Evaluating the environmental impacts of fracking in New Zealand:

An interim report

November 2012

Parliamentary Commissioner for the Environment
Te Kaitiaki Taiao a Te Whare Pāremata

Acknowledgements

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Photography

Cover: Coal seam gas fracking in Ohai, Southland.
Photo courtesy of Dr Murry Cave.

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Commissioner's overview

If someone had said eighteen months ago, that I would be releasing a report on fracking, I would have looked at them in puzzlement. How quickly things change. It was from March last year that the word fracking started to appear in the New Zealand media, and the international media were not much further ahead. Then in March this year I announced that I would investigate fracking, in response to requests from MPs from both sides of the House, from councils, and from members of the public.

The term 'fracking' is a contraction of 'hydraulic fracturing' – injecting fluid containing sand and chemicals at high pressure to fracture rock. Injecting chemicals into the ground to crack the earth far below our feet seems to be a case of human hubris – that ancient Greek word denoting extreme arrogance and lack of humility – and for many, it just feels wrong. New Zealand is just one country where the concern about the technology has grown very rapidly.

The purpose of fracking is to extract previously inaccessible oil and gas from the earth's crust. The reality is that the world is not 'running out' of oil and gas. Rather a number of new technologies are being used, or considered for use, around the world to supplement conventional drilling. In New Zealand fracking is one of these new technologies, deep sea oil drilling is another, and the conversion of coal into liquid fuels another.

In the course of this investigation, I visited Taranaki where fracking has been used for 23 years, and Gisborne and Hawkes Bay – two regions where exploration for oil and gas may lead to widespread use of fracking. On these visits it was evident that concerns about fracking are not limited to threats it poses to the environment. Some concerns are economic, such as the revenue from royalties all flowing to central government and not shared with the regions. Ownership of oil and gas by iwi has been an issue since the nationalisation of mineral resources prior to World War II. And the company executive who reportedly stated that the North Island east coast could become the Texas of the South clearly did not realise that a vision of green pastoral landscapes dotted with wellheads was unlikely to gladden the hearts of many New Zealanders.

The high-level conclusion from the work done to date in this investigation echoes, and is broadly consistent with, the reviews of fracking that have been done elsewhere in the world. That conclusion is that the environmental risks associated with fracking can be managed effectively provided, to quote the United Kingdom Royal Society, "*operational best practices are implemented and enforced through regulation*". But at this stage I cannot be confident that operational best practices are actually being implemented and enforced in this country.

Therefore, the investigation will now enter a second phase that will turn the spotlight on how well the environmental risks associated with fracking are actually regulated and monitored. Consequently this report is being released as an interim report, and as such contains seven interim findings, rather than the usual formal recommendations.

These interim findings are of two kinds. The first four are focused on aspects of oil and gas production that are key to protecting the environment. They are:

- Choosing where to drill.
- Designing and constructing the well.
- Avoiding spills and leaks on the surface.
- Disposing of waste.

Any one of these four managed poorly could lead to contaminants finding their way into groundwater. The potential for important aquifers to be contaminated as a result of fracking is very real. While there is much concern about the chemicals in fracking fluid, the salty water that comes from deep under the ground along with the oil and gas is much greater in volume, and could also contaminate groundwater.

Likewise, when it comes to another major concern, the potential for triggering earthquakes, the same aspects of the process are critical. The process of fracking itself only causes very tiny earthquakes. But if liquids (fracking fluid or wastewater) were to find their way into an already stressed fault, the fault might slip triggering a more significant (though probably small) earthquake.

I have made three interim findings about government oversight and regulation.

The first of these is that the system is complex and fragmented, making oversight extremely important. Unravelling the labyrinthine roles of different central government agencies, and the relevant responsibilities of regional and local government, has been a major exercise in itself. Such complexity works against open transparent government, and important issues can fall between the cracks, no pun intended.

The second is that regulation may not be fit-for-purpose – companies are perhaps being trusted rather too much to all do 'the right thing'. This applies to protecting health and safety as well as the environment, and is an area currently under review by the Government.

The third is that a 'social licence' for fracking has yet to be earned; for example, communication and engagement with local communities has been mixed. Indeed, as this report was going to print, I encountered the headline "*Oil firm to explain illegal flaring*" which is a good illustration of why local communities continue to be skeptical. New Zealand is no different to a number of other countries in this regard. During this investigation it has been a challenge to keep up with the reports on fracking that are being written by and for governments in other countries.

Almost all the fracking operations in New Zealand so far have taken place in Taranaki. But oil and gas exploration permits that cover vast areas of the country have been granted to a number of companies. Generalising from the Taranaki experience so far is of limited value.

If, for instance, exploration drilling on the east coast of the North Island reveals the presence of commercial quantities of oil that can be recovered through fracking, an 'oil rush' would likely follow - many exploration wells could be drilled in a very short time with production not far behind. Such rapid scaling up has led to well-publicised problems in other countries. In an article titled 'Gas goes boom' in June this year, The Economist reported that *"the pace of change has taken many people by surprise."*

The current Government is hoping for and encouraging an economic future built largely on oil and gas. The question is whether the same effort is being put into preparing for the impacts it may have. The scale and speed of change that could occur requires forethought now. We need to prepare for a future that might take us by surprise. New Zealand has its own geology and its own systems for oversight and regulation. But we can and must learn from other countries about what can go wrong.

The big environmental issue that sits behind fracking is climate change.

Natural gas is the most benign of the fossil fuels; it burns cleanly and provides more energy for each molecule of carbon dioxide emitted than any other fossil fuel. The fall in greenhouse gas emissions in the United States over recent years is in part due to cheap gas obtained through fracking replacing coal.

Consequently, some see fracking as helping slow climate change because it allows coal to be phased out and can act as a 'transition' fuel to a low-carbon future. Others argue that huge amounts of gas (and oil to a lesser extent) will continue to lock the world into a fossil fuel future and crowd out investment in alternative sources of energy. This dilemma is examined in this report, but no conclusions either way can be drawn.

There have been calls for a moratorium to be placed on fracking in New Zealand, but I do not think this is justified at present.

Fracking is a complex process and there are many many details that could be put into a report. But with all reports that come from my office, we strive to be clear and concise, as well as accurate. I hope that this report will be a helpful contribution to the public debate.

J. C. Wright

Dr Jan Wright
Parliamentary Commissioner for the Environment

1

Introduction

"… so great is the supply of [bitumen in Babylonia] that it not only suffices for their buildings, which are numerous and large, but the common people … burn it in place of wood. And countless as is the multitude of men who draw it out, the amount remains undiminished, as if derived from some immense source."[1]

– Diodorus Siculus, Bibliotheca historica, c.a. 30 BC

The use of oil and gas is as old as civilisation itself.

Five thousand years ago bitumen seeped from the banks of the Euphrates River on the Arabian Peninsula. The Sumerians and Babylonians used it as mortar in buildings and as pitch for waterproofing boats.[2] It was also exported to Ancient Egypt for the embalming of the dead – the word 'mummy' is derived from the Persian word 'mummeia', which literally means pitch or bitumen.[3]

In many places natural gas seeps out of the earth. The ancient Greek Oracle of Delphi may have derived her wisdom from such a gas seep.[4] It is said on the slopes of Mt Parnassus a goat herdsman noticed his animals behaving strangely near a chasm. When the herdsman approached the goats he felt his mind altered.[5] A temple was soon built around the gas leak and a young woman assigned to inhale from the seep and interpret the future.

The Chinese developed oil and gas wells as early as 300 AD using drill bits attached to bamboo poles.[6] The oil was used to boil brine and produce salt, while gas was used for lighting and heating.[7]

Oil, natural gas, and coal are called 'fossil fuels' because they originate from plants and animals that lived millions of years ago. When these plants and animals died they were buried by layers of sediment. As they sank deeper into the earth, they were squeezed under pressure and 'cooked' by heat, slowly being transformed into hydrocarbons – fossil fuels. The combination of ingredients, pressure, and temperature created different results – sometimes oil and sometimes coal, with gas formed in association with both.

Most of the oil and gas we currently use comes from 'conventional' sources such as the vast oil reserves of the Middle East and New Zealand's own Maui gas field. Conventional oil and gas is easy to access – it involves drilling a well down into an underground reservoir and piping up the oil and gas.

Reserves of conventional oil and gas are decreasing, and new techniques are being used to push the boundaries of what is possible in accessing 'unconventional' sources of these fuels. Oil and gas is now obtained in ways which previously have not been thought physically possible or economically viable – from mining Canadian tar sands to drilling wells in the deep sea. Hydraulic fracturing (or fracking) – cracking rocks to allow previously inaccessible oil and gas to flow – falls into the 'unconventional' category.

Concerns about fracking have risen rapidly in a number of countries. These concerns include potential contamination of groundwater, the risk of inducing earthquakes, the use of chemicals in the process, air pollution, and greenhouse gas emissions.

Calls for greater scrutiny of the process in the United Kingdom led to a review of shale gas fracking by the Royal Society of London.[8] And in August 2012 the Executive Director of the International Energy Agency (IEA) was reported as saying that the industry's 'just-trust-me approach is fuelling public skepticism'.[9]

Fracking has been used for about 20 years in Taranaki, and within New Zealand there have also been calls for the practice to be halted, at least until the impacts are better understood. The Government is encouraging oil and gas exploration, and it seems highly likely that onshore oil and gas activity will expand beyond Taranaki.[10]

Oil and gas is now obtained in ways that were once thought impossible

An unpublished report prepared by Geological and Nuclear Sciences in March 2012 for the Taranaki Regional Council concluded that *"To effectively regulate hydraulic fracturing operations, government (at all levels) must develop regulations that will adequately protect groundwater and the environment in general."*[11]

A poll conducted in June 2012 showed that nearly 70% of New Zealanders support or cautiously support an expansion of the oil and gas industry. In response to the poll result, Prime Minister John Key stated:

> *"New Zealanders, mostly, understand that while we owe it to future generations to do everything we can to protect our environment, we must also do all we can to leave them with a robust and sustainable economy where they can expect a good job and a good standard of living."*[12]

1.1 The purpose of this report

The Parliamentary Commissioner for the Environment is an independent Officer of Parliament, with functions and powers granted by the Environment Act 1986. Her role allows a unique opportunity to provide Members of Parliament with independent advice in their consideration of matters that may have impacts on the quality of the environment.

The Commissioner received many requests to undertake an investigation into fracking. The purpose is two-fold – first, to assess the environmental risks with fracking, and second to assess whether the policies, laws, regulations and institutions in this country are adequate for managing these risks.

It has not been possible in the time available to adequately investigate just how well these risks are actually managed in New Zealand. Consequently, this is an *interim report* and contains interim findings rather than the usual formal recommendations.

For instance, it is clear that the integrity of the casing of a well is of great importance, but how well the current system ensures that well casings meet 'best practice' requires more investigation. Therefore, this investigation will now move into a second phase with a final report planned for release in the first half of next year.

This report has been produced pursuant to s16 of the Environment Act 1986.

Box 1.1: What are oil and gas?

Crude oil is a mixture of hydrocarbon liquids. Some are light and free-flowing like those used to make petrol, and others are heavy and sticky, like bitumen.[13] Crude oil is refined by heating and evaporating the components off one by one. The lighter components form the basis of petrol; heavier components form the basis of jet fuel and diesel.[14]

Natural gas is a mixture of gases. Methane is the lightest and the most prolific of these gases. Indeed, 'methane' and 'natural gas' are often used interchangeably. Two heavier hydrocarbon gases – propane and butane – are often separated from the natural gas, and then blended and compressed to make liquefied petroleum gas (LPG).[15]

Wells generally produce crude oil and natural gas, but mostly one or the other.[16] An in-between form of oil and gas called condensate is produced when some gases condense to liquid form when they are brought to the surface.[17]

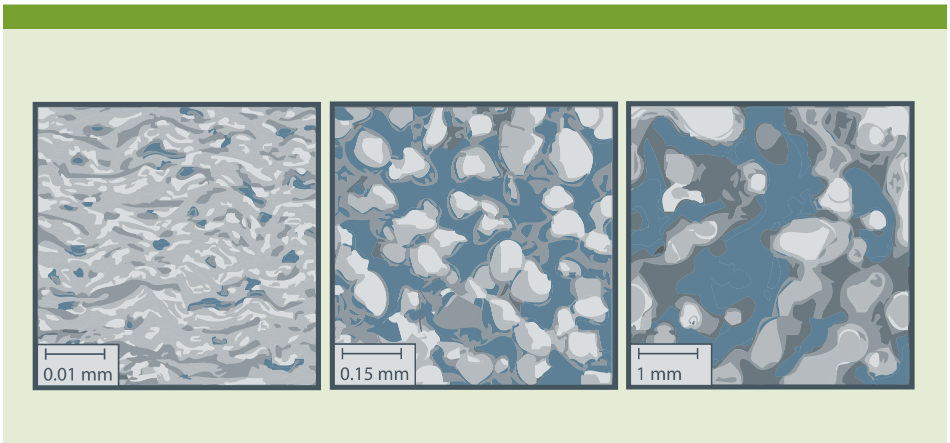
1.2 What is fracking?

Fracking is a contraction of 'hydraulic fracturing' – the practice of using highly pressured fluid to fracture rock. After a well is drilled into the earth, and steel casings are cemented in place, small explosives are used to shoot holes through the casing and into the surrounding rock. Fracking fluid (water, sand, and various chemicals) is then injected at high pressure to crack the rock. The grains of sand hold the tiny cracks in the rock open, allowing oil and gas to flow into the well.

Large amounts of wastewater flow out of the well along with the oil and gas. This is known as 'produced water' since it is produced by the well. Some of this produced water is fracking fluid returning to the surface. The rest is water – often very salty – which was trapped in rock underground.

To understand how fracking works it is important to appreciate the different properties of different types of rock.

Whether rock can hold oil and gas will depend on its *porosity.* If rock is porous it is able to trap the oil and/or gas molecules like liquid in a sponge. And because the oil and gas is buoyant it will try to escape. Whether this is possible depends on the *permeability* of the rock – whether it allows the oil and gas to flow through the rock.[18] Permeability, therefore, is a measure of how well the holes in the sponge are joined up. If the holes are joined up, then the fluids can move through. While a rock may be highly porous, if the spaces are not interconnected, the oil and gas within the closed, isolated pores remains trapped.



Source: Tom Grace, TERC

Figure 1.1 The rock on the left is neither porous or permeable – there are few holes within the rock and they are not joined together. The middle rock is more porous with more holes – but the holes are not joined up so it is still impermeable. In contrast, the rock on the right is very porous and has many paths through it, making it permeable.

Rocks such as pumice, clay and shale can have high porosity, yet are nearly impermeable. In contrast, rocks such as sandstone and limestone may be permeable and allow oil and gas to move upward through the tiny gaps. Upward movement of oil and gas through permeable rock towards the surface continues slowly over time unless it is stopped by an impermeable barrier – a cap rock – through which it cannot pass. The oil and gas then accumulates in porous reservoir rock beneath the cap rock over a very long period of time.

Most oil and gas that has been extracted – conventional oil and gas – is found in capped reservoir rock that is both porous and permeable. Drilling in the right place allows the oil and gas to shoot out. But in rock where permeability is low, oil or gas cannot be extracted so easily. Fracking is a technique that unlocks these resources by creating new pathways along which the oil and gas can travel – cracking the rock to make it permeable.

Fracking is used to create cracks in three types of rock for oil and gas extraction.

- ‘Tight sand’ reservoir rock
- Shale source rock
- Coal seam source rock

Fracking can also be used for other purposes – see Appendix 1. Indeed the earliest uses were mining hard rock like granite and stimulating production from water wells.[19] In New Zealand, it was used (unsuccessfully) to test the strength of rock when building the Clyde Dam.[20]

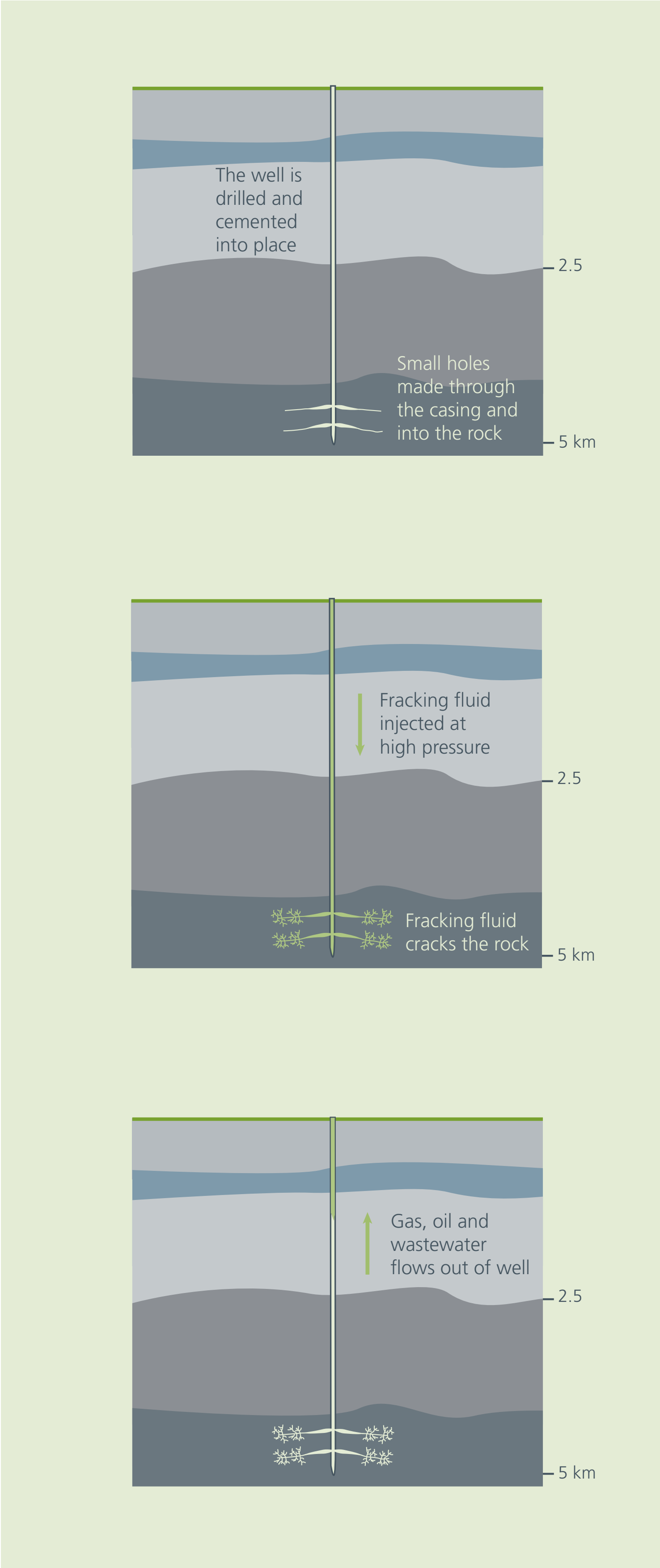


Figure 1.2 The main stages of cracking the rocks so oil and gas can flow.

1.3 Structure of the report

The remainder of this report is structured as follows.

Chapter 2 describes the development of oil and gas production over the last century and a half through to the unconventional techniques increasingly used today.

Chapter 3 is a brief history of oil and gas production in New Zealand from early use by Māori to the controversy over fracking today.

Chapter 4 describes the nature of the environmental risks associated with each stage of oil and gas production where fracking has been used.

Chapter 5 describes the public processes and institutions that govern and regulate oil and gas production in New Zealand.

Chapter 6 looks at the future of oil and gas, and the implications of fracking for climate change – both globally and in New Zealand.

Chapter 7 contains the interim findings of the investigation.

1.4 What the report does not cover

This report is about the environmental effects of fracking for oil and gas and how they are managed in New Zealand. This report does not cover (in any detail):

- the economic and social benefits and costs of fracking
- Māori cultural and spiritual views, and Treaty settlement issues relating to petroleum
- offshore drilling including in the deep sea
- the ownership of or control of access to Crown or private land
- the use of fracking for other purposes, including geothermal power generation.

From conventional oil and gas to fracking

The history of human use of oil and gas started thousands of years ago. Throughout the Middle East, people of ancient history used thick and sticky bitumen for a variety of purposes. From building and road construction, waterproofing agent and sealant, adhesive and decorative tool as well as disinfectant and insecticide, its uses have been many and varied.

Over the last 150 years our reliance on oil and natural gas has diversified and strengthened. From those early uses of oil and gas it is now used for a vast array of different uses – from major industry through to home heating. The most important use of oil is for transport. Indeed, oil has been described as the lifeblood of the modern era.

Modern fracking is one of the latest technological developments to unlock this highly valued energy resource – oil. To date fracking has mainly been used to obtain more gas and this is transforming the energy sector in the United States and Australia.

The rise of fracking, like many new technologies, has not been without controversy.

2.1 The early days

The nineteenth century saw the use of a number of new fuels. By 1821 most large towns in Britain had streetlights powered by gas made from coal.[21] Whale oil had been used in lamps for decades and was eventually replaced by kerosene, made first from coal and later refined from oil. It was in the shadows of a dwindling and increasingly expensive supply of whale oil that 'Colonel' Edwin Drake reputedly drilled the first modern oil well in Pennsylvania in 1859.[22,23] The United States would remain the world's dominant oil producer until 1974.[24]

During the latter half of the nineteenth century, alongside more and more discoveries and development of oil fields, inventors and entrepreneurs were busily perfecting the internal combustion engine – the basis of the modern automobile. Carl Benz patented the first two-stroke internal combustion engine in a working automobile in 1886 and the oil economy began to rev up in earnest.[25]

During World War I all of the major powers came to regard oil as a key military asset, running trucks, trains, tanks, ships, and aeroplanes. Old coal-powered steam engines in trains and ships were quickly replaced. The increased use of oil during the war was so rapid that severe shortages developed.[26]

Large discoveries in the United States, Mexico, Venezuela, and the Soviet Union in the 1920s led to plentiful supplies and very low prices. By 1931 crude oil was selling for only 10 cents a barrel and falling.[27] However, World War II put a quick end to oil surpluses as it fuelled the military machines on all sides.

Source: wikimedia

Figure 2.1 Oil well gusher in 1922 - Okemah, Oklahoma.

Throughout the nineteenth and much of the twentieth century, the natural gas that was found with oil was considered a 'nuisance byproduct'. After being separated from the valuable oil, the gas was burned (flared) to get rid of it.[28] For a long time it was too difficult to transport natural gas over long distances, and instead 'town gas' that could be made locally from coal in gasworks was used. It was not until the middle of the twentieth century that natural gas came into its own as a major fuel.

The 1950s saw demand for oil increase to levels that dwarfed all previous use. Oil not only fuelled the great growth in cars and trucks, but was used to generate electricity and provide the base for petrochemicals like fertilisers, pesticides, and pharmaceuticals. American and European interests secured access to the huge Middle East reserves to power their new oil-driven economies. But with oil prices hovering around a meagre US$2 a barrel for much of the 1950s (US$25 in 2012 dollars), oil producers were keen to tighten their grip and push prices up.[29]

In 1960, the Organization of the Petroleum Exporting Countries (OPEC) was founded with the aim of securing a tighter control on crude oil supply and higher prices. In the next decade, two oil shocks – one in 1973 and one in 1979 – saw the price of oil jump.[30]

Higher oil prices had a profound impact on the way countries looked at and sought energy security. And while the price of crude oil did fall again in the 1980s, a push began to discover new unconventional sources of oil (as well as gas) to shield against further price shocks and diminishing reserves.

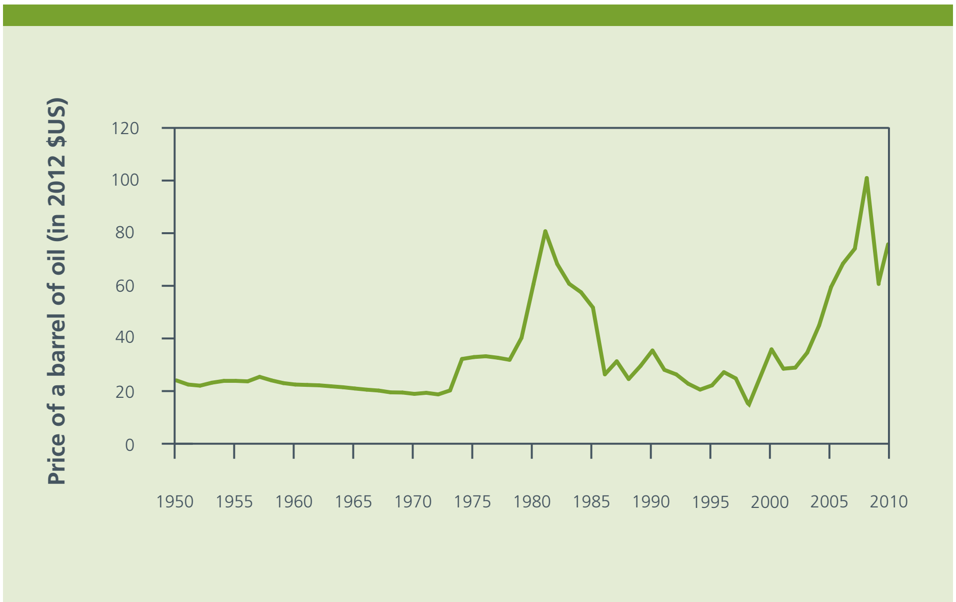


Figure 2.2 The price of oil from 1950 to 2010 showing the effect of the 1973 and 1979 oil shocks.[31]

The term 'unconventional' oil covers a wide range of sources of oil and techniques for obtaining oil and its products. Unconventional sources of oil include the tar sands in Canada and the heavy oil deposits in Venezuela; producing useful fuels from such sources is much more energy-intensive than drilling for and refining conventional oil.

Products that are usually created from crude oil can also be made from natural gas and coal. For instance, petrol has been made from natural gas in New Zealand and diesel is made from coal in South Africa.

Two unconventional techniques for accessing oil and gas are especially relevant to New Zealand – drilling for oil and gas in the deep sea, and fracking.

2.2 The rise of fracking

In the late nineteenth century, cracking rock to get more oil out of wells was done by 'well shooting' – exploding nitroglycerine torpedoes down a well.[32] Hydraulic fracturing of oil wells was first done commercially in March 1949.[33] These early fracking operations used a few thousand litres of fracking fluid made up of crude oil and gasoline and a couple of hundred kilograms of sand.[34]

From the 1960s, a new kind of fracking was tried and later abandoned – exploding nuclear devices to 'stimulate' oil and gas wells (see Box 2.1). After this, improving hydraulic fracturing with high pressure liquid became the main focus of research.[35] Two technologies in particular were developed that led to modern fracking.

Box 2.1: The nuclear experiment – explosive fracking

In 1958 the El Paso Natural Gas Company approached the United States Government with the idea of using nuclear explosions to stimulate access to gas. Three 'nuclear stimulation' tests were conducted between 1969 and 1973 in New Mexico and Colorado. The programme was abandoned in the face of political and public opposition.[36] The Soviet Union also exploded nuclear devices to stimulate oil and gas production, with nuclear fracturing continuing into the 1980s.

In the mid-1970s the United States Government began funding research into higher volume hydraulic fracturing. It used far larger amounts of liquid and sand than had previously been used. A typical frack with this new technology used over a thousand cubic metres of gelled fluid and almost five hundred tonnes of sand.[37]

The next technology off the block in the 1970s and 1980s was fracking in directional and horizontal wells. Instead of simply sending high-pressured liquid down a vertical well to crack the rock, multiple tunnels could be drilled in different directions through oil and gas fields. This led to multi-stage fracking, allowing specific points in wells to be targeted and fracked.

Now in the United States extremely large volumes of 'slickwater' fluid is typically used to frack for shale gas.

The development of these technologies has led to a great increase in the use of fracking around the world to more than 100,000 fracks a year in recent years. In all, more than two million fracks have been performed and have become larger and more complex over time.[38]

2.3 Fracking controversy

Concerns about the environmental impacts of fracking have emerged alongside the rapid growth in the use of the technology in the last decade.

The 2010 documentary film *Gasland*, set in the light of the massive shale gas extraction in the United States since 1997, has received widespread attention. Much of the footage is focused on natural gas contamination of groundwater and shows someone living near a fracking operation igniting the water coming out of kitchen taps. *Gasland* sparked campaigns against fracking in both North America and Europe, with campaigners expressing concerns about contamination of aquifers, extreme levels of water use, earthquakes, air pollution, and climate change.

Government reaction to fracking has varied across different countries and regions. A number of regional governments have banned or put moratoria on fracking. The only two countries which have banned the practice outright are France and Bulgaria.

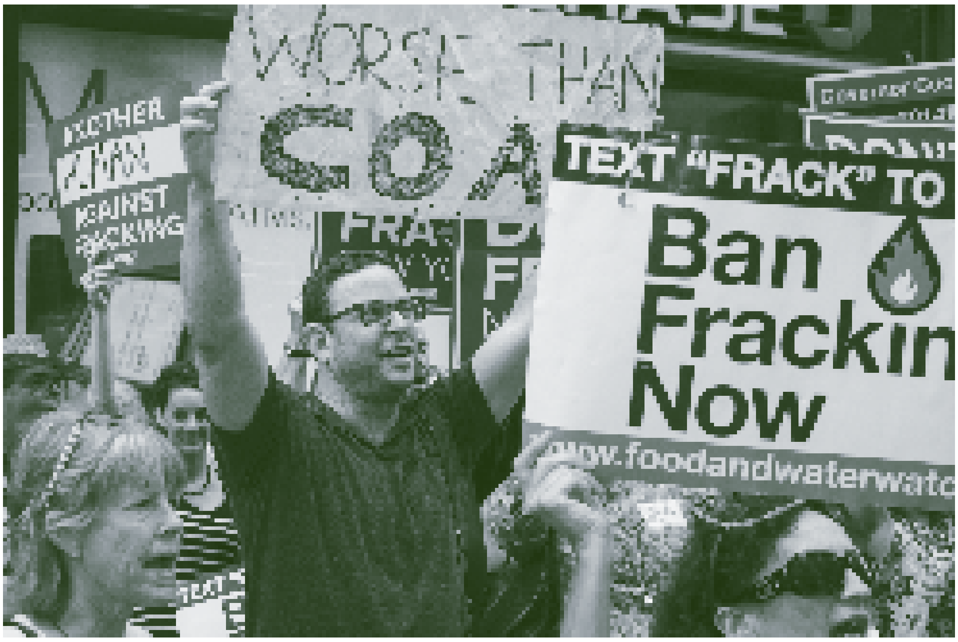
The documentary *Gasland* has received much attention around the world

In Australia, fracking is currently prohibited in Victoria, but New South Wales has recently lifted its moratorium.[39] Queensland is projected to have up to 40,000 coal seam gas wells drilled over the next 20 years.[40] In response, an alliance of farmers and environmentalists concerned about both property rights and the environment are seeking to ‘lock the gate’ on gas companies.

In the United States, prohibitions on fracking have been placed in Vermont, New York, and New Jersey.[41] In Canada, fracking is likely to be prohibited in Quebec.[42]

In response to the widespread controversy about fracking, a growing number of reports are being written around the world. Of particular note, a report from the Royal Society of London concluded that the risks of fracking could be managed as long as *"operational best practices are implemented and enforced through regulation"*.[43] And at an international level, the International Energy Agency has released its 'Golden Rules' for shale gas – high level principles providing guidance on policy and regulations.[44]

The next chapter continues with the story of oil and gas in New Zealand through to today's concerns about fracking.



Source: Adam Welz

Figure 2.3 An anti-fracking demonstration in New York City aimed at New York Governor Andrew Cuomo. The 4-year moratorium on fracking is due to be lifted on 29 November 2012.

New Zealand history of gas and oil

Like elsewhere in the world, in primordial New Zealand oil and gas bubbled and seeped up to the surface of the untouched bush and rivers. Created from the buried life of ancient bush and oceans, New Zealand's oil and gas deposits are sprinkled around the country. They first accumulated in low lying areas and were shunted around by tectonic plates, before ending up in places like Taranaki and the Great South Basin.

From the time Māori first stepped on the shore of Aotearoa, oil and gas was recognised as an important *taonga* (treasure). Heightened interest in petroleum arrived with European settlement. Until recently, New Zealand's gas and especially oil reserves were thought to be limited, but fracking is opening up access to previously unreachable oil and gas resources.

3.1 Early discoveries of oil and gas in New Zealand

Natural resources are *taonga* for Māori because they are a part of *Papatūānuku*, and also because they provide food, water and even warmth. They include resources beneath the Earth's surface such as oil and gas. Māori interpreted the existence of gas seepages as a connection to *atua* and so regarded them as *tapu*. A gas seep near Te Puia Springs north of Gisborne is named Te Ahi o te Atu – the fire of the gods.[45]

Māori had many uses for oil and gas and were known to use them for lighting, as a beacon and for dyeing.[46] In some areas the burning of gas seepages was a sign of *ahi kā* – keeping the fires burning on the land. *Ahi kā* signified tribal occupation of land which is a very important concept for Māori.[47]

> *"Māori on the East Coast of the North Island knew of oil seeps. In 1874, some were amused when they heard of the Poverty Bay Petroleum and Kerosene Company's plans to put down a bore. According to Māori tradition, the oil was only on the surface – where a whale had slipped out of the hands of the priest Rongokako."*[48]

Source: GeoSphere

Figure 3.1 The Kotuku oil seep in Westland. Many attempts have been made to commercialise this natural oil seep, but none have been successful.

After European colonisation began in earnest in the nineteenth century, coal and the gas made from it became major sources of energy. Gasworks making 'town gas' from bituminous coal were built in many towns and cities from the 1860s.[49] But some early colonists saw the potential in finding petroleum.

Seepages known to Māori were the first places Europeans targeted. At New Plymouth's foreshore, gas bubbling to the surface and an oil sheen on the sea gave away the treasures that lay beneath. In 1865, samples of oil found in the rocks on the foreshore were to be sent to London for analysis, and the Taranaki provincial government offered a reward of £400 for a commercial discovery of petroleum.[50]

The first well was dug on New Plymouth's foreshore in 1865. While it struck both natural gas and oil, the yield was not significant. Wells with mixed results continued to be developed until World War II. The first commercial oil strike was made in 1906 and a small refinery was built in New Plymouth.

With war looming, all New Zealand's oil and gas reserves were nationalised in 1937. To help increase supply the Government set up clear rules to encourage more prospecting, exploration, and extraction of oil.[51] After war was declared, exploration really started to take off. Oil was a vital strategic asset for powering the war effort, and like other countries New Zealand sought to shelter itself from the risk of supply lines being cut.

3.2 Natural gas and 'Think Big'

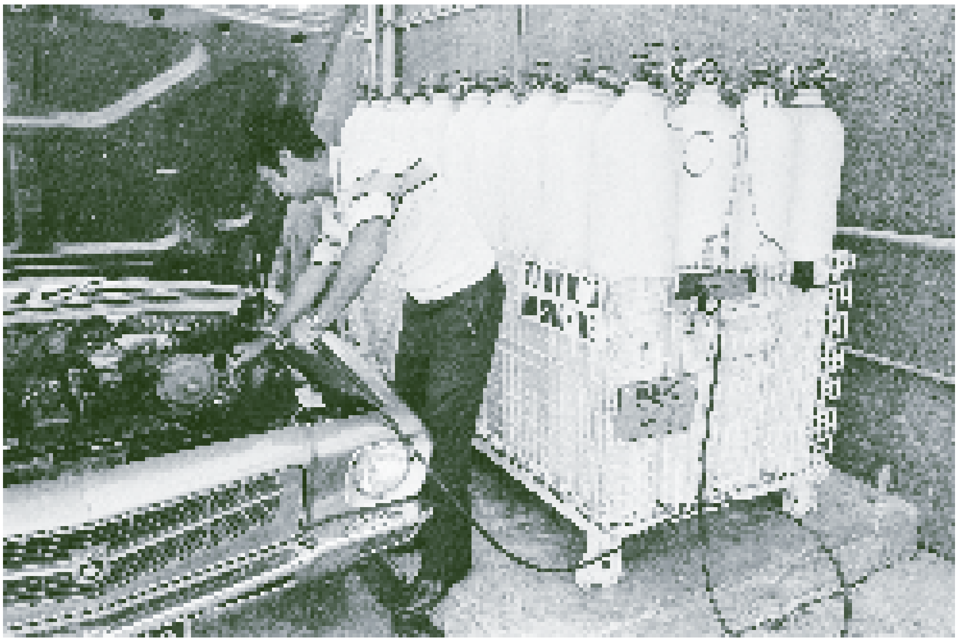
New Zealand, along with other developed countries, was part of the post-war boom driven by oil. And, like others, we too wanted our own oil supply. In 1951 the Government was told by overseas experts that New Zealand could have significant reserves of natural gas, but was unlikely to have oil.

The Kapuni gas field in Taranaki was discovered in 1959 and production began in 1970. In 1969, the 'giant' Maui gas field was discovered about 40km off the coast of Taranaki.

Maui was much larger than Kapuni. When production began in 1979 after the construction of an offshore platform, a huge surplus of gas in New Zealand was created. With the oil shocks of the 1970s the Government developed its 'Think Big' strategy for economic development, largely based on this abundant supply of gas.[52]

Natural gas from Taranaki was piped around the North Island for use in households and industry, and rapidly replaced the town gas made from coal. Power plants that generated electricity using natural gas were built at New Plymouth and Stratford. Many cars were converted to run on compressed natural gas (CNG). Two components of natural gas – propane and butane – were compressed into liquefied petroleum gas (LPG) and used in various ways, especially to fuel vehicles in the South Island where CNG was not available. Two petrochemical plants were constructed in Taranaki to make use of Maui natural gas – the Motunui plant which made synthetic petrol and the Waitara plant which made methanol.[53]

Small oil deposits have also been found in Taranaki since the late 1970s, although none have yet approached the scale of the gas discoveries.



Source: Taxi driver filling his car at New Zealand's first commercial compressed natural gas filling station, Lower Hutt, Wellington. Dominion Post (Newspaper): Photographic negatives and prints of the Evening Post and Dominion newspapers. Ref: EP/1979/1233/4-F. Alexander Turnbull Library, Wellington, New Zealand. http://beta.natlib.govt.nz/records/23228813

Figure 3.2 Taxi driver filling his car at New Zealand's first commercial compressed natural gas filling station, Kings Cross Service Station, Lower Hutt.

3.3 Unconventionals and the prospect of oil

By the early 2000s the gas supply at Maui was dwindling. While smaller fields had been discovered over the past decade, none came close to the size of Maui. And like some other countries, New Zealand started exploring options for more unconventional ways of getting access to natural gas, and especially oil. These 'unconventionals' are usually considerably more expensive than oil and gas obtained from conventional drilling. But as the price of oil has risen and new technologies have been developed, so New Zealand's potential to become an oil-producing country has grown.

New Zealand has a number of potential unconventional sources of oil and gas, as listed below. The first three commonly depend on fracking.

- Extracting natural gas and oil from 'tight sands'. The boundary between tight sands and conventional reservoirs is ill-defined and generally based on whether the reservoir will have an economic production flow without fracking.[54] Fracking in Taranaki to date has been in 'tight sands'.
- Extracting oil and gas from shale. Shale is a dense brittle rock that often contains oil and gas. It can have high porosity, but has low permeability. Interest in extracting oil and gas from shale in New Zealand is currently focused on Gisborne, Hawke's Bay, and the Wairarapa.
- Extracting coal seam gas – the methane that is trapped within coal. Solid Energy has closed its demonstration plant in Huntly in the Waikato, but is moving its coal seam gas operations to Taranaki.[55]
- Deep sea drilling for oil in water that is many times deeper than the water below the Maui platform.
- Underground coal gasification – burning coal together with its associated methane underground to produce syngas. The syngas is a mixture of mostly carbon monoxide and hydrogen. Solid Energy is operating a pilot plant in Huntly.[56]
- Making diesel from lignite (brown coal) in Southland and Otago. Lignite could also be used to make urea fertiliser instead of natural gas.
- Extracting gas hydrates from sediment on the seafloor in the Hikurangi Margin off the east coast of the North Island. Gas hydrates are ice-like solids made of water with gas molecules trapped within.

These unconventionals all have the potential to be converted to useful oil and gas products with the right technology and economic conditions. Many are contentious because of the potential for environmental damage, especially with regard to climate change. However, in the past year it is fracking and deep sea drilling that have received the most attention.

Unconventional oil & gas is controversial because of its potential to ramp up consumption

3.4 Fracking in New Zealand

Fracking has a short history in New Zealand. The first known frack was in 1989 at Petrocorp's Kaimiro-2 gas well in Taranaki, though there may have been earlier instances. Almost all the fracking that has taken place in New Zealand has been done in Taranaki. There have been two unsuccessful attempts to frack for coal seam gas in Ohai in Southland, as well as Solid Energy's coal seam gas pilot in the Waikato.

Currently Baker Hughes is the only contractor with the equipment and ability to carry out hydraulic fracturing in New Zealand.[57]

With a significant increase in fracking for oil and gas on the horizon, and with controversy about fracking overseas, it was inevitable that concerns about the technology would arise in this country.

Until 2011 the word 'fracking' was virtually unknown in New Zealand. But in March that year the first media reports started to appear with the group 'Climate Justice Taranaki' opposing fracking operations.[58] By July the national media was running reports about fracking, with a number of groups and an increasing number of individuals opposed to, or questioning, the practice.

Figure 3.3 Map of New Zealand showing the three regions where fracking has taken place.

3.5 What worries people about fracking?

The concerns expressed about fracking in New Zealand are many and varied. They go beyond the risks that fracking might pose to the physical environment to wider issues such as lack of trust in council regulators and the nation's strategic direction.

The following lists some, though doubtless not all, of the concerns expressed about fracking in New Zealand.

Chemicals in the fracking fluid. To many the use of fracking fluid is the key difference between fracking and traditional oil and gas production, and they worry about water, soil, or air being polluted by the fracking fluid. The use of product names rather than chemical names for some of the ingredients in fracking fluid compounds the concern.

Contamination of aquifers. The injection of fracking fluid and wastewater into the ground and the potential for groundwater contamination is a major focus. As well as fracking chemicals, many are concerned about substances in wastewater such as heavy metals and radioactive materials.

Contamination of soil. Some fear that the practice of 'landfarming' – spreading waste on to agricultural land – may contaminate food as well as groundwater, and that any monitoring that could detect pollutants is inadequate.

Harm to Papatūānuku. For Māori, harming the *mauri* (life force) of the earth mother endangers future sources of *kai* (food) and *wai* (water). Some particular areas are sources of traditional *mahinga kai* for local Māori or are *tapu*.

Earthquakes. The linking of some earthquakes overseas to fracking has led to this being a high profile issue in this geologically active country.

Volumes of water used in fracking fluid. This is less of a concern in Taranaki where the rainfall is high, but a major concern in drier regions where water can sometimes be scarce.[59]

Climate change. There are two concerns about climate change. The first is about methane – a potent greenhouse gas – leaking into the atmosphere. The second is that using more oil and gas will increase carbon dioxide emissions and deter investment in renewable energy.

Cumulative effects. In areas where many well sites may be developed, there are concerns that while the effects of one well might be small, the effects of many could be very large.

Access to land. Since oil and gas were nationalised by the Crown in 1937, land owners cannot stop companies coming on to their land to drill wells.[60] For Māori, this can be seen as another phase of land confiscation.[61]

Local impacts on neighbours. These include air pollution, traffic, odour, and glare from flaring. Some farmers producing products like premium meat, wool, and fruit are worried about the effect nearby fracking operations might have on their access to markets.

Resource consents. Some are concerned that oil and gas activities, including fracking, are being 'rubber stamped' with minimal public input and scrutiny by councils.[62] Specific issues around the granting of resource consents to oil and gas companies include applications for consents not being notified to the public, narrow definition of affected parties, and the 'unbundling' of consents. More broadly, some are concerned that councils are not engaging with their communities in developing plans to manage any expansion of oil and gas activity.

Source: Australian Associated Press

Figure 3.4 Protest against the proposed use of fracking to extract natural gas at Parliament, Wellington, 7 February 2012.

Council capacity and expertise. Some question whether council staff will be able to deal with the technical challenges of fracking and a rapidly expanding oil and gas industry.

Liability for damage. The possibility of damage becoming evident after a well has been abandoned is of concern to some, especially those who envisage the cost of clean-up falling on the public purse. A well may have different owners and operators over the course of its lifetime.

Economic benefit. To some the expansion of the oil and gas industry would be enormously positive, with new jobs and commercial activity stimulating the local economy.[63] Others contend that the economic benefits will bypass regions and local iwi with royalties and taxes captured by central government, profits going offshore, few employment opportunities for local people, and New Zealanders not benefitting directly from cheaper oil and gas.[64]

Strategic direction of the country. For some, fracking is a touchstone for much broader concerns about the country's strategic direction, and they query whether encouraging expansion of the oil and gas industry is the right way to go. Protection of New Zealand's clean green image is often related to this. One concerned citizen wrote to the Commissioner: *"Do we on the East Coast want to look like a mini Texas? I think not!! This is not New Zealand's image."*

This report is necessarily focused on environmental issues associated with fracking, and so does not address all these concerns. The next chapter is a 'walk through' of the process of oil and gas production involving fracking, identifying and discussing the environmental issues that arise at each stage.

4

Environmental issues associated with fracking

This chapter examines the environmental risks associated with each stage of oil and gas production before, during, and after fracking. It is divided into sections each dealing with a stage of the process, beginning with choosing where to drill and ending with abandonment of the well after oil and gas production has ceased.

Two points are important to note.

1. Some of the environmental risks are associated with oil and gas development, regardless of whether fracking is involved or not. These risks are relevant because fracking expands the potential scale of oil and gas exploration and production in New Zealand.

2. This chapter is mainly focused on the experience of fracking in New Zealand to date, but also draws on overseas examples. The nature and degree of the environmental risks that could accompany the potential expansion of fracking in New Zealand are not assessed in this chapter.

4.1 Choosing where to drill

The various environmental impacts of oil and gas production including fracking are strongly dependent on the location of the particular well – the rock structure, the location of faults and aquifers, the proximity to those who may be affected, and so on.

Understanding the geology of a region is essential in assessing the potential for oil and gas to exist, and whether fracking may be required to access it. Oil and gas companies will generally acquire information from any previous exploration to identify where to search.

Seismic surveys are used to more accurately identify where oil and gas reservoirs might be present, and to provide information on the types and layers of rock, the depth and extent of aquifers, and the presence of faults.

Seismic surveying involves generating a seismic wave and analysing the returning wave to assess the geology deep in the earth. On the basis of this information, companies holding permits decide whether and where to undertake exploratory drilling. They also take into account road access, proximity to houses, topography, and land owner agreement.

During the drilling of an exploration or production well, instruments are sent down the well to gather more information about the geology of the location.

Source: GNS Science

Figure 4.1 A geologist fires off an explosive device near Hanmer Springs, Canterbury in the 1980s. Reflected shockwaves are recorded and this data is used to map the geology.

Sources: MBIE, 2010. NZP&M GIS data, Sept 2012

Figure 4.2 Map of petroleum basins and areas with exploration permits. Exploration permits may also apply to areas of coal seam gas, which may not lie within petroleum basins.

4.2 Establishing the well site

The first stage of developing any oil and gas well is to prepare the site. The kinds of preparation required are typical of many industrial activities. But unlike many industrial activities that are clustered close to urban areas, a well site is likely to be surrounded by farmland or bush and may be located close to rural houses.

During this preparation phase, there will be more trucks on local roads, and noise and dust associated with construction. These impacts, which are also concerns during the fracking process, can be managed to some extent. For example, restrictions on operating and transporting times can reduce noise and traffic disturbances, and roads and sites can be watered or sealed to reduce dust.

Well sites can vary in size from a hundred square metres to well over a hectare. A site may contain just one well or several wells drilled in different directions, along with the infrastructure for collecting and processing oil and gas, and dealing with waste.

Preparation of the site includes: building a concrete drill pad; installing storage tanks for chemicals, water and waste material; excavating flare pits and settling ponds for separating out solid wastes; and building bunds to contain leaks, spills, and stormwater.

Managing the environmental effects when building a well site is usually relatively straightforward.

Source: Dr Murry Cave

Figure 4.3 The coal seam gas well site in Ohai, Southland, where fracking was used in 1995.

4.3 Drilling and constructing the well

Activity at the well site becomes much more intense when drilling begins with more noise, ground vibration, bright lights, exhaust fumes from generators and trucks, and the arrival of a drilling rig. Drilling may be carried out 24 hours a day, and the process of drilling can take a few days or several months, depending on the geology, depth of the well, and whether the well is vertical or horizontal.[65] So far there has been only one horizontal well drilled and fracked in New Zealand.[66]

As the hole is drilled, multiple layers of metal casings are inserted and cemented in place. The design and quality of the well construction is of paramount importance in managing the environmental risks of fracking.

Oil and gas, water from the reservoir, and fracking fluid could contaminate freshwater aquifers if a well leaks. Natural gas also could find its way through or up the outside of a leaking well into the air. This is potentially dangerous because of the exposure of workers to gas and the possibility of an explosion in a confined space.

If a well leaks freshwater aquifers could be contaminated

Drilling the well

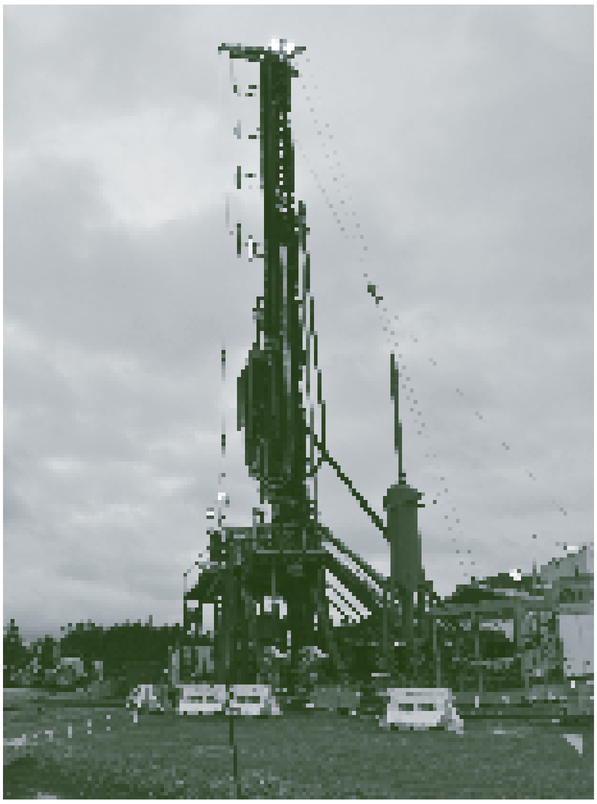
Oil and gas wells where fracking is to be used can be drilled to different depths. In Taranaki, fracked wells have varied in depth from 1,100 to more than 4,400 metres. Wells drilled in the United States to extract oil and gas from shale are generally similar in depth to the wells in Taranaki, though some have been over 6,000 metres deep.[67] Wells drilled to extract coal seam gas are usually much shallower and fracking is done much closer to useable aquifers. The Waikato coal seam gas wells are about 400 metres deep.

A fluid known as ‘drilling mud’ is injected to assist with the drilling.[68] Drilling mud is a mixture of water or oil, with salts and other additives, and can be stored either in mobile containers or in open pits for disposal or reuse. Pits are usually lined to avoid leaks or spills that may contaminate soil or water.

The catastrophic failure of a well either below or above ground – a blowout – is a well-known risk of oil and gas production. It is usually caused by a very high pressure ‘kick’ from a pocket of gas unexpectedly encountered during drilling.

A blowout is not only very dangerous but can be damaging to the environment.[69] After the McKee well blowout in Taranaki in 1995, it took 18 months for the Mangahewa Stream to recover.[70] Although blowouts are rare, fracking does increase the pressure in a well and blowouts have occurred in wells overseas that have been or are being fracked.[71]

Changes in pressure in one well can also affect other wells in the vicinity and lead to blowouts. In Alberta, Canada, fracking of a well caused a blowout to occur in a separate production well over one kilometre away. Oily fluid continued to spray into the air from the production well until fracking stopped at the first well.[72]



Source: Parliamentary Commissioner for the Environment archives

Figure 4.4 A drilling rig at a TAG Oil's Cheal well site in 2012.

Casing and cementing the well

One of the most important challenges in constructing a well is to prevent leaking. This is achieved through lining the well with steel casings which are cemented in place to provide a barrier between the contents of the well and the surrounding rock.

The lining is created through a series of steel pipes nested inside each other, decreasing in diameter as the depth increases. Cement is forced down the well and back up between the wall of the drill hole and the steel casing, fixing it in place and sealing the gap. Current New Zealand oil and gas wells typically have at least three casings that extend to different depths (see Figure 4.5). There is no standard number of casings required in New Zealand.

The combination of cement and steel must be sufficiently dense and strong to ensure there are no gaps through which liquids and gases can escape. This is of great importance from an environmental perspective as any gaps could allow substances from inside the well to escape and travel to the shallower layers of rock and into aquifers. Gaps could also allow fluids to flow up the outside of the well. Wells are almost always drilled through aquifers to reach the oil and gas formation.

A well should be designed to maintain its integrity for the long term. The well casing and cement must be able to handle changes in temperature, pressure, and stress along its entire length – both from fracking itself, but also from natural ground movement and earthquakes. The repeated stress on multi-fracked wells could increase the risk of problems with cement bonding and the connection between the steel casings.

In some cases, conventional wells that were not designed with fracking in mind could be fracked – usually in an attempt to extract more oil or gas from existing wells. These wells may need to be strengthened or modified prior to fracking to ensure well integrity is maintained.[73]

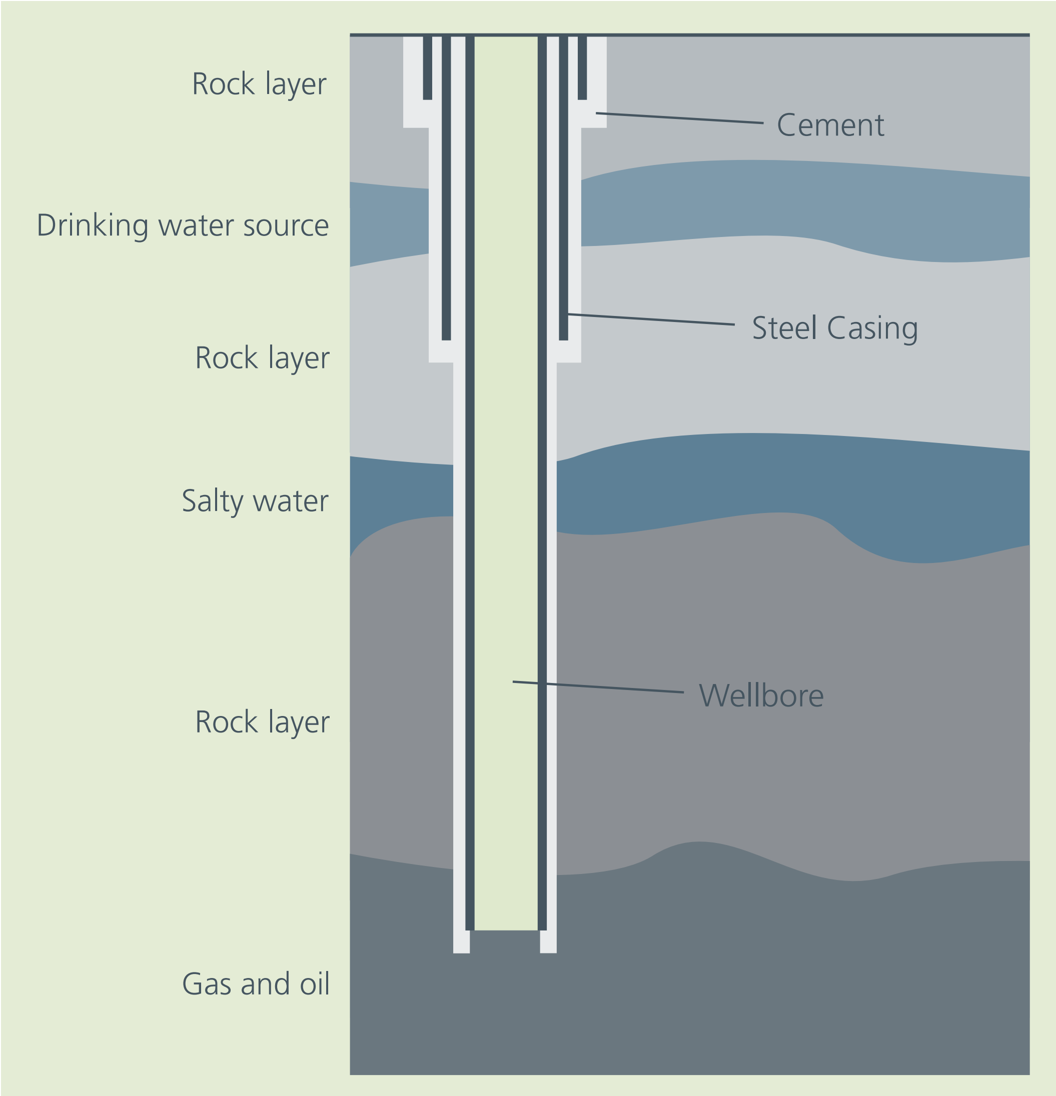


Figure 4.5 Diagram showing the different layers of the well casing. The 'conductor casing' acts as a foundation for the rest of the well and stops several metres below the surface. The 'surface casing' extends through any drinking water source. The 'production casing' extends all the way down into the well.

Quality of construction

The construction aspects that are most important for a leak-free well include the correct composition and quality of the cement used, the installation method, and the setting time. The aim is to ensure that the cement binds tightly to the steel casing and the rock, and leaves no cavities through which liquids and gases could travel. Other important factors are constructing the well to specification, and positioning the casing at the centre of the well before it is cemented in place.[74]

The risk of large earthquakes in New Zealand means that it is also important that the casing and cement are designed to withstand large ground movements.

Overseas, poor well casing design and construction has caused wells to leak, sometimes contaminating groundwater and allowing some methane to escape into the air.[75]

4.4 Fracking the well

When the cement and steel casing is in place, the fracking process can begin.[76] The rocks deep below are cracked in order to allow the gas and oil to flow freely. A perforating gun first shoots holes through the casing and a short way into the rock. Then the fracking fluid is injected under high pressure and is forced through the small holes into the rock, creating cracks.

The sheer weight of the overlying rock naturally limits fracture growth. Cracks are a few millimetres wide, about 30 metres high and extend anywhere from tens of metres to a few hundred metres from the well. The fractures will also vary in length due to the existence of faults, joints, or changes in rock type – these can either provide natural stopping points for a fracture or extend its reach.[77]

Fracking is often done in multiple stages along the same well. There are two reasons for this. Sometimes it is necessary to frack a rock formation in multiple places. Other wells may run through a number of separate formations at different depths that require fracking. In New Zealand, about 30% of all fracked wells have been fracked multiple times at different depths.

The fracking fluid

In New Zealand, most fracking operations have used water-based gels, typically made up of more than 97% water.[78] These fracks in tight sands and coal seams have required between 100 and 350 cubic metres of fracking fluid per frack. The largest multi-frack known to date in Taranaki used over two thousand cubic metres, equivalent to around 70 full tankers.[79]

In the North American shale formations, much larger volumes of fluid – up to 20,000 cubic metres – are usually used for fracking. This is because in the United States a different type of fracking fluid is used (slickwater instead of gel).[80] Appendix 2 provides more information on types of fracking fluid.

Water is either taken from ground or surface water at the site, or from town supply. In New Zealand, most fracks have used water from town supply, which is trucked to the site and stored until required.

The amount of water used during fracking could place demands on water in some areas in the future. In addition, when water is produced during shallow fracking – such as in coal seams – the water table can be lowered.[81]

Three key components of the fracking fluids currently used in Taranaki are:

- a proppant, such as sand, to prop the cracks open
- a gelling substance to carry the sand into the cracks
- a de-gelling substance to thin the gel to allow the fracking fluid to return to the surface while leaving the sand in the fractures.

Some of these chemicals may be toxic to humans or the environment. (Appendix 2 contains more detail on fracking fluid components).

Source: Parliamentary Commissioner for the Environment archives

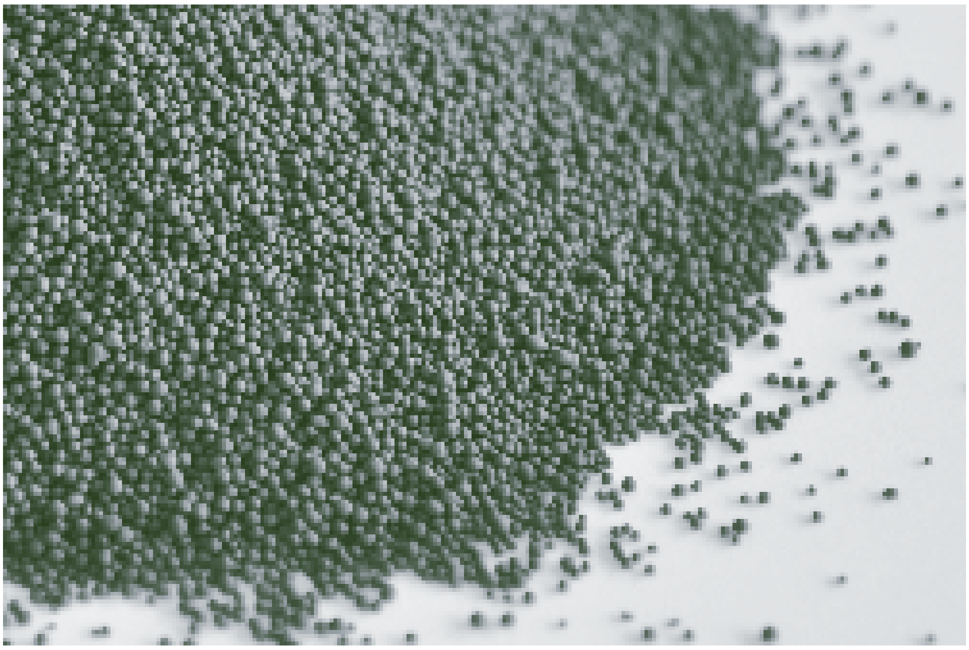
Figure 4.6 The fracking fluid is pumped into the well in a jelly like state (on the left). Once underground the temperature triggers the gel to break down into a liquid (on the right) to make it easier to return to the surface.

The chemicals are trucked to the site, stored in concentrated form, and mixed immediately before fracking. Spills and leaks can occur during transport, storage, and use.

The fracking fluid is injected under high pressure – up to 350 times the pressure in a car tyre.[82] On one visit to a Taranaki fracking site during this investigation, four pump trucks were present and these were to be used simultaneously to create the necessary pressure to fracture the rock.

Between 2001-2005, diesel was used as the base of the fracking fluid in 17 fracks in Taranaki.[83] Diesel contains benzene, toluene, ethylbenzene, and xylenes (BTEX) – volatile compounds that are well-known contaminants of soil and groundwater near oil and gas production sites and petrol stations.[84]

There are two main environmental impacts that can potentially result from the fracking process itself – induced earthquakes and water contamination.



Source: Parliamentary Commissioner for the Environment archives

Figure 4.7 Example of fracking 'sand' or proppant – in this case manufactured ceramic beads. These are around the size of poppy seeds.

Earthquakes

The cracking of the rock that occurs during fracking creates tiny earthquakes. These are generally less than magnitude 2 and cannot be felt at the surface. Natural earthquakes of this size happen many times a day across New Zealand, but are usually not detectable because they are so small.[85]

However, injecting fracking fluid into a well can trigger more significant earthquakes if the fluid finds its way into an active fault. Fluid can push apart the two sides of a stressed fault enough to allow the fault to slip.

It is not possible to trigger significant earthquakes if there is no local active fault. The chance of causing an earthquake on an active fault is affected by a number of variables – the most important being the volume of fluid. The more fluid used, the greater the chance that it will reach a fault at sufficient volume and pressure to cause an earthquake. Other factors include the size of existing faults and how much stress they are under.

Internationally, there are three documented cases where fracking fluid injection has reached nearby active faults and has caused earthquakes. These earthquakes were all less than magnitude 4 and caused no surface damage or water contamination from well damage.[86]

In Taranaki, records from earthquake monitoring systems – both the national system and the Mt Taranaki monitoring system – have been studied to see if there was any relationship between fracking (or wastewater injection) and recorded earthquakes. The conclusion was that prior to 2012, there is no evidence that fracking in Taranaki has caused earthquakes that could be felt at the surface.[87]

There have been no published studies regarding the potential for fracking to cause earthquakes elsewhere in New Zealand.

Figure 4.8 Areas where there are major known active faults. An active fault is defined as one that has moved in recent geological time and is considered likely to move again in the future. The majority of earthquakes occur along faults.

Water contamination

Internationally there are many anecdotal examples of aquifer contamination after nearby wells have been fracked. The United States towns of Dimock in Pennsylvania, Bainbridge in Ohio, and Pavillion in Wyoming are well known for issues relating to water contamination.

There are three main ways that fracking can lead to water contamination. These are from:

- spills and leaks – of chemicals, waste, or oil and gas during transport, storage, and use
- migration – where oil and gas or other fluids travel up through cracks in the rock (either natural or those caused by fracking) and eventually reach aquifers
- failure of the well – where the well is designed or constructed incorrectly to cope with fracking.

Spills and leaks of chemicals, wastewater, and oil and gas are the most likely cause of soil and water contamination associated with fracking sites.[88,89] Spills and leaks can occur during transport, handling, storage, and use. For instance, storage tanks and pits can leak or overflow and pipes can burst. But these risks are relatively easy to manage through good practice, response procedures, and personnel training.

Migration of contaminants into aquifers through the cracks created during the fracking process is only a remote possibility. This is because the cracks are unlikely to be long enough to create pathways in the rock between the fracking zone and aquifers. The likelihood of fracking creating vertical pathways into aquifers is further reduced if there is an impermeable layer of rock (cap rock) above the fracking zone that will limit fracture growth and prevent migration.[90] This appears to have been the case so far in Taranaki and the Waikato, even where the fracking has taken place at shallow depths.[91]

Oil and gas migrates into tight sands and is typically held in place by a cap rock. However, shale and coal seams are source rocks, where oil and gas are formed, and if they are shallow they may not have impermeable cap rocks above them.[92] Gas in coal seams sticks to the coal and is held in place by the water pressure within the seam, and oil and gas in shale is unable to freely migrate due to the impermeability of the shale itself.

Another important factor in limiting migration is the depth of fracking below the ground and aquifers. In tight sands and shale, the distance between where the fracking occurs and aquifers is typically large – anywhere between a thousand to several thousand metres. However, the Manutahi-A1 and B1 wells in Taranaki were fracked only 260 metres below the overlying aquifer.[93]

It is possible that cracks produced by fracking could connect to natural fractures or faults in the ground, and in this way create a pathway that allows fluid to flow to the surface.[94] Indeed, there are places in New Zealand where oil and gas seep out of the ground naturally, indicating a pre-existing pathway.

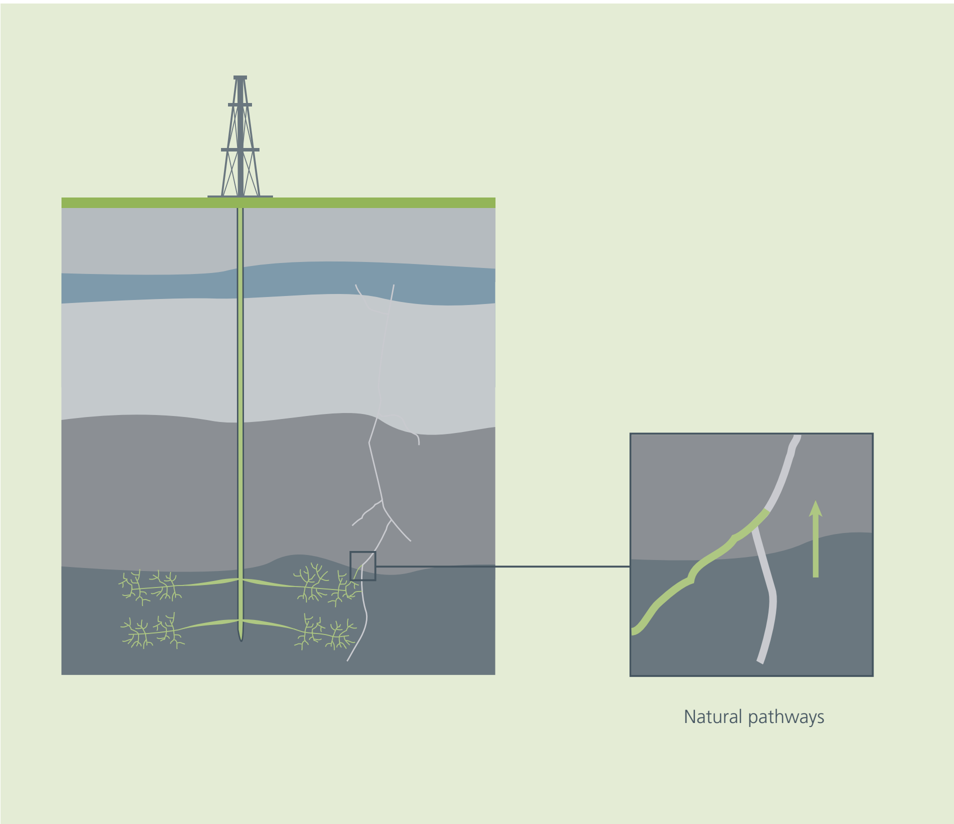
While possible, the probability of fracking fluids migrating to freshwater aquifers or the surface is very unlikely.

Well failure can also cause water contamination. Wells can leak due to poor design or construction, and the long-term effects of fracking on the integrity of any well are largely unknown. In the United Kingdom, it is considered that there is more likelihood of contamination from well failure than from migration through shale rock formations.[95]

In the town of Pavillion in Wyoming, groundwater was contaminated as a result of oil and gas production and fracking. There were many reasons for the contamination, including surface casings that were not deep enough to protect aquifers, and poor cementing that did not form a seal between the well and surrounding rock. To compound these problems, fracking was carried out at shallow depths without a cap rock.[96]

Identifying the cause of groundwater contamination can be difficult, and has often been contested by the industry. In the town of Dimock in Pennsylvania, methane and fracking fluid components were found to have migrated thousands of feet up from the production zone and contaminated water wells. The pathway of the contamination has not been determined, and could be a result of migration, well failure, or a combination of both.[97]

To date, there is no evidence that fracking has caused groundwater contamination in New Zealand, and at the current scale of operations, the risk appears low.



Source: Adapted from the US EPA, 2011b

Figure 4.9 This diagram illustrates how contaminants can migrate through natural pathways. Two other pathways are surface spills and leaks, and contaminants traveling up the outside of the well.

4.5 Flowback and transitioning into production

When the pressure is released after a frack, the 'flowback' period begins. A combination of fracking fluid, water from deep underground, and oil and gas begin to flow out of the well.[98] Over this period which lasts from days to weeks, the volume of this fracking fluid and formation water produced by the well decreases until it is mainly oil and gas that flows from the well. The volumes of fracking fluid and formation water brought to the surface varies from site to site – in some cases little water comes up.[99]

During the flowback period, gas that flows up can be vented into the air or flared. The venting and flaring of gas is the largest source of air pollution from oil and gas extraction.[100] The combination of chemicals can result in smog, and in the United States high levels of ozone related to fracking operations have been found. In one case levels of ozone were similar to those found in highly polluted cities.[101]

It is much better to flare gas than to vent it. Most of the hazardous air pollutants in natural gas break down to less hazardous substances when they are burned.[102] From a climate change perspective also, flaring natural gas is much preferred to venting it because methane is such a potent greenhouse gas.[103]

Air pollution and greenhouse gas emissions can also be effectively reduced through the use of 'green completions' – a series of processes that separate the gas from the returned water more effectively than conventional processes and allow it to be captured rather than vented or flared. However, green completions cannot reduce gas emissions if there is no pipeline in place.

Source: Parliamentary Commissioner for the Environment archives

Figure 4.10 A fracking operation at one of Todd Energy's Mangahewa well sites in Taranaki (2012).

In Taranaki, water, oil, and gas are usually separated and dealt with individually. The water is stored in tanks until disposal, the oil is collected for processing and sale, and the gas is flared until enough is being produced to go into the pipeline.[104]

A well site may contain a number of wells that need fracking. The processes of construction and fracking – and the associated disturbances – will be repeated for each well.

Once fracking is complete most equipment is removed from the site, traffic volumes fall, noise levels decrease, and flaring stops – except during maintenance or in an emergency. The production infrastructure, including separators, pipes, and tanks will remain at the site for the life of the wells.

A well will typically produce oil and/or gas for 20 to 30 years. The nature of the rock type influences both the length and pattern of production. Shale wells produce most in the first few years, before steeply declining.[105]

4.6 Handling the waste

All wells produce waste of various kinds. Waste includes 'drilling mud' and cuttings, fracking flowback, and formation water. These different wastes are dealt with in a number of ways.

A drilling rig might use several hundred tonnes of drilling mud at any one time, and sometimes it is recycled. The rock removed from the drill hole (the cuttings) are separated from the mud. Cuttings amount to between 100 and 500 tonnes per well, depending on the depth of the well.

'Produced water' is mostly water trapped in the rock formation that is brought to the surface along with the oil and gas. The amount and composition of produced water varies depending on the geology, but it is the largest source of waste generated by oil and gas production. If fracking has been used, the produced water will also contain fracking fluid, especially during the flowback period and early on in production.

It is common for formation water to be salty – sometimes saltier than the sea. Because of its origin, it contains some hydrocarbons. Some of these, such as benzene, are volatile and will evaporate once the produced water reaches the surface. A variety of other substances can be present in produced water including heavy metals and naturally occurring radioactive materials.[106]

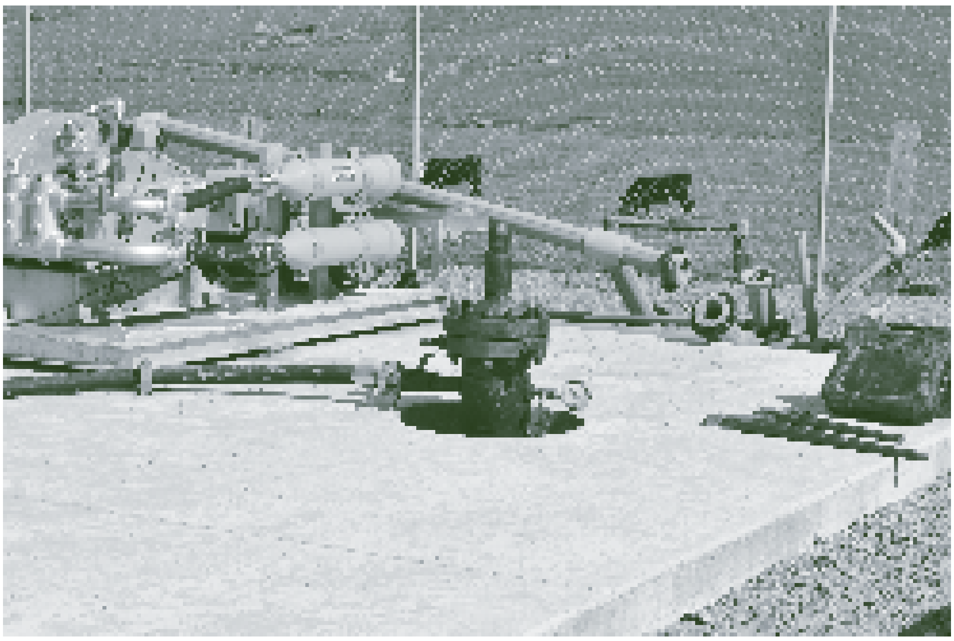
While the composition of fracking fluids has been the focus of much concern, this 'natural' formation water may be a greater challenge for handling and disposal due to the variability of the compounds that are in it.[107]

Conventional oil and gas wells also produce large volumes of water. However, fracking can lead to more wells and thus more produced water.

Wastewater can be temporarily stored in pits or in tanks. In the past, it was often stored in unlined clay pits – sometimes leading to contamination of soil and shallow groundwater. Unlined pits were used at several of the Kapuni well sites in Taranaki to temporarily store wastewater and diesel, including a small amount of returned fracking fluid. Soil beneath these pits is contaminated and is now being removed.[108] Today, polythene-lined pits or large enclosed tanks are used to store wastewater.

In Taranaki, the solids that separate out from produced water and drilling mud are disposed by 'landfarming' or put into landfills. Landfarming involves removing the top soil, spreading the waste over the land, and mixing the waste into the top soil. Over time microorganisms in the soil break down hydrocarbons in the wastes. However, the waste may contain substances including heavy metals that do not break down. Liquid waste including fracking fluid may also be landfarmed.[109]

Currently, liquid waste from oil and gas production in New Zealand is most commonly injected into wells in the ground. Injected wastewater could migrate into aquifers in the same way as fracking fluid could. But there does not appear to be any evidence that this has occurred in New Zealand.



Source: Parliamentary Commissioner for the Environment archives

Figure 4.11 The mothballed Blair-1 reinjection well at Solid Energy's coal seam gas pilot plant near Huntly.

As with fracking fluid injection, there is a risk that wastewater injection could trigger earthquakes.[110] Indeed, there are more documented cases where wastewater injection has been proven to trigger earthquakes than there are for fracking fluid injection.[111] And because wastewater injection involves much greater volumes of fluid over a longer period of time than fracking, it can cause larger earthquakes. For example, in the United States a number of small-to-moderate earthquakes occured in 2011 which appear to be associated with disposal of wastewater – Colorado/New Mexico a 5.3 magnitude earthquake was linked to injection of wastewater.[112, 113]

There is no evidence that wastewater injection from oil and gas operations has caused earthquakes in Taranaki.[114]

Other human activities in New Zealand have caused small earthquakes. For example, filling the lake behind Benmore Dam in Canterbury is thought to have increased the incidence of earthquakes in the area by a factor of three to six times.[115]

Other methods can be used to deal with the wastewater. Wastewater is sometimes sent to an industrial waste facility for treatment. It can also be held in evaporation ponds, or discharged directly to land or water.[116]

4.7 Ending production and abandoning the well

When a well reaches the end of its productive life, it has to be shut down and abandoned. New Zealand has many abandoned wells which are no longer producing. A small number of wells fracked in the past have since been abandoned, including some of the coal seam gas wells in the Waikato.

At abandonment, companies remove as much equipment from the well as possible before plugging all or part of the well with cement. Casing and cementing is cut off below the surface and removed so that land can be returned to other uses. In addition, the company will disassemble any remaining buildings, tanks, and other infrastructure and will restore the land to its former state.

The main risk with abandoned wells is the potential for leakage of oil into water or gas into water or air. Generally, it is not economic to extract every last drop of oil or gas from a reservoir. If the well is not abandoned correctly, some of this remaining oil and gas can escape.

There are examples of poor well abandonment in New Zealand. A study in Taranaki noted that in August 2001, an abandoned oil well in the New Plymouth suburb of Moturoa was found to be leaking oily water and natural gas 88 years after closure. The same study identified nine wells in the Moturoa area of having 'significant risk' of hydrocarbon leakages. One of the wells, Paritutu-1, was drilled in 1993 and was poorly abandoned in 1994. The other eight wells were abandoned prior to modern techniques being introduced in 1965.[117]

Once a well has finished producing, it no longer has any economic value. Therefore, the costs and responsibility for closing down the well, cleaning up the well site, and providing for its future safe maintenance must be planned well ahead.

Source: Parliamentary Commissioner for the Environment archives

Figure 4.12 Abandoned Kaiser-1 well at Solid Energy's coal seam gas pilot plant near Huntly prior to site restoration.

4.8 Summary

This chapter has shown that the process of fracking for oil and gas can and does have environmental effects. Some, like noise and traffic movements and the light from flaring, are effectively unavoidable, although they are localised and are generally at high levels only during the establishment and drilling of the well. Others, such as contamination of aquifers, are very unlikely, though the impacts are potentially more serious. These are summarised below.

Earthquakes

While the fracking itself causes tiny 'micro' earthquakes, these are virtually undetectable at the surface. If a well is fracked near an active fault, larger earthquakes can be caused, although they are still small. There is a higher probability of earthquakes from wastewater injection because it involves larger volumes of water.

Water contamination

Contamination of surface and groundwater with oil and gas, fracking chemicals, or wastewater can occur in three ways.

The most likely cause of contamination is spills and leaks occurring at the surface. However, the severity is typically small and easily managed. Blowouts, on the other hand, are rare but could be very damaging.

Contaminants could travel along natural pathways or the cracks created by fracking and into aquifers if they are nearby. This is the least likely cause of contamination, although the risk is increased when fracking occurs in naturally fractured areas, close to aquifers, or where there is no cap rock.

If the well casing or cement is inadequate or fails, the well itself could leak, causing water contamination. So the correct design and construction of the well is of paramount importance.

Waste management

Disposing of wastewater by injecting it into deep wells is obviously far preferable to piping it into rivers as has been done in the past. However, it still needs to be done correctly to prevent water contamination and earthquakes.

The disposal of waste by 'landfarming' or other methods could also contaminate soil, water, or air, if harmful substances are not first removed.

Local air pollution

Like conventional oil and gas production, or indeed many industrial activities, exhaust emissions from vehicles and machinery will produce some particulates and other air pollutants. But emissions from the well (and possibly from stored wastewater) are likely to be more significant.

During initial well testing, or in an emergency when some natural gas coming out of a well must be disposed of, it is much better to flare the gas than to vent it. Most of the hazardous air pollutants in natural gas break down to less hazardous substances when they are burned.

Greenhouse gases

Methane is a potent greenhouse gas. Some methane from natural gas deposits migrates to the surface through tiny fractures in the ground, and fracking may exacerbate this.

Flaring rather than venting is also preferable as it converts methane to carbon dioxide, which is a less potent greenhouse gas.

Conclusion

The risk of fracking leading to significant environmental damage is critically dependent on each stage of the process being done with great care. The *location* of the well – its proximity to aquifers, major faults, and so on – is especially important, as is the quality of well design and construction (*well integrity*). Chemicals must be handled carefully to prevent *spills* and *leaks*, and *waste* needs to be disposed of appropriately to avoid environmental contamination.

When fracking is done well, the chance and severity of environmental damage are small compared to some other economic activities. On the other hand, when it is done badly, the risks are higher. Thus, managing operations well right through the process is very important.

The next chapter describes the public processes and institutions that govern and control oil and gas production in New Zealand.

5 The role of public agencies in managing fracking

The environmental risks associated with fracking have been outlined in the previous chapter. The purpose of this chapter is to describe the legislation, public institutions, and processes that are set up to manage these risks. This chapter does not address the question of how well this management is actually done.

This chapter is divided in the same way as Chapter 4, following the process of oil and gas production involving fracking beginning with choosing the well site and ending with abandonment of the well.

5.1 Choosing where to drill

Before a company can consider drilling a well, it must obtain a petroleum permit from New Zealand Petroleum & Minerals – a branch within the Ministry of Business, Innovation and Employment (MBIE).[118] Permits are commonly granted in two stages – exploration and mining.[119]

Permits are granted in line with the requirements of the Crown Minerals Act (CMA) for efficient allocation and fair financial return to the Crown.[120] This requires evaluating both the technical and financial capability of the applicant and the anticipated oil and gas production.[121]

The petroleum permit application process does not require an assessment of environmental risks.[122] Seismic survey data is commonly included in a permit application, but this is not for the purpose of evaluating how the geology of the area might increase environmental risks. However, there is a current proposal to include an evaluation of the capability of applicants to meet New Zealand's health and safety, and environmental regulatory requirements.[123]

Once a permit is granted, the holder has the exclusive right to the oil and gas under the ground covered by the permit for a set time period.[124] Permit areas vary in size and a single permit can cover an area of thousands of square kilometres.

The decision of whether and where to drill within a permit area is made by the company. This decision will obviously be made on the basis of commercial criteria but would also be expected to take account of the following:

- Ease of access to the land. Land owners do not own the oil and gas under their land, and cannot prevent a permit-holding company from drilling on their land.[125] Some land owners will readily agree to give companies access to their land, but others will not.[126]
- Ease of gaining resource consents from councils. A company will not be able to drill for oil and gas if it is unable to obtain the necessary resource consents from councils, or if the conditions placed on the consents make the enterprise uneconomic or impracticable.

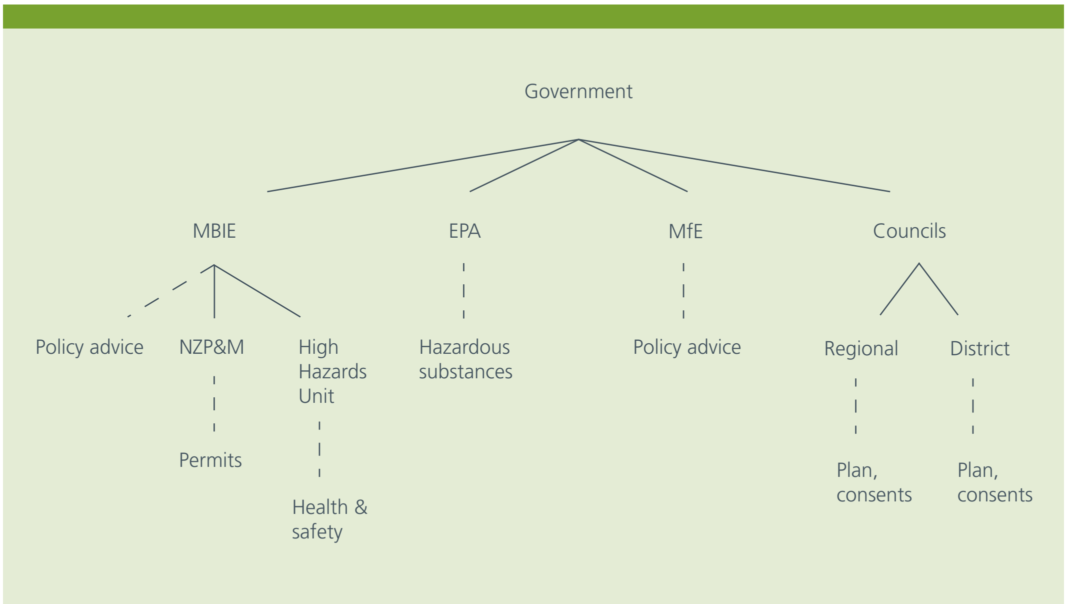


Figure 5.1 There are a number of different agencies involved in regulating the oil and gas industry. Each operate under different legislation and with a different purpose.

5.2 Establishing the well site

Once the company has chosen where to drill, the next step is establishing the well site for exploration or production drilling. At this point, local councils become involved.

Under the Resource Management Act (RMA), regional and district councils set controls in two ways. These are through policies and rules in regional and district plans, and through conditions in resource consents (if granted).[127,128] The Ministry for the Environment (MfE) can provide national guidance to councils.[129]

The establishment of a well site involves earthworks, excavation, access roads, and other amenities. A production well site may be larger and include a production station. Councils are generally experienced at dealing with these kinds of activities and many aspects will be controlled through their plans.

In applying for resource consents, oil and gas companies need to show how they will manage the effects on the environment. For example, earthworks and excavation generate sediment, and a plan to control runoff and protect any waterways would need to be included in an application.

At this stage a spill contingency plan is also required under the Hazardous Substances and New Organisms (HSNO) Act to deal with transport and storage of chemicals used on site.

The consents required for establishing a well site may be applied for together with others likely to be needed later in the process, or they may be 'unbundled' and applied for separately.[130] In this chapter, the different consents are described at each stage of the process, as if they were applied for sequentially, that is to say, 'unbundled'.

Box 5.1: Unbundled consents for exploration in the East Coast Basin

Apache Corporation and TAG Oil recently applied for consent to establish three exploratory well sites in the Gisborne and Tararua districts. These consent applications were not bundled with others for anticipated activities such as drilling and flaring.[131]

There are mixed views on unbundling. Some see this approach as a good way to stage a development, ensure consents are considered on their individual merits, and minimise delays. However, others see it as a 'thin end of the wedge' strategy, preventing consideration of the whole operation, and denying public participation.[132]

5.3 Drilling and constructing the well

Once the well site has been established it is time to drill and construct the well.

Council consents for drilling

In most district and regional plans, drilling a well – whether it be for oil and gas, or for water – is a 'permitted activity' or a 'controlled activity'. In both cases drilling will always be allowed but will be subject to conditions.

In Taranaki, drilling a well is a permitted activity so is only controlled by conditions in the regional plan. In Hawke's Bay, drilling is a controlled activity so resource consent is required, and there will be conditions put in the consent based on the conditions in the regional plan. An example of a condition in the Hawke's Bay plan is that the well bore *"shall be cased and sealed to prevent aquifer cross-connection, and leakage from the ground surface into ground water"*.[133]

Councils are responsible for monitoring compliance with conditions in plans and consents. The cost of monitoring compliance can be charged to the company.[134]

Well design

As described in Chapter 4, the design and construction of the well is critical in preventing environmental damage. The primary way this is achieved is through the oil and gas regulations under the Health and Safety in Employment (HSE) Act.[135] These regulations are designed to protect the health and safety of workers at an oil and gas worksite. But because well integrity is critical for protecting the environment as well as protecting workers, the regulations do provide some environmental protection, although it is incidental to their purpose.

The potential to integrate health and safety concerns with environmental ones has been recognised by the recent Royal Society report, which said: *"The [UK regulations]… should be widened so that well integrity is also considered from an environmental perspective. Wider expertise within or outside of the oil and gas sector may need to be drawn on."*[136]

Before drilling begins, the company must *"take all practicable steps"* to notify the High Hazards Unit in MBIE 20 days before drilling begins.[137] However, the actual drilling plans do not currently require approval from the High Hazards Unit.

The oil and gas regulations under the HSE Act date from 1999, and are currently being reviewed in light of modern health and safety practices. The discussion document released as part of the review identified that *"obligations [relating to well operations] fail to explicitly address a number of areas that are essential for ensuring the safe condition of a well at all stages in its life, from initial design to final plugging and abandonment."*[138]

The discussion document also notes that dangerous incidents (other than failures of the primary pressure containment system of the well) need not be reported to the High Hazards Unit: *"Consequently, we are not learning from these events and we are not getting any indication of how well major accident hazards are being controlled by operators."*[139]

A number of US states are updating their provisions for well construction, and the United States Environmental Protection Agency recognises that the issue of well age and maintenance warrants more study.[140]

Current practice in New Zealand appears to be that companies design and construct their wells based on standards from other countries. For example, TAG Oil, a Canadian company operating in Taranaki, constructs its well casings in accordance with Alberta's Energy Resources Conservation Board Directive 010.[141] New Zealand owned companies often follow industry guidance provided by the American Petroleum Institute.

Source: TAG Oil

Figure 5.2 Construction of a flare pit at TAG Oil's Cheal-C well site in Taranaki. The clearly visible plastic lining is designed to prevent contaminants from leaking into soil and groundwater.

5.4 Fracking the well

Council consents for fracking

If a company wishes to inject fracking fluid into a well, it must obtain a resource consent.[142] No regional council plans currently allow fracking as a permitted activity.

Prior to July 2011, the Taranaki Regional Council did not require resource consents for the more than 50 fracks that were performed.[143] The legality of this was questioned.[144] After receiving legal advice, Taranaki Regional Council now requires resource consent for fracking.[145]

In Marlborough the council plans prohibit the injection of any substance into a well bore, effectively (and presumably inadvertently) prohibiting fracking.[146]

The resource consent required for injecting fracking fluid into a well is for a 'discharge to land',[147] except where the fracking is being done to extract gas from a coal seam. Because water that lies within a coal seam is usually regarded as an aquifer, injecting fracking fluid into a well drilled into a coal seam is a 'discharge to water'.

A resource consent application must always be accompanied by an Assessment of Environmental Effects which details the effect the activity may have on the environment.[148] The detail in the assessment will vary depending on the applicant and the specific requirements of the council.

In granting a consent, the council will set conditions which could include setting specific baseline and ongoing monitoring of local water wells or groundwater. Seismic monitoring could also be required, although so far this has not been the case.

If the base of the fracking fluid is water, as it is in most cases, the company may also need to apply for consent for a water take from surface or groundwater. Most regional councils have established water allocation rules in their plans.

Fracking fluid approval

There are two stages to the approval of a chemical for use in fracking.

A company wishing to use a chemical in fracking fluid must ensure that it is approved under the HSNO Act which is implemented by the Environmental Protection Authority (EPA). A HSNO approval will contain conditions for storage, transport, handling, labelling and disposal. Once a chemical has HSNO approval, that chemical may generally be used by anyone in New Zealand so long as these conditions are met.

The use of chemicals may be considered in the resource consent process. It is largely up to councils to consider the environmental risks of using particular chemicals in fracking fluid. It is not clear whether councils are relying on generic HSNO approvals rather than assessing the environmental risk of the chemicals used at each particular site.

5.5 Flowback and transitioning into production

After a frack, the fracking fluid flows back out of the well, along with formation water from deep underground and the initial flow of oil and/or gas.[149] During this stage, gas that is produced from the well is commonly flared or vented for a time in order to test whether it will continue at a level that justifies the building of a pipeline. Flaring and venting is controlled under three different laws.

Under the CMA, flaring and venting is to be kept to a minimum but can be done in cases of emergency and during initial well testing (as described above).[150]

Under the HSE Act oil and gas regulations, companies are required to take all practicable steps to prevent the uncontrolled release and the safe disposal of hazardous gases. This leads to a preference for flaring over venting in order to avoid methane building up to potentially explosive levels.

Under the RMA, flaring or venting is a discharge of contaminants to air, so can only be done if allowed for by a regional rule or resource consent. Aspects of flaring and venting considered by regional councils would include proximity to people and contents of the gas (if vented) and combustion products (if flared).[151] However, councils cannot consider the impact of greenhouse gas emissions on the climate when consenting a discharge to air.[152]

The light emitted from flaring is typically dealt with by district councils. For example, Stratford District Plan states that no activity shall emit light (including petrochemical flares), or reflect light, that directly shines from the source into any part of a house without the owner's consent.

Source: TAG Oil

Figure 5.3 Pre-production gas is flared in a pit at TAG Oil's Cheal-C well site. Flare pits often capture wastewater as gas is burned off.

5.6 Handling the waste

Ensuring the treatment and disposal of waste is done safely is the responsibility of councils under the RMA. Waste includes drilling mud and cuttings, produced water including returned fracking fluid, sludge from pits, and waste oil and chemicals.

There are three main methods used in New Zealand for treatment and disposal of waste from oil and gas exploration and production – spreading it on to land (landfarming), injecting it into deep wells, and treating it at industrial waste facilities.

Landfarming will usually need resource consents which set limits and requirements for ongoing monitoring to prevent pollution of soil and water. For example, one particular landfarm has consent conditions that limit the thickness of the waste layer that can be applied, the distance of application from surface water, and the concentrations of salts and heavy metals in the soil. This landfarm was inspected by Taranaki Regional Council four times during 2010-11. In this year the council took four soil samples and reviewed others taken by the company.[153]

Prior to May 2011, fracking fluid was not specifically identified by Taranaki Regional Council in landfarming consents because it was assumed to be a general drilling waste. However, this has now changed, and consents are being revised to reflect this.[154]

Source: BTW Company

Figure 5.4 A site in Taranaki (Brown Road) where waste has been disposed of using landfarming. This photo was taken seven months after the waste was buried.

Wastewater injection also requires a resource consent because it is a 'discharge to land'. Wells used for this purpose may be old oil and gas wells, or wells drilled specially for the purpose of disposing of waste, and are covered under the health and safety regulations. As with landfarming, consents include conditions about what and how much can be disposed of in a well, including injection rates. The consents also set limits on the amounts of different contaminants that can be disposed of in this way as well as requirements for monitoring.

There are six wastewater injection sites in Taranaki that are consented for the disposal of fracking fluids. For all of these sites, the council decided there was no risk of contamination of freshwater aquifers. However, only the most recent consents require that groundwater around the well is monitored for contaminants.[155]

Industrial waste facilities are used where landfarming and wastewater injection are unavailable or unsuitable.[156] These facilities have consents for treatment and disposal. For example, Solid Energy's coal seam gas pilot project in Waikato trucked fracking flowback waste to a treatment facility.[157]

5.7 Ending production and abandoning the well

Abandonment of a well is often classed as a permitted activity and consequently resource consent is not required. Councils generally have provisions in their plans for well abandonment and site restoration, but the nature of these provisions can vary widely.[158] However, a national environmental standard for contaminated soil may apply where a well site has contaminated soil and is to be converted to another land use.[159]

Waikato Regional Council's plan addresses well abandonment in terms of a single broad objective, namely "*Holes drilled shall be sealed and abandoned in a manner that prevents cross contamination between different water bodies, or changes in water pressure.*"[160]

In contrast, Gisborne District Council is very prescriptive:

- *Any casing and screen that is not salvaged shall be perforated with a casing ripper.*
- *The upper 1.5 metres of casing shall be completely removed from the borehole.*
- *The bore shall be sealed by concrete, cement grout, or neat cement and shall be placed from the bottom upwards by a suitable method.*
- *The upper 1.5 metres shall be filled with topsoil from the surrounding area.*[161]

A council may require a bond or liability insurance to be paid to deal with environmental impacts such as soil or water contamination that could occur even after the well has ceased production. If the company holding the consent does not fulfil its rehabilitation conditions, then the council can use the bond itself to rehabilitate the site. However, ongoing monitoring – after the well has ceased production – has not usually been required.

Oil and gas companies are required to supply information on abandoned wells to MBIE. This includes information on the identity and location of the well, when it was abandoned, and how it was sealed.[162]

5.8 Summary

The environmental impacts and risks of oil and gas production in general, and of fracking in particular, are strongly dependent on how well the process is done – from choosing where to drill through to the eventual abandonment of the well.

The system is complex

In New Zealand, several different central government agencies and two levels of local councils have roles in oil and gas production.[163] For any one fracking operation each of these different regulatory agencies is involved in different parts of the process, and each has its own areas of particular responsibility.

Some potential gaps have been identified. These include questions around who takes responsibility for assessing site-specific risks to the environment from fracking fluid, examining well integrity for environmental risks, and monitoring abandoned wells. There may be others. In many instances it has been difficult to determine where regulatory responsibilities begin and end, and how effectively they are being implemented.

Highly devolved

The New Zealand system of environmental management is highly devolved. Environmental protection largely falls to the regional councils (and to a considerably lesser extent, the district councils) advised by the Ministry for the Environment.

Each council has its own plans, and conditions in consents are likely to vary widely. Some requirements are expressed in broad high-level terms; others are highly prescriptive. Some regions have yet to encounter oil and gas exploration on any scale, let alone production.

Devolution from central to local government has advantages, but it appears that there is also a significant amount of devolution to the companies themselves. At the moment different companies are using differing international standards for the design and construction of their wells. Some companies in New Zealand may stringently follow international best practice, but others may not.

Oversight and public trust

Whether it be risks to health and safety or to the environment, government oversight and good regulation is needed to address public concerns. In its 'Golden Rules' for fracking, the International Energy Agency has emphasised the need for measurement, disclosure and engagement with the public. This will require a commitment from local and central government and the industry if public trust is to be fostered and a 'social licence' to operate is to be earned.

Determining the extent to which the regulatory system in New Zealand is adequate to ensure international best practice – or even international good practice – presents a number of challenges. It requires a closer examination than has been possible in the preparation of this interim report and will be the focus of the work required for the final report.

The next chapter examines the rise of unconventional oil and gas, and looks at how the use of fracking is likely to expand in both the global and the New Zealand context. The interaction between fracking and the greatest environmental challenge of all – climate change – is explored. A brief overview is provided of some of the significant reviews of fracking being done around the world.

6 Looking to the future

"The pace of change has taken many people by surprise."

– The Economist on Australia's gas rush, 2 June 2012

We cannot predict the future by simply extrapolating from the past. The development of fracking and other unconventional oil and gas technologies has led to rapid changes in some countries and may well do so in New Zealand.

This chapter has four sections, each dealing with an aspect of the future of fracking.

6.1 The rise of unconventional oil and gas

Over time as a finite resource is exploited, production rises to a peak and then declines. At the time of the oil price shocks in the 1970s, the concept of 'peak oil' was prominent in public debate. The energy debate polarised into two strongly held views. On the one hand, there were those who saw oil being increasingly replaced by coal and nuclear power. On the other, there were those who argued that the world should shift from dependence on finite non-renewable forms of energy to renewable forms of energy such as solar.

There has been a recent peak in oil production, but it is a peak in the production of conventional oil that is easy to access.[164] The development of technologies such as fracking is making extraction of previously inaccessible oil and gas deposits possible. The rise of such 'unconventionals' shows that the world is not running out of oil and gas any time soon. And there is plenty of coal, albeit much of low quality, that can be processed into liquid fuels and petrochemicals.

In the United States, where most fracking has taken place so far, the growth in the extraction of natural gas has been particularly dramatic. In 2000, shale gas amounted to just 1% of the natural gas used in the country; 11 years later it was 25%.[165]

The world's hunger for energy continues to increase, largely driven by the rapidly growing economies of China and India. Some shift to renewable energy is occurring and the falling price of photovoltaic solar cells is a particularly encouraging development. But it seems inevitable that unconventional oil and gas will form a major part of the energy mix for some time to come.

The International Energy Agency (IEA) predicts that the global impact of the unconventional fuel, shale gas, is likely to be far more significant than fracking for oil.[166] Outside of the United States, countries with significant potential for shale gas include China, India, Canada, Mexico, South Africa, Australia, Argentina, Algeria, Libya, Russia, and Saudi Arabia.[167] It may be, however, that in New Zealand fracking for oil becomes more significant than fracking for gas.

Nearly 40 years ago, the 'energy crisis' led many countries, including New Zealand, to develop policies of national self-sufficiency in energy. But the big issue now is not a potential lack of energy, but rather the carbon dioxide that is an unwanted byproduct of using fossil fuels. It is not peak oil we should worry about, but the climate change that is being largely driven by the carbon dioxide we are putting into the atmosphere.

In the next section, the implications of fracking for climate change are discussed.

Source: Bruce Gordon, EcoFlight

Figure 6.1 Aerial photo of well sites in the Jonah natural gas field, Upper Green River Valley, Wyoming 2006.

6.2 What about climate change and fracking?

Climate change is the greatest environmental challenge the world faces. The main greenhouse gas responsible for climate change is carbon dioxide. Oil and gas are fossil fuels that, when burned, emit carbon dioxide into the atmosphere – carbon that was stored aeons ago in plants and animals.

Because fracking enables more oil and gas to be extracted than would be possible through conventional drilling, fracking would seem to inexorably lead to increasing emissions of carbon dioxide. The reasoning is that the increased supply of oil and gas will discourage investment in renewables and energy efficiency, and thus delay the transition to a low carbon future.

But some argue that fracking actually helps in the fight against climate change. This argument rests on the relative carbon intensity of coal and natural gas. Coal is about twice as carbon-intensive as natural gas – each unit of energy obtained by burning coal is accompanied by twice as much carbon dioxide as each unit of energy obtained by burning natural gas.[168]

Indeed, in the United States a significant fall in carbon dioxide emissions has been attributed to shale gas replacing coal, especially in electricity generation.[169] However, the economic recession also appears to have played a role in reducing carbon dioxide emissions.[170] (See also Box 6.1.)

Box 6.1: The greenhouse gas footprint of gas and coal

The much cited difference in the carbon intensities of coal and natural gas (the two-to-one ratio) applies only to the combustion of coal and gas, not to the total greenhouse gas footprints of the two fuels. The greenhouse gas footprints of gas and coal are a topic of much discussion.

A study led by Robert Howarth from Cornell University concluded that the greenhouse gas footprint of 'fracked gas' was 20 – 100% greater than that of coal and 20 – 40% greater than that of gas obtained using conventional methods.[171] However, this study has been criticised for overestimating the greenhouse gas footprint of 'fracked gas'.[172]

Other studies suggest that fracked gas may only have a slightly higher greenhouse gas footprint than conventional gas.[173] However, greenhouse gas footprints from different wells vary greatly, regardless of whether fracking has been used, depending on the type of equipment used, how old it is and how it is operated.[174]

Fracking can lead to increased emissions of carbon dioxide in some situations and decreased emissions in others. And what happens in one country's economy affects others. Cheap shale gas in the United States has reportedly led to an excess of cheap coal in Europe, raising emissions there.[175]

The IEA has modelled the impact on carbon dioxide emissions of tripling production of natural gas from fracking by 2035. The model predicts that at the global level there would be virtually no impact on net carbon dioxide emissions.[176]

How might fracking affect New Zealand's ability to move toward a low-carbon economy?

Compared with many countries, New Zealand is not highly reliant on coal for fuelling large industries and generating electricity. Most of our electricity generation already comes from renewable sources. The coal that is used for electricity generation and dairy processing could be replaced by gas from fracking, but this would reduce the country's greenhouse gas emissions by only about 1%.[177]

And while fracking could lead to much greater production of oil as well as gas, it is likely that most of the oil would be exported and therefore have less direct effect on energy use within New Zealand.[178]

Natural gas is much more difficult to transport between countries than oil because it must be converted to a liquid. Currently New Zealand does not have a liquefied natural gas (LNG) plant.[179]

In a country like China that is heavily reliant on coal, natural gas obtained through fracking could really help the transition to a low-carbon economy. And because gas burns much more cleanly than coal, substituting gas for coal could make a big difference to the air pollution that plagues China's cities.

But New Zealand is not China, and the net effect of fracking on this country's greenhouse gas emissions could go either way. Plentiful gas from fracking may displace investment in very low-carbon forms of energy; for instance, gas power plants may be built instead of new wind turbines. But on the other hand, gas from fracking may stop investment in more carbon-intensive unconventional energy sources such as Southland lignite.[180]

6.3 How might fracking develop in New Zealand?

There have been fewer than a hundred fracking operations in New Zealand since the technology was first used here in 1989. Almost all have been done in Taranaki to extract oil and gas from tight sands. However, New Zealand appears to be poised on the brink of what could be a large and rapid expansion of oil and gas production. And to quote the Royal Society of London report on shale gas extraction: *"attention must be paid to the way in which risks scale up."*[181]

It is anticipated that many more wells will be drilled in Taranaki – some that will rely on the use of fracking and others that will not.[182] In other cases, existing oil and gas wells will be re-worked using fracking to boost or restart production.

There are no current plans for large-scale production of coal seam gas using fracking. However, while Solid Energy recently closed its pilot plant in the Waikato, the company continues to explore for coal seam gas in inland Taranaki.[183]
And other companies have exploration permits covering large areas of the West Coast, Marlborough, Canterbury, Otago, and Southland.

The greatest potential for a rapid scaling up of fracking lies in the shale rock along the east of the North Island – spanning the Wairarapa through to East Cape.[184] The presence of oil and gas on the East Coast has long been known – to Māori long before Europeans arrived. Since 1955, more than 40 conventional wells have been drilled on the East Coast but none produced an economic flow of oil and/or gas. However, fracking is poised to change this.

Currently two joint ventures hold exploration permits that cover most of the North Island East Coast from East Cape down to Castlepoint.[185] At the time of writing, one exploratory well site is being established near Gisborne and two are being established near Dannevirke.

The nature and scale of the environmental risks associated with fracking are very dependent on the geology (and hydrogeology) of the area where drilling takes place. The geology of the east of the North Island is very different from that of the west coast where most fracking has taken place to date.

The geology of Taranaki consists of sedimentary rocks overlain by volcanic rocks. In contrast, the east coast has a greater mix of rock types overlying ancient greywacke. These east coast shales have been scraped off the Pacific Plate as it has slid (and continues to slide) beneath the Australian Plate. The oil-bearing rocks have become interwoven with other sedimentary layers from the surface to depths as great as five kilometres. The movement of these tectonic plates has resulted in many faults and folds running through the region and frequent earthquakes.

Hydrogeology is also very important – one of the main concerns around fracking is the potential for contaminating water. Aquifers vary greatly in their nature around the country, and while some are well understood, others are not.

It follows that generalising from the Taranaki experience to other parts of the country is of limited value. Moreover, the Taranaki experience to date may not apply to a major scaling up within the region, let alone to potentially very rapid development elsewhere.

With regard to fracking shale on the east coast of the North Island, the following are some of the questions that should be asked – and indeed answered.

- Given that the area is particularly seismically active, what are the implications for well integrity and the injection of wastewater?
- Has the folding and faulting of the rock layers meant that contamination of groundwater is more likely?
- Will the drilling be vertical or horizontal, as a horizontal well has a much greater likelihood of intercepting vertical faults?
- What does the depth of the shale layers mean for proximity to groundwater and aquifers?
- Given that the east coast is much drier (and frequently suffers from summer drought), where will the water required for fracking be taken from?
- How well would the main waste disposal methods used in Taranaki (landfarming and wastewater injection) translate to the east?

6.4 Investigations into fracking in other countries

As concerns about fracking have spread around the world, reports that address these concerns have begun to proliferate.

Of particular significance is the report this year from the IEA titled *Golden Rules for a Golden Age of Gas*. The 'Golden Rules' are high-level principles that provide guidance to governments and industry on how they should respond to the social and environmental challenges that are associated with the rise of fracking.[186]

Another recent key report is a review of fracking by the Royal Society of London. While the Royal Society's conclusion is that the risks of fracking can be managed, it is subject to an important proviso, namely that *"operational best practices are implemented and enforced through regulation."*[187]

In Germany, the Federal Environment Agency has produced a report that concluded better information and clear regulations were needed before fracking operations should continue. In response the German Environment Minister is convening a group of experts in December to discuss how to proceed with fracking in Germany.[188]

In the United States, the Environmental Protection Agency (US EPA), the US Secretary of Energy Advisory Board, the Massachusetts Institute of Technology (MIT), and the University of Texas have all released reports on fracking in the last two years.[189] These have generally been narrower in scope than their European counterparts. With the exception of the University of Texas report, all recommended improved transparency and data collection on fracking operations and their environmental impact.

The US EPA produced a scoping report last year on the potential impacts of fracking on sources of drinking water. The agency has also published a report on groundwater contamination in the town of Pavillion in Wyoming, concluding that it is likely that fracking operations caused the contamination of the local drinking water. The US EPA is now working on a big study on fracking due in 2014, and a progress report will be released in late 2012.

The US Secretary of Energy Advisory Board report looked at how fracking could be done more safely. It recommended more information about fracking operations be provided, best practice be adopted, and more research and development into environmentally friendly techniques be done.

The two university reports focused on the potential for groundwater contamination, although other issues were covered.[190] Both concluded that the practice was unlikely to contaminate groundwater if done safely.

In Australia a review of fracking was undertaken by the Chief Scientist in New South Wales over the last two years. The review was not released publicly, but a moratorium on fracking in the state has since been lifted and new rules set down for fracking operations and well integrity.

In Canada, two substantial reports on the safety of fracking are being prepared – one from Environment Canada and one from a group of experts.

None of these reports so far have called for a moratorium or a permanent ban on fracking, although there are more reports to come. The general theme of the conclusions is that fracking can be done safely if the right environmental regulations are in place and best practice is adopted.

Whether or not New Zealand has such regulations in place and best practice is being used across industry requires further analysis. This report, however, has led to some findings that to a considerable extent echo the conclusions of the emerging international literature. These are presented in the last chapter.

7

Conclusions and interim findings

Cracking rocks far below the ground to allow previously inaccessible oil and gas to flow is part of the global move towards the pursuit of unconventional oil and gas. Fracking has generated much controversy with polarised views, both internationally and also here in New Zealand. This interim report identifies and evaluates the environmental risks associated with fracking and explains the way in which government at both central and local level interacts with the oil and gas industry.

The high-level conclusion from the work done to date in this investigation echoes, and is broadly consistent with, the reviews of fracking that have been done elsewhere in the world. That conclusion is that the environmental risks associated with fracking can be managed effectively provided, to quote the Royal Society of London, "*operational best practices are implemented and enforced through regulation.*"[191]

Currently the oil and gas industry in New Zealand is accelerating within Taranaki. It seems quite likely that it will spread to other parts of the country – enabled by fracking – particularly if oil is discovered in significant quantities.

Evaluation of whether government oversight and regulation of oil and gas production in New Zealand is adequate for managing the environmental risks of an expanding industry will be done in a second phase of this investigation. In the meantime, there are seven interim findings presented in this chapter.

The first four findings relate to the physical processes discussed in Chapter 4 and are essential for good management of environmental risks. They are:

1. Choose the well site carefully
2. Design and construct wells to prevent leaks
3. Prevent spills and leaks on the surface
4. Store and dispose of waste with care

The second three findings relate to aspects of government oversight and regulation. It is anticipated that the questions they lead to will be examined in the second phase of this investigation. They are that:

1. Oversight is complex and fragmented
2. Regulation may be too light-handed
3. A 'social licence' to operate is yet to be earned

When it comes to the interaction between fracking and the biggest environmental challenge of all – climate change – it is not possible to reach any firm conclusions. Because natural gas is less carbon-intensive than coal, gas obtained from fracking could potentially provide a bridge to a lower-carbon future. But there are many factors at play here, and time will tell which dominate at a global level.

7.1 Interim findings - environmental risks

1. Location of the well site

The risk of environmental damage from fracking depends on where drilling – and indeed fracking – takes place. In geological terms, New Zealand is very 'young and active'. Drilling should only take place with great care, if indeed at all, if it is in the vicinity of major faults or aquifers which are used for drinking water or irrigation. Knowledge of the depth and extent of aquifers and of groundwater flows is also critical because contaminants may travel.

The importance of location is highlighted by the IEA's three 'watch where you drill' Golden Rules. For example:

> *"Properly survey the geology of the area to make smart decisions about where to drill and where to hydraulically fracture: assess the risk that deep faults or other geological features could generate earthquakes or permit fluids to pass between geological strata."*[192]

It is important that the geology – and the hydrogeology – of the site is well understood by the regulators as well as the companies. The geology of the North Island east coast is very different from the geology of Taranaki.

2. Design and construction of the well

The integrity of the well is of fundamental importance in ensuring hydrocarbons and produced water (including fracking fluid) cannot escape from the well. The number of layers of the casing, how far down the casing extends, the quality of the cement that binds it to the surrounding rock, and the ability of the casing to remain intact despite ground movements (including earthquakes) are all crucial.

The Royal Society of London found well integrity to be of critical importance:

> *"Ensuring well integrity must remain the highest priority to prevent contamination."*[193]

This theme was reinforced by the IEA's 'Golden Rules' focused on well integrity. For example:

> *"Put in place robust rules on well design, construction, cementing and integrity testing as part of a general performance standard that gas bearing formations must be completely isolated from other strata penetrated by the well, in particular freshwater aquifers."*[194]

3. Surface spills and leaks

Managing the risk of spills and leaks on the surface to avoid soil and water contamination is vital.

One of the ways in which water can be contaminated by fracking is if the storage of hazardous substances (including waste) is not adequate. Actions that reduce the risk of contamination include minimising the use of toxic chemicals, lining storage pits, using tanks as much as possible, and constructing the site to prevent and contain spillage. The recently publicised case of soil contamination in Taranaki shows the importance of lining pits.

Management of spills and leaks appears straightforward. However, a report by the European Parliament stated that:

> *"Most of the accidents and ground water intrusions [in North America] seem to be due to incorrect handling, which could be avoided."*[195]

Fracking fluid has been a consistent concern across jurisdictions because of the chemicals it contains. Many of the international studies identify the nature and handling of fracking fluid as needing improvement. A report by the University of Texas, for example, states:

> *"Chemical additives may pose a higher risk in their concentrated form while being transported or stored on-site than when they are injected into the subsurface for hydraulic fracturing."*[196]

4. Waste disposal

The effective treatment and disposal of waste, particularly the large volumes of produced water that come out of many wells over decades of production, is very important in order to prevent contamination of soil and water. This environmental risk is not specific to fracking because produced water comes out of all 'wet' oil and gas wells. But fracking fluid adds to the amount of produced water and contains some toxic substances. And more importantly, fracking can lead to rapid expansion of the size and extent of the oil and gas industry, and thus to waste disposal becoming a greater challenge.

Currently in New Zealand, wastewater is generally injected back into deep rock layers; again, how safe this will be depends on the local geology. Wastewater that finds its way into an active fault could trigger an earthquake.

7.2 Interim findings - the role of the government

1. Complexity and accountability

Government oversight and regulation of the oil and gas industry is complex and multifaceted. Finding out who is responsible for what during different stages of the process has been a major exercise during this investigation. Three issues are briefly discussed below as illustrations of the kinds of questions that arise.

The risk of environmental damage depends on where a well is drilled – on the geology and hydrogeology. Once granted permits which sometimes cover very large areas, companies appear to decide where to drill with no guidance from either central or local government about where drilling might best take place. Companies drilling wells are also using different design and construction standards.

It is not clear who is responsible for ensuring well integrity – the High Hazards Unit or the regional councils. There is some overlap between risks to the health and safety of workers and risks to the environment. For example, blowouts and methane leaks from wells are dangerous for workers and can damage the environment. Well integrity is critical for both. In New Zealand health and safety regulation is completely separate from environmental regulation. Combining the two regulatory roles to at least some extent is a common theme in other reviews. For example, the Royal Society of London recommended that:

> *"Well designs should be reviewed by the well examiner from both a health and safety perspective and an environmental perspective."*[197]

The Ministry for the Environment has not provided any guidance to councils specifically on fracking. Perhaps the EPA would be better placed to provide such guidance because of the expertise it will need to develop to consider proposals for drilling offshore.

2. 'Light-handed' regulation

Globally the last 30 years has seen a shift away from 'heavy-handed' regulation of industries. The oil and gas sector in New Zealand is no exception. The current approach involves a high degree of reliance on a company being motivated to 'do the right thing' by consumers, by workers, and by the environment. While this has worked well in some circumstances, there are problems with this approach in high risk industries. Oil and gas is one industry where New Zealanders need to have confidence that it is being done safely and in an environmentally responsible way.

In New Zealand, to a considerable extent, companies appear to be not only regulating themselves, but monitoring their own performance. The United Kingdom has a well examination scheme; New Zealand has no such scheme. Companies are required to provide (often highly technical) information to councils, to New Zealand Petroleum & Minerals and to the High Hazard Unit. However, this is no guarantee that the information, is always being understood and used to enforce best practice – or even good practice. New Zealand regulations are currently under review.

It may be that light-handed regulation of the oil and gas industry is working well, but this cannot be assumed. In August 2012, speaking about fracking, the Executive Director of the IEA was reported as saying that the industry's 'just-trust-me approach is fuelling public skepticism.'[198] Such skepticism is one of the real challenges for the industry.

3. A 'social licence' to operate

In releasing the 'Golden Rules' report earlier this year, IEA Chief Economist Fatih Birol warned *"If this new industry is to prosper, it needs to earn and maintain its social licence to operate."*[199]

In New Zealand, it appears that fracking has not yet earned its 'social licence'. Concerns about fracking are many and wide-ranging. They include the potential for contamination of important aquifers, triggering earthquakes, whether regulators have the capacity to deal adequately with concerns, as well as the impact on climate change. The concerns are not just environmental; some are questioning to whom and where the economic benefit will accrue.

Increasing public understanding of the technology should help address some concerns. There may well be some changes in public engagement that could help – for example, combining regional council and district council hearings on applications for resource consents. But ultimately what is needed is trust – trust that government oversight is occurring, and that regulation is not just adequate but enforced, and seen to be so.

As the Western Australian EPA has observed:

> *"…community confidence about the effective management of environmental impacts and risks associated with this industry is best achieved through open and transparent regulatory processes."*[200]

Questions arising from these interim findings will be explored and discussed in phase two of the investigation.

Glossary

Adsorb

When gas or liquid molecules are held on the outside of a solid particle. Coal seam gas is adsorbed to coal, and desorbs when water in the coal seam is extracted.

Aquifer

A layer of permeable rock containing groundwater. The quality of the water will vary, with saltiness generally increasing with depth.

Bore

A hole formed by drilling.

BTEX

Benzene, toluene, ethylbenzene and xylenes. A group of volatile compounds found deep underground and in oil.

Cap rock

An impermeable rock layer that limits the migration of fluid from deeper permeable layers.

Cement bond log

An acoustic test used to verify the quality of cement bond between the well casing and the rock.

CMA

Crown Minerals Act 1991 – the legislation covering the ownership and use of all minerals in New Zealand's sovereign territory.

Coal seam gas

A form of natural gas found within coal seams. It is also called 'coal bed methane' because this gas is almost all methane (about 98%)

Completion

The activities and processes used following drilling to prepare a well for production. Fracking is part of the completion process.

Compressed natural gas (CNG)

Natural gas that is compressed, but still in gas form. Often used as a replacement for petrol in cars.

Controlled activity

A class of activity defined in the Resource Management Act 1991 that requires resource consent. A council must grant the consent, but may include conditions.

Conventional oil and gas

Refers to traditional oil and gas exploration and extraction – generally vertical drilling into permeable formations from which oil and gas is easily extracted.

Crude oil

Raw oil as it is when removed from the ground. The composition of crude oil varies considerably from field to field. Also see Box 1.1.

Enhanced geothermal systems (EGS)

A geothermal plant where cold water is injected into the ground and heated by hot dry rocks to create steam and generate electricity. In contrast, a conventional geothermal plant extracts steam from geothermal reservoirs.

Exploration permit

A permit issued by the Ministry of Business, Innovation and Employment that provides permission to explore for minerals. So far only 11% of exploration permits in New Zealand have resulted in production permits.

Flaring

The process of burning off excess or unusable natural gas. Flaring can occur during emergencies, during the completion stage or when gas cannot be piped or used.

Flare pit

A pit below the gas flare that collects unburnt liquid and solid material. Flares that use a chimney stack do not require a pit.

Flowback

The process of allowing fluids to flow back up the well following fracking. Flowback will include fracking fluid, produced water, and oil and gas.

Formation

A set of rock layers that have comparable geological properties.

Fracking

Contraction of 'hydraulic fracturing'. The process of using pressurised fluid to crack underground rock and release trapped oil and gas.

Fugitive emissions

Greenhouse gas emissions such as methane in natural gas that escape into the atmosphere. Can include gases that migrate, leak, and are vented or are flared.

Green completion

A process (also called a 'reduced emissions completion') which separates gas from wastewater so it can be captured and piped during the completion stage rather than vented or flared.

HSE

Health, Safety in Employment Act 1992 – the legislation covering workplace health and safety in New Zealand.

HSNO

Hazardous Substances and New Organisms Act 1996 – the legislation covering hazardous compounds in New Zealand including many of those found in fracking fluid.

Horizontal well

A well drilled in a generally vertical direction that turns and runs in a generally horizontal direction through the oil and gas bearing formation.

Hydrocarbon

A compound consisting of hydrogen and carbon such as methane (CH_4). Oil, gas and coal contain a mixture of hydrocarbons.

Hydrogeology

The branch of geology concerned with the distribution and movement of groundwater.

Landfarming

A process of treating and disposing of waste on land that usually involves removing topsoil, spreading wastes, and mixing it into the topsoil. Microorganisms in the soil break down biodegradable contaminants over time.

Liquefied natural gas (LNG)

Natural gas compressed into liquid form. LNG is more compressed than CNG. Often used for long-distance transport when pipelines are not available.

Liquefied petroleum gas (LPG)

A mixture of the heavier hydrocarbon gases (propane and butane) compressed into liquid form.

Migration

The process by which gases and liquids (such as oil, salty groundwater and fracking fluids) travel through permeable rock layers.

Natural gas

The mixture of naturally occurring hydrocarbon gases (mostly methane) that form underground. Also see Box 1.1.

NORMs

Naturally Occurring Radioactive Materials. These include radium, radon, and barium and can be present in produced water.

Peak oil

A theoretical point in time when oil production reaches a maximum rate. After peak oil the rate of production is expected to decline.

Permeability

The measure of how easily fluids can pass through a particular type of rock.

Permitted activity

A class of activity defined in the Resource Management Act that does not require resource consent provided it complies with specified requirements.

Porosity

The measure of how much fluid a particular type of rock can hold.

Produced water

Wastewater produced from the well that is mostly naturally occurring and often salty formation water, but can also include returned fracking fluids.

Mining permit

A permit issued by the Ministry of Business, Innovation and Employment that provides permission to extract oil and gas commercially.

Proppant

The part of fracking fluid that is used to prop open fissures created by the fracking process. Proppant is usually grains of sand or small ceramic beads.

Reservoir rock

Rock where oil and gas have collected after migrating from deeper source rock. Reservoir rocks with low permeability are called ‘tight sands’.

RMA

Resource Management Act 1991 – the main legislation covering environmental management in New Zealand.

Royalty

The payment made to the Government for the right to extract oil and gas.

Seismic survey

The process of surveying the geology of an area by 'shooting' seismic waves and measuring their reflection.

Shale

The general term for the 'source rock' of most oil and gas. Shales are made from layers of mud and organic matter buried, heated and compressed. Being very fine grained, shales have low permeability. Extracting oil and gas from shale usually requires fracking.

Slickwater

A thin (watery) type of fracking fluid often used to frack shale formations in the United States.

Source rocks

Rocks in which oil and gas has formed. Shales and coal seams are the main source rocks for oil and gas.

Tight sands

Reservoir rocks (often sandstone) with low permeability (tight). Fracking is used to increase the flow of oil and gas from tight sands reservoirs.

Unconventional oil and gas

A variety of sources of oil and gas other than 'conventional' production from a permeable reservoir. Includes fracking and deep sea drilling, as well as the creation of oil products from tar sands and lignite.

Underground coal gasification (UCG)

The process of burning coal underground to turn it into a mixture of gases (known as syngas) which can be used to make diesel, urea or generate electricity.

Venting

Releasing excess or unusable natural gas into the atmosphere without burning it.

Vertical well

A well drilled in a generally vertical direction without turning horizontal. Most wells descend on an angle, rather than truly vertical.

Wastewater

Wastewater from fracking consists of a mixture of produced water and returned fracking fluid.

Wastewater injection

The process of disposing of wastewater by pumping it down a well.

Water-based gel

A thick (gelled) type of fracking fluid used in all recent New Zealand fracks.

Well abandonment

The process by which a well is sealed. Sometimes called ‘plugged and abandoned’.

Well casing

The steel casing lowered into the well bore.

Well pad

The area around the well constructed to support drilling rigs, storage tanks and other equipment.

Notes

1 Diodorus Siculus, Library of history, Book II, 12.

2 Moorey, 1994, pp. 159, 339.

3 University of Illinois at Chicago, *Hominid evolution, dental anthropology, and human variation*, http://www.uic.edu/classes/osci/osci590/index.html (section 6.2) [Accessed 17 July 2012].

4 National Geographic, *Delphic oracle's lips may have been loosened by gas vapours*, 14 August 2001.

5 Diodorus Siculus, Library of history, Book XVI, 26.

6 American Society of Testing and Materials, *A timeline of highlights from the histories of the ASTM Committee DO2 and the Petroleum Industry*, http://www.astm.org/COMMIT/D02/to1899_index.html [Accessed 17 July 2012].

7 Chishold, 1911.

8 Royal Society and The Royal Academy of Engineering, 2012.

9 Fuelfix, *Fracking concerns are legitimate, international energy chief says*, 17 August 2012.

10 John Key, *Speech to Waitakere Business Club*, 26 January 2012.

11 Zemansky, 2012, p. iv.

12 NZ Herald, *Poll backing for more mineral searches cheers Key*, 5 July 2012.

13 The physical 'thickness' of a fluid is called viscosity. For example, honey has higher viscosity than water.

14 The process of separating hydrocarbons by using their different boiling points is called fractional distillation. 'Cracking' is the process of breaking long hydrocarbon chains into shorter and more useful ones using temperature and catalysts.

15 If gas cannot be sent through pipelines, it can be compressed and transported in a tank. Three forms of compressed gas are common: liquefied petroleum gas (LPG), compressed natural gas (CNG) and liquefied natural gas (LNG). LPG is used to power some vehicles in New Zealand. CNG can also power vehicles and was popular in the 1980s after the oil crises. Natural gas can also be highly compressed into LNG so it can be transported long distance without a pipeline; for example, natural gas for export from New Zealand would need to be converted to LNG.

16 Most wells will then sell both the oil and gas they produce. In New Zealand the exceptions are the Tui and Maari offshore oil wells in Taranaki where the associated gas is either used on site or flared because these wells do not have a gas pipeline to shore. Ministry of Economic Development, 2012, p. 82.

17 Condensate forms from hydrocarbons that are gases underground where it is hot, but which condense into liquids when brought to the surface where it is cooler. Natural gas accompanied by condensate is called 'wet gas'.

18 There are two forms of permeability. Primary permeability is based on the interconnectivity of pore spaces. Secondary permeability is based on natural fractures and joints and is often the bigger factor affecting fluid movement in rock.

19 Watson, 1910, pp. 150–152.

20 Thomson, 1993, p. 61.

21 Gas made from coal is called 'town gas' or 'coal gas'. It is not the same as natural gas that is present in coal seams and can be accessed by fracking. Falkus, 1967.

22 Globally the first commercial oil well tapped into the Baku oil reserves in 1846, which is now located in Azerbaijan.

23 PBS, *Edwin Drake*, http://www.pbs.org/wgbh/theymadeamerica/whomade/drake_lo.html [Accessed 20 August 2012].

24 Hamilton, 2010.

25 Automuseum: *Dr Carl Benz*, http://www.automuseum-dr-carl-benz.de/?section=historie&infopart=meilensteine [Accessed 20 August 2012].

26 PBS, *Extreme oil*, http://www.pbs.org/wnet/extremeoil/history/1850.html [Accessed 20 August 2012].

27 Digital History, *The politics of oil*, http://www.digitalhistory.uh.edu/topic_display.cfm?tcid=96 [Accessed 20 August 2012].

28 Encyclopaedia Britannica Online, *Natural gas*, http://www.britannica.com/EBchecked/topic/406163/natural-gas/50586/History-of-use [Accessed 20 August 2012].

29 British Petroleum, 2010. US$2 a barrel is equivalent to about US$25 a barrel in 2012 dollars. Today the price of a barrel of oil is often over US$100 a barrel.

30 The 1973 oil shock was caused by Arab members of OPEC proclaiming an oil embargo because of the United States' support for Israel during the Yom Kippur War. The 1979 oil shock was because of the Iranian Revolution. The Nelson Institute, *Energy: Responding to crisis*, http://envhist.wisc.edu/cool_stuff/energy/crisis.shtml [Accessed 21 August 2012].

31 The price per barrel of oil is represented in 2012 US dollars. Data for this graph was sourced from the US Energy Information Administration: http://www.eia.gov/ [Accessed 20 August 2012].

32 Schmidt et al., 1981, pp. 1305–1311.

33 Montgomery and Smith, 2010, pp. 27–33.

34 Montgomery and Smith, 2010, pp. 27–33.

35 Linville, 1977.

36 Nordyke, 1988, Volume 7, pp. 1–117; Lederer, *Project Wagon Wheel* http://uwacadweb.uwyo.edu/robertshistory/project_wagon_wheel.htm [Accessed 26 September 2012]

37 Reed, 1982.

38 Data compiled from: Vermylen, 2011; National Petroleum Council, 2007; Economides, 2011.

39 The Australian, *Shell to tackle fracking concerns with education*, 16 October 2012.

40 ABC News, *Coal seam gas: By the numbers*, http://www.abc.net.au/news/specials/coal-seam-gas-by-the-numbers [Accessed 13 November 2012]

41 Environmental Leader, *Don't board the 'fracking banned' wagon*, 14 May 2012.

42 The Globe and Mail, *Quebec gas in peril as PQ signals ban*, 20 September 2012.

43 Royal Society and The Royal Academy of Engineering, 2012, p. 4.

44 International Energy Agency, 2012a.

45 Waitangi Tribunal, 2003, pp. 10 and 42.

46 Waitangi Tribunal, 2003, p. 42.

47 Waitangi Tribunal, 2008, p. 1492.

48 Gregg, R. and Walrond, C., 2009, Oil and gas – Early petroleum exploration, 1865–1960. In: *Te Ara – the Encyclopedia of New Zealand*, http://www.TeAra.govt.nz/en/oil-and-gas/, dated 2 March 2009.

49 There were gasworks in 56 cities and towns by 1916. Cook, M., 2010, Energy supply and use – Coal and coal gas. In: *Te Ara – the Encyclopedia of New Zealand*, http://www.TeAra.govt.nz/en/energy-supply-and-use/, dated 12 April 2010.

50 Gregg, R. and Walrond, C., 2009, Oil and gas – Early petroleum exploration, 1865–1960. In: *Te Ara – the Encyclopedia of New Zealand*, http://www.TeAra.govt.nz/en/oil-and-gas/, dated 2 March 2009.

51 Waitangi Tribunal, 2000b.

52 The Government signed a 'take or pay' contract in 1973 committing to buy Maui gas.

53 Gregg, R. and Walrond, C., 2009, Oil and gas – Early petroleum exploration, 1865–1960. In: *Te Ara – the Encyclopedia of New Zealand*, http://www.TeAra.govt.nz/en/oil-and-gas/, dated 2 March 2009.

54 International Energy Agency, 2012a, p. 21.

55 Solid Energy media release, *Solid Energy to refocus coal seam gas development in Taranaki*, 30 May 2012.

56 Solid Energy, *Underground coal gasification*, http://www.coalnz.com/index.cfm/1,443,969,0.html [Accessed 25 September 2012].

57 The number of fracks taking place is currently too few to attract a second rig. However, if the activity is to increase, industry anticipates that another rig from Australia can be shipped over.

58 For example, Taranaki Daily News, *Gas 'fracking' alarm sounded*, 22 March 2011; and Radio NZ Newswire, *Campaigners urge landowners to ban oil prospectors*, 23 March 2011.

59 For example, Southland Times, *Farmers air concerns at meeting*, 15 August 2012.

60 An access agreement must be negotiated.

61 Dr Api Mahuika, a Ngāti Porou leader, has been reported as saying in 2012: "*We have no idea of what will be left of our lands or the state they will be in post-drilling, nor whether we or the oil companies will be the new landowner*". See Craccum Magazine, University of Auckland, Issue 3, 2012.

62 For example, Taranaki Daily News, *Time to move on? It's time for some facts*, 5 March 2012.

63 The Dominion Post, *Fracking presents sustainable opportunities for New Zealand*, 8 March 2012.

64 Royalties are paid by oil and gas companies to the Government in return for the right to extract and sell the Crown's oil and gas. The current royalty rate is set at the higher of 5% of net revenue (an ad valorem royalty) or 20% of net profit (an accounting profits royalty). Royalties for oil and gas typically generate $400 million a year. Minister of Energy and Resources press release, *Oil and gas Block Offer 2013 gets under way*, 8 November 2012.

65 It can take about two weeks to drill a vertical well and even more for a horizontal well. New York State Department of Environmental Conservation, 2011, Chapter 5, p. 26.

66 The Cheal-BH1 well has a 548-metre horizontal section. Taranaki Regional Council, 2012a, p. 18.

67 Chesapeake Energy, 2011. One well has been drilled to 6,700 metres; Mainland Resources press release, *Mainland sets production casing on its 22,000-ft deep Haynesville Shale well in Mississippi*, 4 January 2011.

68 The mud has a number of important functions including lubricating and cooling the drill bit, returning rock cuttings to the surface and controlling underground pressure.

69 The 2010 Deepwater Horizon disaster in the Gulf of Mexico was caused by a blowout.

70 The McKee-13 blowout was New Zealand's first serious blowout, taking 35 hours to get under control. Poor casing design, inadequate cementing and poor drilling control were identified as contributing factors. Department of Labour, 1996.

71 For example, a Canadian well had a blowout that resulted in fracking fluid, produced water, and gas ejecting from the well. Mechanical failure and operational error were the significant contributing factors that led to the blowout. Energy Resources Conservation Board, 2009.

72 Zemansky, 2012, p. 15.

73 For example, some Kapuni wells will be modified before fracking by replacing the tubing string with a cemented heavy wall completion string. Shell Todd Oil Services Limited, 2012, p. 21.

74 The quality of construction can be tested by a suite of wireline logs. These include magnetic, electrical, and acoustic measurement tools, which provide information about the rock structure, reservoir quality, fluid content, and properties. Cement bond logs – another type of sonic test – can be run to check how well the cement has bonded with the casing and the formations and if there are any irregularities. Pressure tests can be used to verify the integrity of the well.

75 For example, United States Environmental Protection Agency, 2011.

76 Prior to fracking, the entire frack can be modelled on a computer. During fracking, the growth of fractures is often monitored, for example by using radioactive tracers (see Appendix 2) or microseismic sensors. Data obtained can assist the design of subsequent fracks.

77 Todd Energy notes that fractures in their (vertical) wells in the Mangahewa tight sands are 20-40m high and extend about 500m out from the well; Todd 2012, p. 17. According to a study of US shale fracking from horizontal wells, there is a 1% chance of fractures growing 350 metres or more up from the well. The highest fracture observed was 588 metres possibly due to the fractures intersecting existing faults; Davies et al., 2012, p. 1.

78 Other fracking fluids such as compressed carbon dioxide or nitrogen and liquefied petroleum can also be used, although large scale use is not yet common. Shell in Australia is also researching using electrical pulses to frack rocks instead of fluid.

79 Greymouth Petroleum's Turangi-4 well was fracked five times in 2011-2 using a total of 2100 cubic metres of fracking fluid.

80 International Energy Agency, 2012a, p. 30.

81 International Energy Agency, 2012a, pp. 31–32.

82 11,000 psi. Broderick et al., 2011, p. 20.

83 Taranaki Regional Council, 2012a, p. 16. Diesel-based fracking fluids can be used in reservoirs susceptible to water damage. The diesel is recovered with the oil and gas.

84 Leusch et al., 2010, p. 6.

85 New Zealand's Geonet monitoring system typically only records earthquakes greater than magnitude 2 on the Richter scale. However, the tiny earthquakes caused by fracking can be detected using specialised monitoring equipment located close by – often down a nearby well.

86 These three cases all involved a series of small earthquakes. They occurred at: Lancashire, UK (Preese Hall), where the largest event was a magnitude 2.3; Oklahoma, USA (Eola Field), largest event magnitude 2.8; and British Columbia, Canada (Horn River Basin), largest magnitude 3.8. Well deformation was observed at both Preese Hall and Horn River, but there were no reported issues with safety, fluid containment, or fluid confinement. de Pater and Baisch, 2011, p. 3; Holland, 2011, p. 1; British Columbia Oil and Gas Commission, 2012, p. 4.

87 This study was limited by the inability of the Geonet monitoring system to detect a full record of earthquakes less than magnitude 2. As very few earthquakes caused by fracking are greater than magnitude 2, fracking could be causing small earthquakes in Taranaki that are too small to be recorded by Geonet and also probably too small to be felt. Sherburn and Quinn, 2012, p.4.

88 European Parliament, 2011, p. 28.

89 The Taranaki Regional Council Unauthorised Incident Register records reported incidents at well sites in Taranaki, including where fracking has been used. It shows that, at these sites, most incidents that could result in water or soil contamination have involved above ground spills or leaks.

90 Osborn et al., 2011 present evidence for methane contamination of drinking water due to migration caused by fracking. However, the UK Royal Society claims this is unverifiable and highlights the importance of baseline testing of methane prior to gas extraction; Royal Society and The Royal Academy of Engineering, 2012, p. 28. In addition to depth and pathways barriers, migration is unlikely for the following reasons: the well is only under pressure for a short time; fluid components adsorb to rock; volumes of fluid are small compared to the void space in the rock; pressures reduce over distance; and after fracking, fluids are then being drawn towards and up the well. New York State Department of Environmental Conservation, 2011, pp. 6:53–6:54; Taranaki Regional Council, 2012a, p. 21.

91 Taranaki Regional Council, 2012a, p. 21; Golder Associates, 2012.

92 Is it possible that gas from shallow coal seams could more easily migrate to the surface and into the atmosphere. For example, one study has reported high concentrations of methane in the air above a coal seam gas region in Australia. Although the source of methane is not known, the high methane levels could be due to leaks from equipment or migration to the surface. This study is yet to be peer-reviewed and is disputed by the gas companies. Southern Cross University press release, *SCU releases first independent methane observations in Australian CSG fields*, 15 November 2012.

93 Taranaki Regional Council, 2012a, p. 22.

94 In some cases other nearby wells have provided pathways for fluid to flow. Zemansky, 2012, p. 15; Energy Resources Conservation Board, 2012, p. 1.

95 Broderick et al., 2011, p. 74.

96 United States Environmental Protection Agency, 2011a, p. 33.

97 New York City Department of Environmental Protection, 2009, p. 45.

98 Some of the fracking fluid remains trapped underground in the cracked rock – it can vary between 20 and 80%.

99 Oil wells typically produce more water than gas wells. Extracting gas from coal seams produces very large amounts of water.

100 Exhaust fumes from machinery also contribute to air pollution, but are minor compared to venting and flaring.

101 US National Oceanic and Atmospheric Administration press release, *First Wintertime Observations Find Ozone Soaring near Natural Gas Field*, 18 January 2009.

102 Burning natural gas (which is mostly methane) turns it into carbon dioxide, carbon monoxide, water vapour, and other gases. It also produces smoke. These are common air pollutants associated with burning fuels. As with venting, flaring may also allow traces of evaporated chemicals from fracking fluid to find their way into the air.

103 In New Zealand it appears that almost all fugitive emissions from natural gas production are flared rather than vented. According to calculations made using data provided by the Environmental Protection Authority, less than 5% is vented. See Chapter 6 for further discussion.

104 Sometimes in the early stages of flowback – when gas flow is very low – the gas cannot be separated from the water. In this case the water and gas are both sent to storage tanks where the gas is vented off. When it can be separated there is often not enough gas to be sent into the pipeline as the pipes require a minimum pressure.

105 Holditch, 2012.

106 The Ministry of Health's National Radiation Laboratory (NRL) is able to test levels of naturally occurring radioactive materials (NORMs) in formation water, but it appears few requests for testing have been made to date. However, the sampling and analysis that has been done has found levels to be "*low in comparison to what has been noted in some international fields*". Email from the NRL to the Taranaki Regional Council, 3 June 2011.

107 "*Altogether, the toxicity profile of the flowback fluid is likely to be of greater concern than that of the fracturing fluid itself, and is likely to be considered as hazardous waste in the United Kingdom.*" Broderick et al., 2011, p. 79.

108 The pits received initial well flows and fluids produced during well maintenance or workover activities. The contamination is localised within soil and groundwater as deep as 8 metres. Taranaki Regional Council, 2011a, p. 43.

109 For example, Taranaki Regional Council, 2010.

110 Green et al., 2012, p. 2; Ellsworth et al., 2012, p. 1.

111 A two-year study of injection wells in the Barnett Shale, Texas, found evidence of earthquake activity at 17 of the 3,300 injection wells in the region. Frolich, 2012, p. 1.

112 Zoback, 2012, p. 39.

113 One of the first well-studied cases where earthquakes were triggered by waste disposal was in Colorado in 1967. This earthquake, at Rocky Mountain Arsenal, was originally measured on local instruments as magnitude 5.5, but has since been revised to be 4.8. National Research Council, 2012, p. 20.

114 Sherburn and Quinn, 2012, p. 5.

115 Adams, 1974, p. 1.

116 Wastewater was discharged into a stream near two Southland coal seam gas wells that were fracked in 1995. Southgas Joint Venture, 1994, p. 12.

117 The initial leaky well was drilled in 1913 and abandoned fully in 1929. Abandonment practices between 1913 and 1965 typically used a combination of wooden plugs and cement, and casings may have been removed. Modern abandonment practices have been in place since 1965. However, the recently abandoned Paritutu-1 well was identified as having "*moderate probability of failure with the potential to release gas to the atmosphere*". Taranaki Regional Council, 2003, p. 19.

118 Prior to 2012 a 'priority in time' (first in first served) method of allocating permits was used. Permits are now allocated through annual 'block offers' in which New Zealand Petroleum and Minerals nominates blocks and companies compete for the permits.

119 Strictly speaking, three stages: a prospecting permit is the first stage. However, few companies apply for these permits as they are only valid for one year and are non-exclusive.

120 Crown Minerals Act 1991 (CMA) s 12, and the Minerals Programme for Petroleum 2005 (revised 2012) paras 2.11–2.15.

121 Often it becomes a legal obligation for a permit holder to drill at least one exploration well during the life of the permit. Minerals Programme for Petroleum para 5.2.4.

122 Although the Minister has the power to impose any condition he sees fit on any permit (CMA s 25(1)).

123 Crown Minerals (Permitting and Crown Land) Bill 2012, clause 18.

124 While an exploration permit will usually be for an initial term of five years (extendable for a further five years), work programmes tend to be offered on an annual basis. The company will have the option to 'drill or drop' – to relinquish the permit or to commit to the next year's programme, which may include a proposal to drill.

125 Land owners do not own petroleum (as defined in the CMA s 2) or gold, silver, or uranium (CMA s 10) which are all the property of the Crown.

126 The conditions and compensation for access must be agreed by the land owner and the permit holder. If an agreement cannot be reached, an arbitrator can be appointed and mandatory arbitration imposed. If the land falls into the exceptions set out in the CMA s 55(2) then mandatory arbitration cannot be imposed. Any disputes about whether the land falls into the exemptions must be determined by the District Court.

127 Whether or not a resource consent is required will also depend on how the activity of drilling is classified in the plan. For instance, Rule 46 in the Taranaki Regional Fresh Water Plan classifies drilling as a permitted activity with standards that must be followed. This means drilling can occur without the need for resource consent so long as those standards are met.

128 When a company applies to a council for resource consent for an activity, the council must consider the effects of the activity on people and the environment. If the council considers the effects are only minor, it does not 'notify' the consent. This happens in 95% of consent applications. If the council considers the effects on the environment are "more than minor" under the Resource Management Act 1991 (RMA) s 95A, it publicly notifies the consent, and any member of the public is able to make a submission on the application. Notification can also be limited to affected parties. Affected parties could include people living above a well drilled horizontally even if the well head is not on their land.

129 Guidance is provided in two ways: compulsorily through regulations like national environmental standards, or through voluntary documents such as the Guidelines for Assessing and Managing Petroleum Hydrocarbon Contaminated Sites in New Zealand. The Environment Court also has a role – a council plan or consent decision can be appealed to the Court. Consent decisions can only be appealed by those who were submitters. Because of this a non-notified consent decision cannot be re-examined in the Environment Court.

130 Councils have discretion to request application for all consents that will be required for the proposed activity (RMA s 91). The Environment Court has stated that, in general, good resource management practice means identifying from the outset all resource consents that will be needed and applying for them at the one time so they can be considered together. *Affco NZ Ltd v Far North District Council* [1994] NZRMA 224.

131 In contrast, a draft resource consent application prepared by the same companies for a Hawke's Bay site combined site preparation, drilling, flaring and fracking together into one application to the two relevant councils together. Ultimately this application was not lodged due to the land owner withdrawing their support for the operation.

132 Bundling the application for consents from both district and regional councils also allows the consents to be considered in a joint hearing. This simplifies public participation as the joint hearing would be held at one council's office and would consider all of the issues together (RMA 1991 s 102).

133 Hawke's Bay Regional Resource Management Plan Rule 6.3.1.

134 Under s 36 of the RMA, a council has the power to recoup costs involved in assessing and processing resource consents; this can also be extended to monitoring costs. There can be self-monitoring requirements with reports sent to the Council. *Carter Holt Harvey Ltd v Te Runanga O Tuwharetoa Ki Kawerau* [2003] 9 ELRNZ 182.

135 Health and Safety in Employment (Petroleum Exploration and Extraction) Regulations 1999

136 Royal Society and The Royal Academy of Engineering, 2012, p. 27.

137 The High Hazards Unit – a small team with just a few inspectors – was recently created as part of the Government's response to the tragedy at the Pike River coal mine. The information notified includes specifics of well design, drilling fluids, blowout prevention equipment, and summary of geology.

138 Review of the Health and Safety in Employment (Petroleum Exploration and Extraction) Regulations 1999 discussion paper; Department of Labour, 2012, p. 21. The Regulations currently specify a number of international codes of practice that operators must comply with when constructing the well, specifically the Institute of Petroleum Code of Safe Practice in the Petroleum Industry for onshore wells. This United Kingdom institute has since been renamed the Energy Institute. The regulations are being reviewed by MBIE.

139 Department of Labour, 2012, p. 29.

140 United States Environmental Protection Authority, 2011b, p. 35; Royal Society and The Royal Academy of Engineers, 2012, p. 14.

141 Alberta Energy Resources Conservation Board, 2009.

142 Injecting fracking fluid into a well is regarded as a 'discharge' to land or water under the RMA. Such discharges can only be done if allowed by a rule in a plan or given resource consent.

143 A discharge of a contaminant into land cannot occur unless allowed by regulations or resource consent under s 15 of the RMA. The Council considered fracking to have very minimal environmental effects and so s 15 would not apply. Para 4, legal advice to Taranaki Regional Council, 1 August 2011.

144 Climate Justice Taranaki press release, *Was or is Taranaki fracking illegal?*, 21 September 2011.

145 "*You have advised that there is no regional rule currently authorising such a discharge in Taranaki. Nor has the Council granted any resource consents authorising fraccing discharges. On that basis, despite what might be assessed as very minimal environmental effects, fraccing may contravene the RMA in some site-specific circumstances at the present time in Taranaki.*" Para 27, legal advice to Taranaki Regional Council, 1 August 2011. The legal advice [para 30] also advised that whether fracking would have minimal environmental effects should be assessed in resource consent proposal and that the legal test of a 'discharge of a contaminant' is not whether there are minimal environmental effects. It is likely that fracking could have been covered by Rule 44 under the Taranaki Regional Fresh Water Plan and indeed Taranaki Regional Council now uses Rule 44 to regulate fracking. By not regulating fracking prior to July 2011, the Taranaki Regional Council could have been in breach of s 84(1) of the RMA which requires every consent authority to observe and, to the extent of its authority, enforce their policy statement or plan.

146 Marlborough Sounds and Wairau/Awatere resource management plans – Rule 26.1.11.4 and Rule 27.1.4.4 respectively. Anyone wanting to frack would have to apply to change the plan.

147 RMA s 15(1).

148 RMA s 88. The matters to be included in an Assessment of Environmental Effects are set out in Schedule 4 of the RMA.

149 For coal seam gas, the removal of water from the coal seam (dewatering) requires a water take consent.

150 Flaring and venting is to be kept to a minimum to reduce the wastage of a Crown resource. Flaring and testing is limited to 30 days under the Crown Minerals (Petroleum) Regulations 2007 ss 26, 27 and 37, but this can be extended with a permit from central government.

151 Councils must adhere to the National Environmental Standards for Air Quality Regulations 2004 when consenting flaring, however flaring is exempt from the rule prohibiting the burning of oil in the open air (s 10).

152 Greenhouse gas emissions are instead regulated by the Emissions Trading Scheme (under the Climate Change Response Act 2002).

153 Taranaki Regional Council, 2012c.

154 For example, Taranaki Regional Council, 2011c.

155 Taranaki Regional Council, 2012b.

156 Not all wastewater treatment plants (particularly municipal treatment plants) can treat all forms of wastewater. The United States Environmental Protection Agency notes that in the US "*some shale gas wastewater is transported to treatment plants, many of which are not properly equipped to treat this type of wastewater.*" USEPA press release, *EPA Announces Schedule to Develop Natural Gas Wastewater Standards*, 20 October 2011.

157 Solid Energy, 2012; Solid Energy, 2010a.

158 Unless there is a specific condition in the permit or consent, there is no general legal obligation to plug and abandon wells. *Greymouth Petroleum Holdings Ltd v Todd Taranaki Ltd* [2005] NZAR747.

159 Resource Management (National Environmental Standard for Assessing and Managing Contaminants in Soil to Protect Human Health) Regulations 2011. Five sets of contaminated land management guidelines are also widely used by the oil and gas industry.

160 Waikato Regional Plan Rule 3.8.4.6(d).

161 Gisborne District Transitional Regional Plan, Part D, Section 15. These conditions relate to abandoning water bores, and "*more specific requirements are likely to be required for oil or gas exploration bores*". Gisborne District Council, pers. comm., 20 November 2012.

162 Crown Minerals (Petroleum) Regulations 2007 s 47.

163 The central government agencies include New Zealand Petroleum & Minerals (within MBIE), the High Hazards Unit (within MBIE), the EPA, and the Ministry for the Environment. Offshore (beyond 12 nautical miles) the EPA also has a role regulating deep sea oil and gas drilling under the Exclusive Economic Zone and Continental Shelf (Environmental Effects) Act 2012.

164 According to the IEA, global production of conventional crude oil peaked in 2006. International Energy Agency, 2010, p. 6.

165 Yergin, 2011, p. 329.

166 International Energy Agency, 2012a, p. 85.

167 The Economist, *Global resources – a world of plenty*, 14 July 2012.

168 Note that this argument applies to natural gas obtained using fracking, not to unconventionals in general. For instance, the fuels produced from Canadian tar sands are very carbon-intensive.

169 Horinko Group, 2012, p.13.

170 Between 2005 and 2010, the carbon dioxide emissions from electricity generation in the United States fell by 6%, and over the same period the carbon dioxide emissions from transport fell by 8% – yet clearly the fall in transport emissions is not due to fracking. See United States Environmental Protection Agency, Greenhouse Gas Inventory. Note also that new air pollution rules from the US Environmental Protection Agency have reportedly forced the closure of many old coal power plants.

171 Howarth et al., 2011.

172 Notably, the authors assumed that all the gas lost during the flowback period was vented rather than flared, used a Global Warming Potential for methane assessed over 20 years instead of the standard 100 years, and did not allow for gas power plants being more efficient than coal power plants.

173 Jiang et al., 2011; Hultman et al., 2011; US Department of Energy, 2011; Stephenson et al., 2011; Burnham et al., 2012; Weber and Clavin, 2012.

174 Intergovernmental Panel on Climate Change, 2002, p. 106.

175 The Guardian, *Coal resurgence threatens climate change targets*, 29 October 2012.

176 International Energy Agency, 2012a, p. 91.

177 Estimate based on emissions from coal in 2010 as reported in New Zealand's greenhouse gas inventories and the carbon intensities in Table 12.1 of the energy greenhouse gas inventory. A 2% reduction in carbon dioxide from the energy sector is a 1% reduction in total greenhouse gas emissions. Most of New Zealand's greenhouse gas emissions come from transport and agriculture. Ministry for the Environment, 2012; Ministry of Business, Innovation and Employment, 2012, p. 3.

178 Oil from New Zealand wells is almost all exported. The Marsden Point refinery is set up to process 'medium, sour crude' oil, not the 'light, sweet crude' oil found in this country. Ministry of Business, Innovation and Employment, 2012a, p. 6.

179 Natural gas can be 'exported' by using it to make other products, for example, urea fertiliser and methanol. The greater availability of natural gas attributed to fracking has already led to a decision to return the mothballed Waitara Valley methanol plant to production. NZ Herald, *Methanex to restart mothballed methanol plant*, 19 January 2012.

180 See Parliamentary Commissioner for the Environment, 2010. The state-owned enterprise Solid Energy is investigating another unconventional energy source – underground coal gasification (UCG) – with a pilot plant in Huntly. UCG can use fracking. It is similar to the proposed production of diesel and urea from lignite in that it involves the conversion of coal to syngas. See Appendix 1.

181 Royal Society and The Royal Academy of Engineering, 2012, p. 5.

182 For example, Todd Energy plans to "*invest $760 million in further development of its Mangahewa field over the next few years, the work including drilling at least 20 more wells*". Dominion Post, *Fracking essential says Todd Report*, 8 November 2012.

183 Solid Energy said the closure followed "*successfully proving the technology in New Zealand conditions*" and implied that its Taranaki prospect is more attractive because it is closer to "*a number of downstream gas processing plants and associated petrochemical industries*" and New Zealand's two main gas transmission pipelines. The inland Taranaki prospect is estimated to contain enough coal seam gas to run a 400MW power plant for 45 years. Solid Energy media release, *Solid Energy to refocus coal seam gas development in Taranaki*, 30 May 2012. Also note that coal seam gas development may not rely on fracking. Solid Energy believes that directional drilling may be more effective than fracking. Solid Energy, pers. comm., 15 November 2012.

184 TAG Oil estimate that "*over 20 years it is possible that several 1000's of HF [i.e hydraulic fracturing] treatments could take place on the East Coast*"; TAG Oil, response to PCE survey, 24 August 2011. Also note that the geology of shales varies. The rocks of interest in the East Coast Basin – the Waipawa and Whangai shales – are considered oil and gas source rocks and called shales. However, TAG Oil prefers to call them mudstones because they have a higher quartz content and greater porosity than the well-known North American shales. The company therefore believes they may require less effort to fracture; TAG Oil, pers. comm., 1 November 2012.

185 The two joint ventures are Apache Corporation and TAG Oil, and Westech Energy NZ and NZ Energy Corporation.

186 International Energy Agency, 2012a.

187 Royal Society and The Royal Academy of Engineering, 2012, p. 4.

188 Deutsche Welle, *Minister calls for German debate on fracking*, 6 September 2012.

189 United States Environmental Protection Agency, 2011b; United States Department of Energy, 2011; Massachusetts Institute of Technology Energy Initiative, 2011; University of Texas Energy Institute, 2012.

190 The University of Texas report has subsequently come under criticism because the main author has financial ties to the oil and gas industry, and it is now being independently reviewed.

191 Royal Society and The Royal Academy of Engineering, 2012, p. 4.

192 International Energy Agency, 2012a, p. 13.

193 Royal Society and The Royal Academy of Engineering, 2012, p. 4.

194 International Energy Agency, 2012a, p. 13.

195 European Parliament, 2011, p. 27.

196 University of Texas Energy Institute, 2012, p. 32.

197 Royal Society and The Royal Academy of Engineering, 2012, p. 6.

198 Fuelfix. *Fracking concerns are legitimate, international energy chief says*. 17 August 2012.

199 International Energy Agency press release, *IEA sets out the "Golden Rules" needed to usher in a Golden Age of Gas*, 29 May 2012.

200 Western Australia EPA, 2011, p. 2.

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Appendix 1

Other uses of fracking

Hydraulic fracturing is most commonly used to extract oil and gas. However, using pressurised fluid to crack rock was first used to aid the mining of granite and it has a number of other uses. Each use of fracking is different – for example, some do not use any proppant or chemicals.

This appendix answers five questions related to other types of fracking:

1. Does fracking occur naturally?
2. What else has fracking been used for in New Zealand?
3. What else might fracking be used for in New Zealand in the future?
4. Does 'enhanced recovery' for conventional oil and gas cause fracking?
5. Is fracking happening offshore in New Zealand?

1. Does fracking occur naturally?

Hydraulic fracturing can describe any process where rocks crack due to fluid pressure. This can happen naturally over time as underground fluids migrate. Fracture structures called 'pipes' and 'chimneys' can form that can extend several hundreds of metres up through the ground, sometimes to the surface.[1]

2. What else has fracking been used for in New Zealand?

Fracking has been used in New Zealand for three purposes other than to extract oil and gas:

Fracking to test rock strength

In 1983, hydraulic fracturing was used at the Clyde Dam to measure rock stress. Sections of a borehole were sealed off and pressurised until the surrounding rock failed. Twenty-one field tests were conducted, although few meaningful stress results were obtained.[2]

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1 Davies et al., 2012.

2 Thomson, 1993, p. 61.

Fracking to improve groundwater flow

In 2011, the Otago Regional Council fracked a water bore in drought-prone Central Otago in the hope of improving its yield but was unsuccessful.[3] This is unlikely to have been the only use of fracking to improve groundwater flow in New Zealand. Fracking water bores is common in some drier parts of the world.

Fracking to enable underground coal gasification

State-owned enterprise Solid Energy considered using a type of fracking as part of its underground coal gasification (UCG) pilot plant near Huntly.[4] Commonly called hydraulic linking, high-pressure water is used to 'water blast' a pathway between two neighbouring wells (~15m apart). An underground coal seam is ignited and air is pumped down one well to control the burning. The process releases gases, called syngas, which travel to the second well where it can be recovered. Syngas can be burned as a fuel – for example, in a power plant – or converted into diesel or urea.

3. What else might fracking be used for in New Zealand in the future?

Two other main uses of fracking could potentially be used in New Zealand.

Fracking for 'enhanced' geothermal power generation

New Zealand's geothermal power plants do not use fracking.[5] In these 'conventional' geothermal plants, steam is extracted from permeable underground reservoirs of hot water and often the cold wastewater is then re-injected. These processes can unintentionally fracture rock and, like fracking, can cause small earthquakes.

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[3] Otago Regional Council, 2012, p. 15.

[4] "The Pilot Plant Project will utilise either reverse combustion linking or hydro-fracturing to connect the wells." Solid Energy, 2010b, p. 19.

[5] GNS Science backgrounder, 29 August 2012 08/2012. Available at http://www.gns.cri.nz/Home/News-and-Events/Media-Releases/micro-earthquakes

Enhanced geothermal systems (EGS), in contrast, commonly use fracking. These 'unconventional' plants extract heat from dry rocks by injecting water into one well, forcing it through the hot rock, and retrieving the heated water from a recovery well. Like UCG, fracking creates a pathway between wells by forcing open faults and fractures.[6] EGS has generated larger earthquakes than oil and gas fracking.[7]

An EGS plant has been considered in New Zealand.[8]

Fracking to increase a reservoir's capacity to store wastewater or carbon dioxide

Fracking has been used overseas to increase the capacity of reservoirs to store wastewater. And fracking could be used in future to increase the capacity of reservoirs to store carbon dioxide as part of carbon capture and storage operations.

4. Does 'enhanced recovery' for conventional oil and gas cause fracturing?

New Zealand's conventional oil and gas producers use water injection to enhance production in offshore oil fields. Water is injected over time to restore pressure in the reservoir and push oil towards another well. The change in underground pressure can sometimes result in fracturing of the reservoir formation.[9]

5. Is fracking happening offshore in New Zealand?

Fracking has not yet been used offshore in New Zealand.[10] Fracking can be used offshore; for example, many North Sea gas wells have been fracked. However, it does not seem likely in New Zealand waters in the near future because exploration offshore is currently focused on conventional reservoirs.

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[6] EGS fracking can be called 'hydro shearing' because it mainly widens natural faults and fractures. However, the injection of cold water into hot rocks can also crack rocks.

[7] For example, an EGS plant under the city of Basel, Switzerland was shut-down in 2006 after it triggered four earthquakes between magnitude 2.6 and 3.4. National Research Council, p. 64.

[8] For example, in 2009 a feasibility study report was prepared for Fonterra and the Energy Efficiency and Conservation Authority for an EGS plant to supply 8MW of power to the Waitoa dairy factory in the Waikato. East Harbour Energy, 2009.

[9] OMV state that "*…water injection, as undertaken at Maari, is carried out at pumping pressures that might cause fracturing of the formation to occur, it is not HF in the context of the enquiry you are currently undertaking…*". OMV, response to PCE survey, 30 August 2012.

[10] Ministry of Business, Innovation and Employment, pers. comm., 24 July 2012.

Appendix 2

Fracking fluids and wastewater contaminants

Composition of fracking fluids used in New Zealand

The fracking fluids most commonly used in New Zealand are water-based gels containing ceramic beads (proppant) to hold the fractures open. Diesel was used instead of water in 17 fracks in Taranaki prior to 2006.

Overseas it is more common to use a 'slickwater' fracking fluid. Slickwater is often used in shale fracking, whereas gels are more common in conventional and tight sands reservoirs. Slickwater fluid is much thinner than gels, making it easier to pump, but it cannot carry as much proppant per litre of fluid.

The water-based gel fracking fluids used in New Zealand generally consist of 97% water and 3% chemicals (Figure A). Anywhere between 20 and 100 tonnes of proppant will be added to the fluid. Each chemical has a specific purpose (Table A).[1]

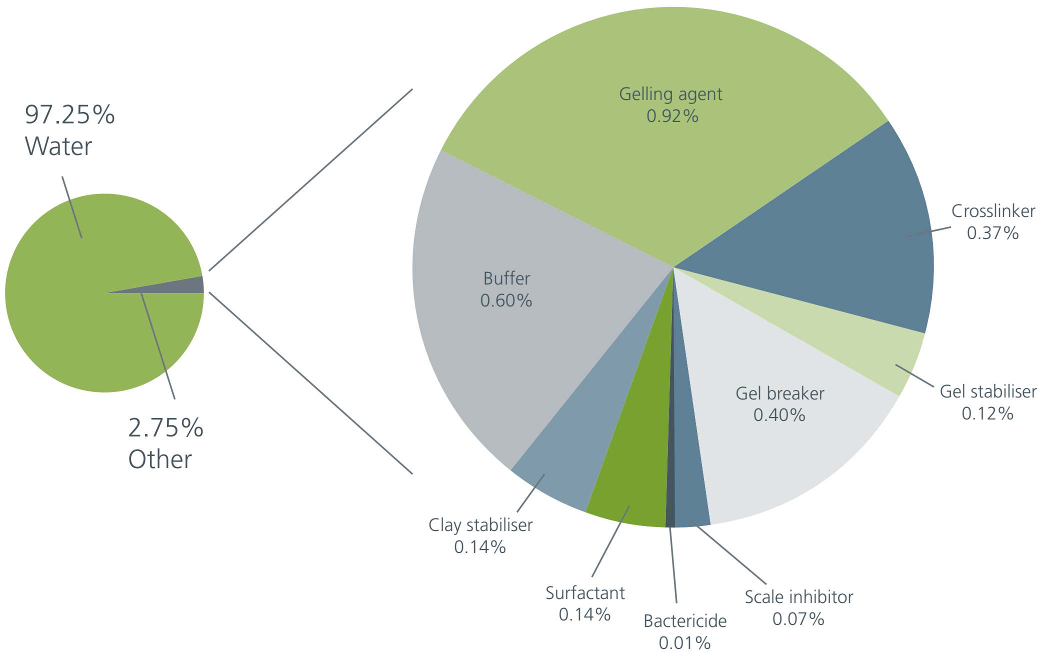

Figure A: A typical breakdown of the components of fracking fluids used in New Zealand. The data is taken from the assessments of environment effects in consent applications for Taranaki fracking operations since July 2011.

[1] Taranaki Regional Council, 2012, p. 5; United States Environmental Protection Agency, 2004, pp. 4–7.

Table A: The components of New Zealand fracking fluids.

Component	Purpose	Example
Gelling agent	thickens the fracking fluid into a gel so it can carry the proppant into the fractures	guar gum
Cross-linker	further thickens the fracking fluid so it can carry even more proppant	sodium tetraborate
Surfactant	lowers the surface tension of the fracking fluid to reduce friction during injection and to aid fluid recovery to the surface after fracking	oxyalkylated alcohols or oxyalkylated alkanolamines
Gel stabiliser	ensures that the gel does not break down at high temperatures	sodium thiosulfate
Gel breaker	turns the gel back into a free-flowing liquid in the well (it may break the gel after a certain amount of time or at a certain temperature) releasing the proppant and increasing the amount of fracking fluid returned to the surface	ammonium persulfate or hydrogen peroxide
Biocide or bactericide	prevents the growth of bacteria that can produce gas (such as hydrogen sulphide), degrade other components of the fracking fluid, and corrode the well casing	tetrakis (hydroxymethyl) phosphonium sulfate or glutaraldehyde
Scale inhibitor	prevents scale from building up in the well and other equipment	ethylene glycol
Clay stabiliser	prevents clay particles in the formation from swelling and blocking fractures when exposed to water	tetramethyl ammonium chloride or choline chloride
Buffer or acidity adjuster	keeps the fracking fluid in the right pH range to allow other components to work effectively	potassium carbonate, sodium hydroxide or potassium chloride
Radioactive tracers	sometimes used to trace the proppant and locate the fractures	iridium-192 or scandium-46

These components have all been used in New Zealand fracking fluids. Some overseas operations also use acids, corrosion inhibitors, iron control agents and friction reducers, but these are not currently used in New Zealand fracking operations. Note that the actual make-up of any fracking fluid can differ depending on the requirements of the planned job.

Most substances used in fracking fluid in New Zealand are classed as hazardous under the Hazardous Substances and New Organisms Act. Some of these chemicals can certainly be harmful, particularly when in concentrated form. Biocides are, by definition, ecotoxic because that is their purpose. However, the chemicals are diluted when mixed into fracking fluid, and risk to the environment depends on many factors.

Wastewater contaminants

Wastewater from fracking contains returned fracking fluid, as well as water and oil and gas from the rock formation. The rock formation is likely to contain various naturally occurring substances that are potentially more harmful than the chemicals in fracking fluids.[2]

Formation water can contain:

- **Salts** like calcium carbonate. These pose no threat to humans, but could potentially harm smaller organisms and damage soil productivity if sprayed on land. Treating water to remove salts is difficult and energy-intensive because salts do not break down over time.[3]
- **Naturally occurring radioactive materials** (NORMs) like radium. Radium-226 and radium-228 are the NORMs of most concern overseas and are carcinogenic if ingested.[4]
- **Heavy metals** like lead and zinc are toxic can bioaccumulate, and can persist in the environment.[5]
- **Organic compounds** like oil, gas, benzene, and naphthalene. Some can vaporise into air when formation water flows to the surface.[6] One example is benzene, which is a hazardous air pollutant.

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2 Broderick et al., 2011, p. 79.

3 Paleontological Research Institution, 2011.

4 Smith et al., 1996.

5 Paleontological Research Institution, 2011.

6 Argonne National Laboratory, 2004.

Appendix 3

Fracking operations in New Zealand

Table B. Taranaki – 'tight sands'

Latest frack	Site	Company	Depth (m)	Notes
1989	Kaimiro-2	Petrocorp Exploration	1300	
1990	Kaimiro-3	Petrocorp Exploration	2000	
1993	Kapuni-15	Shell Todd Oil Services	3600	
1993	Kaimiro-1	Petrocorp Exploration	3600	
1995	Kapuni-8	Shell Todd Oil Services	3400	
1995	Kapuni-6	Shell Todd Oil Services	3500	
1997	Mangahewa-2	Fletcher Challenge	3500	Fracked 3 times
2000	Ngatoro-9	NZ Oil & Gas	1500	
2001	Ngatoro-7	NZ Oil & Gas	1500	
2001	Rimu-A2	Swift Energy	3800	Fracking fluid was diesel based
2001	Rimu-A3	Swift Energy	3500	Fracking fluid was diesel based
2002	Ngatoro-1	NZ Oil & Gas	1600	
2002	Rimu-A2A	Swift Energy	3500	
2003	Kauri-A1	Swift Energy	3300	Fracking fluid was diesel based
2003	Kapuni-5	Shell Todd Oil Services	3400	

2003	Rimu-A1	Swift Energy	3500	Fracking fluid was diesel based
2004	Kauri-E4A	Swift Energy	2400	Fracking fluid was diesel based
2004	Kauri-E5	Swift Energy	2400	Fracking fluid was diesel based
2004	Kauri-E3	Swift Energy	2500	Fracking fluid was diesel based
2005	Kapuni-4	Shell Todd Oil Services	3300	Fracked 3 times
2005	Kauri-E1	Swift Energy	2400	Fracked in 2003 and 2005; fracking fluid was diesel based
2005	Kauri-E7	Swift Energy	2400	Fracking fluid was diesel based
2005	Kauri-E9	Swift Energy	2400	Fracking fluid was diesel based
2005	Kauri-A4	Swift Energy	2400	Fracked in 2003 and 2005; fracking fluid was diesel based
2005	Manutahi-A1	Swift Energy	1100	Fracking fluid was diesel based
2005	Manutahi-B1	Swift Energy	1100	Fracking fluid was diesel based
2005	Kauri-E2	Swift Energy	2400	Fracked in 2003 and 2005; fracking fluid was diesel based
2005	Cardiff-2A-ST1	Austral Pacific	4000	Fracked 3 times
2006	Turangi-1	Greymouth Petroleum	3400	Fracked 3 times
2008	Turangi-3	Greymouth Petroleum	4000	Fracked twice
2008	Turangi-2	Greymouth Petroleum	3400	Fracked 3 times
2009	Kowhai-A1	Greymouth Petroleum	3700	Fracked 4 times

2010	Mangahewa-6	Todd Energy	3900	Fracked 4 times
2010	Cheal-A7	TAG Oil	1700	
2010	Radnor-1B	Greymouth Petroleum	4400	
2010	Cheal-B3	TAG Oil	1700	
2010	Cheal-BH1	TAG Oil	1700	Fracked 5 times; horizontal well
2011	Kapuni-18	Shell Todd Oil Services	3700	Fracked 6 times
2011	Waitui-1	Todd Energy	4300	
2011	Kaimiro-2 ST1	Greymouth Petroleum	3600	
2011	Mangahewa-4	Todd Energy	4000	Fracked 2 times
2011	Onaero-1R	Greymouth Petroleum	3400	
2012	Turangi-4	Greymouth Petroleum	3400	Fracked 6 times
2012	Mangahewa-11	Todd Energy	4000	Fracked 3 times
2012	Mangahewa-5	Todd Energy	3400	Fracked 2 times

Table C. Southland – coal seam gas

Latest frack	Site	Company	Depth (m)	Notes
1995	TP-6	Southgas	480	Fracked 3 times
1995	TP-5	Southgas	350	Fracked 4 times

Table D. Waikato – coal seam gas

Latest frack	Site	Company	Depth (m)	Notes
2007	Jade-1	Solid Energy	420	
2007	Mimi-1	Solid Energy	400	
2007	Kaiser-1	Solid Energy	410	
2007	Jasper-1	Solid Energy	400	
2011	Beckett-1	Solid Energy	370	Fracked 2 times
2011	Renouf-1	Solid Energy	420	
2011	Renouf-2	Solid Energy	480	
2011	Renouf-3	Solid Energy	410	Fracked 2 times

Notes to the tables:

- Information supplied by companies in response to PCE survey
- Taranaki 'tight sands' includes formations that were already in commercial production but were fracked to increase production as well as formations that needed to be fracked to reach commercial production.
- The companies listed are the companies at the time of fracking. Greymouth Petroleum now owns the Petrocorp Exploration and NZ Oil & Gas wells. Todd Energy now owns the Fletcher Challenge well. Origin Energy now owns the Swift Energy wells. TAG Oil now owns the Austral Pacific well.
- The depths listed are the depth of the shallowest frack measured in metres below sea level (m TVDss).
- Cardiff-2A-ST1 is suspended (closed but not abandoned).
- The Southland coal seam gas wells were unsuccessful, so were abandoned. Information from Southgas Resources, 1996.
- The Waikato coal seam gas wells were fracked as part of a now suspended pilot plant.