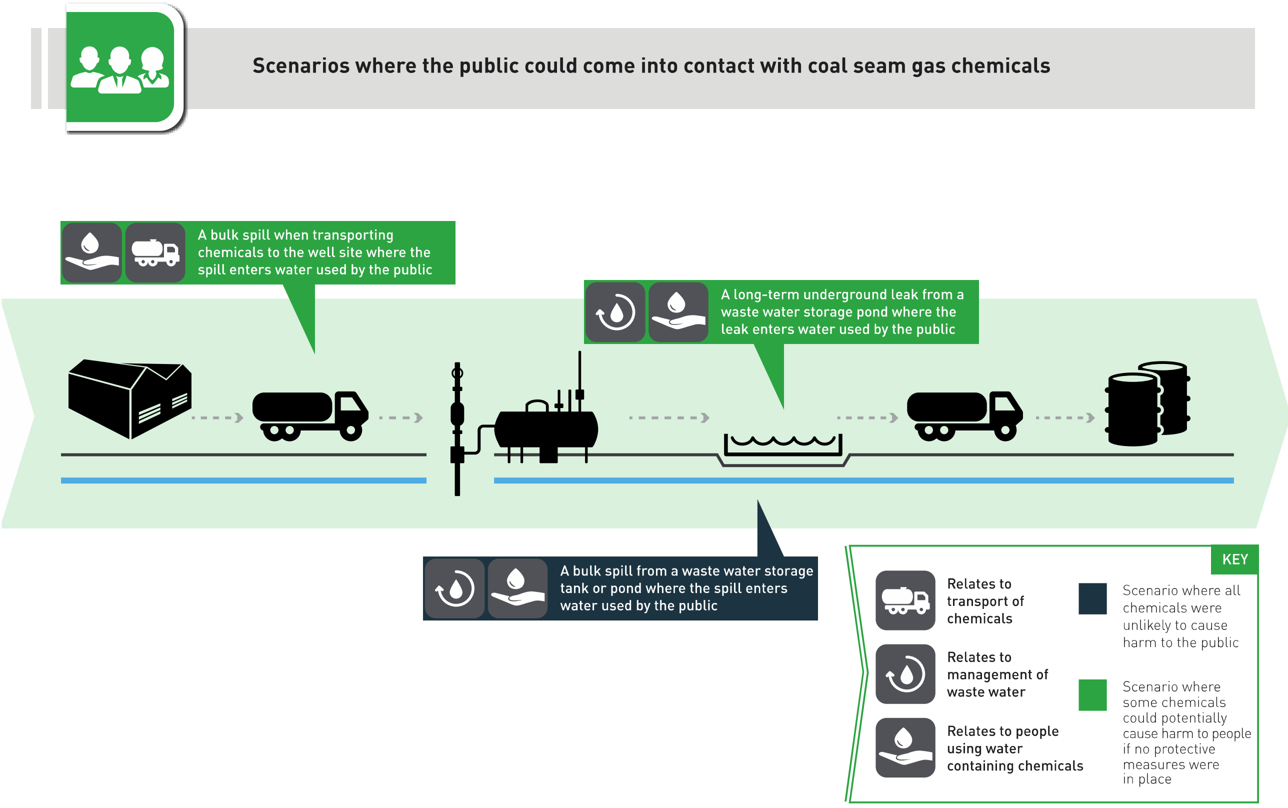
A results table can be found at the end of this document.

Most of the risk assessments did not take into account the safety and handling precautions that are taken to protect people and the environment from industrial chemical use. The chemicals identified as risks are potentially harmful in the specific conditions of the scenarios, which looked at what could happen if no protections were in place. The Assessment examined worst case scenarios with no protections in place because if a chemical is found to be unlikely to cause harm in these extreme situations, we can be confident that it can be used safely.

In reality, these precautions are required by law and significantly reduce any remaining likelihood of any potential harm occurring. The stringent protective measures imposed by state and territory and Commonwealth governments for industry are described in more detail on page 16. These measures significantly reduce the likelihood of potential harm.

What do the results mean for public health?

As members of the public are not involved in the day-to-day coal seam gas extraction process, they are unlikely to come into direct contact with chemicals. It is generally only through large-scale accidental spills and leaks that people could come into contact with the chemicals. This is true of chemicals used in many other activities and sectors.



These scenarios did not take into account all standard precautionary measures that are taken to prevent, contain, clean up or report a spill or leak.

In these pre-mitigation scenarios, the majority of chemicals (73 of the 113 tested) were found to be unlikely to cause harm to public health when used in coal seam gas extraction, even if they were to spill or leak in large volumes without the leak or spill being detected or cleaned up.

There were two scenarios where some chemicals could be a risk to the health of a member of the public in the absence of standard risk management measures: a large transport spill and a long-term below ground leak from a storage pond. Both scenarios require the person to drink, wash with or swim in water containing the chemical on a regular basis over an extended period for harm to occur.

Scenarios where chemicals could potentially cause harm to the public

A member of the public could potentially come into contact with harmful amounts of coal seam gas chemicals in two of the three tested scenarios—a large transport spill or an underground leak from a storage pond for a long period of time. Both scenarios require the person to drink, wash with or swim in water containing the chemical for harm to occur.

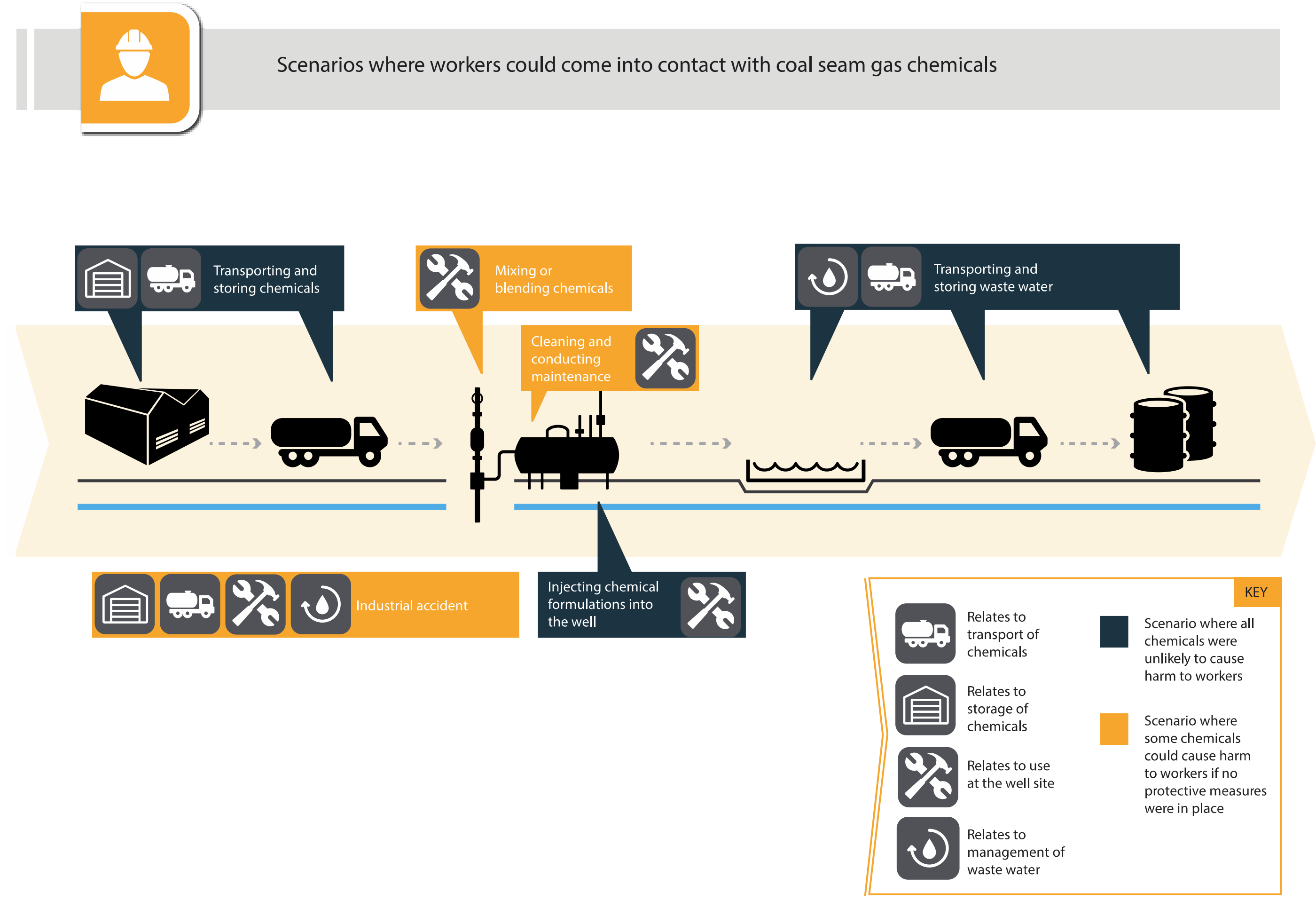
A bulk spill when transporting chemicals to the well site where the spill enters water used by the public

A long-term underground leak from a storage pond where the leak enters water used by the public

Who might come into contact with the chemical	When they might come into contact with the chemical	What chemicals could cause harm	What protects the community from harm
People who drink, wash with or swim in water containing a chemical that has spilled in a large transport accident or leaked from a waste water storage pond.	**Transport spill** A transport accident occurs, resulting in a large spill of chemicals into water used by the public. Under this scenario, a truckload (up to 10,000 kg or 10,000 L) of the chemical would have to spill into nearby water, the spill would have to go undetected, and people would have to continue to drink, wash with or swim in the water for the chemical to pose harm. **Storage pond leak** An underground leak from a waste water storage pond occurs over a long period of time. Under this scenario, the leak would have to go undetected, the waste water would have to be undiluted, the storage pond would have to be within 100m of a groundwater well, the chemical would have to enter surface and groundwater, and people would have to continue to wash in and drink the water for a long period of time. Both scenarios assume that coal seam gas companies will not clean up or notify government authorities of the spill or leak. In practice, they have an enforceable requirement to do so.	If no protective measures were in place, 40 of the 113 chemicals tested could potentially cause harm to the health of people using contaminated water—14 of these in the event of a leak from a storage pond, and 38 of these in the event of a large transport spill. These chemicals are: • Acetic acid • Alcohols, C6-12, ethoxylated • Alkanes, C12-26 branched and linear • Ammonium persulfate • Borax • Boric acid • Boric acid salt, monoethanolamine • Butoxyethanol • Deodorised kerosene • Ester alcohol • Ethanol • Ethoxylated fatty acid I • Ethoxylated fatty acid III • Ethylene glycol • 2-Ethylhexanol heavies • Fatty acids ester • Glutaraldehyde • Hydrogen peroxide • Inner salt of alkyl amines • Isopropanol • Methanol • Methylchloroisothiazolinone • Methylisothiazolone • Organic sulphate • Polyamine • Polymer with substituted alkylacrylamide salt • Sintered bauxite • Sodium borate • Sodium chlorite • Sodium hypochlorite • Sodium persulfate • Sodium sulfite • Sodium thiosulfate • Sulfuric acid, mono-C6-10-alkyl esters, ammonium salts • Terpenes and terpenoids • Terpenes and terpenoids, sweet orange-oil • Tetramethylammonium chloride • THPS • Tributyltetradecyl phosphonium chloride • Triethanolamine	These scenarios looked at what could happen if standard precautions to prevent or control a leak or spill were **not** taken. In practice, the transport and use of industrial chemicals and the storage of waste water is strictly regulated by state and Commonwealth governments. Legislation, regulations and national standards set out requirements for the safe transport of chemicals, including packaging, driver training, safety equipment and vehicle standards. These measures reduce the risk of a spill occurring, or of not being detected and cleaned up if it does occur. Coal seam gas projects also operate under conditions of approval, state and Commonwealth regulations and industry codes of practice which require them to manage chemicals in a way that minimises the risk of causing harm, which includes how they handle and transport chemicals, and how they design, monitor and maintain storage ponds. Companies must also have emergency protocols in place to detect and respond to spills and leaks, including containing, cleaning up and reporting the spill to relevant authorities.

What do the results mean for workers?

Workers may be involved in any or all parts of the coal seam gas extraction process, including storing and transporting chemicals to the well site, preparing and using chemicals in drilling or fracturing, cleaning and maintaining equipment, or managing waste water extracted from the well. During these activities, workers may be working directly with chemicals, sometimes in concentrated forms.



These scenarios did not take into account standard safety and handling precautions such as personal protective equipment or other workplace health and safety strategies, which are required by law.

In these scenarios, the majority of chemicals (65 of the 113 tested) were found to be unlikely to cause harm to workers' health during coal seam gas extraction, even if standard protections weren't in place.

Some chemicals were found to be potentially harmful to workers if one-off contact occurs in the event of an industrial accident, or if repeated contact occurs during long-term mixing and blending or cleaning and maintenance.

Scenarios where chemicals could potentially cause harm to coal seam gas workers

Workers could potentially come into contact with harmful amounts of coal seam gas chemicals when mixing or blending chemicals to produce formulations, performing cleaning and other maintenance activities, or in the event of an industrial accident resulting in one-off contact with a chemical.

Mixing or blending chemicals / Cleaning and conducting maintenance

Who might come into contact with the chemical	When they might come into contact with the chemical	What chemicals could cause harm	What protects workers from harm
Workers involved in mixing and blending chemicals to produce formulations to inject into the well. Workers involved in cleaning or other maintenance activities after drilling or fracturing has occurred.	Inhaling chemicals over a long period of time while mixing and blending or cleaning and maintaining equipment.	If no protective measures were in place, 12 of the 113 chemicals tested could potentially cause harm to the health of workers involved in mixing or cleaning. These chemicals are: • Ammonium persulfate • Bronopol • Calcined silica • Cristobalite • Methanol • Polyamine • Quartz • Sodium hypochlorite • Tetramethylammonium chloride • THPS • Tributyltetradecyl phosphonium chloride • Tridymite	This scenario looked at what could happen if standard safety and handling practices were not in place. In practice, measures to protect coal seam gas workers, such as workplace design, workplace practices, chemical labelling and personal protective equipment, are required by law or industry controls. Work health and safety legislation at the state and Commonwealth level, together with regulations and standards for chemical use, set the requirements for these protections.

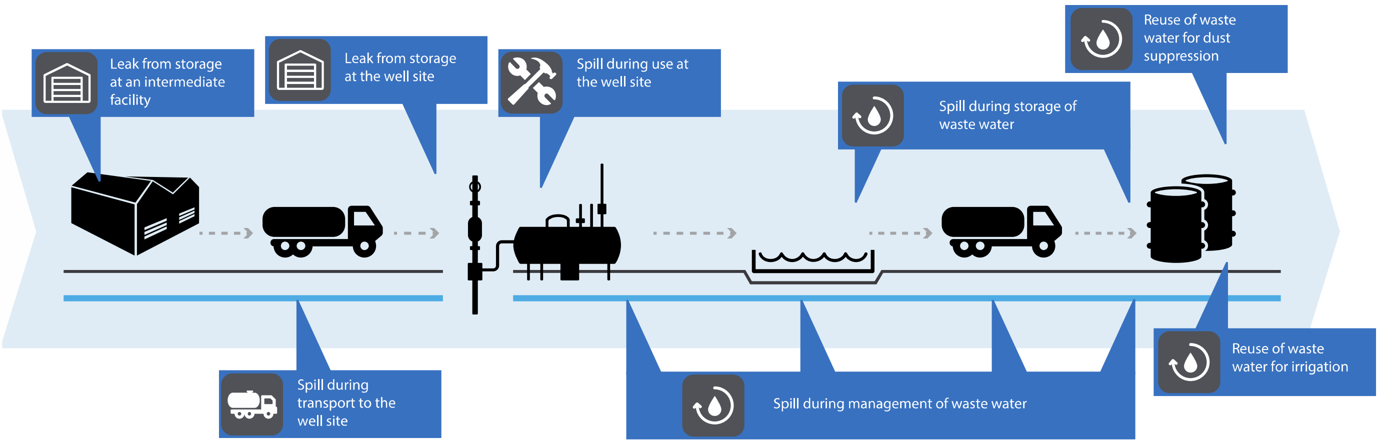
Industrial accident

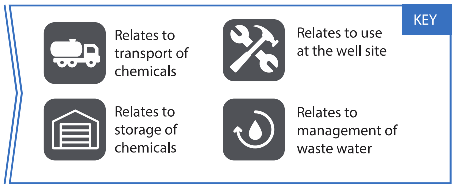
Who might come into contact with the chemical	When they might come into contact with the chemical	What chemicals could cause harm	What protects workers from harm
Workers involved in any activities during the production process when an accident or incident occurs that leads to one-off contact with a chemical.	Spills, accidents or inadvertent contact with a chemical during other activities. The greatest risk is when working with highly concentrated chemicals.	If no protective measures were in place, 44 of the 113 chemicals tested could potentially cause harm to workers in an industrial accident. These chemicals are: • Acetic acid • Alcohols, C6-12, ethoxylated • Ammonium persulfate • Benzisothiazolinone • Bronopol • Butoxyethanol • Caustic soda • Cellulase • Enzyme • Ethanol • Ethanolamine • Ethoxylated fatty acid I • Ethoxylated fatty acid III • Ethylene glycol • Glutaraldehyde • Hemicellulase • Hydrochloric acid • Hydrogen peroxide • Inner salt of alkyl amines • Isopropanol • Lime • Methanol • Methylchloroisothiazolinone • Methylisothiazolone • Organic acid salt • Organic sulphate • Polyamine • Polydimethyldiallyl-ammonium chloride • Potassium carbonate • Sintered bauxite • Slaked lime • Soda ash • Sodium borate • Sodium hypochlorite • Sodium persulfate • Sodium sulfite • Sulfuric acid, mono-C6-10-alkyl esters, ammonium salts • Terpenes and terpenoids • Terpenes and terpenoids, sweet orange-oil • Tetramethylammonium chloride • Tetrasodium EDTA • THPS • Tributyltetradecyl phosphonium chloride • Triethanolamine	Coal seam gas companies have a legal duty to protect workers from harm. Work health and safety legislation requires dangerous chemicals to carry instructions for their safe handling, use and disposal. Companies must also have adequate protective measures in place to reduce the risk of accidental harm from chemicals occurring. These measures may include personal protective equipment, safe work protocols or workplace design. If a chemical spill or incident occurs, by law companies must have emergency protocols in place to detect, contain, clean up, respond to and report the incident.

What do the results mean for the environment?

The Assessment looked at what could happen if a chemical entered the environment through accidental spills and leaks, or intentional reuse of untreated coal seam gas waste water for other purposes.

Scenarios where coal seam gas chemicals could enter the environment





The majority of chemicals (61 of the 113 chemicals tested) were found to be unlikely to cause harm to the environment when used in coal seam gas extraction, even if they were to spill or leak in high volumes.

It is in the event of a transport spill or where untreated waste water containing chemicals is reused for irrigation or dust suppression, that certain chemicals have the potential to cause harm to the environment.

Scenarios where chemicals could potentially cause harm to the environment

Some coal seam gas chemicals could potentially cause harm to the environment, primarily in the event of a transport spill or where waste water is reused for irrigation or dust suppression.

Spill during transport to the well site

When the chemical could enter the environment	What chemicals could cause harm	What protects the environment from harm
A transport accident occurs, resulting in a large spill of a chemical into a nearby water body. Under this scenario, a truck-load (up to 14,000 L) of the chemical would have to spill into surface water, the spill would have to go undetected, and no action would have to be taken to prevent or clean up the spill.	If no protective measures were in place, 15 of the 113 chemicals tested could potentially cause harm to the environment in the event of a transport spill. These chemicals are: • Ammonium persulfate • Boric acid • Caustic soda • Glutaraldehyde • Guar gum • Hydrochloric acid • Methylchloroisothiazolinone • Methylisothiazolone • Polymer with substituted alkylacrylamide salt • Potassium chloride • Soda ash • Sodium chloride • Sulfuric acid potassium salt (1:2) • THPS • Xanthan gum	This scenario looked at what could happen if standard precautions to prevent or control the spill were **not** taken. In practice, the transport and use of industrial chemicals is regulated by the states and Commonwealth. Legislation, regulations and national standards set out the requirements for the safe transport of chemicals, including for packaging, driver training, safety equipment and vehicle standards. These measures reduce the risk of a spill occurring, or of not being detected and cleaned up if it does occur. Coal seam gas projects also operate under conditions of approval, state and Commonwealth regulations and industry codes of practice require companies to manage chemicals in a way that minimises the risk of causing harm, which includes how they handle and transport chemicals. Companies must also have emergency protocols in place to detect and respond to spills, including containing, cleaning up and reporting the spill.

Reuse of waste water for dust suppression | **Reuse of waste water for irrigation**

When the chemical could enter the environment	What chemicals could cause harm	What protects the environment from harm
Waste water from coal seam gas extraction is reused on land for dust suppression or irrigation. Under this scenario, the waste water would have to contain large concentrations of a chemical and be applied repeatedly to land that receives low rainfall.	Four of the 113 chemicals tested could potentially cause harm to the environment when waste water containing the chemicals is reused. These chemicals are: • Borax • Boric acid salt, monoethanolamine • Sodium borate • Boric acid	Conditions of coal seam gas approvals under state and Commonwealth law, together with state water legislation and policies, govern how waste water can be reused and what quality standards it must meet before use.

Where detailed information was unavailable the chemicals could only be assessed at the earliest, most conservative level of testing which was designed to overestimate risk. The chemicals were classed as potentially harmful at this level, but further information and testing would be required to determine the actual level of risk.

Protecting human health and the environment

Industrial chemical use and coal seam gas operations are closely regulated by state, territory and Commonwealth governments, which legally require protective measures to be in place to safeguard human health and the environment.

Legislation, regulations, standards and codes of practice cover the coal seam gas industry including workplace and public health and safety, environmental and water protection, managing and reusing waste water, and the transport, handling, storage and disposal of chemicals. Coal seam gas projects must be assessed and approved under state, territory and Commonwealth environmental laws and may be subject to site-specific conditions including how the companies manage chemical risk.

The risk assessments did not take all these regulatory controls into account.

The Assessment has provided regulators and companies with an additional level of information directly relevant to the coal seam gas industry. This is new knowledge and information that will enable more targeted risk management actions and practices for the safe management of chemicals in coal seam gas operations.

Summary of protections in place

Summary of protections in place: Approving, starting and managing coal seam gas projects

Conditions of approval

When applying for approval for a coal seam gas project, companies must typically:

- disclose the chemicals they plan to use
- assess the potential risks of these chemicals
- demonstrate how they will protect people and the environment from harm.

State regulators or the Commonwealth may set specific conditions of approval to protect health or the environment, including how the companies must manage, monitor and report on chemical risks.

Responding to spills and leaks

If a spill or leak does occur, companies have an enforceable requirement to:

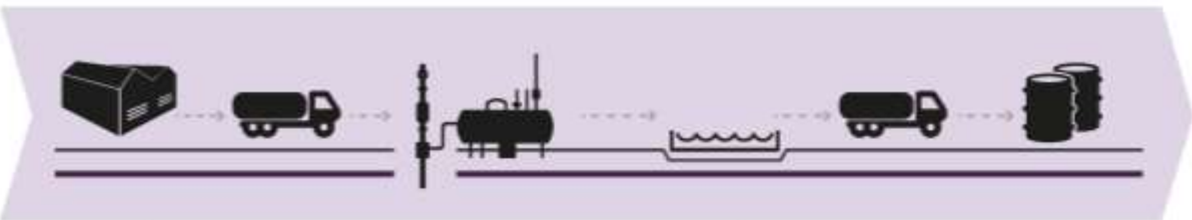
- have emergency response protocols in place that are triggered by an incident
- take immediate action to contain and clean up a spill
- report the spill to relevant authorities such as regulatory bodies, councils, public health officials, emergency services or safe work authorities, so that the spill can be effectively contained, all potentially affected parties are notified, and any necessary further action can be taken to address the spill and reduce the likelihood of such an incident happening in the future.

Preventing harm

Before a coal seam gas project can begin, companies must typically:

- assess the risks of the chemicals they will use, using international best practice methods for assessment
- have comprehensive management plans in place to reduce the chemical risks to an acceptable level specified by the Commonwealth or state regulators
- have their risk assessment and management plans peer reviewed and assessed by governments to ensure they will adequately protect human health and the environment.

The companies' plans and chemical use is subject to ongoing monitoring and regular review to ensure chemicals are being used in a way that minimises the risk of spills or leaks and any harm to people or the environment, occurring. Regular reviews also ensure that new chemicals or practices are included and plans remain current and relevant.



Storing chemicals

Controls on storage of chemicals are set by work health and safety, environment and water legislation at the state and Commonwealth level, as well as industry standards and codes of practice.

Protections include:

- Packaging and labelling requirements, including instructions for the safe storage and handling of the chemical
- Specifications for storage facility design and operation
- Limitations on volumes of chemicals that can be stored or special criteria for storage of larger volumes
- Controls on how chemicals are secured, contained and segregated
- Protocols for responding to spills or leaks
- Duty to protect workers, the public and environment from harm, including safeguarding against spills and leaks

Transporting chemicals

Transport of chemicals is controlled by the Australian Dangerous Goods Code, Commonwealth and state work health and safety legislation, and environment and water legislation.

Protections include:

- Packaging and labelling requirements
- Controls on how chemicals are loaded, stowed, segregated and contained
- Limits on the volumes of chemicals that can be transported
- Vehicle specifications
- Special licensing for drivers and vehicles
- Required safety equipment
- Emergency response protocols
- Duty to protect workers, the public and environment from harm, including safeguarding against crashes and spills

Managing, storing & reusing waste water

How coal seam gas waste water is managed, stored and reused is governed by state law, codes and policy covering water use, public health, environmental protection and coal seam gas industry regulation.

Protections include:

- Site-specific conditions for management, treatment and disposal of waste water
- Controls on how waste water is stored including method of storage and design of ponds, dams or tanks
- Leak detection systems, storage monitoring and leak response protocols
- Treatment requirements and water quality criteria for reused water
- Restrictions on when, where and how waste water can be reused

Handling and using chemicals

How industrial chemicals are handled and used is governed by national and state work health and safety legislation, industry standards and codes of practice, state legislation regulating coal seam gas, and company policy.

Protections include:

- Labelling and Safety Data Sheets that describe potential harm the chemical could cause and instructions for the safe handling, use and disposal of the chemical
- Duty to protect workers, the public and the environment from harm
- Restrictions on use of certain chemicals
- Site-specific work health and safety policies
- Required personal protective equipment such as masks, gloves or glasses
- Engineering, process design or equipment solutions to control risks such as removing chemicals from use, ventilation systems, limiting handling, etc
- Protocol for responding promptly and effectively to incidents and spills

The research and methods established for the Assessment have also led to improved, targeted methods for assessing and managing the risks of chemicals used in coal seam gas operations. A guidance manual based on these improved methods has been peer-reviewed and released as an exposure draft and will be finalised after consultation. The guidance manual will provide a consistent and transparent approach to assessing risks. The guidance manual will provide industry and stakeholders more certainty because assessment requirements will be clear to everybody. Industry will know the standards that will apply and be able to plan early to meet them.

Results table

This table summarises the findings of the Assessment. For each of the 113 chemicals assessed, the table shows whether the chemical is a potential risk to workers, the public or the environment in the absence of all the usual precautions and legal requirements for handling chemicals. If it is a risk, the table also identifies the scenario in which it could cause harm.

		Public health		Coal seam gas workers' health		Environment	
Chemical name	**CAS number[1]**	**Unlikely to cause harm to public**	**Potentially harmful to public health**	**Unlikely to cause harm to workers**	**Potentially harmful to workers health**	**Unlikely to cause harm to environment**	**Potentially harmful to environment**
Acetic acid	64-19-7		In the event of a transport spill		In the event of an industrial accident	✓	
Acetic acid, sodium salt (1:1)	127-09-3	✓		✓		✓	
Alcohols, C6-12, ethoxylated	68439-45-2		In the event of a transport spill or pond leak		In the event of an industrial accident		Limited assessment[2]
Alkanes, C12-26 branched and linear	90622-53-0		In the event of a transport spill	✓		✓	
Amine salt	Confidential Business Information[3]	✓		✓			Limited assessment[2]
Ammonium persulfate	7727-54-0		In the event of a transport spill or pond leak		When mixing and/or cleaning In the event of an industrial accident		In the event of a transport spill
Bentonite	1302-78-9	✓		✓		✓	
Benzisothiazolinone	2634-33-5	✓			In the event of an industrial accident		Limited assessment[2]

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[1] Each chemical is identified by a unique numerical identifier assigned by Chemical Abstracts Service (CAS) to every chemical substance.

2 Where detailed information was unavailable the chemicals could only be assessed at the earliest, most conservative level of testing which was designed to overestimate risk. The chemicals were classed as potentially harmful at this level, but further information and testing would be required to determine the actual level of risk.

3 Confidential Business Information is not disclosed publically but all information was available to the scientists conducting the assessment.

		Public health		Coal seam gas workers' health		Environment	
Chemical name	**CAS number[1]**	**Unlikely to cause harm to public**	**Potentially harmful to public health**	**Unlikely to cause harm to workers**	**Potentially harmful to workers health**	**Unlikely to cause harm to environment**	**Potentially harmful to environment**
Borax	1303-96-4		In the event of a transport spill	✓			When waste water is reused
Boric acid	10043-35-3		In the event of a transport spill	✓			In the event of a transport spill When waste water is reused
Boric acid salt, monoethanolamine	26038-87-9		In the event of a transport spill	✓			When waste water is reused
Bronopol	52-51-7	✓			In the event of an industrial accident When mixing and/or cleaning		Limited assessment[2]
Butoxyethanol	111-76-2		In the event of a transport spill or pond leak		In the event of an industrial accident	✓	
Calcined silica	91053-39-3	✓			When mixing and/or cleaning	✓	
Calcium chloride	10043-52-4	✓		✓		✓	
Carbon dioxide	124-38-9	✓		✓		✓	
Carbonic acid	463-79-6	✓		✓		✓	
Carbonic acid sodium salt (1:1)	144-55-8	✓		✓		✓	
Carbonic acid sodium salt (2:3)	533-96-0	✓		✓		✓	
Caustic soda	1310-73-2	✓			In the event of an industrial accident		In the event of a transport spill
Cellulase	9012-54-8	✓			In the event of an industrial accident	✓	
Cellulose, 2-hydroxyethyl ether	9004-62-0	✓		✓		✓	
Cristobalite	14464-46-1	✓			When mixing and/or cleaning	✓	
D-erythro-Hex-2-enonic acid, γ-lactone, sodium salt (1:1)	6381-77-7	✓		✓			Limited assessment[2]
Deodorised kerosene	64742-47-8		In the event of a transport spill	✓			Limited assessment[2]
Diethylene glycol ethyl ether	111-90-0	✓		✓			Limited assessment[2]

		Public health		Coal seam gas workers' health		Environment	
Chemical name	**CAS number[1]**	**Unlikely to cause harm to public**	**Potentially harmful to public health**	**Unlikely to cause harm to workers**	**Potentially harmful to workers health**	**Unlikely to cause harm to environment**	**Potentially harmful to environment**
Diphosphoric acid, sodium salt (1:2)	7758-16-9	✓		✓			Limited assessment[2]
Enzyme	Confidential Business Information[3]	✓			In the event of an industrial accident	✓	
Ester alcohol	Confidential Business Information[3]		In the event of a transport spill	✓			Limited assessment[2]
Ethanaminium, 2-hydroxy-N,N N-trimethyl-, chloride (1:1)	67-48-1	✓		✓		✓	
Ethanedial	107-22-2	✓		✓		✓	
Ethanol	64-17-5		In the event of a transport spill		In the event of an industrial accident		Limited assessment[2]
Ethanolamine	141-43-5	✓			In the event of an industrial accident		Limited assessment[2]
Ethoxylated fatty acid I	Confidential Business Information[3]		In the event of a transport spill		In the event of an industrial accident		Limited assessment[2]
Ethoxylated fatty acid II	Confidential Business Information[3]	✓		✓			Limited assessment[2]
Ethoxylated fatty acid III	Confidential Business Information[3]		In the event of a transport spill		In the event of an industrial accident		Limited assessment[2]
Ethylene glycol	107-21-1		In the event of a transport spill		In the event of an industrial accident	✓	
2-Ethylhexanol heavies	Confidential Business Information[3]		In the event of a transport spill	✓			Limited assessment[2]
Fatty acids ester	Confidential Business Information[3]		In the event of a transport spill	✓		✓	
Gelatins	9000-70-8	✓		✓		✓	

		Public health		Coal seam gas workers' health		Environment	
Chemical name	CAS number[1]	Unlikely to cause harm to public	Potentially harmful to public health	Unlikely to cause harm to workers	Potentially harmful to workers health	Unlikely to cause harm to environment	Potentially harmful to environment
Glutaraldehyde	111-30-8		In the event of a transport spill		In the event of an industrial accident		In the event of a transport spill
Guar gum	9000-30-0	✓		✓			In the event of a transport spill
Guar gum, carboxymethyl 2-hydroxypropyl ether, sodium salt	68130-15-4	✓		✓		✓	
Hemicellulase	9025-56-3	✓			In the event of an industrial accident	✓	
Hydrochloric acid	7647-01-0	✓			In the event of an industrial accident		In the event of a transport spill
Hydrogen peroxide	7722-84-1		In the event of a transport spill or pond leak		In the event of an industrial accident	✓	
Inner salt of alkyl amines	Confidential Business Information[3]		In the event of a pond leak		In the event of an industrial accident		Limited assessment[2]
Isopropanol	67-63-0		In the event of a transport spill		In the event of an industrial accident		Limited assessment[2]
Lime	1305-78-8	✓			In the event of an industrial accident	✓	
Limestone	1317-65-3	✓		✓		✓	
Magnesium chloride	7786-30-3	✓		✓		✓	
Methanol	67-56-1		In the event of a transport spill or pond leak		When mixing and/or cleaning In the event of an industrial accident	✓	
Methyl isobutyl ketone	108-10-1	✓		✓			Limited assessment[2]
Methylchloroisothiazolinone	26172-55-4		In the event of a transport spill		In the event of an industrial accident		In the event of a transport spill
Methylisothiazolone	2682-20-4		In the event of a transport spill		In the event of an industrial accident		In the event of a transport spill
Natural fibres I	Not specified	✓		✓		✓	
Natural fibres II	Not specified	✓		✓		✓	

		Public health		Coal seam gas workers' health		Environment	
Chemical name	CAS number[1]	Unlikely to cause harm to public	Potentially harmful to public health	Unlikely to cause harm to workers	Potentially harmful to workers health	Unlikely to cause harm to environment	Potentially harmful to environment
Natural fibres III	Confidential Business Information[3]	✓		✓		✓	
Nitric acid, magnesium salt (2:1)	10377-60-3	✓		✓		✓	
Nitrogen	7727-37-9	✓		✓		✓	
Nut hulls	Not specified	✓		✓		✓	
Organic acid salt	Confidential Business Information[3]	✓			In the event of an industrial accident		Limited assessment[2]
Organic sulphate	Confidential Business Information[3]		In the event of a transport spill		In the event of an industrial accident		Limited assessment[2]
Pigment Red 5	6410-41-9	✓		✓			Limited assessment[2]
Polyamine	Confidential Business Information[3]		In the event of a transport spill or pond leak		In the event of an industrial accident When mixing and/or cleaning	✓	
Polyacrylamide / polyacrylate copolymer	Confidential Business Information[3]	✓		✓		✓	
Polyanionic cellulose PAC	Not specified	✓		✓		✓	
Polydimethyldiallyl-ammonium chloride	26062-79-3	✓			In the event of an industrial accident	✓	
Polyesters	Not specified	✓		✓		✓	
Polymer I	Confidential Business Information[3]	✓		✓		✓	
Polymer II	Confidential Business Information[3]	✓		✓			Limited assessment[2]
Polymer with substituted alkylacrylamide salt	Confidential Business		In the event of a transport spill	✓			In the event of a transport spill

		Public health		Coal seam gas workers' health		Environment	
Chemical name	CAS number[1]	Unlikely to cause harm to public	Potentially harmful to public health	Unlikely to cause harm to workers	Potentially harmful to workers health	Unlikely to cause harm to environment	Potentially harmful to environment
	Information[3]						
Polysaccharide	Confidential Business Information[3]	✓		✓		✓	
Potassium carbonate	584-08-7	✓			In the event of an industrial accident	✓	
Potassium chloride	7447-40-7	✓		✓			In the event of a transport spill
Precipitated silica	112926-00-8	✓		✓		✓	
1,2,3-Propanetricarboxylic acid, 2-hydroxy-	77-92-9	✓		✓		✓	
1,2,3-Propanetriol	56-81-5	✓		✓			Limited assessment[2]
2-Propenamide, homopolymer	9003-05-8	✓		✓		✓	
2-Propenoic acid, methyl ester, polymer with 1,1-dichloroethene	25038-72-6	✓		✓		✓	
2-Propenoic acid, polymer with 2-propenamide	9003-06-9	✓		✓		✓	
Quartz	14808-60-7	✓			When mixing and/or cleaning	✓	
Quaternary amine	Confidential Business Information[3]	✓		✓			Limited assessment[2]
Silica	7631-86-9	✓		✓		✓	
Sintered bauxite	144588-68-1		In the event of a pond leak		In the event of an industrial accident	✓	
Slaked lime	1305-62-0	✓			In the event of an industrial accident	✓	
Soda ash	497-19-8	✓			In the event of an industrial accident		In the event of a transport spill
Sodium borate	12008-41-2		In the event of a transport spill or pond leak		In the event of an industrial accident		When waste water is reused

		Public health		Coal seam gas workers' health		Environment	
Chemical name	CAS number[1]	Unlikely to cause harm to public	Potentially harmful to public health	Unlikely to cause harm to workers	Potentially harmful to workers health	Unlikely to cause harm to environment	Potentially harmful to environment
Sodium chloride	7647-14-5	✓		✓			In the event of a transport spill
Sodium chlorite	7758-19-2		In the event of a transport spill or pond leak	✓			Limited assessment
Sodium hypochlorite	7681-52-9		In the event of a transport spill		In the event of an industrial accident When mixing and/or cleaning		Limited assessment[2]
Sodium persulfate	7775-27-1		In the event of a transport spill		In the event of an industrial accident		Limited assessment[2]
Sodium sulphite	7757-83-7		In the event of a transport spill		In the event of an industrial accident		Limited assessment[2]
Sodium thiosulfate	7772-98-7		In the event of a transport spill	✓		✓	
Sulfuric acid ammonium salt (1:2)	7783-20-2	✓		✓			Limited assessment[2]
Sulfuric acid, barium salt (1:1)	7727-43-7	✓		✓		✓	
Sulfuric acid, mono-C6-10-alkyl esters, ammonium salts	68187-17-7		In the event of a transport spill		In the event of an industrial accident		Limited assessment[2]
Sulfuric acid potassium salt (1:2)	7778-80-5	✓		✓			In the event of a transport spill
Sulfuric acid sodium salt (1:2)	7757-82-6	✓		✓			Limited assessment[2]
Talc	14807-96-6	✓		✓		✓	
Terpenes and terpenoids	Confidential Business Information[3]		In the event of a transport spill		In the event of an industrial accident	✓	
Terpenes and terpenoids, sweet orange-oil	68647-72-3		In the event of a transport spill		In the event of an industrial accident		Limited assessment[2]
Tetramethylammonium chloride	75-57-0		In the event of a transport spill or pond leak		In the event of an industrial accident When mixing and/or cleaning		Limited assessment[2]

		Public health		Coal seam gas workers' health		Environment	
Chemical name	**CAS number**[1]	**Unlikely to cause harm to public**	**Potentially harmful to public health**	**Unlikely to cause harm to workers**	**Potentially harmful to workers health**	**Unlikely to cause harm to environment**	**Potentially harmful to environment**
Tetrasodium EDTA	64-02-8	✓			In the event of an industrial accident	✓	
Tetrakis(Hydroxymethyl) Phosphonium Sulphate (THPS)	55566-30-8		In the event of a transport spill or pond leak		When mixing and/or cleaning In the event of an industrial accident		In the event of a transport spill
Tributyltetradecyl phosphonium chloride	81741-28-8		In the event of a transport spill or pond leak		In the event of an industrial accident When mixing and/or cleaning		Limited assessment[2]
Triethanolamine	102-71-6		In the event of a transport spill or pond leak		In the event of an industrial accident	✓	
Tridymite	15468-32-3	✓			When mixing and/or cleaning	✓	
Walnut hulls	Not specified	✓		✓		✓	
Water	7732-18-5	✓		✓		✓	
Wood dust	Not specified	✓		✓		✓	
Wood fibre	Not specified	✓		✓		✓	
Xanthan gum	11138-66-2	✓		✓			In the event of a transport spill

Where can I find out more about the Assessment?

The National assessment of chemicals associated with coal seam gas extraction webpage provides more detailed information about the Assessment, its findings and the measures in place to protect human health and the environment. The full literature reviews and technical reports are also available on this page.

List of Report Titles

This table lists the reports commissioned for the *National assessment of chemicals associated with coal seam gas extraction in Australia*.

	Number	Report Title
Reviewing existing literature	1	Literature review: Summary report (NICNAS, 2017) This review summarises the results of the various literature reviews listed below.
	2	Literature review: Human health Implications (NICNAS, 2017) This report reviews the literature about human health, regulation of chemicals and gas extraction available before 2013.
	3	Literature review: Environmental risks posed by chemicals used in coal seam gas operations (DoEE, 2017) This report reviews the literature about the environment and gas extraction available up until 2013.
	4	Literature review: Hydraulic fracture growth and well integrity (Jeffery et al., 2017) This report reviews the literature about hydraulic fracturing and coal seam gas wells available before 2013.
	5	Literature review: Geogenic contaminants associated with coal seam operations (Apte et al., 2017) This report reviews the literature about naturally occurring chemicals and hydraulic fracturing available before 2013.

<table>
<tr><th></th><th>Number</th><th>Report Title</th></tr>
<tr><td></td><td>6</td><td>Literature review: Identification of potential pathways to shallow groundwater of fluids associated with hydraulic fracturing (Mallants et al., 2017)

This report reviews the literature about leaks, accidents and spills associated with gas extraction available before 2013.</td></tr>
<tr><td>Identifying chemicals</td><td>7</td><td>Identification of chemicals associated with coal seam gas extraction in Australia (NICNAS, 2017)

This report identifies 113 chemicals used in drilling and hydraulic fracturing for coal seam gas in Australia.</td></tr>
<tr><td>Modelling how chemicals could be released during coal seam gas extraction</td><td>8</td><td>Human and environmental exposure conceptualisation: Soil to shallow groundwater pathways (Mallants et al., 2017)

This report describes how chemicals could be released during the coal seam gas extraction process into soil and shallow groundwater.</td></tr>
<tr><td rowspan="3">Modelling how chemicals could be released during coal seam gas extraction

Assessing risks to workers and the public</td><td>9</td><td>Environmental exposure conceptualisation: Surface to surface water pathways (DoEE, 2017)

This report describes how chemicals could be released during coal seam gas extraction processes into the environment and what aquatic plants and animals might be affected.</td></tr>
<tr><td>10</td><td>Human and environmental exposure assessment: Soil to shallow groundwater pathways – A study of predicted environmental concentrations (Mallants et al., 2017)

This report calculates potential concentrations of chemicals in soils and shallow groundwater based on how chemicals could be released during the coal seam gas extraction process.</td></tr>
<tr><td>11</td><td>Chemicals of low concern for human health based on an initial assessment of hazards (NICNAS, 2017)

This report identifies the chemicals used in coal seam gas extraction that are unlikely to cause harm to human health.</td></tr>
</table>

	Number	Report Title
	12	Human health hazards of chemicals associated with coal seam gas extraction in Australia (NICNAS, 2017) Appendix A – Hazard Assessment Sheets (NICNAS, 2017) This report assesses the potential harm that the chemicals used in coal seam gas extraction may cause.
	13	Human health risks associated with surface handling of chemicals used in coal seam gas extraction (NICNAS, 2017) Appendix D – Human health chemical risk assessment sheets (NICNAS, 2017) This report assesses whether chemicals could be harmful to workers or the public in scenarios specific to coal seam gas extraction in Australia.
Assessing risks to the environment	14	Environmental risks associated with surface handling of chemicals used in coal seam gas extraction (DoEE, 2017) Appendices A, B, C, D, F, and G (DoEE, 2017) Appendix E (DoEE, 2017) This report assesses whether chemicals could be harmful to the environment in scenarios specific to coal seam gas extraction in Australia.

Additional supporting research

Deeper groundwater hazard screening for chemicals used in coal seam gas extraction

The Department of the Environment and Energy commissioned CSIRO to conduct further research on how chemicals used in coal seam gas extraction might move from deeper groundwater to other parts of the environment, how long this movement might take, and what the concentrations of chemicals might be at receiving environments such as water bores and streams. The research found that chemicals remaining underground after hydraulic fracturing are unlikely to reach people or ecosystems in concentrations that would cause concern. This conclusion is based on natural dilution and degradation that reduce concentrations to negligible levels. Risks are therefore likely to be very low.

The research developed methods that can be used on a project-by-project basis to assess risks to human health and the environment from chemicals remaining deep underground as a result of hydraulic fracturing in coal seam gas operations. It did not assess the risks associated with any existing or proposed coal seam gas project. The results of this research are available on the Department's website.

Risk Assessment Guidance Manual: for chemicals associated with coal seam gas extraction – Exposure draft

The Department is also developing a chemical risk assessment guidance manual based on the improved methods from the Assessment. This has been peer-reviewed and released as an exposure draft and will be finalised after consultation. The guidance manual will provide a consistent and transparent approach to assessing risks associated with these chemicals.

WHAT DOES FRACKING FLUID CONTAIN?

More than 95% sand and water

Less than 5% other chemicals

CHEMICALS USED IN HYDRAULIC FRACTURING	OTHER COMMON USES
PROPPANTS (eg sand, silica and quartz) Keeps the fracture open to allow gas and water to flow more freely	High purity silica sands for glass-making and metallurgical uses
MICROBIAL CONTROLS (eg tetrakis (hydroxymethyl) phosphonium sulphate)) Helps stop the growth of organisms which could contaminate the coal seam gas and the fracturing fluid	Household bleach, stain remover and disinfectant
BUFFERS, STABILISERS, SOLVENTS ETC (eg 2-Butoxyethanol) Helps bond the chemicals and maintain the stability of the fracturing fluid	Solvent, vinegar, medicinal uses
CLAY MANAGEMENT (eg Sodium Chloride) Minimises clay swelling in the vicinity of the well and in the underground formation	Salt-chemical-based dehumidifiers in domestic and other environments to absorb dampness/moisture from the air
GELLING AGENTS AND BINDERS (eg bentonite, polymers, guar gum) Thicken the fracturing fluid to allow more sand to be carried into the fractures	Pet litter, groundwater barrier, drilling mud
BREAKERS, SURFACTANTS, FRICTION REDUCERS (eg Ammonium Persulfate) Assists in breaking down the chemical bonds and surface tension in the gel, allowing the chemicals to be pumped back out as a fluid	Bleach, etching zinc, soil conditioner, surface cleaners, personal care products, medicines
pH CONTROLLERS (eg acetic acid) Adjusts the pH of the hydraulic fracturing fluid to maximise the effectiveness of other additives	Manufacture of pulp, paper, textiles, soaps and detergents
MINERAL DISSOLUTION AGENTS (eg hydrochloric acid, acetic acid) Helps dissolve minerals and initiate cracks in the rock	Household cleaning, descaling, food production
FOAMING AGENTS (eg 2-Butoxyethanol) Helps carry the proppant and minimise water use	Laundry detergents and household cleaning products
CORROSION INHIBITORS (eg Ethylene Glycol) Prevents pipe corrosion	Plywood, paint, confectionary, cleaning products and camping stoves

While these chemicals are used in other industries, they are not used in the same quantity or concentration. Risks are managed according to the potential hazard and exposure in each industry.

Australian Government
Department of the Environment and Energy

Regulations and Practices to keep People and the Environment Safe: Chemicals used in Coal Seam Gas

Case Study: Ammonium Persulfate

Coal seam gas extraction is regulated by state and Commonwealth governments, which require protective measures to be in place to safeguard health and the environment. While the requirements vary from jurisdiction to jurisdiction, this regulatory framework applies to all aspects of the industry, including the handling and use of chemicals.

The National Assessment of Chemicals Associated with **Coal Seam Gas Extraction in Australia** (the Assessment) found that, in the absence of safety precautions required by law, some chemicals could be a risk to:

- workers in the event of an industrial accident or through short or long-term handling when mixing or cleaning
- the public through a large-scale transport spill or a long-term leak from a storage pond
- the environment through a large-scale transport accident or when waste water is reused.

The **deeper groundwater hazard screening** research found that chemicals remaining underground after hydraulic fracturing are unlikely to reach people or ecosystems in concentrations that would cause concern. This conclusion is based on natural attenuation processes that reduce concentrations (by chemicals being diluted ('watered down') or naturally degraded ('broken down') to negligible levels. Risks are therefore likely to be very low.

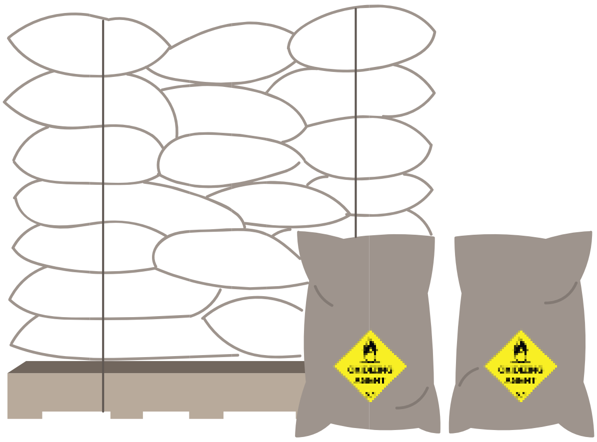
Here, we use the example of one of the chemicals from the Assessment – ammonium persulfate – to illustrate how regulations and industry practices keep people and the environment safe. Ammonium persulfate was found to be potentially harmful, in the absence of safety precautions required by law, in all of the assessed scenarios except the reuse of waste water.

What is ammonium persulfate?

Ammonium persulfate is a white powder that is highly soluble in water. It is a strong oxidising agent, which means that it can speed up the development of a fire and make it burn more intensely. Ammonium persulfate can cause skin and respiratory allergies, irritate the skin and eyes and can be harmful if swallowed or inhaled. It is mainly used outside of the coal seam gas industry, e.g. to etch circuit boards, in making polymers, and in some bleaching products used by hairdressers.

"Breakers" such as ammonium persulfate are used in the coal seam gas industry to dissolve hydraulic fracturing gels so the fracturing chemicals can be pumped back up the well.

— *The Australian Inventory of Chemical Substances*



Industrial chemicals may only be imported or manufactured if they are listed on the Australian Inventory of Chemical Substances (AICS) and satisfy any conditions of use shown on the AICS listing. For a chemical not on AICS, the

National Industrial Chemicals Notification and Assessment Scheme (NICNAS) must assess risks to the environment and human health before adding a chemical to AICS or modifying its listed conditions of use. There are some exemptions to this requirement but they are unlikely to apply to chemicals used in coal seam gas extraction.

Ammonium persulfate (CAS RN: 7727-54-0) was listed in the ACIS as an industrial chemical when it was originally compiled. This means it can be manufactured, imported and used for any industrial purpose in Australia.

NICNAS was established by the *Industrial Chemicals (Notification and Assessment) Act 1989* to assess the risks of industrial chemicals to health and the environment and make recommendations to promote their safe use. NICNAS has assessed ammonium persulfate as a **Priority Existing Chemical** for use in the hairdressing industry and at **Tier 2** in the Inventory Multi-tiered Assessment and Prioritisation (IMAP) framework. The IMAP Tier 2 assessment found that 'current risk management measures are considered adequate to protect public and workers' health and safety, provided that all requirements are met under workplace health and safety, and poisons legislation as adopted by the relevant state or territory'. Neither of the NICNAS assessments considered the use of ammonium persulfate in coal seam gas extraction – this use was considered in the National Assessment.

Protecting against transport spills

State and Federal guidelines set out the way in which a given chemical can be transported or stored. Ammonium persulfate is classified as a dangerous good under the *Australian Dangerous Goods Code (ADG Code) for Transport by Road and Rail.* The ADG Code is given legal force by the *Transport Operations (Road Use Management)*

Act 1995 in Queensland and the *Dangerous Goods*

(Road and Rail Transport) Act 2008 and *Dangerous Goods (Road and Rail* Transport) *Regulation 2014* in NSW.

Under the ADG Code, drivers responsible for moving large quantities of ammonium persulfate must hold a dangerous goods driver's licence. Licences are only granted to people who have completed appropriate training and have an acceptable criminal and traffic history. Vehicles used to transport large quantities of ammonium persulfate must have a dangerous goods vehicle licence. Because ammonium persulfate is an oxidising agent, there are also regulations about what else may be carried on a vehicle loaded with it, the warning symbols to be displayed on the outside of the vehicle, and packaging.

Companies transporting ammonium persulfate must use the Signal Word "Danger" and display the pictograms:

— (GHS03 Flame over Circle)

and;

— (GHS08 Health Hazard).

Companies transporting ammonium persulfate must ensure the packaging and vehicle are marked to signal the dangerous good hazard.

This includes pictograms on the vehicle and marking of the package.

The packaging, storage and transport requirements are outlined in the Safety Data Sheet (SDS) provided by the manufacturer or supplier of the ammonium persulfate. These include precautions such as:

- using specially constructed containers
- keeping containers tightly closed in a dry, cool and well-ventilated place
- protecting the chemical from moisture, keeping away from open flames, hot surfaces and sources of ignition
- keeping ammonium persulfate away from flammable and combustible materials.
- keeping it away from direct sunlight and not storing with strong acids and bases.

Companies involved in coal seam gas extraction also have a general environmental duty of care under the *Environmental Protection Act 1994 (Qld)* and *the Protection of the Environment Operations Act 1997 (NSW).* These laws require companies to take precautions to prevent spills and leaks of chemicals that may harm the environment. In both NSW and Queensland there are specific offences relating to wilfully or negligently releasing a contaminant that harms, or is likely to harm, the environment. There are also requirements to report potentially harmful leaks and spills to state authorities who investigate emergency incidents 24 hours a day, 7 days a week.

Coal seam gas companies respond to these requirements with measures such as internal journey management systems that include expectations that transport workers will read and carry SDS sheets for all hazardous chemicals being transported. Companies also undertake vehicle checks, route planning, timing and tracking of vehicles, and monitoring of drivers for fatigue and speed with systems that can track vehicle movements in real time using GPS. Companies also use emergency response plans and emergency contacts.

Protecting against leaks from storage ponds

Ponds are often used to store water produced during hydraulic fracturing that may contain naturally-occurring salts and minerals or trace quantities of industrial additives such as ammonium persulfate. Ponds must be constructed to minimise the risk that stored water poses to human health and the environment. Specific regulatory requirements apply to the management and storage of water produced during hydraulic fracturing. These regulations vary from state to state and cover the design, approval, construction, operation, and decommissioning of coal seam gas related storage ponds. If the extraction of coal seam gas is likely to have a significant impact on a matter of national environmental significance (which, for coal seam gas projects, includes water resources), the project is required by *Environment Protection Biodiversity Conservation Act 1999* (the EPBC Act) to be referred to the Commonwealth Minister for the Environment and Energy for assessment and approval. As part of an approval under the EPBC Act, the Minister for the Environment and Energy may attach conditions to ensure any impact on protected matters, including water resources for coal seam gas projects and any water resource potentially impacted by the project, are acceptable.

In Queensland, the design of storage ponds must take into account legislative requirements under the *Environmental Protection Act 1994* (Qld), information in guidelines (such as "Structures which are dams or levees constructed as part of environmentally relevant activities (EM634)" and manuals including Manual for Assessing Hazard Consequence and Hydraulic Performance of Structures [EM635]).

In NSW, the requirements are similar and the NSW Dam Safety Committee reviews all design and construction certification reports along with the NSW Government's other regulating bodies. All chemicals used during drilling for exploration activities are required to be listed and the impact to the environment from their use assessed as part of the activity approval process. The Division of Resources and Geoscience assesses this, in accordance with Part 5 Environmental Planning and Assessment Act 1979

In addition, the NSW Code of Practice for Coal Seam Gas Fracture Stimulation also provides requirements for chemicals used during these types of processes.

Suitably qualified and experienced designers must approve and oversee the construction of storage ponds. In Queensland, the construction is typically certified by a Registered Professional Engineer of Queensland. Geotechnical investigation, design, construction and certification of the completed structure are subject to regulatory oversight and must meet specified standards. Ponds that hold water returned from wells that have been hydraulically fractured must be designed with a floor and sides of material that will ensure the contents are kept within the bounds of the containment system during the pond's operational life, and in some cases, a double lining system may be used. Ponds are often required to have a system for detecting leaks through either the floor or sides of the dam, and this further reduces the risk that leaks will affect soil or groundwater.

Coal seam gas companies respond to these requirements with measures such as: • leak detection

- groundwater monitoring of multiple parameters
- seepage monitoring of potential contaminants to groundwater
- annual inspections and reporting (required for regulated ponds).

Protecting workers

Ammonium persulfate can harm workers if they breathe air with ammonium persulfate dust in it, if it gets on their skin or in their eyes, or if they swallow it. Work, health and safety laws require companies to make sure measures are in place to stop any of these things happening. The measures required will depend on a number of conditions including the conditions at the site, handling methods used and how a worker may be exposed. The SDS, required under Commonwealth and state government workplace health and safety legislation, lists the protective measures that may be required (depending on site conditions). These may include ventilation that ensures the concentration of ammonium persulfate in the air stays as low as reasonably practicable and below the workplace exposure standard of 0.1 mg/ m^3 (peak limitation); wearing overalls, chemical goggles, safety shoes, and impervious gloves when handling the chemical; and adequate training for workers. Respiratory protection may also be needed depending on the levels in air in the workplace.

Ammonium persulfate has been classified by Safe Work Australia as a hazardous substance with the following classification: •
Acute toxicity – category 4

- Eye irritation – category 2A
- Specific target organ toxicity (single exposure) – category 3
- Skin irritation – category 2
- Respiratory sensitisation – category 1
- Skin sensitisation – category 1
- Oxidising solid – category 3.

Danger

Businesses have specific duties under Work, Health and Safety regulations to manage the risks to health and safety associated with using, handling, generating and storing hazardous chemicals at a workplace. For more details see the **Safe Work Australia's** website.

For more information on *The National Assessment of Chemicals Associated with Coal Seam Gas Extraction in Australia* visit **http://www.**

environment.gov.au/water/coal-and-coal-seamgas/national-assessment-chemicals

Australian Government

Department of the Environment and Energy

Overview: Deeper groundwater hazard screening for chemicals used in coal seam gas extraction

In summary, the deeper groundwater hazard screening research found that chemicals remaining underground after hydraulic fracturing are unlikely to reach people or groundwater dependent terrestrial ecosystems in concentrations that would cause concern. Risks are therefore likely to be very low. Risks from naturally-occurring chemicals in the coal seam mobilised by hydraulic fracturing are likely to be very low for the same reasons. Note that strict regulatory controls apply to the handling and use of chemicals in coal seam gas extraction.

This research complements the *National assessment of chemicals associated with coal seam gas extraction*, which focussed on risks to human health and the environment from surface handling of chemicals used in coal seam gas extraction.

The research developed methods that can be used on a project-by-project basis to assess risks to human health and the environment from chemicals remaining deep underground as a result of hydraulic fracturing in coal seam gas operations. It did not assess the risks associated with any existing or proposed coal seam gas project, which are considered as part of the State and Federal government approval processes.

The movement of chemicals underground depends on the local geology and the properties of the chemicals. The project therefore used two case study areas, one in the Surat Basin and one in the Gunnedah Basin, to develop the methods. It used information about the chemical and physical properties of 13 chemicals chosen because they represent the range of chemicals used in coal seam gas extraction. Whenever the method made assumptions, care was taken they were always conservative (that is, likely to overestimate rather than underestimate risk factors) so that risks would not be underestimated.

Chemicals in deeper groundwater

Hydraulic fracturing leaves a fraction of the chemicals injected deep underground, and can cause chemicals that occur naturally in the coal seam to move through the underground environment.

This research identified four potential pathways for chemicals to move from a hydraulic fracturing site to places where people or ecosystems might come into contact with them. The project found that all four pathways are either unlikely or extremely unlikely to exist in the study areas, which have similar geology to other areas where coal seam gas extraction is taking place or proposed in Australia.

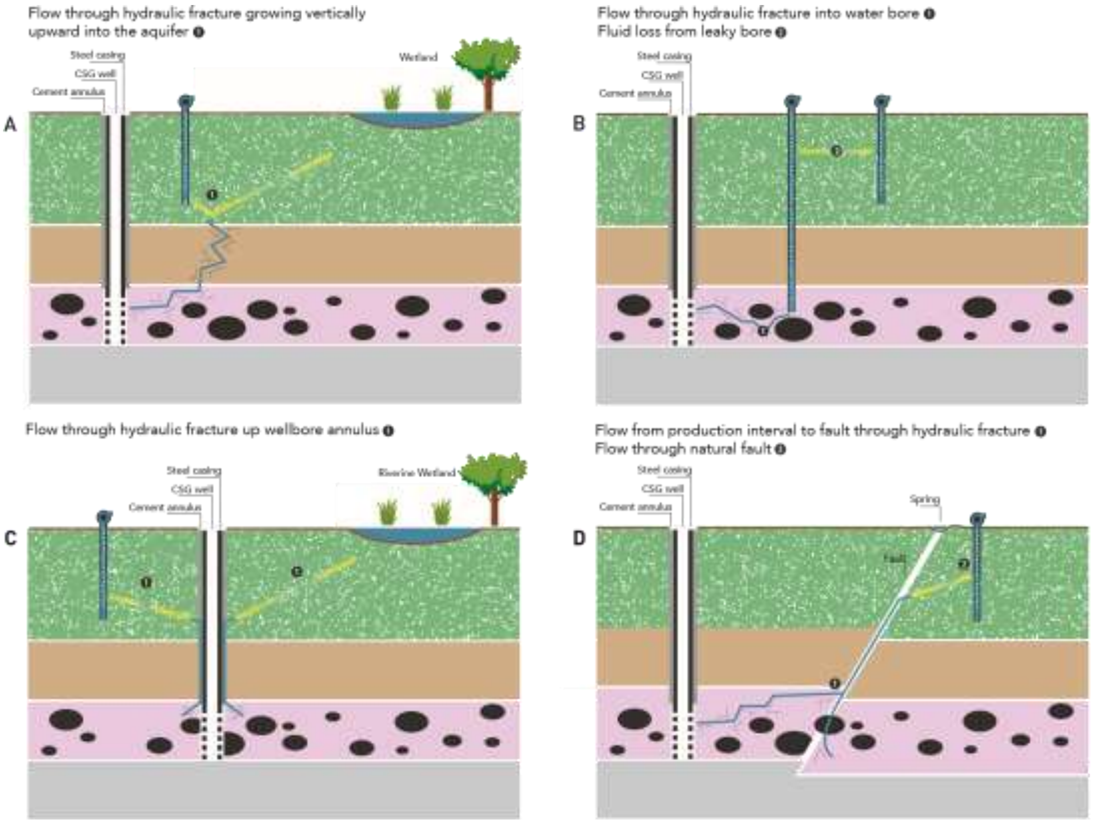
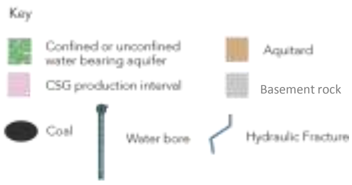


Figure 1: Plausible pathways for chemicals in Deeper Groundwater[1]. First, a fracture might spread from the coal seam targeted by hydraulic fracturing to an aquifer used by people or the environment (pathway A). The second pathway requires a rupture in the casing of the CSG well to result in hydraulic fracturing fluid being injected into an aquifer (pathway C). The other pathways involve chemicals travelling along the targeted coal seam until they encounter either a water bore (pathway B) or a fault leading to an aquifer (pathway D).

[1] Based on Figure 2-31 from deeper groundwater report



Chemicals become less concentrated as they move underground

Where a chemical requires more detailed assessment it will often be useful to calculate how much of it people or ecosystems might come into contact with. This research developed a method to do this.

This method involves calculating how far a chemical must travel to reach a place where people or ecosystems might come into contact with it, how long it will take to get there, and how much its concentration will be reduced when it arrives. The longer a chemical takes to reach a place where people or ecosystems might come into contact with it and the further it has to travel, the more its concentration will be reduced. For most locations investigated, chemicals would not reach people or ecosystems in detectable concentrations.

How long will it take for the chemical to reach a place where people and ecosystems might come into contact with it?

The project used a groundwater model to calculate how fast a chemical could travel along the pathways that might link it to places where people and ecosystems might come into contact with it. The project found that chemicals tend to move extremely slowly underground. In most cases the chemicals would take decades or centuries to reach a place where people and ecosystems might come into contact with it; by this time they are unlikely to do harm.

The time taken to reach a given location depends on the local geology and the properties of the chemical. The properties of the chemical are important because some chemicals ‘stick’ more strongly to surfaces and therefore move more slowly. Most organic chemicals will partially or completely degrade (break down) prior to reaching people or ecosystems.

How far does the chemical need to travel to reach a place where people and ecosystems might come into contact with it?

In each study area, the research identified coal seam gas wells and water-dependent assets such as water bores, surface water features, and vegetation. The project then calculated the distances between each well and each asset. This gave an indication, based on a straight distance, of how far a chemical would need to travel in order to reach an asset. For example, in the Surat Basin there were twenty groundwater bores within 500 metres of a CSG well; all these bores were used to water stock.

How much will the concentration of the chemical be reduced?

The concentration of a chemical can be reduced by dilution ('watered down') or degradation ('broken down').

All chemicals moving though deeper groundwater are diluted. The degree of dilution depends on the volume of hydraulic fracturing fluid injected and how far the chemical travels. The research found that dilution alone reduces the concentration of chemicals that travel 500 metres by a factor of about a thousand (when one million litres of fracturing fluid is injected). Dilution is greater for travel over longer distances.

Organic chemicals are degraded (broken down) by chemical reactions and biological processes. The degree of degradation depends on the chemical, the conditions underground, and how long it takes to reach the location of interest. The conditions underground are important because many chemicals break down faster when temperatures are higher or oxygen is present. Some micro-organisms, which may be found underground, can also speed up the breakdown of some chemicals.

The research calculated how fast sample chemicals break down under the range of conditions found at the study sites. It found that degradation reduces the concentration of many chemicals close to zero over relatively short travel distances. Other chemicals – mostly inorganics – do not degrade at all.

The combined effect of dilution and degradation reduces the concentration of chemicals that travel 500 metres by factors ranging from a thousand (for slowly degrading chemicals) to ten billion (for quickly degrading chemicals). The smaller values are for chemicals that do not degrade. The larger values are for chemicals that degrade quickly and travel through environments conducive to degradation.

Using this research to improve risk assessments

The methods developed in this research can be used to estimate the concentration of a chemical when it reaches a water-dependent asset, such as a water bore or a groundwater-dependent ecosystem. These *predicted environmental concentrations* can be used to assess risks to human health and/or the environment. See the box for an example. More details about assessing risks of chemicals used in coal seam gas extraction can be found in the risk assessment guidance manual.

Dilution alone might reduce the concentration of chemicals reaching places where people and the environment may come into contact with them to an acceptable level. When dilution over short distances is considered, differences in regional geology do not make much difference to how much chemicals are diluted as they travel underground. This means risk assessments over short distances can use the information from the deeper groundwater hazard screening research without any further modelling.

If risk assessments also wish to include degradation for calculating concentrations, differences in regional geology can make a difference to how fast chemicals degrade, so it may be necessary to do some modelling using the approaches set out in the deeper groundwater hazard screening research.

Using the research to calculate predicted environmental concentrations: an example

Suppose a CSG well was hydraulically fractured using one million litres of a fluid containing 525 milligrams per litre of acetic acid and 2600 milligrams per litre of guar gum. There is unlikely to be a pathway for the chemicals to move from the well site to a place where people or ecosystems might come into contact with them. But supposing there was a pathway, would the concentrations of acetic acid and guar gum at a site 1000 metres from the well be a risk to aquatic ecosystems?

Dilution alone would reduce the concentration of acetic acid to 0.2 milligrams a litre. This is well below the concentration of 15 milligrams a litre that has been found to have no effect on aquatic ecosystems. There is no need to consider degradation, which would reduce concentrations further. Note that the chemical would be further diluted if it entered a stream, wetland or other water body.

Dilution alone would reduce the concentration of guar gum to 1 milligram a litre. This is higher than the concentration of 0.22 milligrams a litre that has been found to have no effect on aquatic ecosystems. However, if we take degradation into account (based on an estimation of the time typically taken for a chemical to be carried 1000 metres) the concentration of guar gum falls to 0.001 milligrams a litre. This result holds in the two case study regions. Because local geology can affect degradation, additional modelling might be needed in other regions. Note that the chemical would be further diluted if it entered a stream, wetland or other water body.

The methods developed in this research can be also be used to calculate:

- the maximum concentration of a chemical in hydraulic fracturing fluid that will be reduced to an acceptable concentration at a given distance from the well, and
- the minimum distance between a hydraulically fractured well and a water body, water bore or groundwater-dependent ecosystem needed to reduce a given concentration of a chemical to an acceptable level.